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CALCULATION COVER SHEET

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Document No.: 1160-1Q-2

Title: EVALUATION OF POTENTIALLY DEGRADED CAC HEADER JOINTS

Client: PORTLAND GENERAL ELECTRIC

Project No.: 89121160-1Q

APTECH Office: SUNNYVALE

Sheet No. 1 of 16

Purpose: To calculate the integrity of brazed Cu-Ni header joints in the CAC system where full penetration of the braze metal was not achieved. New loads determined by Bechtel are employed. The original analysis is given in Document No. AES-1074Q-1.

Assumptions: The net section plastic collapse method of Section XI (IWB-3640) of the ASME Code was used to determine allowable degradation in the joints

Results: See conclusions on page 15.

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INTRODUCTION

An evaluation of the CAC header joints was performed during the 1989 refueling outage (1). The loading used in that evaluation was based upon a preliminary assessment of the CAC structure and piping design. Subsequent to this work, a final analysis was performed by Bechtel and new header loads were defined (2).

This evaluation recalculates the header integrity for a worst case degraded condition with the new load definition. A complete background of the header joint design is given in Ref (1). A schematic illustration of the header joint showing the 45° miter butt-brazed joint is given in Figure 1 (1).

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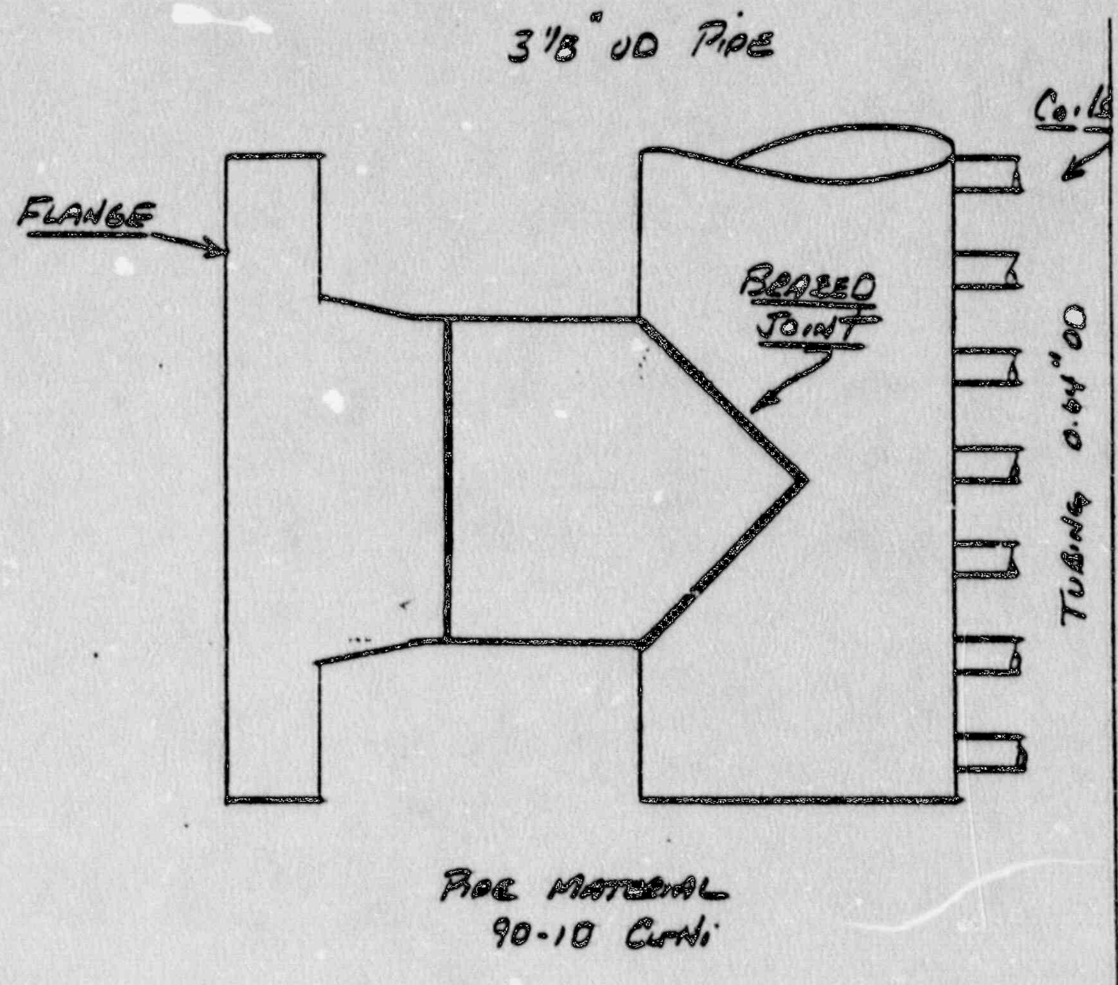

Figure 1 - Header Joint Assembly

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STRESS SUMMARY

A summary of the applied forces and moments for the design loading conditions for the CAC header is given in Table 1 (3). The maximum loads for each component (i.e. dead weight (DW), thermal (THEE2), OBE, and SSE) were identified and tabulated by node number.

The pressure stress and section properties of the header are taken from Ref 1, Section 4 as given below.

$$P_m = \frac{pR}{2t} = 138 psi \qquad \text{primary membrane}$$

$P_b \equiv$ Primary bending.

$Z = 1.72\ in^3$

$A = 2.66\ in^2$

Loadings other than primary loads are not considered in the flaw evaluation of ductile materials per IWB-3640 procedures for austenitic steels. However we will evaluate the effect of secondary stresses on plastic collapse to determine their impact on the flaw tolerance.

TABLE 1

SUMMARY OF HIGHEST LOADS FOR CAC HEADER

(FROM REF 3)

NODE	LOAD	F_A [lbs]	F_B [lbs]	F_C [lbs]	M_A [ft-lbs]	M_B [ft-lbs]	M_C [ft-lbs]
212	DW	-1	-28	0	0	0	-5
112	THER 2	-151	-300	0	0	0	-100
212	OBE (SEIS)	80	146	0	0	0	82
122	SAM (OBE)	914	3221	954	1322	225	767
212	SSE (SEIS)	134	244	0	0	0	137
122	SAM (SSE)	1549	5368	1590	2203	375	1279

NOTE: LOAD COMBINATIONS PER REF (1) for CAC header

SERVICE CONDITION	COMBINATION	ALLOWABLE
NORMAL	P + DW	S_h
UPSET	P + DW + OBE (SEIS)	$1.2 S_h$
EMERGENCY	P + DW + OBE (SEIS)	$1.8 S_h$
FAULTED	P + DW + SSE (SEIS)	$2.4 S_h$
SECONDARY	THER + SAM (OBE)	S_A
	or THER + SAM (OBE) + P + DW	$(S_A + S_h)$

Emergency conditions will not be limiting when compared to faulted since faulted loads are maximum.

A summary of the stresses for P_m, P_b, and expansion type stresses (P_e) is given in Table 2. The bending stresses were computed from the moments given in Table 1 from the following formulas:

$$M_{tot} = \left[M_A^2 + M_B^2 + M_C^2\right]^{1/2}$$

$$P_b = M_{tot}/Z$$

From Table 2, the following stresses are defined.

Normal	P_m = 138psi	P_b = 35psi
Upset	P_m = 138psi	P_b = 607psi
Faulted	P_m = 138psi	P_b = 991psi

The highest secondary (expansion) stress is P_e = 11476psi

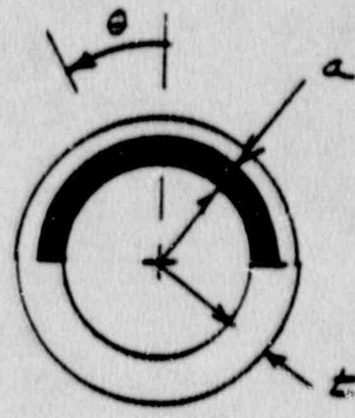
TABLE 2
SUMMARY OF APPLIED STRESSES

LOADING	(psi) P_m	[in-lbs] M_{tot}	(psi) P_b	EXPANSION P_e (psi)
P+DW	138	60	35	–
P+DW+OBE	138	1044	607	–
P+DW+SSE	138	1704	991	–
THER2	–	1200	–	698
SAM(OBE)	–	18538	–	10778

Note: SAM(SSE) loads are not summarized here because they are not part of the design basis.

EVALUATION OF CRACKED CAC BRAZED JOINT

The worst-observed degraded joint was a lack-of-brazed condition ~85% through-wall ($a/t = 0.85$) covering an 180° arc ($\theta = 90°$). (1).



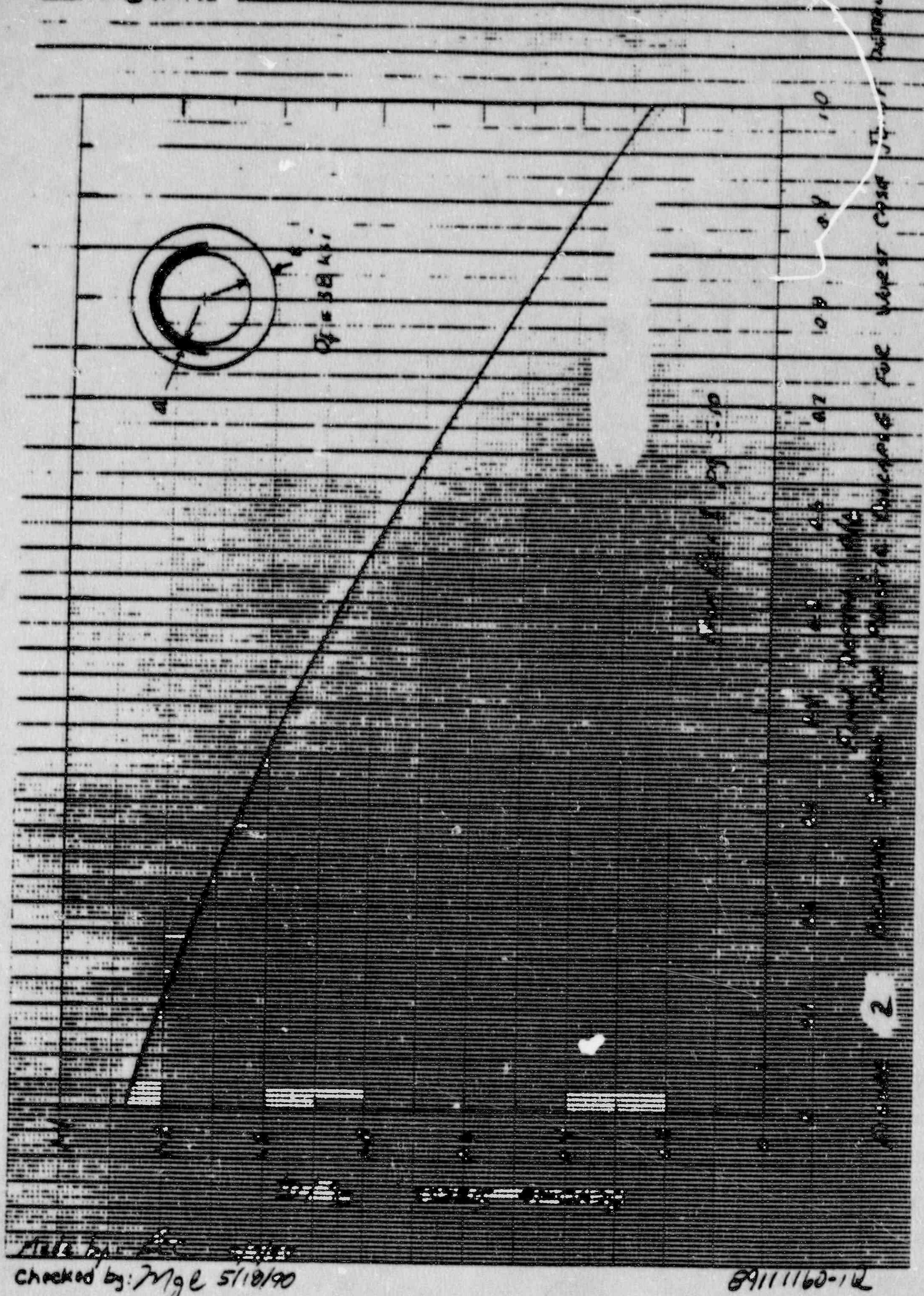
A limit load failure model for the remaining section was developed in Ref 1. and a plot of the bending stress for net-section plastic collapse is given in Figure 2 in this calculation package.

From Figure 2, the critical bending stress ratio (also see pg 5.18 in Ref 1) at $a/t = 0.85$ is

$$\frac{\sigma_b}{\sigma_f} = 0.454$$ (also see pg 5.13 in Ref 1)

$\sigma_f = 38{,}000$ psi (From Ref 1 pg 5.3)

$\sigma_b^c = 17252$ psi (critical bending stress)



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Calculating the available safety margins, excluding the P_e stress because they do not contribute to plastic collapse after gross yielding has occurred per ASME CODE Section XI Appendix C (5).

$$SF = \frac{P_m + \sigma_b^c}{P_m + P_b} \qquad \text{Ref 1 pg 5.8–5.11}$$

$$SF = \frac{138 + 17252}{138 + 607} = \frac{17390}{745} = 23.3 \quad \text{(upset)}$$

$$SF = \frac{138 + 17252}{138 + 991} = \frac{17390}{1129} = 15.4 \quad \text{(faulted)}$$

Therefore, large safety margins against net section plastic collapse exist even for the worst observed degraded joint.

Per Section XI flaw acceptance standards, the inherent safety factors are:

SF = 2.77 Normal/upset Conditions

SF = 1.39 Emergency/Faulted Conditions

Therefore, the computed safety margins for net section plastic collapse exceed the code acceptance margins.

If we conservatively include the P_e stress, the following margins are computed:

$$SF = \frac{P_m + \sigma_b^c - P_e}{P_m + P_b} \qquad \text{(Ref 1 pg 5.8)}$$

(In this case, P_e is the sum of Ther2 and SAM(OBE) equal to 11,476psi from Pg 7)

$$SF = \frac{138 + 17252 - 11476}{138 + 991} = \frac{5914}{1129} = 5.2 \qquad \text{(Faulted)}$$

$$SF = \frac{138 + 17252 - 11476}{138 + 607} = \frac{5914}{745} = 7.9 \qquad \text{(upset)}$$

Even when the expansion loads are included for low toughness considerations as provided for in Section XI Appendix C, a large safety factor is computed. These safety factors meet the flaw acceptance requirements for piping in Section XI for normal/upset and emergency/faulted conditions

LEAK-BEFORE-BREAK MARGINS

The critical bending stress for a through-wall flaw, 120° around the circumference is shown in Figure 2 to be $\sigma_b^c/\sigma_f \simeq 0.258$ or

$$\sigma_b^c = 9805 \text{ psi}$$

(see also pg 5.9 in Ref 1).

For this condition, leakage would occur. The margin that exist for this condition is computed to be

$$SF = \frac{P_m + \sigma_b^c}{P_m + P_b}$$

$$SF = \frac{138+9805}{138+607} = \frac{9943}{745} = 13.3 > 2.77 \text{ (upset)}$$

$$SF = \frac{9943}{138+991} = \frac{9943}{1129} = 8.8 > 1.39 \text{ (Faulted)}$$

∴ Significant margins exist for a leaking joint under primary loads.

(Secondary stresses are ignored because they will relax away once significant plastic deformation occurs).

FATIGUE ANALYSIS

An estimated crack growth (Δa) for a 12 month period of operation was computed in Ref 1 to be 11 mils. This estimate is based on 1 cycle per month when one unit is changed out (i.e. 3 out of the 4 units are operating at any one time). The average crack growth rate was estimated to be 8.8×10^{-4} in/cycle based upon the past duty service of the system. Therefore

$$\Delta a \cong 1 \frac{cycle}{month} (12 \text{ months}) (8.8 \times 10^{-4}) \frac{in}{cycle}$$

$$\Delta a \simeq 0.0106'' \text{ or } \approx 11 \text{ mils}$$

This amount of crack extension is very small and will not reduce the computed safety factors significantly.

CONCLUSIONS

1. The calculated safety factor for a "worst-observed" brazed joint exceeds the safety factors contained in Section XI for flaw acceptance in piping components.

2. In the event that leakage occurs (i.e through-wall flaw, 180° around the circumference), significant safety factors exist under primary loads. These safety factors are greater than the Section XI flaw acceptance criteria.

3. Estimated propagation of potential flaws in existing joints over the next 12 months is only 11 mils, approximately 3.7% of the wall thickness for the existing design.

REFERENCES

1. DOCUMENT NO. AES-1074Q-1, "EVALUATION OF DEGRADED CAC HEADER JOINTS", AES PROJECT 8906 1074Q, (REV 1) (6/16/89)

2. DOCUMENT NO 1160-1Q-1, "CAC NOZZLE CALCS" AES PROJECT 8917 1160-1Q, REV 1 (5/7/90)

3. "CONTAINMENT AIR COOLER CCW NOZZLE QUALIFICATION" LETTER TO M. HOFFMANN FROM R. OMAN (3/29/90) (ECO-3)

4. "PIPE STRESS CRITERIA FOR THE TROJAN NUCLEAR PLANT" BECHTEL CORPORATION, DC-11760-P-002, REV 2, (6/29/85)

5. ASME BOILER & PRESSURE VESSEL CODE, SECTION XI, APPENDIX C, "EVALUATION OF FLAWS IN AUSTENITIC PIPING", 1989 EDITION.