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EVALUATION AND DISPOSITION OF FLAWS AT QUAD CITIES NUCLEAR POWER PLANT UNIT 1 (1987 OUTAGE)

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CERTIFICATION BY REGISTERED PROFESSIONAL ENGINEER

I hereby certify that the revisions to this document and the calculations contained herein were prepared by me or under my direct supervision, 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 activities addressed herein. I am a duly Registered Professional Engineer under the laws of the State of California and am competent to review this document.

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1.0 INTRODUCTION

This report summarizes analyses performed by NUTECH to evaluate flaw indications in the Reactor Recirculation, Residual Heat Removal (RHR), and Core Spray systems at Commonwealth Edison's Quad Cities Nuclear Power Plant Unit 1. Ultrasonic (UT) examinations of welds in these systems since 1984 have identified flaws judged to be intergranular stress corrosion cracking (IGSCC) in the vicinity of a total of thirty-one welds. Seventeen flawed welds in the Reactor Recirculation system were identified prior to and/or after Induction Heating Stress Improvement (IHSI) mitigation of this system during the 1984 outage. Fourteen additional flawed welds were identified during the 1987 outage. Of these fourteen welds, six flawed welds were discovered in the Core Spray and one flawed weld was discovered in the RHR systems not previously mitigated by a stress improvement process. Of the remaining seven welds, five welds in the previously IHSI-mitigated Reactor Recirculation system were discovered to have only axial flaws. The locations of all these welds are shown in Figures 1.0-1 through 1.0-5.

Tables 1.0-1 through 1.0-6 present descriptions of the IGSCC flaw indications at Quad Cities Unit 1. Table 1.0-1 describes flaws in three Reactor Recirculation system welds which were overlay-repaired during the 1984 outage and built-up to "standard" overlays during the 1986 outage. Table 1.0-2 describes flaws in twelve Reactor Recirculation system welds which were overlay-repaired during the 1984 outage and built-up to "standard" overlays during the 1987 outage. Table 1.0-3 describes flaws in one Reactor Recirculation system weld which was "leak barrier" overlay-repaired in 1984 and has had a pipe clamping device on it since that time. Table 1.0-4 describes flaws in eight Reactor Recirculation system welds IHSI-mitigated during the 1984 outage and overlay-repaired during the 1987 outage. Only one of these welds had reported IGSCC-indications prior to IHSI mitigation. Table 1.0-5 describes flaws in six unmitigated Core Spray system welds that were overlay-repaired during the 1987 outage. Table 1.0-6 describes flaws in one RHR system weld that was mitigated by the Mechanical Stress Improvement Process (MSIP) during the 1987 outage. The fifteen flawed welds in Tables 1.0-1 and 1.0-2 having "standard" weld overlay repairs have been surface finished to permit volumetric inspection of the weld overlay repair and part of the original pipe wall. The one "leak barrier" overlay-repair with the pipe clamping device in Table 1.0-3 was ultrasonically inspected for bonding between the overlay and original pipe wall surface in 1984. The fourteen overlay-repaired welds in Tables 1.0-4 and 1.0-5 have been surface finished to permit an ultrasonic bonding inspection of the overlay to the original pipe surface.

The design of previous weld overlay repairs and the analysis of IHSI-mitigated weld flaws discovered during the 1984 outage at Quad Cities Unit 1 are described in NUTECH Report COM-96-202 (Reference 1). The evaluation of three weld overlay repairs built-up during the 1986 outage and the effectiveness of one previously IHSI-mitigated flawed weld re-examined during the 1986 outage at Quad Cities Unit 1 is described in NUTECH Report CEC-47-100 (Reference 2).

The purpose of this report is to demonstrate that the original design margins of safety for the flawed welds at Quad Cities Unit 1 have not been degraded by the presence of IGSCC flaw indications or repairs. In addition, it will be demonstrated that all the overlay repairs initially installed during the 1984 outage and built-up to "standard" designs during the 1986 and 1987 outages are adequately sized to meet anticipated changes to regulatory requirements. Section 2.0 presents a general description of the overlay repairs and build-ups performed at Quad Cities Unit 1 during the 1987 outage. Sections 3.0 and 4.0 present the evaluation criteria and loads used in the analysis of overlay-repaired and stress-improved weld flaws. Section 5.0 presents the evaluation methods and results. Sections 6.0 and 7.0 present a summary of conclusions and the references used in the evaluation.

Table 1.0-1

COMPARISON AND DESCRIPTION

FLAWS OVERLAY-REPAIRED 1984 OUTAGE/

BUILT-UP 1986 OUTAGE

QUAD CITIES UNIT 1

WELD NO.	PIPE SIZE	CONFIG. UP-STREAM	CONFIG. DOWN-STREAM	1984 OUTAGE LENGTH	1984 OUTAGE DEPTH	1984 OUTAGE ORIENT.	1984 OUTAGE LOCATION	1986 OUTAGE (FROM POST-WOR UT EXAM.) LENGTH	1986 OUTAGE REMAINING LIGAMENT	1986 OUTAGE ORIENT.	1986 OUTAGE LOCATION	1987 OUTAGE LENGTH	1987 OUTAGE REMAINING LIGAMENT	1987 OUTAGE ORIENT.	1987 OUTAGE LOCATION
02C-S4	12"	PIPE	ELBOW	4"	44%	CIRC.	PIPE SIDE	0.5" MAX.	0.48" MIN.	3 AXIALS	PIPE SIDE	0.57" MAX.	0.40" MIN.	3 AXIALS	PIPE SIDE
				1" MAX.	*	3 AXIALS	PIPE SIDE								
02J-S4	12"	PIPE	ELBOW	4.25"	35%	CIRC.	PIPE SIDE	0.5" MAX.	0.34" MIN.	16 AXIALS	PIPE SIDE	0.70" MAX.	0.33" MIN	11 AXIALS	PIPE SIDE
				0.6"	<30%	CIRC.	PIPE SIDE								
				2.0"	<30%	CIRC.	PIPE SIDE								
				1.8"	<30%	CIRC.	PIPE SIDE								
				1.6"	<30%	CIRC.	PIPE SIDE								
				3.0"	<30%	CIRC.	PIPE SIDE								
				1.1" MAX.	*	9 AXIALS	PIPE SIDE								
02K-S3	12"	ELBOW	PIPE	1.6"	25%	CIRC.	PIPE SIDE	1.5" MAX.	0.77" MIN.	4 CIRCS.	PIPE SIDE	3.2"	0.50"	CIRC.	ELBOW SIDE
				0.2"	25%	CIRC.	PIPE SIDE	0.75" MAX.	0.54" MIN.	AXIAL	PIPE SIDE	0.60" MAX.	0.35" MIN.	4 AXIALS	ELBOW SIDE
				0.8"	15%	CIRC.	PIPE SIDE								
				8.0"	24%	CIRC.	PIPE SIDE								
				0.6" MAX.	*	5 AXIALS	PIPE SIDE								

* AXIAL FLAW DEPTHS ASSUMED TO BE 100%.

Table 1.0-2

COMPARISON AND DESCRIPTION
FLAWS OVERLAY-REPAIRED 1984 OUTAGE/
BUILT-UP 1987 OUTAGE
QUAD CITIES UNIT 1

	---CONFIG.---			---1984 OUTAGE---				---1986 OUTAGE---				---1987 OUTAGE--- (FROM POST-WOR UT EXAM.)			
WELD NO.	PIPE SIZE	UP-STREAM	DOWN-STREAM	LENGTH	DEPTH	ORIENT.	LOCATION	LENGTH	DEPTH	ORIENT.	LOCATION	LENGTH	REMAINING LIGAMENT	ORIENT.	LOCATION
02B-S4	12"	PIPE	ELBOW	0.5"	(1)	AXIAL	PIPE SIDE		NOT INSPECTED			1.12" MAX.	0.38" MIN.	3 AXIALS	PIPE SIDE
				0.875"	(1)	AXIAL	PIPE SIDE								
02E-S4	12"	PIPE	ELBOW	0.8"	65%	CIRC.	PIPE SIDE		NOT INSPECTED			0.91" MAX.	0.36" MIN.	14 AXIALS	PIPE SIDE
				1.125" MAX.	*	8 AXIALS	PIPE SIDE								
02F-S4	12"	PIPE	ELBOW	0.8" MAX.	*	3 AXIALS	ELBOW SIDE		NOT INSPECTED			0.96"	0.41"	AXIAL	ELBOW SIDE
02G-S3	12"	ELBOW	PIPE	0.75"	50%	CIRC.	PIPE SIDE		NOT INSPECTED			0.96" MAX.	0.38" MIN.	9 AXIALS	PIPE SIDE
				1.125" MAX.	*	7 AXIALS	PIPE SIDE					0.64" MAX.	0.44" MIN.	2 AXIALS	ELBOW SIDE
				0.875"	*	AXIAL	ELBOW SIDE								
02G-S4	12"	PIPE	ELBOW	1"	10%	CIRC.	ELBOW SIDE		NOT INSPECTED			0.70"	0.39"	CIRC.	ELBOW SIDE
				0.125"	*	AXIAL	ELBOW SIDE					0.98" MAX.	0.35" MIN.	3 AXIALS	ELBOW SIDE
												0.42"	0.38"	AXIAL	PIPE SIDE
												1.0" MAX.	0.32" MIN.	LAMINAR	ELBOW SIDE
02H-S3	12"	ELBOW	PIPE	3"	21%	CIRC.	PIPE SIDE		NOT INSPECTED			0.68" MAX.	0.43" MIN.	4 AXIALS	PIPE SIDE
				0.75" MAX.	*	3 AXIALS	PIPE SIDE								
02H-S4	12"	PIPE	ELBOW	0.75" MAX.	*	4 AXIALS	PIPE & ELBOW SIDE		NOT INSPECTED			0.48" MAX.	0.38" MIN.	2 AXIALS	ELBOW SIDE
												0.64" MAX.	0.35" MIN.	11 AXIALS	PIPE SIDE
02J-F6	12"	SWEEP.	PIPE	1.25" MAX.	*	7 AXIALS	PIPE SIDE		NOT INSPECTED			1.02" MAX.	0.26" MIN.	13 AXIALS	PIPE SIDE
02J-S3	12"	ELBOW	PIPE	0.6"	12%	CIRC.	PIPE SIDE		NOT INSPECTED			0.52"	0.43"	AXIAL	ELBOW SIDE
				0.5"	*	AXIAL	PIPE SIDE					0.64" MAX.	0.37" MIN.	4 AXIAL	PIPE SIDE
02K-S4	12"	PIPE	ELBOW	0.25" MAX.	*	2 AXIALS	PIPE SIDE		NOT INSPECTED			0.84"	0.45"	AXIAL	ELBOW SIDE
												0.64" MAX.	0.37" MIN.	7 AXIALS	PIPE SIDE
02B-S7	22"	CROSS	PIPE	0.125"	*	AXIAL	PIPE SIDE		NOT INSPECTED			0.92"	0.36"	AXIAL	CROSS SIDE
02B-S10	22"	PIPE	END CAP	2"	10%	CIRC.	E.C. SIDE		NOT INSPECTED			1.22" MAX.	0.45" MIN.	2 AXIALS	ELBOW SIDE
				0.5"	*	3 AXIALS	E.C. SIDE								

* AXIAL FLAW DEPTHS ASSUMED TO BE 100%.

Table 1.0-3

COMPARISON AND DESCRIPTION

FLAWS OVERLAY-REPAIRED AND PIPE

CLAMPED 1984 OUTAGE

QUAD CITIES UNIT 1

WELD NO.	PIPE SIZE	CONFIG. UP-STREAM	CONFIG. DOWN-STREAM	1984 OUTAGE LENGTH	1984 OUTAGE DEPTH	1984 OUTAGE ORIENT.	1984 OUTAGE LOCATION	19[illegible] OUTAGE LENGTH	19[illegible] OUTAGE REMAINING LIGAMENT	19[illegible] OUTAGE ORIENT.	19[illegible] OUTAGE LOCATION	1987 OUTAGE LENGTH	1987 OUTAGE REMAINING LIGAMENT	1987 OUTAGE ORIENT.	1987 OUTAGE LOCATION
02M-S3	12"	ELBOW	PIPE	1" MAX	*	3 AXIALS	PIPE SIDE	NOT INSPECTED				NOT INSPECTED			

* AXIAL FLAW DEPTHS ASSUMED TO BE 100%.

Table 1.0-4

COMPARISON AND DESCRIPTION

FLAWS IHSI-MITIGATED 1984 OUTAGE/

OVERLAY-REPAIRED 1987 OUTAGE

QUAD CITIES UNIT 1

WELD NO.	PIPE SIZE	COMP. I.D. UP-STREAM	COMP. I.D. DOWN-STREAM	1984 OUTAGE LENGTH	1984 OUTAGE DEPTH	1984 OUTAGE ORIENT.	1984 OUTAGE LOCATION	1986 OUTAGE LENGTH	1986 OUTAGE DEPTH	1986 OUTAGE ORIENT.	1986 OUTAGE LOCATION	1987 OUTAGE (PRE-WOL UT EXAM.) LENGTH	1987 OUTAGE (PRE-WOL UT EXAM.) DEPTH	1987 OUTAGE (PRE-WOL UT EXAM.) ORIENT.	1987 OUTAGE (PRE-WOL UT EXAM.) LOCATION
02C-S3	12"	ELBOW	PIPE	NO REPORTABLE INDICATIONS				NOT INSPECTED				0.75"	10%	AXIAL	PIPE SIDE
												0.85"	10%	AXIAL	PIPE SIDE
02D-S3	12"	ELBOW	PIPE	NO REPORTABLE INDICATIONS				NOT INSPECTED				0.2"	10%	AXIAL	PIPE SIDE
												0.25"	31%	AXIAL	PIPE SIDE
02E-S3	12"	ELBOW	PIPE	NO REPORTABLE INDICATIONS				NOT INSPECTED				1.0"	15%	AXIAL	PIPE SIDE
02F-S3	12"	ELBOW	PIPE	NO REPORTABLE INDICATIONS				NOT INSPECTED				0.80"	9%	AXIAL	PIPE SIDE
												0.54"	20%	AXIAL	PIPE SIDE
												0.80"	13%	AXIAL	PIPE SIDE
												0.76"	27%	AXIAL	PIPE SIDE
												0.77"	10%	AXIAL	PIPE SIDE
												0.40"	14%	AXIAL	PIPE SIDE
02H-S4	12"	PIPE	ELBOW	NO REPORTABLE INDICATIONS				NOT INSPECTED				1"	22%	AXIAL	ELBOW SIDE
02D-F1	22"	VALVE	PIPE	I.D. GEOMETRY				NOT INSPECTED				3.0"	26%	CIRC.	PIPE SIDE
												0.25"	24%	AXIAL	PIPE SIDE
02BS-S3	28"	PIPE	TEE	I.D. GEOMETRY				NOT INSPECTED				5"	15%	CIRC.	PIPE SIDE
												4"	25%	CIRC.	PIPE SIDE
												0.2"	20%	AXIAL	PIPE SIDE
												0.3"	20%	AXIAL	PIPE SIDE
02BS-S9	28"	PIPE	ELBOW	4.0"	0.05"	CIRC.	ELBOW SIDE	1"	23%	CIRC.	ELBOW SIDE	3"	40%	CIRC.	ELBOW SIDE
				1.5"	10%	CIRC.	PIPE SIDE	1"	15%	CIRC.	ELBOW SIDE	2"	35%	CIRC.	ELBOW SIDE
				0.5"	15%	CIRC.	PIPE SIDE	2.5"	20%	CIRC.	ELBOW SIDE	1.5"	30%	CIRC.	ELBOW SIDE
								1"	15%	CIRC.	PIPE SIDE	2.5"	44%	CIRC.	ELBOW SIDE
								1.5"	24%	CIRC.	PIPE SIDE	3.25"	35%	CIRC.	ELBOW SIDE
												3.5"	35%	CIRC.	PIPE SIDE
												6"	40%	CIRC.	PIPE SIDE
												1.5"	20%	CIRC.	PIPE SIDE
												0.75"	35%	AXIAL	ELBOW SIDE

Table 1.0-5

COMPARISON AND DESCRIPTION

UNMITIGATED FLAWS OVERLAY-REPAIRED 1987 OUTAGE

QUAD CITIES UNIT 1

WELD NO.	PIPE SIZE	CONFIG. UP-STREAM	CONFIG. DOWN-STREAM	1984 OUTAGE LENGTH	1984 OUTAGE DEPTH	1984 OUTAGE ORIENT.	1984 OUTAGE LOCATION	1986 OUTAGE LENGTH	1986 OUTAGE DEPTH	1986 OUTAGE ORIENT.	1986 OUTAGE LOCATION	1987 OUTAGE (PRE-WOR UT EXAM.) LENGTH	DEPTH	ORIENT.	LOCATION
14A-F2	10"	PIPE	SAFE END	I.D. GEOMETRY				I.D. ROOT GEOMETRY				0.64"	23%	AXIAL	PIPE SIDE
14A-F11	10"	VALVE	ELBOW	NOT INSPECTED				NOT INSPECTED				0.3"	20%	AXIAL	ELBOW SIDE
14A-S8	10"	PIPE	ELBOW	NOT INSPECTED				I.D. GEOMETRY				1.5"	19%	CIRC.	ELBOW SIDE
												0.3"	32%	AXIAL	ELBOW SIDE
14A-S9	10"	ELBOW	PIPE	NOT INSPECTED				NOT INSPECTED				0.3"	20%	AXIAL	PIPE SIDE
												0.45"	17%	AXIAL	ELBOW SIDE
14B-F2	10"	PIPE	SAFE END	I.D. GEOMETRY				NOT INSPECTED				0.4"	14%	AXIAL	PIPE SIDE
												0.35"	11%	AXIAL	PIPE SIDE
14B-S8	10"	ELBOW	ELBOW	NOT INSPECTED				WELD CROWN FINGER DAMP				0.6"	17%	AXIAL	UPST. SIDE
												0.5"	10%	AXIAL	UPST. SIDE
												0.5"	25%	AXIAL	UPST. SIDE
												0.4"	14%	AXIAL	UPST. SIDE

Table 1.0-6

COMPARISON AND DESCRIPTION

FLAWS MSIP-MITIGATED 1987 OUTAGE

QUAD CITIES UNIT 1

WELD NO.	PIPE SIZE	CONFIG. UP-STREAM	CONFIG. DOWN-STREAM	1984 OUTAGE LENGTH	1984 OUTAGE DEPTH	1984 OUTAGE ORIENT.	1984 OUTAGE LOCATION	1986 OUTAGE LENGTH	1986 OUTAGE DEPTH	1986 OUTAGE ORIENT.	1986 OUTAGE LOCATION	1987 OUTAGE LENGTH	1987 OUTAGE DEPTH	1987 OUTAGE ORIENT.	1987 OUTAGE LOCATION
10BD-S13	16"	PIPE	ELBOW	NOT INSPECTED				NOT INSPECTED				1.5"	18%	CIRC.	PIPE SIDE
												4.75"	20%	CIRC.	PIPE SIDE

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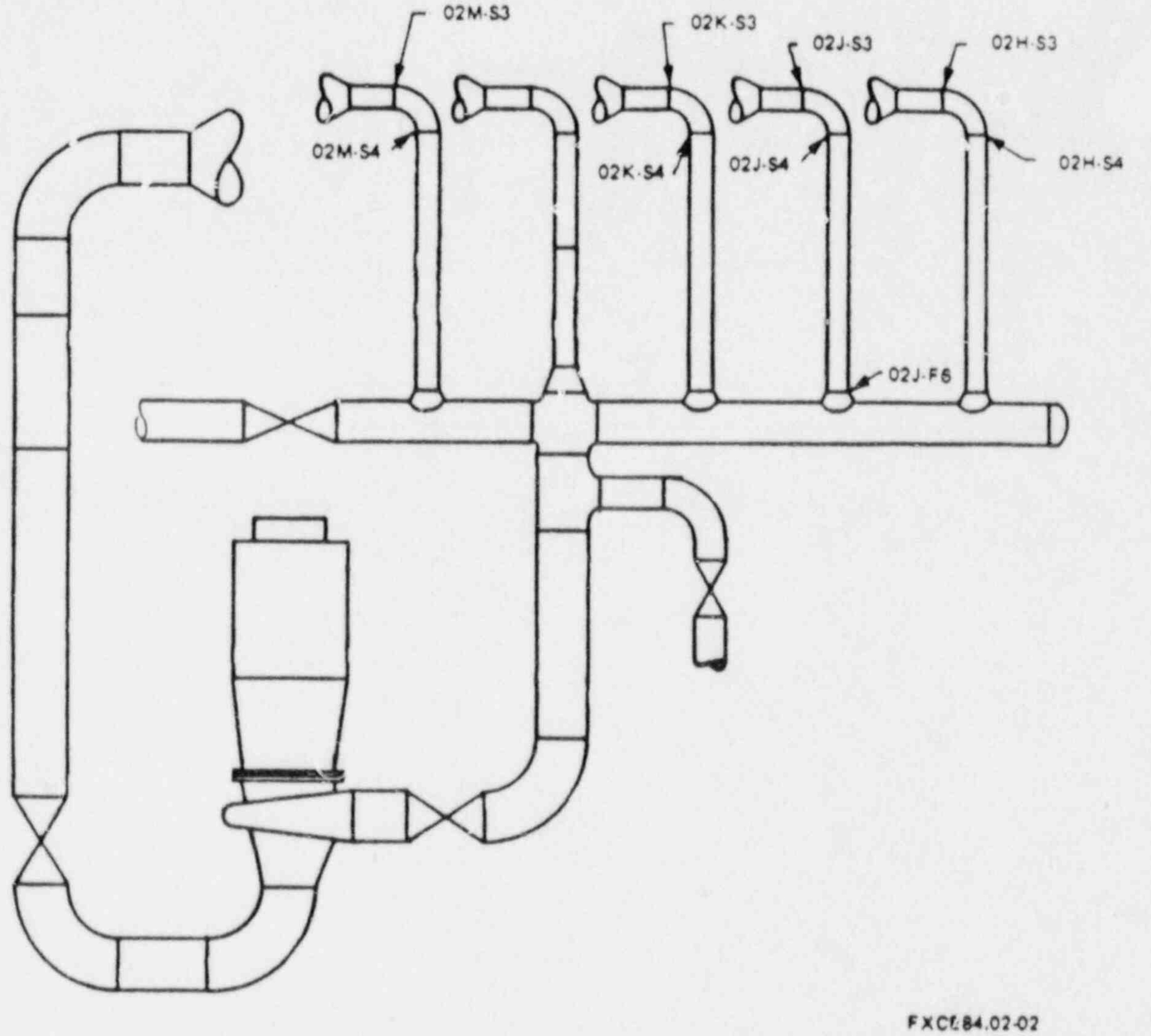

Figure 1.0-1

QUAD CITIES UNIT 1

FLAWED WELD LOCATIONS

REACTOR RECIRCULATION SYSTEM LOOP "A"

(Reference 3)

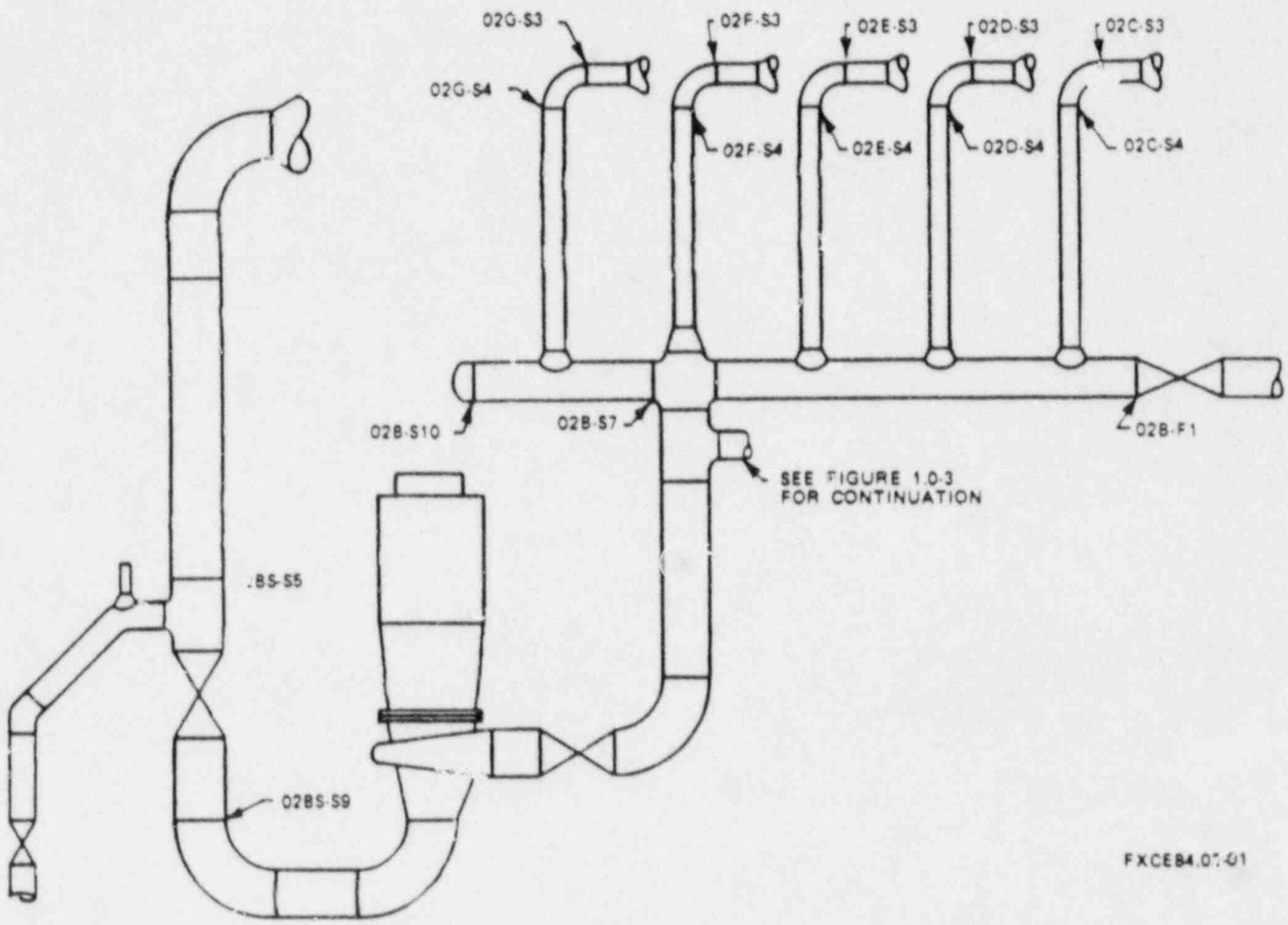

Figure 1.0-2

QUAD CITIES UNIT 1

FLAWED WELD LOCATIONS

REACTOR RECIRCULATION SYSTEM LOOP "B"

(Reference 3)

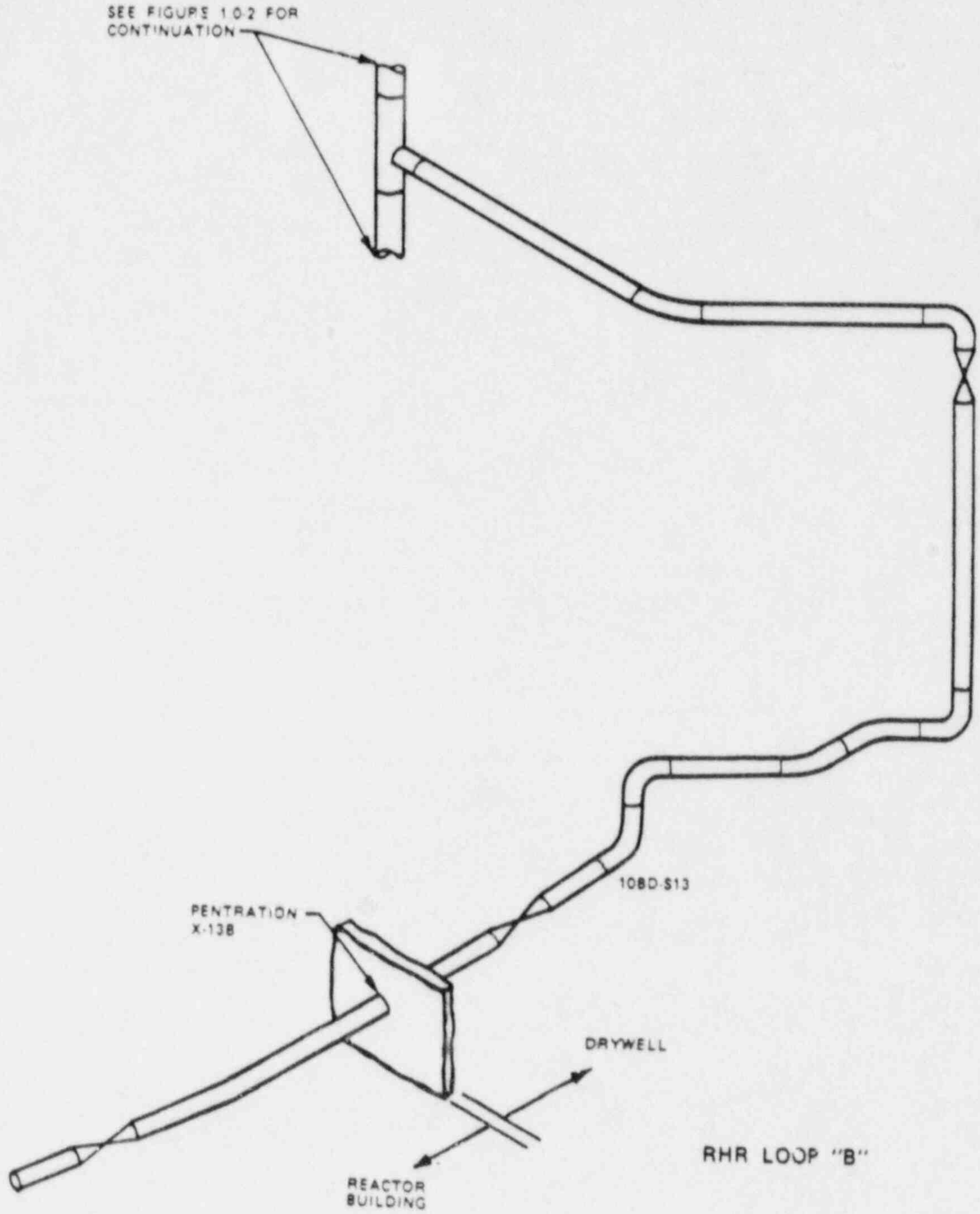

Figure 1.0-3

QUAD CITIES UNIT 1

FLAWED WELD LOCATIONS

RESIDUAL HEAT REMOVAL (RHR) SYSTEM LOOP "B"

(Reference 4)

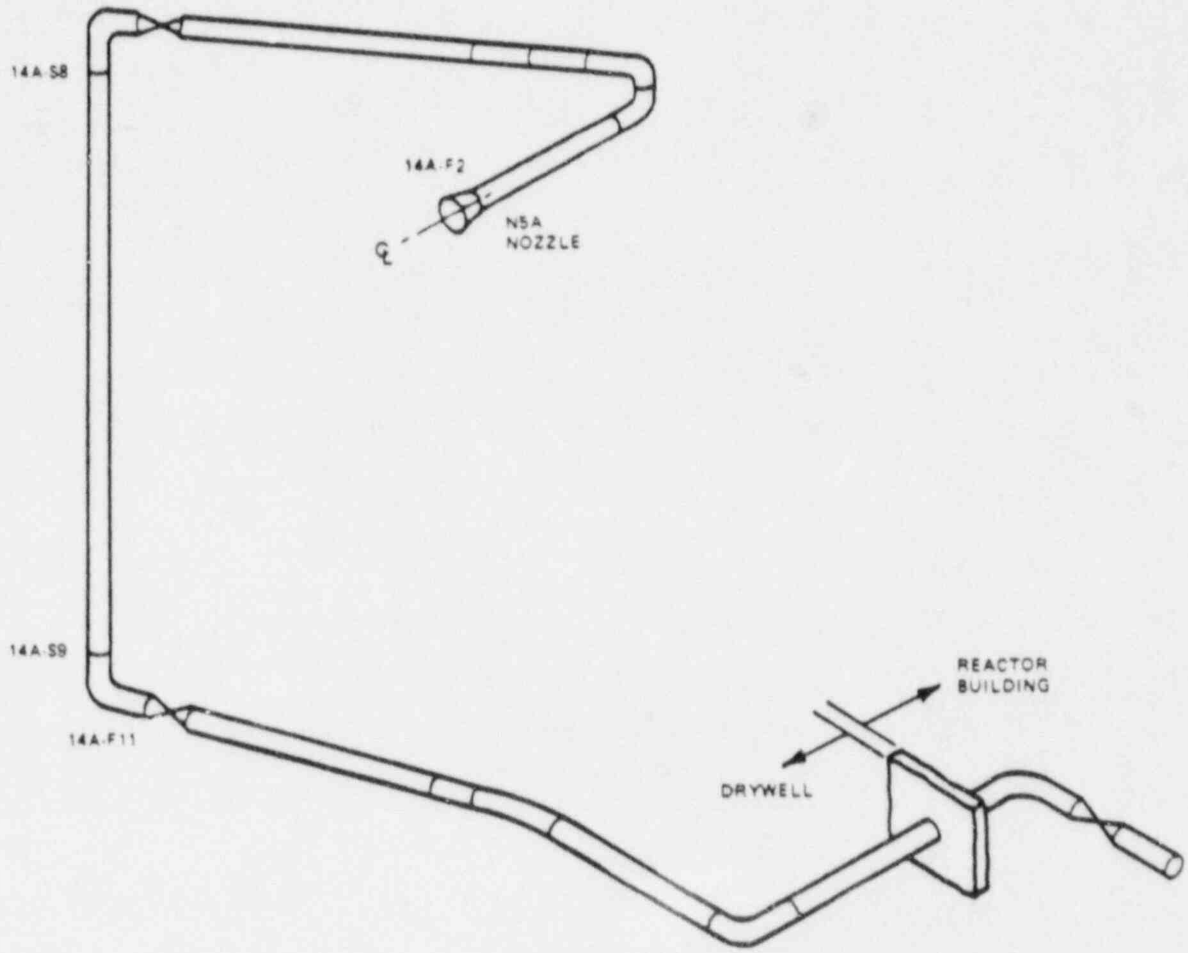

Figure 1.0-4

QUAD CITIES UNIT 1

FLAWED WELD LOCATIONS

CORE SPRAY SYSTEM LOOP "A"

(Reference 5)

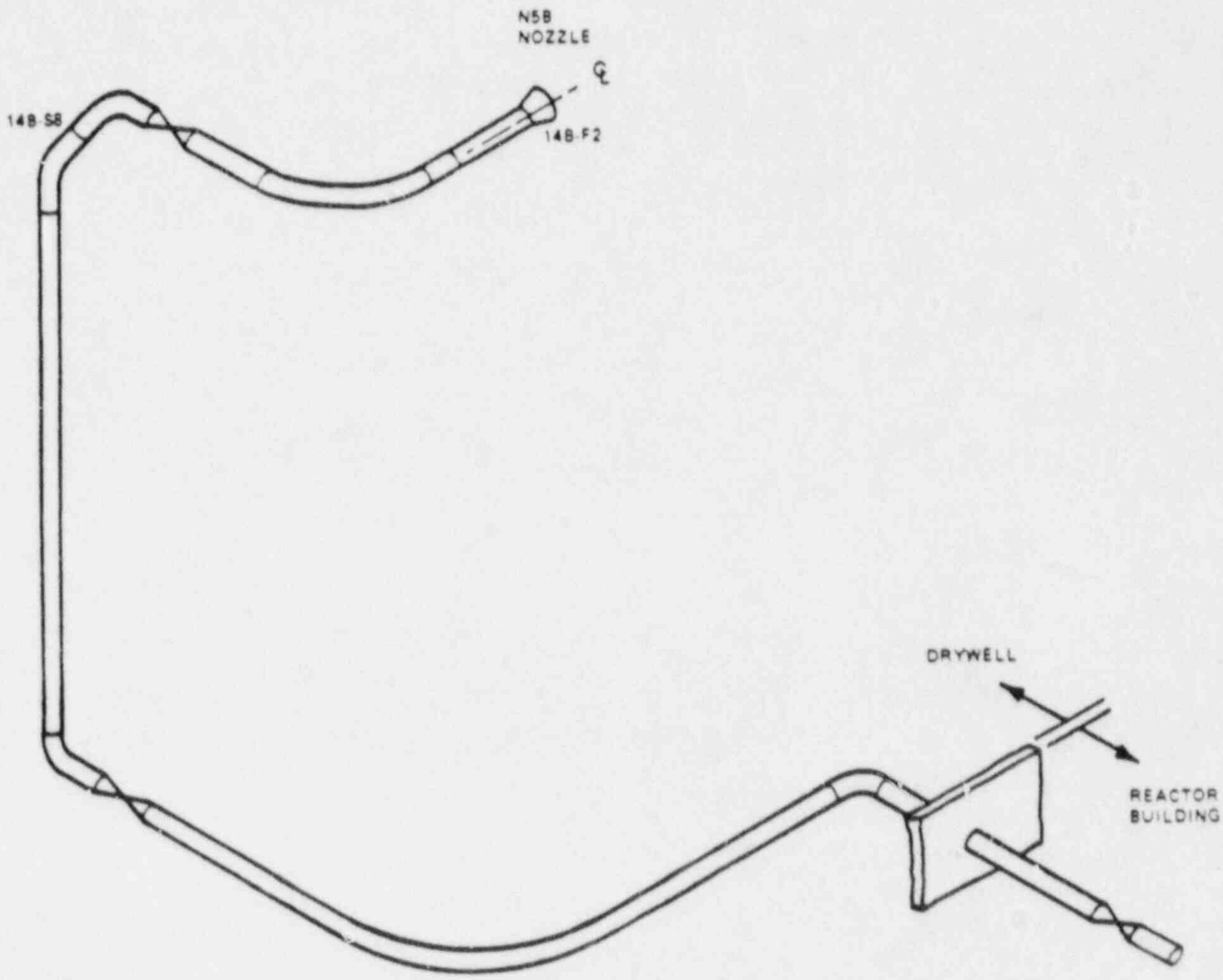

Figure 1.0-5

QUAD CITIES UNIT 1

FLAWED WELD LOCATIONS

CORE SPRAY SYSTEM LOOP "B"

(Reference 5)

2.0 REPAIR DESCRIPTION

The weld overlay repairs implemented at Quad Cities Unit 1 can be placed into three categories. The first category is made up of previous weld overlays from the 1984 outage that were built-up during the 1986 and 1987 outages to meet "standard" (full-structural) design requirements and to enable adequate surface finishing for nondestructive examination (NDE) of the overlays. The second category consists of new weld overlays that were applied during the 1987 outage. The third category is a "leak barrier" overlay repair that was applied during the 1984 outage and has had a pipe clamping device on it since that time.

For all these categories, repairs have been made by increasing the pipe wall thickness through the deposition of weld metal 360 degrees around and to either side of the existing weld. The weld-deposited band provides additional wall thickness to restore the original Code safety margin. In addition, the welding process produces a strong compressive residual stress pattern on the inside portion of the pipe wall (as discussed in the Reference 6 paper), which prevents further crack growth. The deposited weld metal is either Type 308L or Type 309L with controlled delta ferrite content so as to be resistant to the propagation of IGSCC. As-built information for all weld overlays is shown in Figure 2.0-1 and Tables 2.0-1 through 2.0-3.

The nondestructive examination (NDE) of each weld overlay repair applied at Quad Cities Unit 1 consisted of the following:

1. Surface examination of the existing pipe surface at new weld overlay repair locations by the liquid-penetrant testing (PT) technique in accordance with ASME Section XI.

2. Delta ferrite content measurement of the first layer of new overlays or the first layer to increase the length of an existing overlay.

3. Enhanced visual examination of the first weld overlay layer for evidence of IGSCC flaws for new and built-up overlays (discoloration, porosity, etc.).

4. Surface examination of the completed weld overlay by the PT technique in accordance with ASME Section XI.

5. For the weld overlay repairs listed in Table 2.0-1, volumetric examination of the completed weld overlay repair and part of the original pipe wall by the ultrasonic testing (UT) technique developed by EPRI.

6. For the weld overlay repairs listed in Tables 2.0-2 and 2.0-3, UT bonding inspection of the overlay to the original pipe surface in accordance with Commonwealth Edison Special Process Procedures utilizing a straight beam technique.

All UT examinations were performed by EPRI-qualified examiners.

Table 2.0-1

QUAD CITIES UNIT 1

BUILT-UP WELD OVERLAY REPAIR DETAILS

1986 AND 1987 OUTAGES

WELD NO.	PIPE SIZE	WOR (1) TYPE	"A" SIDE COMPONENT TYPE	"A" SIDE DIMEN. "A" (2)	"B" SIDE COMPONENT TYPE	"B" SIDE DIMEN. "B" (2)	TOTAL WOR THICK. "t" (3)	FIRST LAYER THICKNESS "tf" (4)
02C-S4	12"	1	Pipe	2.125"	Elbow	2.125"	0.424"	0.088"
02D-S4	12"	1	Pipe	2.125"	Elbow	2.125"	0.374"	N/A
02E-S4	12"	1	Pipe	2.25"	Elbow	2.25"	0.346"	N/A
02F-S4	12"	1	Pipe	2.0"	Elbow	2.0"	0.294"	0.073"
02G-S3	12"	1	Elbow	2.312"	Pipe	2.312"	0.380"	0.150"
02G-S4	12"	1	Pipe	2.25"	Elbow	2.25"	0.331"	N/A
02H-S3	12"	1	Elbow	2.25"	Pipe	2.25"	0.434"	N/A
02H-S4	12"	1	Pipe	2.25"	Elbow	2.25"	0.330"	N/A
02J-F6	12"	1	Sweepolet	1.50"	Pipe	2.0"	0.260"	N/A
02J-S3	12"	1	Elbow	2.25"	Pipe	2.25"	0.397"	N/A
02J-S4	12"	1	Pipe	2.375"	Elbow	2.375"	0.390"	N/A
02K-S3	12"	1	Elbow	2.25"	Pipe	2.25"	0.365"	N/A
02K-S4	12"	1	Pipe	2.25"	Elbow	2.25"	0.315"	N/A
02B-S7	22"	4	Cross	N/A	Pipe	2.50"	0.559"	0.102"
02B-S10	22"	1	Pipe	3.375"	End Cap	2.375"	0.507"	N/A

NOTES:

1. See Figure 2.0-1 for weld overlay repair (WOR) detail types.
2. "A" and "B" dimensions are within 0.125" accuracy.
3. Total WOR thickness on flawed side of weld.
4. First layer thickness, tf, if low delta ferrite was measured.

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Table 2.0-2

QUAD CITIES UNIT 1

NEW WELD OVERLAY REPAIR DETAILS

1987 OUTAGE

WELD NO.	PIPE SIZE	WOR (1) TYPE	"A" SIDE COMPONENT TYPE	"A" SIDE DIMEN. "A" (2)	"B" SIDE COMPONENT TYPE	"B" SIDE DIMEN. "B" (2)	TOTAL WOR THICK. "t"
14A-F2	10"	3	Pipe	2.250"	Safe End	N/A	0.200"
14A-F11	10"	3	Valve	N/A	Elbow	1.250"	0.191"
14A-S8	10"	2	Pipe	1.75"	Elbow	1.75"	0.236"
14A-S9	10"	2	Elbow	1.375"	Pipe	1.375"	0.187"
14B-F2	10"	3	Pipe	2.00"	Safe End	N/A	0.194"
14B-S8	10"	2	Elbow	1.50"	Elbow	1.50"	0.154"
02C-S3	12"	2	Elbow	2.25"	Pipe	2.25"	0.160"
02D-S3	12"	2	Elbow	2.00"	Pipe	2.00"	0.185"
02E-S3	12"	2	Elbow	2.125"	Pipe	2.125"	0.179"
02F-S3	12"	2	Elbow	2.125"	Pipe	2.125"	0.309"
02M-S4	12"	2	Pipe	2.00"	Elbow	2.00"	0.321"
02B-F1	22"	3	Pipe	4.375"	Valve	N/A	0.185"
02BS-S5	28"	2	Pipe	1.50"	Tee	1.50"	0.231"
02BS-S9	28"	2	Pipe	4.75"	Elbow	4.75"	0.172"

NOTES:

1. See Figure 2.0-1 for weld overlay repair (WOR) detail types.
2. "A" and "B" dimensions are within 0.125" accuracy.

Table 2.0-3

QUAD CITIES UNIT 1

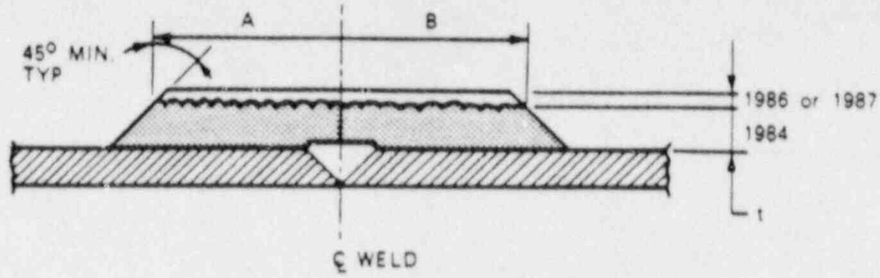
PIPE CLAMPED WELD OVERLAY REPAIR DETAILS

1984 OUTAGE

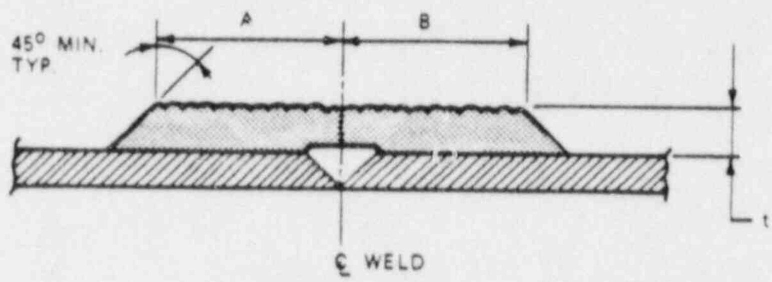
			'A' SIDE		'B' SIDE		TOTAL
WELD NO.	PIPE SIZE	WOR (1) TYPE	COMPONENT TYPE	DIMEN. 'A' (2)	COMPONENT TYPE	DIMEN. 'B' (2)	WOR THICK. "t"
02M-S3	12"	1	Elbow	1.625"	Pipe	2.25"	0.137"

NOTES:

1. See Figure 2.0-1 for weld overlay repair (WOR) detail types.
2. 'A' and 'B' dimensions are within 0.125" accuracy.



Type 1



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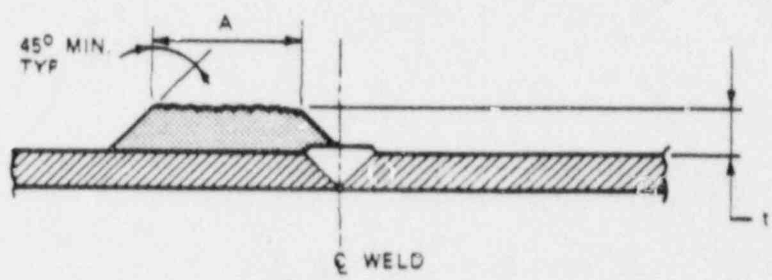
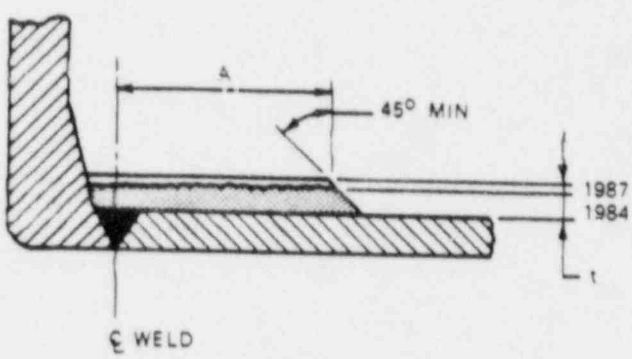


Type 3



Type 4

Figure 2.0-1

GENERAL WELD OVERLAY REPAIR DETAILS

1987 OUTAGE

(U.S. Patent No. 4,624,402)

3.0 EVALUATION CRITERIA

3.1 Stress-Improved Weld Evaluation

For the Quad Cities Unit 1 1987 outage, NUTECH has performed flawed pipe evaluations for Welds 10BD-S13, 02B-F1, 02BS-S5, and 02BS-S9 to justify continued operation. Weld 10BD-S13 (see Table 1.0-6) was MSIP-mitigated during the 1987 outage. Welds 02B-F1, 02BS-S5, and 02BS-S9 (see Table 1.0-4) were stress-improved during the 1987 outage through the use of residual stress improvement "leak barrier" overlay repairs (see Table 2.0-2). The following criteria were used in the evaluation:

1. The beginning-of-fuel cycle (evaluation period) bounding flaw size used in the crack growth analysis was the as-measured flaw depth by 360 degree circumferential length (conservative).

2. The prediction of end-of-fuel cycle (evaluation period) flaw depth was based upon a conservative IGSCC crack growth correlation from NUREG-0313 (Reference 7) as shown in Figure 3.1-1 for a combination of dead weight, internal pressure, differential thermal expansion, and weld overlay shrinkage stresses (caused by weld overlay repair of other welds in the piping system).

3. The calculation of IGSCC flaw growth was based upon conservative original butt-weld, post-IHSI, post-MSIP, and under-the-overlay axial through-wall residual stress distributions.

4. The prediction of end-of-fuel cycle (evaluation period) flaw length was based upon the crack length extension guidelines of NUREG-0313.

5. The predicted end-of-fuel cycle (evaluation period) flaw geometry was compared to Table IWB-3641-5 (Reference 8) allowable flaw size values for a combination of dead weight, internal pressure, seismic, differential thermal expansion, and weld overlay shrinkage stresses.

For Welds 02B-F1, 02BS-S5, and 02BS-S9, the thicknesses of the residual stress improvement "leak barrier" overlay repairs were included in the overall pipe wall thickness used in the flawed pipe evaluations. Because these three welds also contain axial flaw indications, the overlay repairs applied to these welds were evaluated in accordance with the axial flaw criteria described in Section 3.2.

3.2 Conventional Weld Overlay Repair Evaluation

The following criteria were used by NUTECH to design/evaluate all of the weld overlay repairs shown in Tables 2.0-1 through 2.0-3 (except circumferential flaws in Welds 02B-F1, 02BS-S5, and 02BS-S9) that have been implemented or built-up at Quad Cities Unit 1:

1. For welds with circumferential flaws, the circumferential flaw depth was assumed to equal 100% of the original pipe wall thickness by a conservative 360 degree length.

2. For welds with axial flaws, the axial flaw depth was assumed to be a minimum of 100% of the original

pipe wall thickness with a depth equal to the greater of 1.5 times the pipe wall thickness or its measured length. If an axial flaw was drawn up into the overlay due to a steam blow-out, the actual flaw depth was used.

3. Credit was taken for the first layer if the delta ferrite content was at least 7.5 FN. If the ferrite content was below this value, any circumferential or axial flaws were assumed to extent through the first layer.

4. Under-the-overlay repair fatigue crack growth for circumferential and axial flaws was calculated for a 30 year design life based upon a conservative fatigue crack growth correlation derived from data presented in EPRI Document NP-2423-LD (Reference 9).

5. For circumferential flaws, the weld overlay repair strength for a combination of dead weight, internal pressure, and seismic stresses was compared to the net section plastic collapse criteria of ASME Section XI, Table IWB-3641-1. Because this table has an arbitrary cut-off point at a stress ratio of 0.6, NUTECH has developed an expanded version (Table 3.2-1) based upon the Table IWB-3641-1 source equations shown in Figure 3.2-1.

6. For axial flaws, the weld overlay repair was compared to "leak barrier" weld overlay repair criteria presented in Table 3.2-2 from NUTECH Document COM-76-001 (Reference 10).

3.3 Weld 02B-S7 Overlay Repair Evaluation

All of the weld overlay repairs shown in Table 2.0-1 have a center of original butt-weld-to-overlay shoulder length approximately equal to the square root of the original pipe wall thickness times mean radius except for Weld 02B-S7 (this simple rule-of-thumb for acceptable weld overlay repair length has been demonstrated both analytically and experimentally by NUTECH and others). Because of a branch line that would not permit the automated welding machine application of a full length overlay at Weld 02B-S7, an overlay length to the pipe side of this weld of only 2.5" was achieved. End effects created by this shortened overlay affect an assumed through-wall-by-360° flaw on the pipe side of this weld to a greater degree than an assumed flaw on the tee side. Therefore, in addition to the weld overlay repair thickness evaluation criteria discussed in Section 3.2, the stress intensity results of an axisymmetric linear elastic finite element analysis for an assumed through-wall-by-360° flaw on the pipe side of Weld 02B-S7 were compared to ASME Section III (Reference 11), Subsection NB allowable stress intensity criteria. Because this weld had only a single axial flaw indication on its pipe side during the 1984 outage and a single post-overlay axial flaw indication on its tee side during the 1987 outage, only a "leak barrier" overlay repair is required for this weldment. Therefore, the "standard" overlay repair thickness applied to this weld is very conservative.

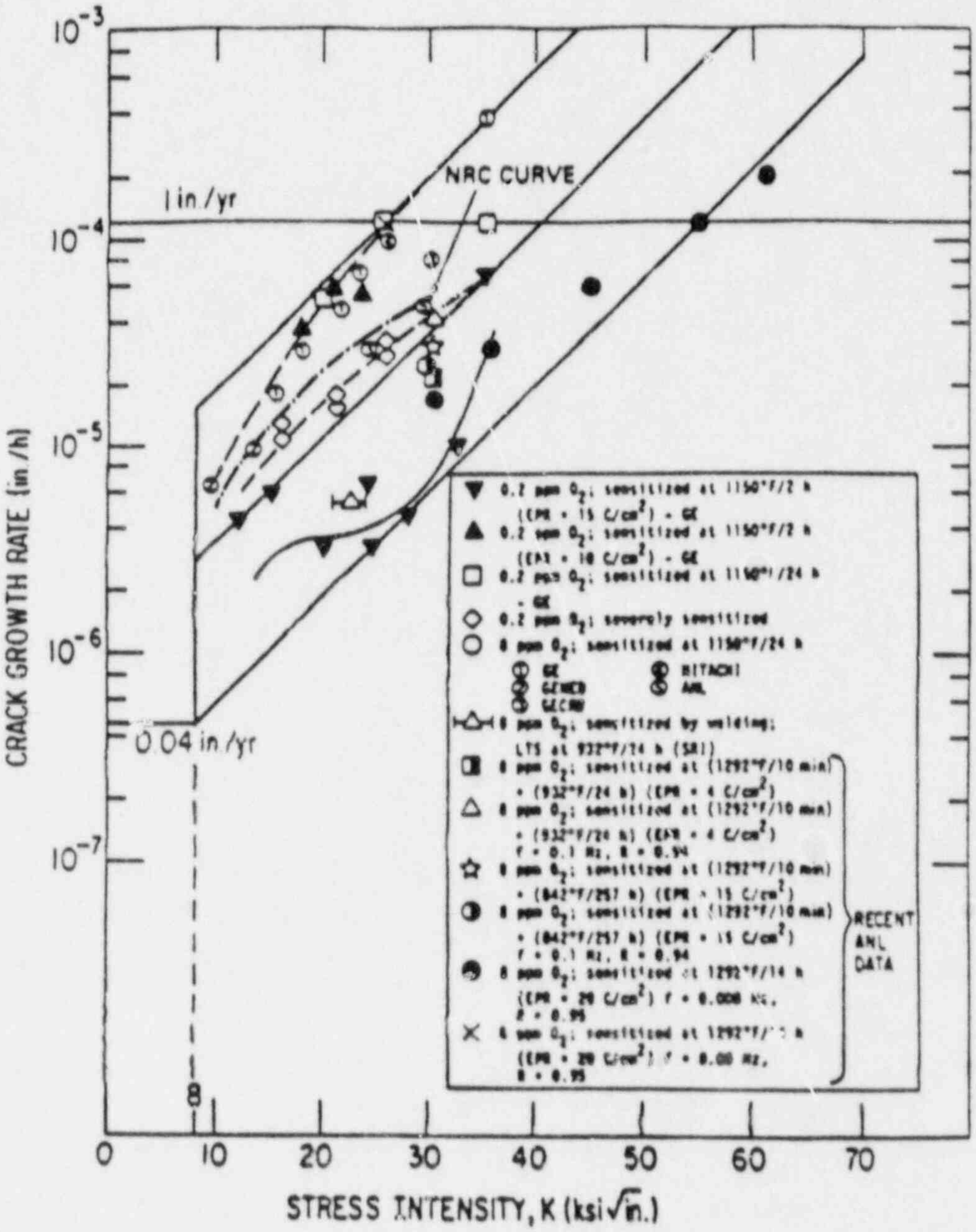


Figure 3.1-1

NUREG-0313

STRESS-CORROSION CRACK GROWTH RATES

(Reference 7)

Table 3.2-1

EXPANDED ALLOWABLE END-OF-EVALUATION PERIOD

FLAW DEPTH(1)-TO-THICKNESS RATIO FOR CIRCUMFERENTIAL FLAWS

NOPMAL OPERATING CONDITIONS

$\frac{P_m + P_b}{S_m}$ [Note (2)]	Ratio of Flaw Length, ℓ_f, to Pipe Circumference [Note (3)] 0.0	0.1	0.2	0.3	0.4	0.5 or More
1.5	(4)	(4)	(4)	(4)	(4)	(4)
1.4	0.75	0.40	0.21	0.15	(4)	(4)
1.3	0.75	0.75	0.39	0.27	0.22	0.19
1.2	0.75	0.75	0.56	0.40	0.32	0.27
1.1	0.75	0.75	0.73	0.51	0.42	0.34
1.0	0.75	0.75	0.75	0.63	0.51	0.41
0.9	0.75	0.75	0.75	0.73	0.59	0.47
0.8	0.75	0.75	0.75	0.75	0.68	0.53
0.7	0.75	0.75	0.75	0.75	0.75	0.58
0.6	0.75	0.75	0.75	0.75	0.75	0.63
0.5 (5)	0.75	0.75	0.75	0.75	0.75	0.68
0.4 (5)	0.75	0.75	0.75	0.75	0.75	0.73
0.36 (5)	0.75	0.75	0.75	0.75	0.75	0.75

NOTES:

(1) Flaw depth = a_n for a surface flaw
$2a_n$ for a subsurface flaw
t = nominal thickness
Linear interpolation is permissable.

(2) P_m = primary membrane stress
P_b = primary bending stress
S_m = allowable design stress intensity (in accordance with Section III)

(3) Circumference based on nominal pipe diameter.

(4) IWB-3514.3 shall be used.

(5) Derived using source equations.

Table 3.2-2

LEAK BARRIER REPAIR CRITERIA

FOR AXIAL FLAWS

(Reference 10)

STRESS RATIO	NONDIMENSIONAL FLAW LENGTH $\ell_f / \sqrt{RT}$						
	0.00	0.25	0.50	1.00	2.00	.....	
≤ 0.40	*	*	*	*	→		IWB-3640
0.50	*	*	*	*	→		IWB-3640
0.60	*	*	*	*	→		IWB-3640
0.70	*	*	*	*	→		IWB-3640
0.80	*	*	*	*	→		IWB-3640
0.90	*	*	*	→	→		IWB-3640
0.95	*	*	→	→	→		IWB-3640
1.00	→	→	→	→	→		IWB-3640

* LEAK BARRIER ONLY REQUIRED

BCOM84.01

STRESS RATIO = $PD / 2 T S_m$

P = MAXIMUM PRESSURE FOR NORMAL OPERATING CONDITIONS

D = NOMINAL OUTSIDE DIAMETER OF THE PIPE

T = NOMINAL THICKNESS

ℓ_f = END-OF-EVALUATION PERIOD FLAW LENGTH

R = NOMINAL RADIUS OF THE PIPE

For $\alpha + \beta < 180^0$

$$\beta = \frac{\frac{5}{6}\pi - \alpha \frac{a}{t}}{2} \text{ (radians)}$$

$$2.773\,(SR) - 0.5 - \frac{6}{\pi}\left(2 \sin \beta - \frac{a}{t} \sin \alpha\right) = 0$$

For $\alpha + \beta \geq 180^0$

$$\beta = \frac{\pi\left(\frac{5}{6} - \frac{a}{t}\right)}{2 - \frac{a}{t}} \text{ (radians)}$$

$$2.773\,(SR) - 0.5 - \frac{6}{\pi}\left(2 - \frac{a}{t}\right) \sin \beta = 0$$

Where:

α = half-crack length (radians)
β = neutral axis location angle (radians)
a = flaw depth (inches)
t = pipe thickness (inches)
SR = stress ratio = $\frac{Pm + Pb}{Sm}$
Pm = primary membrane stress
Pb = primary bending stress
Sm = allowable stress intensity (per ASME Section III Appendices)

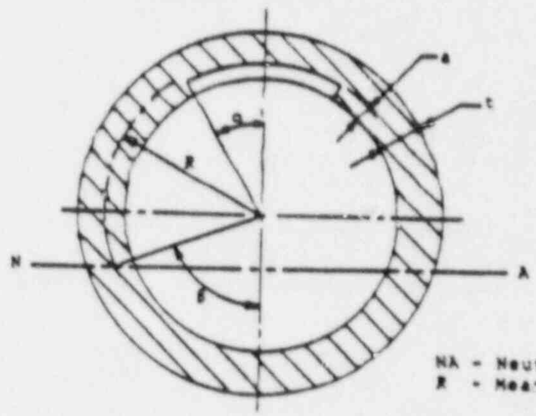


Figure 3.2-1

SOURCE EQUATIONS FOR ALLOWABLE END-OF-EVALUATION PERIOD FLAW DEPTH-TO-THICKNESS RATIOS FOR CIRCUMFERENTIAL FLAWS

4.0 APPLIED AND RESIDUAL STRESSES

Various stress combinations are used in evaluating IGSCC flaws and repairs as explained in Section 3.0. The purpose of this section is to present the stresses acting on the weld locations discussed in this report.

4.1 Primary Stresses

Primary stresses include the effects of dead weight, internal pressure, and seismic loads. The design pressure of 1,250 psi was obtained from the original piping design specification (Reference 12). The dead weight and seismic stresses applied to each weld were obtained from References 13 and 14, respectively. The primary stresses associated with these various loads are shown in Table 4.1-1.

4.2 Secondary Stresses

Secondary stresses include piping system differential thermal expansion stresses and through-pipe wall thermal gradient stresses caused by piping system thermal transients; weld overlay shrinkage-induced stresses; and original butt-weld, post-IHSI, post-MSIP, and under-the-overlay through-wall residual stresses.

1. Thermal Stresses and Transients

   The piping system differential thermal expansion stresses for each weld were obtained from Reference 13 and are shown in Table 4.1-1.

   Reference 1 defines the design transients for the recirculation systems for Quad Cities Unit 1.

These transients were conservatively grouped into three composite transients. The first composite transient is a startup/shutdown transient with a heatup or cooldown rate of 100 degree F per hour. The second composite transient consists of a 50 degree F step temperature change with no change in system internal pressure. The third composite transient is an emergency event with a 416 degree F step temperature change and a system internal pressure change of 75 psi. Figure 4.2-1 presents the number of cycles conservatively postulated during a 30-year balance-of-plant life design. These transients cause the through-wall temperature gradients detailed in Figure 4.2-2.

2. Weld Overlay Shrinkage-Induced Stresses

Each weld overlay causes a small amount of axial shrinkage underneath the overlay. This shrinkage induces bending stresses in the remainder of the piping system. These shrinkage-induced stresses are calculated using NUTECH computer program PISTAR (Reference 15). The actual as-built shrinkages as shown in Table 4.2-1 are used in the analysis. The resulting shrinkage stresses are included in the IGSCC crack growth analysis of stress-improved welds and are shown in Table 4.2-2.

3. Residual Stresses

Figure 4.2-3 presents the original butt-weld axial through-wall residual stress distribution from NUREG-0313 (Reference 7) used in the IGSCC crack growth evaluation of Welds 10BD-S13, 02B-F1, 02BS-S5, and 02BS-S9. Figure 4.2-4 presents the post-IHSI through-wall residual stress distribution from EPRI Document NP-2662-LD (Reference 16) used for Welds 02B-F1, 02BS-S5, and 02BS-S9. Figure 4.2-5 presents the post-MSIP through-wall axial residual stress distribution from an O'Donnell and Associates document (Reference 17) used for Weld 10BD-S13.

Figure 4.2-6 presents the under-the-overlay through-wall axial residual stress distributions used for Welds 02B-F1, 02BS-S5, and 02BS-S9. These distributions were determined using the WELDS II computer program (Reference 18).

Table 4.1-1

QUAD CITIES UNIT 1

PRIMARY AND THERMAL EXPANSION AXIAL STRESSES (1)

WELD NO.	PIPE SIZE	PRESSURE STRESS (PSI)	DEADWEIGHT STRESS (PSI)	THERMAL STRESS (2) (PSI)	OBE STRESS (PSI)	WELD NO.	PIPE SIZE	PRESSURE STRESS (PSI)	DEADWEIGHT STRESS (PSI)	THERMAL STRESS (2) (PSI)	OBE STRESS (PSI)
14A-F2	10"	4247	371	N/A	1737	02H-S3	12"	3861	51	N/A	125
14A-F11	10"	4087	225	N/A	100	02H-S4	12"	3918	50	N/A	98
14A-S8	10"	3870	101	N/A	322	02J-F6	12"	4721	282	N/A	217
14A-S9	10"	4736	99	N/A	136	02J-S3	12"	3992	94	N/A	140
14B-F2	10"	4397	339	N/A	650	02J-S4	12"	4029	67	N/A	71
14B-S8	10"	4534	165	N/A	315	02K-S3	12"	4181	133	N/A	134
02C-S3	12"	3236	466	N/A	285	02K-S4	12"	4432	45	N/A	116
02C-S4	12"	3945	222	N/A	161	02M-S3	12"	3428	922	N/A	301
02D-S3	12"	5102	268	N/A	96	02M-S4	12"	3846	323	N/A	238
02D-S4	12"	4091	127	N/A	48	1090-S13	16"	6925	107	3306	2000 (3)
02E-S3	12"	3095	212	N/A	136	02B-F1	22"	6445	342	522	369
02E-S4	12"	4163	102	N/A	80	02B-S7	22"	4621	61	4780	297
02F-S3	12"	4621	61	N/A	297	02B-S10	22"	4505	0	N/A	0
02F-S4	12"	3770	177	N/A	136	02BS-S5	28"	3949	199	3296	448
02G-S3	12"	4041	170	N/A	229	02BS-S9	28"	6787	88	660	125
02G-S4	12"	3945	68	N/A	131						

NOTES:

1. Based on as-built weld overlay repair thickness, where applicable, plus original pipe wall thickness.

2. Thermal stresses reported at stress-improved flawed welds only.

3. Assumed value.

Table 4.2-1

QUAD CITIES UNIT 1

TOTAL AS-BUILT WELD OVERLAY SHRINKAGES

WELD NO.	AXIAL SHRINKAGE (IN.)	WELD NO.	AXIAL SHRINKAGE (IN.)
14A-F2	0.102	02G-S4	0.304
14A-F11	0.063	02H-S3	0.239
14A-S8	0.174	02H-S4	0.389
14A-S9	0.140	02J-F6	0.198
14B-F2	0.083	02J-S3	0.367
14B-S8	0.112	02J-S4	0.313
02C-S3	0.203	02K-S3	0.480
02C-S4	0.316	02K-S4	0.220
02D-S3	0.148	02M-S3	0.173
02D-S4	0.197	02M-S4	0.265
02E-S3	0.195	02B-F1	0.097
02E-S4	0.242	02B-S7	0.110
02F-S3	0.231	02B-S10	N/A
02F-S4	0.319	02BS-S5	0.032
02G-S3	0.270	02BS-S9	0.088

* Total of axial shrinkages recorded during 1984, 1986, and 1987 outages.

Table 4.2-2

QUAD CITIES UNIT 1

WELD OVERLAY REPAIR AXIAL SHRINKAGE STRESSES

WELD NO.	WOS* STRESS (PSI)
10BD-S13	692
02B-F1	860
02BS-S5	76
02BS-S9	172

* Weld overlay shrinkage (WOS) at stress-improved flawed welds only.

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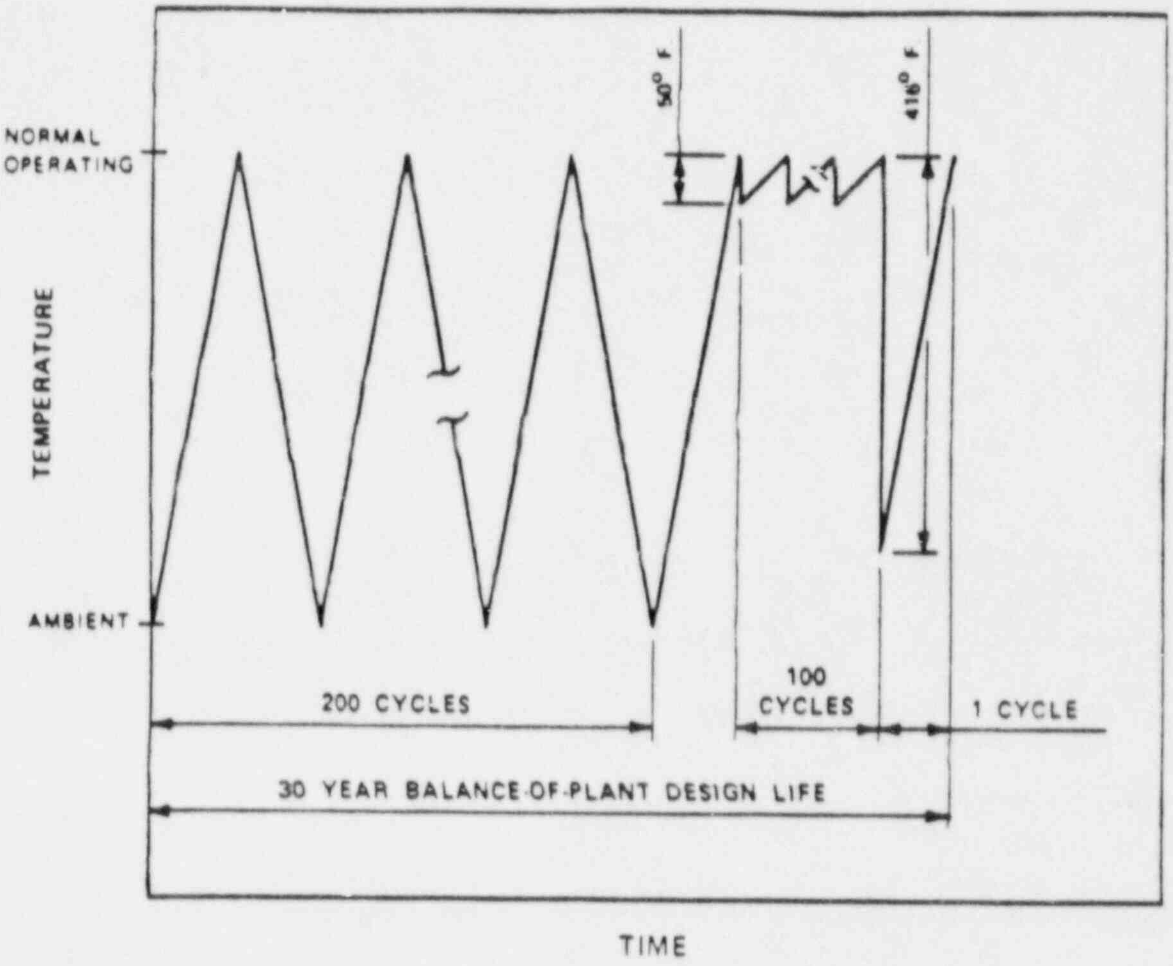
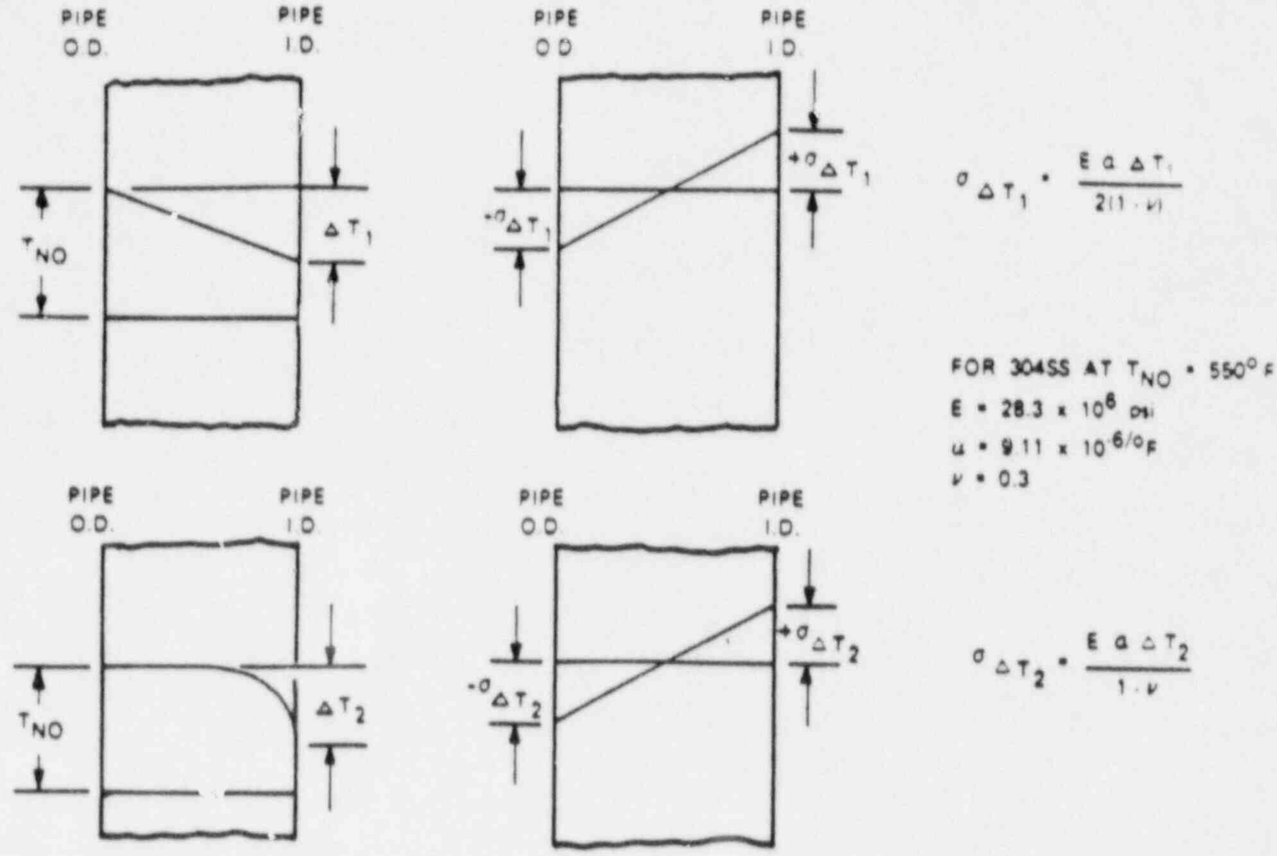


Figure 4.2-1

QUAD CITIES UNIT

THERMAL TRANSIENTS



Pipe Diameter	Parameter	Thermal Transient Cycles: Start-up/ Shutdown	50°F Step Change	416°F Step Change
10" & 12"	ΔT_1	2°F	32°F	265°F
	ΔT_2	0°F	8°F	64°F
20" to 28"	ΔT_1	6°F	36°F	302°F
	ΔT_2	0°F	9°F	75°F

Figure 4.2-2

QUAD CITIES UNIT 1

THROUGH-WALL TEMPERATURE GRADIENTS

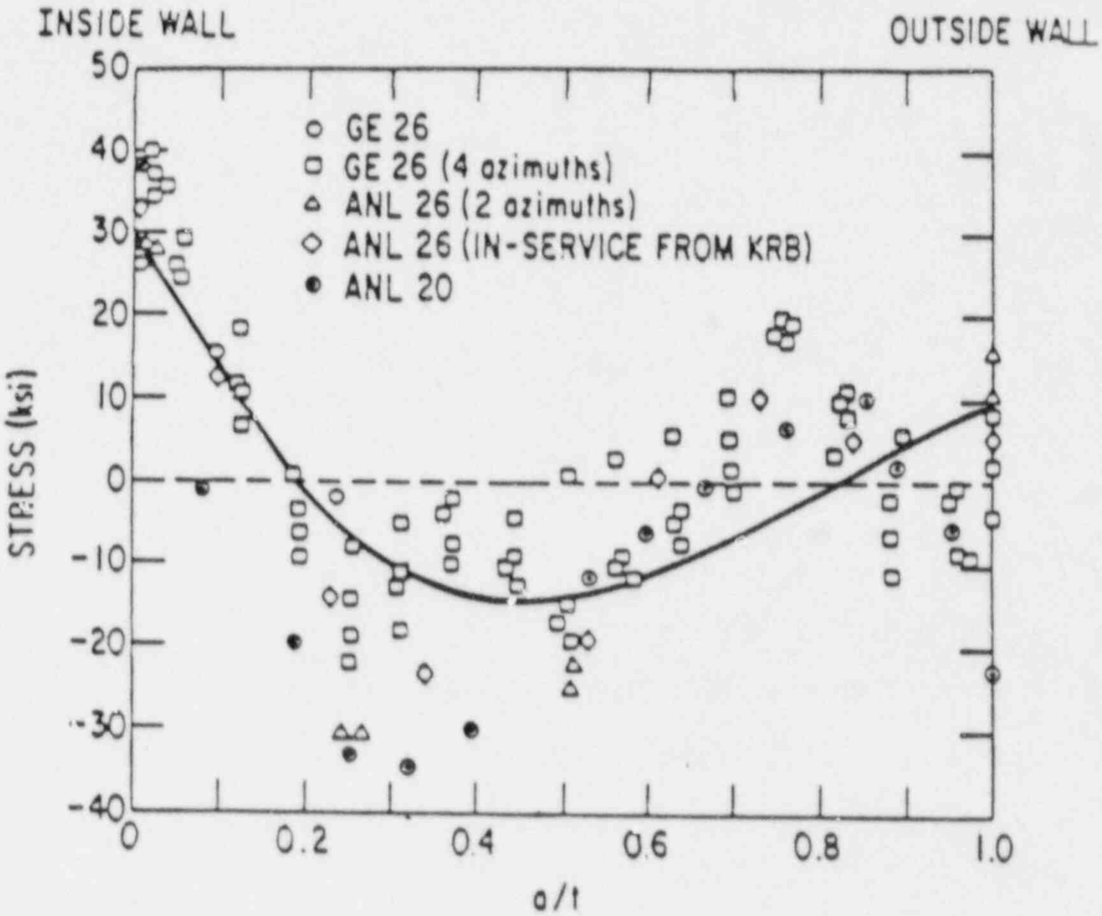


Figure 4.2-3

NUREG-0313 ORIGINAL BUTT-WELD THROUGH-WALL RESIDUAL STRESS DISTRIBUTION

(Reference 7)

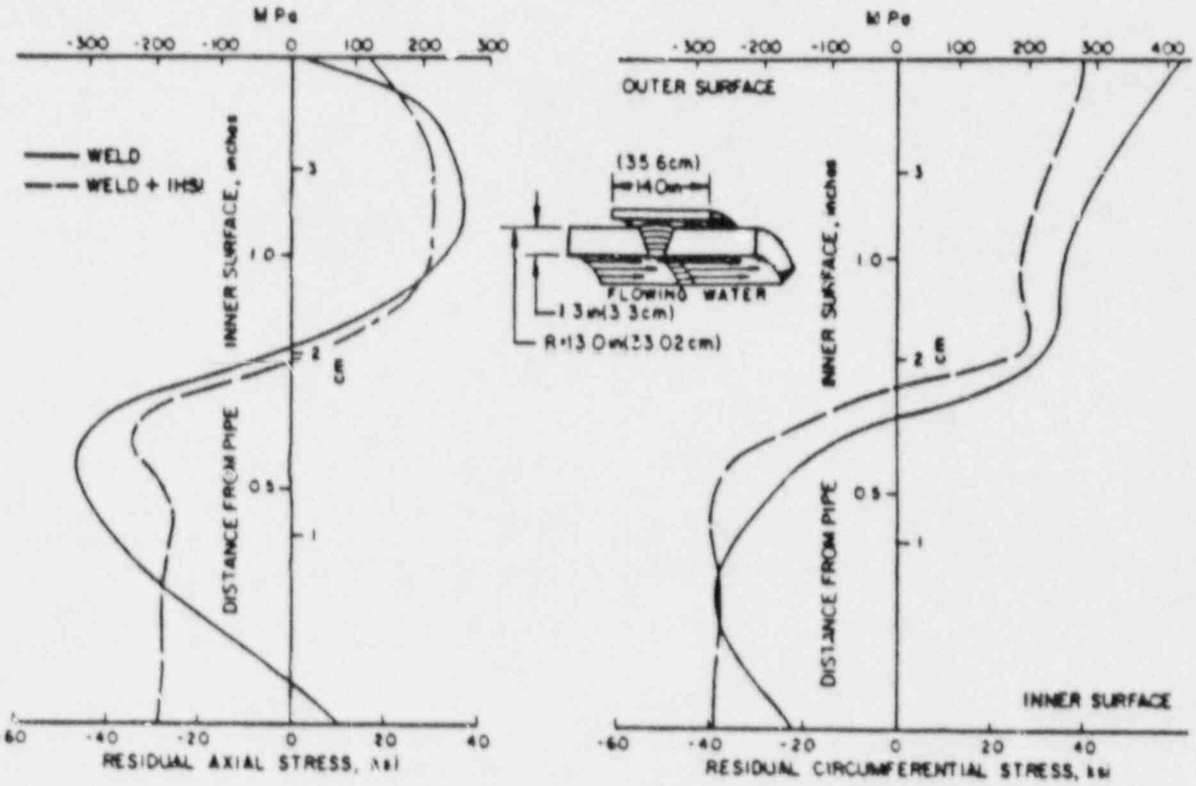


Figure 4.2-4

EPRI POST-IHSI

THROUGH-WALL RESIDUAL STRESS DISTRIBUTION

(Reference 16)

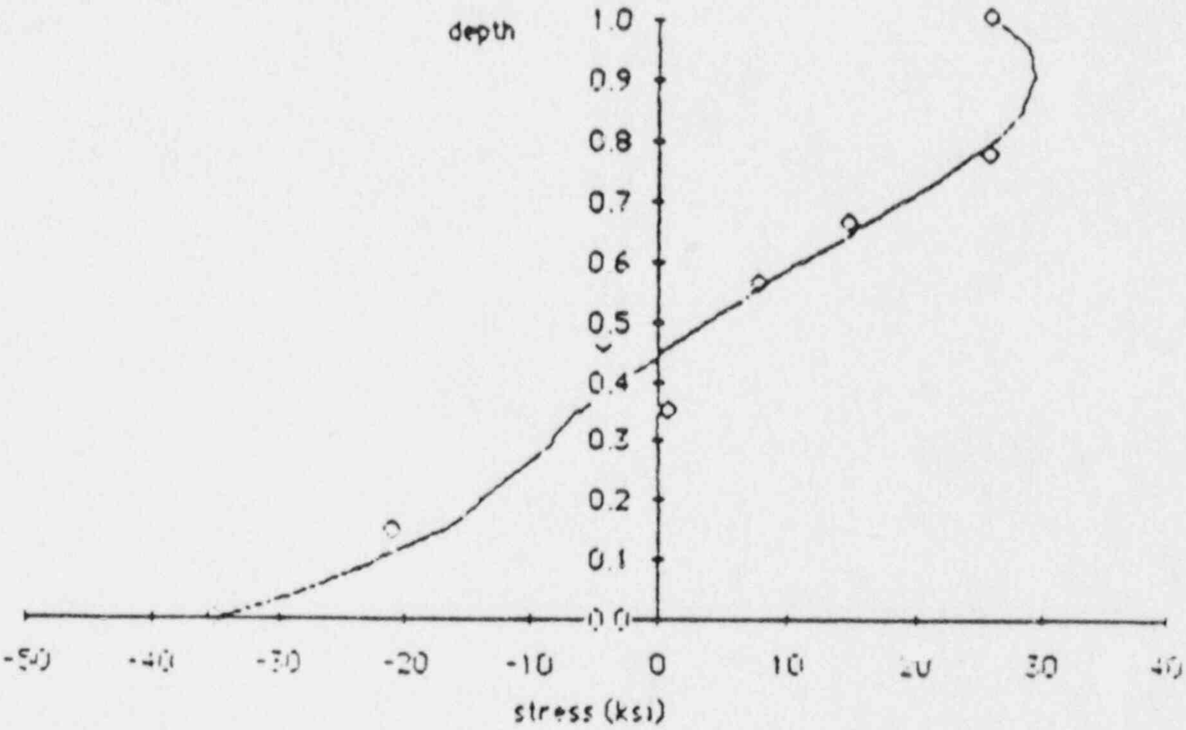
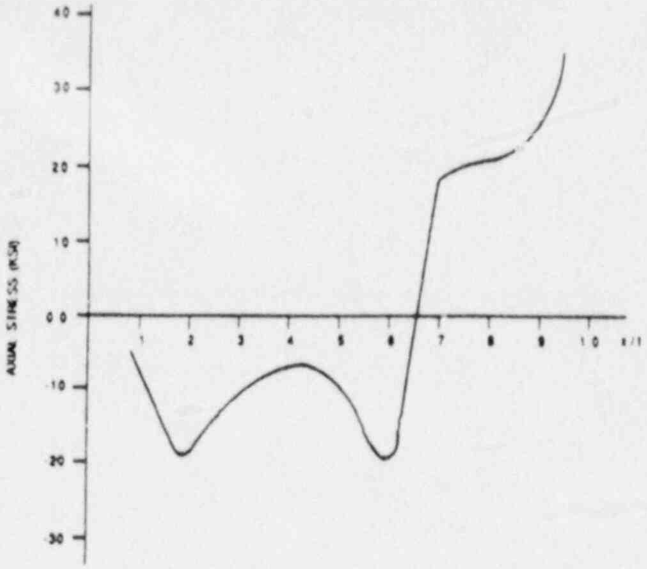


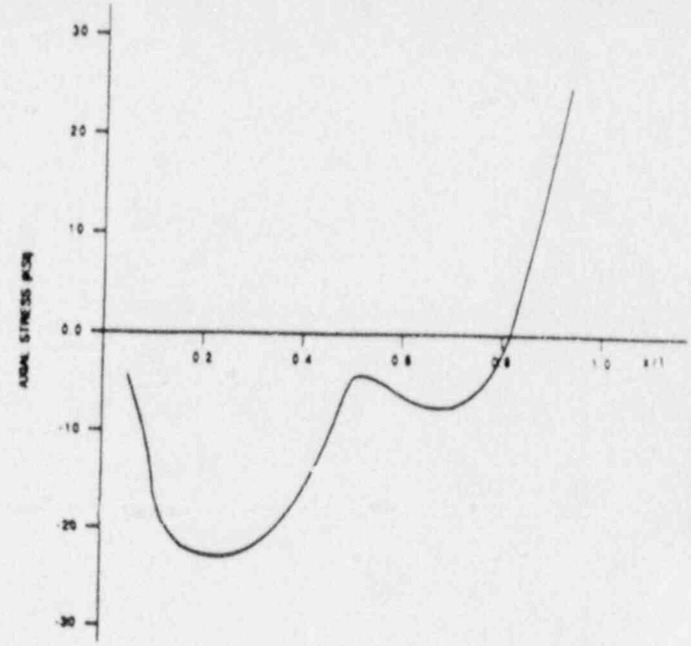
Figure 4.2-5

POST-MSIP THROUGH-WALL RESIDUAL STRESS DISTRIBUTION

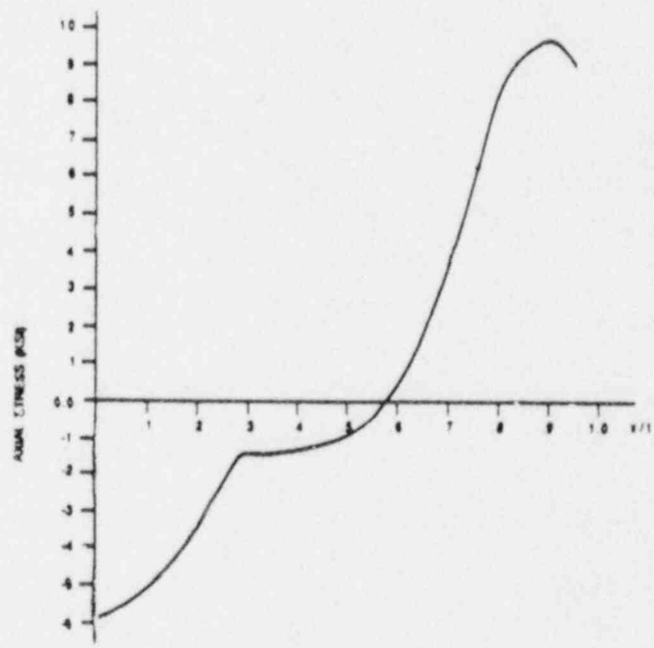
(Reference 17)



22" PIPE TO VALVE



28" PIPE TO ELBOW



28" PIPE TO TEE

Figure 4.2-6

UNDER-THE-OVERLAY THROUGH-WALL RESIDUAL STRESS DISTRIBUTION

5.0 EVALUATION METHODS AND RESULTS

This section presents the evaluation methods and results used to assess the acceptability of the overlay-repaired and stress-improved weld flaw indications at Quad Cities Unit 1.

5.1 Stress-Improved Welds

1. Flawed Pipe Analysis

   Table 5.1-1 presents the pipe and flaw geometric details needed to calculate applied stresses and predict crack growth in the stress-improved flawed welds at Quad Cities Unit 1. NUTECH's NUTCRAK computer program (Reference 19) was used to predict crack growth. The conservative crack growth correlation shown in Figure 5.1-1 f NUREG-0313 (Reference 7) was used where:

   da = differential crack size (inches)
   dt = differential time (hours)
   K = applied stress intensity factor (ksi $\sqrt{in.}$)

   Table 5.1-2 presents the predicted end-of-fuel cycle (evaluation period) flaw depths for the stress-improved flawed welds for the various through-wall residual stress distributions discussed in Section 4.2. Table 5.1-3 presents the predicted end-of-fuel cycle flaw lengths based upon the predicted flaw depth growth and the flaw length extension guidelines discussed in Section 3.1.

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2. Flawed Pipe Evaluation

As discussed in Section 3.1, the predicted end-of-fuel cycle flaw geometries were compared to the requirements of ASME Section XI (Reference 8), Table IWB-3641-5. The results of this evaluation are shown in Table 5.1-4.

5.2 Conventional Weld Overlay Repairs

1. Circumferential Flaw Weld Overlay Repair Evaluation

Table 5.2-1 presents the pipe and flaw geometry details needed to calculate the applied and allowable stress ratios for all the circumferentially flawed overlay-repaired welds at Quad Cities Unit 1 except Welds 02B-F1, 02BS-S5, and 02BS-S9 which are addressed in Section 5.1. Applied stresses are found in Table 4.1-1. Table 5.2-2 presents a comparison of predicted flaw depth ratios due to applied loads versus the allowable flaw depth ratios for the circumferential flaws detailed in Table 5.2-1. As discussed in Section 3.2, the allowable flaw depth ratios shown were calculated using the source equations of ASME Section XI Table IWB-3641-1 with an arbitrary maximum allowable flaw depth ratio of 0.75. As a result, all of the weld overlay repairs shown in Table 5.2-2 meet NUREG-0313, Revision 2 "standard" overlay requirements except for Weld 02G-S3.

Because post-overlay repair surface conditioning grinding provided a final weld overlay repair thickness below NUTECH's requested "standard" overlay repair design thickness, this overlay has a predicted flaw depth ratio (0.77) slightly over the Table IWB-3641-1 maximum allowable flaw depth ratio. Using the alternate flaw evaluation requirements of Paragraph IWB-3642, an applied stress ratio of up to 0.31 is permitted for a flaw ratio fo 0.77 for a net section plastic collapse failure mode (applied stress ratio for Weld 02G-S3 is 0.26). From NUTECH Report CEC-73-205 for Quad Cities Unit 2 Weld 02A-S10 (Reference 21) an applied stress ratio of 0.26 will not cause an unstable tearing failure in a 360° flaw with a depth of up to 80% through-wall (maximum predicted flaw depth ratio for Weld 02G-S3 is 0.77).

Because the Weld 02G-S3 overlay repair meets Paragraph IWB-3642 requirements, only requires 0.03" of additional thickness to meet Paragraph IWB-3641 requirements, and has no detected flaws in its low delta ferrite first layer to date, this weld should be considered as a "standard" overlay to avoid additional man-REM exposure associated with either building-up the overlay thickness or increased UT examinations resulting from the classification of this weld as NUREG-0313 Category F instead of Category E.

2. Axial Flaw Weld Overlay Repair Evaluation

Table 5.2-3 presents the pipe and flaw geometric details needed to determine applied and allowable stress ratios for all the overlay-repaired welds at Quad Cities Unit 1 with axial flaws. Table 5.2-4 presents a comparison of stress ratios for the axial flaws given in Table 5.2-3. The allowable stress ratios shown were determined using the leakage barrier criteria presented in Table 3.2-2.

5.3 Weld 02B-S7 Weld Overlay Repair

Figure 5.3-1 presents the axisymmetric linear elastic finite element model used to evaluate the acceptability of the overlay repair length for Weld 02B-S7 at Quad Cities Unit 1. This model contains a 100% through original pipe wall plus low delta ferrite first layer crack depth with a 360 degree length. The ANSYS computer program (Reference 20) was used to perform this analysis for the applied loads corresponding to the stresses shown in Table 4.1-1. A comparison of the maximum applied stress intensities acting through the weld overlay repair over the assumed crack with ASME Section III (Reference 11), Subsection NB allowable stress intensities is presented in Table 5.3-1.

Table 5.1-1

STRESS-IMPROVED FLAWED WELDS
PIPE AND FLAW GEOMETRIC DETAILS

WELD NO.	NOMINAL O.D. (1) (IN.)	tp (2) (IN.)	to (3) (IN.)	ai (4) (% tp)	ai (4) (IN.)	L (5) (DEGREES)	SUSTAINED STRESS (6) (PSI)
10BD-S13	16.0	0.722	N/A	20	0.144	360	13,230
02B-F1	22.0	1.12	0.185	26	0.291	360	8,169
02BS-S5	28.0	1.24	0.231	25	0.31	360	9,520
02BS-S9	28.0	1.22	0.172	44	0.537	360	7,207

NOTES:

1. O.D. = outside diameter.
2. tp = pipe wall thickness.
3. to = weld overlay repair thickness.
4. ai = beginning-of-fuel cycle (initial) flaw depth.
5. L = crack growth evaluation flaw length.
6. Sustained stress = deadweight + internal pressure + thermal expansion + weld overlay shrinkage stresses from Tables 4.1-1 and 4.2-2.

Table 5.1-2

STRESS-IMPROVED FLAWED WELDS

PREDICTED END-OF-FUEL CYCLE FLAW DEPTHS

WELD NO.	ai (1) (IN.)	af (2) NUREG-0313 R.S. (3) (IN.)	NUREG-0313 R.S. (3) (%(tp+to))	POST-S.I. R.S. (4) (IN.)	POST-S.I. R.S. (4) (%(tp+to))	POST-WOR R.S. (5) (IN.)	POST-WOR R.S. (5) (%(tp+to))
10BD-S13	0.144	0.535	74	0.144	20	N/A	N/A
02B-F1	0.291	0.486	37	0.291	22	0.293	22
02BS-S5	0.31	0.674	46	0.31	21	0.337	23
02BS-S9	0.537	0.709	51	0.537	39	0.537	39

NOTES:

1. ai = beginning-of-fuel cycle (initial) flaw depth.
2. af = end-of-fuel cycle flaw depth.
3. NUREG-0313 residual stress (R.S.) distribution (see Figure 4.2-3).
4. Either IHSI (see Figure 4.2-4) or MSIP (see Figure 4.2-5) post-stress improvement (S.I.) axial residual stress (R.S.) distribution.
5. Under-the-overlay residual stress (R.S.) distributions (see Figure 4.2-6).

Table 5.1-3

STRESS-IMPROVED FLAWED WELDS
PREDICTED END-OF-FUEL CYCLE FLAW LENGTHS

WELD NO.	COMPONENT SIDE	ai (1) (IN.)	Li (2) (IN.)	Li/ai (3)	SHAPE FACTOR (S.F.) (4)	NUREG-0313 R.S. (5) af/ai	NUREG-0313 R.S. (5) Lf (6) (IN.)	POST-S.I. R.S. (5) af/ai	POST-S.I. R.S. (5) Lf (6) (IN.)	POST-WOR R.S. (5) af/ai	POST-WOR R.S. (5) Lf (6) (IN.)
10BD-S13	UPSTREAM	0.144	6.25	43.4	1	3.72	23.2	1	6.25	N/A	N/A
	DNSTREAM	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
						Lf (total)	23.2		6.25		N/A
02B-F1	UPSTREAM	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
	DNSTREAM	0.291	3.0	10.3	af/ai	1.67	8.37	1	3	1.007	3.04
						Lf (total)	8.37		3		3.04
02BS-S5	UPSTREAM	0.31	9.0	29	1	2.17	19.6	1	9.0	1.007	9.78
	DNSTREAM	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
						Lf (total)	19.6		9		9.78
02BS-S9	UPSTREAM	0.537	11.0	20.5	1	1.32	14.5	1	11.0	1	11.0
	DNSTREAM	0.488	12.25	25.1	1	1.45	17.8	1	12.25	1	12.25
						Lf (total)	32.3		23.25		23.25

NOTES:

1. ai = beginning-of-fuel cycle (initial) flaw depth.
   af = end-of-fuel cycle flaw depth.
2. Li = beginning-of-fuel cycle (initial) flaw length.
3. Li/ai = initial flaw size aspect ratio.
4. Per NUREG-0313 (Reference 7);
   a. If Li/ai < 20, shape factor (S.F.) = af/ai
   b. If Li/ai >= 20, S.F. = 1.0.
5. See Table 5.1-2 NOTES for definitions.
6. Lf = (af/ai) × Li × S.F.

Table 5.1-4

STRESS-IMPROVED FLAWED WELDS

ASME SECTION XI TABLE IWB-3641-5

PREDICTED VS. ALLOWABLE FLAW DEPTH RATIOS

		NUREG-0313 RESIDUAL STRESS			POST-S.I. RESIDUAL STRESS			POST-WOR RESIDUAL STRESS		
NO.	S.R. (1)	FLR (2)	PREDICTED af (%) (3)	ALLOWABLE af (%)	FLR (2)	PREDICTED af (%) (3)	ALLOWABLE af (%)	FLR (2)	PREDICTED af (%) (3)	ALLOWABLE af (%)
10BD-S13	0.718	0.46	74	60	0.12	20	60	N/A	N/A	N/A
02B-F1	0.488	0.12	37	60	0.04	22	60	0.04	22	60
02BS-S5	0.498	0.22	46	60	0.10	21	60	0.11	23	60
02BS-S9	0.433	0.37	51	60	0.26	39	60	0.26	39	60

NOTES:

1. S.R. = M * ((deadweight + internal pressure + seismic stresses) + (thermal expansion + weld overlay shrinkage stresses)/2.77)/Sm. Used worst M = 1.08 for SMAW weldment with 28" outside diameter. Sm = 16,950 psi for 304 stainless steel pipe and fittings at 550 degree F operating temperature.

2. FLR = flaw length ratio = predicted end-of-fuel cycle flaw length, Lf, divided by nominal pipe circumference.

3. Predicted end-of-fuel cycle flaw depth, af, from Table 5.1-2.

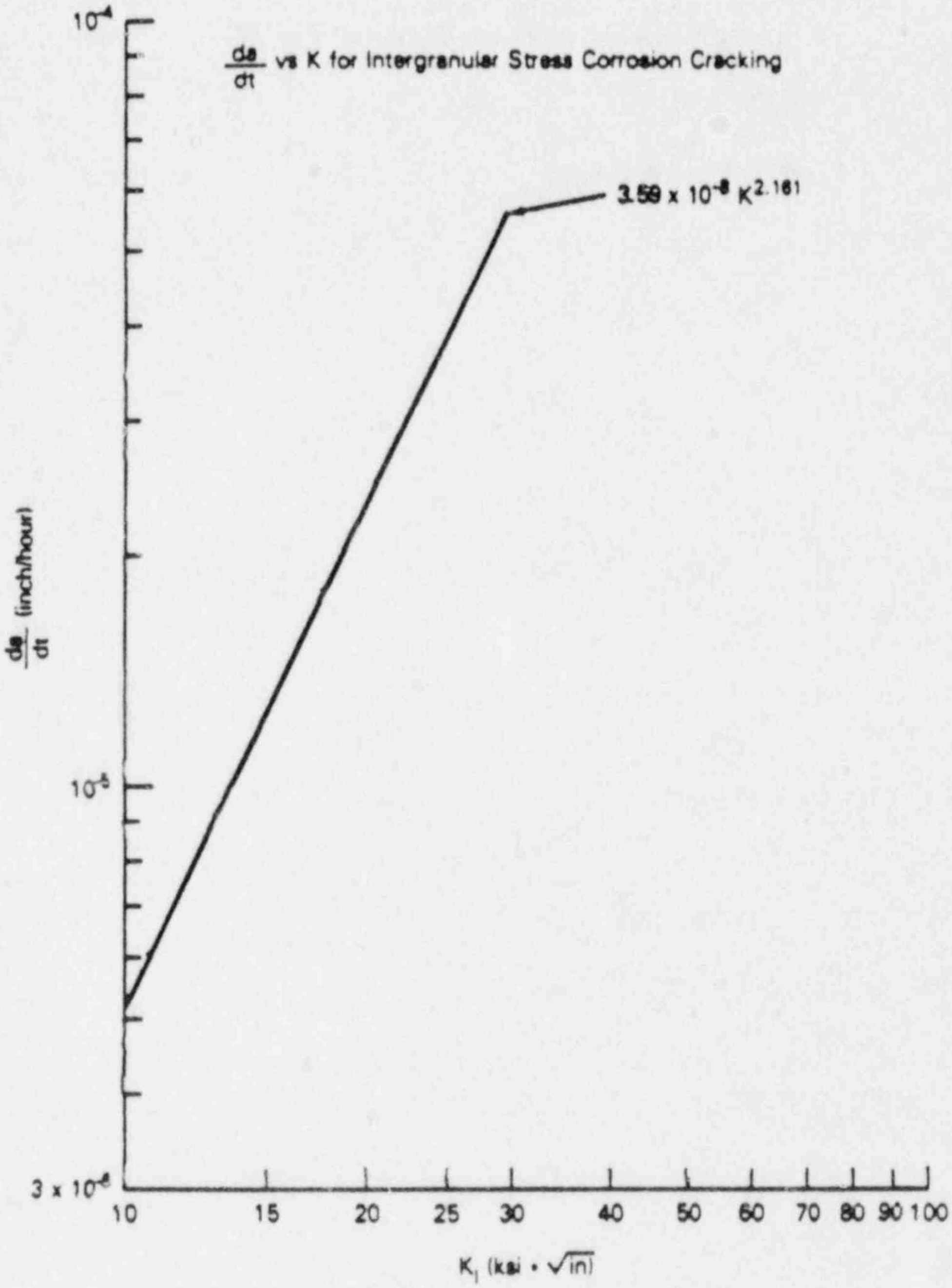

Figure 5.1-1

IGSCC CRACK GROWTH CORRELATION

(Reference 7)

Table 5.2-1

CIRCUMFERENTIALLY FLAWED OVERLAY-REPAIRED WELDS

PIPE AND FLAW GEOMETRIC DETAILS

WELD NO.	NOMINAL O.D. (1) (IN.)	tp (2) (IN.)	to (3) (IN.)	tf (4) (IN.)	t (5) (IN.)	tr (6) (IN.)	a (7) (IN.)	L (8) (DEGREES)
14A-S8	10.75	0.632	0.236	0.000	0.868	0.236	0.637	360
02C-S4	12.75	0.586	0.424	0.089	1.010	0.424	0.679	360
02D-S4	12.75	0.600	0.374	0.000	0.974	0.374	0.605	360
02E-S4	12.75	0.611	0.346	0.000	0.957	0.346	0.616	360
02F-S3	12.75	0.593	0.309	0.000	0.902	0.309	0.598	360
02F-S4	12.75	0.586	0.294	0.073	0.880	0.294	0.664	360
02G-S3	12.75	0.606	0.380	0.150	0.986	0.380	0.761	360
02G-S4	12.75	0.679	0.331	0.000	1.010	0.390	0.684	360
02H-S3	12.75	0.598	0.434	0.000	1.032	0.434	0.603	360
02H-S4	12.75	0.687	0.330	0.000	1.017	0.330	0.692	360
02J-F6	12.75	0.584	0.260	0.000	0.844	0.260	0.589	360
02J-S3	12.75	0.601	0.397	0.000	0.998	0.397	0.606	360
02J-S4	12.75	0.599	0.390	0.000	0.989	0.390	0.604	360
02K-S3	12.75	0.588	0.365	0.000	0.953	0.500	0.593	360
02K-S4	12.75	0.584	0.315	0.000	0.899	0.315	0.589	360
02B-S7	22.0	1.073	0.559	0.102	1.632	0.559	1.180	360
02B-S10	22.0	1.019	0.507	0.000	1.526	0.507	1.024	360

NOTES:

1. O.D. = outside diameter.
2. tp = pipe wall thickness.
3. to = weld overlay repair thickness.
4. tf = low delta ferrite first layer thickness (if applicable).
5. t = tp + to.
6. tr = minimum remaining ligament from UT examination for circ. flaw.
7. a = evaluation flaw depth
   = greater of (tp + tf + 0.005" bounding fatigue crack growth
   or
   (t - tr) + 0.005".
8. L = evaluation flaw length.

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Table 5.2-2

CIRCUMFERENTIALLY FLAWED OVERLAY-REPAIRED WELDS PREDICTED VS. ALLOWABLE FLAW DEPTH RATIOS

WELD NO.	FLR (1)	S.R. (2)	IWB-3641-1 FDR (3)	PREDICTED FDR (4)
14A-S8	1.0	0.27	0.75	0.73
02C-S4	1.0	0.26	0.75	0.67
02D-S4	1.0	0.25	0.75	0.62
02E-S4	1.0	0.26	0.75	0.64
02F-S3	1.0	0.29	0.75	0.66
02F-S4	1.0	0.24	0.75	0.75
02G-S3	1.0	0.26	0.75	0.77
02G-S4	1.0	0.24	0.75	0.68
02H-S3	1.0	0.24	0.75	0.58
02H-S4	1.0	0.24	0.75	0.68
02J-F6	1.0	0.31	0.75	0.70
02J-S3	1.0	0.25	0.75	0.61
02J-S4	1.0	0.25	0.75	0.61
02K-S3	1.0	0.26	0.75	0.62
02K-S4	1.0	0.27	0.75	0.66
02B-S7	1.0	0.29	0.75	0.72
02B-S10	1.0	0.27	0.75	0.67

NOTES:

1. FLR = flaw length ratio = 1.0 for 360 degree assumed flaw length.
2. S.R. = dead weight + internal pressure + seismic stresses from from Table 4.1-1 divided by allowable stress intensity, Sm, defined in NOTES of Table 5.1-4.
3. FDR = allowable flaw depth ratio (a/t) from ASME Section XI (Reference 8), Table IWB-3641-1.
4. Predicted FDR = bounding evaluation flaw depth, a, from Table 5.2-1 divided by pipe + overlay thickness, t, from Table 5.2-1.

Table 5.2-3

AXIALLY FLAWED OVERLAY-REPAIRED WELDS

PIPE AND FLAW GEOMETRIC DETAILS

WELD NO.	NOMINAL O.D. (1) (IN.)	tp (2) (IN.)	L (3) (IN.)	tr' (4) (IN.)	WELD NO.	NOMINAL O.D. (1) (IN.)	tp (2) (IN.)	L (3) (IN.)	tr' (4) (IN.)
14A-F2	10.75	0.592	0.89	0.20	02G-S4	12.75	0.679	1.00	0.32
14A-F11	10.75	0.631	0.95	0.19	02H-S3	12.75	0.598	0.90	0.43
14A-S8	10.75	0.632	1.50	0.24	02H-S4	12.75	0.687	1.03	0.33
14A-S9	10.75	0.601	0.90	0.19	02J-F6	12.75	0.584	1.25	0.26
14B-F2	10.75	0.570	0.86	0.19	02J-S3	12.75	0.601	0.90	0.37
14B-S8	10.75	0.587	0.88	0.13	02J-S4	12.75	0.599	1.10	0.33
02C-S3	12.75	0.601	0.90	0.16	02K-S3	12.75	0.588	0.88	0.35
02C-S4	12.75	0.586	1.00	0.40	02K-S4	12.75	0.584	0.88	0.32
02D-S3	12.75	0.596	0.89	0.19	02M-S3	12.75	0.597	0.90	0.14
02D-S4	12.75	0.600	1.12	0.37	02M-S4	12.75	0.648	1.00	0.32
02E-S3	12.75	0.603	1.00	0.18	02B-F1	22.0	1.095	1.64	0.19
02E-S4	12.75	0.611	1.13	0.35	02B-S7	22.0	1.073	1.61	0.56
02F-S3	12.75	0.593	0.89	0.31	02B-S10	22.0	1.019	1.53	0.45
02F-S4	12.75	0.690	1.04	0.37	02BS-S5	28.0	1.244	1.87	0.22
02G-S3	12.75	0.606	1.13	0.38	02BS-S9	28.0	1.232	1.85	0.17

NOTES:

1. O.D. = outside diameter.
2. tp = pipe wall thickness.
3. L = flaw evaluation length
   = greater of: Measured axial flaw length
   or
   1.5 * tp.
4. tr' = lesser of: Remaining ligament thickness
   or
   WOR thickness (to).

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Table 5.2-4

AXIALLY FLAWED OVERLAY-REPAIRED WELDS
APPLIED VS. ALLOWABLE STRESS RATIOS

WELD NO.	APPLIED STRESS RATIO (1)	ALLOWABLE STRESS RATIO (2)	STANDARD to (3) (IN.)	PREDICTED tr (4) (IN.)	WELD NO.	APPLIED STRESS RATIO (1)	ALLOWABLE STRESS RATIO (2)	STANDARD to (3) (IN.)
14A-F2	0.67	0.90	0.125	0.185	02G-S4	0.692	0.80	0.125
14A-F11	0.63	0.90	0.125	0.175	02H-S3	0.786	0.90	0.125
14A-S8	0.63	0.80	0.125	0.225	02H-S4	0.684	0.80	0.125
14A-S9	0.66	0.90	0.125	0.175	02J-F6	0.805	0.80	0.125
14B-F2	0.70	0.90	0.125	0.175	02J-S3	0.782	0.90	0.125
14B-S8	0.68	0.90	0.125	0.135	02J-S4	0.785	0.80	0.125
02C-S3	0.78	0.90	0.125	0.145	02K-S3	0.800	0.90	0.125
02C-S4	0.80	0.80	0.125	0.385	02K-S4	0.805	0.80	0.125
02D-S3	0.79	0.90	0.125	0.175	02M-S3	0.787	0.90	0.125
02D-S4	0.78	0.80	0.125	0.355	02M-S4	0.776	0.80	0.125
02E-S3	0.78	0.80	0.125	0.165	02B-F1	0.741	0.90	0.125
02E-S4	0.77	0.80	0.125	0.335	02B-S7	0.756	0.90	0.125
02F-S3	0.79	0.90	0.125	0.295	02B-S10	0.796	0.90	0.125
02F-S4	0.80	0.80	0.125	0.355	02BS-S5	0.830	0.90	0.125
02G-S3	0.78	0.80	0.125	0.365	02BS-S9	0.838	0.90	0.125

NOTES:

1. Applied stress ratio is calculated for internal pressure of 1,250 psi using geometric properties from Table 5.2-3 and formula presented in Table 3.2-2 footnotes.

2. Allowable stress ratio per Table 3.2-2.

3. Standard leak barrier overlay repair minimum thickness.

4. Predicted tr = tr' from Table 5.2-3 - 0.015" bounding fatigue crack growth.

Table 5.3-1

WELD 02B-S7

ASME SECTION III CODE RESULTS

STRESS CATEGORY	APPLIED STRESS INTENSITY	USAGE FACTOR	ASME SECTION III ALLOWABLE
PL (1)	12,770 psi	N/A	25,425 psi
PL + Q (2)	21,820 psi	N/A	50,850 psi
PL + Q + F (3):			
Cycle 1 (4)	13,700 psi	0	N/A
Cycle 2 (5)	35,770 psi	0.0003	N/A
Cycle 3 (6)	219,000 psi	0.0059	N/A
COMBINED USAGE FACTOR:		0.0062	1.0

NOTES:

1. PL = primary local membrane stress intensity.
2. Q = discontinuity bending stress intensity.
3. F = peak stress intensity.
4. Cycle 1 = normal startup/shutdown thermal transient.
5. Cycle 2 = 50 degree F step change thermal transient.
6. Cycle 3 = 461 degree F step change thermal transient.

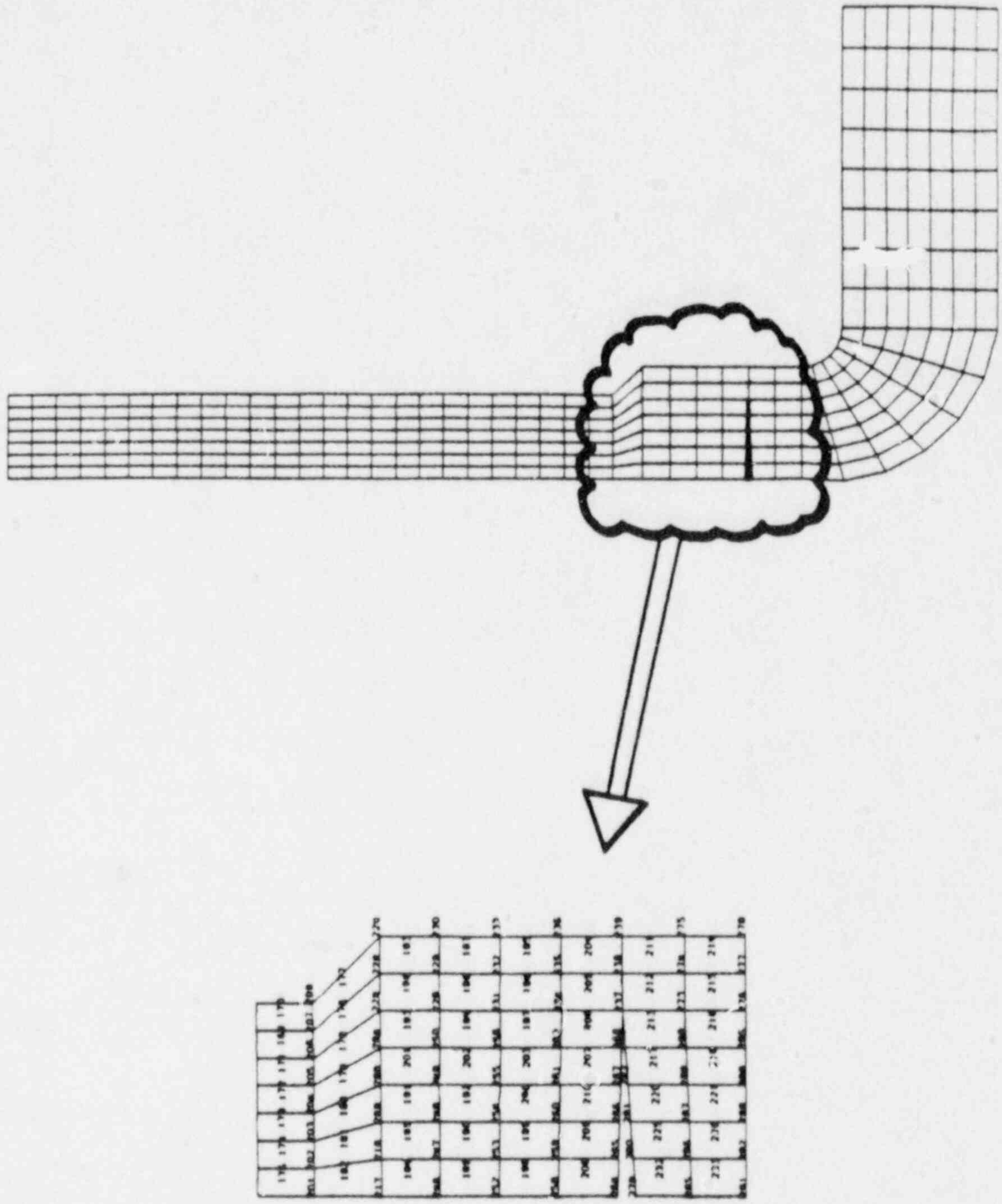

Figure 5.3-1

WELD 02B-S7

FINITE ELEMENT MODEL

6.0 SUMMARY AND CONCLUSIONS

Ultrasonic (UT) examinations performed during the 1984 outage at Commonwealth Edison's Quad Cities Nuclear Power Plant Unit 1 identified flaws judged to be IGSCC in the vicinity of seventeen welds. Fifteen welds were overlay repaired , one weld was shown to be acceptable with only IHSI mitigation, and one weld was both overlay repaired and covered by a pipe clamping device.

During the Quad Cities Unit 1 1986 outage, three of the original fifteen overlay-repaired welds were built-up to "standard" design thicknesses and volumetrically inspected by the UT technique developed by EPRI. The previously IHSI-mitigated weld was also inspected and found to be acceptable for continued operation. None of the other overlay-repaired welds were inspected.

During UT examinations performed during the Quad Cities Unit 1 1987 outage, fourteen new welds were identified as possibly containing IGSCC. Seven of these welds were in systems not stress-improved prior to the 1987 outage. Of the remaining seven welds which were IHSI-mitigated during the 1984 outage, five welds contained only axial flaws which have proven difficult to detect in the past. The last two welds contain relatively minor circumferential indications.

Evaluations presented in this report of the thirty-one Quad Cities Unit 1 welds believed to contain IGSCC demonstrates that the applied stress levels are acceptable for all design conditions. The analyses performed in the evaluation demonstrate that the welds having "standard" weld overlay repairs are acceptable for the balance-of-plant life while all the other flawed welds are acceptable for a minimum of one additional fuel cycle based upon conservative NUREG-0313 (Reference 7) criteria.

7.0 REFERENCES

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2. NUTECH Document CEC-47-100, "Evaluation and Disposition of Indications at Quad Cities Nuclear Power Plant Unit 1", Revision 0.

3. Sargent & Lundy Drawing No. ISI-103, "Inservice Inspection Class 1 - Nuclear Boiler & Reactor Recirculation Piping - Quad Cities Station Unit 1", Revision A.

4. Sargent & Lundy Drawing No. ISI-105, "Inservice Inspection Class 1 - RHRS Piping - Quad Cities Station Unit 1", Revision A.

5. Sargent & Lundy Drawing No. ISI-104, "Inservice Inspection Class 1 - Core Spray Piping - Quad Cities Station Unit 1", Revision D.

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7. NRC Document NUREG-0313, "Technical Report on Material Selection and Processing Guidelines for BWR Coolant Pressure Boundary Piping", Draft Revision 2.

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10. NUTECH Document COM-76-001, "Weld Overlay Design Criteria for Axial Cracks", Revision 0, March 1984.

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17. Porowski, J.S., et. al., "Mechanical Methods of Improving Resistance to Stress Corrosion Cracking in BWR Piping Systems", Transactions of SMiRT Post Conference Seminar No. 2, Davos, Switzerland, August 24-25, 1987.

18. Computer Program WELDS II, Version 1.0.0, July 1983, NUTECH Corporate File No. QASJO.SOFT.2.052.00.

19. NUTECH Computer Program NUTCRAK, Revision 2.0.2, December 1983, NUTECH Corporate File QASJO.SOFT.2.049.00.

20. Computer Program ANSYS, Swanson Analysis Systems, Version 4.1B, NUTECH Corporate File QASJO.SOFT.2.001.01.

21. NUTECH Document CEC-73-205, "Fracture Mechanics Evaluation of Weld 02A-S10 - Quad Cities Nuclear Power Plant Unit 2", Revision 1.