United States Nuclear Regulatory Commission Official Hearing Exhibit
In the Matter of: Entergy Nuclear Operations, Inc. (Indian Point Nuclear Generating Units 2 and 3)
ASLBP #: 07-858-03-LR-BD01
Docket #: 05000247 | 05000286
Exhibit #: RIV00053B-00-BD01 Identified: 10/15/2012
Admitted: 10/15/2012 Withdrawn:
Rejected: Stricken:
Other:

the following elements: the thick portion of the vessel was treated as a cylinder, the tapered portion was treated as a short tapered cylinder, and the thin portion of the vessel wall was treated as a long cylinder.

The thermal stresses were determined by the skin stress method where it is assumed that the inside surface of the vessel is at the same temperature as the reactor coolant and the mean temperature of the shell remains at the steady state temperature. This method is considered conservative.

The fatigue evaluation was made on a cumulative basis where superposition of all transients is taken into consideration.

6.080 CORE BARREL SUPPORT PADS

A. Discussion of Results

The most critical stress intensity occurred for the steady 125 KIP side load and steady 125 KIP vertical load. This stress intensity of 31.1 KSI occurred at the lower outside corner of the juncture of the pad to the vessel wall and compares favorably with the allowable of 35 KSI.

The highest range of stress intensity occurred at the upper outside corner of the juncture of the pad to vessel wall. The value of this range of stress intensity was 40.8 KSI and compares favorably with the 3 S_m allowable of 69.9 KSI.

The fatigue evaluation revealed that the highest cumulative usage factor was 0.02 and occurred at the upper outside corner of the juncture of the pad to vessel wall. This value is well below the allowable of 1.0.

B. Method of Analysis

Thermal, mechanical, and pressure stresses were calculated at various locations on the pad and at the vessel wall for the loads specified in reference 10.

Mechanical stresses were calculated by the flexure formula for bending stress in a beam, pressure stresses were taken from the analysis of the vessel to bottom head juncture, and thermal stresses were determined by the conservative

method of skin stresses. These stresses were resolved into stress intensities and compared with the allowables set forth in reference-/. Stresses due to the cyclic loads were multiplied by a stress concentration factor where applicable and used in a fatigue evaluation.

5.090 BOTTOM HEAD TO SHELL JUNCTURE

A. Discussion of Results

The maximum average primary stress intensity for the bottom head to shell juncture occurs in the cylindrical shell portion of the juncture. The value of this stress intensity is 26.3 KSI and compares favorably with the S_m value of 26.7 KSI.

The highest range of stress intensity for the operating transients occurred on the inside surface at the start of the hemispherical shell. The value of this range of stress intensity was 34.1 KSI and compares favorably with the allowable of 3 S_m = 80 KSI.

The fatigue evaluation revealed that the highest cumulative usage factor was 0.003 and occurred on the inside surface at the start of the hemispherical shell. This value is well below the allowable of 1.0.

B. Method of Analysis

Stresses due to internal pressure were determined by means of a standard interaction analysis. For the purpose of this analysis, the actual structure was divided into the following elements: the cylindrical shell was treated as a long cylinder, the tapered portion of the cylindrical shell was treated as a short tapered cylinder, and the hemispherical section was treated as a long spherical shell.

The thermal stresses were determined by the skin stress method where it is assumed that the inside surface of the vessel is at the same temperature as the reactor coolant and the mean temperature of the shell remains at the steady state temperature. This method is considered conservative.

The fatigue evaluation was made on a cumulative basis where superposition of all transients is taken into consideration.

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6.100 BOTTOM HEAD INSTRUMENTATION PENETRATIONS

A. Discussion of Results

The maximum average primary membrane stress intensity for the bottom head is 26.5 KSI when taking into consideration of the ligament efficiency. This value compares favorably with the S_m value of 26.7 KSI.

At the location where the instrumentation penetration is attached to the bottom head by the J-weld, the maximum range of stress intensity is 55.2 KSI. This range of stress intensity occurs on the inside surface and compares favorably with the allowable of 69.9 KSI.

The fatigue evaluation revealed that the highest cumulative usage factor was 0.14 and occurred on the outside surface of the tube. This value compares favorably with the allowable of 1.0.

B. Method of Analysis

An interaction analysis was performed by dividing the actual structure into the following analytical model: the bottom head was treated as a perforated spherical shell with modified elastic constants and the instrumentation tube as a long cylinder. The effects of the redundants on the bottom head were assumed to be local only. It was assumed that for any condition where there is interference between the tube and head, no bending at the weld can exist. Using mechanical and thermal stresses from this analysis, a fatigue evaluation was made for the J-weld.

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7.000 REFERENCES

1. ASME Boiler and Pressure Vessel Code, Section III for Nuclear Vessels

2. ASME Boiler and Pressure Vessel Code, Section VIII for Unfired Pressure Vessels

3. Tentative Structural Design Basis for Reactor Pressure Vessels and Directly Associated Components (Pressurized, Water Cooled Systems) PB151987, U.S. Department of Commerce

4. Screw-Thread Standard for Federal Service, 1956

5. Code for Pressure Piping, ASA-B 31.1-1953

6. S. Timoshenko and J. N. Goodier, "Theory of Elasticity", McGraw-Hill, 1934

7. S. Timoshenko and S. Woinowsky-Krieger, "Theory of Plates and Shells", McGraw-Hill, 1940

8. S. Timoshenko, "Strength of Materials", Parts 1 and 2, D. Van Nostrand Co., Inc., 1955

9. E. F. Bruhn, "Analysis and Design of Airplane Structures", 1949

10. P. G. Lawson, W. J. Cox, "Mechanics of Materials", John Wiley & Sons, Inc., New York, 1947

11. R. B. Heywood, "Design by Photoelasticity", Chapman and Hill, Ltd., 1952

12. R. E. Peterson, "Stress Concentration Factor", John Wiley and Sons, Inc., New York, 1953

13. Welding Research Council Bulletin No. 49, Stresses in a Spherical Vessel from Radial Loads Acting on a Pipe, Stresses in a Spherical Vessel from External Moments Acting on a Pipe, Influence of a Reinforcing Pad on the Stresses in a Spherical Vessel under Local Loading, P.O. Bijlaard, April 1959

14. Welding Research Council Bulletin No 107, Local Stresses in Spherical and Cylindrical Shells due to External Loadings, K. R. Wichman, A. G. Hooper, and J. L. Mershon, August 1965

15. B. F. Langer, "Applications of Stress Concentration Factors", WAPD-BT-18

16. Sampson, R. C., "Photoelastic Investigation of Stress Distribution in a Perforated Hemispherical Head of Reduced Thickness" Westinghouse Research Report 100FF996-R4

17. W. J. O'Donnell, "The Effects of Local Flexibility on Stresses in a Structure", WAPD(CE)-170

18. J. M. Matusz, W. J. O'Donnell, and R. J. Erdlac, "Local Flexibility Coefficients for the Built in Ends of Beams and Plates", Paper No. 68-WA/PVP-6, Transactions of the ASME

19. Westinghouse Equipment Spec. 676245 and 676514

20. Westinghouse PAR's

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APPENDIX A

DETAILED STRUCTURAL ANALYSIS

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5. DETAILED ANALYSIS:

b. SYSTEM LOADS:

THE CONTROL ROD HOUSING ASSEMBLY SHOWN ON SHEET 5 WILL BE INVESTIGATED FOR THE FOLLOWING LOADS IN THIS ANALYSIS:

1. DESIGN PRESSURE OF 2.5 KSI AT DESIGN TEMPERATURE OF 650°F.
2. OPERATING PRESSURE OF 2.25 KSI AT OPERATING TEMPERATURE.
3. THE THERMAL AND PRESSURE TRANSIENTS AS GIVEN IN REF. 19 FOR THE CONTROL ROD HOUSING TO CLOSURE HEAD WELD.

c. SYSTEM ALLOWABLES:

THE FOLLOWING ALLOWABLE STRESSES ARE BASED ON THE A.S.M.E. NUCLEAR CODE SECTION III, REFERENCE 1 AND ARE RELEVANT FOR THIS ANALYSIS.

1. THE AVERAGE PRIMARY STRESS INTENSITY ACROSS A SOLID SECTION SHALL NOT EXCEED S_m AT DESIGN TEMP. (650°F) AND DESIGN PRESSURE 2.5 KSI.
2. THE LOCAL PRIMARY STRESS PLUS THE AVERAGE PRIMARY STRESS SHALL NOT EXCEED $1.5 S_m$ AT 650°F.
3. THE RANGE OF PRIMARY PLUS SECONDARY STRESS INTENSITY RESULTING FROM MECHANICAL AND THERMAL LOADS SHALL NOT EXCEED $3 S_m$ AT ACTUAL METAL TEMPERATURE AND OPERATING PRESSURE.
4. SHOW THAT EACH POINT MEETS THE REQUIREMENTS FOR PEAK STRESS INTENSITY GIVEN IN N-414.5 OF THE ASME CODE SECTION III. THE PROCEDURE WILL BE AS OUTLINED IN N-415.2 OF SECTION III.

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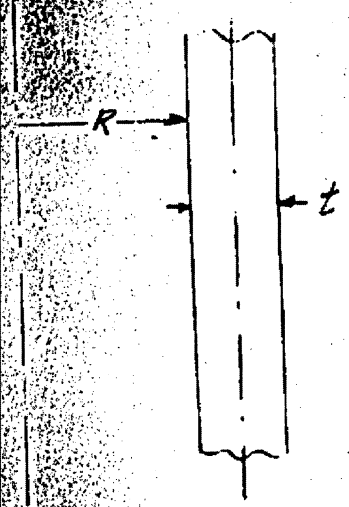
5. Detailed Analysis:

d. Design Sizing:

Consider The Control Rod Housing Wall:



Design Pressure = 2.5 KSI
Design Temperature = 650°F
Materials: Inconel, S_m = 23.3 KSI (From Code Case 1336)
SA 182-F304, S_m = 15.3 KSI (From Ref. 1)

$R = 1.375''$
$t_{act} = 0.625''$
$P = 2.5$ KSI

From N-431 Of Section III, ASME Nuclear Code:

$$t_{REQ'D} = \frac{PR}{S_m - 0.5P}$$

$$= \frac{2.5(1.375)}{23.3 - 0.5(2.5)} = \underline{0.156''} \text{ (For Inconel Tube)}$$

and

$$= \frac{2.5(1.375)}{15.3 - 0.5(2.5)} = \underline{0.245''} \text{ (For SA-182-F304 Stainless Steel)}$$

The 0.625" Actual Thickness Is Adequate For Both Materials; Hence, Criterion S-C-1 Is Satisfied.

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5- DETAILED ANALYSIS:

C: DEVELOPMENT OF CONTINUITY EQUATIONS:

1- ANALYTICAL MODEL:

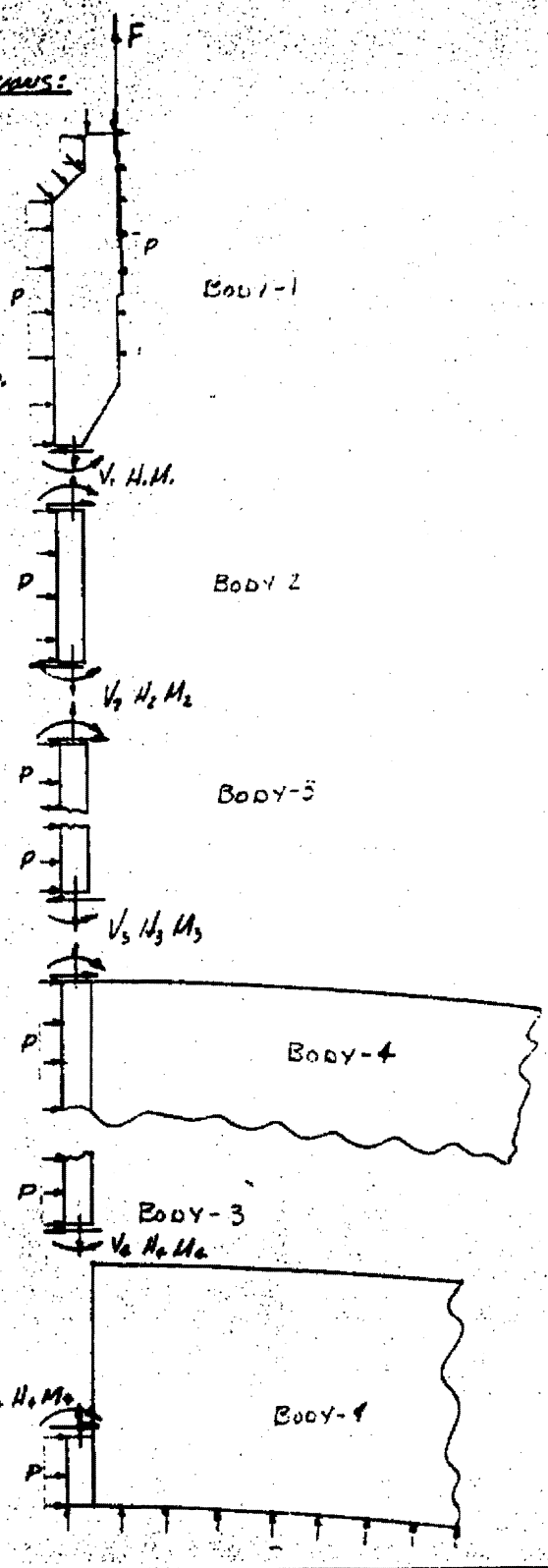
THE ACTUAL STRUCTURE IS DIVIDED INTO THE FOLLOWING ANALYTICAL MODEL TO FACILITATE THE ANALYSIS. THE ASSUMED DIRECTIONS OF THE REDUNDANT FORCES ARE ILLUSTRATED.

BODY-1 (RING)
BODY-2 (LONG CYLINDERICAL SHELL)
BODY-3 (LONG CYLINDERICAL SHELL)
BODY-4 (LONG SPHERICAL SHELL)

$H_1 \rightarrow H_4$, $M_1 \rightarrow M_4$ ARE THE UNKNOWN INTERACTION FORCES

P IS THE APPLIED PRESSURE

F IS THE FLOW OFF LOAD IMPOSED ON THE CONTROL ROD DRIVE MECHANISM ATTACHMENT



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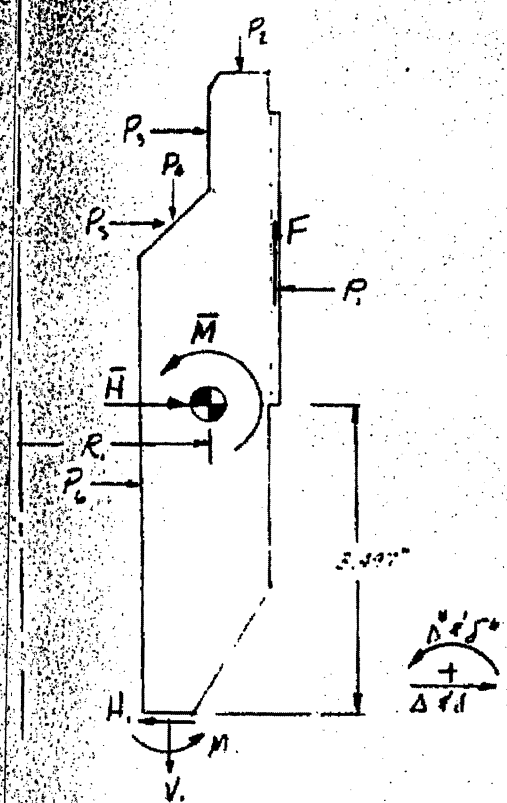
5. Detailed Analysis:

c. Development of Continuity Equations:

2. Moements Due To Redundant And Applied Loads:

Body-1



Force	Magnitude	Radius	Moment Arm
P_1	5.177P	2.880	1.353
F	1.414P	2.939	0.793
P_2	0.730P	2.515	0.375
P_3	1.370P	2.150	3.256
P_4	0.775P	1.763	0.377
P_5	0.775P	1.763	3.154
P_6	5.293P	1.375	0.851
V_1	0.560P	1.688	0.452
H_1	Unknown	1.688	3.497
M_1	Unknown	1.688	~

$A_1 = 9.011 in^2$ $I_1 = 32.069 in^4$ $R_1 = 2.140 in$

$\frac{R_1^2}{I_1} = 0.14058$ $\frac{R_1^2}{A_1} = 0.50822$

$$\bar{H} = -\frac{1.688}{2.140}H_1 - \frac{2.880}{2.140}(5.177P) + \frac{2.150}{2.140}(1.370P) + \frac{1.763}{2.140}(0.775P) + \frac{1.375}{2.140}(5.293P)$$

$$= \underline{-0.78878H_1 - 1.55142P}$$

$$\bar{M} = \frac{1.688}{2.140}\left[-3.497H_1 + M_1 + (0.452)(0.560P)\right] + \frac{2.880}{2.140}(1.353)(5.177P) + \frac{2.933}{2.140}(0.793)(1.414P)$$

$$- \frac{2.515}{2.140}(0.375)(0.730P) - \frac{2.150}{2.140}(3.256)(1.370P) + \frac{1.763}{2.140}\left[0.377(0.775P) - 3.154(3.775P)\right]$$

$$+ \frac{1.375}{2.140}(0.851)(5.293P) = \underline{-2.75838H_1 + 0.78878M_1 + 8.10030P}$$

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5. Detailed Analysis:

C. Development Of Continuity Equations:

2. Movements Due To Redundant And Applied Forces:

Body-3

Deflections Due To Thermal Effects:

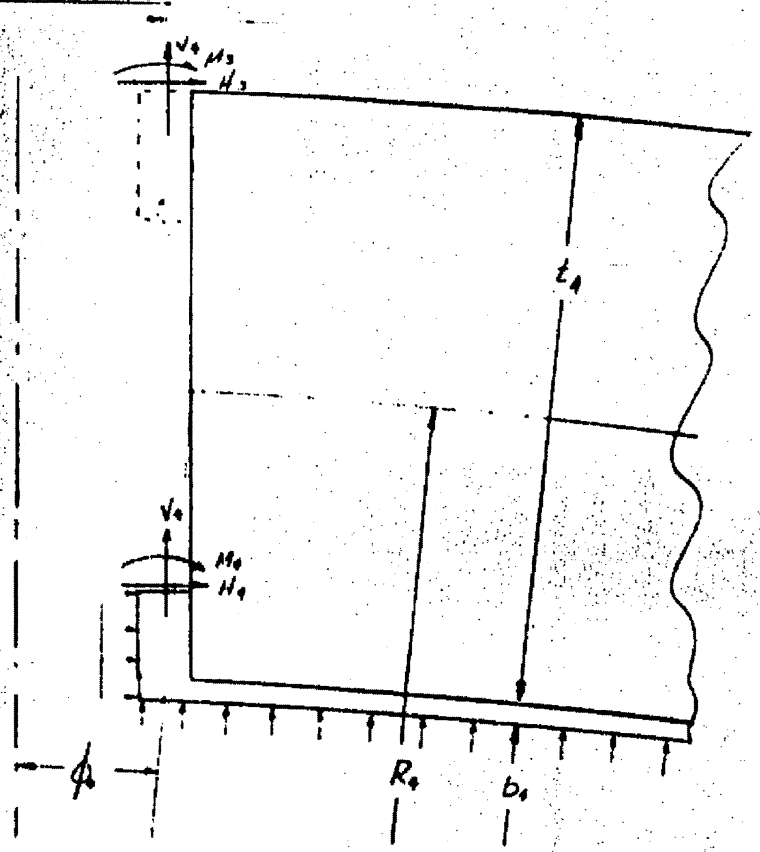
$E\delta_{32} = R_3 E\alpha_m (T_m - 70) \frac{E_{304SS}}{E_{INCONEL}} = 189.570$ (In Terms Of Young's Modulus Of 304 SS) $E\alpha_m = 0.220$, $T_m = 650°F$

$E\delta_{32}^* = E\delta_{33}^* = E\delta_{34}^* = 0$

$E\delta_{33} = R_3 E\alpha_m (T_{m_3} - 70) = 1.688 (E\alpha_m)_3 (T_{m_3} - 70)$

$E\delta_{34} = R_3 (E\alpha_m)_3 (T_{m_3} - 70) = 1.688 (E\alpha_m)_3 (T_{m_3} - 70)$

Body-4:



$R_4 = 89.500''$
$b_4 = 35.781''$
$t_4 = 7.000''$
$\phi_4 = 1°16.8'$

$\frac{E^*}{E} = 0.72$, $\nu^* = 0.295$ } For L.E = 0.666

$\frac{E_{INCONEL}}{E_{304SS}} = 1.13743$

$\Delta\theta^* \Delta\delta^*$
$\Delta\theta\Delta\delta$

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5. DETAILED ANALYSIS:

e. DEVELOPMENT OF CONTINUITY EQUATIONS:

2. MOVEMENTS DUE TO REDUNDANT AND APPLIED FORCES:

BODY-4:

DISPLACEMENTS DUE TO REDUNDANT FORCES:

$$E\Delta_{43} = 0$$

$$E\Delta^*_{43} = -\frac{6.36(1-\nu^2)}{t_3^2}M_3 = \underline{-14.9161 M_3}$$

NOTE THAT THE DEFLECTION IS CONSERVATIVELY IGNORED, AND THAT THE ROTATION IS TAKEN AS EQUAL TO THE LOCAL FLEX. TERM FOR MOMENT ONLY.

$$E\Delta_{44} = 1.408(1-\nu^2)\left[\left(\frac{R_3}{t_3}+\frac{1}{2}\right)\ln\left(\frac{R_3}{t_3}+\frac{1}{2}\right)-\left(\frac{R_3}{t_3}-\frac{1}{2}\right)\ln\left(\frac{R_3}{t_3}-\frac{1}{2}\right)+\frac{1}{2}\right]H_4$$

$$+\frac{2.38(1-\nu-2\nu^2)}{t_3}M_4 = \underline{3.1873 H_4 + 1.9802 M_4}$$

$$E\Delta^*_{44} = -\frac{2.38(1-\nu-2\nu^2)}{t_3}H_4 - \frac{6.36(1-\nu^2)}{t_3^2}M_4 = \underline{-1.9802 H_4 - 14.8161 M_4}$$

FROM REF. 17

DISPLACEMENTS DUE TO PRESSURE:

$$E\delta_{43} = E\delta_{44} = \frac{(1-\nu^4)b_4^2}{2t_4}P\sin\theta\left(\frac{E}{E^*}\right)\left(\frac{E_{INCONEL}}{E_{302\,B}}\right) = \frac{(1-0.285)(85.781)^2}{2(7)}(0.00234)\left(\frac{1}{0.72}\right)(1.13793)P$$

$$= \underline{13.2636P}$$

$$E\delta^*_{43} = E\delta^*_{44} = 0$$

DISPLACEMENTS DUE TO THERMAL EFFECTS:

$$E\delta_{43} = R_4\sin\theta\, E\alpha_m(T_m-70)\frac{E_{INCONEL}}{E_{302\,B}} = 2.276(E\alpha_m)_4(T_{m4}-70)$$

$$E\delta^*_{43} = E\delta^*_{44} = 0$$

$$E\delta_{44} = R_4\sin\theta(E\alpha_m)_4(T_{m4}-70)\frac{E_{INCONEL}}{E_{302\,B}} = 2.276(E\alpha_m)_4(T_{m4}-70)$$

5. Detailed Analysis:

e. Development Of Continuity Equations:

3. Continuity Matrix And Loading Vectors:

A Pressure Solution Will Be Required For Each Juncture, A Thermal Solution Will Be Required At Junctures 2, 3, & 4, And An Interference Fit Solution At Juncture -3 Only. The Matrix And Column Vectors Will Be Arranged As Shown Below.

$$
\left.
\begin{aligned}
E\Delta_{11} - E\Delta_{21} &= E\delta_{21} - E\delta_{11} \\
E\Delta^*_{11} - E\Delta^*_{21} &= E\delta^*_{21} - E\delta_{11} \\
E\Delta_{22} - E\Delta_{32} &= E\delta_{32} - E\delta_{22} \\
E\Delta^*_{22} - E\Delta^*_{32} &= E\delta^*_{32} - E\delta^*_{22} \\
E\Delta_{33} - E\Delta_{43} &= E\delta_{43} - E\delta_{33} \\
E\Delta^*_{33} - E\Delta^*_{43} &= E\delta^*_{43} - E\delta^*_{33} \\
E\Delta_{34} - E\Delta_{44} &= E\delta_{44} - E\delta_{34} \\
E\Delta^*_{34} - E\Delta^*_{44} &= E\delta^*_{44} - E\delta^*_{34}
\end{aligned}
\right\}
$$

Substituting The Deflections And Rotations Into These Compatibility Equations And Writing In Matrix Form Yields The Matrix And Column Vectors As Shown Below,

$$
\begin{bmatrix}
-13.1659 & -13.8818 & 0 & 0 & 0 & 0 & 0 & 0 \\
13.8818 & 35.8507 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & -21.4504 & 1.7115 & 0 & 0 & 0 & 0 \\
0 & 0 & -1.7115 & 67.1955 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & -11.4090 & 14.2776 & 0 & 0 \\
0 & 0 & 0 & 0 & -14.2776 & 50.5559 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & -14.5963 & 12.2974 \\
0 & 0 & 0 & 0 & 0 & 0 & -12.2974 & 50.5559
\end{bmatrix}
\begin{bmatrix} H_1 \\ M_1 \\ H_2 \\ M_2 \\ H_3 \\ M_3 \\ H_4 \\ M_4 \end{bmatrix}
=
$$

$$
\begin{bmatrix} 0.0662\,P \\ -1.1397\,P \\ -0.3908\,P \\ 0 \\ W_P \\ 0 \\ W_P \\ 0 \end{bmatrix}
+
\begin{bmatrix} \\ \\ -52.253 \\ 0 \\ W_T \\ 0 \\ W_T \\ 0 \end{bmatrix}
+
\begin{bmatrix} 0 \\ 0 \\ 0 \\ 0 \\ -E\Delta_{INT} \\ 0 \\ 0 \\ 0 \end{bmatrix}
$$

Where:

$W_P = 10.0087\,P$

$W_T = 2.276\,E\alpha_{m4}(T_{m4} - T_0) - 1.688\,E\alpha_{m3}(T_{m3} - T_0)$

$E\Delta_{INT} = 31(-0.0015)\times 10^3 = 46.5$ kip/in

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5. Detailed Analysis:

e. Development Of Continuity Equations:

1. Redundant Load Values:

Inverting The Above Matrix And Multiplying By The Column Vectors Yields The Following Redundant Shears And Moments.

Redundant Force	Design Pressure P = 2.5 KSI	Temperature Where Applicable	Interference Fit Where Applicable
H_1	$0.04916P = 0.12040$	—	—
M_1	$-0.05[illegible]P = -0.12605$	—	—
H_2	$0.0825P = 0.04563$	2.44095	—
M_2	$0.00046P = 0.00115$	0.06217	—
H_3	$-0.13558W_p = -3.39245$	$-0.13558W_T$	$0.13558E\Delta_{int} = 6.20447$
M_3	$-0.03839W_p = -0.95808$	$-0.03829W_T$	$0.03829E\Delta_{int} = 1.78049$
H_4	$-0.0861W_p = -2.1567$	$-0.08617W_T$	—
M_4	$-0.02096W_p = -0.52416$	$-0.02096W_T$	—

Note That The Above Values For The Redundants H_3 & M_3 Are Valid As Long As There Is Interference Between The Housing And Head. The Values Of H_3 & M_3 Become Zero In The Absence Of Interference.

1. Stresses:

Stresses Will Be Calculated At The Ten Locations As Shown On Sheet-18. Stresses At Location -3 & 4 Will Be Calculated Due To A Temp. Of 660°F. This Will Represent The Maximum Possible Effect Of The Difference In Coef. Of Expansion And Young's Modulus. Stresses At Location -7 & 8 Will Be Calculated Due To The Maximum Interference Fit. Stresses Will Be Calculated At All Locations Due To The Design Pressure Of 2.5 KSI.

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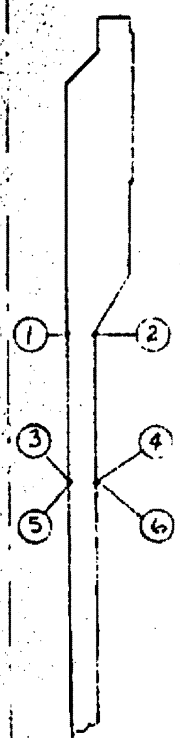
5. Detailed Analysis:

f. Stresses:



Stresses will be calculated at the locations as shown below.

Points 1 & 2:

$$\sigma_x = \pm \frac{6M_1}{t_2^2} + \frac{b_2 P}{2R_2 t_2} = \pm 15.3602 M_1 + 0.896 P$$

$$\sigma_\theta = \pm \frac{\nu 6M_1}{t_2^2} + \frac{E\Delta_{21}}{R} + \frac{b_2 P}{t_2} = \pm 4.6091 M_1 + 0.59241 E\Delta_{21} + 2.2 P$$

Points 3 & 4:

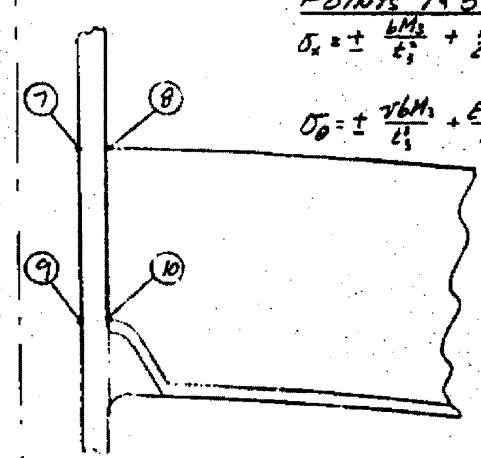
$$\sigma_x = \pm \frac{6M_2}{t_2^2} + \frac{b_2 P}{2R_2 t_2} = \pm 15.3602 M_2 + 0.896 P$$

$$\sigma_\theta = \pm \frac{\nu 6M_2}{t_2^2} + \frac{E\Delta_{22}}{R_2} + \frac{b_2 P}{t_2} = \pm 4.6091 M_2 + 0.59241 E\Delta_{22} + 2.2 P$$

Points 5 & 6:

$$\sigma_x = \pm \frac{6M_3}{t_3^2} + \frac{b_3 P}{2R_3 t_3} = \pm 15.3602 M_3 + 0.896 P$$

$$\sigma_\theta = \pm \frac{\nu 6M_3}{t_3^2} + \frac{E\Delta_{23}}{R_3} + \frac{b_3 P}{t_3} = \pm 4.6091 M_3 + 0.59241 E\Delta_{23} + 2.2 P$$



Points 7 & 8:

$$\sigma_x = \pm \frac{6M_3}{t_3^2} + \frac{b_3 P}{2R_3 t_3} = \pm 15.3602 M_3 + 0.896 P$$

$$\sigma_\theta = \pm \frac{\nu 6M_3}{t_3^2} + \frac{E\Delta_{23}}{R_3} + \frac{b_3 P}{t_3} = \pm 4.6091 M_3 + 0.59241 E\Delta_{23} + 2.2 P$$

Points 9 & 10

$$\sigma_x = \pm \frac{6M_4}{t_3^2} + \frac{b_3 P}{2R_3 t_3}$$
$$= \pm 15.3602 M_4 + 0.896 P$$

$$\sigma_\theta = \pm \frac{\nu 6M_4}{t_3^2} + \frac{E\Delta_{24}}{R_3} + \frac{b_3 P}{t_3}$$
$$= \pm 4.6091 M_4 + 0.59241 E\Delta_{24} + 2.2 P$$

Note that Points 3 & 4 are on the SA-182 Type 304 Stainless Steel and that Points 5 & 6 are on the SB-167 Inconel Material.

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5. Detailed Analysis:

f. Stresses:

Loading	$\frac{6M}{t^2}$	$\frac{PR}{2t}$	σ_x	$\frac{\tau 6M}{t^2}$	$E\Delta$	$\frac{E\Delta}{R}$	$\frac{PR}{t}$	σ_θ	σ_r	Stress Intensity $\sigma_x-\sigma_\theta$	$\sigma_x-\sigma_r$	$\sigma_\theta-\sigma_r$
1	-1.94	2.24	0.30	-0.58	-0.426	-0.25	5.50	4.67	-2.50	-4.37	2.80	7.17
2	1.94	↓	4.18	0.58	-0.426	-0.25	↓	5.83	0	-1.65	4.18	5.83
3	0.97	↓	3.21	0.01	-0.504	-0.30	↓	5.21	-2.50	-2.95	4.76	7.71
4	-0.97	↓	2.27	-0.01	-0.504	-0.30	↓	5.19	0	-2.97	2.27	5.19
5	0.97	↓	3.21	0.01	0.537	0.32	↓	5.71	-2.50	-3.57	4.76	8.33
6	-0.97	↓	2.27	-0.01	0.537	0.32	↓	5.81	0	-3.59	2.27	5.81
7	-14.72	↓	-12.48	-4.41	25.023	14.82	↓	15.91	-2.50	-28.37	-9.98	18.41
8	14.72	↓	16.96	4.41	25.023	14.82	↓	24.73	0	-7.77	16.96	24.73
9	-6.06	↓	-5.82	-2.42	17.111	10.14	↓	13.22	-2.50	-19.04	-3.32	15.72
10	6.06	↓	10.30	2.42	17.111	10.14	↓	18.06	0	-7.76	10.30	18.06
Thermal Stresses Due To Design Temp. Of T = 650°F												
3	0.95	0	0.95	0.29	-26.961	-15.97	0	-15.68	0	16.63	0.95	-15.68
4	-0.95	↓	-0.95	-0.29	-26.961	-15.97	↓	-16.26	↓	15.31	-0.95	-16.26
5	0.95	↓	0.95	0.29	28.736	17.02	↓	17.31	↓	-16.36	0.95	17.31
6	-0.95	↓	-0.95	-0.29	28.736	17.02	↓	16.73	↓	-17.68	-0.95	16.73
Interference Fit Stresses (Δ_{int} = 0.0015 At Juncture 3 Only)												
7	27.35	0	27.35	8.20	-46.500	-27.55	0	-19.35	0	46.70	27.35	-19.35
8	-27.35	0	-27.35	-8.20	-46.500	-27.55	0	-35.75	0	8.40	-27.35	-35.75
Combined Stress (P = 2.5 ksi; T = 650°F; Δ_{int} = 0.0015")												
1	-1.94	2.24	0.30	-0.58	-0.426	-0.25	5.50	4.67	-2.50	-4.37	2.80	7.17
2	1.94	↓	4.18	0.58	-0.426	-0.25	↓	5.83	0	-1.65	4.18	5.83
3	0.97	↓	3.21	0.30	-27.465	-16.27	↓	-10.47	-2.50	13.68	5.71	-7.97
4	-0.97	↓	1.27	-0.30	-27.465	-16.27	↓	-11.07	0	12.34	1.27	-11.07
5	0.97	↓	3.21	0.30	29.271	17.34	↓	23.14	-2.50	-19.93	5.71	25.64
6	-0.97	↓	1.27	-0.30	29.273	17.34	↓	22.54	0	-21.27	1.27	22.54
7	12.63	↓	14.87	3.79	-26.477	-12.73	↓	-3.44	-2.50	18.31	17.37	-0.94
8	-12.63	↓	-10.39	-3.79	-26.477	-12.73	↓	-11.02	0	0.63	-10.39	-11.02
9	-8.06	↓	5.82	-2.42	17.111	10.14	↓	13.22	-2.50	-19.04	-3.32	15.72
10	6.06	↓	10.30	2.42	17.111	10.14	↓	18.06	0	-7.76	10.30	18.06

5. Detailed Analysis:

4. Stresses:

$E\Delta_{32} = -E\Delta_{INT} + (W_P + W_T) \leq 0$ MUST

$E\Delta_{34} = 0.68386(W_P + W_T) \geq 0$ FOR

Transient		Internal Pressure ksi	W_P	T_a °F	$(E\alpha_m)_a$ ksi/°F	T_s °F	$(E\alpha_m)_s$ ksi/°F	W_T	W_P+W_T	$E\Delta_{PTOTAL}$ $E\Delta_{32}$	$E\Delta_{PTOTAL}$ $E\Delta_{34}$
a	0	0.315	3.153	70	0.177	99	0.155	-9.056	-5.903	-52.403	-5.[illegible]
	4.47hrs	3.250	22.520	518	0.156	547	0.217	14.931	37.451	-9.049	25.611
Steady State		2.250	22.520	547	0.156	547	0.217	27.208	49.728	0	34.007
b	0	2.250	22.520	547	0.156	518	0.217	37.851	60.351	0	41.277
	4.47hrs	0.315	3.153	99	0.178	70	0.180	11.749	14.902	-21.598	10.191
c	10min	2.250	22.520	547	0.186	554.8	0.218	23.536	46.056	-0.444	31.496
d	20min	2.250	22.520	554.8	0.156	547	0.217	30.510	53.030	0	36.265
e	100min	2.140	21.419	583.7	0.186	572.8	0.218	32.560	53.979	0	36.914
	2.95hr	2.[illegible]	22.710	583.7	0.186	582	0.218	27.064	51.834	0	35.447
f	40hr	2.250	22.520	583.7	0.186	593	0.219	24.132	47.352	0	32.382
	100hr	2.250	22.620	583.7	0.186	597	0.219	22.654	45.274	-1.226	30.961
	260hr	2.140	21.419	583.7	0.156	585	0.218	27.960	49.379	0	25.768
g	2min	2.250	22.721	555	0.186	567	0.218	22.434	46.155	-0.345	31.564
	3.7min	2.350	22.520	555	0.186	570	0.218	21.330	44.850	-1.650	30.677
	104min	2.150	21.519	555	0.186	555	0.218	26.850	48.319	0	33.078
h	[illegible]	2.220	22.219	554.8	0.186	564	0.218	23.453	45.672	-0.899	31.233
	[illegible]	1.910	19.117	554.8	0.156	546	0.217	30.576	49.693	0	30.188
i	[illegible]	3.125	31.277	70	0.177	70	0.180	0	31.277	-15.223	21.389
j	[illegible]	0.315	3.153	70	0.177	86	0.183	-4.942	-1.789	-48.289	-1.789
	[illegible]	2.500	25.022	400	0.185	400	0.212	30.859	45.881	-0.619	31.376
	[illegible]	1.250	12.511	400	0.185	384	0.211	27.116	39.627	-6.373	27.099
k	~	2.350	23.520	554.8	0.186	548.8	0.217	29.851	53.371	0	36.418
	~	2.150	21.519	554.8	0.156	560.8	0.218	24.631	46.150	-0.250	31.560
l	15min	2.250	22.520	554.8	0.156	521.8	0.217	39.743	62.263	0	42.579
m	10min	2.[illegible]	22.524	554.8	0.186	585	0.218	15.726	43.350	-3.150	29.645
	[illegible]	2.120	21.218	554.8	0.186	596	0.219	10.758	32.006	-14.494	21.888
	160min	1.440	14.413	554.8	0.156	550	0.218	29.605	43.018	-3.452	29.418
n	33min	0.350	3.003	547.0	0.156	430	0.213	72.497	75.500	0	51.631
	4min	0.700	7.006	547.0	0.156	350	0.209	103.151	110.157	0	75.332

COMBUSTION ENGINEERING, INC.

ENGINEERING DEPARTMENT, CHATTANOOGA, TENN.

CHARGE NO. _____

DESCRIPTION Control Rod Housing Stress Analysis

Amp Fatigue Evaluation

NUMBER 5-180-P | A-18

SHEET 21 OF 27

DATE 1-24-67 BY [illegible]

CHECK DATE 1-24-67 BY [illegible]

RTV00000053B

Submitted: December 27, 2011

5. Detailed Analysis:

F. Stresses:

Point	Location	$\frac{6M}{t^2}$	$\frac{PR}{2t}$	$\frac{6M}{t^2}$	$\frac{E\Delta}{R}$	$\frac{PR}{t}$	Point-7 σ_x	σ_θ	σ_r	$\sigma_x-\sigma_\theta$	$\sigma_x-\sigma_r$	$\sigma_\theta-\sigma_r$	Point-8 σ_x	σ_θ	σ_r	$\sigma_x-\sigma_\theta$	$\sigma_x-\sigma_r$	$\sigma_\theta-\sigma_r$
Fo T=727°F		27.35	0	3.20	-27.35	0	27.35	-14.15	0	41.70	27.35	-14.35	-27.35	-35.75	0	8.40	-27.35	-35.75
a	0	30.32	2.02	7.35	-31.06	2.69	31.10	-21.10	-0.32	52.20	31.42	-20.78	-30.54	-39.60		9.06	-30.54	-31.06
	1.0in	5.32	2.02	1.32	-5.36	4.95	7.34	1.17	-2.25	6.15	9.59	3.44	-2.30	-2.01		-.29	-2.30	-7.01
Concentric		0	2.02	0	0	4.95	2.02	4.95	-2.25	-2.93	4.27	7.20	2.02	4.95		-2.93	2.02	4.95
b	0	0	2.02	0	0	4.95	2.02	4.95	-2.25	-2.93	4.27	7.20	2.02	4.95		-2.93	2.02	4.95
	1.0in	19.33	0.29	5.53	-19.72	0.69	19.86	-12.45	-0.32	31.31	19.18	-12.13	-18.30	-23.61		5.31	-18.30	-23.61
c	2.0in	3.26	2.02	5.08	-0.26	4.95	2.28	4.77	-2.25	-2.49	4.53	7.02	1.76	4.61		-2.85	1.76	4.61
d	2.0in	0	2.02	0	0	4.95	2.02	4.95	-2.25	-2.93	4.27	7.20	2.02	4.95		-2.93	2.02	4.95
e	100sec	0	1.92	0	0	4.71	1.92	4.71	-2.14	-2.79	4.06	6.85	1.92	4.71		-2.79	1.92	4.71
	225sec	0	2.04	0	0	5.01	2.04	5.01	-2.28	-2.97	4.32	7.29	2.04	5.01		-2.79	2.04	5.01
f	40sec	0	2.08	0	0	5.10	2.08	5.10	-2.32	-3.02	4.40	7.42	2.08	5.10		-3.02	2.08	5.10
	100sec	2.72	2.02	0.22	-0.73	4.97	2.74	4.46	-2.26	-1.72	5.00	6.72	1.30	4.02		-2.72	1.30	4.02
	225sec	0	2.02	0	0	4.71	1.92	4.71	-2.14	-2.79	4.06	6.85	1.32	4.71		-2.79	1.92	4.71
g	2min	3.20	2.12	3.06	-0.20	5.21	2.32	5.07	-2.37	-2.75	4.69	7.44	1.92	4.95		-3.03	1.92	4.95
	3.2min	2.77	2.11	0.29	-0.98	5.17	3.09	4.48	-2.35	-1.40	5.43	6.83	1.14	3.90		-2.76	1.14	3.90
	10min	0	1.93	0	0	4.73	1.93	4.73	-2.15	-2.80	4.08	6.88	1.73	4.73		-2.80	1.93	4.73

COMBUSTION ENGINEERING, INC. NUMBER S-100-P | A-19

ENGINEERING DEPARTMENT, CHATTANOOGA, TENN. SHEET 22 RTV 000053B

CHARGE NO. Submitted: October 27, 2011

DESCRIPTION Control Rod Housing Stress Analysis CHECK DATE 1-24-67 BY Cooke

Ana Fatigue Evaluation

5. Detailed Analysis:

f. Stresses:

Item	Cycle	$\frac{\alpha V}{t^2}$	$\frac{PR}{2t}$	$\frac{\gamma_b M}{t^2}$	$\frac{E\Delta}{K}$	$\frac{PR}{t}$	Point-7 σ_x	σ_θ	σ_r	$\sigma_x-\sigma_\theta$	$\sigma_x-\sigma_r$	$\sigma_\theta-\sigma_r$	Point-8 σ_x	σ_θ	σ_r	$\sigma_x-\sigma_\theta$	$\sigma_x-\sigma_r$	$\sigma_\theta-\sigma_r$
n	[illegible]	0	1.99	0	0	4.21	1.99	4.21	-2.22	-2.29	4.21	7.10	1.99	4.21	0	-2.29	1.99	4.18
	[illegible]	0	1.71	0	0	4.20	1.71	4.20	-1.91	-2.49	3.62	6.11	1.71	4.20		-2.49	1.71	4.20
i	[illegible]	2.95	2.83	2.09	-9.02	5.78	11.75	2.53	-3.13	11.20	14.88	3.23	-6.15	-4.83		-1.32	-6.15	-4.53
j	[illegible]	23.40	2.28	3.32	-23.61	2.59	28.68	-19.40	-0.52	48.08	29.00	-19.96	-28.12	-36.44		8.32	-28.12	-36.44
	[illegible]	2.36	2.24	3.11	-2.37	6.50	2.60	5.54	-2.50	-2.64	5.10	7.74	1.88	5.02		-3.14	1.88	5.02
	[illegible]	4.04	1.12	1.21	-4.07	2.75	5.16	-0.11	-1.25	5.27	6.41	1.14	-2.42	-2.53		-0.11	-2.42	-2.53
k	~	0	2.11	0	0	5.17	2.11	5.17	-2.35	-3.06	4.46	7.52	2.11	5.17		-3.06	2.11	5.17
	~	0.21	1.93	0.36	-0.21	4.73	2.14	4.58	-2.15	-2.44	4.29	6.73	1.72	4.46		-2.74	1.72	4.46
l	[illegible]	0	2.92	0	0	4.95	2.92	4.95	-2.35	-2.93	4.27	7.20	2.92	4.95		-2.93	2.92	4.95
m	[illegible]	1.85	2.47	3.56	-1.87	5.07	4.32	4.76	-2.76	-0.44	7.08	7.52	2.62	3.64		-3.02	2.62	3.64
	[illegible]	3.52	1.90	2.56	-3.59	4.66	10.42	-1.37	-2.12	11.79	12.54	2.75	-6.62	-6.49		-0.13	-6.62	-6.49
	[illegible]	2.05	1.29	0.61	-2.06	3.17	3.34	1.72	-1.44	1.62	4.78	3.16	-0.76	2.50		-1.26	-0.76	2.50
n	[illegible]	0	2.27	0	0	0.66	2.27	2.66	-0.30	-0.39	0.57	2.96	2.27	2.66		-0.39	2.27	2.66
	[illegible]	0	0.63	0	0	1.54	2.63	1.54	-0.70	-0.91	1.33	2.24	2.63	1.54	i	-0.91	2.63	1.54

$S.I._{MAX}$ = 55.3 KSI @ Point 7 Criterion 5-C-3

RANGE

COMBUSTION ENGINEERING, INC.
ENGINEERING DEPARTMENT, CHATTANOOGA, TENN.

NUMBER S-122-P | A-20
SHEET 23 RJV000053B
Submitted: December 27, 2011
CHARGE NO. _____ DATE _____
DESCRIPTION Cluster Raw Material Stress Analysis CHECK DATE 1-24-67 BY Lewis
Ann Fatigue Evaluation
5. Detailed Analysis
f. Stresses

		$\frac{6M}{t^2}$	$\frac{PR}{2t}$	$\frac{\nu 6M}{t^2}$	$\frac{E\Delta}{R}$	$\frac{PR}{t}$	Point-9 σ_x	σ_θ	σ_r	$\sigma_x-\sigma_\theta$	$\sigma_x-\sigma_r$	$\sigma_\theta-\sigma_r$	Point-10 σ_x	σ_θ	σ_r	$\sigma_x-\sigma_\theta$	$\sigma_x-\sigma_r$	$\sigma_\theta-\sigma_r$	$\sqrt{(\sigma_\theta-\sigma_r)}$
a	0	0	0.28	0	-3.50	0.69	0.28	-2.31	-0.32	2.59	0.60	-2.49	0.29	-2.81	0	3.09	0.28	-2.81	-11.24
	6 min	-12.06	2.02	-3.62	15.17	4.95	-10.04	16.50	-2.25	-26.54	-7.79	18.75	14.08	23.74		-9.66	14.08	23.74	74.96
	5 min 2 min	-16.01	2.02	-4.80	20.15	4.95	-13.99	20.30	-2.25	-34.29	-11.74	22.55	18.23	29.90		-11.87	18.03	29.90	119.60
b	0	-19.43	2.02	-5.83	24.45	4.95	-17.41	23.57	-2.25	-40.98	-15.16	25.32	21.45	35.23		-13.78	21.45	35.23	140.92
	6 min	-4.80	0.28	-1.44	6.04	0.69	-4.52	5.29	-0.32	-9.81	-4.20	5.61	5.08	8.17		-3.09	5.08	8.17	32.68
c	20 min	-14.83	2.02	-4.45	18.66	4.95	-12.81	19.16	-2.25	-31.97	-10.56	21.41	16.85	28.06		-11.21	16.85	28.06	112.24
d	20 min	-17.07	2.02	-5.12	21.48	4.95	-15.05	21.31	-2.25	-36.36	-12.80	23.66	17.09	31.55		-12.46	19.09	31.55	126.20
e	10 sec	-17.38	1.92	-5.21	21.87	4.71	-15.46	21.37	-2.14	-36.83	-13.32	23.51	19.30	31.79		-12.49	19.30	31.79	127.16
	22 sec	-16.69	2.04	-5.01	21.00	5.01	-14.65	21.00	-2.28	-35.65	-12.37	23.28	18.73	31.02		-12.29	18.73	31.02	124.08
f	4 min	-15.24	2.08	-4.57	19.18	5.10	-13.16	19.71	-2.32	-32.87	-10.84	22.03	17.32	29.55		-11.53	17.32	29.55	115.40
	10 sec	-14.58	2.02	-4.37	18.34	4.97	-12.56	18.94	-2.26	-31.50	-10.30	21.20	16.60	27.68		-11.08	16.60	27.68	110.72
	21 sec	-15.90	1.92	-4.77	20.00	4.71	-13.98	19.94	-2.14	-33.92	-11.84	22.08	17.82	29.48		-11.66	17.82	29.48	117.92
g	2 min	-14.86	2.12	-4.46	18.70	5.21	-12.74	19.45	-2.37	-32.19	-10.37	21.82	16.98	28.37		-11.39	16.98	28.37	113.48
	22 min	-14.44	2.11	-4.33	18.17	5.17	-12.33	19.01	-2.35	-31.34	-9.98	21.36	16.55	27.67		-11.12	16.55	27.67	110.68
	9 hr	-15.57	1.93	-4.67	19.60	4.73	-13.64	19.66	-2.15	-33.30	-11.49	21.81	17.50	29.00		-11.50	17.50	29.00	116.00

COMBUSTION ENGINEERING, INC.
ENGINEERING DEPARTMENT, CHATTANOOGA, TENN.

NUMBER S-100-P | A-21
SHEET 24 of RIV990053B
Submitted: December 27, 2011
DATE 7-28-67 BY

CHARGE NO.
DESCRIPTION Control Rod Housing Stress Analysis
CHECK DATE 1-24-67 BY

5. Detailed Analysis:
f. Stresses:

Location	Case	$\frac{\nu M}{t^2}$	$\frac{PR}{2t}$	$\frac{\nu M}{t^2}$	$\frac{ED}{R}$	$\frac{PR}{t}$	Point-9 σ_x	σ_θ	σ_r	$\sigma_x-\sigma_\theta$	$\sigma_x-\sigma_r$	$\sigma_\theta-\sigma_r$	Point-10 σ_x	σ_θ	σ_r	$\sigma_x-\sigma_\theta$	$\sigma_x-\sigma_r$	$\sigma_\theta-\sigma_r$	$4(\sigma_x-\sigma_r)$
n	0 sec	-14.70	1.99	-4.41	18.50	4.98	-13.71	18.97	-2.22	-31.63	-10.49	21.14	16.69	27.79	0	-11.10	16.69	27.79	111.16
	5 sec	-16.10	1.71	-4.83	20.25	4.20	-14.39	19.62	-1.91	-34.01	-12.48	21.53	17.81	29.28		-11.47	17.81	29.28	117.12
i	22 min	-0.37	3.30	-3.52	12.67	6.88	-7.27	16.53	-3.13	-23.80	-4.14	19.66	12.87	22.57		-9.70	12.87	22.57	90.28
j	0 min	0	0.28	0	-1.06	0.69	0.28	-0.37	-0.32	0.65	0.60	-0.05	0.28	-0.37		0.65	0.28	-0.37	-1.48
	5 min	-14.77	2.24	-4.43	18.59	5.50	-12.53	19.66	-2.50	-32.19	-10.03	22.16	17.01	28.52		-11.51	17.01	28.52	114.08
	86 hrs	-12.76	1.12	-3.83	16.05	2.75	-11.64	14.97	-1.25	-26.61	-10.39	16.22	13.88	22.63		-8.75	13.88	22.63	90.52
k	~	-17.18	2.11	-5.15	21.62	5.17	-15.07	21.64	-2.35	-36.71	-12.72	23.99	19.29	31.94		-12.65	19.29	31.94	127.76
	~	-14.86	1.93	-4.46	18.70	4.73	-12.93	18.97	-2.15	-31.90	-10.78	21.12	16.79	27.89		-11.10	16.79	27.89	111.56
l	15 sec	-20.65	2.02	-6.21	25.22	4.95	-18.63	24.16	-2.25	-42.19	-15.78	26.41	22.07	36.18		-14.11	22.07	36.18	144.72
m	10 sec	-13.96	2.47	-4.19	17.56	6.07	-11.49	19.44	-2.76	-30.93	-8.73	22.20	16.43	27.82		-11.39	16.43	27.82	111.28
	23 sec	-10.30	1.90	-3.09	12.97	4.66	-8.40	14.54	-2.12	-22.94	-6.28	16.66	12.20	20.72		-8.52	12.20	20.72	82.88
	140 sec	-13.85	1.29	-4.16	17.43	3.17	-12.56	16.44	-1.44	-29.00	-11.12	17.88	15.14	24.76		-9.62	15.14	24.76	99.04
n	33 sec	-24.31	0.27	-7.29	30.59	0.66	-24.04	23.96	-0.30	-48.00	-23.74	24.26	24.58	38.54		-13.96	24.58	38.54	154.16
	64 sec	-35.47	0.23	-10.64	44.63	1.54	-34.84	35.53	-0.70	-70.37	-34.14	36.23	36.10	56.81		-20.71	36.10	56.81	227.24

SI_{RATE} = 42.36 ksi @ Point-9
= 34.8 ksi @ Point-10

} Criterion 5-2-3

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5: DETAILED ANALYSIS:

f: STRESSES:

CRITERION S.C.-1:

$S.I._{MAX} = \frac{PR}{t} + \frac{P}{2} = \underline{6.75\,KSI} < S_m =$ 15.3 KSI FOR SA-182 TYPE 304 SS, 23.3 KSI FOR SB-167 INCONEL @ 650°F

CRITERION S.C.-2:

$S.I._{MAX} = \frac{PR}{t} + \frac{P}{2} + \frac{E\Delta}{R} = \underline{16.9\,KSI} < 1.5 S_m = 34.95\,KSI$ @ 650°F $\boxed{\text{FOR POINTS 9 \& 10}}$

CRITERION S.C.-3:

$S.I._{MAX} = \sigma_r - \sigma_\theta = \underline{55.3\,KSI} < 3 S_m = 69.9\,KSI$ @ 550°F $\boxed{\text{FOR POINT -7}}$

SEE SHEETS 21 & 22

g: FATIGUE EVALUATION:

CONSIDER JUNCTURE -1

$S.I._{MAX} = (\sigma_\theta - \sigma_r) = 8.96\,KSI$ @ POINT -1 $\boxed{\text{FOR } T = 100°F \text{ \& } P = 3.125\,KSI \text{ TRANSIENT - i (PLANT HYDRO)}}$

$S.I._{MIN} = 0$ FOR $T = 70°F$ & $P = 0$

$S_{ALT} = \frac{S.I._{MAX} - S.I._{MIN}}{2} = \underline{4.5\,KSI}$ FROM FIG. N-415(B) OF SECTION III

$N = \infty \therefore U_{OVERALL} = \underline{0}$

CONSIDER JUNCTURE -2

$S.I._{MAX} = (\sigma_\theta - \sigma_r) = 22.72\,KSI$ @ POINT 5 $\boxed{\text{FOR } T = 550°F \text{ \& } P = 2.76\,KSI \text{ TRANSIENT - iii (LOSS OF LOAD)}}$

$S.I._{MIN} = 0$ FOR $T = 70°F$ & $P = 0$

$S_{ALT} = \frac{S.I._{MAX} - S.I._{MIN}}{2} = \underline{11.36\,KSI}$ FROM FIG. N-415(B) OF SECTION III

$N = \infty \therefore U_{OVERALL} = \underline{0}$

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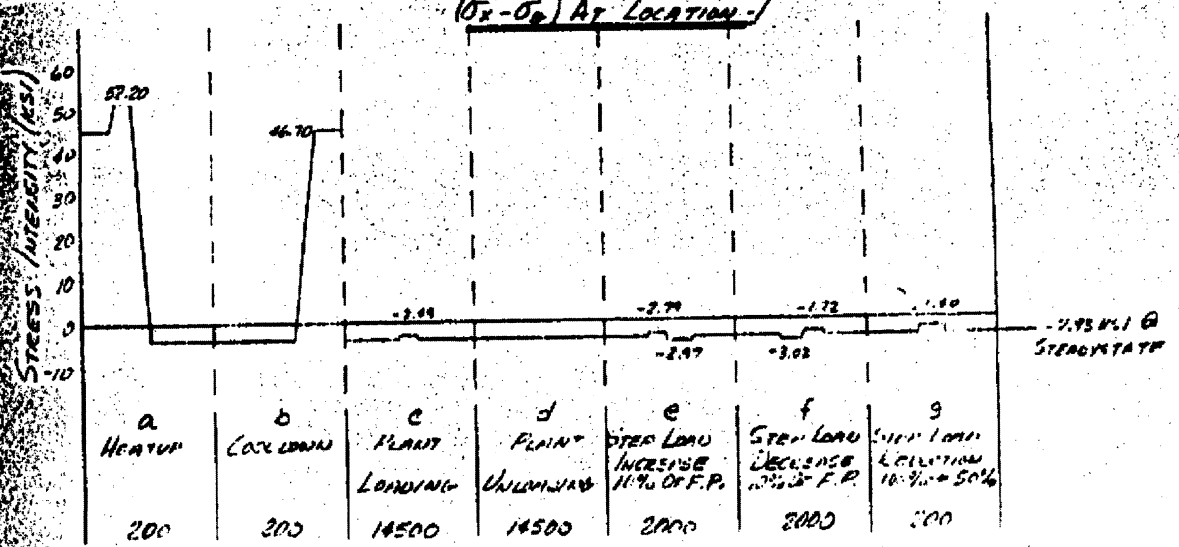
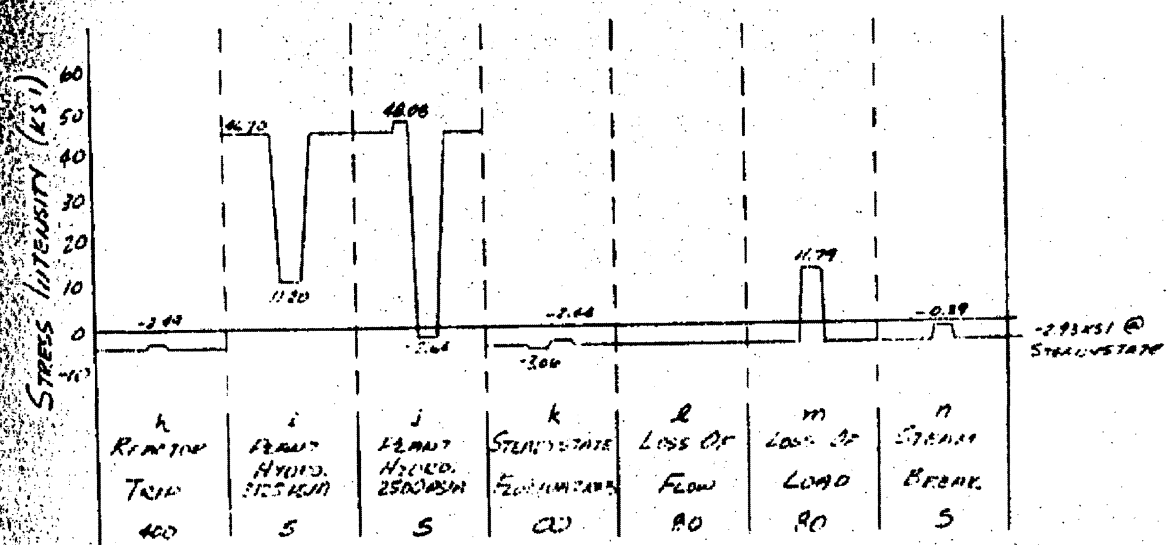
DESCRIPTION CONTROL ROD HOUSING STRESS INTENSITY AND FATIGUE EVALUATION

5. DETAILED ANALYSIS:

5.6 FATIGUE EVALUATION:

$(\sigma_x - \sigma_\theta)$ AT LOCATION 7





S_{max}	S_{min}	Number of Occurrences	S_{alt}	N^*	U
57.20	-3.06	200	27.63	650,000	0.00030
48.06	-2.64	5	25.34	∞	0

*From Fig. N-415(a) of Ref. 1

$U_{overall} = 0.00030$

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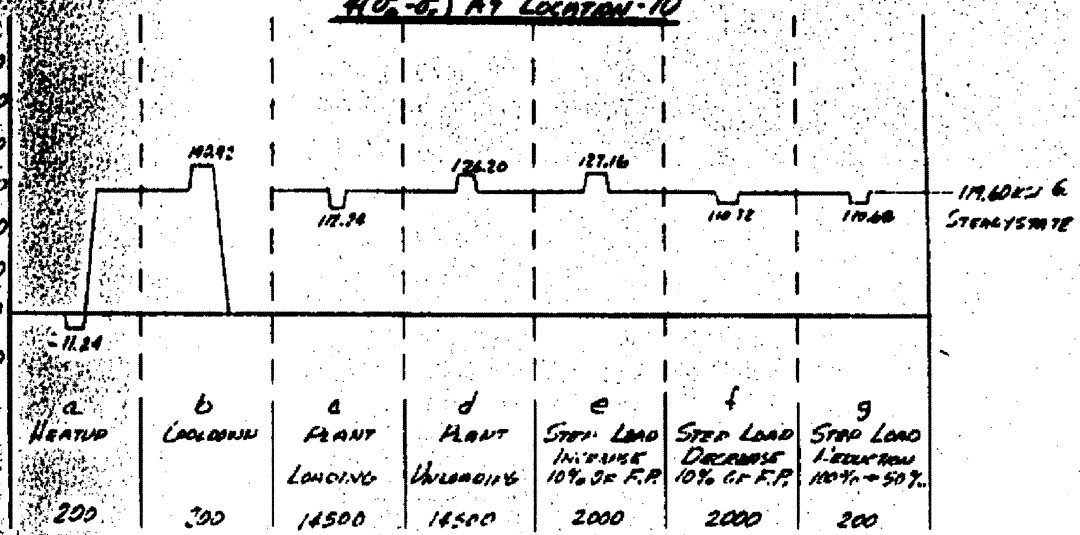
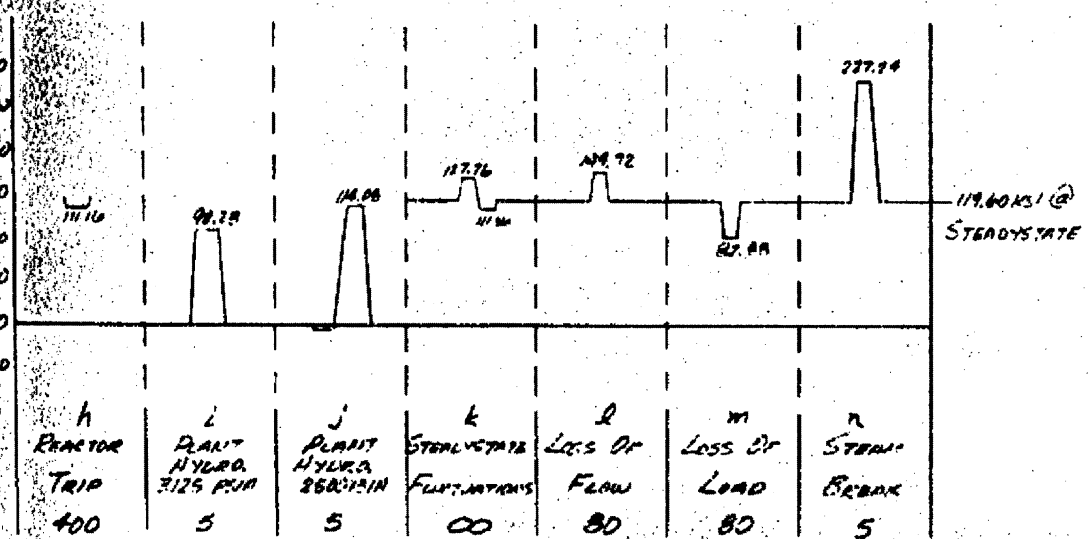
5. Detailed Analysis:

g. Fatigue Evaluation:

$K(\sigma_1 - \sigma_3)$ At Location 10





S_{max}	S_{min}	Number Of Occurrences	S_{alt}	N^*	U
227.24	-11.24	5	119.24	750	0.00666
144.92	-11.24	80	77.98	3600	0.02222
140.92	-11.24	115	76.08	3700	0.03108
114.08	-14.8	5	57.78	11000	0.00045
90.29	0	5	45.14	36000	0.00014
127.80	92.98	80	2546	20	

*From Fig. N-415(B) Of Ref. 1

$U_{overall} = 0.06055$

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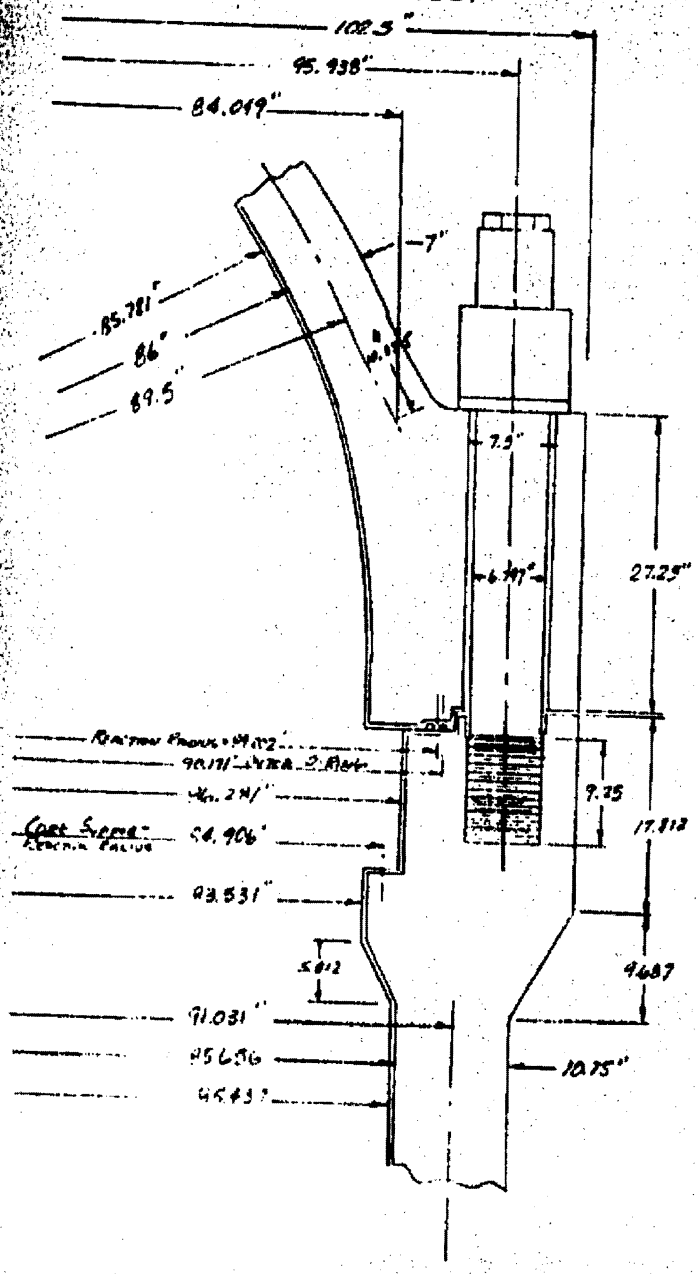
5- DETAILED ANALYSIS:

a. SYSTEM GEOMETRY:

A CROSS SECTION OF THE CLOSURE HEAD, CLOSURE HEAD FLANGE, VESSEL FLANGE, VESSEL, AND CLOSURE STUDS IS SHOWN BELOW. CERTAIN DIMENSIONS OF INTEREST ARE LISTED.



ALL MATERIALS ARE SA-302-B OR HAVE SAME ALLOWABLES EXCEPT NUTS, STUDS AND WASHERS WHICH ARE SA-320 GR. L43

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5. DETAILED ANALYSIS:

b. SYSTEM LOADS:

THE CLOSURE HEAD AND VESSEL ASSEMBLY WILL BE INVESTIGATED FOR THE FOLLOWING LOADS IN THIS ANALYSIS:

1- DESIGN PRESSURE OF 2.5 KSI AT DESIGN TEMP. OF 650°F.
2. INITIAL BOLT-UP 10% GREATER THAN THE DESIGN PRESSURE BLOW OFF LOAD BASED ON THE ℄ OF THE OUTER O-RING.
3- THE CORE AND CORE SUPPORT WEIGHT OF 675 KIPS PLUS THE CORE HOLDDOWN SPRING FORCE OF 660 KIPS.
THE ABOVE LOADS ARE BASED ON WESTINGHOUSE EQUIPMENT SPEC. 676245 AND 676514, REF. 19

c. SYSTEM ALLOWABLES:

THE FOLLOWING ALLOWABLE STRESSES ARE BASED ON THE A.S.M.E. NUCLEAR CODE SECTION III, REFERENCE-1 AND ARE RELEVANT FOR THIS ANALYSIS.

1- THE AVERAGE PRIMARY STRESS INTENSITY ACROSS A SOLID SECTION SHALL NOT EXCEED S_m AT DESIGN TEMP. AND PRESSURE.
2- THE LOCAL PRIMARY STRESS PLUS THE AVERAGE PRIMARY STRESS SHALL NOT EXCEED $1.5S_m$ AT DESIGN TEMP. AND PRESSURE.
3- THE PRIMARY BENDING STRESS ALONE OR COMBINED WITH THE ABOVE SHALL NOT EXCEED $1.5S_m$ AT DESIGN TEMP. AND PRESSURE.
4- THE AVERAGE BOLT STRESS RESULTING FROM THE DESIGN PRESS. BLOW-OFF LOAD PLUS O-RING SEATING LOAD SHALL NOT EXCEED THE S_m VALUE AT THE 650°F DESIGN TEMP.
5- THE MAXIMUM AVERAGE BOLT SERVICE STRESS SHALL NOT EXCEED $2S_m$ AT OPERATING TEMP. AND PRESSURE.
6- THE MAXIMUM BOLT SERVICE STRESS SHALL NOT EXCEED $3S_m$ AT OPERATING TEMP. AND PRESSURE.
7- THE AVERAGE PRIMARY SHEAR STRESS ACROSS A SECTION IN PURE SHEAR (SUCH AS SCREW THREADS) SHALL NOT EXCEED $0.6S_m$ AT DESIGN TEMP.

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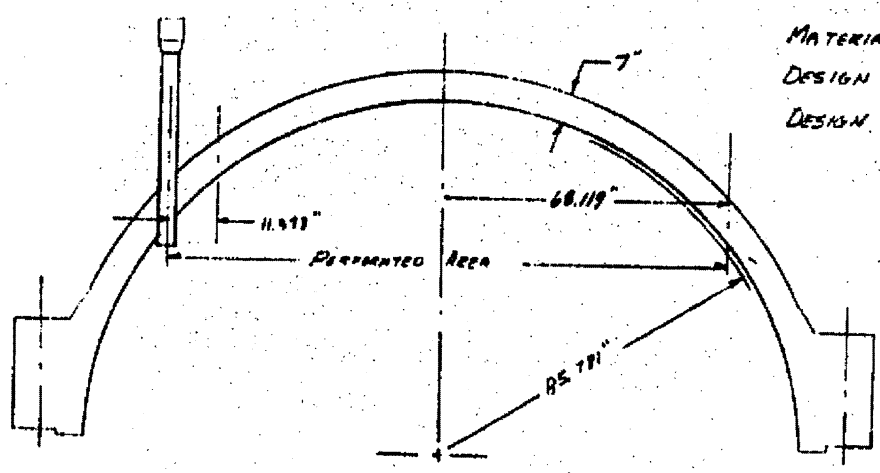
5. DETAILED ANALYSIS:

c. SYSTEM ALLOWABLES:

B. THE AVERAGE BEARING STRESS SHALL NOT EXCEED S_y AT ACTUAL METAL TEMPERATURE.

d. DESIGN SIZING:



MATERIAL : SA-302B
DESIGN PRESS: 2.5 KSI
DESIGN TEMP: 650°F

CONSIDER THE REQUIRED THICKNESS IN THE UN-PERFORATED AREA: REFERENCE PARAGRAPH N-431, SECTION III NUCLEAR CODE:

$$t_{REQ'D\ UNPERFORATED} = \frac{PR}{2S_m - P} = \frac{2.5(36.781)}{2(26.7)-2.5} = 4.213 \text{ in}$$

USE 7" MIN TO ALLOW FOR PENETRATIONS

WHERE: t = SHELL THICKNESS (EXCLUDING CLAD)
P = DESIGN PRESSURE
R = INSIDE RADIUS OF HEAD (TO CLAD SURFACE)
S_m = 26.7 KSI (ALLOWABLE STRESS AT 650°F)

NOTE:
SEE APPENDIX-C FOR JUSTIFICATION OF PENETRATION SPACING.

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5. DETAILED ANALYSIS:

d. DESIGN SIZING:

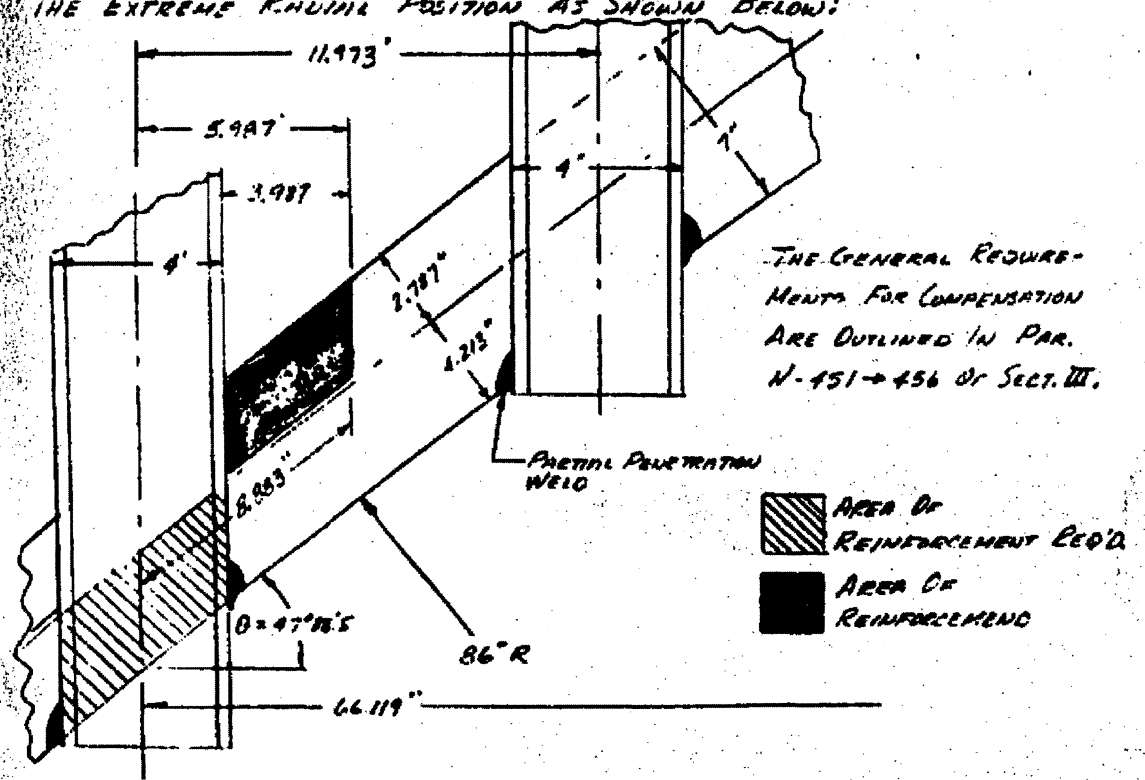
CONSIDER THE REQUIRED THICKNESS IN THE PERFORATED AREA:

SINCE THE HOLES ARE IN A SQUARE PATTERN THE REQUIRED THICKNESS MAY BE CONSERVATIVELY ESTIMATED BY DIVIDING THE REQUIRED SOLID THICKNESS BY THE LIGAMENT EFFICIENCY. THIS INSURES SATISFACTION OF THE PRIMARY STRESS REQUIREMENT IN THE PERFORATED AREA.

$$\eta = \text{LIGAMENT EFFICIENCY} = \frac{11.973 - 4}{11.973} = 0.666$$

$$t_{\substack{REQ'D \\ PERFORATED}} = \frac{t_{SOLID}}{\eta} = \frac{4.213}{0.666} = 6.326'' < 7.000'' \text{ (CRITERION 5-C-1)}$$

ANOTHER APPROACH WHICH MAY BE USED TO INSURE ADEQUATE HEAD THICKNESS IS TO ASSUME THE CONTROL ROD HOUSING AS A CONNECTION WHICH REQUIRES REINFORCEMENT. THE CONTROLLING LOCATION IS AT THE EXTREME RADIAL POSITION AS SHOWN BELOW:



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5. Detailed Analysis:

d. Design Sizing:

The Area Of Reinforcement Required Is:

$$A_{req'd} = \frac{4 \times 4.213}{\cos\theta} = 23.00\ in^2 \qquad \theta = \sin^{-1}\frac{66.119}{99.5} = 47°38.5'$$

Consider Limits Of Reinforcement:

The Limit Of Reinforcement Is Measured Along The Midsurface Of The Nominal Wall Thickness And Is The Larger Of: (See N-454 & 455).

a. The Diameter Of The Finished Opening 4 in., (or)
b. The Finished Radius Of The Opening (2") Plus The Thickness Of The Closure Head (7"). Note That The Control Rod Housing Wall Thickness Cannot Be Counted Because Of The Partial Penetration Weld. This Total Is 9.0 in.

The Horizontal Projection Of b Is:

$$\text{Horiz. Proj.} = 9.0 \cos\theta = 6.066"$$

$$\text{Since } 6.066 > \frac{11.973}{2} \quad \text{Use } \frac{11.973}{2} = 5.987" \text{ (Limit Of Reinforcement)}$$

The Area Furnished For Reinforcement Is:

$$A_{furnished} = \frac{2(3.987)(2.787)}{\cos\theta} = 32.97\ in^2 \qquad \cos\theta = 0.67398$$

Since The Area Furnished For Compensation Exceeds The Area Required, The Reinforcement Requirement Is Satisfied. At Penetrations Closer To The Vertical Axis Of The Head, There Is A Larger Margin Between The Reinforcement Furnished And That Which Is Required. Note That The Vent Nozzle Does Not Require Reinforcement Since It Meets The Requirements Of N-452(a) Or Note 7.