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Report No.: SIR-90-016
Rev. No. 0
Project No.: CPL-09Q
March, 1990

Design Report For Recirculation System Repair and Flaw Evaluation Performed During Fall, 1989 Refueling Outage at Brunswick Steam Electric Plant Unit 2

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1.0 INTRODUCTION

Carolina Power & Light's (CP&L's) Brunswick Steam Electric Plant Unit 2 (BSEP-2) performed augmented ultrasonic examinations as part of its inservice inspection program of austenitic stainless steel welds in the recirculation and related systems during the Fall 1989 refueling outage. During this inspection, indications believed to be due to Intergranular Stress Corrosion Cracking (IGSCC) were identified in the heat affected zones of two welds in the recirculation system. One of the welds, weld 22-AM-1, a 22-inch diameter recirculation header cross-tie valve to pup piece weld, contained one circumferentially orientied IGSCC-like defect. The other weld, weld 28-B10, a 28-inch diameter pipe to pump suction elbow weld, contained 8 axial IGSCC-like indications. The flaws in weld 28-B10 were repaired by application of a weld overlay meeting the "standard" weld overlay criteria of NUREG-0313, Revision 2 (Reference 1). The flaw in weld 22-AM-1, was of a limited circumferential extent and depth. Thus a flaw evaluation was performed for this weld in accordance with the Reference 1 requirements to justify the weld for continued operation without a repair.

The as-built dimensions of the weld overlay repair applied to weld 28-B10, during the Fall, 1989 outage were reviewed and found to meet or exceed the design minimum dimensional requirements for the repair. An evaluation of the effects of the weld overlay induced shrinkage on the existing recirculation piping system, including the replaced recirculation riser piping and safe ends was also performed. Significant stresses do not result from the 1989 weld overlay repair.

This report documents the design analysis and evaluation activities conducted on the flawed welds by Structural Integrity Associates (SI) for CP&L and summarizes the current state of the recirculation piping at BSEP-2. Section 2 defines the design

criteria employed on the affected locations. Section 3 discusses the analysis and weld overlay repair design for the new repair (weld 28-B10) and the crack growth analysis for the flawed weld (22-AM1) for which repair was not required. The analysis of weld overlay induced shrinkage stress is also discussed in Section 3.

2.0 DESIGN CRITERIA

The requirements for design of weld overlay repairs are defined in NUREG-0313, Revision 2 (Reference 1). Flaws are evaluated and the analytical basis for the repairs are in accordance with the requirements of ASME Section XI, IWB-3641 (Reference 2) as specified in NUREG-0313. Weld overlay repairs are considered to be acceptable long term repairs to IGSCC flawed locations if they meet a conservative set of design assumptions which qualify them as "standard" weld overlays, in accordance with NUREG-0313, Rev. 2. The two principal design requirements to qualify a weld overlay as a "standard" weld overlay and therefore IGSCC Category E are:

1. The design basis flaw for the repair is a circumferentially oriented flaw which extends 360° around the component, and is through the original component wall. This conservative assumption eliminates concerns about the reliability of the ultrasonic inspection which initially identified the flaw. In addition, concerns about the toughness of the original butt weld material are not applicable, since no credit is taken in the design process for the load carrying capability of the remaining component wall ligament.

2. Following the repair, the surface finish of the repair must be sufficiently smooth to allow ultrasonic examination through the overlay material and into a portion of the original wall. The purpose of this examination is, in part, to demonstrate that the repair thickness does not degrade with time due to continued flaw propagation.

In addition to the requirements of Reference 1, the requirements of the CP&L Design Basis Document DBD-85-20, Revision 6 (Reference 3) apply to the design of weld overlay repairs at BSEP-2. This document defines the applicable Codes and

regulatory basis for the repairs, and also specifies inspection requirements for in-process and completed repairs.

The applied stresses used in the design for the flaw evaluation and the weld overlay repair were taken from Reference 4 and are summarized in Tables 2-1 and 2-2. As required by ASME Section XI, IWB-3640 (Reference 2), pressure, deadweight, and seismic components were considered in the design of the weld overlay repair for weld 28-B10. Thermal and other secondary stress components are not required to be addressed, since the toughness of the original butt weld material is not a concern for a standard weld overlay, and since no credit is taken for remaining ligament in the original component wall. The stresses used for the crack growth evaluation of weld 22-AM-1 include pressure, deadweight and thermal stresses as well as weld overlay induced shrinkage stresses.

Table 2-1

Stress Components for Flaw Growth Analysis

Weld Number	Pressure Stress (psi)	Deadweight (psi)	Thermal (psi)	Total (psi)
22-AM-1	5502	622	1302	7426

Table 2-2

Stress Components for Weld Overlay Design

Weld Number	Pressure Stress (psi)	Deadweight + Seismic (psi)	Total (psi)
28-B10	6750	1281	8031

3.0 ANALYSIS

As previously noted, flaws were identified in two locations in the recirculation system during the 1989-1990 inspection program at BSEP-2. One location was the 22-inch ring header cross-tie valve to pup piece weld, 22-AM-1. The second location was the 28-inch pipe to pump suction elbow weld, 28-B10. A standard weld overlay repair, as defined in Section 2 of this report, was designed and applied to the weld 28-B10 location. A flaw growth evaluation providing justification for continued operation in accordance with the Reference 1 requirements was performed for weld 22-AM-1. This section describes the design and analysis performed for these two welds, as well as the shrinkage analysis performed for the recirculation system.

3.1 Flaw Characterization

Table 3-1 summarizes the flaw characterizations for the two locations addressed by this report (References 5 and 6). For weld 28-B10, the existence of 8 axial flaw indications exceeds the number allowed by Reference 1 for continued operation without a repair. For weld 22-AM-1, the single circumferential flaw met the Reference 1 conditions such that a crack growth evaluation is permitted to justify continued operation without a repair.

3.2 Weld Overlay Design Calculations

For design of the repair, the flaws in weld 28-B10 were assumed to be circumferentially oriented, to extend 360° around the pipe, and to be through the original component wall thickness. Comparison of the observed flaws listed in Table 3-1 to that assumed for this design demonstrates that this assumption is very conservative.

The weld overlay design thickness was determined using the Structural Integrity Associates computer program pc-CRACK (Reference 7), which automates the calculation of ASME Section XI, IWB-3640 margins and allowable flaw depths. The primary stresses listed in Table 2-2 were used as input to the repair thickness calculations. The computer output for this calculation is included for reference in Appendix A of this report.

In accordance with Reference 1, the outside surface of the weld heat affected zone of the pipe and elbow were surface examined and determined to be free of defects. The initial layer of deposited weld metal contained a ferrite level of greater than 7.5 FN, such that IGSCC credit can be taken for the initial weld layer.

The minimum full thickness weld overlay length L was determined from:

$$L = 1.5 * \sqrt{Rt}$$

where:

R is the pipe outside radius, and

t is the pipe wall thickness

The design thickness and length for the weld overlay for weld 28-B10 are presented in Table 3-2; the as-built dimensions for this overlay repair are also included in Table 3-2 for comparison. The as-built dimensions exceed the design minimum dimensions following surface finish improvement. Consequently, the as-built weld overlay repair for weld 28-B10 is acceptable as a standard weld overlay in accordance with Reference 1.

3.3 Flaw Growth Evaluation For Continued Service Justification

A crack growth evaluation was performed in accordance with the Reference 1 requirements for weld 22-AM-1, the cross-tie valve to pup piece weld in the recirculation system ring header at BSEP-2. The conclusion of the evaluation was that the observed flaw, as described in Table 3-1, will not grow to a depth corresponding to the allowable flaw size permitted by Section XI, Table IWB-3641-5 (Reference 2) in less than 24 months, even under a conservative set of assumptions which include estimated weld overlay shrinkage stresses which are expected to bound the stresses anticipated at this location due to system weld overlay application. The input shrinkage stress was assumed to be that which resulted from system-wide weld overlay application prior to pipe replacement in 1989. These stresses have been reduced by the removal and replacement of the 12" risers in 1989, but were used here as a worst case bounding shrinkage stress case. Without consideration of shrinkage stresses, the remaining acceptable service life of weld 22-AM-1 is greater than 56 months.

Both sets of flaw growth calculations (with the previous riser weld overlay shrinkage stresses and without these shrinkage stresses) were performed using the SI computer program pc-CRACK (Reference 7) and the residual stress correlations and flaw growth methodology of Reference 1.

Applied stresses were taken from the Reference 4 stress report. The initial flaw characterization was taken from Reference 5 as presented in Table 3-1.

The results of this evaluation are presented in Appendix A. The calculations show that the flaw remains below the Section XI allowable for a minimum of 24 months, even including the shrinkage stresses due to the old weld overlay repairs on the risers. The remaining service life is greater than 56 months when the riser shrinkage stresses are not included.

These results confirm that the system may be operated conservatively for the next fuel/operating cycle with weld 22-AM-1 in its present unrepaired condition. This weld should be reinspected and re-evaluated during the next refueling outage in accordance with Reference 1 requirements.

3.4 Weld Overlay Shrinkage Stress Analysis

Weld overlay shrinkage, which helps produce the very favorable residual stress benefits of the weld overlay, also produces secondary stresses at other locations in the repaired system. These stresses may affect the potential for crack growth at unrepaired locations, and consequently the effects of weld overlay induced shrinkage must be assessed in the acceptance evaluation for these repairs. The measured shrinkage values resulting from the application of the single repair applied during the present outage, together with those observed during previous repair activities (Reference 8), are listed in Table 3-3. Note that the Table 3-3 weld overlays include only those repairs on the 22 inch and 28 inch diameter welds. The riser replacement performed during this outage removed all of the 12 inch diameter overlay repairs.

In order to assess the effects of weld overlay shrinkage on unrepaired locations in the recirculation system, a finite element analysis of the entire system was performed using the ALGOR SUPERSAP computer program (Reference 9). The finite element model is shown in Figure 3-1. Weld overlay shrinkage was simulated in the analysis by imposing a fictitious thermal contraction between the locations representing the ends of the repairs in the model. The analysis included not only the measured shrinkage resulting from the single weld overlay applied to weld 28-B10 during the current outage, but also the effects of the remaining previously applied weld overlays on the 22-inch or 28-inch portions of the recirculation system (9 previous weld overlays as illustrated in Table 3-3).

The shrinkage stress results for the three flawed and unrepaired locations in the recirculation system are summarized in Table 3-4. Weld overlay shrinkage induced stress is a secondary stress, which must be addressed in evaluation of flaws accepted without repairs, but are not included in design of standard weld overlays, as discussed in NUREG-0313 (Reference 1). Note that the flaws in two of the three flawed and unrepaired welds are axial, and not affected by shrinkage stresses.

The shrinkage stress to the circumferential flaw in weld 22-AM-1 has been bounded in the flaw analysis in Section 3.3. The results indicate that the stresses predicted to result from the aggregate weld overlay shrinkage in the recirculation system are small enough that effects on unflawed locations will be insignificant.

Table 3-1

Observed Flaws In Welds During 1989-1990 Outage

Weld Number	Flaw Characterization
22-AM-1	**Circumferential:** 2.4" long, 16% through wall, pipe side
28-B10	**Axial:** 8 flaws: 0.55" maximum length, 20% maximum through wall, elbow side

Table 3-2

1989 Weld Overlay Repair Design and As-Built Dimensions

Weld Number	Design Length (in)	Design Thickness (in)	As-Built Length	As-Built Thickness
28-B10	6.20	0.440	6.367	0.573

Table 3-3

Measured Weld Overlay Shrinkage

Weld Number	Total Shrinkage
22AM-5	0.193
22BM-1	0.235
28A-4	0.117
28A-8	0.066
28A-13	0.048
28B-3	0.132
28B-4	0.076
28B-5	0.083
28B-10	0.0705
28B-11	0.085

Table 3-4

Weld Overlay Shrinkage Induced Stresses at Unrepaired, Flawed Welds

Weld Number	Flaw Orientation	Stress (psi)
22-AM-1	Circumferential	320
28-A1	Axial	613
28-B1	Axial	226

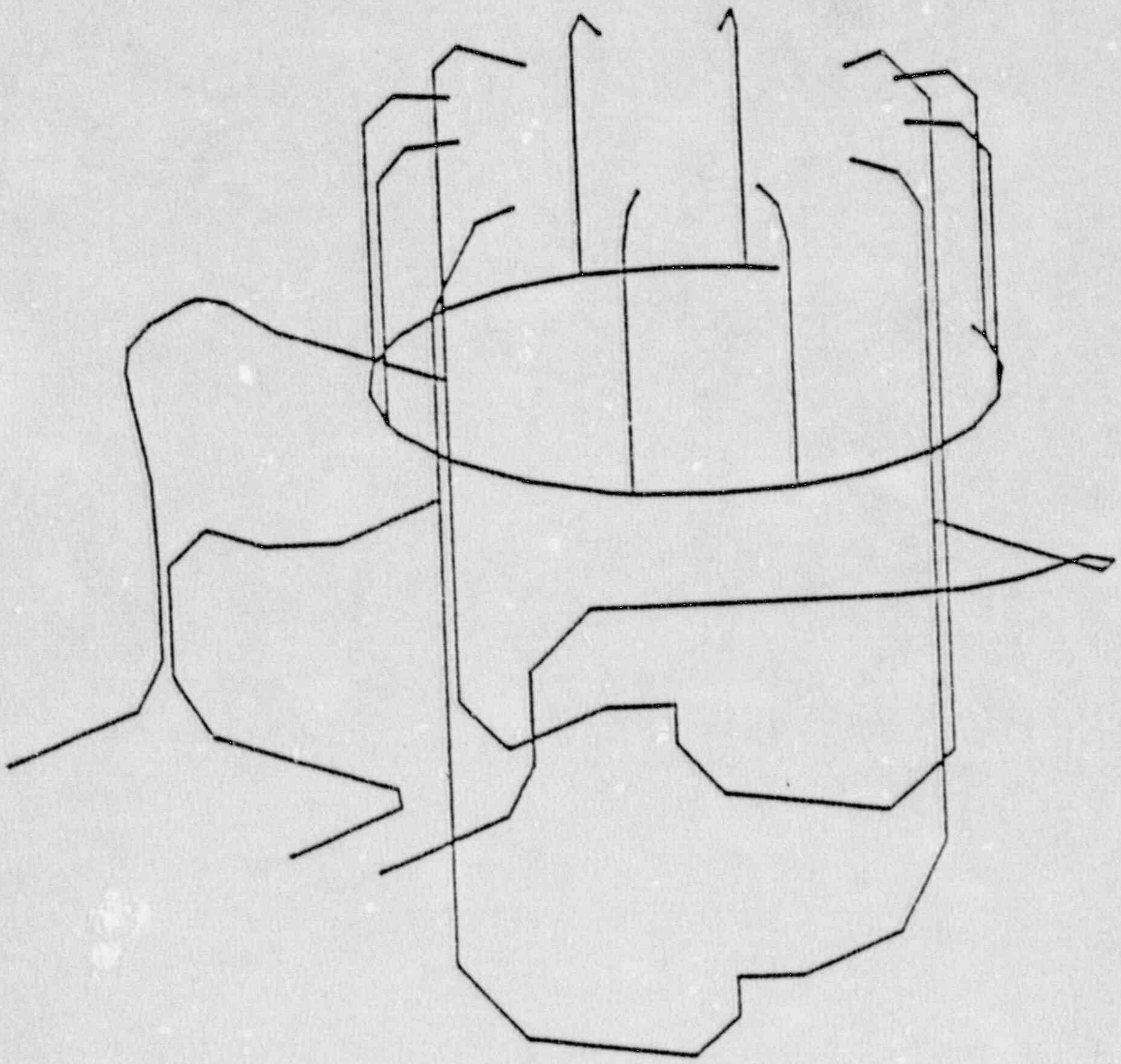


Figure 3-1. Finite Element Model of Recirculation System for Use in Determination of Weld Overlay Shrinkage Induced Stresses

4.0 CONCLUSIONS

During the Fall, 1989, refueling outage, two new flaws were detected in large diameter recirculation system piping components at Brunswick Steam Electric Plant Unit 2. One weld, containing 8 axial flaws, received a standard weld overlay repair in accordance with Reference 1 criteria. The second weld, containing a single, shallow circumferential crack, was analyzed to be suitable for continued service without repair in accordance with the requirements of Reference 1.

Analysis of the effects of weld overlay shrinkage induced stresses was performed, and the resulting stress on the three unrepaired locations in the recirculation system was observed to be acceptably low. The values were conservatively bounded by the prior shrinkage analyses, wherein the weld overlay repaired riser welds were still in the system.

The recirculation system at BSEP2 currently contains 10 locations which have been repaired by the weld overlay technique. There remain two 28-inch flawed and unrepaired nozzle to safe end weldments and one 22-inch flawed and unrepaired cross-tie valve to pup piece weldment. These three welds and other locations in this system have been treated by the Induction Heating Stress Improvement (IHSI) technique or the Mechanical Stress Improvement Process (MSIP) and the plant is currently operating with Hydrogen Water Chemistry (HWC) to mitigate the potential for further IGSCC. Consequently continued operation with these flaws in their present condition is justified.

5.0 REFERENCES

1. NUREG-0313, "Technical Report on Material Selection and Processing Guidelines for BWR Coolant Pressure Boundary Piping", Final Report, Revision 2, U.S. Nuclear Regulatory Commission, January, 1988.

2. American Society of Mechanical Engineers Boiler & Pressure Vessel Code, Section XI, 1983 Edition with Addenda through Winter 1985.

3. CP&L Design Basis Document DBD-85-20, "BSEP Units 1&2 Weld Overlays", Revision 6, October 12, 1989.

4. General Electric Company Report, "Brunswick Units 1 & 2 Recirculation Piping Analysis", Report 23A5485, Revision 0, October 1, 1985.

5. GE Nuclear Energy Indication Resolution Sheet R-070, Examination of BSEP-2 Recirculation System Weld 2B32-RR-22-AM-1, Revision 0, October 16, 1989.

6. GE Nuclear Energy Indication Resolution Sheet R-053 Examination of BSEP-2 Recirculation System Weld 2B32-RR-28B-10, Revision 0, October 11, 1989.

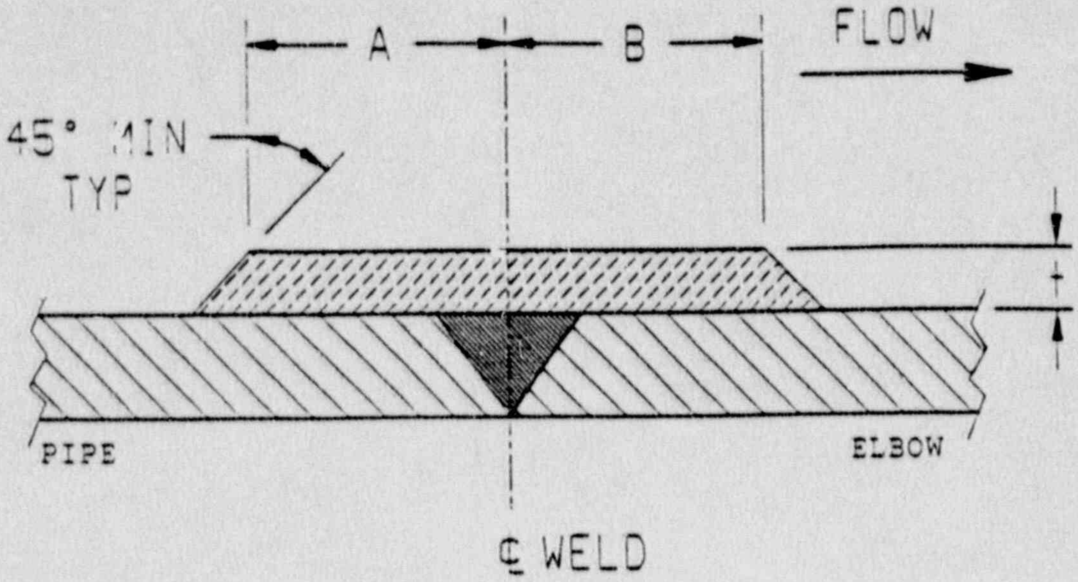
7. Structural Integrity Associates, pc-CRACK program, Version 2.0, August, 1989.

8. Structural Integrity Associates Report, "Design Report For Recirculation System Repairs Performed During Spring 1988 Refueling Outage at Brunswick Steam Electric Plant Unit, 2", SIR-88-010, March, 1988.

9. ALGOR SUPERSAP Computer Program, Version 9.000, ALGOR Interactive Systems, Inc.

APPENDIX A

Repair Design Calculations for Weld 28-B10



WELD OVERLAY

REPAIR DETAILS

WELD NUMBER	FLAW CHARACTERIZATION	DESIGN DIMENSIONS t	A	B	COMMENTS
2B32-RR-28-B10	8 Axials, Max Depth 20%	0.44"	3.1"	3.1"	Standard Design Basis Per NUREG-0313, Revision 2

PREPARED BY: H L Dust[illegible]	DATE 10/26/89	DESCRIPTION: Reactor Recirculation Loop B: 28" Pipe to Pump Suction Elbow Weld	
CHECKED BY: [illegible]	DATE 10/26/89		
JOB NO: CPL-09Q	PLANT / UNIT: Brunswick Steam Electric Plant, Unit 2	STRUCTURAL INTEGRITY ASSOCIATES, INC.	REV 0
FILE NO: CPL-09Q-301	DWG NO: CPL-09Q-001		SHT 1 OF 2

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

Date: 26-Oct-1989
Time: 11:12:22.33

STRUCTURAL REINFORCEMENT SIZING EVALUATION

STRUCTURAL REINFORCEMENT SIZING FOR CIRCUMF. CRACK,WROUGHT/CAST STAINLESS

CPL-09Q, BRUNSWICK UNIT 2, ISI # 28B10

WALL THICKNESS= 1.2000
MEMBRANE STRESS= 6.7500
BENDING STRESS= 1.2810
STRESS RATIO= 0.4738
ALLOWABLE STRESS= 16.9500
FLOW STRESS= 50.8500

	L/CIRCUM					
	0.00	0.10	0.20	0.30	0.40	0.50
FINAL A/T	0.7500	0.7500	0.7500	0.7500	0.7500	0.7393
REINFORCEMENT THICK.	0.4000	0.4000	0.4000	0.4000	0.4000	0.4232

END OF pc-CRACK

APPENDIX B

Flaw Growth Analysis for Weld 22-AM-1

tm
pc-CRACK
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VERSION 2.0

Date: 5-Jan-1990
Time: 12: 1:23.81

STRESS CORROSION CRACK GROWTH ANALYSIS

CPL09: WELD 22 AM-1

INITIAL CRACK SIZE= 0.1800
WALL THICKNESS= 1.1250
MAX CRACK SIZE FOR SCCG= 0.9000

STRESS CORROSION CRACK GROWTH LAW

LAW ID	C	N	Kthres	K1C
NRR	3.590E-08	2.1610	0.0000	200.0000

STRESS COEFFICIENTS

CASE ID	C0	C1	C2	C3
RESID22	30.2573	-193.8645	254.1497	-86.8261
APPLIED	10.0000	0.0000	0.0000	0.0000

CASE ID	Kmax SCALE FACTOR
RESID22	1.00
APPLIED	0.73

TIME	TIME INCREMENT	PRINT INCREMENT
100000.0	1000.0	1000.0

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

CRACK SIZE	---STRESS INTENSITY FACTOR--- CASE RESID22	CASE APPLIED
0.0180	7.452	2.638
0.0360	9.863	3.747
0.0540	11.278	4.610
0.0720	12.127	5.347
0.0900	12.589	6.004
0.1080	12.763	6.606
0.1260	12.787	7.206
0.1440	12.652	7.794
0.1620	12.364	8.361
0.1800	11.944	8.914

pc-CRACK VERSION 2.0

0.1980	11.412	9.454
0.2160	10.780	9.984
0.2340	10.102	1[illegible]535
0.2520	9.383	1[illegible].110
0.2700	8.592	11.685
0.2880	7.738	12.258
0.3060	6.828	12.831
0.3240	5.867	13.405
0.3420	4.925	14.010
0.3600	4.137	14.711
0.3780	3.322	15.420
0.3960	2.486	16.136
0.4140	1.634	16.860
0.4320	0.769	17.591
0.4500	-0.103	18.331
0.4680	-0.972	19.118
0.4860	-1.849	19.915
0.5040	-2.730	20.720
0.5220	-3.612	21.535
0.5400	-4.492	22.359
0.5580	-5.365	23.192
0.5760	-6.317	24.084
0.5940	-7.300	25.004
0.6120	-8.284	25.935
0.6300	-9.265	26.876
0.6480	-10.240	27.828
0.6660	-11.207	28.791
0.6840	-11.891	29.800
0.7020	-12.262	30.858
0.7200	-12.580	31.928
0.7380	-12.841	33.010
0.7560	-13.044	34.104
0.7740	-13.184	35.209
0.7920	-13.492	36.353
0.8100	-14.452	37.588
0.8280	-15.380	38.836
0.8460	-16.269	40.098
0.8640	-17.116	41.374
0.8820	-17.917	42.663
0.9000	-18.668	43.964

TIME	KMAX	DA/DT	DA	A	A/THK
1000.0	18.45	1.954E-05	0.0195	0.1995	0.177
2000.0	18.29	1.918E-05	0.0192	0.2187	0.194
3000.0	18.03	1.858E-05	0.0186	0.2373	0.211
4000.0	17.74	1.794E-05	0.0179	0.2553	0.227
5000.0	17.43	1.727E-05	0.0173	0.2725	0.242
6000.0	17.06	1.650E-05	0.0165	0.2890	0.257
7000.0	16.66	1.567E-05	0.0157	0.3047	0.271

8000.0	16.23	1.481E-05	0.0148	0.3195	0.284
9000.0	15.79	1.395E-05	0.0140	0.3335	0.296
10000.0	15.39	1.320E-05	0.0132	0.3467	0.308
11000.0	15.08	1.264E-05	0.0126	0.3593	0.319
12000.0	14.89	1.229E-05	0.0123	0.3716	0.330
13000.0	14.68	1.193E-05	0.0119	0.3835	0.341
14000.0	14.48	1.158E-05	0.0116	0.3951	0.351
15000.0	14.28	1.123E-05	0.0112	0.4063	0.361
16000.0	14.08	1.089E-05	0.0109	0.4172	0.371
17000.0	13.88	1.057E-05	0.0106	0.4278	0.380
18000.0	13.69	1.025E-05	0.0103	0.4380	0.389
19000.0	13.50	9.948E-06	0.0099	0.4480	0.398
20000.0	13.32	9.658E-06	0.0097	0.4576	0.407
21000.0	13.15	9.405E-06	0.0094	0.4671	0.415
22000.0	13.00	9.169E-06	0.0092	0.4762	0.423
23000.0	12.85	8.941E-06	0.0089	0.4852	0.431
24000.0	12.70	8.721E-06	0.0087	0.4939	0.439
25000.0	12.56	8.512E-06	0.0085	0.5024	0.447
26000.0	12.42	8.310E-06	0.0083	0.5107	0.454
27000.0	12.29	8.119E-06	0.0081	0.5188	0.461
28000.0	12.16	7.935E-06	0.0079	0.5268	0.468
29000.0	12.03	7.761E-06	0.0078	0.5345	0.475
30000.0	11.92	7.595E-06	0.0076	0.5421	0.482
31000.0	11.80	7.437E-06	0.0074	0.5496	0.488
32000.0	11.69	7.289E-06	0.0073	0.5568	0.495
33000.0	11.58	7.145E-06	0.0071	0.5640	0.501
34000.0	11.47	6.990E-06	0.0070	0.5710	0.508
35000.0	11.35	6.837E-06	0.0068	0.5778	0.514
36000.0	11.23	6.687E-06	0.0067	0.5845	0.520
37000.0	11.12	6.539E-06	0.0065	0.5910	0.525
38000.0	11.00	6.396E-06	0.0064	0.5974	0.531
39000.0	10.90	6.260E-06	0.0063	0.6037	0.537
40000.0	10.79	6.129E-06	0.0061	0.6098	0.542
41000.0	10.69	6.003E-06	0.0060	0.6158	0.547
42000.0	10.59	5.883E-06	0.0059	0.6217	0.553
43000.0	10.49	5.768E-06	0.0058	0.6275	0.558
44000.0	10.40	5.657E-06	0.0057	0.6331	0.563
45000.0	10.31	5.551E-06	0.0056	0.6387	0.568
46000.0	10.22	5.451E-06	0.0055	0.6441	0.573
47000.0	10.13	5.354E-06	0.0054	0.649[illegible]	0.577
48000.0	10.05	5.260E-06	0.0053	0.6548	0.582
49000.0	9.98	5.173E-06	0.0052	0.6599	0.587
50000.0	9.90	5.089E-06	0.0051	0.6650	0.591
51000.0	9.82	5.006E-06	0.0050	0.6700	0.596
52000.0	9.82	5.003E-06	0.0050	0.6750	0.600
53000.0	9.84	5.019E-06	0.0050	0.6800	0.604
54000.0	9.85	5.035E-06	0.0050	0.6851	0.609
55000.0	9.89	5.075E-06	0.0051	0.6902	0.613
56000.0	10.00	5.201E-06	0.0052	0.6954	0.618
57000.0	10.12	5.333E-06	0.0053	0.7007	0.623
58000.0	10.24	5.469E-06	0.0055	0.7062	0.628
59000.0	10.37	5.628E-06	0.0056	0.7118	0.633
60000.0	10.52	5.799E-06	0.0058	0.7176	0.638
61000.0	10.67	5.978E-06	0.0060	0.7236	0.643

pc-CRACK VERSION 2.0

62000.0	10.83	6.182E-06	0.0062	0.7297	0.649
63000.0	11.01	6.408E-06	0.0064	0.7361	0.654
64000.0	11.20	6.647E-06	0.0066	0.7428	0.660
65000.0	11.41	6.923E-06	0.0069	0.7497	0.666
66000.0	11.64	7.227E-06	0.0072	0.7569	0.673
67000.0	11.89	7.557E-06	0.0076	0.7645	0.680
68000.0	12.17	7.947E-06	0.0079	0.7724	0.687
69000.0	12.46	8.368E-06	0.0084	0.7808	0.694
70000.0	12.72	8.745E-06	0.0087	0.7896	0.702
71000.0	12.97	9.130E-06	0.0091	0.7987	0.710
72000.0	13.02	9.205E-06	0.0092	0.8079	0.718
73000.0	12.99	9.159E-06	0.0092	0.8171	0.726
74000.0	12.98	9.139E-06	0.0091	0.8[illegible]2	0.734
75000.0	12.97	9.127E-06	0.0091	0.8353	0.743
76000.0	12.93	9.145E-06	0.0091	0.8445	0.751
77000.0	13.00	9.170E-06	0.0092	0.8536	0.759
78000.0	13.04	9.228E-06	0.0092	0.8629	0.767
79000.0	13.08	9.295E-06	0.0093	0.8722	0.775
80000.0	13.15	9.400E-06	0.0094	0.8816	0.784
81000.0	13.22	9.514E-06	0.0095	0.8911	0.792
82000.0	13.33	9.676E-06	0.0097	0.9008	0.801

CRACK SIZE EXCEEDED 0.9000 AT TIME 8.200E+04

END OF pc-CRACK

tm
pc-CRACK

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

ALLOWABLE FLAW SIZE EVALUATIONS
USING ASME SECTION XI, IWB-3640/50 PROCEDURES AND CRITERIA
FOR CIRCUMFERENTIAL CRACKS IN STAINLESS STEEL PIPING

MATERIAL IS SPECIFIED AS SUBMERGED ARC WELD
DEFAULT PROPERTIES:
  DESIGN STRESS = 16.95
  FLOW STRESS = 50.85

CPL-09Q: WELD 22-AM1

THE EVALUATION ASSUMES DEFAULT MATERIAL PROPERTIES

PIPE GEOMETRY:
  OUTER DIAMETER = 22.0000
  WALL THICKNESS = 1.1250
CRACK GEOMETRY:
  CRACK DEPTH = 0.1800
  CRACK LENGTH = 2.4000

THE FLAWED PIPE IS ASSUMED TO FAIL DUE TO UNSTABLE DUCTILE TEARING (EPFM)

THE ALLOWABLE FLAW SIZE IS DETERMINED USING CODE TABLES
AND DEFAULT SAFETY FACTORS FOR NORMAL OPERATING (INCL. UPSET & TEST)
CONDITIONS

MEMBRANE STRESS (Pm)	=	5.5020	(SAFETY FACTOR = 2.770)
BENDING STRESS (Pb)	=	1.3810	(SAFETY FACTOR = 2.770)
EXPANSION STRESS (Pe)	=	1.3020	(SAFETY FACTOR = 1.000)
DESIGN STRESS	=	16.9500	
(Pm + Pb)/Sm	=	0.4061	
STRESS RATIO	=	0.4685	(DOES NOT INCLUDE S.F.)
M FACTOR	=	1.0800	
a/t	=	0.1600	
l/circumference	=	0.0347	
ALLOWABLE a/t	=	0.6000	

	l/circumference					
	0.00	0.10	0.20	0.30	0.40	0.50
ALLOWABLE a/t	0.6000	0.6000	0.6000	0.6000	0.6000	0.4900

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

Date: 5-Jan-1990
Time: 12:59:25.54

STRESS CORROSION CRACK GROWTH ANALYSIS

INITIAL CRACK SIZE= 0.1800
WALL THICKNESS= 1.1250
MAX CRACK SIZE FOR SCCG= 0.9000

STRESS CORROSION CRACK GROWTH LAW

LAW ID	C	N	Kthres	K1C
NRR	3.590E-08	2.1610	0.0000	200.0000

STRESS COEFFICIENTS

CASE ID	C0	C1	C2	C3
RESID22	30.2573	-193.8645	254.1497	-86.8261
APPLIED	10.0000	0.0000	0.0000	0.0000

CASE ID	Kmax SCALE FACTOR
RESID22	1.00
APPLIED	1.10

TIME	TIME INCREMENT	PRINT INCREMENT
100000.0	1000.0	1000.0

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

CRACK SIZE	STRESS INTENSITY FACTOR CASE RESID22	CASE APPLIED
0.0180	7.452	2.638
0.0360	9.963	3.747
0.0540	11.278	4.610
0.0720	12.127	5.347
0.0900	12.589	6.004
0.1080	12.763	6.606
0.1260	12.787	7.206
0.1440	12.652	7.794
0.1620	12.364	8.361
0.1800	11.944	8.914

0.1980	11.412	9.454
0.2160	10.790	9.984
0.2340	10.102	10.535
0.2520	9.383	11.110
0.2700	8.592	11.685
0.2880	7.738	12.258
0.3060	6.828	12.831
0.3240	5.867	13.405
0.3420	4.925	14.010
0.3600	4.137	14.711
0.3780	3.322	15.420
0.3960	2.486	16.136
0.4140	1.634	16.860
0.4320	0.769	17.591
0.4500	-0.103	18.331
0.4680	-0.972	19.118
0.4860	-1.849	19.915
0.5040	-2.730	20.720
0.5220	-3.612	21.535
0.5400	-4.492	22.359
0.5580	-5.365	23.192
0.5760	-6.317	24.084
0.5940	-7.300	25.004
0.6120	-8.284	25.935
0.6300	-9.265	26.876
0.6480	-10.240	27.828
0.6660	-11.207	28.791
0.6840	-11.891	29.800
0.7020	-12.262	30.858
0.7200	-12.580	31.928
0.7380	-12.841	33.010
0.7560	-13.044	34.104
0.7740	-13.184	35.209
0.7920	-13.492	36.353
0.8100	-14.452	37.588
0.8280	-15.380	38.836
0.8460	-16.269	40.098
0.8640	-17.116	41.374
0.8820	-17.917	42.663
0.9000	-18.666	43.964

TIME	KMAX	DA/DT	DA	A	A/THK
1000.0	21.75	2.788E-05	0.0279	0.2079	0.185
2000.0	21.78	2.798E-05	0.0280	0.2359	0.210
3000.0	21.68	2.769E-05	0.0277	0.2636	0.234
4000.0	21.50	2.720E-05	0.0272	0.2908	0.258
5000.0	21.18	2.633E-05	0.0263	0.3171	0.282
6000.0	20.74	2.516E-05	0.0252	0.3422	0.304
7000.0	20.34	2.411E-05	0.0241	0.3664	0.326

pc-CRACK VERSION 2.0

8000.0	20.31	2.404E-05	0.0240	0.3904	0.347
9000.0	20.25	2.389E-05	0.0239	0.4143	0.368
10000.0	20.18	2.371E-05	0.0237	0.4380	0.389
11000.0	20.10	2.351E-05	0.0235	0.4615	0.410
12000.0	20.06	2.341E-05	0.0234	0.4849	0.431
13000.0	20.06	2.340E-05	0.0234	0.5083	0.452
14000.0	20.07	2.343E-05	0.0234	0.5317	0.473
15000.0	20.09	2.349E-05	0.0235	0.5552	0.494
16000.0	20.14	2.361E-05	0.0236	0.5789	0.515
17000.0	20.18	2.372E-05	0.0237	0.6026	0.536
18000.0	20.22	2.383E-05	0.0238	0.6264	0.557
19000.0	20.29	2.399E-05	0.0240	0.6504	0.578
20000.0	20.38	2.423E-05	0.0242	0.6746	0.600
21000.0	20.67	2.497E-05	0.0250	0.6996	0.622
22000.0	21.58	2.740E-05	0.0274	0.7270	0.646
23000.0	22.90	3.117E-05	0.0312	0.7582	0.674
24000.0	24.60	3.638E-05	0.0364	0.7946	0.706
25000.0	26.55	4.291E-05	0.0429	0.8375	0.744
26000.0	27.60	4.667E-05	0.0467	0.8841	0.786
27000.0	29.09	5.228E-05	0.0523	0.9364	0.832

CRACK SIZE EXCEEDED 0.9000 AT TIME 2.700E+04

END OF pc-CRACK

tm
pc-CRACK

VERSION 2.0

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M FACTOR	=	1.0800	
a/t	=	0.1600	
l/circumference	=	0.0347	
ALLOWABLE a/t	=	0.6000	

	l/circumference					
	0.00	0.10	0.20	0.30	0.40	0.50
ALLOWABLE a/t	0.6000	0.6000	0.6000	0.6000	0.6000	0.4900