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DESIGN REPORT
FOR
RECIRCULATION SYSTEM
WELD OVERLAY REPAIRS AND FLAW ANALYSIS
AT
BRUNSWICK STEAM ELECTRIC PLANT
UNIT 1

Prepared for:
Carolina Power and Light Company

Prepared by:
NUTECH, Inc.
San Jose, California

Prepared by:	Reviewed by:
M. E. Kleinsmith Consultant I	H. L. Gustin, P.E. Project Engineer
Approved by:	Issued by:
T. J. Wenner, P.E. Engineering Manager	D. K. Yoshida, P.E. Project Manager
	Date: 9/17/85

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NAME / TITLE	INITIALS
H. L. Gustin, P.E./Project Engineer	HLG
M. E. Kleinsmith/Consultant I	MEK
N. G. Cofie/Senior Consultant	NGC

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20,28	2	MEK 9/17/85	NGC 9/17/85	HLG 9/17/85	revised stresses and crack growth prediction

CERTIFICATION BY REGISTERED PROFESSIONAL ENGINEER

I hereby certify that this document and the calculations contained herein were prepared under my direct supervision, or reviewed by me, and to the best of my knowledge are correct and complete. I further certify that, to the best of my knowledge design margins required by the original Code of Construction have not been reduced as a result of the repairs addressed herein. I am a duly Registered Professional Engineer under the laws of the State of North Carolina and am competent to review this document.

NORTH CAROLINA
PROFESSIONAL
SEAL
12504
ENGINEER
HARRY LATHAM GUSTIN

Certified by:

H. L. Gustin, P.E.

Registered Professional Engineer
State of North Carolina
Registration No. 12504

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1.0 INTRODUCTION

This report summarizes analyses performed by NUTECH to evaluate flaw indications and weld overlay repairs in the Recirculation System at Carolina Power and Light Company's Brunswick Steam Electric Plant Unit 1 (Brunswick 1). The flaw indications addressed in this report were detected during the summer 1985 refueling outage inspection.

Flaw indications were identified adjacent to 23 welds in the Recirculation System. One flaw indication detected by ultrasonic (UT) examination was determined to be acceptable without repair for at least the next 18 months. The remaining flaw indications were repaired by application of weld overlay. The purpose of each overlay is to arrest any further propagation of intergranular stress corrosion cracking (IGSCC), and to restore original design safety margins to the weld. All flaws are in Type 304 stainless steel material. Figure 1.1 shows the location of these flaw indications. Table 1.1 contains a description of each flaw indication and the disposition of each.

Table 1.1
BRUNSWICK UNIT 1 FLAW DISPOSITION

Weld No.	Flaw[a]	Overlay Design (in.)[f] Tmin/No. of Layers	L1	L2	Pipe Size
28-A8	Circumferential 2.25"x25%, upstream	N/A	N/A	N/A	28"
12-AR-A2	Axial, 0.4", upstream[b]	2 layers	1.5	1.5	12"
12-AR-A3	Circumferential, 1.75"x35%, upstream	0.250"	1.5	1.5	12"
12-AR-B3	Axial, 0.5", downstream[b]	2 layers	1.5	1.5	12"
12-AR-C2	Circumferential, 0.6"x50%, downstream	0.260"	1.5	1.5	12"
12-AR-C3	Axial, 0.4", downstream[b]	2 layers	1.5	1.5	12"
12-AR-D2	Axial, 0.60", upstream[b]	2 layers	1.5	1.5	12"
12-AR-D3	Axial, 0.375", downstream[b]	2 layers	1.5	1.5	12"
12-AR-D4	Circumferential, 2.0"x35%, upstream	0.220"	1.5	0.625	12"
12-AR-E3	Axial, 0.4", downstream[b]	2 layers	1.5	1.5	12"
12-BR-F2	Axial, 0.75", downstream[b]	2 layers	1.5	1.5	12"
12-BR-G2	Circumferential, 1.125"x25%, upstream	0.220"	1.5	1.5	12"

Table 1.1
BRUNSWICK UNIT 1 FLAW DISPOSITION
(continued)

Weld No.	Flaw[a]	Overlay Design (in.)[f] Tmin/No. of Layers	L1	L2	Pipe Size
12-BR-G3	Axial, 0.8" upstream[b]	2 layers	1.5	1.5	12"
12-BR-G4	Axial, 0.5", upstream[b]	2 layers	1.5	0.60	12"
12-BR-H2	Axial, 0.4", downstream[b]	2 layers	1.5	1.5	12"
12-BR-H3	Axial, 0.5", upstream[b]	2 layers	1.5	1.5	12"
12-BR-J2	Axial, 0.6" upstream[b]	2 layers	1.5	1.5	12"
12-BR-J3	Circumferential, 4"x60%, downstream	0.230"	1.5	1.5	12"
12-BR-K2	Axial[c]	2 layers	1.5	1.5	12"
12-BR-K3	Axial, 0.75" upstream[b]	2 layers	1.5	1.5	12"
12-BR-K4	Axial, 0.4" upstream[b]	2 layers	1.5	0.55	12"
28-A4	Axial, 0.6", upstream[d]	2 layers	1.6	1.6	28"
28-B4	Axial, 0.6" x25%, upstream[e]	2 layers	1.5	1.5	28"

Table 1.1
BRUNSWICK UNIT 1 FLAW DISPOSITION
(continued)

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[a] Flaw size used in designing overlay

[b] Flaw depth assumed 100%

[c] Leaking flaw undetected by UT, flaw assumed axial .7"x100%

[d] Circumferential flaws present did not require overlay; flaw depth assumed 100%

[e] Circumferential flaws present did not require overlay

[f] See Figure 1.2 for definition of weld overlay dimensions

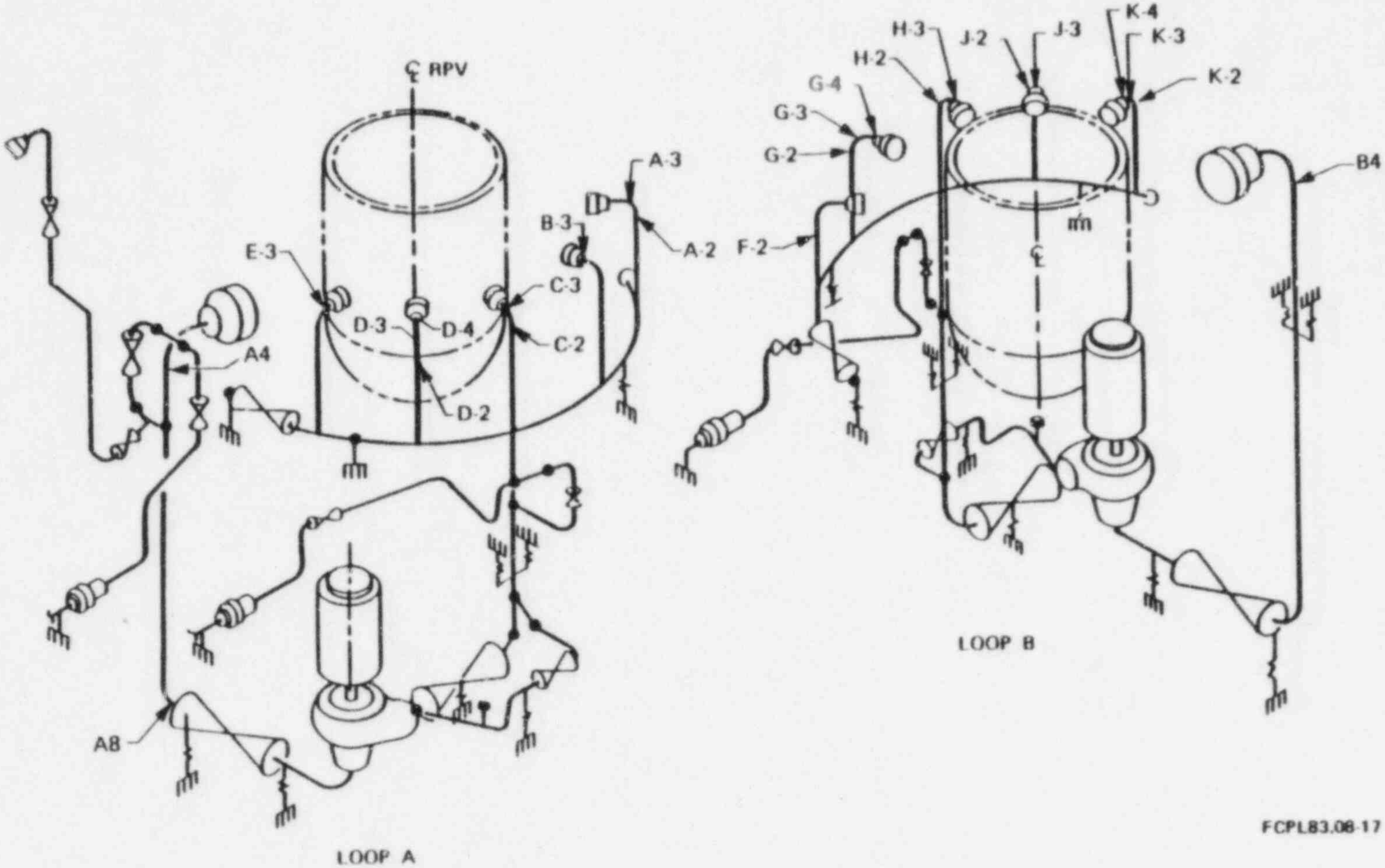

Figure 1.1

CONCEPTUAL DRAWING OF RECIRCULATION SYSTEM

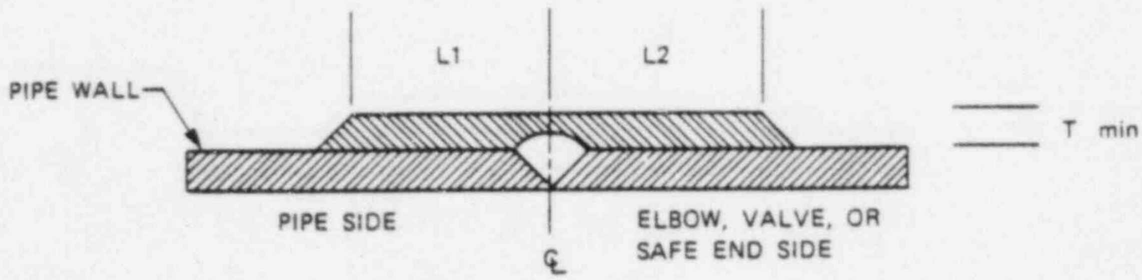

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Figure 1.2
WELD OVERLAY DIMENSION DEFINITION

2.0 REPAIR DESCRIPTION

The UT flaw indications requiring repair were remedied by establishing additional "cast-in-place" pipe wall thickness with weld metal deposited 360 degrees around and to either side of the existing weld, as shown in Figures 2.1 through 2.3. The weld-deposited band over the cracks provides, as a minimum, wall thickness equal to that required to meet the requirements of Reference 1, as modified by Reference 2. NRC Generic Letter 84-11 (Reference 2) requires that the first weld overlay layer not be included in the design thickness. A favorable compressive residual stress distribution results from overlay application, which will tend to inhibit further crack initiation or growth. The deposited weld metal is type 308L, which is resistant to IGSCC propagation. Table 2.1 presents design and as-built information for the overlay repairs applied to Brunswick 1.

All weld overlay repairs were inspected using non-destructive examination. Non-destructive examination of the weld overlays consisted of the following:

1) Surface examination of the first weld overlay layer by the liquid penetrant examination technique in accordance with ASME Section XI (Reference 1).

2) Delta ferrite measurement of the first layer, using a Severn gauge.

3) Surface examination of the completed weld overlay by the liquid penetrant examination technique in accordance with ASME Section XI (Reference 1).

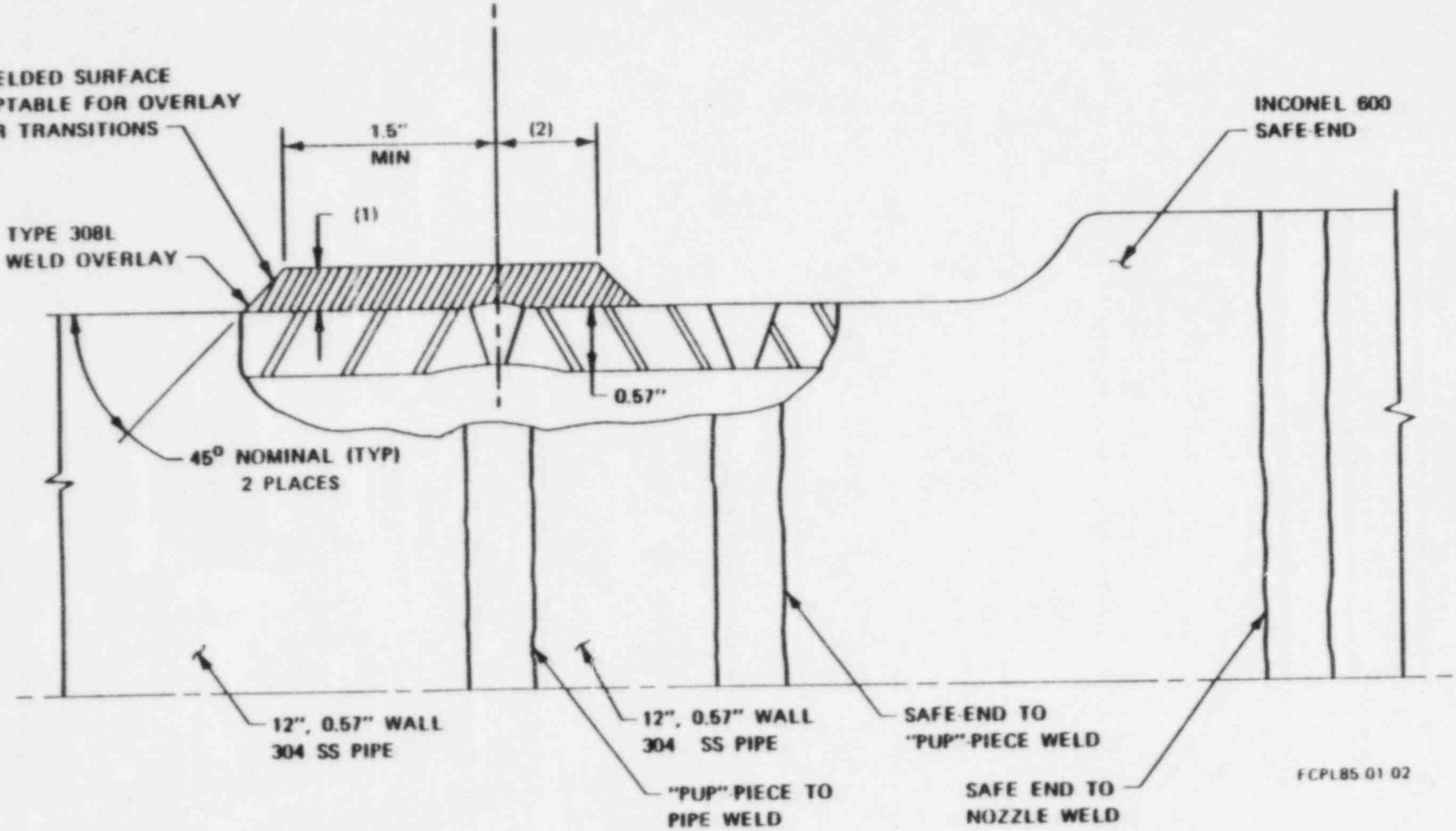
4) Volumetric examination of the completed weld overlay by the ultrasonic examination technique in accordance with ASME Section XI (Reference 1).

5) Volumetric examination of the weld overlay to pipe bond and existing circumferential pipe weld by the ultrasonic examination technique in accordance with recommendations outlined in the EPRI interim report dated April 1985, "Examination of Weld Overlayed Pipe Joints" (Reference 9). 2

Table 2.1
WELD OVERLAY AS-BUILT DIMENSIONS

Weld I.D.	Pipe Size	Design Tmin/ No. of Layers	As-Built Thickness	As-Built Length
12-AR-A2	12	2 layers	0.303	3.453
12-AR-A3	12	0.250	0.419	3.188
12-AR-B3	12	2 layers	0.398	3.43
12-AR-C2	12	0.260	0.435	3.640
12-AR-C3	12	2 layers	0.435	3.037
12-AR-D2	12	2 layers	0.296	3.170
12-AR-D3	12	2 layers	0.317	3.075
12-AR-D4	12	0.220	0.404	2.225
12-AR-E3	12	2 layers	0.373	3.064
12-BR-F2	12	2 layers	0.328	3.453
12-BR-G2	12	0.220	0.418	3.288
12-BR-G3	12	2 layers	0.468	3.050
12-BR-G4	12	2 layers	0.205	2.923
12-BR-H2	12	2 layers	0.280	3.482
12-BR-H3	12	2 layers	0.465	3.175
12-BR-J2	12	2 layers	0.290	3.101
12-BR-J3	12	0.230	0.447	3.115
12-BR-K2	12	2 layers	0.410	3.110
12-BR-K3	12	2 layers	0.320	3.250
12-BR-K4	12	2 layers	0.213	2.425
28-A4	28	2 layers	0.140	3.525
28-B4	28	2 layers	0.163	3.72

*Exclusive of first layer thickness



(1) MINIMUM THICKNESS VARIES, BUT DOES NOT INCLUDE FIRST LAYER THICKNESS

(2) DIMENSION VARIES DEPENDENT UPON EXTENT OF INCONEL

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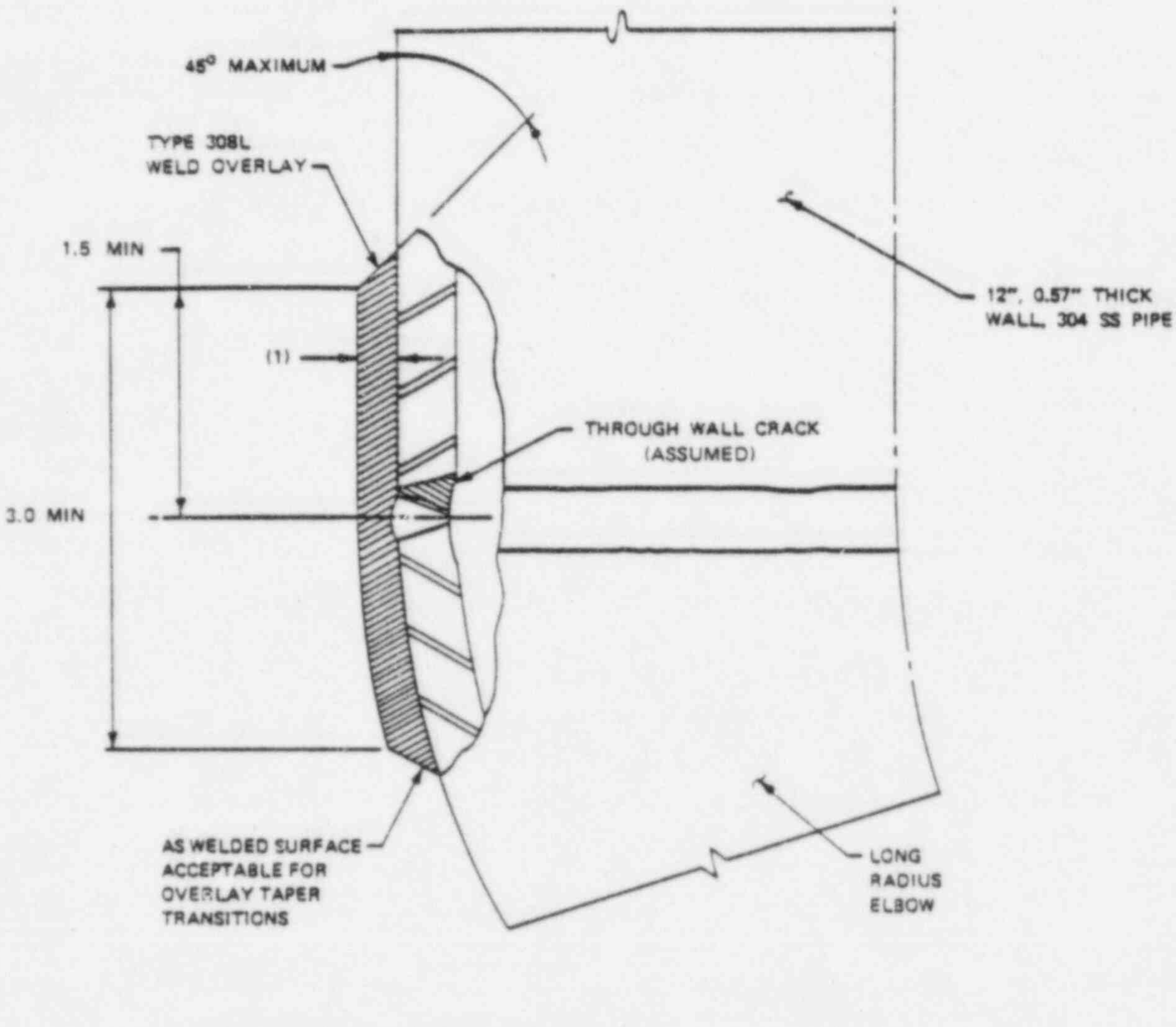
Figure 2.1

CONFIGURATION OF SAFE END-TO-PIPE WELD OVERLAY



(1) MINIMUM THICKNESS VARIES, BUT DOES NOT INCLUDE FIRST LAYER THICKNESS

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Figure 2.2

CONFIGURATION OF 12" ELBOW – TO – PIPE WELD OVERLAY

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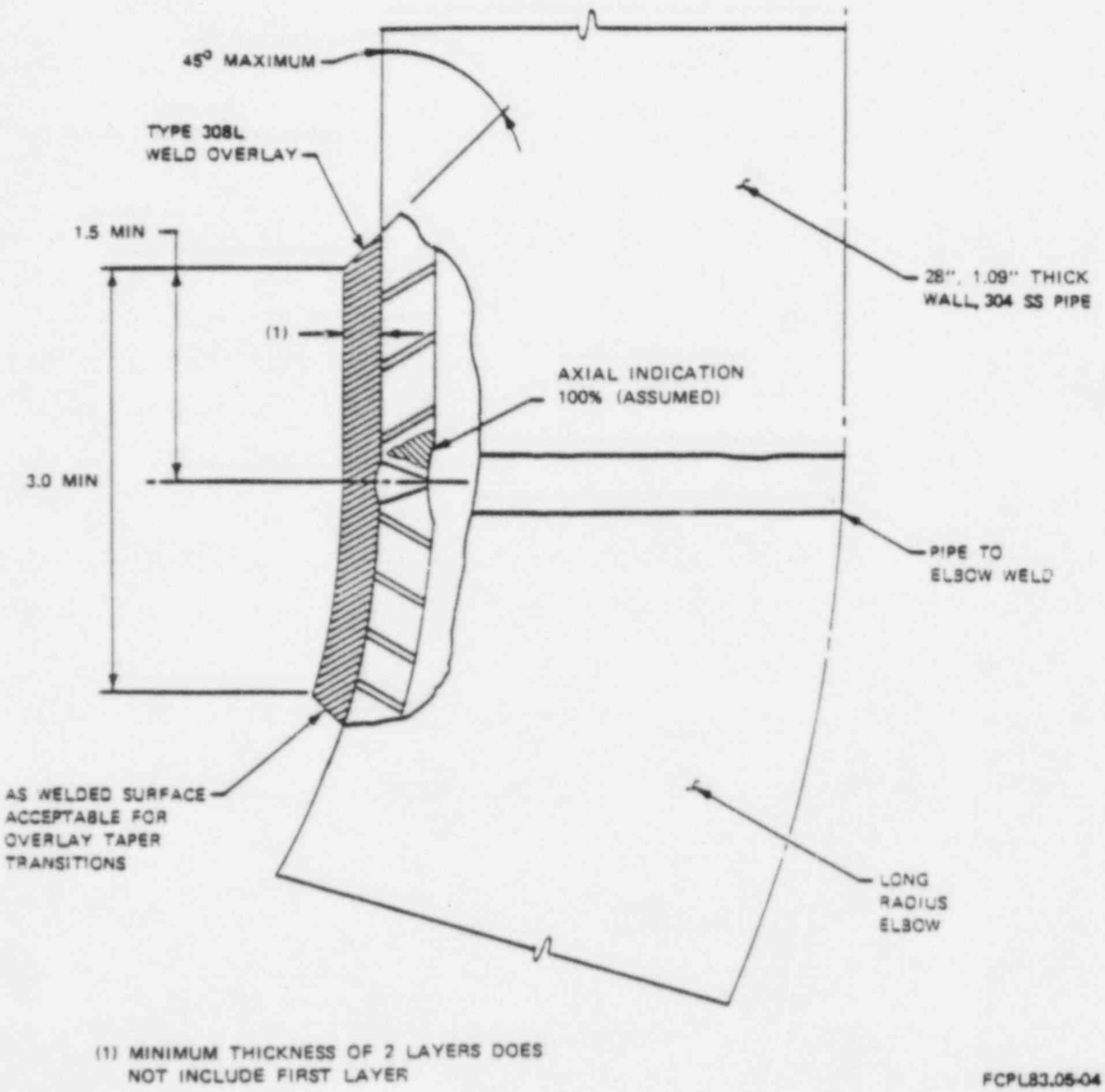

Figure 2.3

CONFIGURATION OF 28" ELBOW – TO – PIPE WELD OVERLAY

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3.0 EVALUATION CRITERIA

This section describes the criteria that are applied in this report to evaluate the acceptability of the weld overlay repairs and flawed pipe analysis. A Section III stress evaluation was not performed as part of this analysis since the Section XI evaluations inherently satisfy Section III requirements.

3.1 Weld Overlay Repair Criteria

Due to the nature of these repairs, the geometric configuration is not directly covered by Section III of the ASME Boiler and Pressure Vessel Code, which is intended for new construction. However, materials, fabrication procedures, and Quality Assurance requirements meet applicable sections of the original construction code. In addition, since conditions conducive to IGSCC led to the need for repairs, IGSCC-resistant materials have been selected for the weld overlay repairs.

A conservative method was used to demonstrate the adequacy of weld overlay repairs. All relevant UT indications were assumed to be through-wall for their measured length. The weld overlays were then designed such that the net section

limit load requirements of Reference 1 were satisfied, in addition to the requirements of Reference 2.

3.2 Flawed Pipe Analysis Criteria

Weld 28-A8 contained a circumferential flaw determined to be 2.25" long with a depth of 20%. Due to its small initial length, the end-of-cycle allowable flaw depth defined in Table IWB-3641-1 of ASME Section XI (Reference 1) is 75% of the pipe wall thickness. The NRC's Generic Letter 84-11 (Reference 2) modifies this depth by a factor of 2/3. The end-of-cycle allowable flaw depth is defined to be 50% of the pipe wall thickness, for the purpose of this analysis.

The upcoming cycle length is 18 months. Therefore the flaw must be shown to be acceptable without repair for at least the next 18 months, utilizing the crack growth law presented in Section 5.2.

4.0 LOADS

The loads considered in the evaluation of UT flaw indications included mechanical loads, internal pressure loads, differential thermal expansion loads, and weld overlay-induced shrinkage loads. Mechanical and internal pressure loads are used in designing weld overlays and are described in Section 4.1. Differential thermal and overlay shrinkage-induced loads are included for crack growth predictions. The weld overlay shrinkage-induced loads are explained in Section 4.2.

4.1 Mechanical, Internal Pressure, and Thermal Loads

Internal pressure information for the Recirculation System was obtained from Reference 3. Deadweight, thermal and seismic loads applied to the Recirculation System welds were obtained from Reference 4. Calculated stresses are included in Table 4.1.

4.2 Weld Overlay Shrinkage - Induced Loads

Weld overlays cause a small amount of axial shrinkage beneath the overlay. The resulting loads are manifested as bending stresses in the remainder of the piping system. Shrinkage loads in the Recirculation System were

calculated using a PISTAR (Reference 5) piping model. Weld overlay shrinkage is discussed further in Section 5.3.

Table 4.1

SUMMARY OF TOTAL STRESSES

Weld No.	Maximum Stress (PSI) Thermal	Seismic	Deadweight + Pressure	Total Stress (PSI) Crack Growth	Wol Design
28-A8	2358	1141	7346	9704	8487
12-AR-A2	--	--	*14030	14030	14030
12-AR-A3	8960	2150	6343	15303	8493
12-AR-B3	--	--	*14030	14030	14030
12-AR-C2	6231	1463	6308	12539	7771
12-AR-C3	--	--	*14030	14030	14030
12-AR-D2	--	--	*12649	12649	12649
12-AR-D3	--	--	*14030	14030	14030
12-AR-D4	10049	2722	6318	16367	9040
12-AR-E3	--	--	*12649	12649	12649
12-BR-F2	--	--	*12649	12649	12649
12-BR-G2	5608	738	6568	12176	7306
12-BR-G3	--	--	*12649	12649	12649
12-BR-G4	--	--	*10768	10768	10768
12-BR-H2	--	--	*10696	10696	10696
12-BR-H3	--	--	*14030	14030	14030
12-BR-J2	--	--	*12649	12649	12649
12-BR-J3	8769	1259	6339	15108	7598
12-BR-K2	--	--	*14030	14030	14030
12-BR-K3	--	--	*12649	12649	12649
12-BR-K4	--	--	*10768	10768	10768
28-A4	--	--	*12880	12880	12880
28-B4	--	--	*13417	13417	13417

* Circumferential stress due to pressure only

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5.0 EVALUATION METHODS AND RESULTS

The flawed welds shown in Table 1.1 were identified by UT inspections during the summer 1985 refueling outage inspection at Brunswick Unit 1. These flawed welds were evaluated based upon the criteria of Section 3 to determine whether an overlay was necessary to meet the requirements of Reference 1 and 2. Only one flawed weld (28-A8) was found to meet the requirements of References 1 and 2 without an overlay repair.

The application of weld overlays imposes a small amount of axial shrinkage at the weld location, which produces secondary stresses on the remainder of the piping system. The analysis made to determine the magnitude of this effect at each weld location and to address its significance is discussed in Section 5.3.

5.1 Code Evaluation - Section XI

All weld overlays were designed assuming flaws were through-wall for their measured length. Welds containing axial flaws only or axial flaws with very small circumferential flaws (as in welds 28-A4 and 28-B4) require only a leakage barrier. This leakage barrier consists of two layers of weld overlay material, with an

additional layer as required by Reference 2. Circumferential flaws in 12" pipe were overlay repaired in accordance with Reference 1. All overlay designs restore the safety margins required in Section IWB-3640 of ASME Section XI (Reference 1). The flaw in weld 28-A8 meets these requirements without repair and will not violate them for at least the next 18 months.

5.2 Fracture Mechanics Evaluation

The allowable end-of-cycle flaw depth was determined from References 1 and 2. Calculation of crack growth due to IGSCC was based on Reference 6 and NUTECH's computer program NUTCRAK (Reference 7). Input to NUTCRAK included the as-measured flaw depth, a conservative residual stress distribution, and the following conservative crack growth law.

$$\frac{da}{dt} = 3.59 \times 10^{-8} K^{2.161} \qquad \text{(Reference 3)}$$

Where da = differential crack depth (in)

dt = differential time (hrs)

K = stress intensity at the crack tip ($ksi \sqrt{in}$)

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Based on this conservative analysis, it was predicted that the flaw in weld 28-A8 would not exceed the end-of-cycle allowable crack depth for at least 22 months.

5.3 Overlay Shrinkage Effect on Recirculation System

The effects of the radial shrinkage are limited to the region adjacent to and directly underneath the weld overlay. Based on Reference 8, the stress due to the radial shrinkage is less than the yield stress at distances greater than about four inches from either end of the overlay.

The effect of the axial weld shrinkage on the Recirculation System was evaluated with the NUTECH computer program PISTAR (Reference 5) using the piping model presented in Figure 5.1. The measured shrinkages due to all overlays applied this outage, as well as those due to previously applied overlays, were imposed as boundary conditions on this model. Since the ASME Code does not limit weld residual stress, all stress indices were set equal to 1.0.

The PISTAR program was used to elastically calculate stress due to weld shrinkage. The maximum calculated stress for an IGSCC susceptible weld was 18.1 ksi at

nozzle weld N2D (weld 12-AR-D4). This weld is a 12" safe-end-to-nozzle weld on a recirculation riser, and was overlay-repaired. None of the stresses reported in Table 5.1 take into account the increased membrane due to overlay. Table 5.1 gives the shrinkage stress for all welds in the recirculation system found to have flaws. Since weld shrinkage-induced stresses are not limited by the ASME Code, the Code acceptability of these welds is not in question. It is judged that stresses of the magnitude calculated will have negligible effect on the integrity or IGSCC susceptibility of these welds.

5.4 Low Toughness Material Concerns

Recently, concerns have been raised that the toughness of weld metal in stainless steel butt welds deposited by flux shielded processes may be substantially lower than that of the surrounding metal. Potentially, this could lead to brittle failure of the butt weld material at an applied load appreciably below the net section collapse lead of the adjacent piping material. As of the date of this report, there is no formal regulatory or Code guidance on this issue.

NUTECH reviewed the weld overlays and unrepaired flaw at Brunswick 1 to address this issue. Most of the repaired flaws are oriented axially and are thus not affected by the toughness concern. The weld overlay as-built thicknesses of welds containing circumferential flaws are large enough to adequately repair 360°x100% flaws, excluding credit for the first overlay layer, as required by Reference 2. Therefore, no credit for the butt weld material need be taken. Finally, the unrepaired flaw in weld 28-A8 is very short and shallow and is thus not of concern.

Table 5.1

SUMMARY OF SHRINKAGE STRESSES AT

RECIRCULATION SYSTEM FLAW LOCATIONS

Weld Number	Overlay	Shrinkage Stress (PSI)
28-A8	No	176
12-AR-A2	Yes	1306
12-AR-A3	Yes	1410
12-AR-B3	Yes	557
12-AR-C2	Yes	1909
12-AR-C3	Yes	2651
12-AR-D2	Yes	6350
12-AR-D3	Yes	4255
12-AR-D4	Yes	18067
12-AR-E3	Yes	5422
12-BR-F2	Yes	743
12-BR-G2	Yes	3348
12-BR-G3	Yes	1230
12-BR-G4	Yes	8923
12-BR-H2	Yes	989
12-BR-H3	Yes	2248
12-BR-J2	Yes	633
12-BR-J3	Yes	812
12-BR-K2	Yes	2534
12-BR-K3	Yes	2216
12-BR-K4	Yes	1125
28-A4	Yes	195
28-B4	Yes	191
12-AR-A4*	Yes	879
12-AR-B2*	Yes	282
12-AR-B4*	Yes	558
12-AR-E2*	Yes	3358
12-BR-F4*	Yes	1008
12-BR-H4*	Yes	6989
28-A14*	Yes	123
28-A15*	Yes	218
28-B8*	Yes	189

* Overlay repaired during a previous outage

NOTE: Bypass loop weld 4A-10 was also overlay repaired. Its shrinkage will not affect the remainder of the system. Shrinkage stress present at this weld is less than 100 psi.

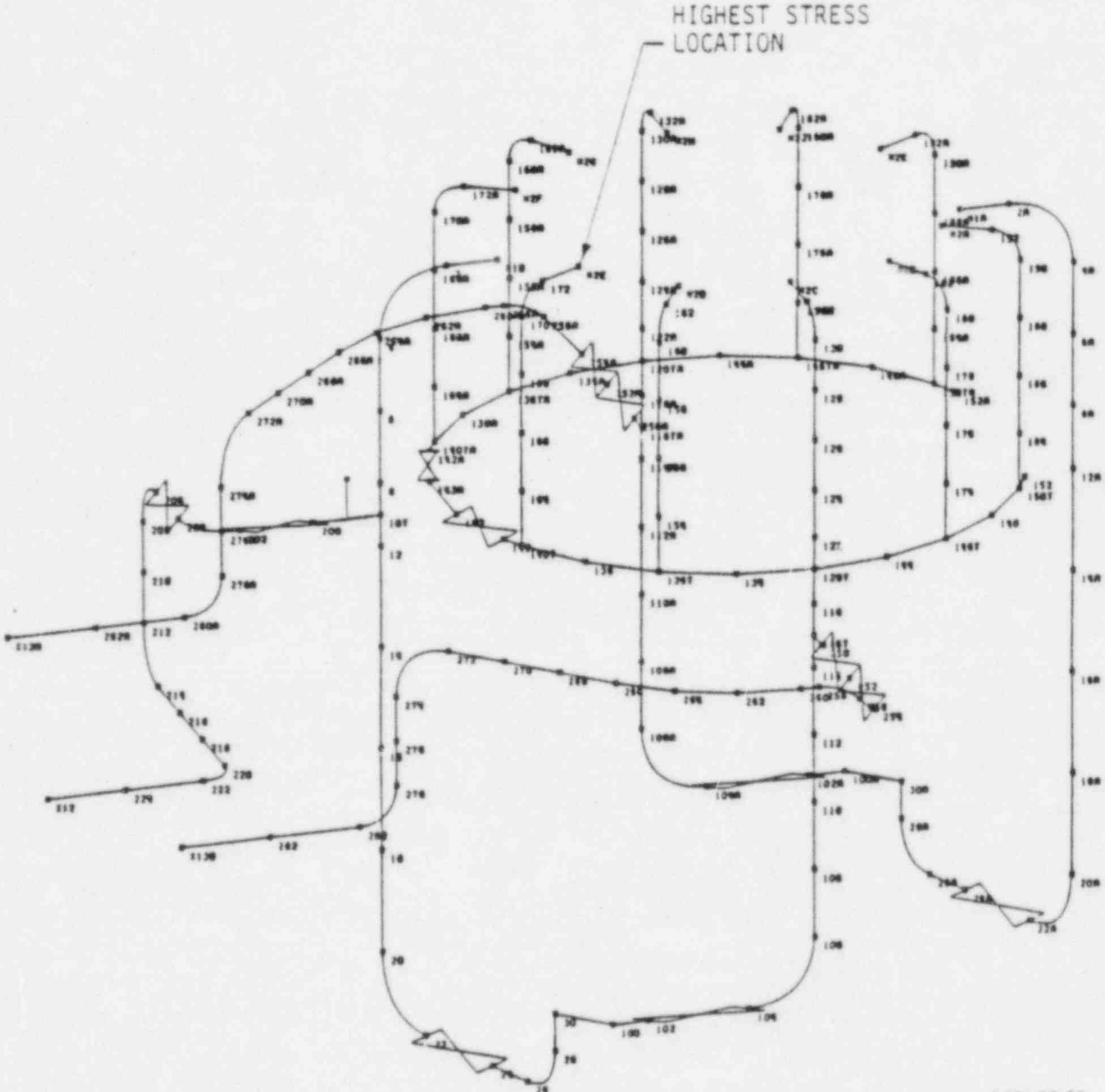

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Figure 5.1

BRUNSWICK UNIT 1
RECIRCULATION SYSTEM PIPING MODEL

6.0 SUMMARY AND CONCLUSION

Evaluation of the repairs to the Recirculation System reported herein shows that the resulting stress levels are acceptable for all design conditions. The stress levels have been assessed from the standpoint of load capacity of the components and the resistance to crack growth.

Acceptance criteria for the analyses have been established in Section 3.0 of this report which demonstrate that:

1. Overlay repaired welds meet margins of safety inherent in IWB-3640 of ASME Section XI (Reference 1).

2. The one flawed weld which did not require weld overlay repair will not exceed the allowable flaw size of Reference 1 as modified by Reference 2 over at least the next 18 months.

Analyses have been performed and results are presented which demonstrate that the repaired welds satisfy these criteria by a large margin. Analyses have also been

performed which demonstrate that the unrepaired weld satisfies these criteria by a large margin.

Furthermore, it is concluded that IGSCC experience in the Reactor Recirculation System at Brunswick Unit 1 does not increase the probability of a design basis pipe rupture at the plant. This conclusion expressly considers the nature of the cracking which has been observed at Brunswick Unit 1, and the likelihood that other similar cracking may have gone undetected. Finally, the possibility that butt welds with extremely low toughness exist at Brunswick 1 has been considered and found not to violate acceptance criteria.

7.0 REFERENCES

1) ASME Boiler and Pressure Vessel Code, Section XI, 1983 Edition with Addenda through Winter 1984, Paragraph IWB-3640, "Acceptance Criteria for Austenitic Steel Piping."

2) NRC Generic Letter 84-11, dated April 19, 1984, File No. CPL030.0012.

3) General Electric Design Specification 22A1417, Revision 2, File No. CPL030.0012.

4) General Electric "Brunswick Steam Electric Plant Unit 1 Recirculation Pipe System Stress Reanalysis," 6/11/85, File No. CPL030.0012.

5) NUTECH Computer Program PISTAR, File No. 08.003.0300, Version 3.2.

6) NUREG 1061, Vol. 1, "Investigation and Evaluation of Stress-Corrosion Cracking in Piping of Boiling Water Reactor Plants," Second Draft, April 1984.

7) NUTECH Computer Program NUTCRAK, Version 2.0.2, File No. 08.039.0005.

8) NUTECH Report NSP-81-105, Revision 2, "Design Report for Recirculation Safe End and Elbow Repairs, Monticello Nuclear Generating Plant," December 1982. File No. 30.1281.0105.

9) EPRI Interim Report, "Examination of Weld Overlayed Pipe Joints," dated April 1985, RP1570-2.