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WELD OVERLAY REPAIR FOR SAFE END-TO-NOZZLE WELD 12-AR-E5

BRUNSWICK STEAM ELECTRIC PLANT UNIT 2

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STRUCTURAL INTEGRITY ASSOCIATES, INC.

Professional Engineer Certification Statement

Weld Overlay Repair For
Safe-End to Nozzle Weld 12-AR-E5
Brunswick Steam Electric Plant Unit 2
SIR-88-003, Rev. 0, March, 1988

I, H. L. Gustin, being a duly registered professional engineer under the laws of the State of North Carolina, certify that this document and the calculations contained herein were prepared by me or under my responsible direction, or reviewed by me, and that this document meets the requirements of Carolina Power & Light Design Basis Document DBD-88-01, Revision 0, 1/88, and the pertinent sections of the ASME Boiler and Pressure Vessel Code (Section XI, 1985 Edition with Winter 1985 Addenda). I further certify that this document is correct and complete to the best of my knowledge and belief, and that I am competent to review this document.

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March 17, 1988

Date

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EXECUTIVE SUMMARY

During the current 1988 refueling outage at the Brunswick Steam Electric Plant Unit 2 (BSEP-2), ultrasonic examination (UT) revealed the presence of a flaw indication in one of the ten 12-inch reactor recirculation inlet nozzle-to-safe end weldments. The flaw has a reported length of 4.8 inches and a maximum through-wall depth of 85%. Based on these flaw characteristics and analyses performed by Structural Integrity Associates, Carolina Power and Light has elected to utilize a weld overlay repair.

This report describes:

- the current flaw characterization, results of prior UT examinations and probable failure mechanism,
- the Inconel temper bead weld overlay repair used to repair the observed flaw indication,
- the design bases for the Inconel temper bead weld overlay,
- the analyses and design of the BSEP-2 specific weld overlay, and
- the industry sponsored welding development and metallurgical testing program used to demonstrate the technical adequacy of this repair approach.

On the basis of this work, it is concluded that the weld overlay repair presented herein will restore original design basis structural margins to the flawed weldment, will produce favorable residual stress patterns and a highly IGSCC resistant barrier to further growth of the observed flaw, and will not have an adverse affect on the adjacent low alloy steel nozzle.

1.0 INTRODUCTION

1.1 Background

During the current outage at the Brunswick Steam Electric Plant Unit 2, ultrasonic examination (UT) revealed the presence of a flaw indication in one of the ten 12-inch reactor recirculation inlet nozzle-to-safe end weldments. The flaw has a reported length of 4.8 inches, and a maximum through-wall depth of 85% and is oriented as illustrated in Figure 1-1. Based on these flaw characteristics and analyses, Carolina Power and Light (CP&L) elected to repair the weld utilizing the weld overlay repair technique. However, because of the proximity of the flaw indication to the low alloy steel reactor vessel nozzle (Figure 1-1), part of the weld overlay is applied over that material, and special requirements associated with welding on low alloy steel are mandated.

The low alloy steel nozzle material composition and wall thickness requires a postweld heat treatment (PWHT) after welding operations. This PWHT is in accordance with the applicable Construction Codes [Reference 1] as referenced by ASME Section XI [Reference 2]. This PWHT "tempers" or softens the hardened martensite in the heat affected zone of the weld. As an option to thermal treatment after welding, the Gas Tungsten Arc Welding (GTAW) process using selective and carefully controlled weld bead placement and heat input has been successfully used to achieve the same tempering effect (References 3 and 4). The nozzle material and other considerations dictate that the temper bead welding technique be used in this weld overlay application. Additionally, Inconel welding filler metal is required for this weld overlay for material compatibility with the Inconel safe end and weld materials.

The Inconel temper bead weld overlay was developed by Structural Integrity Associates (SI) with Georgia Power Company (GPC) in 1985 as a contingency repair for nozzle-to-safe end weldments (Reference 3). Additional sponsorship for this activity was provided by the Electric Power Research Institute (EPRI). While not required for GPC's Plant Hatch, the repair technique was utilized successfully in 1986 at Vermont Yankee for the repair of a 10-inch P-3 core spray nozzle-to-safe end (Inconel) weldment. Inconel temper bead weld overlays have also been applied to recirculation inlet nozzle-to-safe end weldments in a foreign BWR. This work is summarized in Section 5 of this report.

1.2 Materials of Construction

As illustrated in Figure 1-1, the low alloy steel (P-3 per ASME Section IX) reactor pressure vessel nozzle was buttered on the weld end preparation and inside bore with Inconel 182 prior to the reactor pressure vessel postweld heat treatment. The Inconel 600 safe end was then welded to the buttered nozzle with Inconel weld filler metal (Alloy 82 and 182). The specific materials of construction are identified in Table 1-1.

TABLE 1-1

Materials of Construction
Reactor Recirculation Inlet Safe End-to-Nozzle Weld

Component	Material
Reactor Nozzle	SA 508 Class 2
Nozzle butter	Inconel 182
Safe End	Inconel 600
Welding Filler Metal	Inconel 182 and 82

These material combinations dictate the use of Inconel welding filler metal as opposed to the "industry standard" type 308L stainless steel welding filler metal for weld overlays. The IGSCC resistant Inconel 82 filler metal has been selected for the design and application of this weld overlay.

1.3 Flaw Characterization

The current (1988) ultrasonic examination (UT) of this weldment (12-AR-E5) was performed by the General Electric Company using automated techniques ("SMART UT"). 45 and 60 degree refracted L-wave and 45 degree shear wave transducers were used in the examination, with other specific transducers used in the through-wall flaw depth sizing. The flaw characteristics are reported in Reference 5 and are summarized in the following table.

TABLE 1-2

UT Flaw Characterization

Length, in.	4.8
Through-wall depth	85%
Side of Weld	Downstream (nozzle)
Orientation	Circumferential (with axial components)
Location	5~6:00 (Near Bottom Dead Center)

From the UT data, it would appear that the flaw initiated in the postweld heat treated Inconel 182 butter on the reactor vessel nozzle. The flaw growth was such that the flaw may have penetrated the "nose" of the low alloy steel nozzle near the weld end preparation (See Figure 1-1). The major extent of the flaw is in the nozzle-to-safe end weld material and buttering.

1.4 Prior Examination History

The subject weld was ultrasonically examined manually by Southwest Research in 1984. A 2-3/4 inch long embedded defect was reported as part of that examination. The weld was also examined in 1986 using the automated GE SMART UT. Due to transducer spatial limitations, only a limited examination was performed in 1986. It is believed today that this examination would have revealed a flaw in this location if the depth was >50% through-wall. The current 1988 examination was less limited, and therefore provided a more complete scan. It should be noted that the flaw length, measuring from 20% DAC to 20% DAC, is the same (2-3/4 inch) as that measured in the 1984 UT examination. This indicates that no large flaw length changes have occurred between the 1984 and the the current examination.

1.5 Probable Failure Mechanism(s)

While the failure mode can only be determined with maximum certainty by destructive (metallurgical) examination, there are factors which allow for a determination of the probable flaw initiation and growth mechanism for this flaw based on the above ultrasonic flaw characterization. These factors include:

- While IGSCC growth rates in the low alloy steel are very slow, minor IGSCC penetration into low-alloy steel in a similar reactor vessel nozzle has been observed recently in a foreign plant (BWR).

- The main flaw growth was observed in the thermally sensitized Inconel 182 buttering and weld filler metal which is not resistant to IGSCC. These materials are also susceptible to crevice attack.

- Analytically predicted growth rates, based on laboratory data on IGSCC crack growth in Inconel 182 weld metal, are consistent with the UT examination history of this weld.

These factors indicate that the flaw initiation in the Inconel 182 butter was most likely caused by crevice corrosion or stress corrosion (IGSCC). Flaw growth in the Inconel is then predicted to be by IGSCC, consistent with analytically predicted IGSCC crack growth rates.

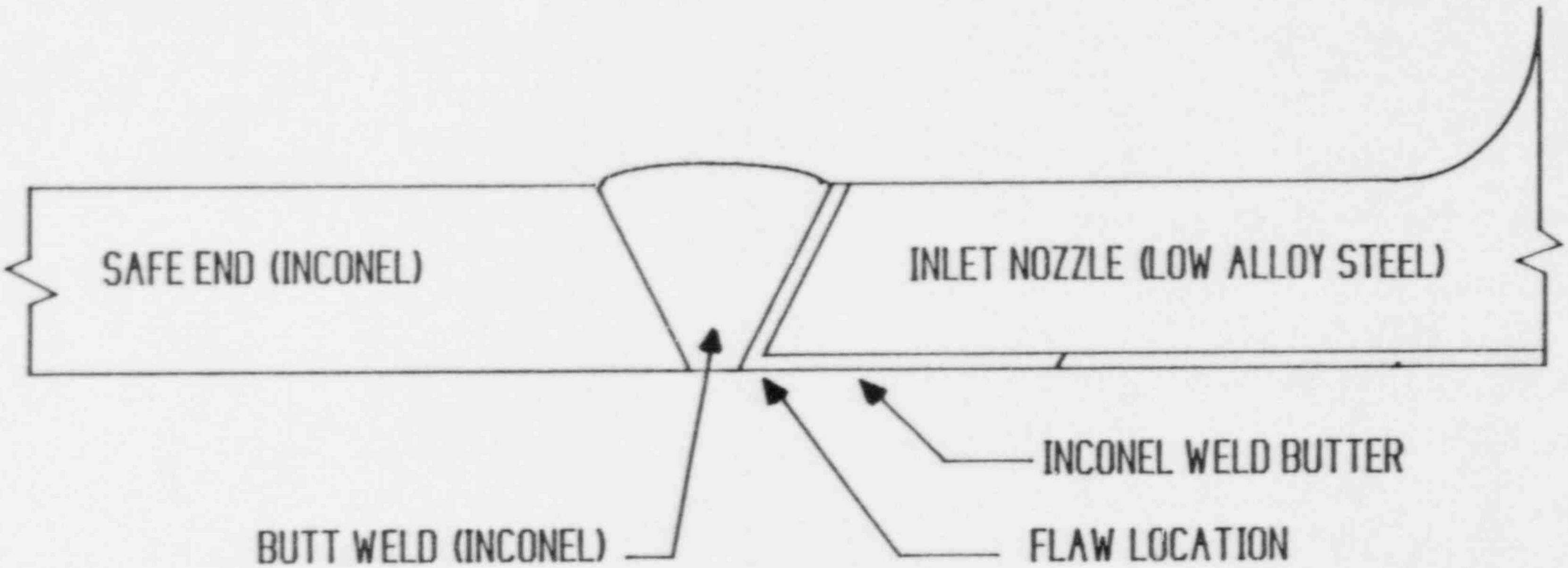

Figure 1-1. BSEP-2 Original Nozzle to Safe End Weld Configuration 12-AR-E5 Showing Approximate Location of Observed Flaw Indication

2.0 REPAIR DESCRIPTION

An Inconel temper bead weld overlay repair technique has been developed and qualified over the last few years as a repair for flawed low alloy steel nozzle-to-Inconel safe end weldments. Application of the repair is a multi-step process in order to:

- achieve the desired tempering of the low alloy steel nozzle heat affected zone, and

- achieve the beneficial effects associated with the weld overlay repair.

This section of the report describes the application of the temper bead weld overlay and the specific application at Brunswick Unit 2.

2.1 General

The weld overlay has been used as a repair for Intergranular Stress Corrosion Cracking (IGSCC) of stainless steel piping in BWRs since early 1982. The repair serves to structurally reinforce the flawed weldment, thereby re-establishing Code design safety margins. Two additional aspects of the weld overlay repair are also important considerations in some applications.

- The weld overlay is applied using material with demonstrated IGSCC resistance, thereby serving as a "barrier" against further IGSCC flaw growth and leakage.

- Application of the weld overlay with water in the piping serves to establish a through-wall temperature differential which promotes favorable compressive residual stresses on the inside portion of the pipe wall. These residual stresses inhibit the initiation of new IGSCC and serve to "arrest" IGSCC flaw growth in relatively shallow flaws.

2.2 Temper Bead Weld Overlay Application

The application of the temper bead weld overlay is a multi-step process. These steps are illustrated in Figures 2-1 through 2-3 and are briefly described in the following paragraphs.

2.2.1 Temper Bead Layers

The initial step in application of the temper bead weld overlay is to establish a "barrier" of as-deposited welding filler material, as a minimum, on the low alloy steel nozzle side of the weldment (Figure 2-1). The main reasons for this barrier layer are:

- to temper the heat affected zone created by deposition of the first layer(s),

- to deposit adequate thickness such that any heat from additional weld layers will not affect the low alloy steel nozzle material, and

- to deposit weld metal free of dilution with the low alloy steel base material.

This temper layer (minimum of the first three layers) is applied with the piping "dry" (drained of water). The first three layers also provide for the dilution effects of the welding filler metal with the low alloy steel nozzle base metal. These first three layers are then "discarded," that is not accounted for in the design weld overlay thickness. After deposition of these initial layers, the piping system may be re-filled with water for the remaining temper layers or may remain dry, if the outage schedule permits.

2.2.2 Safe End Layers

As illustrated in Figure 2-2, the piping is then filled with water and the weld overlay is applied on the safe end side of the weldment. In the case of the Brunswick 2 weld overlay, the temper bead layer extended over the weldment and onto the safe end material. This extension was due to the considerations of the effects of the residual and applied construction stresses from weld overlay application on the thermal sleeve attachment weld located in the safe end bore.

The weld overlay extension on the safe end side ties in with the temper layers and is flush with the temper layers upon completion. Care is exercised to achieve good weld quality in the tie ins.

2.2.3 Fill Layers

With the piping filled with water, additional full width layers are applied (Figure 2-3). These layers are applied to achieve the desired weld overlay thickness and the residual stress benefits of the weld overlay application.

Additional material is deposited to account for surface conditioning for subsequent UT examinations.

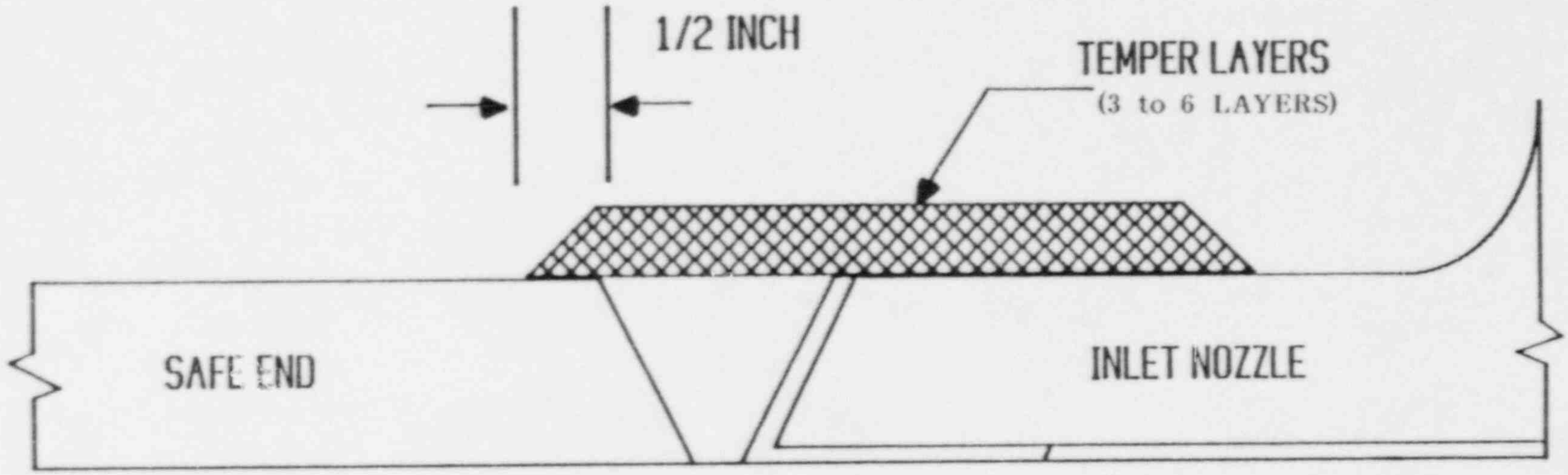

Figure 2-1. First Step in Inconel Temper Bead Repair Process. Temper Bead Layers Applied With Inside of Pipe Dry and Prescribed Welding Parameters to Temper Low Alloy Steel Nozzle

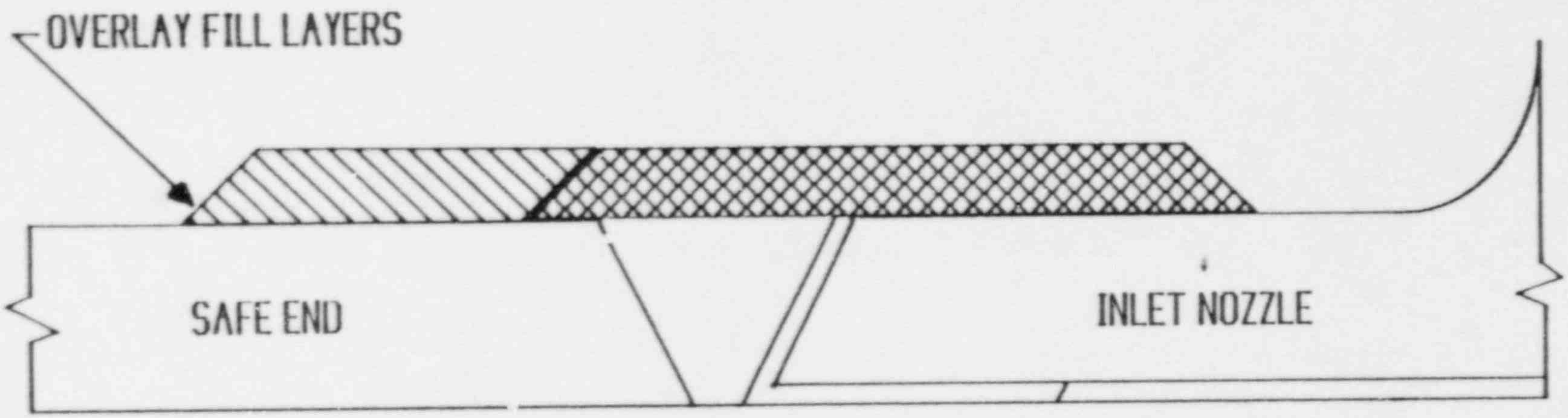

Figure 2-2. Second Step in Inconel Temper Bead Repair Process. Additional Weld Overlay Layers Applied on Safe End Side of Weld Using Standard Weld Overlay Parameters

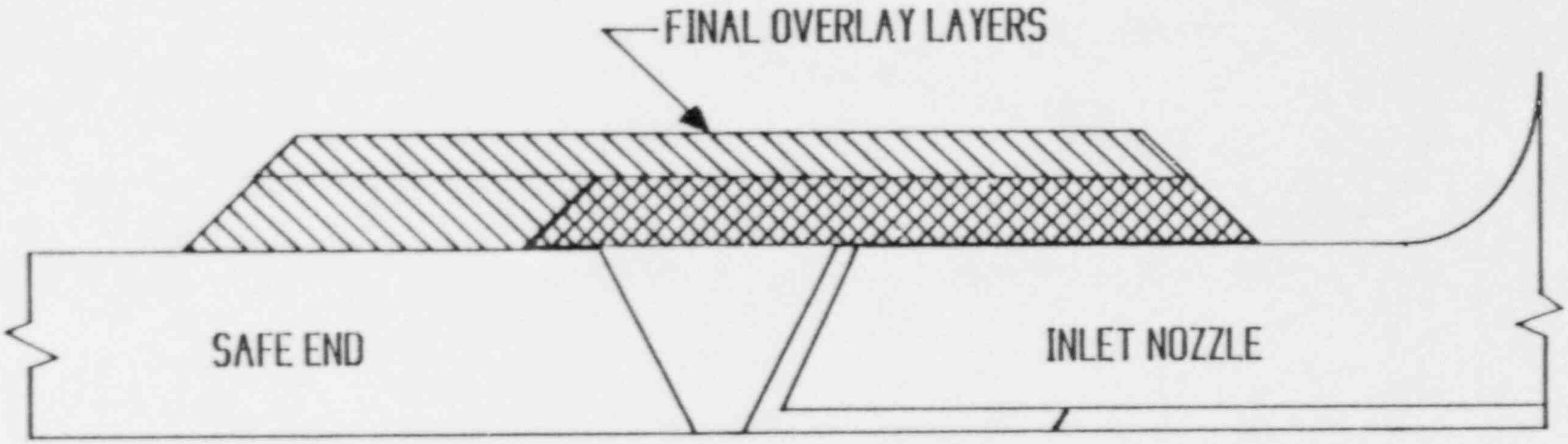

Figure 2-3. Third Step in Inconel Temper Bead Repair Process. Remaining Weld Overlay Fill Layers Applied to Achieve Design Thickness Using Standard Weld Overlay Parameters

3.0 DESIGN CRITERIA

The design of weld overlay repairs in BWR piping is governed by NUREG-0313, Revision 2 (Reference 6), and takes guidance from ASME Section XI, Paragraph IWB-3640 (Reference 2). Inconel 600 (Ni-Cr-Fe) materials, including Inconel 182 weld metal are austenitic materials subject to intergranular stress corrosion cracking in BWR coolant, similar to the austenitic stainless steel piping materials which are the primary topic of Reference 6. Therefore the standard weld overlay repair criteria of Reference 6 are considered applicable to this repair, with some supplemental criteria as noted below.

Inconel 82 weld metal has been accepted by the NRC as IGSCC resistant material in NUREG-0313 Revision 2. Consequently, weld overlay application using Inconel 82 weld metal is an acceptable alternative for some locations with IGSCC flaw indications where use of stainless steel weld metal (308L) is not practical. The safe end-to-nozzle weld at Brunswick Unit 2 is one such location. Although Inconel 82 weld metal is taken to be IGSCC resistant, the commonly used Inconel 182 material frequently used in buttering of low alloy steel nozzles is not. In addition, welding of Inconel 82 over the low alloy steel base material (as is done in the weld overlay repair applied at Brunswick) causes dilution of the Inconel weld metal with iron from the nozzle material. Thus, the resulting weld overlay cannot be considered to be resistant to IGSCC propagation until the chemistry of the weld overlay material returns to Inconel 82 composition. Experimental results discussed in Section 5 of this report demonstrate that this requires three welded layers to achieve this result. Consequently, a supplemental design criteria for this weld overlay is that no credit for the first three welded layers may be taken in meeting the structural reinforcement requirements of the design, since these layers are potentially not resistant to IGSCC propagation.

With the above material limitations on the overlay design, the repair is designed to meet the requirements of the NUREG-0313, Revision 2 "standard" weld overlay. The repair is designed based upon an assumed through-wall flaw, extending 360° circumferentially. Pressure, deadweight, and seismic stresses are considered in sizing the thickness of the repair. Stresses are taken from Reference 7, and scaled to reflect the design wall thickness of the safe end-to-pipe weld. As in the case of conventional stainless steel weld overlays, length of the repair is dictated by the length needed to provide favorable residual stresses in the vicinity of the observed crack, structural load transfer requirements, and inspectability of the completed overlay. Because no credit for the existing component wall thickness is taken in the design, and because the Inconel 82 weld overlay is made with the "high toughness" GTAW welding process, secondary stresses such as thermal expansion and weld overlay shrinkage-induced stresses need not be considered in the overlay sizing calculations.

As an additional demonstration of the adequacy of the repair, crack growth calculations are performed to address the potential for crack propagation into the diluted material. For these analyses, secondary stresses are included. The acceptance criterion for the crack growth analysis is that the continued flaw propagation would not reduce the structural adequacy of the repair over the design life of the repair.

4.0 DESIGN ANALYSES

This section describes the weld overlay design analyses for the nozzle-to-safe end weld, 12-AR-E5. The analyses include determination of piping loads and stresses, sizing of weld overlay thickness and length, consideration of weld residual stresses and determination of crack growth after weld overlay. The resulting overlay design drawing is documented in the Appendix.

4.1 Weld Overlay Sizing

4.1.1 Piping Loads and Stresses

The piping stress analyses for the recirculation system in the Brunswick Steam Electric Plant was performed by General Electric (GE), Reference 7. To generate the appropriate stresses for analysis of tho nozzle-to-safe end weld, the axial loads and the bending moments at the nearest node in the piping model to the 12-AR-E5 weld location were extracted from Reference 7. Then the applied stresses were calculated using F/A and M/Z, where F = axial force, A = pipe area, M = resultant bending moments and Z = pipe section modulus. The axial stress due to internal pressure was calculated using the equation for a thick wall cylinder with ends capped.

The resulting stresses are presented in Table 4-1 for all ten nozzle-to-safe end welds, including 12-AR-E5. The dimensions at the weld location were obtained from Reference 8. Stresses were calculated for the load cases of operating pressure, dead weight, operating thermal, operating basis earthquake (OBE) and safe shutdown earthquake (SSE).

For the weld 12-AR-E5, the axial pressure stress is 3.88 ksi. The stresses due to deadweight and operating thermal conditions

Table 4-1

Applied Stress Summary for BSEP-2 Recirculation Inlet Nozzle to Safe-End Welds

OD = 15.5 in
THK = 0.875 in
ID = 13.75 in

AREA = 40.20 in^2
Z = 139.1 in^3
PRESSURE = 1.05 ksi

WELD #	STRESS (KSI) PRES.	DW	THERM	OBE	SSE	PR+DW +THERM	PR+DW +TH +SSE
12-AR-A5	3.878	0.112	1.024	1.4126	2.482	5.014	7.497
12-AR-B5	3.878	0.308	0.968	2.1704	3.808	5.155	8.964
12-AR-C5	3.878	0.766	1.376	3.0332	5.258	6.021	11.27
12-AR-D5	3.878	0.236	1.166	1.7872	3.123	5.282	8.405
12-AR-E5	3.878	0.950	1.040	0.9121	1.586	5.868	7.455
12-BR-F5	3.878	0.261	1.198	1.0025	1.760	5.338	7.098
12-BR-G5	3.878	0.516	1.163	1.7768	3.088	5.558	8.646
12-BR-H5	3.878	0.811	0.964	2.8298	5.267	5.653	10.92
12-BR-J5	3.878	0.609	0.626	1.7466	3.030	5.113	8.144
12-BR-K5	3.878	0.110	0.740	1.2437	2.185	4.729	6.915

WELD OVERLAY SHRINKAGE STRESS:

STRESS = 6.34 ksi

(MAXIMUM CALCULATED AT ANY 12" PIPE LOCATION IN BSEP-2) are 0.95 ksi and 1.04 ksi respectively. For seismic loadings, they are 0.91 ksi for OBE and 1.59 ksi for SSE.

4.1.2 Weld Overlay Thickness

The weld overlay thickness is determined using ASME Section XI Table IWB-3641-1 (Reference 2) as the design criterion. The principle is to add additional material through welding such that the stress ratio decreases, because of the thicker wall thickness, to a lower level such that the existing flaw size to the new wall thickness ratio will meet the allowable a/t in Table IWB-3641-1, where a is flaw depth, and t is the pipe wall thickness.

The design process requires a number of iterations to achieve the minimum required additional thickness to satisfy the above criterion. The iterative process has been automated in the Structural Integrity Associates computer program **pc-CRACK**, Reference 9. The inputs to this program for weld overlay thickness design are pipe wall thickness, primary membrane stress, primary bending stress and overlay material allowable stress. In accordance with Reference 8, the original wall thickness is 0.875 in. The membrane stress due to pressure as presented in Table -1, is 3.88 ksi. The primary bending stress is 1.86 ksi due to the deadweight and OBE. The design allowable stress for Inconel is 23.3 ksi at 550°F, Reference 1. Inputting these parameters results in a required weld overlay thickness for weld 12-AR-E5 of 0.2917 inches, as indicated in the **pc-CRACK** output in Table 4-2. The final allowable a/t ratio is 75% of the final wall thickness for all l/circum ratios.

4.1.3 Weld Overlay Length

In keeping with standard weld overlay design practice, the weld overlay length was chosen so as to provide full overlay thickness

Table 4-2

Calculation of Weld Overlay Design Thickness
(Reference 9)

```
                          tm
                     pc-CRACK
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             SAN JOSE, CA (408)978-8200
                    VERSION 1.2

      STRUCTURAL REINFORCEMENT SIZING EVALUATION


STRUCTURAL REINFORCEMENT SIZING FOR CIRCUMF. CRACK,WROUGHT/CAST STAINLESS

CPL, WELD 12-AR-E5

WALL THICKNESS=    0.8750
MEMBRANE STRESS=    3.8800
BENDING STRESS=     1.8621
STRESS RATIO=    0.2464
ALLOWABLE STRESS=   23.3000
FLOW STRESS=   69.9000
                                    L/CIRCUM
                          0.00   0.10   0.20   0.30   0.40   0.50
FINAL A/T               0.7500 0.7500 0.7500 0.7500 0.7500 0.7500
REINFORCEMENT THICK.    0.2917 0.2917 0.2917 0.2917 0.2917 0.2917

                        END OF pc-CRACK
```

for a length of 1.0 $\sqrt{Rt}$ on both sides of the centerline of the original weldment, where R is the mean radius and t original design thickness of the weldment (7.3125" and 0.875", respectively). Thus the minimum required length of the weld overlay is 5.06 inches. Sizing the overlay length in this manner has been shown in numerous prior studies to produce a favorable postweld residual stress distribution over the entire IGSCC susceptible zone of the original weldment, and to allow sufficient material for load transfer from the piping on either side of the flawed weldment into the overlay. This length was also reviewed by BSEP Inservice Inspection personnel who confirmed that it provides sufficient access for ultrasonic inspection of the overlay and the outer 25% of the original weldment.

4.1.4 As-Built Dimensions of Repair

In the design of this repair, three minimum dimensions were specified. The as-built dimensions exceeded the required design minimum values in all cases. The design and as-built dimensions are compared below:

	Design Minimum in	As-Built in
1. Minimum Temper Thickness	0.125	0.20
2. Minimum Structural Repair Thickness	0.3	0.373
3. Minimum Full Thickness Length	5.4	5.799

4.2 Residual Stresses

A detailed residual stress analysis of the BSEP-2 nozzle-to-safe end weld 12-AR-E5 has not been performed. Instead, assurance that the subject repair produces a favorable postweld residual stress pattern has been established by review of the residual stress analysis performed in the EPRI/Georgia Power study reported in Reference 3.

An assessment of the results from Reference 3 and its applicability to the Brunswick repair has been performed. Residual stress analyses for a nominal 12 inch diameter pipe dissimilar metal weld between a 304 stainless steel safe end and a low alloy SA 508 Class 2 nozzle with an Inconel 182 weld and an Inconel 82 weld overlay are reported in Reference 3. Figure 4-1 shows the mathematical model used in this analysis.

Figure 4-2 presents the through-wall residual stress, both axial and hoop, before application of the overlay. There are three stress profiles in Figure 4-2. The first curve, curve A, is the stress in the 304 SS side of the butt weld. The second curve, curve B, is the stress in the low alloy steel side of the butt weld. The third curve, curve C, is at the location beyond the end of the overlay to be applied.

Figure 4-3 presents the through-wall residual stress after the the application of overlay for the same locations as presented in Figure 4-2. They all show compressive stresses, both in axial and hoop directions, extended to the original pipe wall thickness.

In the evaluation presented in Reference 3, the nominal pipe size was 12 inches, which is comparable to the Brunswick pipe size. The original wall thickness was about 1.2 inches which is thicker than the 0.875 inches used in this evaluation. The overlay size analyzed in Reference 3 was about 0.6 inches which compares to the as-built minimum weld overlay thickness of the BSEP-2 repair of 0.573 inches (base thickness of 0.200 inch with structural overlay thickness of 0.373 inch as illustrated in Appendix A). Therefore it is judged that the residual stress results presented in Reference 3 are a typical pattern for a 12 inch nozzle-to-safe end weldment and are thus applicable to the BSEP-2 recirculation nozzle repair.

4.3 Crack Growth Analyses

A crack growth analysis is performed to evaluate the effectiveness of the Inconel weld overlay in arresting the existing flaw in weld 12-AR-E5.

4.3.1 Crack Growth Law

In recent years, experimental studies on the IGSCC resistance of the Inconel weld material have been conducted. [References 10 to 13] A summary of the experimental results of these studies is presented in Reference 3 for a wide variety of inconel material, (Inconel 132, Inconel 182, Inconel 625, Inconel 82, alloys R-135, 600, 690, 625, 671) under different environments.

Table 4-3 presents test data on the crack growth rates for Inconel 600, Inconel 82 and Inconel 182, Reference 11. The crack growth rate varies from 1.7×10^{-7} to 3.2×10^{-7} mm/sec at an average stress intensity factor of 45 MPa $\sqrt{m}$. The results in Table 4-3 are plotted in Figure 4-4, along with other crack growth rates observed in austenitic steel in the BWR environment. Since the crack growth rate data are available at only one stress intensity factor level for the Inconel alloys, it was assumed that the crack growth rate would be parallel to the best estimated crack growth rate of the stainless steel curve. The

Table 4-3

TEST DATA FOR CRACK-GROWTH TESTS IN PURE WATER CONTAINING
7 ppm O_2 AND 1 ppm H_2SO_4 AT 288°C and 7.93 MPa

[Reference 11]

Material	Heat Treatment	Exposure Time, hours	Initial K, $MPa.m^{1/2}$	Crack Growth mm	Final K, $MPa.m^{1/2}$	Average Growth Rate, $mm.s^{-1}$
alloy 600	FS[1] + LTS[2]	4129	49.4	4.8	43.4[3]	$3.2x10^{-7}$
I-82	FS + LTS	4129	49.4	4.0	45.2[3]	$2.7x10^{-7}$
I-182	FS + LTS	4129	49.4	2.5	46.0[3]	$1.7x10^{-7}$
alloy 690	FS + LTS	3048	50	0.0	45[4]	0.0
alloy 690	FS + LTS	3048	60	0.0	54[4]	0.0
alloy 690	FS + LTS	3048	70	0.24	63[4]	$2.2x10^{-8}$

1 Furnace sensitized - 621°C for 24 h.

2 Low temperature sensitized - 449°C for 24 h.

3 Reduction in K was due to a combination of crack growth and relaxation.

4 Reduction in K was due entirely to load relaxation.

crack growth rate, in the form of Paris law, is determined to be as follows:

$$\frac{da}{dt} = 1.078 \times 10^{-7} K^{2.26} \text{ in/hr}$$

Proprietary crack growth data reported by General Electric in Reference 14 shows this crack growth law to be conservative.

4.3.2 Stress Intensity Factor Calculation

A full circumferential crack model in a cylinder was used to calculate the stress intensity factor due to different loading cases for weld 12-AR-E5. The loading cases considered are pressure, deadweight, thermal expansion, weld overlay shrinkage, and postweld overlay residual stress. For postweld overlay residual stress, axial stress case B of Figure 4-3 was used. Due to the differences in the Brunswick wall thickness (1.3 in) versus the analysis thickness (1.7 inches), the postweld overlay residual stresses were scaled down to 1.3 inch for the purpose of determining the stress intensity factor.

The stress intensity factor calculation was performed using pc-CRACK, Reference 9. Figure 4-5 presents the stress profiles of the postweld overlay residual stress along with the other loading cases. The postweld overlay stress profile was curve fit to a third order polynomial equation. The other loading cases were assumed to be constant throughout the wall thickness. In calculating the stress intensity factor, the pressure, deadweight, thermal and shrinkage were scaled down to account for the additional wall thickness provided by the weld overlay. Figure 4-5 also presents stress intensity factor versus the crack depth curves for individual load cases (curves 1 to 5). Curve 6 in Figure 4-5 is the total applied stress intensity factor (pressure + deadweight + thermal + shrinkage + weld overlay residual stress). Because of the weld overlay residual stress pattern due to the weld overlay, the resultant stress intensity factor remains compressive throughout the original weldment wall thickness.

4.3.3 Crack Growth Results

A crack growth analysis for the existing crack in weld 12-AR-E5 was performed using the crack growth law presented in Figure 4-4 and the stress intensity factor results shown in Figure 4-5. From the ultrasonic inspection, it was found that the through-wall dimension of th observed flaw was 85% of the original wall thickness (0.875 inch from Reference 5), or 0.744 inch. At a crack depth of 0.744 inch, the total applied stress intensity factor due to pressure, deadweight, thermal, shrinkage and postweld overlay residual was found to be -30.32 ksi $\sqrt{in}$. Due to the compressive nature of the crack tip stress intensity factor, no crack extension would be expected due to stress corrosion crack growth.

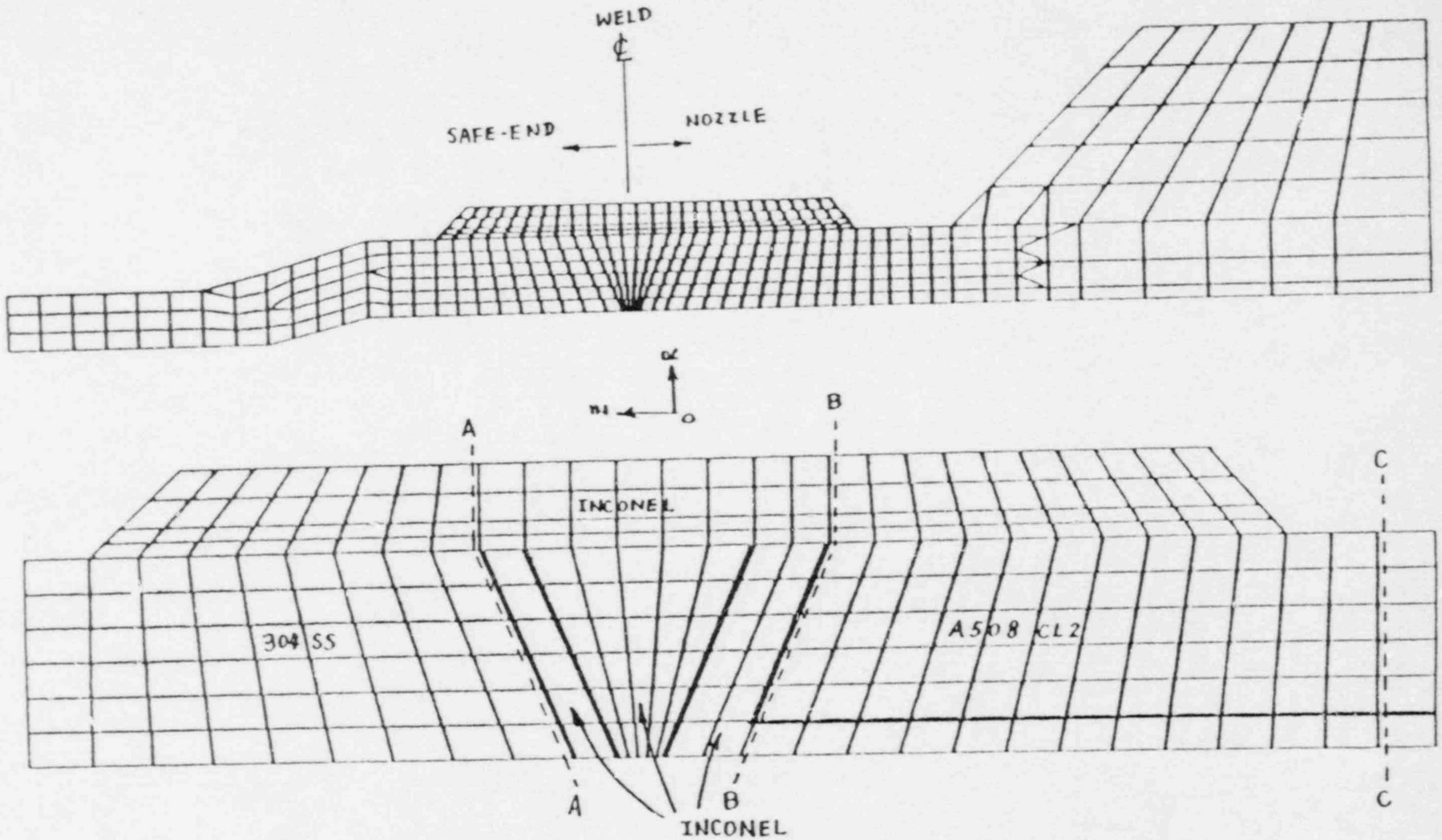
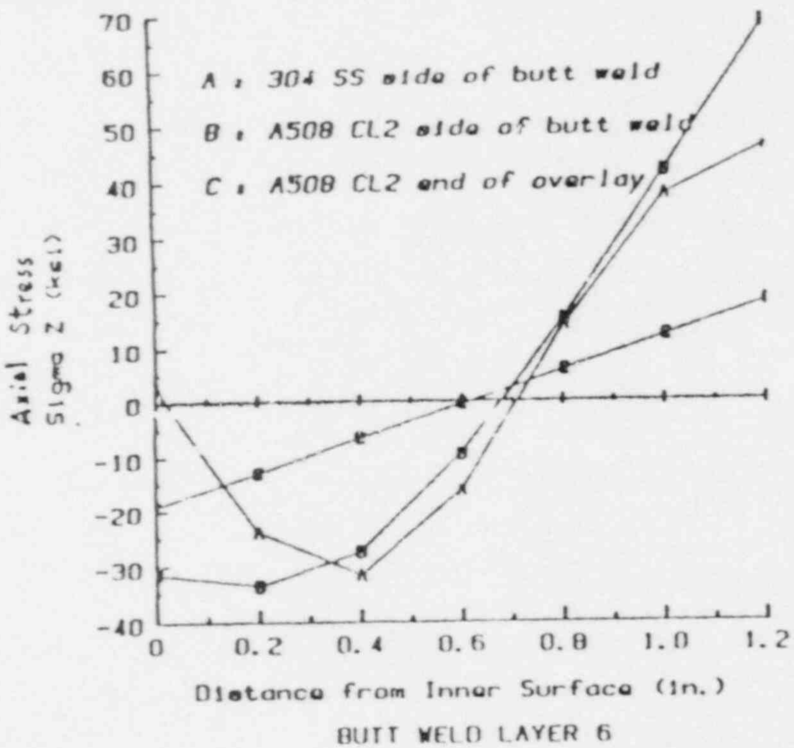


Figure 4-1. Finite Element Mesh for the Weld Overlay Residual Stress Analysis of Reference 3



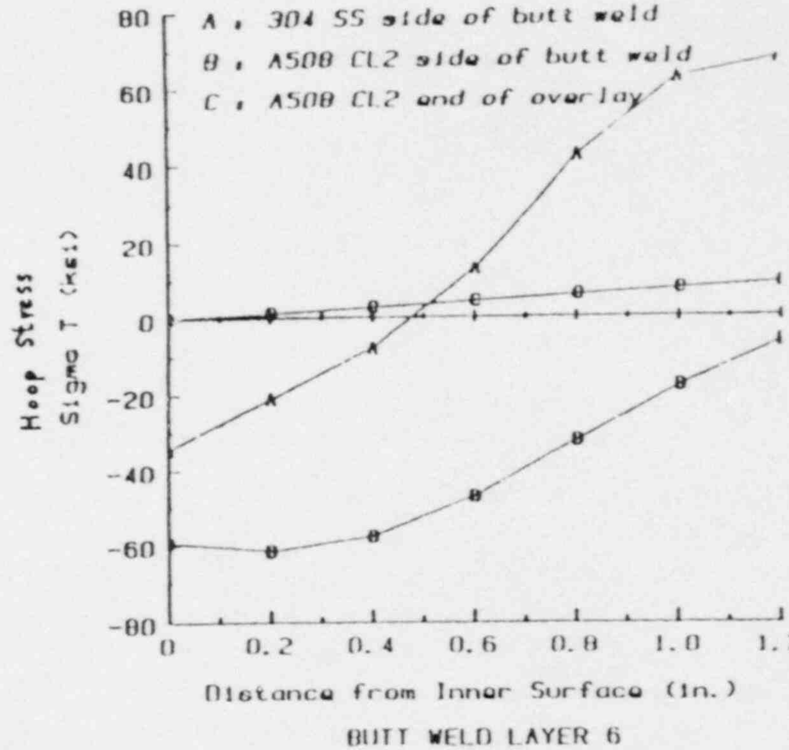


Figure 4-2. Through-Wall Residual Stress Before Application of the Overlay [Reference 3]

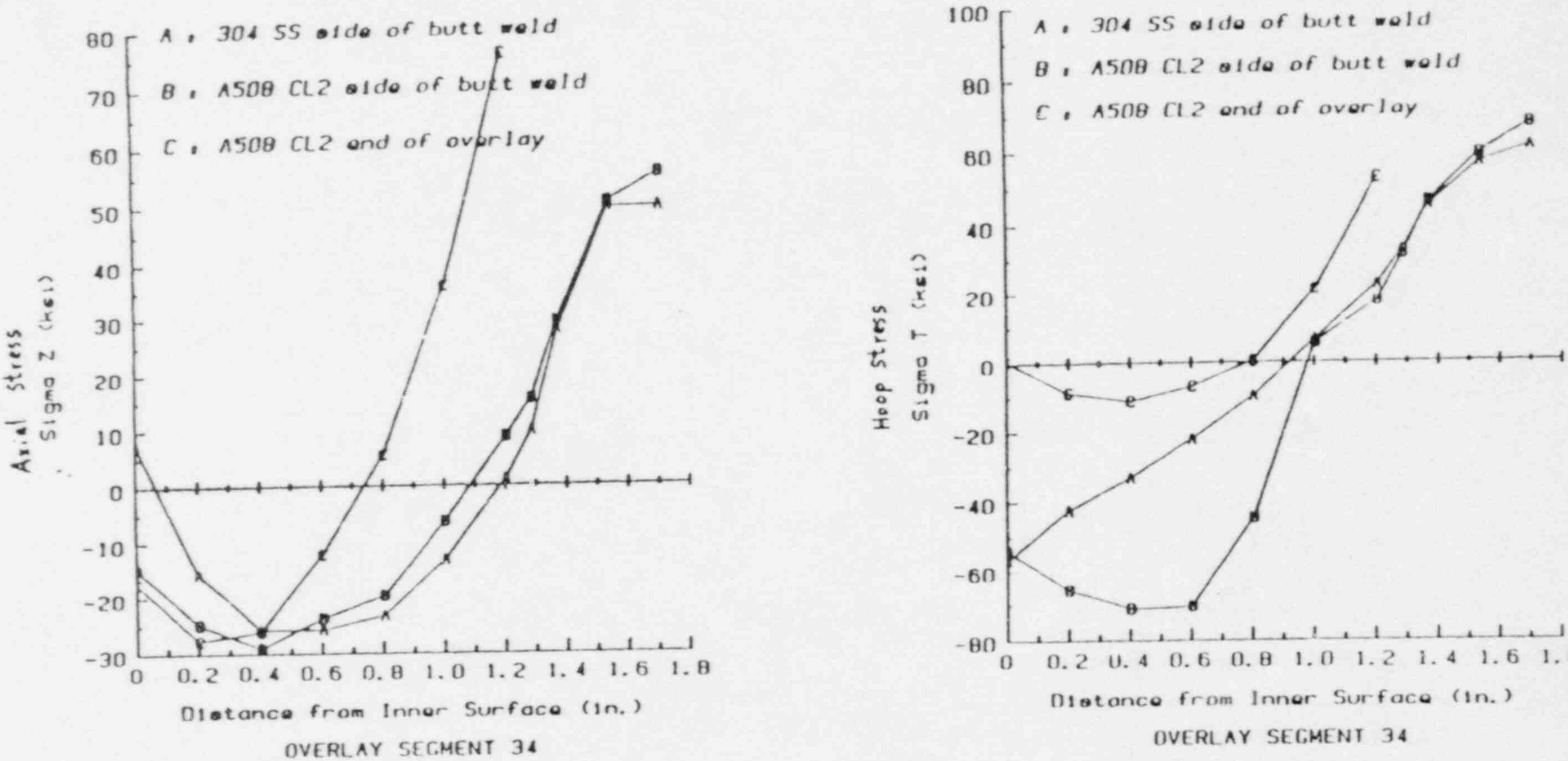


Figure 4-3. Through-Wall Residual Stress After Application of the Overlay [Reference 3]

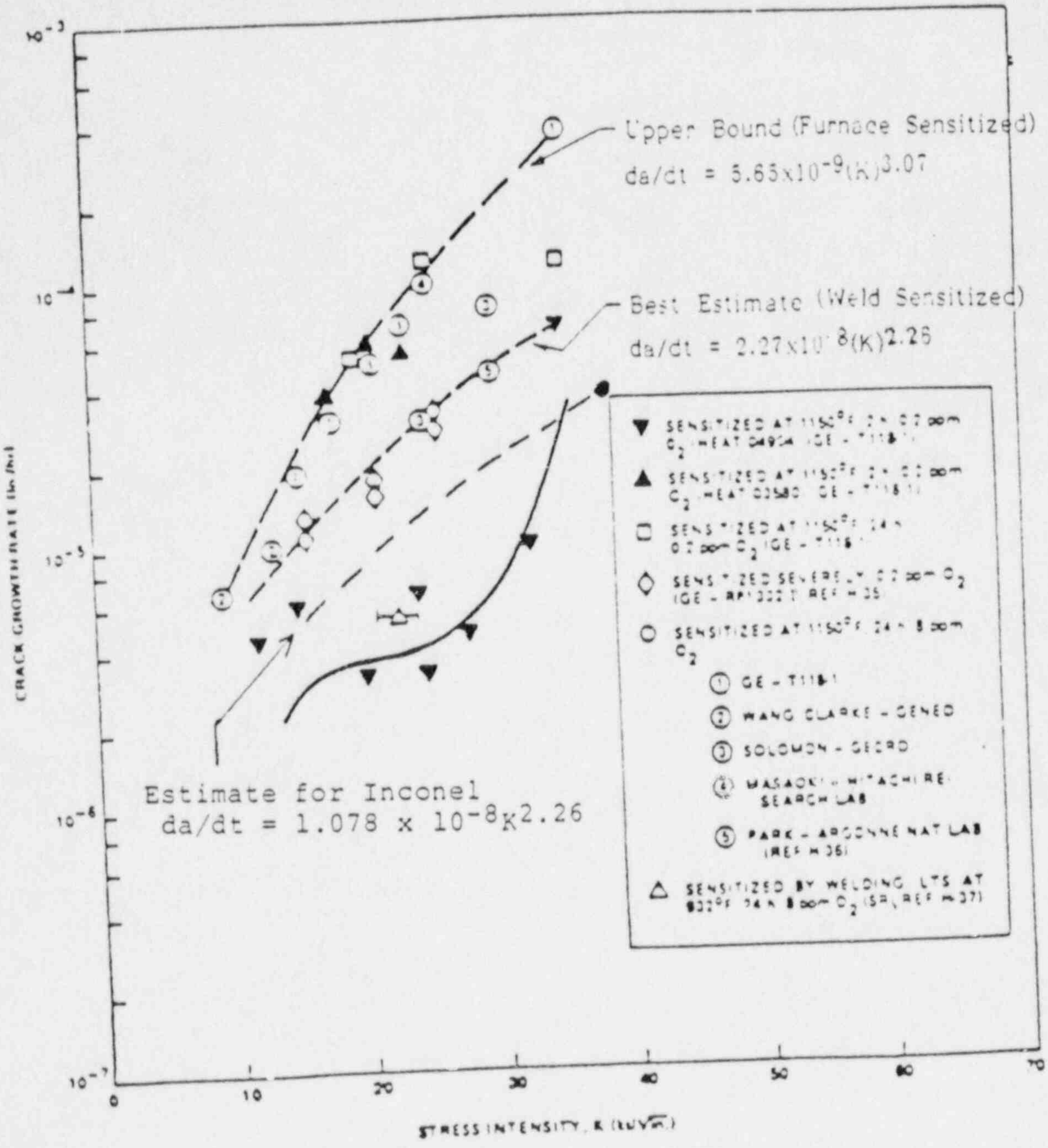


Figure 4-4. CRACK GROWTH RATE CURVES USED IN ANALYSIS AND SUPPORTING DATA (FROM EPRI NP-2472 AND EPRI-1566-2, Interim Report)

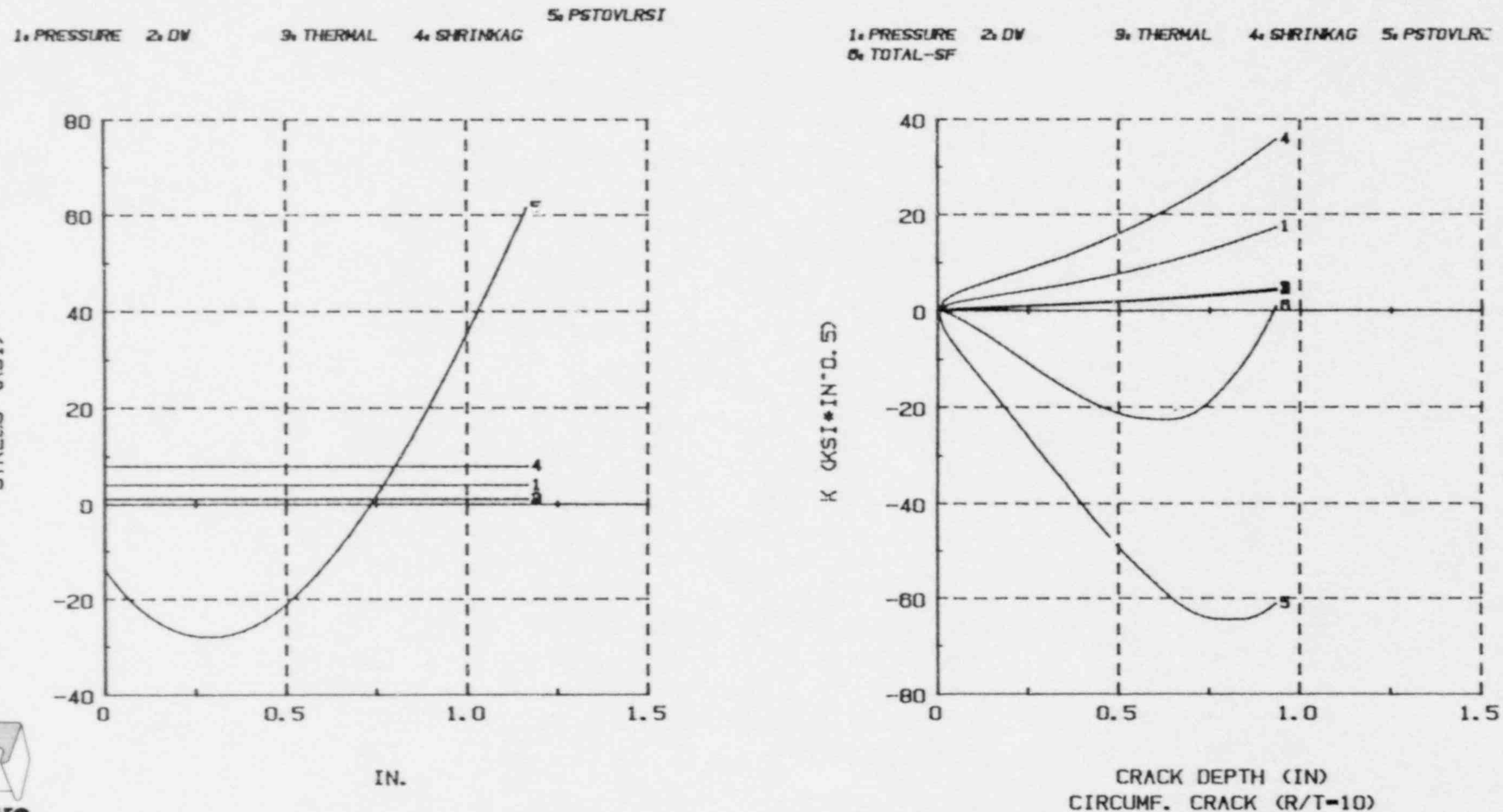


Figure 4-5. Applied Stresses and Stress Intensity Factors for BSEP-2 Weld 12-AR-E5 Weld Overlay Repair

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5.0 METALLURGICAL CONSIDERATIONS

The Inconel weld overlay procedure utilized in the BSEP-2 weld 12-AR-E5 repair follows the procedure and technical approach for Inconel weld overlays reported in Reference 3. This section of the report presents a summary and overview of the procedure development and significant test results from that program, which are the basis for the current BSEP-2 weld overlay.

5.1 Background

The ASME Boiler and Pressure Vessel Code contains criteria and requirements for heat treatments associated with the welding of low alloy steel quenched and tempered components. In particular, for pressure boundary components, such as low alloy steel vessels and nozzles, Section III of the Code (Reference 1) contains preheat, post-heat and postweld heat treatment criteria. Section XI of the Code (Reference 2) provides heat treatment criteria and controls for repair welding to pressure vessel materials. The criteria applied by Section XI allow for, in addition to the standard Section III approach, the use of a "half bead" repair using the shielded metal arc welding technique. When applied according to the criteria of Article IWB-4000 of Section XI, this "half bead" approach requires no postweld heat treatment of the component. Specifically, subarticle IWB-4340 provides the criteria for welding dissimilar materials to P-3 materials using this half bead welding technique, that is, welding according to IWB-4340 and removal of approximately one-half of the first layer by grinding. The second layer, when deposited according to IWB-4340, provides grain refinement and tempering of the underlying P-3 material heat affected zone when deposited over the half bead remaining from the first layer of weld deposition. Thus, when using the half bead weld repair approach on low alloy steel components, no postweld heat treatment is required.

One restriction of the repair approach described in IWB-4340 is that only the shielded metal arc welding technique is allowed. Addressing this limitation, a program was initiated in 1978 by the Electric Power Research Institute (EPRI) and the Babcock and Wilcox Company (B&W) to examine and optimize the welding process for performing such weld repairs to P-3 components (Reference 15). During that study, the welding processes evaluated included the Shielded Metal Arc Welding process, the Gas Metal Arc Welding process, the Gas Tungsten Arc Welding process and the somewhat non-conventional explosive welding and electron beam welding processes. The principal objective of the EPRI/B&W program was to develop an alternative to the half bead technique which was amenable to automation, allowing for greater ease of use in a radiation environment. The other objective of the program was to develop a process which was readily reproducible and which deposited a high quality weld, one in which the fracture toughness of the weld deposit would not be significantly undermined.

The EPRI/B&W program was successfully completed in 1983. The program demonstrated that the machine gas tungsten arc process could be qualified for repair of a pressure vessel cavity using specific welding controls. The results of this investigation, reported in Reference 15, provided the basis for a second welding development program, reported in Reference 3, which qualified an Inconel weld overlay for the repair of cylindrical nozzle-to-safe end welds in which part of the repair impinges on the low alloy steel nozzle.

5.2 Inconel Weld Overlay Procedure Development

Fundamental to the weld overlay development approach taken in Reference 3 was that the essential weld variables of Reference 15 would be maintained, as closely as possible, while developing the orbital weld repair approach needed for weld overlay repair. In doing so, it was anticipated that the heat input required to

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provide the necessary grain refinement and tempering to the P-3 material would be preserved. A further expectation was that an ASME Section XI Code Case on the topic, which at the time of the study was under consideration, could be referenced and could form the basis of a licensing submittal to the Nuclear Regulatory Commission (NRC) in the event that an Inconel weld overlay repair was required at a domestic light water reactor nozzle-to-safe end joint. The Code Case N-432, Reference 4, was approved in February, 1986.

The best of the temper bead procedures identified in the EPRI/B&W program (Reference 15), was selected as the weld procedure to follow in development of the weld overlay temper bead approach for the low alloy steel side of the overlay. This procedure had produced the most favorable low alloy steel properties following weld repair in that program. The important welding variables and welding information from that procedure are reproduced in Table 5-1 of this report.

The approach used in Reference 3 for overlay welding of the stainless steel side of the joint was established so as to follow the standard for overlay repairs performed on numerous BWR pipe welds in the United States and Europe. In this approach, water backing is provided and stringer beads are deposited so as to obtain a favorable post-repair residual stress pattern, while minimizing axial and radial shrinkage beneath the overlay. Consequently, a composite Inconel weld overlay was designed as a "temper bead" overlay for the P-3 material, followed by a "standard" weld overlay on the P-8 safe end and covering over the Inconel temper bead layers, as illustrated schematically in Figures 2-1 through 2-3 of this report. The final overlay length and thickness were selected using conventional weld overlay design considerations for stainless steel pipe weld overlays.

The welding equipment, welding materials and welding parameters used in development of this temper bead weld overlay technique

Table 5-1

Welding Parameters Used In Procedure F
Weld In Reference [15]

	Layer 1	Layer 2	Layer 3
Current (A)	180	200	220
Voltage (V)	11	11	11
Wire Feed (ipm)	39	59	65
Travel (ipm)	8.5	7	6
Bead Overlap (%)	50	50	50
Preheat (^{O}F)	300	300	300
Max. Interpass (^{O}F)	500	500	500

Wire Diameter -- 0.035 Inch

Shielding Gas -- AR 18 CFH

Electrode -- 2% Thoria Tungsten; 5/32-Inch Diameter;
2-1/2-Inch Total Stick-out (With Long Gas Cup);
Tip: 22.5^{O} Included Angle

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are presented in detail in Reference 3. The important parameters and equipment information are summarized in Table 5-2. An Arc Machine was selected to perform the orbital welding using 0.035 inch diameter Inconel 82 bare wire. Preheat was maintained between 300°F and 400°F, post-heat between 450°F and 500°F consistent with the requirements of ASME IWB-4340. A series of initial welding trials were conducted on a 12-inch carbon steel pipe in order to select the specific orbital welding parameters for the repair.

Following these initial trials, fabrication of a nozzle-to-safe end mockup and qualification of an Inconel weld overlay repair was initiated.

5.3 Fabrication of Mockup Weldment

A mockup program was conducted in the Reference 3 development program to provide ASME Code required tensile, bend and toughness specimens as well as for metallurgical specimens which could be used for hardness and microstructure evaluations. The mockup utilized a surplus 12-inch diameter ASME SA 508 Class 2 low alloy steel recirculation system inlet nozzle purchased from Babcock and Wilcox Company. The material had received a heat treatment prior to purchase for this program. This nozzle was counterbored and weld prepared, buttered using Inconel 182 weld metal and postweld heat treated at 1150°F for 24 hours to simulate a production vessel condition as installed prior to being prepped for the dissimilar metal girth weld to a Type 304 stainless steel safe end mockup. The stainless steel safe end portion of the mockup consisted of a 12 inch pipe which was also weld prepped and buttered using Inconel 182 weld metal. The girth weld which formed the basis of the mockup Inconel overlay was welded with Inconel 82 using the ARC machine to deposit the girth weld.

Table 5-2

Temper Bead Weld Overlay Parameter Information
(Reference 3)

Layer 1 Parameters

- Current: 120 Amps: 1/3 of time
  210 Amps: 2/3 of time
- Voltage: 11 Volts
- No oscillation
- Wire Size 0.035" diameter Sandvik ER NI CR-3 wire
- Torch Angle 90°
- Shield Gas: Welding Grade Argon at 30 ft^3/hour
  - Wire Feed
  - 30 inches/minute - 1/3 of the time
  - 43 inches/minute - 2/3 of the time
- Travel Speed: 8.5 inches/minute
- Bead overlap was 50%
- Preheat and interpass 300°F to 400°F during entire layer
- Double down welding
- Heat input of 14,000 J/inch

Layer 2 Parameters

- Current: 140 Amps: 1/3 of time
  230 Amps: 2/3 of time
- Voltage: 11 volts
- No oscillation
- Wire size: 0.035 inch diameter
- Torch Angle - 90°
- Shield Gas: Argon @ 30 ft^3/hour
  - Wire Feed
  - 51 inches/minute: 1/3 of time
  - 63 inches/minute: 2/3 of time
- Travel Speed: 7 inches/minute
- Bead and interpass temperature 300°F to 400°F
- Heat input: 19,000 J/inch
- Double down welding
- Bead Overlap was 50%

Layer 3 Parameters

- Current: 160 Amps: 1/3 of time
  250 Amps: 2/3 of time
- Voltage: 11 Volts
- Oscillation: 0.156 inches
  - 0.2 second excursion
  - Pulse synchronization
    - 0.4 second dwell on each side of bead
- Wire size: 0.035 inch
- Torch angle: as layer 1
- Shield gas: as layer 1
- Wire feed:
  - 56 inches/minute: 1/3 of time
  - 69 inches/minute: 2/3 of time
- Bead overlap: 50%
- Heat input: 24,000 J/inch
- Preheat and interpass temperature
  - 300°F and 400°F

Following Third Layer

- Hold preheat until postheat

Post Heat -- 450°F to 500°F
Hold three hours and slow cool

Fill with tap water
- used 3 gpm flow

Complete overlay with
- second layer weld parameters

EXCEPT

- Preheat and interpass temperatures are 70°F to 110°F
- Can use orbital welding procedure or continue double down

The nozzle and safe end welded together, are presented in Figure 5-1. (Photograph of nozzle and safe end assembly prior to overlay). A total of two test welds were fabricated in order to provide for the mechanical property specimens and to provide for the metallographic samples. Figures 5-2 and 5-3 present cross sections of the nozzle mockup containing both the complete dissimilar metal overlay weld and an excavated region (denoted groove weld) which received a simulated Inconel 82 overlay weld from which mechanical property specimens were obtained (Figure 5-3). An illustration of the two welds together are presented in Figure 5-4.

The mechanical property specimen groove weld (region A in Figure 5-4) was welded using the weld parameters of Table 5-2 which were developed for the Inconel 82 weld overlay. These welding parameters were readily maintained at the flat base of the cavity. However, the side wall parameters were modified somewhat so that a sound weld could be obtained. This modification included welding in essentially the flat position, i.e., the nozzle and safe end were vertical and the welding torch was tilted to the vertical as much as required to reach the flat side of the bevel, presented in Figure 5-4 area 4, region A. The purpose of the shallow angle on one side of the groove was to provide accessibility to the torch to the flat side of the groove to provide a heat affected zone in that area simulating the temper bead heat affected zone. All other welding parameters were the same as was used on the orbital weld except oscillation and automatic voltage control could not be used because of the orientation of the torch to the orbital drive.

The actual dissimilar metal weld overlay mockup (region B in Figure 5-4) was "temper bead" welded on the low alloy steel side of the joint first, using the layer 1, layer 2 and layer 3 parameters in Table 5-2. Preheat of 350°F was applied for 1/2 hour to provide for hydrogen migration in compliance with ASME Section XI. Following the completion of the "temper bead" layers, the mockup received a post-heat of 450°F to 500°F for three hours followed by a slow cool consistent with the requirements of IWB-4340 of the Code. The mockup was then filled with tap water and the initial three layers of the Inconel 82 overlay were deposited on the stainless steel side of the joint, using the layer 2 parameters of Table 5-2 with the exception that preheat and interpass temperatures were 70°F and 110°F, respectively. When three Inconel 82 weld overlay layers were completed across the entire joint, the layer 2 parameters were used with water inside the mockup for the remainder of the overlay. A total of seven layers were required to fabricate this full structural weld overlay. A metallurgical section of the completed overlay is presented in Figure 5-2. The tempering and grain refinement on the P-3 material appeared to be nearly complete following the third "temper bead" layer. Any further heat input which affects the low alloy steel can only assist in further tempering.

5.4 Test Results

5.4.1 Mechanical Property Tests

Tensile and Charpy bars were removed from the mockup groove weld as presented schematically in Figure 5-4, region A. The tensile bars (as well as the bend bars) were fabricated such that the test section included the Inconel 82 weld metal and the low alloy steel heat affected zone produced along a nearly vertical side wall of the groove weld. The Charpy bars were removed such that the root of the V-notch was at the weld/heat affected zone interface, just penetrating the heat affected zone, as shown in Figure 5-4, region A.

The Charpy and tensile property data for the groove weld Inconel overlay mockup are presented in Table 5-3. The two tensile test runs botn failed in the low alloy steel base metal at stresses of 93.2 ksi and 92.8 ksi, respectively. These results compare very

Table 5-3

Mechanical Property Results on Specimens Removed From Groove Weld In Overlay Mockup (Reference 3)

Charpy Impact Properties at 40°F

Location	Specimen No.	Absorbed Energy (ft-lbs)	Fracture Appearance (% Shear)	Lateral Expansion (inches)
P-3 HAZ	A	67	60	0.056
	B	88	70	0.066
	C	69	50	0.051
P-3 Base Metal	G	65	50	0.053
	I	83	70	0.056
	K	76	50	0.053

Tensile Test Results

Specimen No.	Ultimate Tensile Strength (ksi)	Failure Location
1	93.2	P-3 Base Metal
2	92.8	P-3 Base Metal

favorably with the tensile test results presented on the certified material test reports for this heat of material. The Charpy V-notch results for the heat affected zone taken at 40°F show that the heat affected zone and the base metal had essentially the same absorbed energy, percentage of shear fracture and lateral expansion. The bend tests also showed no fissuring in the dilution zone material. Some tearing was noted in the Inconel 82 weld metal in the bend tests, however. This tearing was the result of the significant difference in yield strength of the Inconel 82 as compared to the low alloy steel. As the specimen was pulled around the bend mandrel, it is believed that the significant difference in flow characteristics between the two materials (Inconel 82 versus SA 508 Class 2) caused a large strain concentration in the Inconel at the fusion line and resulted in the small amount of tearing observed. This tearing is believed to be an artifact of the bend test technique and not the result of any welding problem. Additional bend specimens were made and tested so that the bottom of the weld groove was centered in the bend radius similar to an ASME Section IX longitudinal bend. This bend passed with no indications.

5.4.2 Metallurgical Tests

The mechanical property test results reported in Section 5.4.1 verified that the Inconel 82 weld overlay repair did not degrade the strength or toughness of the low alloy steel weld heat affected zone. Further, the bend test results indicated that the weldment deposited provided a sound metallurgical bond between the low alloy steel nozzle and the Inconel overlay. In addition to those mechanical property tests, microstructure and microhardness determination were performed on the groove weld, the dissimilar metal mockup weld and the three layer "temper bead" weld, as described in this section of the report. The results of these and other metallurgical examinations are presented below.

A comparison of these microstructural and microhardness results with standard postweld heat treatment results was also made and is presented. In addition, comparison of these microhardness data with the data developed in the EPRI/B&W program is reported.

The first low alloy steel specimen examined metallurgically was a three layer temper bead weldment performed on the low alloy steel nozzle forging. Figure 5-5 presents a macrophotograph of a section of this specimen (taken at the 3 o'clock azimuth) illustrating the bead penetration and bead overlap for this Inconel weld overlay test coupon. Detailed microhardness measurements were performed on this three layer temper bead test sample. The microhardness measurements were performed in the P-3 material heat affected zone in the approximate center of the section extending from the weld fusion line into the low alloy steel starting 50μ into the P-3 material. This measurement approach was taken to maintain consistency with the EPRI/B&W approach (Reference 15). A Knoop-500 gram indentor was used for these and all microhardness measurements performed in this program, also to be consistent with the microhardness data in the EPRI/B&W program. The maximum hardness in the heat affected zone in this sample reported in Reference 3 was 372 KHN, which corresponds to an equivalent Rockwell hardness of approximately R_C37. The maximum hardness appears to lie in the heat affected zone approximately 300 to 1000μ from the weld fusion line.

Extensive metallurgical and microhardness measurements were also performed on the P-3 side of the actual Inconel weld overlay weld (Figure 5-4, Region B). Microhardness measurements were performed beneath the overlay to provide representative values. Measurements were also performed at the extremity of the overlay in the P-3 material to evaluate the effects of incomplete tempering at the overlay edge, and in the heat affected zone of the original Inconel 182 butter, a region which had received a postweld heat treatment following the butter application.

The weld overlay microhardness results from the Inconel weld overlay are compared to the six layer EPRI/B&W microhardness results (Reference 15) in Figure 5-6. One observes a maximum hardnesses ranging from 351 to 363 KHN (R_c35 to 37) for the Inconel weld overlay, as compared to a maximum hardness of approximately 330 KHN (R_c32 to R_c33) in the EPRI/B&W six layer repair. The small hardness differences between the Inconel overlay repair and the B & W plate repair are most likely the result of heat-to-heat hardenability differences. When a comparison of the two approaches was performed on the same B & W plate, the hardness results were virtually identical [Reference 3]. The base metal hardness in the P-3 nozzle used in this study is approximately 210-220 KHN, similar to what was observed in the EPRI/B&W study. The maximum hardness observed in the Inconel buttered, postweld heat treated portion of the original weldment was 300 KHN (R_c30).

5.5 Applicability to BSEP-2 Weld 12-AR-E5

The above procedure development and test results indicate the ability to produce an acceptable weld overlay repair for application near and on a low alloy steel reactor vessel nozzle, without postweld heat treatment after the repair. The repair parameters have been developed consistent with ASME Code requirements, specifically ASME Section XI and Code Case N-432. Tensile, bend and toughness tests were performed on a mockup simulation of the overlay repair and were demonstrated to confirm to the requirements of the Code. Additionally, an evaluation of the metallurgical structure and hardness was performed to address the concern for high hardness, potentially brittle material in untempered regions of the low alloy steel weld heat affected zone. For all instances in which a multi-layer weld overlay was deposited, the maximum hardness in the low alloy steel heat affected zone was less than R_c37. Although this is higher than the expected hardness levels of R_c30 for a normally postweld heat treated weldment of this type, the test results and literature investigations verify that sufficient tempering is achieved to provide adequate fracture toughness and embrittlement resistance for this class of material.

Vendor specific welding procedures and procedure qualifications (Reference 16) are being used for the Brunswick Unit 2 repair are consistent with the welding techniques and parameters of References 3 and 4. Therefore the above results and conclusions regarding acceptability of the Inconel weld overlay repair process are directly applicable to this repair. Specific input from this welding development program have been incorporated into the repair design, as shown the weld overlay design drawing (Appendix).

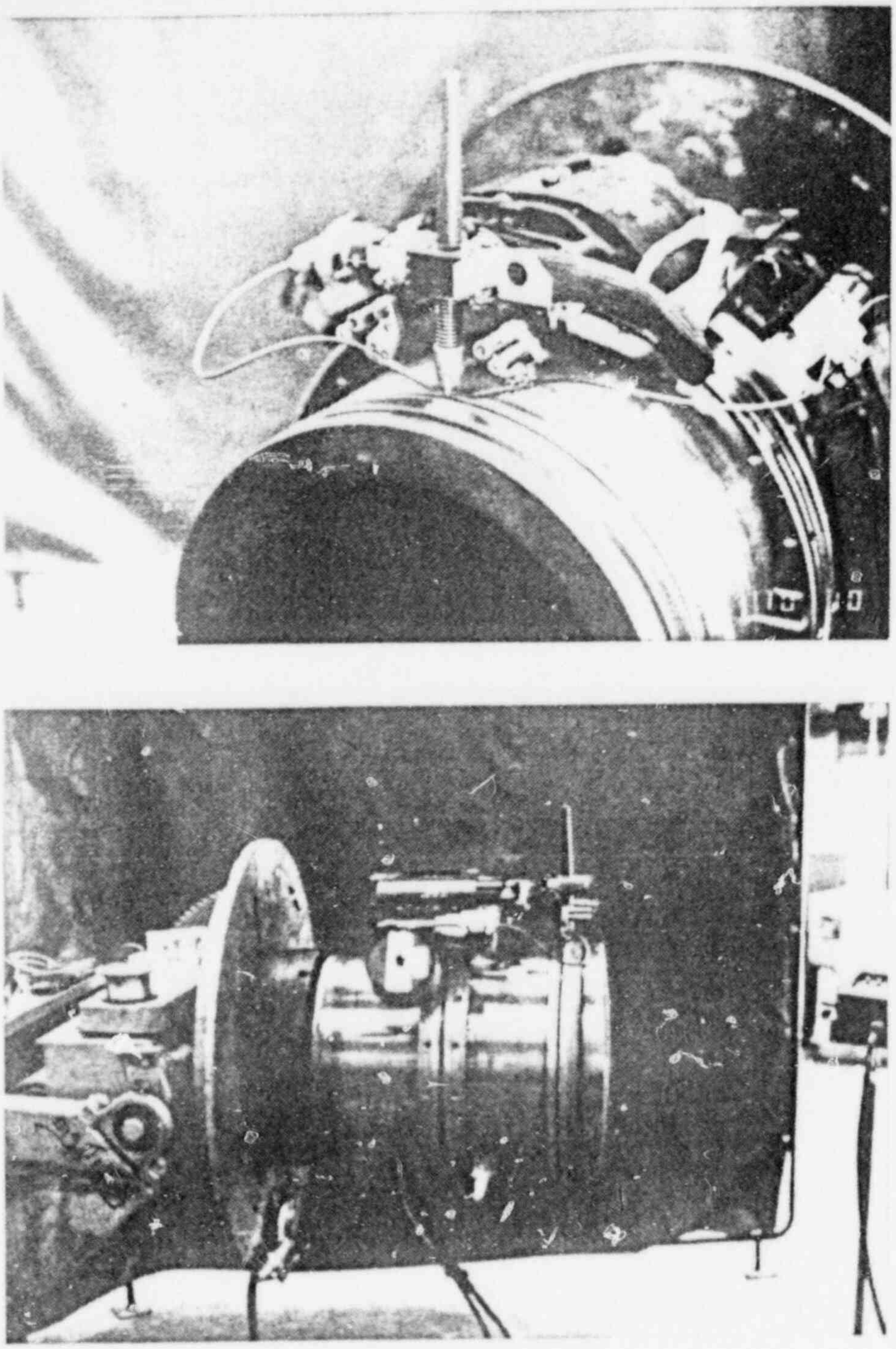


Figure 5-1. Nozzle to Safe End Assembly Girth Welded Prior to Weld Overlay [Reference 3]

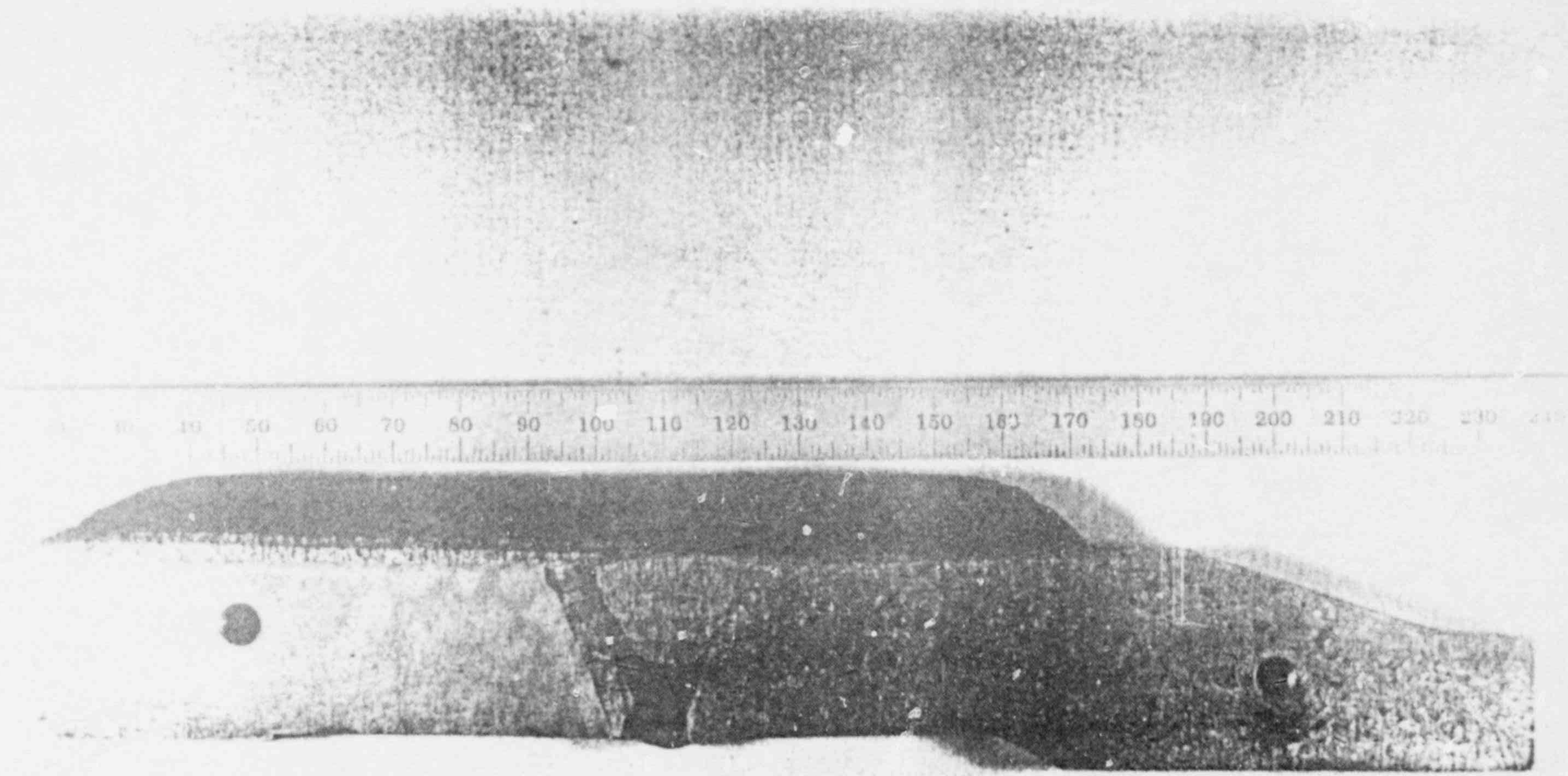


Figure 5-2. Cross Section Containing Inconel 82 Weld Overlay on Nozzle to Safe End [Reference 3]

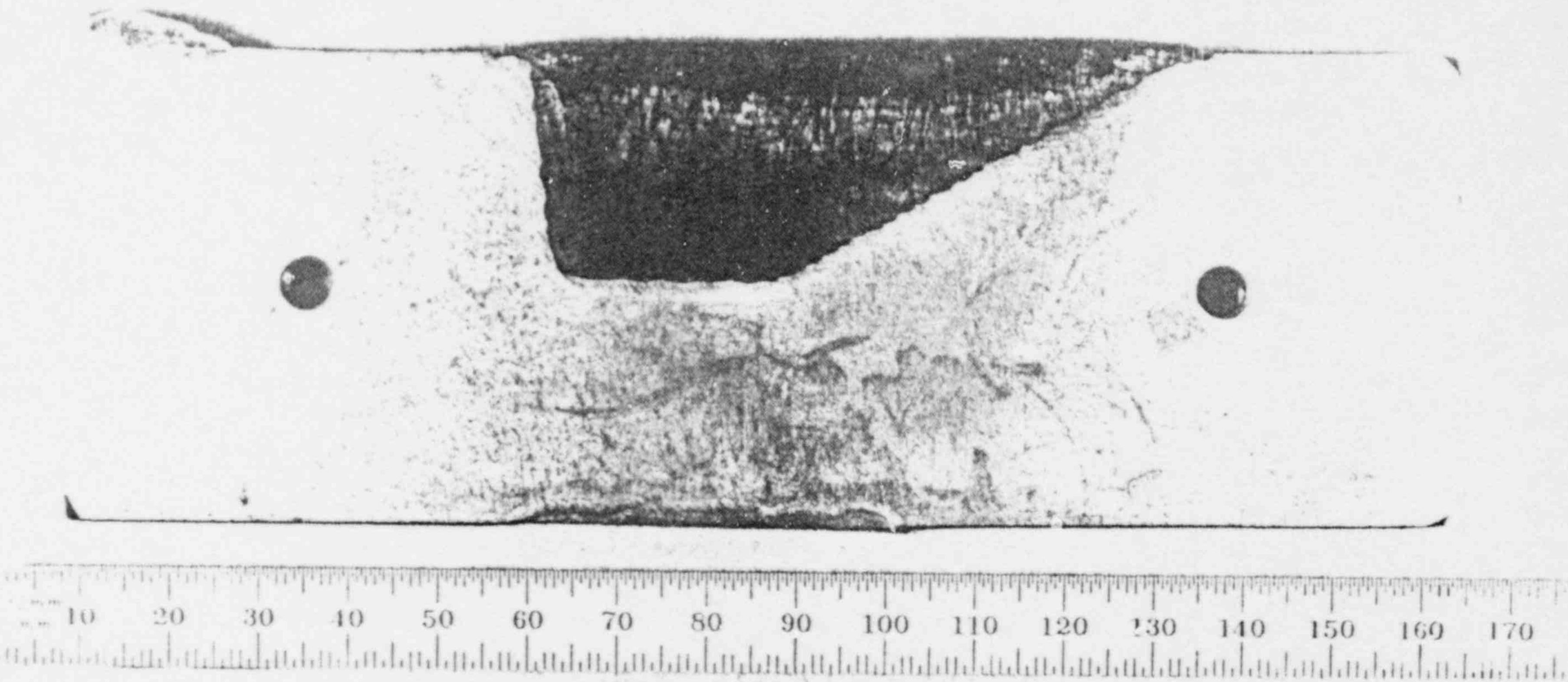


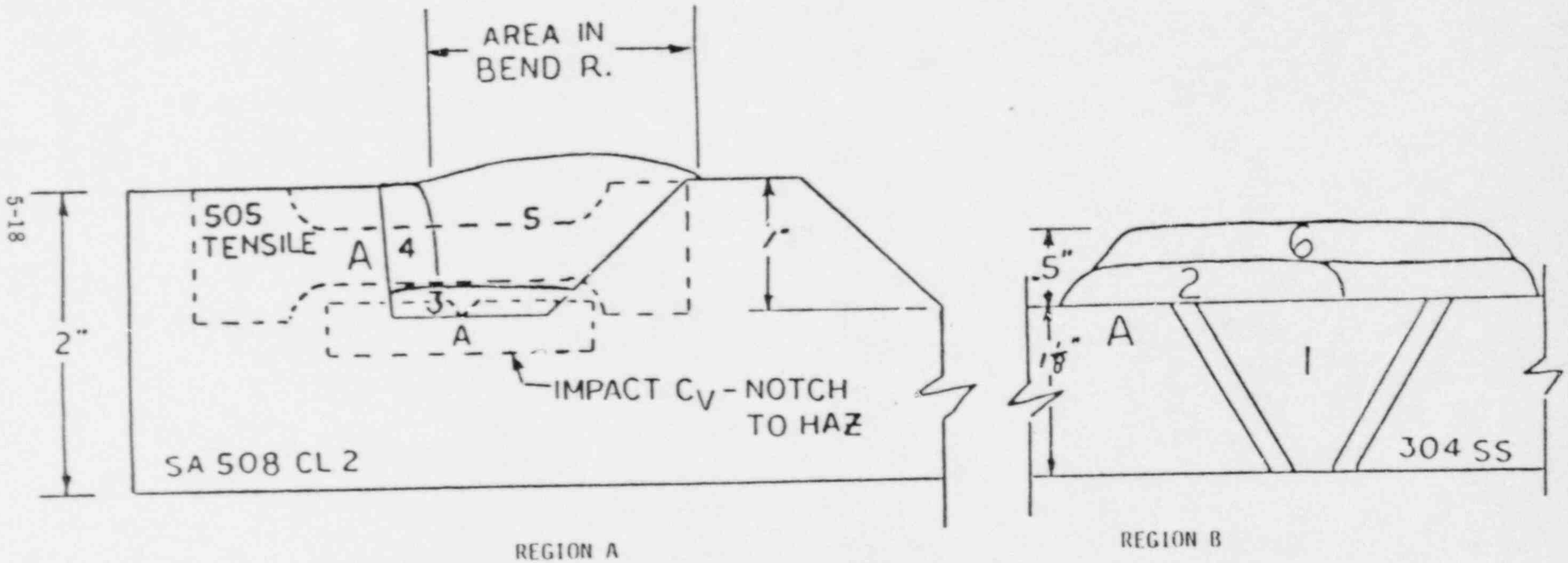
Figure 5-3. Groove Weld in P-3 Nozzle From Which Mechanical Property Specimens Were Taken [Reference 3]

1. NOZZLE TO SAFEND WELD-INCONEL BUTTER AND BUTT WELD

2-4. THREE LAYER TEMPER BEAD WELD

5-6. OVERLAY AND GROOVE COMPLETED WITH WATER BACKING

A. LOCATION OF MICROHARDNESS SURVEY



5-18

Figure 5-4. Schematic Representation of Inconel Overlay and Groove Weld Identifying Temper Bead Welds and Locations for Mechanical Property Specimens

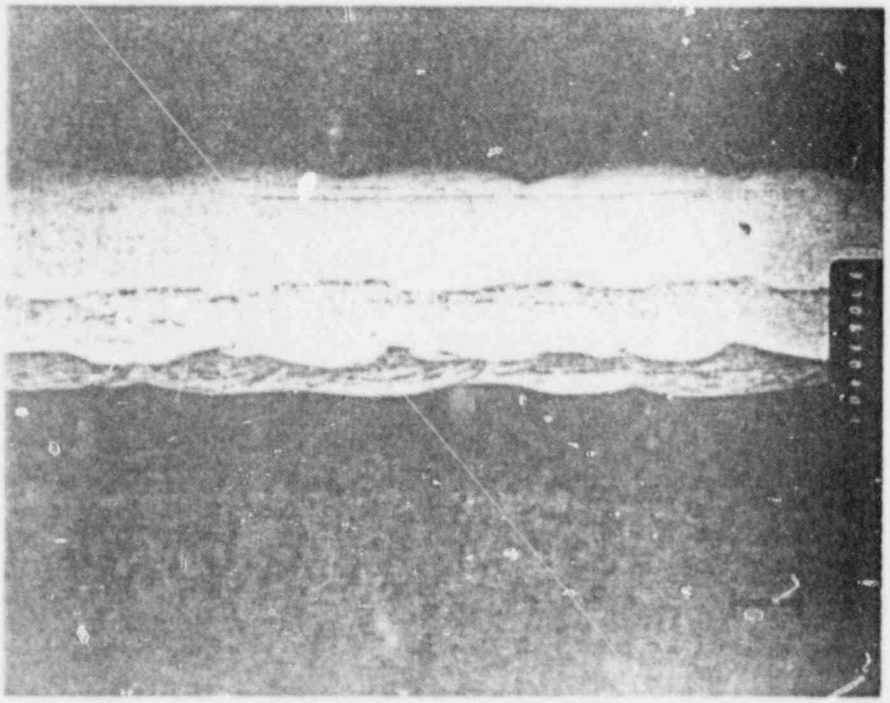


Figure 5-5. Metallography of Three Layer Inconel Overlay on P-3 Nozzle Including Heat Affected Zone - Three O'Clock Azimuth (6.3X)

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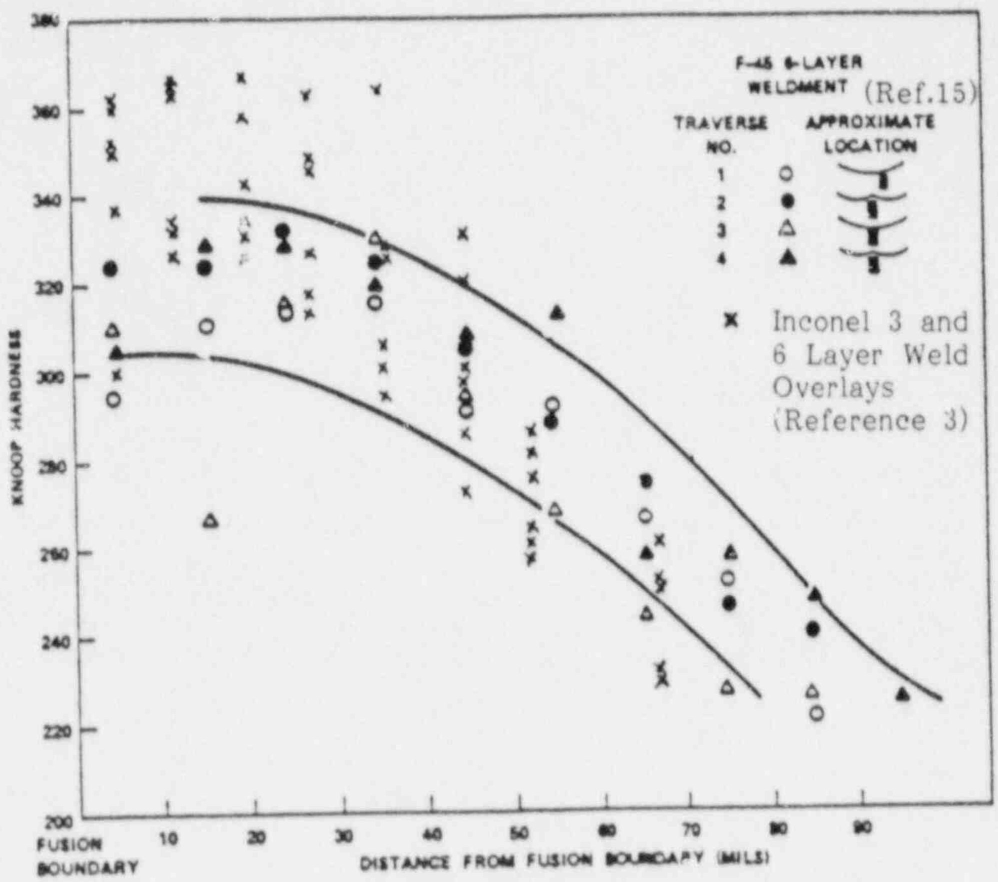

Figure 5-6. Comparison of Weld HAZ Microhardness Results from References 3 and 15. Results Indicate Inconel Weld Overlay Process Provides Essential Equivalent Tempering as Best EPRI/B&W Process

6.0 SUMMARY AND CONCLUSIONS

During the current 1988 refueling outage at the Brunswick Steam Electric Plant Unit 2 (BSEP-2), ultrasonic examination (UT) revealed the presence of a flaw indication in one of the ten 12-inch reactor recirculation inlet nozzle-to-safe end weldments. The flaw has a reported length of 4.8 inches and a maximum through-wall depth of 85%. Based on these flaw characteristics and analyses performed by Structural Integrity Associates, Carolina Power and Light has elected to utilize a weld overlay repair.

This report describes:

- the current flaw characterization, results of prior UT examinations and probable failure mechanism,
- the Inconel temper bead weld overlay repair used to repair the observed flaw indication,
- the design bases for the Inconel temper bead weld overlay,
- the analyses and design of the BSEP-2 specific weld overlay, and
- the industry sponsored welding development and metallurgical testing program used to demonstrate the technical adequacy of this repair approach.

On the basis of this work, it is concluded that the weld overlay repair presented herein will restore original design basis structural margins to the flawed weldment, will produce favorable residual stress patterns and a highly IGSCC resistant barrier to further growth of the observed flaw, and will not have an adverse affect on the adjacent low alloy steel nozzle.

7.0 REFERENCES

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2. ASME Boiler and Pressure Vessel Code, Section XI, "Rules for Inservice Inspection of Nuclear Power Plant Components," 1983 Edition with Addenda through Winter 1985.

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4. ASME Boiler and Pressure Vessel Code, Code Case N-432, "Repair Welding Using Automatic or Machine Gas Tungsten Arc Welding (GTAW) Temperbead Technique, Section XI, Division 1, February 20, 1986.

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16. GE Weld Procedure Specification and Procedure Qualification Report for BSEP-2 Weld 12-AR-E5 Weld Overlay Repair.

APPENDIX

Weld Overlay Design Drawing
BSEP-12-AR-E5

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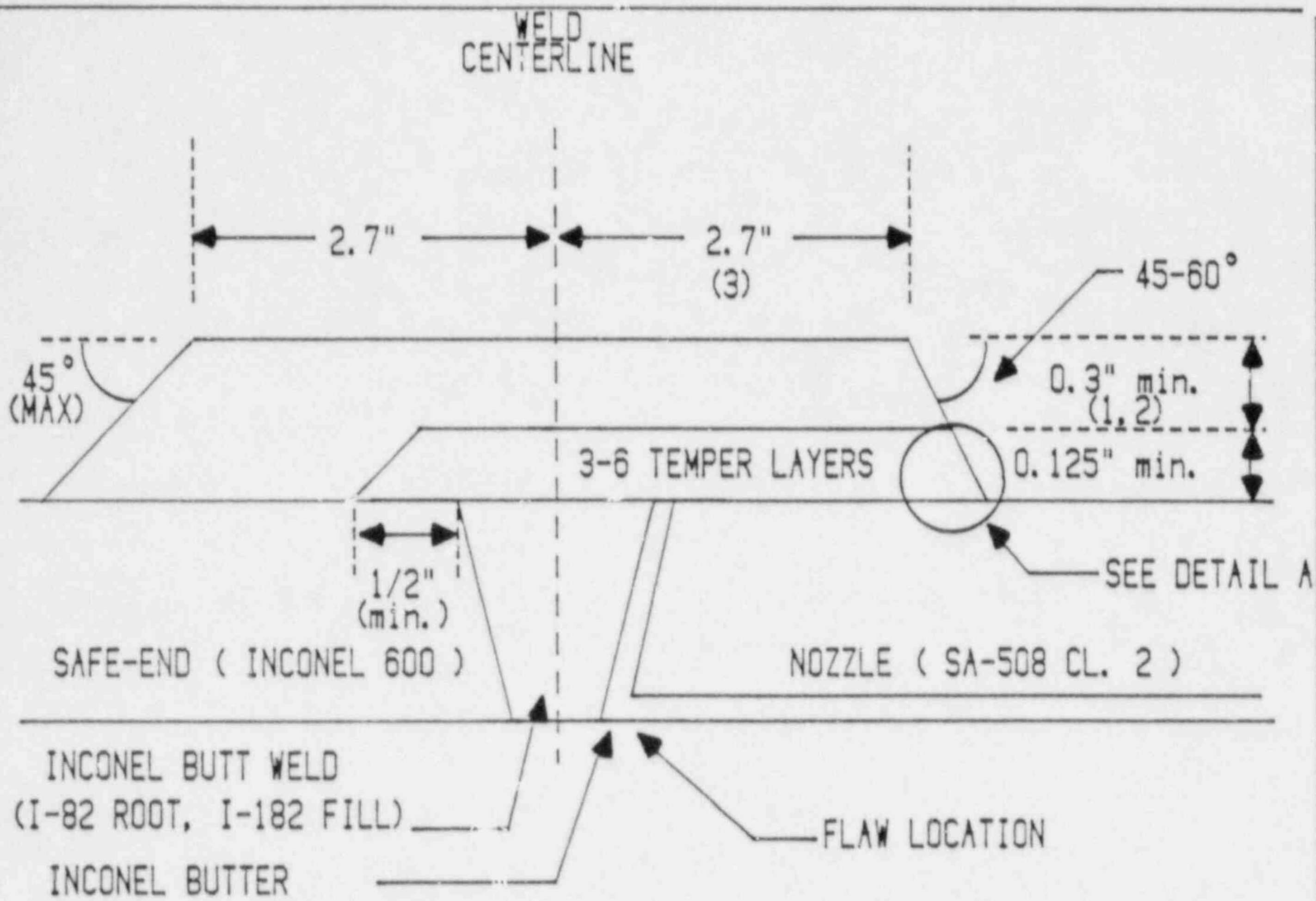
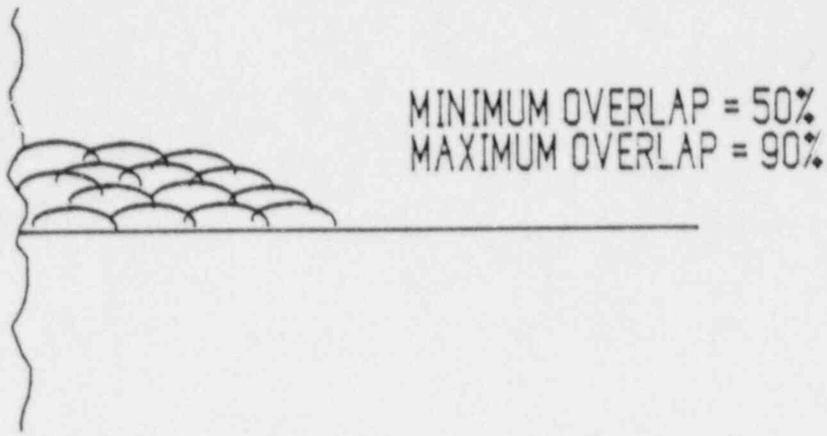


CAROLINA POWER & LIGHT COMPANY
BRUNSWICK STEAM ELECTRIC PLANT UNIT 2
WELD OVERLAY REPAIR DETAIL
SAFE END TO NOZZLE WELD

NOTES:
1. WELD OVERLAY DESIGN THICKNESS IS 0.3" AFTER FIRST 3 TEMPER LAYERS.
2. WELD LAYERS TO BE APPLIED IN ACCORDANCE WITH CP&L APPROVED CONTRACTOR WELDING PROCEDURES
3. FULL THICKNESS OF OVERLAY MUST EXTEND AT LEAST 2.0" BEYOND THE BUTTER-NOZZLE INTERFACE.

SI PROJECT NUMBER: CPL-01Q
WELD NUMBER: 2B32-RR-12-AR-E5
DRAWING NUMBER: BSEP2-12-AR-E5, PAGE 1 OF 2 REVISION: 3
PREPARED BY/DATE: [illegible] / 1-28-88
REVIEWED BY/DATE: [illegible] / 1-28-88
ISSUED BY/DATE: [illegible] / 1-28-88



DETAIL "A"

DRAWING NUMBER: BSEP2-12-AR-E5 PAGE 2 OF 2
REVISION: 3

STRUCTURAL INTEGRITY ASSOCIATES, INC.

ENCLOSURE 2

STRUCTURAL INTEGRITY ASSOCIATES INC.

DESIGN REPORT NO. SIR-88-010