50-254

SUMMARY

OF

QUAD CITIES UNIT 1

1986 REFUELING OUTAGE

FLAW EVALUATIONS AND DISPOSITIONS

Prepared for:

Commonwealth Edison Company

Prepared by:

NUTECH Engineers

TABLE OF CONTENTS

1.0 FLAWED WELD DETAILS

Table 1.0-1 presents details of the indications detected during the 1984 refueling outage at Quad Cities Unit 1. Table 1.0-2 presents details of indications observed during the 1986 refueling outage. Figures 1.0-1 and 1.0-2 present the locations of the flawed welds in the recirculation system piping.

Table 1.0-1

QUAD CITIES UNIT 1
FLAWED WELD DETAILS
1984 REFUELING OUTAGE

Weld ID	Pipe Size	Configuration	Indications Description
02C-S4	12"	P-E	4" int. x 44% circ. (P.S.) 3 - 1" max. long axials (P.S.)
02D-S4	12"	P-E	0.5" long axial (P.S.) 0.875" long axial (P.S.)
02E-S4	12"	P-E	0.8" x 65% circ. (P.S.) 8 - 1.125" max. long axials (P.S.)
02F-S4	12"	P-E	3 - 0.8" max. long axials (E.S.)
02G-S3	12"	P-E	0.75" x 50% circ. (P.S.) 7 - 1.125" max. long axials (P.S.) 0.875" long axial (E.S.)
02G-S4	12"	P-E	1" x 18% circ. with 0.125" long axial (E.S.)
02H-S3	12"	P-E	3" x 21% circ. (P.S.) 3 - 0.75" max. long axials (P.S.)
02H-S4	12"	P-E	4 - 0.75" max. long axials (P.S. & E.S.)
02J-F6	12"	P-SW	7 - 1.25" max. long axials (P.S.)
02J-S3	12"	P-E	0.6" x 12% circ. with 0.5" long axial (P.S.)
02J-S4	12"	P-E	4.25" x 55% circ. (P.S.) 0.6" x < 30% circ. (P.S.) 2.0" x < 30% circ. (P.S.) 1.8" x < 30% circ. (P.S.) 1.6" x < 30% circ. (P.S.) 3.0" x < 30% circ. (P.S.) 9 - 1.1" max. long axials (P.S.)

Table 1.0-1

(Concluded)

QUAD CITIES UNIT 1

FLAWED WELD DETAILS

1984 REFUELING OUTAGE

Weld ID	Pipe Size	Configu-ration	Indications Description
02K-S3	12"	P-E	1.6" x 25% circ. (P.S.) 0.2" x 25% circ. (P.S.) 0.8" x 15% circ. (P.S.) 8.0" x 24% circ. (P.S.) 5 - 0.625" max. long axials (P.S.)
02K-S4	12"	P-E	2 - 0.25" long axials (P.S.)
02M-S3	12"	P-E	3 - 1" max. long axials (P.S.)
02B-S7	22"	P-X	0.125" long axial (P.S.)
02B-S10	22"	P-EC	2" x 10% circ. with 3 - 0.5" max. long axials (EC.S.)
02BS-S9[3]	28"	P-E	1.5" x 18% circ. (P.S.) 0.5" x 15% circ. (P.S.) 4" x 0.050" circ. (E.S.)

NOTES:

1. Axial flaw lengths from weld centerline to maximum extent of axial flaw along pipe inside diameter surface.

2. Percent flaw depths based upon original pipe wall thickness.

3. For Weld 02BS-S9, 4" x 0.050" circ. is slag indication from original construction.

4. P - Pipe
   E - Elbow
   SW - Sweepolet
   X - Cross

   P.S. - Pipe Side
   E.S. - Elbow Side
   EC.S. - End Cap Side
   EC - End Cap

Table 1.0-2

QUAD CITIES UNIT 1
FLAWED WELD DETAILS
1986 REFUELING OUTAGE

Weld ID	Pipe Size	Configuration	Indications Description
02C-S4(1)	12"	P-E	4 axials (P.S.): 0.619" max. depth (0.480" min. remaining ligament) 0.5" max. length
02J-S4(1)	12"	P-E	16 axials (P.S.): 0.615" max. depth (0.340" min. remaining ligament) 0.5" max. length
02K-S3(1)	12"	P-E	4 circs. (P.S.): 0.190" max. depth (0.770" min. remaining ligament) 1.5" max. length 1 axial (P.S.): 0.540" max. depth (0.420" min. remaining ligament) 0.75" max. length
02BS-S9(2)	28"	P-E	1" x 15% circ. (P.S.) 1.5" x 24% circ. (P.S.) 1" x 23% circ. (E.S.) 1" x 15% circ. (E.S.) 2.5" x 20% circ. (E.S.)

NOTES:

1. Maximum flaw depth measured from pipe inside diameter surface.
2. Percent flaw depths based upon original pipe wall thickness.
3. P - Pipe; E - Elbow; P.S. - Pipe Side; E.S. - Elbow Side

nutech ENGINEERS

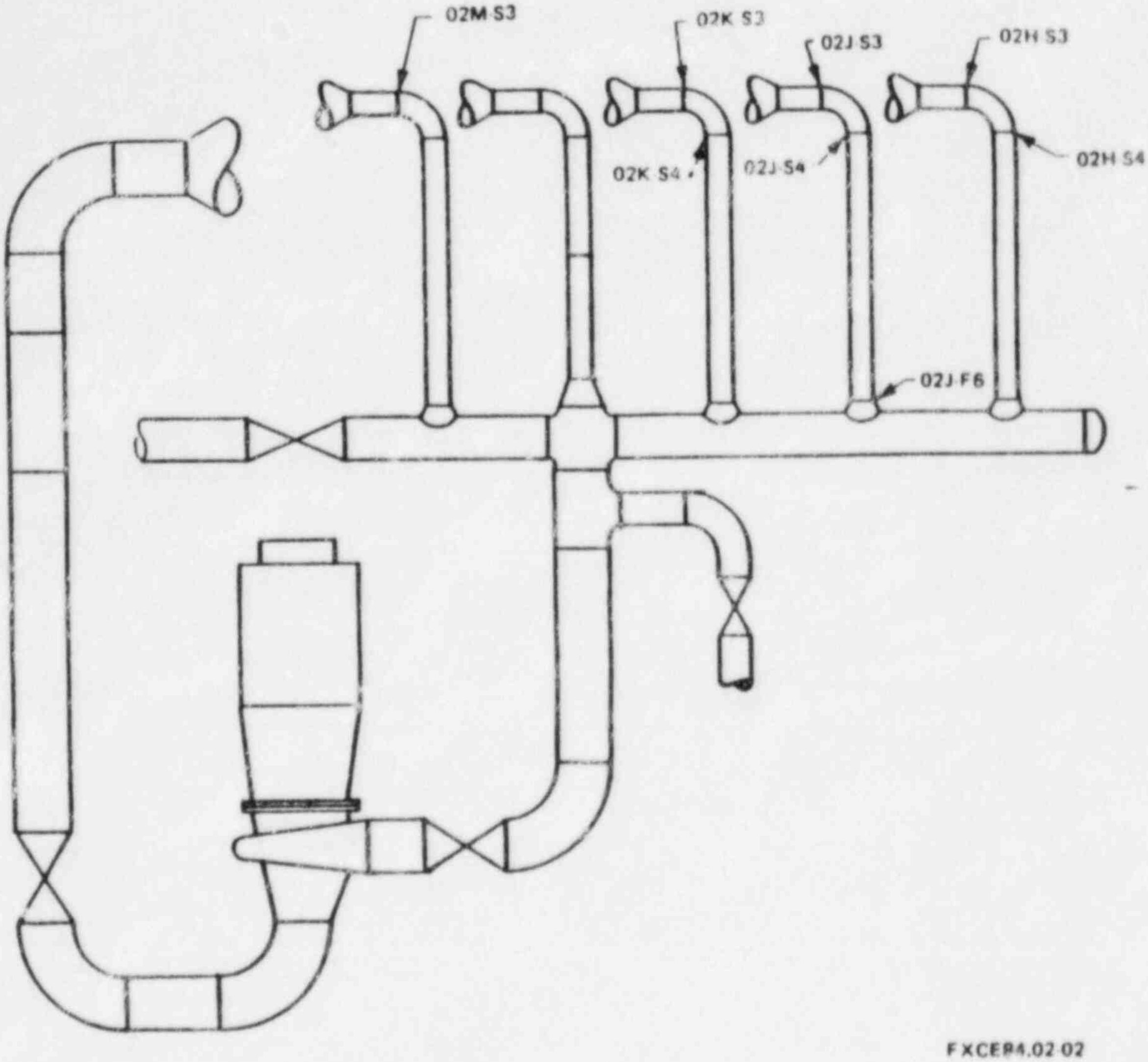


Figure 1.0-1

QUAD CITIES UNIT 1

FLAWED WELD LOCATIONS

RECIRCULATION SYSTEM LOOP "A"

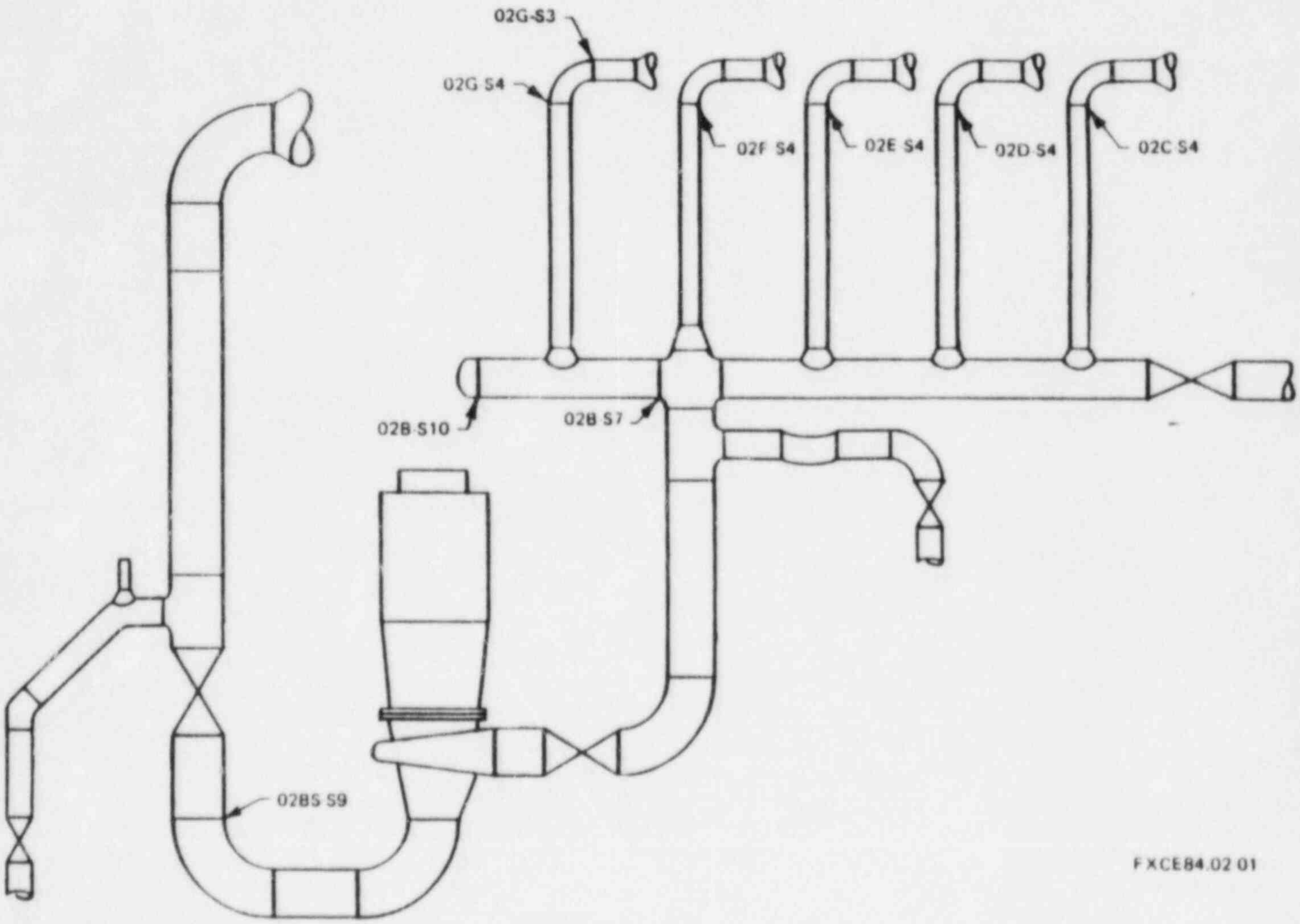


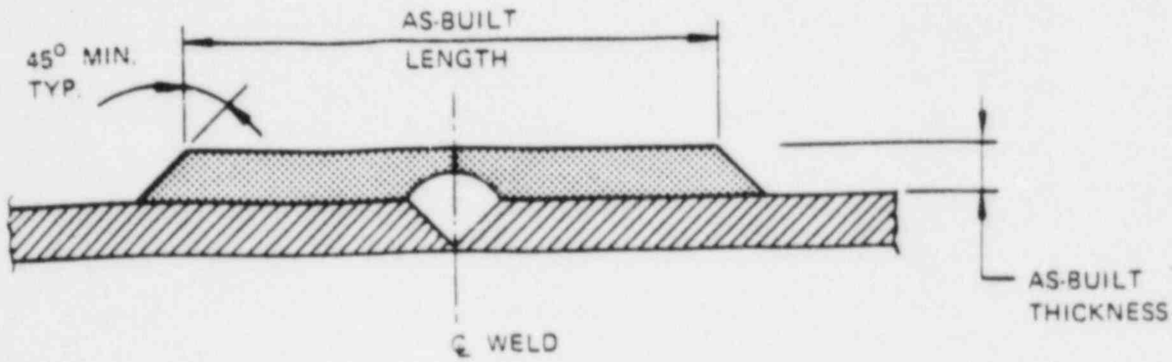
Figure 1.0-2

QUAD CITIES UNIT 1
FLAWED WELD LOCATIONS
RECIRCULATION SYSTEM LOOP "B"

2.0 REPAIR DETAILS

Table 2.0-1 presents as-built details of weld overlay repairs implemented during the Quad Cities Unit 1 1984 refueling outage. Table 2.0-2 presents as-built details for weld overlay repairs built-up during the 1986 refueling outage.

Weld 02BS-S9 was treated by Induction Heating Stress Improvement (IHSI) during the 1984 refueling outage.



Patent applied for

Weld ID	As-Built Thickness	As-Built Length (2)
02C-S4	0.225" (1)	4.21"
02D-S4	0.216"	3.60"
02E-S4	0.282"	4.56"
02F-S4	0.090" (1)	2.85"
02G-S3	0.228" (1)	4.63"
02G-S4	0.379"	4.38"
02H-S3	0.300"	4.65"
02H-S4	0.198"	4.25"
02J-F6	0.316"	3.20"
02J-S3	0.222"	4.37"
02J-S4	0.239"	4.68"
02K-S3	0.237"	4.65"
02K-S4	0.207"	3.39"
02M-S3	0.136"	3.67"
02B-S7	0.240" (1)	2.37"
02B-S10	0.219"	3.15"

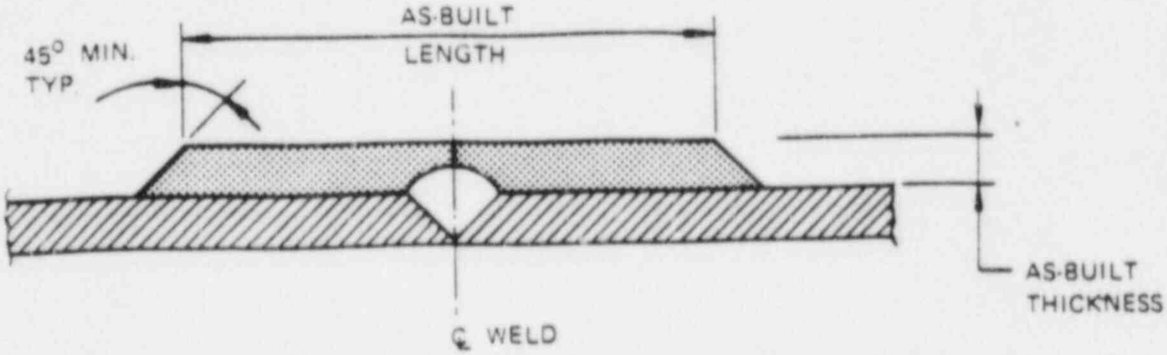
NOTES:

1. Thickness does not include low delta ferrite first layer.

2. As-built length at design thickness.

Figure 2.0-1

QUAD CITIES UNIT 1
WELD OVERLAY REPAIR DETAILS
1984 REFUELING OUTAGE



Patent applied for

Weld ID	As-Built Thickness	As-Built Length (2)
02C-S4	0.424" (1)	4.21"
02J-S4	0.370"	4.68"
02K-S3	0.375"	4.65"

NOTES:

1. Thickness does not include low delta ferrite first layer.

2. As-built length at original design thickness.

Figure 2.0-2

QUAD CITIES UNIT 1
WELD OVERLAY REPAIR DETAILS
1986 REFUELING OUTAGE

3.0 EVALUATION CRITERIA

3.1 Flawed Pipe Analysis

The following criteria were used by NUTECH to justify further operation of Quad Cities Unit 1 with the detected flaws in Weld 02BS-S9:

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

2. The prediction of end-of-fuel cycle (evaluation period) flaw size was based upon a conservative IGSCC crack growth correlation which closely agrees with the NRR curve presented in Figure 3.1-1 from NUREG-1061, Volume 1 (Reference 4) using a combination of dead weight, internal pressure, differential thermal expansion, and weld overlay shrinkage stresses.

3. The calculation of IGSCC flaw growth was based upon conservative butt weld through-wall residual stress distributions.

4. As currently required by USNRC Generic Letter 84-11 (Reference 2), the predicted end-of-fuel cycle (evaluation period) flaw size was compared to 2/3 of the ASME Section XI (Reference 3) Table IWB-3641-1 allowable flaw depth values for a combination of dead weight, internal pressure, and seismic stresses.

5. Because the allowable flaw sizes in ASME Section XI Paragraph IWB-3640 are currently being revised to take account of the low fracture toughness associated with flux welds, the predicted end-of-fuel cycle (evaluation period) flaw size was compared to Table IWB-3641-5 (Reference 6) allowable flaw depth values for a combination of dead weight, internal pressure, seismic, <u>and</u> differential thermal expansion/weld overlay shrinkage stresses. This table has been adopted for inclusion into the Winter 1986 Addenda to ASME Section XI.

3.2 1984 Weld Overlay Repair Evaluation

NUTECH Document COM-96-202 (Reference 1) discusses the evaluation and design criteria used for the flawed welds which were overlay repaired during the 1984 refueling outage. The following criteria were used by NUTECH to justify an additional fuel cycle of operation:

1. For nominal pipe sizes less than or equal to 12", a circumferential flaw was assumed to have a 100% through-wall-by-as-measured length geometry.

2. For nominal pipe sizes greater than 12", a circumferential flaw was assumed to have a depth of twice the maximum ultrasonically measured flaw depth over its as-measured length.

3. For flaws assumed to have a 100% through-wall depth, a bounding fatigue-induced flaw growth of 0.010" into the overlay material was used based upon the NUTECH design report for recirculation safe end and elbow repairs at Monticello (Reference 7) for a 5 year design life.

4. The weld overlay repair strength for a combination of dead weight, internal pressure, and seismic stresses was compared to the net section collapse criteria of ASME Section XI, Table IWB-3641-1.

5. Because the allowable flaw sizes in ASME Section XI Paragraph IWB-3640 are currently being revised to take account of the low fracture toughness associated with flux welds, the weld overlay repairs implemented in 1984 were also evaluated using the following criteria:

   a. Circumferential flaws were assumed to have a 100% through-wall-by-360 length geometry. The overlay repaired flaw was then compared to ASME Section XI Table IWB-3641-1 allowable flaw depth values for a combination of dead weight, internal pressure, and seismic stresses. This approach eliminates the need to evaluate these weldments relative to the proposed ASME Section XI code committee changes to IWB-3640 (Reference 6). Table IWB-3641-1 arbitrarily stops at a minimum stress ratio of 0.6, therefore NUTECH has developed Table 3.2-1 based upon the Table IWB-3641-1 source equations shown in Figure 3.2-1. This expanded table presents allowable flaw depth ratios for flaw length ratios greater than or equal to 0.5 with stress ratios less than 0.6.

   b. For those overlay-repaired welds requiring some credit for the uncracked portion of the flux weld, the criteria of Section 3.1, Paragraph 5 were used. The use of these criteria conservatively assume that the weld overlay repair material has the same low fracture toughness as the flux weld.

All welds with only axial flaws detected in 1984 were evaluated using the following criteria:

1. An axial flaw was assumed to have a 100% through-wall-by-as-measured length geometry.

2. The weld overlay repair implemented in 1984 was compared to the leakage barrier criteria presented in Table 3.2-2 from NUTECH Document COM-76-001 (Reference 8).

3.3 1986 Weld Overlay Repair Evaluation

Welds 02C-S4, 02J-S4, and 02K-S3 required surface finish grinding to allow Generic Letter 84-11 required ultrasonic examinations during the 1986 refueling outage. Because it was anticipated that this grinding might reduce the thicknesses of the overlay repairs on these welds below the existing minimum design thicknesses, these overlays were built-up to new design thicknesses based upon the following criteria:

1. Existing flaw depth was assumed to equal 100% of the original pipe wall thickness by a conservative 360° circumferential length.

2. Under-the-overlay repair fatigue crack growth 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).

3. The weld overlay repair strength for a combination of dead weight, internal pressure, and seismic stresses was compared to the net section collapse criteria of ASME Section XI Table IWB-3641-1.

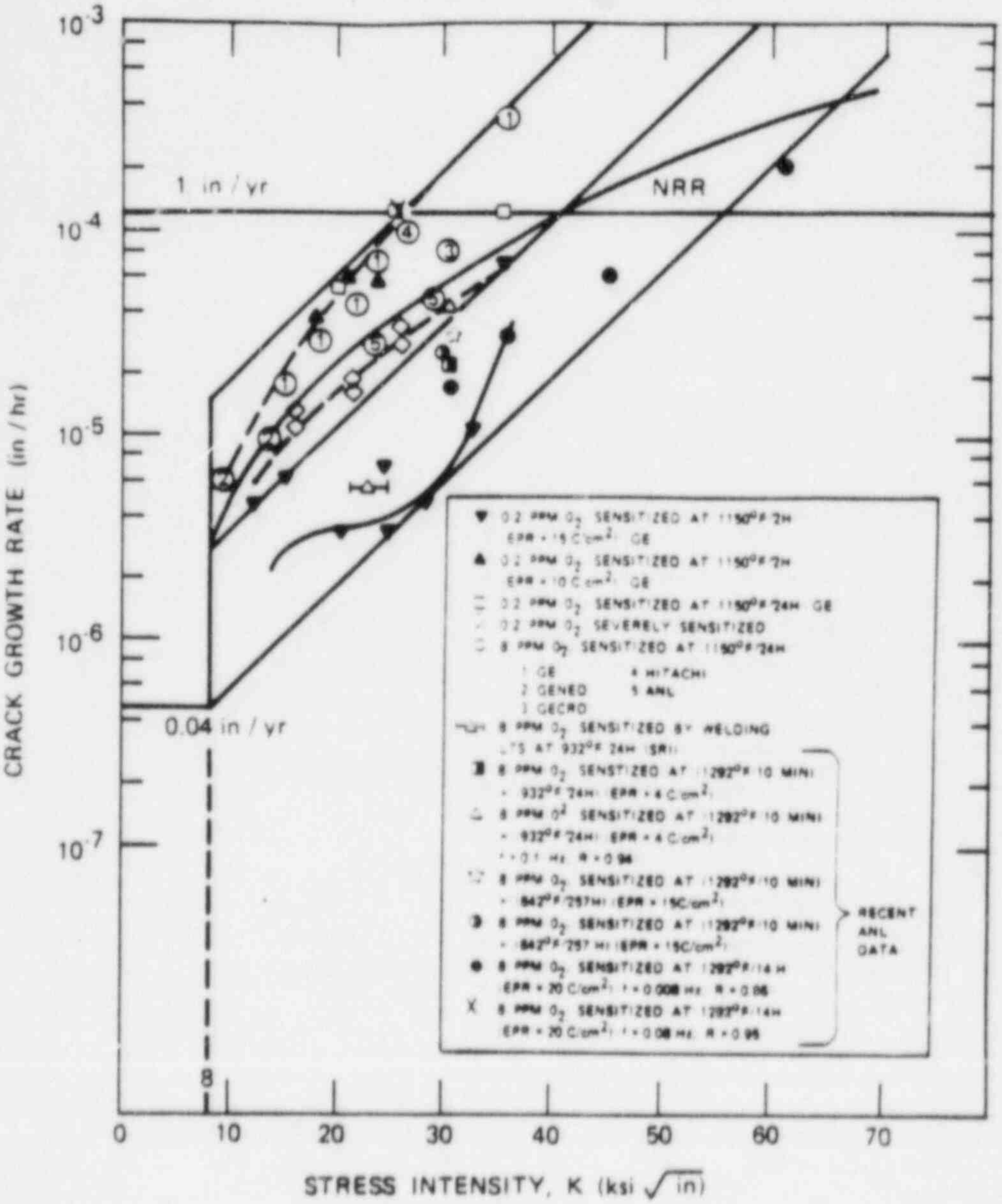


Figure 3.1-1

<u>NUREG-1061, VOLUME 1</u>

<u>STRESS-CORROSION CRACK GROWTH RATES</u>

(Reference 4)

Table 3.2-1

EXPANDED ALLOWABLE END-OF-EVALUATION PERIOD

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

NORMAL 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

LEAKAGE BARRIER REPAIR CRITERIA

FOR AXIAL FLAWS

(Reference 8)

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

8COM84.01

* LEAK BARRIER ONLY REQUIRED

STRESS RATIO = PD / 2 T Sm

P = MAXIMUM PRESSURE FOR NORMAL OP'.RATING 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 $\alpha + \beta < 180^0$

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

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

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

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

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

Where:

ℓ = flaw length (inches)
r = pipe radius (inches)
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)

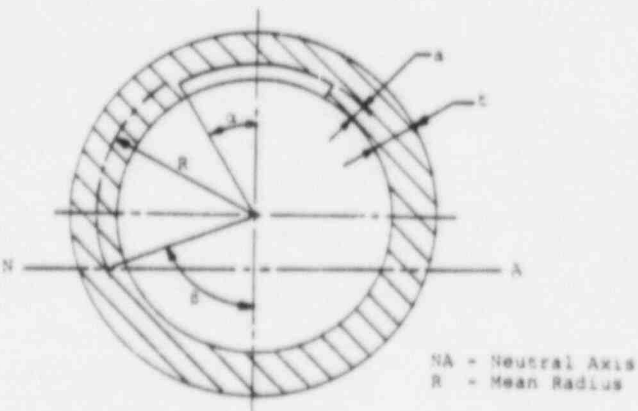


Figure 3.2-1

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

4.0 APPLIED AND RESIDUAL STRESSES

4.1 Primary Stresses

Table 4.1-1 presents the dead weight, internal pressure, and OBE seismic stresses acting on the as-built overlay-repaired welds and Weld 02BS-S9.

4.2 Secondary Stresses

Table 4.1-1 presents the piping system differential thermal expansion stresses acting on the as-built overlay-repaired welds and Weld 02BS-S9. Table 4.2-1 presents the as-built weld overlay shrinkages which cause the shrinkage-induced stress at Weld 02BS-S9 shown in Table 4.2-2.

Figure 4.2-1 illustrates the design thermal transients used to perform a fatigue crack growth analysis. These transients cause the through-wall temperature gradients shown in Figure 4.2-2.

Figure 4.2-3 presents the post-IHSI through-wall residual stress distributions used in the IGSCC crack growth analysis for Weld 02BS-S9. Figure 4.2-4 presents the under-the-overlay through-wall residual stress distributions used in the fatigue crack growth analysis of the overlay repairs built-up during the 1986 refueling outage.

Table 4.1-1

QUAD CITIES UNIT 1

PRIMARY AND THERMAL EXPANSION AXIAL STRESSES (PSI)

	Primary			Secondary
Weld ID	Dead Weight	Internal Pressure	OBE Seismic	Thermal Expansion
02C-S4*	222	3,949	239	424
02D-S4*	117	4,974	64	619
02E-S4*	112	4,596	111	1,331
02F-S4*	243	5,208	224	1,258
02G-S3*	186	4,412	251	2,779
02G-S4*	69	4,133	137	759
02H-S3*	60	4,502	251	232
02H-S4*	64	5,089	208	205
02J-F6*	263	4,422	342	254
02J-S3*	117	4,937	283	249
02J-S4*	69	4,172	128	95
02K-S3*	132	4,150	199	366
02K-S4*	52	5,031	188	105
02M-S3*	936	5,526	398	606
02B-S7*	26	4,831	362	117
02B-S10*	0	5,240	0	0
02BS-S9	90	6,439	128	676

* Based upon as-built weld overlay repair thickness plus original pipe wall thickness.

Table 4.2-1

QUAD CITIES UNIT 1

AS-BUILT WELD OVERLAY SHRINKAGES

Weld ID	Axial Shrinkage (in.)
02C-S4	0.316*
02D-S4	0.157
02E-S4	0.242
02F-S4	0.160
02G-S3	0.256
02G-S4	0.278
02H-S3	0.239
02H-S4	0.219
02J-F6	0.148
02J-S3	0.279
02J-S4	0.300*
02K-S3	0.480*
02K-S4	0.139
02M-S3	0.173
02B-S7	0.043
02B-S10	0.030

* 1984 shrinkage measurements bound 1986 measurements.

Table 4.2-2

QUAD CITIES UNIT 1

WELD OVERLAY SHRINKAGE-INDUCED STRESSES

Weld ID	Stress (psi)
02BS-S9	900

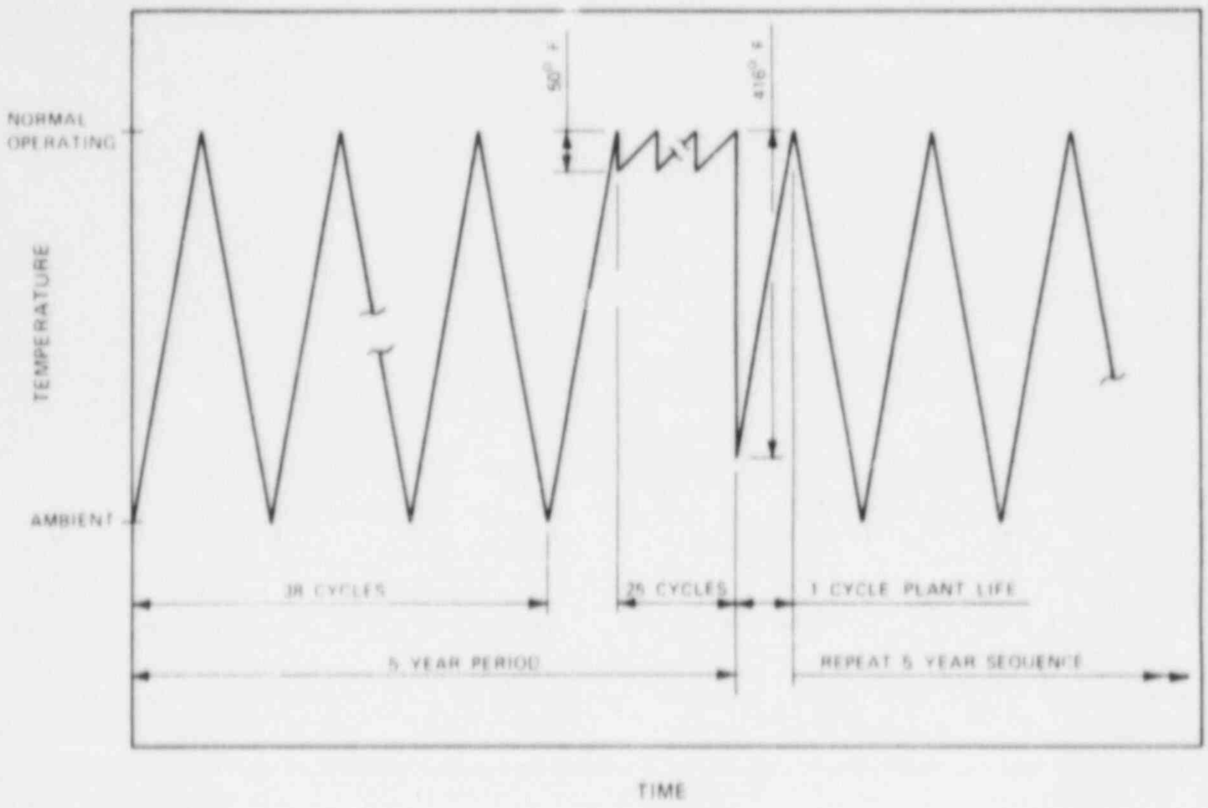
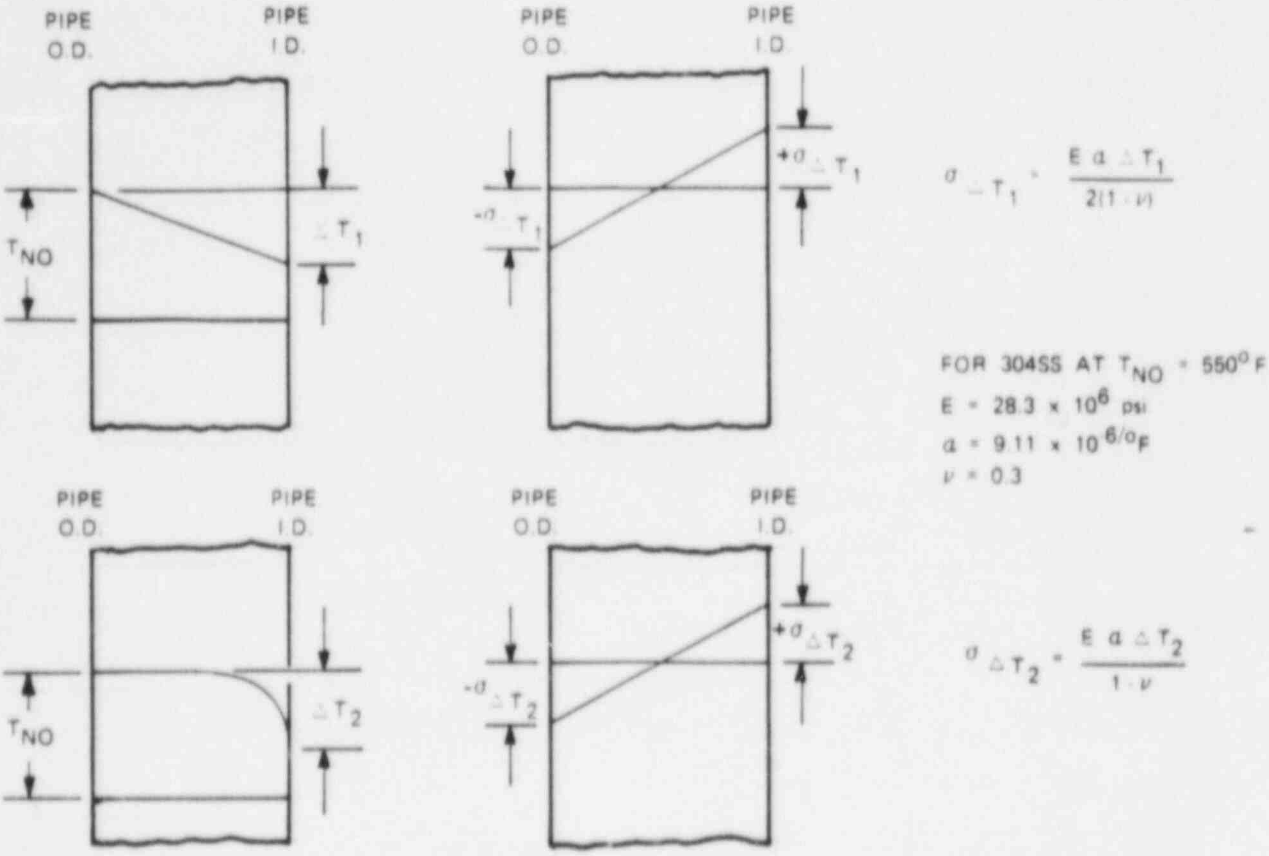


Figure 4.2-1

QUAD CITIES UNIT 1
THERMAL TRANSIENTS



PIPE DIAMETER	PARAMETER	NORMAL START-UP CYCLE (CYCLE 1)	SMALL TEMPERATURE CHANGE (CYCLE 2)	EMERGENCY CYCLE (CYCLE 3)
12"	EQUIVALENT LINEAR TEMPERATURE ΔT_1	1° F	38° F	316° F
12"	PEAK TEMPERATURE ΔT_2	0° F	10° F	79° F

Figure 4.2-2

QUAD CITIES UNIT 1

THROUGH-WALL TEMPERATURE GRADIENTS

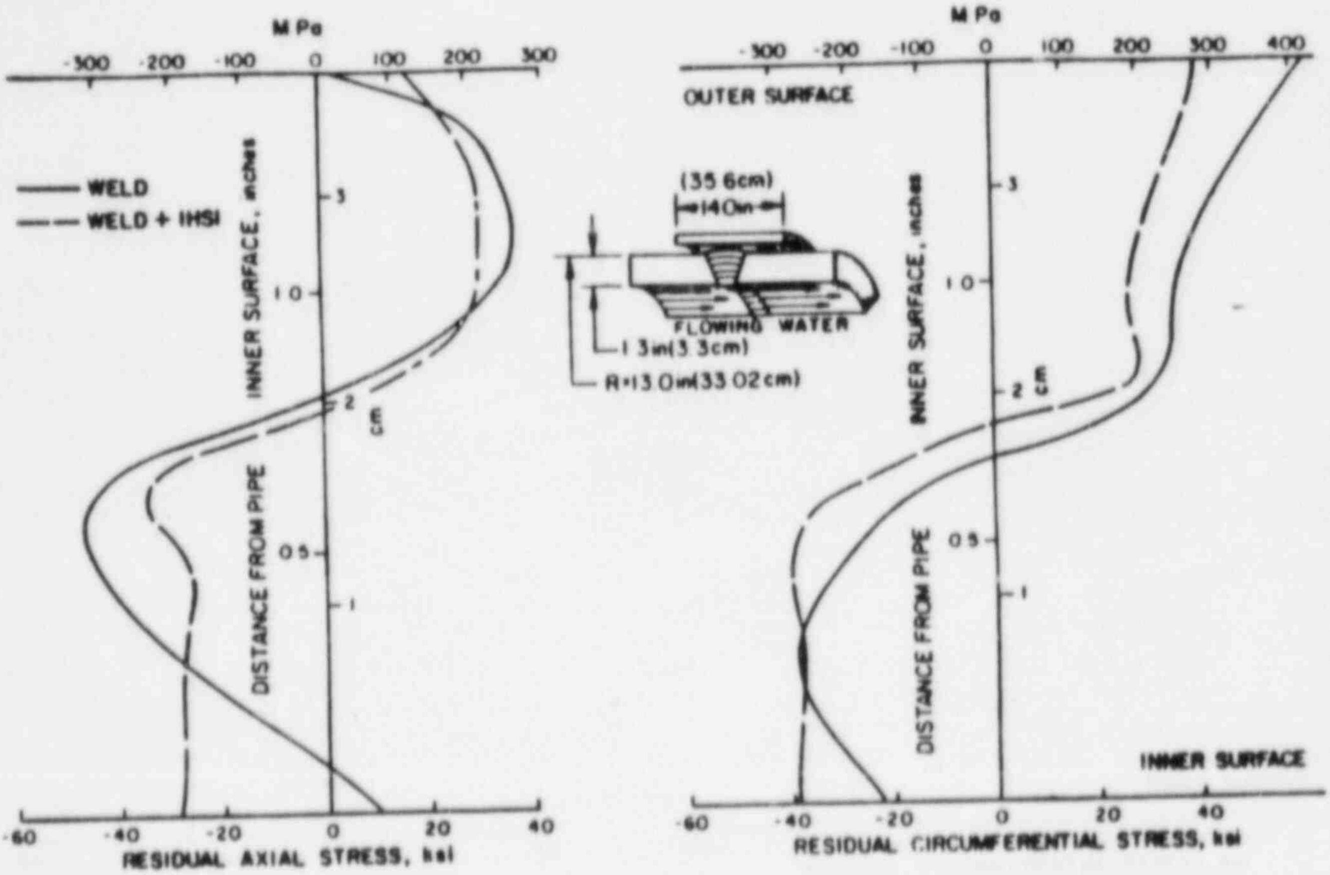


Figure 4.2-3

PRE- AND POST-IHSI THROUGH-WALL
RESIDUAL STRESS DISTRIBUTIONS
(Reference 14)

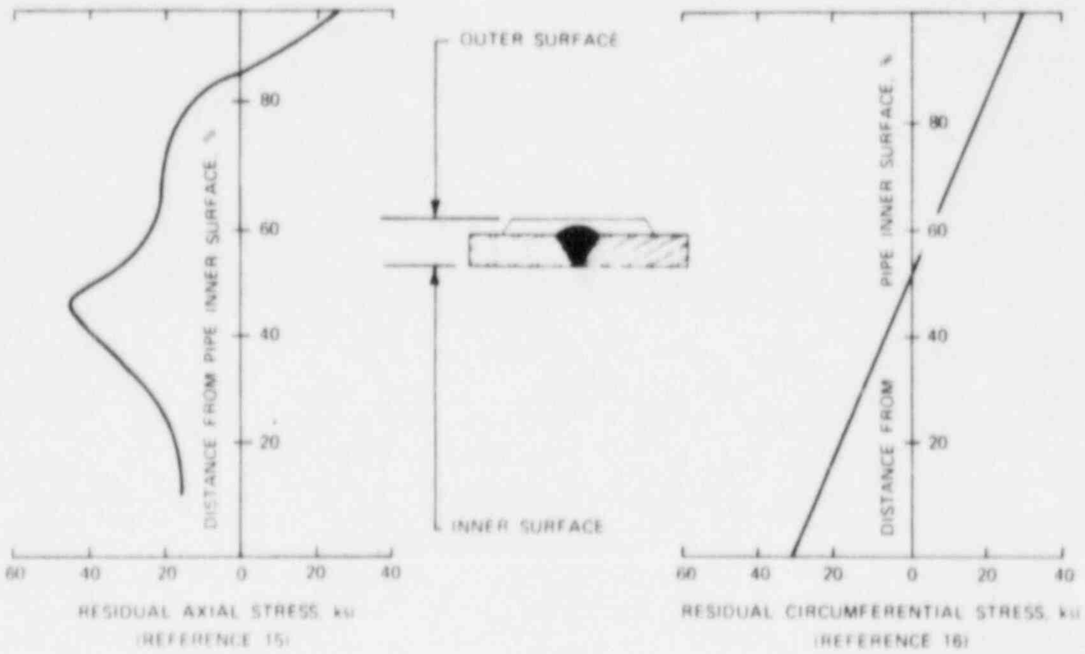


Figure 4.2-4

UNDER-THE-OVERLAY THROUGH-WALL
RESIDUAL STRESS DISTRIBUTIONS

5.0 EVALUATION RESULTS

5.1 Weld 02BS-S9

5.1.1 IGSCC Crack Growth Analysis

Table 5.1-1 presents the pipe and flaw geometric details and sustained stress combinations needed to predict IGSCC crack growth in Quad Cities Unit 1 flawed Weld 02BS-S9. NUTECH's NUTCRAK computer program (Reference 17) was used to predict radial crack growth using the following conservation crack growth correlation:

$$\frac{da}{dt} = 3.58 \times 10^{-8} K^{2.161}$$

Where:

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

As discussed in Section 3.1, this crack growth correlation closely agrees with the NRR curve presented in Figure 3.1-1 from NUREG-1061, Volume 1 (Reference 4).

Table 5.1-2 presents the predicted end-of-fuel cycle flaw depth for Weld 02BS-S9. As seen in the table, no growth is predicted during the next 18-month fuel cycle. In addition, the evaluation indicates that no further IGSCC crack growth is expected for the balance-of-plant life.

5.1.2 Flawed Pipe Evaluation

As discussed in Section 3.1, the predicted end-of-fuel cycle flaw depth for Weld 02BS-S9 was compared to two different evaluation criteria. Table 5.1-3 presents flaw geometric details and primary stress combinations needed to evaluate the requirements of USNRC Generic Letter 84-11 (Reference 2) and ASME Section XI (Reference 3) Table IWB-3641-1. Table 5.1-4 presents flaw geometric details and primary plus secondary stress combinations needed to evaluate the requirements of proposed ASME Section XI Table IWB-3641-5 (Reference 6).

5.2 <u>1984 Overlay-Repaired Welds</u>

5.2.1 Circumferential Flaw Weld Overlay Repair Evaluation

Table 5.2-1 presents the pipe, weld overlay, and flaw geometric details needed to evaluate the weld overlay repairs applied to circumferentially flawed welds during the 1984 refueling outage. Table 5.2-2 presents the flaw geometric details and primary stress combinations needed to evaluate these welds in accordance with USNRC Generic Letter 84-11, ASME Section XI Table IWB-3641-1, and Section 3.2, Paragraphs 1 through 4. Table 5.2-3 presents this data for the assumed 100% through-wall-by-360° length circumferential flaw geometry discussed in Section 3.2, Paragraph 5a. For those overlay-repaired welds needing some credit for the uncracked flux weld, Table 5.2-4 presents the flaw geometric details and primary plus secondary stress combinations needed to evaluate these welds in accordance with proposed ASME Section XI Table IWB-3641-5.

5.2.2 Axial Flaw Weld Overlay Repair Evaluation

Table 5.2-5 presents the pipe and flaw geometric details needed to determine applied and allowable stress ratios for the axially flawed overlay-repaired welds at Quad Cities Unit 1. Table 5.2-6 presents a comparison of stress ratios due to applied loads versus the allowable stress ratios for the axial flaws given in Table 5.2-6. The allowable stress ratios shown were determined using the leakage barrier criteria presented in Table 3.2-2.

5.3 1986 Redesigned Overlay-Repaired Welds

5.3.1 Fatigue Crack Growth Analysis

Tables 5.3-1 and 5.3-2 present the pipe, weld overlay, and flaw geometric details and cyclic stress combinations needed to predict fatigue crack growth in Quad Cities Unit 1 Welds 02C-S4, 02J-S4, and 02K-S3. NUTECH's NUTCRAK computer program was used to predict radial crack growth for axial and circumferential flaws using the following conservative crack growth correlation:

$$\frac{da}{dN} = 2.84 \times 10^{-8} K^{2.57}$$

Where:

da = differential crack size (inches)
dN = differential stress cycle
K = applied stress intensity factor (ksi $\sqrt{in}$)

As discussed in Section 3.3, this crack growth correlation is derived from fatigue crack growth data presented in EPRI Document NP-2423-LD (Reference 9).

Table 5.3-3 presents the predicted fatigue crack growth depth for a 30 year design life.

5.3.2 Circumferential Flaw Weld Overlay Repair Evaluation

Table 5.3-4 presents the pipe, weld overlay, and flaw geometric details and primary stress combinations needed to evaluate the weld overlay repairs applied to circumferential flaws in accordance with USNRC Generic Letter 84-11, ASME Section XI Table IWB-3641-1, and Section 3.3.

5.3.3 Axial Flaw Weld Overlay Repair Evaluation

Table 5.3-5 presents a comparison of stress ratios due to applied loads versus the allowable stress ratios for the axial flaws given in Table 1.0-2. The allowable stress ratios shown were determined using the leakage barrier criteria presented in Table 3.2-2.

Table 5.1-1

WELD 02BS-S9

PIPE AND FLAW GEOMETRIC DETAILS AND SUSTAINED STRESS COMBINATIONS

Weld ID	Nominal O.D.(1) (in.)	$t^{(2)}$ (in.)	$a^{(3)}$ (in.)	$L^{(4)}$	Sustained Stress(5) (psi)
02BS-S9	28	1.359	0.326	360°	8,105

NOTES:

1. O.D. = outside diameter
2. t = pipe wall thickness
3. a = beginning-of-fuel cycle flaw depth
4. L = evaluation flaw length
5. Sustained stress = dead weight + internal pressure + thermal expansion + weld overlay shrinkage stresses from Tables 4.1-1 and 4.2-2.

Table 5.1-2

WELD 02BS-S9

PREDICTED END-OF-FUEL CYCLE FLAW DEPTHS

Weld ID	Beginning-of-Fuel Cycle Flaw Depth Ratio (1)	End-of-Fuel Cycle Flaw Depth Ratio (2)
02BS-S9	0.24	0.24

NOTES:

1. Beginning-of-fuel cycle flaw size used flaw depth ratio ($\frac{a}{t}$) from Table 5.1-1 and 360° circumferential length.

2. Predicted end-of-fuel cycle flaw depth based upon combination of dead weight, internal pressure, thermal expansion, weld overlay shrinkage and post-IHSI residual stresses.

Table 5.1-3

WELD 02BS-S9

GENERIC LETTER 84-11/TABLE IWB-3641-1

PREDICTED VS. ALLOWABLE FLAW DEPTH RATIOS

Weld ID	L[1] (in.)	FLR[2]	SR[3]	IWB-3641-1 FDR[4]	GL 84-11 FDR[5]	Predicted FDR[6]
02BS-S9	4.5	0.05	0.39	0.75	0.50	0.24

NOTES:

1. Flaw length, L, is maximum combination of circumferential flaw lengths on either side of weld from Table 1.0-2.
2. FLR = flaw length ratio = flaw length, L, divided by nominal pipe circumference.
3. SR = dead weight plus internal pressure plus seismic stresses (Table 4.1-1) divided by allowable stress intensity, S_m. From ASME Section III (Reference 18) Appendix I, Table I-1.2, S_m = 16,950 psi for 304 stainless steel pipe and fittings at 550°F operating temperature.
4. FDR = flaw depth ratio ($\frac{a}{t}$) from ASME Section XI (Reference 3) Table IWB-3641-1.
5. Allowable flaw depth ratio ($\frac{a}{t}$ x 2/3) per USNRC Generic Letter 84-11 (Reference 2).
6. Predicted end-of-fuel cycle flaw depth ratio from Table 5.1-2.

Table 5.1-4

WELD 02BS-S9

PROPOSED TABLE IWB-3641-5

PREDICTED VS. ALLOWABLE FLAW DEPTH RATIOS

Weld ID	L[1] (in.)	FLR[2]	SR[3]	IWB-3641-1 FDR[4]	Predicted FDR[6]
02BS-S9	4.5	0.05	0.49	0.6	0.24

NOTES:

1. Flaw length, L, is maximum combination of circumferential flaw lengths on either side of weld from Table 1.0-2.
2. FLR = flaw length ratio = flaw length, L, divided by nominal pipe circumference.
3. SR = M [(dead weight plus internal pressure plus seismic stresses) + (thermal expansion plus weld overlay shrinkage stresses divided by 2.77)] divided by allowable stress intensity, S_m, defined in Note 3, Table 5.1-3. Used worst M = 1.144 for SAW weldment greater than 24 inches in diameter.
4. FDR = flaw depth ratio ($\frac{a}{t}$) from proposed ASME Section XI Table IWB-3641-5 (Reference 6).
5. Predicted end-of-fuel cycle flaw depth ratio from Table 5.1-2.

Table 5.2-1

1984 OVERLAY-REPAIRED WELDS

PIPE, OVERLAY, AND FLAW GEOMETRIC DETAILS

CIRCUMFERENTIALLY FLAWED WELDS

Weld ID	Nominal O.D.[1] (in.)	L[2] (in.)	t_p[3] (in.)	t_o[4] (in.)	a[5] (in.)	Design FDR[7]
02E-S4	12.75	0.8	0.585	0.282	0.595	0.69
02G-S3	12.75	0.75	0.585	0.318	0.675[6]	0.75
02G-S4	12.75	1.0	0.585	0.379	0.595	0.62
02H-S3	12.75	3.0	0.585	0.300	0.595	0.67
02J-S3	12.75	0.6	0.585	0.222	0.595	0.74
02B-S10	22.0	2.0	1.093	0.219	0.219	0.17

NOTES:

1. O.D. = outside diameter.
2. Flaw length, L, is maximum combination of circumferential flaw lengths on either side of weld from Table 1.0-1.
3. t_p = original pipe wall thickness.
4. t_o = weld overlay repair thickness from Table 2.0-1.
5. a = design flaw depth per Section 3.2 evaluation criteria.
6. Includes low delta ferrite first layer assumed to be 0.090" thick.
7. Design flaw depth ratio, FDR, is design flaw depth, a, divided by (t_o + t_p).

Table 5.2-2

1984 OVERLAY-REPAIRED WELDS
GENERIC LETTER 84-11/TABLE IWB-3641-1
DESIGN VS. ALLOWABLE FLAW DEPTH RATIOS

Weld ID	FLR(1)	SR(2)	IWB-3641-1 FDR(3)	Design FDR(4)
02E-S4	0.02	0.28	0.75	0.69
02G-S3	0.02	0.29	0.75	0.75
02G-S4	0.02	0.26	0.75	0.62
02H-S3	0.07	0.28	0.75	0.67
02J-S3	0.01	0.31	0.75	0.74
02B-S10	0.03	0.31	0.75	0.17

NOTES:

1. FLR = flaw length ratio = flaw length, L, from Table 5.2-1 divided by nominal pipe circumference.
2. SR = dead weight plus internal pressure plus seismic stresses (Table 4.1-1) divided by allowable stress intensity, S_m, defined in Note 3, Table 5.1-3.
3. FDR = allowable flaw depth ratio ($\frac{a}{t}$) from ASME Section XI (Reference 3) Table IWB-3641-1.
4. Design FDR from Table 5.2-1.

nutech ENGINEERS

Table 5.2-3

1984 OVERLAY-REPAIRED WELDS
GENERIC LETTER 84-11/EXPANDED TABLE IWB-3641-1
100% X 360° VS. ALLOWABLE FLAW DEPTH RATIOS

Weld ID	FLR(1)	SR(2)	Expanded IWB-3641-1 FDR(3)	Design FDR(4)	
02E-S4	1.0	0.28	0.75	0.69	
02G-S3	1.0	0.29	0.75	0.75	
02G-S4	1.0	0.26	0.75	0.62	
02H-S3	1.0	0.28	0.75	0.67	
02J-S3	1.0	0.31	0.75	0.74	
02B-S10	1.0	0.31	0.75	0.84	NA(5)

NOTES:

1. FLR = flaw length ratio = 1.0 for 360° assumed flaw length.
2. SR from Table 5.2-2.
3. FDR = allowable flaw depth ratio ($\frac{a}{t}$) from Table 3.2-1.
4. From Table 5.2-1, design FDR = (t_p + 0.010")/(t_p + t_o).
5. Not acceptable for conservative 100% x 360° flaw assumption.

nutech ENGINEERS

Table 5.2-4

1984 OVERLAY-REPAIRED WELDS

PROPOSED TABLE IWB-3641-5

DESIGN VS. ALLOWABLE FLAW DEPTH RATIOS

Weld ID	FLR(1)	SR(2)	IWB-3641-5 FDR(3)	Design FDR(4)
02B-S10	0.03	0.33	0.6	0.17

NOTES:

1. FLR from Table 5.2-2.

2. SR = M[(dead weight plus internal pressure plus OBE seismic stresses) + (thermal expansion stress divided by 2.77)] divided by allowable stress intensity, S_m, defined in Note 3, Table 5.1-3. Used worst M = 1.08 for SAW weldment less than 24 inches in diameter.

3. FDR = flaw depth ratio ($\frac{a}{t}$) from proposed ASME Section XI Table IWB-3641-5 (Reference 6).

4. Design FDR from Table 5.2-1.

nutech ENGINEERS

Table 5.2-5

1984 OVERLAY-REPAIRED WELDS

PIPE AND FLAW GEOMETRIC DETAILS

AXIALLY FLAWED WELDS

Weld ID	Nominal O.D.(1) (in.)	L(2) (in.)	t_p(3) (in.)
02D-S4	12.75	0.875	0.585
02E-S4	12.75	1.125	0.585
02F-S4	12.75	0.8	0.585
02G-S3	12.75	1.125	0.585
02G-S4	12.75	0.125	0.585
02H-S3	12.75	0.75	0.585
02H-S4	12.75	0.75	0.585
02J-F6	12.75	1.25	0.585
02J-S3	12.75	0.5	0.585
02K-S4	12.75	0.25	0.585
02M-S3	12.75	1.0	0.585
02B-S7	22.0	0.125	1.093
02B-S10	22.0	0.5	1.093

NOTES:

1. O.D. = outside diameter.
2. Flaw length, L, is maximum single axial flaw length on either side of weld from Table 1.0-1.
3. t_p = original pipe wall thickness.

Table 5.2-6

1984 OVERLAY-REPAIRED WELDS

APPLIED VS. ALLOWABLE STRESS RATIOS

AXIALLY FLAWED WELDS

Weld ID	Applied Stress Ratio (1)	Allowable Stress Ratio (2)	Standard t_o (3) (in.)	Actual t_o (4) (in.)
02D-S4	0.80	0.90	0.125	0.216
02E-S4	0.80	0.80	0.125	0.282
02F-S4	0.80	0.90	0.125	0.180 (5)
02G-S3	0.80	0.80	0.125	0.318 (5)
02G-S4	0.80	0.95	0.125	0.379
02H-S3	0.80	0.90	0.125	0.300
02H-S4	0.80	0.90	0.125	0.198
02J-F6	0.80	0.80	0.125	0.316
02J-S3	0.80	0.95	0.125	0.222
02K-S4	0.80	0.95	0.125	0.207
02M-S3	0.80	0.80	0.125	0.136-
02B-S7	0.74	0.95	0.125	0.330 (5)
02B-S10	0.74	0.95	0.125	0.219

NOTES:

1. Applied stress ratio is calculated for internal pressure of 1,250 psi using geometric properties from Table 5.2-5 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. As-built weld overlay repair thickness.
5. Includes low delta ferrite first layer assumed to be 0.090" thick.

nutech ENGINEERS

Table 5.3-1

1986 OVERLAY-REPAIRED WELDS
PIPE, OVERLAY, AND CIRCUMFERENTIAL FLAW GEOMETRIC DETAILS AND CYCLIC STRESS COMBINATIONS

Weld ID	Nominal O.D.[1] (in.)	t_p[2] (in.)	t_o[3] (in.)	t[5] (in.)	a[6] (in.)	L[7]	Cyclic Stress[8] (psi)
02C-S4	12.75	0.585	0.514[4]	1.099	0.675	360°	4,373
02J-S4	12.75	0.585	0.370	0.955	0.585	360°	4,267
02K-S3	12.75	0.585	0.375	0.960	0.585	360°	4,516
Bounding Case	12.75	0.585	0.235	0.820	0.585	360°	5,404[9]

NOTES:

1. O.D. = outside diameter.
2. t_p = original pipe wall thickness.
3. t_o = weld overlay repair thickness from Table 2.0-2.
4. Includes low delta ferrite first layer assumed to be 0.090" thick.
5. t = $t_p + t_o$.
6. a = evaluation flaw depth = 100% x t_p (conservative).
7. L = evaluation flaw length.
8. Cyclic stress = internal pressure + thermal expansion stresses from Table 4.1-1.
9. Cyclic stress increases to 5,890 psi during emergency cycle due to 75 psi increase in internal pressure.

Table 5.3-2

1986 OVERLAY-REPAIRED WELDS

PIPE, OVERLAY, AND AXIAL FLAW GEOMETRIC

DETAILS AND CYCLIC STRESS COMBINATIONS

Weld ID	Nominal O.D.(1) (in.)	t(2) (in.)	a(3) (in.)	L(4) (in.)	Cyclic Stress(5) (psi)
02C-S4	12.75	1.099	0.619	1.0	7,898
02J-S4	12.75	0.955	0.615	1.1	8,344
02K-S3	12.75	0.960	0.540	0.75	8,300
Bounding Case	12.75	0.955	0.619	(6)	8,344(7)

NOTES:

1. O.D. = outside diameter.
2. t = $t_p + t_o$ from Table 5.3-1.
3. a = beginning of evaluation period flaw depth from Table 1.0-2.
4. L = maximum axial flaw length from Table 1.0-1 and 1.0-2.
5. Cyclic stress acting on axial flaw is hoop internal pressure stress = 2 x Table 4.1-1 internal pressure stresses.
6. Evaluation flaw length = infinitely long axial length.
7. Cyclic stress increases to 8,845 psi during emergency cycle due to 75 psi increase in internal pressure.

Table 5.3-3

1986 OVERLAY-REPAIRED WELDS

PREDICTED 30 YEAR FATIGUE CRACK DEPTHS

Crack Orientation	Beginning-of-Evaluation Period Flaw Depth (1)	End-of-Evaluation Period Flaw Depth (2)
Circumferential	0.585"	0.590"
Axial	0.619"	0.640"

NOTES:

1. Bounding beginning-of-evaluation period flaw depth from Table 5.3-2.

2. Predicted end-of-evaluation period flaw depth based upon combination of internal pressure, thermal expansion (for circ. flaw), through-wall temperature gradient, and under-the-overlay residual stresses.

Table 5.3-4

1986 OVERLAY-REPAIRED WELDS

GENERIC LETTER 84-11/TABLE IWB-3641-1

DESIGN VS. ALLOWABLE FLAW DEPTH RATIOS

Weld ID	FLR(1)	SR(2)	IWB-3641-1 FDR(3)	Predicted FDR(4)
02C-S4	1.0	0.26	0.75	0.54
02J-S4	1.0	0.26	0.75	0.62
02K-S3	1.0	0.26	0.75	0.61

NOTES:

1. FLR = flaw length ratio = 1.0 for 360° assumed flaw length.

2. SR = dead weight plus internal pressure plus seismic stresses (Table 4.1-1) divided by allowable stress intensity, S_m, defined in Note 3, Table 5.1-3.

3. FDR = allowable flaw depth ratio ($\frac{a}{t}$) from ASME Section XI (Reference 3) Table IWB-3641-1.

4. Predicted FDR = bounding end-of-evaluation period circumferential flaw depth from Table 5.3-3 divided by "t" from Table 5.3-1.

Table 5.3-5

1986 OVERLAY-REPAIRED WELDS

APPLIED VS. ALLOWABLE STRESS RATIOS

AXIALLY FLAWED WELDS

Weld ID	Applied Stress Ratio (1)	Allowable Stress Ratio (2)	Standard t_o (3) (in.)	Remaining Ligament (4) (in.)
02C-S4	0.80	0.80	0.125	0.459
02J-S4	0.80	0.80	0.125	0.315
02K-S3	0.80	0.90	0.125	0.320

NOTES:

1. Applied stress ratio is calculated for internal pressure of 1,250 psi using geometric properties from Tables 5.3-1 and 5.3-2 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. Remaining ligament = t_o + t_p from Table 5.3-1 minus bounding end-of-evaluation period axial flaw depth from Table 5.3-3.

nutech ENGINEERS

6.0 SUMMARY AND CONCLUSIONS

Quad Cities Nuclear Power Plant Unit 1 has recently completed its first fuel cycle of operation with flaws identified during its 1984 refueling outage. Ultrasonic examinations performed in 1984 detected flaws judged to be IGSCC in the vicinity of 17 recirculation system welds. Evaluations documented in NUTECH's 1984 flaw evaluation and disposition report (Reference 1) determined the need for weld overlay repairs at 16 of these welds and the acceptability of Weld 02BS-S9 with IHSI only.

During the 1986 refueling outage, ultrasonic examinations were performed on 4 of the 17 flawed welds as required by Generic Letter 84-11 (Reference 2). To allow for required surface finish grinding, the overlay repairs on Welds 02C-S4, 02J-S4, and 02K-S3 were built-up to design thicknesses required for a 30 year design life.

The crack growth analyses and flawed pipe/weld overlay repair evaluations presented in this report demonstrate that the original design margins of safety inherent in the Code for the flawed welds have not been degraded and that these overlay-repaired and IHSI-mitigated welds are acceptable for a minimum of one additional fuel cycle.

7.0 REFERENCES

1. NUTECH Document COM-96-202, "Evaluation and Disposition of IGSCC Flaws at Quad Cities Nuclear Power Station Unit 1," Revision 0.

2. USNRC Generic Letter 84-11, "Inspections of BWR Stainless Steel Piping," April 19, 1984.

3. ASME Boiler and Pressure Vessel Code Section XI, 1983 Edition with Addenda through Winter 1983.

4. U.S. Nuclear Regulatory Commission Document No. NUREG-1061, Volume 1, "Investigation and Evaluation of Stress-Corrosion Cracking in Piping of Boiling Water Reactor Plants," April 1984, Second Draft attached to SECY-84-301, dated July 30, 1984.

5. USNRC Document, "Safety Evaluation by the Office of Nuclear Reactor Regulation - Inspection and Repair of Reactor Coolant System Piping at Quad Cities Unit 2," attached to J. A. Zwolinski (USNRC) letter to D. L. Farrar (CECo), dated January 7, 1986.

6. ASME Section XI Task Group on Pipe Flaw Evaluation Document, "Proposed IWB-3640 Change for Evaluation of Flux Weldments," presented at March 1985 ASME meeting, Palm Springs, California.

7. NUTECH Document NSP-81-105, "Design Report for Recirculation Safe End and Elbow Repairs - Monticello Nuclear Generating Plant," Revision 2.

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

9. EPRI Document NP-2423-LD, "Stress Corrosion Cracking of Type-304 Stainless Steel in High-Purity Water: A Compilation of Crack Growth Rates," Interim Report, June 1982.

10. Sargent & Lundy Document R-2330, "Specification for Piping System - Quad Cities Units 1 and 2," with all supplements through Supplement 25.

11. EDS Nuclear Report No. 04-0591-0047, "IGSCC Evaluation for the Piping System of Quad Cities Nuclear Station, Unit 1," Revision 0, August 1982.

12. Letter, W. F. Tschudi (Impell Corp.) to A. K. Rao (NUTECH), "Data for IGSCC Evaluation, Quad Cities Unit 1," April 19, 1984.

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

14. EPRI Document No. NP-2662-LD, "Computational Residual Stress Analysis for Induction Heating of Welded BWR Pipes," December 1982.

15. EPRI Document, "Continued Service Justification for Weld Overlay Pipe Repairs," Final Draft, May 25, 1984.

16. NUTECH Document HLG-84-001, "Weld Residual Stress Data Base for IGSCC Crack Growth Calculations," January 10, 1984.

17. NUTECH Computer Program NUTCRAK, Revision 2.0.2, December 1983, NUTECH Corporate File 08.039.0005.

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