PHILADELPHIA ELECTRIC COMPANY

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PEACH BOTTOM ATOMIC POWER STATION
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WELD OVERLAY DESIGN AND ANALYSIS
FOR INDICATIONS IN THE RECIRCULATION
AND RESIDUAL HEAT REMOVAL SYSTEM

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WELD OVERLAY DESIGN AND ANALYSIS FOR THE INDICATIONS IN THE PEACH BOTTOM UNIT 3 RECIRCULATION AND RESIDUAL HEAT REMOVAL SYSTEM

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CONTENTS

TABLES

ILLUSTRATIONS

1. ABSTRACT

This report documents the technical basis for analyzing Intergranular Stress Corrosion Cracking indications found in the Peach Bottom Unit 3 pipe welds. Three analyses were completed:

- Fracture mechanics analysis of indications not requiring repair
- Design of weld overlays for indications that require repair
- Determination of the effect of the weld overlay shrinkage on the system.

The analyses are in compliance with the requirements of the ASME Code Section XI and the NRC Generic Letter 84-11. The results verify that the fracture mechanics analysis and the weld overlay designs assure acceptable margins for at least 18 months of continued operation.

2. INTRODUCTION AND SUMMARY

2.1 Background

In 1983, 15 weld overlays were applied to Peach Bottom Unit 3 Recirculation and Residual Heat Removal (RHR) System piping welds. Ten of these were riser welds, the other five were 20" RHR suction line welds. At the same time many welds were treated with Induction Heating Stress Improvement (IHSI) to mitigate further cracking.

2.2 Inspection

During the recent in-service inspection, Intergranular Stress Corrosion Cracking (IGSCC) indications were found in 30 additional Recirculation and Residual Heat Removal System piping welds. Figures 1 through 3 show the locations of the recent indications as well as the 1983 weld overlays.

2.3 Summary

This report documents the technical basis for analyzing the indications (fracture mechanics), designing the weld overlays, and determining the shrinkage stress. Of the thirty welds with indications, eighteen required overlay repair and twelve were acceptable for continued operation without repair for at least 18 months. The remedial action taken and prior IHSI treatment history for each weld are shown in Tables 1 and 2.

Fracture mechanics analyses determined acceptability without repair for many of these indications. These analyses evaluated the crack growth for one refueling cycle (18 months of operation). The analyses demonstrate compliance with the requirements of Generic Letter 84-11 as well as the newly developed acceptance criteria for flux weldments (References 1 and 2).

Weld overlay designs were provided and applied to those welds that were found to require repair. The weld overlay designs provide full structural reinforcement, even with a postulated 360° through wall crack. Therefore, uncertainty in flaw sizing does not influence the weld overlay design. These designs maintain the ASME Code safety margins, paragraph IWB-3642, Section XI (Reference 3), and are consistent with NRC positions (i.e. no credit for the first layer, etc.).

Shrinkage Stress analyses modeled the local axial shrinkage that results from application of the weld overlay. This induced axial shrinkage will produce stresses throughout the piping system. These stresses were added to the applied stresses used in the fracture mechanics analyses.

The three analyses are in compliance with the requirements of the ASME Code Section XI and the NRC Generic Letter 84-11. The results verify that the flaw acceptance analysis and the weld overlay designs assure acceptable margins for at least 18 months of continued operation.

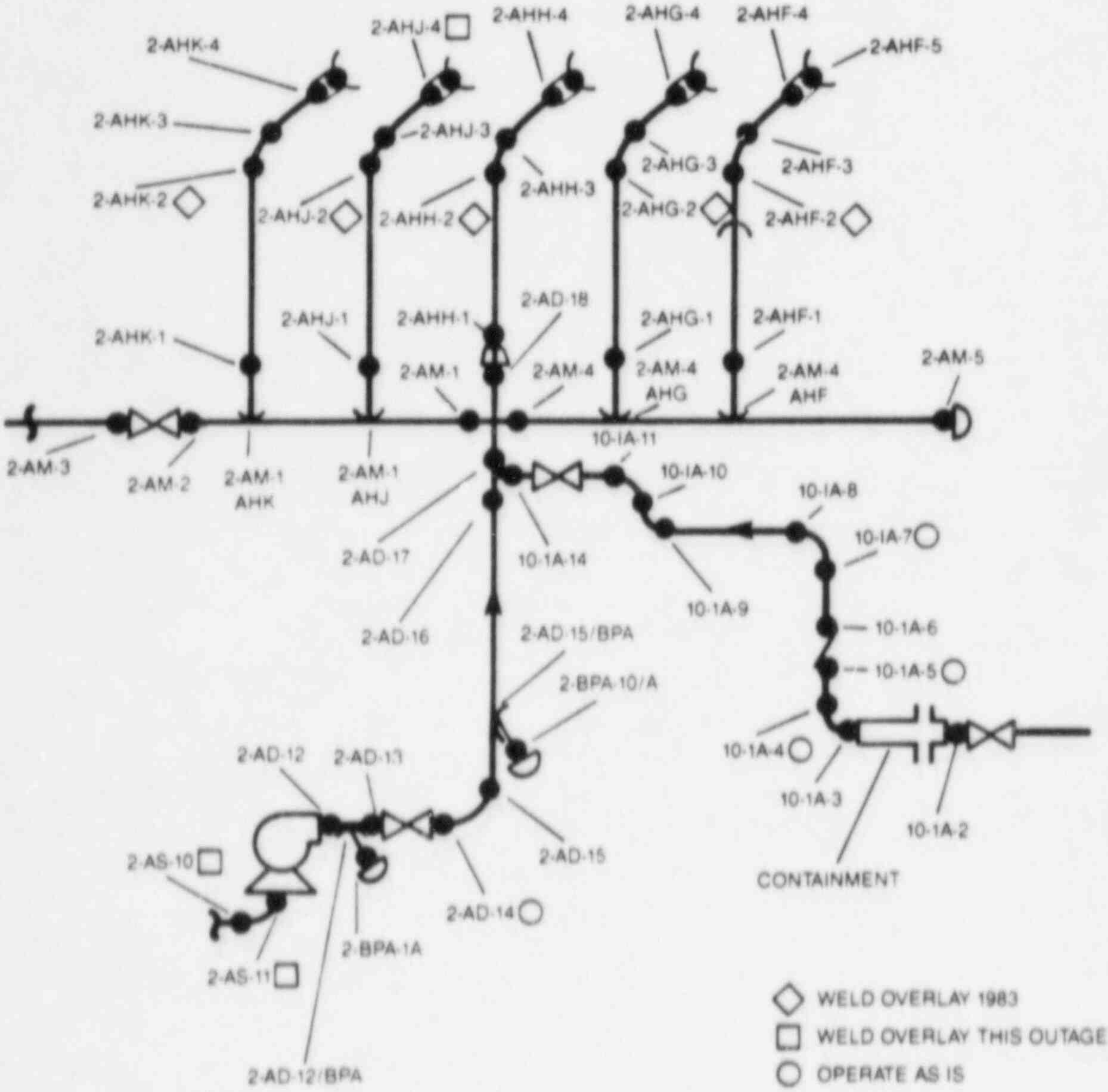


Figure 1 Recirculation and RHR Piping Loop A—Discharge Side — Weld Identification

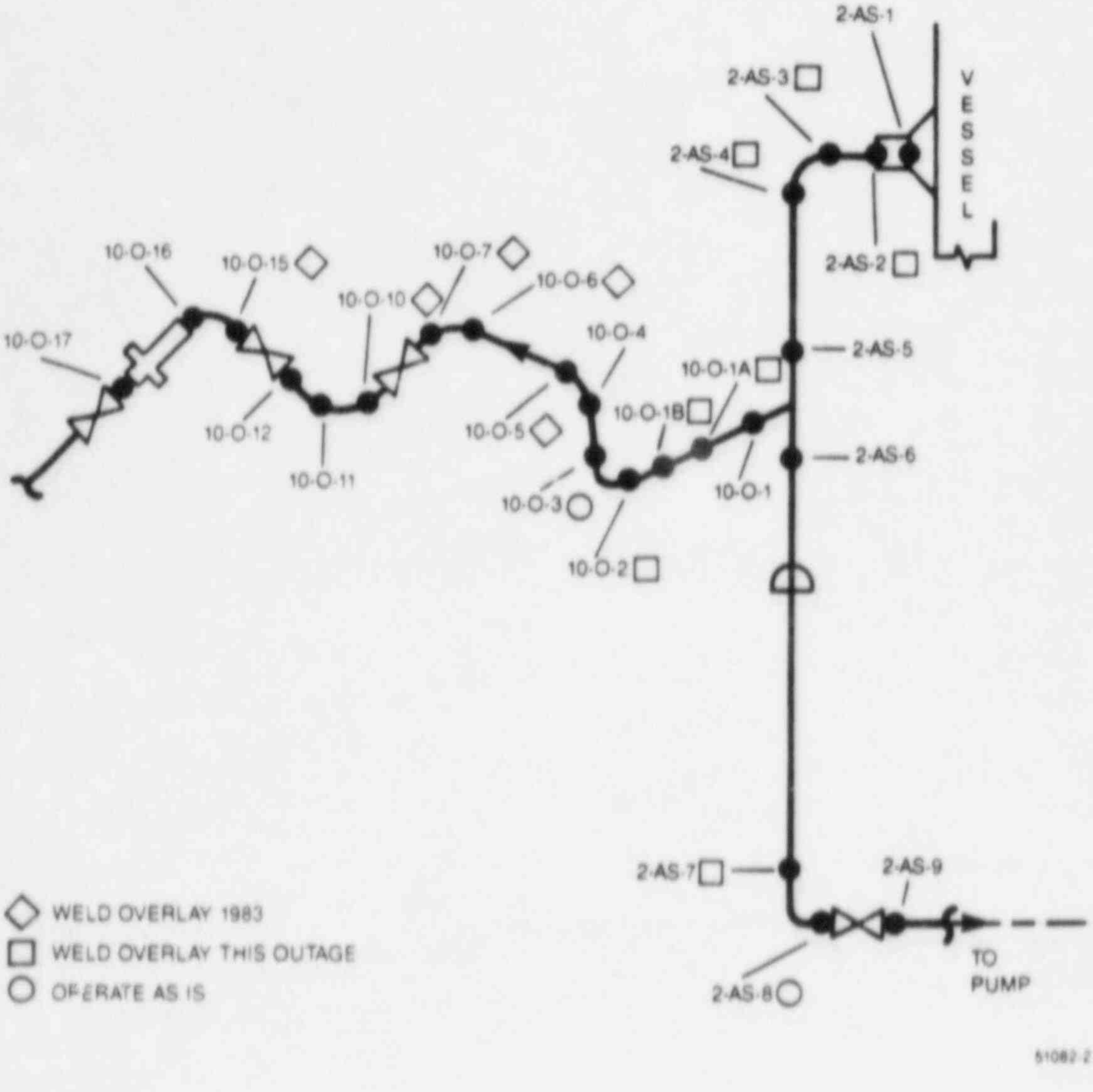


Figure 2 Recirculation and RHR Piping Loop A — Suction Side — Weld Identification

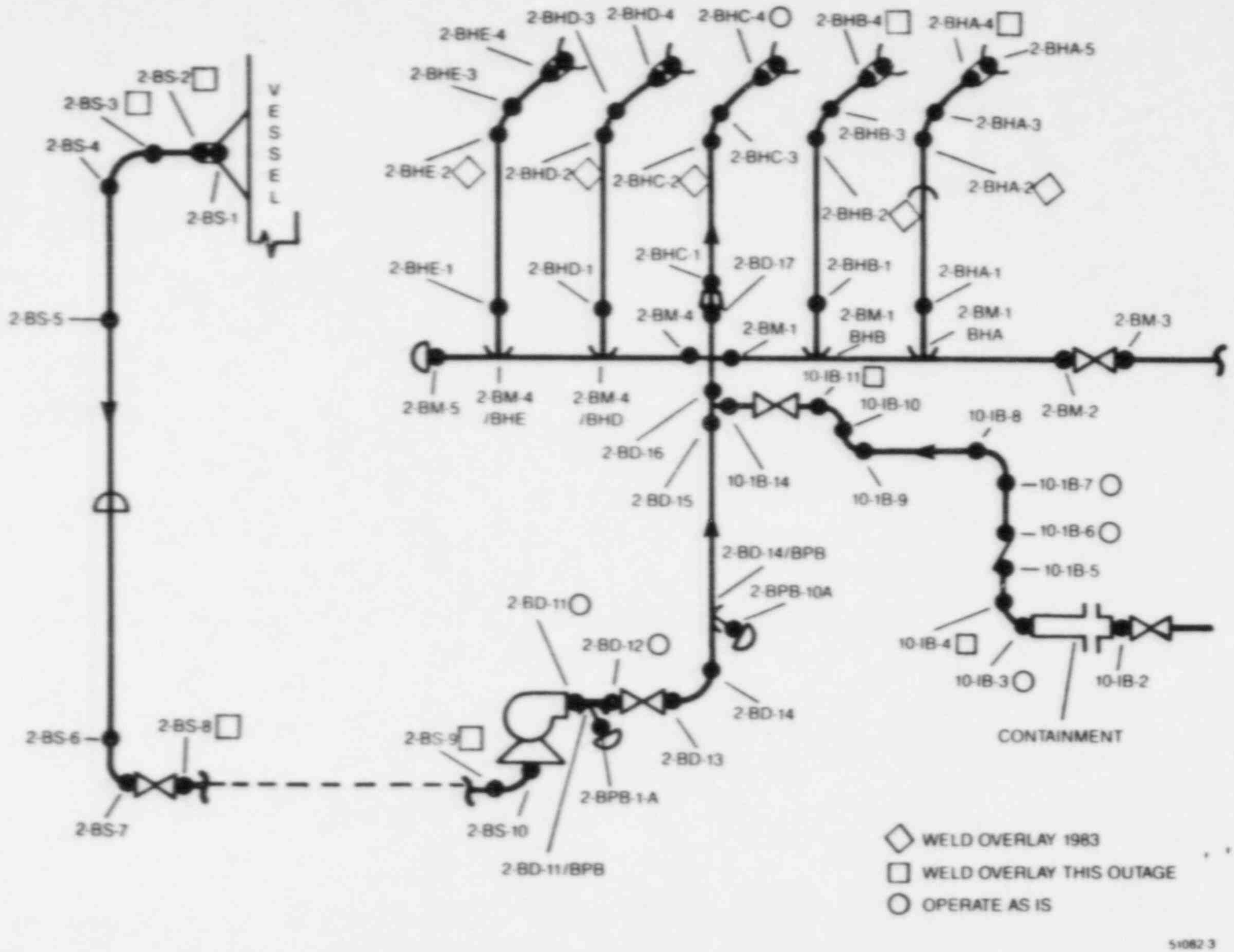


Figure 3 Recirculation and RHR Piping Loop B Weld Identification

TABLE 1 RECIRCULATION AND RHR PIPING WELD INDICATIONS LOOP A

Weld Identification	Weld Type	Pipe Size	Disposition	Treatment
2-AHJ-4	SS. Pipe+ SS. Safe End	12	Weld Overlay	IHSI '83
10-0-1A	SS. Pipe+ SS. Pipe+	20	Weld Overlay	IHSI '83
10-0-1B	SS. Pipe+ SS. Pipe+	20	Weld Overlay	IHSI '83
10-0-02	SS. Pipe+ SS. Elbow	20	Weld Overlay	IHSI '83
10-0-03	SS. Elbow SS. Pipe+	20	Operate As-is	IHSI '83
10-IA-4	SS. Pipe SS. Elbow+	24	Operate As-is	IHSI '83
10-IA-5	SS. Pipe+ Cast SS. Valve	24	Operate As-is	IHSI '83
10-IA-7	SS. Elbow SS. Pipe+	24	Operate As-is	IHSI '83
2-AS-02	SS. Pipe+ SS. Safe End+	28	Weld Overlay	IHSI '83
2-AS-03	SS. Pipe+ SS. Elbow+	28	Weld Overlay	IHSI '83
2-AS-04	SS. Elbow+ SS. Pipe+	28	Weld Overlay	IHSI '83
2-AS-07	SS. Pipe SS. Elbow+	28	Weld Overlay	IHSI '83

+ Side of Indication

TABLE 1 RECIRCULATION AND RHR PIPING WELD INDICATIONS LOOP A
(Continued)

Weld Identification	Weld Type	Pipe Size	Disposition	Treatment
2-AS-08	SS. Elbow+ Cast SS. Valve	28	Operate As-is	IHSI '83
2-AS-10	SS. Pipe+ SS. Elbow+	28	Weld Overlay	IHSI '83
2-AS-11	SS. Elbow+ Cast SS. Pump Casing	28	Weld Overlay	IHSI '83
2-AD-14	SS. Elbow+ Cast SS. Valve	28	Operate As-is	IHSI '83

\+ Side of Indication

TABLE 2 RECIRCULATION AND RHR PIPING WELD INDICATIONS LOOP B

WELD IDENTIFICATION	WELD TYPE	PIPE SIZE	DISPOSITION	TREATMENT
2-BHA-4	SS. Pipe^{+} SS. Safe End	12	Weld Overlay	IHSI '83
2-BHB-4	SS. Pipe^{+} SS. Safe End	12	Weld Overlay	IHSI '83
2-BHC-4	SS. Pipe^{+} SS. Safe End	12	Operate As-is	IHSI '83
10-IB-3	SS. Elbow^{+} SS. Penet.	24	Operate As-is	No IHSI
10-IB-4	SS. Pipe SS. Elbow^{+}	24	Weld Overlay	IHSI '83
10-IB-6	SS. Pipe^{+} Cast SS. Valve	24	Operate As-is	IHSI '83
10-IB-7	SS. Elbow SS. Pipe^{+}	24	Operate As-is	IHSI '83
10-IB-11	CS. Pipe SS. Elbow^{+}	24	Weld Overlay	No IHSI
2-BS-02	SS. Pipe^{+} SS. Safe End^{+}	28	Weld Overlay	IHSI '83
2-BS-03	SS. Pipe^{+} SS. Elbow^{+}	28	Weld Overlay	IHSI '83
2-BS-08	SS. Pipe^{+} Cast SS. Valve	28	Weld Overlay	No IHSI
2-BS-09	SS. Pipe^{+} SS. Elbow^{+}	28	Weld Overlay	IHSI '83
2-BD-11	SS. Pipe^{+} Cast SS. Pipe	28	Operate As-is	No IHSI
2-BD-12	SS. Pipe^{+} Cast SS. Valve	28	Operate As-is	No IHSI

+ Side of Indication

3. FRACTURE MECHANICS ANALYSIS

This section discusses the technical basis and results of the crack growth analyses. The discussion in this section is limited to the twelve welds with indications that were not repaired.

3.1 Method

Crack growth analyses were performed to determine the depth of the cracks after 18 months of operation. The Buchalet-Bamford polynomial fit method (Reference 4) was used to calculate the stress intensity factors. Crack growth was determined using the upper bound weld sensitized crack growth data shown in Figure 4, (Reference 5).

3.2 Assumptions

The crack was conservatively assumed to have an initial depth equal to the maximum reported depth and length equal to the sum of the individual lengths.

A detailed summary of the composite crack indication sizing is shown in Appendix A. All sizing was performed by GE and most sizing was independently verified by Southwest Research Institute (SWRI). A summary of the sizing assumptions for these analyses is shown in Tables 3 and 4. Where measured wall thickness was not available, the nominal thickness was used. This is conservative, since the as-built thickness is greater than the nominal thickness.

3.3 Stresses

The applied stresses consisted of the original design stresses (pressure, thermal expansion, and dead weight) and weld overlay shrinkage stress, as shown in Tables 5 and 6. For the crack growth analysis these stresses were conservatively assumed to be membrane stresses. The design stresses were determined using the appropriate piping stress reports (References 6, 7, 8, and 9). Weld overlay shrinkage stresses were determined using a piping system finite element model, as discussed in Section 5 of this report.

In addition, one of the following two residual stress distribution assumptions were applied:

Large diameter (>20 inches) pipe weld residual stress, as described in Reference 10, see Figure 5, applies to the large diameter pipes that are not treated with Induction Heating Stress Improvement (IHSI).

No credit was taken for the favorable compressive stresses in pipes that are IHSI treated. However, it was assumed that the pipe was free from the pipe weld residual stress after IHSI. The rationale for this conservative assumption is discussed in the following two paragraphs.

The IHSI treatment involves induction heating on the outer surface of the pipe while cooling the inside surface with flowing water. The effect is to create a high tensile stress on the inside surface where it is cold and compressive stress on the outside surface where it is hot. As the pipe cools, the reversed loading produces a compressive stress on the inside surface. Tests and analyses have shown IHSI treatment to be effective in producing compressive residual stresses even if fairly deep (25-30%) flaws are present.

Even if the benefit of compressive IHSI stresses is not considered, the plasticity that occurs during this treatment will neutralize existing as welded stress distributions. Therefore, this analysis conservatively assumes no residual stress, which allows for the removal of the weld residual stress, but takes no credit for the beneficial IHSI residual stresses.

Using these stresses, a crack growth evaluation was performed for each indication and compared to the following criteria.

3.4 Criteria

The first criterion is that the crack should not exceed the limit for net section collapse using a safety factor of 3.0.

The second criterion is that the crack should not exceed 2/3 of the limits for depth and length provided in the ASME Code Section XI, Paragraph IWB-3640.

The last criterion is that the crack should not exceed the limit on allowable flaw size, proposed for the ASME Code Section XI in Table IWB-3641-5, for a specific stress ratio. The stress ratio is calculated using the following equation.

$$\text{Stress Ratio} = M(P_m + P_b + P_e/2.77) / S_m$$

$P_m + P_b$ = pressure, dead weight, and seismic stress; ksi

P_e = thermal expansion stress; ksi

M = 1.08

S_m = 16.9 ksi

3.5 Results

Based on the evaluations, operation as-is is acceptable for the following twelve welds; the detailed results are contained in Appendix B.

WELDS ACCEPTABLE FOR OPERATING AS-IS

Loop A	Loop B
10-0-03	2-BHC-4
10-IA-4	10-IB-3
10-IA-5	10-IB-6
10-IA-7	10-IB-7
2-AS-8	2-BD-11
2-AD-14	2-BD-12

As defined in the three criteria, the analyses demonstrate compliance with the requirements of the NRC Generic Letter 84-11 as well as the newly developed acceptance criteria for flux weldments.

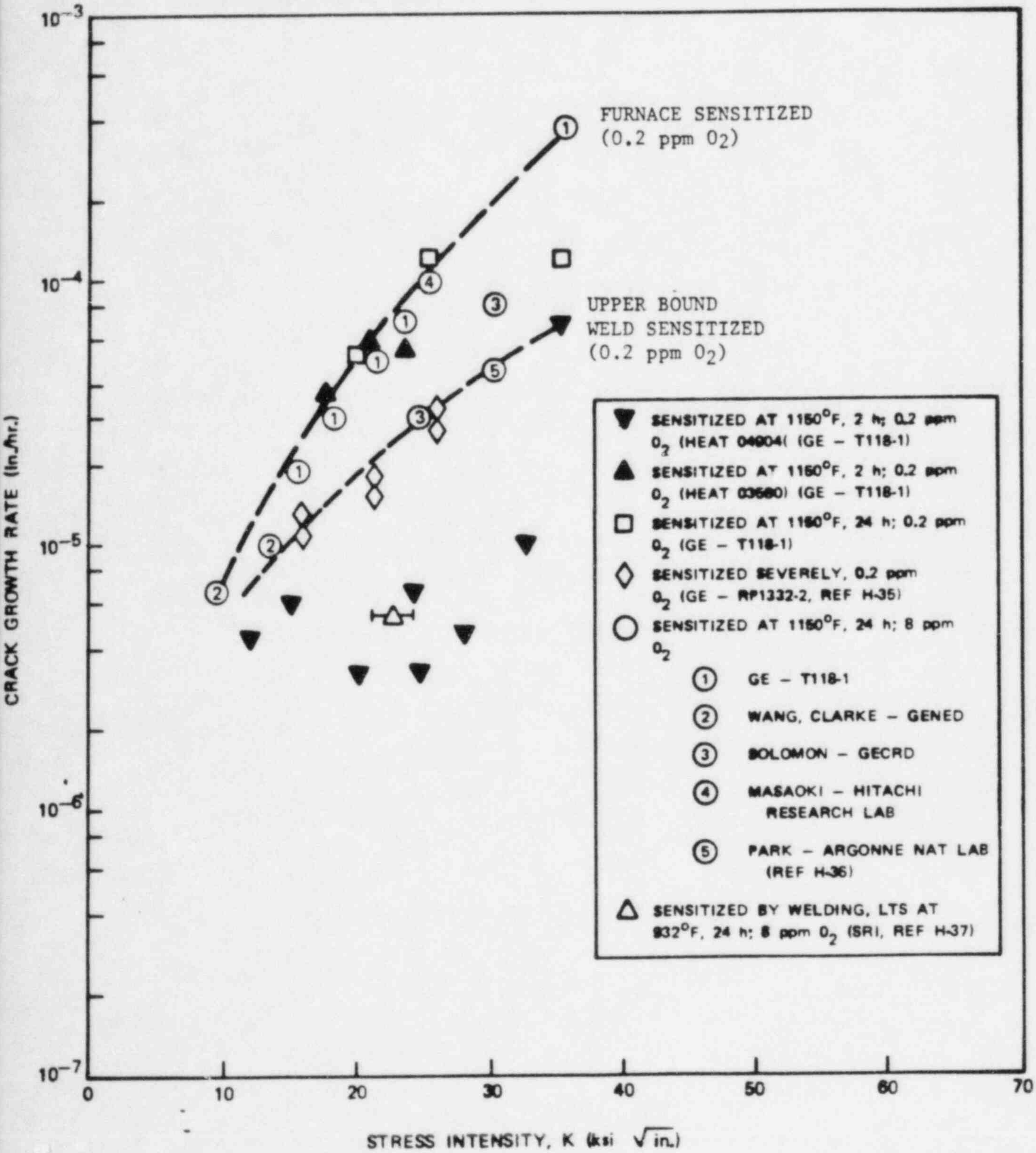


Figure 4. Crack Growth Data and Disposition Curve

TABLE 3 RECIRCULATION AND RHR PIPING WELD INDICATIONS LOOP A
ASSUMPTIONS FOR ANALYSIS

WELD IDENTIFICATION	WELD TYPE	PIPE SIZE (in.)	MEASURED WALL THICKNESS (in.)	CRACK ORIENTATION	CRACK* DEPTH (%/in.)	CRACK** LENGTH (in.)	TREATMENT
2-AHJ-4	SS. Pipe+ SS. Safe End	12	0.80	Circumferential	25/0.20	18	IHSI
10-0-1A	SS. Pipe+ SS. Pipe+	20	0.84 0.82	Circumferential Circumferential	30/0.252 25/0.205	7.25 3	IHSI
10-0-1B	SS. Pipe+ SS. Pipe+	20	0.76 0.80	Circumferential Circumferential & Axial	35/0.266 25/0.200	13 15	IHSI
10-0-02	SS. Pipe+ SS. Elbow	20	0.80	Circumferential	40/0.320	63	IHSI
10-0-03	SS. Elbow SS. Pipe+	20	0.84	Circumferential	25/0.210	16	IHSI
10-IA-4	SS. Pipe SS. Elbow+	24	1.20	Circumferential	10/0.120	1.25	IHSI
10-IA-5	SS. Pipe+ Cast SS. Valve	24	1.20	Circumferential	10/0.120	12	IHSI
10-IA-7	SS. Elbow SS. Pipe+	24	1.15	Circumferential	10/0.115	1.12	IHSI

* Maximum Crack Depth Reported
** The Length Equals the Sum of the Individual Lengths of the Reported Indications
\+ Side of Indication

TABLE 3 RECIRCULATION AND RHR PIPING WELD INDICATIONS LOOP A
ASSUMPTIONS FOR ANALYSIS (Continued)

WELD IDENTIFICATION	WELD TYPE	PIPE SIZE (in.)	MEASURED WALL THICKNESS (in.)	CRACK ORIENTATION	CRACK* DEPTH (%/in.)	CRACK** LENGTH (in.)	TREATMENT
2-AS-02	SS. Pipe+ SS. Safe End+	28	1.15 1.25	Circumferential Circumferential	35/0.403 35/0.438	11 39	IHSI
2-AS-03	SS. Pipe+ SS. Elbow+	28	1.15 1.20	Circumferential Circumferential	40/0.460 40/0.480	39 19	IHSI
2-AS-04	SS. Elbow+ SS. Pipe+	28	1.25 1.125	Circumferential Circumferential	45/0.562 40/0.450	40 12	IHSI
2-AS-07	SS. Pipe SS. Elbow+	28	1.30	Circumferential	35/0.455	52	IHSI
2-AS-08	SS. Elbow+ Cast SS. Valve	28	1.138***	Circumferential	21/0.239 Peak 40/0.455	36	IHSI
2-AS-10	SS. Pipe+ SS. Elbow+	28	1.138***	Circumferential Circumferential	40/0.455 35/0.398	53 66	IHSI
2-AS-11	SS. Elbow+ Cast SS. Pump Casing	28	1.3	Circumferential	35/0.455	43	IHSI
2-AD-14	SS. Elbow+ Cast SS. Valve	28	1.45	Circumferential	20/0.29	6	IHSI

* Maximum Crack Depth Reported
** The Length Equals the Sum of the Individual Lengths of the Reported Indications
*** Nominal Thickness
+ Side of Indication

TABLE 4 RECIRCULATION AND RHR PIPING WELD INDICATIONS LOOP B
ASSUMPTIONS FOR ANALYSIS

WELD IDENTIFICATION	WELD TYPE	PIPE SIZE (in.)	MEASURED WALL THICKNESS (in.)	CRACK ORIENTATION	CRACK* DEPTH (%/in.)	CRACK** LENGTH (in.)	TREATMENT
2-BHA-4	SS. Pipe+ SS. Safe End	12	0.80	Circumferential	35/0.280	17	IHSI
2-BHB-4	SS. Pipe+ SS. Safe End	12	0.825	Circumferential	35/0.289	5	IHSI
2-BHC-4	SS. Pipe+ SS. Safe End	12	0.85	Circumferential	20/0.170	5	IHSI
10-IB-3	SS. Elbow+ SS. Penet.	24	1.5	Circumferential	20/0.300	4	NO IHSI
10-IB-4	SS. Pipe SS. Elbow+	24	1.24	Circumferential	50/0.625	25.5	IHSI
10-IB-6	SS. Pipe+ Cast SS. Valve	24	1.25	Circumferential	10/0.125	6	IHSI
10-IB-7	SS. Elbow SS. Pipe+	24	1.20	Circumferential	10/0.120	4	IHSI
10-IB-11	CS. Pipe SS. Elbow+	24	1.50	Circumferential	35/0.437	12	NO IHSI

* Maximum Crack Depth Reported

** The Length Equals the Sum of the Individual Lengths of the Reported Indications

+ Side of Indication

TABLE 4 RECIRCULATION AND RHR PIPING WELD INDICATIONS LOOP B
ASSUMPTIONS FOR ANALYSIS (Continued)

WELD IDENTIFICATION	WELD TYPE	PIPE SIZE (in.)	MEASURED WALL THICKNESS (in.)	CRACK ORIENTATION	CRACK* DEPTH (%/in.)	CRACK** LENGTH (in.)	TREATMENT
2-BS-02	SS. Pipe+	28	1.20	Circumferential	55/0.66	60.4	IHSI
	SS. Safe End+		1.25	Circumferential	70/0.875	47	
2-BS-03	SS. Pipe+	28	1.15	Axial & Circumferential	40/0.460	37	IHSI
	SS. Elbow+		1.25	Circumferential	45/0.562	43	
2-BS-08	SS. Pipe+ Cast SS. Valve	28	1.138***	Circumferential	35/0.398	46	NO IHSI
2-BS-09	SS. Pipe+	28	1.15	Axial & Circumferential	30/0.345	52	IHSI
	SS. Elbow+		1.25	Circumferential	40/0.50	62	IHSI
2-BD-11	SS. Pipe+ Cast SS. Pipe	28	1.30	Circumferential	30/0.390	27	NO IHSI
2-BD-12	SS. Pipe+ Cast SS. Valve	28	1.138***	Circumferential	21/0.285 Peak 30/0.341	43	NO IHSI

* Maximum Crack Depth Reported
** The Length Equals the Sum of the Individual Lengths of the Reported Indications
*** Nominal Thickness
\+ Side of Indication

TABLE 5 RECIRCULATION AND RHR PIPING WELD STRESSES LOOP A

WELD IDENTIFICATION	PIPE SIZE (in.)	MEASURED WALL THICKNESS (in.)	DESIGN PRESSURE/ STRESS (ksi)	DESIGN THERMAL EXPANSION STRESS (ksi)	DESIGN DEAD-WEIGHT STRESS (ksi)	DESIGN SEISMIC STRESS (OBE) (ksi)	SHRINKAGE STRESS (ksi)
2-AHJ-4	12	0.80	1.3/5.20	8.20	2.20	0.80	-
10-0-1A	20	0.82	1.05/6.40	7.38	0.43	1.11	-
10-0-1B	20	0.76	1.05/6.90	7.90	0.46	1.19	-
10-0-02	20	0.80	1.05/6.56	6.80	0.40	1.10	-
10-0-03	20	0.84	1.05/6.25	5.60	0.30	0.80	2.0
10-IA-4	24	1.20	1.3/6.50	9.30	0.20	0.80	0.0
10-IA-5	24	1.20	1.3/6.50	5.60	0.20	0.70	0.0
10-IA-7	24	1.15	1.3/6.80	10.70	0.20	0.90	0.0
2-AS-02	28	1.15	1.05/6.39	3.65	0.91	1.60	-
2-AS-03	28	1.15	1.05/6.39	2.90	1.22	1.19	-
2-AS-04	28	1.25	1.05/6.53	1.68	1.49	1.25	-
2-AS-07	28	1.30	1.05/5.65	0.80	0.70	0.60	-
2-AS-08	28	1.138*	1.05/6.46	1.00	0.43	1.28	0.1
2-AS-10	28	1.138*	1.05/6.46	0.72	0.61	1.60	-
2-AS-11	28	1.30	1.05/5.65	0.53	0.68	1.54	-
2-AD-14	28	1.45	1.3/6.28	0.88	0.70	0.85	0.70

* Nominal Thickness

TABLE 6 RECIRCULATION AND RHR PIPING WELD STRESSES LOOP B

WELD IDENTIFICATION	PIPE SIZE (in.)	MEASURED WALL THICKNESS (in.)	PRESSURE/ STRESS (ksi)	THERMAL EXPANSION STRESS (ksi)	DEAD-WEIGHT STRESS (ksi)	SEISMIC STRESS (OBE) (ksi)	SHRINKAGE STRESS (ksi)
2-BHA-4	12	0.80	1.3/4.90	6.9	0.60	1.10	-
2-BHB-4	12	0.825	1.3/4.73	6.1	0.85	0.70	-
2-BHC-4	12	0.85	1.3/4.60	4.2	2.30	1.10	0.4
10-IB-3	24	1.5	1.3/5.20	6.7	0.07	1.09	1.7
10-IB-4	24	1.24	1.3/6.29	9.3	0.22	1.02	
10-IB-6	24	1.25	1.3/6.24	5.1	0.40	0.60	2.7
10-IB-7	24	1.20	1.3/6.50	10.4	0.17	0.50	4.2
10-IB-11	24	1.25	1.3/5.20	8.0	0.09	0.53	-
2-BS-02	28	1.20	1.05/6.12	1.25	0.44	0.79	-
2-BS-03	28	1.15	1.05/6.39	1.30	0.45	0.68	-
2-BS-08	28	1.138*	1.05/6.49	0.50	0.33	0.81	-
2-BS-09	28	1.15	1.05/7.91	0.56	0.37	1.34	-
2-BD-11	28	1.3	1.3/7.00	0.59	0.27	1.04	1.3
2-BD-12	28	1.138*	1.3/8.00	0.71	0.27	0.77	1.0

* Nominal Thickness

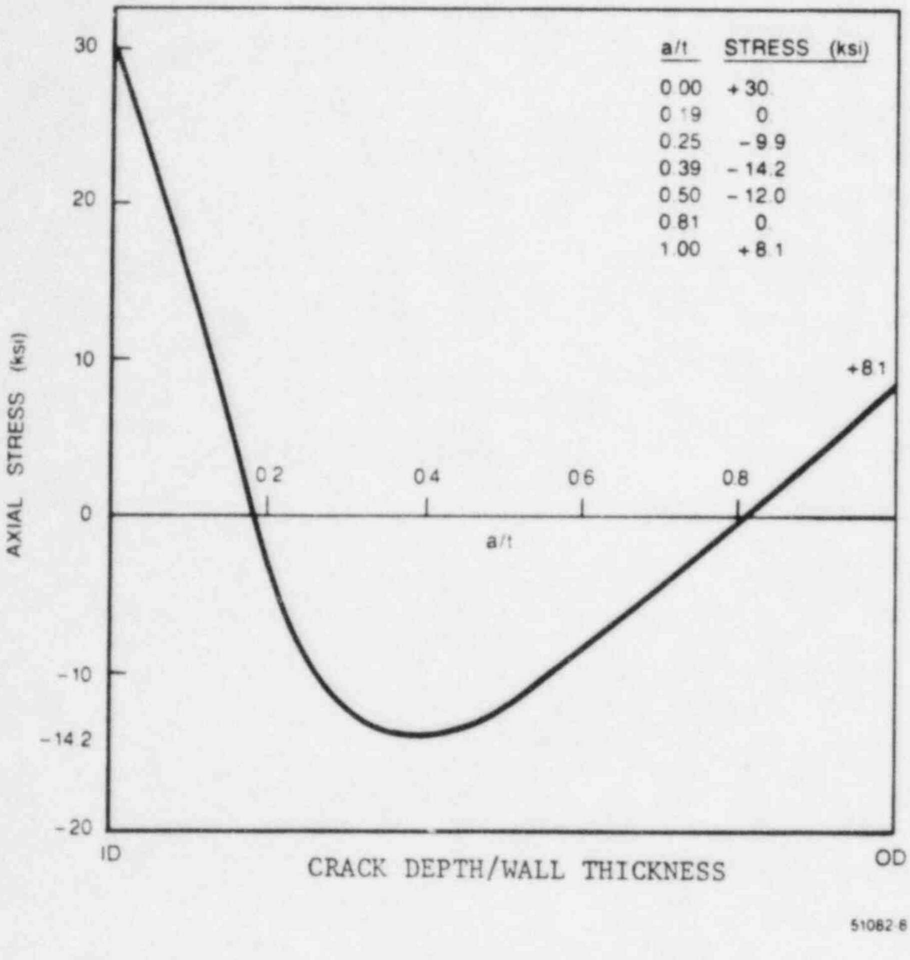


Figure 5 Large Diameter Pipe Axial Weld Residual Stress Distribution (22 in. to 28 in.)

4. WELD OVERLAY DESIGN

This section discusses the basis for the design of the weld overlay and the detailed geometric considerations.

4.1 Process

The weld overlay designs consist of a continuous 360° band of weld metal applied to the outside surface of the pipe directly above the crack indication. The overlay weld metal is Type 308L stainless steel containing low carbon and high ferrite. It is deposited using an automatic gas tungsten arc welding technique (GTAW) with water cooling the inside of the pipe. This process produces a very high quality, high toughness weld consisting of material resistant to Intergranular Stress Corrosion Cracking (IGSCC) while typically producing a compressive residual stress at the inside surface of the pipe and through a portion of the inner wall.

In accordance with the requirements of NRC Generic Letter 84-11, the overlay design thickness only includes material deposited after the first layer (or layers) that pass the liquid penetrant examination requirements. A second General Electric requirement for first layer ferrite measurement is also applied to consider possible reduction of the weld deposit ferrite content and pick-up of carbon from the base material. The ferrite content of the first layer is measured and must meet a minimum average of 8.0 Ferrite Number (FN) with no individual readings less than 5.0 FN. If the first layer fails to meet this requirement, additional layers are deposited until the required ferrite content is obtained.
This requirement, coupled with the use of 308L weld material, assures that the overlay first layer is highly resistant to IGSCC.

4.2 Assumptions

Due to the conservative assumption of a through wall fully circumferential flaw, the weld overlay thickness is independent of flaw size. Therefore, uncertainty in flaw sizing does not influence the weld overlay design.

The overlay is designed to provide full structural reinforcement while maintaining the ASME Code intended safety margins. This design has been termed the Type I full structural overlay. Also, no credit is taken for the beneficial compressive residual stress induced by the heat sink (water cooled) weld overlay process that would reduce crack growth through the thickness.

4.3 Methodology

The methods for designing the thickness and width of the weld overlay are described in this section.

4.3.1 Thickness

The minimum weld overlay thickness necessary to achieve full structural reinforcement is that thickness which provides the appropriate factor of safety against net section collapse of the adjacent material for a postulated 360° through wall crack. The depth at which net section collapse occurs is a function of the material flow stress, the overall wall thickness including the weld overlay, and the applied primary membrane and bending stresses. The primary membrane stress is produced by pressure, and the primary bending stress is the sum of the dead weight and seismic stresses. The stresses are summarized in Tables 3 and 4 for each weld.

Paragraph IWB-3642 of the ASME Code, Section XI can be used to determine the allowable overlay thickness using a safety factor of 3.0 on applied loading. Assuming that the indication is fully circumferential, the method described in Reference 11 can be used. In the reference report Equations (1) and (2) define a relationship between the applied loads, the flow stress, and the critical crack depth to pipe thickness ratio.

$$\beta = \frac{\pi\left(1 - a/t - P_m/\sigma_f\right)}{2 - a/t} \qquad (1)$$

$$P_b = \frac{2\sigma_f}{\pi}\left(2 - a/t\right)\sin\beta \qquad (2)$$

where: σ_f = Material Flow Stress = 3 S_m

P_m = Primary Membrane Stress

P_b = Primary Bending Stress

a = Crack Depth (equal to pipe wall thickness)

t = Total Thickness (pipe wall + weld overlay thickness)

An iteration scheme is performed using these equations until the minimum required weld overlay thickness is determined. A factor of safety of 3.0 is used in accordance with IWB-3642. Since the weld overlay is composed of tough GTAW weld material, the criterion for flux weldments does not apply.

As discussed previously weld overlays do not include the first layer or layers that do not pass liquid penetrant examination or delta ferrite requirements. This is to consider any potential cracking defects that might propagate to the first layer, as well as possible dilution (reduction) of ferrite and increase in the carbon content in the first layer.

4.3.2 Width

Unlike the thickness requirements for weld overlay designs, there are no specific requirements for the weld overlay widths. However, the overlay width must be sufficient to provide structural reinforcement and access for future overlay in-service inspection. As it became apparent that a large number of overlays would be required, the need to minimize system shrinkage stress was identified. Therefore, finite element analyses were performed to justify minimizing the width of the weld overlay. This analysis showed that a minimum weld overlay width of $\sqrt{Rt}$ (where R = radius and t = wall thickness) provides the required structural reinforcement and overlay design margins. In addition, UT inspection during this outage of the 1983 20" RHR overlays confirmed that this narrower design could be successfully in-service examined should operation beyond one refueling cycle be desired. Accordingly, this design was implemented on all remaining overlays.

4.4 Results

The weld overlay designs are summarized in Tables 7 and 8; detailed results are contained in Appendix C. The typical wide and narrow designs are shown in Figures 6 and 7. Other representative designs are shown in Figures 8 through 12.

The specific overlay design for each weld was based on consideration of such factors as:

- o Weld crown geometry,
- o proximity to other welds, valves, and carbon steel pipes, and
- o ultrasonic testing requirements for future in-service inspection.

The slope of the overlay end was set to one-to-one (width-to-thickness) for geometric considerations and to reduce stress concentration effects. Some earlier designs used a three-to-one slope, however, the one-to-one slope is fully acceptable from a Code stress concentration and piping fatigue usage point of view. The one-to-one slope also provides greater straight length on the overlay outside diameter surface for UT angle beam examination.

The weld overlay designs provide conservative safety margins for a typical Type I full structural overlay and are acceptable for at least 18 months of continued operation.

TABLE 7 RECIRCULATION AND RHR PIPING WELD OVERLAY RECOMMENDATIONS LOOP A

WELD IDENTIFICATION	WELD TYPE	PIPE SIZE (in.)	MEASURED WALL THICKNESS (in.)	CRACK ORIENTATION	OVERLAY DESIGN THICKNESS* /WIDTH (in.) /(in.)
2-AHJ-4	SS. Pipe+	12	0.80	Circumferential	0.25/5.0
	SS. Safe End				
10-0-1A	SS. Pipe+	20	0.84	Circumferential	0.26/3.5
	SS. Pipe+		0.82	Circumferential	
10-0-1B	SS. Pipe+	20	0.76	Circumferential	0.26/Note
	SS. Pipe+		0.80	Circumferential & Axial	
10-0-02	SS. Pipe+	20	0.80	Circumferential	0.26/Note
	SS. Elbow				
2-AS-02	SS. Pipe+	28	1.15	Circumferential	0.39/4.15
	SS. Safe End+				
2-AS-03	SS. Pipe+	28	1.15	Circumferential	0.39/4.3
	SS. Elbow+		1.20	Circumferential	
2-AS-04	SS. Elbow+	28	1.25	Circumferential	0.39/4.8
	SS. Pipe+		1.125	Circumferential	
2-AS-07	SS. Pipe	28	1.30	Circumferential	0.36/4.5
	SS. Elbow+				

(Note: Length was adjusted to consider proximity of welds 10-0-1B and 10-0-2 to each other. The overlay length is continuous between the welds and extends 2.5 inches beyond the centerline of each weld).

* Min Overlay Thickness After First Layer to Pass all required examinations.

\+ Side of Indication.

TABLE 7 RECIRCULATION AND RHR PIPING WELD OVERLAY RECOMMENDATIONS LOOP A

(Continued)

WELD IDENTIFICATION	WELD TYPE	PIPE SIZE (in.)	MEASURED WALL THICKNESS (in.)	CRACK ORIENTATION	OVERLAY DESIGN THICKNESS* /WIDTH (in.) /(in.)
2-AS-10	SS. Pipe+	28	1.138**	Circumferential	0.38/4.5
	SS. Elbow+			Circumferential	
2-AS-11	SS. Elbow+	28	1.30	Circumferential	0.39/3.5
	Cast SS. Pump Casing				

* Min Overlay Thickness After First Layer to Pass all required examinations

** Nominal Thickness

\+ Side of Indication

TABLE 8 RECIRCULATION AND RHR PIPING WELD OVERLAY RECOMMENDATIONS LOOP B

WELD IDENTIFICATION	WELD TYPE	PIPE SIZE (in.)	MEASURED WALL THICKNESS (in.)	CRACK ORIENTATION	OVERLAY DESIGN THICKNESS* /WIDTH (in.) /(in.)
2-BHA-4	SS. Pipe+ SS. Safe End	12	0.80	Circumferential	0.21/5.0
2-BHB-4	SS. Pipe+ SS. Safe End	12	0.825	Circumferential	0.21/5.0
10-IB-4	SS. Pipe SS. Elbow+	24	1.24	Circumferential	0.37/6.0
10-IB-11	CS. Pipe SS. Elbow+	24	1.5	Circumferential	0.35/3.0
2-BS-02	SS. Pipe+ SS. Safe End+	28	1.20	Circumferential Circumferential	0.34/6.0
2-BS-03	SS. Pipe+ SS. Elbow+	28	1.15 1.25	Axial & Circumferential Circumferential	0.34/6.0
2-BS-08	SS. Pipe+ Cast SS. Valve	28	1.138**	Circumferential	0.345/Note
2-BS-09	SS. Pipe+ SS. Elbow+	28	1.15 1.25	Axial & Circumferential Circumferential	0.435/4.5

(Note: Length was adjusted to consider proximity to the valve. The length is 3.0 inches on the pipe side and blended on the valve side)

* Min Overlay Thickness After First Layer to pass all required examinations

** Nominal Thickness

\+ Side of Indication

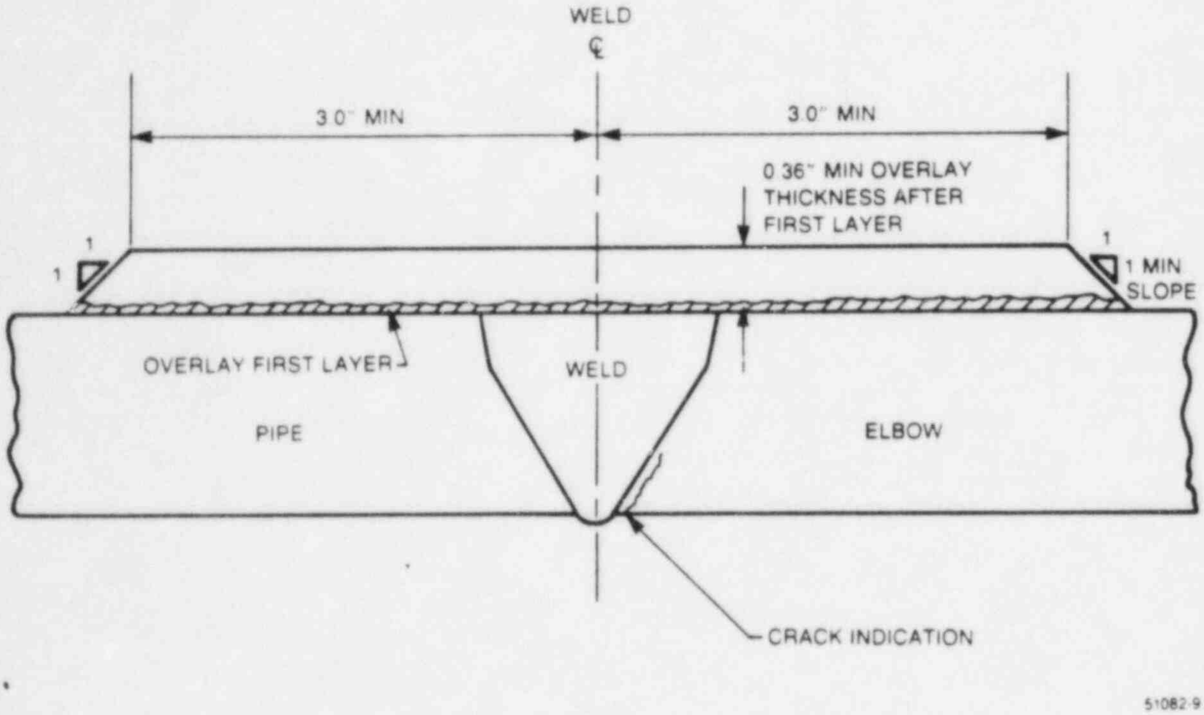


Figure 6 Wide Weld Overlay Design for Weld 2-AS-7 (Typical Wide Design)

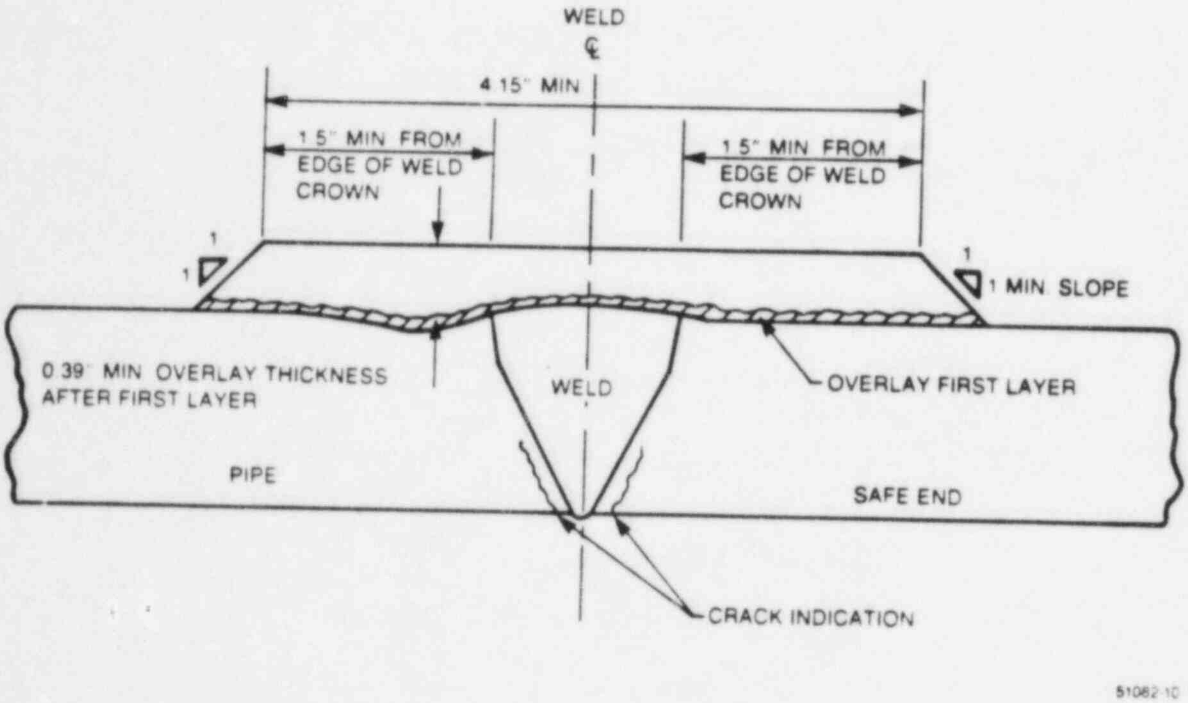


Figure 7 Narrow Weld Overlay Design for Weld 2-AS-2 (Typical Narrow Design)

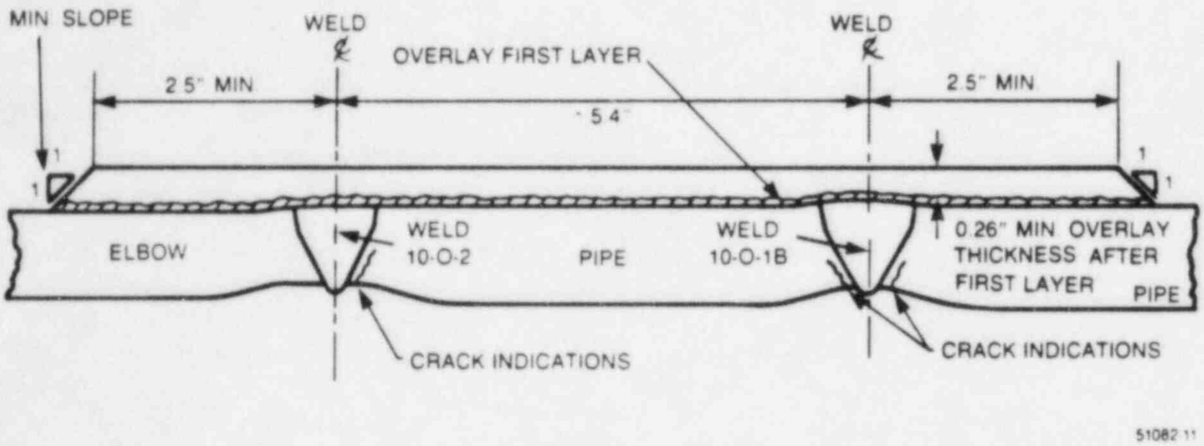


Figure 8 Weld Overlay Design for 10-O-2 and 10-O-1B

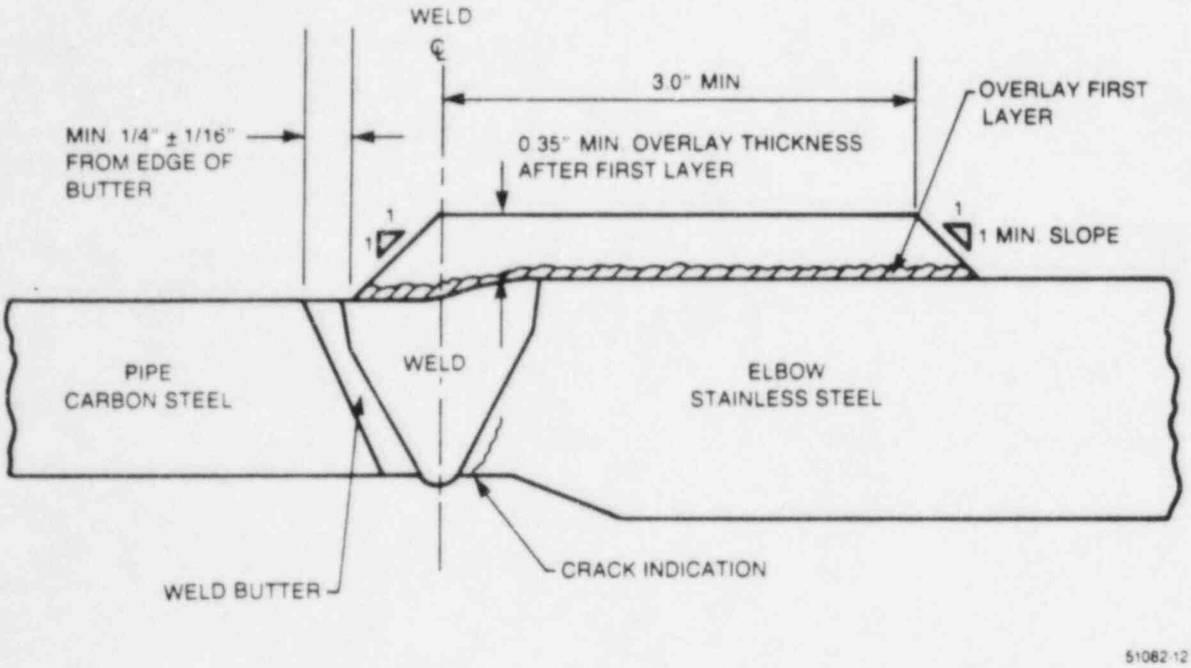
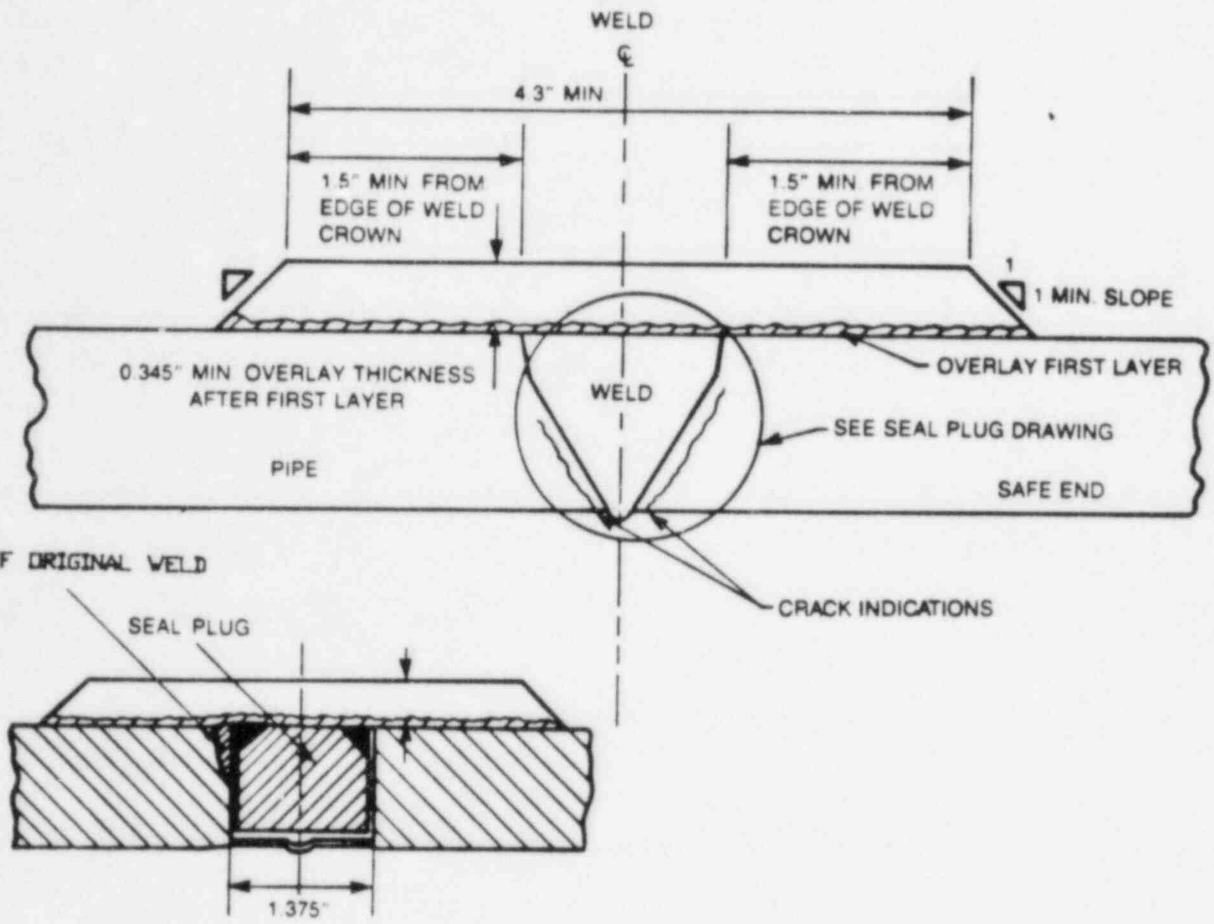


Figure 9 Weld Overlay Design for Weld 10-IB-11



Circular Seal Plug — (At Core Sample)

51082-13

Figure 10 Weld Overlay Design for Weld 2-BS-2 (Including Repair of Metallurgical Core Sample Hole)

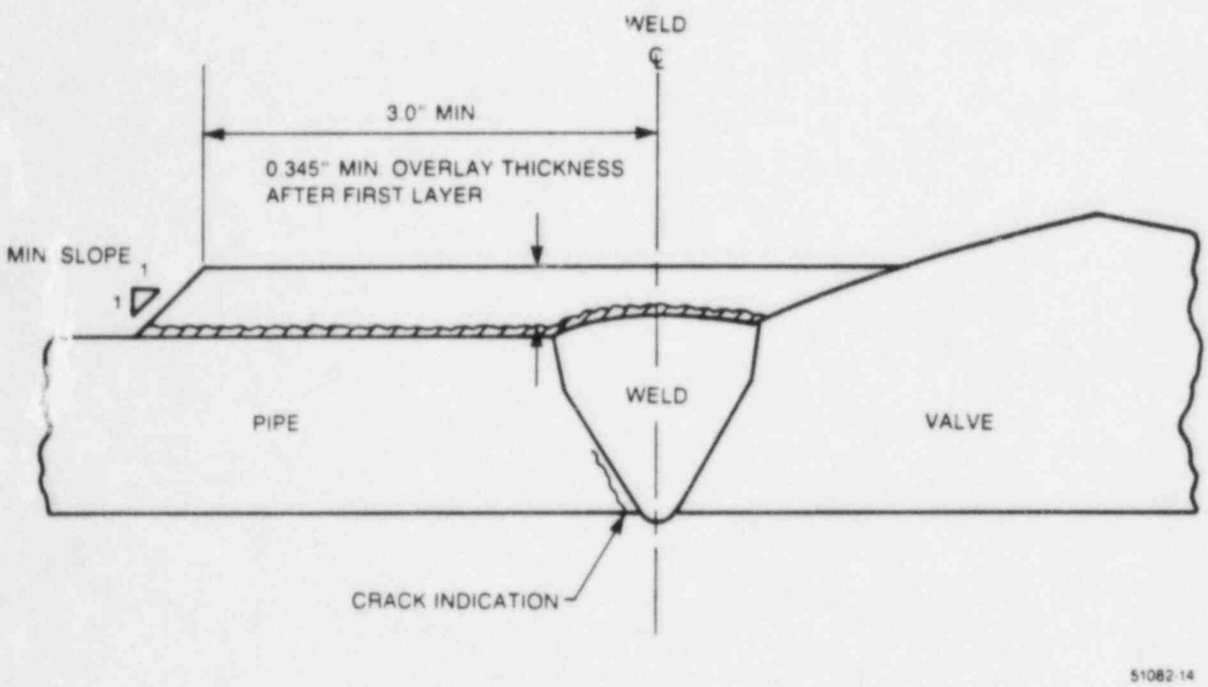


Figure 11 Weld Overlay Design for Weld 2-BS-8

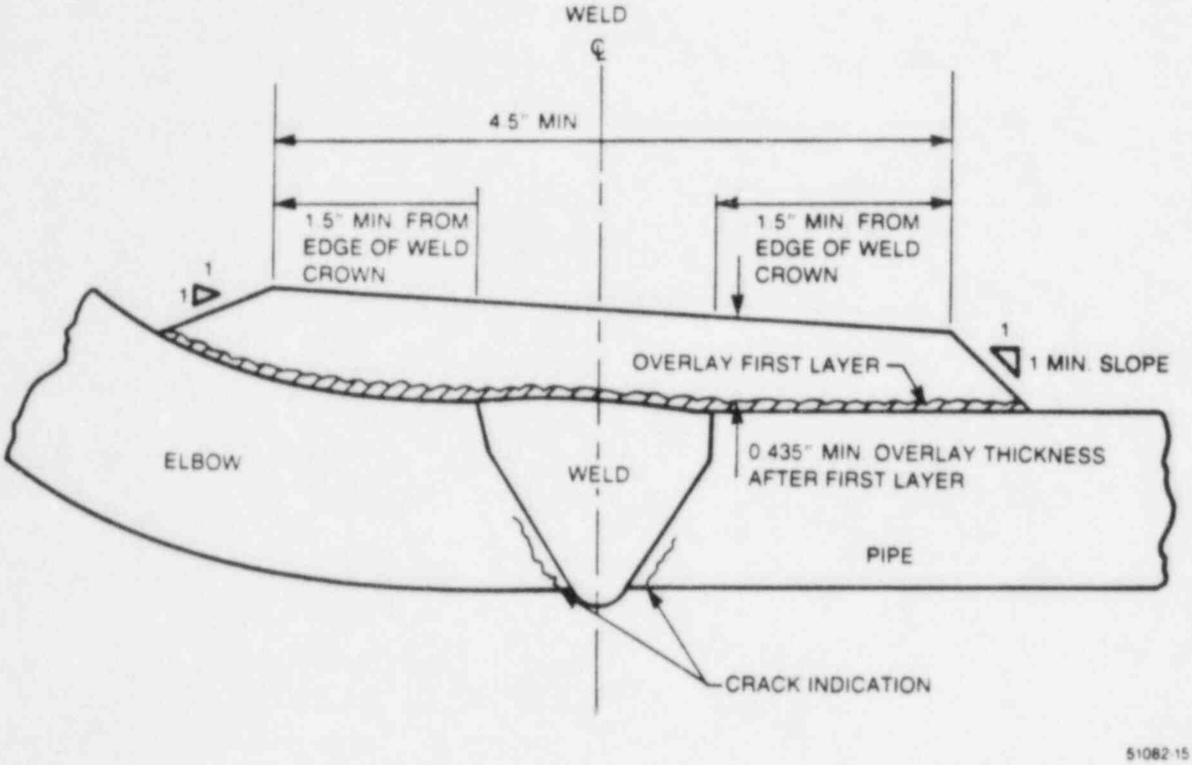


Figure 12 Weld Overlay Design for Weld 2-BS-9

5. WELD OVERLAY SHRINKAGE

Shrinkage analyses were performed to simulate the local axial shrinkage that results from application of the weld overlay. This induced axial shrinkage will produce stresses through the piping system.

5.1 Method

The analysis was performed using the piping analysis code, PISYS (Reference 12) and a finite element model of the Peach Bottom Unit 3 piping system. Four shrinkage analyses were performed during the course of the outage to determine the shrinkage stresses for joints known to require weld overlays. As additional welds were found to require overlay repair, shrinkage stresses were re-evaluated. These four cases are shown in Table 9 (see Figures 1 through 3 for weld locations).

5.2 Assumptions

The weld overlay shrinkage values are based on measured shrinkages for completed weld overlays and assumed shrinkages for weld overlays not completed at the time of the analysis. The assumed shrinkages are based on mockup and field experience and are considered conservative. Following the completion of the overlay welding, a shrinkage analysis of the entire system was completed using measured shrinkages.

The shrinkage values and welds analyzed for each case are summarized in Table 9. The effective width in Table 9 is the distance along the pipe over which the shrinkage is applied in the model. This distance is typically about 1 inch beyond the ends of the overlay, and is consistent with the location where axial shrinkage measurements are made. The stresses are summarized in Tables 3 and 4. The final as-built shrinkage stresses for the entire system are summarized in Appendix D.

5.3 Results

Presently, there are no specific Code requirements regarding shrinkage stress. However, weld shrinkage stress is similar in nature to cold spring stress. These are acceptable since the stresses are well below the material yield strength. The weld shrinkage stress, which could be considered a sustained stress, requires special evaluation for crack indications that are recommended for operation as-is. Therefore, these stresses were added to the applied stresses used in the fracture mechanics analyses.

TABLE 9 WELD OVERLAY SHRINKAGE CASES

Case 1: A shrinkage analysis of the Loop B 24" RHR with shrinkages on the following welds.

	WELD	SHRINKAGE INCH	EFFECTIVE WIDTH INCH
LOOP B			
24" RHR	10-IB-3	0.375	4.0
	10-IB-4	0.375	6.0
	10-IB-6	0.375	6.0
	10-IB-7	0.375	6.0
	10-IB-11	0.020	6.0

Case 2: A shrinkage analysis of the Loop A 20" RHR with shrinkages on the following welds.

	WELD	SHRINKAGE INCH	EFFECTIVE WIDTH INCH
LOOP A			
20" RHR	10-0-2	0.13*	6.0
	10-0-1A	0.25	6.0
	10-0-1B	0.25	6.0
	10-0-5	0.33*	6.0
	10-0-6	0.18*	6.0
	10-0-7	0.19*	4.0
	10-0-10	0.17*	4.0
	10-0-15	0.15*	4.0

* As built shrinkage

TABLE 9 WELD OVERLAY SHRINKAGE CASES (Continued)

Case 3: A shrinkage analysis of the Loop A 20" RHR and 28" Line with shrinkages on the following welds.

	WELD	SHRINKAGE INCH	EFFECTIVE WIDTH INCH
LOOP A 20" RHR	10-0-2	0.13*	6.0
	10-0-1B	0.25	6.0
	10-0-5	0.33*	6.0
	10-0-6	0.18*	6.0
	10-0-7	0.19*	4.0
	10-0-10	0.17*	4.0
	10-0-15	0.15*	4.0
28" Line	2-AS-2	0.19	8.0
	2-AS-3	0.19	8.0
	2-AS-4	0.19	8.0
	2-AS-7	0.19	8.0
	2-AS-8	0.19	8.0
	2-AS-10	0.19	8.0
	2-AD-14	0.19	8.0

Case 4: A shrinkage analysis of the Loop B 28" Recirculation Line with shrinkages on the following welds.

WELD	SHRINKAGE INCH	EFFECTIVE WIDTH INCH
2-BS-2	0.19	8.0
2-BS-3	0.19	8.0
2-BS-8	0.19	8.0

* As built shrinkage

6. CONCLUSIONS

Where appropriate, fracture mechanics analyses and weld overlay designs were prepared for the indications in the Peach Bottom 3 recirculation and residual heat removal systems. A summary of the resolution for each weld is shown in Tables 1 and 2. Details of the flaw evaluation are shown in Appendix B. The weld overlay dimensions are summarized in Tables 7 and 8; detailed results are contained in Appendix C.

Of the 30 new crack indications reported during this outage the following dispositions have been applied:

- 12 welds are acceptable for operation without repair for at least 18 months.
- 18 welds were repaired with a full structural overlay.

The analyses and overlay repair program are in compliance with the requirements of the ASME Code Section XI and the NRC Generic Letter 84-11. The analyses and repairs provide the technical justification for return to service of the piping system and operation for at least 18 months.

7. REFERENCES

1. Letter to All Licensees of Operating Reactors, Applicants for Operating License, and Holders of Construction Permits for Boiling Water Reactors from United States Nuclear Regulatory Commission, Inspections of BWR Stainless Steel Piping (Generic Letter 84-11), Nuclear Regulatory Commission, Washington, D.C., April 19, 1984.

2. Letter to Task Group, R. Gamble, S. Bush, and B.D. Liaw from Section XI Task Group on Piping Flaw Evaluation, Evaluation of Stainless Steel Flux Weldments: (a) Proposed Code Copy Modification to IWB-3640, (b) Technical Basis Document, March 29, 1985.

3. ASME Boiler and Pressure Vessel Code, Section XI, 1980 Edition, including Appendix X, "Acceptance Criteria for Flaws in Austenitic Piping," approved April 1983.

4. C. B. Buchalet and W. H. Bamford, "Stress Intensity Factor Solution for Continuous Surface Flaws in Reactor Pressure Vessels," Mechanics of Crack Growth, ASTM STP 590, 1976.

5. R. M. Horn and S. Ranganath, "Determination of Crack Growth Rates in Sensitized Austenitic Piping," Proceedings: Second Seminar on Countermeasures for Pipe Cracking in BWRs, Volume 1: Problem Resolution, EPRI, Palo Alto, CA, (EPRI NP-3684-SR), September, 1984, pp. 10-iii through 10-12.

6. B. Cheek, Peach Bottom Recirculation System Design Recirculation System Design Report, General Electric - Nuclear Energy Division, San Jose, CA, October 27, 1970, (22A2619). Used for Loop A Recirculation System.

7. Computer Analysis of the Loop A 20" RHR from Bechtel.

8. T. V. Pham, Peach Bottom Recirculation System Design Recirculation System Design Report Loop B, General Electric - Nuclear Energy Business Group, October 9, 1981, (22A6081).

9. Computer Analysis of the Loop B 20" RHR from Bechtel.

10. General Electric Company, The Growth and Stability of Stress Corrosion Cracks in Large Diameter BWR Piping, Electric Power Research Institute, Palo Alto, CA, July 1982, (EPRI NP-2472 Volume 2).

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12. PISYS05, GE Piping System Analysis Computer Program, NEDE-24077, April 1979.

APPENDIX A Summary of Crack Indication Sizing

This appendix contains a detailed summary of the Peach Bottom Unit 3 crack indication sizing.

CONTENTS

TABLE A.1 Recirculation and RHR Piping Weld Indications Loop A

Weld Ident.	Weld Type	Pipe Size (in.)	Measured Wall Thk. (in.)	Crack Indications Length / Depth (in. / %.)	Disposition
2-AHJ-4	SS. Pipe+ SS. Safe End	12	0.80	0 - 1 / 20-25	Weld Overlay
				4 - 16 / 20-25	
				17 - 19 / 20-25	
				28 - 29 / 20-25	
				36 - 38 / 20-25	
10-0-1A	SS. Pipe+	20	0.84	13 - 17 / 15	Weld Overlay
				59.5 - 62.75/ 30	
	SS. Pipe+		0.82	58 - 61 / 25	
10-0-1B	SS. Pipe+	20	0.76	2 - 4 / 35	Weld Overlay
				10 - 11 / 15-25	
				12.5 - 13.5 / 15-25	
				25 - 26 / 15-25	
				46 - 48 / 15-25	
				52 - 58 / 15-25	
	SS. Pipe+		0.80	23 - 28 / 15-25	
				43 - 44 / 15-25	
				52 - 61 / 15-25	
10-0-02	SS. Pipe+ SS. Elbow	20	0.80	360° / 5-40	Weld Overlay
10-0-03	SS. Elbow SS. Pipe+	20	0.84	0 - 2 / 25	Operate As-is
				14 - 19 / 20	
				39 - 42 / 22	
				58 - 64 / 25	
10-IA-4	SS. Pipe SS. Elbow+	24	1.20	0 - 1.25 / 10	Operate As-is
10-IA-5	SS. Pipe+ Cast SS. Valve	24	1.20	0 - 2 / 5	Operate As-is
				22 - 24 / 10	
				56 - 64 / 5-10	

+ Side of Indication

TABLE A.1 Recirculation and RHR Piping Weld Indications Loop A (Continued)

Weld Ident.	Weld Type	Pipe Size (in.)	Measured Wall Thk. (in.)	Crack Indications Length / Depth (in. / %.)	Disposition
10-IA-7	SS. Elbow SS. Pipe+	24	1.15	1.125-2.25 / 5-10	Operate As-is
2-AS-02	SS. Pipe+	28	1.15	0 - 3 / 30-35 75 - 80 / 30-35 86 - 89 / 30-35	Overlay
	SS. Safe End+		1.25	6 - 20 / 30-35 28 - 32 / 30-35 63 - 80 / 30-35 85 - 89 / 30-35	
2-AS-03	SS. Pipe+	28	1.15	7 - 12 / 25 18 - 19 / 30 36 - 40 / 30 47 - 62 / 35 70 - 83 / 35-40 88 - 89 / 20	Overlay
	SS. Elbow+		1.20	2 - 10 / 40 75 - 86 / 40	
2-AS-04	SS. Elbow+	28	1.25	5 - 13 / 40-45 34 - 38 / 40 47 - 54 / 25 67 - 88 / 25-40	Overlay
	SS. Pipe+		1.125	0 / 25 17 / 30 25 / 30 44 / 35 53 - 57 / 35 67 - 75 / 25-40	
2-AS-07	SS. Pipe SS. Elbow+	28	1.30	4 - 30 / 20-35 47 - 49 / 20 61 - 85 / 15-30	Overlay

+ Side of Indication
* Nominal Thickness, Not Measured

TABLE A.1 Recirculation and RHR Piping Weld Indications Loop A
(Continued)

Weld Ident.	Weld Type	Pipe Size (in.)	Measured Wall Thk. (in.)	Crack Indications Length / Depth (in. / %)	Disposition
2-AS-08	SS. Elbow+ Cast SS. Valve	28	1.138*	0 - 4 / 20	Operate As Is
				18 - 40 / 20-40	
				54 - 58 / 20-35	
				74 - 78 / 20	
				88 - 90 / 20	
2-AS-10	SS. Pipe+	28	1.138*	11 - 16 / 20-25	Weld Overlay
				22 - 40 / 15-40	
				46 - 55 / 30	
				58 - 72 / 30-35	
				77 - 84 / 30	
	SS. Elbow+			0 - 50 / 20-35	
				54 - 58 / 20	
				62 / 20-30	
				67 / 20-30	
				70 / 20-30	
				76 - 88 / 15-35	
2-AS-11	SS. Elbow+ Cast SS. Pump Casing	28	1.30	0 - 14 / 20	Weld Overlay
				16 - 20 / 30	
				35 - 41 / 30	
				44 - 50 / 35	
				53 - 54 / 20	
				57 - 60 / 35	
				71 - 76 / 30	
				86 - 90 / 35	
2-AD-14	SS. Elbow+ Cast SS. Valve	28	1.45	42 - 48 / 20	Operate As-is

+ Side of Indication
* Nominal Thickness, Not Measured

TABLE A.2 Recirculation and RHR Piping Weld Indications Loop B

Weld Ident.	Weld Type	Pipe Size (in.)	Measured Wall Thk. (in.)	Crack Indications Length / Depth (in. / %.)	Disposition
2-BHA-4	SS. Pipe+ SS. Safe End	12	0.80	0 - 1 / 10-15 4 - 7 / 10-15 21 - 29 / 5-10 33 - 40 / 10-35	Weld Overlay
2-BHB-4	SS. Pipe+ SS. Safe End	12	0.825	8 - 11 / 18-20 17 - 19 / 25-35	Weld Overlay
2-BHC-4	SS. Pipe+ SS. Safe End	12	0.85	17 - 20 / 15-20 24 - 26 / 15-20	Operate As-is
10-IB-3	SS. Elbow+ SS. Penet.	24	1.5	57 - 59 / 18-20 69 - 71 / 15-20	Operate As-is
10-IB-4	SS. Pipe SS. Elbow+	24	1.24	16 - 25 / 40-50 25 - 26.5 / 20 26 - 28 / 35-40 28 - 36 /<20 36 - 40 /<20 47 - 48 / 20	Weld Overlay
10-IB-6	SS. Pipe+ Cast SS. Valve	24	1.25	34.5- 36 / 5-10 62 - 66.5 / 5-10	Operate As-is
10-IB-7	SS. Elbow SS. Pipe+	24	1.20	9 - 13 / 10	Operate As-is
10-IB-11	CS. Pipe SS. Elbow+	24	1.5	59 - 68 / 35	Weld Overlay

+ Side of Indication

TABLE A.2 Recirculation and RHR Piping Weld Indications Loop B
(Continued)

Weld Ident.	Weld Type	Pipe Size (in.)	Measured Wall Thk. (in.)	Crack Indications Length / Depth (in. / %.)	Disposition
2-BS-02	SS. Pipe+	28	1.20	0 - 30 / 35-40	Weld Overlay
				41 - 50 / 25-40	
				60 - 75 / 55	
				85 - 90 / 40	
	SS. Safe End+		1.25	13 - 27 / 40-60	
				35 - 50 / 50-70	
				60 - 70 / 50-57	
				82 - 90 / 25	
2-BS-03	SS. Pipe+	28	1.15	0 - 25 / 20-40	Weld Overlay
				63 - 65 / 15	
				73 - 75 / 15	
				82 - 90 / 10-15	
	SS. Elbow+		1.25	0 - 32 / 25-45	
				70 - 73 / 25	
				77 - 80 / 30	
				85 - 90 / 25	
2-BS-08	SS. Pipe+	28	1.138*	16 - 19 / 20	Weld Overlay
	Cast SS. Valve			22 - 31 / 15-30	
				43.5 - 60.5 / 15-30	
				63 - 70 / 15-30	
				72 - 79 / 15-20	
				81 - 85 / 15-35	
2-BS-09	SS. Pipe+	28	1.15	4 - 27 / 10-30	Weld Overlay
				28 / 20	
				40 - 45 / 20-25	
				52 - 54 / 10-25	
				59 - 67 / 10-25	
				73 - 83 / 10-25	
				85 - 89 / 10-30	
	SS. Elbow+		1.25	3 - 16 / 10-30	
				18 - 44 / 10-30	
				47 - 50 / 10-25	
				57 - 58 / 10-25	
				67 - 86 / 10-40	

+ Side of Indication
* Nominal Thickness, Not Measured

TABLE A.2 Recirculation and RHR Piping Weld Indications Loop B (Continued)

Weld Ident.	Weld Type	Pipe Size (in.)	Measured Wall Thk. (in.)	Crack Indications Length / Depth (in. / %.)	Disposition
2-BD-11	SS. Pipe+ Cast SS. Pipe	28	1.3	0 - 2 / 19-20	Operate As-is
				5 - 6 / 15-20	
				9 - 11 / 20-30	
				14 - 17 / 19-20	
				19 - 21 / 20-30	
				25 - 30 / 12-20	
				35 - 39 / 12	
				50 - 54 / 15-30	
				56 - 59 / 20-30	
				88 - 89 / 19-20	
2-BD-12	SS. Pipe+ Cast SS. Valve	28	1.138*	3 - 11 / 20-30	Operate As-is
				16 - 17 / 25-30	
				22 - 25 / 20	
				35 - 41 / 5	
				46 - 60 / 20-25	
				63 - 68 / 20-30	
				75 - 81 / 20	

\+ Side of Indication
* Nominal Thickness, Not Measured

APPENDIX B Flaw Evaluation Results

This appendix contains the results of the Peach Bottom Unit 3 fracture mechanics analyses for the flaws that were acceptable to operate as-is.

B.1 Stresses

The applied stresses consisted of the pressure, thermal expansion, dead weight and shrinkage stress. In addition, one of the following two residual stress distribution assumptions were used:

Large diameter (>20 inches) pipe weld residual stress applies to large diameter pipes that are not treated with Induction Heating Stress Improvement (IHSI).

No credit was taken for the favorable compressive stresses in pipes that are IHSI treated. However, it was assumed that the pipe was free from the pipe weld residual stress after IHSI.

B.2 Assumptions

The crack was conservatively assumed to have an initial depth equal to the maximum reported depth and length equal to the sum of the individual lengths. In addition welds 2-AS-8 and 2-BD-12 were analyzed using the average depth since the measured maximum depths were highly localized peaks (or cusps) at separate locations.

A crack growth evaluation was performed for each crack indication and compared to the following criteria.

B.3 Criteria

The limits for each criterion are based on pressure and piping stresses calculated for each weld.

The first criterion was that the crack should not exceed the limit for net section collapse using a safety factor of 3.0.

The second criterion was that the crack should not exceed 2/3 of the limits for depth and length provided in the ASME Code Section XI, Paragraph IWB-3640.

The last criterion was that the crack should not exceed the limit on allowable flaw size, proposed for the ASME Code Section XI in Table IWB-3641-5, for a specific stress ratio.

B.4 Results

Based on the evaluations, operation as-is is acceptable for the following twelve welds. As shown in these figures, the analyses demonstrate compliance with the requirements of the NRC Generic Letter 84-11 as well as the newly developed acceptance criteria for flux weldments.

CONTENTS

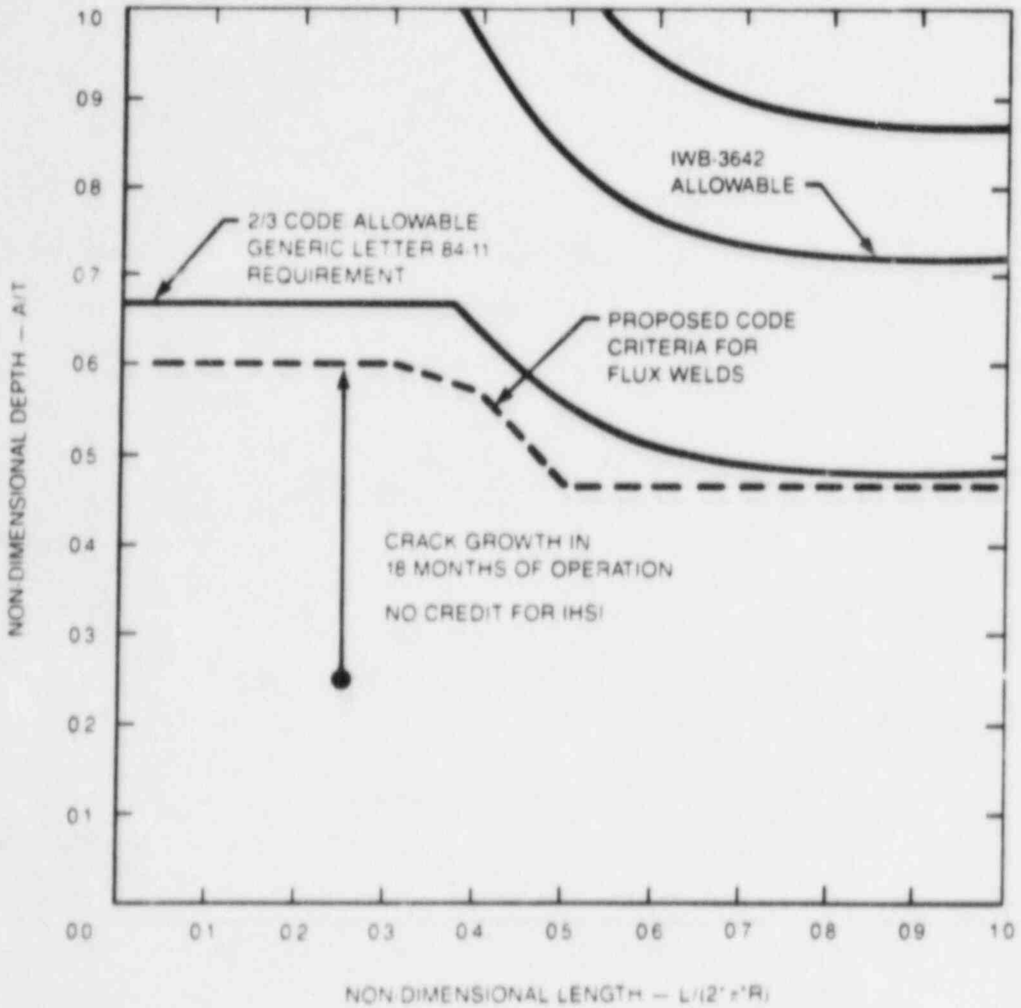


Figure B.1 Flaw Acceptance Diagram for Weld 10-O-03 No Credit for IHSI

APPLIED STRESS FOR WELD 10-0-3

MEMBRANE_STRESS:

Pressure	=	6.3 ksi
Thermal Expansion	=	5.6 ksi
Dead Weight	=	0.3 ksi
Shrinkage	=	2.0 ksi

BENDING_STRESS:

No Residual Stress

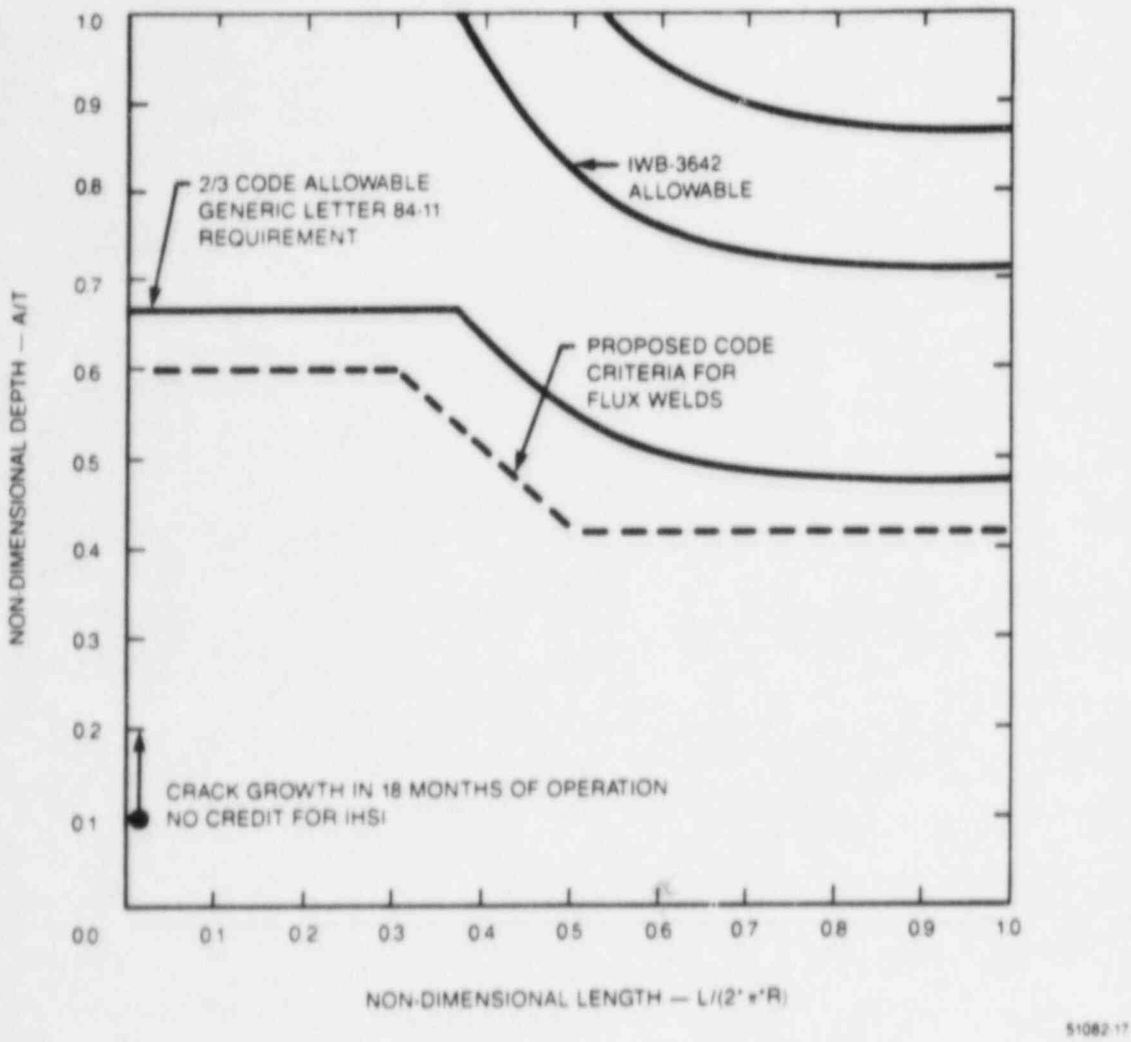


*Figure B.2 Flaw Acceptance Diagram for Weld 10-IA-4
No Credit for IHSI*

APPLIED STRESS FOR WELD 10-IA-4

MEMBRANE_STRESS:

Pressure	= 6.5 ksi
Thermal Expansion	= 9.3 ksi
Dead Weight	= 0.2 ksi
Shrinkage	= 0.0 ksi

BENDING_STRESS:

No Residual Stress

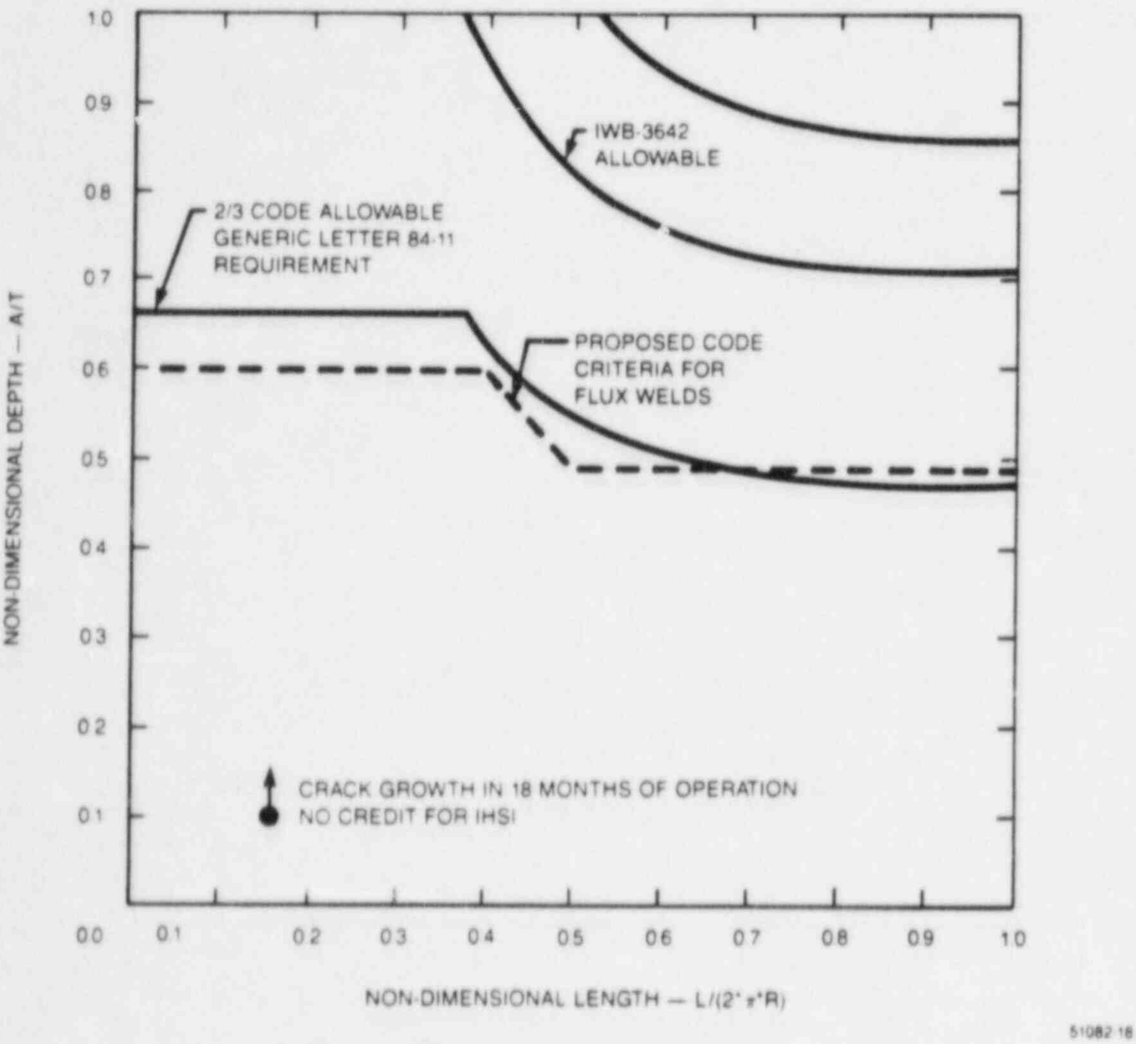


Figure B.3 Flaw Acceptance Diagram for Weld 10-IA-5 No Credit for IHSI

APPLIED STRESS FOR WELD 10-IA-5

MEMBRANE_STRESS:

Pressure = 6.5 ksi

Thermal Expansion = 5.6 ksi

Dead Weight = 0.2 ksi

Shrinkage = 0.0 ksi

BENDING_STRESS:

No Residual Stress

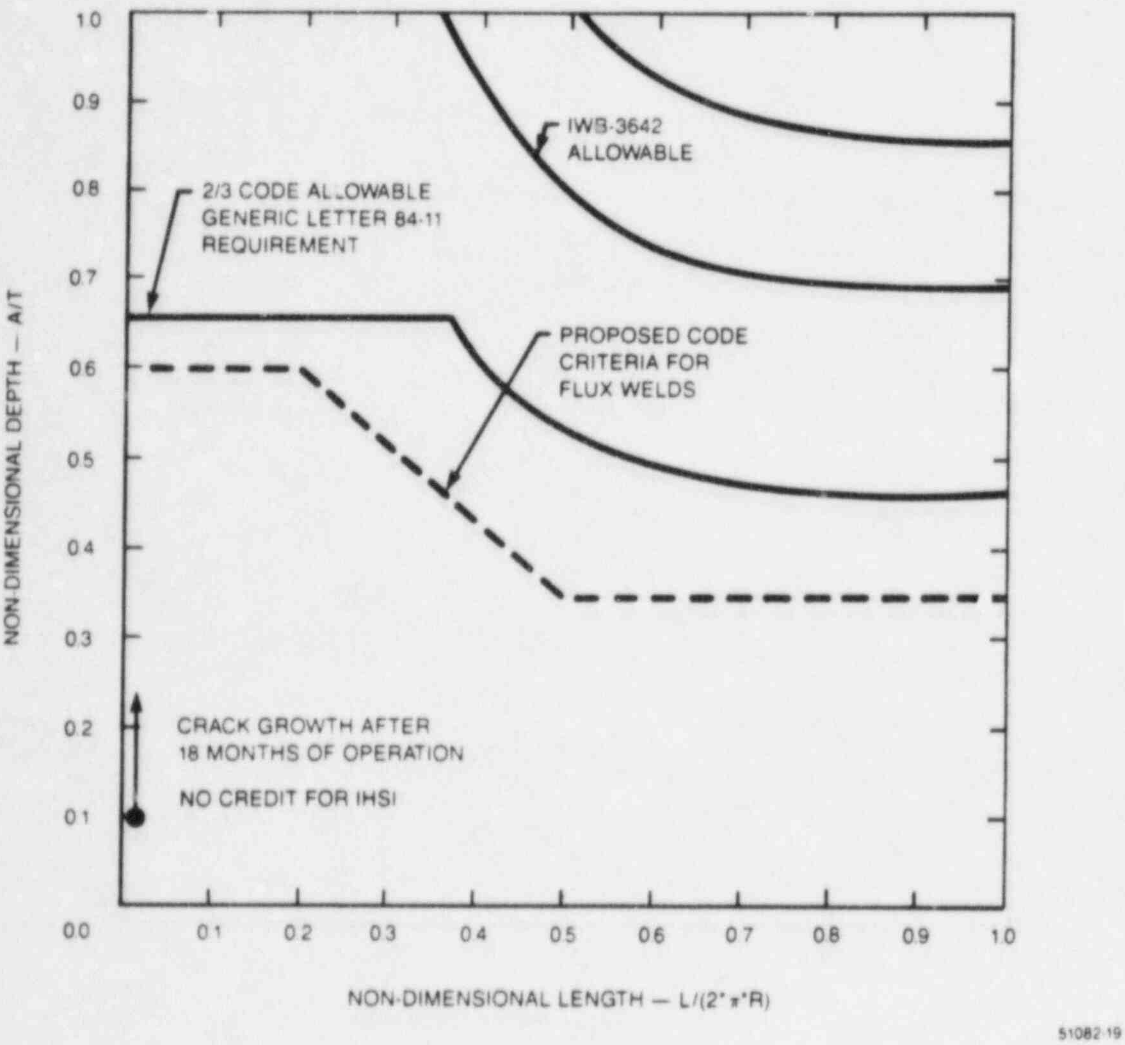


Figure B.4 Flaw Acceptance Diagram for Weld 10-IA-7
No Credit for IHSI

APPLIED STRESS FOR WELD 10-IA-7

MEMBRANE_STRESS:

Pressure = 6.8 ksi

Thermal Expansion =10.7 ksi

Dead Weight = 0.2 ksi

Shrinkage = 0.0 ksi

BENDING_STRESS:

No Residual Stress

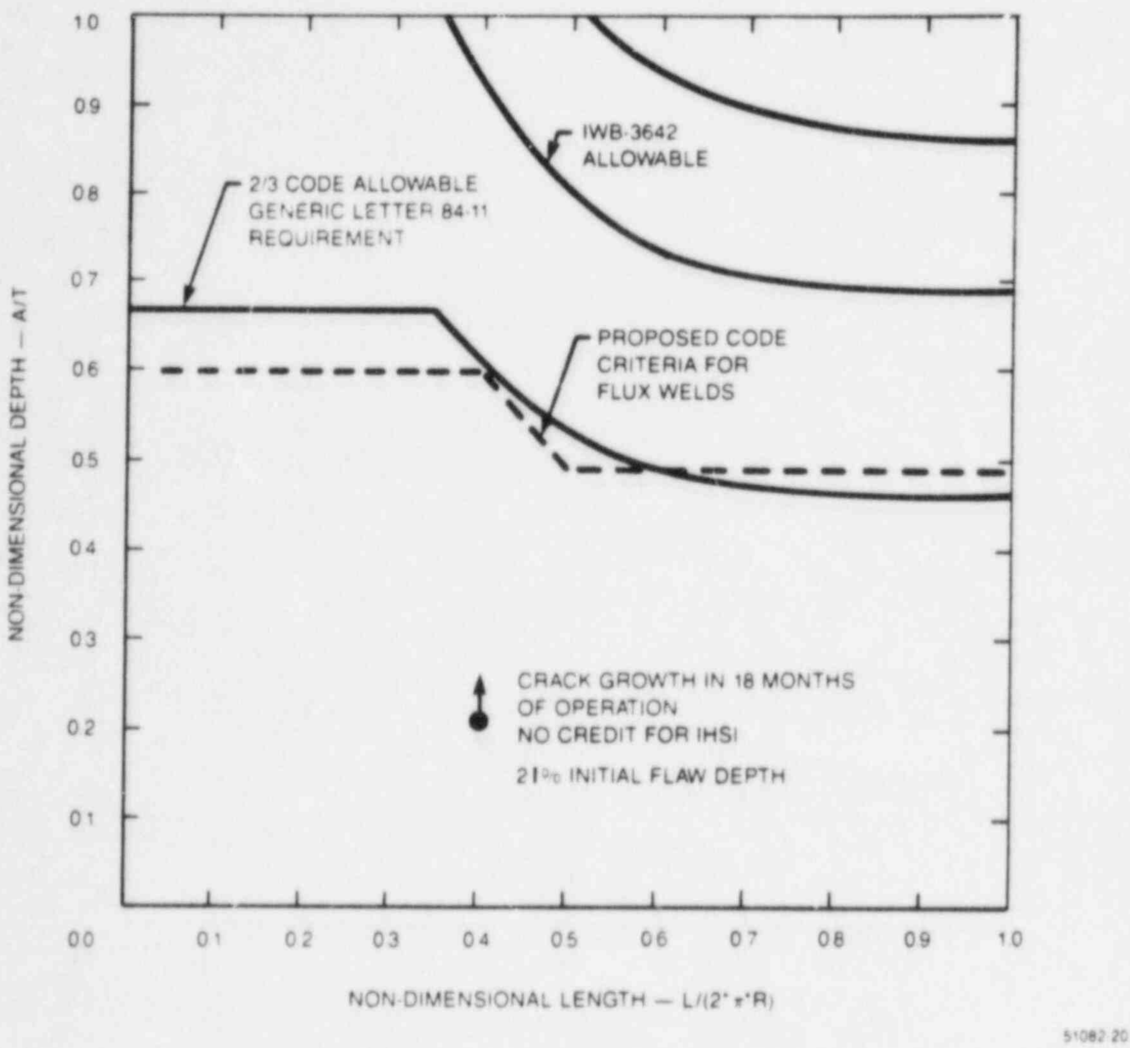


Figure B.5 Flaw Acceptance Diagram for Weld 2-AS-8
No Credit for IHSI-Assuming Average Flaw Depth

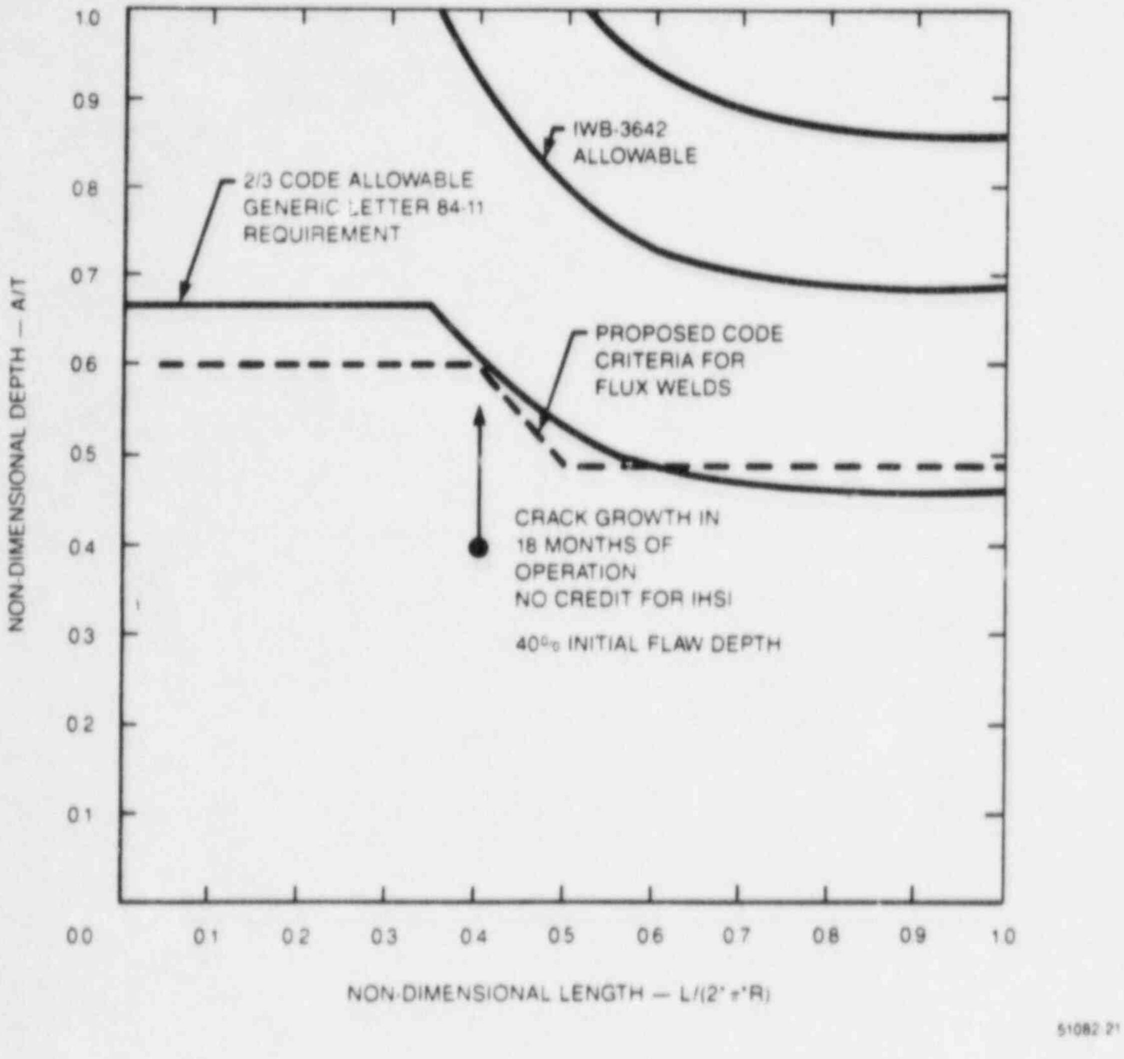


*Figure B.6 Flaw Acceptance Diagram for Weld 2-AS-8
No Credit for IHSI-Assuming Maximum Flaw Depth*

APPLIED STRESS FOR WELD 2-AS-8

MEMBRANE_STRESS:

Pressure	= 6.5 ksi
Thermal Expansion	= 1.0 ksi
Dead Weight	= 0.4 ksi
Shrinkage	= 0.1 ksi

BENDING_STRESS:

No Residual Stress

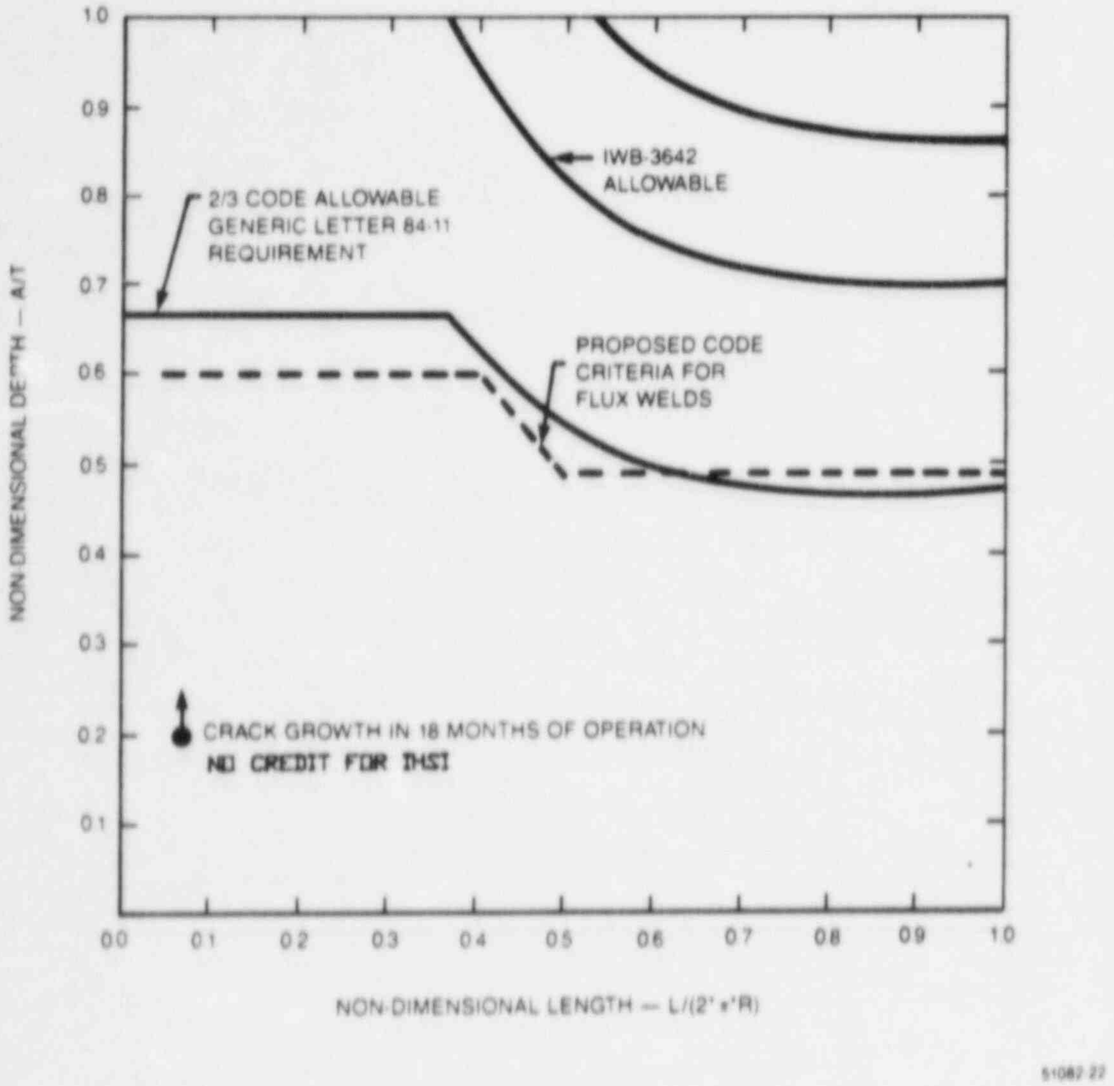


Figure B.7 Flaw Acceptance Diagram for Weld 2-AD-14 No Credit for IHSI

APPLIED STRESS FOR WELD 2-AD-14

MEMBRANE_STRESS:

Pressure = 6.3 ksi

Thermal Expansion = 0.9 ksi

Dead Weight = 0.7 ksi

Shrinkage = 0.7 ksi

BENDING_STRESS:

No Residual Stress

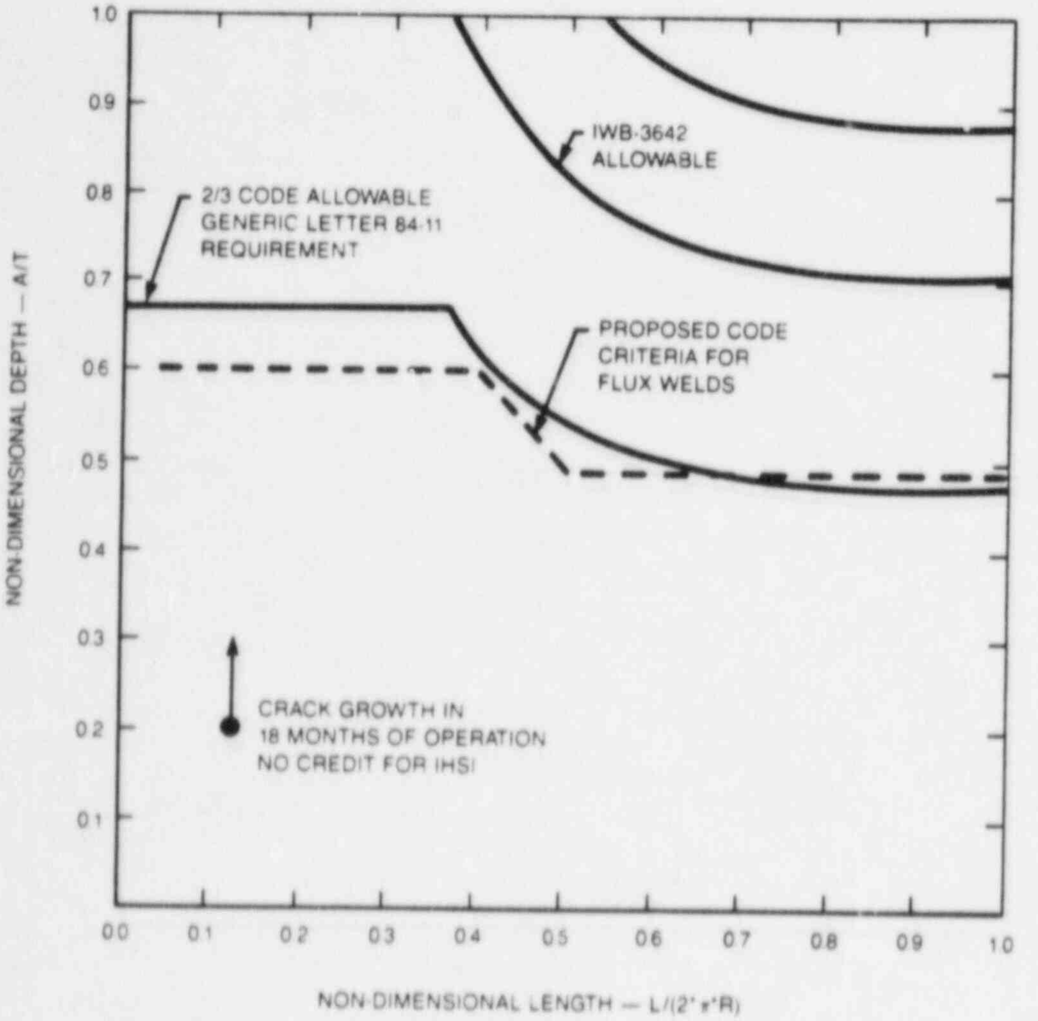


Figure B.8 Flaw Acceptance Diagram for Weld 2-BHC-4 No Credit for IHSI

APPLIED STRESS FOR WELD 2-BHC-4

MEMBRANE_STRESS:

Pressure = 4.6 ksi

Thermal Expansion = 4.2 ksi

Dead Weight = 2.3 ksi

Shrinkage = 0.4 ksi

BENDING_STRESS:

No Residual Stress

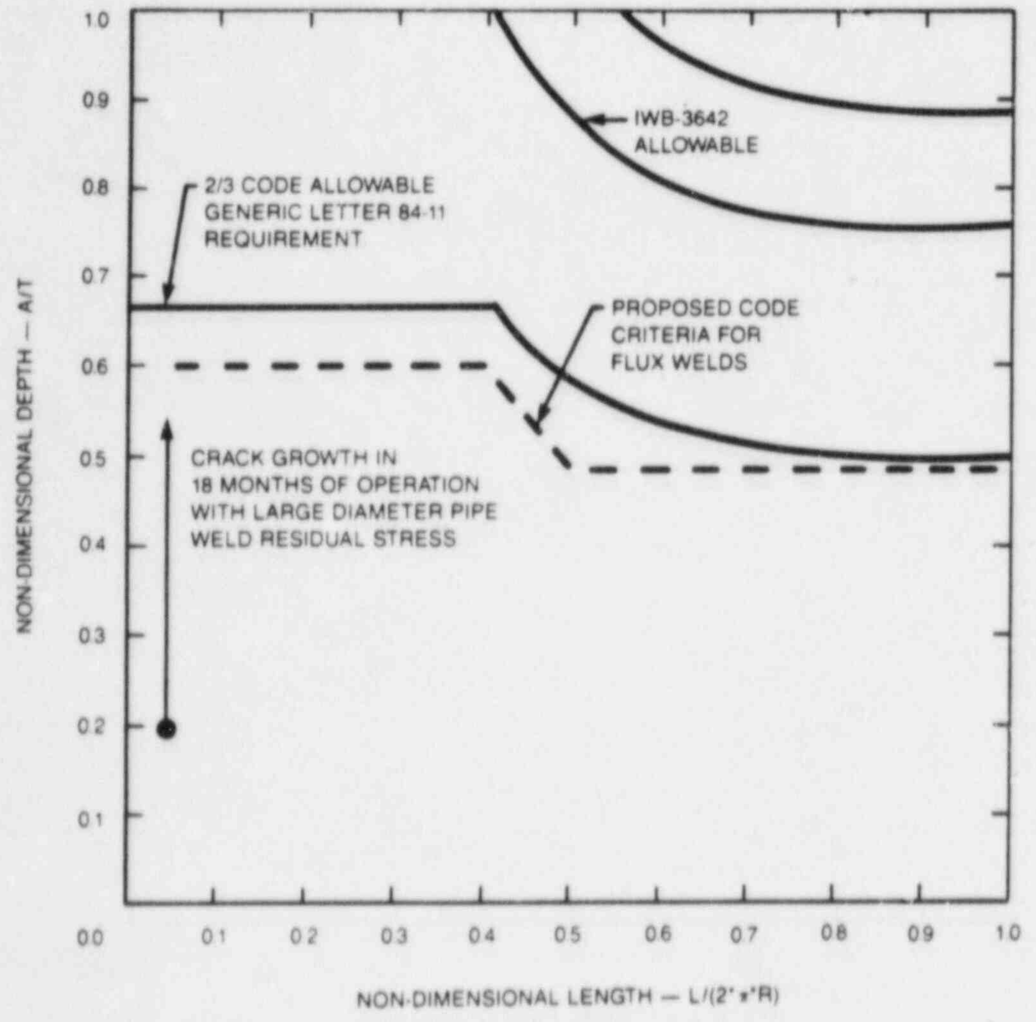


Figure B.9 Flaw Acceptance Diagram for Weld 10-IB-3 Large Diameter Pipe Weld Residual Stress

APPLIED STRESS FOR WELD 10-IB-3

MEMBRANE_STRESS:

Pressure = 5.2 ksi

Thermal Expansion = 6.7 ksi

Dead Weight = 0.1 ksi

Shrinkage = 1.7 ksi

BENDING_STRESS:

Large Diameter Pipe Weld Residual Stress

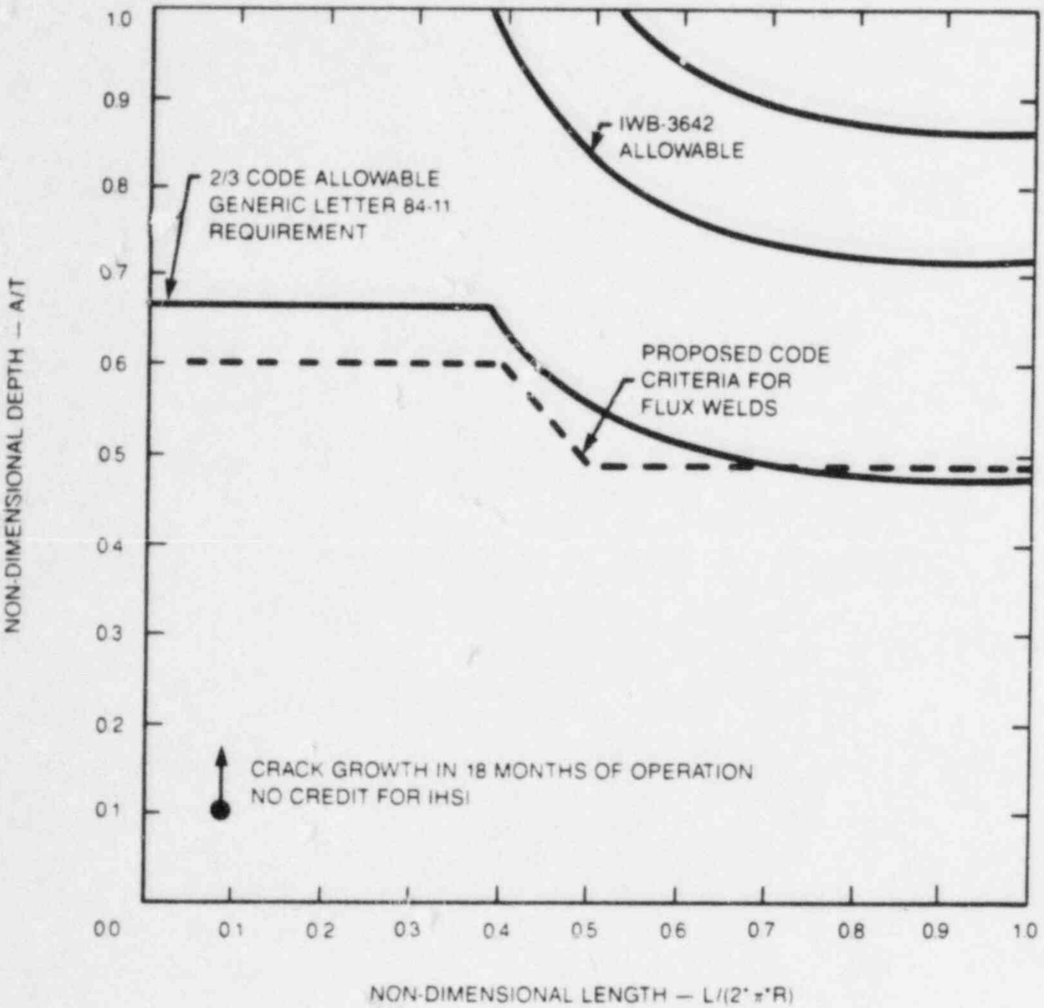


Figure B.10 Flaw Acceptance Diagram for Weld 10-IB-6
No Credit for IHSI

APPLIED STRESS FOR WELD 10-IB-6

MEMBRANE_STRESS:

Pressure = 6.2 ksi

Thermal Expansion = 5.1 ksi

Dead Weight = 0.4 ksi

Shrinkage = 2.7 ksi

BENDING_STRESS:

No Residual Stress

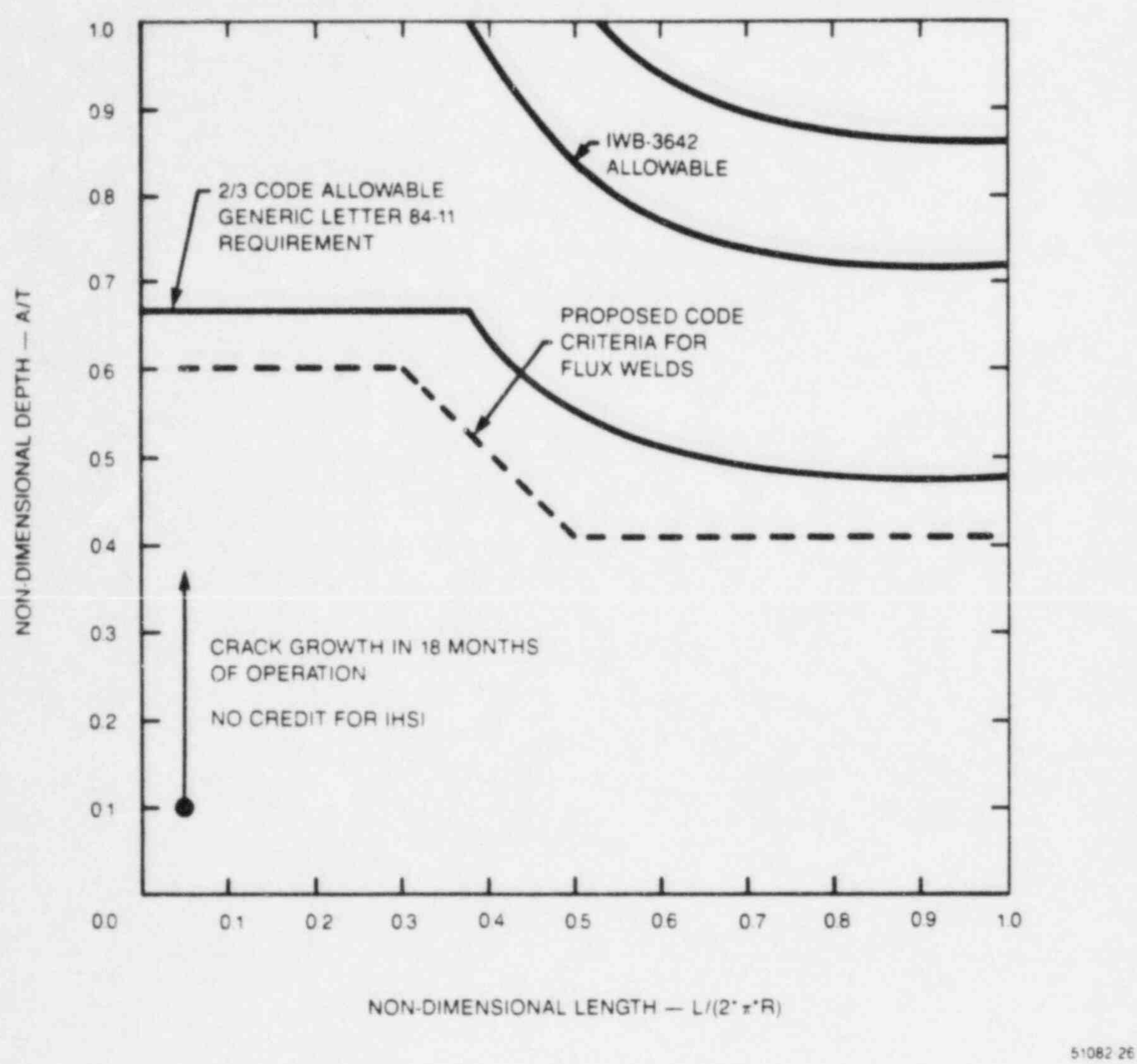


Figure B.11 Flaw Acceptance Diagram for Weld 10-IB-7
No Credit for IHSI

APPLIED STRESS FOR WELD 10-IB-7

MEMBRANE_STRESS:

Pressure	=	6.5 ksi
Thermal Expansion	=	10.4 ksi
Dead Weight	=	0.2 ksi
Shrinkage	=	4.2 ksi

BENDING_STRESS:

No Residual Stress

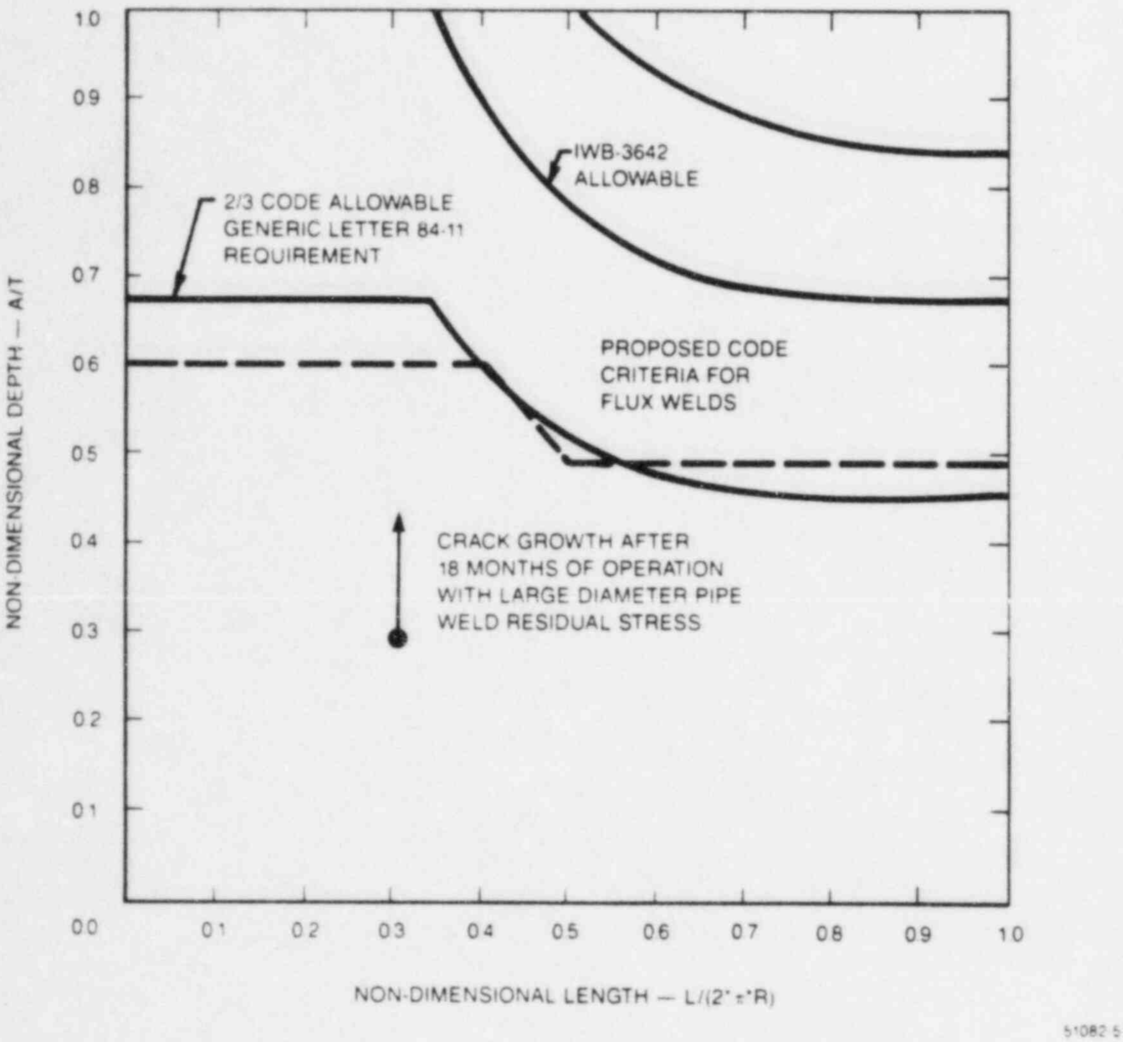


Figure B.12 Flaw Acceptance Diagram for Weld 2-BD-11 Large Diameter Pipe Weld Residual Stress

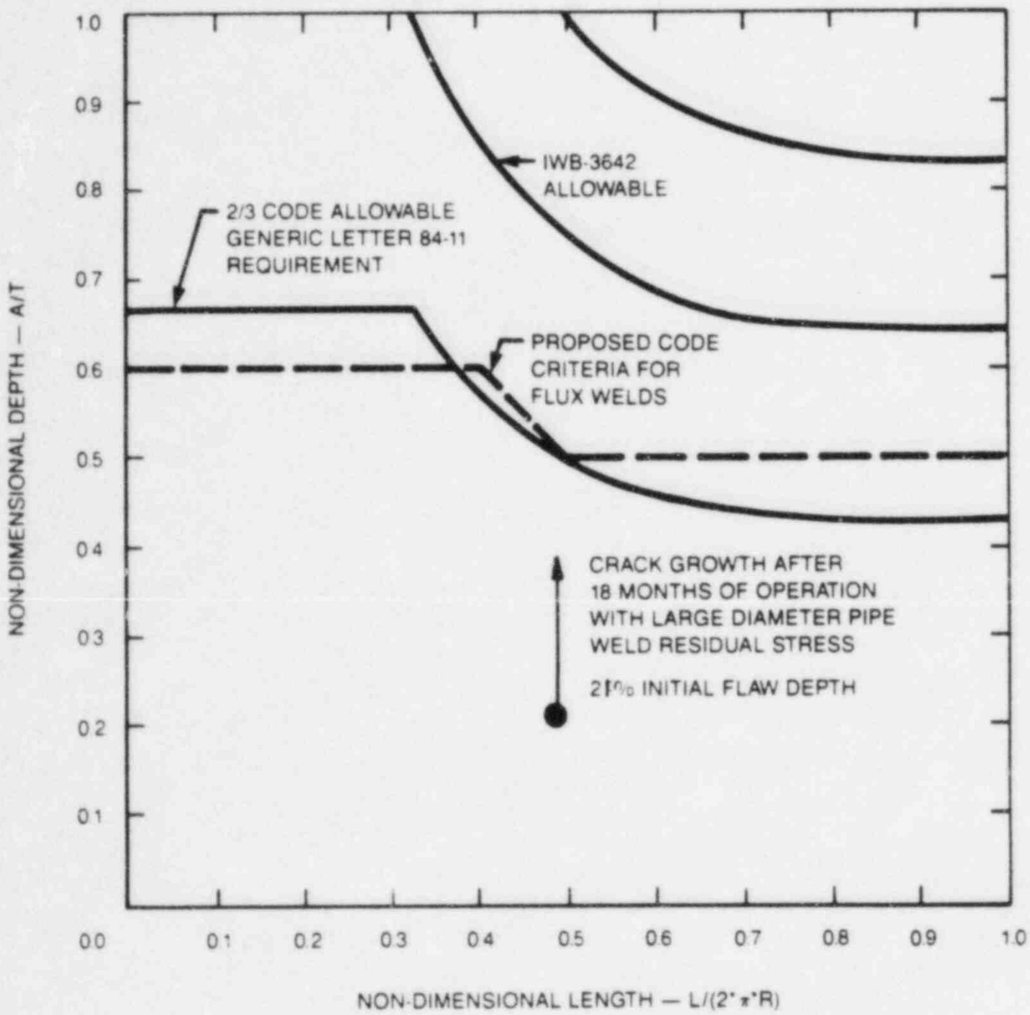
APPLIED STRESS FOR WELD 2-BD-11

MEMBRANE_STRESS:

Pressure	= 7.0 ksi
Thermal Expansion	= 0.6 ksi
Dead Weight	= 0.3 ksi
Shrinkage	= 1.3 ksi

BENDING_STRESS:

Large Diameter Pipe Weld Residual Stress



51082-6

Figure B.13 Flaw Acceptance Diagram for Weld 2-BD-12 Large Diameter Pipe Weld Residual Stress Assuming Average Flaw Depth

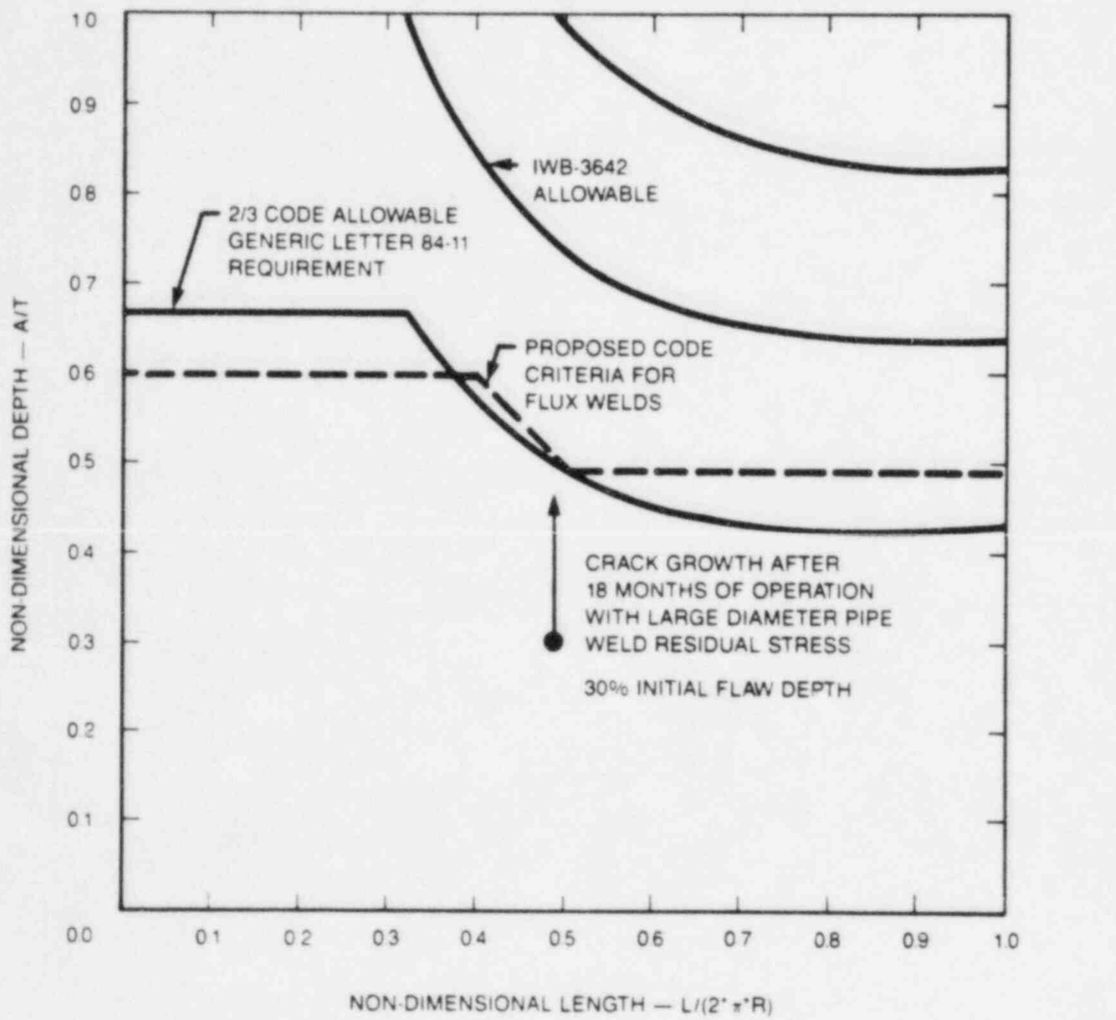


Figure B.14 Flaw Acceptance Diagram for Weld 2-BD-12 Large Diameter Pipe Weld Residual Stress Assuming Maximum Flaw Depth

APPLIED STRESS FOR WELD 2-BD-12

MEMBRANE_STRESS:

Pressure = 8.0 ksi

Thermal Expansion = 0.7 ksi

Dead Weight = 0.3 ksi

Shrinkage = 1.0 ksi

BENDING_STRESS:

Large Diameter Pipe Weld Residual Stress

APPENDIX C Weld Overlay Designs

This appendix contains the details of the Peach Bottom Unit 3 weld overlay designs for the flaws that required repair.

C.1 Process

The weld overlay designs consist of a continuous 360° band of weld metal applied to the outside surface of the pipe directly above the crack indication. The overlay weld metal is Type 308L stainless steel containing low carbon and high ferrite. This material is resistant to Intergranular Stress Corrosion Cracking (IGSCC).

C.2 Assumptions

Due to the conservative assumption of a through wall fully circumferential flaw, the weld overlay thickness is independent of flaw size. Therefore, uncertainty in flaw sizing does not influence the weld overlay design.

The overlay is designed to provide full structural reinforcement while maintaining the ASME Code intended safety margins. This design has been termed the Type I full structural overlay. Also, no credit is taken for the beneficial compressive residual stress induced by the heat sink (water cooled) weld overlay process that would reduce crack growth through the thickness.

C.3 Results

The specific overlay design for each weld was based on consideration of such factors as:

- Weld crown geometry,
- proximity to other welds, valves, and carbon steel pipes, and
- ultrasonic testing requirements for better in-service inspection.

In accordance with the requirements of the NRC Generic Letter 84-11, the overlay design thickness includes material deposited after the first layer (or layers) that pass liquid penetrant examination requirements.

The weld overlay designs provide conservative safety margins for a typical Type I full structural overlay and are acceptable for at least 18 months of continued operation.

CONTENTS

WELD ID: PB3 WELD 2-AHJ-4

PIPE THICKNESS = 0.80 INCH
PIPE DIAMETER = 12.75 INCH

PRIMARY LOADS (STRESS):
PRESSURE = 5.18 KSI
DEAD WEIGHT = 2.20 KSI
SEISMIC = 0.80 KSI

WOT	T / (T+WOT)	PM (KSI)	PB (KSI) ACTUAL	PB (KSI) CALC	(PM+PB)/SM (ACTUAL)	(PM+PB)/3SM (CALC)
0.245	0.766	4.118	2.297	15.147	0.380	0.380

PRIMARY STRESS RATIOS (ADJUSTED):
PM/SM = 0.244
(PM+PB)/SM = 0.380

MINIMUM REQUIRED WELD OVERLAY THICKNESS = 0.245 INCH
MINIMUM REQUIRED WELD OVERLAY WIDTH = 2.3 INCH

WELD ID: PB3 WELD 10-0-1A

PIPE THICKNESS = 0.82 INCH
PIPE DIAMETER = 20.00 INCH

PRIMARY LOADS (STRESS):
PRESSURE = 6.40 KSI
DEAD WEIGHT = 0.43 KSI
SEISMIC = 1.11 KSI

WOT	T / (T+WOT)	PM (KSI)	PB (KSI) ACTUAL	PB (KSI) CALC	(PM+PB)/SM (ACTUAL)	(PM+PB)/3SM (CALC)
0.255	0.763	5.008	1.175	13.749	0.366	0.370

PRIMARY STRESS RATIOS (ADJUSTED):
PM/SM = 0.296
(PM+PB)/SM = 0.366

MINIMUM REQUIRED WELD OVERLAY THICKNESS = 0.255 INCH
MINIMUM REQUIRED WELD OVERLAY WIDTH = 2.9 INCH

WELD ID: PB3 WELD 10-0-1B

PIPE THICKNESS = 0.76 INCH
PIPE DIAMETER = 20.00 INCH

PRIMARY LOADS (STRESS):
PRESSURE = 6.91 KSI
DEAD WEIGHT = 0.46 KSI
SEISMIC = 1.19 KSI

WOT	I / T+WOT	PM (KSI)	PB (KSI) ACTUAL	PB (KSI) CALC	PM+PB / SM (ACTUAL)	PM+PB / 3SM (CALC)
0.255	0.749	5.304	1.235	14.533	0.387	0.391

PRIMARY STRESS RATIOS (ADJUSTED):
PM/SM = 0.314
(PM+PB)/SM = 0.387

MINIMUM REQUIRED WELD OVERLAY THICKNESS = 0.255 INCH
MINIMUM REQUIRED WELD OVERLAY WIDTH = 2.8 INCH

WELD ID: PB3 WELD 10-0-02

PIPE THICKNESS = 0.80 INCH
PIPE DIAMETER = 20.00 INCH

PRIMARY LOADS (STRESS):
PRESSURE = 6.56 KSI
DEAD WEIGHT = 0.40 KSI
SEISMIC = 1.10 KSI

WOT	I / T+WOT	PM (KSI)	PB (KSI) ACTUAL	PB (KSI) CALC	PM+PB / SM (ACTUAL)	PM+PB / 3SM (CALC)
0.255	0.758	5.103	1.137	14.001	0.369	0.377

PRIMARY STRESS RATIOS (ADJUSTED):
PM/SM = 0.302
(PM+PB)/SM = 0.369

MINIMUM REQUIRED WELD OVERLAY THICKNESS = 0.255 INCH
MINIMUM REQUIRED WELD OVERLAY WIDTH = 2.8 INCH

WELD ID: PB3 WELD 2-AS-2

PIPE THICKNESS = 1.15 INCH
PIPE DIAMETER = 28.00 INCH

PRIMARY LOADS (STRESS):
PRESSURE = 6.39 KSI
DEAD WEIGHT = 0.91 KSI
SEISMIC = 1.60 KSI

WOT	T/(T+WOT)	PM (KSI)	PB (KSI) ACTUAL	PB (KSI) CALC	(PM+PB)/SM (ACTUAL)	(PM+PB)/3SM (CALC)
0.390	0.747	4.906	1.874	15.464	0.401	0.402

PRIMARY STRESS RATIOS (ADJUSTED):
PM/SM = 0.290
(PM+PB)/SM = 0.401

MINIMUM REQUIRED WELD OVERLAY THICKNESS = 0.390 INCH
MINIMUM REQUIRED WELD OVERLAY WIDTH = 4.0 INCH

WELD ID: PB3 WELD 2-AS-3

PIPE THICKNESS = 1.15 INCH
PIPE DIAMETER = 28.00 INCH

PRIMARY LOADS (STRESS):
PRESSURE = 6.39 KSI
DEAD WEIGHT = 1.22 KSI
SEISMIC = 1.19 KSI

WOT	T / (T+WOT)	PM (KSI)	PB (KSI) ACTUAL	PB (KSI) CALC	(PM+PB)/SM (ACTUAL)	(PM+PB)/3SM (CALC)
0.390	0.747	4.906	1.800	15.464	0.397	0.402

PRIMARY STRESS RATIOS (ADJUSTED):
PM/SM = 0.290
(PM+PB)/SM = 0.397

MINIMUM REQUIRED WELD OVERLAY THICKNESS = 0.390 INCH
MINIMUM REQUIRED WELD OVERLAY WIDTH = 4.0 INCH

WELD ID: PB3 WELD 2-AS-4

PIPE THICKNESS = 1.13 INCH
PIPE DIAMETER = 28.00 INCH

PRIMARY LOADS (STRESS):

PRESSURE = 6.53 KSI
DEAD WEIGHT = 1.49 KSI
SEISMIC = 1.25 KSI

WOT	T / T+WOT	PM (KSI)	PB (KSI) ACTUAL	PB (KSI) CALC	PM+PB / SM (ACTUAL)	PM+PB / 3SM (CALC)
0.400	0.738	4.957	2.021	16.220	0.413	0.418

PRIMARY STRESS RATIOS (ADJUSTED):

PM/SM = 0.293
(PM+PB)/SM = 0.413

MINIMUM REQUIRED WELD OVERLAY THICKNESS = 0.400 INCH
MINIMUM REQUIRED WELD OVERLAY WIDTH = 4.0 INCH

WELD ID: PB3 WELD 2-AS-7

PIPE THICKNESS = 1.30 INCH
PIPE DIAMETER = 28.00 INCH

PRIMARY LOADS (STRESS):

PRESSURE = 5.65 KSI
DEAD WEIGHT = 0.70 KSI
SEISMIC = 0.60 KSI

WOT	I / T+WOT	PM (KSI)	PB (KSI) ACTUAL	PB (KSI) CALC	PM+PB / SM (ACTUAL)	PM+PB / 3SM (CALC)
0.355	0.785	4.554	1.021	12.425	0.330	0.335

PRIMARY STRESS RATIOS (ADJUSTED):

PM/SM = 0.269
(PM+PB)/SM = 0.330

MINIMUM REQUIRED WELD OVERLAY THICKNESS = 0.355 INCH
MINIMUM REQUIRED WELD OVERLAY WIDTH = 4.3 INCH

WELD ID: PB3 WELD 2-AS-10

PIPE THICKNESS = 1.14 INCH
PIPE DIAMETER = 28.00 INCH

PRIMARY LOADS (STRESS):
PRESSURE = 6.46 KSI
DEAD WEIGHT = 0.61 KSI
SEISMIC = 1.60 KSI

WOT	T / T+WOT	PM (KSI)	PB (KSI) ACTUAL	PB (KSI) CALC	PM+PB / SM (ACTUAL)	PM+PB / 3SM (CALC)
0.380	0.750	4.973	1.657	15.063	0.392	0.395

PRIMARY STRESS RATIOS (ADJUSTED):
PM/SM = 0.294
(PM+PB)/SM = 0.392

MINIMUM REQUIRED WELD OVERLAY THICKNESS = 0.380 INCH
MINIMUM REQUIRED WELD OVERLAY WIDTH = 4.0 INCH

WELD ID: PB3 WELD 2-AS-11

PIPE THICKNESS = 1.30 INCH
PIPE DIAMETER = 28.00 INCH

PRIMARY LOADS (STRESS):
PRESSURE = 5.65 KSI
DEAD WEIGHT = 0.68 KSI
SEISMIC = 1.54 KSI

WOT	I / T+WOT	PM (KSI)	PB (KSI) ACTUAL	PB (KSI) CALC	PM+PB / SM (ACTUAL)	PM+PB / 3SM (CALC)
0.390	0.769	4.470	1.708	14.142	0.366	0.367

PRIMARY STRESS RATIOS (ADJUSTED):
PM/SM = 0.265
(PM+PB)/SM = 0.366

MINIMUM REQUIRED WELD OVERLAY THICKNESS = 0.390 INCH
MINIMUM REQUIRED WELD OVERLAY WIDTH = 4.3 INCH

WELD ID: PB3 WELD 2-BHA-4

PIPE THICKNESS = 0.80 INCH
PIPE DIAMETER = 12.00 INCH

PRIMARY LOADS (STRESS):
PRESSURE = 4.87 KSI
DEAD WEIGHT = 0.60 KSI
SEISMIC = 1.10 KSI

WOT	T / T+WOT	PM (KSI)	PB (KSI) ACTUAL	PB (KSI) CALC	PM+PB / SM (ACTUAL)	PM+PB / 3SM (CALC)
0.205	0.796	4.013	1.353	12.435	0.318	0.324

PRIMARY STRESS RATIOS (ADJUSTED):
PM/SM = 0.237
(PM+PB)/SM = 0.318

MINIMUM REQUIRED WELD OVERLAY THICKNESS = 0.205 INCH
MINIMUM REQUIRED WELD OVERLAY WIDTH = 2.2 INCH

WELD ID: PB3 WELD 2-BHR-4

PIPE THICKNESS = 0.82 INCH
PIPE DIAMETER = 12.00 INCH

PRIMARY LOADS (STRESS):

PRESSURE = 4.73 KSI
DEAD WEIGHT = 0.85 KSI
SEISMIC = 0.70 KSI

WOT	T / T+WOT	PM (KSI)	PB (KSI) ACTUAL	PB (KSI) CALC	PM+PB / SM (ACTUAL)	PM+PB / 3SM (CALC)
0.200	0.805	3.932	1.248	11.733	0.306	0.309

PRIMARY STRESS RATIOS (ADJUSTED):

PM/SM = 0.233
(PM+PB)/SM = 0.306

MINIMUM REQUIRED WELD OVERLAY THICKNESS = 0.200 INCH
MINIMUM REQUIRED WELD OVERLAY WIDTH = 2.2 INCH

WELD ID: PB3 WELD 10-IB-4

PIPE THICKNESS = 1.24 INCH
PIPE DIAMETER = 24.00 INCH

PRIMARY LOADS (STRESS):
PRESSURE = 6.29 KSI
DEAD WEIGHT = 0.22 KSI
SEISMIC = 1.02 KSI

WOT	T / (T+WOT)	PM (KSI)	PB (KSI) ACTUAL	PB (KSI) CALC	(PM+PB)/SM (ACTUAL)	(PM+PB)/3SM (CALC)
0.370	0.770	4.994	0.955	13.067	0.352	0.356

PRIMARY STRESS RATIOS (ADJUSTED):
PM/SM = 0.296
(PM+PB)/SM = 0.352

MINIMUM REQUIRED WELD OVERLAY THICKNESS = 0.370 INCH
MINIMUM REQUIRED WELD OVERLAY WIDTH = 3.9 INCH

WELD ID: PB3 WELD 10-IB-11

PIPE THICKNESS = 1.50 INCH
PIPE DIAMETER = 24.00 INCH

PRIMARY LOADS (STRESS):
PRESSURE = 5.20 KSI
DEAD WEIGHT = 0.09 KSI
SEISMIC = 0.53 KSI

WOT	T / T+WOT	PM (KSI)	PB (KSI) ACTUAL	PB (KSI) CALC	PM+PB / SM (ACTUAL)	PM+PB / 3SM (CALC)
0.350	0.811	4.339	0.504	10.375	0.287	0.290

PRIMARY STRESS RATIOS (ADJUSTED):
PM/SM = 0.257
(PM+PB)/SM = 0.287

MINIMUM REQUIRED WELD OVERLAY THICKNESS = 0.350 INCH
MINIMUM REQUIRED WELD OVERLAY WIDTH = 4.2 INCH

WELD ID: PB3 WELD 2-BS-2

PIPE THICKNESS = 1.20 INCH
PIPE DIAMETER = 28.00 INCH

PRIMARY LOADS (STRESS):
PRESSURE = 6.12 KSI
DEAD WEIGHT = 0.44 KSI
SEISMIC = 0.79 KSI

			PB (KSI)		PM+PB	PM+PB
	I	PM			SM	3SM
WOT	T+WOT	(KSI)	ACTUAL	CALC	(ACTUAL)	(CALC)
0.345	0.777	4.875	0.955	12.666	0.345	0.346

PRIMARY STRESS RATIOS (ADJUSTED):
PM/SM = 0.288
(PM+PB)/SM = 0.345

MINIMUM REQUIRED WELD OVERLAY THICKNESS = 0.345 INCH
MINIMUM REQUIRED WELD OVERLAY WIDTH = 4.1 INCH

WELD ID: PB3 WELD 2-BS-3

PIPE THICKNESS = 1.15 INCH
PIPE DIAMETER = 28.00 INCH

PRIMARY LOADS (STRESS):
PRESSURE = 6.39 KSI
DEAD WEIGHT = 0.45 KSI
SEISMIC = 0.68 KSI

WOT	A / (T+WOT)	PM (KSI)	PB (KSI) ACTUAL	PB (KSI) CALC	(PM+PB)/SM (ACTUAL)	(PM+PB)/3SM (CALC)
0.340	0.772	5.053	0.872	12.799	0.351	0.352

PRIMARY STRESS RATIOS (ADJUSTED):
PM/SM = 0.299
(PM+PB)/SM = 0.351

MINIMUM REQUIRED WELD OVERLAY THICKNESS = 0.340 INCH
MINIMUM REQUIRED WELD OVERLAY WIDTH = 4.0 INCH

WELD ID: PB3 WELD 2-BS-8

PIPE THICKNESS = 1.14 INCH
PIPE DIAMETER = 28.15 INCH

PRIMARY LOADS (STRESS):
PRESSURE = 6.49 KSI
DEAD WEIGHT = 0.33 KSI
SEISMIC = 0.81 KSI

WOT	___I_ T+WOT	PM (KSI)	PB (KSI) ACTUAL	 CALC	_PM+PB SM (ACTUAL)	_PM+PB 3SM (CALC)
0.345	0.767	5.104	0.875	13.130	0.354	0.360

PRIMARY STRESS RATIOS (ADJUSTED):
PM/SM = 0.302
(PM+PB)/SM = 0.354

MINIMUM REQUIRED WELD OVERLAY THICKNESS = 0.345 INCH
MINIMUM REQUIRED WELD OVERLAY WIDTH = 4.0 INCH

WELD ID: PB3 WELD 2-BS-9

PIPE THICKNESS = 1.15 INCH
PIPE DIAMETER = 28.00 INCH

PRIMARY LOADS (STRESS):
PRESSURE = 7.91 KSI
DEAD WEIGHT = 0.37 KSI
SEISMIC = 1.34 KSI

WOT	I / T+WOT	PM (KSI)	PB (KSI) ACTUAL	PB (KSI) CALC	PM+PB / SM (ACTUAL)	PM+PB / 3SM (CALC)
0.435	0.726	5.920	1.241	15.590	0.424	0.424

PRIMARY STRESS RATIOS (ADJUSTED):
PM/SM = 0.350
(PM+PB)/SM = 0.424

MINIMUM REQUIRED WELD OVERLAY THICKNESS = 0.435 INCH
MINIMUM REQUIRED WELD OVERLAY WIDTH = 4.0 INCH

APPENDIX D As-Built Shrinkage Stresses

This appendix contains the results of the final as-built shrinkage analysis.

D.1 Method and Assumptions

The analysis was performed using the piping analysis code, PISYS. The weld overlay shrinkage values are based on the measured shrinkages shown in Table D.1.

D.2 Results

(To be included when shrinkage analysis is completed)