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CPL-21-103
Revision 1
March 1985
CPL021.0103

DESIGN REPORT FOR RECIRCULATION AND REACTOR WATER CLEAN-UP SYSTEMS WELD OVERLAY REPAIRS AND FLAW ANALYSIS AT BRUNSWICK STEAM ELECTRIC PLANT UNIT 1

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REVISION CONTROL SHEET

TITLE: Design Report for Recirculation and Reactor Water Clean-up Weld Overlay Repairs and Flaw Analysis at Brunswick Steam Electric Plant Unit 1

DOCUMENT FILE NUMBER: CPL021.0103

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AFFECTED PAGE(S)	DOC REV	PREPARED BY / DATE	ACCURACY CHECK BY / DATE	CRITERIA CHECK BY / DATE	REMARKS
i-vi	0	MEK/2-26-85	HLG 2/26/85	HLG 2/26/85	Initial Issue
1-41	0	MEK/2-26-85	HLG 2/26/85	HLG 2/26/85	
i-iii	1	MEK/3-21-85	HLG 3/22/85	HLG 3/22/85	Revised Report Title
10-14	1	MEK/3-21-85	HLG 3/22/85	HLG 3/22/85	Added Weld I.D. Numbers

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QEP 3-3.1.1
REV 1

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 Illinois and am competent to review this document.

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HLG 2/26/85
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HLG 3/22/85
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1.0 INTRODUCTION

This report summarizes analyses performed by NUTECH to evaluate flaw indications in the Recirculation System and to design weld overlay repairs on the Recirculation System and the Reactor Water Clean-Up (RWCU) System at Carolina Power and Light Company's Brunswick Steam Electric Plant Unit 1 (Brunswick 1). One flaw indication detected by ultrasonic (UT) examination was determined to be acceptable without repair for at least the next 6 months. Eleven 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. The flaw indications addressed in this report were detected during the November 1984 mid-cycle inspection.

Flaw indications were identified adjacent to 6 welds in the Recirculation System and adjacent to 6 welds in the RWCU System. 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.

During the UT inspection of IGSCC susceptible welds in the RWCU, flaws were identified in welds 6-RWCU-16 (inside containment) and 6-RWCU-17 (outside containment). Between these two welds is weld X-14 which is part of the penetration flued head assembly, and which is inaccessible. CP&L made the conservative decision to cut the process line outside of containment and inspect this weld from the inside. The dye penetrant (PT) method was used. A circumferential flaw extending approximately 180° with significant bleed out was identified. The inspectors determined that the PT indications observed suggested the presence of a deep flaw. CP&L and NUTECH agreed to repair this flaw by application of weld metal on the inside of the pipe at the affected location. This repair is comparable in concept to the other overlay repairs performed at Brunswick Unit 1.

Table 1.1

BRUNSWICK UNIT 1 FLAW DISPOSITION

Weld No.	Flaw[a]	OVERLAY DESIGN, INCHES T_{min}	L_1	L_2	Pipe Size
28-B-12-A	2.5"x10% Pipe Side	N/A	N/A	N/A	28"
12-AR-A4A	1.6"x19% Pipe Side	0.19	1.5	(b)	12"
12-AR-B2A	2.0"x20% Pipe Side	0.19	1.5	1.5	12"
12-AR-B4A	1.0"x45% Pipe Side	0.19	1.5	(b)	12"
12-BR-F4A	0.5x23% 4.0"x9% Pipe Side	0.19	1.5	(b)	12"
X-14-C	5.5" (c) 2.0" (c) Pipe Side	0.25	1.5	1.5	6"
RWCU-6-4A	1.25"x10% Elbow Side	0.16	1.5	1.5	6"
RWCU-6-6A	2.75"x31% Elbow Side	0.18	1.25	1.25	6"
RWCU-6-7A	3.0"x81% Elbow Side	0.17	1.25	1.25	6"

Table 1.1

(Continued)

BRUNSWICK UNIT 1 FLAW DISPOSITION

Weld No.	Flaw[a]	OVERLAY DESIGN, INCHES T_{min}	L_1	L_2	Pipe Size
RWCU-6-8A	1.125"x23% Pipe Side 1.125"x19% Elbow Side	0.185	1.25	1.25	6"
RWCU-6-10A	2.75"x14% Elbow Side	0.17	1.25	1.25	6"
1-RR-4A10-A	(d) Weldolet Side	0.125	1.0	(e)	4"

NOTES: a. All flaws are circumferential unless otherwise noted.

b. Effective length varies (See Figures 2.1 and 2.2).

c. Flaws detected from I.D. by P.T., assumed to be through-wall for measured length.

d. Leaking flaw. Unable to size due to geometric constraints. Assumed to be either circumferential 2" long or axial 1/2" long.

e. Overlay to extend to and blend smoothly with weldolet.

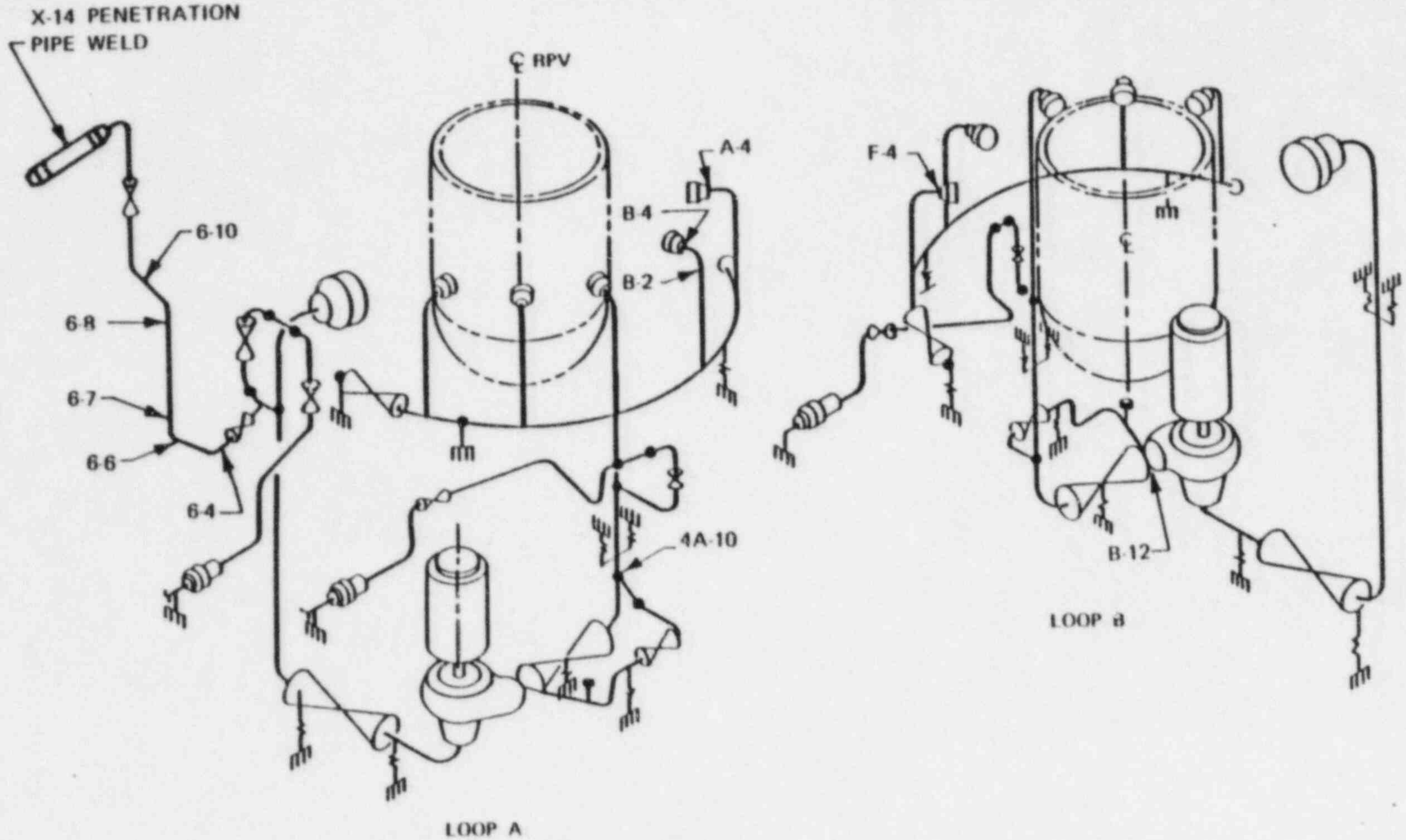

Figure 1.1

CONCEPTUAL DRAWING OF RECIRCULATION SYSTEM

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2.0 REPAIR DESCRIPTION

The UT and PT 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 2.6. 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. Also, a favorable compressive residual stress 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.

The flaw observed in weld X-14, which was not accessible from the outside of the pipe, was repaired by applying weld metal on the inside of the pipe at the flawed location. This inside overlay ("inlay") was applied around the entire circumference of the pipe, and extended axially approximately 5 inches, centered on the flaw.

All weld overlay repairs were inspected using non-destructive examination. The non-destructive examination of the completed weld "inlay" applied to the X-14 penetration weld, Figure 2.5, included a PT examination (in accordance with ASME Section XI) of the completed overlay and 1" either side of it (to demonstrate that no new flaws had been opened by overlay application), UT thickness, UT pre-service inspection (in accordance with ASME Section XI), and delta ferrite measurement after overlay completion. Non-destructive examination of the remaining 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.

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.

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

5) Volumetric examination of the weld overlay and existing circumferential pipe weld by the ultrasonic examination technique in accordance with ASME Section XI (Reference 1).

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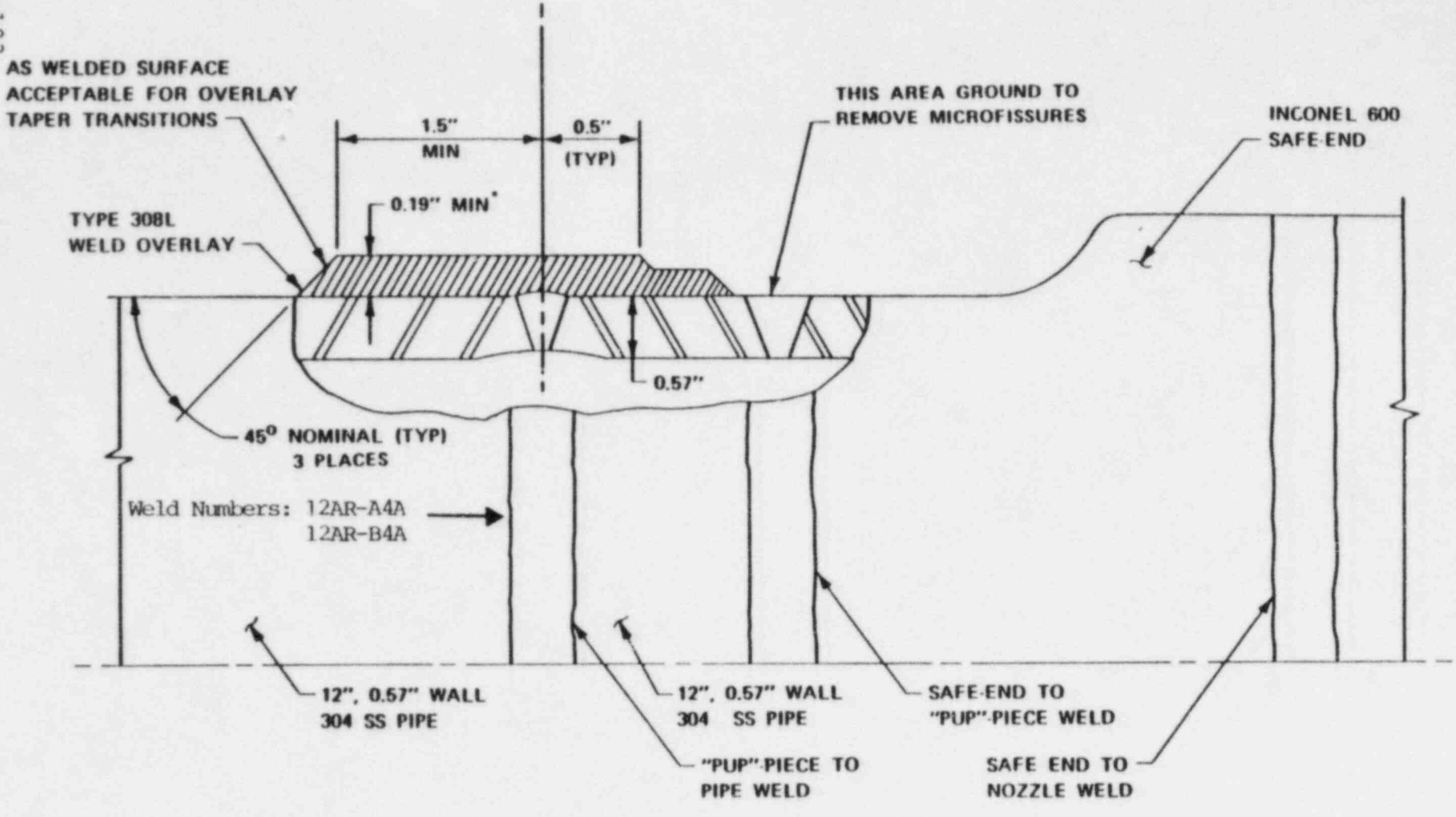
Table 2.1

WELD OVERLAY AS-BUILT DIMENSIONS

Weld I.D.	Pipe Size	Design* Thickness	As-Built* Thickness	As-Built Length
6-RWCU-4A	6"	0.16	0.217	2.771
6-RWCU-6A	6"	0.18	0.473	2.808
6-RWCU-7A	6"	0.17	0.252	2.460
6-RWCU-8A	6"	0.185	0.189	2.890
6-RWCU-10A	6"	0.17	0.215	2.565
12-AR-A4A	12"	0.19	0.351	2.515
12-AR-B2A	12"	0.19	0.205	3.450
12-AR-B4A	12"	0.19	0.262	2.200
12-BR-F4A	12"	0.19	0.290	2.620
1-RR-4A10-A	4"	0.125	0.409	1.732
PENT. X-14-C	6"	0.25	0.440	5.800

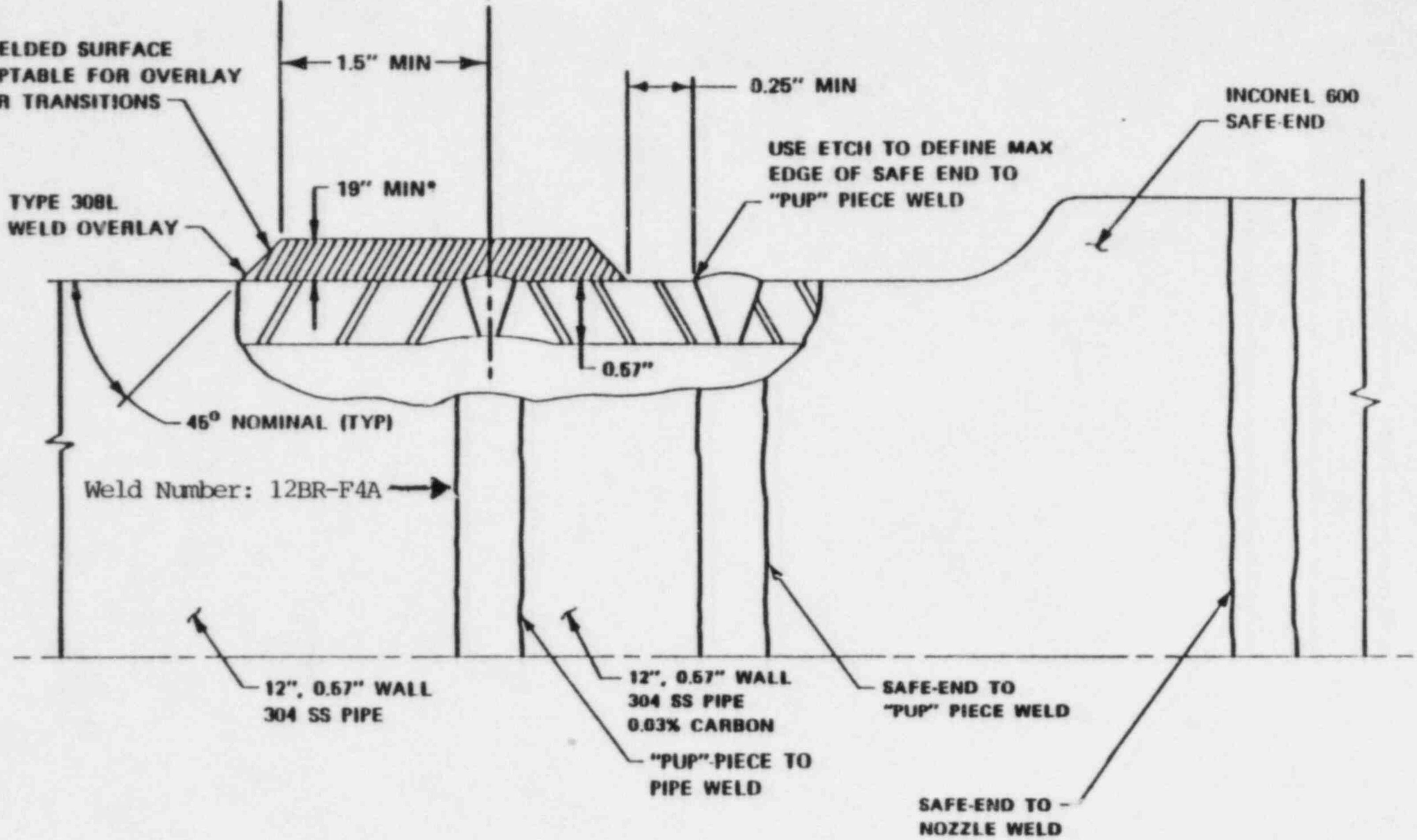
* Does not include first overlay layer.



* DOES NOT INCLUDE FIRST OVERLAY LAYER THICKNESS.

Figure 2.1

**CONFIGURATION OF SAFE END TO PIPE WELD OVERLAY
(OVERLAY MICROFISSURES REMOVED)**



* DOES NOT INCLUDE FIRST OVERLAY LAYER THICKNESS

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Figure 2.2

CONFIGURATION OF SAFE END TO PIPE WELD OVERLAY
(THERMAL SLEEVE OMITTED)

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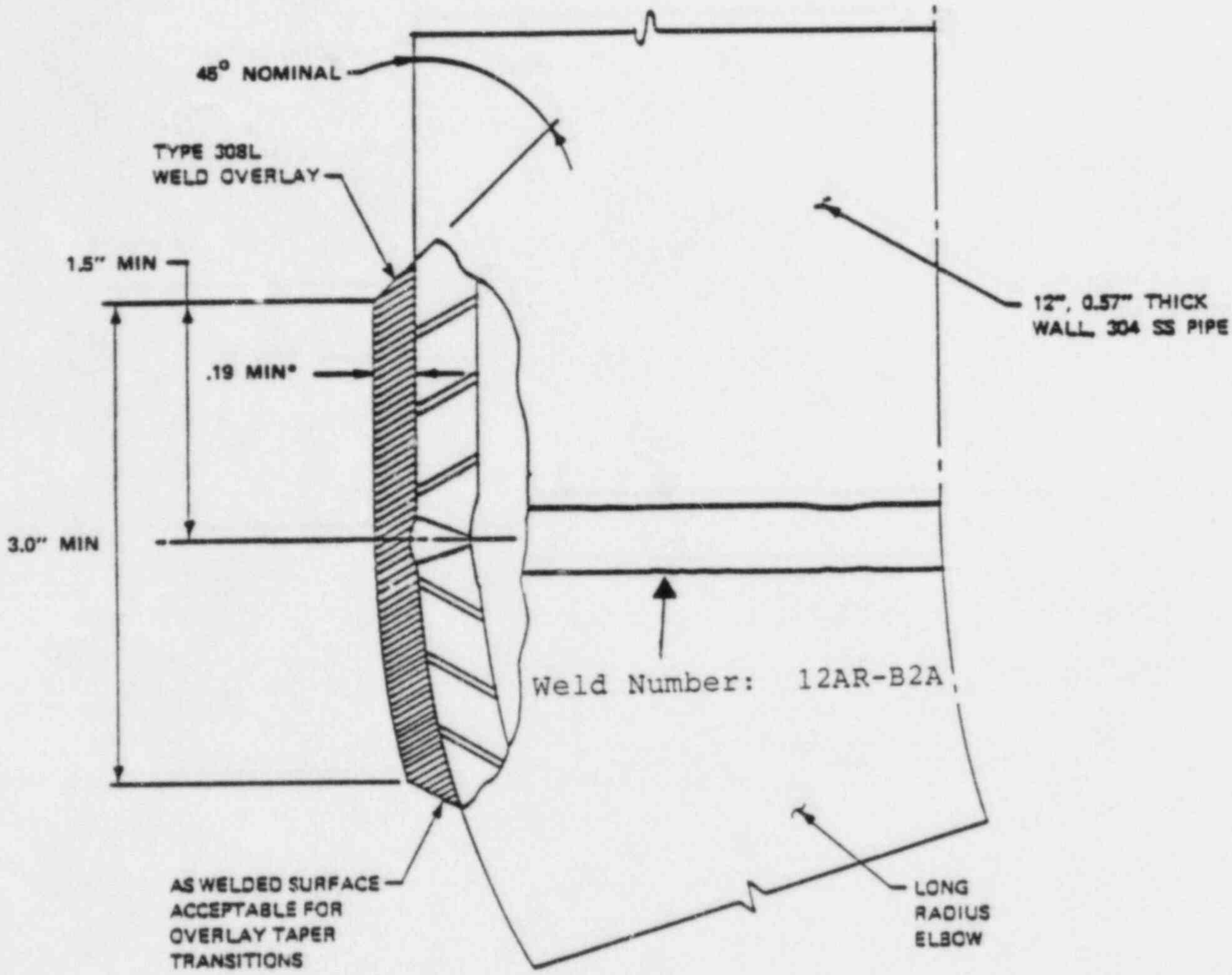

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Figure 2.3
CONFIGURATION OF 12"
ELBOW TO PIPE WELD OVERLAY

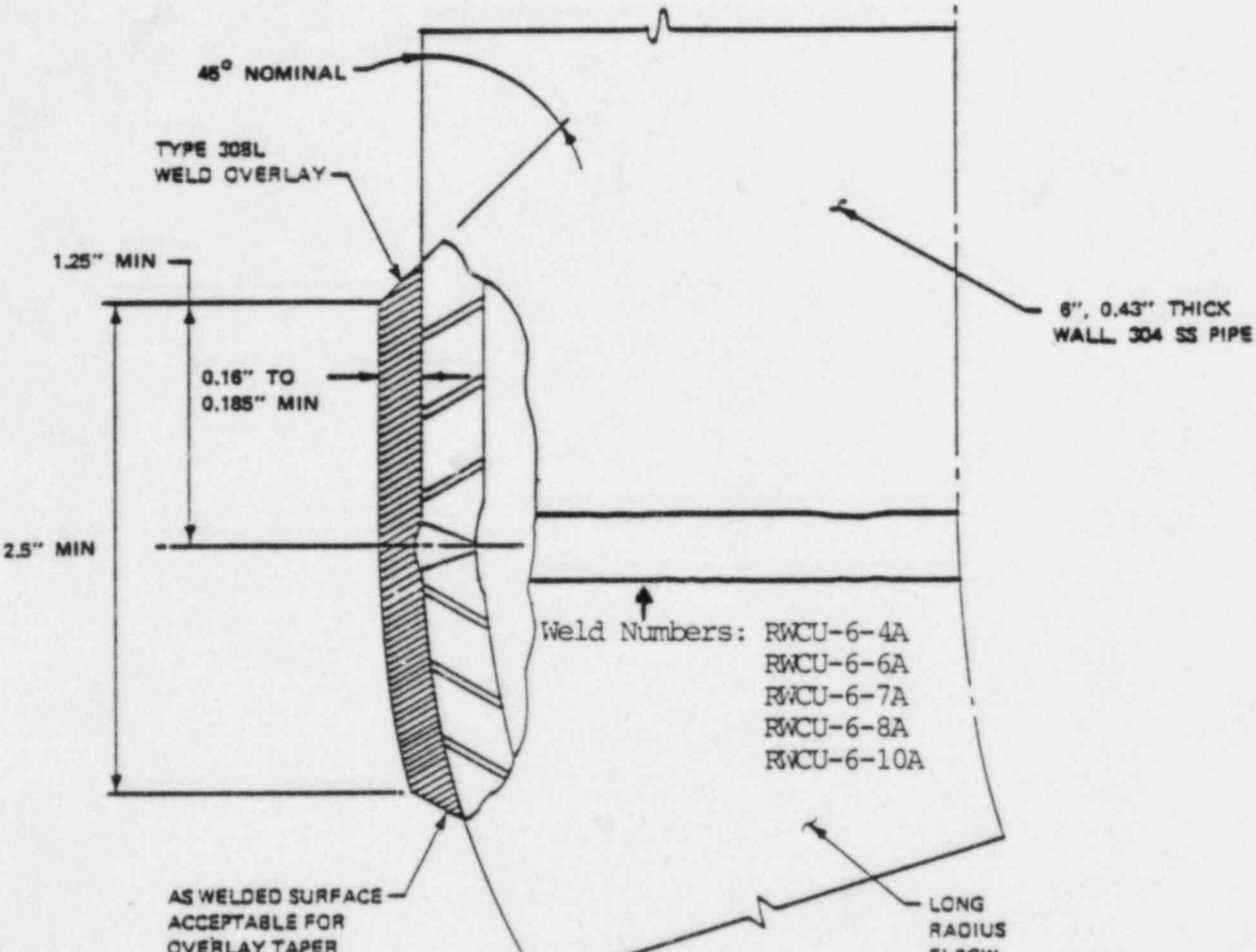

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Figure 2.4
CONFIGURATION OF 6"
ELBOW TO PIPE WELD OVERLAY

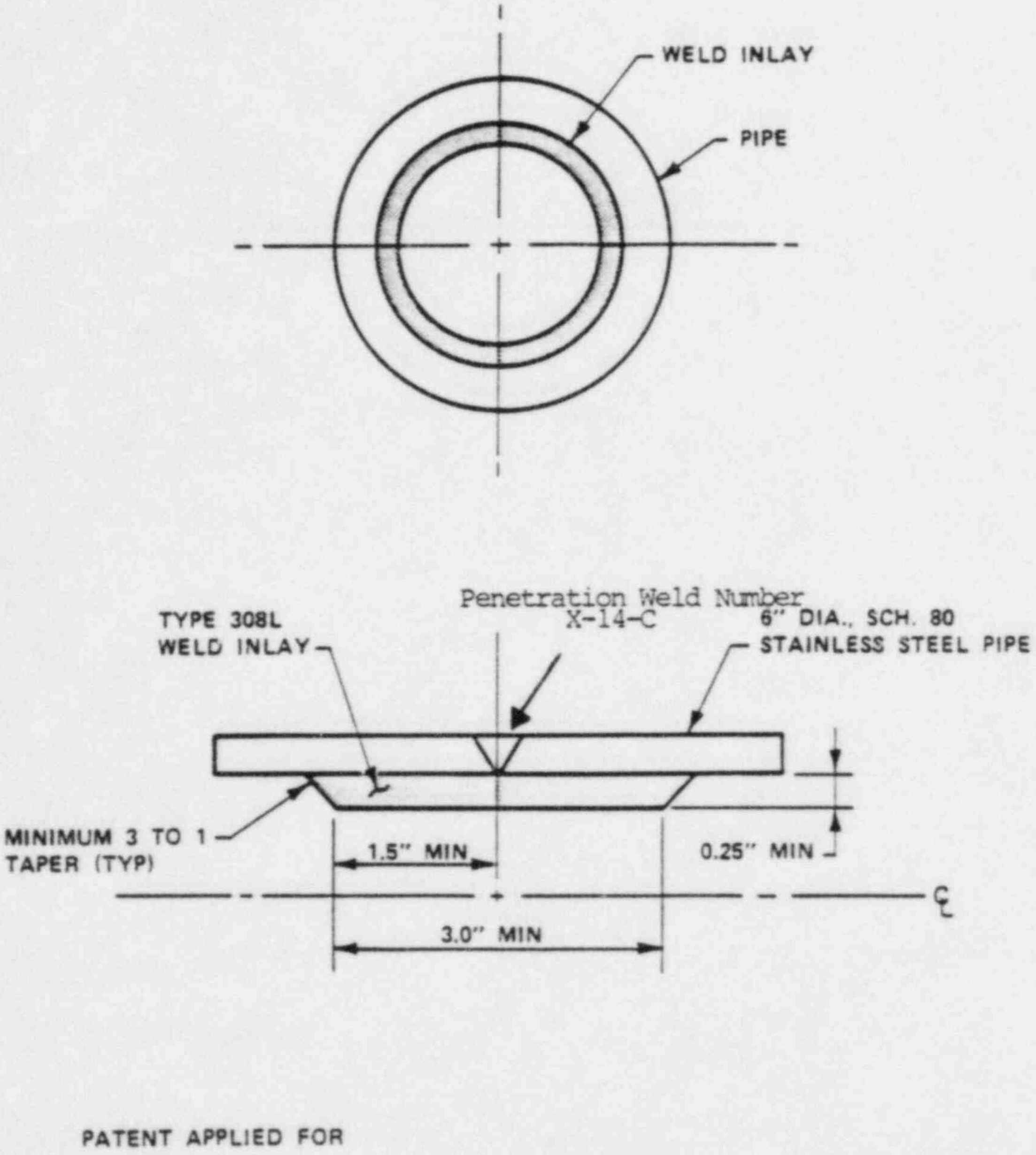
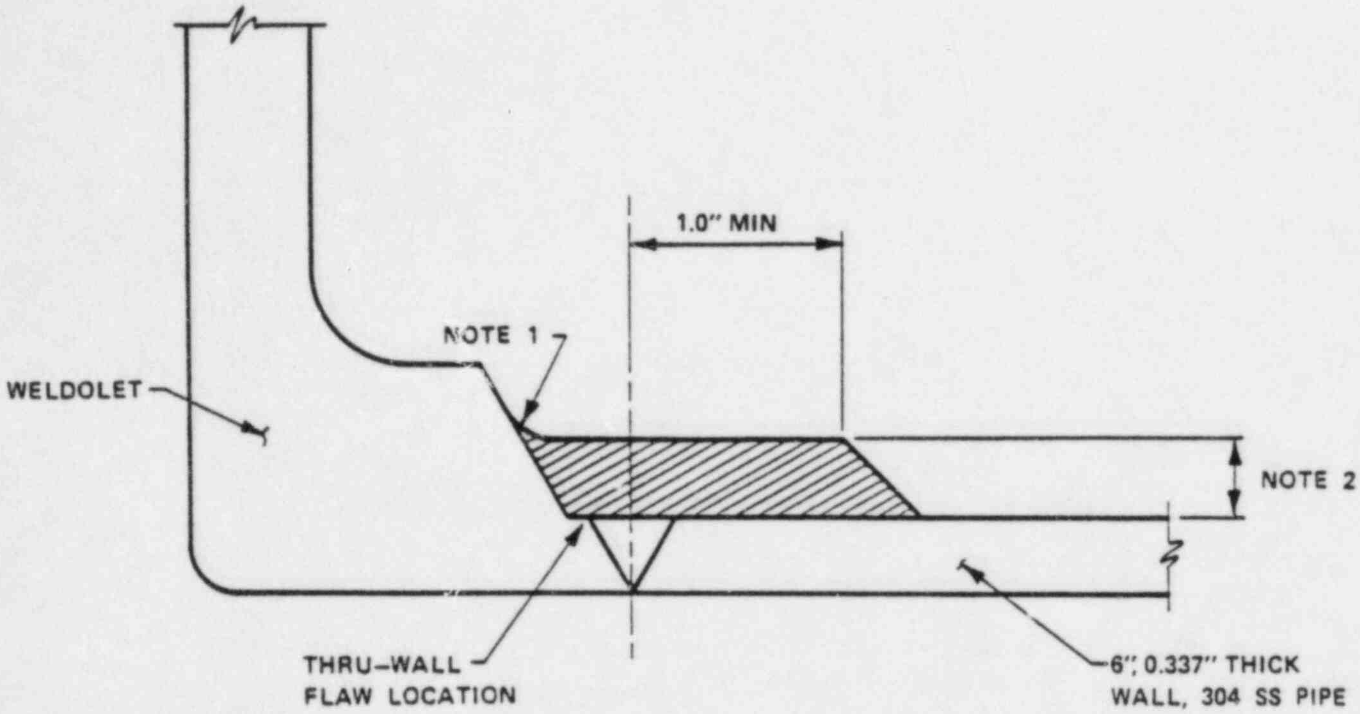


Figure 2.5

SCHEMATIC DIAGRAM OF RWCU WELD INLAY

WELD NO. 1–RR–4A10–A



NOTES:

1. OVERLAY SHALL EXTEND TO WELDOLET ON WELDOLET SIDE. FINAL SURFACE OF WELD OVERLAY SHALL BLEND SMOOTHLY INTO CONTOUR OF WELDOLET.
2. THICKNESS OF OVERLAY SHALL BE 0.125" MINIMUM, NOT INCLUDING FIRST LAYER.

Figure 2.6

CONFIGURATION OF 4" PIPE TO WELDOLET OVERLAY

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 code stress evaluation was not performed as part of this analysis since the Section XI evaluations are considered adequate.

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 and PT 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.

The overlay repair applied to the inside of weld X-14 was originally designed using IWB-3641 of ASME Section XI (Reference 1) as a basis. The as-built overlay thickness (See Table 2.1) was greater than the original pipe wall thickness, so further stress evaluation was unnecessary. The effects of the inside overlay on system performance (e.g., flow capability, etc.) were evaluated by others under the direction of CP&L, and shown to be negligible.

3.2 Flawed Pipe Analysis Criteria

Weld 28-B-12 contained a circumferential flaw determined to be 2.5" long with a depth of 10%. Due to its small initial size, the end-of-cycle allowable flaw depth defined in Table IWB-3641-1 of ASME Section XI (Reference 1) is 75% of the through-wall thickness. The NRC's Generic Letter 84-11 (Reference 2) modifies this end-of-cycle allowable flaw depth by a factor of 2/3, causing it to become 50% of the through-wall depth.

The upcoming cycle length in this instance is 6 months due to the fact that the inspection took place in mid-cycle. The flaw was shown to be acceptable without repair for at least the next 6 months, utilizing the crack growth law presented in Section 5.2. This crack growth law was obtained from a curve fit of data presented in NUREG-1061 (Reference 14).

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. An explanation of the thermal transient conditions which cause differential thermal expansion loads is presented in Section 4.2, and the weld overlay shrinkage-induced loads are explained in Section 4.3.

4.1 Mechanical and Internal Pressure Loads

Internal pressure information for the Recirculation and RWCU Systems was obtained from Reference 3. Deadweight and seismic loads applied to the Recirculation System welds were obtained from Reference 4. Reference 5 supplied the deadweight and seismic loads applied to the RWCU System. Calculated stresses are included in Table 4.1

4.2 Thermal Loads

The thermal expansion loads for each weld in the Recirculation System were obtained from a computer model (Reference 5). The NUTECH computer program PISTAR (Reference 6) was used. Reference 3 defines several types of transients for which the Recirculation System is designed. These transients were conservatively grouped into three composite transients. The first composite transient is a start up/shutdown transient with a heatup or cooldown rate of 100°F per hour. The second composite transient consists of a 50°F step change in temperature with no change in pressure. The third composite transient is an emergency event with a 416°F step change in temperature and a corresponding change in pressure of 1325 psi. In the five year design life, there are 38 startup/shutdown cycles, 25 small temperature change cycles, and one emergency cycle.

Thermal expansion loads for the RWCU System welds were obtained from Reference 7.

4.3 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 6) piping model. Weld overlay shrinkage is discussed further in Section 5.2.

Table 4.1

SUMMARY OF TOTAL STRESSES

Weld I.D.	Maximum Stress (PSI) Dead Weight	Maximum Stress (PSI) Thermal	Maximum Stress (PSI) Seismic	Maximum Stress (PSI) Pressure	Total Stress (PSI) Crack Growth	Total Stress (PSI) Wol Design
12" AR-A4A	311	4494	3823	7015	11820	11149
12" AR-B4A	591	4745	3108	7015	12351	10714
12" AR-B2A	409	3235	1985	7015	10659	9409
12" BR-F4A	323	2250	1534	7015	9588	8872
28"-B-12A	868	870	3053	6928	8666	10849
6" X-14-C Penetration Weld	2159	10310	6495	4000	16469	12654
6"-RWCU-10A	561	2483	3322	4000	7044	7883
6"-RWCU-8A	366	4954	3560	4000	9320	7926
6"-RWCU-7A	593	3718	913	4000	8311	5506
6"-RWCU-6A	483	3318	1074	4000	7801	5557
6"-RWCU-4A	572	2537	1837	4000	7109	6409

5.0 EVALUATION METHODS AND RESULTS

The flawed welds shown in Table 1.1 were identified by UT and PT inspections during the November 1984 mid-cycle inspection at Brunswick Unit 1. These flawed welds were evaluated using the methods of Section 3 to determine whether an overlay was necessary to meet the requirements of Reference 1 and 2. Only one flawed weld (28-B-12) 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 5.2

5.1 Code Evaluation - Section XI

All weld overlays were designed assuming flaws were through-wall for their measured length. All overlay designs restore the safety margins required in Section IWB-3640 of ASME Section XI (Reference 1). The flaw in weld 28-B-12 meets these requirements without repair and will not violate them for at least the next 6 months.

5.2 Fracture Mechanics Evaluation

The allowable end-of-cycle flaw depth was determined from Reference 1 and 2. Calculation of crack growth due to IGSCC was based on Reference 10 and NUTECH's computer program NUTCRAK (Reference 13). Input to NUTCRAK included the as-measured flaw depth, a conservative residual stress distribution, and the following conservative crack growth law.

$$\frac{da}{dt} = 3.59 \times 10^{-8} K^{2.161}$$ (Reference 14)

Where da = differential crack depth

dt = differential time

K = stress intensity at the crack tip

Based on this conservative analysis, it was predicted that the flaw in weld 28-B-12 would not exceed the end of cycle allowable crack depth for at least 41 months.

5.3 Overlay Shrinkage Effect on Recirculation and RWCU Systems

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 4 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 6) 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 16.7 KSI at weld 12-AR-B4. This weld is a 12" pipe-to-safe-end weld on a recirculation riser. This weld was overlaid. The above stress value does not include the stress reduction at this location due to the application of weld material. Table 5.1 gives the shrinkage stress for all welds in the recirculation system found to have flaws this outage.

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.

The RWCU System welds were not analyzed for weld overlay shrinkage-induced stresses, since a spool piece was removed from the affected piping after the overlays were applied. Displacement-controlled stresses due to weld overlay shrinkage were thereby relieved, and are therefore not a concern.

Table 5.1

SUMMARY OF SHRINKAGE STRESSES AT

RECIRCULATION SYSTEM FLAW LOCATIONS

Weld Number	Overlay	Shrinkage Stress (PSI)
28-B-12-A	NO	121
12-AR-A4A	YES	6787
12-AR-B2A	YES	5330
12-AR-B4A	YES	15517*
12-BR-F4A	YES	654

* Includes allowance for additional wall thickness due to weld overlay application.

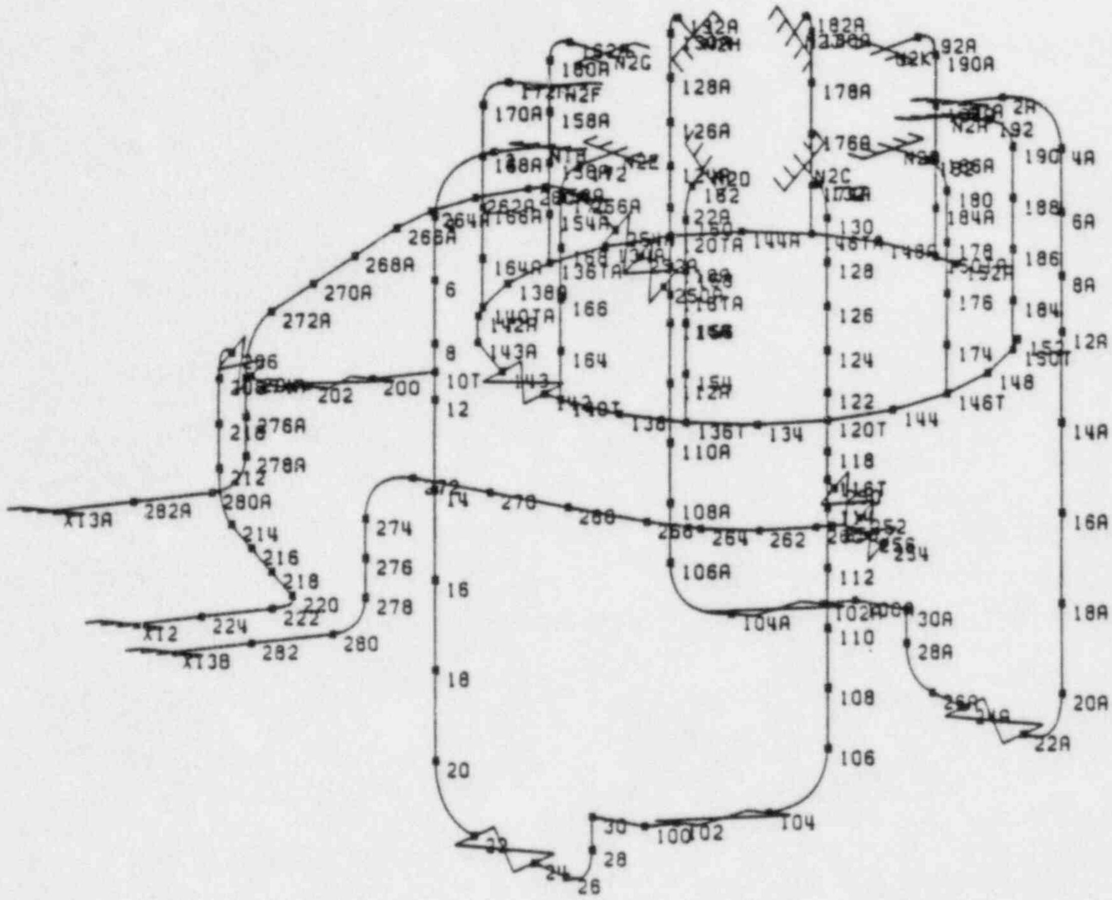


Figure 5.1

BRUNSWICK UNIT 1
RECIRCULATION SYSTEM PIPING MODEL

6.0 LEAK-BEFORE-BREAK ASSESSMENT

The following considerations apply to welds with undetected flaws or welds with IGSCC flaws judged to be small enough not to require repair. These considerations form the basis for continued plant operation for another fuel cycle.

6.1 Net Section Collapse

The effect of IGSCC on the structural integrity of piping is evaluated through the use of a simple "strength of materials" approach to assess the load carrying capacity of a piping section after the cracked portion has been removed. Studies have shown (Reference 10 and 11) that this approach gives a conservative, lower-bound estimate of the loads which would cause unstable fracture of the cracked section. Typical results of such an analysis are shown in Figure 6.1 (Reference 10). This figure defines the locus of limiting crack depths and lengths for circumferential cracks which are predicted by the net section collapse method to cause failure. Curves are presented for both typical piping systems stresses and stress levels equal to ASME Code limits. Note that a very large percentage of pipe wall can be cracked before reaching these limits

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(40% to 60% of circumference for through-wall cracks, and 65% to 85% of wall thickness for 360° part-through cracks). Also shown in Figure 6.1 is a sampling of cracks which have been detected in service, either through UT examination or leakage. In each case there has been a significant margin between the size of the crack observed and that predicted to cause failure under service loading conditions.

6.2 Leak Versus Break Flaw Configuration

Perhaps of more significance to the leak-before-break argument is the flaw configuration depicted in Figure 6.2. This configuration addresses the concerns raised by the occurrence of part-through flaws growing circumferentially before breaking through the outside surface to cause leakage. Figure 6.2 presents typical size limitations on such flaws based on the conservative net section collapse method of Section 6.1. Note that very large crack sizes are predicted. Also shown on this figure are typical detectability limits for short through-wall flaws (which are amenable to leak detection) and long part-through flaws (which are amenable to detection by UT). The margins between the detectability limits and the conservative, net section collapse failure limits are substantial. It is

noteworthy that the likelihood of flaws developing which are characterized by the vertical axis of figure 6.2 (constant depth 360° circumferential cracks) is so remote as to be considered impossible. Material and stress asymmetries always tend to propagate one portion of the crack faster than the bulk of the crack front, which will eventually result in "leak-before-break". This observation is borne out by extensive field experience with BWR IGSCC.

6.3 Axial Cracks

Axial cracks can grow through the wall but remain short in the axial direction. This behavior is consistent with expectations for axial IGSCC since the presence of a sensitized weld heat-affected zone is necessary, and this heat-affected zone is generally limited to approximately 0.25 inch on either side of the weld. Since the major loadings in the net section collapse analysis are bending moments on the cross section due to seismic loadings, and since these loads do not exist in the circumferential direction, the above leak-before-break arguments are even more persuasive for axially oriented cracks. There is no known mechanism for axial cracks to lengthen before growing through-wall and leaking, and the potential rupture loading on axial cracks is less than that on circumferential cracks.

6.4 Multiple Cracks

Analyses performed for EPRI (Reference 12) indicate that the occurrence of multiple cracks in a weld, or cracking in multiple welds in a single piping line does not invalidate the leak-before-break arguments discussed above.

6.5 Nondestructive Examination

The primary means of nondestructive examination for IGSCC in BWR piping is ultrasonics. This method has been the subject of considerable research and development in recent years, and significant improvements in its ability to detect IGSCC have been achieved. Figure 6.2 illustrates a significant aspect of UT detection capability with respect to leak-before-break. The types of cracking most likely to go undetected by UT are relatively short circumferential or axial cracks which are most amenable to detection by leakage monitoring. Conversely, as part-through cracks lengthen, and thus become more of a concern with respect to leak-before-break, they become more readily detectable by UT.

One weld in the RCWU System, the X-14 penetration weld, was inaccessible to UT examination from the outside.

Therefore, a portion of the adjoining piping was removed and the weld was inspected from the inside by the liquid penetrant (PT) method. Flaws were detected by this method and a subsequent "weld inlay" repair was made.

6.6 Leakage Detection

Typically, leakage detection for BWR reactor coolant system piping is through sump level and drywell activity monitoring. These systems have sensitivities on the order of 1.0 gallon per minute (GPM). Plant technical specification and administrative limits typically require investigation/corrective action at 5.0 GPM unidentified leakage, or when there is a 2.0 GPM increase in unidentified leakage in a 24 hour period.

Table 6.1 provides a tabulation of typical flaw sizes which cause 5.0 GPM leakage in various size piping assuming a membrane stress of $S_m/2$ (Reference 10).

Also shown in this table are the critical crack lengths for through-wall cracks based on the net section collapse method of analysis discussed above. For conservatism, the leakage values are based on pressure stress only, while the critical crack lengths are based on the sum of all combined loads, including seismic.

Considering other normal operating loads in the leakage analysis would result in higher rates of leakage for a given crack size. Note that there is considerable margin between the crack length which produces 5.0 GPM leakage and the critical crack length, and that this margin increases with increasing pipe size.

6.7 Historical Experience

The above theories regarding crack detectability have been supported by experience (Reference 12). Indeed, of the large number of IGSCC inciderts to date in BWR piping, none have come close to violating the structural integrity of the piping.

Table 6.1

EFFECT OF PIPE SIZE ON THE RATIO OF THE CRACK LENGTH FOR 5 GPM LEAK RATE AND THE CRITICAL CRACK LENGTH (ASSUMED STRESS $\sigma = S_m / 2$) (REFERENCE 14)

NOMINAL PIPE SIZE	CRACK LENGTH FOR 5 GPM LEAK (in.)	CRITICAL CRACK LENGTH ℓ_c (in.)	ℓ/ℓ_c
4" SCH 80	4.50	6.54	0.688
10" SCH 80	4.86	15.95	0.305
24" SCH 80	4.97	35.79	0.139

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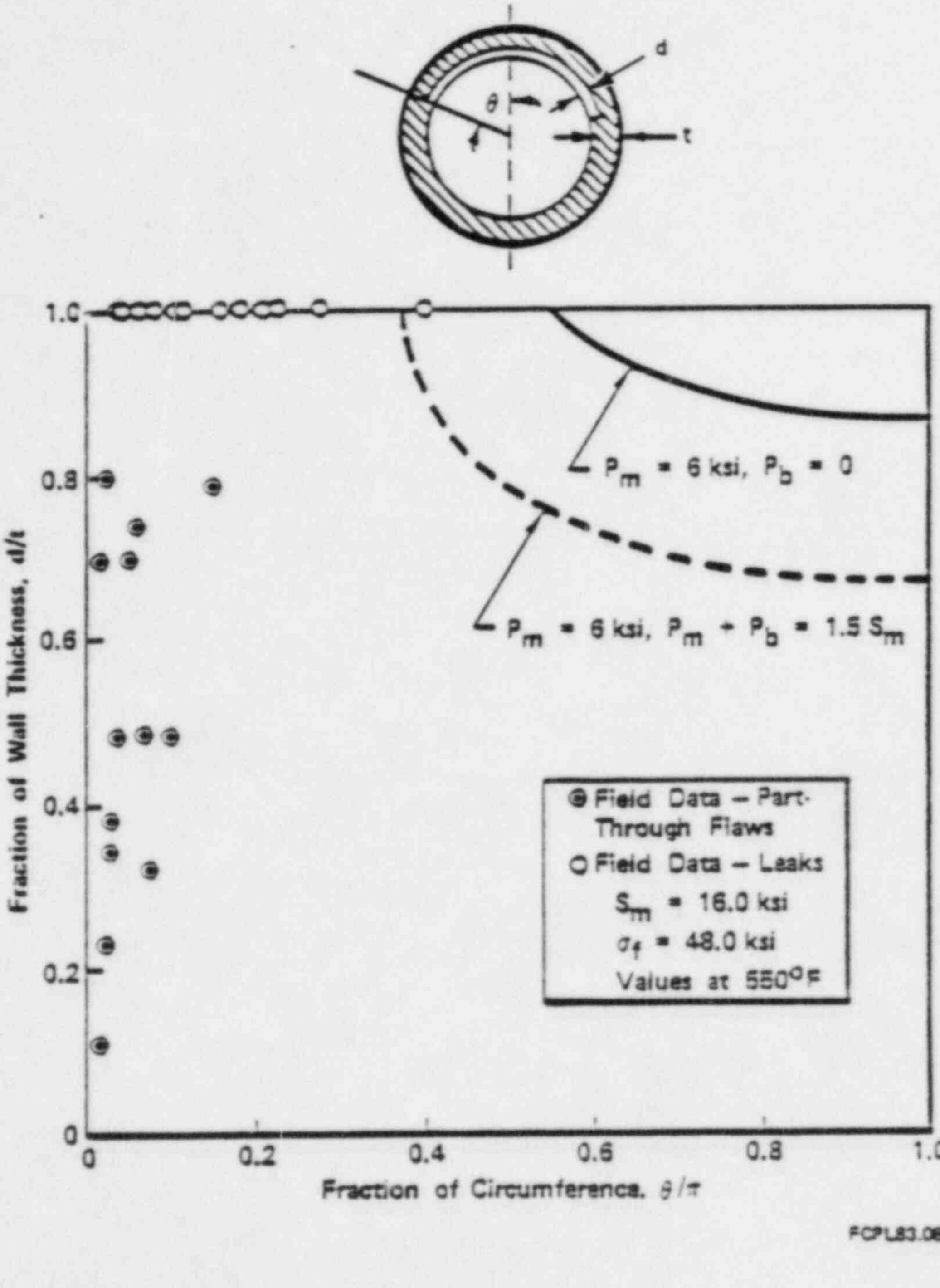

Figure 6.1

TYPICAL RESULT OF NET SECTION COLLAPSE ANALYSIS OF CRACKED STAINLESS STEEL PIPE (REFERENCE 14)

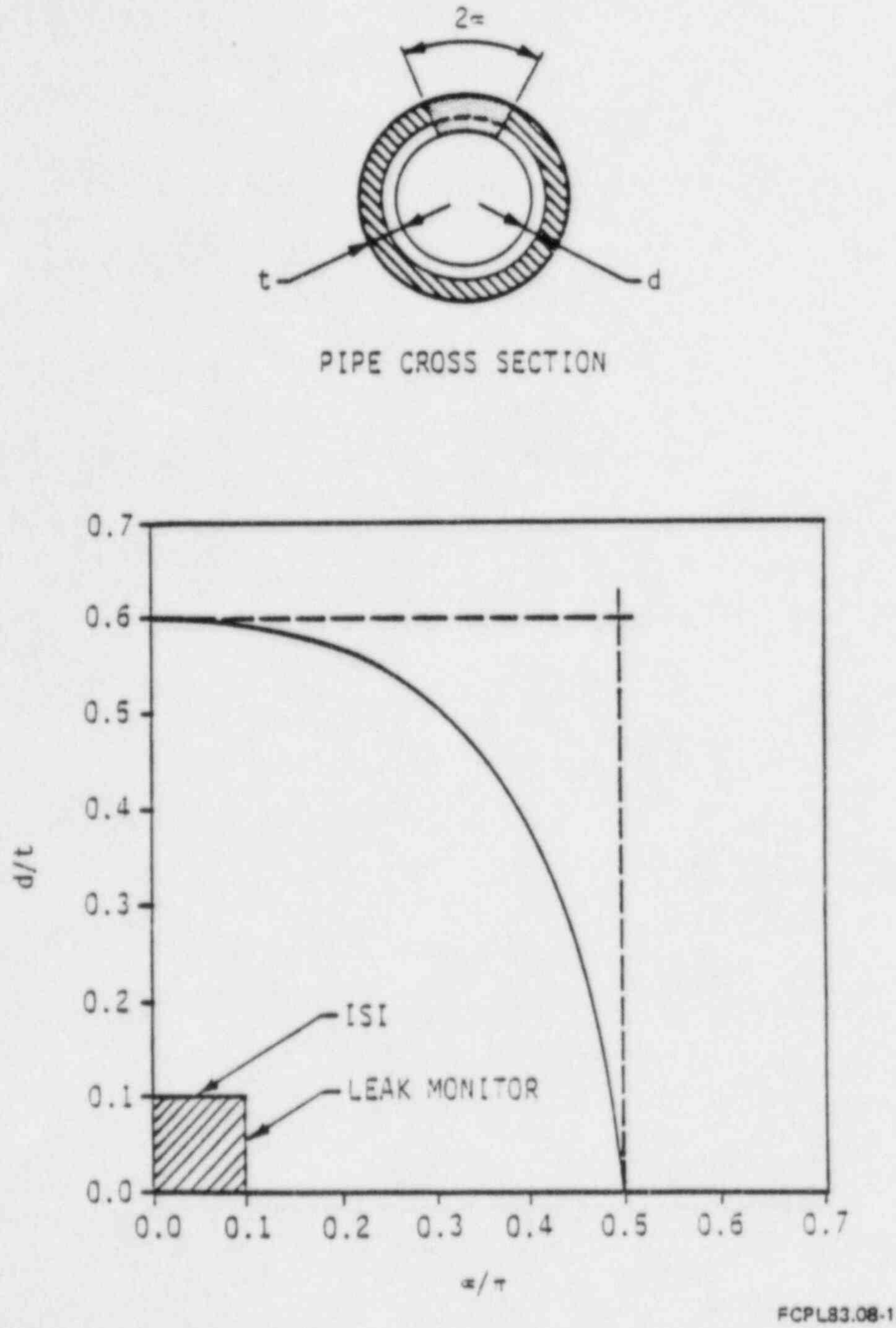

Figure 6.2

TYPICAL PIPE CRACK FAILURE LOCUS FOR COMBINED THROUGH-WALL PLUS 360° PART-THROUGH CRACK

7.0 SUMMARY AND CONCLUSION

Evaluation of the repairs to the Recirculation and Reactor Water Clean-up Systems 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. There is no loss of design safety margin over that provided by the current Code for Class 1 piping and pressure vessels (ASME Section III, Subsection NB).

2. During the design evaluation period of 5 years for each repair, the observed cracks will not grow to the point where the above safety margins would be reduced.

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 and Reactor Water Cleanup Systems 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 repaired at Brunswick Unit 1, and the likelihood that other similar cracking may have gone undetected. The conclusion is based primarily on the extremely high inherent toughness and ductility of the stainless steel piping material. Cracks in such piping grow through-wall and leak before affecting its structural load carrying capacity.

8.0 REFERENCES

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

2) NRC Generic Letter 84-11, dated April 19, 1984.

3) General Electric Design Specification 22A1417, Revision 2, File No. CPL021.0013.

4) General Electric "Brunswick Recirculation Pipes Stress Results for Multi-Support Response Spectra Input from UE&C Method 1," Rev. 0, 9/24/84, File No. CPL021.0013.

5) "Weld Overlay Shrinkage - Thermal Expansion, Brunswick 1," NUTECH Document No. CPL-09-302, Rev. 0, File No. CPL021.0013.

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

7) United Engineers RWCU Stress Calculations, Telecopied to Dean Yoshida of NUTECH Engineers 11-20-84, from Carolina Power and Light, UEC-14930, Rev. 11, 4-26-77, File No. CPL021.0013.

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) ASME Boiler and Pressure Vessel Code, Section III, 1983 Edition with Addenda through Winter 1983.

10) EPRI-NP-2472, "The Growth and Stability of Stress Corrosion Cracks in Large-Diameter BWR Piping, July 1982.

11) EPRI-NP-2261, "Application of Tearing Modulus Stability Concepts to Nuclear Piping," February 1982.

12) Presentation by EPRI and BWR Owners Group to U.S. Nuclear Regulatory Commission, "Status of BWR IGSCC Development Program," October 15, 1982.

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

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

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