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DESIGN REPORT FOR EVALUATION AND DISPOSITION OF IGSCC FLAWS AT PLANT E. I. HATCH UNIT 1

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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 5-17-85

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Date: May 17, 1985

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1.0 INTRODUCTION

This report summarizes the analyses performed by NUTECH to demonstrate the adequacy of weld overlay repairs and to evaluate unrepaired flaw indications in the Reactor Recirculation and Residual Heat Removal (RHR) systems at Georgia Power Company's Plant E. I. Hatch Unit 1. Ultrasonic (UT) examination of welds in these systems during both the fall 1982 and fall 1984 outages identified flaw indications in a total of 27 welds which were judged to be due to intergranular stress corrosion cracking (IGSCC). All of the flaws are in Type 304 stainless steel material. Tables 1.1 and 1.2 contain a description of each flaw indication as well as its disposition.

Weld overlays were applied to 6 of these welds during the fall 1982 outage and 17 of these welds during the fall 1984 outage. The purpose of each overlay is to arrest any further propagation of the cracking and to restore the required safety margins to the weld.

Flaw evaluations were performed for one weld (1B31-1RC-22AM-1BC-1) during the fall 1982 outage and four welds (including weld 1B31-1RC-22AM-1BC-1) during the fall 1984 outage. The purpose of the evaluations was to

assure that the original design safety margins for these welds has not been reduced, and that the flaws would not grow to an unacceptable size during the next fuel cycle. The evaluations determined that these four welds did not require weld overlay repair. Tables 1.1 and 1.2 contain a description of these flaw indications.

All weld overlays were designed, and all flaws were evaluated in accordance with NRC Generic Letter 84-11 (Reference 1).

Table 1.1

PLANT E. I. HATCH UNIT 1
FLAW DISPOSITION
FALL 1984 OUTAGE

Weld Number	Flaw Description	Overlay Design $t^{(1)}$	Overlay Design L/2
1B31-1RC-12AR-F-2	Circ. 20-30% x 360°	0.23	2.0
1B31-1RC-12AR-F-3	Circ. 20-30% x 360°	0.23	2.0
1B31-1RC-12AR-H-2	Circ. 20-30% x 360°	0.23	2.0
1B31-1RC-12AR-H-3	Circ. 20-30% x 360°	0.23	2.0
1B31-1RC-12AR-K-2	Circ. 30% x 360°	0.23	2.0
1B31-1RC-12AR-K-3	Circ. 30% x 360°	0.23	2.0
1B31-1RC-12AR-J-3	Circ. 20-30% x 360°	0.23	2.0
1B31-1RC-12BR-C-2	Circ. 20-30% x 360°	0.23	2.0
1B31-1RC-12BR-C-3	Circ. 25% x 360°	0.23	2.0
1B31-1RC-12BR-D-3	Circ. 20% x 360°	0.23	2.0
1B31-1RC-12BR-E-2	Circ. 25% x 360°	0.23	2.0
1B31-1RC-12BR-E-3	Circ. 30% x 360°	0.23	2.0
1E11-1RHR-24A-R-13	Axial 50% x 1.75"	two layers	(2)
1B31-1RC-28A-10	Circ. 50% x 360°	0.42	4.25(3)
1B31-1RC-28B-11	Circ. 49% x 360°	0.42	4.25(3)
1B31-1RC-28B-3	Circ. 32% x 360°	0.44	3.0
1B31-1RC-28B-4	Circ. 31% x 360°	0.44	3.0
1B31-1RC-28B-16	Axial 17% x 1"	No Overlay	
1B31-1RC-28A-6	Axial 16% x 0.5"	No Overlay	
1B31-1RC-22AM-1BC-1	Intermittent Circ.; Nom. 11% Spot 18%	No Overlay	
1B31-1RC-22BM-1BC-1	Intermittent Circ.; Max. 29%	No Overlay	

Notes:
1. The effective thickness, t, is exclusive of the thickness of the initial layer.
2. L/2 = C/2 + 0.75" on valve side; L/2 = C/2 + 2.25" on tee side.
3. L/2 = entire overlay length, which is on the elbow side of the groove weld centerline.

Table 1.2

PLANT E. I. HATCH UNIT 1
FLAW DISPOSITION
FALL 1982 OUTAGE

Weld Number	Flaw Description	Overlay Design t	Overlay Design L/2
1B31-1RC-22AM-1	Axial 63% x 1/2"	0.25	*
1B31-1RC-22AM-4	Axial 72% x 1/2"	0.25	*
1B31-1RC-22BM-1	Axial 64% x 1/2"	0.25	*
1B31-1RC-22BM-4	Axial 67% x 1/2"	0.25	*
1E11-1RHR-20B-D-3	Axial 94% x 3/8"	0.4	3.5
	Circ. 33% x 1-1/2"	0.4	3.5
1E11-1RHR-24B-R-13	Axial 47% x 1/2"	0.3	4.0
1B31-1RC-22AM-1BC-1	Transverse 12% x 1/2" Maximum	No Overlay	

* L/2 = 3.0" on pipe side; L/2 = 3.5" on end cap side

2.0 REPAIR DESCRIPTION

The UT flaw indications requiring repair have been remedied by increasing the pipe wall thickness through the deposition of weld metal 360° around and to either side of the existing weld. Elbow-to-pump welds 1B31-1RC-28A-10 and 1B31-1RC-28B-11 were only overlaid on the elbow side of the groove weld centerline, however, to avoid welding on the cast pump casing, which is resistant to IGSCC.

The weld-deposited band provides additional wall thickness to restore the original design safety margin. In addition, the welding process produces a strongly compressive residual stress distribution on the inside portion of the pipe wall which inhibits initiation of new IGSCC flaws. The deposited weld metal is Type 308L with controlled delta ferrite content of 5-20 FN, which is resistant to IGSCC. Design and as-built information for all overlays is presented in Tables 1.1 and 2.1, respectively. Typical overlay designs are shown in Figures 2.1 to 2.7. Note that Figures 2.1 through 2.7 define the overlay taper angle as typically 45°. It has been shown that much larger values are acceptable (Reference 2).

The nondestructive examination of each weld overlay included:

1) Delta ferrite content measurement of the first and final overlay layers, using a Severn gauge.

2) Surface examination of the base material, first overlay layer, and completed weld overlay by the liquid penetrant examination technique in accordance with ASME Section XI (Reference 1).

3) Volumetric examination of the completed weld overlay by the ultrasonic examination technique to demonstrate proper bonding and quality of the applied overlay material.

Table 2.1

WELD OVERLAY AS-BUILT DIMENSIONS

Weld I.D.	As-Built Thickness (1) (Inches)	As-Built Length (Inches)
1B31-1RC-12AR-F-2	0.569	4.0
1B31-1RC-12AR-F-3	0.263	4.0
1B31-1RC-12AR-H-2	0.475	4.0
1B31-1RC-12AR-H-3	0.359	4.25
1B31-1RC-12AR-K-2	0.309	4.625
1B31-1RC-12AR-K-3	0.313	4.25
1B31-1RC-12AR-J-3	0.279	4.188
1B31-1RC-12BR-C-2	0.461	4.0
1B31-1RC-12BR-C-3	0.325	4.0
1B31-1RC-12BR-D-3	0.344	4.125
1B31-1RC-12BR-E-2	0.353	4.0
1B31-1RC-12BR-E-3	0.347	4.0
1E11-1RHR-24A-R-13	0.191	4.0
1B31-1RC-28A-10	0.503	4.5
1B31-1RC-28B-11	0.480	4.625
1B31-1RC-28B-3	0.534	6.0
1B31-1RC-28B-4	0.636	6.125

(1) Not including first overlay layer.

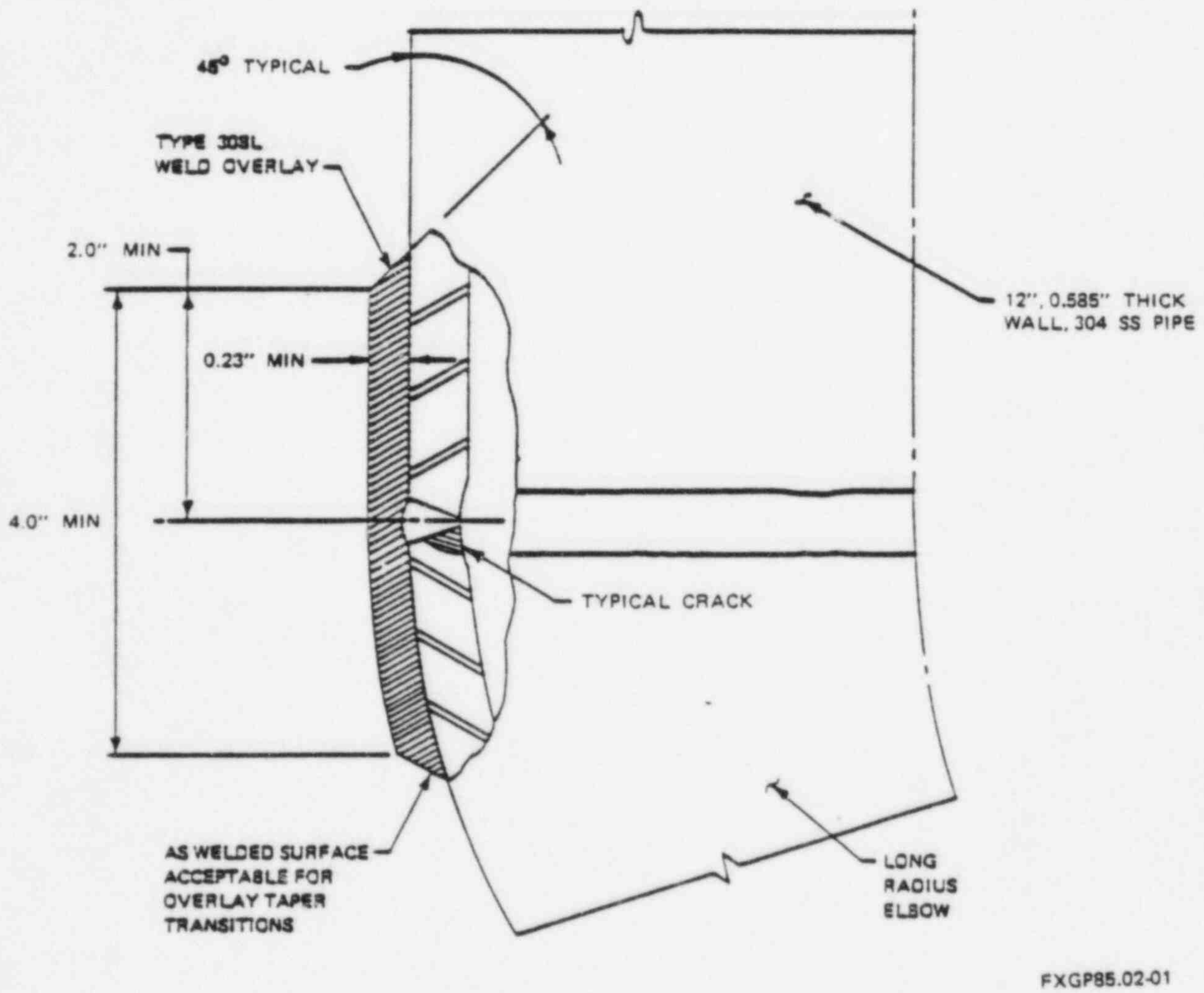

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Figure 2.1
TYPICAL CONFIGURATION OF 12"
ELBOW-TO-PIPE WELD OVERLAY

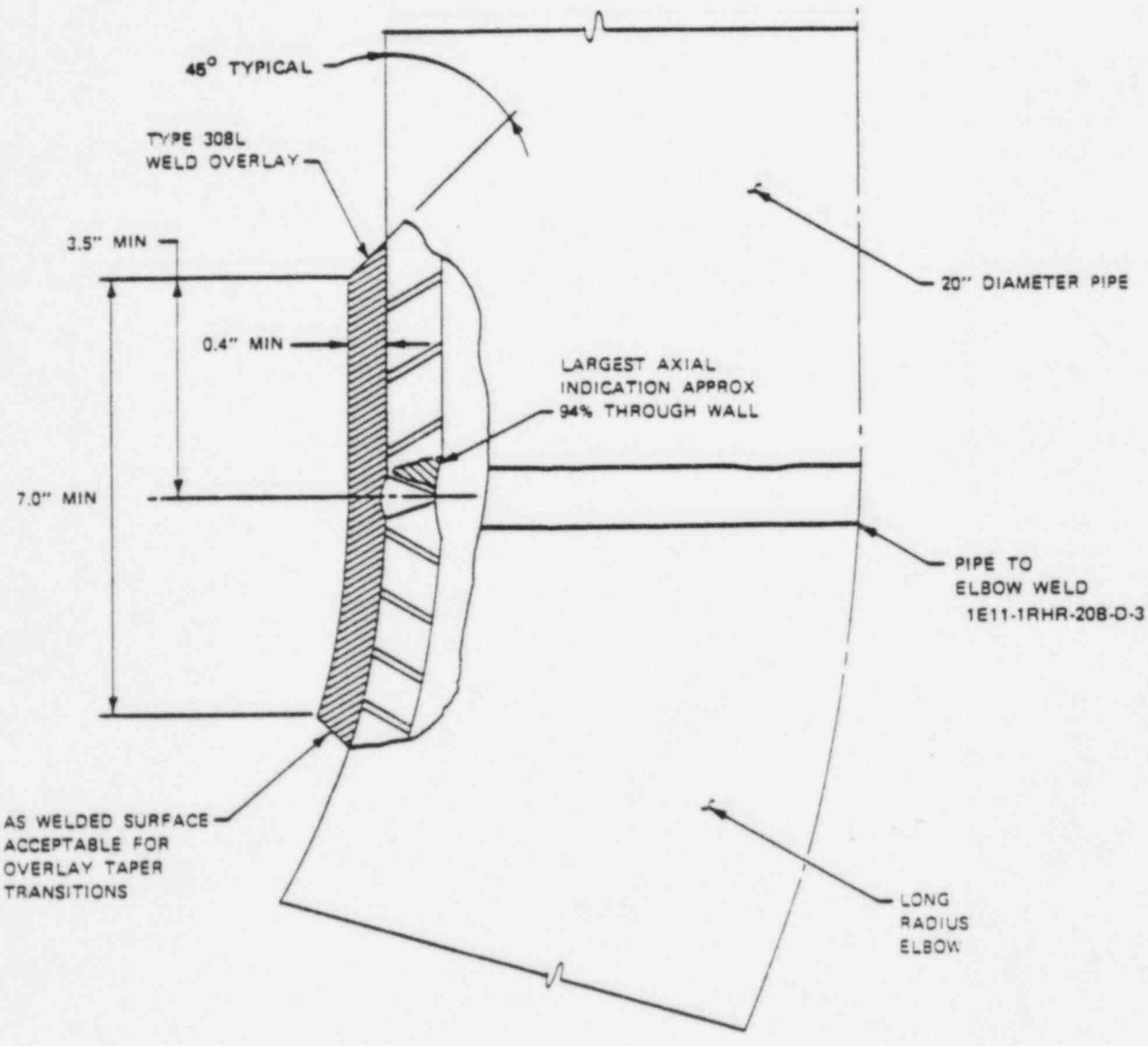

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Figure 2.2

TYPICAL CONFIGURATION OF 20" ELBOW-TO-PIPE
WELD OVERLAY

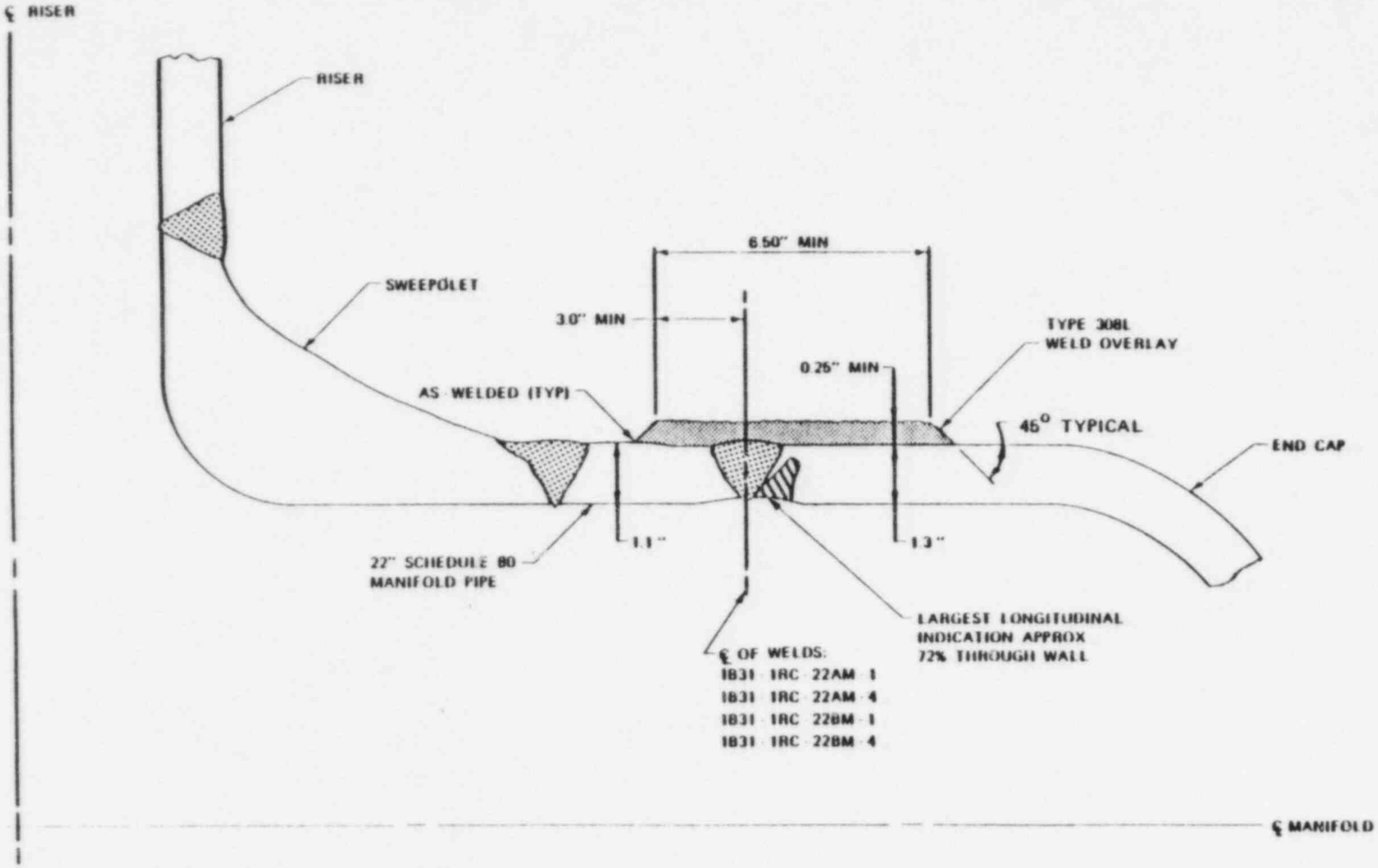

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Figure 2.3

TYPICAL CONFIGURATION OF 22" END CAP
WELD OVERLAY

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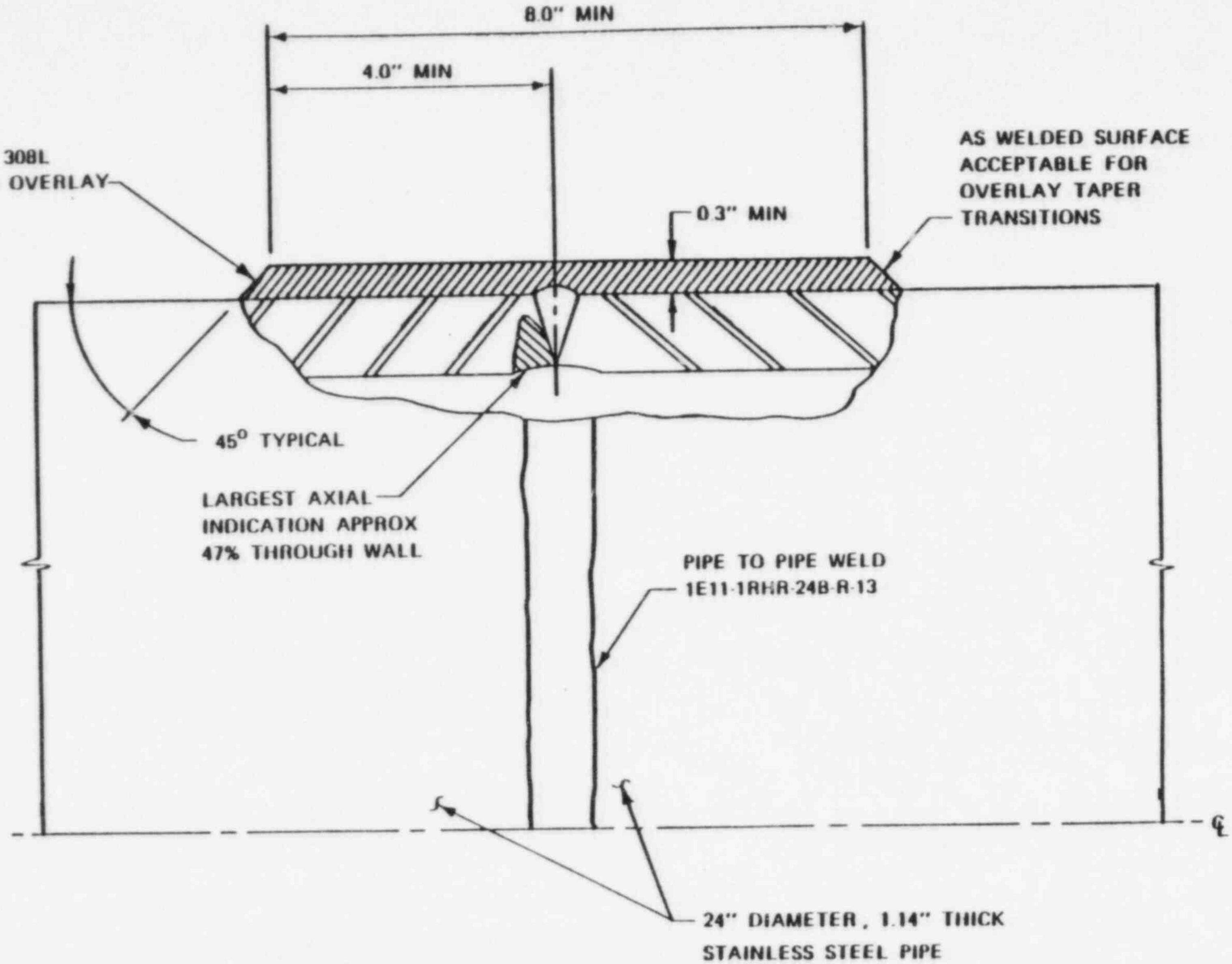

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Figure 2.4

TYPICAL CONFIGURATION OF 24" PIPE-TO-PIPE
WELD OVERLAY

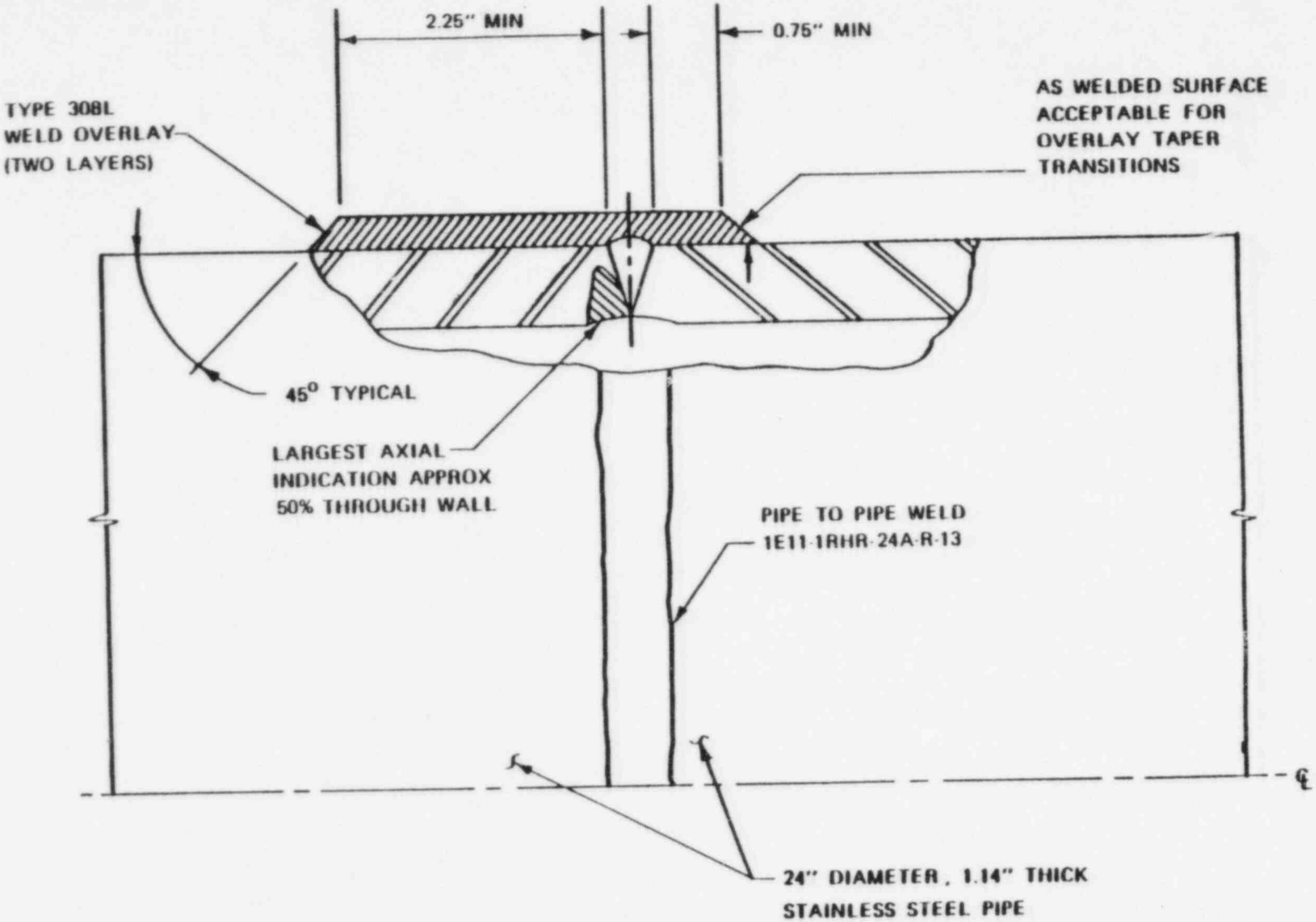

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Figure 2.5

TYPICAL CONFIGURATION OF 24" PIPE-TO-PIPE
WELD OVERLAY LEAK BARRIER

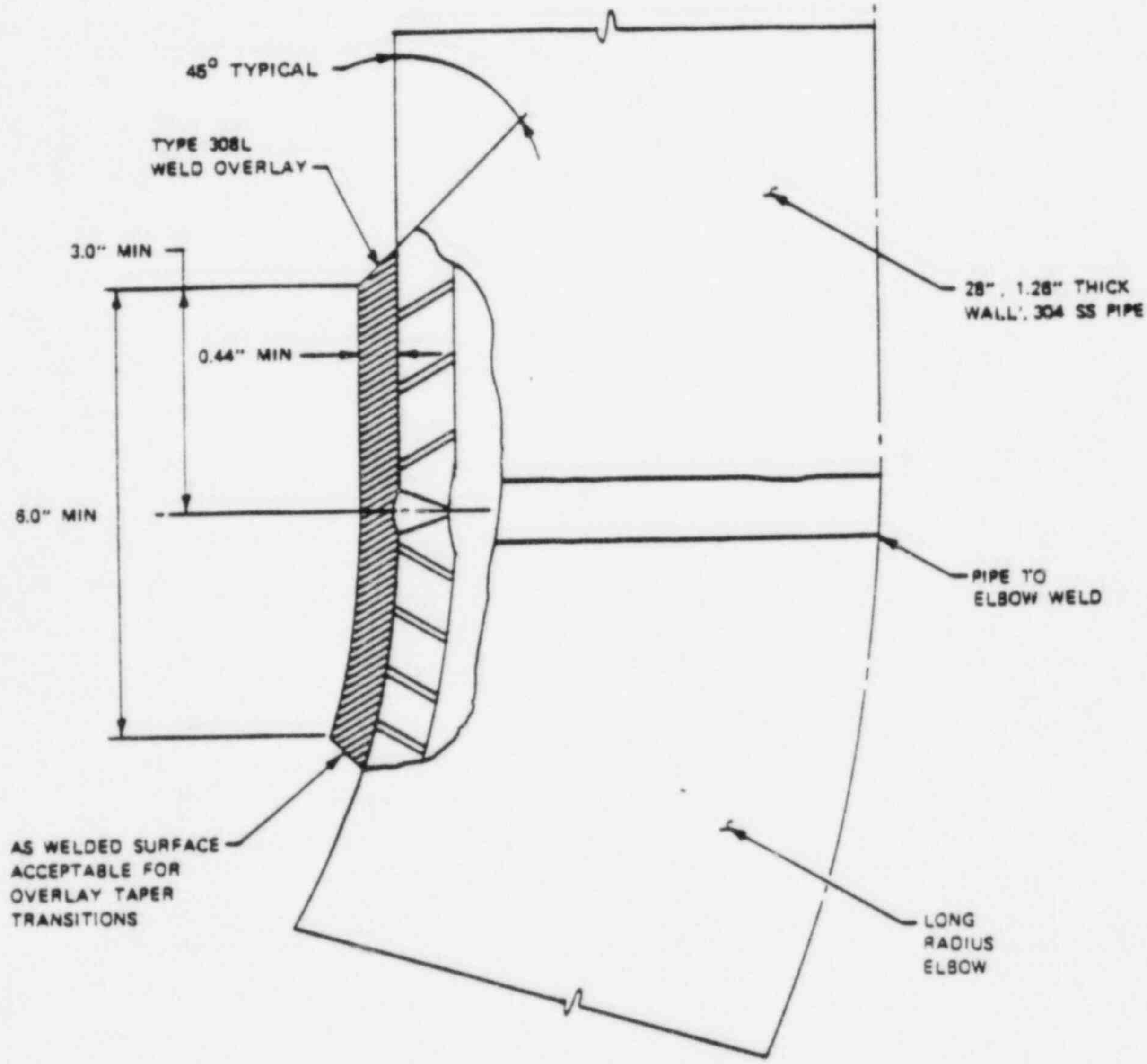

Figure 2.6

TYPICAL CONFIGURATION OF 28" PIPE-TO-ELBOW WELD OVERLAY

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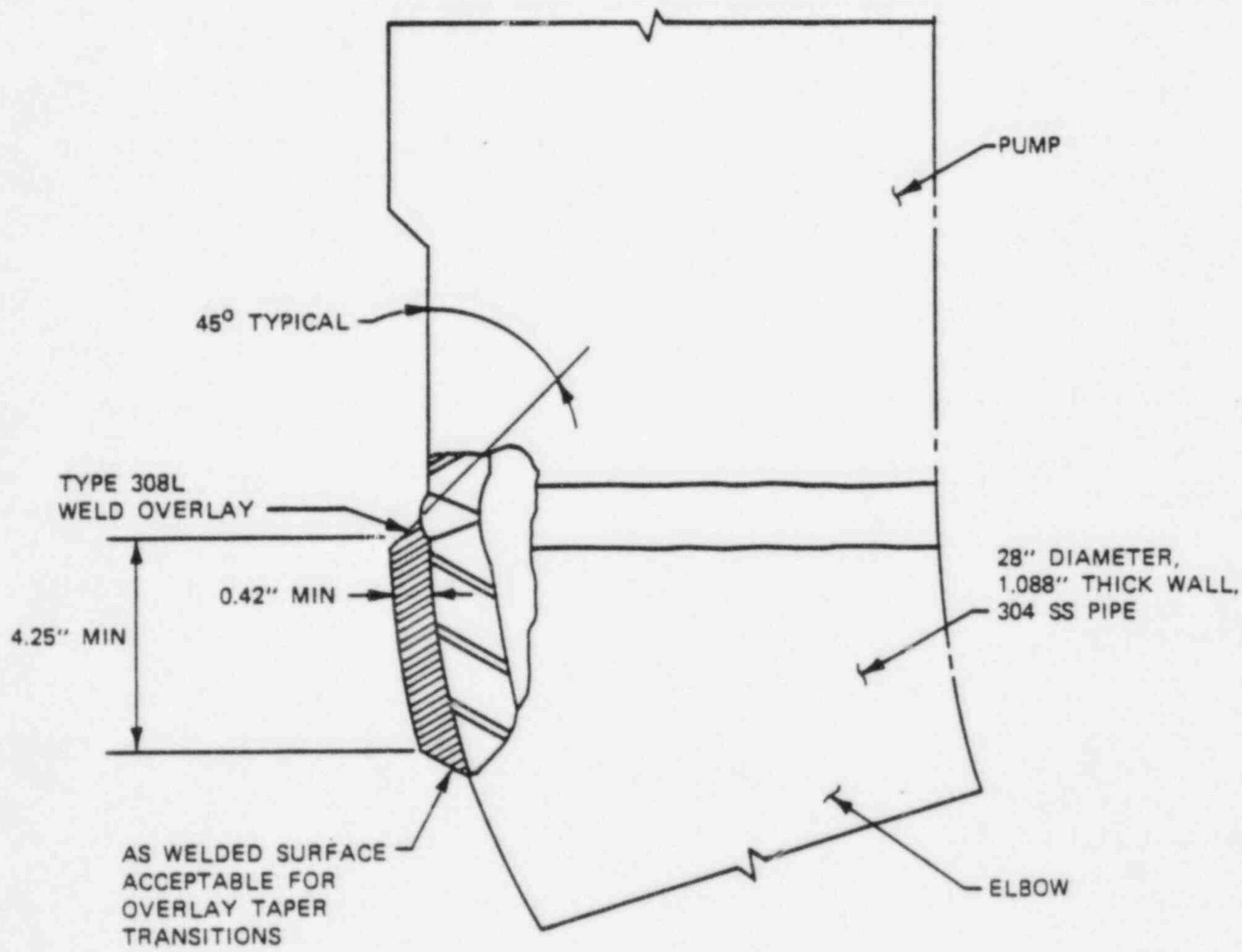

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Figure 2.7

TYPICAL CONFIGURATION OF 28" ELBOW-TO-PUMP WELD OVERLAY

3.0 EVALUATION CRITERIA

This section describes the criteria used to establish the acceptability of the weld overlay repairs and flawed pipe analyses. All evaluations and repairs were performed in accordance with NRC Generic Letter 84-11, dated April 1984 (Reference 1).

3.1 Weld Overlay Repair Criteria

Highly conservative assumptions were used for all evaluations. All flaws requiring repair were assumed to be through-wall for the measured length and were evaluated in accordance with the criteria of References 1, 3 and 5. All designs were performed in accordance with the requirements of ASME Section XI, Paragraph IWB-3641-1 (Reference 3), and NRC Generic Letter 84-11 (Reference 1) when circumferential flaws were present. For the repair to weld 24A-R-13 which contained only an axial flaw, the leakage barrier approach (Reference 2) was used.

Due to the nature of these repairs, the geometric configuration is not specifically covered by Section III of the ASME Boiler and Pressure Vessel Code (Reference 4), which is intended for new construction. However, the

materials, fabrication procedures, and quality assurance requirements used for weld overlay repairs are in accordance with applicable sections of this Code. The intent of the design criteria is to assure equivalent margins of safety for strength and fatigue considerations as provided in the ASME Section III Design Rules. In addition, because of the IGSCC conditions that led to the need for repairs, IGSCC resistant materials were used for the weld overlay.

3.2 Flawed Pipe Analysis Criteria

Those flawed welds which were determined not to require weld overlay repair were shown to meet the criteria given in Paragraph IWB-3600 of Reference 3 and Reference 1. Reference 1 defines the acceptable end-of-cycle flaw depth to be 2/3 of the Reference 3 allowable depth. A highly conservative crack growth correlation was used to demonstrate that evaluated flaws will not grow to an unacceptable flaw size by the IGSCC mechanism during the next fuel cycle.

4.0 LOADS

The loads considered in the evaluation of the UT flaw indications included mechanical loads, internal pressure, differential thermal expansion loads, and weld overlay shrinkage-induced loads. The mechanical and internal pressure loads used in the analyses are described in Section 4.1. A discussion of the thermal transient conditions which cause differential thermal expansion loads is presented in Section 4.2. The loads induced by weld overlay shrinkage are discussed in Section 4.3.

4.1 Mechanical and Internal Pressure Loads

The design pressures of 1325 psi (discharge side) and 1050 psi (suction side) were obtained from Reference 6. The deadweight and seismic loads were obtained from Reference 7.

4.2 Thermal Loads

The thermal expansion loads for each weld were obtained from Reference 8. These loads were calculated based on information found in Reference 6, which defines several types of transients for which the Recirculation and RHR

systems are designed. These transients were conservatively grouped into three composite transients. The first composite transient is a startup/shutdown transient with a heatup or cool down rate of 100°F per hour. The second composite transient consists of a 50°F step temperature change with no change in pressure. The third composite transient is an emergency event with a 416°F step temperature change and a pressure change of 1325 psi. In the five year overlay design life, there are 38 startup/shutdown cycles, 25 small temperature change cycles, and one emergency cycle.

4.3 Weld Overlay Shrinkage-Induced Stresses

Application of a weld overlay causes a small amount of axial shrinkage underneath the overlay. This shrinkage may induce bending stresses in the remainder of the piping system, depending on the location of the overlay. Shrinkage-induced stresses were calculated using NUTECH computer program PISTAR (Reference 9), together with field overlay shrinkage measurements. The resulting stresses are included in the crack growth analyses for all unrepaired flaw locations.

5.0 EVALUATION METHODS AND RESULTS

The flawed welds shown in Table 1.1 were identified by UT inspections during the fall 1984 outage at Plant E. I. Hatch Unit 1. Stress information for these welds is presented in Table 5.6. Note that for 28A-6 and 28B-16 only a composite stress value is given. These welds contained only axial flaws, and were evaluated for crack growth using the hoop stress. The flawed welds shown in Table 1.2 were identified during the fall 1982 outage at Unit 1. Each flawed weld was evaluated to determine if an overlay was required to meet the requirements of References 1 and 3. Where a repair was shown to be necessary, a weld overlay was designed to met the requirements of Paragraph IWB-3641 of Reference 3 assuming the flaw was through-wall for its measured length. Since flaws were assumed through-wall, the beneficial effects of weld overlays on crack growth were not addressed. The effect and significance of weld overlay shrinkage-induced stresses are discussed in Section 5.5.

5.1 Description of Geometries Analyzed

Six distinct flaw geometries required weld overlay repair at Hatch Unit 1. These were: 12-inch diameter

pipe-to-elbow (12 cases), 28-inch diameter pipe-to-elbow (two cases), 28-inch diameter elbow-to-pump (two cases), 24-inch diameter pipe-to-pipe (two cases), 22-inch diameter pipe-to-end cap (four cases), and 20-inch diameter elbow-to-pipe (one case). Code stress and fatigue evaluations which bound the cases listed in Tables 1.1 and 1.2 are summarized in Tables 5.1 to 5.5. For additional information see Reference 10. Analysis results for the locations with only axial flaws are discussed in Section 5.3.

5.2 Code Stress Analysis

Finite element models of the bounding weld overlay repairs were developed using the ANSYS (Reference 11) computer program. The models were based on a composite worst case flaw and on minimum design overlay thickness. The as-built thickness exclusive of the first overlay layer is greater than or equal to the minimum design thickness at Hatch 1 . The stresses in the overlaid weld due to the design pressure and applied moments as described in Sections 4.1 and 4.2 were calculated using the ANSYS models.

The results of stress analyses per Reference 4 are presented in Tables 5.1 through 5.5. (The 28" elbow-to-

pump repair is bounded by the 28" pipe-to-elbow case). The allowable stresses from Reference 4 are also given. The weld overlay repairs at Hatch 1 satisfy the Reference 4 requirements.

For the purpose of fatigue evaluation, the temperature distribution at the weld overlay repaired locations, subject to the thermal transients defined in Section 4.2 were calculated using charts 16 and 23 of Reference 12, as discussed in Reference 10.

5.3 Treatment of Axial Flaws

Axial IGSCC crack length is limited on either end by the original weld and the extent of sensitized material in the weld heat affected zone (HAZ). The tabulated allowable axial crack sizes in Reference 3 Paragraph IWB-3640 are truncated at a maximum depth of 75% of the pipe thickness and are therefore very conservative for axial IGSCC.

The ASME Code minimum wall thickness is based on maintaining a factor of safety of 3.0 on load against pipe failure. Pipe thickness in excess of the Code minimum thickness provides a reserve margin which can be used to tolerate short, through-wall (or less than through-wall)

axial cracks. The length of through-wall axial cracks which maintains a factor of safety of 3.0 on load during normal operation is calculated in Reference 5 as a function of the applied stress.

Whenever the combination of an axial crack and applied load results in a factor of safety of 3.0 or more on load, the axial crack, even if it is through-wall, maintains the originally required Code safety factor. For such cases, only a "leakage barrier" overlay is required. Such an overlay not only adequately repairs the known axial flaw, but also produces a compressive residual stress distribution on the inside surface of the pipe. This distribution will inhibit further IGSCC initiation.

5.4 Effect on Recirculation and Residual Heat Removal Systems

The effects of the radial shrinkage of the weld overlay are limited to the region adjacent to and underneath the overlay. The stresses due to the radial shrinkage are less than yield stress at distances greater than four inches from the ends of the overlay (Reference 13).

The effects of the axial weld shrinkage on the repaired systems were evaluated with the NUTECH computer program PISTAR (Reference 9) using the piping model shown in Figure 5.1. The measured shrinkages of all weld overlay repairs were imposed as boundary conditions on this model. Since the ASME Code does not limit weld residual stresses, all stress indices were set equal to 1.0.

Weld residual stresses are steady state secondary stresses. They are not limited by the ASME Code (Reference 4), and therefore, the Code acceptability of these welds is not in question.

The highest shrinkage-induced stresses calculated by the PISTAR analysis occurred at riser nozzles N2D, N2C, N2H, N2J, and N2G. These stresses were in the range of 12-16 ksi. Steady state secondary stresses of this magnitude are judged to have negligible effect on the integrity of these locations, but may affect IGSCC crack growth at locations with unrepaired flaws.

Table 5.7 presents weld overlay shrinkage-induced stresses for all welds with flaw indications. The maximum shrinkage stress value at any location containing an unrepaired flaw is less than 1 ksi.

Stresses of this magnitude have a negligible effect on the acceptability of the weld without repair.

5.5 Evaluation of Flaws in Unrepaired Welds

The prediction of crack growth for the flaws in unrepaired welds required the following inputs:

1) Steady state applied stress.
2) Weld residual stress.
3) Flaw characterization.
4) Crack growth model.
5) Crack growth law.

Conservative assumptions were used for applied stress, residual stress, crack growth model and crack growth law. Thus, the result of the analysis is a very conservative prediction of crack depth versus time.

The moments and forces due to operating pressure, dead weight and thermal expansion were obtained from References 6, 7, and 8. In addition, the stress due to the axial weld shrinkage of the overlays was added to the other steady state stresses (Section 5.4) for the final crack growth calculations.

A conservative IGSCC crack growth correlation for weld sensitized material was used based upon Reference 14:

$$\frac{da}{dT} = 3.59 \times 10^{-8} K^{2.161}$$

where:

da = Differential crack size (inch)

dT = Differential time (hour)

K = Applied stress intensity factor (ksi $\sqrt{in}$)

The crack growth model is a linear interpolation between an inside diameter (I.D.) cracked cylinder and an edge-cracked plate. The crack growth model assumes a 360° crack. The magnification factors for an I.D. cracked cylinder and an edge-cracked plate were obtained from Reference 15.

The predicted crack growth for the unrepaired flaws was calculated with the NUTECH computer program NUTCRAK (Reference 15). Allowable crack depth was obtained by taking 2/3 of the IWB-3641-1 (Reference 3) source equation values, as required by Reference 1. This analysis demonstrates that the unrepaired flaws at Hatch Unit 1 will not exceed their allowable depths during the

next fuel cycle (see Figures 5.2 and 5.3 for bounding crack growth curves).

Table 5.1

<u>12" PIPE-TO-ELBOW CODE STRESS RESULTS</u>

CATEGORY	EQUATION NUMBER	ACTUAL STRESS OR USAGE FACTOR	SECTION III NB ALLOWABLE
S	N/A	N/A	S_m = 14,300 PSI**
PRIMARY	(9)	18,700 PSI	21,450 PSI
PRIMARY + SECONDARY	(10)	34,200 PSI	42,900 PSI
PEAK CYCLE 1 CYCLE 2 CYCLE 3	(11)	 (29,500) 5* (13,000) 5* (135,500) 5*	N/A
USAGE FACTOR (5 YR)	N/A	0.03	1.0

* THE FACTOR OF 5 IS THE CONSERVATIVELY ASSUMED FATIGUE STRENGTH REDUCTION FACTOR.

** ALLOWABLE BASED ON TYPE 308L WELD OVERLAY MATERIAL.

Table 5.2

20" PIPE-TO-ELBOW CODE STRESS RESULTS

CATEGORY	EQUATION NUMBER	ACTUAL STRESS OR THICKNESS	SECTION III NB ALLOWABLE
S	N/A	N/A	S_m = 16,800 PSI
PRIMARY	(9)	16,200 PSI	25,200 PSI
PRIMARY + SECONDARY	(10)	19,600 PSI	50,400 PSI
PEAK CYCLE 1 CYCLE 2 CYCLE 3	(11)	(16,200)5* (8,800)5 (83,900)5	N/A
USAGE FACTOR (5 YR)	N/A	0.01	1.0

* THE FACTOR OF 5 IS THE CONSERVATIVELY ASSUMED FATIGUE STRENGTH REDUCTION FACTOR.

Table 5.3

22" PIPE-TO-END CAP CODE STRESS RESULTS

CATEGORY	EQUATION NUMBER	ACTUAL STRESS OR THICKNESS	SECTION III NB ALLOWABLE
S	N/A	N/A	S_m = 16,800 PSI
PRIMARY	(9)	10,590 PSI	25,200 PSI
PRIMARY + SECONDARY	(10)	18,950 PSI	50,400 PSI
PEAK CYCLE 1 CYCLE 2 CYCLE 3	(11)	(23,370)5* (16,950)5 (129,300)5	N/A
USAGE FACTOR (5 YR)	N/A	0.02	1.0

* THE FACTOR OF 5 IS THE CONSERVATIVELY ASSUMED FATIGUE STRENGTH REDUCTION FACTOR.

Table 5.4

24" PIPE-TO-PIPE CODE STRESS RESULTS

CATEGORY	EQUATION NUMBER	ACTUAL STRESS OR THICKNESS	SECTION III NB ALLOWABLE
S	N/A	N/A	S_m = 16,800 PSI
PRIMARY	(9)	12,300 PSI	25,200 PSI
PRIMARY + SECONDARY	(10)	16,000 PSI	50,400 PSI
PEAK CYCLE 1 CYCLE 2 CYCLE 3	(11)	(19,500)5* (12,950)5 (125,400)5	N/A
USAGE FACTOR (5 YR)	N/A	0.019	1.0

* THE FACTOR OF 5 IS THE CONSERVATIVELY ASSUMED FATIGUE STRENGTH REDUCTION FACTOR.

Table 5.5

28" PIPE-TO-ELBOW CODE STRESS RESULTS
(Bounds 28" Elbow-to-Pump Case)

CATEGORY	EQUATION NUMBER	ACTUAL STRESS OR USAGE FACTOR	SECTION III NB ALLOWABLE
S	N / A	N / A	S_m = 16,800 psi
PRIMARY	(9)	20,000 psi	25,200 psi
PRIMARY + SECONDARY	(10)	64,500 psi**	50,400 psi
PEAK CYCLE 1 CYCLE 2 CYCLE 3	(11)	5 (64,200)* 5 (5,400) 5 (74,200)	N / A
USAGE FACTOR (5 YR)	N / A	0.71***	1.00

NPRE83.62-36

*A FACTOR OF 5 IS THE CONSERVATIVELY ASSUMED FATIGUE STRENGTH REDUCTION FACTOR.

**ACCEPTABLE BASED ON THE SIMPLIFIED ELASTIC/PLASTIC DISCONTINUITY ANALYSIS.

***USAGE IS BASED ON A BOUNDING ANALYSIS WHICH USED A 360° CRACK TO REPRESENT A UT MEASURED CRACK LENGTH OF 50°. ACTUAL USAGE FACTOR IS MUCH LOWER.

Table 5.6

WELD STRESS INFORMATION - 1984 ANALYSES

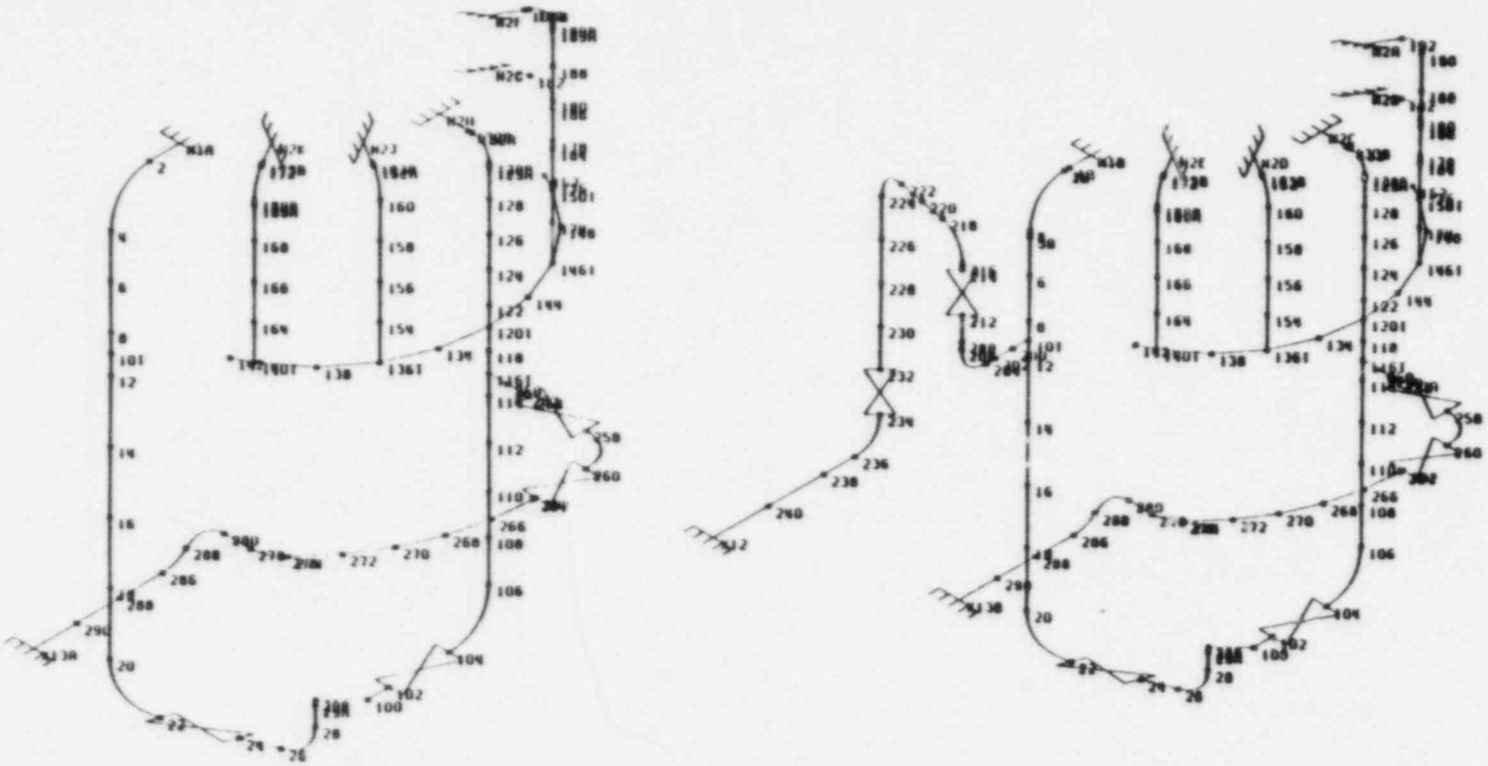
Weld No.	Pipe O.D.	Pipe Wall Thickness	Deadweight Stress	Thermal Stress	Seismic Stress	Pressure Stress	Crack Calc. DW+TH +P	W.O.L. Design DW+SE1 +P
28B-3	28.00"	1.116"	828	1093	1559	5819	7722	8206
28B-4	28.00"	1.116"	568	917	1652	5819	7304	8039
12AR-K-2	12.75"	0.568"	415	3260	1936	7436	11111	9787
12AR-H-2	12.75"	0.568"	646	1481	1720	7436	9563	9802
12AR-J-3	12.75"	0.568"	1050	1497	1132	7436	9983	9618
12BR-C-2	12.75"	0.568"	534	1481	2032	7436	9451	10002
12AR-K-3	12.75"	0.568"	756	4215	2977	7436	12407	11169
12AR-H-3	12.75"	0.568"	731	2915	2358	7436	11082	10525
24A-R-13	24.00"	1.020"	1036	5111	4350	7749	13896	13135
12BR-C-3	12.75"	12.75"	419	2915	2146	7436	10770	10001
12BR-D-3	12.75"	0.568"	453	1497	2527	7436	9386	10416
12BR-E-2	12.75"	0.568"	442	1200	2225	7436	9078	10103
12BR-E-3	12.75"	0.568"	784	1855	3190	7436	10075	11410
12AR-F-2	12.75"	0.568"	419	1200	2064	7436	9055	9919
12AR-F-3	12.75"	0.568"	489	1855	2892	7436	9780	10817
28A-10	28.00"	1.088"	408	492	1647	6755	7655	8810
28B-11	28.00"	1.088"	494	492	1618	6755	7741	8867
22AM-1BC-1	22.00"	1.00"*	61	1588	903	7288	8937	8252
22BM-1BC-1	22.00"	1.00"*	145	1588	906	7288	9021	8339
28A-6	28.00"	1.116	-	-	-	-	13172	-
28B-16	28.00"	1.263	-	-	-	-	14687	-

* Since sweepolet wall thickness varies, thickness conservatively assumed to be 1.00".

Table 5.7

PLANT E. I. HATCH UNIT 1
WELD OVERLAY INDUCED SHRINKAGE STRESSES

Weld ID	Stress (psi)
28A-10	77
24A-R-13	676
12AR-J-3	3025
12AR-K-2	1661
12AR-K-3	714
12AR-H-2	2991
12AR-H-3	2071
12AR-F-2	1165
12AR-F-3	1112
28B-11	58
28B-3	241
28B-4	112
12BR-C-2	2443
12BR-C-3	1398
12BR-D-3	2813
12BR-E-2	1438
12BR-E-3	566
24B-R-13	932
20B-D-3	590
22AM-1BC-1	810
22BM-1BC-1	581
28A-6	246
28B-16	189



HATCH 1 LOOP A

HATCH 1 LOOP B

Figure 5.1

PLANT E.I. HATCH UNIT 1 REACTOR RECIRCULATION

SYSTEM PIPING MODEL

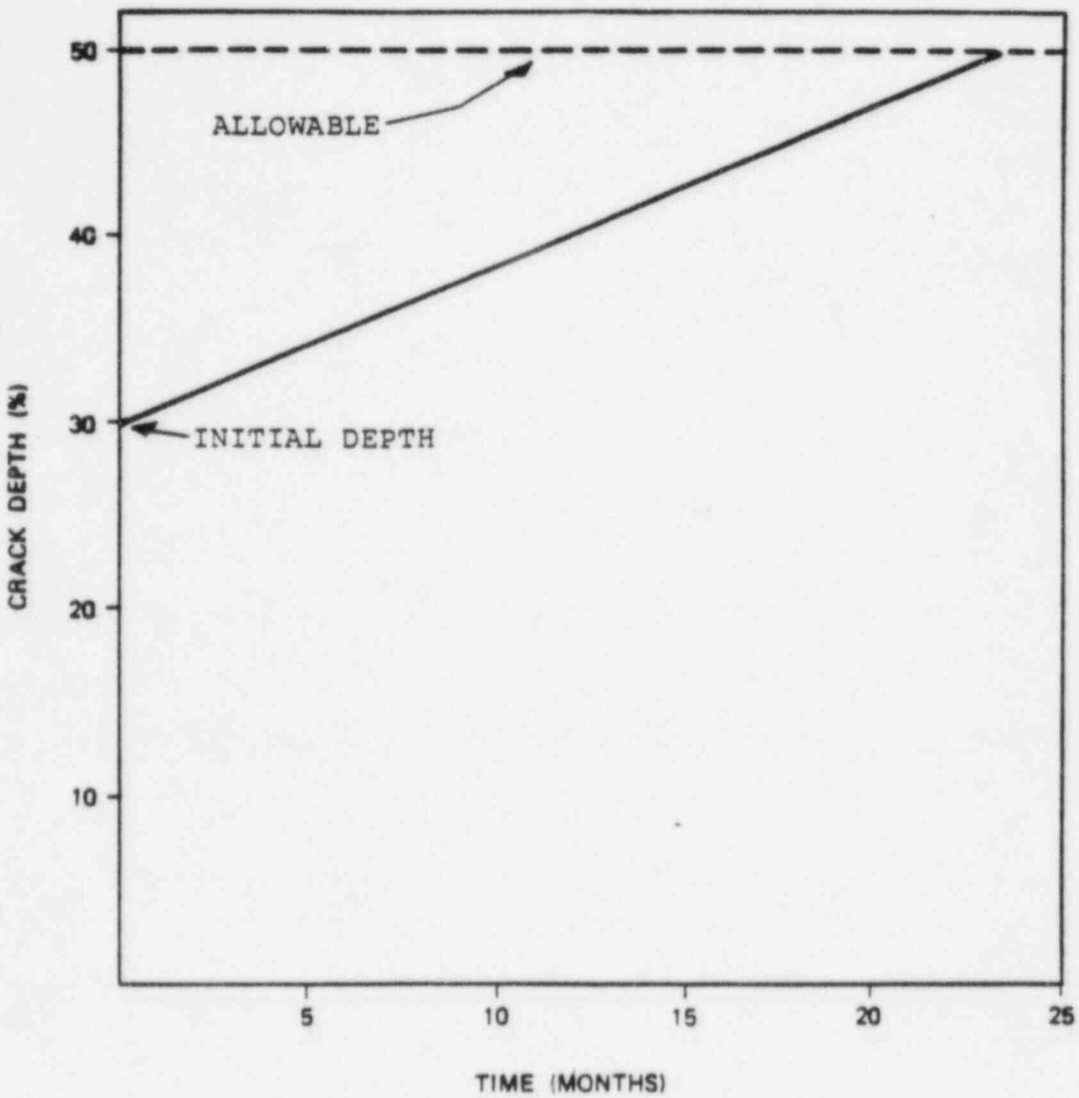


Figure 5.2

CRACK GROWTH VERSUS TIME - 22" SWEEPOLET

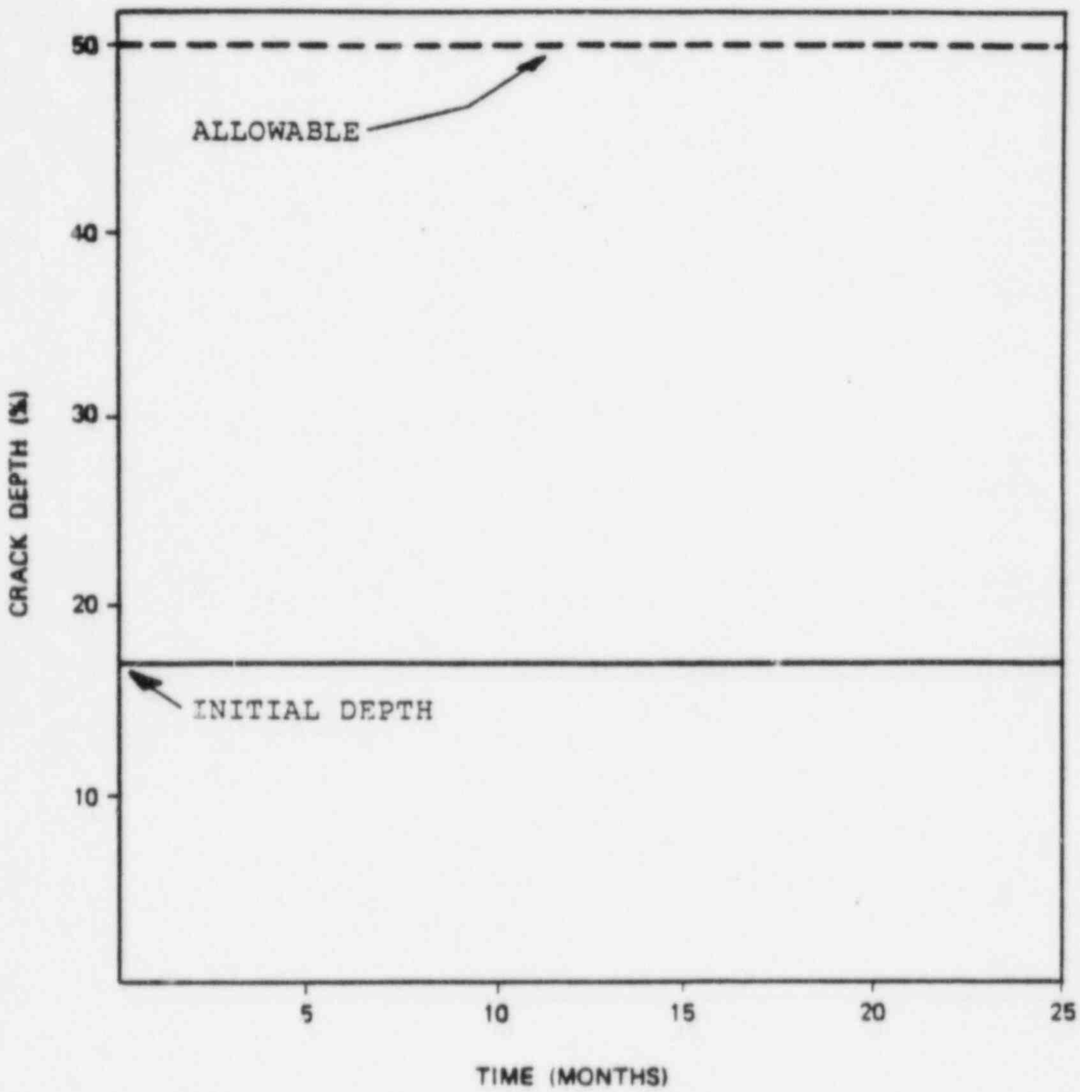


Figure 5.3

CRACK GROWTH VERSUS TIME - 28" PIPE-TO-ELBOW

6.0 LEAK-BEFORE-BREAK ASSESSMENT

For welds with undetected flaws, or containing IGSCC indications which are judged to be small enough to not require a repair, the following considerations provide additional support 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 (References 16 and 17) that this approach gives a conservative, lower-bound estimate of the loads which would cause unstable fracture of the cracked section in wrought 304 stainless steel piping material. Typical results of such an analysis are shown in Figure 6.1 (Reference 17). 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 system 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 (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 crack observed and that predicted to cause failure under service loading conditions. Also, as discussed below, there is still considerable margin between these net section collapse limits and the actual cracks which would cause instability.

6.2 Tearing Modulus Analysis

Elastic-plastic fracture mechanics analyses are presented in Reference 17 which give a different representation of the crack tolerance capacity of wrought stainless steel piping material than the net section collapse approach described above. Figures 6.2 and 6.3 graphically depict the results of such an analysis (Reference 17). Through-wall circumferential defects of arc length equal to 60° through 300° were assumed at various cross sections of a typical BWR

Recirculation System. Loads were applied to these sections of sufficient magnitude to produce net section limit load, and the resulting values of tearing modulus were compared to that required to cause unstable fracture (Figure 6.2). Note that in all cases there is substantial margin, indicating that the net section collapse limits of the previous section are not really failure limits. Figure 6.3 summarizes the results of all such analyses performed for 60° through-wall cracks in terms of margin on tearing modulus for stability. The margin in all cases is substantial.

6.3 Low Toughness Material Concerns

As mentioned in Sections 6.1 and 6.2, the generic statements made here regarding net section collapse and tearing modulus results as a basis for justifying leak-before-break arguments assume inherently high toughness and ductility of wrought stainless steel piping material. Recently, concerns about the validity of these arguments have been raised because of experimental work which suggests 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 base metal.

Potentially, this could lead to brittle failure of the weld material at an applied load appreciably below the net section collapse load of the adjacent piping material. As of the date of this report, there is no formal regulatory or Code guidance on this issue.

To address this situation for Hatch 1, NUTECH reviewed the weld overlays and unrepaired flaws discussed earlier in this report. All weld overlays were applied with the GTAW process, which is of less concern with regard to material toughness than are flux shielded processes. All circumferential flaws were assumed through-wall, and were sized as 360° long. The overlay designs were thus based upon 360° through-wall flaws, so the toughness of the original butt weld material is not important.

Unrepaired flaws fall into two categories. Two welds (28A-6 and 28B-16) contained only very short, shallow axial flaws, and were thus not of concern.

Two sweepolet to header welds (22AM-1BC-1 and 22BM-1BC-1) contained short circumferential flaws and required further evaluation. A Tearing Modulus analysis for these welds was conducted using the

worst case material properties for the butt weld metal. Although the actual flaws were very shallow, for the purpose of the analysis they were assumed to be through-wall. For the bounding applied loads, the flaws were shown to be stable. For three times the bounding applied loads, the flaws were shown to be marginally stable. Because of the conservative nature of the analysis the flaws are judged to be acceptable.

6.4 Leak Versus Break Flaw Configuration

Of perhaps more significance to the leak-before-break argument is the flaw configuration depicted in Figure 6.4. 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 6.4 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 shown in Figure 6.4 (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.

6.5 Axial Cracks

Several of the IGSCC occurrences at Plant E. I. Hatch Unit 1 were short, axial cracks. These 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.

6.6 Multiple Cracks

Analyses performed for EPRI (Reference 18) 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.

6.7 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 6.4 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.

6.8 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 $S_m/2$.

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.

6.9 Historical Experience

The above theories regarding crack detectability have been supported by experience (Reference 18). Indeed, of the large number of IGSCC incidents 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 $s = S_m/2$)

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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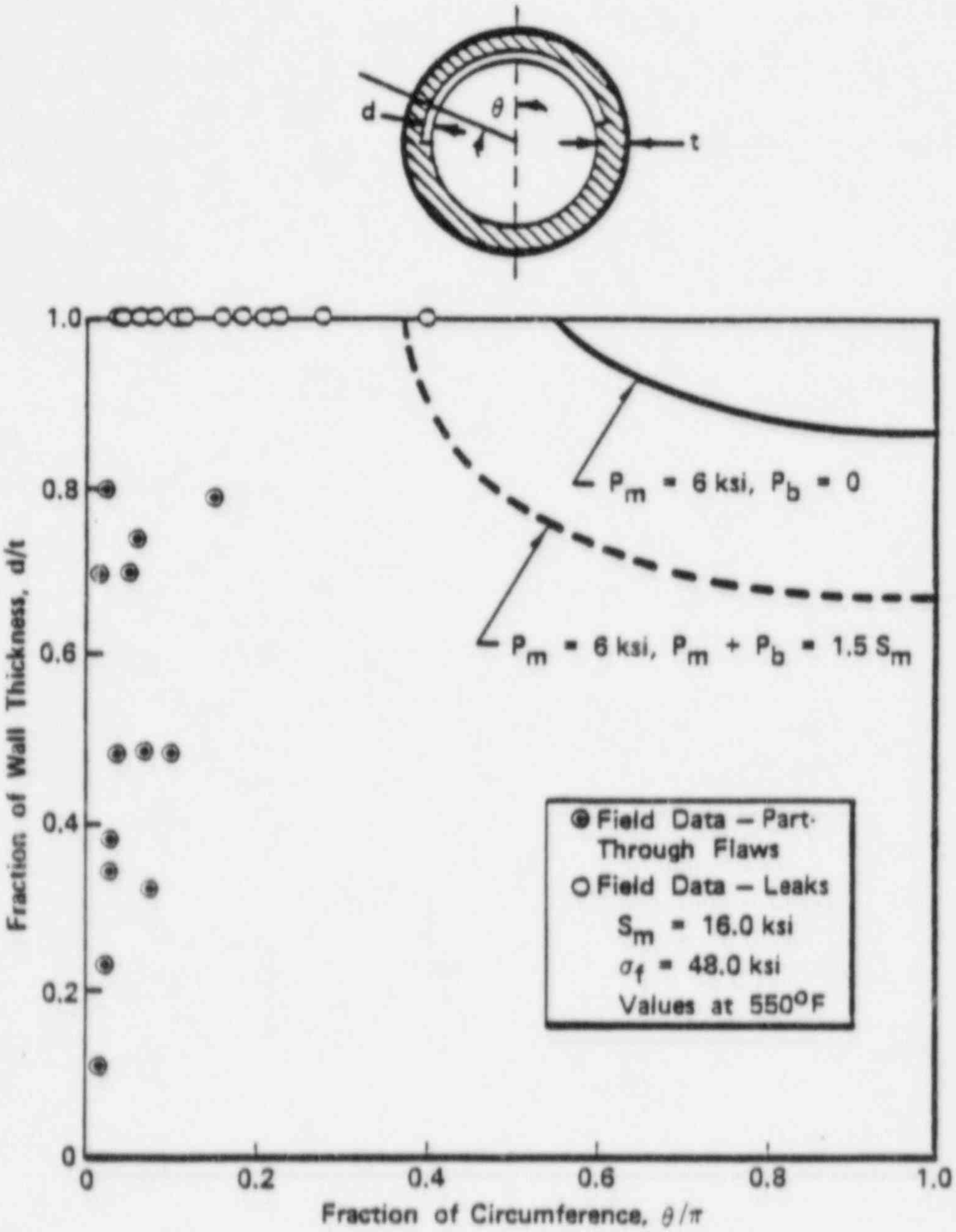


Figure 6.1

TYPICAL RESULT OF NET SECTION COLLAPSE ANALYSIS OF CRACKED STAINLESS STELL PIPE

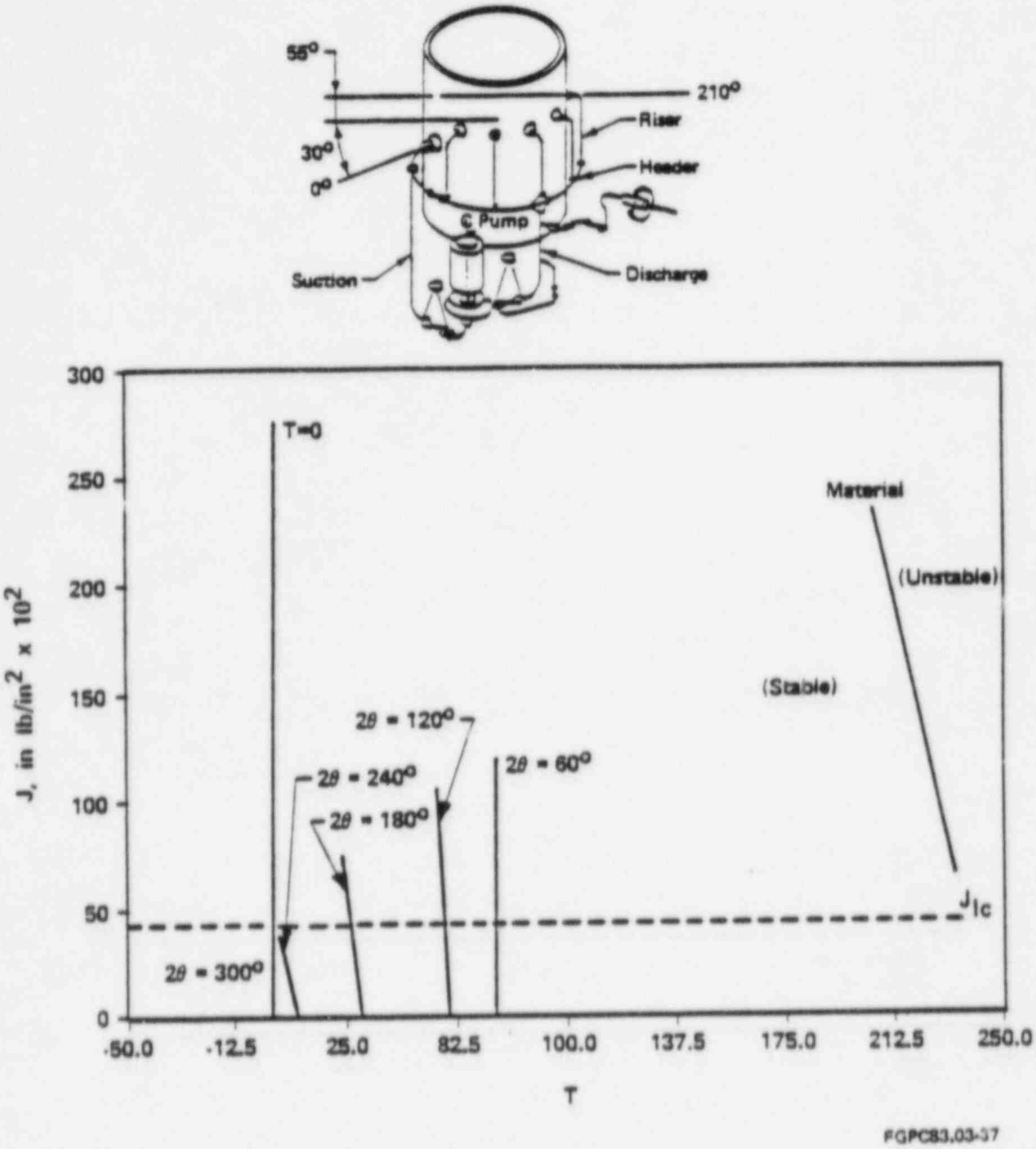


Figure 6.2

STABILITY ANALYSIS FOR BWR RECIRCULATION SYSTEM

(STAINLESS STEEL)

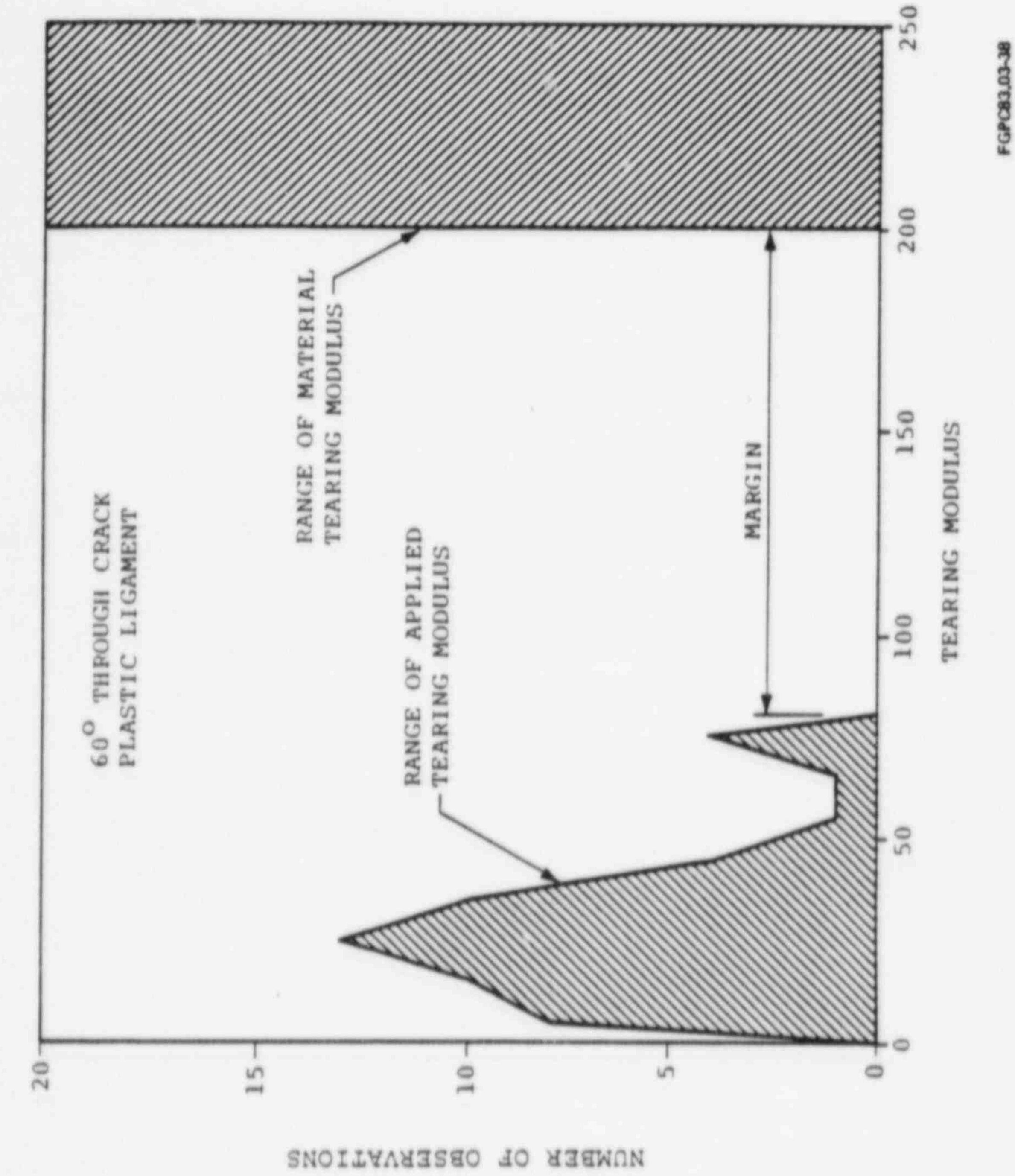
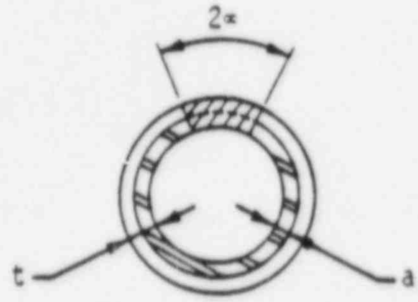


Figure 6.3

SUMMARY OF LEAK-BEFORE-BREAK ASSESSMENT

OF BWR RECIRCULATION SYSTEM



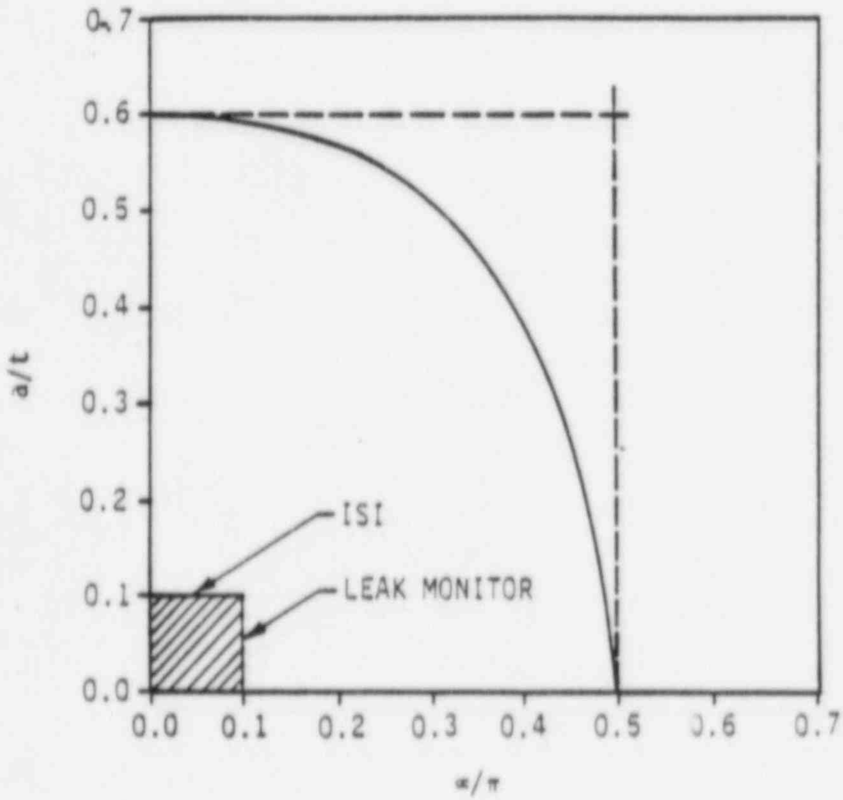


Figure 6.4

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

7.0 SUMMARY AND CONCLUSIONS

Evaluation of the weld overlay repairs to the Recirculation and RHR systems at Hatch Unit 1 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 one cycle 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.

Additional margin is incorporated in the weld overlay design criteria. All overlay designs are based on the assumption that flaws are through-wall for the measured length, even though ultrasonic measurement of flaws demonstrates that flaws are much less severe (see Tables 1.1 and 1.2) in general. Furthermore, the design and analysis of the weld overlays takes no credit for the first weld overlay layer, in accordance with NRC Generic Letter 84-11 (Reference 1). The above arguments support the conclusion that the weld overlay repairs at Hatch Unit 1 are conservatively adequate for their intended purpose.

Analyses have also been performed which demonstrate that those welds with unrepaired flaws satisfy the acceptance criteria of References 1 and 3.

Furthermore, it is concluded that IGSCC experienced in the Recirculation and Residual Heat Removal systems at Plant E. I. Hatch 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 identified at Plant E. I. Hatch 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, and on evaluation in accordance with IWB-3642 (Reference 3) for the potentially lower toughness and ductility associated with the butt weld material. Cracks in such piping grow through-wall and leak before affecting its structural load carrying capacity.

8.0 REFERENCES

1. NRC Generic Letter 84-11, dated April 19, 1984, NUTECH File No. COM096.0010.0001.

2. Structural Integrity Letter PCR-84-098, "Reconciliation of Weld Overlays With Large End Angles" from P. C. Riccardella (SIA) to R. Godby (GPC) dated December 17, 1984.

3. ASME Boiler and Pressure Vessel Code Section XI, 1983 Edition, Winter 1983 Addendum.

4. ASME Boiler and Pressure Vessel Code, Section III, (Subsection NB and Appendix I) 1980 Edition with Addenda through Summer 1980.

5. NUTECH Report COM-76-001, "Weld Overlay Design Criteria for Axial Cracks," Revision 0, March 1984, NUTECH File COM076.0208.

6. General Electric Design Specification 22A1344, Rev. 3.

7. GE Letter No. G-GPC-4-500, "Hatch 1 Seismic Evaluation for Replacement Recirculation Valve Operators," NUTECH File XGP009.0025.

8. NUTECH Calculation Package No. GPC-04-303, "Weld Overlay Thermal Analysis, PISTAR Piping Analysis," NUTECH File XGP009.0025.

9. NUTECH Computer Program PISTAR, Version 2.0, Users Manual, Volume 1, TR-76-002, Revision 4, File No. 08.003.0300.

10. NUTECH Report GPC-04-104, Revision 1, "Design Report for Recirculation System and Residual Heat Removal System Weld Overlay Repairs and Flaw Evaluation at E. I. Hatch Nuclear Power Plant Unit 1" March, 1983, File No. GPC004.0104.

11. ANSYS Computer Program, Swanson Analysis Systems, Revision 4, NUTECH File No. 08.061.

12. Schneider, P.J., "Temperature Response Charts," John Wiley and Sons, 1963.

13. 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.

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

15. NUTECH Computer Program NUTCRAK, Version 2.0, Revision 2, December 1983, File No. 08.039.0005.

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

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

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