

WCAP-12913

Structural Evaluation of
Salem Nuclear Plant Units 1 and 2
Pressurizer Surge Lines,
Considering the Effects of
Thermal Stratification

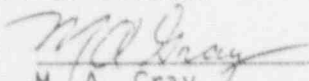
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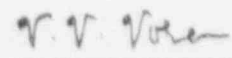
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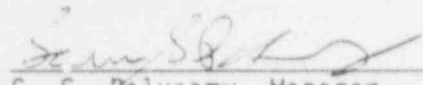
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EXECUTIVE SUMMARY

Thermal stratification has been identified as a concern which can affect the structural integrity of piping systems in nuclear plants since 1979, when a leak was discovered in a PWR feedwater line. In the pressurizer surge line, stratification can result from the difference in densities between the hot leg water and generally hotter pressurizer water. Stratification with large temperature differences can produce very high stresses, and this can lead to integrity concerns. Study of the surge line behavior has concluded that the largest temperature differences occur during certain modes of plant heatup and cooldown.

This report has been prepared to demonstrate compliance with the requirements of NRC Bulletin 88-11 for the Salem Nuclear Plant Units 1 and 2. Prior to the issuance of the bulletin, the Westinghouse Owners Group had a program in place to investigate the issue, and recommend actions by member utilities. That program provided the technical basis for the plant specific transient development reported here for the Salem Nuclear Plant Units 1 and 2.

This transient development utilized a number of sources, including plant operating procedures, surge line monitoring data from other similar units, and historical records for each unit. This transient information was used as input to a structural and stress analysis of the surge line for the two units. A review and comparison of the piping and support configurations for the units led to the conclusion that the surge lines are nearly identical, and thus one analysis could be done to apply to both units, for the stratification transient development.

The existing configuration for both Salem units have been analyzed in this WCAP. The results of the analyses indicate small contacts at one pipe whip restraint and "bottoming-out" of variable spring hangers for the 320°F ΔT . ASME Code allowables were shown to be exceeded for both Salem units under this existing configuration. However, by taking credit for insulation crushability and modifying spring hangers to avoid "bottomed-out" condition, the ASME Code

stress limits and cumulative usage factor requirements have been shown to be acceptable for the remainder of the licensed operation of both units. No whip restraint gap modifications are necessary to show Code acceptance if the spring can travel allowances are satisfied.

The spring hanger and whip restraint displacements resulting from normal thermal and stratification have also been provided in Section 4 for both the existing and future support configurations, for future verification of proper gaps in the pipe whip restraints and sufficient travel allowance in the spring hangers, to allow for pipe movement at all thermal conditions. The structural analysis which resulted in this recommendation is discussed in Sections 3 and 4.

This work has led to the conclusion that Salem Units 1 and 2 are in full compliance with the requirements of NRC Bulletin 88-11, provided the spring hanger modifications discussed on the following page are implemented, and a limitation of 320°F on the temperature differential between the pressurizer liquid space and RCS hot leg is imposed.

Until the spring hanger modifications are implemented, the existing Justification for Continued Operation (JCO), Reference 14, is still valid for the Salem units, in view of this plant specific analysis.

The existing JCO was based on the assessment without detailed reanalysis and indicated acceptability of continued operation for an additional ten heatup and cooldown cycles from the date of the Westinghouse Owner's Group (WOG) bounding evaluation, i.e. June 1989.

SUMMARY OF RESULTS, AND STATUS OF 88-11 QUALIFICATION

Salem Unit 1

Salem Unit 2

Operating History through 1990

Date of commercial operation	6/30/77	10/13/81
Years of water-solid heatups	0	0
Years of steam-bubble heatups	14	10
System delta T limit (assumed)	320°F	320°F
Number of 320°F exceedances	None	One

Maximum Stress and Usage Factor Results

Equation 12 stress/allowable* (ksi)	49.6/52.9	50.0/52.9
Fatigue usage/allowable	0.6/1.0	0.6/1.0

Pressurizer Surge Nozzle Results

Maximum stress intensity range/allowable (ksi)	47.3/57.9	47.3/57.9
Fatigue usage/allowable	0.50/1.00	0.50/1.00

Remaining Actions by Utility

Spring hanger modification required	Allow sufficient travel allowance on both units (Table 4-1A)
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Status of 88-11 Requirements

All analysis requirements met with above modifications

*Results for future configuration. See Table 3-2 for results for existing configuration

SECTION 1.0
BACKGROUND AND INTRODUCTION

The Salem Nuclear Plant Units 1 and 2 are four loop pressurized water reactors, designed to be as nearly identical as practical, in both hardware and operation. This report has been developed to provide the technical basis and results of a plant-specific structural evaluation for the effects of thermal stratification of the pressurizer surge lines for both of these units.

The operation of a pressurized water reactor requires the primary coolant loops to be water solid, and this is accomplished through a pressurizer vessel, connected to one of the hot legs by the pressurizer surge line. A typical four loop arrangement is shown in Figure 1-1, with the surge line highlighted.

The pressurizer vessel contains steam and water at saturated conditions with the steam-water interface level typically between 25 and 60% of the volume depending on the plant operating conditions. From the time the steam bubble is initially drawn during the heatup operation to hot standby conditions, the level is maintained at approximately 25% to 35%. During power ascension, the pressurizer level varies between 22% and 50% depending on reactor thermal power. The steam bubble provides a pressure cushion effect in the event of sudden changes in Reactor Coolant System (RCS) mass inventory. Spray operation reduces system pressure by condensing some of the steam. Electric heaters, at the bottom of the pressurizer, are energized to raise the liquid temperature to generate additional steam and increase RCS pressure.

As illustrated in Figure 1-1, the bottom of the pressurizer vessel is connected to the hot leg of one of the coolant loops by the surge line. The surge line of Unit 1 is 14 inch schedule 140, and the surge line of Unit 2 is 14 inch schedule 160. Both are stainless steel.

1.1 Background

During the period from 1982 to 1988, a number of utilities reported unexpected movement of the pressurizer surge line, as evidenced by crushed insulation,

gap closures in the pipe whip restraints, and in some cases unusual snubber movement. Investigation of this problem revealed that the movement was caused by thermal stratification in the surge line.

Thermal stratification had not been considered in the original design of any pressurizer surge line, and was known to have been the cause of service-induced cracking in feedwater line piping, first discovered in 1979. Further instances of service-induced cracking from thermal stratification surfaced in 1988, with a crack in a safety injection line, and a separate occurrence with a crack in a residual heat removal line. Each of the above incidents resulted in at least one through-wall crack, which was detected through leakage, and led to a plant shutdown. Although no through wall cracks were found in surge lines, inservice inspections of one plant in the U.S. and another in Switzerland mistakenly claimed to have found sizeable cracks in the pressurizer surge line. Although both these findings were subsequently disproved, the previous history of stratified flow in other lines led the USNRC to issue Bulletin 88-11 in December of 1988. A copy of this bulletin is included as Appendix B.

The bulletin requested utilities to establish and implement a program to confirm the integrity of the pressurizer surge line. The program required both visual inspection of the surge line and demonstration that the design requirements of the surge line are satisfied, including the consideration of stratification effects.

Prior to the issuance of NRC Bulletin 88-11, the Westinghouse Owners Group had implemented a program to address the issue of surge line stratification. A bounding evaluation was performed and presented to the NRC in April of 1989. This evaluation compared all the WOG plants to those for which a detailed plant specific analysis had been performed. Since this evaluation was unable to demonstrate the full design life for all plants, a generic justification for continued operation was developed for use by each of the WOG plants, the basis of which was documented in references [1] and [2].

The Westinghouse Owners Group implemented a program for generic detailed analysis in June of 1989, and this program involved individual detailed analyses of groups of plants. This approach permitted a more realistic

approach than could be obtained from a single bounding analysis for all plants, and the results were published in June of 1990 [3].*

The followup to the Westinghouse Owners Group Program is a performance of evaluations which could not be performed on a generic basis. The goal of this report is to accomplish these followup actions, and to therefore complete the requirements of the NRC Bulletin 88-11 for Salem Units 1 and 2.

1.2 Description of Surge Line Thermal Stratification

It will be useful to describe the phenomenon of stratification, before dealing with its effects. Thermal stratification in the pressurizer surge line is the direct result of the difference in densities between the pressurizer water and the generally cooler RCS hot leg water. The warmer lighter pressurizer water tends to float on the cooler heavier hot leg water. The potential for stratification is increased as the difference in temperature between the pressurizer and the hot leg increases and as the insurge or outsurge flow rates decrease.

At power, when the difference in temperature between the pressurizer and hot leg is relatively small, the extent and effects of stratification have been observed to be small. However, during certain modes of plant heatup and cooldown, this difference in system temperature could be as large as 320°F, in which case the effects of stratification are significant, and must be accounted for.

Thermal stratification in the surge line causes two effects:

- o Bending of the pipe different than that predicted in the original design.
- o Potentially reduced fatigue life of the piping due to the higher stress resulting from stratification and striping.

*Numbers in brackets refer to references listed in Section 7.

1.3 Scope of Work

The primary purpose of this work was to develop transients applicable to the Salem units which include the effects of stratification and to evaluate these effects on the structural integrity of the surge lines. This work will therefore complete the demonstration of compliance with the requirements of NRC Bulletin 88-11.

The transients were developed following the same general approach originally established for the Westinghouse Owners Group. Conservatism inherent in the original approach were refined through the use of monitoring results, plant operating procedures, operator interviews, and historical data on plant operation. This process is discussed in Section 2.

The resulting transients were used to perform an analysis of the surge line, wherein the existing support configuration was carefully modeled, and surge line displacements, stresses, support loads and nozzle loads were determined. This analysis and its results are discussed in Section 3 and 4.

The stresses were used to perform a fatigue analysis for the surge line, and the methodology and results of this work are discussed in Section 5. The summary and conclusions of this work are summarized in Section 6.

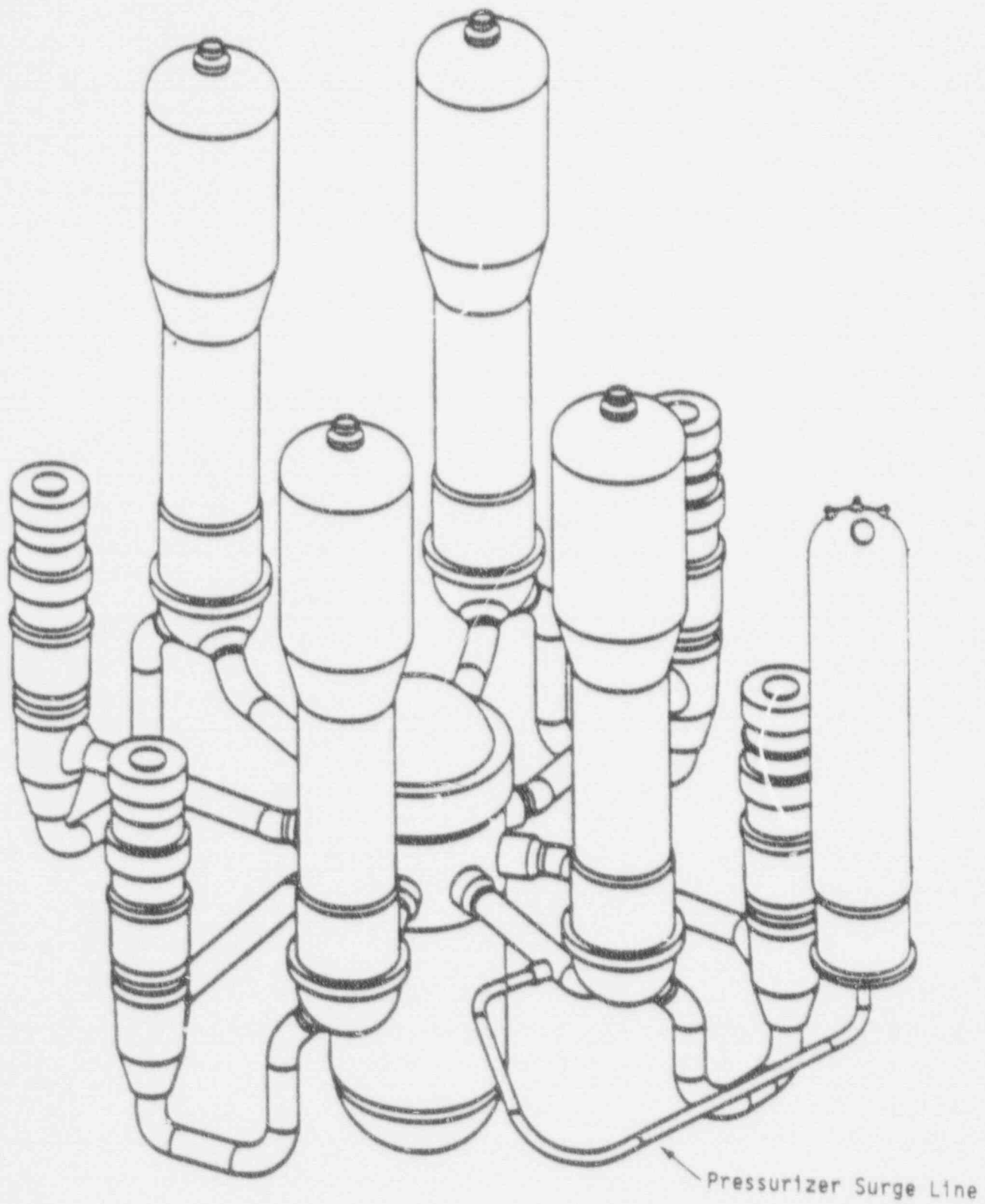


Figure 1-1. Typical 4-Loop Plant Loop Layout

SECTION 2.0
SURGE LINE TRANSIENT AND TEMPERATURE PROFILE DEVELOPMENT

2.1 General Approach

The transients for the pressurizer surge line were developed from a number of sources, including the most recent systems standard design transients. The heatup and cooldown transients, which involve the majority of the severe stratification occurrences, were developed from review of the plant operating procedures, operator interviews, monitoring data and historical records for each unit. The total number of heatup and cooldown events specified remains unchanged at 200 each, but a number of sub-events within each heatup and cooldown cycle have been defined to reflect stratification effects, as described in more detail later.

The normal and upset transients, except for heatup and cooldown, for the Salem Units 1 and 2 surge lines are provided in Table 2-1. For each of the transients the surge line fluid temperature was modified from the original design assumption of uniform temperature to a stratified distribution, according to the predicted temperature differentials between the pressurizer and hot leg, as listed in the table. The transients have been characterized as either insurge/outsurges (I/O in the table) or fluctuations (F). Insurge/outsurge transients are generally more severe, because they result in the greatest temperature change in the top or bottom of the pipe. Typical temperature profiles for insurges and outsurges are shown in Figure 2-1.

Transients identified as fluctuations (F) typically involve low surge flow rates and smaller temperature differences between the pressurizer and hot leg, so the resulting stratification stresses are much lower. This type of cycle is important to include in the analysis, but is generally not the major contributor to fatigue usage.

In addition to the plant specific operating history discussed above, the development of transients which are applicable to Salem Units 1 and 2 was based on the work already accomplished under programs completed for the Westinghouse Owners Group [1,2,3]. In this work all the Westinghouse plants were grouped based on the similarity of their response to stratification. The three most important factors influencing the effects of stratification were found to be the structural layout, support configuration, and plant operation.

The transient development for the Salem units took advantage of the similarity in the surge line layout for the two units, as well as the similarity of the operating procedures. A detailed comparison of the piping and support configurations for the units appears in Section 3.1.

The transients developed here, and used in the structural analysis, have taken advantage of the monitoring data collected during the WOG program, as well as historical operation data for the Salem Units. Each of these will be discussed in the sections which follow.

2.2 System Design Information

The thermal design transients for a typical Reactor Coolant System, including the pressurizer surge line, are defined in Westinghouse Systems Standard Design Criteria.

The design transients for the surge line consist of two major categories:

- (a) Heatup and Cooldown transients
- (b) Normal and Upset operation transients (by definition, the emergency and faulted transients are not considered in the ASME Section III fatigue life assessment of components).

In the evaluation of surge line stratification, the transient events considered encompass the normal and upset design events defined in FSAR chapter 5.2.

The total number of heatup-cooldown cycles (200) remains unchanged. However, sub-events and the associated number of occurrences ("Label", "Type" and "Cycle" columns of Tables 2-1 and 2-2 have been defined to reflect stratification effects, as described later.

2.3 Development of Normal and Upset Transients

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2.4 Monitoring Results and Operator Interviews

2.4.1 Monitoring

Monitoring information collected as part of the Westinghouse Owners Group generic detailed analysis [3] was utilized in this analysis. The pressurizer surge line monitoring programs utilized externally mounted temperature sensors (resistance temperature detectors or thermocouples). The temperature sensors were attached to the outside surface of the pipe at various circumferential and axial locations. In all cases these temperature sensors were securely clamped to the piping outer wall using clamps, taking care to properly insulate the area against heat loss due to thermal convection or radiation.

The typical temperature sensor configuration at a given pipe location consists of two to five sensors mounted as shown in Figure 2-2. Temperature sensor configurations were mounted at various axial locations. The multiple axial locations give a good picture of how the top to bottom temperature distribution may vary along the longitudinal axis of the pipe. In addition, many pressurizer surge line monitoring programs utilized displacement sensors mounted at various axial locations to detect horizontal and vertical movements, as shown in Figure 2-2. Typically, data was collected at []^{a,c,e} intervals or less, during periods of high system delta T.

Existing plant instrumentation was used to record various system parameters. These system parameters were useful in correlating plant actions with stratification in the surge line. A list of typical plant parameters monitored is given below.

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Data from the temporary sensors was stored on magnetic floppy disks and converted to hard copy time history plots with the use of common spreadsheet software. Data from existing plant instrumentation was obtained from the utility plant computer.

2.4.2 Operational Practices

Based on a review of the Salem Units 1 and 2 heatup and cooldown operating procedures and operational interviews conducted at a number of WOG utilities,

it was determined that both units heat up and cool down in a manner similar to other plants that heat up with a steam bubble in the pressurizer. Heatups and cooldowns are used here to characterize plant operation because they represent the periods during which the temperature difference between the pressurizer and the hot leg is the greatest. A brief description of the Salem heatup and cooldown procedures follows.

At the beginning of the heatup, the reactor coolant system (RCS) is filled and vented and a steam bubble is drawn in the pressurizer with the RCS pressure less than 325 psig. As the RCS temperature is being raised, the pressure is limited to 375 psig for temperatures less than 312 deg F. The RCS pressure is maintained between 325 and 350 psig using the pressurizer heaters and pressurizer spray. The pressurizer level is maintained at 22% by controlling charging and letdown flow. The remainder of the heatup is performed within the 100°F/hour limit.

In terms of system delta temperatures, the cooldown is basically the reverse of heatup. During RCS cooldown, all reactor coolant pumps (RCP's) are running until the RCS temperature reaches 400°F, at which time one RCP is shut down. At RCS temperature of 350°F, one additional RCP is turned off. When the RCS temperature reaches 350°F and the RCS pressure is less than 375 psig, the Residual Heat Removal (RHR) system is activated. Upon reaching 250°F, another RCP is turned off. When the RCS is less than 200 deg F, and the chemistry check is completed, the last RCP is turned off. At this point, the pressurizer pressure and, therefore, the cooldown are controlled by the auxiliary spray operation.

This analysis is based on the assumption of a maximum temperature difference between the pressurizer liquid space and the RCS hot leg ("system delta T") of 320°F for future operation. Public Service Electric and Gas Company must confirm this assumption for both Salem Units.

2.5 Historical Operation

Historical records from the plant (operator logs, surveillance test reports, etc.) were reviewed. From this review a maximum system delta T distribution and the number of delta T exceedances of 320°F was obtained. Use of this information in the analysis is described in Section 2. The results of the review are listed below, as percentages of the total number of past heatup and cooldown events for which data was available.

<u>System ΔT Range (°F)</u>	<u>Unit 1</u>		<u>Unit 2</u>	
	<u>Number of Heatups & Cooldowns</u>	<u>% of Total</u>	<u>Number of Heatups & Cooldowns</u>	<u>% of Total</u>

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This table does not include data prior to 1984 since none could be obtained. It was assumed that the operational practices from 1984 to present adequately represent the prior operation of the units. The highest observed system delta T was 325°F, which was the only exceedance of 320°F.

The above information was used to ensure that the transients analyzed for the Salem units encompassed the prior operating history of the plant. Comparison of this information to the distribution used in the evaluation confirmed applicability to the Salem Units. This is illustrated in Figure 2-3. [

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2.6 Development of Heatup and Cooldown Transients

The heatup and cooldown transients used in the analysis were developed from a number of sources, as discussed in the overall approach. The transients were built upon the extensive work done for the Westinghouse Owners Group [1,2,3], coupled with plant specific considerations for Salem Units 1 and 2.

The transients were developed based on monitoring data, historical operation and operator interviews conducted at a large number of plants. For each monitoring location, the top-to-bottom differential temperature (pipe delta T) vs. time was recorded, along with the temperatures of the pressurizer and hot leg during the same time period. The difference between the pressurizer and hot leg temperature was termed the system delta T.

From the pipe and system delta T information collected in the WOG[1,2,3] effort, individual plants' monitoring data was reduced to categorize stratification cycles (changes in relatively steady-state stratified conditions) using the rainflow cycle counting method. This method considers delta T range as opposed to absolute values.

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The resulting distributions (for I/O transients) were cycles in each RSS range above 0.3, for each mode (5,4,3 and 2). A separate distribution was determined for the reactor coolant loop nozzle and for a chosen critical pipe location. Next, a representative RSS distribution was determined by multiplying the average number of occurrences in each RSS range by two. Therefore, there is margin of 100% on the average number of cycles per heatup in each mode of operation.

Transients, which are represented by delta T pipe with a corresponding number of cycles were developed by combining the delta T system and cycle distributions. For mode 5, delta T system is represented by a historical system distribution developed from plant operating records. As discussed in Section 2.5, the historical delta T system distribution was shown to encompass the prior operating history of the Salem units. For modes 4, 3 and 2, the delta T system was defined by maximum values. The values were based on the maximum system delta T obtained from the monitored plants for each mode of operation.

An analysis was conducted to determine the average number of stratification cycles per cooldown relative to the average number of stratification cycles per heatup. [

ja,c,e The transients for all modes were then enveloped in ranges of ΔT_{pipe} , i.e., all cycles from transients within each ΔT_{pipe} range were added and assigned to the pre-defined ranges. These cycles were then applied in the fatigue analysis with the maximum ΔT_{pipe} for each range. The values used are as follows:

<u>For Cycles Within Pipe Delta T Range</u>	<u>Pipe Delta T</u>
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This grouping was done to simplify the fatigue analysis. The actual number of cycles used in the analysis for the heatup and cooldown events is shown in Table 2-2.

The final result of this complex process is a table of transients corresponding to the subevents of the heatup and cooldown process. A mathematical description of the methodology used is given in Appendix C.

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^{a,c,e} The critical location is the location with the highest combination of pipe delta T and number of stratification cycles.

Because of main coolant pipe flow effects, the stratification transients loadings at the RCS hot leg nozzle are different. These transients have been applied to the main body of the nozzle as well as the pipe to nozzle girth butt weld.

Plant monitoring included sensors located near the RCS hot leg nozzle to surge line pipe weld. Based on the monitoring, a set of transients was developed for the nozzle region to reflect conditions when stratification could occur in the nozzle. The primary factor affecting these transients was the flow in the main coolant pipe. Significant stratification was noted only when the reactor coolant pump in the loop with the surge line was not operating. Transients were then developed using a conservative number of "pump trips."

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^{a,c,e} Therefore, the fatigue analysis of the RCS hot leg nozzle was performed using the "nozzle transients" and the "pipe transients." The analysis included both the stratification loadings from the nozzle transients, and the pressure and bending loads from the piping transients.

The total transients for heatup and cooldown are identified as HC1 thru HC9 for the pipe, and HC1 thru HC9 for the RCS hot leg nozzle as shown in Tables 2-2(a) and 2-2(b) respectively. Transients HC8 and HC9 for the pipe and HC9 for the nozzle represent transients which occur during later stages of the heatup.

As indicated in Section 2.5, based on a review of Salem Units 1 and 2 operating records, there was an event in which the system delta T exceeded the transient basis upper limit of [

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2.7 Axial Stratification Profile Development

In addition to transients, a profile of the [

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Two types of profile envelope the stratified temperature distributions observed and predicted to occur in the line. These two profiles are a [

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The second case [

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These three configurations are illustrated in Figure 2-5. [

]a.c.e

Review and study of the monitoring data for all the plants revealed a consistent pattern of development of delta T as a function of distance from the hot leg intersection. This pattern was consistent throughout the heatup/cool-down process, for a given plant geometry. This pattern was used along with plant operating practices to provide a realistic yet somewhat conservative portrayal of the pipe delta T along the surge line.

The combination of the hot/cold interface and pipe delta T as functions of distance along the surge line forms a profile for each individual plant analyzed. Since Unit 1 and Unit 2 have similar surge line configurations, the

profile applies to both units. The resulting profile is illustrated in Figure 2-6 in which the term "location" is defined in Figure 3-5.

2.8 Striping Transients

The transients developed for the evaluation of thermal striping are shown in Table 2-3.

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Striping transients use the labels HST and CST denoting striping transients (ST). Table 2-3 contains a summary of the HST1 to HST8 and CST1 to CST7 thermal striping transients which are similar in their definition of events to the heatup and cooldown transient definition.

These striping transients were developed during plant specific surge line evaluations and are considered to be a conservative representation of striping in the surge line[3]. Section 5 contains more information on specifically how the striping loading was considered in the fatigue evaluation.

TABLE 2-1
 SURGE LINE TRANSIENTS WITH STRATIFICATION
 NORMAL AND UPSET TRANSIENT LIST - SALEM UNIT 1 OR UNIT 2

LABEL	TYPE	CYCLES	TEMPERATURES (°F)		
			MAX ΔT_{Strat}	NOMINAL PRZ T	RCS T
[

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See notes on next page

TABLE 2-1 (Cont'd.)
 SURGE LINE TRANSIENTS WITH STRATIFICATION
 NORMAL AND UPSET TRANSIENT LIST - SALEM UNIT 1 OR UNIT 2

LABEL	TYPE	CYCLES	MAX ΔT_{Strat}	TEMPERATURES (°F)	
				PRZ T	NOMINAL RCS T
[

]a.c.e

TABLE 2-2a
 SURGE LINE PIPE TRANSIENTS WITH STRATIFICATION - SALEM
 HEATUP/COOLDOWN (HC) - 200 CYCLES TOTAL

LABEL	TYPE	CYCLES	TEMPERATURES (°F)		
			MAX ΔT_{Strat}	NOMINAL PRZ T	RCS T

[

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TABLE 2-2b
 SURGE LINE NOZZLE TRANSIENTS WITH STRATIFICATION - SALEM
 HEATUP/COOLDOWN (HC) - 200 CYCLES TOTAL

LABEL	TYPE	CYCLES	TEMPERATURES (°F)	
			MAX ΔT_{strat}	NOMINAL PRZ T RCS f
[

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TABLE 2-3
SURGE LINE TRANSIENTS - STRIPING
FOR HEATUP (H) and COOLDOWN (C) - UNIT 1 OR UNIT 2

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Figure 2-1. Typical Insurge-Outsurge (I/O) Temperature Profiles

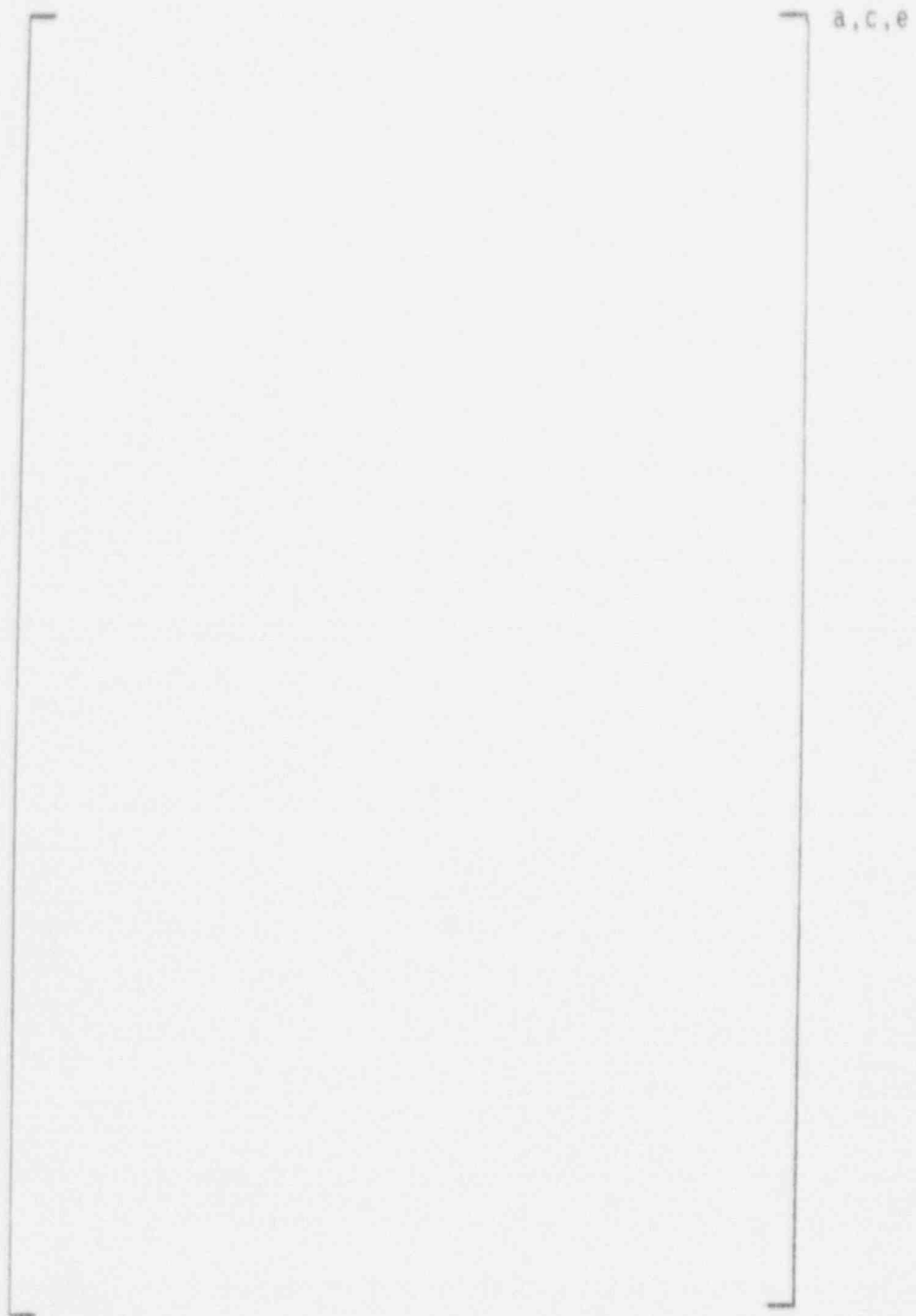


Figure 2-2. Typical Monitoring Locations

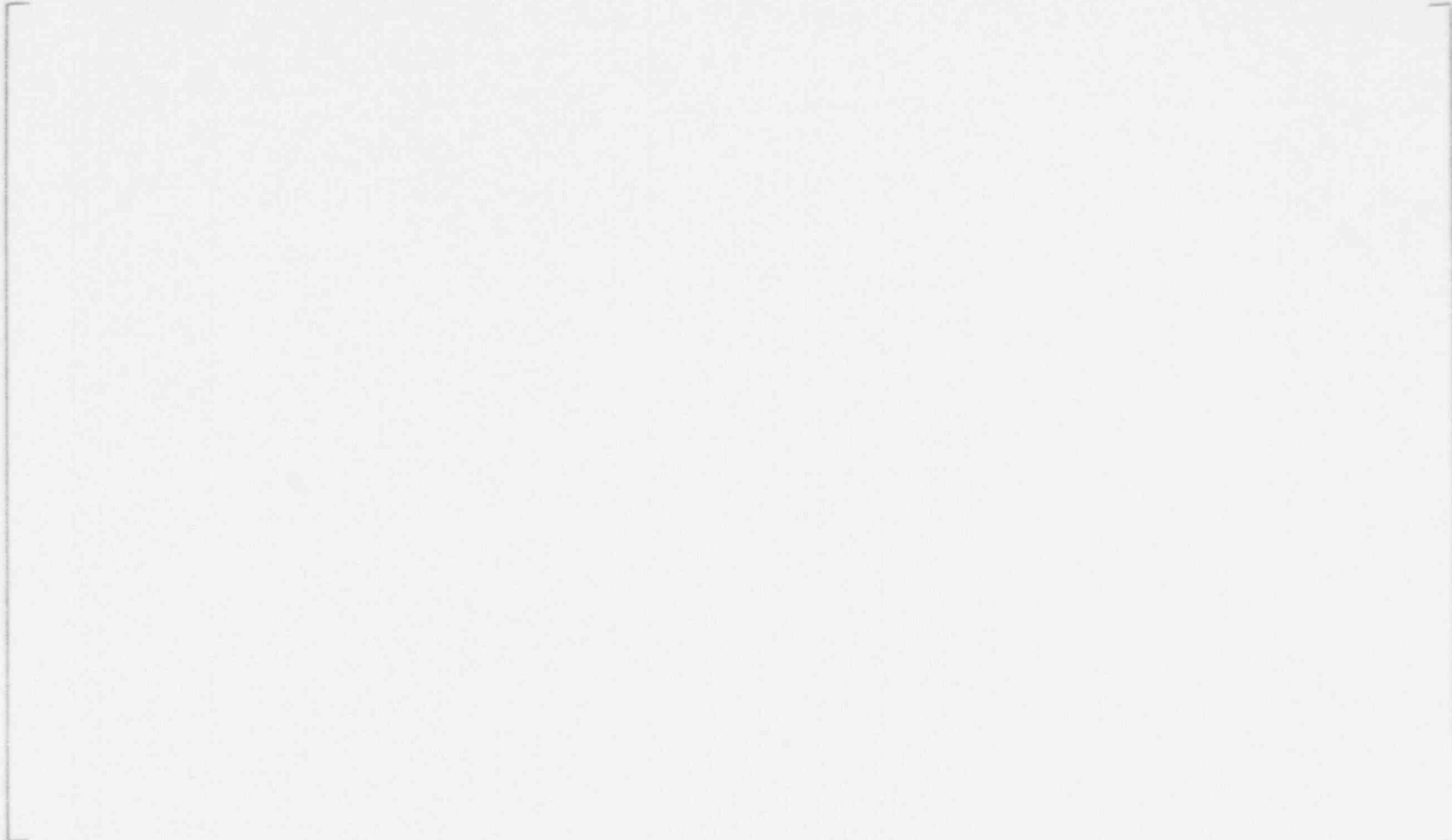


Figure 2-3. Summary of Historical Data Distribution from Salem Units 1 and 2, Compared to the Distribution Used in the Analysis

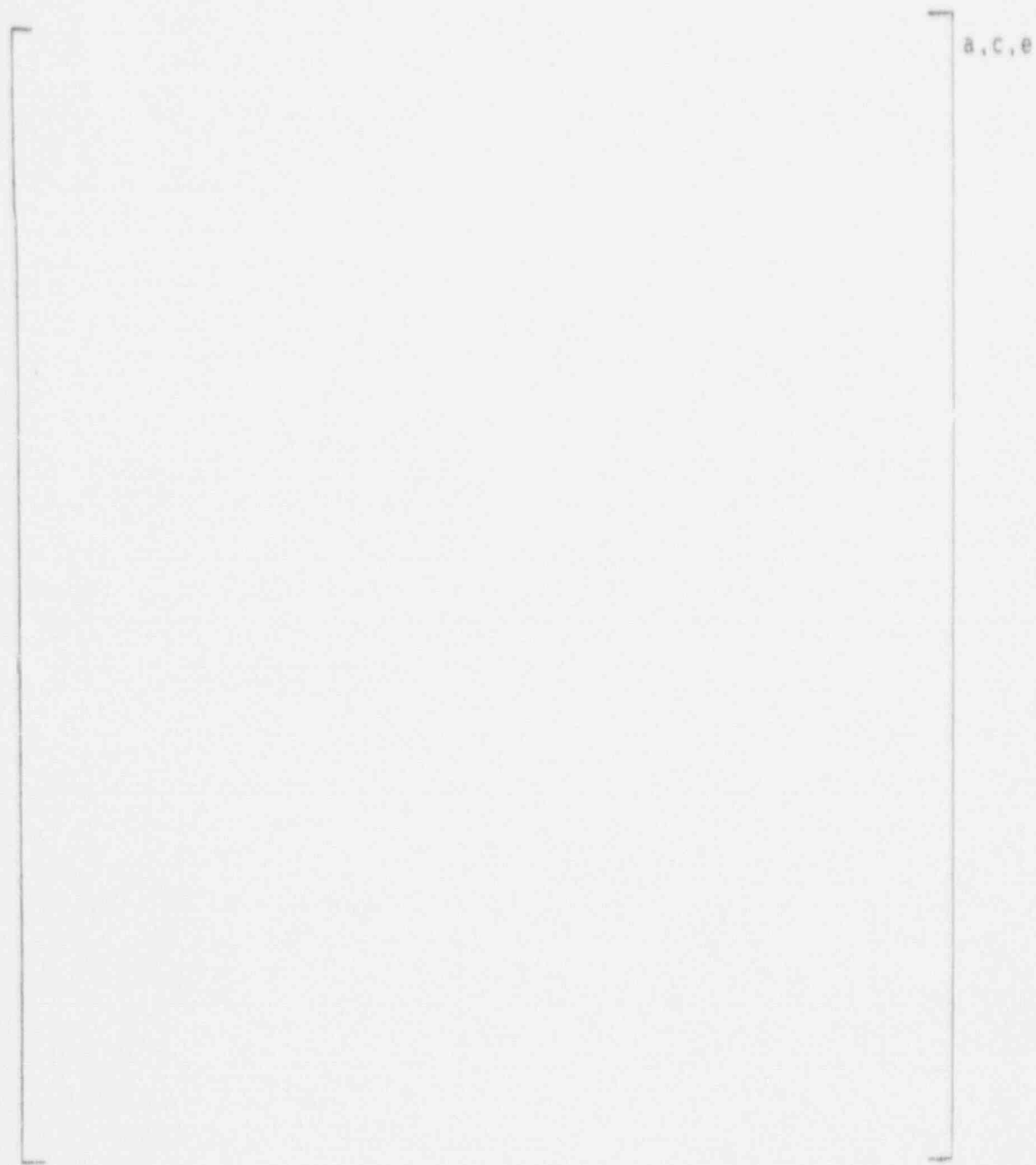


Figure 2-4. Example Axial Stratification Profile for Low Flow Conditions

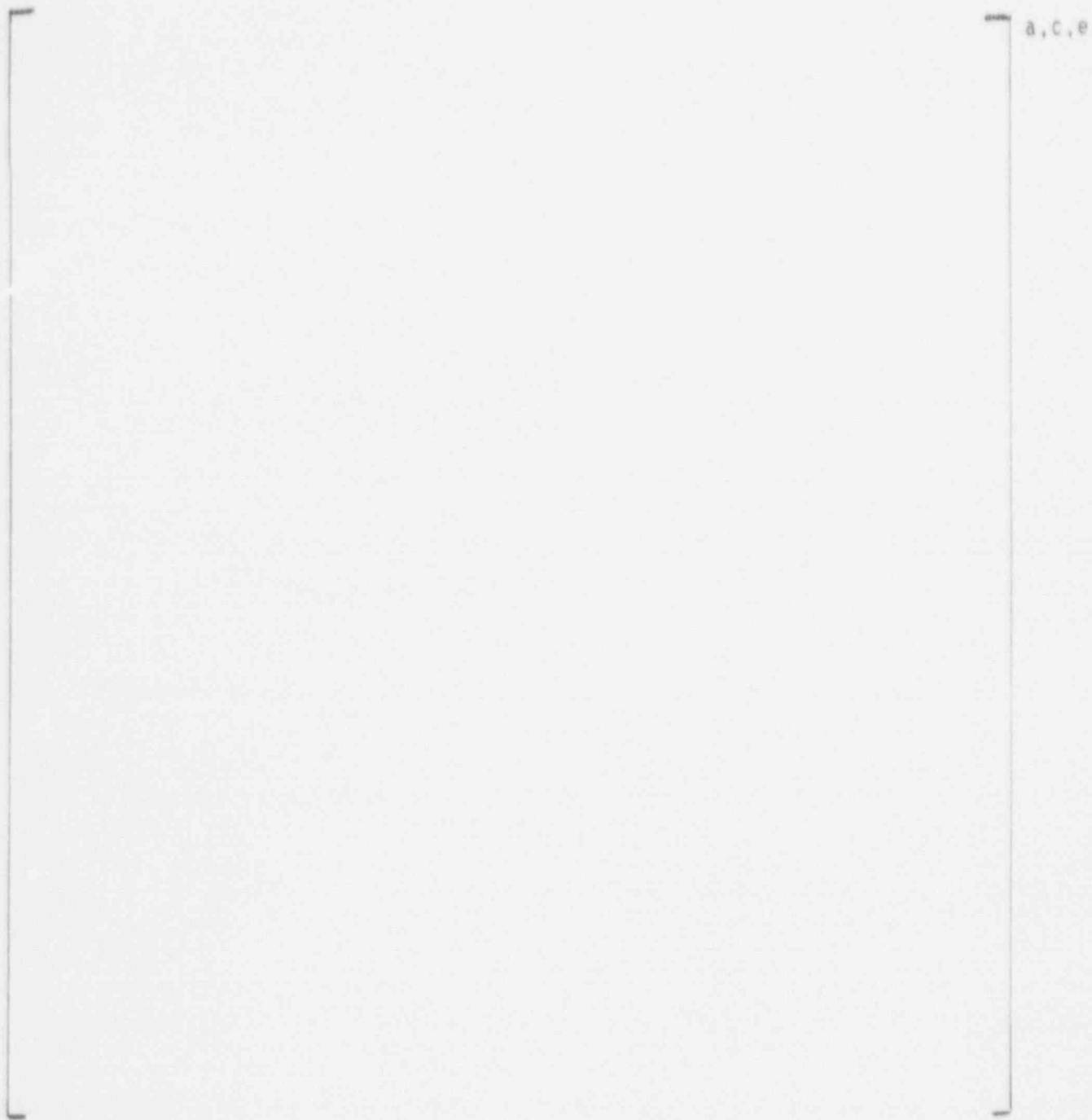


Figure 2-5. Geometry Considerations

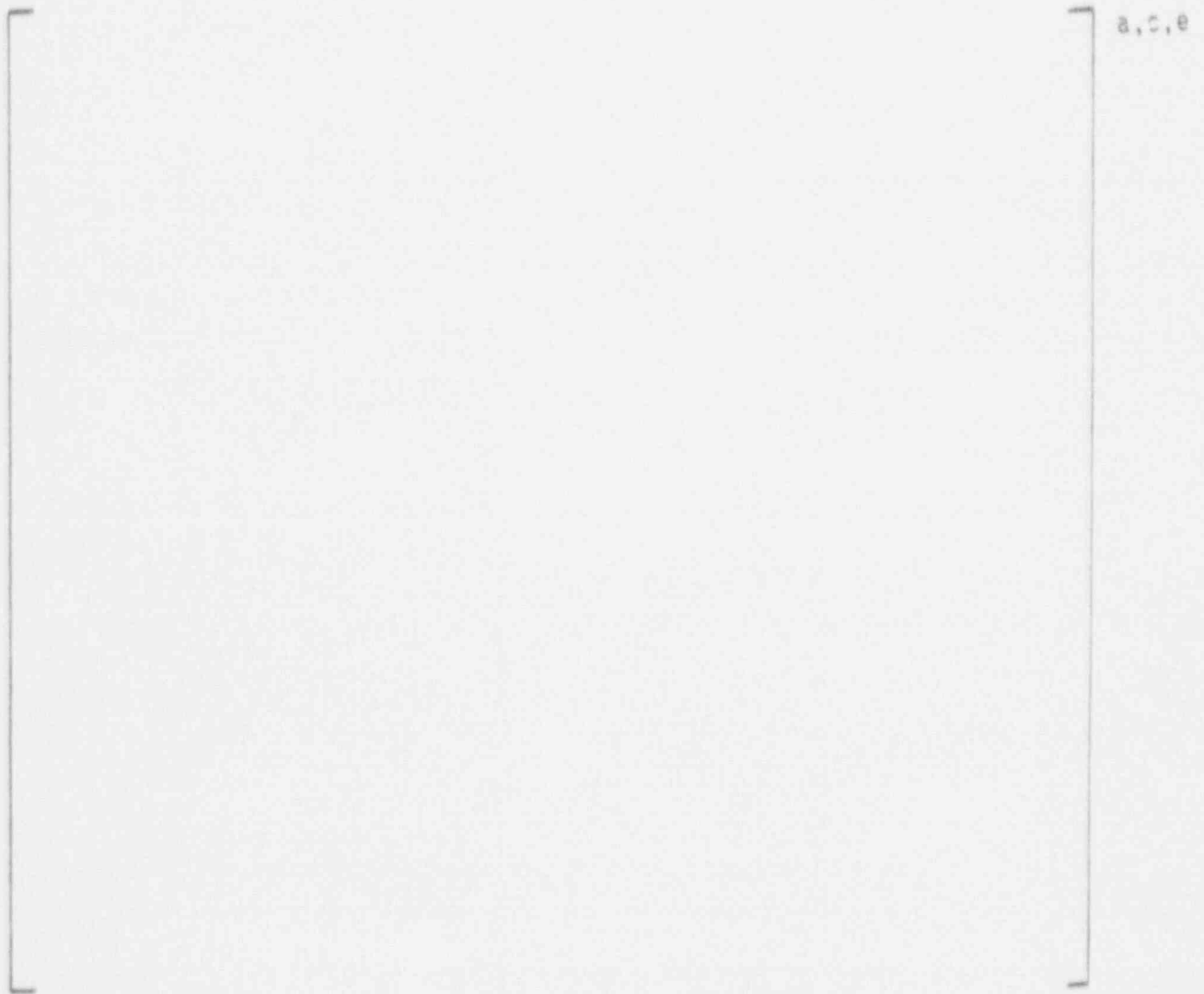


Figure 2-6. Temperature Profile Analyzed for Salem Units 1 and 2

SECTION 3.0
STRESS ANALYSES

The flow diagram (Figure 3-1) describes the procedure to determine the effects of thermal stratification on the pressurizer surge line based on transients developed in section 2.0. [

]a.c.e

3.1 Surge Line Layouts

The Salem Units 1 & 2 surge line layouts are documented in references 6 and 7 and the Unit 1 layout is shown schematically in Figure 3-2. The two Salem units are mirror images of each other along plant East-West. The support configurations of Salem surge lines are the same. Below is a table summarizing the existing Salem surge line support configuration.

Salem Units 1 and 2

<u>Support</u>		<u>Node</u>	<u>Type</u>
<u>Unit 1</u>	<u>Unit 2</u>		
R-239776-1	R-240185-1	1040	Pipe Whip Restraint
R-239776-2	R-240185-2	1070	Pipe Whip Restraint
R-239776-3	R-240185-3	1090	Pipe Whip Restraint
R-239776-4	R-240185-4	1120	Pipe Whip Restraint
R-239776-5	R-240185-5	1200	Pipe Whip Restraint
R-239776-6	R-240185-6	1220	Pipe Whip Restraint
R-239776-7	R-240185-7	1140	Pipe Whip Restraint
C-PSH-1	2C-PSH-1	1170	Variable Spring Hanger
C-PSH-2	2C-PSH-2	1110	Variable Spring Hanger
C-PSH-3	2C-PSH-3	1060	Variable Spring Hanger

It can be seen from the table above that both of the Salem surge lines contain three variable spring hangers and seven pipe whip restrainers. In some cases these supports can cause higher thermal loads if displacement from thermal stratification exceed available displacement limits. The piping sizes are 14 inch schedule 140 for Unit 1 and schedule 160 for Unit 2, and the pipe material is stainless steel, SA 376-Type 316, for both units. The hot leg nozzle material is SA-182, F316 for both units.

3.2 Piping System Global Structural Analysis

The Salem Units 1 and 2 piping systems were modeled by pipe, elbow, and non-linear spring elements using the ANSYS computer code described in Appendix A. The geometric and material parameters are included. [

]a,c,e

Each thermal profile loading defined in section 2 was broken into [

]a,c,e Table 3-1 shows the loading cases considered in the analysis. To encompass all plant operations, [

]a,c,e

[]^{a,c,e} Consequently, all the thermal transient loadings defined in section 2 could be evaluated.

[

] ^{a,c,e}

In order to meet the ASME Section III Code stress limits, global structural models of the surge lines were developed using the information provided by references 6 and 7 and the ANSYS general purpose finite element computer code. A model was constructed using [

] ^{a,c,e} to reflect the layout of straight pipe, bends and field welds as shown in Figure 3-2.

For the stratified condition, [

] ^{a,c,e}

The global piping stress analysis was based on two models for the Salem Units. The first model represents the existing support configuration and the second model represents the future configuration. The existing configuration has the actual gaps at all whip restraints and actual spring travel allowances at all spring hanger locations (see Table 3-2). The future support configuration represents a modified configuration in which no spring hangers will bottom-out, and whip restraint gaps are the same as those in the existing configuration. In addition, the beneficial effect of insulation crushability was taken into account for the future configuration. The results of the ANSYS global structural analyses provide the thermal expansion moments. The ASME Section III equation (12) stress intensity range was evaluated for both configurations. A system delta T of [] ^{a,c,e} was evaluated for the existing configuration in addition to 320°F for the future configuration. For

the Salem Units, the maximum ASME equation (12) stress intensity range in the surge line was found to be under the code allowable of $3S_m$ for the future configuration. Maximum equation (12) and equation (13) stress intensity ranges are shown in Table 3-3.

The pressurizer nozzle loads from thermal stratification in the surge line were also evaluated according to the requirements of the ASME code. The evaluation using transients detailed in Reference [13] plus the moment loading from this analysis calculated primary plus secondary stress intensities and the fatigue usage factors. For the Unit 1 and 2 pressurizer nozzles, the maximum stress intensity range is 47.3 ksi compared to the code allowable value of 57.9 ksi. The maximum fatigue usage factor will be reported in Section 5. It was found that the Salem pressurizer surge nozzles met the code stress requirements.

3.3 Local Stresses-Methodology and Results

3.3.1 Explanation of Local Stress

Figure 3-3 depicts the local axial stress components in a beam with a sharply nonlinear metal temperature gradient. Local axial stresses develop due to the restraint of axial expansion or contraction. This restraint is provided by the material in the adjacent beam cross section. For a linear top-to-bottom temperature gradient, the local axial stress would not exist. [

] a, c, e

3.3.2 Finite Element Model of Pipe for Local Stress

A short description of the pipe finite element model is shown in Figure 3-4. The model with thermal boundary conditions is shown in Figure 3-5. Due to

symmetry of the geometry and thermal loading, only half of the cross section was required for modeling and analysis. [

]a,c,e

3.3.3 Pipe Local Stress Results

Figure 3-6 shows the temperature distributions through the pipe wall [

]a,c,e

3.3.4 RCL Hot Leg Nozzle Analysis

Detailed surge line nozzle finite element models were developed to evaluate the effects of thermal stratification. The 14 inch schedule 160 model is shown in Figure 3-10. The schedule 140 model is similar. Loading cases included [

]a,c,e A summary of stresses in the RCL nozzle (location 1) due to thermal stratification is given in Tables 3-4A and 3-4B. A summary of representative stresses for unit loading is shown in Table 3-5.

3.4 Total Stress from Global and Local Analyses

[

]a.c.e

[

]a.c.e

3.5 Thermal Striping

3.5.1 Background

At the time when the feedwater line cracking problems in PWR's were first discovered, it was postulated that thermal oscillations (striping) may significantly contribute to the fatigue cracking problems. These oscillations were thought to be due to either mixing of hot and cold fluid, or turbulence in the hot-to-cold stratification layer from strong buoyancy forces during low flow rate conditions. (See Figure 3-11 which shows the thermal striping fluctuation in a pipe). Thermal striping was verified to occur during subsequent flow model

tests. Results of the flow model tests were used to establish boundary conditions for the stratification analysis and to provide striping oscillation data for evaluating high cycle fatigue.

Thermal striping was also examined during water model flow tests performed for the Liquid Metal Fast Breeder Reactor (LMFBR) primary pipe loop. The stratified flow was observed to have a dynamic interface region which oscillated in a wave pattern. These dynamic oscillations were shown to produce significant fatigue damage (primary crack initiation). The same interface oscillations were observed in experimental studies of thermal striping which were performed in Japan by Mitsubishi Heavy Industries. The thermal striping evaluation process was discussed in detail in references 3, 8, 9, and 10.

3.5.2 Thermal Striping Stresses

Thermal striping stresses are a result of differences between the pipe inside surface wall and the average through wall temperatures which occur with time, due to the oscillation of the hot and cold stratified boundary. (See Figure 3-12, which shows a typical temperature distribution through the pipe wall). [

]a,c,e

The peak stress range and stress intensity was calculated from a 3-D finite element analysis. [

]a,c,e The methods used to determine alternating stress intensity are defined in the ASME Code [4]. Several locations were evaluated in order to determine the location where stress intensity was a maximum.

Stresses were intensified by K_3 to account for the worst stress concentration for all piping elements in the surge line. The worst piping element was the butt weld.

[

]a,c,e

3.5.3 Factors Which Affect Striping Stress

The factors which affect striping are discussed briefly below:

[

]a,c,e

1

J a . c . e

TABLE 3-1
TEMPERATURE DATA USED IN THE ANALYSIS

Type of Operation	Max System $\Delta T(^{\circ}F)$	Analysis Cases	Pressurizer Temp ($^{\circ}F$)	RCL Temp ($^{\circ}F$)	T_{Top} ($^{\circ}F$)	T_{Bot} ($^{\circ}F$)	Pipe $\Delta T (^{\circ}F)$
-------------------	----------------------------------	----------------	----------------------------------	--------------------------	---------------------------	---------------------------	-----------------------------

[

j a . c . e

TABLE 3-2

SALEM UNIT 1&2 SURGE LINE AS-ANALYZED GAPS

<u>Unit 1</u> <u>Restraint No.</u>	<u>As-Analyzed</u> <u>Gap (In.)</u>	<u>Unit 2</u> <u>Restraint No.</u>	<u>As-Analyzed</u> <u>Gap (In.)</u>
---------------------------------------	--	---------------------------------------	--

[

ja.c.e

TABLE 3-3

Summary of Salem Units 1 & 2 Surge Lines
Thermal Stratification Stress Results

ASME Code Equation	Analysis Configuration	Stress		Code Allowable (ksi)
		Unit 1	Unit 2	
12	Existing *	55.8	58.4	52.9
	Future †	49.6	50.0	52.9
13	Existing & Future	45.0	45.0	50.1

- * Existing configuration represents the effects of actual spring hanger bottomed-out, existing whip restraint gaps, and insulation crushability under all thermal loadings with maximum system delta T = 325°F
- † Future configuration represents no bottoming-out of spring hangers, existing whip restraint gaps, and insulation crushability under all thermal loadings with maximum system delta T = 320°F

TABLE 3-4A

SALEM UNIT 1 SURGE LINE
 MAXIMUM LOCAL AXIAL STRESS AT ANALYZED LOCATIONS

Profile Location*	Surface	Local Axial Stress (psi)	
		Maximum Tensile	Maximum Compressive
] a.c.e	
] a.c.e	

* See Figure 3-5

** RCL nozzle transition

*** RCL nozzle safe end and weld

[] a.c.e

TABLE 3-4B
SALEM UNIT 2 SURGE LINE
MAXIMUM LOCAL AXIAL STRESS AT ANALYZED LOCATIONS

Profile Location*	Surface	Local Axial Stress (psi)	
		Maximum Tensile	Maximum Compressive
] a,c,e	

- * See Figure 3-5
- ** RCL nozzle safe end
- *** RCL nozzle safe end weld

[] a,c,e

TABLE 3-5
 SUMMARY OF PRESSURE AND BENDING INDUCED STRESSES
 IN THE SURGE LINE RCL NOZZLE FOR UNIT LOAD CASES

Location	Diametral Location	Unit Loading Condition	All Stress in psi				
			Linearized Stress Intensity Range		Peak Stress Intensity Range		
			Inside	Outside	Inside	Outside	
							a,c,e

TAP " 3-6

STRIPING FREQUENCY AT 2 MA' LOCATIONS FROM 15 TEST RUNS

Frequency (HZ)			Total
			Duration
			# Cycles
%	%	%	Lgth. in
Min (Duration)	Max (Duration)	Avg (Duration)	Seconds



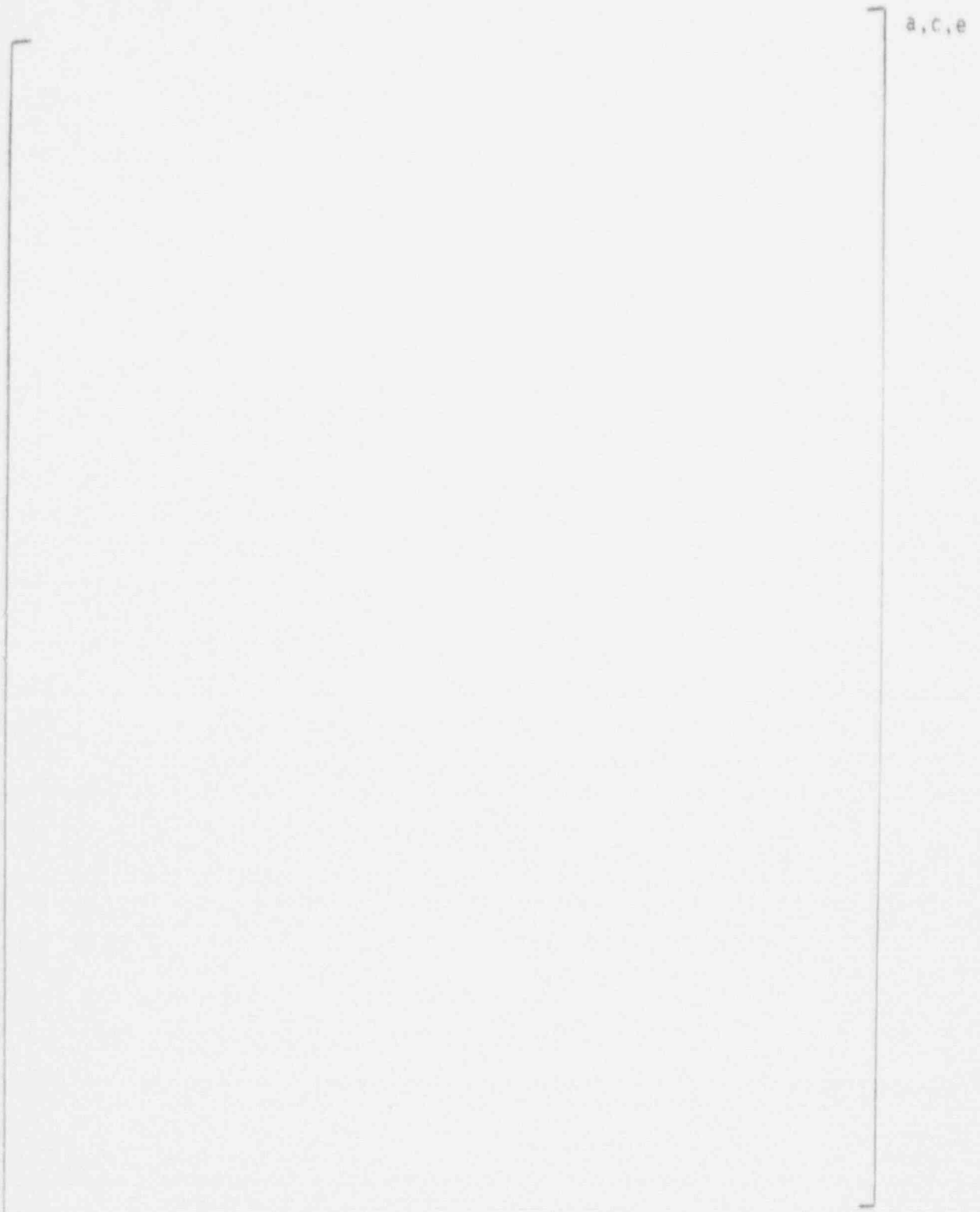


Figure 3-1. Schematic of Stress Analysis Procedure

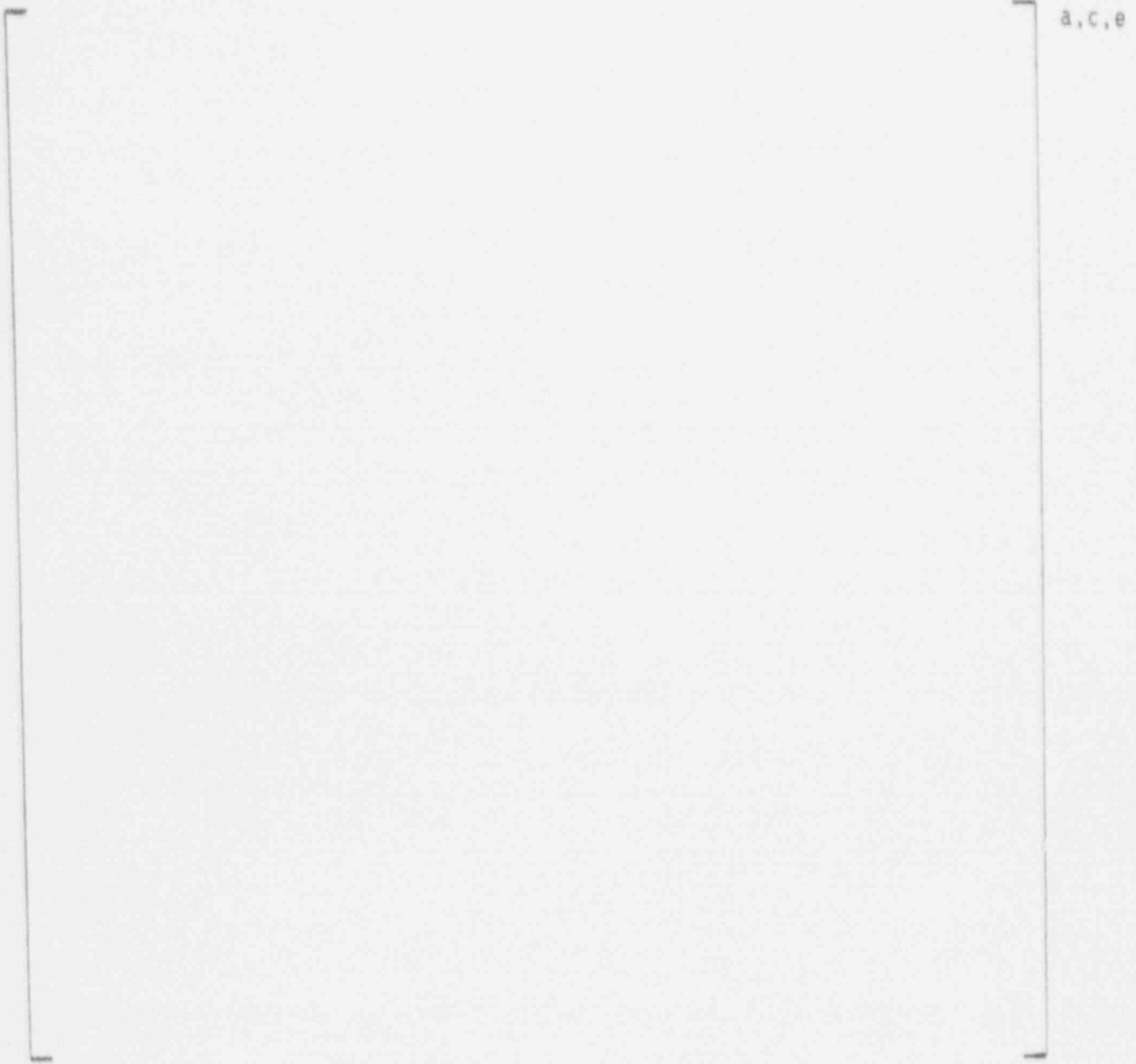


Figure 3-2. Pressurizer Surge Line Layout



Figure 3-3. Local Axial Stress in Piping Due to Thermal Stratification

a,c,e

Figure 3-4. Local Stress - Finite Element Models/Loading



Figure 3-5. Piping Local Stress Model and Thermal Boundary Conditions

a, c, e

Figure 3-6. Surge Line Temperature Distribution at []^{a, c, e} Axial Locations

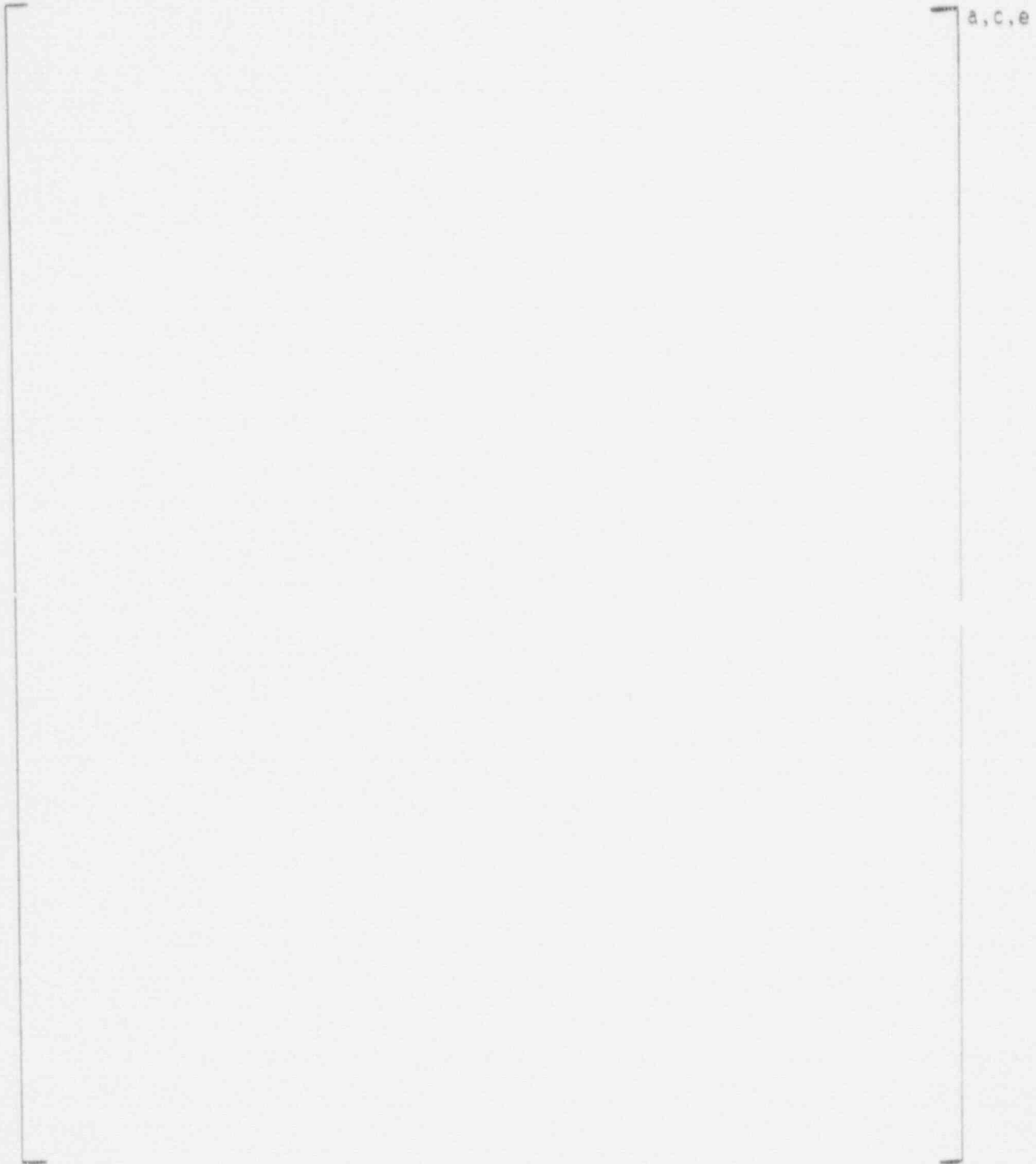


Figure 3-7. Surge Line Local Axial Stress Distribution at []^{a,c,e}
Axial Locations

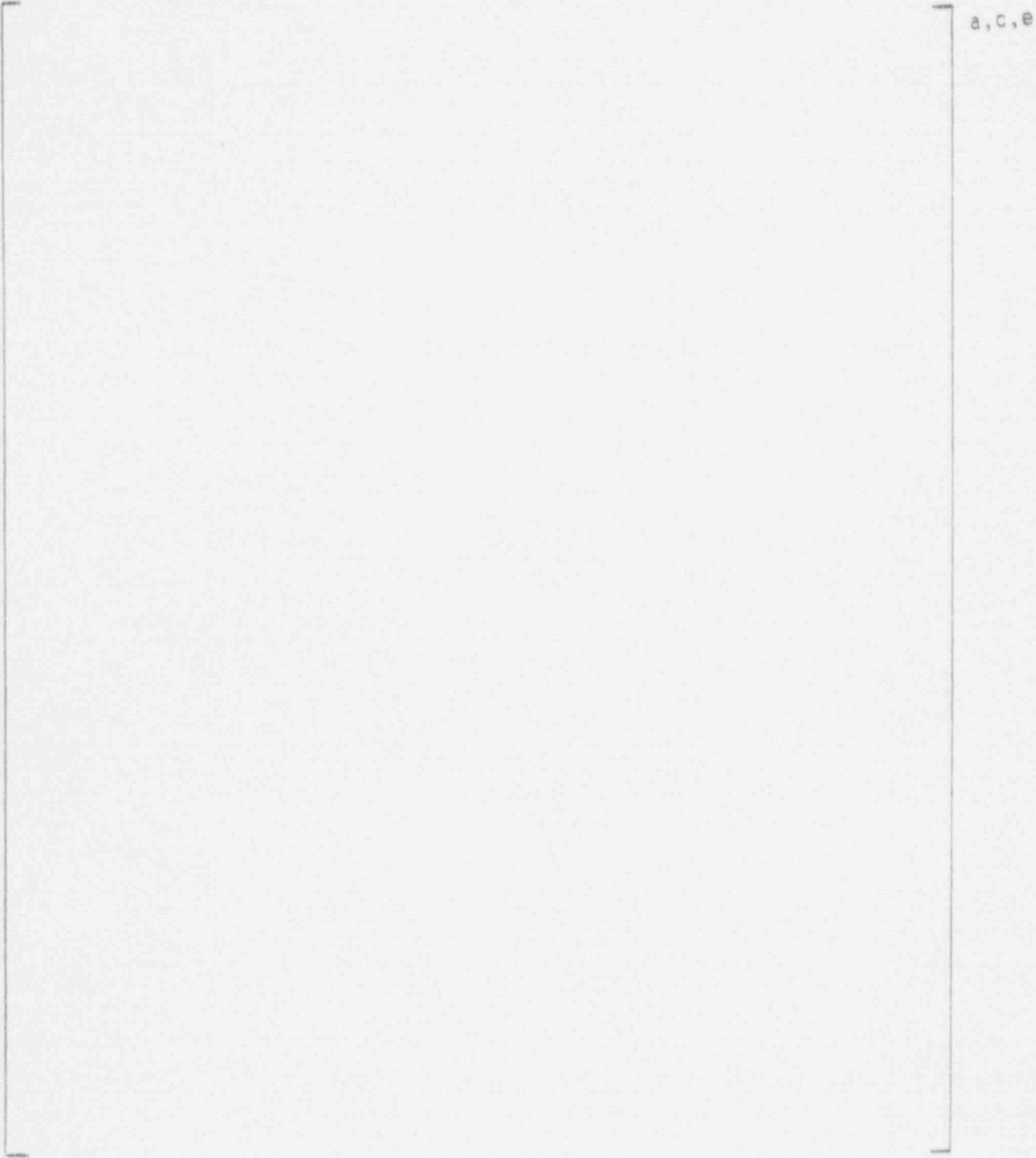


Figure 3-8. Surge Line Local Axial Stress on Inside Surface at
[]^{a,c,e} Axial Locations

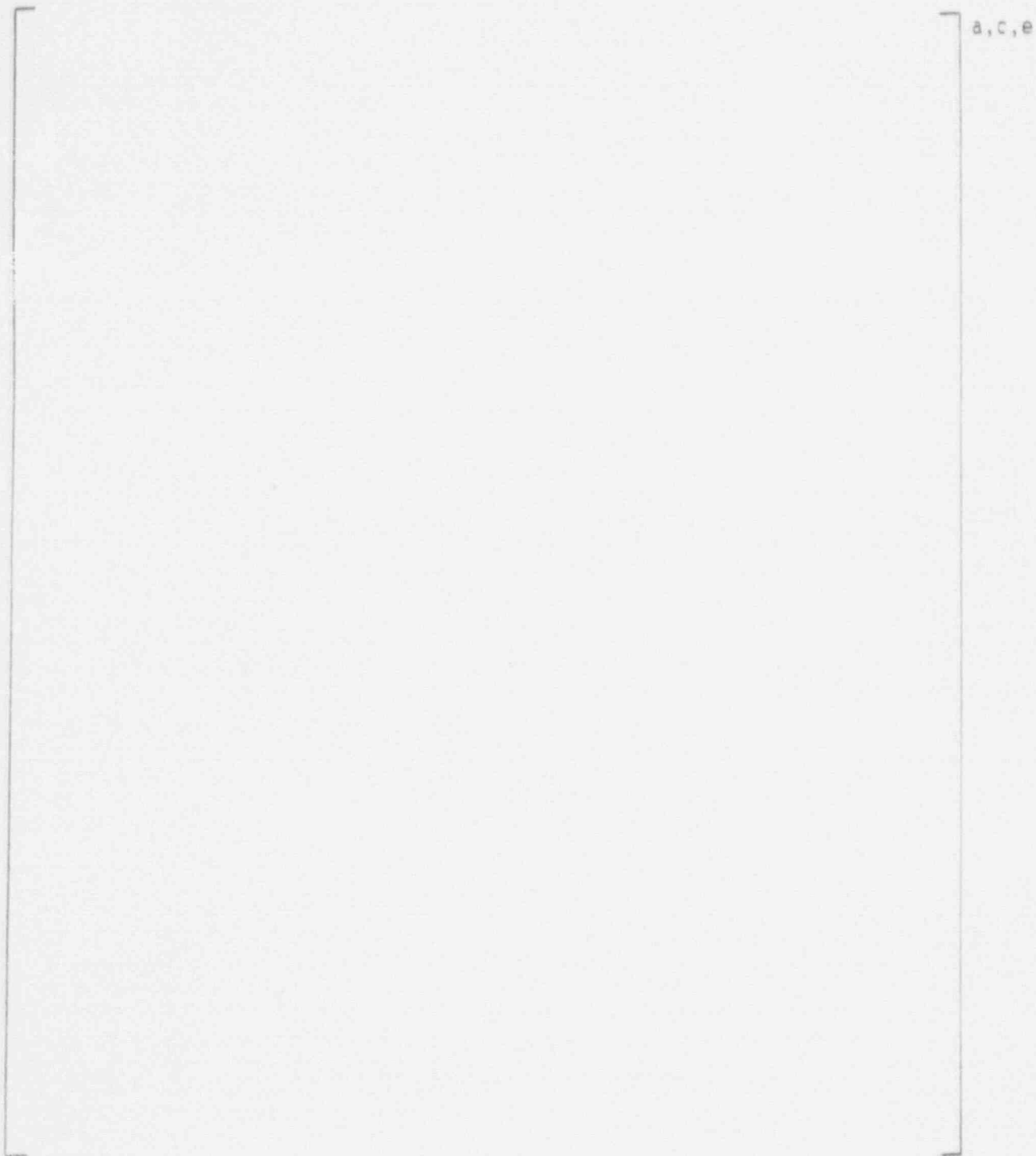


Figure 3-9. Surge Line Local Axial Stress on Outside Surface at
[]^{a,c,e} Axial Locations

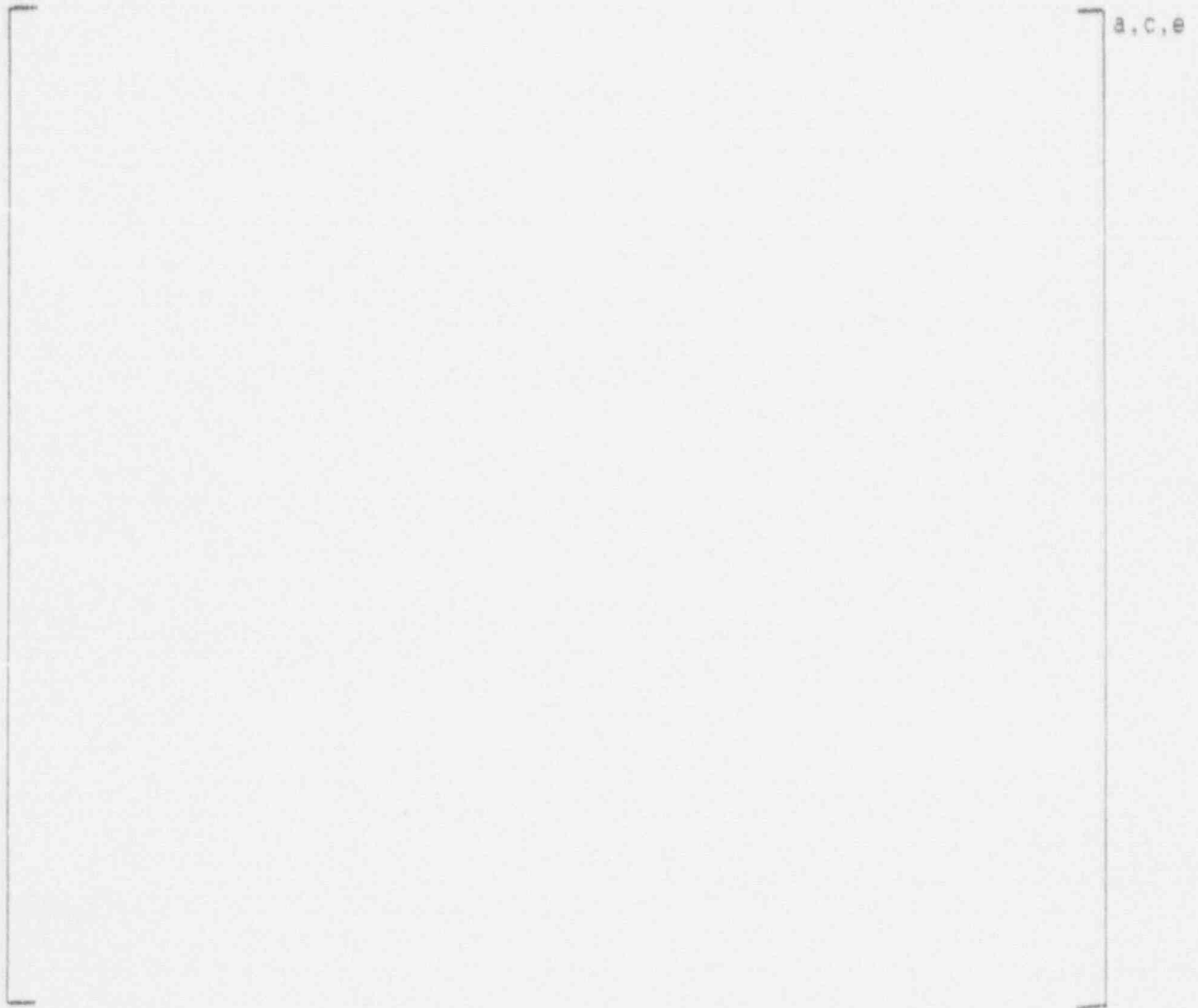


Figure 3-10. Surge Line RCL Nozzle 3-D WECAN Model: 14 Inch Schedule 160



Figure 3-11. Thermal Striping Fluctuation

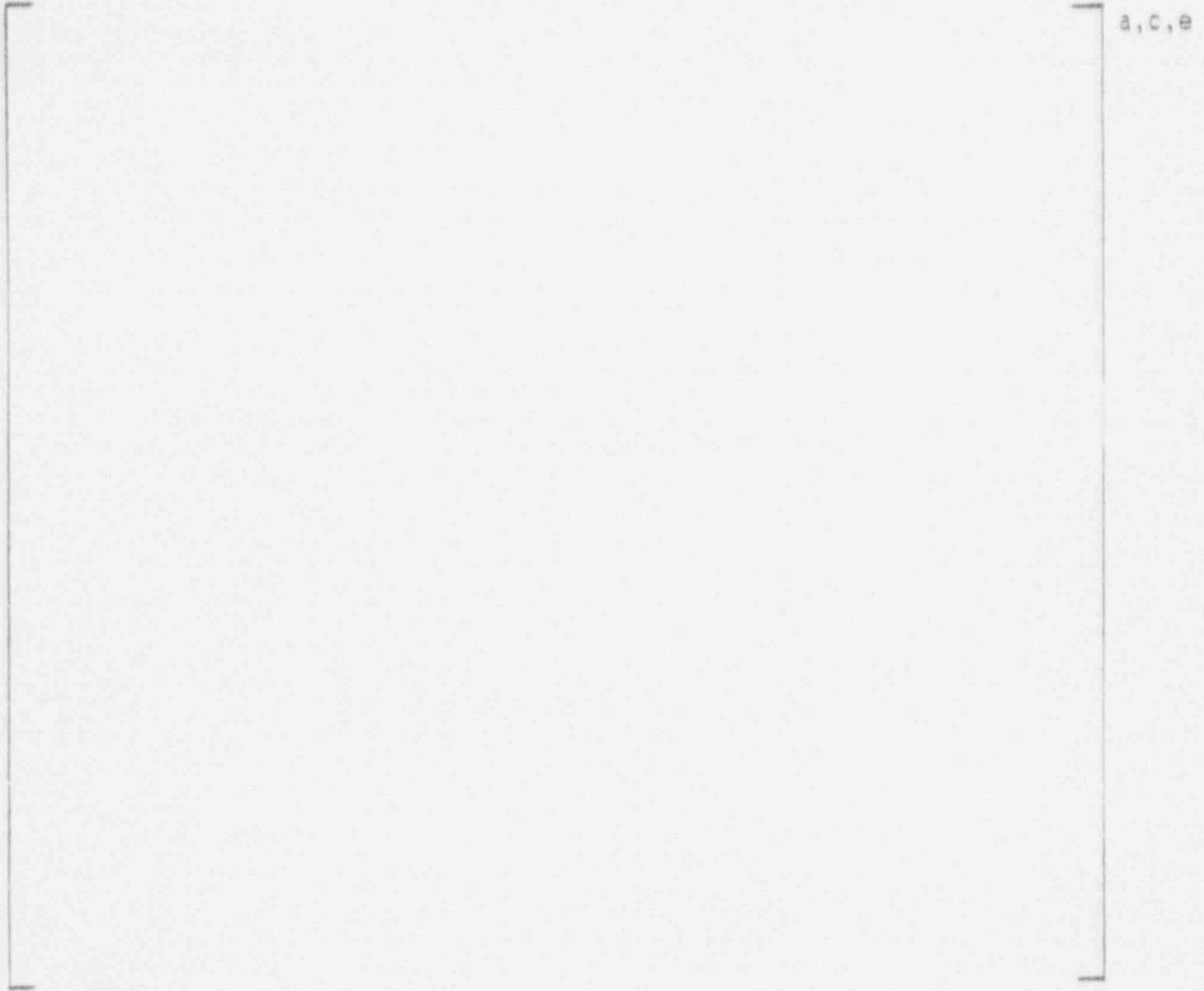


Figure 3-12. Thermal Striping Temperature Distribution

SECTION 4.0
DISPLACEMENTS AT SUPPORT LOCATIONS

The Salem Unit 1 and 2 plant specific piping displacements at the whip restraints/hangers along the surge line were calculated under the thermal stratification and normal thermal loads for both existing and future support configurations.

Tables 4-1A and 4-1B show the maximum surge line piping displacements at the whip restraints and spring hangers for the future support configuration. Future support configuration is based on the existing whip restraint gaps but with no "bottomed-out" spring hangers and taking credit for insulation crushability. Piping displacements at the whip restraints and spring hangers for the existing configuration are shown in Tables 4-2A and 4-2B. The existing configuration is based on the existing whip restraint gaps with the effects of "bottomed-out" spring hangers and also taking credit for insulation crushability.

Based on the stress analysis in Section 3, no whip restraint gap modification is necessary to satisfy the ASME Code requirements, provided that the future whip restraint gaps are not smaller than those used in the analysis (Table 3-2) and confirmed by Ref. 7. However, the travel allowance in the spring hangers must be modified to accommodate the piping displacements shown in Tables 4-1A and 4-1B for the future configuration.

TABLE 4-1(A)

Salem Surge Line Maximum Piping Displacement at Restraint Locations
Under Thermal Stratification (Future Configuration)

Support		Node	Displacement (in)		
Unit 1	Unit 2		DX	DY	DZ
					a,c,e

- Note: (1) The displacements shown are for Unit 1
 (2) The displacements are in the coordinate system given in Figure 3-2. For Unit 2 displacements, the signs of DZ must be reversed since Unit 2 is a mirror image of Unit 1 about the East-West axis. DX and DY are the same as tabulated above for Unit 2.
 (3) The displacements tabulated are for a system delta T of 320°F.

TABLE 4-1(B)

Salem Surge Line Maximum Piping Displacement at Restraint Locations
Under Normal Operating Thermal (Future Configuration)

Support		Node	Displacement (in)		
Unit 1	Unit 2		DX	DY	DZ
[a,c,e

- Note: (1) The displacements shown are for Unit 1
 (2) The displacements are in the coordinate system given in Figure 3-2. For Unit 2 displacements, the signs of DZ must be reversed since Unit 2 is a mirror image of Unit 1 about the East-west axis. DX and DY are the same as tabulated above for Unit 2.

TABLE 4-2(A)
 SALEM SURGE LINE MAXIMUM PIPING DISPLACEMENTS AT RESTRAINT LOCATIONS
 UNDER THERMAL STRATIFICATION*
 (Existing Configuration)

NODE	UNIT 1			UNIT 2				
	SUPPORT	DX	DY	DZ	SUPPORT	DX	DY	DZ
[Empty Table Body]								

4-4

a,c,e

Note: Displacements in inches

* System Delta T equals 320°F

TABLE 4-2(B)
 SALEM SURGE LINE MAXIMUM PIPING DISPLACEMENTS AT RESTRAINT LOCATIONS
 UNDER NORMAL OPERATING THERMAL
 (Existing Configuration)

NODE	SUPPORT	UNIT 1			UNIT 2			DZ	a,c,e
		DX	DY	DZ	SUPPORT	DX	DY		
[Empty table body]									

4-5

Note: Displacements in inches

SECTION 5.0
ASME SECTION III FATIGUE USAGE FACTOR EVALUATION

5.1 Methodology

Surge line fatigue evaluations have typically been performed using the methods of ASME Section III, NB-3600 for all piping components [

]a.c.e

Because of the nature of the stratification loading, as well as the magnitudes of the stresses produced, the more detailed and accurate methods of NB-3200 were employed using finite element analysis for all loading conditions. Application of these methods, as well as specific interpretation of Code stress values to evaluate fatigue results, is described in this section.

Inputs to the fatigue evaluation included the transients developed in section 2.0, and the global loadings and resulting stresses obtained using the methods described in section 3.0. In general, the stresses due to stratification were categorized according to the ASME Code methods and used to evaluate Code stresses and fatigue cumulative usage factors. It should be noted that, [

]a.c.e

5.1.1 Basis

The ASME Code, Section III, 1986 Edition [4] was used to evaluate fatigue on surge lines with stratification loading. This was based on the requirement of NRC Bulletin 88-11 (Appendix B of this report) to use the "latest ASME Section III requirements incorporating high cycle fatigue".

Specific requirements for class 1 fatigue evaluation of piping components are given in NB-3653. These requirements must be met for Level A and Level B type loadings according to NB-3653 and NB-3654.

According to NB-3611 and NB-3630, the methods of NB-3200 may be used in lieu of the NB-3600 methods. This approach was used to evaluate the surge line components under stratification loading. Since the NB-3650 requirements and equations correlate to those in NB-3200, the results of the fatigue evaluation are reported in terms of the NB-3650 piping stress equations. These equations and requirements are summarized in Tables 5-1 and 5-2.

The methods used to evaluate these requirements for the surge line components are described in the following sections.

5.1.2 Fatigue Stress Equations

Stress Classification

The stresses in a component are classified in the ASME Code based on the nature of the stress, the loading that causes the stress, and the geometric characteristics that influence the stress. This classification determines the acceptable limits on the stress values and, in terms of NB-3653, the respective equation where the stress should be included. Table NB-3217-2 provides guidance for stress classification in piping components, which is reflected in terms of the NB-3653 equations.

The terms in Equations 10, 11, 12 and 13 include stress indices which adjust nominal stresses to account for secondary and peak effects for a given component. Equations 10, 12 and 13 calculate secondary stresses, which are obtained from nominal values using stress indices C1, C2, C3 and C3' for pressure, moment and thermal transient stresses. Equation 11 includes the K1, K2 and K3 indices in the pressure, moment and thermal transient stress terms in order to represent peak stresses caused by local concentration, such as notches and weld effects. The NB-3653 equations use simplified formulas to

determine nominal stress based on straight pipe dimensions. [

]a,c,e

For the RCL nozzles, three dimensional (3-D) finite element analysis was used as described in Section 3.0. [

]a,c,e

Classification of local stress due to thermal stratification was addressed with respect to the thermal transient stress terms in the NB-3653 equations. Equation 10 includes a $T_a - T_b$ term, classified as "Q" stress in NB-3200, which represents stress due to differential thermal expansion at gross structural discontinuities. [

]a,c,e The impact of this on the selection of components for evaluation is discussed in Section 5.1.3.

Stress Combinations

The stresses in a given component due to pressure, moment and local thermal stratification loadings were calculated using the finite element models described in Section 3.0. [

]a,c,e This was done for specific components as follows:

[

]a,c,e

[

]a,c,e

From the stress profiles created, the stresses for Equations 10 and 11 could be determined for any point in the section. Experience with the geometries and loading showed that certain points in the finite element models consistently produced the worst case fatigue stresses and resulting usage factors, in each stratified axial location. [

]a,c,e

Equation 12 Stress

Code Equation 12 stress represents the maximum range of stress due to thermal expansion moments as described in Section 3.2. This used an enveloping approach, identifying the highest stressed location in the model. By evaluating the worst locations in this manner, the remaining locations were inherently addressed.

Equation 13 Stress

Equation 13 stress, presented in Section 3.2, is due to pressure, design mechanical loads and differential thermal expansion at structural discontinuities. Based on the transient set defined for stratification, the design pressures were not significantly different from previous design transients. Design mechanical loads are defined as deadweight plus seismic OBE loads.

The "Ta-Tb" term of Equation 13 is only applicable at structural discontinuities. [

]a,c,e

Thermal Stress Ratchet

The requirements of NB-3222.5 are a function of the thermal transient stress and pressure stress in a component, and are independent of the global moment loading. As such, these requirements were evaluated for controlling components using applicable stresses due to pressure and stratification transients.

Allowable Stresses

Allowable stress, S_m , was determined based on note 3 of Figure NB-3222-1. For secondary stresses due to a temperature transient or thermal expansion loads ("restraint of free end deflection"), the value of S_m was taken as the average of the S_m values at the highest and lowest temperatures of the metal during the transient. The metal temperatures were determined from the transient definition. When part of the secondary stress was due to mechanical load, the value of S_m was taken at the highest metal temperature during the transient.

5.1.3 Selection of Components for Evaluation

Based on the results of the global analyses and the considerations for controlling stresses in Section 5.1.2, [

] ^{a,c,e} The method to evaluate usage factors using stresses determined according to Section 3.0 is described below.

5.2 Fatigue Usage Factors

Cumulative usage factors were calculated for the controlling components using the methods described in NB-3222.4(e), based on NB-3653.5. Application of these methods is summarized below.

Transient Loadcases and Combinations

From the transients described in Section 2.0, specific loadcases were developed for the usage evaluation. [

] ^{a,c,e}

Each loadcase was assigned the number of cycles of the associated transient as defined in Section 2.0. These were input to the usage factor evaluation, along with the stress data as described above.

Usage factors were calculated at controlling locations in the component as follows:

- 1) Equation 10, K_e , Equation 11 and resulting Equation 14 (alternating stress - Salt) are calculated as described above for every possible combination of the loadsets.
- 2) For each value of Salt, the design fatigue curve was used to determine the maximum number of cycles which would be allowed if this type of cycle were the only one acting. These values, $N_1, N_2 \dots N_n$, were determined from Code Figures I-9.2.1 and I-9.2.2, curve C, for austenitic stainless steels.
- 3) Using the actual cycles of each transient loadset, n_1, n_2, \dots, n_n , calculate the usage factors $U_1, U_2 \dots U_n$ from $U_i = n_i/N_i$. This is done for all possible combinations. Cycles are used up for each combination in the order of decreasing Salt. When N_i is greater than 10^{11} cycles, the value of U_i is taken as zero.

[

a,c,e

- 4) The cumulative usage factor, U_{cum} , was calculated as $U_{cum} = U_1 + U_2 + \dots + U_n$. To this was added the usage factor due to thermal striping, as described below, to obtain total U_{cum} . The Code allowable value is 1.0.

5.3 Fatigue Due to Thermal Striping

The usage factors calculated using the methods of Section 5.2 do not include the effects of thermal striping. [

] ^{a,c,e}

Thermal striping stresses are a result of differences between the pipe inside surface wall and the average through wall temperatures which occur with time, due to the oscillation of the hot and cold stratified boundary. This type of stress is defined as a thermal discontinuity peak stress for ASME fatigue analysis. The peak stress is then used in the calculation of the ASME fatigue usage factor.

[

] ^{a,c,e} The methods used to determine alternating stress intensity are defined in the ASME code. Several locations were evaluated in order to determine the location where stress intensity was a maximum.

Thermal striping transients are shown as a ΔT level and number of cycles. The striping ΔT for each cycle of every transient is assumed to attenuate and follow the slope of the curve shown on Figure 5-2. Figure 5-2 is conservatively represented by a series of 5 degree temperature steps. Each step lasts []^{a,c,e} seconds. Fluctuations are then calculated at each temperature step. Since a constant frequency of []^{a,c,e} is used in all of the usage factor calculations, the total fluctuations per step is constant and becomes:

$$[]^{\text{a,c,e}}$$

Each striping transient is a group of steps with []^{a,c,e} fluctuations per step. For each transient, the steps begin at the maximum ΔT and decreases by []^{a,c,e} steps down to the endurance limit of ΔT equal to []^{a,c,e}. The cycles for all transients which have a temperature step at the same level were added together. This became the total cycles at a step. The total cycles were multiplied by []^{a,c,e} to obtain total fluctuations. This results in total fluctuations at each step. This calculation is performed for each step plateau from []^{a,c,e} to obtain total fluctuations. Allowable fluctuations and ultimately a usage factor at each plateau is calculated from the stress which exists at the ΔT for each step. The total striping usage factor is the sum of all usage factors from each plateau.

The usage factor due to striping, alone, was calculated to be a maximum of []^{a,c,e}. This is reflected in the results to be discussed below.

5.4 Fatigue Usage Results

NRC Bulletin 88-11 [5] requires fatigue analysis be performed in accordance with the latest ASME III requirements incorporating high cycle fatigue and thermal stratification transients. ASME fatigue usage factors have been calculated considering the phenomenon of thermal stratification and thermal striping at various locations in the surge line. Total stresses included the

[]^{a,c,e} The total stresses for all transients in the bounding set were used to form combinations to calculate alternating stresses and resulting fatigue damage in the manner defined by the Code. Of this total stress, the stresses in the 14 inch pipe due to [

] ^{a,c,e}

The maximum usage factor on Salem surge lines occurred at [

] ^{a,c,e}

It is also concluded that the Salem pressurizer surge nozzles meet the code stress allowables under the thermal stratification loading from the surge line and the transient detailed in reference [13], and meet the fatigue usage requirements of ASME Section III, with a maximum cumulative usage factor equal to 0.50.

TABLE 5-1
CODE/CRITERIA

- o ASME B&PV Code, Sec. III, 1986 Edition
 - NB3600
 - NB3200

- o Level A/B Service Limits
 - Primary Plus Secondary Stress Intensity $\leq 3S_m$ (Eq. 10)

 - Simplified Elastic-Plastic Analysis
 - Expansion Stress, $S_e \leq 3S_m$ (Eq. 12) - Global Analysis
 - Primary Plus Secondary Excluding Thermal Bending $< 3S_m$ (Eq. 13)
 - Elastic-Plastic Penalty Factor $1.0 \leq K_e \leq 3.333$

 - Peak Stress (Eq. 11)/Cumulative Usage Factor (U_{cum})
 - $S_{alt} = K_e S_p / 2$ (Eq. 14)
 - Design Fatigue Curve
 - $U_{cum} \leq 1.0$

TABLE 5-2
SUMMARY OF ASME FATIGUE REQUIREMENTS

Parameter	Description	Allowable (if applicable)
Equation 10	Primary plus secondary stress intensity; if exceeded, simplified elastic-plastic analysis may be performed	< 3Sm
K_e	Elastic-plastic penalty factor; required for simplified elastic-plastic analysis when Eq. 10 is exceeded; applied to alternating stress intensity	
Equation 12	Expansion stress; required for simplified elastic-plastic analysis when Eq. 10 is exceeded	< 3Sm
Equation 13	Primary plus secondary stress intensity excluding thermal bending stress; required for simplified elastic-plastic analysis when Eq. 10 is exceeded	< 3Sm
Thermal Stress Ratchet	Limit on radial thermal gradient stress to prevent cyclic distortion; required for use of Eq. 13	
Equation 11	Peak stress intensity - Input to Eq. 14	
Equation 14	Alternating stress intensity - Input to U_{cum}	
U_{cum}	Cumulative usage factor (fatigue damage)	< 1.0

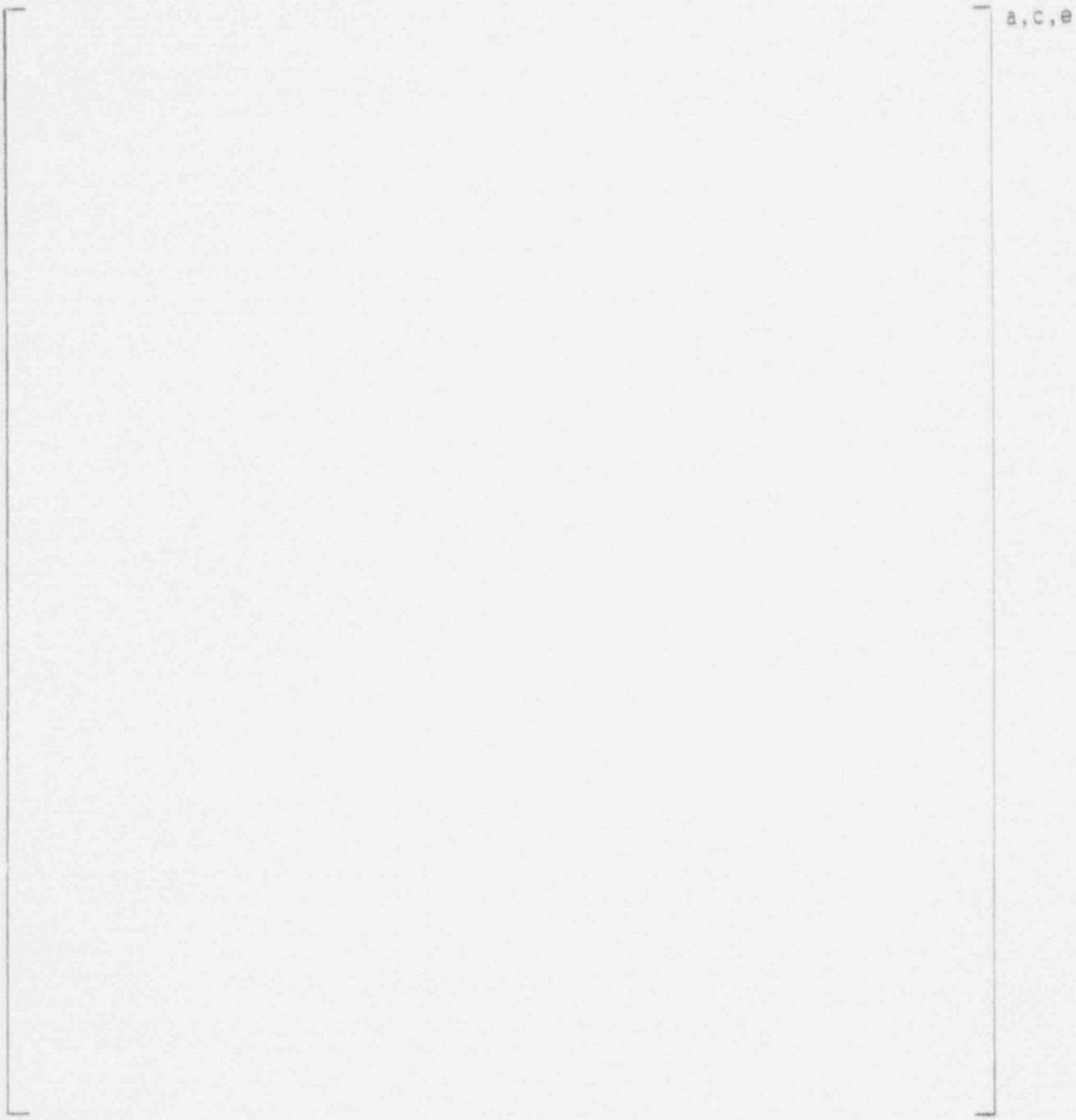


Figure 5-1. Striping Finite Element Model



Figure 5-2. Attenuation of Thermal Striping Potential by Molecular Conduction (Interface Wave Height of One Inch)

SECTION 6.0
SUMMARY AND CONCLUSIONS

The subject of pressurizer surge line integrity has been under intense investigation since 1988. The NRC issued Bulletin 88-11 in December of 1988, but the Westinghouse Owners Group had put a program in place earlier that year, and this allowed all members to make a timely response to the bulletin.

The Owners Group programs were completed in June of 1990, and have been followed by a series of plant specific evaluations. This report has documented the results of the plant specific evaluation for Salem Units 1 and 2.

Following the general approach used in developing the surge line stratification transients for the WOG, a set of transients and stratification profile were developed specifically for Salem Units 1 and 2. A study was made of the historical operating experience at the Salem Units 1 and 2, and this information, as well as plant operating procedures and monitoring results (from similar plants), was used in development of the transients and profiles.

Based on the stress analysis in Section 3 and fatigue evaluation in Section 5, it is not necessary to modify the existing whip restraint gaps for ASME Code acceptability provided sufficient travel allowances are maintained in all the variable spring hangers.

The results of this plant specific analysis along with support modification demonstrate acceptance to the requirements of the ASME Code Section III, including both stress limits and fatigue usage for the full licensed life of the plant. This report demonstrates that the Salem Units have completely satisfied the requirements of NRC Bulletin 88-11.

SECTION 7.0

REFERENCES

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APPENDIX A
LIST OF COMPUTER PROGRAMS

This appendix lists and summarizes the computer codes used in the pressurizer surge line thermal stratification. The codes are:

1. WECAN
2. STRFAT2
3. ANSYS
4. FATRK/CMS

A.1 WECAN

A.1.1 Description

WECAN is a Westinghouse-developed, general purpose finite element program. It contains universally accepted two-dimensional and three-dimensional isoparametric elements that can be used in many different types of finite element analyses. Quadrilateral and triangular structural elements are used for plane strain, plane stress, and axisymmetric analyses. Brick and wedge structural elements are used for three-dimensional analyses. Companion heat conduction elements are used for steady state heat conduction analyses and transient heat conduction analyses.

A.1.2 Feature Used

The temperatures obtained from a static heat conduction analysis, or at a specific time in a transient heat conduction analysis, can be automatically input to a static structural analysis where the heat conduction elements are replaced by corresponding structural elements. Pressure and external loads can also be include in the WECAN structural analysis. Such coupled thermal-stress analyses are a standard application used extensively on an industry wide basis.

A.1.3 Program Verification

Both the WECAN program and input for the WECAN verification problems, currently numbering over four hundred, are maintained under configuration control. Verification problems include coupled thermal-stress analyses for the quadrilateral, triangular, brick, and wedge isoparametric elements. These problems are an integral part of the WECAN quality assurance procedures. When a change is made to WECAN, as part of the reverification process, the configured inputs for the coupled thermal-stress verification problems are used to reverify WECAN for coupled thermal-stress analyses.

A.2 STRFAT2

A.2.1 Description

STRFAT2 is a program which computes the alternating peak stress on the inside surface of a flat plate and the usage factor due to striping on the surface. The program is applicable to be used for striping on the inside surface of a pipe if the program assumptions are considered to apply for the particular pipe being evaluated.

For striping the fluid temperature is a sinusoidal variation with numerous cycles.

The frequency, convection film coefficient, and pipe material properties are input.

The program computes maximum alternating stress based on the maximum difference between inside surface skin temperature and the average through wall temperature.

A.2.2 Feature Used

The program is used to calculate striping usage factor based on a ratio of actual cycles of stress for a specified length of time divided by allowable cycles of stress at maximum the alternating stress level. Design fatigue curves for several materials are contained into the program. However, the user has the option to input any other fatigue design curve, by designating that the fatigue curve is to be user defined.

A.2.3 Program Verification

STRFAT2 is verified to Westinghouse procedures by independent review of the stress equations and calculations.

A.3 ANSYS

A.3.1 Description

ANSYS is a public domain, general purpose finite element code.

A.3.2 Feature Used

The ANSYS elements used for the analysis of stratification effects in the surge line are STIF 20 (straight pipe), STIF 60 (elbow and bends) and STIF14 (spring-damper for supports).

A.3.3 Program Verification

As described in section 3.2, the application of ANSYS for stratification has been independently verified by comparison to WESTDYN (Westinghouse piping analysis code) and WECAN (finite element code). The results from ANSYS are also verified against closed form solutions for simple beam configurations.

A.4 FATRK/CMS

A.4.1 Description

FATRK/CMS is a Westinghouse developed computer code for fatigue tracking (FATRK) as used in the Cycle Monitoring System (CMS) for structural components of nuclear power plants. The transfer function method is used for transient thermal stress calculations. The bending stresses (due to global stratification effects, ordinary thermal expansion and seismic) and the pressure stresses are also included. The fatigue usage factors are evaluated in accordance with the guidelines given in the ASME Boiler and Pressure Vessel Code, Section III, Subsections NB-3200 and NB-3600.

The code can be used both as a regular analysis program or an on-line monitoring device.

A.4.2 Feature Used

FATRK/CMS is used as an analysis program for the present application. The input data which include the weight functions for thermal stresses, the unit bending stress, the unit pressure stress, the bending moment vs stratification temperatures, etc. are prepared for all locations and geometric conditions. These data, as stored in the independent files, can be appropriately retrieved for required analyses. The transient data files contain the time history of temperature, pressure, number of occurrence, and additional condition necessary for data flowing. The program prints out the total usage factors, and the transients pairing information which determine the stress range magnitudes and number of cycles. The detailed stress data may also be printed.

A.4.3 Program Verification

FATRK/CMS is verified according to Westinghouse procedures with several levels of independent calculations.

APPENDIX B

USNRC BULLETIN 88-11

In December of 1988 the NRC issued this bulletin, and it has led to an extensive investigation of surge line integrity, culminating in this and other plant specific reports. The bulletin is reproduced in its entirety in the pages which follow.

UNITED STATES
NUCLEAR REGULATORY COMMISSION
OFFICE OF NUCLEAR REACTOR REGULATION
WASHINGTON, D.C. 20555

December 20, 1988

NRC BULLETIN NO. 88-11: PRESSURIZER SURGE LINE THERMAL STRATIFICATION

Addressees:

All holders of operating licenses or construction permits for pressurized water reactors (PWRs).

Purpose:

The purpose of this bulletin is to (1) request that addressees establish and implement a program to confirm pressurizer surge line integrity in view of the occurrence of thermal stratification and (2) require addressees to inform the staff of the actions taken to resolve this issue.

Description of Circumstances:

The licensee for the Trojan plant has observed unexpected movement of the pressurizer surge line during inspections performed at each refueling outage since 1982, when monitoring of the line movements began. During the last refueling outage, the licensee found that in addition to unexpected gap closures in the pipe whip restraints, the piping actually contacted two restraints. Although the licensee had repeatedly adjusted shims and gap sizes based on analysis of various postulated conditions, the problem had not been resolved. The most recent investigation by the licensee confirmed that the movement of piping was caused by thermal stratification in the line. This phenomenon was not considered in the original piping design. On October 7, 1988, the staff issued Information Notice 88-80, "Unexpected Piping Movement Attributed to Thermal Stratification," regarding the Trojan experience and indicated that further generic communication may be forthcoming. The licensee for Beaver Valley 2 has also noticed unusual snubber movement and significantly larger-than-expected surge line displacement during power ascension.

The concerns raised by the above observations are similar to those described in NRC Bulletins 79-13 (Revision 2, dated October 16, 1979), "Cracking in Feedwater System Piping" and 88-08 (dated June 22, 1988), "Thermal Stresses in Piping Connected to Reactor Coolant Systems."

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Discussion:

Unexpected piping movements are highly undesirable because of potential high piping stress that may exceed design limits for fatigue and stresses. The problem can be more acute when the piping expansion is restricted, such as through contact with pipe whip restraints. Plastic deformation can result, which can lead to high local stresses, low cycle fatigue and functional impairment of the line. Analysis performed by the Trojan licensee indicated that thermal stratification occurs in the pressurizer surge line during heatup, cooldown, and steady-state operations of the plant.

During a typical plant heatup, water in the pressurizer is heated to about 440°F; a steam bubble is then formed in the pressurizer. Although the exact phenomenon is not thoroughly understood, as the hot water flows (at a very low flowrate) from the pressurizer through the surge line to the hot-leg piping, the hot water rides on a layer of cooler water, causing the upper part of the pipe to be heated to a higher temperature than the lower part (see Figure 1). The differential temperature could be as high as 300°F, based on expected conditions during typical plant operations. Under this condition, differential thermal expansion of the pipe metal can cause the pipe to deflect significantly.

For the specific configuration of the pressurizer surge line in the Trojan plant, the line deflected downward and when the surge line contacted two pipe whip restraints, it underwent plastic deformation, resulting in permanent deformation of the pipe.

The Trojan event demonstrates that thermal stratification in the pressurizer surge line causes unexpected piping movement and potential plastic deformation. The licensing basis according to 10 CFR 50.55a for all PWRs requires that the licensee meet the American Society of Mechanical Engineers Boiler and Pressure Vessel Code Sections III and XI and to reconcile the pipe stresses and fatigue evaluation when any significant differences are observed between measured data and the analytical results for the hypothesized conditions. Staff evaluation indicates that the thermal stratification phenomenon could occur in all PWR surge lines and may invalidate the analyses supporting the integrity of the surge line. The staff's concerns include unexpected bending and thermal striping (rapid oscillation of the thermal boundary interface along the piping inside surface) as they affect the overall integrity of the surge line for its design life (e.g., the increase of fatigue).

Actions Requested:

Addressees are requested to take the following actions:

1. For all licensees of operating PWRs:
 - a. Licensees are requested to conduct a visual inspection (ASME, Section XI, VT-3) of the pressurizer surge line at the first available cold shutdown after receipt of this bulletin which exceeds seven days.

This inspection should determine any gross discernable distress or structural damage in the entire pressurizer surge line, including piping, pipe supports, pipe whip restraints, and anchor bolts.

- b. Within four months of receipt of this Bulletin, licensees of plants in operation over 10 years (i.e., low power license prior to January 1, 1979) are requested to demonstrate that the pressurizer surge line meets the applicable design codes* and other FSAR and regulatory commitments for the licensed life of the plant, considering the phenomenon of thermal stratification and thermal striping in the fatigue and stress evaluations. This may be accomplished by performing a plant specific or generic bounding analysis. If the latter option is selected, licensees should demonstrate applicability of the referenced generic bounding analysis. Licensees of plants in operation less than ten years (i.e., low power license after January 1, 1979), should complete the foregoing analysis within one year of receipt of this bulletin. Since any piping distress observed by addressees in performing action 1.a may affect the analysis, the licensee should verify that the bounding analysis remains valid. If the opportunity to perform the visual inspection in 1.a does not occur within the periods specified in this requested item, incorporation of the results of the visual inspection into the analysis should be performed in a supplemental analysis as appropriate.

Where the analysis shows that the surge line does not meet the requirements and licensing commitments stated above for the duration of the license, the licensee should submit a justification for continued operation or bring the plant to cold shutdown, as appropriate, and implement Items 1.c and 1.d below to develop a detailed analysis of the surge line.

- c. If the analysis in 1.b does not show compliance with the requirements and licensing commitments stated therein for the duration of the operating license, the licensee is requested to obtain plant specific data on thermal stratification, thermal striping, and line deflections. The licensee may choose, for example, either to install instruments on the surge line to detect temperature distribution and thermal movements or to obtain data through collective efforts, such as from other plants with a similar surge line design. If the latter option is selected, the licensee should demonstrate similarity in geometry and operation.
- d. Based on the applicable plant specific or referenced data, licensees are requested to update their stress and fatigue analyses to ensure compliance with applicable Code requirements, incorporating any observations from 1.a above. The analysis should be completed no later than two years after receipt of this bulletin. If a licensee

*Fatigue analysis should be performed in accordance with the latest ASME Section III requirements incorporating high cycle fatigue.

is unable to show compliance with the applicable design codes and other FSAR and regulatory commitments, the licensee is requested to submit a justification for continued operation and a description of the proposed corrective actions for effecting long term resolution.

2. For all applicants for PWR Operating Licenses:
 - a. Before issuance of the low power license, applicants are requested to demonstrate that the pressurizer surge line meets the applicable design codes and other FSAR and regulatory commitments for the licensed life of the plant. This may be accomplished by performing a plant-specific or generic bounding analysis. The analysis should include consideration of thermal stratification and thermal striping to ensure that fatigue and stresses are in compliance with applicable code limits. The analysis and hot functional testing should verify that piping thermal deflections result in no adverse consequences, such as contacting the pipe whip restraints. If analysis or test results show Code noncompliance, conduct of all actions specified below is requested.
 - b. Applicants are requested to evaluate operational alternatives or piping modifications needed to reduce fatigue and stresses to acceptable levels.
 - c. Applicants are requested to either monitor the surge line for the effects of thermal stratification, beginning with hot functional testing, or obtain data through collective efforts to assess the extent of thermal stratification, thermal striping and piping deflections.
 - d. Applicants are requested to update stress and fatigue analyses, as necessary, to ensure Code compliance.* The analyses should be completed no later than one year after issuance of the low power license.
3. Addressees are requested to generate records to document the development and implementation of the program requested by Items 1 or 2, as well as any subsequent corrective actions, and maintain these records in accordance with 10 CFR Part 50, Appendix B and plant procedures.

Reporting Requirements:

1. Addressees shall report to the NRC any discernable distress and damage observed in Action 1.a along with corrective actions taken or plans and schedules for repair before restart of the unit.

*If compliance with the applicable codes is not demonstrated for the full duration of an operating license, the staff may impose a license condition such that normal operation is restricted to the duration that compliance is actually demonstrated.

2. Addressees who cannot meet the schedule described in Items 1 or 2 of Actions Requested are required to submit to the NRC within 60 days of receipt of this bulletin an alternative schedule with justification for the requested schedule.
3. Addressees shall submit a letter within 30 days after the completion of these actions which notifies the NRC that the actions requested in Items 1b, 1d or 2 of Actions Requested have been performed and that the results are available for inspection. The letter shall include the justification for continued operation, if appropriate, a description of the analytical approaches used, and a summary of the results.

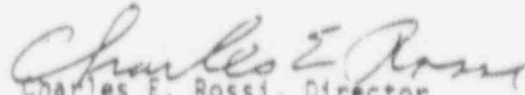
Although not requested by this bulletin, addressees are encouraged to work collectively to address the technical concerns associated with this issue, as well as to share pressurizer surge line data and operational experience. In addition, addressees are encouraged to review piping in other systems which may experience thermal stratification and thermal striping, especially in light of the previously mentioned Bulletins 79-13 and 88-08. The NRC staff intends to review operational experience giving appropriate recognition to this phenomenon, so as to determine if further generic communications are in order.

The letters required above shall be addressed to the U.S. Nuclear Regulatory Commission, ATTN: Document Control Desk, Washington, D.C. 20555, under oath or affirmation under the provisions of Section 182a, Atomic Energy Act of 1954, as amended. In addition, a copy shall be submitted to the appropriate Regional Administrator.

This request is covered by Office of Management and Budget Clearance Number 3150-0011 which expires December 31, 1989. The estimated average burden hours is approximately 3000 person-hours per licensee response, including assessment of the new requirements, searching data sources, gathering and analyzing the data, and preparing the required reports. These estimated average burden hours pertain only to these identified response-related matters and do not include the time for actual implementation of physical changes, such as test equipment installation or component modification. The estimated average radiation exposure is approximately 3.5 person-rems per licensee response.

Comments on the accuracy of this estimate and suggestions to reduce the burden may be directed to the Office of Management and Budget, Room 3208, New Executive Office Building, Washington, D.C. 20503, and to the U.S. Nuclear Regulatory Commission, Records and Reports Management Branch, Office of Administration and Resource Management, Washington, D.C. 20555.

If you have any questions about this matter, please contact one of the technical contacts listed below or the Regional Administrator of the appropriate regional office.



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Attachments:

1. Figure 1
2. List of Recently Issued NRC Bulletins

Surge Line Stratification

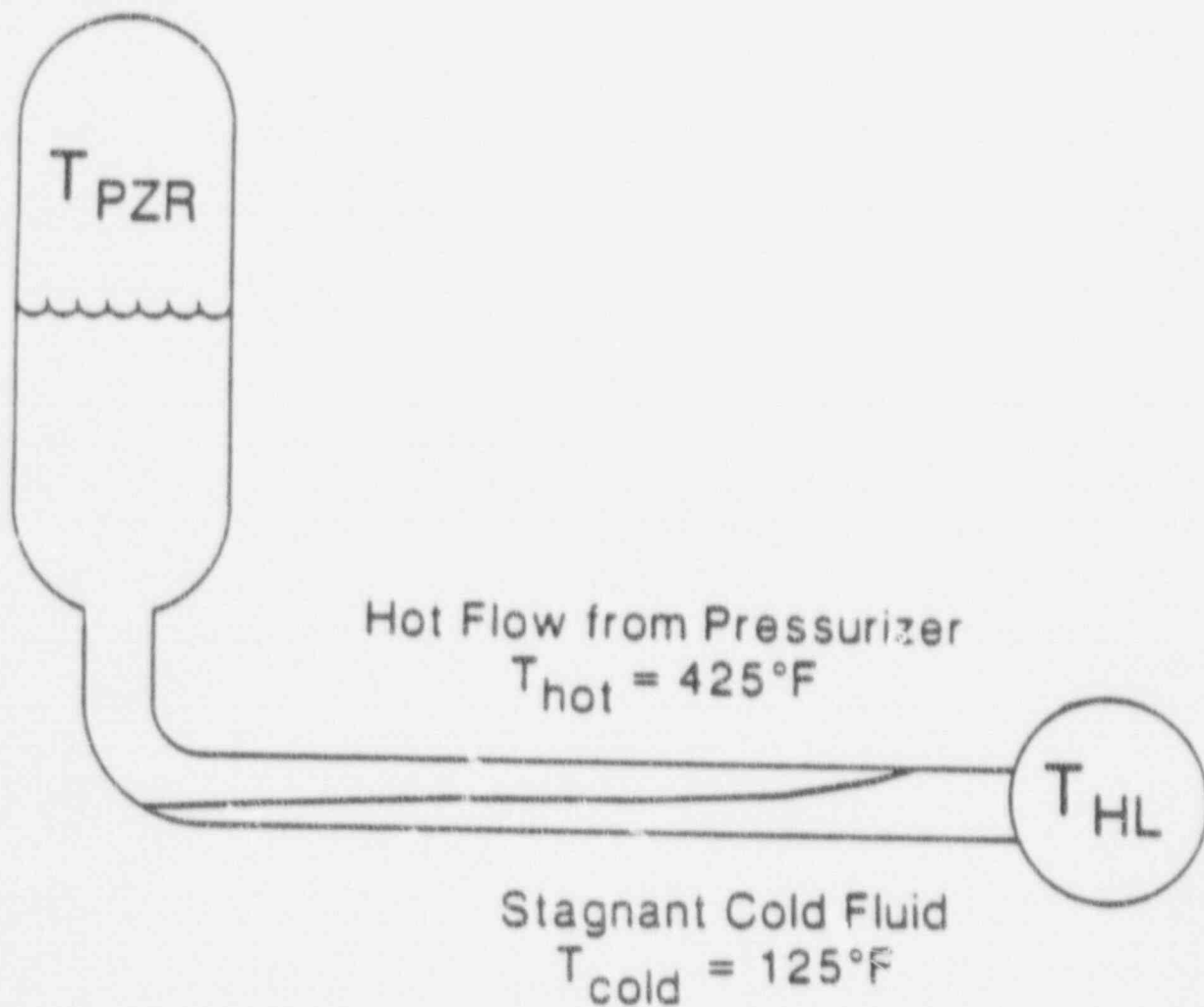


Figure 1

APPENDIX C

TRANSIENT DEVELOPMENT DETAILS

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