Attachment 3 to AEP:NRC:6055-03

WESTINGHOUSE REPORT WCAP-16428-NP, REVISION 1, D. C. COOK UNIT 1 PRESSURIZER SAFETY VALVE NOZZLE SAFE-END WELD OVERLAY REPAIR

Westinghouse Non-Proprietary Class 3

WCAP-16428-NP
Revision 1

May 2005

D. C. Cook Unit 1 Pressurizer Safety Valve Nozzle Safe-End Weld Overlay Repair

Westinghouse

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1 INTRODUCTION

During the refueling outage in April 2005, an axially oriented indication was detected in the pressurizer safety valve nozzle to safe-end dissimilar metal weld at Donald C. Cook Unit 1. The nozzle is integrally cast into the pressurizer head, which is cast carbon steel SA216WCC. The nozzle was buttered with Alloy 82/182 filler metal and welded with Alloy 82/182 filler metal to a forged stainless steel safe-end. The function of the safe-end is to connect the pressurizer nozzle to the stainless steel pipe which leads to safety valve inlet. During subsequent ultrasonic testing (UT) examinations, the indication was found to initiate at the inside surface of the nozzle, extending approximately 1.23" into the Alloy 82/182 weld and spanning 0.4" along the axis of the nozzle. The total wall-thickness at the weld location is 1.405". The indication was confined in the Alloy 82/182 weld material, there was no evidence that the indication extended into the adjacent stainless steel or carbon steel. A full structural weld overlay repair was performed to maintain weld integrity.

Weld overlay is a repair and/or mitigation technique used to reinforce nozzle safe end regions and pipes susceptible to PWSCC (primary water stress corrosion cracking). ASME Code Case N-504-2 [3], "Alternate Rules for Repairs of Classes 1, 2, and 3 Austenitic Stainless Steel Piping" was used as guidance for the weld overlay design, which permits the use of weld deposit to build up the pipe thickness to the established acceptability requirements of Section XI, IWB-3640. The weld repair involves applying a specified thickness of weld material over the region in a configuration that assures that the structural integrity will be maintained. The weld material, Alloy 52, is applied by the GTAW (Gas Tungsten Arc Welding) process, and is considered highly resistant to IGSCC, TGSCC, (intergranular and transgranular stress corrosion cracking, respectively) and PWSCC. This process also minimizes the thickness and installation time of the weld overlay. The reinforcement material forms a structural barrier to stress corrosion cracking and produces a favorable residual stress condition that mitigates future crack initiation and/or propagation.

This report will describe the geometry created for the weld overlay repair for the pressurizer safety valve nozzle safe-end, and provide the technical basis for its application. A finite element analysis was performed to determine the residual stresses resulting from the overlay repair, and these results were used to evaluate the acceptability of the repair, as will be discussed in detail in this report.

Note that there are several locations in this report where proprietary information has been identified and bracketed. For each of the bracketed locations, the reason for the proprietary classification is given, using a standardized system. The proprietary brackets are labeled with three different letters, to provide this information, and the explanation for each letter is given below:

a. The information reveals the distinguishing aspects of a process or component, structure, tool, method, etc., and the prevention of its use by Westinghouse's competitors, without license from Westinghouse, gives Westinghouse a competitive economic advantage.

c. The information, if used by a competitor, would reduce the competitor's expenditure of resources or improve the competitor's advantage in the design, manufacture, shipment, installation, assurance of quality, or licensing of a similar product.

e. The information reveals aspects of past, present, or future Westinghouse or customer funded development plans and programs of potential commercial value to Westinghouse.

2 BACKGROUND

The Westinghouse Series 84 Pressurizer is designed for use in the primary loop of a closed cycle, pressurized light water nuclear power plant. Its function is to maintain the required reactor coolant system (RCS) pressure during steady state operation, limit the pressure changes caused by RCS thermal expansion and contraction during normal power plant load transients, and prevent the pressure in the RCS from exceeding the design pressure. The 1800 cubic foot units have three safety nozzles and one relief nozzle located in the upper head (Figure 2-1). Self actuating safety valves are designed to accommodate large volume insurges that are beyond the pressure limiting capability of the spray system and to prevent primary plant pressure from exceeding the design pressure by more than ten percent. A power-operated relief valve is set to open at slightly below design pressure, to minimize use of the safety valves.

During the spring 2005 outage at D. C. Cook Unit 1, actions were initiated to characterize the weld contours of the safety and relief nozzles, and informational UT exams were carried out. The welds were inspected to meet industry recommendations given in EPRI Material Reliability Program Letter MRP-2004-05 [23]. It was one of these exams that identified the indication of interest, which was axial, and extends over the majority of the Alloy 82/182 weld region. The depth of the flaw was found to be 1.23 inches, or 87.5 percent of the wall thickness. Because of the depth of the flaw, and the potential for future propagation, a weld overlay repair was applied.

The degradation mechanism is concluded to be PWSCC since the UT results indicate the flaw was oriented axially, multifaceted, and confined to the nickel alloy weld metal. This is consistent with recent industry findings. In September of 2003, cracking and leakage were discovered on pressurizer safety and relief nozzles in Unit 2 of Tsuruga Power Plant. Samples removed for destructive examinations contained the entire weld and a portion of the base metal on each side of the weld. Radiography was performed to confirm the linear flaws. Metallurgical failure analysis showed that the cracks initiated from the inside diameter surface, were axially oriented and were intergranular or interdendritic in nature. The conclusion of the metallurgical analysis was that the nozzle flaws were caused by PWSCC in the nozzle to safe end weld [1].

In accordance with ASME Code Case N-504-2 [3], weld metal is applied circumferentially around the pipe in the vicinity of the flawed weldment to restore ASME Code Section XI margins. An analysis of the repaired weldment is performed using paragraph (g) of the Code Case as guidance to assure that the remaining flaw will not propagate unacceptably. According to ASME Code Case N-504-2, the weld overlay is to be designed to maintain all structural requirements assuming that a through-wall defect has penetrated 360° of the pipe circumference. The weld overlay provides a replacement pressure boundary and an effective barrier to any further crack growth because of the excellent corrosion resistance inherent in the chemistry of deposits with ERNiCrFe-7 (Alloy 52) bare wire filler material or the ENiCrFe-7 (Alloy 152). Alloy 52 nickel-based weld repair material will be used rather than austenitic stainless steel as required by ASME Code Case N-504-2. All welding was accomplished using the automated machine gas tungsten arc welding (GTAW) process. Manual GTAW was used for final contour build-up. ASME Section III was used to provide guidance for repair inspection and post welding heat treatment requirements [2].

Weld overlay repairs were first applied to address intergranular stress corrosion cracking (IGSCC) in weld heat affected zones (HAZs) of boiling water reactor stainless steel piping as an alternative to pipe replacement. Weld overlays have been used extensively in BWR stainless steel piping and safe-end weld repairs. This report will provide weld overlay design and qualification for the nozzle to safe end weld for the Westinghouse Model D Series 84 Pressurizer safety nozzle (Figures 2-1 and 2-2).

Weld overlays have been used extensively in BWRs to repair flawed weldments since 1982 and have been shown to produce favorable compressive residual stresses on the inner portion of the pipe wall [5], which minimizes further crack growth. Many BWR weld overlay repairs were applied using stainless steel. However, in recent years, Alloy 52 has been used.

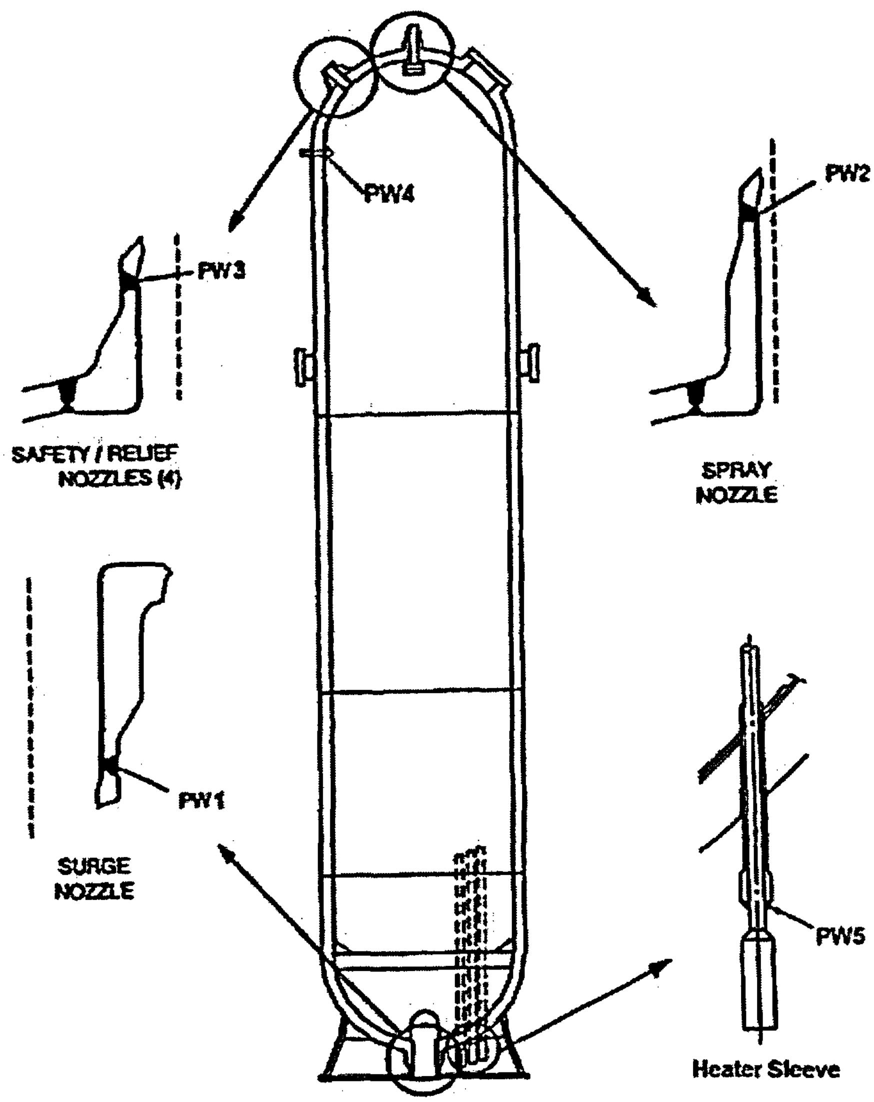

Figure 2-1 Westinghouse Pressurizer Configuration

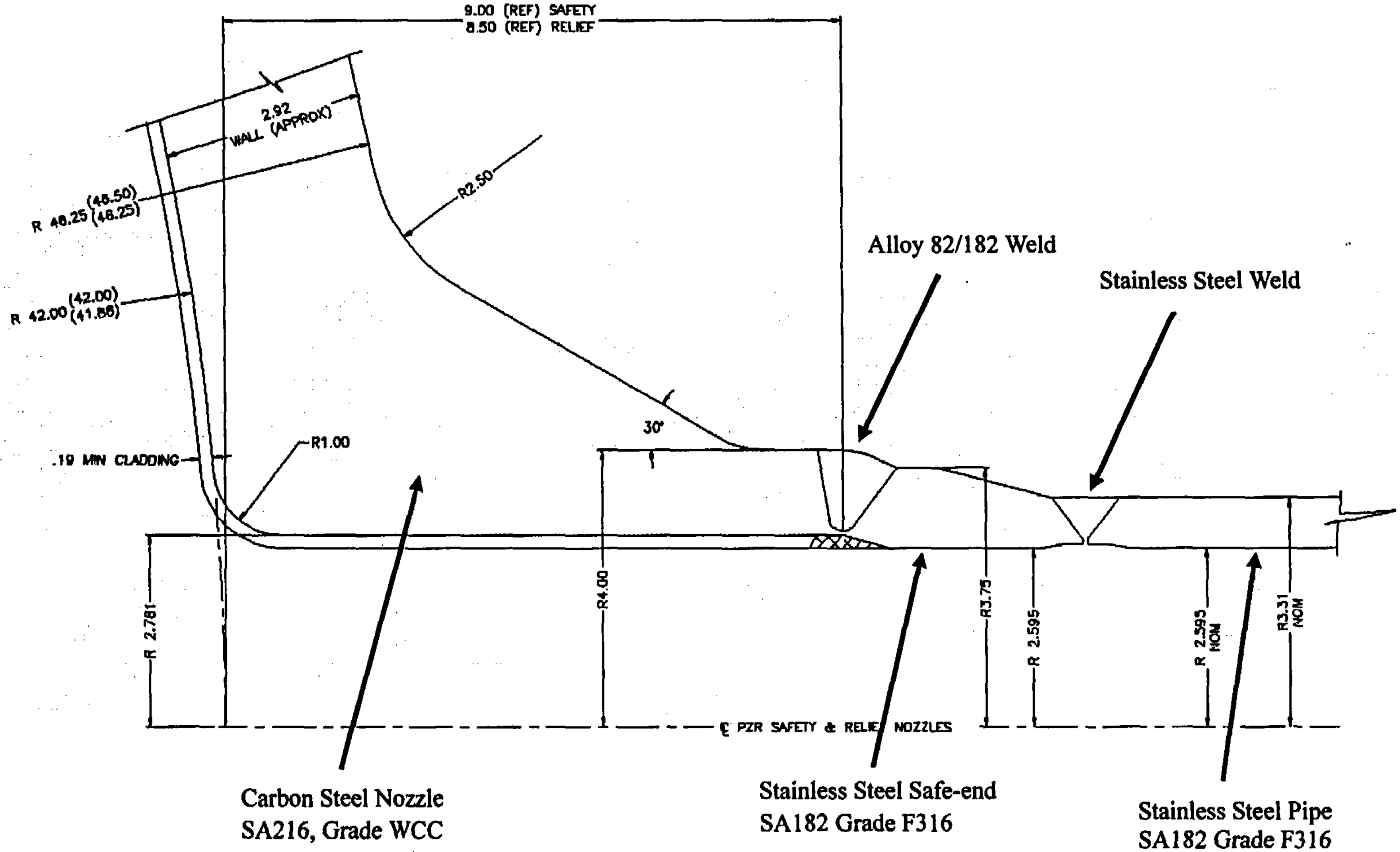

Figure 2-2 Pressurizer Safety Nozzle Geometry for the Cast Head Configuration

3 WELD OVERLAY DESIGN METHODOLOGY

The evaluation of the overlay thickness was calculated in accordance with ASME Section XI Rules for Inservice Inspection of Nuclear Power Plant Components, IWB-3640 [9], to ensure that the pressurizer safety nozzle weld overlay will provide a structural barrier that is reliable and durable, along with the guidelines of ASME Code Case N-504-2 for structural weld overlays. It is assumed that the crack is 360° in circumference, and through-wall.

3.1 DESIGN CRITERIA

The weld overlay was designed as a full structural weld in accordance with the requirements of ASME Code Case N-504-2 [3]. The overlay will extend around the full circumference of the safe-end for the required length and thickness. In accordance with ASME Section XI, IWB-3640 [9], the maximum allowable depth (a_f) for axial and circumferential flaws on the inside surface is 75 percent of the wall thickness. However, the actual allowable flaw size must be calculated in accordance with ASME Section XI Appendix C. For this case an allowable of 75 percent through-wall can be used, therefore the required repair thickness can be defined by:

$$\frac{t}{(t+h)} = 0.75$$

Where: t = wall thickness at the location of indication, 1.405 inches

h = thickness of weld overlay repair, 0.468 inches

For circumferential flaws the overlay length and end slope of the reinforcement is sufficient to provide for load redistribution from the pipe into the deposited weld metal and back into the pipe without violating applicable stress limits of Section III. The length should extend axially at least $0.75\sqrt{Rt}$ beyond each end of the observed flaws, where R and t are the outer radius and nominal wall thickness of the pipe/nozzle, prior to deposition the weld overlay, and the end slope should be no steeper than 45 degrees [3].

For axial flaws, as in this case, such reinforcement is not necessary, as Code Case N-504-2 states that the axial length of the weld overlay shall cover the weldments and the heat affected zone on each side of the weldments, with a minimum overlap of ½ in. on each end of the observed flaws. The weld overlay repair is to be applied 360° around the component to provide a full structural barrier. The repair design is shown schematically in Figure 3-1.

3.2 NOZZLE SAFE-END WELD OVERLAY DESIGN

To avoid any stress risers and to allow for future inspections, the weld material is extended and tapered across the pipe and nozzle side. Therefore, the length of the actual weld overlay exceeds the minimum length required by ASME Code Case N-504-2 for load redistribution. It is important to note that the inspection requirements are a controlling factor in weld overlay repair design. The length of the weld overlay must be sufficient for inspection of an area that is ½ inch beyond the required repair length and covers the outer 25% of the original wall thickness. Any geometric transitions must be gradual and the surface sufficiently smooth for proper operation of the inspection probe. The design shown in Figure 3-1 is considered inspectable based on current industry inspection techniques.

As indicated in the weld overlay design drawing (Figure 3-1), the design shows the minimum required thicknesses to meet the code case requirements. The cross-hatch sections indicate the structural requirements for the overlay repair, the gray area represents weld deposits that were added to facilitate inspection needs.

The weld overlay design values (thickness and length) supplied in this report are considered minimum acceptable values. Additional passes or a larger thickness will not invalidate the original analysis. The minimum thickness for the safety nozzle to safe end weld overlay repair is 0.468" with additional layers for dilution.

The weld overlay repair extends over the safe end to pipe weld as well, for inspectability reasons. The weld overlay in this region is also thick enough to qualify as a structural overlay. The thickness of the weld overlay at this location is approximately 0.48", in addition to the original thickness of 0.715".

a,c,e

Figure 3-1 Westinghouse Pressurizer Safety Nozzle Weld Overlay Design

4 MATERIAL PROPERTIES

4.1 MATERIALS

Typically, the material for the safe end and stainless steel piping are assumed to be the same. For this safety nozzle, the material of the safe end and stainless steel piping is SA 182 Grade F-316 [15]. The safe end to nozzle weld is Alloy 82/182 [15], the pressurizer nozzle and shell is ASME SA-216 Grade WCC [15].

4.2 WELD OVERLAY MATERIAL PROPERTIES

[

]a,c,e

Table 4-1a Material Properties for Stainless Steel

a,c,e

Table 4-1b Stress-Strain Values for Stainless Steel

a,c,e

Table 4-2a Material Properties for SA 216 Grade WCC

Property		70°F	200°F	400°F	600°F	800°F	1000°F	1200°F	1400°F	1600°F	1800°F	2000°F	2200°F	2400°F	2500°F
Coefficient of Thermal Expansion	ALPX (in/in/ °F)	6.50E-6	6.67E-6	7.07E-6	7.42E-6	7.76E-6	8.12E-6	8.48E-6	8.83E-6	-	-	-	-	-	-
Conductivity	KXX (Btu/hr-ft-°F)	35.1	33.6	30.9	28.0	25.2	22.4	19.5	16.4	-	-	-	-	-	-
Modulus of Elasticity	EX (psi)	29.5E6	-	-	26.7E6	-	-	21.8E6	-	-	17.4E6	-	14.3E6	-	-
Specific Heat	C (BTU/lbm-°F)	0.105	0.114	0.125	0.134	0.147	0.165	0.186	0.415	-	-	-	-	-	-
Poisson's Ratio	NUXY	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3
Density	DENS (lbs/in^3)	0.279	0.279	0.279	0.279	0.279	0.279	0.279	0.279	0.279	0.279	0.279	0.279	0.279	0.279

Table 4-2b Stress-Strain Values for SA 216 Grade WCC

a,c,e

[ ]

Table 4-3a Material Properties for Alloy 690, 600

a,c,e

Table 4-3b Stress-Strain Values for Alloy 690, 600

a,c,e

5 WELD OVERLAY FINITE ELEMENT ANALYSIS

5.1 OBJECTIVE OF THE ANALYSIS

The objective of this analysis is to determine stresses produced by a safety nozzle weld overlay repair and to evaluate the stresses for the Section XI requirements. This includes analysis to simulate the weld repair process to evaluate residual weld stresses. These analyses were performed using the ANSYS 7.1 finite element analysis program [6].

The plant specific geometry of the safety nozzle [15] was used to create the finite element model used in the analysis. Crack growth evaluations were performed using the stress results to show that the overlay is sized adequately and within allowable crack growth limits.

5.2 MODEL

The model was developed to capture the parts of the structure which are critical to the safety nozzle. This includes a portion of the pressurizer shell attached to the safety nozzle and a length of stainless steel pipe attached to the safe end. The overall model is shown in Figure 5-1. The pressurizer shell is fixed in the rotated axial (Y) direction to simulate the rest of the pressurizer shell. The stainless steel piping is coupled in the axial direction to simulate the remaining stainless steel piping material not included in the model.

The model uses PLANE42 for the structural elements and PLANE55 for the thermal elements, each with 4 nodes. The model is axisymmetric and uses isotropic, temperature dependent material properties as summarized in Section 4. Higher order elements are not used in this application because the plasticity treatment in the elements does not derive a significant benefit of the higher order shape functions. The typical analysis sequence involves a heat transfer analysis which determines applicable heat flow and temperatures (steady state or transient). The same model is used, with the element type switched from PLANE55 to PLANE42 and appropriate structural boundary conditions applied. The nodal temperatures are read into the structural model to capture the steady state or transient thermal stresses.

[

]a,c,e

5.3 WELD REPAIR SIMULATION AND DESIGN LOAD ANALYSIS

An analysis was performed to determine residual weld stresses in the repaired safety nozzle butt weld regions, to support the ASME Section XI evaluations. [

]a,c,e

[

]a,c,e

The structural analysis used a similar process. [

]a,c,e The final residual weld stresses, at normal operating conditions are shown in Figures 5-4 through 5-7 (The percentage through wall indicated in Figures 5-4 through 5-7 is equal to the original wall thickness at 100%, beyond which point is the weld overlay). The general trend of these plots indicates compressive stresses at the inside surface of the nozzle due to the weld overlay repair and tensile stress at the outside surface of the nozzle and the weld overlay. This is consistent with industry experience of weld overlay repairs.

The weld cut locations for which the through-wall stresses were taken can be found in Figure 5-3. Contour plots of the weld overlay were taken in the hoop and axial directions at the final operating and ambient condition time steps. These nodal stress plots average the results across the weld overlay boundary. Figures 5-8 and 5-9 provide the stress contours at ambient conditions, which indicates compressive stress on the inside surface of the both the stainless steel and Inconel welds. Figures 5-10 and 5-11 provide the stress contours at operational conditions, which also indicates that the inside surface of the nozzle experiences compressive stress due to the weld overlay repair.

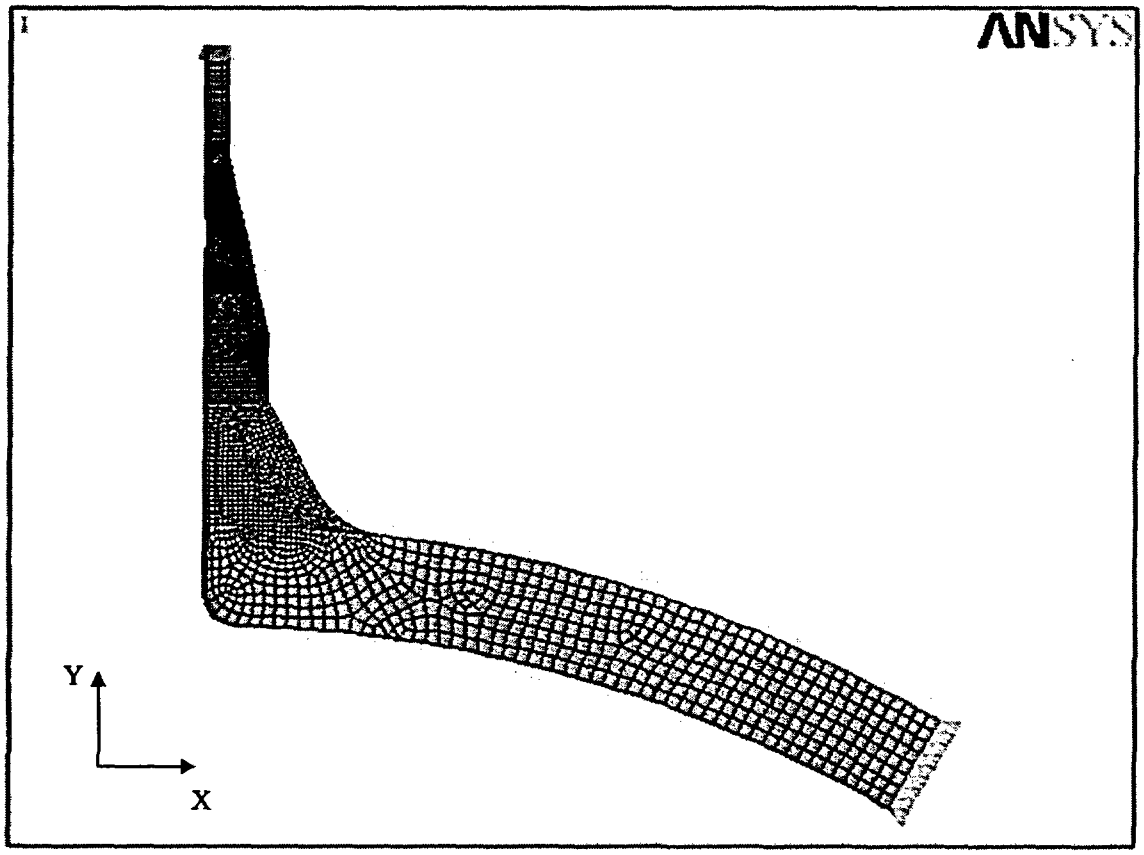

Figure 5-1 Axisymmetric Finite Element Model Used for Safety Nozzle Weld Overlay Analysis

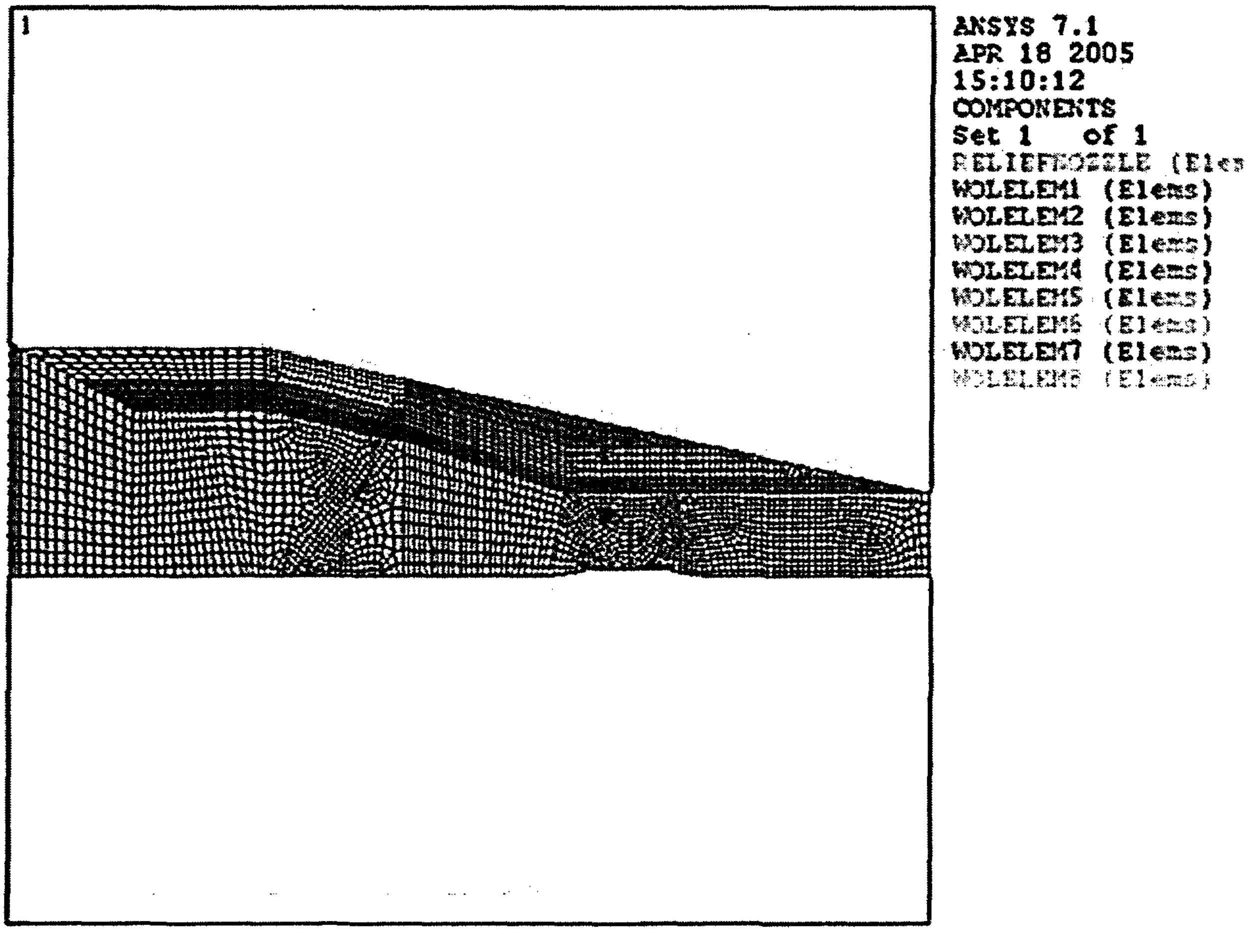

Figure 5-2 Model of Weld Overlay Segments for the Safety Nozzle Weld Overlay Stress Analysis

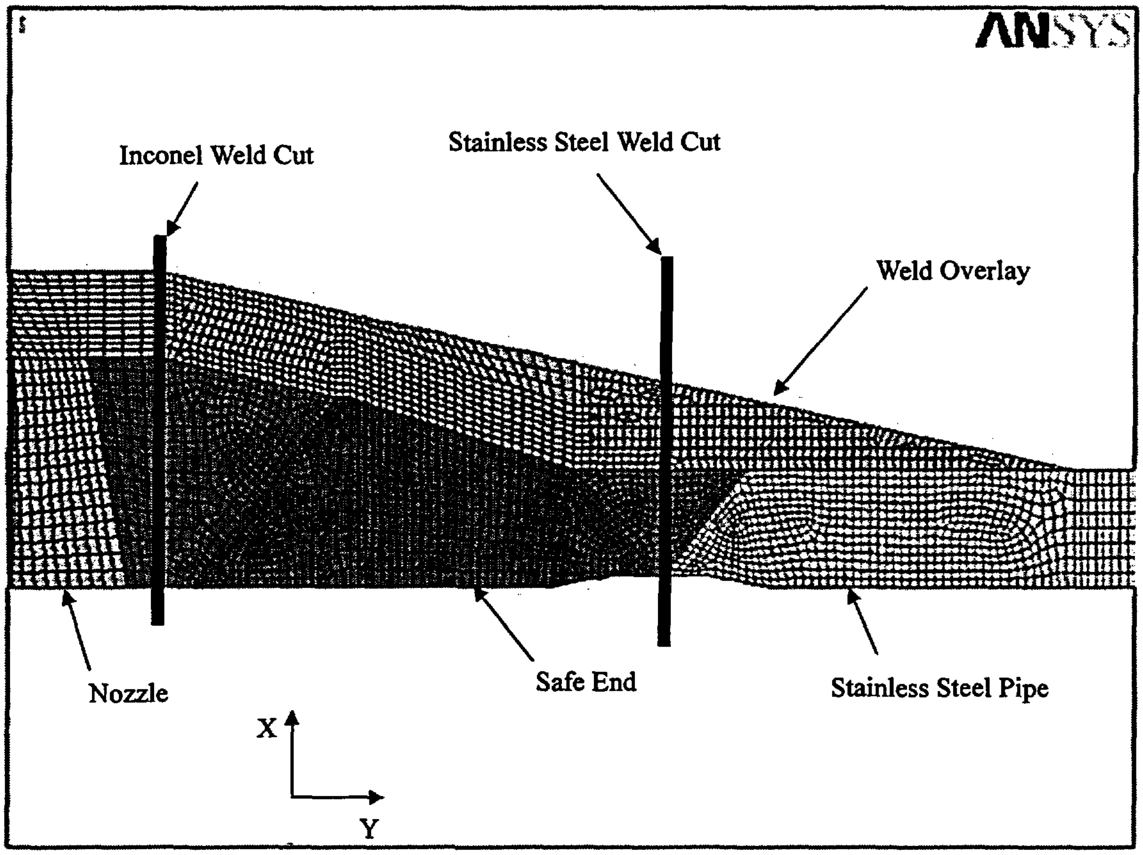

Figure 5-3 Limiting Sections of Safety Nozzle Weld Overlay (Stress Paths for Figure 5-4 through 5-7)

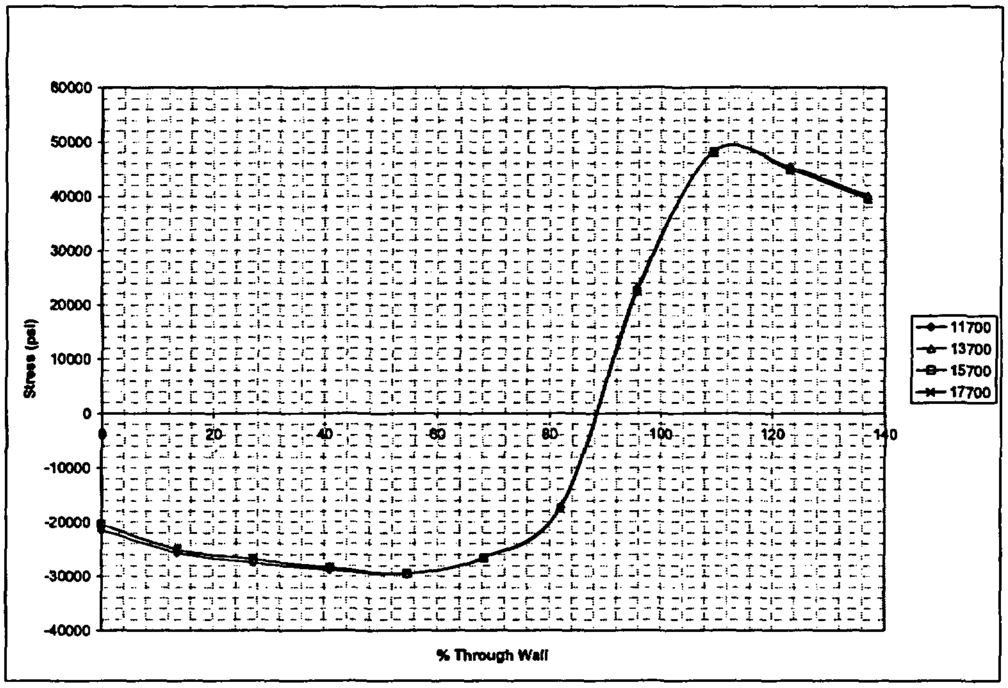

Figure 5-4* Axial Through-Wall Residual Stress Distribution at Alloy 82/182 Weld Location

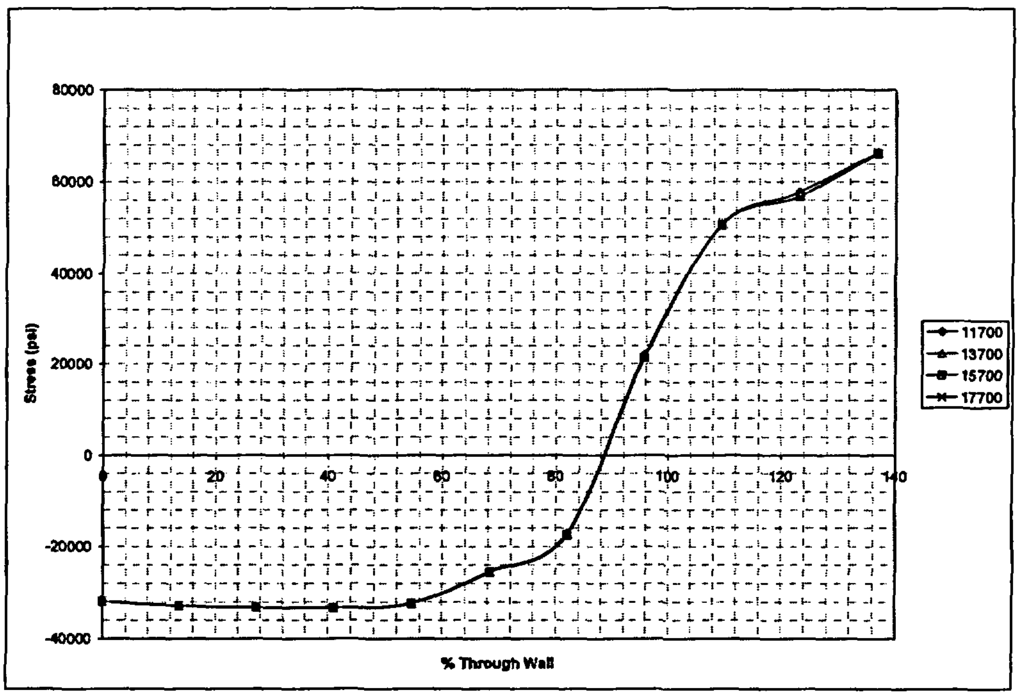

Figure 5-5* Hoop-Through Wall Residual Stress Distribution at Alloy 82/182 Weld Location

* Note, the percent through wall indicated on the X-axis is equal to the original wall thickness at 100%, beyond which point is the weld overlay

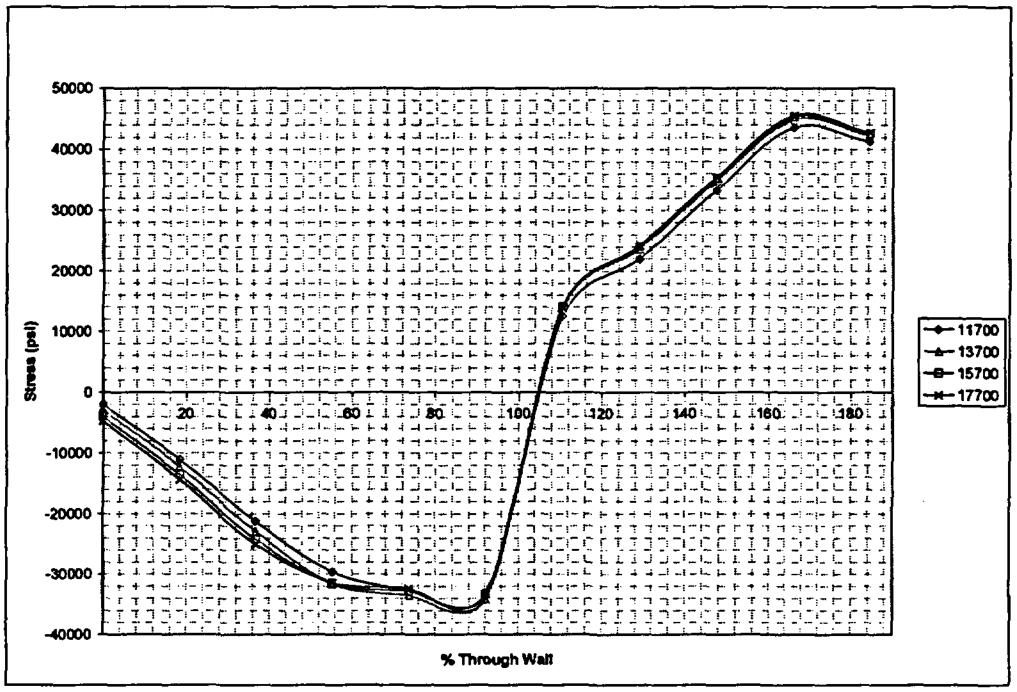

Figure 5-6* Axial Through-Wall Residual Stress Distribution at Stainless Steel Weld Location

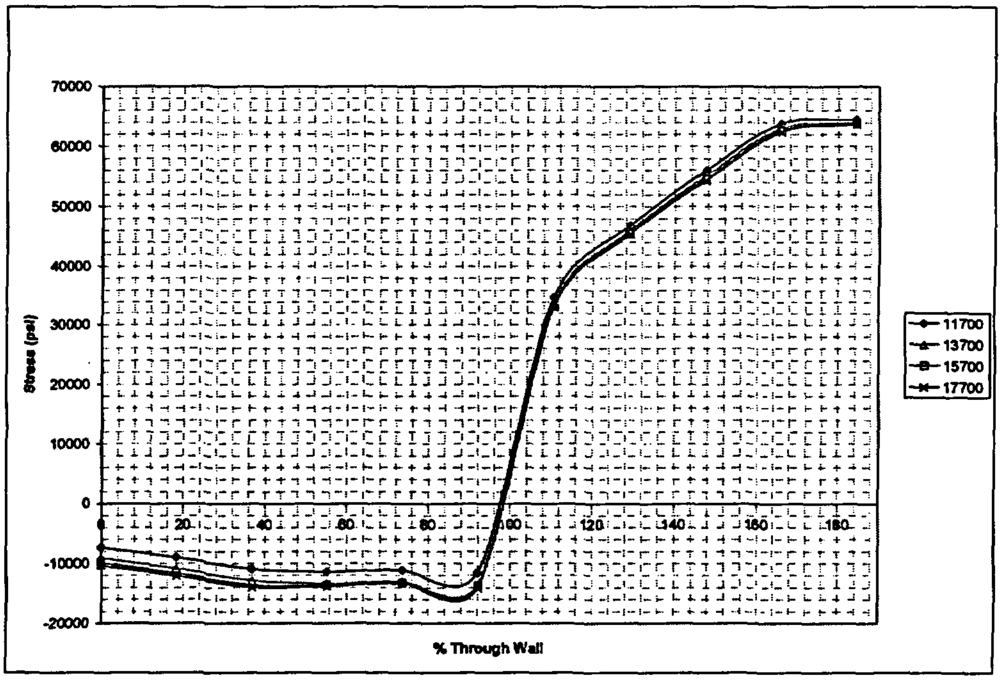

Figure 5-7* Hoop Through-Wall Residual Stress Distribution at Stainless Steel Weld Location

* Note, the percent through wall indicated on the X-axis is equal to the original wall thickness at 100%, beyond which point is the weld overlay

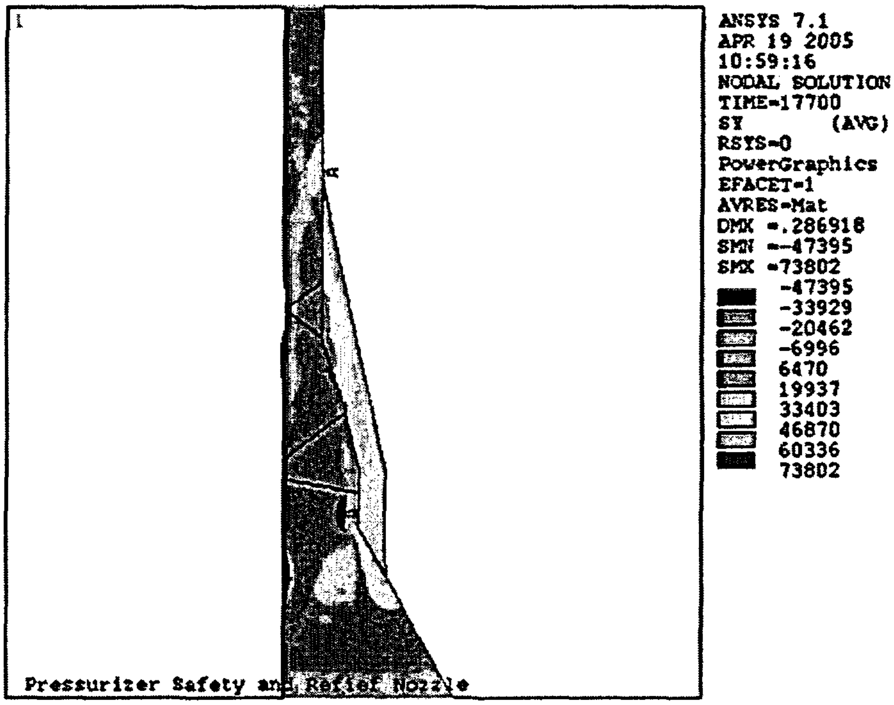

Figure 5-8 Axial Residual Stress Contour Plot at Ambient Conditions

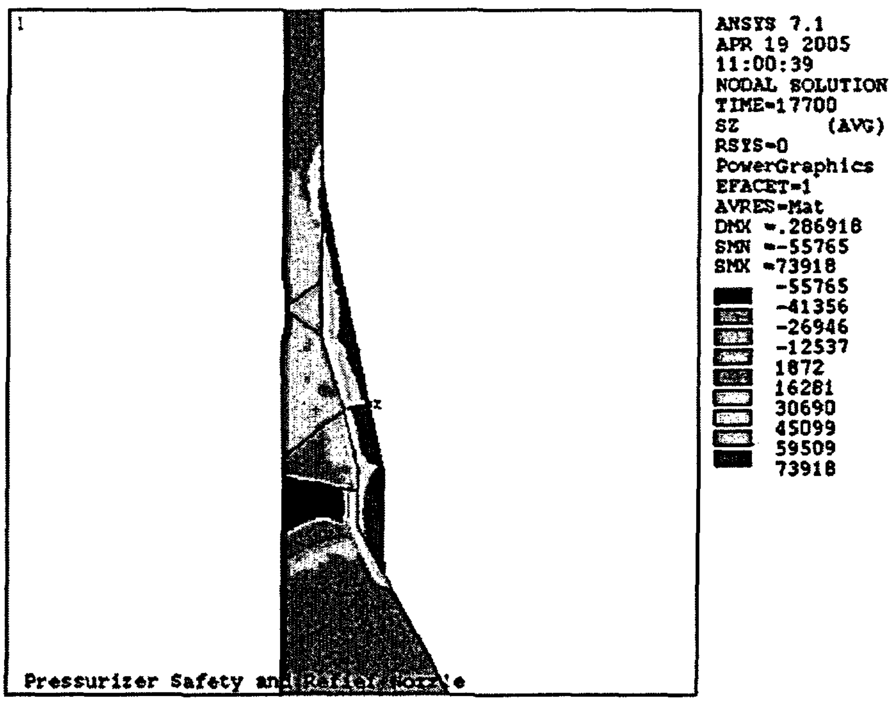

Figure 5-9 Hoop Residual Stress Contour Plot at Ambient Conditions

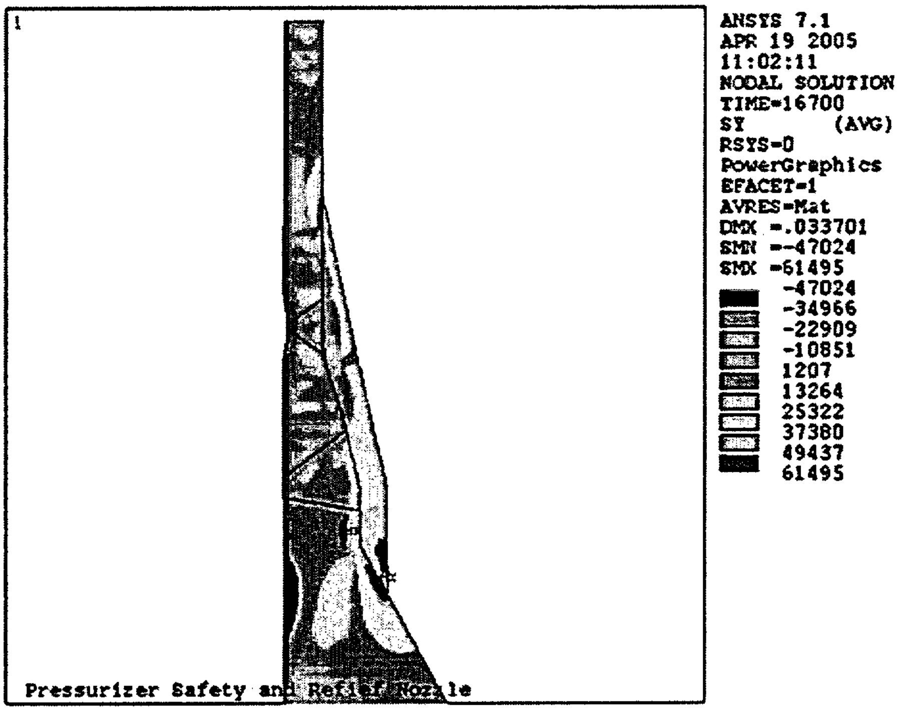

Figure 5-10 Axial Residual Stress Contour Plot at Operational Conditions

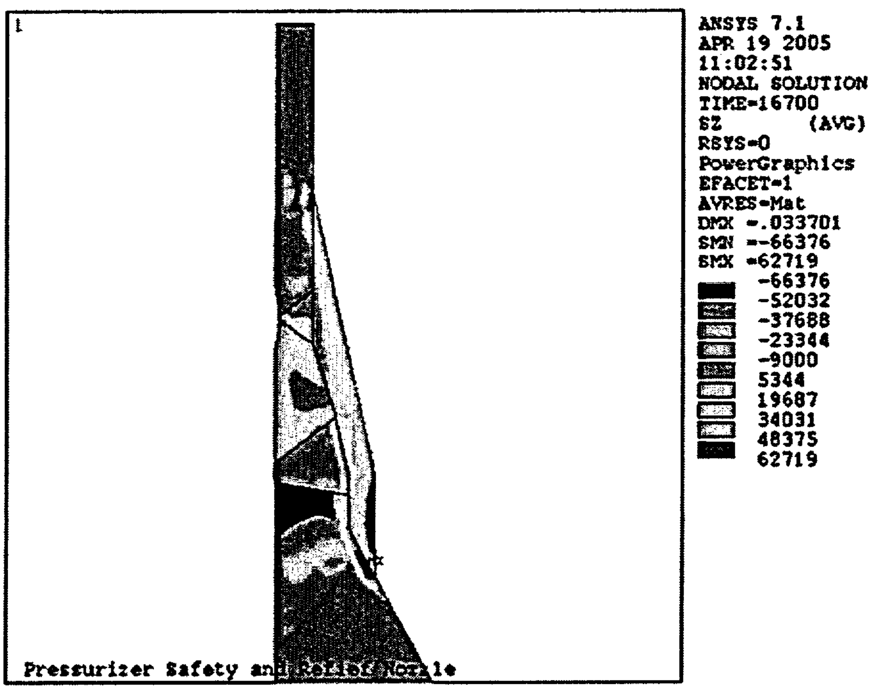

Figure 5-11 Hoop Residual Stress Contour Plot at Operational Conditions

6 CRACK GROWTH ANALYSIS

6.1 INTRODUCTION

The effectiveness of a weld overlay repair with Alloy 52 weld material is demonstrated using crack growth analysis, to ensure that the weld overlay does not deteriorate during service. Using the residual stresses developed by the finite element model of the weld overlay process, future crack growth was evaluated for the safety nozzle safe-end location, considering fatigue crack growth, using the key operational transients which affect the region.

The weld metal, Alloy 52, is the material used in weld overlay repairs for the safety nozzle safe-end. The advantage of this alloy is its highly resistant nature to TGSCC and PWSCC, so there was no need to evaluate future stress corrosion cracking. The fatigue crack growth calculations were carried out assuming that the original pipe section is cracked through.

6.2 ALLOWABLE FLAW SIZE DETERMINATION

The critical flaw size is not directly calculated as part of the flaw evaluation process for stainless steels or nickel-base alloys [10]. Instead, the failure mode and critical flaw size are incorporated directly into the flaw evaluation technical basis, and therefore into the tables of "Allowable End-of-Evaluation Period Flaw Depth to Thickness Ratio," which are contained in paragraph IWB-3640. A more accurate determination of the allowable depth can be made using the methodology of ASME Section XI, Appendix C [9].

The allowable flaw sizes of paragraph IWB-3640 for the high toughness base materials were determined based on the assumption that plastic collapse would be achieved and would be the dominant mode of failure. In performing the analyses necessary to determine allowable flaw depths and fatigue crack growth for the flaw evaluations, it is important that all the applicable loadings are considered, nozzle loads at the safety nozzle location can be found in Table 6-2. All repair welding was accomplished using automated machine gas tungsten arc welding (GTAW) process. Therefore, Appendix C of the ASME Code Section XI was used for the evaluation.

6.3 PRESSURIZER SAFETY NOZZLE TRANSIENTS AND PIPING LOADS

The design transients and the number of occurrences of these transients over the design life of the components are required to perform fatigue crack growth analysis. The design transients for typical Westinghouse Series 84 Pressurizer safety nozzle are contained in Table 6-1.

Table 6-1 Summary of Transients

Number	Transient Identification	Number of Occurrences
	Normal Conditions	
1	Heatup and cooldown	200
2	Unit loading	18,300
3	Unit unloading	18,300
4	Large step load	4,200
	Upset Conditions	
5	Loss of load	480
6	Loss of power	40
7	Loss of flow	80
8	Inadvertent spray	10
9	OBE	400
	Test Conditions	
10	Leak test	50

The loading conditions which were evaluated include thermal expansion (normal and upset), pressure, deadweight, seismic (OBE), and valve thrust. The piping loads used in the evaluation are listed in Table 6-2. The stress intensity values were calculated using the following equations:

$$\sigma_m = \frac{F_x}{A} \qquad (6\text{-}1)$$

$$\sigma_b = \frac{1}{Z}[M_y^2 + M_z^2]^{0.5}$$

where:

F_x = axial force component (membrane)

M_y, M_z = moment components (bending)

A = cross-section area

Z = section modulus

Table 6-2 Pressurizer Safety Nozzle Loads (X - North, Y- Vertical Up, Z - East) [13]						
	F_x (lb)	F_y (lb)	F_z (lb)	M_x(in-lb)	M_y(in-lb)	M_z(in-lb)
Deadweight	20	-1040	60	18230	-950	-11150
Max. Thermal	-140	-2069	-690	-28480	26920	-64200
Max. OBE	1031	1523	852	18491	18177	33944
Max. Valve Thrust	2230	3985	1460	44943	31261	48836

6.4 STRESS CORROSION CRACK GROWTH

Longitudinal or axial flaws result from hoop stresses such as pressure, thermal transient loading, and residual stresses. Therefore, only hoop stress due to residual, transient loading, and pressure stresses were considered. The finite element analysis shows the residual stress [Section 5] produced during the repair process is significantly compressive on the inside surface of the pipe. Even when the hoop stress due to pressure is superimposed on the residual stress, the total stress on the inside surface of the pipe remains compressive. This results in a negative stress intensity factor ~50% through the wall. Since PWSCC does not occur under compressive stress, the overlay repair mitigates PWSCC for axial flaw.

A circumferential flaw, on the other hand, is caused by axial stresses from pressure loads, thermal transient loads, and residual stresses. The axial residual stress is also compressive at the inside surface of the pipe. In comparison to the normal operational loads, the residual stresses are much higher. Therefore, PWSCC of the postulated circumferential flaw is not expected. Thus, if only PWSCC were being considered, no growth of either axial or circumferential flaws would be expected.

The weld overlay material is Alloy 52, which is applied to the both stainless steel weld and the Inconel weld on the safe-end. In nickel base alloys (Alloy 52 or 690) there are no ferrites, and the PWSCC resistance comes from the high level of chromium in the alloy. Therefore, the initial layer can be retained as PWSCC resistant provided the chromium level is sufficient. When diluted with carbon steel, the chromium level of the diluted first layer produced by an Alloy 52 weld overlay is expected to be less than 25% since the carbon steel does not contain chromium. The chromium level of the deposit should approach 25% by the second layer of weld material, thereby producing a deposit that is resistant to PWSCC. However, neither layer is credited towards the weld overlay repair for added conservatism.

PWSCC growth of an axial or circumferential flaw will not occur and will not penetrate the original pipe wall due to the significant compressive residual stress from the weld overlay repair process. Considering the improbable scenario where PWSCC is not fully mitigated, the likelihood of PWSCC growing beyond the original pipe wall is negligible due to the highly resistant Alloy 52 material. This conclusion is consistent with similar results for BWR weld overlay.

6.5 FATIGUE CRACK GROWTH

The fatigue crack growth analysis procedure involves postulating an initial flaw at the regions of concern. In this case, the initial postulated flaw is equal to the original wall-thickness, 1.405 inches for the Inconel weld location and 0.715 inches for the stainless steel weld location. The postulated flaws are subject to cyclic loads due to transients. The input required for a fatigue crack growth analysis is basically the information necessary to calculate the parameter ΔK_I (range of stress intensity factor), which depends on the crack size, crack shape, geometry of the structural component where a crack is postulated, and the applied cyclic stresses.

The transients considered in the analysis are the design transients for typical Westinghouse Series 84 Pressurizer at the safety nozzle location, as shown in Table 6-1. The transient stresses were combined with through-wall residual stress distribution from the finite element analysis to determine ΔK_I. Once ΔK_I is calculated, the growth due to a particular stress cycle can be calculated by an equation developed from References 11, 17, and 18. This incremental growth is then added to the original crack size, and the analysis proceeds to the next cycle or transient. The procedure is continued in this manner until all of the analytical transients predicted to occur in the remaining design life of operation have been analyzed. The fatigue crack growth is calculated by computer program FCG Reference [4].

Fatigue Crack Growth Rate Reference Curves for Alloy 52

The fatigue crack growth rate reference curve for these nickel base alloys was obtained from the literature. The material properties of Alloy 600 and Alloy 52 are very similar, therefore it is assumed the crack growth rate of Alloy 600 can be applied to Alloy 52. The crack growth rate is a function of both R Ratio (K_{min}/K_{max}) and the range of applied stress intensity factor. Using the results reported in References 19 through 22, a model was developed for application to water environment, as shown below.

$$\frac{da}{dN} = C S_R S_{ENV} \Delta K^n \qquad (6\text{-}2)$$

where: $C = 4.835\times10^{-14} + 1.622\times10^{-16}T - 1.490\times10^{-18}T^2 + 4.355\times10^{-21}T^3$

$S_R = [1 - 0.82R]^{-2.2}$

$S_{ENV} = 1 + A[CS_R\Delta K^n]^{m-1} T_R^{1-m}$

$A = 4.4\times10^{-7}$

$m = 0.33$

$n = 4.1$

where: $T = {}^oC$

$\Delta K = MPa\sqrt{meter}$

$R = K_{min} / K_{max}$

This model was proposed by Chopra et al in Reference 22, and was judged to be conservative for this application, as it includes data for water environments with Oxygen contents up to 10 ppb, as shown in Figure 6-1. The typical PWR water chemistry has an Oxygen level which is too low to measure, since it is scavenged by the presence of a Hydrogen overpressure. This factor was accounted for by the choice of a rise time of 30 seconds for the model.

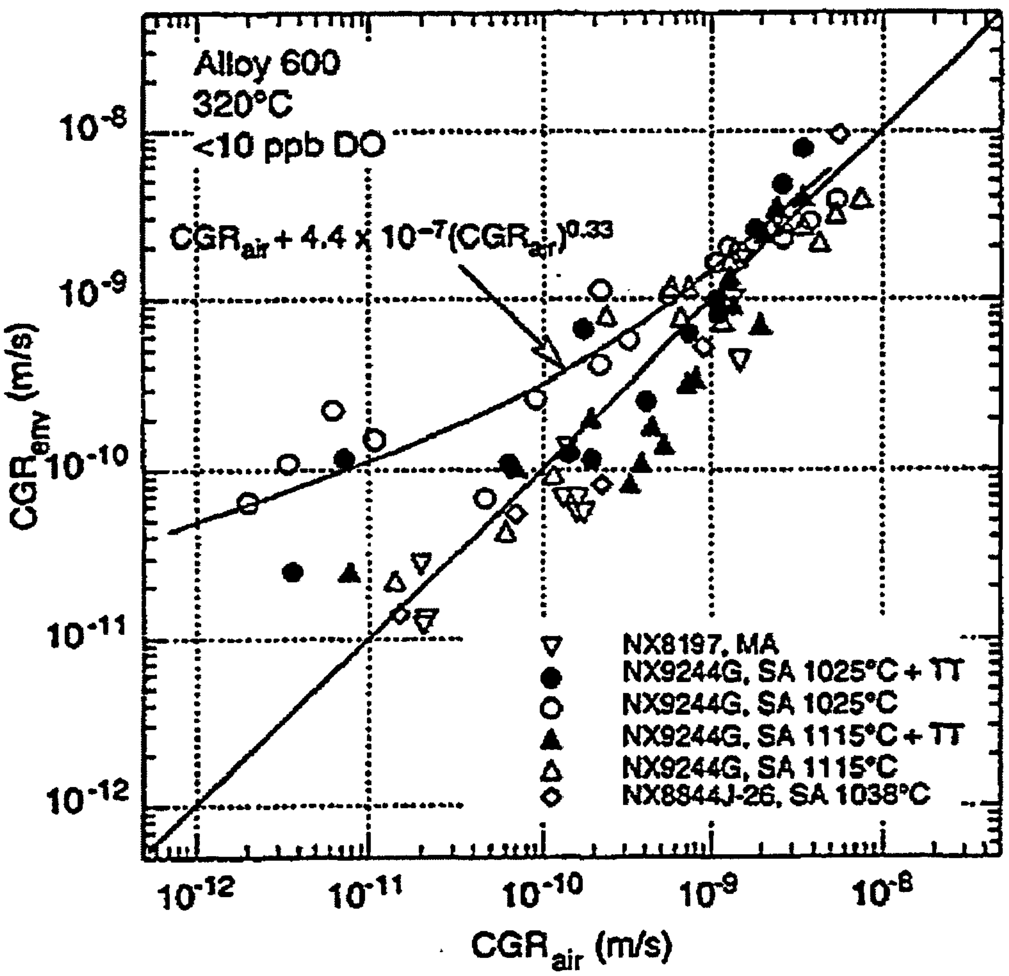

Figure 6-1 Fatigue Crack Growth Model Development for Water Environment

Fatigue Crack Growth Rate Reference Curves for Stainless Steel

The reference crack growth law used for the stainless steel appears in Section XI, Appendix C (1989 Edition, Figure 6-2) for air environments and its basis is provided in Reference 12. For water environments, an environmental factor of 2 was used, based on the crack growth tests in PWR environments reported by Reference 14.

$$\frac{da}{dN} = C_o S \, \Delta K_I^{\,n} \qquad (6\text{-}3)$$

where: $\frac{da}{dN}$ = crack growth rate, inches per cycle

C_o = material coefficient $(C_o = 10^{[-10.009 + 8.12E-04T - 1.13E-06T^2 + 1.02E-09T^3]})$

S = (S = 1.0 for R=0; S=1+1.8R for 0<R<0.79; S = -43.35+57.97R, for 0.79<R<1.0)

n = material property slope (=3.30)

ΔK_I = stress intensity factor range, $ksi\sqrt{in}$

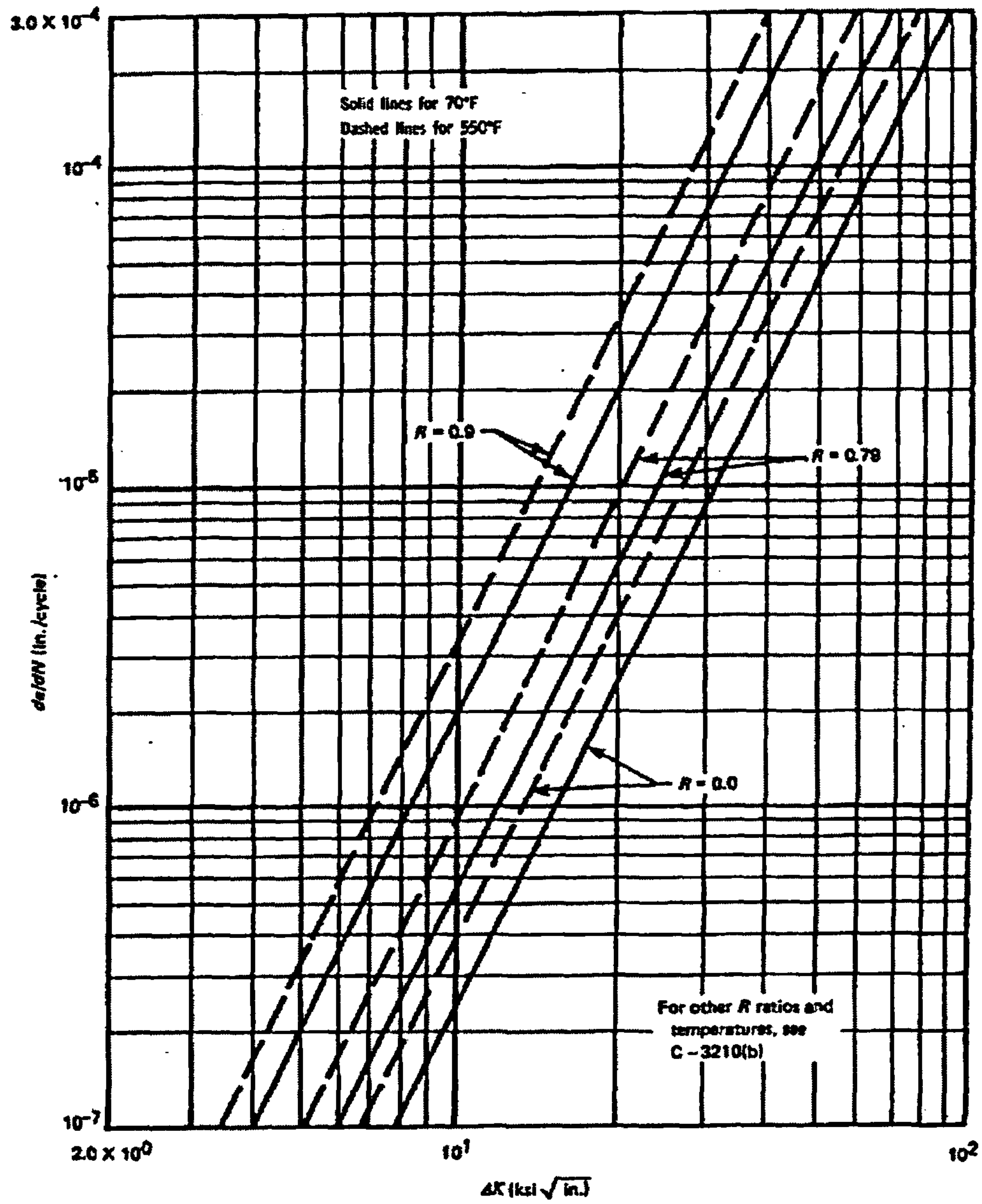

FIG. C-3210-1 REFERENCE FATIGUE CRACK GROWTH CURVES FOR AUSTENITIC STAINLESS STEELS IN AIR ENVIRONMENTS

Figure 6-2 Reference Crack Growth Rate Curves for Stainless Steel in Air Environments [12]

The results of the fatigue crack growth analysis indicate that crack growth is non-existent for the Alloy 82/182 weld location even after 40 years of service, as shown in Table 6-3 and Table 6-5 for axial and circumferential flaws, respectively. The evaluation was carried out using an initial flaw size equal to the original wall thickness (1.405"), not accounting for any remaining ligament. This is due to the high compressive stresses produced during the repair process. The crack growth evaluation shows that the compressive residual stresses from the weld overlay repair is sufficient to mitigate any further crack growth.

Fatigue crack growth is insignificant for the stainless steel weld location after 40 years of operation, as shown in Table 6-4 and Table 6-6 for axial and circumferential flaws, respectively. This is also due the high compressive residual stresses. Although no cracking was found in this location, an initial flaw size equal to the original wall thickness (0.715") was used for the evaluation. In addition, to fulfill inspection requirements, the weld metal deposited at this location is beyond code requirements for structural weld overlay therefore providing a higher flaw tolerance allowable to this region if any cracking is to occur.

Table 6-3 Fatigue Crack Growth Results for Safety Nozzle Safe-End Inconel Weld Location, Axial Flaw

Aspect Ratio	Time (years)				
	Initial Flaw Size (in.)	10	20	30	40
2	1.405	1.4050 (in.)	1.4050 (in.)	1.4050 (in.)	1.4050 (in.)
3	1.405	14050 (in.)	14050 (in.)	14050 (in.)	14050 (in.)
6	1.405	1.4050 (in.)	1.4050 (in.)	1.4050 (in.)	1.4050 (in.)
10	1.405	1.4050 (in.)	1.4050 (in.)	1.4050 (in.)	1.4050 (in.)
100	1.405	1.4050 (in.)	1.4050 (in.)	1.4050 (in.)	1.4050 (in.)

Table 6-4 Fatigue Crack Growth Results for Safety Nozzle Safe-End Stainless Steel Weld Location, Axial Flaw

Aspect Ratio	Time (years)				
	Initial Flaw Size (in.)	10	20	30	40
2	0.715	0.7150 (in.)	0.7151 (in.)	0.7151 (in.)	0.7152 (in.)
3	0.715	0.7152 (in.)	0.7153 (in.)	0.7155 (in.)	0.7156 (in.)
6	0.715	0.7155 (in.)	0.7160 (in.)	0.7165 (in.)	0.7170 (in.)
10	0.715	0.7159 (in.)	0.7169 (in.)	0.7178 (in.)	0.7187 (in.)
100	0.715	0.7173 (in.)	0.7196 (in.)	0.7219 (in.)	0.7243 (in.)

Table 6-5 Fatigue Crack Growth Results for Safety Nozzle Safe-End Inconel Weld Location, Circumferential Flaw					
Aspect Ratio	Time (years)				
	Initial Flaw Size (in.)	10	20	30	40
2	1.405	1.4050 (in.)	1.4050 (in.)	1.4050 (in.)	1.4050 (in.)
3	1.405	14050 (in.)	14050 (in.)	14050 (in.)	14050 (in.)
6	1.405	1.4050 (in.)	1.4050 (in.)	1.4050 (in.)	1.4050 (in.)
10	1.405	1.4050 (in.)	1.4050 (in.)	1.4050 (in.)	1.4050 (in.)
100	1.405	1.4050 (in.)	1.4050 (in.)	1.4050 (in.)	1.4050 (in.)

Table 6-6 Fatigue Crack Growth Results for Safety Safe-End Stainless Steel Weld Location, Circumferential Flaw					
Aspect Ratio	Time (years)				
	Initial Flaw Size (in.)	10	20	30	40
2	0.715	0.7150 (in.)	0.7150 (in.)	0.7150 (in.)	0.7150 (in.)
3	0.715	0.7150 (in.)	0.7150 (in.)	0.7150 (in.)	0.7150 (in.)
6	0.715	0.7151 (in.)	0.7152 (in.)	0.7153 (in.)	0.7153 (in.)
10	0.715	0.7153 (in.)	0.7155 (in.)	0.7158 (in.)	0.7160 (in.)
100	0.715	0.7160 (in.)	0.7170 (in.)	0.7181 (in.)	0.7191 (in.)

6.6 STRESS REPORT RECONCILIATION

The addition of the weld material (approximately 50-60 pounds) is small in comparison to the weight of the piping, nozzle, and safe end. Therefore, the nozzle moments, deadweight, and seismic stresses with respect to primary stresses will not be significantly affected. Hence, the current stress analysis of the nozzle and piping will not be significantly impacted by the added weld mass.

It is not required by ASME Code Case N-504-2 to evaluate the primary stresses nor the primary plus secondary stresses for the safety nozzle weld overlay repair. However, to assess the general impact of the weld overlay on the safety nozzle, finite element analysis were performed for the nozzle/safe end region using models both with and without the overlay repair. The intent of this evaluation is to conduct a comparative study to assess whether the weld overlay increases or decreases the applicable safety nozzle hoop and axial stresses, and not to perform a fatigue analysis. If the stresses are about the same or reduced with the weld material, the original stress reports will be valid for the primary plus secondary stress limits, and no further reconciliation of the ASME code design analysis is required.

For the pressure loading case, the total stresses are lower for the model with the weld overlay than without due to the increase in wall thickness. However, the thermal stresses were higher, due to the dissimilar metal weld. Therefore the pressure plus thermal stresses are higher for the model with weld overlay than without. The results indicate that the primary stresses are lower; however, the secondary and the primary plus secondary stresses resulting from a safety nozzle weld overlay repair will be higher than in the original safety nozzle. Even though primary plus secondary stresses are higher now than before the application of the weld overlay, a comparison of the usage before and after the weld overlay is not necessary because the previously described fatigue crack growth analysis can be used to qualify the fatigue status.

Shrinkage effects due to weld overlay repair were considered using the ANSYS finite element model. A node on the inside surface and at the end of the stainless steel pipe (but removed from the constraints) was chosen to demonstrate the axial displacement of the safety nozzle. The axial displacement (UY) of the stainless steel pipe will determine effects on piping loads. A node on the inside surface of the safe-end was chosen to demonstrate the radial displacement (UX) of the safety nozzle. The displacement of these two locations can be seen in Table 6 -7. Due to the insignificant change in both axial and radial displacement, shrinkage effects were deemed negligible. In addition, the overlay is blended smoothly to the nozzle interface as well as the stainless steel pipe interface to reduce any stress intensification.

Table 6-7 Safety Nozzle Axial and Radial Displacements Due to Weld Overlay Repair

Location	Displacement Orientation	Displacement (inches)
Inside Surface of Stainless Steel Pipe	Axial	-0.0211
Inside Surface of Safe-end	Radial	-0.0237

7 WELD OVERLAY ACCEPTANCE INSPECTION

The final requirement of Code Case N-504-2 is a UT inspection of the weld overlay. Since the overlay extends over both the Alloy 182/82 weld and the stainless steel weld, both were investigated, as well as the overlay itself. The inspectability of the entire region was improved by the overlay process, because it produced a smoother surface on the outside of the nozzle than the original surface.

The overlay was found to be defect-free, a remarkable achievement compared to previous overlays, which typically have 15 to 20 indications to be resolved. A small area of lack of fusion was identified between the overlay and the nozzle, but it was acceptable to the standards of Section XI, IWB-3500.

As part of the acceptance inspection, the stainless steel weld was scanned, and an additional indication was found in that weld [24]. The UT determined wall thickness at this location was 0.75 inches, and the indication was axially oriented, and was not surface breaking. The through-wall dimension was 0.29 inches, with a ligament of 0.09 inches between the indication and the ID surface. This qualified the indication as embedded, according to the criteria of Section XI. The indication was found to be nearly circular, as its width was 0.30 inches.

This indication can be evaluated for acceptability using the flaw acceptance criteria of IWB-3640, but the weld overlay repair extends over this region, as discussed in Section 3, and so it has already been repaired. Therefore, the additional indication has already been dealt with, and no further action is necessary.

8 SUMMARY

The pressurizer safety nozzle weld overlay design was based on the requirements of Code Case N-504-2 and ASME Section XI IWB-3640. Both finite element stress analysis and fatigue crack growth showed that the repair meets the appropriate requirements. In accordance to ASME Code Case N-504-2, the minimum weld overlay thickness for the safety nozzle is 0.468 inches, not including dilution or sacrificial layers. The weld overlay design values (thickness, number of passes) supplied in this report are considered minimum acceptable values. Additional passes or a larger thickness will not invalidate the original analysis.

The use of Alloy 52 weld material is widely accepted in the industry for its stress corrosion resistant property and along with the GTAW process will further reinforce the effectiveness of a structural weld overlay repair for the safety nozzle. The weld residual stress was demonstrated to provide a favorable stress field to mitigate PWSCC. The finite element analysis performed showed that the weld overlay repair results in a compressive stress field on the inside surface of the pipe, essentially eliminating the potential for any axial or circumferential crack propagation. The compressive residual stress also dramatically reduced the potential for fatigue crack growth to occur.

The added thickness to the nozzle safe end will further ensure the structural integrity of the safety nozzle due to the weld overlay repair. Consequently, the weld overlay repair method is a viable PWSCC mitigation and repair method, and has demonstrated to have many successful repairs in previous applications.

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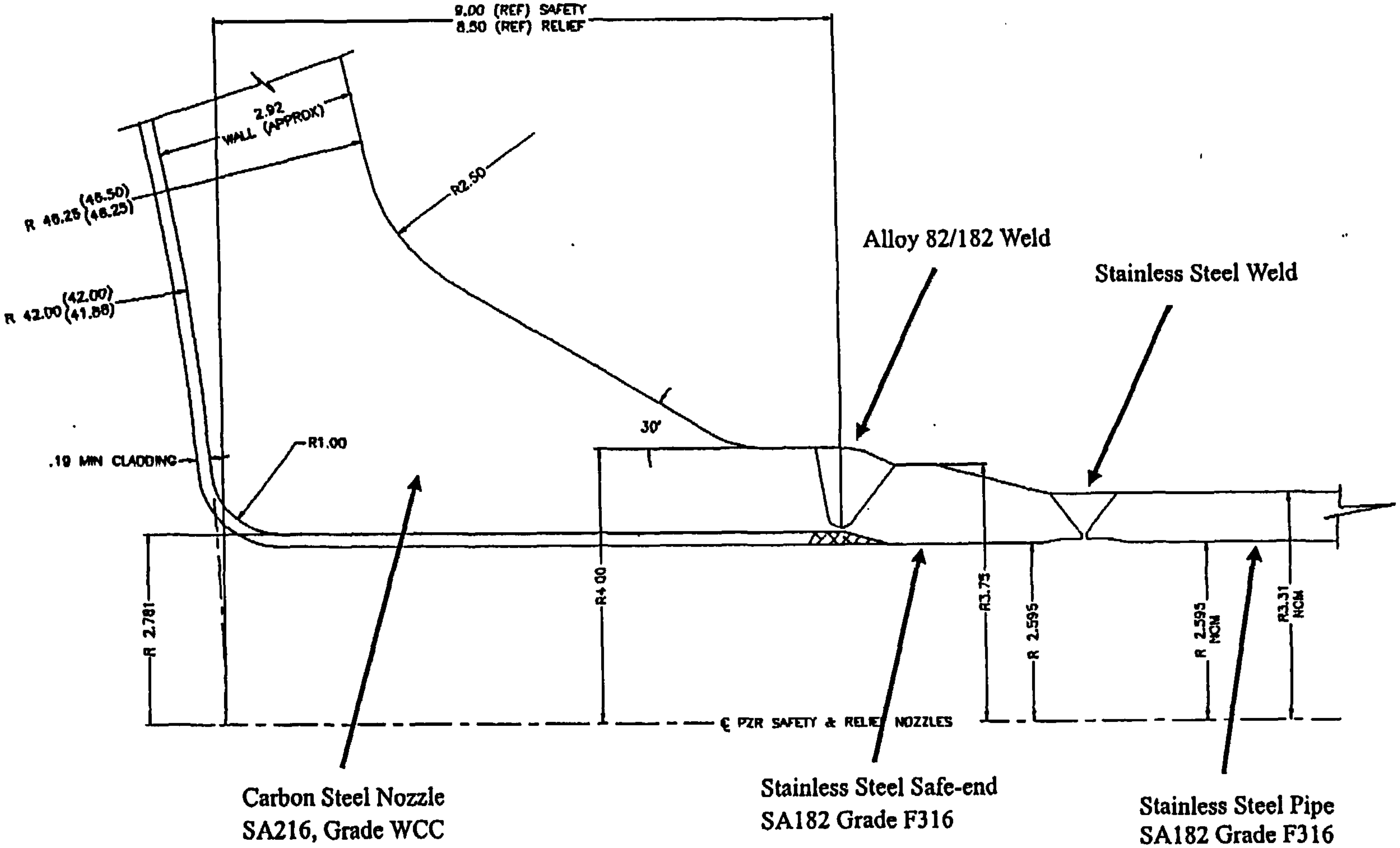
Attachment 4 to AEP:NRC:6055-03

DRAWINGS ILLUSTRATING THE WELD CONFIGURATION AND FLAW LOCATION

The component labeled "Stainless Steel Pipe" in the first drawing is the same component labeled "Stainless Steel Elbow" in the second drawing.



Pressurizer Safety Nozzle Geometry for the Cast Head Configuration

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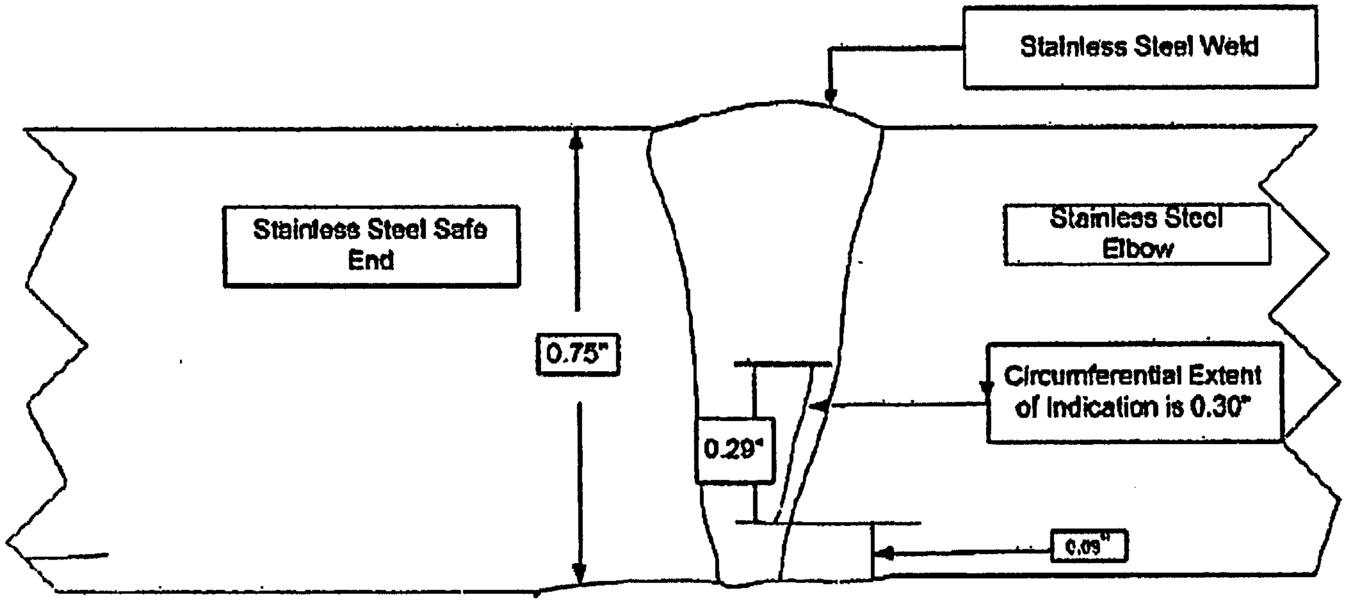

View Looking in the Circular Direction

Cook Nuclear Plant
1-RC-9-01F

NOTE: This form is derived from 12 EHP 5040.PWD.001. It or a form similar to it may be used provided the content is consistent with the current revision of that procedure.

Attachment 5 to AEP:NRC:6055-03

REACTOR COOLANT SYSTEM DESIGN TRANSIENTS – PROJECTION TO 60 YEARS

Table 4.3-1
RCS Design Transients—Projection to 60 Years

Design Transient	Number of Design Transients	Number of Transients Logged as of 10/31/98		Projected Number of Transients at 60 Years of Operation[1]	
		Unit 1	Unit 2	Unit 1	Unit 2
Level A Limits (Normal)					
Heatup events	200	44	50	110	145
Cooldown events	200	44	49	110	142
Unit loading at 5% of full power per minute	18300 (U2) 11680 (U1)	Not monitored. Since the units are base loaded, the frequency of loading/unloading transients will be of the same order as the number of heatup and cooldown cycles. Therefore, this transient does not need to be tracked.			
Unit unloading at 5% of full power per minute	18300 (U2) 11680 (U1)	Not monitored. See comment above.			
10% step load increase	2000	73[2]	73[2]	183	212
10% step load decrease	2000	57[2]	57[2]	143	166
Large step load decrease with steam dump	200	1	0	3	0
Feedwater cycling/hot standby (secondary side)	18300	Not monitored. I&M has modified the plant design and operations to preclude feedwater nozzle cracking from being a concern.			
Turbine roll test	10	0	0	0	0
Steady-state fluctuations	Infinite	NA	NA	NA	NA
Level B Limits (Upset)					
Loss of load	80	0	0	0	0
Loss of AC electrical power	40	3	2	8	6
Loss of flow in one loop	80	0	0	0	0

Table 4.3-1 (Continued)
RCS Design Transients—Projection to 60 Years

Design Transient	Number of Design Transients	Number of Transients Logged as of 10/31/98		Projected Number of Transients at 60 Years of Operation[1]	
		Unit 1	Unit 2	Unit 1	Unit 2
Reactor trip	400	69.19	68.95	173	200
Operating basis earthquakes – except RPV	400	0	0	0	0
Operating basis earthquakes – RPV	200	0	0	0	0
Level C Limits (Emergency)	None				
Level D Limits (Faulted)					
Large reactor coolant pipe break	1	0	0	0	0
Steam line break	1	0	0	0	0
Safe shutdown earthquake	1	0	0	0	0
Test Conditions					
Primary side leak test	50	1	1	3	3
Hydrostatic test (primary)	5	1	1	3	3
Hydrostatic test (secondary)	5	1	1	3	3

1. Projected cycles = cycles as of 10/25/98 * 2.5 (Unit 1) or *2.9 (Unit 2). Numbers are rounded up to the nearest whole number. 2.5 = 60 years/24 years of operation for Unit 1 and 2.9=60 years/21 years of operation for Unit 2.
2. Only one value for both units.

Attachment 6 to AEP:NRC:6055-03

DIT-S-01504-00

AEP DESIGN INFORMATION TRANSMITTAL (DIT)

DIT Form, Part 1

☒ SAFETY-RELATED ☐ NON-SAFETY-RELATED	**Originating Organization** ☒ AEP ☐ Other (specify)	DIT No DIT-S-~~01505~~ 01504-00 KNK 6/15/05
D.C. Cook Unit: 1 System Designation RCS		Page 1 of 3 To Chris Ng, Westinghouse

Subject: Provide ultrasonic data from Weld 1-RC-9-01F examination for IWB-3600 analysis

Paul Donavin	Principal Engineer	[signature]	5/18/05
Preparer	Position	Preparer's Signature	Date
Roy E. Hall	ISI Program Owner	R E Hall	5/18/05
Reviewer	Position	Reviewer's Signature	Date
Carl R. Lane	ENG. PROG. SUPV.	Carl Lane	5/18/05
Approver	Position	Approver's Signature	Date

Status of Information: ☒ Approved for Use ☐ Unverified

Method and Schedule of Verification for Unverified DITs N/A

CR# N/A

Holds Associated with Unverified DITs: None

Description of Information: The attached field walkdown data describes the indication in the subject weld.

Purpose of Issuance (Including any Precautions or Limitations):
The purpose of this information is to provide input to the IWB-3600 Analysis.

Source of Information: Attached field walkdown report

Engineering Judgement Used? ☐ Yes ☒ No

Controlled Reference / Document No.:

Uncontrolled Reference / Document No.:

Distribution: Copy to Requestor Chris Ng, Westinghouse
Copy to DIT Administrator File
Original to NDM (Transmitted by DIT Administrator)

This form is derived from the information in 12-EHP-5040-DES-001, Control of Design Input.

AEP DESIGN INFORMATION TRANSMITTAL (DIT)

DIT Form, Part 2

FIELD DATA WALKDOWN

(Use Continuation Sheets as required)

SCOPE: (Describe the desired data to be collected. Provide component ID's, document references, plant locations, etc., as needed.)

Provide data on the indication in Weld 1-RC-9-01F including available dimensions and orientation

Prepared by: (Print/Sign) _Paul Donavin / Paul R Donavin Date: 5/18/05

Item	Data	Observed By (Initial)	Verified By (Initial)
1	Flaw orientation and dimensional data (see attached sketch) in the fusion zone of 1-RC-9-01F.	REH	PRD
2	UT-05-067. NDE REPORT FOR 1-RC-9-01F.	REH	PRD

Data Collected By:
Roy E. Hall ROY E. HALL R E Hall REH 5/18/05 5/18/05
(Print Name/Signature) (Initials) Date

Two-party Verification Performed By
Paul R. Donavin / Paul R Donavin PRD 5/18/05
(Print Name/Signature) (Initials) Date

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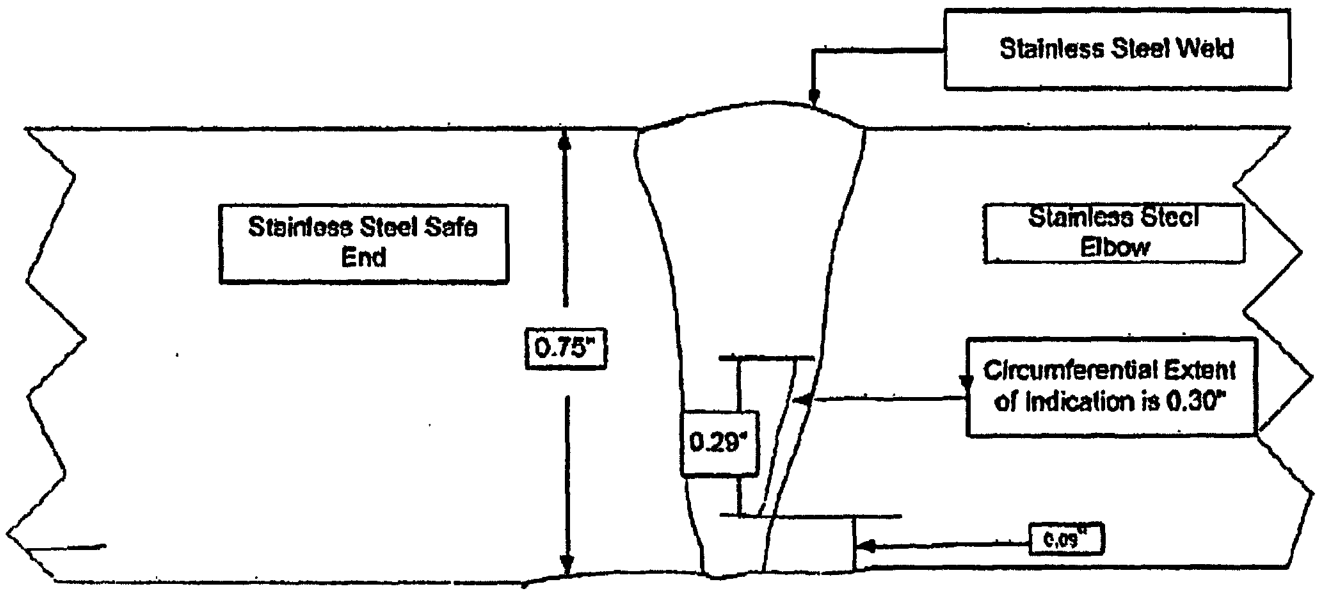
DIT-S-01504-00



View Looking in the Circular Direction

Cook Nuclear Plant
1-RC-9-01F

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