VIRGINIA ELECTRIC AND POWER COMPANY
RICHMOND, VIRGINIA 23261

June 17, 2015

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U.S. Nuclear Regulatory Commission
Attention: Document Control Desk
Washington, D.C. 20555

Serial No. 15-290
NL&OS/GDM R0
Docket No. 50-338
License No. NPF-4

VIRGINIA ELECTRIC AND POWER COMPANY (DOMINION)
NORTH ANNA POWER STATION UNIT 1 – RELIEF REQUEST N1-I4-CMP-001
ASME SECTION XI INSERVICE INSPECTION PROGRAM
REVISED SUMMARY RESULTS OF THE STRESS ANALYSES FOR THE STEAM GENERATOR HOT LEG INLET NOZZLES FULL STRUCTURAL WELD OVERLAY FINAL CONFIGURATIONS

By letter dated March 30, 2011 (Serial No. 11-120), Dominion requested NRC approval for a proposed alternative to certain ASME Code Section XI - 2004 Edition requirements associated with Steam Generator hot leg nozzle repairs. The proposed alternative permitted the application of full structural weld overlays (FSWOLs) to mitigate the potential for primary water stress corrosion cracking (PWSCC) susceptibility at North Anna Power Station (North Anna) Unit 1. By letter dated March 13, 2012, the NRC approved Relief Request N1-I4-CMP-001 that permits the use of FSWOLs as an alternative.

Dominion installed FSWOLs on the Steam Generator hot leg nozzle dissimilar metal welds during the North Anna Unit 1 spring 2012 refueling outage. As a condition of the alternative, Dominion committed to provide a summary of the stress analysis performed for each of the FSWOL final configurations. The summary of the stress analysis performed for the three Steam Generator hot leg nozzles was provided to the NRC by letter dated April 26, 2012 (Serial No. 12-308).

Subsequent to the April 26, 2012 submittal, the vendor who performed the stress analysis for the FSWOL final configurations identified an error in their analysis. Specifically, an incorrect formula was used in the original calculations for determining critical flaw sizes. Consequently, the vendor has corrected their calculations using the correct formula. The revised calculations resulted in smaller critical flaw sizes which have an impact on the Leak-Before-Break results reported in Table 2-4 of the summary results included in Dominion's April 26, 2012 letter. While the results show that the leakage values are less than originally reported, they are still higher than the minimum allowed detection rate of 10.0 gpm. Therefore, there is no adverse impact on the original conclusions. Other sections of the report remain unchanged. The revised summary report, which includes the updated Leak-Before-Break results in Table 2-4, is provided in the attachment for your information.

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NRR

If you have any questions or require additional information, please contact Mr. Gary D. Miller at (804) 273-2771.

Respectfully,

Mark. D. Sartain
Vice President – Nuclear Engineering

Commitments made in this letter: None

Attachment: Revised Stress Analysis Summary for the Steam Generator Hot Leg Nozzles

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Attachment

REVISED STRESS ANALYSIS SUMMARY FOR THE STEAM GENERATOR HOT LEG NOZZLES

Virginia Electric and Power Company
(Dominion)
North Anna Power Station Unit 1

Revised Stress Analysis Summary for the Steam Generator Hot Leg Nozzles
North Anna Power Station Unit 1

1.0 INTRODUCTION

Virginia Electric and Power Company (Dominion) applied full structural weld overlays (FSWOLs) on dissimilar metal welds (DMWs) between the low alloy steel nozzle and stainless steel safe end of the three Steam Generator (SG) Hot Leg Inlet nozzles at North Anna Power Station Unit 1.

The purpose of these overlays is to eliminate dependence upon 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].

This report, which satisfies Dominion Commitment No. 1 of the Relief Request [2], summarizes the results of the nozzle specific residual stress analyses and the fracture mechanics evaluations, and also documents that all ASME Code, Section III stress and fatigue criteria are met. This information was submitted prior to entry into Mode 4 following completion of the overlays.

The requirements for the design of weld overlay repairs are defined in the Relief Request [2], which is based on ASME Code Case N-740-2 [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 FSWOLs is a circumferentially oriented flaw that extends 360° around the component; that is, completely through the original component wall thickness. A combination of internal pressure, deadweight, seismic and other dynamic 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 Code, Section III stress and fatigue usage evaluations are also performed that supplement the existing safe end and nozzle stress reports, to demonstrate that the overlaid components continue to meet ASME Code, Section III requirements. The original construction Code for the SG Hot Leg Inlet nozzles was ASME Code, Section III, 1968 Edition with Addenda through Winter 1968. However, as allowed by the ASME Code Section XI, Code Editions and Addenda later than the original construction Code may be used. ASME Code, Section III, 2004 [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 compressive 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.

Finally, evaluations will be 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 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 ASME Code, Section XI, IWB-3640 [4] evaluation methodology. Loads and stress combinations were provided by Dominion. Normal Operating (Level A), Upset (Level B), Emergency (Level C), and Faulted (Level D) load combinations were considered in this evaluation, and the design was based on the more limiting results. Additionally, per the seismic margin management plan [10], increased seismic loads were also considered in the evaluation. The resulting minimum required overlay thicknesses are summarized in Table 2-1.

As stated in Section 1.0, FSWOLs were installed using Alloy 52M filler metal. However, Alloy 52M weld metal has demonstrated sensitivity to certain impurities, such as sulfur, when deposited onto austenitic stainless steel base materials. Therefore, a buffer (transitional) layer of austenitic stainless steel filler metal was applied across the austenitic stainless steel base material. The austenitic stainless steel buffer layer is not included in the structural weld overlay thickness defined above.

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 the Relief Request [2] and ASME Code Case N-740-2 [3], the minimum weld overlay length required for structural reinforcement was established by evaluating the axial shear stress due to transfer of primary axial loads from the safe end into the overlay and back into the nozzle, on either side of the weld 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 schematic of the weld overlay design for the North Anna Unit 1 SG Hot Leg Inlet nozzles is illustrated in Figure 2-1. The design was reviewed by qualified NDE personnel to ensure that it meets inspectability requirements, and the overlay was designed to satisfy full structural requirements for the DMWs. The design thickness and length specified on the design drawing bounds the calculated minimum values, and may be greater to facilitate the desired geometry for examination.

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

	Location	**SG Hot Leg Inlet Nozzle**
Minimum Thickness (in.)	Nozzle Side	1.37
	Safe End Side	1.37
Minimum Length (in.)	Nozzle Side	2.58
	Safe End Side	3.81

* Length shown is the minimum required for structural acceptance and does not include additional length necessary to meet inspectability requirements.

2.2 ASME Code, Section III Stress Analyses

Stress intensities for the weld overlaid SG Hot Leg Inlet nozzles were determined from finite element analyses for the various specified load combinations and transients using the ANSYS software package [6]. Linearized stresses were evaluated at various stress locations using 3-dimensional solid models. A typical finite element model showing stress path locations is provided in Figure 2-2. 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.

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

Nozzle	**Load Combination**	**Type**	**Calculated**	**Allowable**
SG Hot Leg Inlet Nozzle	Level A/B	Primary + Secondary (P +Q) (ksi)*	44.63	51.69
	Fatigue	Cumulative Usage Factor	0.56	1.000

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

2.3 Residual Stress Analysis

Weld residual stresses for the North Anna SG Hot Leg Inlet 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]. A two-dimensional, axisymmetric finite element model was developed for the SG Hot Leg Inlet nozzle configurations. The modeling of weld nuggets used in the analysis to lump the combined effects of several weld beads is illustrated in Figure 2-3. The model 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.

An analysis was performed to simulate the welding process of the ID weld repair, the safe end-to pipe weld, the overlay welding process, and finally, a slow heatup to operating temperature. The analysis 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 a non-linear elastic-plastic stress pass to calculate the residual stress due to the temperature cycling from the application of each lumped weld pass. Since residual stress is a function of the welding history, the stress pass for each nugget was applied to the residual stress field induced from all previously applied weld nuggets.

After completion of the weld overlay simulation, the model was allowed to cool to a uniform steady state temperature of 70°F, and then heated up to a uniform steady state temperature of 621.9°F and a pressure of 2,235 psig to obtain the residual stresses at normal operating conditions.

The resulting residual stresses were evaluated on two paths through the DMW. These path definitions are shown in Figure 2-4. The resulting through wall residual stresses along these paths are shown in Figure 2-5.

2.4 Section XI Crack Growth Analyses

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 or the as-found cracks in the weld 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 analysis, the 40 year design quantity of cycles for each applied transient was applied. Since the examination volume for the PDI qualified post-overlay UT inspections includes the weld overlay thickness plus the outer 25% of the pre-WOL wall thickness, an ID connected flaw that is 75% of the pre-WOL weld

thickness is assumed as the largest flaw that could escape detection by this examination. Thus, crack growth is computed assuming an initial flaw depth of 75% of the pre-WOL weld thickness for the "A" and "C" SG Hot Leg Inlet nozzles. For the "B" SG Hot Leg Inlet nozzle, the as-found flaws were used in the analysis. As the flaws were 100% throughwall, ID connected flaws that were 100% of the pre-WOL machined weld thickness were used. The amount of time it takes for this assumed flaw to reach the overlay design basis thickness is then calculated. The results are shown in Table 2-3 for all nozzles.

For crack growth due to PWSCC, the total sustained stress intensity factor during normal steady state plant operating conditions 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.

Table 2-3: Crack Growth Results

Flaw	**Time for Postulated Flaw to Reach Overlay Design Basis Thickness**
	"A" and "C" SG Hot Leg Inlet Nozzle
Circumferential (DMW)[1]	16 years
Axial (DMW)[1]	18 years
	"B" SG Hot Leg Inlet Nozzle
Circumferential (DMW)[1]	10 years
Axial (DMW)[1]	13 years

Notes:
1. DMW = Dissimilar metal weld.

2.5 Leak-Before-Break Evaluation

A leak-before-break (LBB) evaluation that includes the weld overlay was performed. The evaluation has demonstrated that with the application of the weld overlay, the LBB margins required in SRP 3.6.3 [8] and NUREG-1061, Vol. 3 [9] are maintained. A range of weld overlay thicknesses was also evaluated, showing that the actual thickness

attained during overlay application does not change the LBB behavior significantly. The results of the LBB evaluation, specifically the leakage values for the critical flaw sizes, are shown in Table 2-4. All the leakage values exceed the minimum allowable leak detection rate.

Table 2-4: Leak-Before-Break Leakage Results

	Path 1	**Path 2**	**Path 3**	**Minimum Allowed Leak Detection Rate**
Min. WOL, gpm	55.56	12.85	84.86	10.0
Max. WOL, gpm	57.72	12.97	84.47	10.0

2.6 Evaluation of As-Built Conditions

The Relief Request [2] and Code Case N-740-2 [3] require evaluation of the as-built weld overlays to determine the effects of any changes in applied loads, as a result of weld shrinkage from the entire overlay, on other items in the piping system. These evaluations will be performed and documented separately from this report and will include the effects of the disposition of any non-conformances that occurred during weld overlay installation. In anticipation of the required as-built evaluations, calculations were performed based on design dimensions to confirm that the overlays would not adversely affect critical piping components. Specifically, the effect of the added weight of the overlays on the adjacent piping systems, based on maximum design dimensions, was evaluated and found to be insignificant.

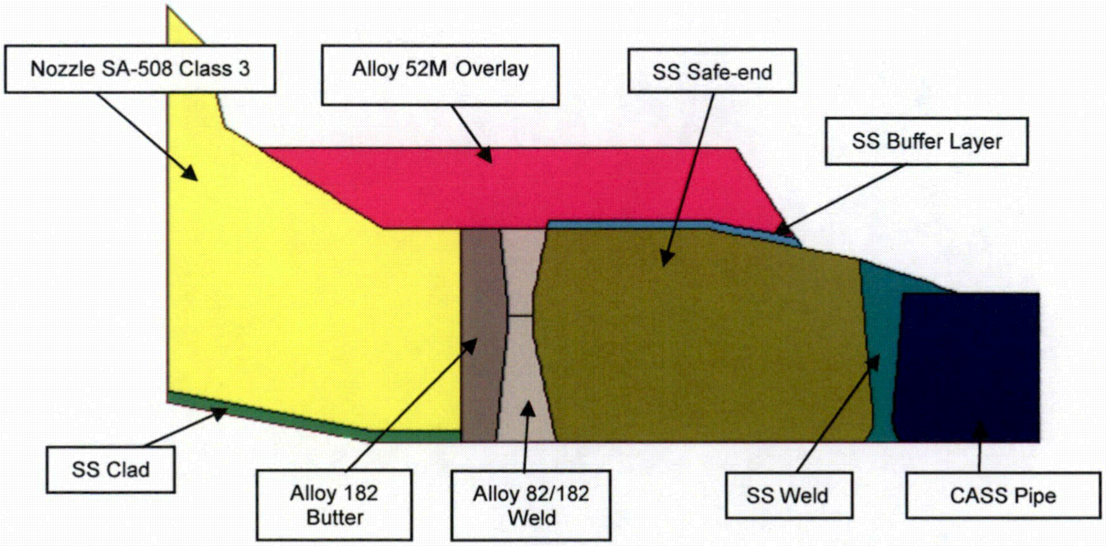
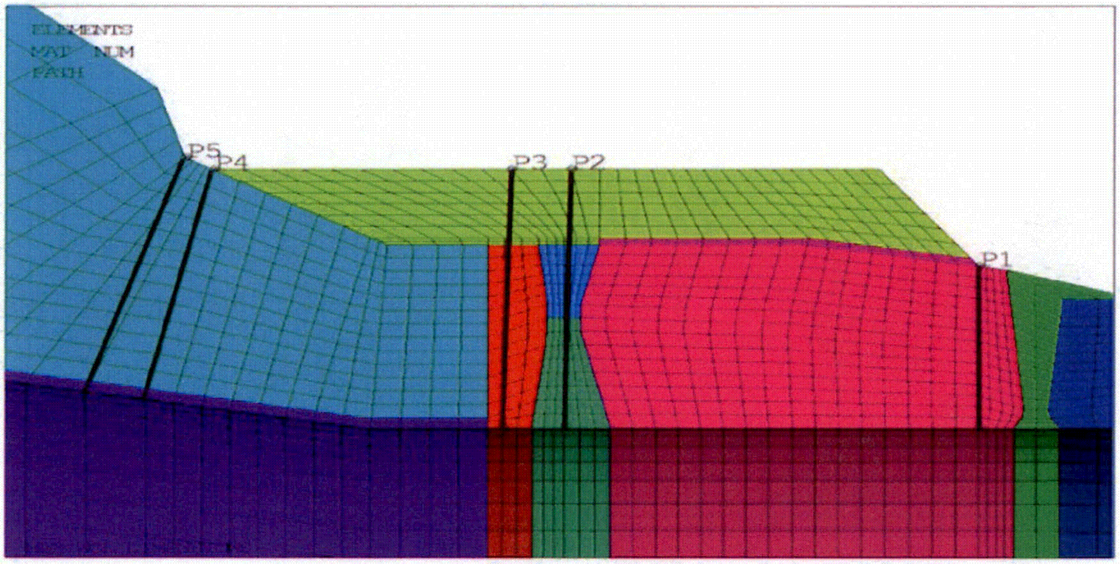


Figure 2-1: Illustration of Weld Overlay Design



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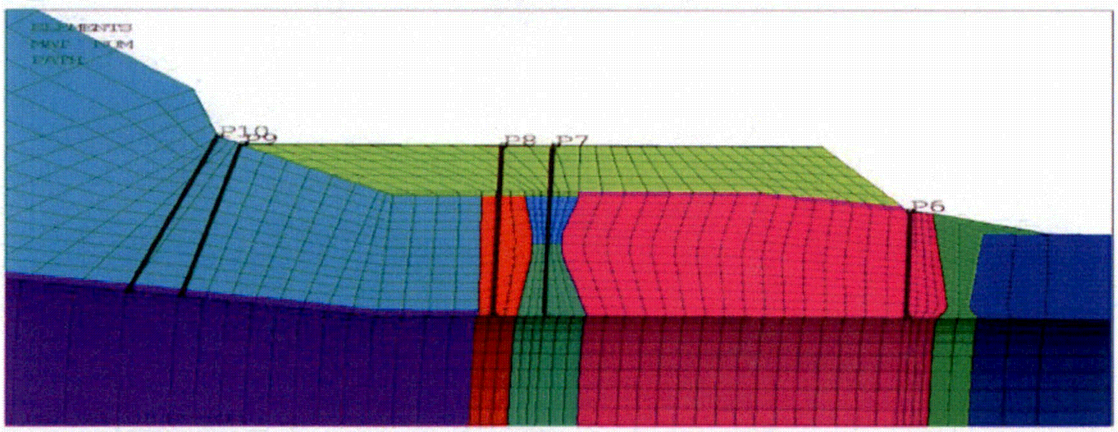
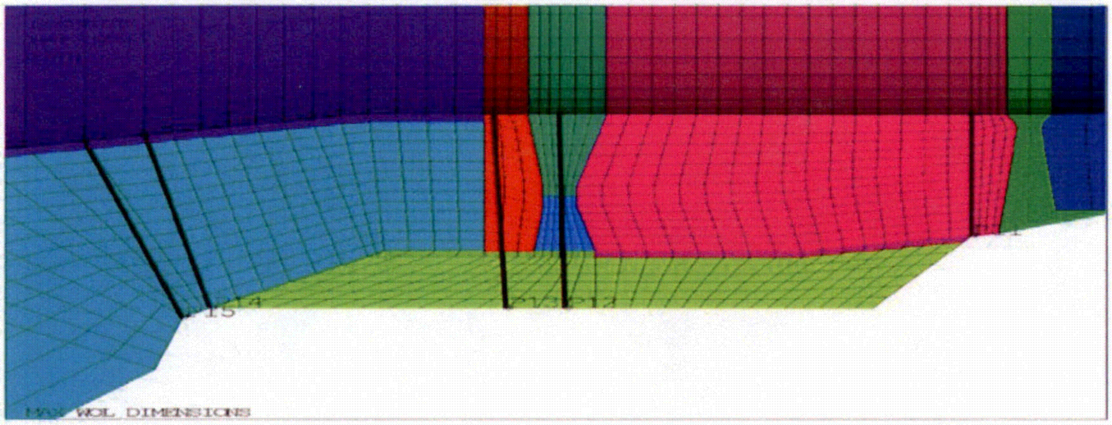


90° Section



180° Section

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

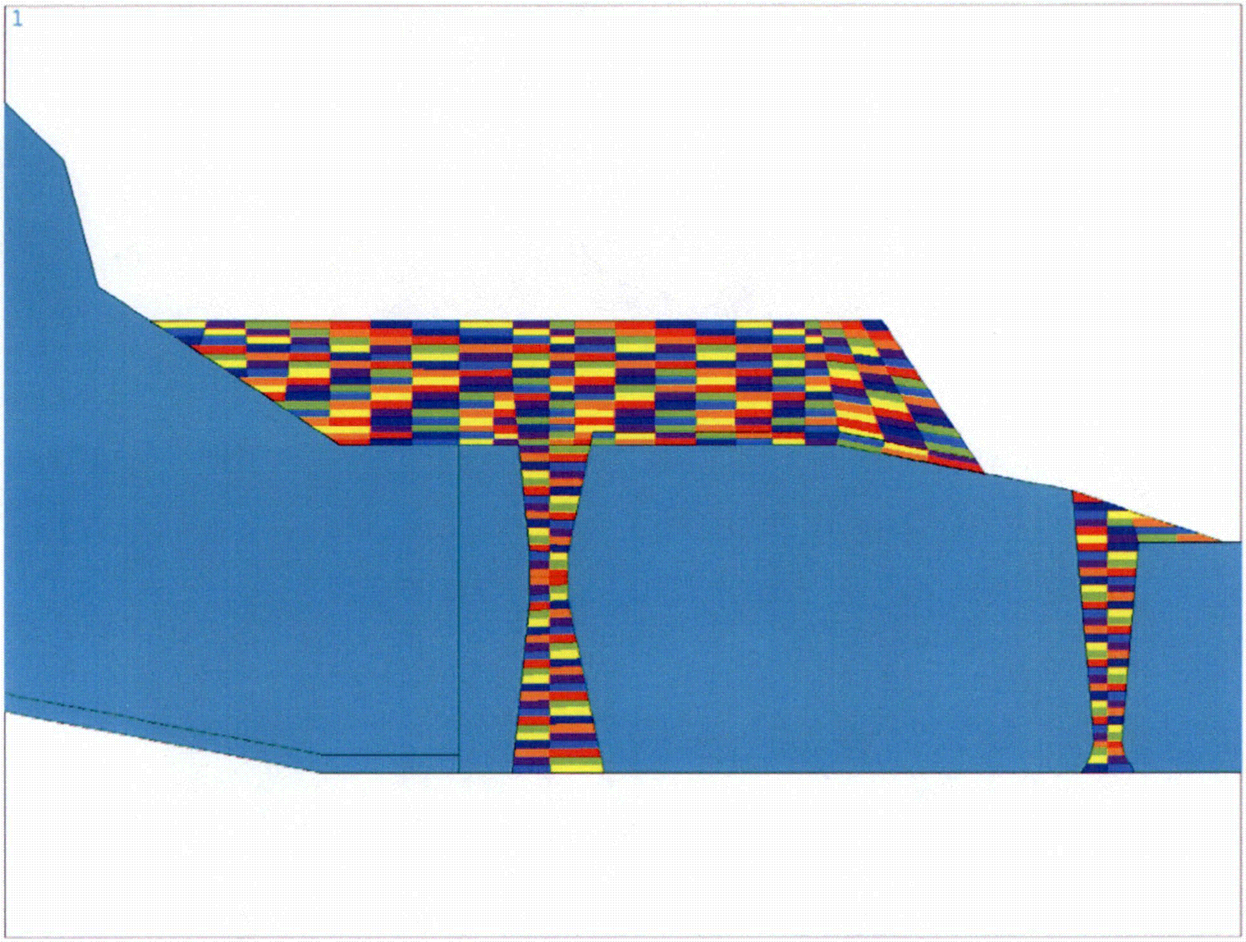


Figure 2-3: Finite Element Model for Residual Stress Analysis showing Nuggets used for Welding Simulations

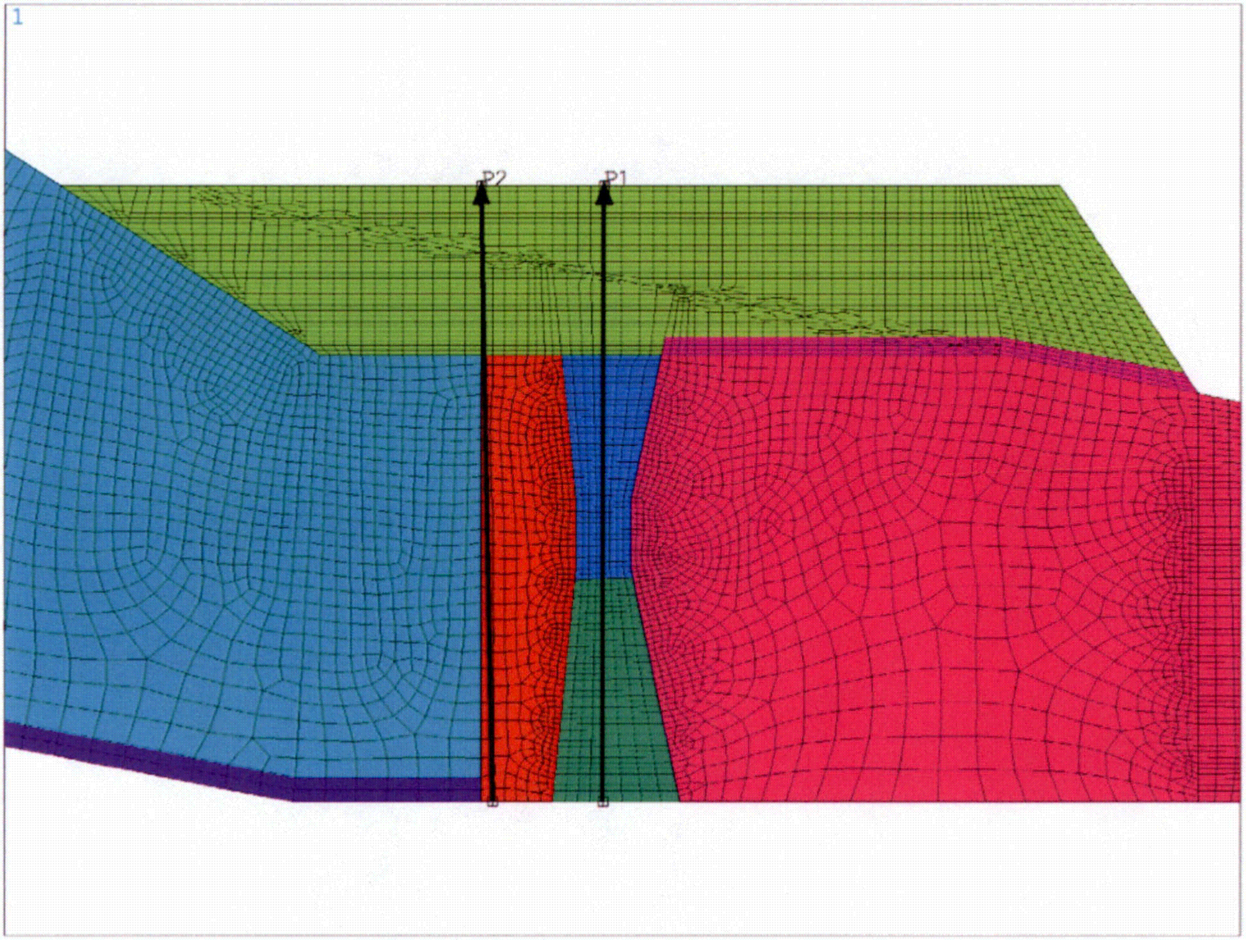


Figure 2-4: Finite Element Model for Residual Stress Analysis showing Stress Paths

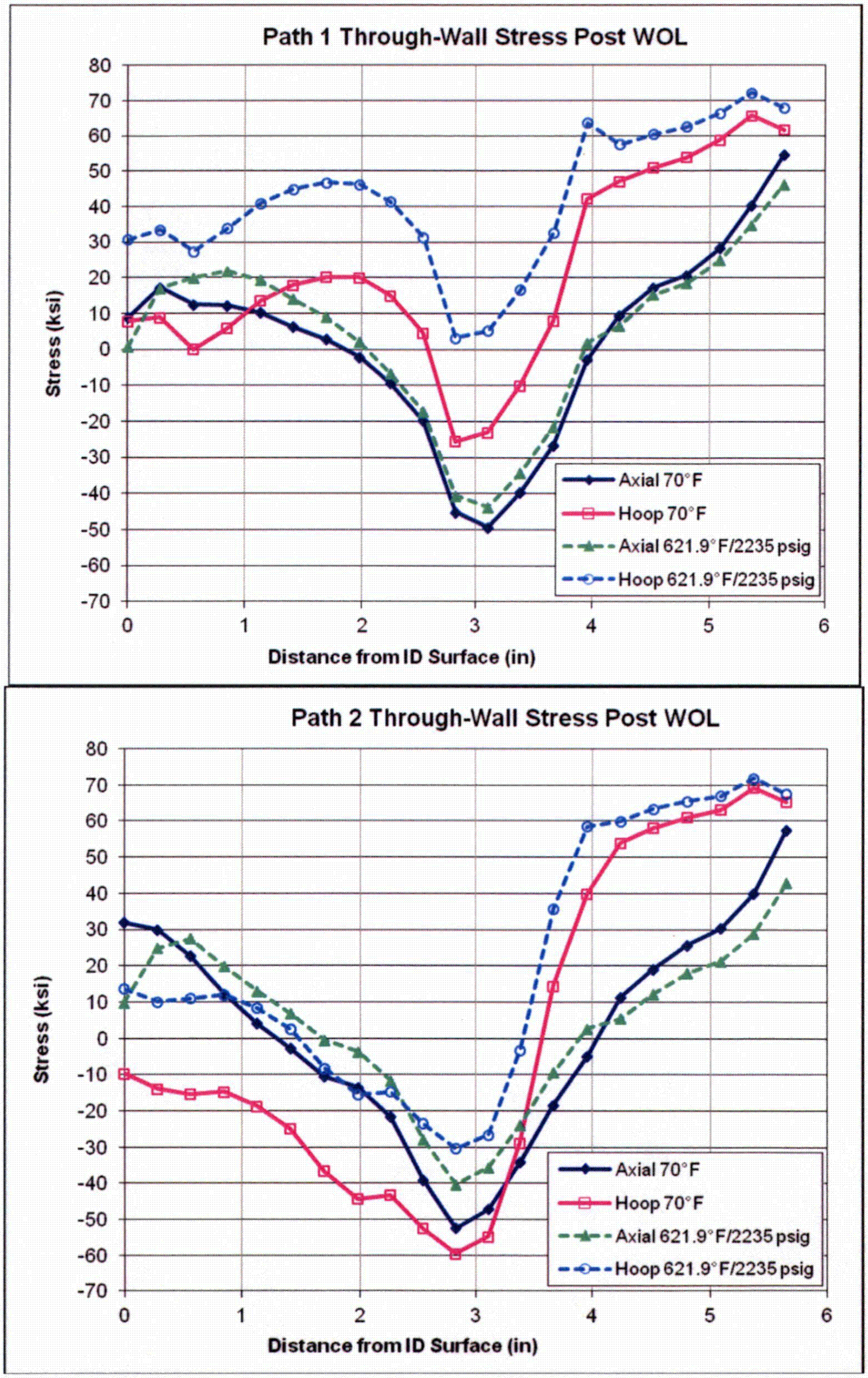


Figure 2-5: Residual Stress Results along Stress Paths through the DMW

3.0 CONCLUSIONS

The design of the North Anna Power Station, Unit 1 weld overlay was performed in accordance with the requirements of the Relief Request [2], which is based on ASME Code Case N-740-2 [3]. The weld overlay design is demonstrated to provide long-term mitigation of PWSCC in these welds based on the following:

- In accordance with the Relief Request [2], structural design of the overlays was performed to meet the requirements of ASME Code, Section XI, IWB-3640 [4] based on an assumed circumferential flaw 100% through and 360° around the original welds (which bounds a 100% through-wall axial flaw). The resulting FSWOLs 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.

- Application of the weld overlays was shown to not impact the conclusions of the existing nozzle Stress Report. Following application of the overlay, all ASME Code, Section III stress and fatigue criteria are met.

- A nozzle specific residual stress analysis was performed, after first simulating a severe ID weld repair in the nozzle-to-safe-end weld, prior to applying the weld overlay. The post weld overlay residual stresses were shown to result in beneficial compressive stresses or reduced tensile stresses on the inside surface of the components, and into the thickness of the original DMW, assuring that future PWSCC initiation or crack growth into the overlay is highly unlikely.

- A fracture mechanics analysis was 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 to examine the nozzles. Both fatigue and PWSCC crack growth were considered, and found to be acceptable.

- Leak-before-break evaluations were performed to demonstrate that the weld overlay, when implemented, would meet regulatory requirements for critical flaw and leak detection.

Based on the above observations and the fact that nozzle-to-safe end weld overlays have been applied to other plants since 1986 with no subsequent problems identified, it is concluded that the North Anna Power Station, Unit 1 SG Hot Leg Inlet nozzle DMWs have received long term mitigation against PWSCC.

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. Virginia Electric and Power Company, North Anna Power Station Unit 1 Relief Request No. N1-I4-CMP-001, "Use of Weld Overlays as an Alternative Repair Technique for Steam Generator Hot Leg Nozzles," Docket No. 50-338, dated March 30, 2011.

3. ASME Boiler and Pressure Vessel Code, Code Case N-740-2, "Full Structural Dissimilar Metal Weld Overlay for Repair or Mitigation of Class 1, 2, and 3 Items, Section XI, Division 1."

4. ASME Boiler and Pressure Vessel Code, Section XI, Rules for Inservice Inspection of Nuclear Power Plant Components, 2004 Edition.

5. ASME Boiler and Pressure Vessel Code, Section III, Rules for Construction of Nuclear Facility Components, 2004.

6. ANSYS Mechanical APDL and PrepPost, Release 12.1 x64, ANSYS, Inc., November 2009.

7. *Materials Reliability Program: Technical Basis for Preemptive Weld Overlays for Alloy 82/182 Butt Welds in PWRs (MRP-169), Revision 1,* EPRI, Palo Alto, CA: 2008. 1016602.

8. NUREG-0800, "U.S. Nuclear Regulatory Commission Standard Review Plan, Office of Nuclear Reactor Regulation, Section 3.6.3, Leak-Before-Break Evaluation Procedure," Revision 1, March 2007.

9. NUREG-1061, Volume 3, "Report of the U.S. Nuclear Regulatory Commission Piping Review Committee," prepared by the Piping Review Committee, NRC, April 1985.

10. North Anna Standard No. STD-GN-0038, Rev. 11, "Seismic Margin Management Plan (SMMP) for North Anna Units 1 and 2 Structures, Systems and Components to Address the August 23, 2011 M5.8 Mineral VA Earthquake."