STRUCTURAL INTEGRITY ASSOCIATES, INC.

CALCULATION PACKAGE

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PROJECT NAME: BRUNSWICK UNIT 1 OUTAGE SUPPORT

CLIENT: CAROLINA POWER & LIGHT

CALCULATION TITLE:

FLAW EVALUATION - RHR VALVE TO RECIRC. TEE

PROBLEM STATEMENT OR OBJECTIVE OF THE CALCULATION:

ULTRASONIC FLAW INDICATIONS (AXIAL ORIENTATION) BELIEVED TO BE ORIGINAL CONSTRUCTION DISCONTINUITIES HAVE BEEN DETECTED IN THE RHR VALVES (CAST CARBON STEEL) NEAR THE RECIRC. TEE. THIS CALCULATION EVALUATES THE LARGEST INDICATION TO DEMONSTRATE ACCEPTABILITY OF THESE INDICATIONS IN ACCORDANCE WITH ASME SECTION XI.

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CPL BSEP-1 RHR VALVE EVALUATION, FRACTURE MECHANICS

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1.0 INTRODUCTION

AS DESCRIBED IN THE PROBLEM STATEMENT ON PAGE 1 OF THIS CALC. PACK., FLAW INDICATIONS OF AXIAL ORIENTATION HAVE BEEN FOUND BY UT IN THE BSEP-1 RHR CARBON STEEL VALVES. THESE INDICATIONS AND THE EVALUATION APPROACH ARE DESCRIBED BELOW.

1.1 FLAW INDICATIONS

DETAILS OF THE RHR VALVE NEAR THE RECIRC. TEE WELD ARE SHOWN IN FIGURE 1.[1]* AXIAL INDICATIONS WERE FOUND IN THE 2.75" REDUCED SECTION, OUTSIDE THE ASME CODE INSPECTION VOLUME FOR THE WELD.[2]

THESE INDICATIONS ARE BELIEVED TO BE ORIGINAL CONSTRUCTION DISCONTINUITIES IN THESE ASTM 216-WCB CASTINGS[3].

INSPECTION SUMMARY SHEETS FOR THE LARGEST, DEEPEST (1.1" DEEP, FROM I.D. SURFACE) INDICATION ARE SHOWN

* REFS. LISTED IN SECTION 6.0.

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IN APPENDIX A.[2,7] AS DESCRIBED IN APPENDIX A, THE INDICATION'S END POINT ON THE VALVE SIDE COULD NOT BE DETERMINED BECAUSE OF THE VALVE CONFIGURATION.[2]

1.2 OBJECTIVE AND APPROACH

THE OBJECTIVE IS TO ANALYZE THE LARGEST INDICATION, DESCRIBED ABOVE, FOR ACCEPTANCE PER ASME SECTION XI. THE LATEST EDITION OF SECTION XI [4] IS EMPLOYED TO GAIN MAXIMUM GUIDANCE FOR THIS EVALUATION. BOTH ELASTIC-PLASTIC (EPFM) AND LINEAR ELASTIC (LEFM) FRACTURE-MECHANICS METHODS WERE USED TO CROSS-CHECK THE RESULTS.

STRESSES DUE TO PRESSURE AND THERMAL EXPANSION OF DISSIMILAR MATERIALS (TEE AND VALVE) WERE OBTAINED FROM A FINITE ELEMENT ANALYSIS [5,6].

ACTUAL MATERIAL PROPERTIES FROM THE VALVES [7], FROM CMTR'S, ARE SHOWN IN APPENDIX B, AND WERE USED TO DERIVE APPLICABLE TOUGHNESS AND TENSILE PROPERTIES FOR THE FRACTURE MECHANICS EVALUATIONS.

THE SI COMPUTER PROGRAM, PC-CRACK [8] WAS USED FOR THE EVALUATIONS OF CRITICAL FLAW SIZES AND STRESSES. CODE MARGINS [4] WERE EMPLOYED. SUBCRITICAL CRACK GROWTH WAS NOT ANALYZED IN DETAIL, SINCE THESE INDICATIONS ARE NOT CONSIDERED TO BE SERVICE-INDUCED [2] AND PRONE TO SUBSEQUENT GROWTH.

2.0 STRESS ANALYSIS RESULTS

A SUMMARY OF THE STRESS ANALYSIS [5, 6] RESULTS USED IN THIS FLAW EVALUATION IS SEEN IN TABLE 1. THE CROSS-SECTIONS SUMMARIZED ARE SHOWN IN FIGURE 2, WITH THE LARGEST FLAW INDICATION SUPERIMPOSED.

BOTH PRESSURE STRESS (σ_p) RESULTS AND THERMAL EXPANSION STRESS (σ_T) RESULTS DUE TO THE DISSIMILAR MATERIALS AT THE TEE (STAINLESS STEEL TEE / CARBON STEEL VALVE) ARE SHOWN. FOR CURVE-FITTING THE STRESS DISTRIBUTIONS AT SECTIONS A (REDUCED SECTION) AND C (THICK SECTION, NOT INSPECTED), THE HOOP PRESSURE STRESSES ARE MULTIPLIED BY 3.75 (1.25 TO ACCOUNT FOR 1250 PSI. PRESSURE [7] VS. 1000 PSI. PRESSURE ANALYSIS, AND 3 FOR ASME [4] SAFETY FACTOR). THE SAFETY FACTOR ON THE THERMAL STRESS IS 1 [4]. THE DISTANCE FROM THE I.D. (X) IS ALSO SHOWN FOR CURVE-FITTING FOR THE

LEFM ANALYSES. CURVE-FITTING RESULTS ARE SHOWN IN APPENDICES D AND E FOR STRESSES AT SECTIONS A AND C IN FIGURE 2. SECTION A STRESSES WERE USED FOR THE LEFM REDUCED SECTION (A-B) ANALYSES, AND SECTION C STRESSES WERE USED FOR THE THICK SECTION (C) ANALYSIS, SHOWN IN APPENDICES D AND E. WELD RESIDUAL STRESSES WERE ASSUMED TO BE ZERO, BASED ON FIGURE 3 [10].

BECAUSE OF LIMITATIONS IN THE EPFM CRACK MODELS [8,9], ONLY AN INFINITE LENGTH SURFACE CRACK WITH CONSTANT HOOP STRESS (VERSUS A THRU-WALL DISTRIBUTION) WAS ANALYZED IN APPENDIX C. THUS, AVERAGE STRESSES IN THE REDUCED SECTION (A-B) WERE USED FOR THE EPFM ANALYSIS, EVEN THOUGH THE INFINITE CRACK WOULD EXTEND INTO MUCH COLDER STRESS REGIONS (SECTION C AND BEYOND). THE AVERAGE BETWEEN THE I.D. AND THE O.D. "$\sigma_p \times 3.75$" VALUES AT SECTION A IS 41.757 KSI., AND AT SECTION B IS 28.857, FOR AN AVERAGE

OF 35.307 KSI., DUE TO PRESSURE AND WITH A SAFETY FACTOR OF 3. SIMILARLY, FOR A SAFETY FACTOR OF 1 ON THERMAL STRESS, THE AVERAGE THERMAL STRESS IN THE REDUCED SECTION (A-B) IS 6.49 KSI. THUS, A TOTAL PRESSURE PLUS THERMAL STRESS OF 41.797 KSI., INCLUDING SAFETY FACTORS, IS USED TO EVALUATE THE EPFM RESULTS IN APPENDIX C.

SINCE THE EPFM CRACK MODEL [8,9] ONLY ACCEPTS PRESSURE AS AN INPUT (OR OUTPUT, FOR COMPUTING CRITICAL PRESSURE), THE APPROPRIATE CONVERSION BETWEEN STRESS AND PRESSURE (BASED ON THE MODEL) IS SHOWN IN APPENDIX C. FOR A STRESS OF 41.797 KSI., THE CORRESPONDING PRESSURES FOR THE MINIMUM THICKNESS (SECTION A) AND THE AVERAGE THICKNESS (SECTIONS A-B) ARE ABOUT 5.4 KSI. AND 4.9 KSI., RESPECTIVELY. THESE PRESSURES SHOULD BE USED TO INTERPRET THE EPFM RESULTS IN APPENDIX C.

3.0 MATERIAL PROPERTIES

TENSILE AND TOUGHNESS PARAMETERS FOR THE EPFM AND LEFM EVALUATIONS WERE DERIVED FROM ACTUAL "B" VALVE (THE SITE OF THE LARGEST INDICATION) PROPERTIES IN APPENDIX B AS FOLLOWS. THE MATERIAL SPECIFICATION IS ASTM A216 WCB [13].

3.1 TENSILE STRESS-STRAIN

THE ROOM TEMP. Y.S. OF 79.9 KSI. IN APPENDIX B WAS RATIOED TO ADJUST FOR THE TEMPERATURE OF 532°F (APP. B) BY USING THE S_y VALUES IN SECTION III OF THE CODE [1], TO GIVE A Y.S. OF 62.8 KSI. AT 532°F. BASED ON [11], THE UTS AT ROOM TEMP. AND 532°F WOULD BE THE SAME, AT 100.1 KSI. AN ELASTIC MODULUS OF E = 27,100 KSI. WAS TAKEN FROM [11],

USING THE METHODS OF [12], RAMBERG-OSGOOD STRESS-STRAIN PARAMETERS WERE DERIVED AS SHOWN IN TABLE 2 AND AS ILLUSTRATED FOR TRUE STRESS-STRAIN IN FIGURE 4.

THESE Y.S. AND UTS VALUES ARE REASONABLY CLOSE TO THOSE SHOWN IN TABLE 3 [10] FOR 80XX SMAW AND SAW WELDS, WHICH MIGHT BE EXPECTED FOR A NORMALIZED AND TEMPERED (1650°F + 1250°F, 5 HR. FROM THE CMTR [13]) CASTING.

3.2 TOUGHNESS

CMTR CHARPY V-NOTCH TOUGHNESS VALUES OF 21, 32 AND 31 FT-LB. AT -20°F ARE SHOWN IN APPENDIX B FOR THE B-VALVE BEING EVALUATED. THESE VALUES ARE QUITE GOOD FOR THIS LOW TEMPERATURE, AND IT IS FULLY EXPECTED THAT THE TOUGHNESS WOULD INCREASE TO AT LEAST 35 FT-LB. FOR A TEST TEMPERATURE EQUAL TO THE LOWEST HYDRO TEST TEMPERATURE OF 164°F (APP. B). IT IS ALSO EXPECTED THAT 164°F WOULD PRODUCE UPPER SHELF CHARPY TOUGHNESS FOR THIS MATERIAL.

FIGURE 5, FROM [10], SHOWS A CORRELATION (ALSO USED IN [4]) BETWEEN CVN ENERGY AND J_{Ic}. FOR CVN = 35 FT-LB., J_{IC} = 350 IN-LB/IN.^{2}, OR 0.35 IN-KIP/IN.^{2}. THIS IS IN GOOD AGREEMENT WITH J_{ic} MIN. VALUES IN TABLE 4, FROM [10], FOR 80XX SMAW AND SAW WELDS. THE J-RESISTANCE (J-R) CURVE CORRESPONDING TO THIS J_{IC}, AND FOR THESE MATERIALS, IS SHOWN IN FIGURE 6, FROM [10]. THE CURVE IN FIGURE 6 IS USED FOR THE EPFM ANALYSES IN APP. C, AS SHOWN IN THE CURVE-FIT IN FIGURE 7.

FOR J_{ic} = 0.35 IN-KIP/IN.^{2}, E = 27,100 KSI., AND POISSON'S RATIO ν = 0.3, THE FOLLOWING EQUATION [10], IS USED TO DERIVE K_{IC} = 102.1 KSI $\sqrt{IN}$ FOR THE LEFM ANALYSES.

$$K_{IC} = \sqrt{\frac{J_{Ic} E}{(1-\nu^2)}}$$

4.0 FRACTURE MECHANICS FLAW EVALUATIONS

ELASTIC-PLASTIC (EPFM) ANALYSES FOR AN INFINITE LENGTH AXIAL FLAW, AND LINEAR ELASTIC (LEFM) ANALYSES FOR FINITE LENGTH AXIAL FLAWS IN THE REDUCED SECTION OF THE VALVE (TO SHOW AN ACCEPTABLE FLAW LENGTH GREATER THAN THE REDUCED SECTION LENGTH) AND FOR AN INFINITE LENGTH FLAW IN THE LOWER-STRESSED THICK SECTION WERE PERFORMED. CURSORY FATIGUE CRACK GROWTH CHECKS WERE ALSO MADE TO ASSURE THAT ANY PREDICTED GROWTH WOULD BE INSIGNIFICANT.

4.1 ELASTIC-PLASTIC (EPFM)

PC-CRACK [8] RESULTS FOR THIS ANALYSIS ARE SHOWN IN APPENDIX C. TWO CALCULATIONS ARE DONE: (1) FOR THE REDUCED SECTION AVERAGE THICKNESS (SECTIONS A-B IN FIG. 2) OF 1.695", AND (2) FOR THE SECTION A MINIMUM THICKNESS OF 1.535". CRITICAL PRESSURES FOR AN INFINITE

LENGTH AXIAL CRACK 1.1" DEEP WERE COMPUTED AS 6.73 KSI. AND 5.66 KSI. BOTH THE CRITICAL PRESSURES ARE ABOVE THE CORRESPONDING PRESSURES OF 5.7 KSI. AND 4.9 KSI., DISCUSSED IN SECTION 2.0 AS REPRESENTING AVERAGE REDUCED SECTION (A-B) STRESSES (WITH SAFETY FACTORS) FOR THE PC-CRACK MODEL. AGAIN, THE AVERAGE TOTAL PRESSURE AND THERMAL STRESS (WITH SAFETY FACTORS) IS 41.797 KSI., AND CORRESPONDS TO THE PC-CRACK PRESSURES OF 5.4 AND 4.9 KSI AS SHOWN IN THE TABLE IN APP. C.

SINCE THE CRITICAL PRESSURES ARE ABOVE THE ACTUAL PRESSURES FOR THE MODEL, THE INFINITE LENGTH, 1.1" DEEP CRACK IS PREDICTED AS STABLE, AND ACCEPTABLE.

4.2 LINEAR ELASTIC (LEFM)

4.2.1 REDUCED SECTION

LEFM RESULTS FOR THE VALVE

REDUCED SECTION ARE GIVEN IN APP. D, AND SHOWN IN FIGURES 8 THROUGH 10. ANALYSES WERE MADE TO COMPUTE K VS. CRACK DEPTH (WITH SAFETY FACTORS INCLUDED) FOR CRACK ASPECT RATIOS (c/a) OF 2, 5 & 10, IN ORDER TO DERIVE AN ALLOWABLE LENGTH FOR THE REDUCED SECTION.

RESULTS ARE COMPARED TO THE FRACTURE TOUGHNESS, K_{Ic} = 102.1 KSI$\sqrt{IN}$, DERIVED FROM THE "B" VALVE PROPERTIES. TABLE 5 AND FIGURE 10 SUMMARIZE THE RESULTS FOR 1.1" DEEP FLAWS, IN TERMS OF K VS. CRACK LENGTH. INTERPOLATING ON FIGURE 10, THE ALLOWABLE LENGTH, WHERE K = K_{Ic} = 102.1 KSI$\sqrt{IN}$., IS SEEN TO BE 4.6". THIS ALLOWABLE LENGTH IS LONGER THAN THE REDUCED SECTION PLUS THE VALVE TAPER LENGTH OF 2.75" + 1.6" (FIG. 1), AND A FLAW OF THAT LENGTH IS ACCEPTABLE.

4.2.2 THICK SECTION

APPENDIX E AND FIGURE 11 SHOW THE CEFM RESULTS FOR AN INFINITE LENGTH AXIAL FLAW IN THE THICK SECTION OF THE VALVE (SECTION C, FIG. 2) WHICH COULD NOT BE INSPECTED. SUCH A FLAW IS SEEN TO BE ALLOWED TO A DEPTH OF ABOUT 1.25" BEFORE SAFETY MARGINS WOULD BE VIOLATED, LARGER THAN THE MAXIMUM POSTULATED DEPTH IN THIS REGION OF 1.1".

4.3. CRACK GROWTH CONSIDERATIONS

BECAUSE THE INDICATION IS IN THE VICINITY OF A DISSIMILAR METAL WELD, AND HOOP PRESSURE AND THERMAL STRESSES ARE SEEN TO BE HIGH IN THE VICINITY OF SECTION A (FIG. 2) AS A RESULT OF GOING FROM AMBIENT TO OPERATING CONDITIONS (TABLE 1), FATIGUE CRACK GROWTH OF THE FLAW WAS

CONSIDERED, AS FOLLOWS.

FIGURE 12 SHOWS THE ASME CODE [4] FATIGUE CRACK GROWTH LAWS WHICH ARE APPLICABLE. THE LAW FOR LOW R (STRESS RATIO) IS EMPLOYED, SINCE WELD RESIDUAL STRESSES SHOULD BE NEGLIGIBLE OR COMPRESSIVE (SEE FIG. 3). AT THE INDICATION LOCATION. THAT LAW IS:

$$\frac{da}{dN} = 0.101\ \Delta K^{1.95}$$

WHERE da/dN IS IN MICRO-INCHES PER CYCLE AND ΔK IS IN KSI $\sqrt{IN}$.

SAFETY FACTORS ON STRESS OR K ARE NOT USED [4] FOR CRACK GROWTH ANALYSES. ALSO, A REALISTIC ESTIMATE OF THE INDICATION LENGTH FOR THE MAXIMUM DEPTH OF 1.1" IS GIVEN AS 2.2" BY THE K SOLUTIONS IN TABLE 5 FOR L/A = 2. DIVIDING THE PRESSURE K IN TABLE 5 BY 3, TO REMOVE THE SAFETY FACTOR, AND

ADDING THE THERMAL K OF 13.3 KSI$\sqrt{IN.}$ IN TABLE 5 GIVES $\Delta K = 31$ KSI$\sqrt{IN.}$ FOR MAXIMUM PRESSURE AND THERMAL VARIATIONS. THIS VALUE OF $\Delta K = 31$ KSI$\sqrt{IN}$, AND THE ABOVE GROWTH, PREDICTS A GROWTH OF 8.175×10^{-5} IN./CYCLE. MULTIPLYING THAT GROWTH RATE BY 117 STARTUP CYCLES[14] GIVES PREDICTED GROWTH OF ONLY 0.0095" OVER THE LIFE OF THE PLANT. LESS SEVERE TRANSIENTS, ALTHOUGH POTENTIALLY NUMEROUS, WOULD PLACE THE ANALYSIS ON THE LOWER PART OF THE BILINEAR LAW IN FIG. 12, AND WOULD RESULT IN NEGLIGIBLE PREDICTED GROWTH. THE ABOVE ESTIMATES OF CRACK GROWTH ARE JUDGED NEGLIGIBLE COMPARED TO OTHER CONSERVATISMS WITH STRESSES AND CRACK MODELS IN THIS CALCULATION.

5.0 CONCLUSIONS

1. EPFM WAS USED WITH PROPERTIES DERIVED FROM BSEP-1 RHR VALVE CMTR RESULTS, AND WITH STRESSES FROM FINITE ELEMENT ANALYSIS, TO SHOW THAT AN INFINITELY LONG AXIAL CRACK WITH DEPTH IN EXCESS OF THE 1.1" MAXIMUM INDICATION DEPTH IS ACCEPTABLE.

2. LEFM WAS USED AS A CROSS-CHECK TO SHOW THAT AN AXIAL CRACK 1.1" DEEP WOULD BE ACCEPTABLE OVER THE LENGTH OF THE VALVE REDUCED SECTION AND TAPER. AN INFINITELY LONG FLAW 1.25" DEEP IS ACCEPTABLE FOR THE THICKER SECTIONS OF THE VALVE WHICH WERE NOT INSPECTABLE.

3. PREDICTED FATIGUE CRACK GROWTH IS NEGLIGIBLE.

4. ASME SECTION XI SAFETY MARGINS ARE MET FOR THE LARGEST INDICATION WHICH ENVELOPES THE OTHER INDICATIONS.

5. THE REPORTED INDICATIONS ARE CONSIDERED ACCEPTABLE AS-IS.

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4. ASME B&PV CODE, SECTION XI, 1989 EDITION WITH 1990 ADDENDUM, IWB-3600 AND APPENDICES H AND A.
5. SI CALC. PACK., "STRESS ANALYSIS OF RHR VALVE TO RECIRC. TEE", SI FILE CPL-16Q-304, REV. 0.
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9. V. KUMAR, ET. AL., "AN ENGINEERING APPROACH FOR ELASTIC-PLASTIC FRACTURE ANALYSIS", EPRI REPORT NP-1931, JULY 1981.
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11. ASME B&PV CODE, SECTION III, 1989 EDITION WITH 1990 ADDENDUM, APPENDIX I.
12. T.L. GERBER, ET. AL., "EVALUATION OF HIGH-ENERGY PIPE RUPTURE EXPERIMENTS", EPRI REPORT NP-5531, JAN. 1988.

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TABLE 1

Hoop Stress

	Node	Radius (in.)		σ_p [1]	σ_T [2]	$\sigma_p \times 3.75$
			X			
Section A [3]	217	12.295	1.535	10.34 ksi	5.82 ksi	38.775
	216	12.14"	1.38	10.51 ksi	6.96 ksi	39.413
	215	11.86"	1.10	10.74 ksi	8.86 ksi	40.275
	214	11.59"	0.83	10.96 ksi	10.29 ksi	41.100
	213	11.31"	0.55	11.21 ksi	11.38 ksi	42.038
	212	11.08"	0.27	11.50 ksi	12.20 ksi	43.125
	211	10.76"	0	11.98 ksi	13.22 ksi	44.938
Section B [3]	161	12.295		5.79 ksi	(-) 0.86 ksi	21.713
	160	12.14"		6.20 ksi	0.70 ksi	
	159	11.80"		6.86 ksi	2.37 ksi	
	158	11.46"		7.50 ksi	3.75 ksi	
	157	11.12"		8.15 ksi	5.09 ksi	
	156	10.78"		8.85 ksi	6.44 ksi	
	155	10.44"		9.60 ksi	7.78 ksi	36.000
			X			
Section C [3]	105	12.571"	2.988	3.76 ksi	0.39 ksi	14.100
	104	12.47"	2.887	4.15 ksi	0.58 ksi	15.563
	103	11.97"	1.987	4.62 ksi	0.99 ksi	17.325
	102	11.48"	1.497	5.15 ksi	1.45 ksi	19.313
	101	10.98"	0.997	5.71 ksi	2.04 ksi	21.413
	100	10.48"	0.497	6.30 ksi	2.64 ksi	23.625
	99	9.983"	0	6.68 ksi	2.99 ksi	25.050

NOTES:
1. For 1000 psig internal pressure.
2. For 532°F steady state temperature, with a 70°F stress free temperature.
3. See figure 2.

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TABLE 2.

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RAMBERG-OSGOOD CONSTANTS FROM TENSILE TEST DATA
(ALPHA, N, YS) , 532°F.

YS (KSI)	UTS (KSI)	EL (%)	E (KSI)	e,tot -0.10 e,uniform (IN/IN)	1+e,u	1+(YS/E)	N	ALPHA
62.8	100.1	22.5	27100	0.125	1.125	1.002	8.490	0.358

$$\frac{\varepsilon}{\varepsilon_o} = \frac{\sigma}{\sigma_o} + \alpha \left(\frac{\sigma}{\sigma_o}\right)^n$$

$$\varepsilon_o = \frac{\sigma_o}{E}$$

WHERE: $\varepsilon, \varepsilon_o$ = TRUE STRAIN, YIELD STRAIN.

σ, σ_o = TRUE STRESS, YIELD STRESS.

E = ELASTIC MODULUS.

α, n = RAMBERG-OSGOOD TRUE STRESS-STRAIN LAW CONSTANTS.

α AND n ARE CALCULATED FROM TENSILE TEST RESULTS AS FOLLOWS [12]:

$$\sigma_o = \sigma_y \text{ , (YIELD STRESS)}$$

$$n = 1 / \ln(1 + e_u)$$

$$\alpha = \left[\frac{\ln(1+e_u)}{\ln(1+\sigma_y/E)} - \frac{\sigma_u (1+e_u)}{\sigma_y (1+\sigma_y/E)}\right]\left[\frac{\sigma_u (1+e_u)}{\sigma_y (1+\sigma_y/E)}\right]^{-n}$$

WHERE: σ_u = UTS, (ULTIMATE TENSILE STRESS)

e_u = ENGINEERING STRAIN AT UTS, (ARBITRARILY TAKEN AS FRACTURE STRAIN MINUS 0.10).

TABLE 3.

SUMMARY OF TENSILE DATA AT 450-550°F FOR
J-TOUGHNESS TESTED FERRITIC PIPING MATERIALS [10]

Material	Condition	Yield (ksi)	Ultimate (ksi)
Base Metal	----	31 - 52	65 - 85
70XX SMAW	PWHT	34	61
80XX SMAW	PWHT	73 - 75	88
SAW	PWHT	50 - 64	72 - 105

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TABLE 4.

SUMMARY OF AVAILABLE J_{IC} DATA FOR FERRITIC PIPING MATERIALS AT 220-550°F [10]

MATERIAL	NUMBER OF TESTS	J_{IC} (in-lb/in^2)
Base Metals[1]	42	588 - 2300
70XX SMAW		
As-Welded	3	Avg = 721
PWHT	5	1311 - 1723
80XX SMAW		
As-Welded	-	-
PWHT	4	345 - 532
SAW		
As-Welded	3	Avg = 424
PWHT	18	335 - 1350

1. Includes LC and LT orientations

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TABLE 5.

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K VS. CRACK LENGTH
FOR AXIAL CRACKS 1.1" DEEP IN 1.535" WALL
SF=3 ON PRESSURE STRESS, SF=1 ON THERMAL STRESS

CRACK LENGTH/ DEPTH (l/a)	CRACK LENGTH (IN)	K PRESSURE (KSI.IN^0.5)	K THERMAL (KSI.IN^0.5)	K TOTAL (KSI.IN^0.5)
---	0.0	0.0	0.0	0.0
2	2.2	53.0	13.3	66.3
5	5.5	91.2	23.7	114.9
10	11.0	131.0	34.6	165.6

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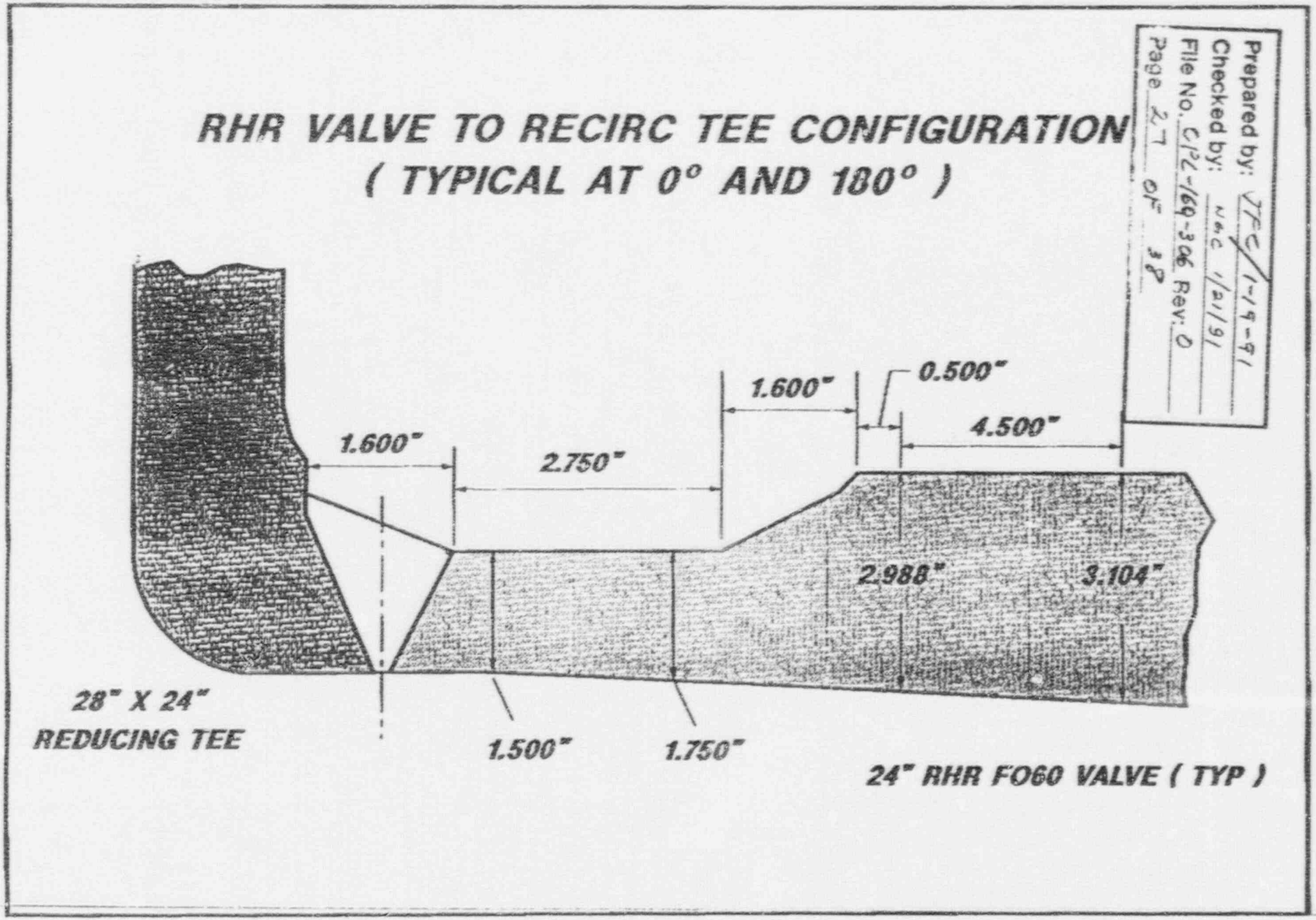
RHR VALVE TO RECIRC TEE CONFIGURATION
(TYPICAL AT 0° AND 180°)
Prepared by: JFC 1-19-91
Checked by: NAC 1/21/91
File No. C12-1169-306 Rev: 0
Page 27 of 38
1.600"
2.750"
1.600"
0.500"
4.500"
2.988"
3.104"
28" X 24"
REDUCING TEE
1.500"
1.750"
24" RHR FO60 VALVE (TYP)

FIGURE 1. [1]

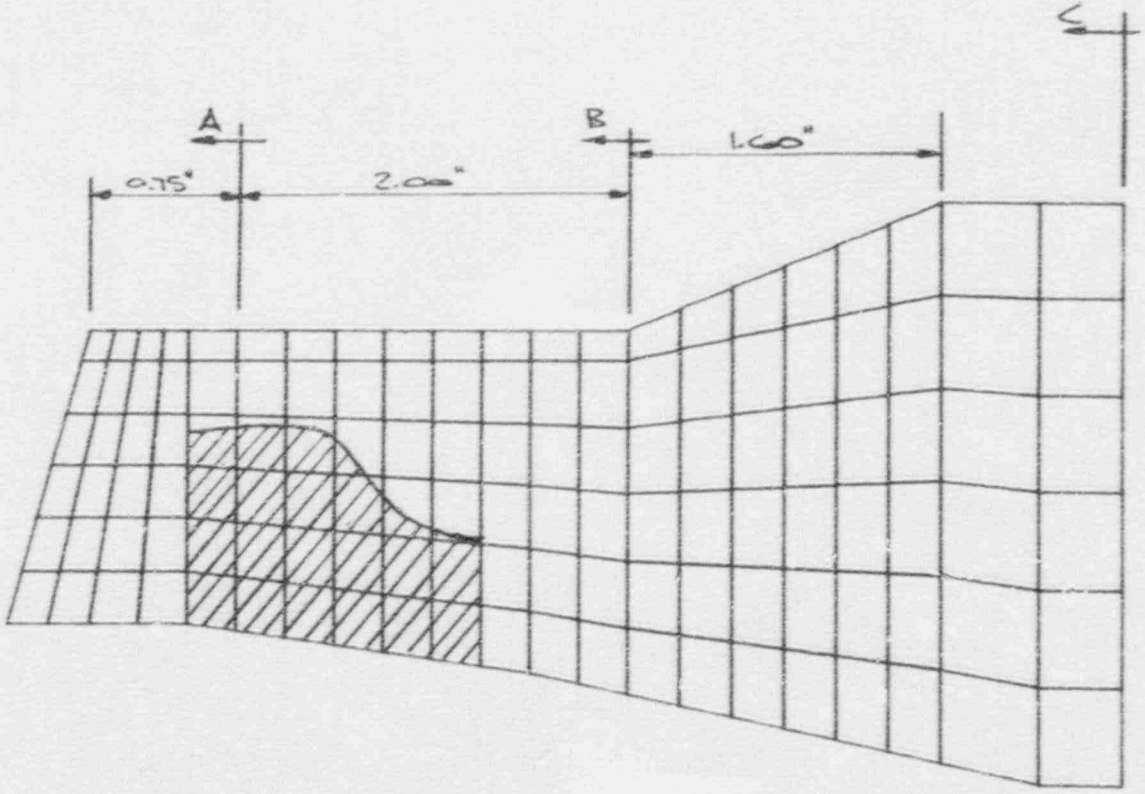

FIGURE 2. (FULL SCALE)

FINITE ELEMENT MODEL

Prepared by: JPC 1-18-91
Checked by: MGC 1/21/91
File No. CPL-169-306 Rev: 0
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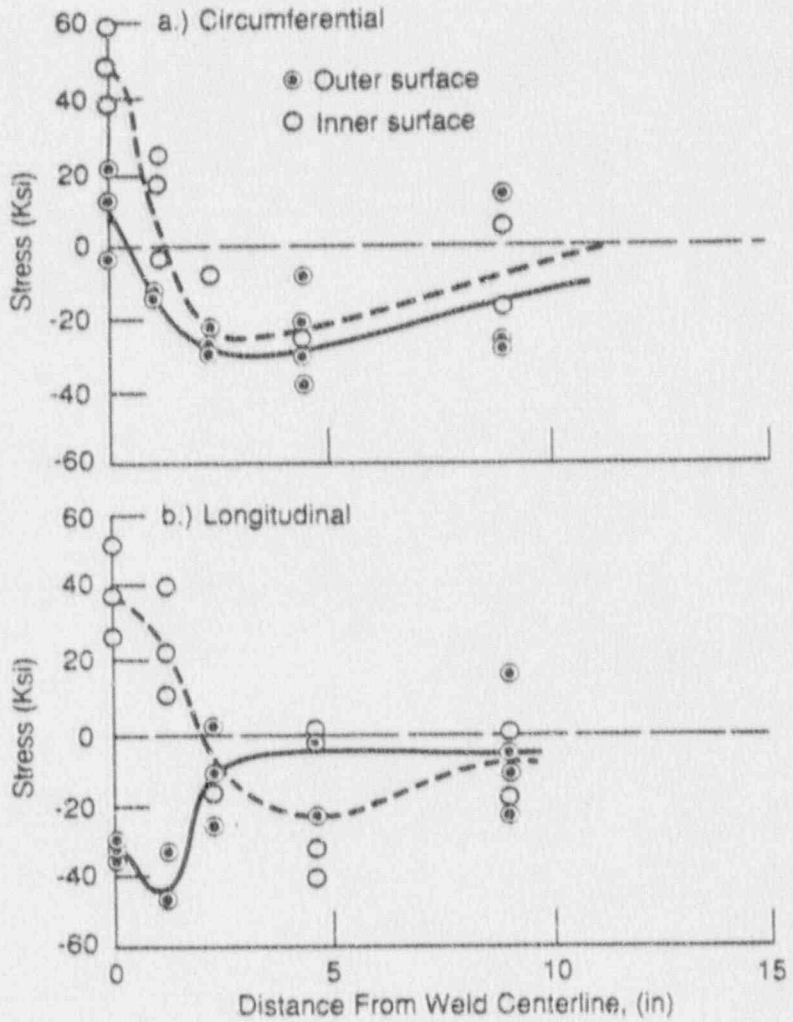

Figure 3. Residual Stresses in a Girth-Welded Low-Carbon Steel Pipe 7/16-inch Wall Thickness 30-inch Diameter and 30-inch Length [10].

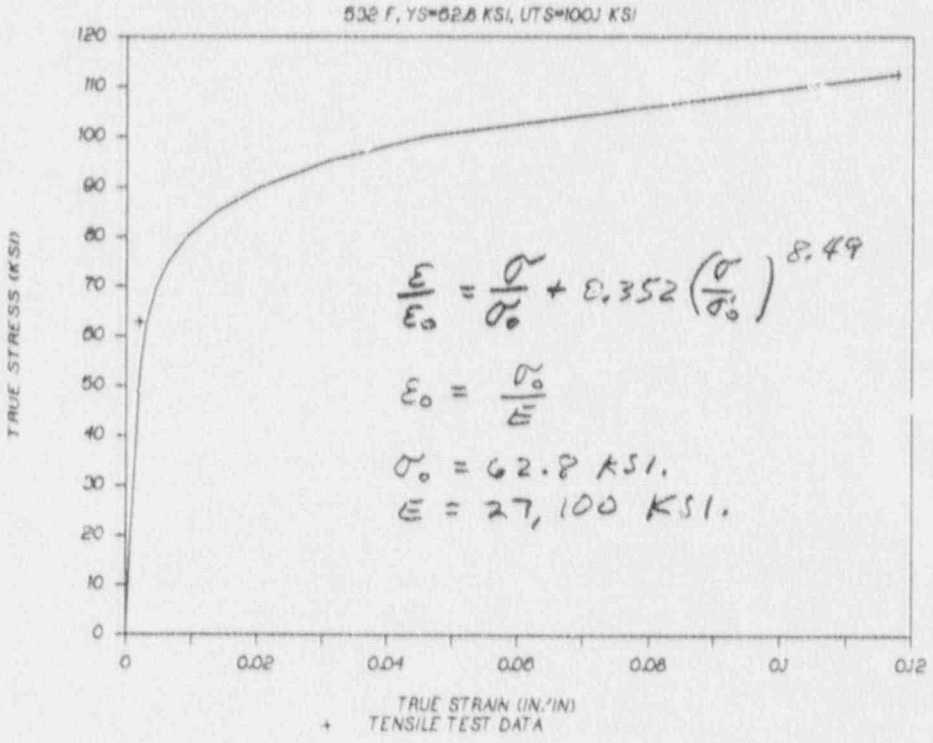

FIGURE 4. COMPARISON OF TENSILE TEST DATA (ADJUSTED FOR 532°F) WITH RAMBERG-OSGOOD LAW.

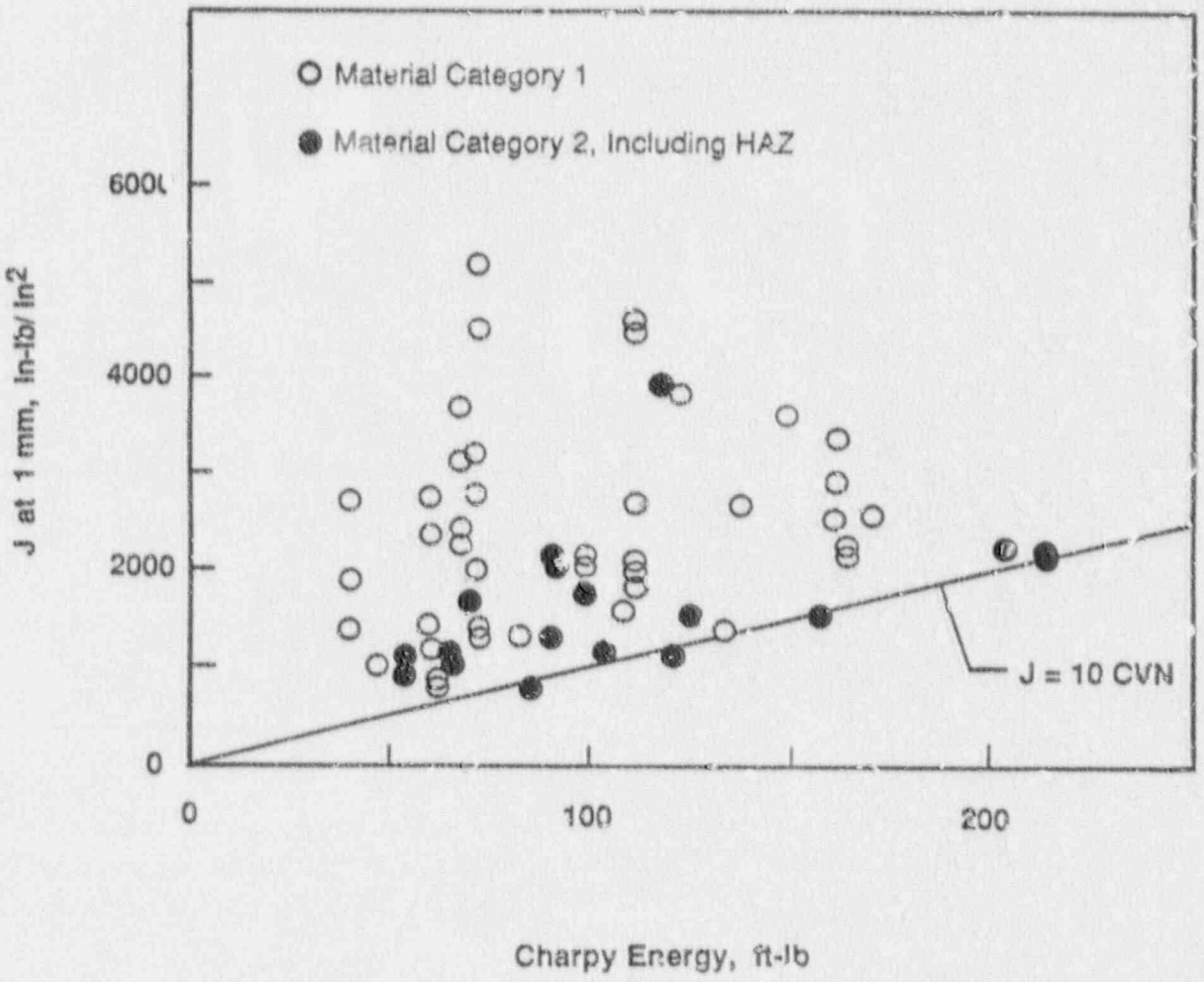

Figure 5. J @ 1mm Versus Charpy Energy for Carbon Steel Piping [10].

Prepared by: JFC/1-18-91
Checked by: NGC 1/21/91
File No. CP&-169-306 Rev: 0
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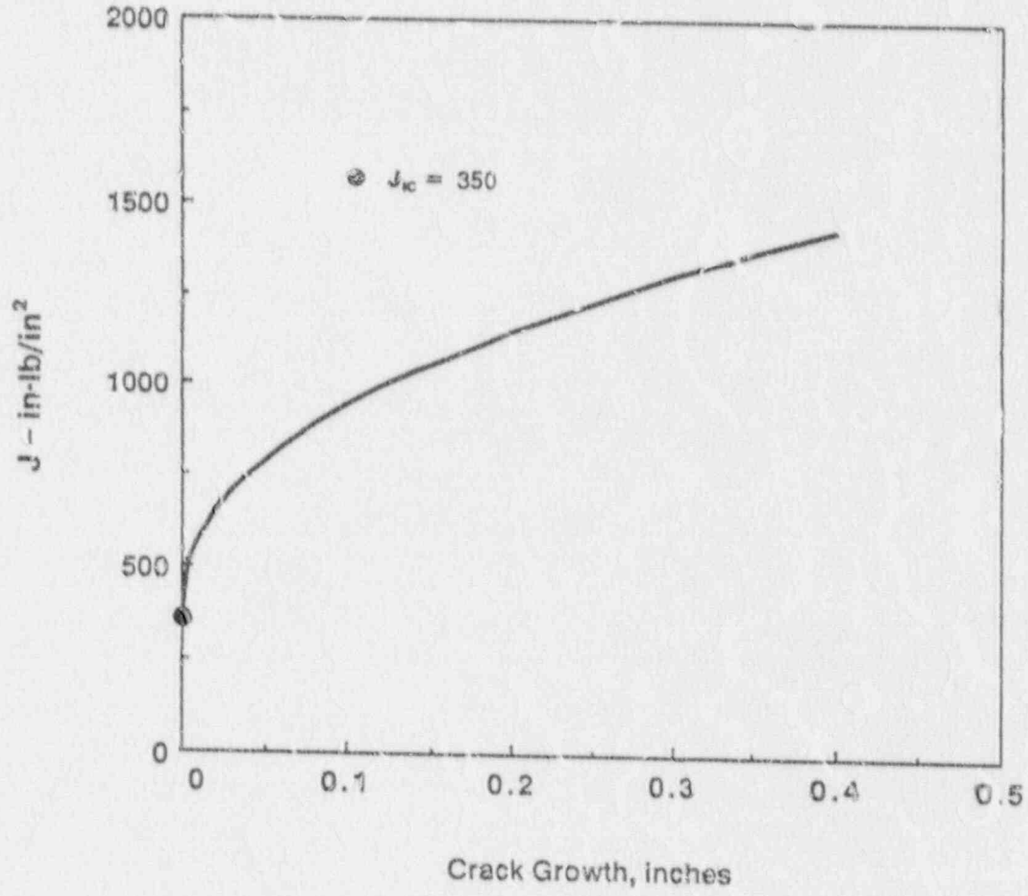

Figure 6. J-R Curve for Category 2 Materials [10]

Prepared by: CFC 1-19-91
Checked by: MGC 1/21/91
File No. CPL-168-306 Rev: 0
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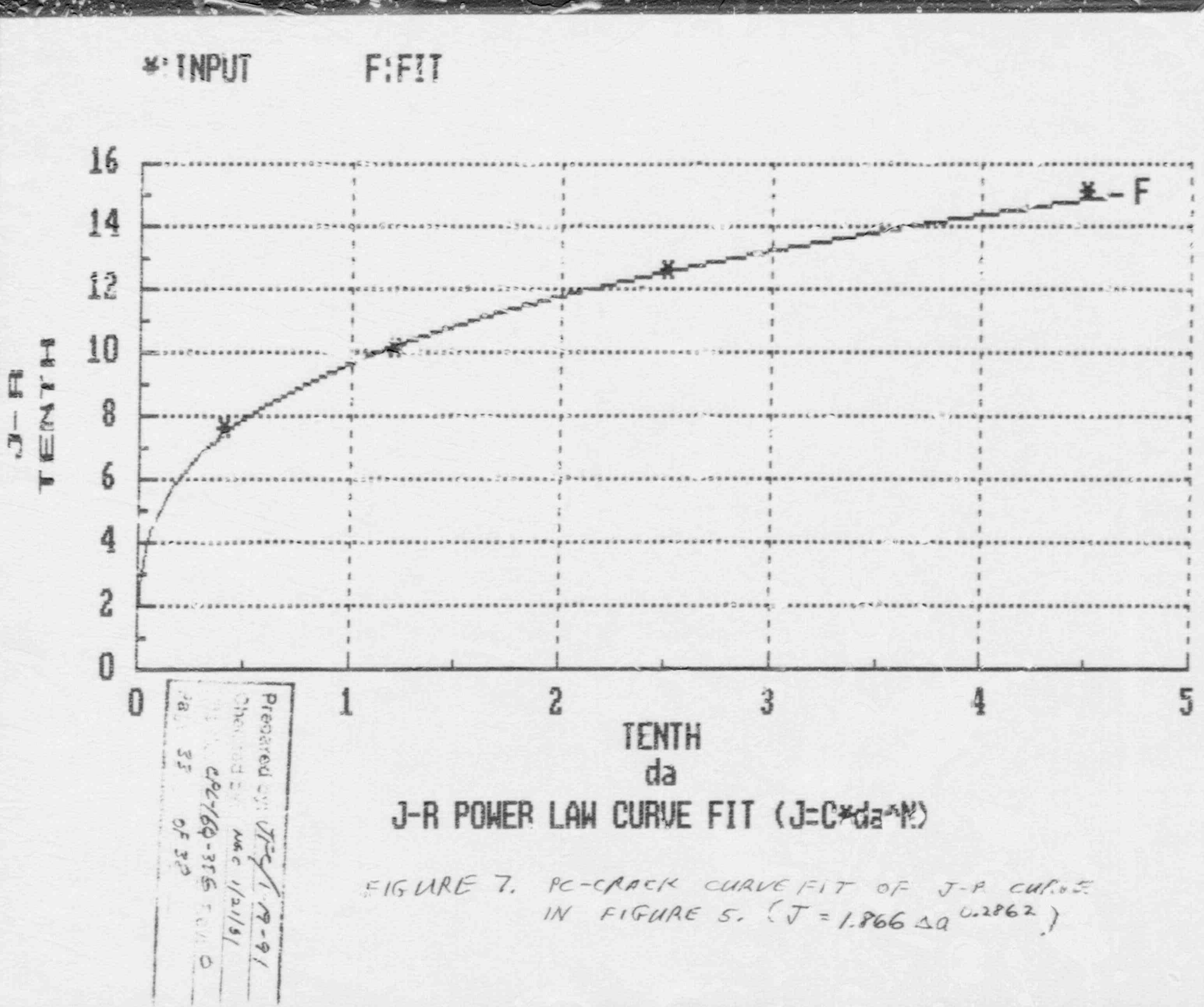

FIGURE 7. PC-CRACK CURVE FIT OF J-R CURVE IN FIGURE 5. ($J = 1.866\,\Delta a^{0.2862}$)

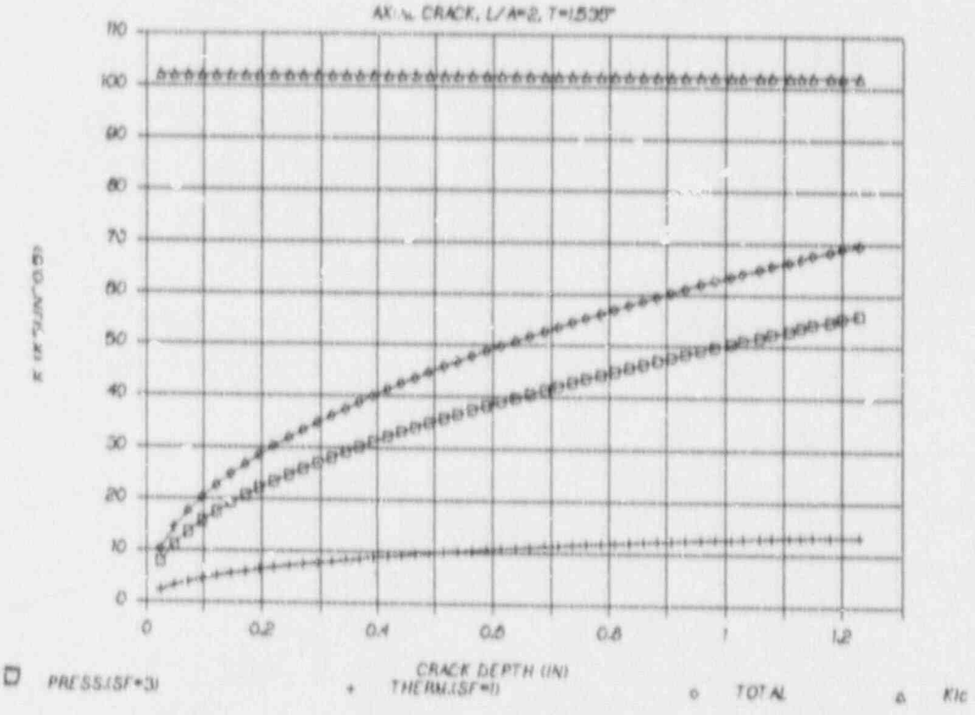

FIGURE 8.

STRESS INTENSITY FACTOR VS. CRACK DEPTH FOR SECTION A (CRACK ASPECT RATIO = 2).

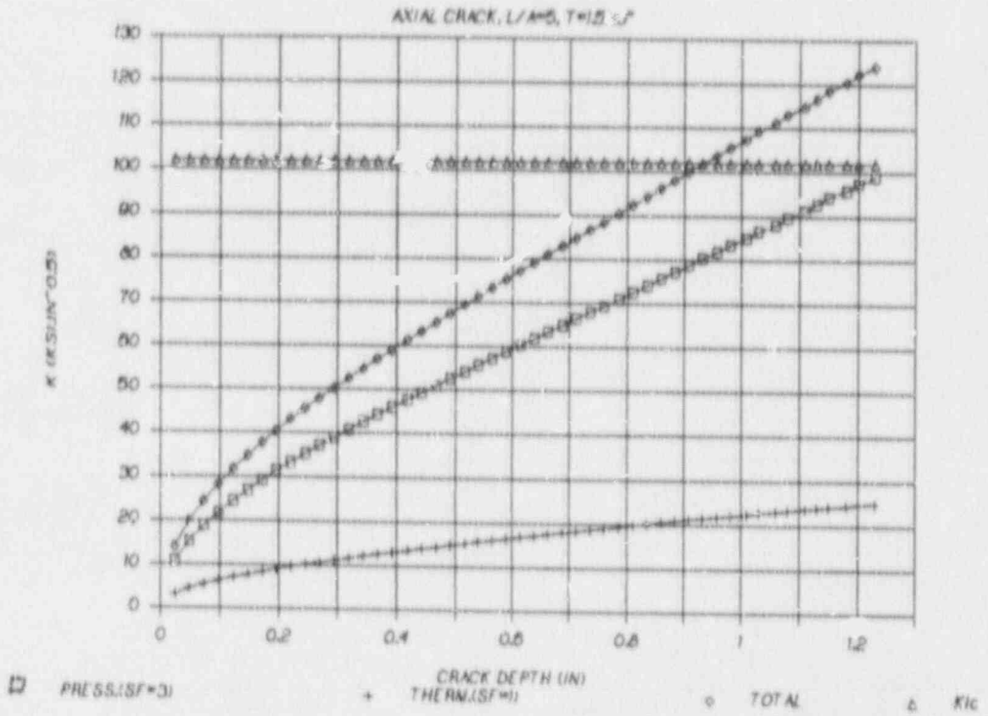

FIGURE 7.

STRESS INTENSITY FACTOR VS. CRACK DEPTH AT SECTION A (CRACK ASPECT RATIO = 5).

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Checked by:	NGC 1/21/91
File No:	SPC 69-306 Rev: 0
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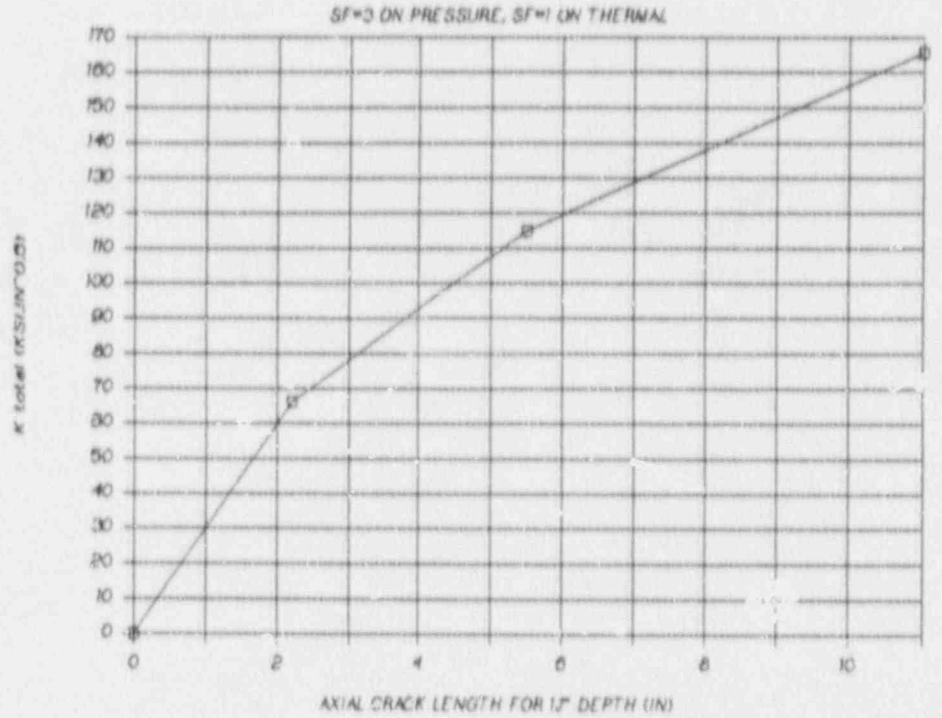

FIGURE 10.

STRESS INTENSITY FACTOR VS. CRACK LENGTH AT SECTION A FOR A CRACK DEPTH OF 1.1 IN.

Prepared by: JFC/1-19-91
Checked by: NAC 1/21/91
File No. CPL-168-306 Rev: 0
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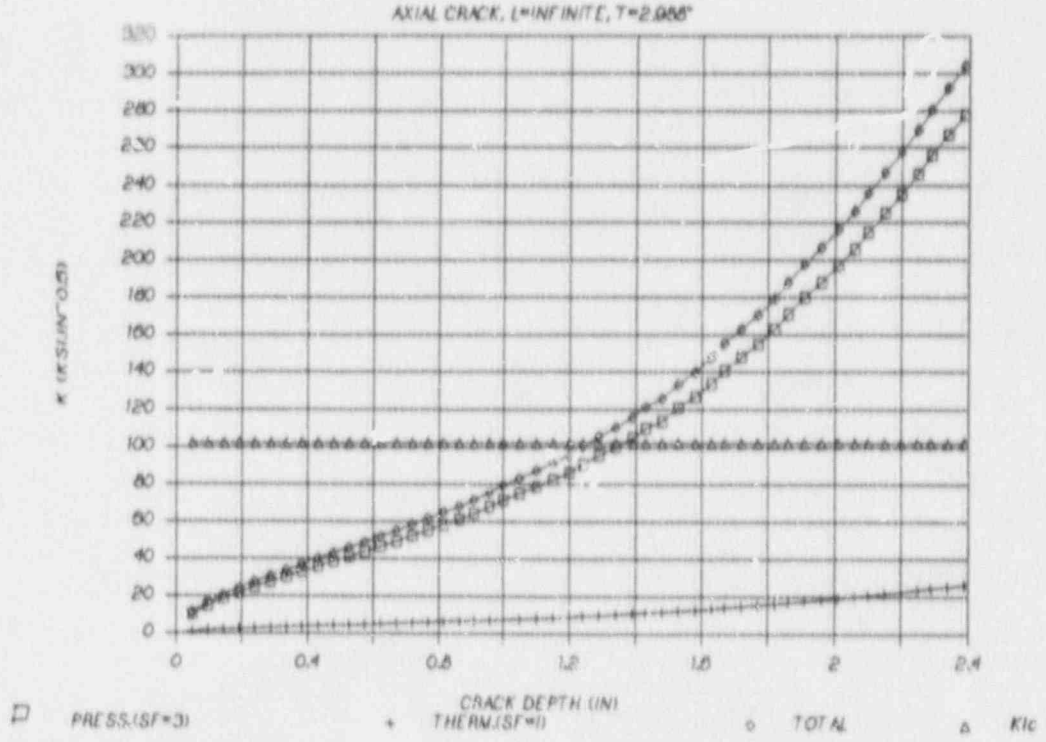

FIGURE 11.

STRESS INTENSITY FACTOR VS. CRACK DEPTH AT SECTION C (INFINITE LENGTH)

Prepared by: JFC 1-17-91
Checked by: MGC 1/21/91
File No. C PL-160-306 Rev: 0
Page 37 OF 38

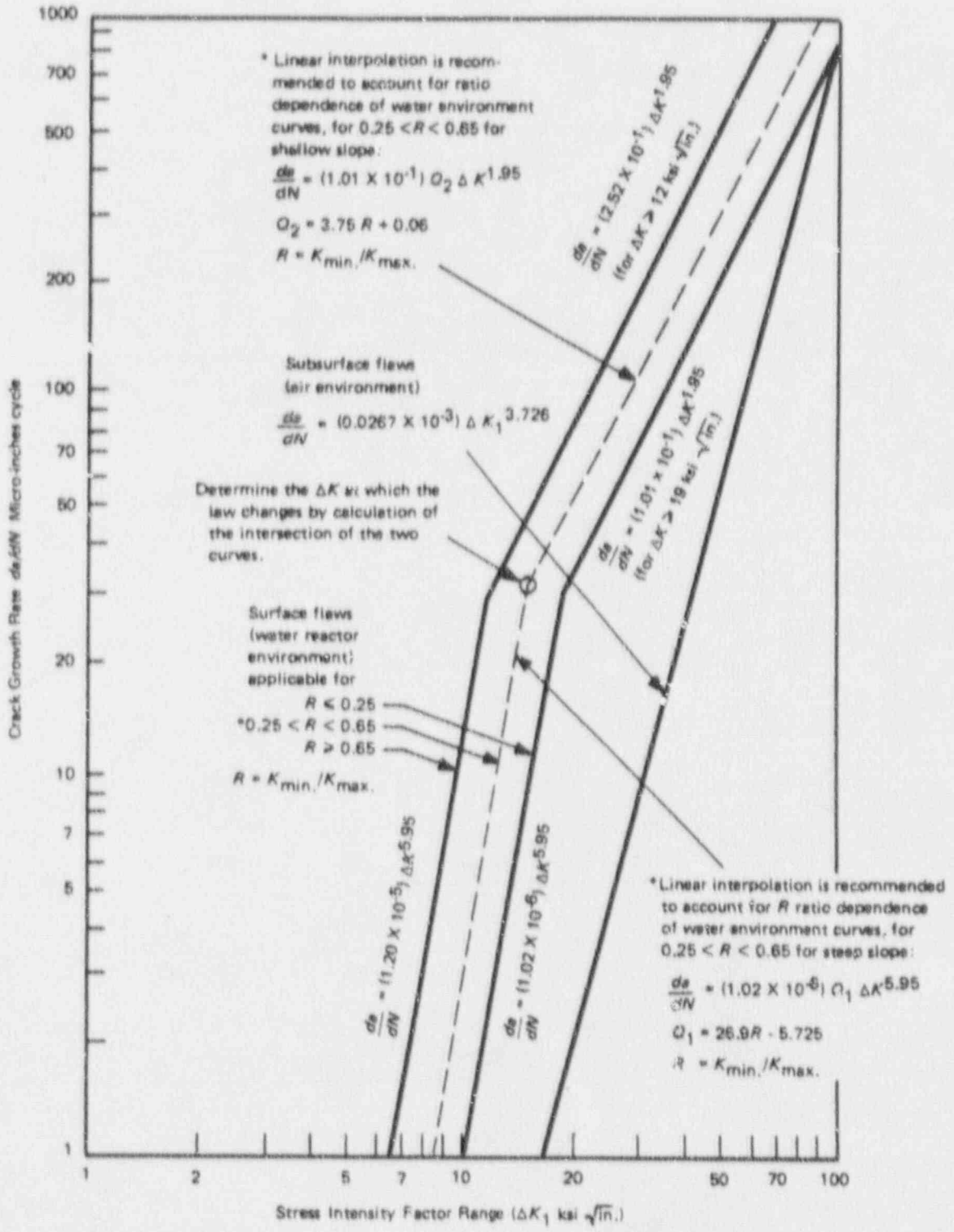

FIG. A-4300-1 REFERENCE FATIGUE CRACK GROWTH CURVES FOR CARBON AND LOW ALLOY FERRITIC STEELS [4].

FIGURE 12.

Prepared by: JFC/1-19-91
Checked by: NGC 1/21/91
File No. CPL-169-306 Rev: 0
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APPENDIX A.

FLAW INDICATION SUMMARY SHEETS [2]

	Revision	0				
	Preparer/Date	JFC/1-19-91				
	Checker/Date	NGC 1/21/91				
File No. CPL-168-306				Page A-1 of A-4		

FOR INFORMATION ONLY

GE Nuclear Energy

SUMMARY SHEET

REPORT NO.: R-111

PROJECT:
BRUNSWICK STEAM ELECTRIC PLANT
UNIT 1 - ISI-90-SN736

PROCEDURE:	GE-PT-100	0		N/A
PROCEDURE:	GE-UT-106	REV. 0	PDR NO.	BSE2-3
PROCEDURE:	GE-UT-200	REV. 2	PDR NO.	N/A
PROCEDURE:	GE-UT-102	REV. 2	PDR NO.	N/A

SYSTEM: RHR
WELD NO.: 1B32RD2A2-87-FWA33
CONFIGURATION: VALVE TO TEE

EXAM: T. WALTER/P. WRIGHT LVL II/II
EXAM: K. GEERTSBERGER LVL II
EXAM: W. ARMES/C. MINOR LVL II/III

NDE METHOD: ☐ MT ☑ PT ☑ UT ☐ VT

WELD TYPE: ☑ CIRCUMFERENTIAL ☐ LONGITUDINAL ☐ OTHER N/A

CAL SHEET NO.(S): C-171/C-172/C-173/C-174
C-175/C-176/C-177

REPORT NO.(S): R-111

DURING THE ULTRASONIC EXAMINATION OF THE ABOVE REFERENCED WELD, NO INDICATIONS WERE ASSOCIATED WITH ISSUE WERE RECORDED BY "SMART UT" SYSTEM DURING 45° SHEAR WAVE, 45° AND 60° REFRACTED LONGITUDINAL WAVE SEARCH UNITS. THE "SMART UT" SYSTEM DID RECORD TWO (2) NON-GEOMETRIC INDICATIONS WHICH HAVE THE FOLLOWING PARAMETERS:

	DISTANCE FROM ZERO REFERENCE	LENGTH	THRU-WALL DIMENSION	%THRU-WALL	SIDE OF WELD	TYPE OF REFLECTOR	SEARCH UNITS UTILIZED
1)	7.6"	*1.50"	.80"	52%	UPST	**PLANAR	0°, 45°S 45°RL, 60°RL
2)	65.7"	*1.50"	1.10"	71%	UPST	**PLANAR	0°, 45°S 45°RL, 60°RL

* INDICATIONS' END POINT ON THE VALVE SIDE CANNOT BE DETERMINED (SEE PLOT SHEETS).
** AXIALLY ORIENTED

ADDITIONALLY A 0° LONGITUDINAL WAVE SEARCH UNIT WAS UTILIZED TO CONFIRM THE PRESENCE AND ORIENTATION OF THESE INDICATIONS.

THE 45° SHEAR WAVE SEARCH UNIT ALSO RECORDED NON-RELEVANT INDICATIONS, BEAM REDIRECT AND INSIDE SURFACE GEOMETRY FROM THE UPSTREAM SIDE OF THE WELD.

THE 45° RL SEARCH UNIT RECORDED NON-RELEVANT INDICATIONS, ACOUSTIC INTERFACE, ROOT AND INSIDE SURFACE GEOMETRY FROM THE UPSTREAM SIDE OF THE WELD.

THE 60° RL SEARCH UNIT RECORDED NON-RELEVANT INDICATIONS, SHEAR COMPONENT AND INSIDE SURFACE GEOMETRY FROM THE UPSTREAM SIDE OF THE WELD.

A MANUAL EXAMINATION WAS PERFORMED FROM THE DOWNSTREAM SIDE OF THE WELD, UTILIZING 45° SHEAR WAVE, 45° AND 60° REFRACTED LONGITUDINAL WAVE SEARCH UNITS. THESE EXAMINATIONS RESULTED IN NO RECORDABLE INDICATONS.

Prepared by: JFC 1-15-91
Checked by: JAC 1/21/91
File No. CPL-166-706 Rev: 0
Page A-2

SUMMARIZED BY: LEVEL II DATE 1-8-91

REVIEWED: LEVEL III DATE 1-9-91

REVIEWED: LEVEL II DATE 1-9-91

Prepared by: JFC/1-19-91
Checked by: NGC 1/21/91
File No. CPL-160-706 Rev: 0
Page A-3 of A-4

GE Nuclear Energy

INDICATION PLOT SHEET

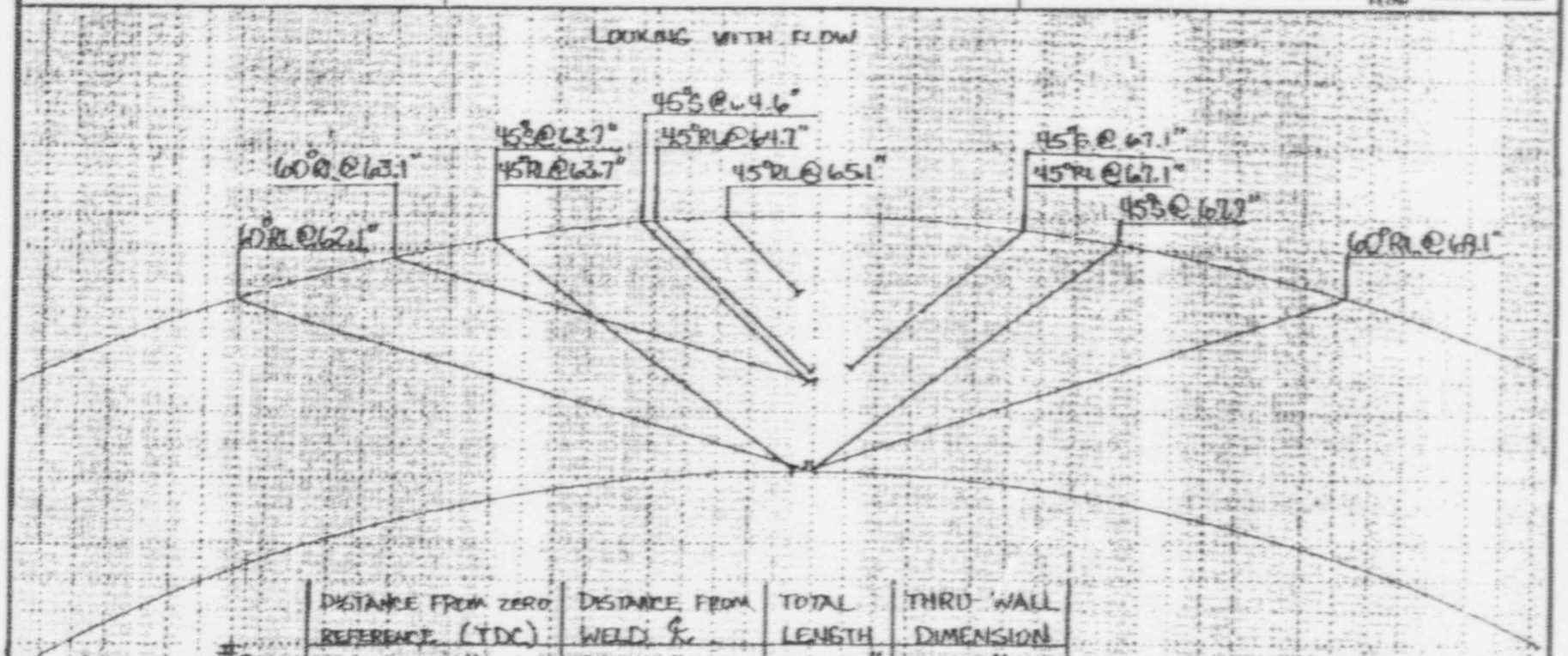
SITE: BRUNSWICK UNIT: 1
PROJECT NO: 151-90-SNT35

REPORT NO. R-111

SYSTEM: RHR

COMPONENT ID NO: 1B32RDZAZ-87-FWA33

CONFIGURATION: VALVE — TEE



	DISTANCE FROM ZERO REFERENCE (TDC)	DISTANCE FROM WELD ℄	TOTAL LENGTH	THRU-WALL DIMENSION
INDICATION #2	65.7"	* 1.10"	** 1.60"	1.10"

* NO EXAMINATION PERFORMED FROM WELD ℄ TO 1.10" DUE TO CONFIGURATION OF TEE.
** EXAMINATION LIMITED TO 2.6" FROM WELD ℄ DUE TO CONFIGURATION OF VALVE

FOR INFORMATION ONLY

P. A-3

Drawn By	Level	Date	Reviewed By	Level	Date	Reviewed By	Title	Date
[signature]	II	1-7-91	[signature]	III	1-9-91	[signature]	QC	1-9-91

Page 6 of 32

Prepared by: JFC/1-19-91
Checked by: MAC 1/21/91
File No. CPL-169-306 Rev: 0
Page A-40 A-4

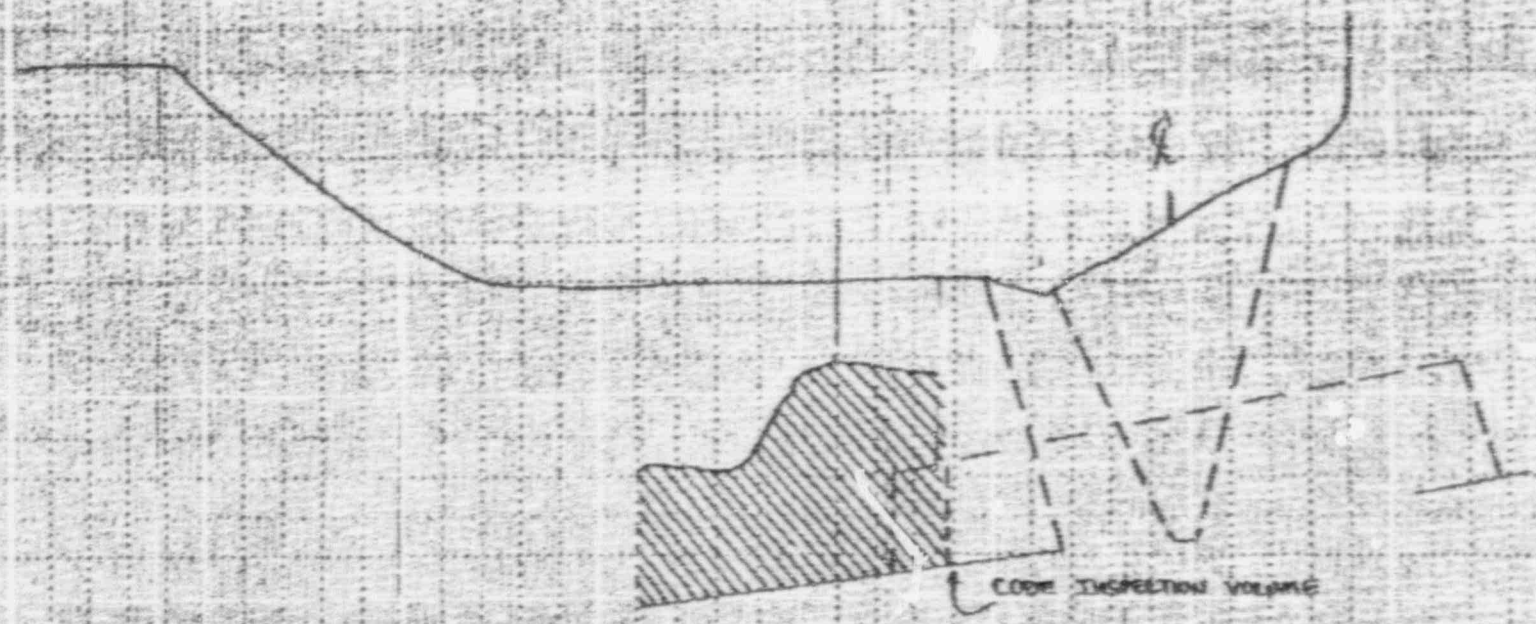
GE Nuclear Energy

INDICATION PLOT SHEET

SITE: BRUNSWICK UNIT: 1
PROJECT NO: 151-90 SW735

REPORT NO. R-111

SYSTEM: RHR
COMPONENT ID NO: 1B32RDZA2-BT-FWA33
CONFIGURATION: Valve FLOW TEE



SHADED AREA REPRESENTS ORIENTATION OF INDICATION #2 @ 65° FROM ZERO REFERENCE (TDC)

EXAMINATIONS WERE LIMITED TO THE SHADED AREA DUE TO THE CONFIGURATION OF THE VALVE AND TEE, INDICATION END POINTS CAN NOT BE DETERMINED ON THE VALVE SIDE

FOR INFORMATION ONLY

P. A-4

Drawn By	Level	Date	Reviewed By	Level	Date	Reviewed By	Title	Date
Ronald C. Law	II	1-7-91	B. A. Caldwell	III	1-9-91	L. Vi	QC	1-9-91

FORM 137 1-15-90

APPENDIX B.

MATERIAL PROPERTIES AND OPERATING CONDITIONS FOR BSEP-1 RHR VALVES [7]

	Revision	0				
	Preparer/Date	JFC/1-19-91				
	Checker/Date	MAC 1/21/91				
File No. CPL-160-306				Page B-1 of B-2		

BNP UNIT 1 RHR VALVES 1-E11-F060A/F060B

HYDROSTATIC TEST PRESSURE AND TEMPERATURE (ASME XI CRITERIA)

1088 TO 1103 PSIG 164°F MIN/?07 F MAX

NORMAL OPERATING TEMPERATURE AND PRESSURE

532°F/ 1250 PSIG* (SAME AS RECIRC SYSTEM DISCHARGE)

* Based on known suction pressure and pump curves. No direct reading recirculation system discharge pressure gauges.

PHYSICAL PROPERTIES AS REPORTED ON CMTRS

CHARPY IMPACT TEST RESULTS

F060A - FT. LBS. AT -20°F 21-18-22

F060B - FT. LBS. AT -20°F 21-32-31

ULTIMATE TENSILE STRENGTH

F060A - 99,100 PSI

F060B - 100,100 PSI

YIELD STRENGTH

F060A - 81,500 PSI

F060B - 79,900 PSI

ELONGATION (%)

F060A - 22.5

F060B - 22.5

Prepared by: JFG/1-19-91
Checked by: NGC 1/21/91
File No. CPL-169-306 Rev: 0
Page B-2 of B-2

JIM GATES
1/17/91

P. B-2

APPENDIX C.

ELASTIC-PLASTIC FRACTURE MECHANICS PC-CRACK OUTPUT FOR INFINITE LENGTH FLAW

	Revision	0				
	Preparer/Date	JTC 1-19-91				
	Checker/Date	NAC 1/21/91				

File No. CPL-16Q-306

tm

pc-CRACK
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STRUCTURAL INTEGRITY ASSOCIATES, INC.
SAN JOSE, CA (408)978-8200
VERSION 2.0

P. C-2

Date: 18-Jan-1991
Time: 10:59: 8.33

CASE 1. - USING AVERAGE WALL OF 1.695" FOR REGION OF REDUCED THICKNESS.

INSTABILITY EVALUATION

CP&L BSEP-1 RHR VALVE

crack model:AXIAL CRACK IN CYLINDER UNDER INTERNAL PRESSURE

MATERIAL PROPERTIES:-
FLOW STRESS(SIGMAf)= 81.4500
YIELD STRESS(SIGMAo)= 62.8000
YIELD STRAIN(EPSILONo)= 2.317E-03
YOUNG MODULUS= 2.710E+04
POISSON RATIO= 0.3000

RAMBERG-OSGOOD STRESS-STRAIN LAW:-
ALPHApl= 0.3520
Npl= 8.4900

GEOMETRIC PROPERTIES:-
OUTSIDE DIAMETER= 12.2950
WALL THICKNESS (t)= 1.6950

OTHER CONDITIONS:-
PLANE STRAIN <1> OR
PLANE STRESS <2>= 1
dA= 1.695E-02

LOADING CONDITIONS:-
PRESSURE= 1.0000

CRACK DEPTH(a)= 1.1000
(a/t)= 0.6490

a/t(a/b)	F	H
0.0000	1.1220	38.7137
0.1250	1.1853	16.1976
0.2500	1.3515	10.6242
0.3750	1.6641	6.6517
0.5000	1.9766	2.6793
0.6250	2.4176	1.6100
0.7500	2.8586	0.5408

Prepared by: JFC/1-19-91
Checked by: NGC 1/21/91
File No. CPL-160-306 Rev: 0
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P. C-3

MATERIAL J-R CURVE:CPLRHRVL
J= 1.8657 * (da)^ 0.2862
J1c= 0.3500
Jmax= 2.0000

INCREMENTATION:-
PRESSURE INCREMENT= 0.2500
NUMBER OF INCREMENTS= 100

INCREMENT PRESSURE
WITH CRACK SIZE ADJUSTMENT FROM MATERIAL R-CURVE

STRESS	Aadj	Jappl	Tappl	Tmat	dA
1.0000	1.1000	0.0130	0.1395	522514.8725	0.0000
1.2500	1.1000	0.0204	0.2199	169317.1298	0.0000
1.5000	1.1000	0.0296	0.3200	67070.6710	0.0000
1.7500	1.1000	0.0406	0.4408	30498.7427	0.0000
2.0000	1.1000	0.0535	0.5833	15335.2663	0.0000
2.2500	1.1000	0.0683	0.7484	8323.6917	0.0000
2.5000	1.1000	0.0852	0.9372	4798.0118	0.0000
2.7500	1.1000	0.1042	1.1507	2903.3481	0.0000
3.0000	1.1000	0.1255	1.3896	1828.7059	0.0000
3.2500	1.1000	0.1490	1.6548	1191.2933	0.0000
3.5000	1.1000	0.1749	1.9468	798.6976	0.0000
3.7500	1.1000	0.2033	2.2663	548.9717	0.0000
4.0000	1.1000	0.2342	2.6136	385.6303	0.0000
4.2500	1.1000	0.2678	2.9892	276.1507	0.0000
4.5000	1.1000	0.3040	3.3936	201.1703	0.0000
4.7500	1.1000	0.3431	3.8274	148.8190	0.0000
5.0000	1.1040	0.3892	4.3177	108.6527	0.0042
5.2500	1.1062	0.4371	4.8310	81.3661	0.0063
5.5000	1.1091	0.4896	5.3869	61.3100	0.0093
5.7500	1.1133	0.5481	5.9954	46.2792	0.0138
6.0000	1.1196	0.6144	6.6727	34.8122	0.0206
6.2500	1.1313	0.6961	7.4767	25.4945	0.0319
6.5000	1.1518	0.8042	[illegible]97	17.7902	0.0529
6.7500	1.2100	1.0198	1 7	9.8370	0.1212

BY INTERPOLATION

Jcrit= 0.9995
Tcrit= 10.5866
PRESSUREcrit= 6.7264
w= 1.2830

MATERIAL J-R CURVE: CPLRHRVL

da	Jmat	Tmat
0.0020	0.3500	184.1541
0.0026	0.3500	152.1712
0.0034	0.3671	125.7428
0.0045	0.3963	103.9044
0.0058	0.4278	85.8588
0.0076	0.4618	70.9473

Prepared by: JFC/1-19-91
Checked by: NGC 1/21/91
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0.0099	0.4985	58.6255
0.0130	0.5381	48.4437
0.0170	0.5809	40.0302
0.0222	0.6271	33.0780
0.0290	0.6769	27.3332
0.0378	0.7308	22.5861
0.0494	0.7888	18.6634
0.0646	0.8516	15.4221
0.0843	0.9193	12.7436
0.1102	0.9924	10.5304
0.1439	1.0712	8.7015
0.1881	1.1564	7.1903
0.2457	1.2484	5.9415
0.3209	1.3476	4.9096
0.4193	1.4547	4.0569
0.5477	1.5704	3.3523
0.7156	1.6953	2.7701
0.9348	1.8300	2.2890
1.2212	1.9755	1.8915

END OF pc-CRACK

Prepared by: JFC/1-19-91
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File No. CPL-160-306 Rev: 0
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tm

pc-CRACK

STRUCTURAL INTEGRITY ASSOCIATES, INC.
SAN JOSE, CA (408)978-8200

VERSION 2.0

Date: 18-Jan-1991
Time: 10:49:48.47

CASE 2. - USING MINIMUM WALL AT SECTION A. OF 1.535" FOR REGION OF REDUCED THICKNESS.

INSTABILITY EVALUATION

CP&L BSEP-1 RHR VALVE

crack model:AXIAL CRACK IN CYLINDER UNDER INTERNAL PRESSURE

MATERIAL PROPERTIES:-
FLOW STRESS(SIGMAf)= 81.4500
YIELD STRESS(SIGMAo)= 62.8000
YIELD STRAIN(EPSILONo)= 2.317E-03
YOUNG MODULUS= 2.710E+04
POISSON RATIO= 0.3000

RAMBERG-OSGOOD STRESS-STRAIN LAW:-
ALPHApl= 0.3520
Npl= 8.4900

GEOMETRIC PROPERTIES:-
OUTSIDE DIAMETER= 12.2950
WALL THICKNESS (t)= 1.5350

OTHER CONDITIONS:-
PLANE STRAIN <1> OR
PLANE STRESS <2>= 1
dA= 1.535E-02

LOADING CONDITIONS:-
PRESSURE= 1.0000

CRACK DEPTH(a)= 1.1000
(a/t)= 0.7166

a/t(a/b)	F	H
0.0000	1.1220	37.7045
0.1250	1.1860	15.8513
0.2500	1.3561	10.4580
0.3750	1.6762	6.5798
0.5000	1.9963	2.7016
0.6250	2.4626	1.6309
0.7500	2.9289	0.5602

Prepared by: JFC/1-19-91
Checked by: NGC 1/21/91
File No. CPL-169-306 Rev: 0
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P. C-6

MATERIAL J-R CURVE:CPLRHRVL
J= 1.8657 * (da)^ 0.2862
J1c= 0.3500
Jmax= 2.0000

INCREMENTATION:-
PRESSURE INCREMENT= 0.2500
NUMBER OF INCREMENTS= 100

INCREMENT PRESSURE
WITH CRACK SIZE ADJUSTMENT FROM MATERIAL R-CURVE

STRESS	Aadj	Jappl	Tappl	Tmat	dA
1.0000	1.1000	0.0194	0.2144	191977.1739	0.0000
1.2500	1.1000	0.0306	0.3391	61806.4586	0.0000
1.5000	1.1000	0.0445	0.4952	24305.4611	0.0000
1.7500	1.1000	0.0612	0.6839	10966.8747	0.0000
2.0000	1.1000	0.0808	0.9066	5470.7578	0.0000
2.2500	1.1000	0.1036	1.1642	2946.3047	0.0000
2.5000	1.1000	0.1296	1.4573	1685.7285	0.0000
2.7500	1.1000	0.1590	1.7863	1013.0642	0.0000
3.0000	1.1000	0.1918	2.1512	634.1657	0.0000
3.2500	1.1000	0.2283	2.5520	410.9066	0.0000
3.5000	1.1000	0.2685	2.9891	274.2345	0.0000
3.7500	1.1000	0.3125	3.4633	187.7712	0.0000
4.0000	1.1032	0.3637	3.9923	128.7034	0.0033
4.2500	1.1053	0.4185	4.5617	90.6521	0.0054
4.5000	1.1085	0.4797	5.1911	64.5174	0.0087
4.7500	1.1133	0.5490	5.9035	46.0917	0.0139
5.0000	1.1211	0.6296	6.7452	32.7498	0.0225
5.2500	1.1374	0.7355	7.8710	22.2262	0.0387
5.5000	1.1912	0.9441	9.1252	11.9226	0.0926
5.7500	1.1926	1.0629	10.5339	8.8731	0.1401

BY INTERPOLATION

Jcrit= 1.0187
Tcrit= 10.0091
PRESSUREcrit= 5.6569
w= 0.8668

MATERIAL J-R CURVE: CPLRHRVL

da	Jmat	Tmat
0.0020	0.3500	184.1541
0.0026	0.3500	152.1019
0.0034	0.3672	125.6283
0.0045	0.3965	103.7626
0.0058	0.4281	85.7026
0.0076	0.4622	70.7859
0.0100	0.4990	58.4655
0.0130	0.5388	48.2895
0.0171	0.5817	39.8847
0.0223	0.6281	32.9427

Prepared by: JFC/1-19-91
Checked by: MGC 1/21/91
File No. CPL-168-306 Rev: 0
Page C-6 of C-8

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0.0291	0.6782	27.2090
0.0381	0.7322	22.4732
0.0498	0.7906	18.5617
0.0651	0.8536	15.3310
0.0851	0.9216	12.6626
0.1112	0.9951	10.4587
0.1454	1.0744	8.6383
0.1901	1.1600	7.1348
0.2485	1.2525	5.8930
0.3249	1.3523	4.8673
0.4247	1.4601	4.0202
0.5551	1.5764	3.3204
0.7257	1.7021	2.7425
0.9486	1.8377	2.2652
1.2401	1.9842	1.8709

END OF pc-CRACK

Prepared by: JTC/1-19-91
Checked by: NEC 1/21/91
File No. CAL/69-306 Rev: 0
Page C-7 of C-8

CPL-16Q
PCCRACK EPFM AXIAL FLAW PRESSURE VS. HOOP STRESS

Ro(IN):	12.295	Ro(IN):	12.295	SIGMAh=
t(IN):	1.695	t(IN):	1.535	(2*p*Ro^2)/
Ri(IN):	10.6	Ri(IN):	10.76	(Ro^2-Ri^2)

PRESS. (KSI)	HOOP STRESS (KSI)	PRESS. (KSI)	HOOP STRESS (KSI)
1.00	7.791	1.00	8.543
1.25	9.738	1.25	10.679
1.50	11.686	1.50	12.815
1.75	13.634	1.75	14.950
2.00	15.581	2.00	17.086
2.25	17.529	2.25	19.222
2.50	19.477	2.50	21.358
2.75	21.424	2.75	23.493
3.00	23.372	3.00	25.629
3.25	25.320	3.25	27.765
3.50	27.267	3.50	29.901
3.75	29.215	3.75	32.036
4.00	31.163	4.00	34.172
4.25	33.110	4.25	36.308
4.50	35.058	4.50	38.444
4.75	37.006	4.75	40.580
5.00	38.954	5.00	42.715
5.25	40.901	5.25	44.851
5.50	42.849	5.50	46.987
5.75	44.797	5.75	49.123
6.00	46.744	6.00	51.258
6.25	48.692	6.25	53.394
6.50	50.640	6.50	55.530
6.75	52.587	6.75	57.666
7.00	54.535	7.00	59.801
7.25	56.483	7.25	61.937
7.50	58.430	7.50	64.073
7.75	60.378	7.75	66.209
8.00	62.326	8.00	68.344
8.25	64.273	8.25	70.480
8.50	66.221	8.50	72.616
8.75	68.169	8.75	74.752
9.00	70.116	9.00	76.888
9.25	72.064	9.25	79.023
9.50	74.012	9.50	81.159
9.75	75.959	9.75	83.295
10.00	77.907	10.00	85.431
10.25	79.855	10.25	87.566

Prepared by: JFC/1-19-91
Checked by: NGC 1/21/91
File No. CPL-16Q-306 Rev: 0
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APPENDIX D.

LINEAR ELASTIC FRACTURE MECHANICS
PC-CRACK OUTPUT FOR FINITE LENGTH FLAWS
IN REDUCED SECTION OF VALVE.

tm

pc-CRACK
(C) COPYRIGHT 1984, 1988
STRUCTURAL INTEGRITY ASSOCIATES, INC.
SAN JOSE, CA (408)978-8200
VERSION 2.0

Date: 18-Jan-1991
Time: 11:26:26.65

LEAST SQUARE CURVE FIT OF STRESS PROFILE

CPL RHR PRESSURE STRESSES AT 1.535" SECTION (1250 PSI, SF=3)

TERM	COEFFICIENT
C0	4.473E+01
C1	-6.757E+00
C2	4.039E+00
C3	-1.408E+00

COEFFICIENT OF DETERMINATION R^2= 0.9998
CORRELATION COEFFICIENT= 0.9996

X VALUE	Y VALUE	Y CALC	DIFF
0.000E+00	4.474E+01	4.473E+01	1.300E-02
2.700E-01	4.313E+01	4.317E+01	-4.246E-02
5.500E-01	4.204E+01	4.200E+01	4.148E-02
8.300E-01	4.110E+01	4.109E+01	5.239E-03
1.100E+00	4.027E+01	4.031E+01	-3.163E-02
1.380E+00	3.941E+01	3.939E+01	1.918E-02
1.535E+00	3.877E+01	3.878E+01	-4.801E-03

END OF pc-CRACK

Prepared by: JFC/1-19-91
Checked by: NAC 1/21/91
File No. CPL-169-306 Rev: 0
Page D-2 of D-11

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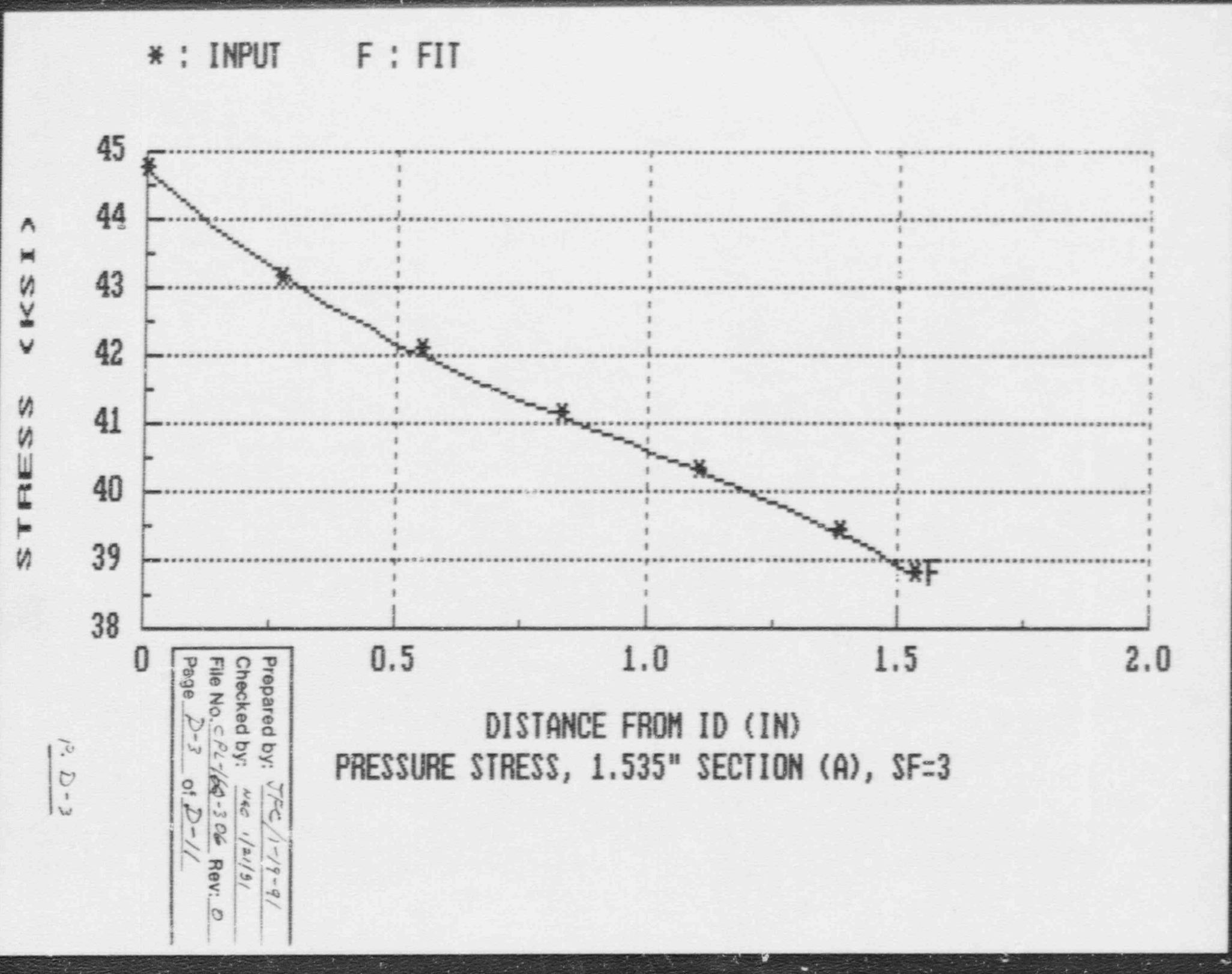
* : INPUT F : FIT
STRESS (KSI)
45
44
43
42
41
40
39
38
0
0.5
1.0
1.5
2.0
*F
DISTANCE FROM ID (IN)
PRESSURE STRESS, 1.535" SECTION (A), SF=3
Prepared by: JFC 1-19-91
Checked by: MEC 1/21/91
File No. CPL7/[illegible]-306 Rev: 0
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tm

pc-CRACK
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SAN JOSE, CA (408)978-8200
VERSION 2.0

Date: 18-Jan-1991
Time: 11:39:50.75

LEAST SQUARE CURVE FIT OF STRESS PROFILE

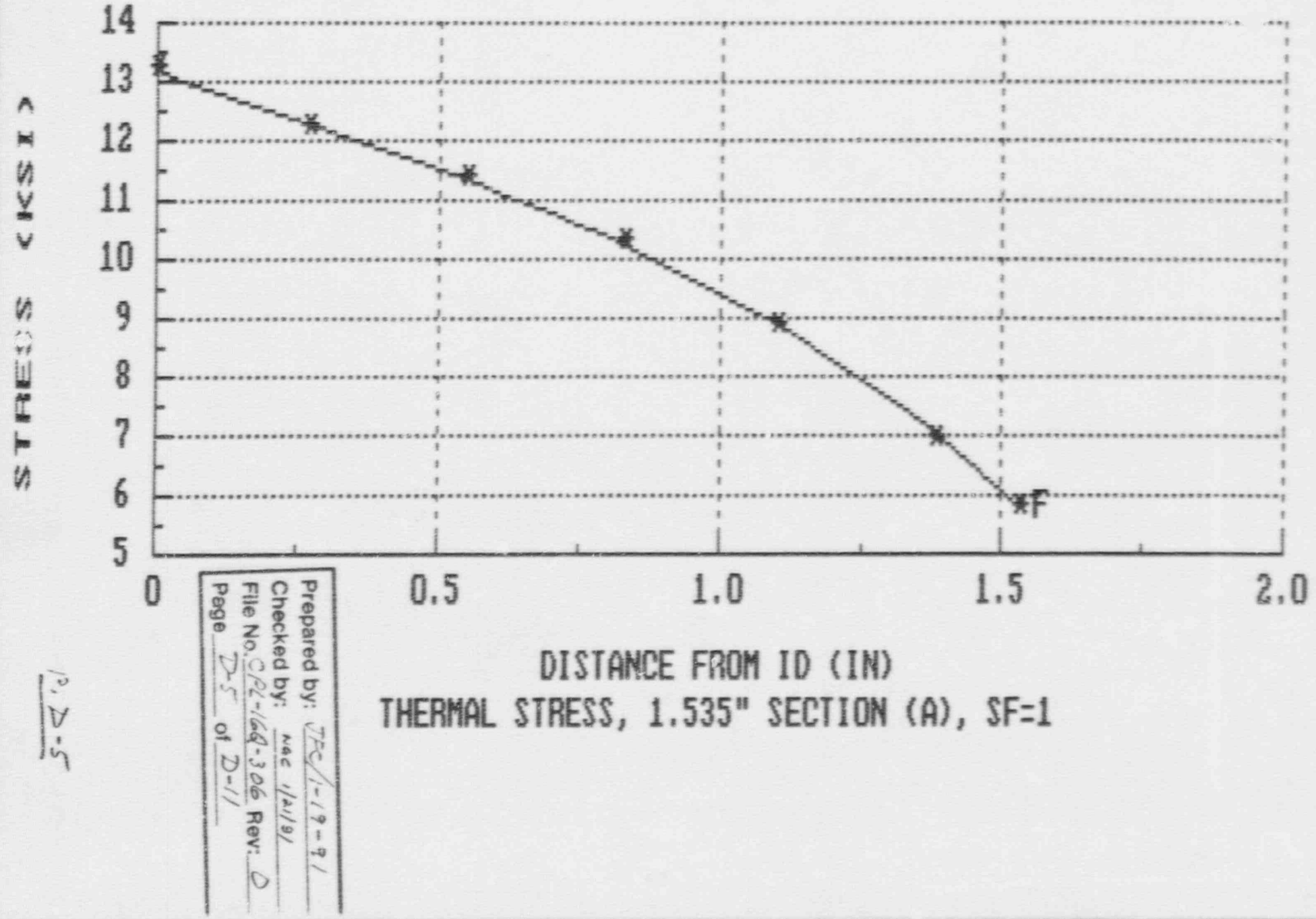
CPL RHR THERMAL STRESSES AT 1.535" SECTION (532 F, SF=1)

TERM	COEFFICIENT
C0	1.319E+01
C1	-3.456E+00
C2	7.880E-01
C3	-1.097E+00

COEFFICIENT OF DETERMINATION R^2= 0.9995
CORRELATION COEFFICIENT= 0.9990

X VALUE	Y VALUE	Y CALC	DIFF
0.000E+00	1.322E+01	1.319E+01	3.419E-02
2.700E-01	1.220E+01	1.229E+01	-8.856E-02
5.500E-01	1.138E+01	1.134E+01	3.910E-02
8.300E-01	1.029E+01	1.023E+01	5.703E-02
1.100E+00	8.860E+00	8.878E+00	-1.762E-02
1.380E+00	6.960E+00	7.034E+00	-7.422E-02
1.535E+00	5.820E+00	5.770E+00	5.008E-02

END OF pc-CRACK



Prepared by: JPC 1-19-91
Checked by: NAC 1/21/91
File No. CPL-1669-306 Rev: 0
Page D-5 of D-11

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tm

pc-CRACK

STRUCTURAL INTEGRITY ASSOCIATES, INC.
SAN JOSE, CA (408)978-8200

VERSION 2.0

P. D-6

CASE 1: - L/A = 2 (ASPECT RATIO)

Date: 18-Jan-1991
Time: 11:59:48.95

LINEAR ELASTIC FRACTURE MECHANICS EVALUATION

CPL RHR VALVE, 1.535" SECTION (A), SF=3 ON PRESSURE, SF=1 ON THERMAL

crack model:ELLIPTICAL LONGITUDINAL CRACK IN CYLINDER(T/R=0.1,A/L=0.5)

WALL THICKNESS (t)= 1.5350

STRESS COEFFICIENTS

CASE ID	C0	C1	C2	C3
PRESSA	44.7250	-6.7567	4.0393	-1.4076
THERMA	13.1858	-3.4559	0.7880	-1.0970

CRACK SIZE	STRESS INTENSITY FACTOR CASE PRESSA	CASE THERMA
0.0246	7.858	2.312
0.0491	11.105	3.261
0.0737	13.590	3.983
0.0982	15.682	4.586
0.1228	17.522	5.113
0.1474	19.183	5.586
0.1719	20.707	6.017
0.1965	22.123	6.414
0.2210	23.452	6.783
0.2456	24.708	7.130
0.2702	25.903	7.456
0.2947	27.043	7.766
0.3193	28.141	8.061
0.3438	29.202	8.343
0.3684	30.227	8.613
0.3930	31.220	8.871
0.4175	32.183	9.119
0.4421	33.120	9.358
0.4666	34.032	9.587
0.4912	34.916	9.806
0.5158	35.780	10.017
0.5403	36.625	10.220
0.5649	37.453	10.416
0.5894	38.263	10.605
0.6140	39.059	10.788
0.6386	39.847	10.966

Prepared by: JFC/1-19-91
Checked by: NGC 1/21/91
File No. CPL-169-306 Rev: 0
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0.6631	40.623	11.138
0.6877	41.385	11.304
0.7122	42.137	11.463
0.7368	42.877	11.618
0.7614	43.606	11.766
0.7859	44.329	11.909
0.8105	45.043	12.046
0.8350	45.747	12.177
0.8596	46.444	12.302
0.8842	47.131	12.422
0.9087	47.811	12.536
0.9333	48.487	12.646
0.9578	49.158	12.751
0.9824	49.823	12.850
1.0070	50.481	12.944
1.0315	51.132	13.032
1.0561	51.776	13.114
1.0806	52.413	13.190
1.1052	53.038	13.259
1.1298	53.658	13.322
1.1543	54.271	13.379
1.1789	54.879	13.430
1.2034	55.481	13.475
1.2280	56.077	13.513

END OF pc-CRACK

Prepared by: JFC 1-19-91
Checked by: NGC 1/21/91
File No. CAL-169-306 Rev: 0
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tm

pc-CRACK

P. D-8

VERSION 2.0

CASE 2. — L/A = 5 (ASPECT RATIO)

Date: 18-Jan-1991
Time: 11:50:54.86

LINEAR ELASTIC FRACTURE MECHANICS EVALUATION

CPL RHR VALVE, 1.535" SECTION (A), SF=3 ON PRESSURE, SF=1 ON THERMAL

crack model:ELLIPTICAL LONGITUDINAL CRACK IN CYLINDER(T/R=0.1,A/L=0.2)

WALL THICKNESS (t)= 1.5350

STRESS COEFFICIENTS

CASE ID	C0	C1	C2	C3
PRESSA	44.7250	-6.7567	4.0393	-1.4076
THERMA	13.1858	-3.4559	0.7880	-1.0970

CRACK SIZE	STRESS INTENSITY FACTOR CASE PRESSA	CASE THERMA
0.0246	10.771	3.170
0.0491	15.294	4.493
0.0737	18.807	5.515
0.0982	21.806	6.382
0.1228	24.481	7.151
0.1474	26.929	7.851
0.1719	29.204	8.498
0.1965	31.347	9.104
0.2210	33.383	9.676
0.2456	35.332	10.220
0.2702	37.208	10.740
0.2947	39.022	11.240
0.3193	40.810	11.730
0.3438	42.581	12.212
0.3684	44.315	12.681
0.3930	46.017	13.138
0.4175	47.690	13.584
0.4421	49.338	14.020
0.4666	50.966	14.448
0.4912	52.580	14.868
0.5158	54.176	15.281
0.5403	55.757	15.687
0.5649	57.324	16.086
0.5894	58.878	16.477
0.6140	60.421	16.862
0.6386	61.945	17.238

Prepared by: JFC/1-19-91
Checked by: NAC 1/21/91
File No. CPC-164-306 Rev: 0
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P. D-9

0.6631	63.459	17.608
0.6877	64.965	17.973
0.7122	66.462	18.331
0.7368	67.952	18.684
0.7614	69.436	19.031
0.7859	70.988	19.392
0.8105	72.561	19.754
0.8350	74.132	20.111
0.8596	75.701	20.463
0.8842	77.26[illegible]	20.810
0.9087	78.83[illegible]	21.151
0.9333	80.392	21.485
0.9578	81.942	21.812
0.9824	83.492	22.133
1.0070	85.041	22.449
1.0315	86.589	22.758
1.0561	88.136	23.062
1.0806	89.686	23.361
1.1052	91.245	23.656
1.1298	92.805	23.946
1.1543	94.365	24.229
1.1789	95.924	24.505
1.2034	97.484	24.775
1.2280	99.044	25.038

END OF pc-CRACK

Prepared by: JFC/1-19-91
Checked by: NGC 1/21/91
File No. CAL-169-306 Rev: 0
Page D-9 of D-11

pc-CRACK

STRUCTURAL INTEGRITY ASSOCIATES, INC.
SAN JOSE, CA (408)978-8200
VERSION 2.0

CASE 3. - L/A = 10 (ASPECT RATIO)

Date: 18-Jan-1991
Time: 12:40:31.88

LINEAR ELASTIC FRACTURE MECHANICS EVALUATION

CPL RHR VALVE, 1.535" SECTION (A), SF=3 ON PRESSURE, SF=1 ON THERMAL

crack Godel:ELLIPTICAL LONGITUDINAL CRACK IN CYLINDER(T/R=0.1,A/L=0.1)

WALL THICKNESS (t)= 1.5350

STRESS COEFFICIENTS

CASE ID	C0	C1	C2	C3
PRESSA	44.7250	-6.7567	4.0383	-1.4076
THERMA	13.1858	-3.4559	0.7880	-1.0970

CRACK SIZE	STRESS INTENSITY FACTOR CASE PRESSA	CASE THERMA
0.0246	11.706	3.445
0.0491	16.696	4.905
0.0737	20.621	6.047
0.0982	24.013	7.029
0.1228	27.071	7.910
0.1474	29.902	8.721
0.1719	32.566	9.480
0.1965	35.101	10.199
0.2210	37.536	10.886
0.2456	39.889	11.546
0.2702	42.175	12.184
0.2947	44.406	12.803
0.3193	46.713	13.441
0.3438	49.119	14.105
0.3684	51.508	14.761
0.3930	53.885	15.410
0.4175	56.252	16.053
0.4421	58.612	16.691
0.4666	60.967	17.324
0.4912	63.319	17.953
0.5158	65.670	18.578
0.5403	68.021	19.200
0.5649	70.374	19.818
0.5894	72.730	20.433
0.6140	75.089	21.045
0.6386	77.452	21.654

Prepared by: JFC/1-19-91
Checked by: NGC 1/21/91
File No. CPL-16Q-305 Rev: 0
Page D-10 of D-11

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0.6631	79.820	22.260
0.6877	82.193	22.864
0.7122	84.572	23.465
0.7368	86.958	24.063
0.7614	89.351	24.658
0.7859	92.088	25.345
0.8105	94.958	26.062
0.8350	97.847	26.779
0.8596	100.756	27.495
0.8842	103.686	28.211
0.9087	106.636	28.926
0.9333	109.610	29.641
0.9578	112.611	30.357
0.9824	115.631	31.072
1.0070	118.670	31.784
1.0315	121.729	32.494
1.0561	124.807	33.202
1.0806	127.900	33.906
1.1052	131.004	34.604
1.1298	134.125	35.299
1.1543	137.265	35.989
1.1789	140.422	36.676
1.2034	143.596	37.358
1.2280	146.788	38.036

END OF pc-CRACK

Prepared by: JFC/1-19-91
Checked by: NGC 1/21/91
File No. CPL-160-305 Rev: 0
Page D-11 of D-11

APPENDIX E.

LINEAR ELASTIC FRACTURE MECHANICS PC-CRACK OUTPUT FOR INFINITE LENGTH FLAW IN THICK SECTION OF VALVE.

	Revision	0				
	Preparer/Date	JFC/1-19-91				
	Checker/Date	N&C 1/21/91				

File No. CPL-160-306

tm

pc-CRACK
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SAN JOSE, CA (408)978-8200
VERSION 2.0

Date: 18-Jan-1991
Time: 14:39:35.48

LEAST SQUARE CURVE FIT OF STRESS PROFILE

CPL RHR PRESSURE STRESSES AT 2.988" SECTION (1250 PSI, SF=3)

TERM	COEFFICIENT
C0	2.510E+01
C1	-2.763E+00
C2	-1.131E+00
C3	2.766E-01

COEFFICIENT OF DETERMINATION R^2= 0.9996
CORRELATION COEFFICIENT= 0.9992

X VALUE	Y VALUE	Y CALC	DIFF
0.000E+00	2.505E+01	2.510E+01	-5.171E-02
4.970E-01	2.362E+01	2.348E+01	1.417E-01
9.970E-01	2.141E+01	2.150E+01	-8.464E-02
1.497E+00	1.931E+01	1.936E+01	-4.742E-02
1.987E+00	1.732E+01	1.732E+01	6.118E-03
2.487E+00	1.556E+01	1.549E+01	6.925E-02
2.988E+00	1.410E+01	1.413E+01	-3.328E-02

END OF pc-CRACK

Prepared by: JFC/1-19-91
Checked by: N&C 1/21/91
File No. CR-169-306 Rev: 0
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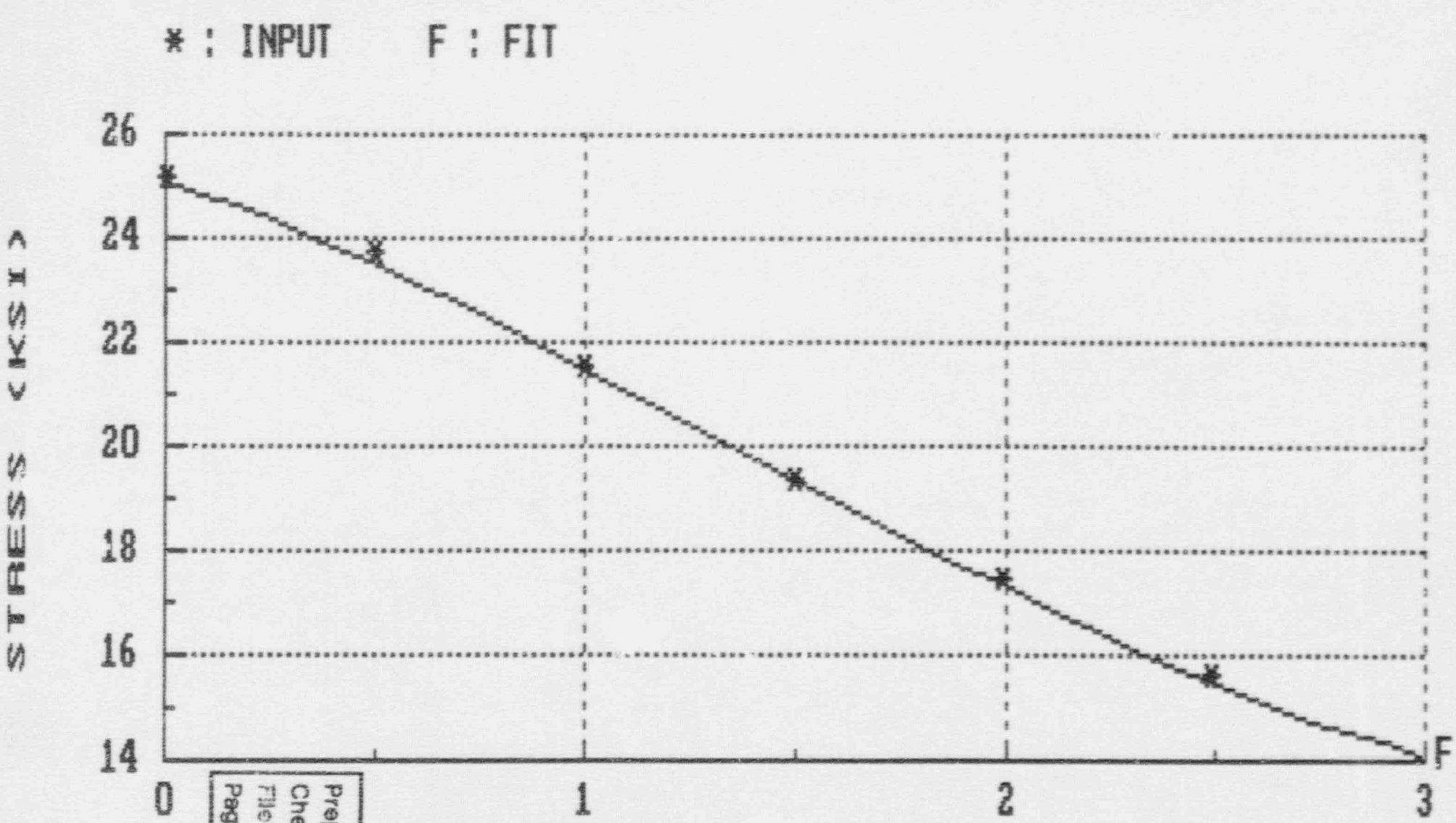
P. E-2



Prepared by: JTC 1-19-91
Checked by: [illegible] 1/21/91
File No. CPV/60-206 Rev: 2
Page C-3 of C-7

C-3

tm

pc-CRACK
(C) COPYRIGHT 1984, 1988
STRUCTURAL INTEGRITY ASSOCIATES, INC.
SAN JOSE, CA (408)978-8200
VERSION 2.0

Date: 18-Jan-1991
Time: 14:49:56.80

LEAST SQUARE CURVE FIT OF STRESS PROFILE

CPL RHR THERMAL STRESSES AT 2.988" SECTION (532 F, SF=1)

TERM	COEFFICIENT
C0	3.005E+00
C1	-6.115E-01
C2	-4.677E-01
C3	1.274E-01

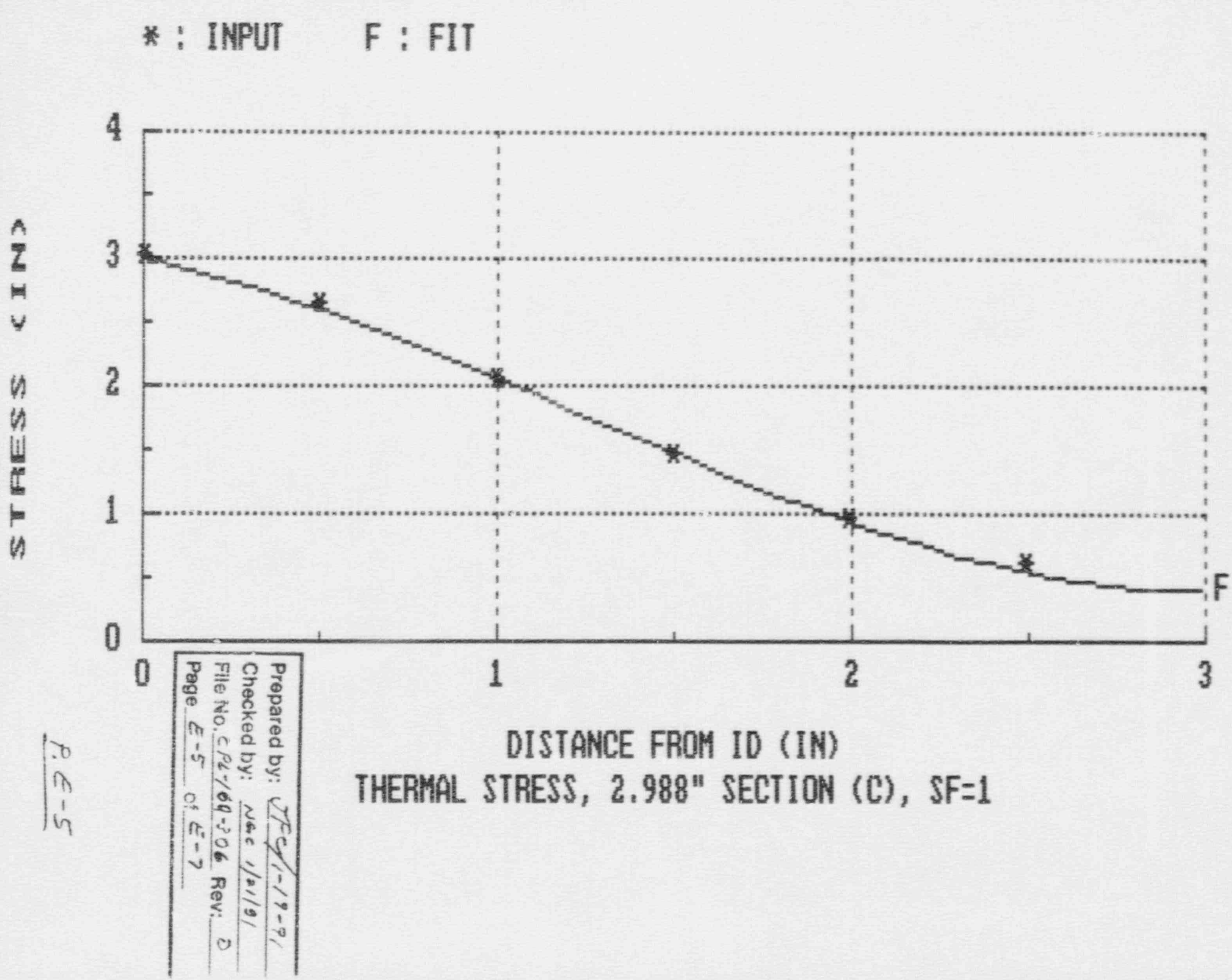
COEFFICIENT OF DETERMINATION R^2= 0.9995
CORRELATION COEFFICIENT= 0.9989

X VALUE	Y VALUE	Y CALC	DIFF
0.000E+00	2.990E+00	3.005E+00	-1.508E-02
4.970E-01	2.640E+00	2.601E+00	3.872E-02
9.970E-01	2.040E+00	2.057E+00	-1.683E-02
1.497E+00	1.450E+00	1.469E+00	-1.913E-02
1.987E+00	9.400E-01	9.434E-01	-3.357E-03
2.487E+00	5.800E-01	5.520E-01	2.797E-02
2.988E+00	3.900E-01	4.023E-01	-1.229E-02

END OF pc-CRACK

Prepared by: JFC/1-19-91
Checked by: NSC 1/21/91
File No. CPL-69-306 Rev: 0
Page E-4 of E-7

P.E-4



Prepared by: JFC 11-19-91
Checked by: MGC 1/21/91
File No. CPY/09-206 Rev. 0
Page E-5 of E-7

P. E-5

tm

pc-CRACK

VERSION 2.0

P.E-6

Date: 18-Jan-1991
Time: 15: 1:20.79

LINEAR ELASTIC FRACTURE MECHANICS EVALUATION

CPL RHR VALVE, 2.988" SECTION (C), SF=3 ON PRESSURE, SF=1 ON THERMAL

crack model:LONGITUDINAL CRACK IN CYLINDER(T/R=0.1)

WALL THICKNESS (t)= 2.9880

STRESS COEFFICIENTS

CASE ID	C0	C1	C2	C3
PRESSC	25.1017	-2.7628	-1.1305	0.2766
THERMC	3.0051	-0.6115	-0.4677	0.1274

CRACK SIZE	STRESS INTENSITY FACTOR CASE PRESSC	CASE THERMC
0.0478	10.313	1.231
0.0956	14.858	1.768
0.1434	18.530	2.198
0.1912	21.778	2.575
0.2390	24.771	2.919
0.2868	27.594	3.239
0.3347	30.420	3.557
0.3825	33.216	3.869
0.4303	35.962	4.172
0.4781	38.673	4.467
0.5259	41.356	4.757
0.5737	44.019	5.041
0.6215	46.775	5.332
0.6693	49.640	5.632
0.7171	52.510	5.928
0.7649	55.386	6.221
0.8127	58.268	6.512
0.8605	61.159	6.799
0.9084	64.223	7.101
0.9562	67.811	7.457
1.0040	71.435	7.813
1.0518	75.094	8.167
1.0996	78.786	8.520
1.1474	82.509	8.870
1.1952	86.261	9.219
1.2430	90.832	9.655

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1.2908	95.456	10.091
1.3386	100.131	10.527
1.3864	104.855	10.963
1.4342	109.625	11.397
1.4820	114.441	11.831
1.5299	120.609	12.409
1.5777	127.295	13.039
1.6255	134.067	13.671
1.6733	140.921	14.304
1.7211	147.853	14.938
1.7689	154.862	15.573
1.8167	162.583	16.275
1.8645	171.034	17.043
1.9123	179.576	17.812
1.9601	188.207	18.581
2.0079	196.923	19.349
2.0557	205.720	20.116
2.1036	214.912	20.911
2.1514	225.133	21.793
2.1992	235.444	22.674
2.2470	245.842	23.551
2.2948	256.323	24.426
2.3426	266.884	25.297
2.3904	277.522	26.165

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