From: Elton, Loree [leelton@STPEGS.COM]
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To: Muniz, Adrian; Dyer, Linda; Wunder, George; Tonacci, Mark; Eudy, Michael; Plisco, Loren; Anand, Raj; Foster, Rocky; Joseph, Stacy; Govan, Tekia; Tai, Tom
Subject: Transmittal of Letter U7-C-STP-NRC-100019
Attachments: U7-C-STP-NRC-100019 + Enclosure.pdf

Please find attached a courtesy copy of letter number U7-C-STP-NRC-100019, which contains the response to the NRC staff question included in Request for Additional Information (RAI) letter number 305 related to Combined License Application (COLA) Part 2, Tier 2, Section 4.6.

The official version of this correspondence will be placed in today's mail. Please call John Price at 972-754-8221 if you have any questions concerning this letter.

Loree Elton
Licensing, STP 3 & 4
leelton@stpegs.com
361-972-4644

Hearing Identifier: SouthTexas34Public_EX
Email Number: 2022

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From: Elton, Loree

Created By: leelton@STPEGS.COM

Recipients:
"Muniz, Adrian" <Adrian.Muniz@nrc.gov>
Tracking Status: None
"Dyer, Linda" <lcdyer@STPEGS.COM>
Tracking Status: None
"Wunder, George" <George.Wunder@nrc.gov>
Tracking Status: None
"Tonacci, Mark" <Mark.Tonacci@nrc.gov>
Tracking Status: None
"Eudy, Michael" <Michael.Eudy@nrc.gov>
Tracking Status: None
"Plisco, Loren" <Loren.Plisco@nrc.gov>
Tracking Status: None
"Anand, Raj" <Raj.Anand@nrc.gov>
Tracking Status: None
"Foster, Rocky" <Rocky.Foster@nrc.gov>
Tracking Status: None
"Joseph, Stacy" <Stacy.Joseph@nrc.gov>
Tracking Status: None
"Govan, Tekia" <Tekia.Govan@nrc.gov>
Tracking Status: None
"Tai, Tom" <Tom.Tai@nrc.gov>
Tracking Status: None

Post Office: exgmb1.CORP.STPEGS.NET

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Nuclear Operating Company

South Texas Project Electric Generating Station 4000 Avenue F - Suite A Bay City, Texas 77414

January 25,2010
U7-C-STP-NRC-100019

U. S. Nuclear Regulatory Commission
Attention: Document Control Desk
One White Flint North
11555 Rockville Pike
Rockville MD 20852-2738

South Texas Project
Units 3 and 4
Docket Nos. 52-012 and 52-013
Response to Request for Additional Information

Attached is the response to the NRC staff question included in Request for Additional Information (RAI) letter number 305 related to Combined License Application (COLA) Part 2, Tier 2, Section 4.6. The attachment addresses the response to RAI question 04.06-4 and references the enclosure which provides the requested topical report GENE-637-019-0893, Revision 0, "Analysis Guidelines for Backfill Modification of RPV Water Level Instrumentation." This submittal completes the response to RAI letter number 305.

There are no commitments in this letter.

If you have any questions, please contact me at (361) 972-7136, or Bill Mookhoek at (361) 972-7274.

I declare under penalty of perjury that the foregoing is true and correct.

Executed on 1/25/10

Scott Head
Manager, Regulatory Affairs
South Texas Project Units 3 & 4

Attachment: RAI 04.06-4

Enclosure: RAI 04.06-4 Topical Report, GENE-637-019-0893, Rev. 0, "Analysis Guidelines for Backfill Modification of RPV Water Level Instrumentation," August 1993

cc: w/o attachment except*
(paper copy)

Director, Office of New Reactors
U. S. Nuclear Regulatory Commission
One White Flint North
11555 Rockville Pike
Rockville, MD 20852-2738

Regional Administrator, Region IV
U. S. Nuclear Regulatory Commission
611 Ryan Plaza Drive, Suite 400
Arlington, Texas 76011-8064

Kathy C. Perkins, RN, MBA
Assistant Commissioner
Division for Regulatory Services
Texas Department of State Health Services
P. O. Box 149347
Austin, Texas 78714-9347

Alice Hamilton Rogers, P.E.
Inspection Unit Manager
Texas Department of State Health Services
P.O. Box 149347
Austin, TX 87814-9347

C. M. Canady
City of Austin
Electric Utility Department
721 Barton Springs Road
Austin, TX 78704

*Steven P. Frantz, Esquire
A. H. Gutterman, Esquire
Morgan, Lewis & Bockius LLP
1111 Pennsylvania Ave. NW
Washington D.C. 20004

*George F. Wunder
*Tekia Govan
Two White Flint North
11545 Rockville Pike
Rockville, MD 20852

(electronic copy)

*George F. Wunder
*Tekia Govan
Loren R. Plisco
U. S. Nuclear Regulatory Commission

Steve Winn
Joseph Kiwak
Eli Smith
Nuclear Innovation North America

Jon C. Wood, Esquire
Cox Smith Matthews

J. J. Nesrsta
Kevin Pollo
L. D. Blaylock
CPS Energy

RAI 04.06-4

QUESTION:

This is a follow-up RAI to RAI 2370. In order to complete the review of the applicant's response to RAI 2370, provide the topical report GENE-637-019-0893, "Analysis Guidelines for Backfill Modification of RPV Water Level Instrumentation," Rev. 0.

RESPONSE:

To support the NRC confirmation of the correct purge flow rate for the water level instrumentation flow control system, STPNOC is providing as an enclosure to this RAI a copy of GENE-637-019-0893, "Analysis Guidelines for Backfill Modification of RPV Water Level Instrumentation," Revision 0. The correct purge flow rate is found in Section 1.2 of the report.

No COLA changes or revisions are required as part of this response.

GENE-637-019-0893, Rev 0
DRF A00-05696
August 1993

Analysis Guidelines

for

Backfill Modification of RPV Water Level Instrumentation

Prepared for BWR Owners' Group

D. K. Rao
H. S. Mehta
P. Wei
J. L. Leong
R. Muralidharan
F. J. Moody

Reviewed by: J.K. Sawabe for
R. R. Ghosh, Lead Engineer
Nuclear Boiler System

Hwang Choe
H. Choe, Project Manager
Special Plant Applications

Approved by: [illegible] for
G. B. Stramback, Project Manager
BWROG Water Level Project

General Electric Company
San Jose, California
August 1993

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this document is gratefully appreciated.

M. K. Parker
J. D. Solomon
H. Hwang
D. T. Reamon
G. Ballas
D. Young
M. Esfarjany
T. H. Le
S. S. Wang
L. H. Youngborg

IMPORTANT NOTICE REGARDING CONTENTS OF THIS REPORT

Please Read Carefully

The only undertaking of General Electric Company (GE) respecting information in this document are contained in the contract between the Boiling Water Reactor Owners' Group (BWROG) and GE, as identified in the respective utilities' BWROG Standing Purchase Order for the performance of the work described herein, and nothing in this document shall be construed as changing those individual contracts. The use of this information, except as defined by said contracts, or for any purpose other than that for which it is intended, is not authorized; and with respect to any other unauthorized use, neither GE, nor any of the contributors to this document makes any representation or warranty, and assumes no liability as to the completeness, accuracy, or usefulness of the information contained in this document.

Table of Contents

Description	Page
Executive Summary	1
1. Background	2
1.1 Brief Description of Dissolved Gas Phenomenon in Reactor Water Level Instrumentation System	2
1.2 Summary Description of Reference Leg Backfill Modification and Basis for Selecting Backfill Flow Rate	3
1.3 List of Required Analyses and Evaluations for the Reference Leg Backfill Modification	3
2. Guidelines for Thermal Hydraulic and Thermal Stress Analyses	8
2.1 Condensing Chamber	10
2.2 Steam Leg	22
2.3 Water Level Instrumentation Nozzle	29
3. Guidelines for End Point Calibration Bias Analysis	52
3.1 Discussion	52
3.2 Assumptions Used	52
3.3 Analysis	53
3.4 Example Calculations for End Point Calibration Bias	55
4. Guidelines for System Impact Evaluations	56
4.1 CRD System Transients	56
4.2 Off Rated Operational Conditions	62
4.3 Single Failure Impact on Safety Trips	63

List of Tables

Table.	Description	Page
2.1	Example Calculations for Mixed Mean CC Model	32
2.2	Example Calculations for Backfill Flow Temperatures from CC Inlet to IN	32
4.1	Example Calculations for 100 psi Pressure Disturbance in the CRD System	60

List of Figures

Figure	Description	Page
1.1	Schematic Diagram of Water Level Instrumentation System	6
1.2	Schematic Diagram of Water Level Instrumentation System with Backfill Modification	7
2.1	Example Condensing Chamber	33
2.2	Definition of Steam and Water Zones	33
2.3	Energy Balance for Differential Element of Water Flow	34
2.4	Example Three Dimensional Analysis Model for CC Water and Wall Temperature Distributions	35
2.5	Geometry of Steam Leg and Condensing Chamber Used in the Example Calculation	36
2.6	Temperature Distribution as a Function of Water Depth at CC Outlet at Various Backfill Flow Rates	37
2.7	Three Dimensional Water Temperature Distribution Inside CC	38
2.8	Finite Element Model of Condensing Chamber for Stress Analysis	39
2.9	Calculated Temperature Distribution in the Condensing Chamber Used in Stress Analysis	40
2.10	Calculated Steady State X-Direction Stress Distribution in the Condensing Chamber	41
2.11	Calculated Steady State Y-Direction Stress Distribution in the Condensing Chamber	42
2.12	Calculated Steady State Z-Direction Stress Distribution in the Condensing Chamber	43
2.13	Calculated Steady State Equivalent Stress Distribution in the Condensing Chamber	44
2.14	Boundary Conditions for Steam Leg with Gas Bound CC for Stress Analysis	45
2.15	Mathematical Model of Steam Leg Piping for Stress Analysis	46
2.16	Finite Element Model of Steam Leg Piping Cross Section for Stress Analysis	47
2.17	Calculated Steady State Temperature Distribution in the Steam Leg Piping Section for Stress Analysis	48
2.18	Calculated Steady State Axial Stress Distribution in the Steam Leg Piping Section	49
2.19	Temperature and Calculated Equivalent Linear Temperature Along Pipe Circumference	50
2.20	Backfill Flow Rate as a Function of SL Length to Meet 100°F Temperature Difference Criterion	51
4.1	Schematic Diagram for CRD Pump Transient Example Calculation	61

Executive Summary

The guidelines contained in this document were prepared to assist BWROG member utilities in performing analyses to support the Reactor Pressure Vessel (RPV) Water Level Instrumentation System Backfill Modification. The modification consists of supplying backfill water flow from the Control Rod Drive (CRD) system to the water level instrumentation reference leg.

The minimum backfill flow has been established by a BWROG test and is not within the scope of the analysis guidelines discussed in this document. Above this minimum backfill flow rate, the transport of noncondensables into the reference leg is precluded. The maximum backfill flow rate is determined by the allowable stresses in the water level instrumentation components and the allowable error in the indicated water level. The analysis guidelines in this document establish a procedure for evaluating the effect of backfill flow on component thermal stresses with respect to potential fatigue failures and for determining the endpoint calibration bias to take account of flow and density effects. The applicable acceptance criteria, assumptions used, and evaluation procedures are specified. Example calculations are provided.

Guidelines for system impact evaluations of the backfill modification during CRD system transients, off-rated operating conditions, and with a single failure are also provided.

1. Background

1.1 Brief Description of Dissolved Gas Phenomenon in Reactor Water Level Instrumentation System

Noncondensable gases (hydrogen and oxygen) are generated in the RPV due to the radiolysis of the reactor water. The noncondensables can accumulate in the condensing chamber (CC) of the water level instrumentation system (Figure 1.1) because they are present in the steam that enters the CC. The noncondensables carried into the CC subsequently dissolve in the condensed water in the CC. Part of the dissolved noncondensables are returned to the RPV in the condensate return flow and some noncondensables can be transported to the reference leg (RL) due to a leak in the RL, thermal convection of water in the RL, or gaseous diffusion. A leak and thermal convection are the dominant mechanisms for the transport of noncondensables. During RPV depressurization (either rapid or slow), the dissolved noncondensables can come out of solution and travel up the RL due to the density difference between the noncondensables and the water. This can result in the formation of gas pockets (large bubbles) in the RL, which in turn, can cause some of the water in the CC to overflow into the steam leg (SL) and thus be transferred back to the RPV. This reduction of water inventory in the CC and RL can result in a potentially incorrect (biased high) RPV water level indication (incorrect indications on the order of one to three feet have been observed). This occurrence has been observed occasionally during shutdown at some operating plants. This incorrect water level indication has been investigated and it has been concluded to not represent a significant safety hazard in two GE reports (See 1 and 2 below).

The NRC has notified the holders of BWR operating licenses (NRC Bulletin 93-03, dated May 28, 1993) that they should implement modifications to the Water Level Instrumentation System during the first cold shutdown after July 30, 1993, to ensure that the water level system design provides high reliability. In view of the short implementation schedules imposed by the NRC, the modification that can be most expeditiously implemented is the one that duplicates the modification that was installed at the Millstone 1 plant. The modification involves providing continuous backfill flow to the RL with water from the Control Rod Drive (CRD) system (Figure 1.2).

---

1. BWR Reactor Vessel Water Level Instrumentation, a Report Prepared for BWROG GENE-770-15-0692, August 1992.
2. Supplementary Information Regarding RPV Water Level Errors Due to Noncondensable Gas in Cold Reference Legs of BWRs, GENE-666-04-0593, May 1993.

1.2 Summary Description of Reference Leg Backfill Modification and Basis for Selecting Backfill Flow Rate

The Reference Leg Backfill Modification prevents the transport of noncondensable gases from the CC to the RL. The water in the RL is continuously replaced (backfilled) by a steady flow of water from the CRD system. The water enters the RL at a location outside the drywell and leaves the RL at the CC. The water is then transferred from the CC to the RPV through the SL and the Water Level Instrumentation Nozzle (IN). The backfill flow is relatively low (on the order of 4 lb/hr) and is significantly cooler at the injection point than in the CC, SL, and IN. The minimum required backfill flow rate is that above which noncondensable gases in the CC cannot be transported to the RL either due to the presence of small leaks in the RL, or due to thermal convection currents resulting from temperature gradients in the CC and RL water. The minimum required backfill flow rate was established by testing performed for the BWROG (see 3 below). The backfill flow rate of 4 lb/hr has been shown to be above the acceptable minimum value based on thermal convection cell considerations. The maximum backfill flow is limited by either the maximum allowable thermal stresses in the CC, SL, and IN walls, or the maximum allowable endpoint calibration bias. The maximum flow rate should consider the off rated conditions such as startup or shutdown. During such conditions, the RPV pressure may become 0 psig.

Because the component geometries of the RL, CC, and SL, as well as the RL leak rate, are plant specific, a plant specific backfill flow rate may have to be determined. The analyses and evaluations discussed in this document are based on the assumption of no leak. An assessment of the RL leakage rate should be made to determine the plant specific backfill flow rate in addition to the analyses made in this document.

This document provides the guidelines for performing the analyses related to the maximum backfill flow rate and system impact evaluations of the modification.

1.3 List of Required Analyses and Evaluations for the Reference Leg Backfill Modification

1.3.1 Analyses for Maximum Backfill Flow Rate

The following analyses are required to demonstrate the acceptability of the maximum allowable flow rates:

3. Testing of Boiling Water Reactor Water Level Instrumentation Reference Leg Backfill Modification Concept, First Draft, a Report Prepared for BWROG, C.D.I. Report No. 93-06, August 1992.

1. Thermal hydraulic analyses of the RL, CC, SL, and IN to calculate the boundary conditions required for performing the stress analyses described below. Based on the thermal boundary conditions, the limiting stress locations are identified so that only the limiting locations are evaluated for thermal stresses. The thermal-hydraulic analyses include

    - Hydrodynamic analyses for the SL to determine the water flow depth and heat transfer area

    - Heat transfer calculations to obtain the inlet and outlet temperatures, temperature distributions, and related parameters such as heat transfer coefficients and steam condensation rates.

2. Stress analyses to evaluate the integrity of the CC, SL, and IN under the cyclic thermal loading caused by the relatively low temperature backfill flow.

3. End point calibration bias analyses to determine the effects of the increased water density and the backfill flow in the RL on the indicated water level.

1.3.2 System Impact Evaluations

The impact of the backfill flow modification on the water level instrumentation system, as well as on the overall reactor system needs to be evaluated. The following evaluations are included in this document:

1. CRD System Transients,

2. Off Rated Operational Conditions, and

3. Single Failure Impact on Safety Trips.

1.3.3 Guidelines Document Format

The following items are included:

1. Acceptance Criteria (e.g., allowable stresses, allowable measurement error),

2. Assumptions Used,

3. Analysis Procedure,

4. Example Calculations,

The example calculations use backfill flow rates for normal, off-rated and degraded operating conditions. Also included is the functional relationship between the minimum required steam leg length and the backfill flow rate that ensures acceptable temperatures at the IN.

For each guideline, an example is included. The example is based on the Fermi Unit 2 plant geometry, which is readily available at the time of this guideline preparation. The development of the guidelines is relatively independent of the geometry for individual plants, and the Fermi Unit 2 plant geometry is used to verify the validity of the governing equations used in the analyses. The Fermi Unit 2 geometry has a horizontal CC with connections to the RL at the side of the CC instead of at the bottom. The side connection provides more conservative results, as discussed in Section 2.1.3.4, and the use of the Fermi Unit 2 CC geometry is therefore acceptable. The Fermi-2 arrangement also has a flow restricting orifice in the SL, which is not typical. Therefore, the example calculations do not model the SL orifice. This guidelines document does not include the details of the computer codes used for the three dimensional temperature distributions, the three dimensional stress analysis, or the methodology used in the end point calibration bias calculations.

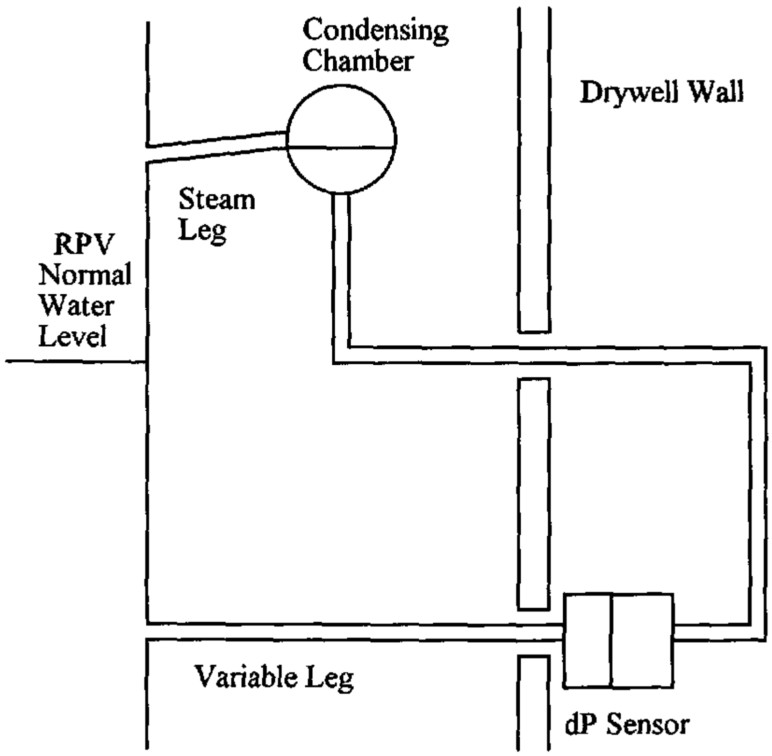


Figure 1.1 Schematic Diagram of Water Level Instrumentation System

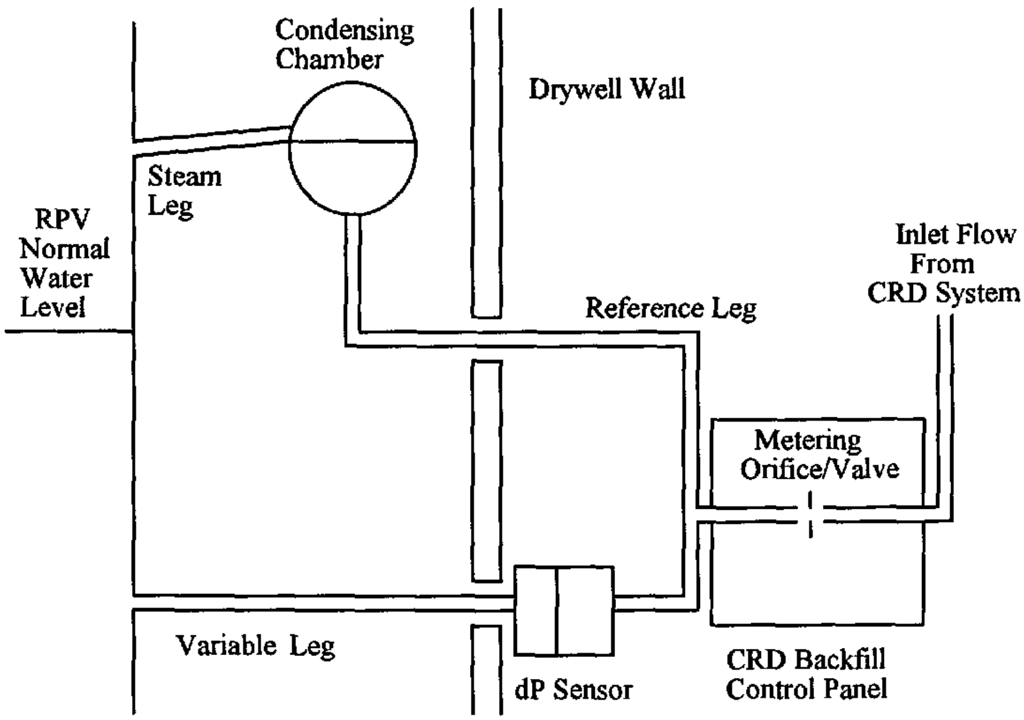


Figure 1.2 Schematic Diagram of Water Level Instrumentation System with Backfill Modification

2. Guidelines for Thermal Hydraulic and Thermal Stress Analyses

Introduction

This section provides the guidelines for performing the thermal-hydraulic analyses and the stress analyses for the CC, SL, and IN of the Water Level Instrumentation System. The thermal hydraulic analyses are performed in order to calculate the heat transfer coefficients, inlet and outlet temperatures, and steam condensation rates and thus determine the temperature distributions. The results of the thermal-hydraulic analyses are used as boundary conditions for the stress analyses in order to determine the allowable stresses and thermal fatigue loadings.

The thermal hydraulic analyses are performed in stages for the following components of the Water Level Instrumentation System as described:

Reference Leg:

Calculations for the RL are performed using a one dimensional conduction and convection model to take into account the pre-heating of the backfill water prior to entering the CC.

Condensing Chamber:

The following models are used:

- A one dimensional mixed mean temperature model considers the effects of steam condensation on the CC walls and water surface, heat conduction on the CC walls , and heat losses from the outside surface of the CC walls to the drywell environment. This model provides the water temperature distribution in the axial (x) direction as the water flows from the CC inlet to the outlet and towards the steam leg. This model assumes uniform water temperature in radial and circumferential directions.

- A one dimensional thermal stratification model assumes that the cold water enters the CC through the bottom, or sinks to the bottom of the CC due to its higher density and then rises to the surface as its temperature increases. This model provides the water temperature distribution in the vertical (y) direction as the backfill water flows from the bottom of the CC towards the water surface and then exits the CC. This model assumes uniform water temperature in the horizontal plane.

- Combined application of the one dimensional models described above provides the temperature distributions in the axial and vertical directions for both side entry and bottom entry CCs.

- A three dimensional finite element analysis is performed to serve as a benchmark case for the one dimensional models described above. The three dimensional hydraulic calculations should be done if the one dimensional analysis results indicate that the stresses are unacceptable.

Steam Leg:

Calculations for the SL are based on the one dimensional mixed mean temperature model discussed above. This model provides the bulk water temperature distribution in the axial (x) direction as the water flows in the SL from the CC outlet to the RPV.

Hydrodynamic evaluations for flow rates in the SL are based on open channel flow theory. For very low flow rates, where surface tension effects predominate, a "water puddle" depth correlation can be used. For higher flow rates, the Chezy-Manning formula can be used in the sloped sections and the minimum energy principle can be used in the horizontal sections.

Instrumentation Nozzle:

Due to the low backfill flow rates, high cycle temperature fluctuation in the CC and SL are not expected to occur, except near the IN, where random flow paths and "dribbling" of the water stream cannot be ruled out. To preclude the occurrence of high cycle thermal fatigue at the IN, the backfill flow rate should be kept small so that the water entering the IN is within 100°F of the reactor temperature.

The thermal hydraulic analyses that provide the water temperature are performed for the following combinations:

- Normal Operating Conditions (Example backfill flow rate = 4 lb/hr):
    - CC in steam filled condition
    - SL in gas bound condition
- Off Rated Operating Conditions (Example backfill flow rate = 10 lb/hr):
    - CC in steam filled condition
    - SL in gas bound condition
- Degraded Operating Conditions (such as Backfill Flow Control Valve Stuck Open; Example backfill flow rates = 15 lb/hr and 45 lb/hr)
    - CC in steam filled condition
    - SL in gas bound condition

Based on these thermal hydraulic analyses, the most limiting stress locations/conditions are determined for CC, SL, and IN. The stress analyses are then performed for the limiting conditions for CC, SL, and IN.

The following conditions are identified as the most limiting for the stress analyses:

- For the CC, the temperature distribution is calculated assuming that the CC is steam filled. This maximizes the temperature gradient, and therefore the thermal stresses, in the CC walls. This condition occurs immediately after reactor startup.
- For the SL, the temperature distribution is calculated assuming that the SL is steam filled. However, the temperature of the water entering the SL assumes gas bound conditions in the CC. This combination of assumptions minimizes the temperature of the water entering the SL and maximizes the steam zone temperature, thus resulting in the maximum temperature gradient and thermal stresses in the SL walls. The gas bound condition in the CC occurs from a few to several months after reactor startup.
- For the IN, the temperature distribution takes credit for the heating of the water flowing in the SL. For the same reasons as for the SL, the gas bound CC provides the most limiting condition in the IN.

2.1 Condensing Chamber

2.1.1 Discussion

The CC (Figure 2.1) is a reservoir of water that is connected to the top of the RL. The CC provides makeup to the RL in order to maintain the RL full of water. Steam condenses in the CC and the resulting condensate makes up for any minor leaks in the RL. The excess condensate overflows into the SL and returns to the RPV.

The SL and RL are located such that a constant quantity of water is maintained in the CC. This ensures that the hydrostatic pressure at the pressure transmitter at the bottom of RL is kept constant by the constant height of water in the RL and CC. The CC is typically cylindrical in shape with its axis oriented horizontally for most plants. Some plants have the CCs oriented vertically. The example analysis described in this document was performed for a horizontally oriented CC with the RL connected to one circular end face and the SL to the other end face of the CC.

For the thermal hydraulic analysis of the CC, both one-dimensional and three-dimensional models are used. The one dimensional models are coupled to provide the axial (x) and vertical (y) direction temperature distributions. The one dimensional mixed mean model is used to calculate the temperature distribution in the x direction at the bottom of the CC. Then the one dimensional stratification model is used to obtain the temperature distribution in the y direction at each axial (x) location. The use of the one dimensional approximation is benchmarked by comparison against the three dimensional model results for the example used, and should provide more severe thermal boundary conditions than the three dimensional analysis. If the one dimensional approximation for the thermal hydraulic analysis is not expected to provide an acceptable stress result, a three dimensional hydraulic analysis is recommended.

2.1.2 Thermal Hydraulic Analysis

2.1.2.1. Temperature of Backfill Flow Entering the CC

Water in the RL outside the drywell is assumed to be at equilibrium with the reactor building temperature, about 80°F. When the water enters the drywell, its temperature increases asymptotically to drywell temperature by convection from the drywell environment and heat conduction through the RL walls. The water temperature increase is calculated from the equation:

$$(T_{DW}-T_W)/(T_{DW}-T_{RB}) = \exp(-UP_o\, x/mC_p)$$

where

x	Distance of RL pipe measured from drywell wall (ft)
T_{DW}	Drywell temperature (F)
T_{RB}	Water temperature in the reactor building (F)
T_W	Water temperature in the RL
U	Overall heat transfer coefficient (Btu/hr-sq ft-F)
D_o	Pipe outside diameter (ft), $P_o = \pi D_o$
D_i	Pipe inside diameter (ft), $P_w = \pi D_i$
t	Pipe wall thickness (ft), (Do-Di)/2
h_w	Heat Transfer Coefficient between water and pipe (Btu/hr-sq. ft-deg F)
h_o	Heat Transfer Coefficient between pipe and air (Btu/hr-sq. ft.-deg F)
k_p	Thermal Conductivity of pipe (Btu/hr-ft-deg F)
UD_o	$1/(1/h_wD_i + 1/h_oD_o + 2t/k_p(D_o+D_i))$
m	Backfill flow rate (lb/hr)
C_p	Specific heat of water (Btu/lb-deg F)

Typically, T_W approaches T_{DW} within several feet of distance from the drywell penetration, depending on the backfill flow rate. The RL water temperature should be calculated for both the normal and maximum flow rate conditions.

A similar form of equation can be used to calculate warm up and cooldown of CRD water in the reactor building: Use the expression for T_W above, with T_{DW} replaced by T_{RB} and T_{RB} replaced by T_{CRD} (T_{CRD} is the temperature of CRD water entering the reactor building.)

Because the CC walls are at a higher temperature than the drywell, the inlet pipe to the CC is at a higher temperature up to a short distance (typically a few inches) away from the CC. Thus, the water entering the CC is warmed by convection from the inlet pipe. The water temperature entering the CC is therefore slightly higher than the drywell temperature. The CC inlet temperature (T_{in}) is calculated based on the following equation:

$$(T_{in} - T_{DW})/(T_c - T_{DW}) = (1 - \lambda_1/C_1)^{-1}$$

where

T_{in} Water temperature entering the CC (F)
T_c Average wall temperature where RL is attached to the CC wall (F)
P_w Wetted perimeter inside the pipe (ft), πD_i
P_o Perimeter outside the pipe (ft), πD_o
A_p Cross sectional area of pipe (sq ft), $\pi(D_o^2 - D_i^2)/4$
λ_1 Absolute value of the negative root of the equation $\lambda_1^3 + C_1 \lambda_1^2 + C_2 \lambda_1 + C_3 = 0$ with
$C_1 = -(h_w P_w)/(mC_p)$
$C_2 = -(h_w P_w + h_o P_o)/(k_p A_p)$
$C_3 = (h_w P_w)(h_o P_o)/((k_p A_p)(mC_p))$

An initial value of T_c may be taken as the average of the steam and the drywell air temperatures. After calculating the mixed mean CC water temperature (T_w) using the method described in Section 2.1.2.4, T_c may be refined using an iterative process to obtain the final values of T_{in} and T_c. Typically, the equation for T_{in} reduces to:

$$(T_{in} - T_{DW})/(T_C - T_{DW}) \cong 0.05$$

The above expressions are applicable to both side entry and bottom entry RLs.

2.1.2.2 One Dimensional Mixed Mean Water Temperature Model

This model provides the water temperature distribution in the axial (x) direction as the water flows from the CC inlet to the outlet and towards the steam leg.

The steam condenses on the walls and on the water surface. The condensate joins the water flowing in the CC. The water temperature increases due to the mixing of the condensate streams from the walls and water surface with the water in the CC, due to heat transfer from the steam/water interface to CC water, and due to heat conduction from the wall in the water zone (Figures 2.2 and 2.3). The model considers the following phenomena:

- Steam condensation on the wall surface and the water surface

- Heat conduction in the θ direction (Axial direction conduction is neglected).

- Convective heat transfer from the pipe wall to the water and steam regions and the drywell environment.
- Uniform temperature of the CC water in radial and circumferential directions.
- The model takes account of the semi circular symmetry in the CC and the continuity of the temperature and its gradient between the steam and water zones of the CC walls.

Thus, the water temperature in the CC can be expressed as a function of distance (x) by the following expression:

$$(c(T_{stm}-T_w) + b)/(b^2-ac)^{1/2} = \coth((b^2-ac)^{1/2}\,x + \coth^{-1}((c(T_{stm}-T_{in}) + b)/(b^2-ac)^{1/2}))$$

where a, b, and c are expressions for the following quantities:

$$a = 2\,Z_1(T_{stm}-T_{DW})/m\,C_p$$
$$b = ((h_i\,S)/2 + Z_2)/(m\,C_p) + Z_3/(m\,H_{fg})$$
$$c = (h_i\,S + 2\,Z_4)/(m\,H_{fg})$$

Z_1, Z_2, Z_3, and Z_4 are expressions defined as follows:

$$Z_1 = R_oh_oR_i\,[(N/D)\,(h_{con} - h_w)/(R_ih_{con} + R_oh_o) - h_w(\pi-\theta_i)]/(R_ih_w + R_oh_o)$$

$$Z_2 = (N/D)(R_ih_w)/(R_ih_w + R_oh_o) + R_oh_oR_ih_w(\pi-\theta_i)/(R_ih_w + R_oh_o)$$

$$Z_3 = (T_{stm} - T_{DW})\,(R_ih_{con})[R_oh_o\theta_i/(R_ih_{con} + R_oh_o) + R_oh_oR_i(h_{con}-h_w)(m_2/(m_1D)) * \mathrm{Sinh}(m_1\theta_i)\,\mathrm{Sinh}(m_2(\pi-\theta_i))/((R_ih_{con} + R_oh_o)(R_ih_w + R_oh_o))]$$

$$Z_4 = (R_ih_{con}\,m_2/(m_1D))\,(R_ih_w/(R_ih_w + R_oh_o))\mathrm{Sinh}(m_1\theta_i)\,\mathrm{Sinh}(m_2(\pi-\theta_i))$$

N and D are contractions of the following :

$$N = m_1\mathrm{Sinh}(m_1\theta_i)\,\mathrm{Sinh}(m_2(\pi-\theta_i))\,(k_ptm_2/R_{avg} - R_oh_o/m_2)$$

$$D = m_1\mathrm{Sinh}(m_1\theta_i)\,\mathrm{Cosh}(m_2(\pi-\theta_i)) + m_2\mathrm{Cosh}(m_1\theta_i)\,\mathrm{Sinh}(m_2(\pi-\theta_i))$$

where

T_{stm}	Temperature of steam (F), typically 550°F
T_{in}	Bulk average water temperature at x = 0
m^2_1	$R_{avg}\,(R_ih_{con} + R_oh_o)/(k_pt)$
m^2_2	$R_{avg}\,(R_ih_w + R_oh_o)/(k_pt)$
S	Area of water surface per unit length of x (ft)

H_{fg} Heat of vaporization for water (Btu/lb)
R_o $= D_o/2$, $R_i = D_i/2$, $R_{avg} = (R_o+R_i)/2$
h_{con} Condensation heat transfer coefficient on the wall (Btu/hr - sq. ft.-deg F)
θ_i Circumferential angle occupied by the steam space measured from the high point (rad.)
h_i Heat transfer coefficient for water side on the water/steam interface (Btu/hr - sq. ft.-deg F)

The above expression assumes that heat losses from the end walls are small and can be neglected. It also assumes a constant water flow rate in the CC (i.e., the amount of condensate flow is negligibly small compared to the backfill flow). The heat addition due to condensate is considered, but the mass flow rate is assumed to be constant. This assumption is valid for small values of axial distance (x), large values of m, or well-insulated walls and small water surfaces (i.e., negligible condensation rates). A more rigorous treatment would require updating the value of water flow rate (m) as a function of x in order to take account of condensate addition from the walls and the water surface. The effect of condensate addition is a slower increase in water temperature and thus, a lower value of water temperature at the CC outlet.

The water flow rate is updated using the following method:

1. Select an incremental value of flow length (dx). Set $T_w = T_{in}$ and $m = m_{old}$ = flow rate entering the CC.

2. Calculate the condensation rates on the walls (m_L)and the water surface (m_{fg}) using:

$$m_L = 2(Z_3 + Z_4(T_{stm}-T_w))/H_{fg}$$

$$m_{fg} = h_i\, S(T_{stm}-T_w)/H_{fg}$$

3. Update the average water flow rate over the flow length, dx, using:

$$m_{new} = m_{old} + (m_L + m_{fg})dx/2$$

4. Calculate T_w using the expression provided above with $m = m_{new}$.

5. Calculate the average value of T_w over the flow length, dx, using:

$$T_w = (T_{in} + T_w)/2$$

6. Repeat steps 2 through 4 to obtain final values of T_w and m over the flow length dx.

2.1.2.3 One Dimensional Stratification Model

The one dimensional thermal stratification model assumes that the cold water enters the CC through the bottom, or sinks to the bottom of the CC due to its higher density and then rises to the surface as its temperature increases. This model provides the water temperature profile in the vertical (y) direction as the water flows from the bottom of the CC towards the water surface and then exits the CC.

Heat loss from the water to the wall and thence to the drywell environment is neglected in the stratification model. The water temperature as a function of CC depth, $T_w(y)$ is given by:

$$(T_w(y) - T_{in})/(T_{stm} - T_{in}) = 1 - (1 - \exp(-Vy/\alpha))/(1 - \exp(-VH/\alpha))$$

where

$T_w(y)$	Water temperature at depth y (F)
α	Thermal diffusivity of the water layer, defined by $\alpha = k/(\rho C_p)$
V	Water velocity defined by $V = m/(\rho A)$
k	Thermal conductivity of water (Btu/hr-ft-F)
ρ	Density of Water (lb/cu ft)
A	Flow area of water (sq ft), defined as water volume divided by total water depth, H
H	Total water depth (ft)

2.1.2.4. Three Dimensional Water Temperature Distribution Model

The three dimensional finite element analysis is performed to serve as a benchmark case for the one dimensional models described above.

A computational fluid dynamics (CFD) code is used for the analysis. This analysis divides the water and CC walls into a set of finite elements (see Figure 2.4) and calculates the flow and temperature fields at steady state conditions. The backfill flow entering the CC is modeled as a fully developed flow in the inlet pipe. The model takes account of heat transfer from the steam to the CC walls and the water surface, as well as from the CC walls to the water and the drywell environment.

The boundary conditions for the 3-D analysis are as follows:

A. Hydrodynamic:

No slip boundary condition applies everywhere except the following area:

1. Entrance pipe has parabolic velocity profile with mass flow rate, m.

2. Exit pipe has open channel flow.

3. On the water surface, mass flux (m") due to steam condensation may be calculated by considering the steam condensation on the CC wall in the steam space and on the water surface.

B. Thermal:

1. Entrance pipe has uniform temperature, T_{in}

2. Water surface is at saturation conditions with temperature, T_{stm}

3. Steam space temperature at T_{stm} with h_{con} to the wall.

4. Environmental temperature of T_{DW} with h_o to the environment.

2.1.2.5. CC Water Temperature Example Calculations

The example calculations provided in this section are representative only. Plant specific analyses should be performed for the individual plants.

The models described above were used to calculate the temperature distributions in the CC under steam filled conditions. For gas bound conditions, there is no heating of water. Figure 2.5 shows the arrangement used in the example calculation and shows also the steam/gas interface for the gas bound CC. Four backfill flow rates were used:

Case 1 - Steam Filled CC, m = 4 lb/hr
Case 2 - Steam Filled CC, m = 10 lb/hr.
Case 3 - Steam Filled CC, m = 15 lb/hr
Case 4 - Steam Filled CC, m = 45 lb/hr.

The horizontally oriented side entry CC was used as the example case. The two one dimensional models were used to provide temperature distributions in the axial (x) and vertical (y) directions. The results are benchmarked against the three dimensional calculations. The three dimensional calculation shows that the buoyancy effect is dominant and there is a recirculation flow within the CC. This indicates the need for determining the temperature distributions in both the x and y directions. The one dimensional mixed mean temperature model is therefore used to calculate the water temperature near the bottom of the CC (i.e., the lowest temperature in the y direction). The one dimensional stratification model is then used to calculate the temperature in the y direction at each axial (x) location.

For the bottom entry CC, a similar one dimensional approach can be used. The three dimensional evaluation (for the example side entry CC) shows that the flow pattern in the CC is dominated by the buoyancy effect due to the density difference in the water. The same phenomenon can be reasonably assumed for the bottom entry CC based on a qualitative assessment of the flow pattern that would occur. The basis for the assumption is that the driving force due to density difference is about two orders of magnitude greater than the driving force due to flow velocity. Given the above assumption, the cold water entering through the bottom of the CC tends to spread over the bottom surface of the CC uniformly and gradually fill the CC. The water surface is at saturation temperature and the cold water gets heated as it rises relatively uniformly toward the surface and then exits the CC from the side of the CC. The assumption of uniform spreading of water as it rises in the CC requires that the backfill flow divides into two streams as it enters at the bottom of the CC. The flow rates in the two streams are assumed to be proportional to the CC water surface areas on either side. With this assumption, the one dimensional mixed mean temperature model is applicable for the water temperature calculation at the bottom of the CC. The one dimensional stratification model can then be used to calculate the temperature distribution in the vertical (y) direction at each location in the axial (x) direction.

It is judged that the approach described above will provide reasonable thermal hydraulic inputs to the stress analysis. A three dimensional evaluation would be needed if a more realistic temperature distribution is required.

2.1.2.5.1 One Dimensional Mixed Mean Temperature Model

The following values were used for the inputs to the example calculations for the CC:

h_w	20 Btu/hr-sq ft-F
h_o	5 Btu/hr-sq ft-F
h_{con}	4000 Btu/hr-sq ft-F
h_i	15 Btu/hr-sq ft- deg F for side entry CC and k/δ for a bottom entry CC where δ = water depth
k_p	8 Btu/hr-ft-F
R_o	0.1979 ft
Ri	0.1541 ft
t	0.0438 ft
R_{avg}	0.176 ft
T_{stm}	550°F
T_{DW}	135°F
T_{in}	150°F
θ_i	1.7516 radians
x	0.35 ft.
m	4, 10, 15, and 45 lb/hr
H_{fg}	640.8 Btu/lb.
S	0.3032 sq. ft.

The results are shown in Table 2.1. The results show that at a nominal backfill flow rate, the water temperature at the CC outlet increases to 393°F. At high backfill flow (for degraded conditions such as stuck open flow control valve), the water temperature at the CC outlet increases to 196°F for the steam filled CC condition. These temperatures are used as the temperatures at the bottom of the CC for the purposes of calculating the y direction temperature in the stratification model.

2.1.2.5.2 One Dimensional Stratification Model

The following values were used for the inputs to the example calculations for the CC:

T_{stm}	550°F
T_{DW}	135°F
T_{in}	CC outlet temperature from mixed mean temperature model (Table 2.1)
H	0.1264 ft.
A	0.0798 sq ft
k	0.39 Btu/hr-ft-F
C_p	1 Btu/lb-F
ρ	61 lb/cu ft

The results are shown in Figure 2.6. The results show that there is a thin water layer near the surface in which there is a temperature gradient from the steam temperature (550°F) at the surface to the temperature at the bottom of the CC, while the bulk of the water stays at the CC bottom temperature.

2.1.2.5.3. Three Dimensional Finite Element Model

The following values were used for the inputs to the example calculations for the CC:

T_{stm}	550°F
T_{DW}	135°F
T_{in}	150°F
H_{con}	4000 Btu/hr-sq ft-deg F
h_o	5 Btu/hr-sq ft-deg F
m	4 lb/hr
k_p	10.9 Btu/hr-ft-deg F
ρ_p	488 lb/cu ft
$C_{p,p}$	0.11 Btu/lb-deg F
k	0.355 Btu/hr-ft-deg F (average value at 350°F)
C_p	1.16 Btu/lb-deg F (average value at 350°F)
ρ	density of water assumed to vary linearly between 150°F and 450°F
ν	viscosity of water assumed to vary linearly between 150°F and 450°F

The model shown in Figure 2.4 was analyzed for the flow field and the temperature distribution. The resulting temperature distribution for m = 4 lb/hr is shown in Figure 2.7. Some of the major findings from the three dimensional analysis are:

1. Overall flow field is dominated by the natural circulation induced by the density difference between the incoming cold water (ρ = 61.2 lb/ cu ft) and the condensate (ρ =

45.9 lb/cu ft). The cold incoming water flows down to the bottom of the entrance RL pipe and flows toward the SL through the bottom part of the CC. Water near the top surface flows toward the entrance pipe instead of the exit pipe.

2. As a result of this flow pattern, the cold incoming water is gradually heated as it flows through the bottom of the CC; the temperature gradient between the top and the bottom decreases in the axial direction. The resulting temperature field shown in Figure 2.7 indicates that the one dimensional mixed mean water temperature model could be combined with the one dimensional stratification model and provide a conservative approximation to this complex temperature field. In other words, the one dimensional mixed mean temperature model can be applied to the cold stream at the bottom of the CC. The one dimensional stratification model can then be applied at each axial location.

The insight obtained from this analysis with the side entry CC can be applied to the bottom entry CC. The flow field is dominated by the natural circulation flow in both cases.

2.1.3 Stress Analysis

The geometry of the CC and the temperature and heat transfer boundary conditions to be defined from thermal hydraulic analysis are complex enough that a three dimensional finite element analysis of the condensing chamber (CC) is necessary to determine the resulting stresses. Figure 2.8 shows an example of the such a finite element model of the CC. This model is for the case where the water entry is from the side rather than at the bottom.

2.1.3.1. Acceptance Criteria

The stresses produced in the CC by the backfill modification are potentially significant such that a detailed fatigue evaluation, typically done for ASME Class 1 components, is deemed necessary. Because the additional stresses produced by the backfill modification are displacement-controlled or secondary in terms of the ASME Code terminology, only the primary plus secondary stress (P+Q) evaluation and the fatigue usage calculation is necessary. The acceptance criteria provided in Paragraph NB-3200, ASME Section III, are the following:

(P+Q) range $\leq 3S_m$

Cumulative Fatigue Usage ≤ 1.0

The limit on the (P+Q) range for a load state pair may be exceeded provided that the requirements of simplified elastic-plastic analysis (ASME Section III, Paragraph NB-3228.5) are met. A key requirement in that analysis is that the (P+Q) range, excluding thermal bending stresses, shall be $\leq 3S_m$.

2.1.3.2. Assumptions Used

The inlet and outlet ends of the CC are subject to bending moments resulting from loadings such as weight, thermal expansion, and seismic loads. In addition, thermal stratification moments (see Section 2.2.3) are also present. The magnitudes of these moments are specific to the piping configuration. The steam filled case is the governing case for the CC stress analysis. However, the stratification-induced moment is expected to be low for this case since the temperature of water exiting the CC is high (close to 550 F for the 4 lb/hr case, per Figure 2.6). This was taken into consideration in selecting the following values for the purpose of the analysis:

Thermal Stratification Moment:	200 in-lb
Moment from Other Loadings:	500 in-lb

The following stress indices were assumed at the location of the highest stresses:

"C" index:	1.2
"K" index:	1.8

2.1.3.3. Analysis Procedure

The analysis procedure involves a finite element temperature and stress analysis. The input temperatures were obtained from the results of a three dimensional thermal hydraulic analysis described earlier in this report. From a review of the finite elements stress results, suitable cross-sections were identified where the P+Q ranges are calculated. A likely location is the CC outlet or CC inlet since the expected temperature gradient there would produce high stresses.

A key step in the fatigue evaluation is the identification of the load states. Two load states are expected to be significant: gas bound and steam filled.

The significant cyclic loadings are the following:

- Internal Pressure (1050 psia)
- Temperature Gradient Stresses
- Attached Piping Moments (e.g., seismic, thermal expansion and thermal stratification- induced moments)

2.1.3.4. Example Calculations

The example calculations provided in this section are representative only. Plant specific analyses should be performed for the individual plants.

Figure 2.9 shows the calculated temperature distributions in the CC for a make up flow rate of 4 lb/hr. These temperatures were calculated from the thermal hydraulic analysis of the CC and were imported into the ANSYS stress analysis model. The ANSYS model used three dimensional solid elements (Element No. 45). It is seen that the temperature variations are the greatest at the inlet end of the CC and thus, the likely location for the highest stresses.

Figures 2.10 through 2.13 show the stress distributions calculated using the temperature distribution shown in Figure 2.9. In the cylindrical region of the inlet pipe, the Y and Z correspond to the axial and circumferential directions, respectively. The stresses are the highest in the inlet region near the junction with the CC wall, since that region represents a large thickness discontinuity. The highest surface stress (local peak stress) occurs on the inside and is approximately equal to 67000 psi.

The stresses for two separate load cases consisting of internal pressure of 1050 psia and a unit end moment were also calculated. The stresses from these loadings were combined to obtain the appropriate stress ranges. The steam filled case combined with the zero load state provided the highest stress range.

The P + Q stress intensity ranges were calculated at a number of sections. The highest (P+Q) stress was calculated to be 66400 psi. This is the stress intensity between the steam filled case and the zero load state. Since this exceeds the 3Sm value for Type 316L stainless steel (41175 psi at 575°F), a simplified elastic-plastic analysis was deemed to be necessary. When the thermal bending was taken out, the stress range for this load pair was calculated to be approximately 40000 psi. This stress range is less than the allowable value of 41175 psi. The usage factor, assuming 120 events, was calculated to be approximately 0.6. Since this value is less than 1.0, it is acceptable.

The analysis presented here is for the side entry CC configuration. Most of the BWR plants have the bottom entry CC configuration. The thermal gradients at the bottom of the CC for the bottom entry design are expected to be significantly lower than those calculated for the side entry design considered in this analysis. Also, based on engineering judgment, it is concluded that the thermal gradient stresses at the outlet end of the bottom entry design are expected to be very similar to those calculated for the side entry design. A review of the results for S_y shows that the maximum surface stresses in the outlet region are less than 40000 psi, compared to the surface peak stress of approximately 67000 psi at the inlet end. Based on this, it is concluded that the bottom entry type CC will show larger ASME code margins than the margins calculated above for the side entry design.

2.2 Steam Leg

2.2.1 Discussion

The Steam leg (SL) is a length of pipe that connects the CC to the Water Level Instrumentation Nozzle (IN). The SL carries steam from the IN to the CC and overflow water from the CC to the IN.

2.2.2 Thermal Hydraulic Analysis

The stress analysis for the SL requires two types of thermal boundary conditions: one that defines the temperature distribution at each cross section of the SL, and the other that defines the axial variation. The limiting thermal boundary conditions for the cross sectional temperature distribution occurs near the CC when the CC is gas bound. This is defined in Section 2.2.2.1. The axial variation of water temperature in the SL is defined in Section 2.2.2.2.

2.2.2.1 Limiting Thermal Boundary Conditions for the SL Cross Section

This section defines the thermal boundary conditions for the limiting cross section of the SL (see Figure 2.14). The temperature of the steam is 550°F (saturation temperature at reactor operating conditions), and the bulk water temperature of 150°F is used. In addition, the following heat transfer coefficients are used.

- Condensing heat transfer coefficient on pipe walls in steam zone:	4000/Btu/hr-sq ft-F
- Heat transfer coefficient on pipe walls in water zone:	200 Btu/hr-sq ft-F
- Heat transfer coefficient on pipe outside (insulated) walls:	2 Btu/hr-sq ft-F

2.2.2.2. Axial Water Temperature Variation in the SL

The one-dimensional mixed mean temperature model discussed in Section 2.1.2.2 is applied for analysis of water temperature profile in the SL. The steam temperature above the water stream is at 550°F. This model requires a water film heat transfer area, S, as input and the related hydrodynamic evaluation is presented here.

The water flow in the SL is an open channel flow and is heated by steam condensing on the pipe inner wall or on the water surface. The heat transfer calculation depends on the flow velocity and the heat transfer area between water and steam. This section summarizes methods for predicting water depth in a horizontal or sloped pipe, with a given volume inflow at one end and an open discharge at the other. Once the water depth is determined, the bulk average velocity and the width of water channel can be calculated for the given flow rate.

The water channel width, S, can be expressed as a function of water depth, y, for the pipe with radius, R, as follows:

$$S = 2R\,(2\,y/R - (y/R)^2\,)^{1/2}$$

or

$$S^* = S/R = 2\,(2\,y^* - (y^*)^2\,)^{1/2}$$

where $y^* = y/R$

It is expected that the surface tension effect will dominate for low flow rates (near 4 lb/hr) and the water depth should be calculated by the so-called "puddle depth" correlation. For higher flow rates, the minimum energy principle should be used for a horizontal pipe and Chezy-Manning formula for a sloped pipe. These high flow rate correlations should be used when they predict a greater water depth than the puddle depth.

A. Puddle Depth

When the surface tension force is equated to the hydrostatic pressure force on a horizontal strip of water that is resting on a horizontal surface, the equilibrium water depth is given by

$$z_p = (2g_o\sigma\,/g\rho)^{1/2}$$

where

σ is the surface tension (lb/ft)
ρ is the water density (lb/cu ft)

The value of z_p is calculated to be approximately 0.084 inch at 550°F and 1000 psi, and 0.16 inch at room temperature.

B. Water Depth in a Horizontal Pipe

A horizontal circular pipe of inside radius, R, is considered with a steady water volume flow rate, Q. The principle of minimum energy was applied to express the water flow depth in the form

$$Q^2/(gR^5) = -\,(A^{*\,2})\,(1 - y^*) + (2/3)\,A^*\,(2y^* - y^{*\,2}\,)^{3/2}$$

where g is the acceleration of gravity, $y^* = y/R$ is the normalized water depth, and $A^* = A/R^2$ is the normalized flow area occupied by the water, given by

$$A^* = -\,(1 - y^*)\,(2y^* - y^{*\,2}\,)^{1/2} + \arccos\,(1 - y^*)$$

The minimum energy principle can be used for short pipe lengths, such as the SL, where flow rates and friction losses are small..

C. Water Depth in a Sloped Pipe

For a sloped pipe, the Chezy-Manning formula is applicable, and gives the following correlation:

$$Q = AV, \text{ and}$$

$$V = 1.49\, R_h^{2/3}\, S^{1/2} / n$$

where

Q	Volumetric flow rate (cu ft/sec)
A	Flow area (sq ft)
V	Velocity (ft/sec)
R_h	Hydraulic radius (ft), given by $R_h = A/P_h$
P_h	Wetted perimeter (ft), $P_h = 2R \arccos(1\text{-}y^*)$
S	Slope, tan θ
n	Manning's Roughness Coefficient (See Table 10.1 of Fluid Mechanics by F. M. White, for example)

Since A and R_h are functions of y, it may require several iterations to obtain water depth, y, for a given Q.

2.2.2.3. Example Calculations for Axial Water Temperature Variation in the SL

The example calculations provided in this section are representative only. Plant specific analyses should be performed for the individual plants.

The following cases were calculated:

Cases 1, 2, 3 and 4 are covered in Section 2.1.2.5.
Case 5 - Gas Bound Condition, m = 4 lb/hr
Case 6 - Gas Bound Condition, m = 10 lb/hr
Case 7 - Gas Bound Condition, m = 15 lb/hr
Case 8 - Gas Bound Condition, m = 45 lb/hr

The following values were used for the inputs to the example calculations:

h_w	200 Btu/hr-sq ft-F
h_o	2 Btu/hr-sq ft-F
h_i	100 Btu/hr-sq ft-deg F (conduction limited)
h_{con}	4000 Btu/hr-sq ft-deg F
k_p	8 Btu/hr-ft-F

R_o	0.05479 ft
R_i	0.03395 ft
t	0.02084 ft
R_{avg}	0.04437 ft
T_{stm}	550°F
T_{DW}	135°F
T_{in}	150°F (for Gas Bound Conditions)
θ_i	2.5466 radians
S	0.038059 sq ft
x	4 ft.
m	4, 10, 15, and 45 lb/hr
H_{fg}	640.8 Btu/lb.
y	0.005834 ft

Table 2.2 shows the temperature distribution results from CC inlet to SL outlet.

2.2.3. Stress and Fatigue Analysis

Without the backfill modification, the steam leg piping does not experience significant temperature stresses. Additionally, the ASME Code allows Class 1 lines smaller than 2-inch nominal diameter that do not require an explicit fatigue usage evaluation to be analyzed by Class 2 rules. Therefore, the previous analyses of the steam leg piping are likely to have used the Class 2 piping procedures. The addition of the backfill modification introduces significant temperature stresses. Therefore, a fatigue evaluation similar to that required for Class 1 piping is necessary.

2.2.3.1. Acceptance Criteria

The acceptance criteria are those given in Paragraph NB-3600 of ASME Section III. Because the additional stresses produced by the backfill modification are displacement-controlled or secondary in terms of the ASME Code terminology, only the primary plus secondary stress (P+Q) evaluation and the fatigue usage calculation is necessary. The acceptance criteria provided in paragraph NB-3200, ASME Section III, are the following:

(P+Q) range $\leq 3\ S_m$
Cumulative Fatigue Usage ≤ 1.0

The limit on the (P+Q) range for a load state pair may be exceeded provided that the requirements of simplified elastic-plastic analysis (ASME Section III, Paragraph NB-3228.5) are met. A key requirement in that analysis is that the (P+Q) range, excluding thermal bending stresses, shall be $\leq 3S_m$.

2.2.3.2. Assumptions Used

A maximum value of 1000 in-lb was assumed for the thermal expansion moment along the length of the steam leg piping. The fatigue usage factor calculated in this section does not include that contributed by a seismic event. Although this contribution is not expected to be significant, a procedure similar to the one outlined here can be followed to determine it. The only non-zero term in the equations would be the moment loading term.

2.2.3.3. Analysis Procedure

The stress and fatigue analysis of the steam leg piping consists of two steps.

- The first step is to calculate the temperatures and stresses at any cross-section due to stratified flow. This is done using a finite element model of a typical cross-section of the steam leg piping. From the temperature analysis, equivalent linear temperature ΔT_1 and the nonlinear portion ΔT_2 are calculated. The linear temperature ΔT_1 is a temperature gradient through the full section of the pipe. The stress information is not directly used but serves as a check on the validity of the calculated ΔT_1 and ΔT_2 values. The ΔT_1 and ΔT_2 values may be first generated for the limiting case and can be scaled linearly for other cases.

- In the second step, a finite element model of the steam leg from nozzle end to the condensing chamber is prepared and a conventional class 1 piping analysis is conducted. The ΔT_1 values calculated in the first step are then input into the analysis to determine the bending moments produced by flow stratification. The calculated stratification bending moments along with the thermal expansion moments and the ΔT_2 information are then used in defining load states for the Code fatigue evaluation. The load states defined for the fatigue evaluation typically would be: normal operation with CC steam-filled, normal operation with CC gas-filled, normal operation $\pm$ seismic. The outcome of this step would be the fatigue usage factors at the critical locations in the steam leg piping.

2.2.3.4. Example calculations

The example calculations provided in this section are representative only. Plant specific analyses should be performed for the individual plants.

Figure 2.15 shows the steam leg configuration used in the example calculation. It was assumed that the CC end of the steam leg piping is constrained in all directions except in the axial direction. The nozzle end of the piping was assumed fixed in all directions. The nominal diameter of the pipe is 1-inch Schedule 160. The temperatures and heat transfer conditions assumed in the pipe section at the exit from CC are specified in Section 2.2.2.1. The water temperature is expected to increase towards the nozzle as a result of heating from the steam.

Figure 2.16 shows the finite element model of the pipe cross-section. Figures 2.17 and 2.18 show the calculated steady state temperature and stress distributions, respectively. The peak stress occurring at the inside surface of the bottom of the pipe is oriented along the pipe axis and its magnitude is approximately 35,700 psi.

The temperature distribution along the mid-radius of the pipe was characterized in terms of a linear component (ΔT_1) and a non-linear component (ΔT_2) as shown in Figure 2.19. The calculated values ΔT_1 and ΔT_2 are 91.6°F and 77.9°F, respectively.
For the 4 lbs/hr backfill rate case considered in this example evaluation, the water temperature at the entrance to the nozzle is essentially at the reactor temperature. Thus the ΔT_1 and ΔT_2 values at the nozzle are essentially zero. Thus, the values of ΔT_1 and ΔT_2 calculated by the finite element analysis were assumed to vary linearly from full value at the CC exit to zero at the nozzle entrance for this example. For more accurate results, water temperature distribution calculated in 2.2.2.3 using the formula given in 2.1.2.2 can be used. The use of linear variation would provide more conservative results.

The appropriate ΔT_1 values were used in the finite element model to determine the resulting bending moments due to stratification. As expected, the value of this moment is highest at the CC end and is close to zero at the nozzle end. Because its ASME Code stress indices are the highest (therefore, correspondingly the highest fatigue usage), a socket weld was assumed located close to the CC end. The stratification bending moment at this socket weld location was determined as 2700 in-lbs.

The Code equation for the primary plus secondary stress evaluation is the following:

$$S_n = C_1(P_O D_O)/(2t) + C_2(D_O M_i)/(2I) + C_3\, E_{ab}\, |\alpha_a T_a - \alpha_a T_b| \leq 3S_m$$

The above equation is to be satisfied for every pair of load sets. The peak stress intensity is then calculated for each pair of load sets using the following:

$$\begin{aligned} Sp = {} & K_1 C_1(P_O D_O)/(2t) + K_2 C_2(D_O M_i)/(2I) + K_3 E\alpha|\delta T_1|/[2(1-\nu)] \\ & + K_3 C_3 E_{ab}\, |\alpha_a T_a - \alpha_a T_b| + E\alpha|\Delta T_2|/(1-\nu) \end{aligned}$$

The nomenclature used in the preceding equations, with the exception of the δT_1 term, is defined in Paragraph NB-3600 of Section III, ASME Code. The quantity δT_1 in the above equation is the quantity ΔT_1 in the Code equation (the change was necessary since ΔT_1 was already defined earlier in this document to characterize the linear range of stratified temperature distribution).

The stress indices used for the socket weld location are the following:

$C_1 = 1.8$	$K_1 = 3.0$
$C_2 = 2.1$	$K_2 = 2.0$

$C_3 = 2.0 \qquad K_3 = 3.0$

The material for the steam leg piping and the associated fittings was assumed as Type 316L stainless steel because the use of 316L is more conservative. The material properties used for this were:

S_m = 13,725 psi (@ 575° F)
E = 28.3×10^6 psi
α = 8.43×10^{-6} (also the same for α_a and α_b)

The following values were used for the normal operation load state in evaluating the S_n and S_p values:

P_o	1050 psi
D_o	1.315 in.
t	0.25 in.
Mi	M1 + M2
M1	stratification moment = 2700 in-lbs.
M2	thermal expansion moment = 1000 in-lbs (assumed)
δT_1	30°F (based on pipe finite element results, see Figure 2.17)
ΔT_2	78°F
$\lvert T_a - T_b \rvert$	10°F (assumed)

The calculations presented next are for the load state pair consisting of normal operation as one of the load states and the other being the zero load state.

$$S_n = 4970 + 40{,}723 + 4765 = 50{,}458 \text{ psi}$$

$$3S_m = 41{,}175 \text{ psi}$$

$$S_p = 14{,}910 + 81{,}446 + 15{,}312 + 14{,}295 + 26{,}549 = 152{,}512 \text{ psi}$$

Since the value of S_n exceeds $3S_m$, a K_e factor was calculated as 1.751.
The alternating stress, S_a for fatigue usage evaluation was then calculated as follows:

$$S_{alt} = (1/2)\, K_e\, S_p = 133{,}524 \text{ psi}$$

For this value of S_{alt} and using the Code fatigue curve of Figure I-9.2, the allowable number of cycles were obtained as 800. The number of actual cycles for the life of the plant were assumed to be 120. This gives a fatigue usage factor of (120/800) or 0.15. In order to calculate the total fatigue usage, one need to add any fatigue usage contributed by normal operation $\pm$ seismic load set.

2.3 Water Level Instrumentation Nozzle

2.3.1 Discussion

The Water Level Instrumentation Nozzle (IN) connects the RPV to the SL. It is typically a short piece of pipe that penetrates the RPV wall and is welded to the RPV wall on one end and the SL on the other. The nozzle has a small blend radius on the inner wall of the RPV.

2.3.2 Thermal Hydraulic Analysis

To preclude the occurrence of high cycle thermal fatigue on the IN during the normal condition (4 lb/hr), the backfill flow rate should be limited such that the water entering the RPV is within 100°F of the reactor temperature (see 2.3.3.1).

The one dimensional mixed mean temperature model has been used for a sensitivity evaluation for a given SL length and the backfill flow rate to meet the 100°F temperature difference criterion. This evaluation assumes a gas bound CC (i.e., no heating in CC) and, takes credit for the heating of the water while it travels through the SL.

Figure 2.20 shows the results, where backfill flow rate is plotted as a function of the SL pipe length. This evaluation is based on the geometry specified in Figure 2.5 with a 1 inch Schedule 160 SL. It should be noted that the results are sensitive to plant-specific geometry (e.g., SL pipe size, length, slope, etc.). The total SL length to be used for this calculation is shown as "SL Length in Example" in Figure 2.5, and the basis for selecting such a length is as follows. In the SL, natural circulation induced by the density difference between steam and non-condensable gases keeps steam circulating in the horizontal portion of the SL and part of sloped section of the SL. Steam heats up the water in the steam filled portion of the SL and the IN before it reaches the RPV inside wall. The total SL length to be used includes the sloped SL not blocked by non-condensable gases, the horizontal section of the SL, and the IN all the way through the RPV wall.

2.3.3 Stress Analysis

The nominal diameter of this nozzle is typically two inches. The nozzle and the safe end materials are either inconel (SB166) or Type 304 stainless steel. The nozzle is attached to the vessel by a J-weld and the safe end, if any, is attached to the nozzle by a circumferential butt weld.

2.3.3.1. Acceptance Criteria

Because this nozzle is part of the reactor pressure vessel (RPV), the acceptance criteria are essentially the ASME Code requirements to which the RPV was designed and analyzed. The ASME Code evaluation of this nozzle is documented as a part of the RPV stress report. The Code evaluation consists of the determination and the comparison with the allowable values of the primary and primary plus secondary stresses, and a calculation of the fatigue usage factor. The allowable value for the cumulative fatigue usage factor is 1.0. Because this nozzle is small and the thermal cycle duty from the cycles defined in the thermal cycle chart is insignificant, one approach that has generally been used in several RPV stress reports is to justify exemption from fatigue calculation using the rules of either Paragraph N-415.1 [for plants using older Code versions] or Paragraph NB-3222.4 (d) [for plants using later versions of the Code]. The calculated rapid cycling thermal stresses resulting from the backfill modification should be evaluated with respect to the fatigue exemption criteria. If this criterion is satisfied, then the Code criteria regarding fatigue evaluation are satisfied. Because the backfill modification only produces thermal stresses that are secondary, the primary stress evaluation is not affected.

The mixing of the steam and the entering backfill water, which is at a lower temperature than the nominal steam temperature of 550°F, would produce rapid temperature cycling at the nozzle weld and adjacent vessel surfaces.

The fatigue exemption criteria of the Code limits the cyclic temperature difference (ΔT) at any point to $S_a/(2E\alpha)$, where S_a is the value obtained from the applicable design fatigue curve of the Code. The S_a value was obtained as 28.2 ksi from the code S-N curve (Figure I-9.2) at 10^6 cycles. This gives the acceptable value of ΔT for normal operation (4 lb/hr) as 59°F. This temperature range should be applied to the metal surface. The metal surface temperature range is considerably less than the fluid temperature range.

The reduction in cyclic temperature range that the metal surface experiences was determined using a closed form solution for a semi-infinite plate subjected to cyclic fluid temperature changes at its surface. The reduction factor was determined as:

$$\text{Reduction Factor} = RF = 1 / (1 + 2m + 2m^2)^{1/2}$$

where

m	$(k/h_f)\ (0.5\omega/\alpha)^{1/2}$
k	Metal thermal conductivity (Btu/hr-ft-F)
h_f	Convective heat transfer coefficient (Btu/hr-sq ft-F)
ω	Cyclic frequency of temperature change (rad/hr)
α	Thermal diffusivity of metal (sq ft/hr)

The material properties of stainless steel were used in evaluating the above equation. Based on a review of feedwater nozzle thermal fatigue analysis/testing, the use of a cyclic frequency of 1 Hertz and h_f = 4000 Btu/hr-sq ft-deg F was judged to be conservative. The predominant frequency in the feedwater nozzle was much lower than 1 Hz and h_f was also much lower than the above value. With the selected frequency and

h_f, the reduction factor is about the same but with a much greater number of cycles. With the selected value of ω and h_f, the reduction factor was calculated to be 0.57. This indicates that the metal surface temperature will experience only 57% of the cyclic temperature range of the fluid. Combined with the 59°F calculated from the allowable fatigue exemption criteria, the allowable water temperature difference is calculated to be 59/0.57 = 104°F. Conservatively, 100°F was selected.

There are two different approaches to establish the degraded condition flow rate and the total duration for the degraded condition:

1. Lower the degraded flow rate from 45 lb/hr so that the fatigue exemption criteria can still be met with the desired duration for the degraded condition. This requires a plant unique evaluation, or

2. Perform the fatigue evaluation of the IN for the given flow rate based on the plant specific information so that a realistic duration for the degraded condition can be obtained.

In either case, a plant specific evaluation will be required.

2.3.3.2 Assumptions Used

The frequency of temperature cycling, due to the mixing of steam and backfill water at the nozzle opening in the RPV, during the degraded flow conditions is assumed to be 1 Hertz.

2.3.3.3 Analysis Procedure

No fatigue evaluation is needed if the fatigue exemption criteria are followed.

2.3.3.4 Example Calculation

The example calculations provided in this section are representative only. Plant specific analyses should be performed for the individual plants.

The calculated difference between the backfill fluid temperature at the nozzle and the nominal RPV temperature (550°F) during normal operation (4 lb/hr) is small (see Table 2.2). Thus the criterion of < 100°F is satisfied.

Table 2.1 Example Calculations for Mixed Mean CC Model

(Steam Filled CC)

Case No.	Flow Rate (lb/hr)	Cond. Chmbr. Inlet Temp.(F)	Cond. Chmbr. Bottom Outlet Temp. (F)
1)	4	150	393
2)*	10	150	300
3)*	15	150	263
4)*	45	150	196

Table 2.2 Example Calculations for Backfill Flow Temperatures from CC Inlet to IN

(Gas Bound Conditions)

Case No.	Flow Rate (lb/hr)	CC Inlet Temp. (F)	CC Outlet Temp. (F)	IN Temp (SL Outlet) (F)
5)	4	150	150	541
6)	10	150	150	522
7)	15	150	150	503
8)	45	150	150	404

* For the high flow rate cases (10 lb/hr, 15 lb/hr, and 45 lb/hr), the one dimensional coupled mixed mean and stratification model produces significantly conservative results when compared to the three dimensional finite element model results.

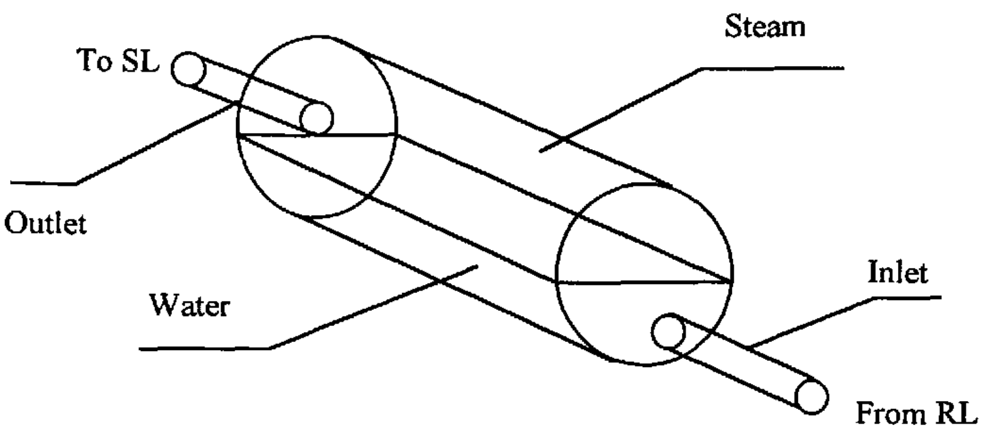


Figure 2.1 Example Condensing Chamber

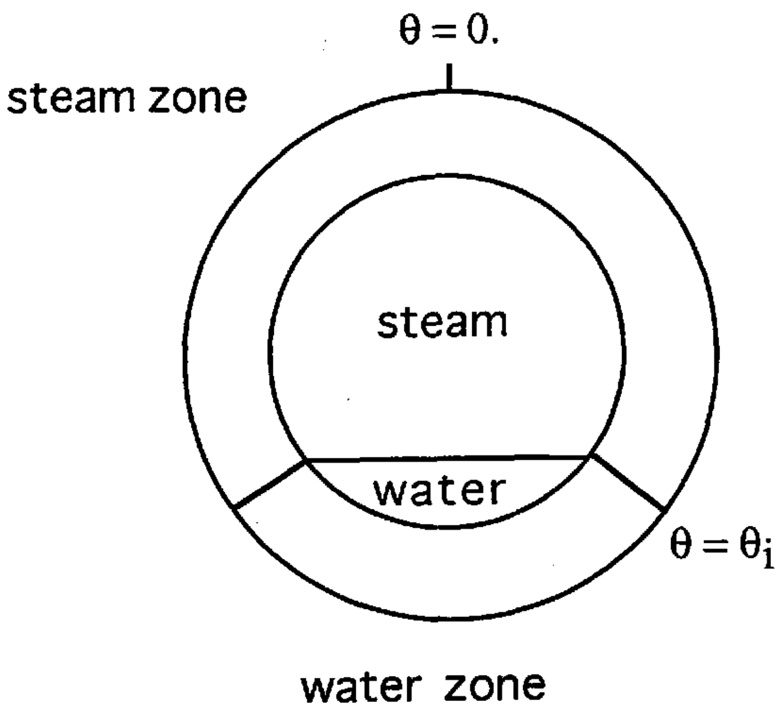


Figure 2.2 Definition of Steam and Water Zones

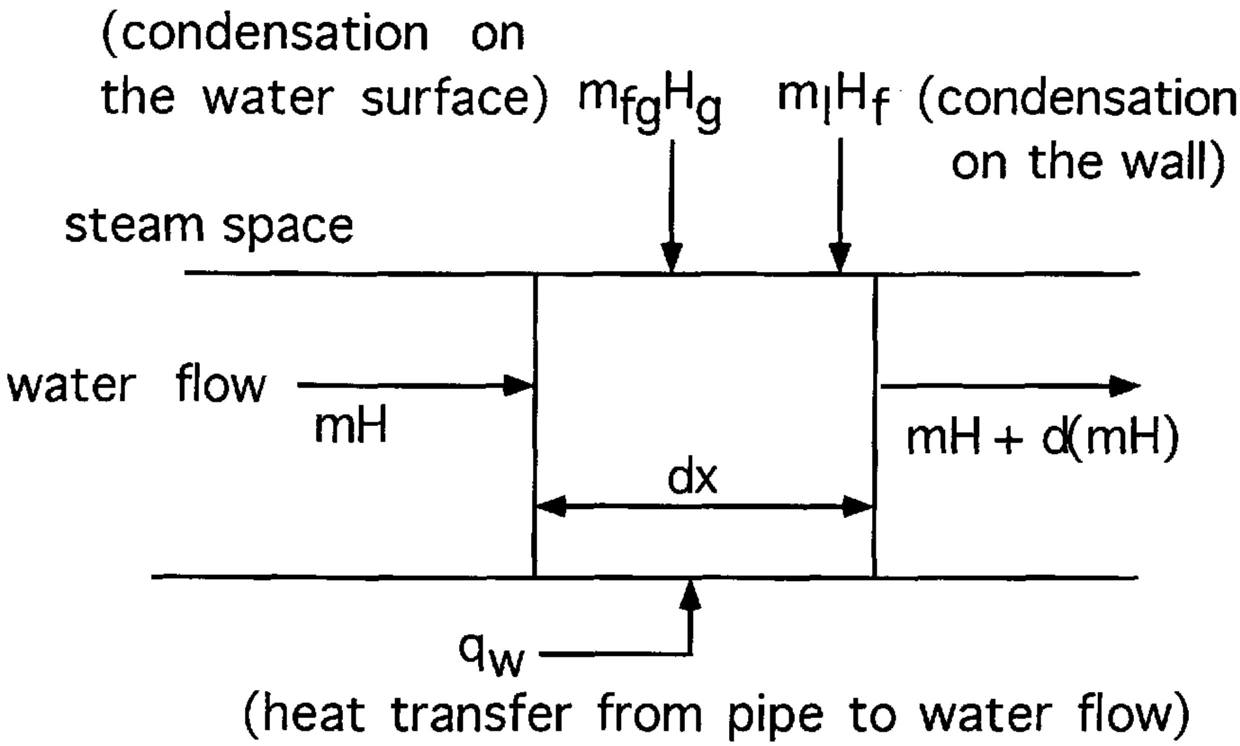


Figure 2.3 Energy Balance for Differential Element of Water Flow

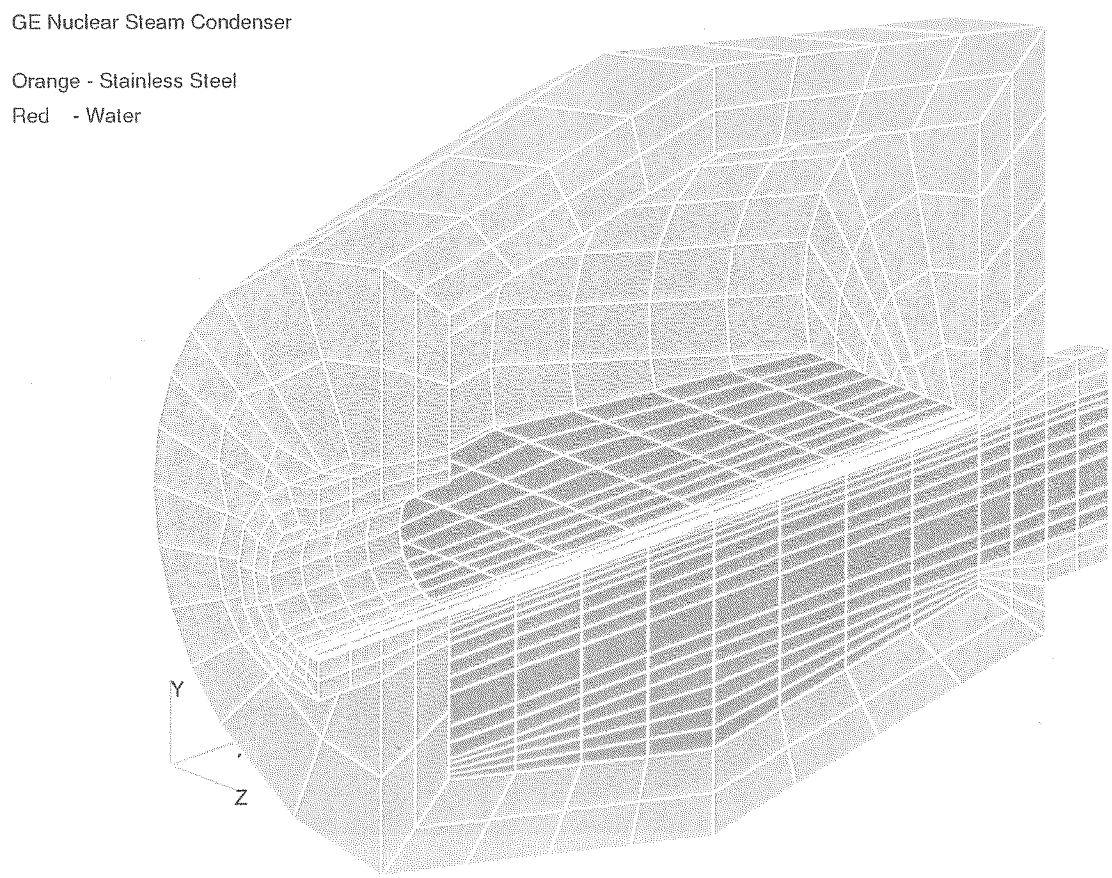


Figure 2.4 Example Three Dimensional Analysis Model for CC Water and Wall Temperature Distributions

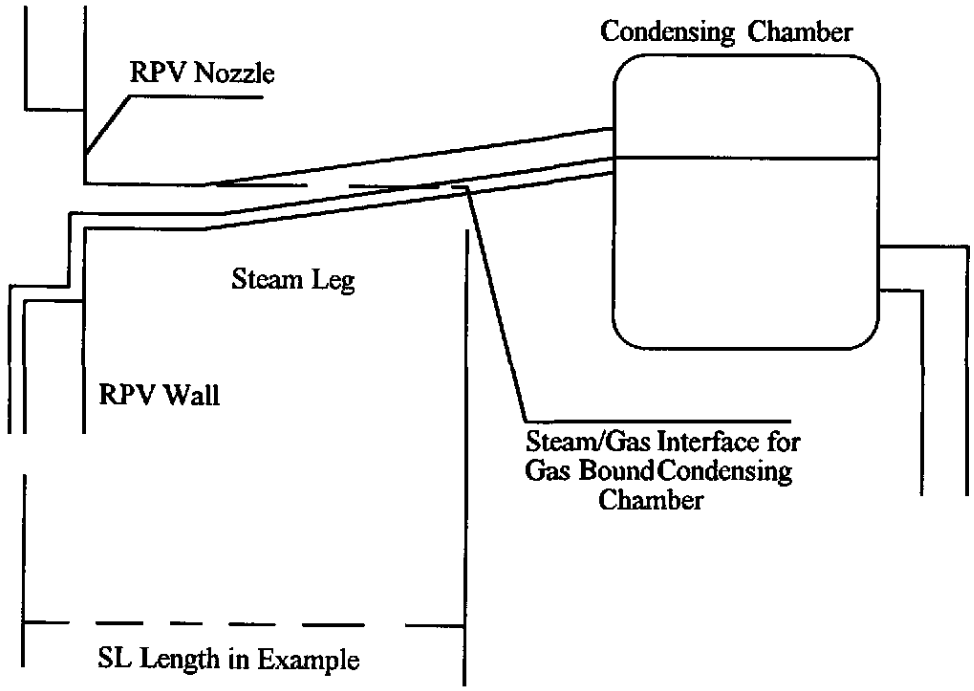


Figure 2.5: Geometry of Steam Leg and Condensing Chamber Used in the Example Calculation

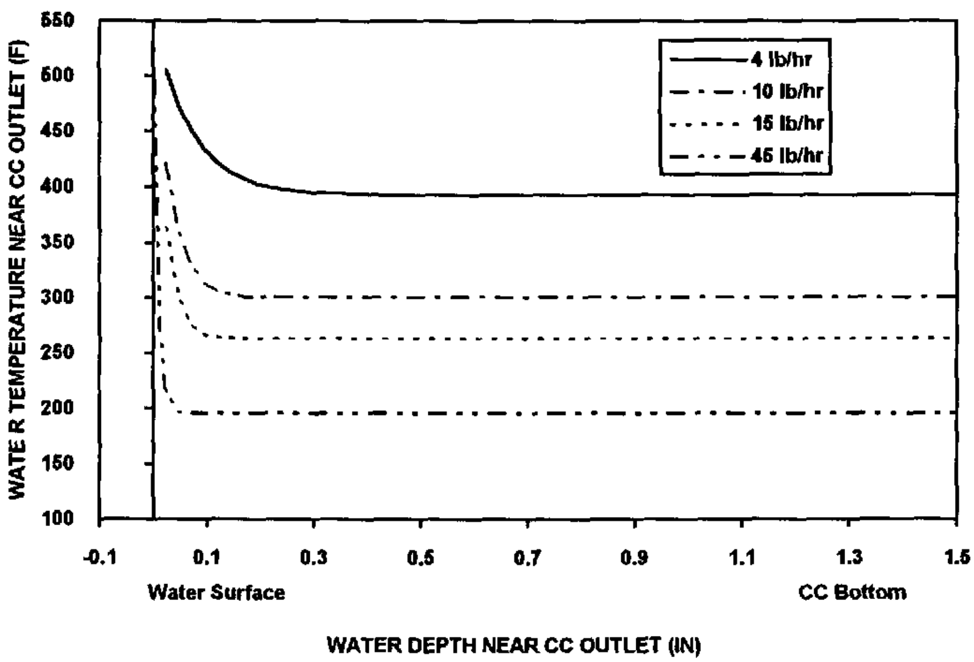


Figure 2.6 Temperature Distribution as a Function of Water Depth at CC Outlet at Various Backfill Flow Rates

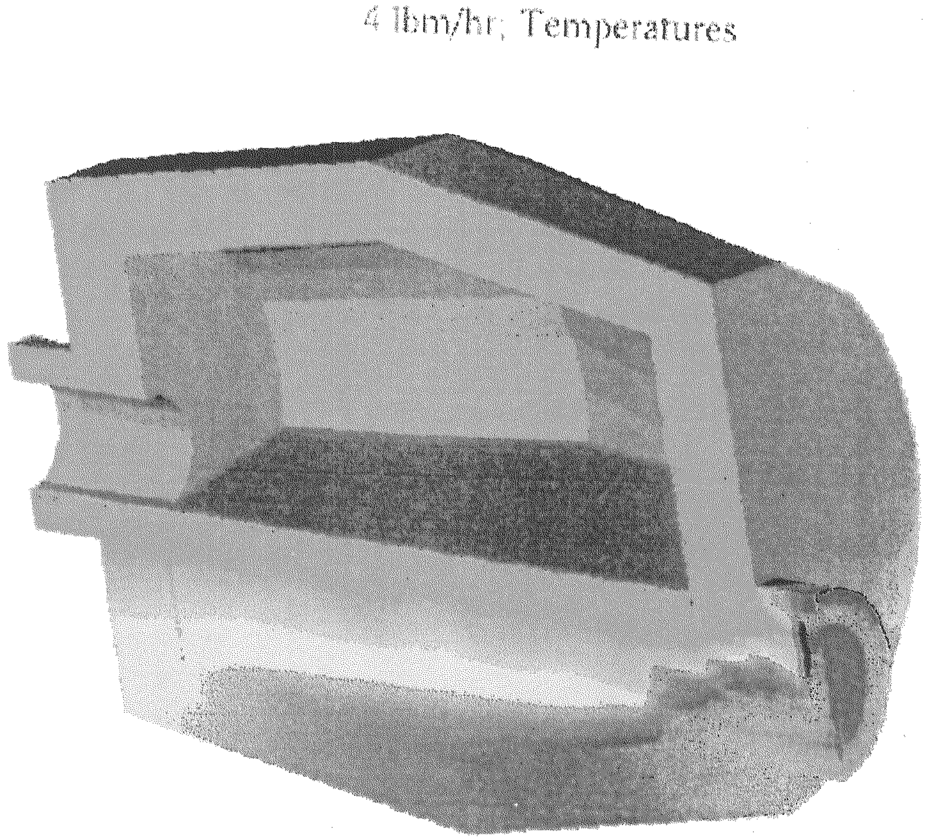


Figure 2.7 Three Dimensional Water Temperature Distribution Inside CC

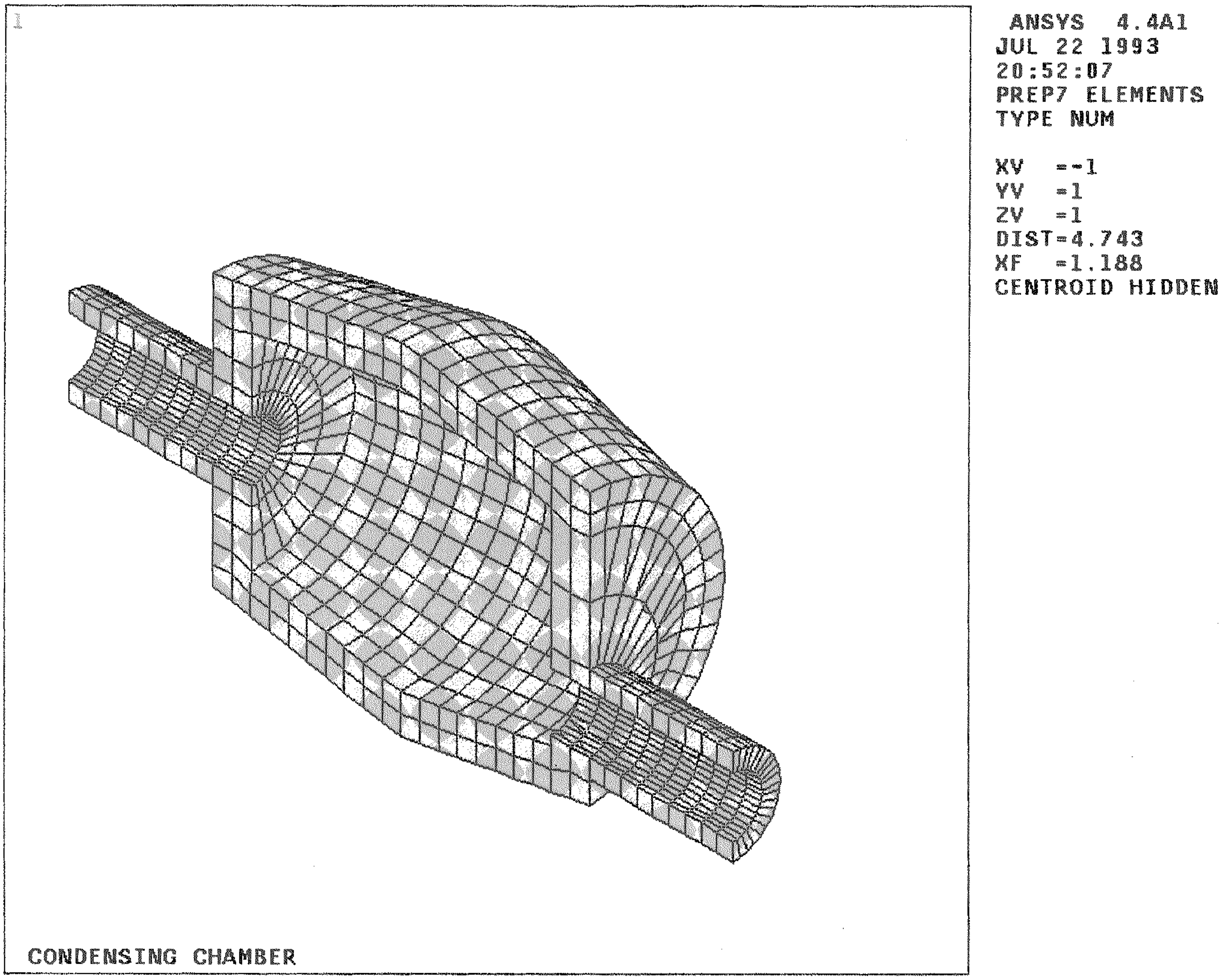


Figure 2.8 Finite Element Model of Condensing Chamber for Stress Analysis

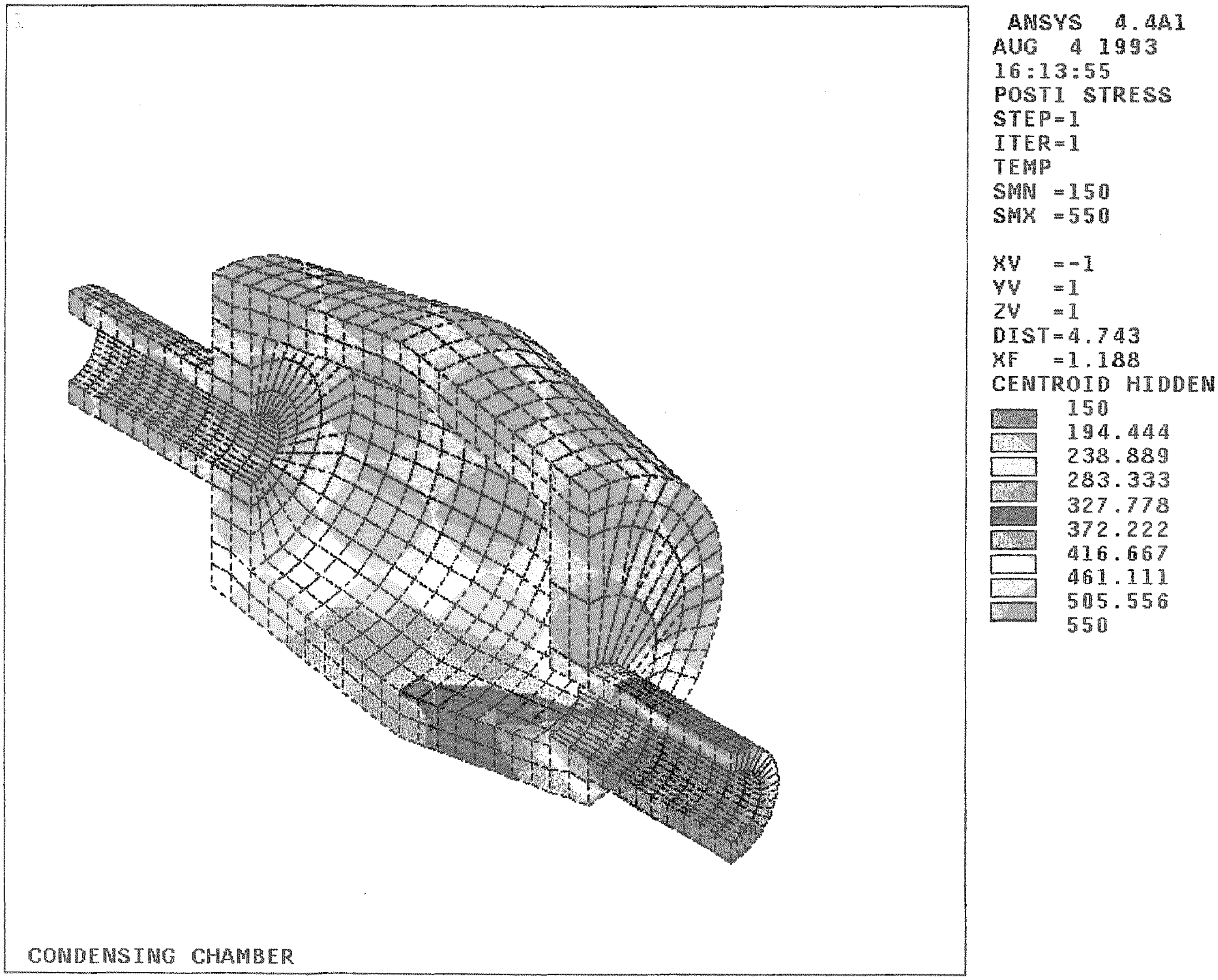


Figure 2.9 Calculated Temperature Distribution in the Condensing Chamber Used in Stress Analysis

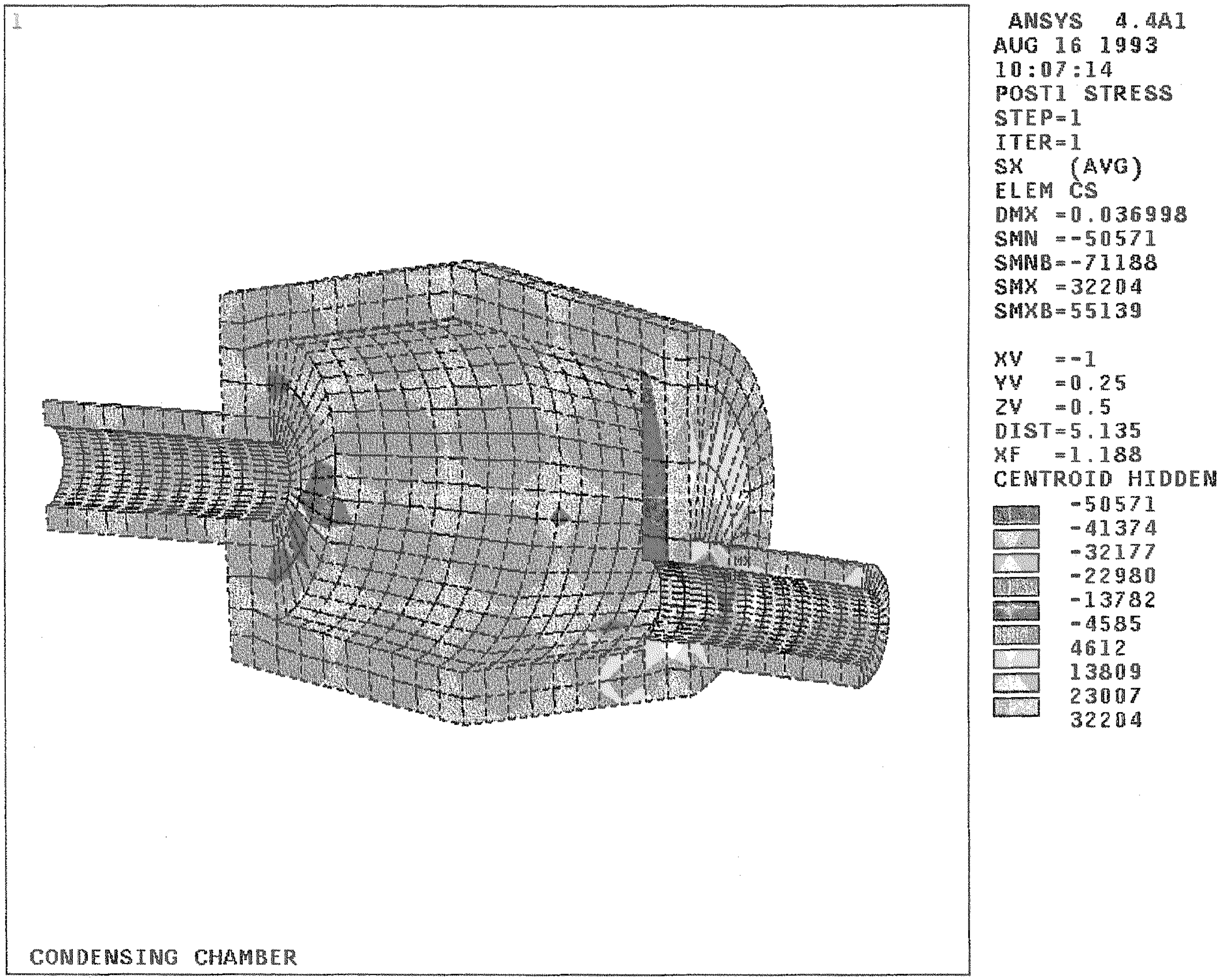


Figure 2.10 Calculated Steady State X-Direction Stress Distribution in the Condensing Chamber

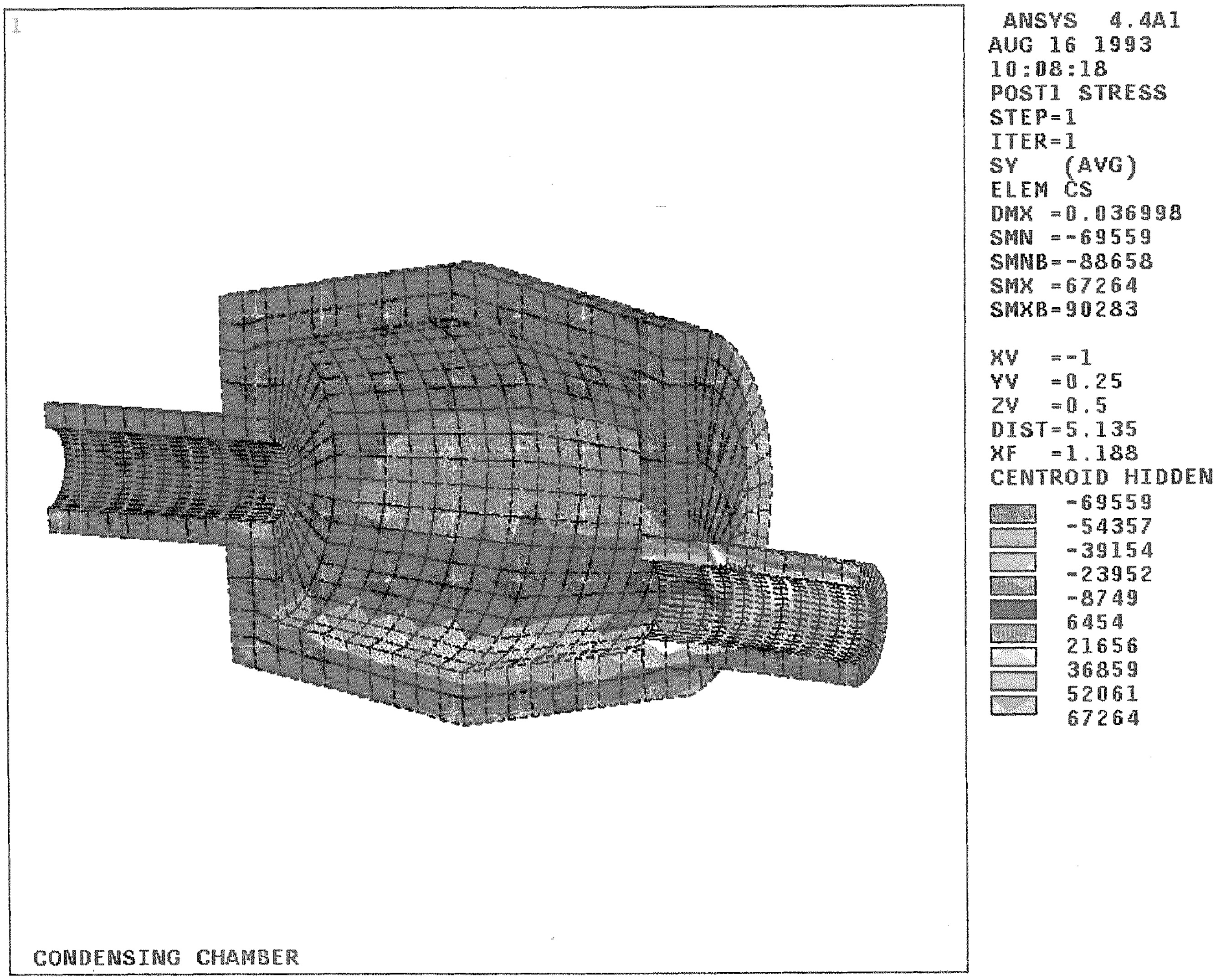


Figure 2.11 Calculated Steady State Y-Direction Stress Distribution in the Condensing Chamber

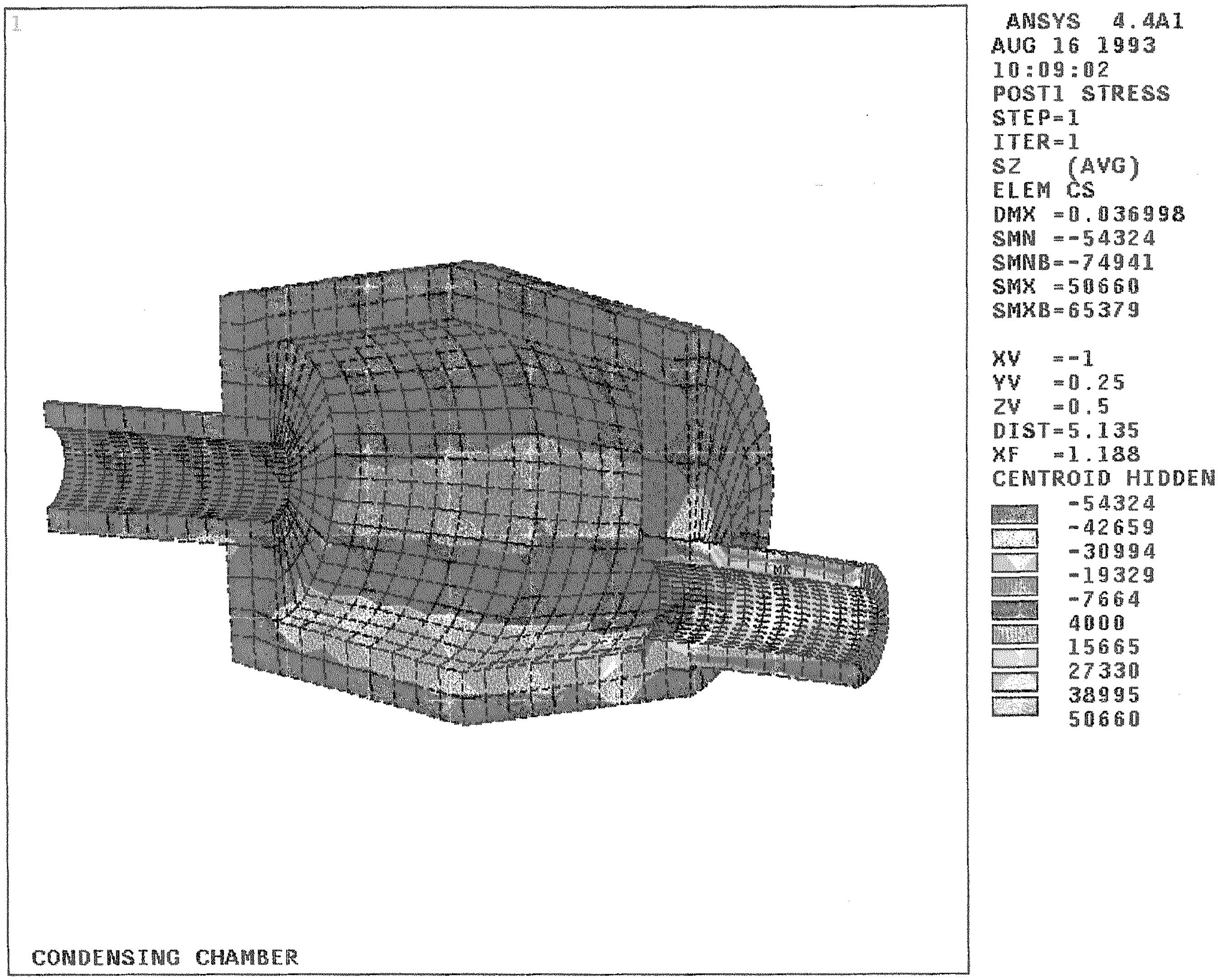


Figure 2.12 Calculated Steady State Z-Direction Stress Distribution in the Condensing Chamber

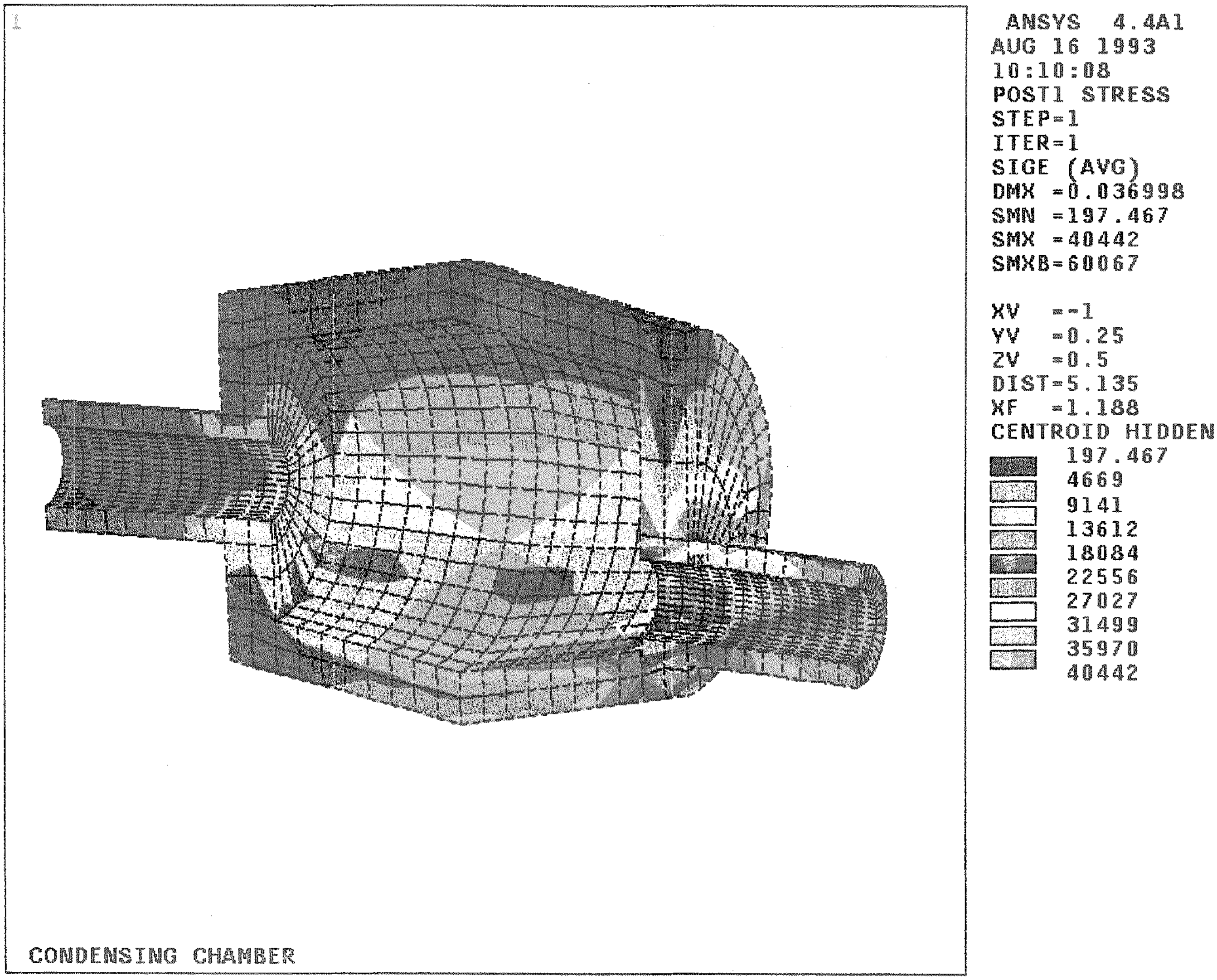


Figure 2.13 Calculated Steady State Equivalent Stress Distribution in the Condensing Chamber

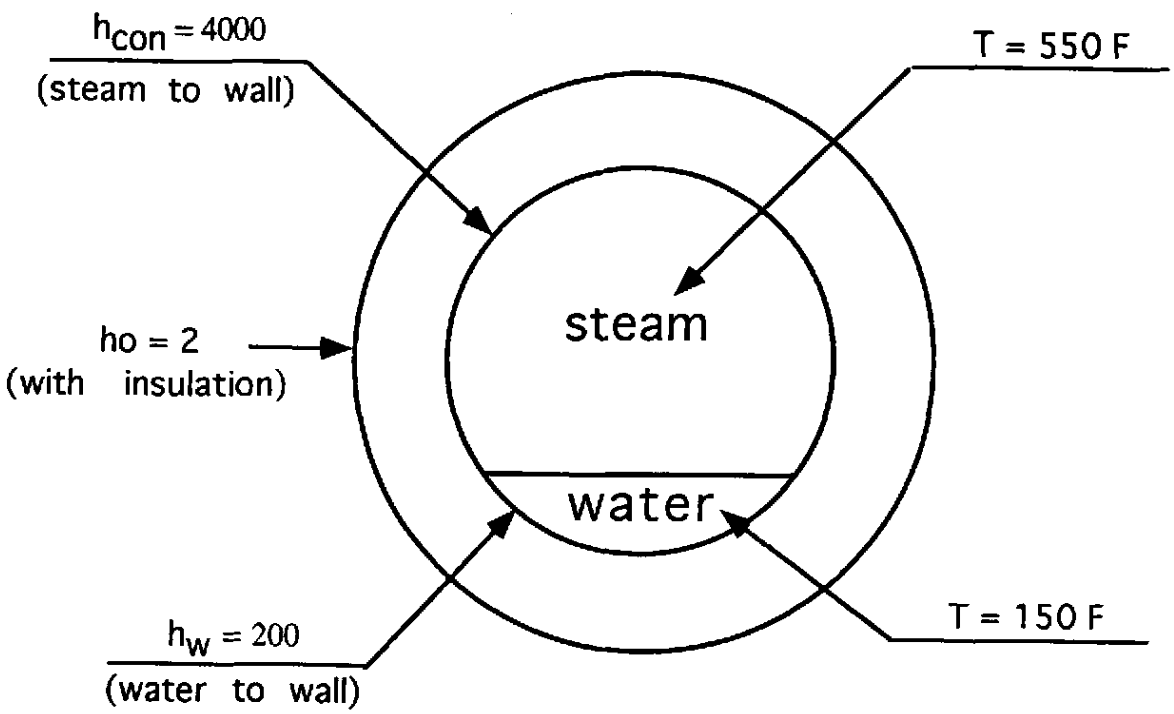


Figure 2.14 Boundary Conditions for Steam Leg with Gas Bound CC for Stress Analysis

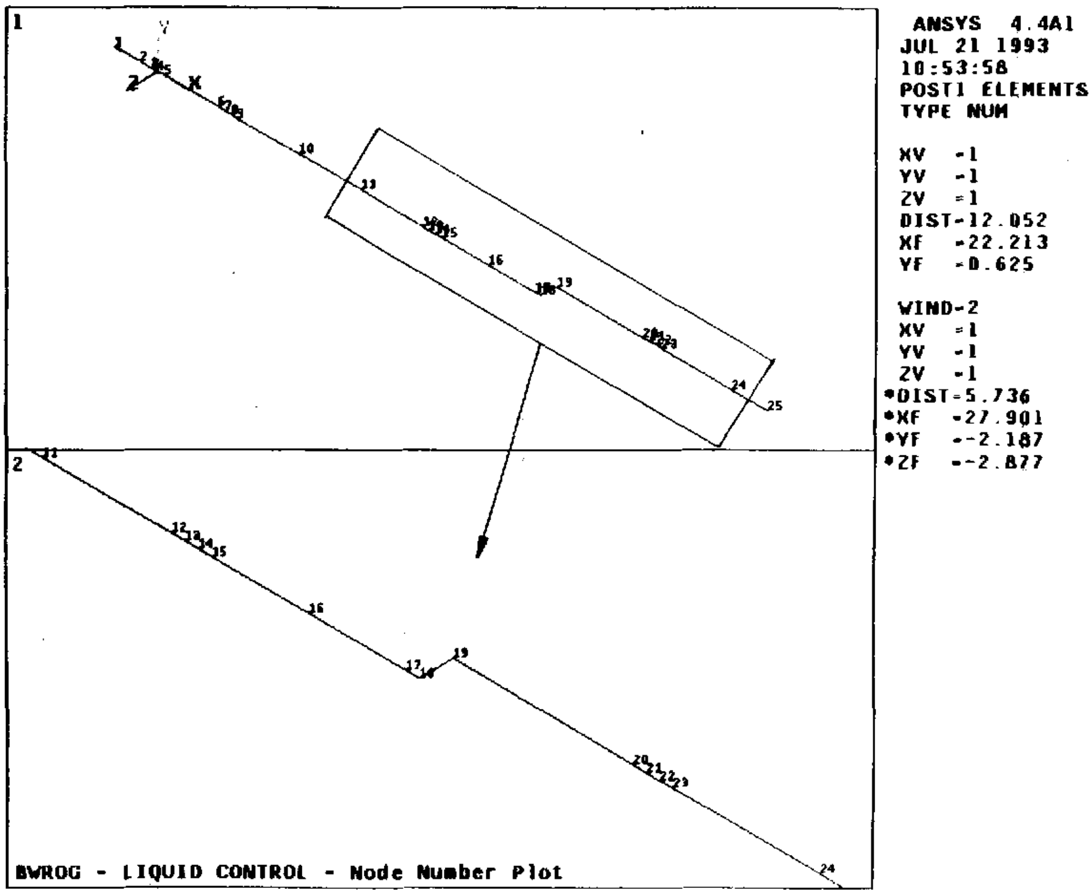


Figure 2.15 Mathematical Model of Steam Leg Piping for Stress Analysis

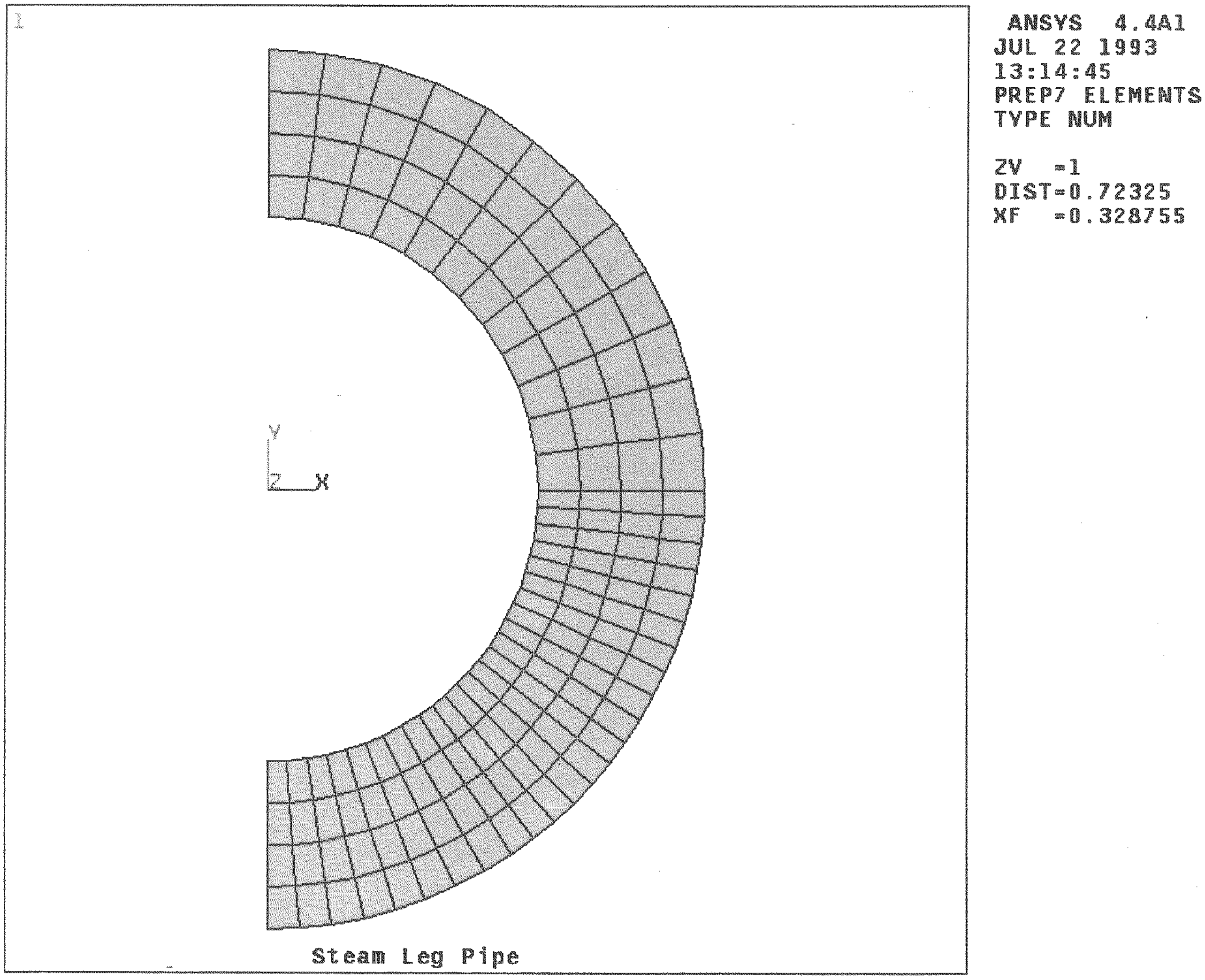


Figure 2.16 Finite Element Model of Steam Leg Piping Cross Section for Stress Analysis

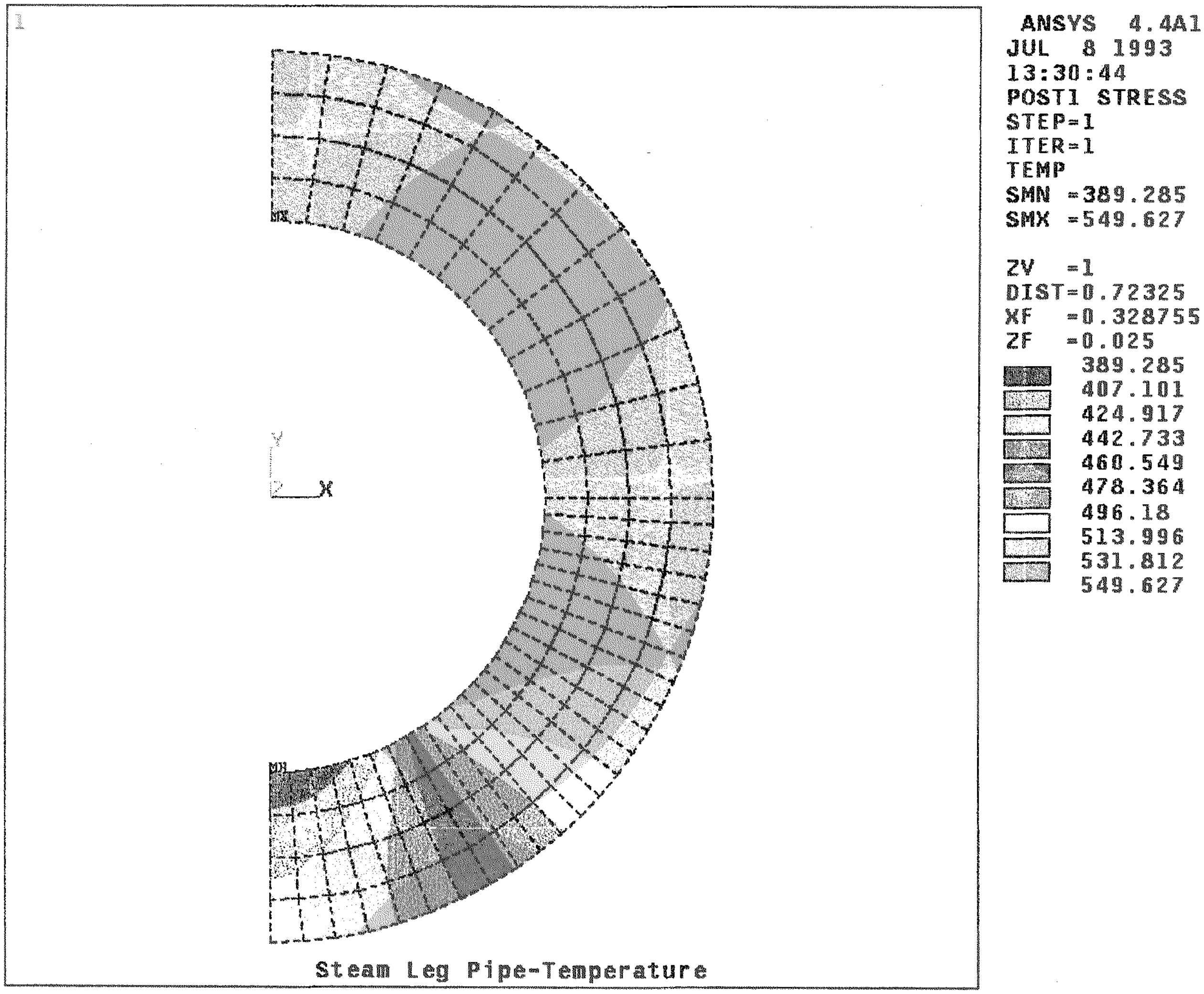


Figure 2.17 Calculated Steady State Temperature Distribution in the Steam Leg Piping Section for Stress Analysis

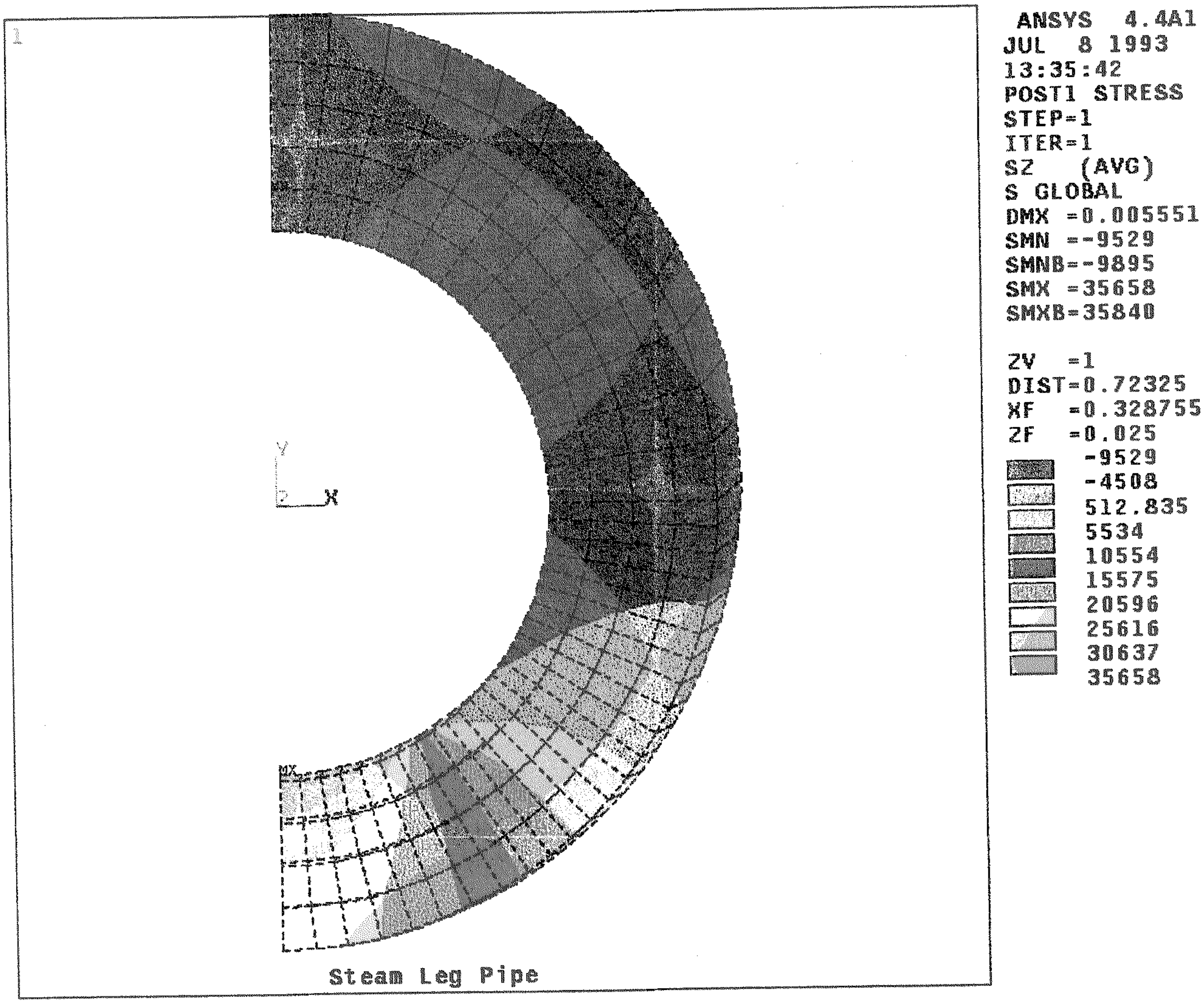


Figure 2.18 Calculated Steady State Axial Stress Distribution in the Steam Leg Piping Section

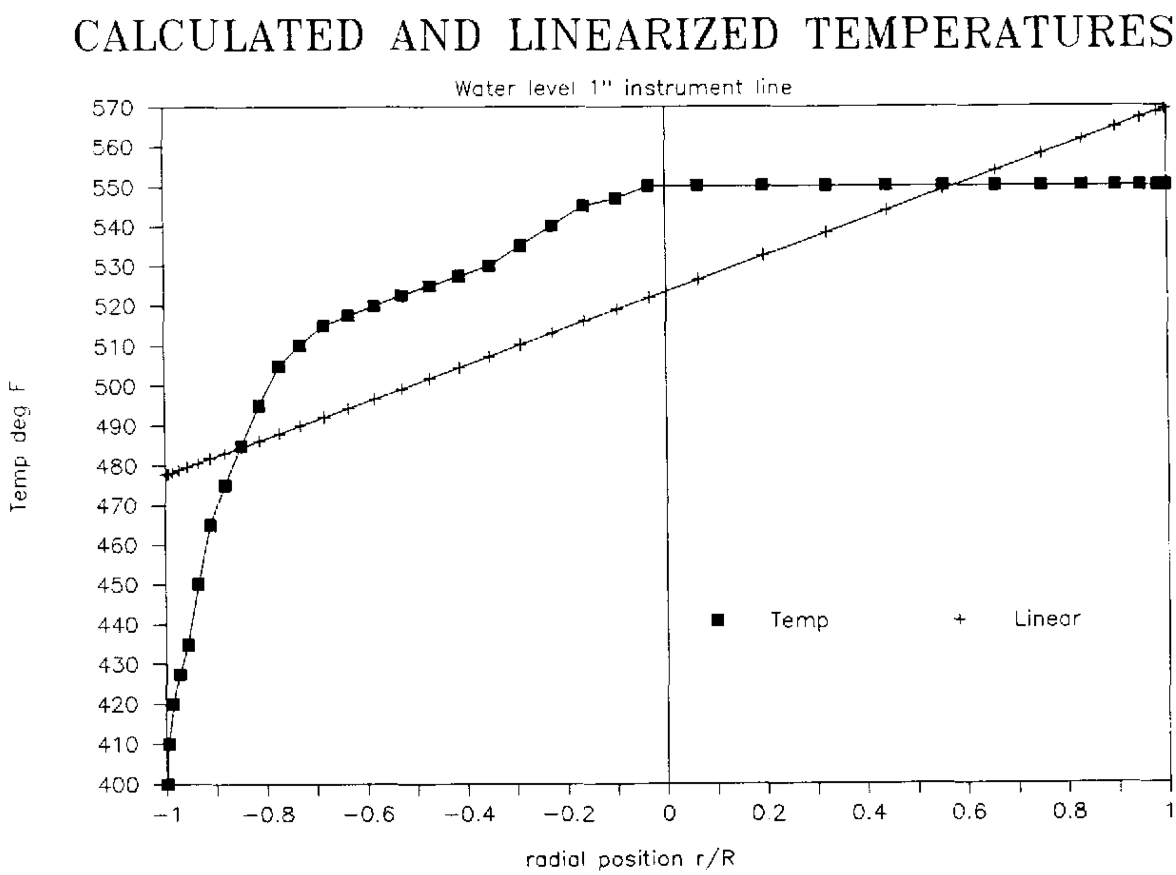


Figure 2.19 **Temperature and Calculated Equivalent Linear Temperature Along Pipe Circumference**

Gas bound condition is assumed
SL Inlet Temperature is 150°F
SL pipe size is 1 inch

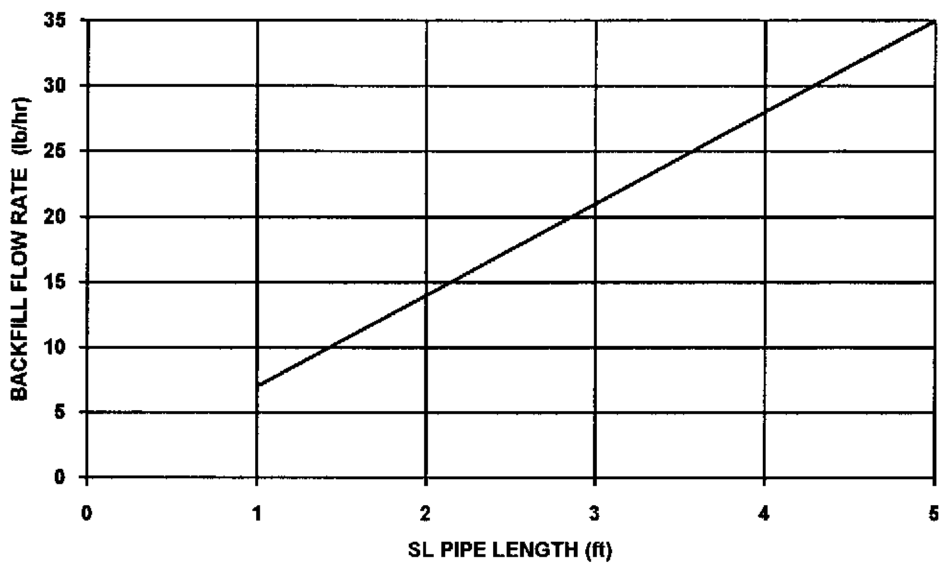


Figure 2.20 Backfill Flow Rate as a Function of SL Length to Meet 100°F Temperature Difference Criterion

3. Guidelines for End Point Calibration Bias Analysis

3.1 Discussion

The purpose of this section is to establish a procedure to calculate the water level calibration bias throughout the RL due to:

- The backfill flow and
- The water density change due to the backfill flow being at a relatively low temperature.

In the example calculation, the portion of the pipe from the drywell penetration to the CC is subjected to the drywell temperature and the RL outside the drywell is assumed to be at the ambient temperature of the reactor building. The flow bias calculation therefore considers the entire RL length that has backfill flow. The temperature bias calculation on the other hand considers only the length of the RL from the drywell penetration to the CC.

The two effects, friction loss and density change, directly affect the calibration of the reactor water level instruments connected to the RL. The introduction of the cold backfill flow will result in an indicated decrease in the water level (but not an actual decrease in the water level). The low reactor water level trip initiations will occur early and the high water level trip initiations will occur late. The early safety trip initiations are acceptable from the standpoint of plant safety, though possibly not from the standpoint of plant operations. If the late high water level safety trip initiations are not acceptable from the standpoint of plant safety, then a plant has two options to accommodate this bias. The first is to lower the nominal trip setpoint and allowable values to take account of the bias. The second is to increase the analytical limit and re-perform the plant safety analyses to confirm the acceptability of the new analytical limit.

3.2 Assumptions Used

1) The flow rate remains constant.
2) There is no air in the total length of the reference leg. Ensure that air does not get in at the instrument rack during instrument calibration and/or instrument replacement.
3) RL leakage flow is ignored. The RL leakage flow consists of both the external leakage and the internal leakage. When leakage flow is assessed, the effect of leakage flow should be added.
4) Drywell temperature is assumed to be constant at 165°F. Because only the calibration bias due to cold backfill flow is considered, the use of constant temperature instead of the actual drywell temperature distribution is justified.
5) The effect of thermal expansion on the pipe wall is ignored.
6) The effects of thermal convection are ignored.
7) The heat transfer coefficient around the RL is constant.
8) The RL water temperature in the reactor building is assumed to be the same with and without the backfill modification.
9) Injection point is assumed to be at the base of the transmitter.

10) Velocity of the air in the drywell and reactor buildings is 10 ft/sec.
11) Heat capacity of the fluid is assumed to be constant.

3.3 Analysis

3.3.1 Flow Bias

An equation has been derived to calculate the head loss due to the velocity of the fluid inside a pipe. The head loss due to friction is based on the determination that the flow is a laminar flow. In addition, an equation has been derived to calculate head loss due to bends in the pipe. The loss coefficient involved in calculating the head loss is determined based on the geometry of the bends.

The pressure at the pressure transmitter on the RL side is the sum of the following factors:

- The dome pressure
- The vertical length of the RL
- The static pressure change due to the dynamic head
- The friction loss due to the viscosity of water
- The head loss due to bends and tees in the RL

The last three items constitute the calibration bias due to the backfill flow and are calculated. The changes of viscosity, density, and velocity as a function of temperature are considered.

The following equation determines the pressure at the pressure transmitter without the backfill modification.

$$P_1 = P_R + \gamma_1 \Delta h$$

With the backfill modification, the equation is modified to

$$P_2 = P_R + \Sigma\gamma_i \Delta h_i + \Sigma\gamma_i dh_{Li} + \gamma_3 (v^2/2g)$$

where

γ_1	Specific weights of water without the backfill modification
γ_i	Specific weights of water with the backfill modification (may be broken up into multiple segments)
Δh_i	Change in vertical elevation (may be broken up into multiple segments)
h	Vertical elevation
P_1	Pressure at the pressure transmitter on the RL side without the backfill modification
P_2	Pressure at the pressure transmitter on the RL side with the backfill modification
P_R	Pressure in the CC steam space

- dh_{Li} Head loss due to friction, bends, tees, expansion and contractions in the pipe (may be broken up into multiple segments).
- v Velocity of water entering the CC.
- g Gravitational acceleration constant
- γ_3 Specific weight of water entering the CC

By comparing the above equations, the total bias is calculated:

$$P_2 - P_1 = \Sigma\gamma_i \Delta h_i + \Sigma\gamma_i dhL_i + \gamma_3 (v^2/2g) - \gamma_1\Delta h$$

In the above equation, the first and last terms represent the temperature bias (h_{TB}). The second and third terms represent the flow bias (h_{FB}).

Head losses due to friction are determined based on the calculated Reynolds number of a laminar flow, the velocity and viscosity of the fluid, and the length and diameter of the pipe along the RL.

Head losses due to bends in the pipe are determined based on the bend radius, the degree of the bends, and the velocity of the fluid.

Head losses due to contractions and expansions in the pipe are determined based on the changes in diameter of the pipe and the changes in velocity and viscosity of the fluid as a result of the changes in the diameter.

The head loss at the tee is determined based on the diameter ratio of the branch and the run of the tee, the flow split ratio, and the corner radius.

The pipe is subdivided into one foot segments, and the head loss is calculated for each segment.

The total flow bias is the sum of the head losses and the velocity head.

3.3.2 Temperature Bias

The temperature of the backfill flow in the reactor building is equal to the reactor building ambient temperature for this example. Thus the temperature bias in the reactor building is not affected by the backfill modification because the specific weight difference (γ_i - γ_1) term is zero. However, this term is not zero in the drywell because the backfill flow gradually heats up as it travels through the RL.

The change in temperature results in a specific weight change throughout the length of the RL. The temperature change is calculated by the equation provided in Section 2.1.2.1. This temperature change also has an effect on the heat capacity and viscosity of the water. Equations, as a function of temperature, have been derived to calculate the density and viscosity of the fluid.

In order to determine the specific weight, heat capacity and viscosity, the RL is subdivided into one foot segments. The net change of the hydrostatic head due to the temperature variation along the RL is calculated to provide the temperature bias by the following equation:

$$h_{TB} = 1/\gamma_0 \, \Sigma(\gamma_i - \gamma_1) \, \Delta h_i$$

where

h_{TB}	Head loss due to temperature bias
γ_i	Specific weights of water with the backfill modification (may be broken up into multiple segments)
Δh_i	Change in vertical elevation (may be broken up into multiple segments)
γ_0	Specific weight of water at standard conditions

The summation is made for one foot segments. The horizontal portion does not contribute to the bias because the equation considers the elevation change,.

3.4 Example Calculations for End Point Calibration Bias

The temperature gradients and pressure effects are then used as inputs into the reactor water level calibration endpoints to determine the error in the indicated water level.

3.4.1 Flow Bias

For the example calculation with 4 lb/hr backfill flow and RPV pressure at 1050 psia, the flow bias is calculated to be 0.14 in water. When the backfill flow increases to approximately 10 lb/hr, the flow bias is 0.37 in water. The flow biases for the normal and off rated operating conditions are thus small. The flow bias for the degraded system operating condition (45 lb/hr) is 1.9 in water.

3.4.2 Temperature Bias

For the 4 lb/hr backfill flow condition, the temperature bias is calculated to be 0.82 in water (narrow range). For backfill flows of 10 lb/hr and 45 lb/hr, the temperature biases are 1 in water and 1.5 in water, respectively.

4. Guidelines for System Impact Evaluations

4.1 CRD System Transients

4.1.1 Discussion

Because the backfill flow is supplied by the CRD system, variations in CRD system pressure would affect the backfill flow. These variations could occur as a result of normal operational events such as control rod movements and scrams as well as operational transients such as CRD pump start and stop, pump switching, and two pump operations.

The check valves in the system can sometimes generate pressure waves due to reverse flow. Part of this pressure wave will be transmitted to the RL. The withdrawal or insertion of control rod drives also causes abrupt pressure disturbances in the CRD piping, which can propagate to the RL and lead to level indication errors. The magnitude of such errors is tolerable if the pressure disturbance is attenuated sufficiently during its passage from the CRD piping through the backfill flow control valve and other components.

The following evaluation addresses the issues discussed above.

4.1.2 Evaluation

The CRD system will normally provide flow to the backfill system at a pressure of approximately 300 psi above the reactor pressure of 1050 psia. The pressure reduction component in the backfill system (e.g., a metering orifice or valve) will reduce this pressure to within 1 psi above reactor pressure. Thus, the nominal backfill flow (approx. 4 lb/hr) will be maintained with a pressure difference of 300 psi across the pressure reduction component. In the event of a slow change in CRD pressure, the backfill flow would stabilize to a new steady state value. The new backfill flow rate can be estimated by the following relationship:

$$m_c/m_n = (DP_c/DP_n)^{1/2}$$

where

m_c Flow during off-normal CRD pressures
m_n Flow during normal CRD pressures
DP_c Pressure difference during off-normal CRD pressures
DP_n Pressure difference during normal CRD pressures

This relationship should be used with caution. Due to the low flow rate, the flow will be laminar and the pressure drop due to friction will be proportional to flow in the pipe. The pressure drop in the valves and fittings will still follow the above relationship. When the majority of the pressure drop is due to the fittings and valves, the above formula is still useful.

The pressure disturbance (Δp) that can be generated by check valve closure can be calculated by the equation:

$$\Delta p = \rho \, c \, \Delta V$$

where

ρ	Density of water (lb/cu ft)
c	Sonic velocity (ft/sec)
ΔV	Flow velocity change due to check valve closure (ft/sec)

During sudden changes in CRD system pressure, the CRD backfill flow would be affected in a manner similar to a water hammer in a piping system. The pressure reduction component and other flow restrictions would attenuate the pressure wave. Attenuation of pressure waves through orifice type restrictions can be obtained from the equation:

$$DP_t/DP_a = ((1 + 2B)^{1/2} - 1)/B$$

B is defined in terms of the loss coefficient in the restriction, the density of water, and the sonic speed in water as follows:

$$B = KgDP_a/(2\rho c^2)$$

where

K	orifice loss coefficient
g	32 (lbm-ft/lbf-sec^2)
ρ	density of backfill water (lb/cu ft)
c	sonic speed in the backfill water (ft/sec)
DP_t	Transmitted pressure wave
DP_a	Incident pressure wave

(For example, if CRD system pressure is 1350 psig, an incident pressure wave of 1750 psig would result in a DP_a of 400 psi.)

The attenuation equation stated above applies to orifices and valves. For changes in pipe cross section areas, the following method may be used.

A pressure disturbance will decrease when passing from a smaller pipe to a larger pipe and will increase when passing from a larger pipe to a smaller pipe. The transmitted disturbance can be obtained from

$$DP_t/DP_a = 2/(1 + At/Aa)$$

where

At	Pipe area of section in which the disturbance is transmitted
Aa	Pipe area of section from which the disturbance arrives.

If a set of "n" geometric attenuations occurs in series as a pressure disturbance propagates through a pipe, the pressure disturbance transmitted at the nth attenuation is given by:

$$DP_{t,n}/DP_a = F1\ F2 \ldots Fi \ldots Fn$$

where $Fi = DP_{t,i}/DP_{a,i}$

4.1.3 Example Calculation

The example calculations provided in this section are representative only. Plant specific analyses should be performed for the individual plants.

Consider the piping schematic of Figure 4.1, for which the source pressure is 1450 psig upstream of the orifice in the 1 inch line. A 200 psi pressure loss occurs across the orifice, the pressure regulator, filters, and metering valves in the line. These elements can be approximated by a single, equivalent orifice. The loss coefficient for this orifice at 4 lb/hr can be calculated for the 200 psi pressure loss. The flow also enters a 3/8 inch line. The parallel connections are provided for performing maintenance activities and only one flow path is assumed to be open in this example (more attenuation would occur if both flow paths were to be open). Pressure losses of 50 psi each are assumed to occur across the flow meter, control valve, and the metering valve for a 4 lb/hr flow. The flow is then supplied to the RL by a 1 inch line. An additional pressure loss of 50 psi occurs across an orifice, check valves, and a gate valve before the pressure transmitter.

For a flow rate of 4 lb/hr, water density of 61 lb/cu ft, and a pressure loss of 200 psi, the equivalent orifice loss coefficient is 2.28×10^9 referred to the 1 inch line. For the same flow rate and a pressure loss of 50 psi, the equivalent loss coefficient for the flow meter and metering valve is 2.2×10^7 referred to the 3/8 inch line. Note that the foregoing discussion is for illustrative purposes only. In order to ensure that orifice plugging has not occurred, it may be necessary to place the orifice downstream of the filters and to institute a suitable surveillance program.

Table 4.1 shows how a 100 psi pressure disturbance in the CRD piping system is attenuated by the time it arrives at the reference leg.

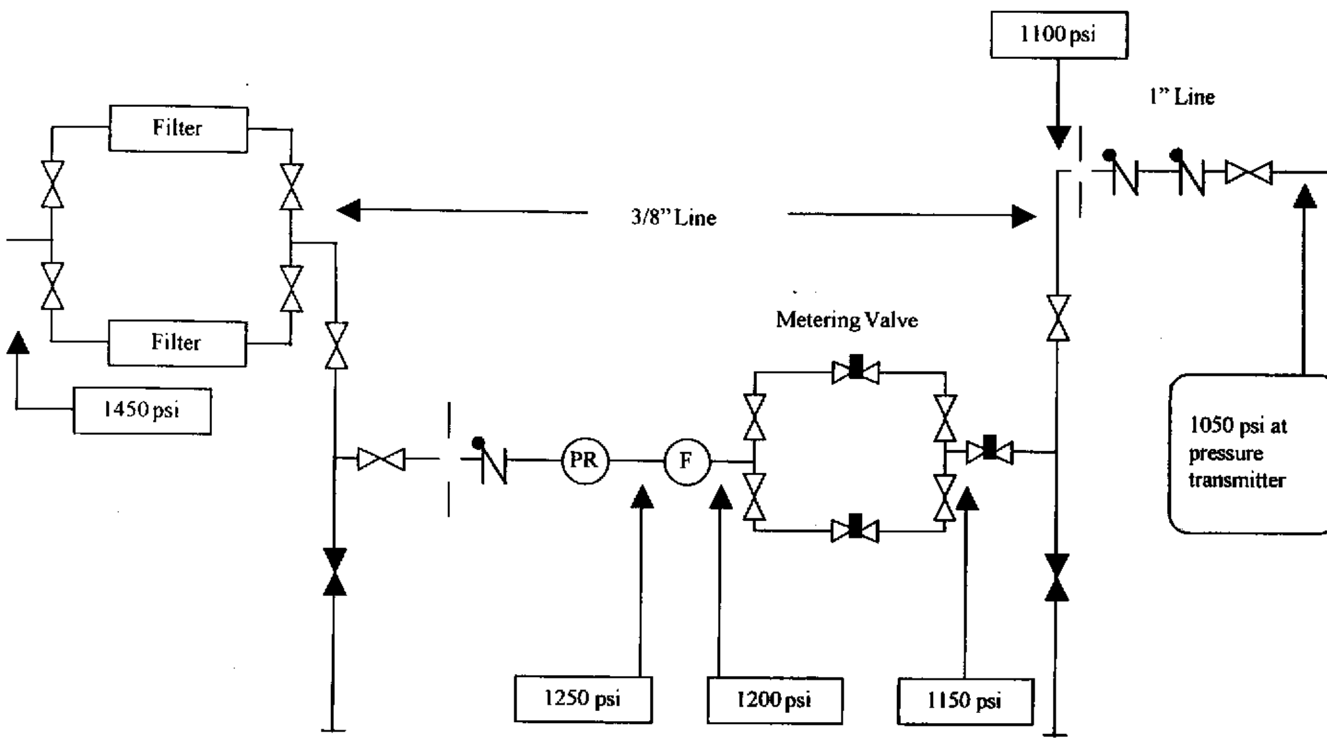
The 100 psi pressure difference is attenuated to 0.011 psi when it reaches the reference leg, which is a factor of 10,000 times less than the original pressure disturbance of 100 psi. The resulting level error for 0.011 psi is about 0.3 inch.

The preceding example is based on the attenuation factors associated with an impulse type pressure disturbance. Less acoustic attenuation is expected at lower frequencies. It is best to treat pressure disturbances of longer wavelengths by the method of characteristics applied to the entire piping system. Generally, such an analysis allows for echoes in all branches of the piping, as well as attenuation from free surfaces and other geometric configurations, such as branches, valves, orifices, and area channels.

When the CRD flow backfill panel is designed to meet the backfill flow rate as well as the pressure disturbance requirements, and the hardware is fabricated and installed, pre-operational testing should be performed to ensure that no undesirable pressure wave is transmitted to the RL.

Table 4.1 Example Calculation for 100 psi Pressure Disturbance in the CRD System

Description	Ratio of Transmitted/Arriving Disturbance	Transmitted Pressure Disturbance(psi)
Downstream of Pressure Regulator	0.0019	0.19
3/8 in Pipe	1.67	0.321
After Flow Meter	0.29	0.093
After Metering Valve in 3/8 in Pipe	0.47	0.044
1 in Pipe	0.32	0.014
Downstream from Exit Orifice (1 in Pipe)	0.778	0.011



Note: This schematic is for illustrative purposes only. It does not represent a proposed or recommended GE design.

Figure 4.1 Schematic Diagram for CRD Pump Transient Example Calculation

4.2 Off Rated Operational Conditions

4.2.1 Discussion

Plant operation other than at rated conditions would affect the performance of the Water Level Instrumentation System. Plant operating modes other than full power that require evaluation are:

- Events that result in gradual changes in CRD system and RPV pressures, such as startup from cold conditions (e.g., following refueling), Hot Shutdown, and Cold Shutdown,
- Events that result in rapid changes in RPV pressure, and
- Extended periods of hot standby with the RPV isolated from the main condenser.

4.2.2 Evaluation

Under normal conditions, normal backfill flow is maintained with the pressure difference between the CRD system and the RPV of approximately 300 psi. The impact of off rated operating conditions on the backfill system during gradual changes in RPV pressure is to change the backfill flow given by the pressure drop / flow relationship stated in Section 4.1.2. Such conditions could be encountered during startup, cooldown, and other orderly changes in pressures. During startup, for example, the CRD system is pressurized before the RPV pressure reaches operating pressure. In such a condition, the pressure difference between the CRD system is more than the pressure difference during normal conditions. In the limit, the RPV pressure could be 0 psig, which is equivalent to a pressure difference of approximately 1350 psi. The backfill flow during off-normal RPV pressure conditions may be calculated using the pressure drop / flow relationship.

For example, if the RPV pressure is 0 psig, the pressure flow relationship stated in Section 4.1.2 may be used to estimate the new backfill flow rate:

$$m_c/m_n = (1350/300)^{1/2}$$

This represents a 2.1 times increase in the normal backfill flow. For a nominal backfill flow of 4 lb/hr during normal RPV pressure, the Zero RPV Pressure flow may become approximately 10 lb/hr, considering laminar friction factors. The actual flow rate under 0 psig RPV pressure conditions should be verified by testing. The increased flow effect during zero RPV pressure should be evaluated for thermal stresses in the CC, SL, and IN.

Events that result in sudden changes in RPV pressure, such as turbine trip (pressure increase) could result in a transitory reduction in the backfill flow, until RPV pressure is reduced by power reduction (scram) and Safety Relief Valve (SRV) actuations. Such reductions in flow normally would be of short duration so reduced performance of the backfill system should not be a concern. Events that cause a decrease in RPV pressure (e.g., inadvertent SRV actuations) would cause an increase in backfill flow. These backfill flow rate changes can be calculated based on the pressure drop / flow relationship. However, with a proper flow control design the magnitude of backfill flow rate change is expected to be small, and should have little impact on indicated water level.

During hot standby, an increase in RPV pressure could occur, which in turn would reduce the pressure difference between the CRD system and the RPV. However, the RPV pressure increase would be limited by plant trips such as the scram on RPV high pressure. Thus the impact on backfill flow change would be bounded by the zero RPV pressure condition discussed above.

4.3 Single Failure Impact on Safety Trips

4.3.1 Background

The purpose of this section is to assess the consequences of the failure of the backfill system to perform as designed on the performance of the reactor and its safety systems. The backfill modification system failure could be broadly categorized as either (1) total loss of backfill flow caused by the CRD or the backfill system failure, or (2) an increase of backfill flow rate above the nominal value caused by the failure of the flow control valve. The first category of failure will lead to the currently existing condition, i.e., before the incorporation of the modifications. The expected reactor safety system performance and its consequences for this case are documented in two GE reports [referred to in Section 1.1] and will not be addressed in this document. A separate BWROG program to address the system out of service time will cover this issue.

The main issue that is considered here is the potential consequences of a high backfill flow (called "degraded condition flow" in this document), which could be an order of magnitude higher than the nominal flow. It has been postulated that such increased backfill flow could cause fluctuations in the sensed water level, which might initiate not only transient events but also affect the water level trips associated with the reactor safety systems. Guidelines are provided in Section 4.3.2 for performing a plant specific evaluation of such an impact of increased backfill flow. These guidelines are qualitative in nature because they involve the trip logics of the reactor safety systems, which are unique to each plant.

4.3.2 Single Failure Evaluation

A background study on the thermal hydraulic phenomena that could be the primary cause for any impact on the safety trips must first be performed. The primary consequence of increased backfill flow in a RL due to the failure of the flow control valve is an increased pressure drop in that RL and hence, in the end point calibration bias, as discussed in Section 3. If this calculated bias is high enough to require a new setpoint calibration, the bias could be reduced through backfill system design changes either by ensuring a lower degraded condition flow rate, or by injecting the backfill flow as close to the drywell penetration as possible, which would reduce the frictional losses. Approximately 3.0" of bias of the indicated water level may be tolerated. Such backfill system design changes might eliminate the need for a new setpoint calibration. The backfill system design should address methods for preventing gas introduction into the RL, such as during calibration activities.

A secondary concern is the consequences of the flow disturbances that could potentially be induced in the steam leg by the increased backfill flow. Even if the increased backfill flow is low enough to preclude periodic plug flow in the steam leg, the potential for unstable condensation, and hence flow oscillation, exists in the steam legs. The possibility of unstable condensation and flow oscillation would depend on the SL geometry. The consequence of such oscillations on sensed level of one or more level instruments is judged to be the primary parameter impacting safety system trips. However, the feedwater control system may maintain the water level based on the average value of the reactor water level because of the high frequency nature of the unstable condensation (~ 5Hz or higher).

Depending on plant unique geometry and ECCS and reactor water level control trip logics, a plant specific evaluation may have to be performed.