B&W NUCLEAR TECHNOLOGIES

CALCULATION SUMMARY SHEET (CSS)

DOCUMENT IDENTIFIER 32-1236235-00

TITLE FM Assessment of CR-3 PRZ WP-15 Weld Flaw until End-of-Life

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REF. PAGE(S)	31		

PURPOSE AND SUMMARY OF RESULTS:

Purpose

During 9R Section XI examinations of the CR-3 pressurizer, a flaw indication was detected in the WP-15 weld connecting the surge nozzle to the lower head. The flaw was determined to exceed the flaw acceptance standards of ASME Section XI, IWB-3500.

The purpose of this document is to determine the acceptability of the reported unacceptable indication per the IWB-3000 acceptance standards of the ASME Boiler and Pressure Vessel Code, Section XI. Through the understanding of stresses, material properties, and geometry acting on this body, a linear elastic fracture mechanics analysis is performed in accordance with the ASME Boiler and Pressure Vessel Code, Section XI to ensure that the flaw indication will not reach a critical length in the CR-3 design life.

Summary of Results

Table 4-3 shows the results of this analysis. A small amount of fatigue crack growth is expected to occur over the design life of this component (~0.0026 in.) Furthermore, fracture toughness margins do not exceed $\sqrt{10}$ for Normal/Upset conditions and $\sqrt{2}$ for the Emergency/Faulted conditions. Also, the limit load margin was found to be acceptable for all expected loading conditions. Hence, the CR-3 WP-15 surge nozzle-to-lower head weld flaw indication has been found to be acceptable by IWB-3612 criteria for continued safe operation until end-of-life.

Note: This document is classified as BWNT Non-Proprietary.

THE FOLLOWING COMPUTER CODES HAVE BEEN USED IN THIS DOCUMENT:

CODE / VERSION / REV	CODE / VERSION / REV

THIS DOCUMENT CONTAINS ASSUMPTIONS THAT MUST BE VERIFIED PRIOR TO USE ON SAFETY-RELATED WORK

YES ( ) NO (X)

RECORD OF REVISIONS

Revision	Description of Revision	Date
00	Original Release	1/95

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1.0 Introduction

During 9R Section XI examinations of the CR-3 pressurizer, a flaw indication was detected in the WP-15 weld connecting the surge nozzle to the lower head. The flaw was determined to exceed the flaw acceptance standards of ASME Section XI, IWB-3500.

A fatigue crack growth analysis, Ref. 8, was prepared to justify continued operation of the plant. Due to time constraints and lack of detailed stresses at the location of the flaw, the analysis was performed assuming the maximum stress ranges from any transient were applicable for all transient cycles. This very conservative approach resulted in a flaw acceptability of only one fuel cycle.

The purpose of this document is to determine the acceptability of the reported unacceptable indication per the IWB-3000 acceptance standards of the ASME Boiler and Pressure Vessel Code, Section XI[1]. Through the understanding of stresses[6], material properties[2], and geometry (Section 2.0) acting on this body, a linear elastic fracture mechanics analysis will be performed in accordance with the ASME Boiler and Pressure Vessel Code, Section XI[1] to ensure that the flaw indication will not reach a critical length in the CR-3 design life.

The following is a summary of the analytical procedure undertaken:

(a) Characterize the flaw in accordance with IWB-3610[1].
(b) Using A-2000[1], resolve the actual flaw into a simple flaw to be analyzed.
(c) Determine stresses at the location of the observed flaw for normal & upset, emergency, and faulted conditions.
(d) Using A-4000[1], determine the necessary material properties.
(e) Calculate stress intensity factors for each condition in accordance with A-3000[1].
(f) Evaluate the flaw evaluation criteria of IWB-3600[1] to determine whether the observed flaw is acceptable for continued operation.

2.0 Overview Description of Geometry and Flaw

2.1 Geometry and Material Involved

The geometry of the pressurizer surge nozzle is given in Reference 2 and is summarized in Figure 2-1. The component consists of a A-508 Class 1 carbon steel (modified by ASME B&PV Code Case 1332-4[10]), nozzle welded to the SA-516 Grade 70 carbon steel lower head. Both the nozzle and pressurizer head are clad with stainless steel to prevent reactor coolant fluid from contacting the carbon steel base metal.

The initial weld was performed using the Semi-Automatic Gas Metal Arc welding process with fabricated McKay E70A1 flux cored weld wire (WP-15 Rev 4). Weld repairs were performed at various times using the Shielded Metal Arc welding process using E7015-A1 electrodes (B&W manufactured) or E7018-A1 electrodes (WP-15 Alt 1 Rev 3).[5]

Furthermore, post-weld heat treatment (PWHT) was performed at 1100°F to 1150°F for 12 hours total.[5] Hence, with this amount of stress relief, the effect of weld residual stresses was deemed to be negligible.

2.2 Flaw Geometry

Figure 2-2 shows the location and size of the indication found by ultrasonic testing. The following section will demonstrate how this flaw is to be evaluated.

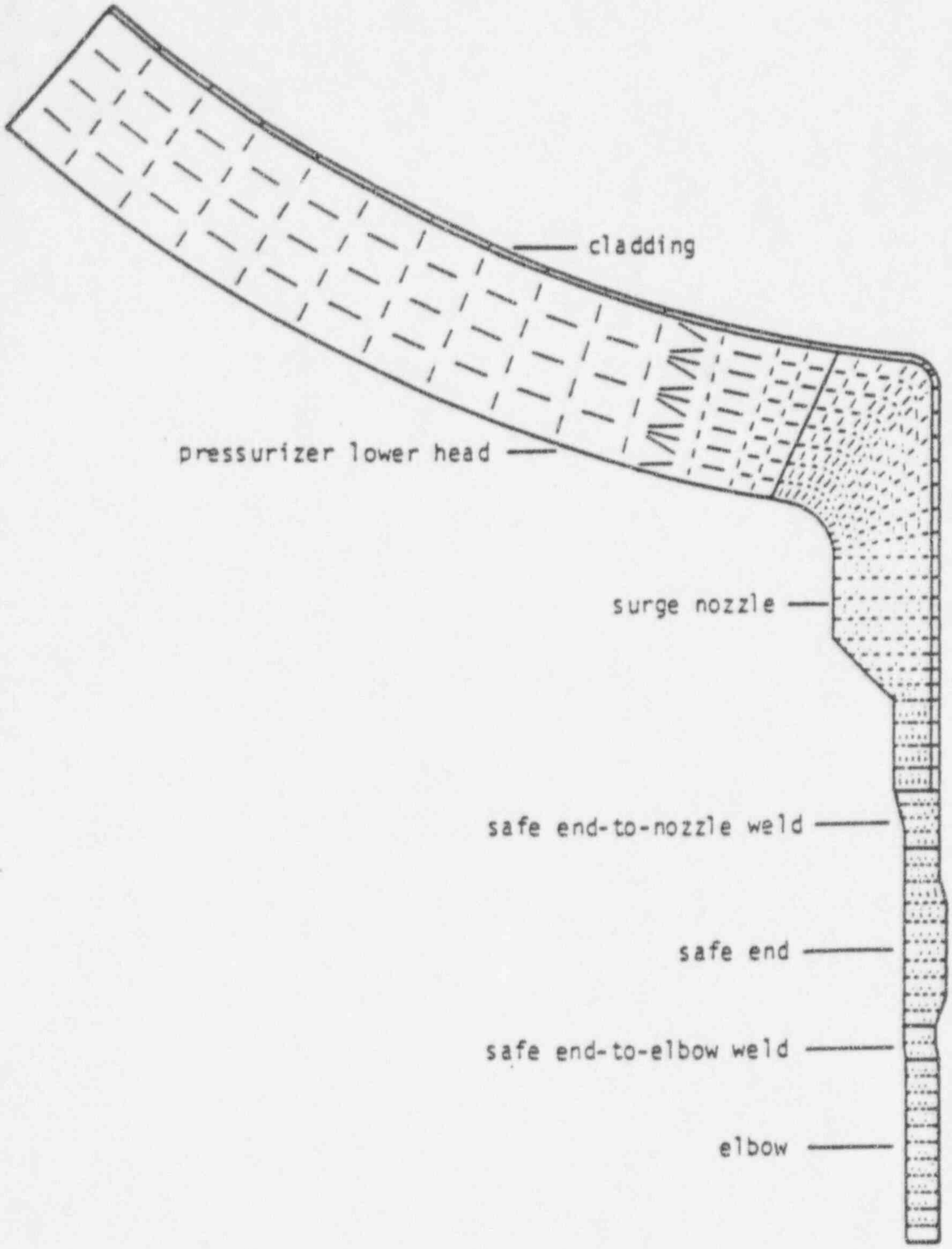

Figure 2-1 Geometry of the Pressurizer Surge Nozzle[2]

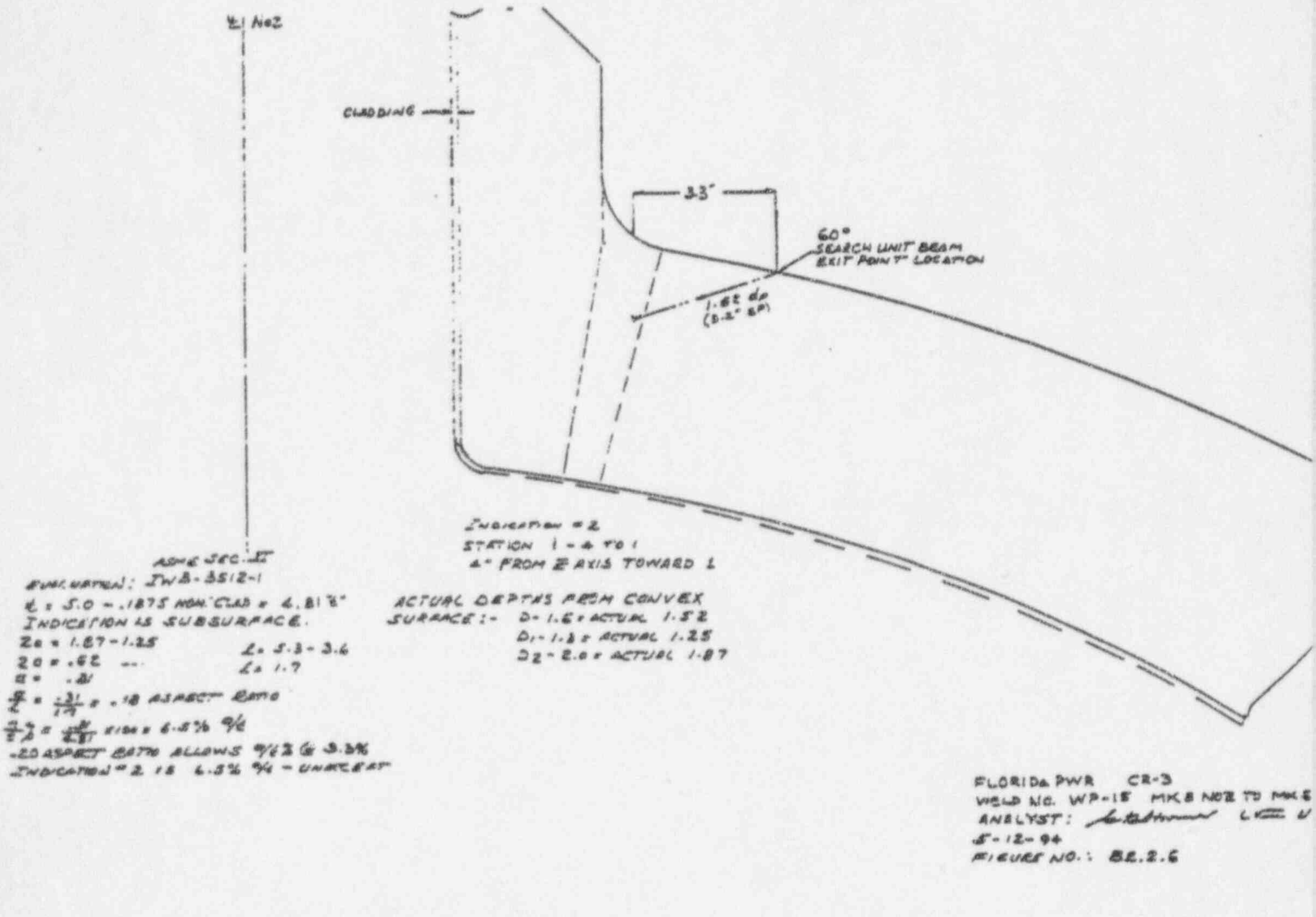

Figure 2-2 Location and Size of Flaw Indication Detected by Ultrasonic Testing in CR-3's Pressurizer Surge Nozzle

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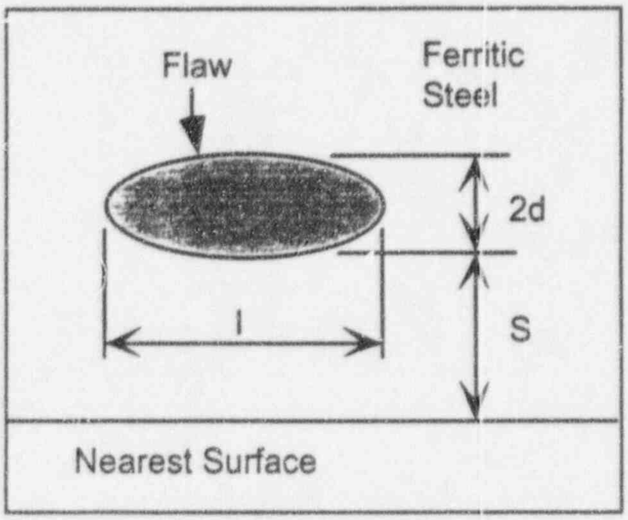
3.0 Resolution of Actual Flaw into a Simple Flaw to be Analyzed

3.1 Characterize Flaw in Accordance with IWB-3610[1]

Using Figure 3-1, it is possible to characterize the subsurface flaw contained entirely in the ferritic steel as either a surface or a subsurface flaw depending on the relationship between S and d. As seen, the flaw can be characterized as subsurface.



If $S \geq 0.4d$, then a subsurface flaw is assumed.
If $S < 0.4d$, then a surface flaw is assumed.

$S = 1.21$ in. $2d = 0.62$ in.

$1.21 > 0.4(.31)$

$1.21 > 0.12$

Therefore, a subsurface flaw will be used.

Figure 3-1 Characterization and Proximity Rules for Analytical Evaluation of Components[1]

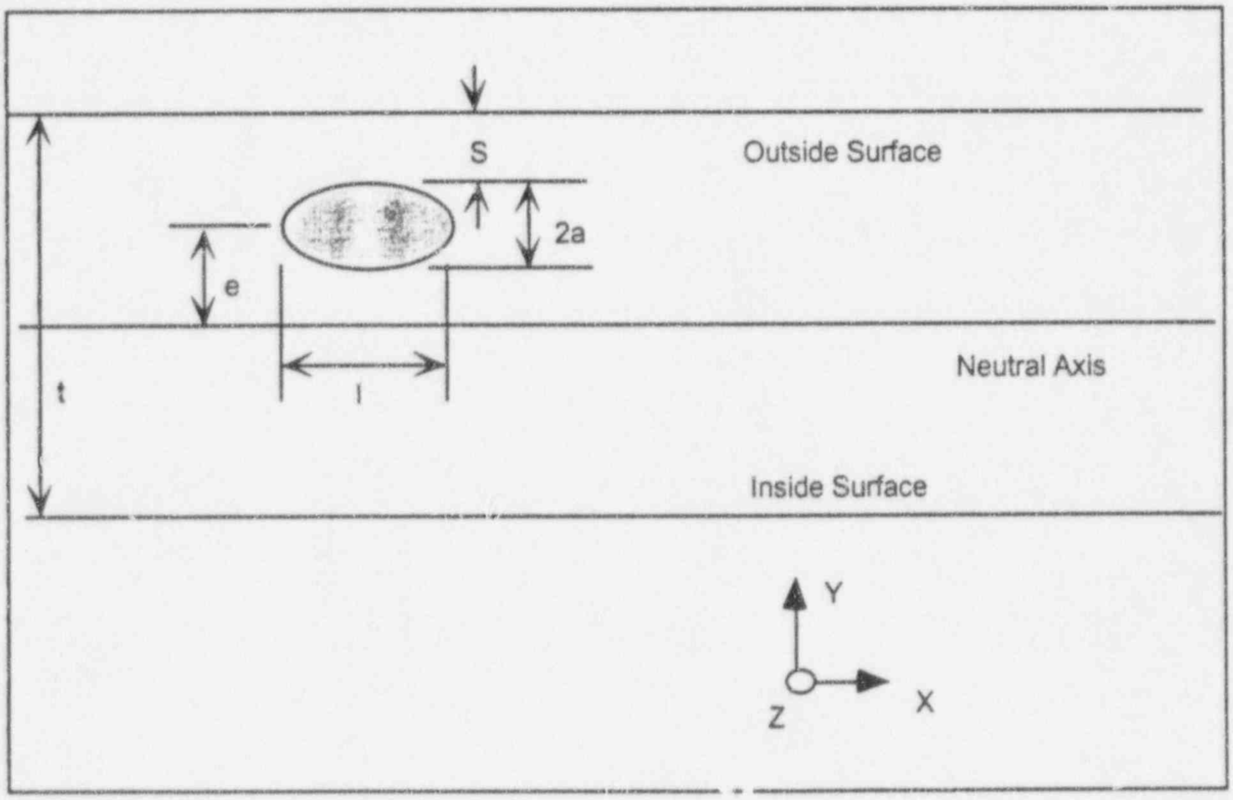
3.2 Flaw Shape and Location

The flaw indication is completely circumscribed by an elliptical planar area as outlined in IWA-3300[1]. For purposes of this analysis, the flaw is considered in its actual location per IWA-3300[1].

3.3 Flaw Orientation

As shown in Figure 2-2, the indication is a non-planar elliptical subsurface flaw and should be projected in planes normal to the stresses that are related to the longitudinal and radial directions per IWA-3340[1]. However, the radial stress, as shown in Ref. 6, is found to be insignificant. In order to perform a conservative analysis, the flaw will be assumed to be normal to the longitudinal stress.

The flaw model used for this analysis is depicted below in Figure 3-2.



S = 1.21 in.
2a = 0.62 in.
e = 0.855 in.
l = 1.70 in.
t = 4.75 in.

Figure 3-2 Simplified Flaw Geometry Used for Analysis

4.0 Fracture Mechanics Assessment

4.1 IWB-3612 Flaw Acceptance Criteria Based on Evaluation

A flaw is acceptable if the applied stress intensity factor satisfies the following IWB-3612[1] criteria.

(a) For normal and upset condition:

$$K_I < \frac{K_{Ia}}{\sqrt{10}}$$

where

K_I = the maximum applied stress intensity factor for normal and upset conditions based on **final** crack length.

K_{Ia} = crack arrest fracture toughness for the corresponding crack tip temperature.

(b) For emergency and faulted condition:

$$K_I < \frac{K_{Ic}}{\sqrt{2}}$$

K_I = the maximum applied stress intensity factor for emergency and faulted conditions based on **final** crack length.

K_{Ic} = fracture initiation fracture toughness for the corresponding crack tip temperature.

4.2 Stress Intensity Factor

The stress intensity factor for the flaw model is calculated using the following equation:

$$K_I = (\sigma_m M_m + \sigma_b M_b) \sqrt{\frac{\pi a}{Q}}$$

where

σ_m, σ_b = membrane and bending stresses, ksi.
a = minor half-diameter, in.
Q = flaw shape parameter
M_m = correction factor for membrane stress
M_b = correction factor for bending stress

In Section III - Appendix G and Section XI - Apeendix A of the ASME Code, the small-scale plasticity adjustment is hidden in the flaw shape parameter, Q. The flaw shape parameter is assumed to follow Figure A-3300-1[1] as follows:

$$Q = 1 + 4.593\ (a/l)^{1.65} - 0.212\ (\sigma/\sigma_y)^2$$

where σ is conservatively assumed to be the sum of the absolute value of the membrane stress and the absolute value of the bending stress.

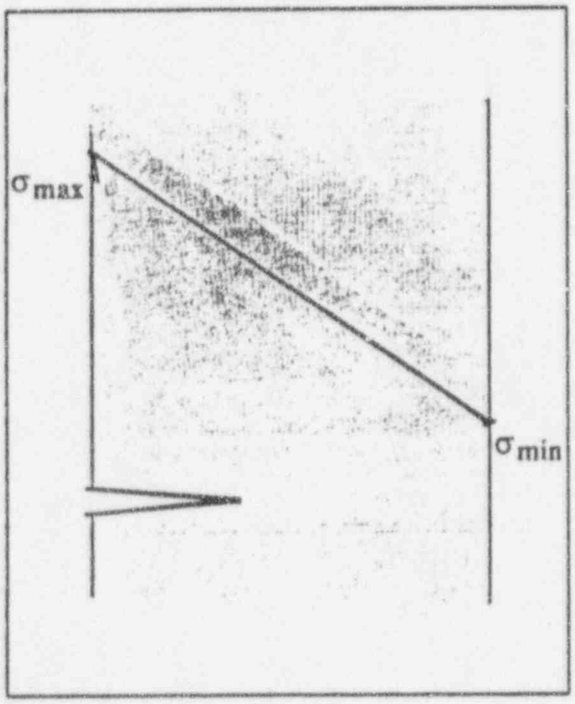
M_m, M_b are the loading type correction factors from the ASME Section XI, Appendix A procedure given graphically in Figures A-3300-2 and A-3300-4 for subsurface flaws in Appendix A. Note that no corrections for aspect ratio, a/l, are provided for the buried flaws. The "Pt1" designation in Figures A-3300-2 and A-3300-4 refers to the point on the crack front nearest the closest surface and "Pt2" is the other point on the minor axis. A polynomial form by Cipolla[4] (listed as part of the FORTRAN program listing in Appendix B of this document) is available which corresponds to the ASME Section XI, Appendix A curves. It is this form that will be utilized to determine the loading type coefficients when the stress intensity factor calculations are made.

4.3 Stresses for Evaluation

Stresses in the surge nozzle-to-pressurizer weld (the flaw location) are caused by the pressure, thermal, and external loadings associated with thermal stratification of the surge line.

As given by Ref. 6, the opening mode longitudinal stresses are given at the inside and outside surface of the pressurizer at the location of the surge nozzle-to-lower head weld. However, as defined by the stress intensity factor solution being used, the stresses should be broken into membrane and bending components. Fig. 4-1 demonstrates how the membrane, σ_m, and bending, σ_b, stress components are defined. Note that the bending stress is defined as being positive on the outboard side of the neutral axis. Section 4.6 gives magnitudes of the membrane and bending stresses utilized for analysis of the Normal/Upset and Emergency/Faulted conditions.

Figure 4-1 Definition of Membrane and Bending Stress Components



$$\sigma_m = (\sigma_{max} + \sigma_{min}) / 2$$

$$\sigma_b = (\sigma_{max} - \sigma_{min}) / 2$$

4.4 Limit Load Solution

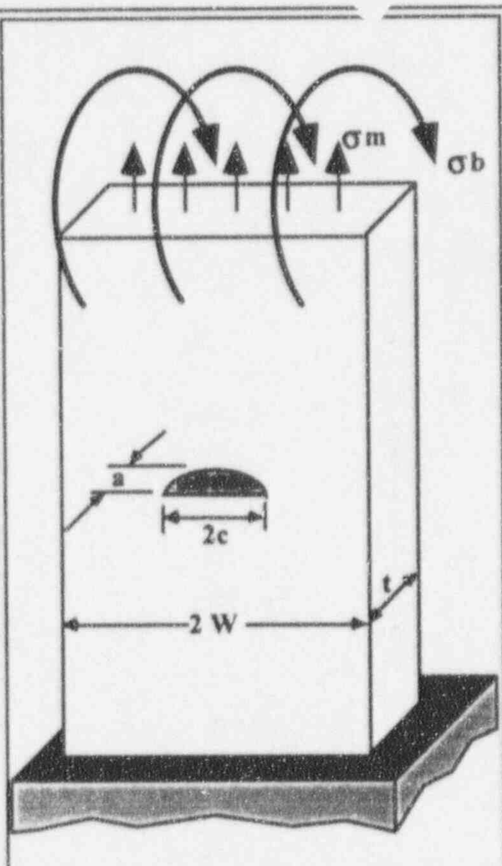
In addition to failure by brittle fracture, a net section collapse failure needs to be assessed. The safest approach in a fracture mechanics assessment is to adopt an analysis that spans the entire range from linear elastic to fully plastic behavior. Such an analysis accounts for the two extremes of brittle fracture and plastic collapse.

The limit load solution for a semi-elliptical surface crack in a flat plate subject to combined tension and bending is used in this analysis, see Figure 4-2. This is a conservative assumption for the embedded flaw being analyzed, since the bending stress will have a greater effect on a surface flaw than on an embedded flaw. The crack depth, a, is postulated to be the 0.62 in. for the initial crack depth while the initial crack length, 2c, is modeled as 1.70 in. In addition, the width of the plate is assumed to be infinite.

Since no margin of safety is applied to the limit load condition, the component will not fail by plastic collapse if

$$\sigma_m / \sigma_{m(L)} < 1$$

Figure 4-2 Plastic Collapse Solution Utilized in this Analysis[7]



$$\sigma_{m(L)} = 3\sigma_Y(1-\alpha)^2 / (\lambda + (\lambda^2 + 9(1-\alpha)^2)^{.5})$$

where

$$\alpha = (a/t) / (1 + t/c)$$

$$\lambda = \sigma_b / \sigma_m$$

$$\sigma_Y = (\sigma_{YS} + \sigma_{TS}) / 2$$

Prepared by: L.T. Hill Date: 12/15/94

Reviewed by: D.E. Killian Date: 1/25/95

4.5 Fatigue Crack Growth

In order to determine the final crack length, a_f, as required by IWB-3612[1], a fatigue crack growth will be required to be performed. The fatigue crack growth rate da/dN of the material is characterized in terms of the range of applied stress intensity factor ΔK_I. The Paris Law characterization is of the form:

$$\frac{da}{dN}=C_o(\Delta K_I)^n$$

where

ΔK_I = $(\Delta\sigma_m M_m + \Delta\sigma_b M_b)\sqrt{(\pi a/Q)}$
C_o = scaling constant
n = the slope of the log (da/dN) versus log (ΔK_I)

Using Figure A-4300-1[1], the coefficients C_o and n are 2.67E-11 and 3.726. Note that the scaling constant C_o produces fatigue crack growth rates in units of in./cycle where ΔK_I is in units of ksi$\sqrt{}$in. Also if the R ratio (K_{min}/K_{max}) < 0 (i.e. K_{min} < 0) then K_{min} is set equal to 0. This is to prevent the non-conservative effect of crack closure (i.e. reverse yielding at the crack tip which retards fatigue crack growth).

4.6 Spectrum Analysis Required for Fatigue Crack Growth

Reference 2 states the number of cyclic stresses that the current flaw indication could undergo in the life of this component. Table 4-1 demonstrates the number of transients per design life and the associated number of stress cycles per transient.

To predict the life of a component subjected to a variable load history (such as for the surge nozzle-to-lower head weld geometry), it is necessary to reduce the complex history into a number of events which can be compared to the available constant amplitude test data.

First, it is necessary to determine the severity of each individual Peak-Valley, PV, within a given transient. This is done in this analysis by computing the stress intensity factor at point 1 for flaw dimensions corresponding to the initial flaw size. From this, the PVs are sorted based on this stress intensity factor.

Once the PVs have been categorized, they must be combined to form completed fatigue cycles. The following methodology is the most conservative method for matching PVs. The most damaging combination of PVs (matching of the PV with the highest stress intensity factor with the PV having the lowest stress intensity factor) is obtained by first forming the largest possible cycle. The next largest cycle possible is then formed by using the remaining PVs available, and so on, until all PVs have been used. The procedure is repeated for each of the Normal/Upset transients studied. Section 5.0 gives further details on the application of this technique through the development of a FORTRAN computer program. The results of this analysis are shown in Table 4-2.

Table 4-1 Number of Normal/ Upset Fatigue Cycles that the Pressurizer Surge Nozzle Undergoes

Transient	Number of Transients	Fatigue Cycles / Transient	Total Fatigue Cycles
hu1a1	10	35	350
hu1a2	8	32	256
hu1a3	45	33	1485
hu1a4	29	34	986
hu1a5	148	33	4884
cd1b1	40	38	1520
cd1b2	200	34	6800
2a	1440	1	1440
2b	1440	2	2880
3	48000	1	48000
4	48000	1	48000
7	310	2	620
8a	80	1	80
8b	162	1	162
8c	88	1	88
8d	70	1	70
14	40	1	40
20b	20000	1	20000
20d2	34000	1	34000
22a1	5	1	5
22b1	15	1	15
22c1	10	1	10
22d1	10	1	10
22a2	7	5	35
22b2	42	5	210
22c2	7	5	35
22d2	100	5	500

172481 Fatigue Cycles in Design Life

Table 4-2 Spectrum History For WP-15 Surge Nozzle-to-Lower Head of Pressurizer Weld

Cycles in Design Life	Max Stress State Mem (ksi)	Max Stress State Bend (ksi)	Min Stress State Mem (ksi)	Min Stress State Bend (ksi)	@ max SIF Crack Tip Temp (deg F)	@point 1 Max SIF (ksi√in)	@point 1 Min SIF (ksi√in)
Transient: hula1							
10	13.95	21.75	.95	-29.55	521.00	24.69	-11.79
10	11.10	21.20	1.75	-24.25	342.00	20.64	-8.39
10	12.55	15.35	1.80	-14.50	513.00	18.79	-4.06
10	8.70	20.40	2.35	-12.15	249.00	17.31	-2.61
10	11.15	13.55	2.35	-11.65	521.00	16.27	-2.41
10	11.45	12.65	4.75	-14.55	414.00	16.12	-1.39
10	11.95	10.45	2.70	-9.10	508.00	15.53	-1.09
10	10.65	12.25	2.25	-7.15	521.00	15.08	-.74
10	8.45	16.55	2.40	-6.30	223.00	14.95	-.27
10	11.40	10.40	2.25	-5.95	407.00	14.94	-.27
10	11.30	9.70	2.55	-6.35	508.00	14.50	-.16
10	8.30	15.40	3.30	-8.00	216.00	14.21	-.12
10	9.95	10.75	2.45	-5.85	510.00	13.63	-.06
10	9.30	12.10	.05	.05	513.00	13.62	.06
10	10.30	7.50	4.70	-10.50	504.00	12.47	.17
10	10.25	7.55	2.45	-2.65	503.00	12.45	1.17
10	10.35	6.35	2.45	-2.65	502.00	12.01	1.17
10	4.05	19.85	4.90	-7.60	241.00	12.00	1.48
10	9.70	6.80	3.85	-2.65	504.00	11.58	2.42
10	6.40	11.90	6.60	-8.40	189.00	10.64	2.73
10	5.95	12.85	8.10	-10.10	276.00	10.63	3.48
10	9.00	5.60	3.10	2.50	502.00	10.39	3.72
10	7.55	8.55	6.85	-5.95	114.00	10.28	3.89
10	6.65	10.25	6.60	-5.30	171.00	10.16	3.90
10	7.20	9.00	8.20	-7.20	171.00	10.14	4.66
10	5.70	11.40	8.00	-5.70	189.00	9.75	5.04
10	6.55	8.15	7.35	-3.45	257.00	9.16	5.28
10	5.80	9.50	8.35	-5.05	264.00	9.02	5.61
10	5.80	7.90	4.30	4.70	114.00	8.35	5.66
10	3.80	12.10	5.30	3.20	177.00	8.23	5.97
10	8.80	-.40	8.55	-4.55	446.00	7.74	5.98
10	8.45	.35	8.60	-4.00	547.00	7.70	6.23
10	7.95	.85	8.30	-2.40	449.00	7.45	6.54
10	8.15	.35	8.55	-1.25	547.00	7.43	7.19
10	5.65	5.95	5.90	5.20	503.00	7.40	7.33
Transient: hula2							
8	12.70	18.50	-.20	-22.10	427.00	20.86	-9.15
8	10.90	19.90	.55	-17.75	521.00	19.58	-6.54
8	10.40	15.60	1.05	-12.55	521.00	16.55	-3.94
8	11.90	10.70	1.55	-12.65	407.00	15.61	-3.53
8	9.25	15.95	1.35	-9.65	521.00	15.49	-2.52
8	10.75	11.25	1.50	-9.50	508.00	14.69	-2.32
8	9.35	12.15	3.90	-14.60	513.00	13.69	-2.19

Table 4-2 (continued)

Cycles in Design Life	Max Stress State Mem (ksi)	Max Stress State Bend (ksi)	Min Stress State Mem (ksi)	Min Stress State Bend (ksi)	@ max SIF Crack Tip Temp (deg F)	@point 1 Max SIF (ksi√in)	@point 1 Min SIF (ksi√in)
8	9.85	9.05	1.20	-8.40	407.00	12.74	-2.16
8	6.40	16.20	1.40	-7.80	223.00	12.64	-1.75
8	10.30	7.50	1.55	-7.85	504.00	12.47	-1.63
8	6.90	12.30	1.70	-6.50	189.00	11.31	-.98
8	6.25	13.55	1.30	-4.90	177.00	11.24	-.72
8	6.10	13.80	3.90	-10.80	177.00	11.21	-.67
8	9.65	5.75	3.90	-10.00	502.00	11.07	-.36
8	6.30	12.90	3.20	-7.60	307.00	11.00	-.06
8	7.05	9.35	.00	.00	508.00	10.15	.00
8	5.25	12.65	1.75	-3.35	189.00	9.86	.28
8	5.70	11.50	4.05	-7.55	189.00	9.79	.73
8	5.10	12.60	1.55	-1.65	276.00	9.69	.75
8	5.85	10.25	4.10	-7.60	283.00	9.39	.75
8	5.10	9.40	3.95	-5.85	264.00	8.32	1.29
8	5.05	7.85	3.30	-2.70	114.00	7.63	1.91
8	8.55	-1.25	4.90	-4.20	542.00	7.19	2.77
8	5.05	6.75	4.05	-.75	511.00	7.17	3.32
8	8.30	-.80	1.75	4.85	542.00	7.13	3.42
8	5.75	4.85	7.65	-8.85	503.00	7.05	3.53
8	2.55	11.85	8.00	-8.60	177.00	6.95	3.95
8	2.50	11.80	3.45	4.45	177.00	6.88	4.79
8	5.70	3.90	7.55	-5.15	502.00	6.62	4.83
8	7.95	-1.45	4.50	2.90	542.00	6.57	5.13
8	9.45	-5.45	4.80	4.10	513.00	6.48	5.88
8	9.20	-5.50	3.70	6.90	513.00	6.23	5.99
Transient: hu1a3							
45	11.25	13.85	-.10	-20.40	521.00	16.54	-8.29
45	11.55	12.35	.50	-16.80	513.00	16.08	-6.18
45	10.95	12.55	1.80	-11.20	513.00	15.55	-2.73
45	10.75	11.25	1.80	-10.60	508.00	14.69	-2.49
45	11.40	8.40	1.35	-8.65	503.00	13.98	-2.12
45	8.50	13.80	1.95	-9.75	521.00	13.62	-2.02
45	7.25	15.75	1.50	-8.50	521.00	13.29	-1.93
45	6.20	16.20	3.75	-12.75	223.00	12.43	-1.58
45	10.25	7.35	1.35	-6.55	503.00	12.36	-1.31
45	9.75	7.75	1.55	-6.75	503.00	12.05	-1.21
45	10.10	6.90	1.80	-5.80	503.00	12.01	-.62
45	9.65	5.75	3.70	-9.20	502.00	11.07	-.23
45	6.65	11.75	1.80	-4.70	283.00	10.82	-.20
45	6.00	12.90	.05	.05	177.00	10.70	.06
45	5.95	11.95	4.10	-7.80	307.00	10.23	.68
45	3.15	17.15	3.40	-5.70	241.00	9.82	.85
45	5.45	11.15	1.90	-1.90	283.00	9.40	.96
45	5.30	10.90	3.95	-6.55	141.00	9.15	1.02
45	6.20	7.80	2.15	-1.75	511.00	8.68	1.24

Table 4-2 (continued)

Cycles in Design Life	Max Stress State Mem (ksi)	Max Stress State Bend (ksi)	Min Stress State Mem (ksi)	Min Stress State Bend (ksi)	@ max SIF Crack Tip Temp (deg F)	@point 1 Max SIF (ksi√in)	@point 1 Min SIF (ksi√in)
45	5.45	9.25	4.25	-5.05	283.00	8.58	1.87
45	4.65	9.65	3.80	-2.70	264.00	8.00	2.36
45	4.60	8.30	4.60	-3.70	171.00	7.39	2.69
45	8.55	-1.25	4.75	-3.55	542.00	7.19	2.89
45	8.25	-.55	1.70	4.50	542.00	7.18	3.24
45	7.90	-.40	4.00	.10	542.00	6.92	3.60
45	4.75	6.75	3.25	3.75	98.00	6.90	4.34
45	8.80	-2.70	3.65	3.25	532.00	6.89	4.50
45	8.30	-2.30	4.05	2.55	532.00	6.58	4.59
45	5.40	3.80	7.75	-5.85	502.00	6.30	4.75
45	4.75	5.05	4.20	3.20	504.00	6.21	4.98
45	8.55	-4.35	8.30	-6.40	532.00	6.05	5.06
45	2.75	8.95	4.45	3.25	141.00	5.95	5.23
45	2.35	9.65	7.60	-3.30	141.00	5.86	5.57
Transient: hu1a4							
29	11.35	14.05	.35	-28.15	513.00	16.75	-11.58
29	11.15	13.55	1.05	-22.75	521.00	16.27	-8.31
29	9.40	15.70	1.35	-10.65	521.00	15.52	-2.91
29	10.65	12.25	1.95	-11.45	521.00	15.08	-2.69
29	7.40	18.00	2.45	-12.45	249.00	14.58	-2.64
29	11.25	9.75	1.50	-9.50	508.00	14.47	-2.32
29	9.30	12.10	1.35	-7.75	513.00	13.62	-1.77
29	7.20	15.10	1.50	-7.50	223.00	12.92	-1.54
29	10.30	7.50	4.85	-14.75	504.00	12.47	-1.38
29	7.15	13.35	2.50	-9.30	189.00	12.04	-1.35
29	10.35	6.35	2.20	-7.90	502.00	12.01	-1.07
29	8.90	8.80	1.45	-4.35	508.00	11.69	-.37
29	6.90	12.30	2.35	-6.05	189.00	11.31	-.22
29	6.10	13.10	.00	.00	276.00	10.89	.00
29	9.00	5.60	3.00	-5.90	502.00	10.39	.42
29	5.75	11.55	2.35	-2.45	189.00	9.86	1.15
29	5.85	10.15	2.60	-2.50	283.00	9.35	1.36
29	5.35	10.75	5.00	-7.60	141.00	9.13	1.57
29	6.40	7.60	2.40	-1.40	511.00	8.78	1.60
29	6.95	6.35	3.55	-3.15	504.00	8.77	1.96
29	4.90	10.10	3.95	-2.85	171.00	8.43	2.43
29	5.95	7.55	6.15	-7.55	257.00	8.34	2.64
29	5.10	9.40	4.40	-2.20	264.00	8.32	3.08
29	3.35	12.25	4.50	-2.40	177.00	7.87	3.10
29	3.35	12.05	5.80	-4.60	177.00	7.79	3.44
29	8.45	.35	4.90	-.90	547.00	7.70	4.02
29	5.80	6.10	2.25	5.55	503.00	7.60	4.14
29	8.15	.35	3.75	3.15	547.00	7.43	4.55
29	6.00	5.10	8.10	-6.10	403.00	7.38	4.98
29	8.50	-1.30	7.05	-3.45	542.00	7.13	5.01

Table 4-2 (continued)

Cycles in Design Life	Max Stress State Mem (ksi)	Max Stress State Bend (ksi)	Min Stress State Mem (ksi)	Min Stress State Bend (ksi)	@ max SIF Crack Tip Temp (deg F)	@point 1 Max SIF (ksi√in)	@point 1 Min SIF (ksi√in)
29	8.30	-2.40	8.00	-5.70	532.00	6.54	5.04
29	4.40	6.60	4.10	4.20	161.00	6.51	5.28
29	8.60	-4.00	4.70	4.10	532.00	6.23	5.79
29	5.45	3.35	4.40	4.80	152.00	6.17	5.79
Transient: hu1a5							
148	11.35	14.05	-.10	-18.10	513.00	16.75	-7.28
148	11.15	13.55	.60	-14.50	521.00	16.27	-5.13
148	9.40	15.70	1.80	-11.20	521.00	15.52	-2.73
148	10.65	12.25	2.40	-12.40	521.00	15.08	-2.67
148	11.25	9.75	.80	-7.90	508.00	14.47	-2.32
148	9.30	12.10	1.55	-8.35	513.00	13.62	-1.83
148	10.30	7.50	4.85	-14.85	504.00	12.47	-1.42
148	4.15	20.25	2.55	-9.35	241.00	12.29	-1.32
148	10.35	6.35	1.60	-6.70	502.00	12.01	-1.14
148	8.90	8.80	2.20	-8.00	508.00	11.69	-1.11
148	5.60	15.10	1.45	-5.85	223.00	11.31	-.95
148	6.10	13.10	1.85	-5.85	276.00	10.89	-.59
148	9.00	5.60	2.35	-6.05	502.00	10.39	-.22
148	5.85	11.65	.10	.00	189.00	10.00	.09
148	5.25	11.55	4.85	-10.65	141.00	9.38	.25
148	5.45	11.05	3.00	-5.90	283.00	9.35	.42
148	5.35	10.75	2.85	-3.65	141.00	9.13	1.14
148	6.00	9.20	5.00	-7.80	114.00	9.08	1.49
148	6.40	7.60	3.55	-3.15	511.00	8.78	1.96
148	6.90	6.40	4.05	-3.55	504.00	8.75	2.26
148	3.90	12.40	3.95	-2.65	177.00	8.46	2.51
148	5.95	7.55	6.15	-7.55	257.00	8.34	2.64
148	4.85	8.55	1.45	3.65	114.00	7.73	2.69
148	8.45	.35	4.40	-2.20	547.00	7.70	3.08
148	5.80	6.10	4.55	-2.35	503.00	7.60	3.16
148	6.05	5.35	4.90	-.90	403.00	7.53	4.02
148	8.15	.35	3.75	3.15	547.00	7.43	4.55
148	4.50	8.10	8.10	-6.10	171.00	7.22	4.98
148	8.55	-1.25	7.05	-3.45	542.00	7.19	5.01
148	4.70	6.60	8.00	-5.70	98.00	6.79	5.04
148	8.30	-2.40	4.70	4.10	532.00	6.54	5.79
148	4.30	6.40	4.40	4.80	98.00	6.34	5.79
148	8.60	-4.00	5.45	3.25	532.00	6.23	6.13
Transient: cd1b1							
40	12.90	19.50	.60	-19.20	521.00	21.75	-7.12
40	11.60	7.80	.55	-18.85	504.00	13.90	-7.02
40	7.25	16.55	.95	-15.85	276.00	13.69	-5.38
40	7.00	16.50	.70	-15.30	342.00	13.40	-5.38
40	6.00	17.40	2.75	-19.25	216.00	12.81	-5.20
40	5.70	17.40	.30	-13.90	216.00	12.50	-5.16

Table 4-2 (continued)

Cycles in Design Life	Max Stress State Mem (ksi)	Max Stress State Bend (ksi)	Min Stress State Mem (ksi)	Min Stress State Bend (ksi)	@ max SIF Crack Tip Temp (deg F)	@point 1 Max SIF (ksi√in)	@point 1 Min SIF (ksi√in)
40	10.85	6.15	.85	-14.25	502.00	12.40	-4.81
40	6.50	13.10	2.35	-16.25	177.00	11.28	-4.29
40	6.75	12.05	1.15	-13.05	189.00	11.05	-4.05
40	6.20	12.70	2.00	-14.30	189.00	10.81	-3.80
40	9.45	4.35	2.40	-13.70	502.00	10.28	-3.19
40	5.55	12.55	1.75	-10.65	177.00	10.11	-2.55
40	5.70	12.20	2.55	-11.65	189.00	10.10	-2.23
40	6.75	9.75	2.30	-10.70	521.00	10.03	-2.08
40	6.50	10.20	2.05	-9.95	171.00	9.99	-2.01
40	6.45	10.05	2.45	-8.95	521.00	9.88	-1.26
40	6.30	9.90	.20	-3.20	521.00	9.67	-1.04
40	9.75	1.95	2.75	-8.85	449.00	9.55	-.95
40	6.15	9.95	3.45	-9.45	171.00	9.55	-.55
40	5.95	10.05	2.60	-7.40	171.00	9.40	-.52
40	5.15	10.55	2.80	-7.80	217.00	8.85	-.50
40	4.35	11.85	3.20	-8.00	521.00	8.65	-.21
40	9.15	.95	3.20	-7.30	547.00	8.59	.06
40	4.75	9.15	3.10	-6.90	213.00	7.89	.12
40	4.40	9.90	3.85	-8.45	217.00	7.87	.20
40	4.80	9.00	2.10	-4.00	213.00	7.87	.34
40	5.35	7.65	2.95	-5.85	161.00	7.82	.39
40	5.65	5.45	.35	1.65	155.00	7.20	.94
40	9.50	-4.10	5.05	-9.05	445.00	7.02	1.06
40	4.60	7.20	5.30	-8.80	161.00	6.94	1.38
40	5.30	5.40	4.20	-6.10	253.00	6.86	1.42
40	4.85	6.25	2.55	2.75	161.00	6.79	3.32
40	2.90	9.50	2.25	3.85	171.00	6.31	3.48
40	5.50	3.50	5.40	-3.20	152.00	6.28	3.60
40	5.10	4.20	5.40	-3.10	502.00	6.19	3.64
40	3.55	7.15	5.25	-2.35	114.00	5.96	3.79
40	4.45	5.05	5.10	-.60	504.00	5.94	4.31
40	2.65	8.05	7.30	-5.40	171.00	5.50	4.51
Transient: cd1b2							
200	8.85	13.85	.20	-15.60	521.00	14.01	-5.95
200	10.85	6.15	3.20	-20.50	502.00	12.40	-5.34
200	9.45	4.35	1.10	-14.50	502.00	10.28	-4.69
200	5.40	12.50	.95	-13.45	189.00	9.94	-4.39
200	5.10	12.00	1.60	-14.30	177.00	9.43	-4.16
200	9.15	.95	1.00	-12.00	547.00	8.59	-3.76
200	4.70	9.90	1.50	-13.10	171.00	8.15	-3.76
200	4.10	11.00	1.40	-12.10	141.00	8.05	-3.45
200	6.25	6.05	1.45	-11.05	504.00	8.00	-2.98
200	4.35	9.85	1.00	-9.80	141.00	7.80	-2.89
200	4.40	9.20	.10	-7.40	141.00	7.58	-2.75
200	4.60	8.70	1.50	-10.10	114.00	7.56	-2.56

Table 4-2 (continued)

Cycles in Design Life	Max Stress State Mem (ksi)	Max Stress State Bend (ksi)	Min Stress State Mem (ksi)	Min Stress State Bend (ksi)	@ max SIF Crack Tip Temp (deg F)	@point 1 Max SIF (ksi√in)	@point 1 Min SIF (ksi√in)
200	4.30	8.90	.15	-5.85	171.00	7.36	-2.11
200	4.00	9.20	1.55	-8.15	217.00	7.21	-1.75
200	4.35	8.05	2.15	-8.95	267.00	7.06	-1.53
200	4.20	8.00	1.80	-7.40	114.00	6.90	-1.24
200	4.95	4.95	3.35	-10.55	155.00	6.35	-1.07
200	4.90	4.30	.20	-3.20	155.00	6.05	-1.04
200	3.90	6.40	1.50	-5.80	98.00	5.98	-.89
200	2.60	8.80	1.95	-6.75	171.00	5.75	-.85
200	4.80	3.20	2.40	-7.30	152.00	5.52	-.66
200	3.55	6.05	1.85	-5.85	257.00	5.52	-.59
200	3.60	5.50	.35	-2.15	161.00	5.34	-.51
200	3.35	4.45	1.95	-5.65	253.00	4.70	-.43
200	3.30	4.50	1.95	-5.35	253.00	4.68	-.31
200	3.50	4.00	2.00	-4.30	253.00	4.66	.14
200	3.35	3.85	1.90	-3.80	155.00	4.47	.24
200	7.25	-5.45	2.35	-4.45	513.00	4.44	.39
200	3.20	4.00	1.10	2.00	155.00	4.39	1.74
200	5.40	-1.70	1.20	2.50	446.00	4.17	2.02
200	2.85	4.05	2.00	2.20	88.00	4.10	2.62
200	2.45	4.25	3.80	-1.30	253.00	3.81	2.89
200	1.30	6.60	1.50	4.40	267.00	3.70	3.02
200	4.75	-3.05	4.75	-3.15	542.00	3.08	3.04
Transient: 2a							
1440	10.35	8.35	9.00	3.80	504.00	12.91	9.62
Transient: 2b							
1440	10.35	9.75	7.70	-1.40	511.00	13.56	6.36
1440	10.25	9.25	8.55	3.65	511.00	13.23	9.14
Transient: 3							
48000	10.50	10.80	9.10	3.80	511.00	14.21	9.72
Transient: 4							
48000	9.80	6.10	8.15	-.75	502.00	11.37	7.01
Transient: 7							
310	10.10	8.00	8.00	-1.10	504.00	12.50	6.75
310	9.35	6.85	8.55	3.65	504.00	11.26	9.14
Transient: 8a							
80	9.60	7.60	9.10	-3.50	504.00	11.84	6.87
Transient: 8b							
162	10.45	8.25	9.05	2.75	504.00	12.96	9.23
Transient: 8c							
88	10.85	5.85	9.40	1.00	502.00	12.27	8.84
Transient: 8d							
70	10.45	5.15	9.75	1.35	502.00	11.57	9.30
Transient: 14							
40	9.05	7.25	8.45	3.65	504.00	11.15	9.05

Table 4-2 (continued)

Cycles in Design Life	Max Stress State Mem (ksi)	Max Stress State Bend (ksi)	Min Stress State Mem (ksi)	Min Stress State Bend (ksi)	@ max SIF Crack Tip Temp (deg F)	@point 1 Max SIF (ksi√in)	@point 1 Min SIF (ksi√in)
Transient: 20b							
20000	8.60	5.80	8.45	3.65	502.00	10.09	9.05
Transient: 20d2							
34000	8.95	7.25	9.65	3.95	504.00	11.05	10.30
Transient: 22a1							
5	8.00	14.60	2.25	.95	177.00	13.50	2.36
Transient: 22b1							
15	6.00	12.50	1.20	.50	177.00	10.52	1.26
Transient: 22c1							
10	7.50	10.50	4.15	1.65	141.00	11.09	4.33
Transient: 22d1							
10	6.35	9.25	3.45	1.35	114.00	9.44	3.59
Transient: 22a2							
7	7.85	14.55	3.35	-14.65	177.00	13.32	-2.72
7	7.50	11.00	3.60	-12.70	141.00	11.31	-1.70
7	7.45	10.55	3.60	-12.10	141.00	11.06	-1.46
7	7.15	9.05	4.10	-5.60	114.00	10.11	1.52
7	2.20	1.00	2.20	1.00	70.00	2.34	2.34
Transient: 22b2							
42	5.90	12.50	2.05	-12.65	177.00	10.42	-3.08
42	5.55	8.85	2.60	-7.40	114.00	8.51	-.52
42	5.50	8.50	2.60	-7.10	114.00	8.32	-.40
42	5.25	7.45	2.70	-5.40	114.00	7.65	.34
42	1.15	.45	1.15	.45	70.00	1.19	1.19
Transient: 22c2							
7	8.00	11.10	4.30	-9.40	521.00	11.85	.24
7	7.85	10.55	4.65	-4.25	521.00	11.45	2.53
7	7.40	10.60	4.95	-2.95	141.00	11.04	3.29
7	7.70	8.80	5.10	-2.50	511.00	10.53	3.60
7	4.05	1.65	4.05	1.65	300.00	4.24	4.24
Transient: 22d2							
100	6.80	9.70	3.45	-11.35	521.00	10.06	-1.30
100	6.90	8.80	4.10	-3.00	511.00	9.77	2.51
100	6.25	9.25	4.10	-2.80	114.00	9.34	2.59
100	6.55	7.65	4.20	-2.40	511.00	8.94	2.83
100	3.35	1.35	3.35	1.35	300.00	3.50	3.50

4.7 Material Properties

4.7.1 Fracture Toughness

According to the applicable weld data sheet and procedure qualification[9] (Attachment 1), weld WP-15 can be conservatively evaluated using a RT_{ndt} of 10°F.

The fracture toughness of weld WP-15 was assumed to follow the lower bound ASME Section XI fracture toughness curves (Figure A-4200-1)[1] as follows[7]:

$K_{Ia} = 26.78 + 1.233 \exp [0.0145 (T-RT_{ndt} + 160)]$
and
$K_{Ic} = 33.20 + 2.806 \exp [0.02 (T-RT_{ndt} + 100)]$ (Temp in °F and K_{Ic},K_{Ia} in ksi$\sqrt{in}$)

where T is the crack tip temperature.

Because the upper shelf is not quantified by these equations, a cut-off was imposed at 200 ksi$\sqrt{in}$.

4.7.2 Material Strength

The material yield strength is utilized in this analysis for purposes of determining the flaw shape parameter, Q. (this equation contains a small-scale plasticity correction). Also, the material flow stress (taken as the average of the yield and ultimate strengths) is used in the limit load calculations.

In order to ensure the highest plasticity correction (and hence the largest applied stress intensity factor), the lowest material yield strength is desired. Hence, the material yield and ultimate strengths taken at 600°F are 26.6 ksi and 70.0 ksi, respectively.[11] Thus, the corresponding flow stress is 48.3 ksi.

5.0 Procedure Used in Analysis

Based on the information given in the previous sections, two FORTRAN programs were created. The first program takes the required stress and crack tip temperature information from Ref. 6 and creates the spectrum history required.

The first program , SORT.F, takes the opening mode stress for each PV and converts into membrane and bending components. Next, the stress intensity factor is calculated at the point nearest the surface (Point 1) for the initial flaw size for each PV in a transient. Finally, the fatigue cycles are completed by matching the most damaging combination of PVs (matching of the PV with the highest stress intensity factor with the PV having the lowest stress intensity factor). The next largest cycle possible is then formed by using the remaining PVs available, and so on, until all PVs have been used. The procedure is repeated for each of the transients studied. In addition, for each fatigue cycle created the crack tip temperature for the maximum stress state is given (for use in determining the fracture toughness of the weld material) and the number of times that the fatigue cycle is expected to occur in the design life of this component are included with the fatigue pair. The program listing can be found in Appendix A, with the program output summarized in Table 4-2 and written to fiche (FRAC2.INP).

The second program, BURIED.F, calculates the fatigue crack growth based on the required number of cycles per fatigue group, stress level and flaw size as previously discussed. This phase of the program is schematically shown in Figure 4-3. Since the actual order of the spectrum is unknown, when checking the fracture toughness margins per IWB-3612 and limit load margins after the fatigue crack growth analysis is performed, it is important to check the maximum stress state (and the associated crack tip temperature) within a fatigue group to ensure the margins are satisfied. Recall that the fracture toughness is a function of crack tip temperature, hence the higher temperature the higher the fracture toughness. This second phase of BURIED.F is schematically shown in Figure 4-4, with the program listed in Appendix B. The output for this program is summarized in Table 4-3 and is written to fiche (BURIED2.OUT).

It should be noted that the Emergency/Faulted conditions are evaluated by assuming the maximum stress state within a fatigue group is completely membrane (i.e. E/F membrane stress = N/U membrane + N/U bending). This is an extremely conservative approach of estimating the severity of emergency/faulted conditions.

Verification of SORT.F and BURIED.F can be found in Appendix C.

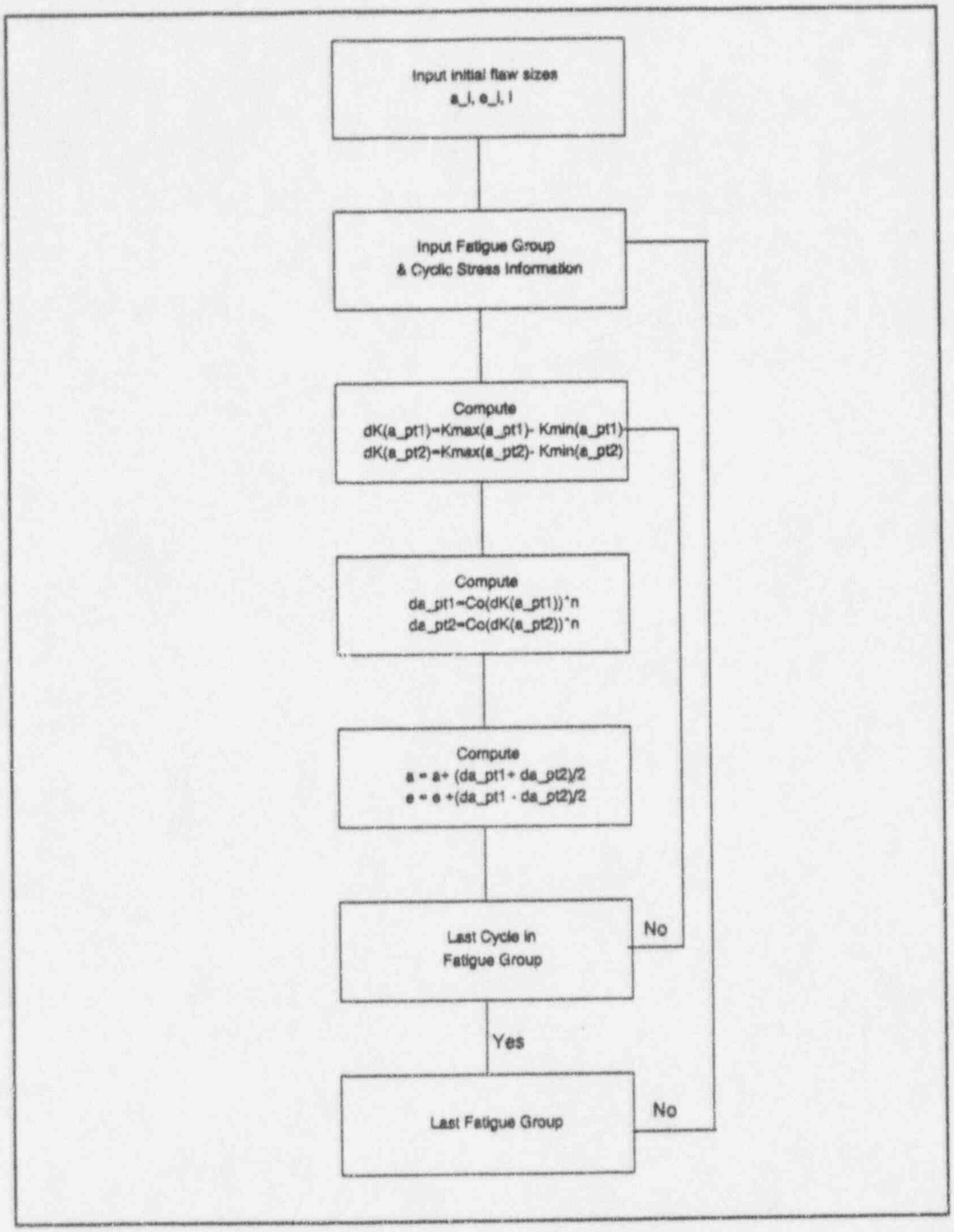


Figure 4-3 Procedure Used in BURIED.F in Calculating Fatigue Crack Growth of N/U Transients

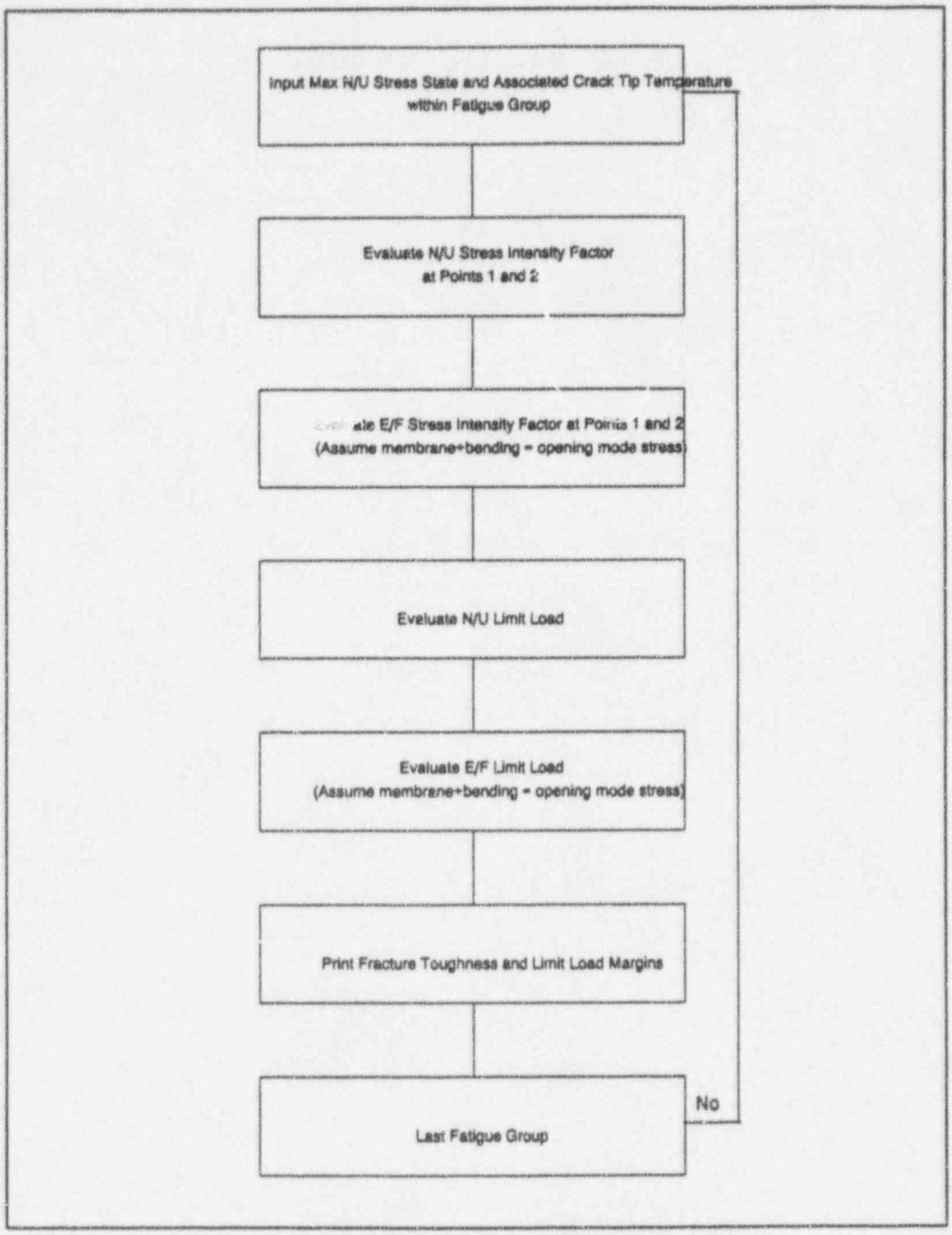


Figure 4-4 Procedure Used in BURIED.F for Determination of Fracture Toughness and Limit Load Margins for N/U and E/F Conditions
(Based on flaw dimensions after Fatigue Crack Growth)

6.0 Results and Conclusions

Table 4-3 shows the results of this analysis. A small amount of fatigue crack growth is expected to occur over the design life of this component (~0.0026 in.) Furthermore, fracture toughness margins do not exceed the $\sqrt{10}$ for Normal/Upset conditions and $\sqrt{2}$ for the Emergency/Faulted conditions. Also, the limit load margin was found to be less than 1 for expected loading conditions. Hence, the CR-3 WP-15 surge nozzle-to-lower head weld flaw indication has been found to be acceptable by IWB-3612 criteria for continued safe operation until end-of-life.

Table 4-3 Results of Fracture Mechanics Assessment of the WP-15 Weld Flaw Evaluation

<u>Fatigue Crack Growth Analysis</u>

Cumulative Fatigue Cycles	a (in.)	c (in.)	Transient
0.	.31000	.85500	
350.	.31013	.85503	hula1
606.	.31020	.85505	hula2
2091.	.31045	.85510	hula3
3077.	.31062	.85514	hula4
7961.	.31142	.85531	hula5
9481.	.31166	.85537	cd1b1
16281.	.31200	.85544	cd1b2
17721.	.31200	.85544	2a
20601.	.31205	.85546	2b
68601.	.31231	.85555	3
116601.	.31254	.85563	4
117221.	.31254	.85563	7
117301.	.31254	.85564	8a
117551.	.31254	.85564	8b
117621.	.31254	.85564	8c
117661.	.31254	.85564	8d
137661.	.31254	.85564	14
171661.	.31254	.85564	20b
171666.	.31254	.85564	20d2
171681.	.31254	.85564	22a1
171691.	.31254	.85564	22b1
171701.	.31254	.85564	22c1
171715.	.31255	.85564	22d1
171736.	.31255	.85564	22a2
171946.	.31256	.85564	22b2
17198[illegible].	.31256	.85564	22c2
1724[illegible]1.	.31258	.85565	22d2

Prepared by: L.T. Hill Date: 12/15/94

Reviewed by: D.E. Killian Date: 1/25/95

Table 4-3 (continued)

Fracture Toughness and Limit Load Margins

For Max Stress Intensity Factor in Stress Pair

Crack Tip Temp	FT Margin Point 1 N/U	FT Margin Point 1 E/F	FT Margin Point 2 N/U	FT Margin Point 2 E/F	LL Margin N/U	LL Margin E/F	Transient
521.00	8.076	5.272	9.156	5.281	.490	.754	hu1a1
427.00	9.558	6.328	10.778	6.339	.432	.659	hu1a2
521.00	12.056	8.265	13.424	8.279	.357	.530	hu1a3
513.00	11.902	8.151	13.259	8.164	.361	.537	hu1a4
513.00	11.902	8.151	13.259	8.164	.361	.537	hu1a5
521.00	9.167	6.023	10.367	6.033	.447	.684	cd1b1
521.00	14.229	9.282	16.136	9.297	.311	.480	cd1b2
504.00	15.442	11.513	16.717	11.531	.287	.395	2a
511.00	14.700	10.637	16.068	10.654	.300	.425	2b
511.00	14.025	9.973	15.420	9.989	.313	.450	3
502.00	17.541	13.706	18.717	13.729	.255	.336	4
504.00	15.943	11.928	17.241	11.947	.278	.382	7
504.00	16.843	12.602	18.213	12.623	.265	.36[illegible]	8a
504.00	15.379	11.513	16.627	11.531	.288	.395	8b
502.00	16.251	13.007	17.218	13.028	.275	.353	8c
502.00	17.227	13.986	18.178	14.009	.261	.330	8d
504.00	17.880	13.349	19.348	13.370	.250	.344	14
502.00	19.753	15.219	21.166	15.244	.228	.304	20b
504.00	18.036	13.436	19.530	13.458	.248	.342	20d2
177.00	12.408	9.329	14.246	9.344	.304	.477	22a1
177.00	15.919	11.648	18.479	11.667	.245	.391	22b1
141.00	9.942	12.000	11.177	12.019	.251	.380	22c1
114.00	8.815	13.928	9.94[illegible]	13.950	.216	.330	22d1
177.00	12.573	9.423	14.455	9.438	.301	.473	22a2
177.00	16.067	11.717	18.678	11.736	.243	.389	22b2
521.00	16.820	11.250	18.897	11.268	.267	.404	22c2
521.00	19.813	13.176	22.307	13.197	.229	.349	22d2

7.0 References

1. ASME Boiler and Pressure Vessel Code, Section XI, 1983 Edition, July, 1983.

2. BWNT Document 32-1179379, "Lower Loop Pressurizer Surge Nozzle Analysis," NSS-3.

3. Bloom, J.M., "Assessment of Defects and Design of Components Allowing for De fects,",RDD:89:1012-02-01:01, May 1989, Alliance, OH.

4. Cipolla, R.C., FAA-EPRI-75-4-3, April 1975.

5. Stuckey, K.B. ,Internal BWNT Memo, Dated 10 November 1994 (Attachment 2).

6. BWNT Document 32-1235087-00, "CR-3 PRZ Surge Nozzle Stresses", November 1994.

7. Anderson, T.L., "Fracture Mechanics: Fundamentals and Applications", CRC Press, Boca Raton, FL, 1991.

8. BWNT Document, "CR-3 Pressurizer Surge Nozzle Flaw Evaluation", May 1994.

9. Florida Power Corporation Microfilm Card Numbers 1X4054 through 1X04061, "Manufacture Data Report for Pressurizer", Microfilm Cards of Original Construction Records, Information Supplied by Bob Reynolds of FPC (Attachment 1).

10. ASME Boiler and Pressure Vessel Code, "Case 1332-4 Requirements for Steel Forgings, Section III", Approved by Council, December 7, 1966.

11. ASME Boiler and Pressure Vessel Code, Section III, 1965 Edition (with addenda through Summer 1967).

Reference 9 is not available for entry into the BWNT Record Center but may be referenced as design input as permitted by BWNT-0402-01, Appendix 2.

Project Manager Approval: R.L. Black

Appendix A - SORT.F -- FORTRAN Program Listing used to Create Fatigue Spectrum History

This appendix contains proprietary information.

Appendix B - BURIED.F -- FORTRAN Program Listing Used to Evaluate Fatigue Crack Growth of the WP-15 Weld Flaw and to Evaluate the Required Fracture Toughness and Limit Load Margins

This appendix contains proprietary information.

Appendix C - FORTRAN Programs Verification

This appendix contains a set of calculations used to verify the FORTRAN programs listed in Appendices A, SORT.F, and B, BURIED.F. **It should be noted that the program listings contained in Apprendices A and B also contain numerous comment cards explaining the various program commands and routines. By reviewing the comment cards and the FORTRAN statements that follow, it is possible to verify that the intended procedure has been satisfied.**

Feature Used in Both SORT.F and BURIED.F

Stress Intensity Factor

Input Parameters:

a = 0.31 in.
l = 1.70 in.
t = 4.75 in.
e = 0.855 in.
σ_{yield} = 25.9 ksi
σ_{mem} = 0.05 ksi
σ_{bend} = 0.05 ksi
Point = 1 (point on crack closest to surface)

Hand Calculation:

M_m (e/t,a/t,Pt1) = $1 + 0.5948\,(a/t)^2 + 0.4812\,(a/t)^4 + 0.3963\,(a/t)^6 + 0.3354*(a/t)^8 + 0.303*\,(a/t/(1-e/t))^{20}/[(1-e/t-a/t)^{.5}]$
= 1.0164

M_b (e/t,a/t, Pt1) = .84086850 + (E/T*(1.509002 + E/T*(.12940970 *A/T-0.60377800) +A/T*(-.7731469+.04428577*A/T))+A/T*(0.8841685-.07410377*A/T) -.8338377)*(1.0/(1.0-E/T-A/T)$^{.5}$)
= 0.4366

Q = $1+4.593*(a/l)**1.65 - 1./6.*((\sigma_{mem}m_m+\sigma_{bend}m_b)/\sigma_{yield})^2$
= 1.277

K = $(\sigma_{mem}M_m + \sigma_{bend}M_b)\,(\pi a/Q)^{.5}$
= 0.06344 ksi$\sqrt{in}$

Summary:

	Hand Calc	BURIED.F	SORT.F
Mm	1.0164	1.0163667	1.0163667
Mb	0.4366	0.4365798	0.4365798
Q	1.277	1.2770770	1.2770770
K_pt1 (ksi in$^{.5}$)	0.06344	0.0634400	0.0634400

Feature Used in SORT.F

Breaking Inside and Outside Surface Longitudinal Stresses into Membrane and Bending Components

Input Parameters: Stresses taken from PV #1, transient: hu1a1

σ_{inner} = 0.0 ksi

σ_{outer} = 0.1 ksi

Hand Calculation:

$$\sigma_{mem} = (\sigma_{outer} + \sigma_{inner})/2. = (0.1 + 0.0)/\ 2 = 0.5 \text{ ksi}$$
$$\sigma_{bend} = (\sigma_{outer} - \sigma_{inner})/2. = (0.1 - 0.0)/\ 2 = 0.5 \text{ ksi}$$

This corresponds exactly to the SORT.F output file, FRAC2.INP.

Creation of Fatigue Cycles Based on Sorting of PVs

Table 4-2 shows the pairing of PVs based on SIFs for each transient. This table confirms that the maximum PVs are paired with the minimum PVs for each transient.

Feature Used in BURIED.F

Limit Load Solution

Input Parameters:

a_ll = 0.6243702173 in.

c = 0.85 in.

t = 4.75 in.

σ_{flow} = 52.8 ksi

σ_{mem} = 13.95 ksi — Max stress state in Transient hu1a1

σ_{bend} = 21.75 ksi

Hand Calculation:

$$\alpha = (a/t)\ /\ (1 + t/c)$$
$$\lambda = \sigma_b\ /\ \sigma_m$$

$$\sigma_{m(L)} = 3\ \sigma_{flow}\ (1-\alpha)^2/\ (\lambda+(\lambda^2 + 9(1-\alpha)^2)^{0.5}$$
$$= 31.131 \text{ ksi}$$

Computer output for this Limit Load Solution = 31.13137195 ksi

Fracture Toughness Calculation

Input Parameter: ct_temp = 521°F

Hand Calculation:

K_{Ic}=33.2+2.806*exp(.02*(ctemp-10+100)) = 569103.91 ksi√in

K_{Ia}=26.78+1.233*exp(.0145*(ctemp-10+160)) = 20748.76 ksi√in

Computer output for the fracture toughness is the same. Note, however, that because the upper shelf is not quantified by these equations, a cut-off was imposed at 200 ksi√in.

Fatigue Crack Growth for One Cycle

Input Parameters:

initial crack depth = 0.3100 in.

Point 2

Kpt2_max = 19.10221035535215

Kpt2_min = -7.20950034447816 Note: R ratio < 0, therefore, Kpt2_min = 0.0

dkpt2 = 19.10221035535215

Point 1

Kpt1_max = 21.93384431786706

Kpt1_min = -10.5738326272854 Note: R ratio < 0, therefore, Kpt1_min = 0.0

dkpt1 = 21.93384431786706

Hand Calculation: Determine crack growth in 1 Fatigue Cycle	Computer Output BURIED.F output
dpt1 = 2.67E-11(21.9338)$^{3.726}$ = 2.65E-6 in.	2.651580670796285E-06
dpt2 = 2.67E-11(19.1022)$^{3.726}$ = 1.58E-6 in.	1.584268698316173E-06
da = (dpt1+dpt2)/2 = 2.12E-6 in.	.0000021179246845
de = (dpt1- dpt2)/2 = 5.34E-7 in.	.0000005336559861
new a = a + da = 0.31000212 in.	.3100021179246845
new e = e + de = 0.855000534 in.	.8550005336559861

Appendix D - Microfiche

File Name	Date	Description
fat.inp	1/25/95	Stress results from Reference 6 for the nozzle-to-head region. The stresses include all PVs for each N/U transient. The stresses include the effect of surge line stratification.
frac2.inp	1/25/95	Output of SORT.F. Also, serves as input for BURIED.F.
buried2.out	1/25/95	Results of Fatigue Crack Growth and the assessment of the final crack size based on IWB-3612 Fracture Toughness Margins for N/U and E/F conditions. In addition, the limit load condition is checked.

Attachment 1 - Letter from R.B. Reynolds to E.E. Organ Showing Fracture Toughness Data of WP-15 Weld

Florida Power CORPORATION

B&W Nuclear Technologies
3315 Old Forest Road
Lynchburg, VA. 24506-0935

November 30, 1994
SNES94-0346

Attention: Mr. E. E. Organ

Subject: Pressurizer Surge Nozzle to Lower Head Weld Data

Reference: Pressurizer Manufacturers Data Report
FPC Construction Records in Microfiche Card Files
1X04059, 1X04060, and 1X04061

Mr. Organ:

Due to potential problems with legibility of including the actual weld data sheets in the surge nozzle flaw analysis (BWNT 32-1235116-00), the following data was extracted from the weld data sheets and procedures qualifications for WP-15, the weld between the surge nozzle and lower head. Two weld data sheets were located in the Referenced FPC records, i.e. WP-15 and WP-15 Alt. 1.

WP-15 identifies Quality Control Specification W-54 "General Specification for Automatic and Semi-Automatic Gas Metal Arc Welding of Vessels for Special Products or Commercial Nuclear Applications". The Procedure Qualification number is PQ-1085 which identifies the weld material as 7/64" diameter (McKay) 70A1 flux core filler wire with 45 CFH CO_2 shielding gas. The minimum preheat was 150 degrees F with a maximum interpass temperature of 500 degrees F. The postweld heat treatment was 1100-1150 degrees F for a minimum of 5 hours. The Charpy V-notch was performed at +10 degrees F with 240 ft-lbs energy applied. The absorbed energy is documented to be 37 ft-lbs, 34 ft-lbs, and 50 ft-lbs.

WP-15 Alt. 1 identifies Quality Control Specification W-50 "General Specification for Manual Metal Arc Welding of Vessels for Nuclear or Special Applications". The Procedure Qualification number is PQ-1887A which identifies the weld material as ASTM A316 E7015/7016/7018. The minimum preheat was 150 degrees F with a maximum interpass temperature of 500 degrees F. The postweld heat treatment was 1100-1150 degrees F for a minimum of 5 hours. The Charpy V-notch was performed at +10 degrees F with 240 ft-lbs energy applied. The absorbed energy is documented to be 84 ft-lbs, 86 ft-lbs, and 112 ft-lbs.

If there are any questions, please call.

R. B. Reynolds, Site Nuclear Engineering Services

A. Petrowsky, Supervisor, Site Nuclear Engineering Services

cc: Record Management

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Prepared by: L.T. Hill Date: 12/15/94

Reviewed by: D.E. Killian Date: 1/25/95

Attachment 2 ..ernal BWNT Memo from K.B. Stuckey to L.T. Hill, dated 11/10/1994
(Gives detailed information concerning the WP-15 Weld)

B&W NUCLEAR TECHNOLOGIES

To	Lance Hill		BWNS-20553B-5 (10/89)
From	Ken Stuckey	Customer or File	CR3 PZR
Subj.	Surge Nozzle to Pressurizer Attachment Weld	Date	November 10, 1994

Refernce: 1) BWNT Drawing 02-1185600E00 Schematic Drawing "620-0007-59 Pressurizer".
2) BWNT Drawing 135433E-2 Lower Head Assembly abd Details "620-0007-59 Pressurizer".

Based on review of Canton Manufacturing and Quality Assurance Records, and the references, ! have cnncluded the following relevant to the subject:

PWHT (Stress Relief) was performed at 1100°F to 1150°F for 12 hours total.

The initial weld was performed using the Semi-Automatic Gas Metal Arc welding process with fabricated McKay E70A1 flux cored weld wire (WP-15 Rev 4).I was unable to readily determine other specific information relative to these consumables.

Weld repairs were performed at various times using the Shielded Metal Arc welding process using E7015-A1 electrodes (B&W manufactured) or E7018-A1 electrodes (WP-15 Alt 1 Rev 3).

Please advise if more information is needed on this matter.

Prepared by: L.T. Hill Date: 12/15/94

Reviewed by: D.E. Killian Date: 1/25/95