CENC 1122

ANALYTICAL REPORT
FOR
INDIAN POINT
REACTOR VESSEL - UNIT NO. 3

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...N ENGINEERING, INC.
...NOOGA, TENN.

Cockrell
Lowry

REPORT NUMBER 1122
SUBJECT CATEGORY
"ANALYTICAL REPORT"

COMBUSTION ENGINEERING, INC.
NUCLEAR COMPONENTS ENGINEERING DEPARTMENT
C.E. CONTRACT NO. 3366

ANALYTICAL REPORT

FOR

INDIAN POINT REACTOR VESSEL UNIT NO. 3

C. R. COCKRELL AND J. C. LOWRY

JUNE, 1969

1.000 ABSTRACT

The structural integrity of the 173 in. I.D. Indian Point Reactor Vessel - Unit No. 3 designed and fabricated under contract to the Atomic Power Division of the Westinghouse Electric Corporation is established by the results of the detailed structural and thermal analysis contained in this report.

PREPARED BY

[illegible] Cockrell Lead Structural Engineer	J. [illegible] Lowry Lead Heat Transfer Engineer

APPROVED BY

F. P. Hill Supervisor of [illegible] Analytical Group	H. [illegible] Dolli Supervisor of Contract En[illegible] [illegible]

CERTIFIED BY ________

CERTIFICATE NO. ________

STATE OF TENNESSEE

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2.000 INTRODUCTION

2.010 Subject

The Indian Point Reactor Vessel - Unit No. 3 is a 173 in. I.D. pressurized water reactor. The vessel is of cylindrical shape terminating in a hemispherical head at the bottom and a bolted flange at the top. Four inlet and four outlet nozzles are located in the cylindrical wall section. The vessel is supported by four weld built-up pads located on the underside of two inlet nozzles and two outlet nozzles. The closure head is of the hemispherical type. The closure seal is of the O-ring type.

2.020 Purpose

This report contains the detailed structural and thermal analysis required to substantiate the adequacy of the design of the 173 in. I.D. Indian Point Reactor Vessel.

2.030 Scope

The detailed analytical work necessary to justify the reactor vessel and its associated parts included in the contract are contained in this report. All equations used are shown and intermediate answers and final answers are usually presented in tabular form.

APPENDIX A

DETAILED STRUCTURAL ANALYSIS

TABLE OF CONTENTS

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

CHARGE NO.

DESCRIPTION *Control Rod Housing Stress Analysis And Fatigue Evaluation*

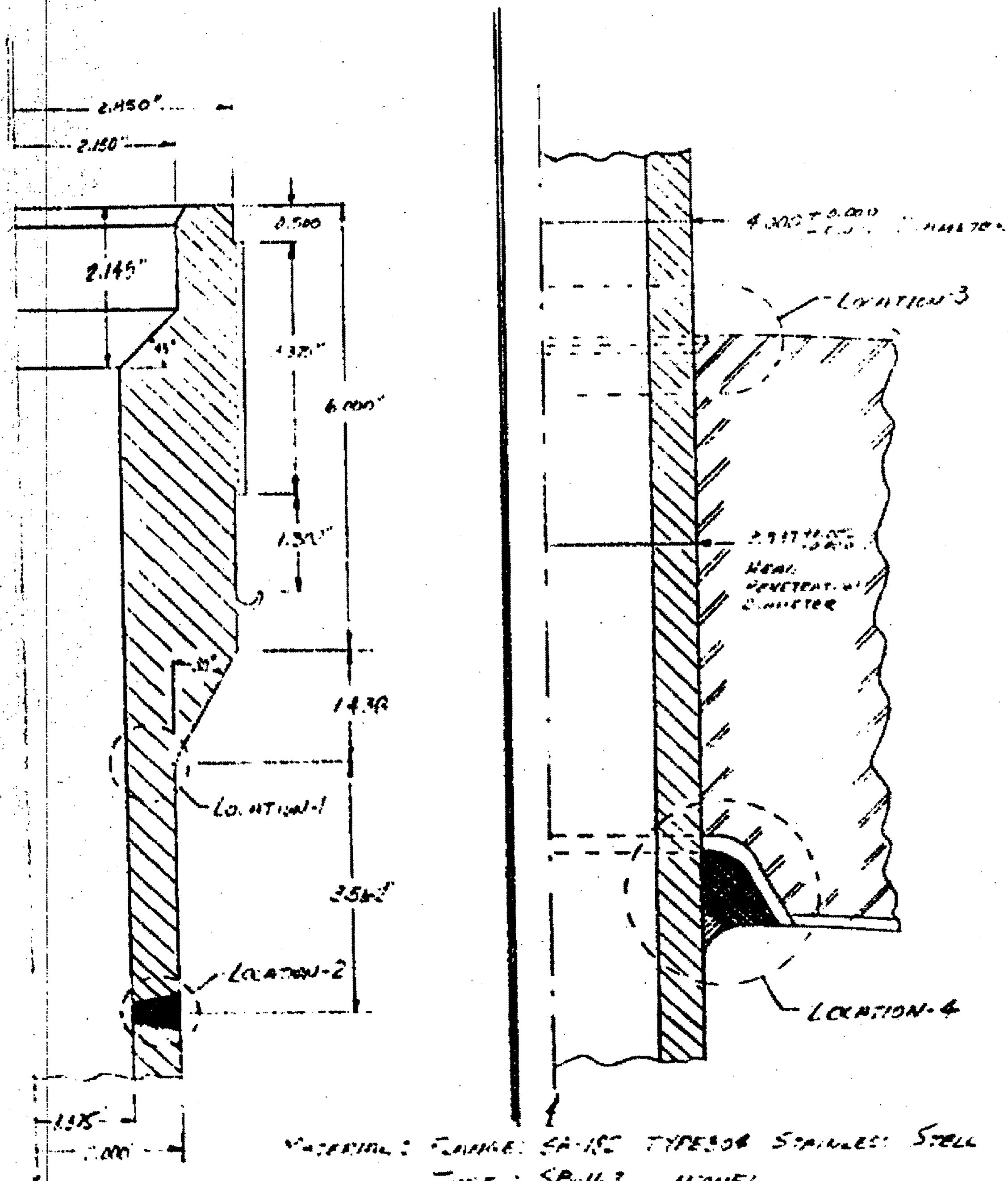
NUMBER

DATE 1-24-67 BY Cockrell

CHECK DATE 1-24-67 BY Cooley

5. Detailed Analysis:

a. System Geometry:



Material: Flange: SA-182 Type 304 Stainless Steel
Tube: SB-167 Inconel

Submitted: December 27, 2011

ACKNOWLEDGEMENT

Acknowledgement is hereby made of the important contributions rendered by the following individuals:

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J. S. Meek

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5. DETAILED ANALYSIS:

C. DEVELOPMENT OF CONTINUITY EQUATIONS

2. MOVEMENTS DUE TO REDUNDANT AND APPLIED LOADS:

BODY-1:

DISPLACEMENTS DUE TO REDUNDANT FORCES:

$$E\Delta_{11} = \frac{R^2}{A_1}\bar{H} + h_1 \frac{R^2}{I_1}\bar{M} = -1.7569 H_1 + 0.3378 M_1$$

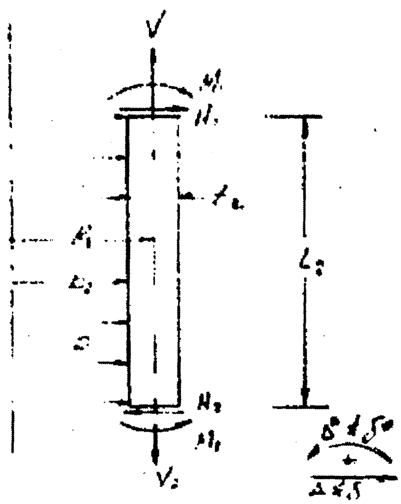
$$E\Delta_{11}^{*} = \frac{R^2}{I}\bar{M} = -0.3378 H_1 + 0.1109 M_1$$

DISPLACEMENTS DUE TO APPLIED FORCES:

$$E\delta_{11} = \frac{R^2}{A}\bar{H} + h_1 \frac{R^2}{I_1}\bar{M} = 3.1937P$$

$$E\delta_{11}^{*} = \frac{R^2}{I_1}\bar{M} = 1.1387P$$

BODY-2:



$R_2 = 1.698"$ $L_2 = .562"$

$h_2 = .75"$

$t_2 = 0.625"$

$\beta^4 = \frac{3(1-\nu^2)}{R^2 t^2} = 2.45278$ $\beta^2 = 1.56613$

$\beta = 1.25145$

$D = \frac{E t^3}{12(1-\nu^2)} = 0.02236E$

$V_2 = 0.560P$

NOTE THAT FOR BODY-2 TO BE A LONG CYLINDER, βL MUST BE GREATER THAN 3. THE ACTUAL βL = 4.40; HENCE BODY-2 IS A LONG CYLINDER.

5. Detailed Analysis:

e. Development Of Continuity Equations:

2. Movements Due To Redundant And Applied Forces:

Body-2:

Displacements Due To Redundant Forces:

$$E\Delta_{21} = \frac{E}{2\beta^3 D}\left[\frac{1}{\beta}H_1 + M_1\right] = 11.4090 H_1 + 14.2776 M_1$$

$$E\Delta^*_{21} = \frac{-E}{2\beta^2 D}\left[H_1 + 2\beta M_1\right] = -14.2776 H_1 - 35.7398 M_1$$

$$E\Delta_{22} = \frac{-E}{2\beta^3 D}\left[\frac{1}{\beta}H_2 - M_2\right] = -11.4090 H_2 + 14.2776 M_2$$

$$E\Delta^*_{22} = \frac{-E}{2\beta^2 D}\left[H_2 - 2\beta M_2\right] = -14.2776 H_2 + 35.73[illegible] M_2$$

Displacements Due To Applied Loads:

$$E\delta_{21} - E\delta_{22} = \frac{b_2^2}{t_2}\left(\frac{R_1}{b_2} - \frac{\nu}{2}\right)P = 3.2599P$$

$$E\delta^*_{21} = E\delta^*_{22} = 0$$

Displacements Due To Thermal Effects:

$$E\delta_{22} = b_2 E\alpha_m (T_m - 70) = 291.823$$

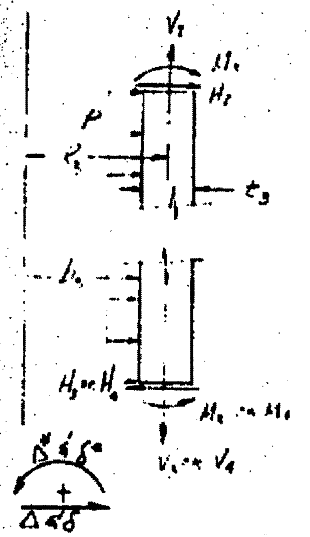
For $E\alpha = 0.247$ k/°F, $T_m = 650°F$

$$E\delta^*_{22} = 0$$

Due To The Difference In Coefficients Of Thermal Expansion For The 304 Stainless Steel And The Inconel Materials, A Mismatch In Radial Expansion Occurs At Cut-2 On A Rise In Temperature. This Mismatch Will Cause Thermal Stresses. An Interaction Analysis Of The Junction Will Enable Stresses To Be Calculated For Both Pressure And Temperature. Note Also That The Difference In Elastic Moduli Is Taken Into Account.

5- DETAILED ANALYSIS:
e. DEVELOPMENT OF CONTINUITY EQUATIONS:
2. MOVEMENTS DUE TO REDUNDANT AND APPLIED FORCES:

BODY-3:



$R_3 = 1.658''$
$b_3 = 1.375''$
$t_3 = 0.625$

$\beta^4 = \frac{3(1-\nu^2)}{R^2t^2} = 2.45278 \quad \beta^2 = 1.56613$
$\beta = 1.25145$

$D = \frac{Et^3}{12(1-\nu^2)} = 0.02236E$
$V_2 = V_3 = 0.560P$

$\frac{E_{SS}}{E_{INCO}} = 0.93013$ @ 650°F

DISPLACEMENTS DUE TO REDUNDANT FORCES

$E\Delta_{22} = \frac{E_{ss}}{2\beta^3D}\left[\frac{1}{\beta}H_2 + M_2\right]\frac{E_{SS}}{E_{INCO}} = 10.0416H_2 + 12.5661M_2$
$E\Delta^*_{22} = \frac{-E_{ss}}{2\beta^2D}\left[H_2 + 2\beta M_2\right]\frac{E_{SS}}{E_{INCO}} = -12.5661H_2 - 31.4557M_2$
(IN TERMS OF YIELD MOMENTS OR FORCES)

$E\Delta_{33} = \frac{-E}{2\beta^3D}\left[\frac{1}{\beta}H_3 - M_3\right] = -11.4090H_3 + 14.2776M_3$

$E\Delta^*_{33} = \frac{-E}{2\beta^2D}\left[H_3 - 2\beta M_3\right] = -14.2776H_3 + 35.7358M_3$

$E\Delta_{44} = \frac{-E}{2\beta^3D}\left[\frac{1}{\beta}H_4 - M_4\right] = -11.4090H_4 + 14.2776M_4$

$E\Delta^*_{44} = \frac{-E}{2\beta^2D}\left[H_4 - 2\beta M_4\right] = -14.2776H_4 + 35.7358M_4$

Submitted: December 27, 2011

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

CHARGE NO. ____________

DESCRIPTION: Control Rod Housing Stress Analysis And Fatigue Evaluation

NUMBER ____ SHEET 13 OF 27

DATE 1-24-67 BY Cockrell

CHECK DATE 1-24-67 BY Caudle

5- Detailed Analysis:

C. Development Of Continuity Equations:

2- Movements Due To Redundant And Applied Forces

Body-3:

Displacements Due To Applied Forces:

$$E\delta_{32} = \frac{b_3^2}{t_3}\left(\frac{R_3}{b_3} - \frac{\nu}{2}\right)\frac{E_{brass}}{E_{Inconel}} = \frac{(1.375)^2}{0.625}\left(\frac{1.4?}{1.375} - \frac{0.3}{2}\right)(0.88013) = \underline{2.8591P}$$ *

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

$$E\delta_{33} = E\Delta_{INT} + \frac{b_3^2}{t_3}\left(\frac{R_3}{b_3} - \frac{\nu}{2}\right) = \underline{E\Delta_{INT} + 3.2599P}$$

(See Note Below) $(\Delta_{INT})_{MAX} = 0.0015''$

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

$$E\delta_{34} = \frac{b_3^2}{t_3}\left(\frac{R_3}{b_3} - \frac{\nu}{2}\right) = 3.2599P$$

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

* In Terms Of Young's Modulus Of 304SS.

Note That Stresses Are Developed Where The Control Rod Housing Enters The Closure Head Due To The Interference Fit (Designated By $E\Delta_{INT}$ Above) And The Expansion Of The Pipe Due To Pressure. The Net Deflection Of The Housing Is Assumed To Be Equal To The Deflection Of The Hole In The Head Taking Into Account Of The Original Interference Fit. Rotation Of The Housing Is Assumed To Be Zero.
Theoretically The Head Expands More Under Pressure Than The Housing Does (See $E\Delta_{43}$ Due To Pressure As Given On Sheet-15). When The Point Is Reached Where There Is No Longer Contact Between The Head And The Housing, The Interaction Equations Are No Longer Valid. When This Occurs, The Stresses In The Housing Becomes Equal To The Pressure Stresses Alone.
Note Also That The Interference Fit Is Relieved Due To A Rise In Temperature; This Effect Will Be Accounted For In The Fatigue Evaluation.

3.000 DESIGN CRITERIA

The design shall be in accordance with the ASME Boiler and Pressure Vessel Code Section III, Nuclear Vessels and Special Case Rulings in effect on the date of purchase order.

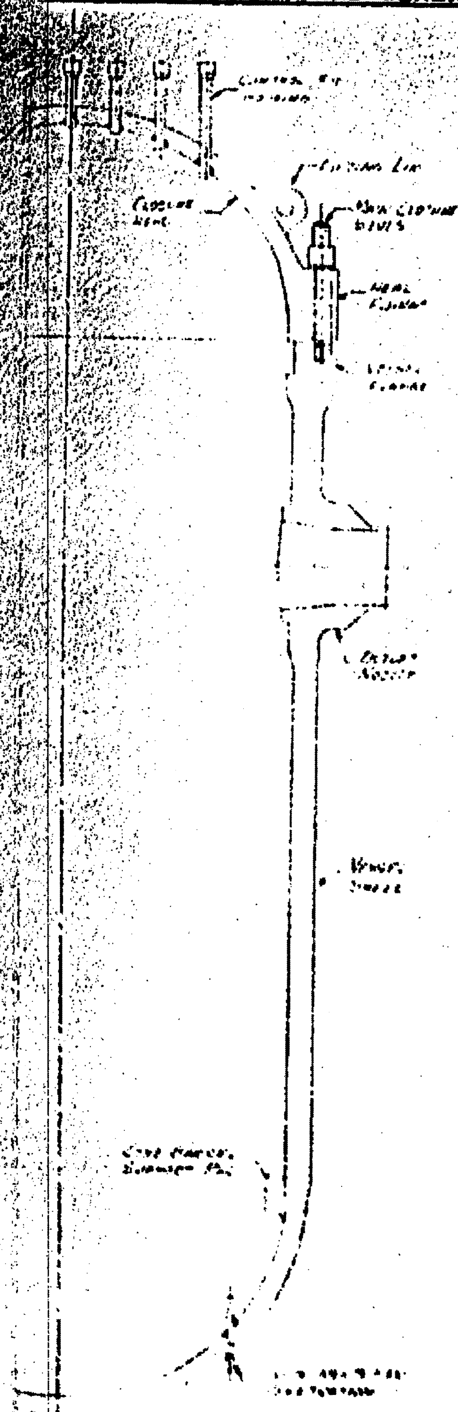
The design parameters used were

Design Pressure.............................. 2500 psia
Normal Operating Pressure .... 2235 psig
Design Temperature .... 650°F
Normal Operating Inlet Water Temp........... 557°F
Normal Operating Outlet Water Temp.........611.7°F
Design Life .... 40 years

	Transient Condition	Occurrences	Ref. Fig. in Ref. 19
1.	Plant heatup at 100°F/Hr.	200	4.4.1
2.	Plant cooldown at 100°F/Hr.	200	4.4.1
3.	Plant loading at 5% of full power per min.	14,500	4.4.2
4.	Plant unloading at 5% of full power per min.	14,500	4.4.2
5.	Step load increase 10% of full power - not to exceed full power	2,000	4.4.3
6.	Step load decrease of 10% from 50% power	2,000	4.4.3
7.	Step load decrease of 50% of full power	200	4.4.4
8.	Reactor trip	400	4.4.5
9.	Hydro test 3125 psia	5	4.4.6
10.	Hydro test 2500 psia	5	4.4.7
11.	Steady state fluctuations	10^6	None
12.	Loss of flow, one pump	80	4.4.8
13.	Loss of load	80	4.4.9
14.	Steam break	5	

Material Allowables	Sm @ 70°F	Sm @ 550°F
SA-240 Typ. 316	20.0 KSI	17.6 KSI
SA-302B	26.7	26.7
SA-336	26.7	26.7
ASTM-A540-B24	43.3	36.8
Inconel	23.3	23.3

4.000 GEOMETRY AND GENERAL CONFIGURATION



This sketch shows the general configuration and relative locations of component parts. The nomenclature shown is used consistently throughout this report. For detailed drawings of component parts, see Appendix C.

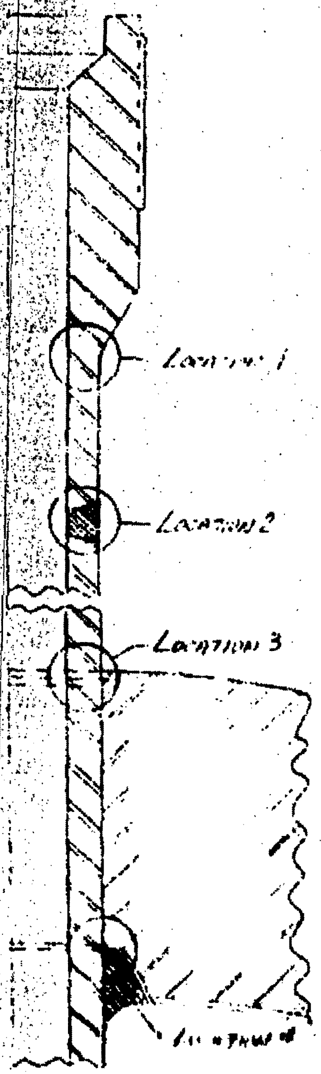
Reference Drawings

Title	Drawing No.
1. Control Rod Mechanism Housing Details	E-234-051
2. Control Rod Penetration Details	E-234-052
3. Closure Head Forming & Welding	E-234-046
4. Closure Head Machining	E-234-047
5. Stud, Nut & Washer Detail	E-234-049
6. Pressure Vessel Forming & Welding	E-234-042
7. Pressure Vessel Final Machining	E-234-044
8. Nozzle Details	E-23[illegible]-045
9. Miscellaneous Attachments	E-23[illegible]-050
10. Miscellaneous Details	E-23[illegible]-055
11. Bottom Head Forming & Welding	E-234-043
12. Instrumentation Penet. Assembly & Details - Bottom Head	E-23[illegible]-056

5.000 SUMMARY OF RESULTS

Results of the detailed structural analysis presented in Appendix A are summarized on Pages 7 through 17 for locations of major interest.

5.010 CONTROL ROD HOUSINGS



Location - 1

Stresses Due to Operating Pressure of 2.25 KSI

SURFACE	STRESS			STRESS INTENSITY		
	σ_x	σ_θ	σ_r	$\sigma_x - \sigma_\theta$	$\sigma_x - \sigma_r$	$\sigma_\theta - \sigma_r$
INSIDE	2.27	4.20	-2.25	-3.43	2.52	6.45
OUTSIDE	3.76	5.25	0	1.49	3.76	5.25

The maximum stress intensity for operating pressure is $\sigma_\theta - \sigma_r = 6.45$ KSI on the inside surface.

The overall usage factor for fatigue was U = 0.

Location - 2

Stresses Due to Operating Pressure of 2.5 KSI and Design Temperature of 650°F

SURFACE	STRESS			STRESS INTENSITY		
FOR SA-182 TYPE 304SS FLANGE						
	σ_x	σ_θ	σ_r	$\sigma_x - \sigma_\theta$	$\sigma_x - \sigma_r$	$\sigma_\theta - \sigma_r$
INSIDE	3.21	-10.47	-2.5	13.68	5.71	-7.97
OUTSIDE	1.27	-11.07	0	12.34	1.27	-11.07
FOR SB-167 INCONEL TUBE						
INSIDE	3.21	23.14	-2.5	-19.93	5.71	25.64
OUTSIDE	1.27	22.54	0	-21.27	1.27	22.54

The maximum stress intensity for design pressure of 2.5 KSI and the design temperature of 650°F is $\sigma_\theta - \sigma_r = 25.6$ KSI and was located on the inside surface of the inconel tube material.

The overall usage factor for fatigue was U = 0.

Location - 3

Stresses Due to Operating Pressure of 2.25 KSI and Maximum and Minimum Interference Fit with Closure Head

Surface	Interference = 0.003			Pressure = 0			Interference = 0.003			Pressure = 2.25 KSI		
	Stress			Stress Intensity			Stress			Stress Intensity		
	σ_x	σ_θ	σ_r	$\sigma_x-\sigma_\theta$	$\sigma_x-\sigma_r$	$\sigma_\theta-\sigma_r$	σ_x	σ_θ	σ_r	$\sigma_x-\sigma_\theta$	$\sigma_x-\sigma_r$	$\sigma_\theta-\sigma_r$
Inside	27.35	-19.35	0	46.70	27.35	-19.55	14.37	-5.03	-2.25	19.90	17.12	-2.78
Outside	-27.35	-35.75	0	9.40	-27.35	-35.75	-12.09	-13.49	0	1.40	-12.09	-13.49
	Interference = 0			Pressure = 0			Interference = 0			Pressure = 2.25 KSI		
Inside	0	0	0	0	0	0	-12.49	14.32	-2.25	-26.80	-10.73	16.57
Outside	0	0	0	0	0	0	15.26	22.26	0	-7.00	15.26	22.26

The maximum stress intensity is $\sigma_x - \sigma_\theta$ = 46.7 KSI and occurs for the condition of maximum interference and zero internal pressure. This stress intensity is on the inside surface.

The maximum range of stress is 55.3 KSI and occurs on the inside surface.

The overall usage factor for fatigue was U = 0.0003.

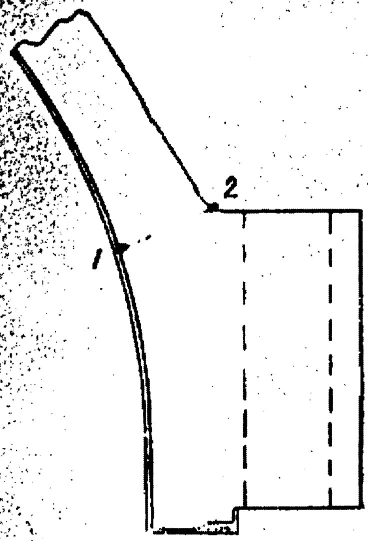
Location - 4

The maximum stress intensity for the J-weld is $\sigma_x - \sigma_\theta$ = 42.2 KSI and occurs on the inside surface. The maximum range of stress intensity is 42.8 at the same location.

The overall usage factor for fatigue was U = 0.06 and occurred on the outside surface.

5.020 CLOSURE HEAD FLANGE AND SHELL

Primary Stress Intensities



Bolt Up Condition

Location	Stress			Stress Intensity		
	σ_x	σ_θ	σ_r	$\sigma_x-\sigma_\theta$	$\sigma_x-\sigma_r$	$\sigma_\theta-\sigma_r$
1	-21.7	-2.5	0	-19.2	-21.7	-2.5
2	23.4	13.9	0	9.5	23.4	13.9
	Bolt-Up Plus Design Press. = 2.5 KSI					
1	-12.2	6.1	-2.5	-18.3	-9.6	8.6
2	35.8	24.0	0	11.8	35.8	24.0

Range of Stress Intensity

The highest range of stress intensity for the head flange to closure head juncture was located on the inside surface (Location - 1). The value of this range of stress intensity is 50.4 KSI and compares favorably with the allowable of 80 KSI.

Fatigue Evaluation

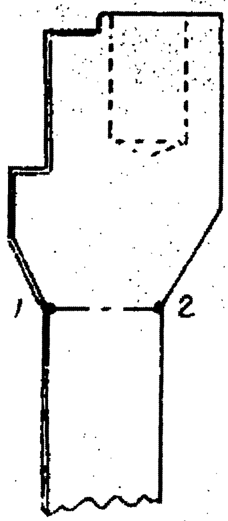
The following overall usage factors were calculated at the two above locations:

Location - 1 U = 0.004

Location - 2 U = 0.015

The maximum allowable usage factor is 1.0.

5.030 VESSEL FLANGE AND SHELL



Primary Stress Intensity

Bolt Up Condition

LOCATION	STRESS			STRESS INTENSITY		
	σ_x	σ_θ	σ_r	$\sigma_x-\sigma_\theta$	$\sigma_x-\sigma_r$	$\sigma_\theta-\sigma_r$
1	-20.8	-4.7	0	-16.1	-20.8	-4.7
2	20.9	7.8	0	13.0	20.8	7.9
	BOLT-UP PLUS DESIGN PRESS = 25KSI					
1	-10.2	14.1	-2.5	-24.3	-7.7	16.6
2	28.8	25.8	0	3.0	29.9	25.8

Range of Stress Intensity

The highest range of stress intensity for the vessel flange to vessel shell juncture was located on the inside surface (Location - 1). The value of this range of stress intensity is 45.4 KSI and compares favorably with the allowable of 80 KSI.

Fatigue Evaluation

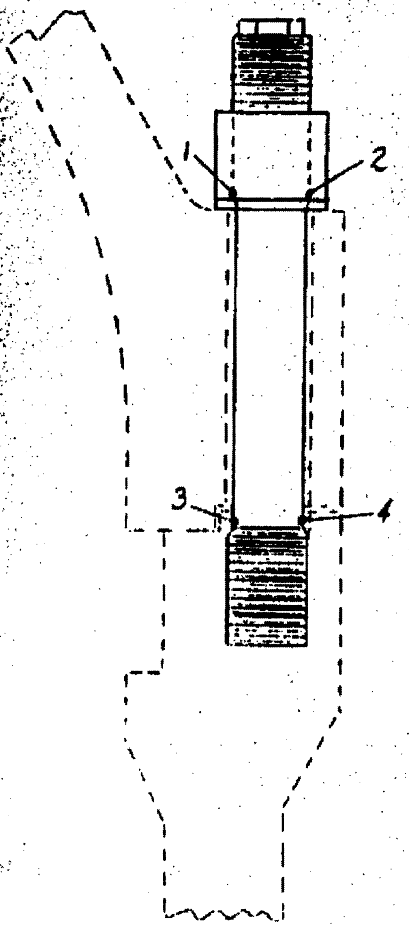
The following overall usage factors were calculated at the two above locations:

Location - 1 U = 0.005

Location - 2 U = 0.00002

The maximum allowable usage factor is 1.0.

5.040 MAIN CLOSURE STUDS



Average Bolt Stress:

The average bolt stress resulting from the design pressure flow off load plus O-ring seating load was 34.4 KSI. The allowable stress is 34.8 KSI.

Maximum Average Bolt Service Stress

The maximum average bolt service stress for the bolt-up condition was 36.8 KSI compared to the allowable of 86.6 KSI. For the bolt-up plus operating pressure condition, this stress was 39.6 KSI compared to the allowable of 73.5 KSI.

Maximum Bolt Service Stress

The maximum bolt service stress was 95.9 KSI and occurred at Location - 3. This stress occurred during the heat-up cycle of the 2500 psi hydrostatic test. This stress compares favorably with the allowable of 116.4 KSI.

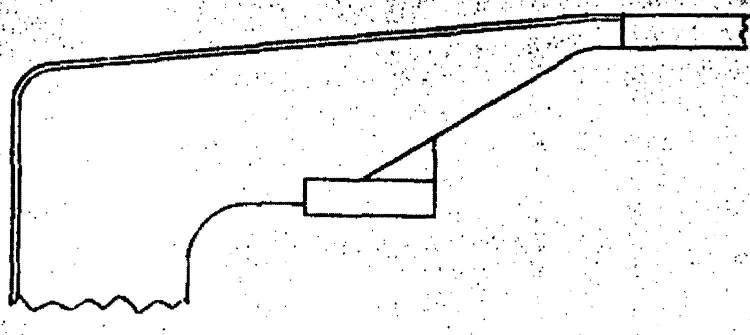
Fatigue Evaluation

The maximum overall usage factor for the closure studs was U = 0.313 and occurred at the point where it enters the vessel flange (Location - 3). This usage factor compares favorably with the allowable of 1.0.

Maximum Bearing Stress

The maximum bearing stress between the closure stud washer and closure head flange was 39.8 KSI and compares with the allowable of 40 KSI for the flange material. This value occurred during the heatup cycle of the 2500 psi hydrostatic test.

5.050 INLET NOZZLE AND VESSEL SUPPORT



Primary Membrane Stress Intensity

The maximum average primary membrane stress intensity for the inlet nozzle was at the juncture of the nozzles to the vessel wall on the longitudinal axis. The value of this stress intensity was 21.1 KSI and compares favorably with the allowable of 26.7 KSI.

The same location gave the highest value of average primary plus local primary stress. The value of this stress intensity was 32.3 KSI and compares favorably with the allowable of 1.5 S_m = 40 KSI.

Range of Stress Intensity

The highest range of stress intensity occurred at the juncture of the nozzle to vessel wall on the outside surface in the longitudinal direction. The value of this range of stress intensity was 45.5 KSI and compares favorably with the allowable of 80 KSI.

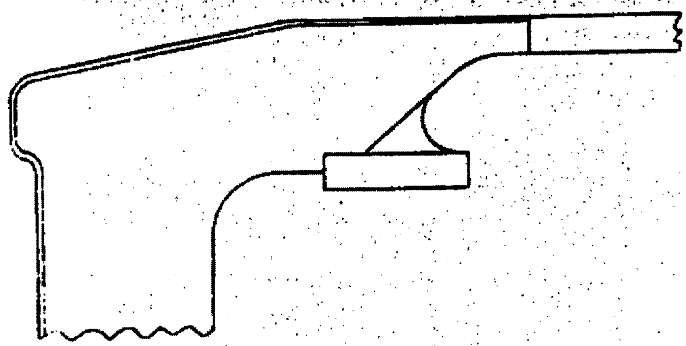
Bearing Stress on Support Pad

The bearing stress on the underside of the support pad for dead weight and thermal pipe reactions only was 3.0 KSI. This stress was not to exceed 5.0 KSI for this condition.

Fatigue Evaluation

The maximum overall usage factor for the inlet nozzle was U = 0.042 and occurred at the nozzle-vessel wall juncture on the outside surface in the circumferential direction. This value compares favorably with the allowable of 1.0.

5.060 OUTLET NOZZLE AND VESSEL SUPPORT



Primary Membrane Stress Intensity

The maximum average primary membrane stress intensity for the outlet nozzle was at the juncture of the nozzle to the vessel wall on the longitudinal axis. The value of this stress intensity was 21.1 KSI and compares favorably with the allowable of 26.7 KSI.

The same location gave the highest value of average primary plus local primary stress. The value of this stress intensity was 32.3 KSI and compares favorably with the allowable of $1.5\ S_m = 40$ KSI.

Range of Stress Intensity

The highest range of stress intensity occurred at the juncture of the nozzle to vessel wall on the outside surface in the longitudinal direction. The value of this range of stress intensity was 45.5 KSI and compares favorably with the allowable of 80 KSI.

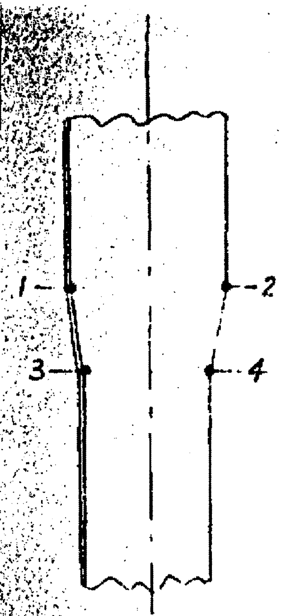
Bearing Stress on Support Pad

The bearing stress on the underside of the support pad for dead weight and thermal pipe reactions only was 3.6 KSI. This stress was not to exceed 5.0 KSI for this condition.

Fatigue Evaluation

The maximum overall usage factor for the outlet nozzle was U = 0.022 and occurred at the nozzle-vessel juncture on the inside surface in the longitudinal direction. This value compares favorably with the allowable of U = 1.0.

5.070 VESSEL WALL TRANSITION



Primary Membrane Stress Intensity

The maximum average primary membrane stress intensity for the vessel wall transition occurs in the thin portion of the vessel wall. The value of this stress intensity was 26.3 KSI and compares favorably with the allowable stress intensity of 26.7 KSI.

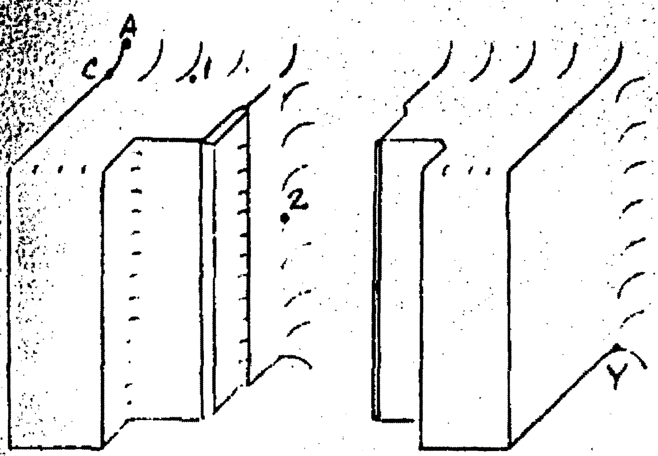
Range of Stress Intensity

The highest range of stress intensity occurred at Location - 1 as shown above. The value of this range of stress intensity was 37.9 KSI and compares favorably with the allowable of 80 KSI.

Fatigue Evaluation

The maximum overall usage factor for the vessel wall transition was U = 0.002 and occurredat Location - 2 as shown above. This value compares favorably with the allowable of U = 1.0.

5.080 CORE BARREL SUPPORT PADS



Stresses Due to Insertion of Core

The maximum stress intensity during insertion of the core occurred at Location - 1. The value of this stress intensity was 10.7 KSI and compares favorably with the allowable of 35 KSI. The maximum shear stress occurs at Location -/ 2 and is 10.4 KSI which compares favorably with the allowable of 18.6 KSI.

Stresses Due to Steady Loads

The most critical stress intensity for the steady 125 KIP side load and steady 125 KIP vertical load (due to thermal growth) occurred at the vessel wall (Location - Y as shown above). The value of this stress intensity was 31.1 KSI and compares favorably with the allowable of 35 KSI.

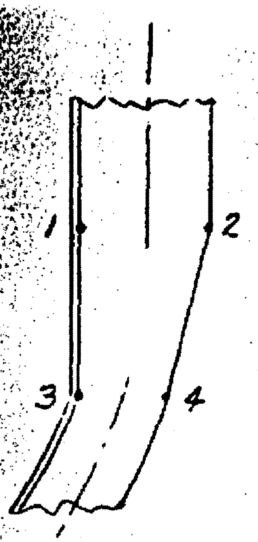
Range of Stress Intensity

The highest range of stress intensity occured at Location - C as shown above. The value of this range of stress intensity was 40.8 KSI and compares favorably with the allowable of 69.9 KSI.

Fatigue Evaluation

The fatigue evaluation disclosed that the highest overall usage factor for the pads was 0.02 and occurred at the upper corner of the pad at the pad-to-vessel juncture Location - A. This value compares favorably with the allowable of U = 1.0.

5.090 BOTTOM HEAD TO SHELL JUNCTURE



Primary Membrane Stress Intensity

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

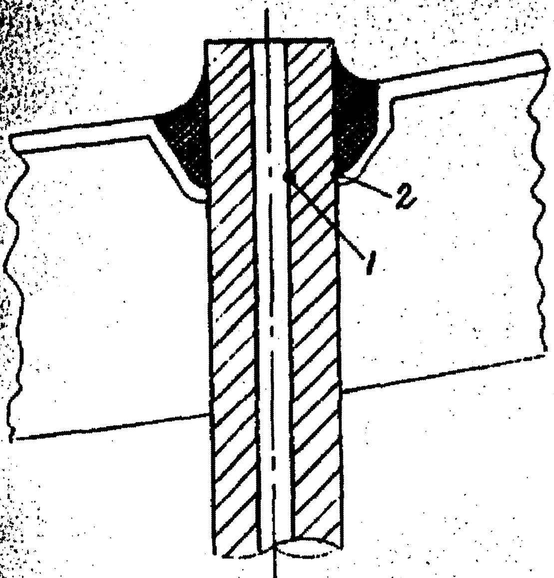
Range of Stress Intensity

The highest range of stress intensity occurred at Location - 3 as shown above. The value of this range of stress intensity was 34.1 KSI and compares favorably to the allowable range of stress intensity of 80 KSI.

Fatigue Evaluation

The fatigue evaluation disclosed that the highest overall usage factor for the bottom head to shell juncture was 0.003 and occurred at Location - 3 as shown above. This value compares favorably with the allowable of U = 1.0.

5.100 BOTTOM HEAD INSTRUMENTATION PENETRATIONS



Primary Membrane Stress Intensity

The maximum average primary membrane stress intensity occurs in the bottom head when taking into consideration the ligament efficiency. The value of the stress intensity is 26.5 KSI and compares favorably with the allowable of 26.7 KSI.

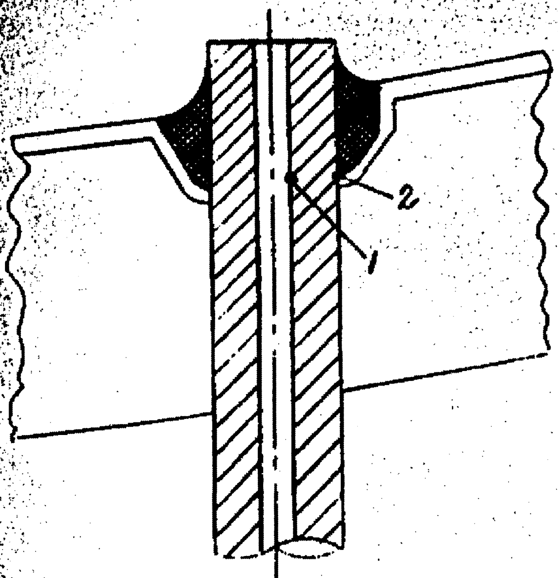
Range of Stress Intensity

The highest range of stress intensity occurred on the inside surface of the tube - Location - 1 as shown above. The value of this range of stress intensity is 55.2 KSI and compares favorably with the allowable of 69.9 KSI.

Fatigue Evaluation

The fatigue evaluation disclosed that the highest overall usage factor for the bottom head instrumentation was 0.14 and occurred on the outside surface of the tube - Location - 2 as shown above. The value compares favorably with the allowable of U = 1.0.

5.100 BOTTOM HEAD INSTRUMENTATION PENETRATIONS



Primary Membrane Stress Intensity

The maximum average primary membrane stress intensity occurs in the bottom head when taking into consideration the ligament efficiency. The value of the stress intensity is 26.5 KSI and compares favorably with the allowable of 26.7 KSI.

Range of Stress Intensity

The highest range of stress intensity occurred on the inside surface of the tube - Location - 1 as shown above. The value of this range of stress intensity is 55.2 KSI and compares favorably with the allowable of 69.9 KSI.

Fatigue Evaluation

The fatigue evaluation disclosed that the highest overall usage factor for the bottom head instrumentation was 0.14 and occurred on the outside surface of the tube - Location - 2 as shown above. The value compares favorably with the allowable of U = 1.0.

6.000 DISCUSSION OF RESULTS & METHOD OF ANALYSIS

6.010 Control Rod Housings

A. Discussion of Results

Location - 1

For the juncture of the CRDM flange to tube, the maximum stress intensity for design pressure is 7.2 KSI and occurs on the inside surface. The allowable for the 304 stainless steel at the design temperature is 1.5 S_m = 23 KSI.

Location - 2

For the 304 stainless steel at the bi-metallic weld, the maximum primary plus secondary stress intensity was 13.7 KSI on the inside surface. This stress intensity occurred for the design temperature and pressure. For the operating conditions, the maximum range of stress intensity was 11.1 KSI and compares favorably with the allowable of 3 S_m = 45.9 KSI.

For the inconel portion of the tube, the maximum stress intensity for the design conditions occurred on the inside surface. The value of this stress intensity was 25.6 KSI. For the operating transients, the maximum range of stress intensity was 21.8 KSI and compares favorably with the allowable of 3 S_m = 69.9 KSI.

Location - 3

At the point where the CRDM housing enters the closure head, stresses are induced in the tube at zero pressure due to the interference fit. The stress intensity at the maximum interference and zero pressure is 46.7 KSI. For the operating transients, the maximum range of stress intensity was 55.3 KSI and compares favorably with the allowable of 3 S_m = 69.9 KSI.

The fatigue evaluation revealed that the highest cumulative usage factor was 0.0003 for the inside surface. This compares favorably with the allowable of 1.0.

Location - 4

At the location where the CRDM housing is attached to the closure head by the J-weld, the maximum range of stress intensity is 42.8 KSI and compares favorably with the allowable of 3 S_m = 69.9 KSI. This range of stress intensity occurs on the inside surface.

From the standpoint of fatigue, the most critical location will be on the outside portion of the tube where a stress concentration factor of four was used. The cumulative usage factor at this location was 0.06 and compares favorably with the allowable of 1.0.

B. Method of Analysis

Location - 1

An interaction analysis was performed at cut one assuming the CRDM housing flange to be a ring and the tube a long cylinder.

Location - 2

An interaction analysis was performed at cut two taking into consideration that elements 2 and 3 are long cylinders having different values of Young's Modulus of Elasticity and coefficients of thermal expansion.

Location - 3

An interaction analysis was performed at cut three by taking the housing as a cylinder and setting its deflection equal to the deflection of the radius of the head penetration and conservatively assuming its rotation equal to the local flexibility as if it were solidly attached. It was assumed that the forces exerted on the head by the tube have negligible effect on the head.

Location - 4

An interaction analysis was performed by dividing the actual structure into the following analytical model: the closure head was treated as a perforated spherical shell with modified elastic constants and the CRDM housing as a long cylinder. The effects of the redundants on the closure 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.

6.020 CLOSURE HEAD FLANGE AND SHELL

A. Discussion of Results

The maximum primary stress intensity at the closure head flange to shell juncture was 35.8 KSI for the bolt-up plus design pressure condition. This stress occurs on the outside surface of the juncture of the head to flange and compares favorably with the allowable of 1.5 S_m = 40 KSI.

The highest range of stress intensity for this juncture was 50.4 KSI on the inside surface and compares favorably with the allowable of 3 S_m = 80 KSI.

The fatigue evaluation revealed that the highest cumulative usage factor was 0.015 and occurred for the outside surface. This value compares favorably with the allowable of 1.0.

B. Method of Analysis

The closure head, closure head flange, vessel flange, vessel shell, and closure studs were all evaluated in the same analysis. The actual structure was divided into the following elements: the closure head dome was treated as a long sphere, the closure head flange was treated as a ring, the vessel flange and studs were combined as one element with the flange treated as a ring and the studs as cantilever beams fixed to the flange, and the vessel shell was treated as a long cylinder.

Using the above described analytical model, an interaction analysis was performed to determine the stresses due to the mechanical and thermal loadings for the heatup and cooldown cycle. For the remaining transients, the conservative skin stress method was used for determining thermal stresses. These stresses were evaluated in light of the strength and fatigue requirements of the ASME Boiler and Pressure Vessel Code, Section III.

6.030 VESSEL FLANGE AND SHELL

A. Discussion of Results

The maximum primary stress intensity at the vessel flange to vessel shell juncture was 28.8 KSI for the boltup plus design pressure condition. This stress occurred on the outside surface of the juncture flange to vessel shell and compares favorably to the allowable of 1.5 S_m = 40 KSI.

The highest range of stress intensity for this juncture was 45.4 KSI on the inside surface and compares favorably with the allowable of 3 S_m = 80 KSI.

The fatigue evaluation revealed that the highest cumulative usage factor was 0.005 and occurred for the inside surface. This value compares favorably with the allowable of 1.0.

B. Method of Analysis

See Section 6.020-B, Method of Analysis, Closure Head Flange and Shell.

6.040 MAIN CLOSURE STUDS

A. Discussion of Results

The maximum average bolt service stress for the cold boltup condition was 36.8 KSI and compares favorably with the allowable of 2 S_m = 86.6 KSI. For the boltup plus operating pressure, the average bolt service stress is 39.6 KSI and compares favorably with the allowable of 2 S_m = 73.5 KSI at temperature.

The maximum bolt service stress was 95.9 KSI and occurred on the inside surface of the stud where it enters the vessel flange. This stress occurred during the heatup cycle of the 2500 PSI hydrostatic test and compares favorably with the allowable of 3 S_m = 116.4 KSI.

A fatigue evaluation was performed on the studs using the method outlined in Para. N-416.2 of the ASME Boiler and Pressure Vessel Code, Section III. The maximum cumulative usage factor for the studs was 0.313 on the inside surface of the stud where it enters the vessel flange. The allowable usage factor is 1.0.

The maximum bearing stress between the closure stud washers and closure head flange was 39.8 KSI. This stress occurred during the heatup cycle of the 2500 PSI hydrostatic test and compares favorably with the allowable of 1.5 S_m for the flange material.

B. Method of Analysis

See Section 6.020-B, Method of Analysis, Closure Head Flange and Shell.

6.050 INLET NOZZLE AND VESSEL SUPPORTS

A. Discussion of Results

The maximum average primary membrane stress intensity for the inlet nozzle occurred at the juncture of the nozzle to the vessel wall on the longitudinal axis. The value of this stress intensity was 21.1 KSI and compares favorably with the allowable of 26.7 KSI.

The same location gave the highest value of average primary plus local primary stress. The value of this stress intensity was 32.3 KSI and compares favorably with the allowable of 1.5 S_m = 40 KSI.

The highest range of stress intensity for the operating transients occurred at the juncture of the nozzle to vessel wall on the outside surface in the longitudinal direction. The value of this range of stress intensity was 45.5 KSI and compares favorably with the allowable of 80 KSI.

The bearing stress on the underside of the support pad for dead weight and the thermal pipe reactions only was 3.0 KSI. This stress was to be limited to 5.0 KSI under this condition.

The fatigue evaluation revealed that the highest cumulative usage factor was 0.042 and occurred at the nozzle to vessel wall juncture on the outside surface in the circumferential direction. This value compares favorably with the allowable of 1.0. The cumulative usage factor through the nozzle wall and weld built-up support pad was found to be 0.007 on the outside surface of the pad.

B. Method of Analysis

For the analysis of the nozzle and nozzle to shell juncture, the loads considered were internal pressure, operating transients, thermally induced and seismic pipe reactions, static weight of vessel, earthquake loading, and expansion and contraction.

The stresses resulting from all external loads were determined in the nozzle by the use of the standard formula for direct stress plus bending stress in a beam. At the juncture of the nozzle to vessel wall, these stresses were determined by the methods presented in references 19, 20, and 21.

The pressure stresses were determined in the nozzle by performing an interaction analysis. The actual structure was divided into the following elements: the thin portion of the nozzle was treated as a cylinder, the tapered portion was treated as a tapered cylinder, the reinforcement portion was treated as a cylinder, and the vessel was treated by idealizing it as a spherical segment of the same thickness as the vessel and with a mid-radius 1.5 times the actual radius of the vessel.

The thermal stresses for the operating transients were determined by performing an interaction with the above analytical model.

For the fatigue evaluation, pressure stresses were determined by the stress index method set forth in Article I-6 of the ASME Boiler and Pressure Vessel Code, Section III. Peak stresses resulting from the external loads and the thermal transients were determined by concentrating the stresses as determined by the above described methods. Combining these stresses enabled the fatigue evaluation to be performed.

6.060 OUTLET NOZZLE AND VESSEL SUPPORT

A. Discussion of Results

The maximum average primary membrane stress intensity for the outlet nozzle occurred at the juncture of the nozzle to the vessel wall on the longitudinal axis. The value of this stress intensity was 21.1 KSI and compares favorably with the allowable of 26.7 KSI.

The same location gave the highest value of average primary plus local primary stress. The value of this stress intensity was 32.3 KSI and compares favorably with the allowable of 1.5 S_m = 40 KSI.

The highest range of stress intensity for the operating transients occurred at the juncture of the nozzle to vessel wall on the outside surface in the longitudinal direction. The value of this range of stress intensity was 54.1 KSI and compares favorably with the allowable of 80 KSI.

The bearing stress on the underside of the support pad for the dead weight and the thermal pipe reactions only was 3.6 KSI. This stress was to be limited to 5.0 KSI under this condition.

The fatigue evaluation revealed that the highest cumulative usage factor was 0.022 and occurred at the nozzle to vessel wall juncture on the inside surface in the longitudinal direction. This value compares favorably with the allowable of 1.0. The cumulative usage factor through the nozzle wall and the weld built-up support pad was found to be 0.011 on the outside surface of the pad.

B. Method of Analysis

See Section 6.050, Method of Analysis, Inlet Nozzle and Vessel Supports for the method of analysis.

6.070 VESSEL WALL TRANSITION

A. Discussion of Results

The maximum average primary stress intensity for the vessel wall transition occurs in the thin portion of the vessel wall. 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 inside surface at the large end of the taper. The value of this range of stress intensity was 37.9 KSI and compares favorably with the allowable of $3\ S_m = 80$ KSI.

The fatigue evaluation revealed that the highest cumulative usage factor was 0.002 and occurred on the outside surface at the large end of the taper. 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