NON-PROPRIETARY

BAW-2127
Supplement 3
December 1993

THE B&W OWNERS GROUP

MATERIALS COMMITTEE

Plant-Specific Analysis

in Response to

Nuclear Regulatory Commission
Bulletin 88-11

"Pressurizer Surge Line Thermal Stratification"

Davis-Besse Nuclear Power Station Unit 1

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PLANT-SPECIFIC ANALYSIS
IN RESPONSE TO
NUCLEAR REGULATORY COMMISSION
BULLETIN 88-11
"PRESSURIZER SURGE LINE THERMAL STRATIFICATION"

Prepared for

Toledo Edison Company

Prepared by
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EXECUTIVE SUMMARY

Purpose:

The purpose of this supplement is to report on the re-evaluation of information contained in Supplement 1 due to the changed analysis bases of section 8. Davis-Besse Nuclear Power Station Unit 1 (DB-1), the only operating B&WOG raised-loop plant, requires a plant-specific evaluation which is summarized in this report supplement. As with the lowered-loop plant evaluation, the plant-specific evaluation for Davis-Besse Unit 1 involved comprehensive instrumentation. The evaluation also involved assessment of operating practices and procedures, collection and review of historical plant data, and development of new design basis transient conditions for the surge line to conservatively account for thermal cycling, thermal stratification, and thermal striping. The evaluation of thermal striping incorporated the best available data to characterize this phenomenon as it may occur in the surge line.

Background:

On December 20, 1988 the Nuclear Regulatory Commission issued NRC Bulletin 88-11. The bulletin addressed technical concerns associated with thermal stratification in the pressurizer surge line and required utilities to establish and implement a program to ensure the structural integrity of the surge line. The B&W Owners Group (B&WOG) has developed a comprehensive program to address the requirements of the bulletin. This program and its results were summarized in BAW-2127, "Final Submittal for Nuclear Regulatory Commission Bulletin 88-11 "Pressurizer Surge Line Thermal Stratification" for the B&W-designed lowered-loop plants. In September 1991, Supplement 1, Plant-Specific Analysis in Response to Nuclear Regulatory Commission Bulletin 88-11 "Pressurizer Surge Line Thermal Stratification" Davis-Besse Nuclear Power Station Unit 1, presented the results for the B&W-designed raised loop plant. In May 1992, Supplement 2, Pressurizer Surge Line Thermal Stratification for the B&W 177-FA Nuclear Plants Summary

Report, "Fatigue Stress Analysis of the Surge Line Elbows" provided an alternate analysis in answer to the one open elbow exception from the NRC.

Summary:

The structural analysis for the new design conditions has shown that the Davis-Besse Unit 1 surge line can meet its 40-year design life given the completion of procedural and design modifications. Detailed finite element analyses have been performed on the pressurizer surge nozzle, on the surge line to hot leg nozzle, and on the limiting portions (the elbows) of the pressurizer surge line piping. At all points in the surge line and the associated nozzles, the cumulative fatigue usage factor remains less than one for the design life.

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1. INTRODUCTION

This report is a supplement to Final Submittal for Nuclear Regulatory Commission Bulletin 88-11 "Pressurizer Surge Line Thermal Stratification" (Reference 1) and summarizes the B&W Owners Group program addressing the technical issues described in NRC Bulletin 88-11 (Reference 2) for the Davis-Besse Nuclear Power Station Unit 1. The analyses described in this report confirm that all surge line pressure boundary components (including all nozzles) will satisfy applicable code stress allowables for the Davis-Besse Unit 1.

The introduction briefly reiterates the background for the thermal stratification, striping and cycling issues, and a summary of the plant-specific surge line fatigue analysis results and conclusions for Davis-Besse Unit 1. The remaining sections of the report are as follows:

- Section 2 reviews the technical approach which has been developed by the B&W Owners Group,
- Section 3 discusses the plant-specific approach for Davis-Besse Unit 1,
- Section 4 describes the development of the new design basis thermal-hydraulic conditions for the Davis-Besse Unit 1 surge line,
- Sections 5 and 6 describe the stress and fatigue analyses performed for the Davis-Besse Unit 1 surge line piping and its nozzles,
- Section 7 provides conclusions resulting from the Davis-Besse Unit 1 plant-specific analysis with regard to new design basis transients which represent surge line thermal conditions and the structural integrity of the surge line,
- Section 8 states the conditions which form the basis for the analysis,
- Section 9 lists all references, and
- Appendix A provides a supplement to Section 3.1 and contains a detailed discussion of the data acquisition for the Davis-Besse Unit 1 surge line.

1.1 Background

The surge line in B&W 177 fuel assembly (177-FA) plants, including Davis-Besse Unit 1, contains approximately 50 feet of piping which connects the pressurizer lower head and the reactor coolant hot leg piping. During plant operation, the reactor coolant system (RCS) is pressurized with a steam bubble in the pressurizer. Thus, the pressurizer contains saturated fluid while the remainder of the RCS is subcooled with temperatures cooler than the pressurizer fluid by 43°F or more. The surge line provides the means by which the pressurizer accommodates changes in RCS inventory. The reactor coolant flows through the surge line during surges into and out of the pressurizer. During reactor coolant pump operations, there is normally a small outflow from the pressurizer due to continuous minimum pressurizer spray flow.

Due to differences in density, the reactor coolant can stratify in the horizontal piping sections whereby the fluid temperature varies from top to bottom with the warmer fluid located above the denser (cooler) fluid. This phenomenon, known as thermal stratification, is most pronounced during outsurges from the pressurizer. During an insurge or outsurge under stratified conditions, thermal striping may occur at the fluid layer interface. Thermal striping is a rapid oscillation of the thermal boundary interface caused by interfacial waves and turbulence effects. The original surge line fatigue analyses performed for the B&W 177-FA plants did not account for thermal stratification which causes additional bending moments in the piping, nor did the analyses account for thermal striping which affects the fatigue usage at the inner surface of the pipe.

In order to confirm pressurizer surge line integrity, the Nuclear Regulatory Commission issued NRC Bulletin Number 88-11, Pressurizer Surge Line Thermal Stratification (December 20, 1988). This bulletin requires certain actions of licensees of all operating pressurized water reactors (PWRs). The applicable actions are paraphrased below:

1a. At the first available cold shutdown after receipt of the bulletin, and which exceeds seven days, conduct a visual inspection of the pressurizer surge line.

1b. Within four months of receipt of the bulletin, licensees of plants in operation over ten years 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 thermal stratification and thermal striping in the fatigue and stress evaluations; or provide the staff with a justification for continued operation while a detailed analysis of the surge line is performed that implements items 1c and 1d below.

1c. If necessary, obtain plant-specific surge line thermal and displacement data. Data can be obtained through collective efforts if sufficient similarities in geometry and operation can be demonstrated.

1d. Update the fatigue and stress analyses to ensure compliance with the applicable Code and Regulatory requirements within two years of receipt of the Bulletin or submit a justification for continued operation and a description of the proposed corrective actions for effecting long-term resolution.

A portion of the B&W Owners Group program was presented to the Nuclear Regulatory Commission Staff on September 29, 1988 and April 7, 1989. An interim evaluation, BAW-2085, dated May 1989, provided the staff with a justification for near term operation for all of the operating B&W 177-FA plants (Reference 3). The NRC concluded that sufficient information had been provided to justify near term operation for B&W plants until the final report could be completed (Reference 4).

The final report for the lowered-loop plants was completed and submitted to the NRC in December 1990. Supplement 1 to this report, describing the plant-specific analysis and providing a basis for a Justification for Continued Operation (JCO) for the raised loop Davis-Besse Unit 1 plant, was submitted to the NRC in September 1991 (Reference 8). This report used the same methodology applied in Reference 1. Questions from the NRC, regarding these methods and the applied analysis, were answered by Reference 11.

The NRC SER, based on the lowered loop plant final report (Reference 1), contained an open item regarding the analytical technique used to demonstrate acceptable integrity of the surge line elbows. A similar open item was included in the NRC acceptance of the JCO for Davis-Besse Unit 1 (Reference 12). As a result, the B&WOG performed a shakedown analysis of the surge line and a strain based fatigue analysis of all surge line elbows. The preliminary results were presented to the NRC at a meeting with the B&W Owners Group Thermal Stratification Working Group on January 15, 1992. The second supplement to BAW-2127 summarized the results from these analyses to demonstrate the integrity of the surge line elbows in order to resolve the NRC open item. This was accepted by the NRC for the lowered loop plants (Reference 10).

This supplement summarizes the plant-specific evaluation for the Davis-Besse Unit 1 raised-loop plant, and documents compliance with action items 1b, 1c, and 1d of NRC Bulletin 88-11. The method accepted for the lowered loop plants in the second supplement has also been used in this supplement. The intent of this document is to address the issues involved in the JCO for Davis-Besse Unit 1 (Reference 12).

Supplement 3 replaces Supplement 1. The primary change between these supplements is due to deferral of certain modifications (Ref 12). Time period T4, discussed in section 4, has been extended for two refueling outages to account for this deferral. This increases the number of cycles during time period T4 and decreases those during time period T5. Table 4-2 shows the new number of events for design transients considered in this supplement. The transient list and description (Table 4-1) has not been changed. The additional cycles assumed for time period T4 are based on conservative estimates.

1.2 Conclusion

Given the completion of the design modifications described in Section 8, the surge line for Davis-Besse Unit 1 is shown to fulfill the 40-year licensed plant life. The structural analysis of the surge line and associated nozzles has accounted for thermal conditions (thermal stratification, thermal striping, and thermal cycling) existing during the life of the plant. The highest cumulative usage factor for 40 years of operation (240 heatup/cooldown cycles) has a value of 0.93 and occurs in the nozzle-to-head corner of the pressurizer nozzle. The second highest cumulative usage factor for the 40 years of operation occurs at the end of the nozzle taper of the hot leg nozzle and has a value of 0.81. Within the surge line proper, the highest cumulative usage factor is 0.76 and occurs in the straight pipe in the lower horizontal run at the beginning of the second elbow (elbow B on Figure 5-1). The cumulative usage factor for the snubber stanchion (a welded attachment) is 0.26.

2. OVERVIEW OF B&W OWNER'S GROUP PROGRAM

The B&W Owner's Group Materials Committee report, hereafter referred to as the main report (Reference 1), includes a detailed discussion of the program developed to address the technical concerns identified in NRC Bulletin 88-11. The discussion of the program will not be repeated in this supplement, but will be reviewed briefly. The program is divided into two basic sections: the design basis thermal transients and structural analyses required to assess the integrity of the surge line and associated nozzles for the balance of the design life of each of the plants. This supplement is a summary of the program that addresses the plant-specific evaluation for the Davis-Besse Unit 1 raised-loop plant. The key elements of the program are as shown in Figure 2-1 of the main report except that the surge line data is taken at Davis-Besse Unit 1.

2.1 Development of New Design Basis Conditions

The thermal-hydraulic phenomena which must be accounted for in the surge line are thermal stratification, thermal striping, and thermal cycling. As these phenomena occur to some degree in almost all modes of plant operation, the surge line conditions must be carefully considered from cold shutdown through heatup, power escalation, normal power operation, and cooldown.

Thermal cycling is associated with coolant mass and temperature changes in the reactor coolant system (RCS). Thermal stratification can occur in the surge line only during moderate to low flow rates through the surge line and may exist in a steady state as well as in a transient condition. Thermal striping requires the existence of thermal stratification. The main report considers the requirements for a quantitative treatment of these phenomena in Subsection 2.1.

Davis-Besse Unit 1 was instrumented to record the thermal transients in the surge line for plant heatup, power escalation, full power operation, and plant cooldown. Surge line displacement instrumentation was also added to the surge line. The Davis-Besse Unit 1 data collection process, described in more detail in Appendix A, provided circumferential temperature measurements at several axial locations along the surge line in addition to displacement measurements for each major displacement axis.

As performed for the lowered-loop plants, a review of the operating procedures provided a better understanding of those plant evolutions likely to cause surge line upsets. The operating procedure review and consideration of the hourly heatup and cooldown data over the plant operating history provided the bases for generating design basis surge line transients for plant heatup, cooldown, and power operation.

As described in Subsection 2.1 of the main report, an important part of the operating procedure review dealt with the potential upper bound for the pressurizer to hot leg temperature difference as described in the lowered-loop analysis. For Davis-Besse Unit 1, the maximum calculated surge line top-to-bottom temperature difference is 358F for the design transients, as discussed in Subsection 4.5.1.2. The maximum surge line top-to-bottom temperature difference measured at Davis-Besse Unit 1 was 253F.

The relationship of thermal striping amplitude and frequency to the pipe fluid conditions for Davis-Besse Unit 1 are based on the Battelle data as discussed in Subsections 2.1 and 4.3 of the main report. The thermal striping data correlation permits the determination of striping characteristics for any given surge line flow rate and imposed top-to-bottom temperature difference. The product of the thermal-hydraulic program is a revised set of surge line design basis transient descriptions that account for thermal cycling, thermal stratification, and thermal striping. Design transients considered in the previous design basis for the surge line were modified to account for all three thermal phenomena. All design basis transients involving surges were considered in the evaluation.

Results of the thermal-hydraulics part of the program consists of the input for the stress analysis of the surge line itself, the associated nozzles at each end, and the one-inch diameter drain nozzle connection at the bottom of the lower horizontal run. The stress analysis portion of the program is described in the next subsection.

2.2 Stress Analysis

The stress analysis procedure is essentially the same as that used for the lowered-loop plants. The first phase of the stress analysis involved building a structural mathematical model containing the pressurizer, the surge line, the hot leg, the reactor vessel and the steam generator. This structural mathematical model was verified by using the measured surge line temperature data from the Davis-Besse Unit 1 heatup of June 1990 to predict surge line displacements. These predicted surge line displacements agree well with the measured surge line displacements (see Subsection 5.1.4 and Figures 5-2, 5-3, and 5-4).

The structural loading analysis was performed using the new thermal-hydraulic design basis and considering potential surge line whip restraint interference with the gaps set at the as-measured conditions for each of the eight whip restraints. The internal forces and moments were generated from the structural loading analysis and were used for the stress analysis of the surge line and the nozzles associated with its endpoints. Loading cases were developed for each period of history using the measured restraint gap data representative of the period.

The applicable piping code is the 1986 Edition of ASME Code NB-3600, in accordance with NRC Bulletin 88-11 which states: "Fatigue analysis should be performed in accordance with the latest ASME Section III requirements incorporating high cycle fatigue." A Code reconciliation was performed with a review of the surge line stress report for Davis-Besse Unit 1.

Using the method described in supplement 2 (Reference 9) for the elbows and simplified equations elsewhere in the surge line, all stress intensity values (Equations 12 and 13, and Thermal Stress Ratchet) were found to be within the allowables (taken from ASME Section III, Appendix I). To account for the thermal-hydraulic conditions defined in the new design basis, the surge line fatigue analysis includes thermal stratification, pressure ranges between the thermal stratification conditions, thermal striping, fluid flow and temperature changes leading to through-wall temperature gradients, and the additional localized stress due to the non-linearity of the top-to-bottom temperature profile.

In the NB-3600 fatigue analysis, all applicable surge line locations were analyzed, including the drain line nozzle and the snubber stanchion which were considered as branch connections. The total cumulative usage factor is less than 1.0 at all surge line locations.

In addition to the structural analysis of the surge line described above, detailed stress analyses of the pressurizer and hot leg nozzles were performed to demonstrate compliance with the ASME Code, Section III.

Finite element models were made of both nozzles and the thermal and pressure stresses were calculated using the revised design basis transient descriptions as input. Piping loads acting on the nozzles were taken from the structural analysis of the surge line and were combined with the pressure and thermal stresses. Stress and fatigue analyses were performed in accordance with the requirements of the 1986 Edition of the ASME Code, Section III, NB-3200 and NB-3600. The analyses demonstrate that the cumulative usage factor for each nozzle is less than 1.0.

3. PLANT-SPECIFIC APPROACH FOR DAVIS-BESSE UNIT 1

Section 3 of the main report (Reference 1) describes the decision to evaluate the lowered-loop plants generically and the need for a plant-specific approach for the Davis-Besse Unit 1 plant. The assessment addressed two different types of factors: (1) those that are inherent in the equipment design and (2) the plant-specific operating and surveillance procedures that may influence the surge line conditions.

3.1 Comparison of Configurations

As described in Section 3.1 of the main report, the lowered-loop plants are sufficiently similar to be evaluated generically. However, the differences between Davis-Besse Unit 1 and the lowered-loop plants led to the decision to install special instrumentation at Davis-Besse to gather data during the heatup from the 6th refueling outage in the summer of 1990. Considerations leading to this decision were as follows:

- The Davis-Besse surge line configuration differs significantly from the lowered-loop plants as shown in Figures 3.1 and 3.2 of the main report. The lower horizontal run is somewhat shorter, and there is an upper horizontal run in excess of 20 feet compared to 2.5 feet in the lowered-loop plants.

- The surge line at Davis-Besse Unit 1 incorporates eight fixed pipe whip restraint structures, with impact collars clamped to the surge line. In addition to placing a limit on pipe displacement, these impact collars interrupt the insulation, permitting gaps on either side. The increased heat loss affects the magnitude of the stratification temperature differences.

- At Davis-Besse the power-operated relief valve (PORV) inlet condensate drain is connected to the surge line drain upstream of the drain isolation valve. Condensate reflux into the surge line depends upon heat losses from the line, and could have some influence on the surge line stratification response.

3.2 Plant Operations

Section 3.2 of the main report considers the plant operational aspects of a generic evaluation of the B&WOG plants. The magnitude and number of thermal cycles applied to the pressurizer surge line were evaluated to formulate the design basis cycles. The evaluation included review of applicable plant operating procedures and plant data as well as interviews of the plant operators. Plant data from the instrumented Davis-Besse Unit 1 surge line and historical operating data for plant heatup and cooldown events for Davis-Besse Unit 1 provide most of the bases for describing the design transients for Davis-Besse Unit 1. All of the B&W plants operate in a similar fashion as described in the main report; however, certain differences between the sets of design transients for Davis-Besse Unit 1 and those for the lowered-loop plants have resulted from this evaluation. These differences are discussed in detail in Section 4.4.

3.3 Conclusion

While the lowered-loop plant configuration and plant operations are quite similar and a generic development of design basis transients is justified, Davis-Besse Unit 1, which is a raised-loop B&W plant, requires a plant-specific analysis due to the differences discussed in Section 3.1. The analysis for Davis-Besse Unit 1 is addressed in this supplemental report.

The methodology described in the main report is generally applicable to the Davis-Besse Unit 1 analysis. This includes the correlation of stratification and striping, the synthesis of design transients, the structural modeling techniques, the structural loading analysis, and the fatigue analyses of the surge line and its associated nozzles. Differences from the material contained in the main report, due to plant-specific structural and operating conditions are identified and justified in this supplement.

4. DEVELOPMENT OF NEW DESIGN BASIS FOR SURGE LINE

4.1 Instrumentation of Davis-Besse Unit 1 Surge Line

Plant-specific thermal and displacement data for the Davis-Besse Unit 1 surge line were collected for the following reasons:

- The original Davis-Besse Unit 1 instrumentation does not supply sufficient data for an understanding of the thermal conditions throughout the line.
- Differences inherent in the design of Oconee Unit 1 and Davis-Besse Unit 1 result in different thermal conditions for the two surge line configurations.
- The surge lines have differences in geometric layout, draining arrangements, piping supports and restraints, and insulation.

The objectives and the technical approach for data collection have been identical for the Oconee and Davis-Besse instrumentation programs. The objectives of the Davis-Besse surge line instrumentation program have been to determine:

- The magnitude of the thermal stratification including the maximum top-to-bottom piping temperature differential,
- Variations in the thermal stratification with axial position along the surge line,
- The changes in surge line displacement that result from thermal stratification,
- The plant operations that cause thermal stratification cycles, and
- The temperature response of the surge line to changes in surge line conditions.

To meet the objectives, a comprehensive instrumentation package was installed that has included 46 thermocouples mounted on the outside circumference of the surge line and 14 displacement instruments affixed to various parts of the line. The thermocouples and displacement instruments were connected to a data acquisition system allowing continuous monitoring of all instruments. In addition, numerous permanent plant computer signals were recorded with this data acquisition system and the plant computer system. Details of the instrumentation and the data acquisition system are included in Appendix A.

The instrumentation package and data acquisition system were installed in April and May of 1990 during the Sixth Davis-Besse Unit 1 Refueling Outage (6RFO). Data were recorded as the plant prepared for and went into its normal heatup in early June. There was no interference with normal plant operations and no changes to procedures were made to accommodate the data acquisition or to reduce the effects of potential thermal stratification. Data were recorded throughout the heatup, power escalation, and for several days near full power.

4.2 Correlation of Surge Line Temperatures

The correlation of the Davis-Besse Unit 1 surge line temperatures versus plant conditions paralleled that of the lowered-loop plants, as described in Section 4.2 of the main report. Measurements and methods specific to the Davis Besse analysis are described below.

Plant Temperature Measurements

The Davis-Besse Unit 1 surge line temperatures were measured at eight cross sections distributed throughout the horizontal portions of the line, as shown in Figure A-2. At six of these instrumented cross sections, seven thermocouples were distributed over the pipe circumference to provide uniform and complete coverage of the temperature profile across the height of the pipe; top- and bottom-of-pipe thermocouples were used at the remaining two locations.

Surge line temperatures were recorded at twenty-second intervals through much of June and July 1990. These measurements spanned two heatups, a cooldown, power escalation, and operation near full power. For ease of handling and analysis, the interval of almost continuous data from 10 June through 12 July were divided into the following three data sets:

June 10-18, 1990
June 23-30, 1990
July 1-12, 1990

The major plant conditions during data collection are outlined below. The indicated events were identified by reviewing logs, and by examining time-based traces of spray valve position, spray line temperature, pressurizer level, core power, primary flow rate, and reactor coolant pump power.

June 10-18, 1990 Data

The June 10-18, 1990 data encompassed a heatup. Initially, the plant was cold and pressurized with nitrogen. Considering time zero as 0000 hours, on June 10th,[1] a pressurizer steam bubble was established at about 20 hours. Pumps were operated briefly and independently for venting, between 83.7 and 85.3 hours. Reactor coolant heatup was begun at 122 hours using 2 pumps; a third pump was added at 146.5 hours and the fourth at 202 hours.

June 23-30, 1990 Data

The measurements of June 23-30, 1990 began with a plant cooldown in progress. Two reactor coolant pumps were operating until 6 hours. Auxiliary spray was actuated intermittently between 6.6 and 33.3 hours. The pressurizer was blanketed with nitrogen beyond 20 hours. Conditions remained largely quiescent through 90 hours. Then the pressurizer level was reduced, and a steam bubble was drawn beyond 95 hours. The reactor coolant pumps were operated individually and briefly for venting, between 110.4 and 111.1 hours. The heatup was started at 123.3 hours using 2 pumps; a third pump was activated at 140.5 hours, and the fourth at 157 hours. Spray was activated briefly at 165.3 and 175.2 hours. Minimum continuous spray flow was interrupted for approximately 1 hour starting at 169.2 hours.

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[1] All references to times for various changes in plant conditions are referenced to 0000 hours of the first day of the data collection period.

July 1-12, 1990 Data

The data taken during July 1-12, 1990 involved power escalation. Four reactor coolant pumps were operated throughout the measurement period, except for 3-pump operation from 38.4 to 38.7 hours. Spray was used intermittently, and was maintained for 8 hours starting at approximately 210 hours. Power operation began at 62 hours; power was increased beyond approximately 40% of full power at 105 hours, and beyond approximately 60% at 172 hours.

The acquired plant data were extensively cross-plotted and compared. The local temperature distributions, the sequential response of temperature versus location in the surge line, and their responses to insurges and outsurges generally confirmed the sensitivity and self-consistency of the surge line temperature measurements.

The Davis-Besse Unit 1 surge line temperature measurements were processed in the same fashion as the Oconee measurements, as described in Section 4.2.2 of the main report. Interface elevations and both local and extreme temperature differences were extracted from the data. Maximum top-to-bottom temperature differences were determined separately for the lower- and upper-elevation piping runs.

Correlation

The Davis-Besse Unit 1 surge line correlations were developed in much the same fashion as those of the lowered-loop plants, as described in Section 4.2.3 of the main report. The major plant conditions affecting the surge line temperatures were:

- Surge line flow rate (or pressurizer level versus time)
- System pressure (or saturation temperature)
- Hot leg temperature

The supplementary plant conditions included: reactor coolant pump status, spray status, magnitude of pressurizer level oscillations, core power level, and the status of the decay heat removal system during a cooldown. Correlations were developed for the elevation of the thermal interface in the lower- and upper-elevation piping runs, as well as for the following temperatures:

- Top- and bottom-of-pipe, lower-elevation run
- Top- and bottom-of-pipe, upper-elevation run
- Pressurizer nozzle (fluid)

Each of these temperature correlations pertained to a surge line piping outside metal temperature. The exception is the pressurizer nozzle fluid temperature, as described below. Additionally, an estimate of the riser average temperature was formed from the bracketing pipe temperatures. The temperature at the hot leg-to-surge line nozzle was taken to be that of the top of pipe in the upper-elevation run. This temperature was used to determine the temporal extremes of the hot leg-to-surge line nozzle temperature. The top-to-bottom temperature difference in the upper-elevation piping was used to characterize the stratification temperature difference at the nozzle.

The pressurizer nozzle correlation provided a direct estimate of the temperature of the nozzle fluid, rather than metal. This correlation basically varied the nozzle fluid temperature toward the temperature of the source fluid in proportion to the volume of fluid displaced during a flow event. The source fluid temperature for an outsurge was the saturation temperature. However, the temperature at the nozzle required treatment of the 200 ft^3 volume of the lower pressurizer which is located below the pressurizer heaters and may contain coolant below the saturation temperature. The current outsurge fluid displacement was obtained by integrating the preceding surge line volumetric flow rates. The predicted nozzle fluid temperature thus increased toward the current saturation temperature as the current outsurge displacement approached 200 ft^3.

Insurge predictions were handled in two phases. The first phase involved the temperatures predicted for the lower-elevation piping; the source temperature for the second phase was the hot-leg temperature. The associated fluid volumes were 5 ft^3 (approximately one-half of the volume of the lower-elevation piping run), and the total surge line volume, 22.3 ft^3. The outsurge and second-stage insurge source temperatures were modified using rudimentary heat balances to estimate the heat losses to ambient.

This type of correlation was necessitated by the absence of a temperature measurement near the nozzle. The performance of this correlation was checked by comparing its predictions to the nozzle metal temperatures observed in Oconee, as well as by examining its response to test cases. After the original analysis, Toledo Edison instrumented the pressurizer nozzle with thermocouples and took data during the October 1991 heatup. This data has been evaluated and provides confirmation that the correlation used is conservative and appropriate.

The correlations of pressurizer nozzle fluid temperature provided estimates of temperature versus time. These temperatures were processed to obtain the extreme temperatures (peaks and valleys, or PVs), in the same manner as for the other surge line temperatures. The incremental changes of the nozzle fluid temperature were compared to the corresponding time increments to obtain rates of change. A change-weighting method was used to obtain rates of change which were more appropriate for stress analysis than those derived directly from incremental time steps.

The resulting weighted rates of change tended to reflect those rates of change which were large, persistent, and significant for the stress analysis.

The surge line outside-wall temperature measurements, and therefore the correlations based on these measurements, reflected the thermal time constant of the wall. Temperature changes of relatively short duration were separately identified for comparison with those predicted by the correlations. The temperature changes during selected short duration events were combined with the general results of the temperature predictions for further consideration. The temperature change associated with a short duration event was the difference between the pre-event temperature and the fluid temperature based on the fluid volume displaced during the event. The selection criteria for short duration events were as follows:

1. Surge line mass flow rate greater than 10,000 lbm/h (insurge or outsurge).

2. Duration (of flow rates greater than one-half of the maximum flow rate) less than 12 minutes.

3. Temperature changes greater than 50F.

These criteria were selected such that all events of significance for stress or fatigue were considered.

4.3 Thermal Striping

Thermal striping in the Davis-Besse Unit 1 surge line was evaluated using the same correlations and techniques as have been used for the lowered-loop plants, and as described in Section 4.3 of the main report. In the Davis-Besse calculations, however, the surge line fluid velocity was modified to account for the makeup system cycling experienced at Davis-Besse. This modified velocity has been used whenever the makeup system controls were placed in automatic. Then the fluid velocity was required to be at least as large as the surge line velocities that had been observed (based on rates of change of pressurizer level) during the more extreme cyclic variations of pressurizer level. This velocity was used to evaluate the Richardson number and hence the maximum striping amplitude; an increased velocity obtained a smaller Richardson number and a larger maximum striping amplitude.

4.4 Review of Operational History

A review of the operating history of the Davis-Besse Unit 1 plant was performed in a manner similar to that performed for the lowered-loop plants. Historical operating data were collected for plant heatup and cooldown events for Davis-Besse Unit 1. These data were retrieved for 31 of 40 heatups and 32 of 39 cooldowns, ending with the heatup from the 6th refueling outage in June 1990. The recorded parameters included hourly data for the pressurizer, RCS cold leg, and surge line (original thermocouple) temperature and pressurizer level. The data were sufficiently complete to characterize the limiting temperatures for RCS and pressurizer heatup and cooldown for past operations with a high level of confidence. This historical review provided substantial support for the selection of limiting temperatures for use in stress and fatigue analysis.

In combination with Davis-Besse data, data collected earlier for the analysis of the lowered-loop plant surge line were employed in describing the Davis-Besse heatup and cooldown transient. Specifically, the lowered-loop plant data were used in definition of the typical flow rates in the surge line as derived from pressurizer level variations with time.

In conjunction with the review of plant data, operating and surveillance procedures were reviewed for Davis-Besse Unit 1 to identify those events that might cause thermal stratification cycles. Because of this review, certain differences between the sets of design transients for Davis-Besse Unit 1 and those for the lowered-loop plants resulted. Transient events were added to include the conditions of (1) inservice makeup pump testing, and (2) complete interruption of pressurizer spray bypass flow. Certain design events were deleted including HPI injection tests and miscellaneous pressurizer spray actuations. The HPI injection tests were eliminated as a design transient for the surge line for Davis-Besse Unit 1 because this test is conducted with the pressurizer at or near ambient temperatures. It was determined that the miscellaneous spray actuations occur infrequently at the plant and that spray actuations are predominately of the variety associated with operations to change the boron concentration in the pressurizer; as a result, the miscellaneous spray flow events are included in the separately described transient for pressurizer boron equilibration (Transient 20D2).

The operating procedures for Davis-Besse Unit 1 were used as the basis for determining the major flow events accounted for in the heatup and cooldown design transients. Random flow events, the particular causes of which have not been identified, were also included to ensure that typical pressurizer level changes are reflected in the design transients. The data for pressurizer level versus time collected for the analysis of the lowered-loop surge line, in addition to data specific to Davis-Besse Unit 1, were used to characterize the random flow events included in the heatup and cooldown design transients for Davis-Besse Unit 1.

The design heatup and cooldown transient descriptions were generated based on plant data as well as plant limits for the relationship between pressurizer temperature and RCS temperature. To conservatively generate design transient conditions for the surge line for past heatup events, two sets of temperature differential curves were used to ensure a conservative representation overall. One curve represents the maximum differential likely to be seen in any operation experienced in the past by Davis-Besse Unit 1. This maximum temperature difference (MTD) curve is configured to be strongly conservative, and to cover those few heatups not covered in the recorded hourly data. The second curve is configured to produce a more realistic, but still conservative representation of the data. This curve bounds 80 percent of all the plant data.

A certain fraction of the past events were specified to have occurred with conditions defined by the strongly conservative MTD curve. The remaining events were evaluated on the basis of the conservative representation of plant data provided by the second curve.

The maximum temperature difference (MTD) curve bounds all the plant data with the exception of three short operating periods (a few hours) which occurred during the actual heatups. The overall maximum temperature differentials for the heatup covered by the MTD curve were not exceeded, however, the differences during these short periods exceeded a small portion of the bounding curve by 20°F or less. These short periods are negligible in the analysis, and the MTD curve used as a basis for the development of design transients is a strongly conservative representation of past operations.

For generating descriptions of future design heatup and cooldown events, the recommended operating limits for the pressurizer and RCS temperatures given in Section 8 of BAW-2127 were used with the added restriction that the maximum pressurizer temperature be limited to 415F when the RCS temperature is below 185F. The RC temperature of 185F was selected sufficiently low to provide adequate flexibility for pressurizer operation; a more restrictive temperature of as high as 230F could be justified based on a review of plant data but would not provide the same degree of operating flexibility.

As a result of the review of plant data and operating procedures, the following major differences were identified between operations at Davis-Besse Unit 1 and those for the lowered-loop plants:

1. At Davis-Besse Unit 1, the maximum pressurizer pressure and temperatures at which the plant is operated during low temperature conditions in the RCS are lower than for the other operating plants; this is because the Decay Heat Removal System relief valves are used for low temperature overpressure protection below about 250F in the RCS, which limits the maximum allowable pressurizer pressure. This is consistent with the restriction that the maximum pressurizer temperature is limited to 415F when the reactor coolant temperature is below 185F as reflected in the analysis.

2. The control of pressurizer level with the makeup valve operating under automatic control at Davis-Besse Unit 1 results in cycling of the makeup valve and small amplitude variations in pressurizer level on the order of +/- 1 inch of level. This cycling is pronounced during plant operation at low pressure and substantially subsides during operation at high temperature and pressure (Modes 1, 2, and 3).

3. The duration of heatup operations at Davis-Besse Unit 1 appears to be significantly longer than is typical for the other plants. Also, a large amount of time has been spent between consecutive cooldown and heatup events with the RCS at low temperature and the pressurizer maintained at an elevated temperature (up to 415°F).

The above differences in operations were factored into the descriptions of the design heatup and cooldown transients for Davis-Besse Unit 1.

4.5 Development of Revised Design Basis Transients

The revised surge line design basis transients are listed in Table 4-1. These redefined transients comprise the bases for the reevaluation of the structural integrity of the surge line piping and nozzles. Table 4-2 presents the design number of events for each type of transient. The bases for the number of events for design purposes are provided in the following subsections.

The design basis plant heatup and cooldown transients were completely redefined in this program. Other transients included in the design basis were generally retained in terms of the existing surge line boundary conditions of pressurizer and RCS temperatures and surge line flow rates, but thermal stratification and striping were included in the surge line transient descriptions. In addition to the changes made to the design heatup and cooldown transients, a number of transients were added and other modifications made to the set of design basis events as a result of the review of the operating history and the operating procedures for Davis-Besse Unit 1.

In general, the development of the revised design basis transients for Davis-Besse Unit 1 followed the same process used for the lowered-loop plants. The process used to generate the boundary conditions of temperature and the surge line flow rates for plant heatup and cooldown transients are discussed below.

Plant data were used to characterize the variations in RCS and pressurizer temperatures with time. Using the plant data, tabulations of the durations of various modes of operation, i.e., time spent below 200F temperature, time spent in the actual heatup process, at temperature plateaus, and at hot zero power at the end of the heatup, were used to arrive at a description of the typical variation of RCS temperature with time for the design heatup and cooldown transients.

Plant data were used to plot the paths taken during actual heatup and cooldown operations in terms of pressurizer-to-RCS temperature differential as a function of RCS temperature. These traces established both bounding and typical variations of pressurizer-to-RCS temperature differentials with RCS temperature. For one of the design heatup transients, the bounding variation of the pressurizer-to-RCS temperature differential was based upon the maximum temperature difference (MTD) curve which generally bounds the plant data and is strongly conservative. Given the RCS temperature at any point in time for the design transient, generated as described above, the variation of pressurizer-to-

RCS temperature differential was used to establish the pressurizer temperature for the heatup and cooldown transient based on either the generally bounding MTD curve or the plant data.

The pressurizer surge line flow rates were generated based on known, quantifiable plant operations, or other flow rates based on typical plant data for pressurizer level change versus time (for which the exact cause of the flow could not be identified).

A simulation of the makeup system control of the pressurizer level was used to generate the flow response in the surge line as a result of changes to the net make up volumetric flow rate (difference between in-flow to and out-flow from the RCS). With the makeup controls in automatic, a change to the net effective makeup volumetric flow rate will perturb the pressurizer level, causing the makeup valve to be repositioned to restore pressurizer level to the setpoint. The calculation of the surge rate includes the effects of the following:

- Changes, or upsets, in the net makeup volumetric flow to the RCS;
- Effects of RC volume change caused by the time rate of change of temperature of the reactor coolant;
- Effects of the general trend in pressurizer level, e.g., effects of change in pressurizer level setpoint by the operator;
- Effects of spray rate, either automatic or manual spray operations (e.g., for cooling the pressurizer to depressurize the RCS or for adjustments of pressurizer boron concentration);
- Effects of operator adjustments of letdown to maintain both the level and the desired makeup flow rate.

Based on a review of plant procedures, a list of the operations in the plant that potentially affect the surge line flow rate was generated. To the extent possible, the likely numbers of flow changes and the magnitudes of the changes of flow rate into (or out of) the RCS were estimated. Using these estimates for upsets of the net volumetric makeup into the RCS, and including additional "random" events, the pressurizer surge line flow rates and pressurizer level response were calculated. A number of random events were added to the simulation to ensure that the total number of level changes agrees with the number of level change events derived from the plant data for heatup and cooldown operations. The random flow rate events were characterized by a statistical analysis of the plant data for pressurizer level changes.

The surge line boundary conditions of pressurizer temperature and hot leg temperature, along with the surge line flow rates described for each design transient were used simultaneously to generate consistent sets of both stratification and striping temperature differences.

The striping calculations utilize a correlation for the cumulative frequency of occurrence of striping temperature change as a function of striping amplitude. The maximum striping amplitude was correlated to the Richardson number. For a given design transient, the thermal response of the surge line was calculated as a function of time, and at each time interval (time cut) as the calculation advances, the distribution of the frequency of striping cycles was calculated for each degree F increment of striping temperature difference. The number of cycles for each increment of striping temperature differences was calculated by multiplying the frequency by the length of the time interval. The number of cycles in each increment of striping temperature difference was accumulated as the calculation progresses to arrive at a total for the entire transient.

For each piping location and type of component (pipe or elbow), the thermal striping was evaluated considering a range of from 1/2 to 4 seconds for the period. The critical period giving the maximum stress caused by the thermal striping was used for each particular location.

4.5.1 Heatup Transients

4.5.1.1 Heatup Transient Descriptions and Number of Occurrences

A number of different categories of design heatup transients have been described for Davis-Besse Unit 1. The various categories arise from considerations of (1) time in plant life (past or future), (2) whether the pressurizer temperature represents a bounding upper limit or a variation typical of plant operations, (3) the various time intervals corresponding to operations with different measured whip restraint clearances, and (4) accommodation of the period of limited clearance between the snubber stanchion and the west wall of the compartment.

The various time categories for the design heatup transients are defined as follows:

Time Category	Description	Restraint Gaps
T1	For time period 1/77 through 5/80	Minimum original gaps
T2	Time period 6/80 to 5/82	As measured gaps 6/80
T3	Time period 6/82 to time of modification of snubber stanchion clearance to west wall, 12/84, and through 11/88	As measured gaps 6/82
T4	Time period 12/88 to time of modification of gap clearances made during the month of 4/90 and through the 9th fuel cycle, anticipated to end 9/94	As measured gaps 12/88 and 4/90
T5	Future events, beginning after Refueling Outage No. 9	Restraints gapped to allow free motion

A set of two types of heatup events are specified for each time category, one odd-numbered and one even-numbered design event type. Generally, odd-numbered design heatup transients represent the generally bounding variation of pressurizer pressure with RCS temperature, e.g., 1A1, 1A3, 1A5, etc. Even-numbered design transients generally represent variations of pressurizer temperature that are more typical of the available plant data. Considered together, these transients provide a conservative representation for both historical and future operations.

For purposes of simplification, each of the design heatup transients is specified with the same heatup duration and sequence of major events. Particular transients may differ in terms of the following parameters: (1) initial variation of RCS temperature prior to starting of RC pumps for plant heatup, (2) pressurizer temperature versus time, and (3) the number and timing of random flow events caused by unidentified operations in the plant.

Variations of RCS temperature at the beginning of the heatup are based on typical operating data for the plant. The pressurizer temperatures and pressures versus time that have been specified for each of the design heatup transients are based on either the maximum allowable RCS pressure limit or the available plant data. Refer to Figure 4-1. The number of random flow events included in the design heatup transient varies with the average lengths of time spent in the various phases of heatup, as derived from the available plant data for the particular time category.

Each heatup transient includes a phase at the beginning of the plant heatup, prior to starting the RC pumps, where the RCS temperature is maintained at approximately 100F and the pressurizer temperature is somewhat greater than 400F. The duration of this time period for the design heatups is set at about 40 hours. To account for time spent in this operating condition in excess of 40 hours on a per heatup basis, a separate transient is described, Transient 1C1.

The duration of the design heatup transient was selected to bound the majority of historical data for the heatup times. In some cases, this bounding value for the duration of heatup is significantly greater than the average of the plant data for the set of heatup events corresponding to the particular time category. However, the numbers of random flow upsets are based on the appropriate average duration obtained from the plant data, not the bounding value of time specified for the design heatup.

A process was used in generating plant parameters for the design heatup transients similar to that used for the lowered-loop plants, described in the main body of this report. Descriptions of the various specified design heatup types are presented below.

Transients 1A1, 1A2	Time category T1 -- for Transient 1A1, the RCS temperature at the beginning of the heatup is specified as 70F, heating to 100F in 12 hours prior to starting RC pumps for plant heatup; the pressurizer temperature is based on (1) the upper bound of plant data for RCS temperatures from ambient to 280F and (2) a generally

	bounding RC pressure curve corresponding to the maximum temperature differential (MTD) curve for RCS temperatures from 280F to hot, zero power conditions. For Transient 1A2, the RCS temperature is specified to start and be maintained at 100F prior to running RC pumps. The pressurizer temperature is based on (1) the upper bound of plant data for RCS temperatures from ambient to 280F and (2) the typical variation with RC temperature as obtained from plant data for RCS temperatures from 280F to hot, zero power conditions.
Transients 1A3, 1A4	Time category T2 -- for Transient 1A3, the RCS temperature is specified to start and be maintained at 100F prior to running RC pumps. The pressurizer temperature is based on (1) the upper bound of plant data for RCS temperatures from ambient to 280F and (2) a generally bounding RC pressure curve corresponding to the maximum temperature differential (MTD) curve for RCS temperatures from 280F to hot, zero power conditions. For Transient 1A4, the RCS temperature is specified to start and be maintained at 100F prior to running RC pumps. The pressurizer temperature is based on (1) the upper bound of plant data for RCS temperatures from ambient to 280F and (2) the typical variation with RC temperature as obtained from plant data for RCS temperatures from 280F to hot, zero power conditions.
Transients 1A5, 1A6	Time category T3 -- for Transients 1A5 and 1A6, same as Transients 1A3 and 1A4 except the pressurizer conditions are based on plant data for the time spanning category T3. For RCS temperatures above 280F, the pressurizer conditions for Transient 1A5 are based upon the maximum temperature differential (MTD) curve.

Transients 1A7, 1A8

Time category T4 -- During preparation of supplement 1 plant data were available describing the variation of pressurizer pressure conditions for all heatup transients in this time category; consequently, the design transients were limited to one representative type of transient, 1A8. (There was no need to specify a bounding curve for conditions of pressurizer temperature at RCS temperatures above 280F, corresponding to the odd-numbered, i.e., 1A7, transient type.) The number of cycles of transient 1A8 has been increased for Supplement 3 to account for additional operation with this measured restraint gap configuration. Due to the small number of cycles involved, the use of the representative transient 1A8 is considered appropriate. The pressurizer temperature is based on (1) the upper bound of plant data for RCS temperatures from ambient to 280F and (2) the typical variation with RC temperature as obtained from plant data for RCS temperatures from 280F to hot, zero power conditions.

Transients 1A9, 1A10

Time category T5 -- for Transient 1A9, the RCS temperature at the beginning of the heatup is specified as 70F, heating to 100F in 12 hours prior to running RC pumps for plant heatup. The pressurizer temperature is based on the upper bound of the plant data for RCS temperatures from ambient to approximately 185F and the recommended operating pressure-temperature limits specified in Section 8 of BAW-2127 for RCS temperatures above 185F (refer to item 1, page 4-9). The pressurizer temperature has been specified at a high value (sufficient to operate RC pumps) early in the heatup; this reflects the conditions experienced frequently in the plant where the RC pressure is raised to supply the required NPSH for extended periods prior to actually starting the pumps.

For Transient 1A10, the initial RCS temperature of 100F is maintained until running RC pumps for plant heatup. The pressurizer temperature is based on the recommended operating conditions for heatup. The pressurizer temperature is specified to increase to the value required to operate RC pumps just prior to actual running of the pumps to begin RCS venting operations and plant heatup.

The recommended operating conditions for allowable pressurizer temperature variation with RC temperature for future heatup operations, Transients 1A9 and 1A10, are equivalent to the recommendations made for plant heatup of the lowered-loop plants given in Section 8 of BAW-2127 except for the added restriction that the maximum pressurizer temperature is limited to 415F when the RCS temperature is below 185F.

The total numbers of occurrences of heatup events for a given time category are based on a tabulation of historical heatup events supplied by Toledo Edison. The total number of heatups for time category T4 has been increased based on a conservative estimate provided by Toledo Edison. In each of the time categories for the heatup transients, the numbers of transient events are distributed with 15 percent of the events for the type based on the strongly conservative MTD curve (odd-numbered design events) and the remaining 85 percent for the type with the more typical variation of pressurizer temperature (even-numbered design events). The total number of events for time category T1 from the tabulation of heatup events supplied by Toledo Edison has been increased to account for the two hot functional tests conducted during the initial operations for plant startup. Based on the durations of these hot functional test operations, an equivalent of seven additional heatup events has been included in the design numbers of events specified for this time category.

4.5.1.2 Maximum Pressurizer-to-RCS Temperature Difference

A maximum stratification temperature differential was specified for three design transient events to account for operating conditions during which the system pressure and the pressurizer temperature may have reached the maximum allowed by either (1) the RCS pressure corresponding to operation at the relief setting of the Decay Heat Removal System relief valves at RCS temperatures below 280F, or (2) the strongly conservative MTD curve at temperatures above 280F. These operating pressures were specified for Transient 1A1 and the resulting maximum thermal stratification in the surge line for this transient is 358F.

4.5.1.3 Boundary Conditions for Temperatures Versus Time

The variation of RCS temperature with time for the revised design heatup transients is based on plant data. The available plant data for heatup events was used to arrive at average time durations for the various phases of heatup such as (1) operations with the RCS temperature below 200F, (2) operations when RCS temperatures are increasing, (3) intermediate temperature plateaus, and (4) at hot, zero power conditions prior to power escalation. For purposes of simplification, the durations of each of the design heatup transients are identical even though the average duration of the historical heatup events differ for the individual time categories. The total duration and the durations of each of the different phases of the design heatup were selected to bound the average values obtained from plant data for the heatup events in each time category. The total duration specified for each of the design heatup transients is seven days, or 168 hours. The transient is described for the operations ranging from cold conditions to 8 percent power, consistent with the range of conditions specified in the original design heatup transient for the plant.

The traces of pressurizer temperature versus time shown in Figure 4-1 for the boundary condition on the surge line at the pressurizer are based on one of the following: (1) the MTD curve for the RCS (for 1A1, 1A3, and 1A5), (2) plant data (remainder of historical heatup transients), or (3) recommended limits for heatup operations (future transients). The pressurizer temperature versus RC temperature relationships for each of the various design transients for plant heatup are described in Section 4.5.1.1.

4.5.1.4 Surge Line Flow Rates for Design Heatup Transients

Changes of flow rate in the pressurizer surge line piping can lead to thermal stratification transients. It is not possible to describe every plant event that influences the surge line flow rate and affects the thermal transients for the surge line piping and nozzles. However, by quantifying the major influences on the flow rate and supplementing these with random flow events, design heatup transients can be generated which are conservative representations of the actual plant transients in terms of the number and magnitude of surge line flow events.

Each heatup transient type (Transient 1A1 through 1A10) is specified with the same basic set of quantifiable flow rate events; however, the number and timing of the added random flow events may vary for some of the transients. The number and timing of the added random flow events varies for the different time categories of transients based on historical differences in the average times required to complete the plant heatup.

Typical plant heatup operations that may affect the net makeup flow to the RCS are listed in Table 4-3. Those operations judged to be significant and quantifiable are the major events taken into account in the descriptions of the design transients. These events include RCS temperature changes, RC pump starts, certain surveillance tests, and RCS venting operations. The response of the makeup flow rate controls to each of these events is accounted for in the development of the transients.

The random flow events incorporated into the design transients are based on measured pressurizer level data for both the lowered-loop plants and the Davis-Besse plant. The available plant data was statistically analyzed to characterize the random flow events in terms of the magnitudes of flow rates and pressurizer level changes. Descriptions of the random flow events are based on the following:

1. Plant heatup data were evaluated to determine the mean and standard deviation parameters for flow rates and pressurizer level changes during plant operations over various ranges of RCS temperatures. The average

numbers of flow events were determined for heatup operations for the various ranges of RCS temperatures.

2. The average numbers of flow events described for the design heatup transients were determined so that the numbers of events per unit of operating time specified for the design events are consistent with the plant data.

3. The numbers of random flow events included in the design events were set so that the sum of the defined events and the random events are equivalent to the average of the total number of events per heatup transient as obtained from the plant data.

4. The flow change data were treated as a normally distributed, random variable and divided into three representative ranges of magnitude of equal probability based on the normal distribution curve. Flow rates bounding these three ranges of flows are used to describe the random flow events and the three bounding flow rate events are specified to occur in a recurring sequence during the heatup transient.

5. The random events were spaced uniformly over the appropriate times corresponding to the specified operating RCS temperature ranges.

The automatic operation of the makeup valve controls at the Davis-Besse plant has resulted in cyclic stroking of the control valve and small amplitude variations in pressurizer level. The cycling is most prominent when reactor coolant pressure is low and the makeup control valve must control flow at low rates across a large differential pressure. Under these conditions, the makeup valve operations are characterized by opening of the valve and adding flow to the RCS at a high rate for a period of about 1 minute followed by closing of the valve with a minimum flow for a period of about three minutes. During the time the valve is open, a surge flow into the pressurizer exists and upon closing, an outsurge takes place. These oscillations are not directly described as a component of the surge line flow rate since the effect on the global stratification in the surge line is small. However, the surge line flow rate into and out of the pressurizer does affect thermal striping in the line. The effects of the makeup cycling on thermal striping are taken into account in the thermal stratification and striping calculations. The design transients are conservatively specified to include this makeup cycling for all past historical heatup events. Future heatup events are also specified to include makeup cycling and the associated thermal striping.

For the design heatup transients, the pressurizer spray, when active, is considered to be actuated in one of three modes, (1) manual actuation for purposes of pressurizer boron equilibration, (2) automatic spray operation, and (3) minimum continuous bypass spray. To describe the effects of large spray flow rates, i.e., cases of boron equilibration in the pressurizer or automatic actuation of spray, the spray flow rate component of the surge line flow rate is specified. When the main spray valve is closed the minimum continuous bypass spray flow rate is used. This flow rate may range from 1.5 to 5 gpm with all RC pumps operating. Since there is a significant uncertainty in determining the magnitude of the minimum continuous spray flow rate, the stratification correlation model instead uses the number of operating RC pumps to determine the thermal response of the surge line; the bypass spray rate is not explicitly specified.

The Davis-Besse pressurizer spray valve is adjusted to pass a maximum flow rate of approximately 190 gpm for control of pressure transients which potentially might occur during plant power operation. The valve is occasionally throttled open during normal operations to adjust the pressurizer boron concentration. For the design heatup transients, pressurizer spray actuations are specified for the manual operations to adjust the boron concentration at cold conditions and at hot conditions. A number of automatic actuations are specified to account for potential actuations of the spray during power escalation to 8 percent power at the end of the heatup transient.

4.5.2 Cooldown Transients

4.5.2.1 Cooldown Transient Descriptions and Number of Occurrences

Similar to the design heatup transients, the cooldown events were described for five different categories of operating times. Categories T1 through T4 are specified for historical events, and category T5 for future events. Refer to Section 4.5.1 for a description of each of the time categories. The design cooldown transient describes the plant operations and the thermal response of the surge line during the power reduction from 8% power to hot, zero power and then plant cooldown to refueling temperature, approximately 140F hot leg temperature.

The RCS temperatures and pressurizer temperatures for the design cooldown transients are shown in Figure 4-2. The descriptions of the design cooldown transients are essentially identical except for the pressurizer temperature versus time and the associated spray flow rates required for spraydown of the pressurizer. For purposes of simplification, other parameters such as duration of cooldown, RCS temperature versus time, and sequence of events are essentially the same for the various cooldown transients.

Each time category has associated with it a set of two cooldown events, with these cooldown events differing only in the temperature versus time trace for the pressurizer temperature. The set of plant transients for time category T1 consists of design cooldown transients 1B1 and 1B2. The two types of transients in each time category, i.e., odd-numbered and even-numbered transients, are specified to describe (1) a strongly conservative envelope based on the generally bounding MTD curve and (2) a temperature trace that is typical of the plant data. Overall, approximately 15 percent of the transients specified for a time category are assigned to the transient type with the bounding trace of pressurizer temperature (odd-numbered events) and the remaining 85 percent assigned to the transient described with the typical trace for pressurizer temperature (even-numbered events).

The design cooldown transients for Davis-Besse Unit 1 are described below.

Transients 1B1, 1B2	Time category T1 -- for Transient 1B1, the pressurizer temperature is based on (1) a generally bounding RC

pressure curve corresponding to the maximum temperature differential (MTD) curve for RCS temperatures from hot, zero power conditions down to about 280F and (2) upper bound of plant data for RCS temperatures from 280F and below with the Decay Heat Removal System operating.

For Transient 1B2, as discussed in Section 4.5.1.3, the pressurizer temperature conservatively represents the available plant data for RCS temperatures above 280F and bounds all of the plant data for conditions with the Decay Heat Removal System in operation below about 280F.

Transients 1B3, 1B4

Time category T2 -- for Transient 1B3, the pressurizer temperature conservatively represents the plant data at RCS temperatures above 280F and bounds all the available plant data at temperatures below 280F with the Decay Heat Removal System operating.

For Transient 1B4, the pressurizer temperature is based on a conservative representation of pressurizer temperature from the plant data for RCS temperatures above 280F and an upper bound of all the plant data below 280F.

Transients 1B5, 1B6

Time category T3 -- for Transients 1B5 and 1B6, the bases for the pressurizer temperature variations with RCS temperature are defined to be identical to that for Transients 1B3 and 1B4, respectively. The bounding envelopes selected for Transients 1B3 and 1B4 also bound the plant data for time category T3.

Transient 1B8

Time category T4 -- for Transient 1B8, the pressurizer temperature bases are defined to be identical to that for Transient 1B4, which are bounding for the plant data of time category T4. (No transient is described for 1B7 for the same reasons as discussed previously in Section 4.5.1 for the design heatup events for time category T4.)

Transients 1B9, 1B10

Time category T5 -- for Transient 1B9, the pressurizer temperature is based on the recommended guidelines given in Section 8 of the main report below about 280F with the additional restriction that the pressurizer temperature is less than 415F when the RCS temperature is below 185F. At RCS temperatures above 280F, the specified pressurizer temperature bounds the available plant data for the entire operating history of the plant.

For Transient 1B10, the pressurizer temperature is based on the recommended guidelines given in Section 8 of the main report with the additional restriction that the pressurizer temperature is less than 415F when the RCS temperature is below 185F.

4.5.2.2 Boundary Temperatures as a Function of Time

Based on the available plant data, the time specified in the design cooldown transients for cooling the plant and filling and depressurizing the pressurizer is 72 hours. The time durations for each portion of the design cooldown transient have been estimated using the available plant data for the following phases of the cooldown operations:

Power decrease from 8 percent power to hot, zero power,
Cooldown operations (with average RCS temperature decreasing),
RCS temperature plateaus during cooldown,
RCS temperature below 200F with pressurizer hot, and
Pressurizer fill and spraydown at end of plant cooldown.

Similar to the original design transient for cooldown of the plant, the RCS temperatures versus time for the design cooldown transients are defined over the range of operations from an initial power level of 8 percent to the point where the hot leg temperature reaches the refueling temperature of 140F. The duration of the typical design transient was lengthened to be more representative of the actual plant operations. Temperature plateaus were added and cooldown rates adjusted to give reasonable agreement between the design transients and the available data. The pressurizer temperature versus time plots for the design cooldown transients were developed based on the relationship of pressurizer temperature to RCS temperature based on the plant data.

Based on the available plant data, the plant cooldown frequently is terminated without completely depressurizing and cooling down the pressurizer. For purposes of determining typical values for the total duration of cooldown operations from the historical data, the cooldown was considered to end at a time corresponding to about 24 hours after the RCS temperature decreases below 200F. The excess operating time not included in the plant cooldown with the pressurizer hot and the RCS at a low temperature is included in a separate design event, Transient 1C1. For those historical cooldown transients where the pressurizer is cooled to near ambient, the plant cooldown was considered to end when the temperature difference between the pressurizer and the RCS hot leg decreases below about 50F.

4.5.2.3 Surge Line Flow Rates for Design Cooldown Transients

The flow events for the design cooldown transients were developed in a manner similar to the methods used to describe the flow events for the design heatup transients as discussed in Section 4.5.1.4.

Operations that were judged to be significant and quantifiable are considered the major events to be accounted for in the cooldown transients. The makeup flow response to each flow event is accounted for in the development of the transients. Surge line flow rates include the effects of operations to spray down the pressurizer for either boron concentration adjustments or cooling and depressurizing the system.

Random type of flow events were added to ensure that the total number of flow events for the design transients properly represent the historical operating experience. Available plant data for both Davis-Besse Unit 1 and the lowered-loop plants were statistically analyzed to describe the flow events included in the design transients. The method used to characterize the random flow events for the design heatup transients, outlined in Section 4.5.1.4, was used to describe the flow events for the design cooldown transients.

4.5.3 Other Design Transients

Plant parameters for the original design transients previously described for Davis-Besse Unit 1 for operations at hot conditions were generally retained, however, the surge line conditions for these transients were revised to include the effects of thermal stratification and thermal striping. Existing descriptions of RCS parameters of temperatures, pressures, and spray flow rates remain unchanged for most of these original design basis transients. The set of these transients originally described for operations at hot conditions was revised and expanded somewhat to reflect the results of the review of the plant operating history and procedures. Also, in some cases, changes were made in the numbers of events for the design transients to more appropriately reflect the types and frequencies of certain operations in the plant.

Modifications and additions to the original set of design transients for operations at hot conditions are discussed below. Unlike the set of design transients for the lowered-loop plants, the set of design transients for Davis-Besse Unit 1 does not include the effects of testing HPI safety injection or HPI suction check valve tests. These tests do not produce any significant thermal transients on the surge line piping and nozzles because the tests are conducted at very low pressures (i.e., pressurizer temperature near ambient), with the reactor vessel head removed.

4.5.3.1 Operations at Cold, Pressurized Conditions - Transient 1C1

The historical records for Davis-Besse indicate a substantial amount of operating time has accrued under conditions with the RCS average temperature at cold conditions, i.e., approximately 100F, and the pressurizer temperature at approximately 400F. As discussed previously, this type of operation has occurred under conditions where the plant was maintained with an elevated pressurizer temperature either between successive cooldown and heatup events or between initial pressurization and the time of actual RCS heating in the early phases of plant heatup operations. To properly describe these operating conditions in terms of the thermal effects on the surge line piping and nozzles, actual plant data for pressurizer level versus time was used to establish a representative history for the flow rate variation with time. Typical data for these operations over a period of 10 days were used to characterize the surge line conditions. The particular data used for describing the design transient were taken from measurements for the month of November, 1988 (12th through the 22nd).

4.5.3.2 Steady State Temperature Variations - Transient 13

The design transient for describing steady state operations at power was redefined. In order to properly reflect the operations under these conditions which involve surge line flow and temperature oscillations caused by normal control variations in average RC temperatures and makeup valve cycling, a representative set of plant measurements of pressurizer level versus time was used to characterize the surge line variations of flow rate. The plant data were recorded during the time that the plant variables were being monitored to determine the surge line temperature stratification parameters. A representative period of eight hours of operation of the plant near full power was selected for this design transient description. The operation includes effects of the cycling of the makeup valve. The number of design events specified for stress and fatigue evaluation of the surge line piping and nozzles for this design transient corresponds to the total possible number of eight-hour operating intervals at power over the 40-year service life of the plant based on a plant capacity factor of 0.8.

4.5.3.3 Pressurizer-RCS Boron Equilibration - Transient 20D2

Transient 20D was added to the set of design transients for the surge line to describe the effects of spray and heater operations to equalize the pressurizer and RCS boron concentrations. The operation involves use of spray flow through the pressurizer to cause the boron concentration to approach that in the RCS. A modulated spray flow rate of about 50 gpm was used in the description of the spray transient. This heater and spray operation is normally performed approximately twice a week for a period of about eight hours for each operation. The number of boron equilibration events specified allows for these operations biweekly over the 40 year service life of the plant, with an additional number of design events included to allow for other miscellaneous, undefined, spray actuations occurring in the plant.

4.5.3.4 Total Interruption of Spray Flow - Transient 20E

A minimum spray line flow rate is normally maintained in the plant when the pressurizer to RCS temperature difference is greater than about 250F, to minimize the effects of thermal transients on the pressurizer spray nozzle. Although infrequent, this flow rate is reduced to zero occasionally in the plant if the spray isolation valve is closed. The surge line temperatures are affected by the change in the flow rate and the surge line temperatures are normally decreased somewhat under conditions of zero bypass flow until the flow is restored, causing the surge line to be subjected to one thermal cycle for each interruption in the minimum flow. The number of events for design purposes is specified as 20, based on past experience indicating a frequency of one interruption every two years in the plant.

4.5.3.5 Inservice Makeup Pump Test - Transient 22E

The Quarterly Inservice Makeup Pump Test involves the starting and running of a standby makeup pump for a short period of time. Upon starting the pump, the additional makeup flow rate causes an insurge into the pressurizer. This insurge, and the following action to restore the pressurizer level to the desired setpoint produces a surge line thermal transient. The number of events of this type specified for design purposes is 160.

4.6 Design Transients Summary

For the purposes of design analysis of the Davis-Besse Unit 1 surge line, the design transients were redefined to incorporate the effects of thermal stratification and striping. The design plant heatup and cooldown transients for the surge line were completely redefined. Certain other design transients were added or revised to more accurately reflect the actual operations in the plant.

Table 4-2 lists the design transients and the number of events of each type of transient for analysis purposes.

Calculations of the stratification and striping thermal cycles were performed for each type of design transient. These numbers of thermal cycles for each event and the number of design transients of each type as given in Table 4-2 determine the total numbers of thermal cycles considered in the revised design analysis of the surge line. Table 4-4 provides a brief summary of some of the important results of the stratification and striping calculations including the maximum stratification temperature reversal, the distribution of cumulative numbers of stratification temperature reversals, and the maximum striping amplitude. Results shown are for the lower horizontal section of piping which generally experiences the maximum thermal stratification magnitude in the piping.

Two columns are shown for the maximum significant striping delta-T. The past values pertain to the existing surge line configuration. The future values reflect Toledo Edison's commitment to perform modifications to the surge line supports configuration and thermal insulation.

Table 4-1. Surge Line Design Basis Transient List

Transient ID	Transient Description	Modification from Original Transients (ODB - Original Design Basis)
1A1	Time category T1 - RC Temperature of 70F to 8% full power (FP), a generally bounding pressure curve specifies P/T relationship	Defined to realistically represent the most severe heatup from the available plant data for time T1
1A2	Time T1 - Trc of 100F to 8%FP, RC pressures specify P/T relationship - bounding below 280F RCS and typical of plant data above 280F	Defined to realistically represent heatups occurring with RC pressures higher than typical values over the range of RC temperatures
1A3	Time category T2 - Trc of 100F to 8%FP, RC pressures specify P/T relationship - bounding below 280F RCS and conservatively representative of plant data above 280F	Defined to realistically represent the most severe heatup from the available plant data for time T2
1A4	Time T2 - Trc of 100F to 8%FP, RC pressures specify P/T relationship - bounding below 280F RCS and typical of plant data above 280F	Defined to represent the typical heatup events for time T2
1A5	Time category T3, otherwise same as 1A3	
1A6	Time T3, otherwise same as 1A4	
1A7	(No transient defined)	
1A8	Time T4, otherwise same as 1A4	
1A9	Time category T5 - Trc of 70F to 8%FP, RC pressures specify P/T relationship - bounds plant data below an RCS temperature of about 185F and recommended limits above 185F	Defined to conservatively represent future heatups

Table 4-1. Surge Line Design Basis Transient List (cont.)

Transient ID	Transient Description	Modification from Original Transients (ODB - Original Design Basis)
1A10	Time T5 - Trc of 100F to 8%FP, RC pressures specify P/T relationship - bounds plant data below an RCS temperature of about 185F and recommended limits above 185F	Defined to represent typical future heatups
1B1	Time category T1 - 8%FP to refueling temperature, P/T relationship based on a generally bounding pressure curve above 280F and upper bound of plant data below 280F	Defined to represent a bounding cooldown based on least limiting Appendix G limits (highest pressures) and plant data for time T1
1B2	Time T1 - 8%FP to refueling temperature, P/T relationship based on a conservative representation of plant data above 280F and bounds all plant data below 280F	Defined to conservatively bound most cooldown events for time T1
1B3	Time category T2 - 8%FP to refueling temperature, P/T relationship based on a conservative representation of plant data above 280F and bounds all plant data below 280F	Defined to conservatively bound cooldown events for time T2
1B4	Time T2 - 8%FP to refueling temperature, P/T relationship based on typical plant data above 280F and bound of all plant data below 280F	Defined to represent typical cooldown events for time T2
1B5	Time category T3, otherwise same as 1B3	
1B6	Time T3, otherwise same as 1B4	

Table 4-1. Surge Line Design Basis Transient List (cont.)

Transient ID	Transient Description	Modification from Original Transients (ODB - Original Design Basis)
1B7	(No transient specified)	
1B8	Time T4, otherwise same as 1B4	
1B9	Time category T5 - 8%FP to refueling temperature, P/T relationship based on bound of all plant data above 280F and recommended operating limits below 280F	Defined to conservatively bound most cooldown events for time T5
1B10	Time T5 - 8%FP to refueling temperature, P/T relationship based on recommended operating limits	Defined to represent typical cooldown events for time T5
1C1	Cold RCS, Pressurized Operations	Defined to represent operations with the RCS at 100F and the pressurizer at 415F
2A	Power Change from 0% to 15% FP	Surge line temperatures based on ODB boundary conditions.
2B	Power Change from 15% to 0% FP	Surge line temperatures based on ODB boundary conditions.
3	Power loading 8% to 100% FP	Surge Line temperatures based on ODB boundary conditions.
4	Power unloading 100 to 8 percent	Surge Line temperatures based on ODB boundary conditions.
5	Ten percent step load power increase	Surge Line temperatures based on ODB boundary conditions.
6	Ten percent step load power decrease	Surge Line temperatures based on ODB boundary conditions.
7	Step Load decrease 100 to 8% FP	Surge Line temperatures based on ODB boundary conditions.

Table 4-1. Surge Line Design Basis Transient List (cont.)

Transient ID	Transient Description	Modification from Original Transients (ODB - Original Design Basis)
8	Reactor Trip	All trips now included under the category of type 8A, 8B, or 8C transients. Previously, certain other trips were specified separately.
9	Rapid Depressurization	Surge Line temps based on ODB boundary conditions.
10	Change of RC Flow Rate	Surge Line temps based on ODB boundary conditions.
13	Steady State Temperature Variations	Surge Line temps based on typical plant data for RCS temperature variations and makeup valve cycling.
14	Control Rod Drop	Surge Line temps based on ODB boundary conditions.
19	Feed and Bleed Operations	Surge Line temps based on ODB boundary conditions.
20	Miscellaneous Transients	A new transient was incorporated to describe pressurizer spray and heater operations used to equilibrate pressurizer & RCS boron concentrations. Transient 20B, previously described as a miscellaneous spray actuation event, was deleted. An additional transient was included to describe the complete interruption of spray flow.
22	Test Transients	A transient was added for the Inservice Makeup Pump Test.

Table 4-2. Design Transients - Numbers of Events

Description	Event Type	Number	Total Events
Heat from cold conditions to 8% full power	1A1 (T1)	3	
	1A2 (T1)	17	
	1A3 (T2)	1	
	1A4 (T2)	5	
	1A5 (T3)	2	
	1A6 (T3)	12	
	1A7 (T4)	--	
	1A8 (T4)	10	
	1A9 (T5)	32	
	1A10 (T5)	158	240
Cooldown from 8% full power	1B1 (T1)	3	
	1B2 (T1)	17	
	1B3 (T2)	1	
	1B4 (T2)	5	
	1B5 (T3)	2	
	1B6 (T3)	12	
	1B7 (T4)	--	
	1B8 (T4)	10	
	1B9 (T5)	32	
	1B10 (T5)	158	240
RCS Cold, Pressurized Operations	1C1 (T1)	9	
	1C1 (T2)	1	
	1C1 (T3)	4	
	1C1 (T4)	6	
	1C1 (T5)	30	50
Power change 0% to 15%	2A		1440
Power change 15% to 0%	2B		1440
Power loading 8% to 100%	3		1800

Table 4-2. Design Transients - Number of Events (cont.)

Description	Event Type	Number	Total Events
Power unloading 100% to 8%	4		1800
Step load increase of 10%	5		8000
Step load decrease of 10%	6		8000
Step load reduction 100% to 8%	7		310
Reactor trip	8A	80	
	8B	232	
	8C	88	400
Rapid depressurization	9		40
Change of RC flow rate	10		20
Steady-state temperature variation	13		35000
Control rod drop	14		40
Makeup and Letdown feed and bleed operations	19		40000
Miscellaneous makeup flow change	20A		30000
	20B		--
	20C		4.0E6
Misc. - Pressurizer heater/spray operation	20D2		6000
Complete interruption of spray flow	20E		20
Quarterly inservice makeup pump test	22E		160

Table 4-3. Events Affecting Surge Line Flow for Plant Heatup and Cooldown

<u>Plant Heatup</u>

High pressure injection check valve testing (at reactor coolant pressure <50 psig)

Forming steam pocket in pressurizer at 50 psig

Pressurizer pressurization (affects letdown rate and reactor coolant system volume and mass)

Purging of pressurizer nitrogen through vent lines

Adjusting pressurizer level setpoint

Controlling pressurizer level in auto (w/ valve and controller deadbands)

Drawing of pressurizer chemistry sample

Testing of PORV (at 100 psig or 200 psig)

Adjusting pressurizer level with LD flow

Placing makeup and purification in service (start makeup pump at <150 psig)

Pressurizing to 150 < reactor coolant pressure < 175 psig

Placing reactor coolant pump seal return in service (makeup and purification system)

Adjusting of reactor coolant pump seal injection/return flows

Venting reactor coolant system

RCS heating without reactor coolant pump operating

Venting reactor coolant pumps for initial operation

Running each pump for 5 minutes (initial run after filling of reactor coolant system)

Re-venting reactor coolant system (control rod drive mechanism and high point vents), re-venting reactor coolant pump

Drawing steam generator vacuum by opening turbine bypass valves

Starting 2 reactor coolant pumps (in same loop) to commence heatup w/ pump power

Pressurizing steam lines by closing turbine bypass valves (affects HU rate)

Table 4-3. Events Affecting Surge Line Flow for Plant Heatup and Cooldown

(cont.)

Holding reactor coolant system temperature (e.g., at 250F for reactor coolant system chemistry in spec)

Isolating low-pressure injection at 280F (affects heatup rate)

Opening spray line block valve (when reactor coolant system temperature reaches 200F)

Closing letdown orifice manual bypass

Adjusting makeup flow rate with increasing reactor coolant system pressure

Starting third reactor coolant pump

Performing steam generator fill, soak, drain operations (300 - 400F)

Pressurizing reactor coolant system after steam generator fill, soak, drain operations

Adjusting makeup bypass flow rate (at reactor coolant pressure >500 psig, 1000 psig, and 1500 psig)

Holding reactor coolant system temperature for reactor trip and reactor protection system reset (at 1700 to 1725 psig)

Pressurizer spray controlling in auto at 2155 psig, heaters on for boron equilibration

Starting 4th reactor coolant pump at 480F

Cycling of turbine bypass valves (in manual) every 20 minutes - temperature holds at >500F

Turbine bypass valves controlling steam pressure at 870 psig in auto

Adjusting boron concentration in reactor coolant system (changing makeup/LD)

Physics testing at hot zero power

Surveillance testing

Plant Cooldown

Degassing pressurizer and reactor coolant system (vent pressurizer to waste gas header)

Table 4-3. Events Affecting Surge Line Flow for Plant Heatup and Cooldown

(cont.)

Decreasing pressurizer level, 28% to 0% full power (operator adjusts setpoint)

Decreasing reactor power demand in manual at <0.5%/min and reducing average temperature

Reducing turbine load demand (manually) w/ auto opening of turbine bypass valves to hold pressure reducing turbine load to <20 MW and tripping turbine

Adjusting pressurizer level to 85 inches at 532F average temp

Controlling pressurizer level in auto (w/ valve and controller deadbands)

Sampling boron concentration in reactor coolant system

Adjusting boron in reactor coolant system (changing makeup/LD flow rates)

Tripping reactor coolant pump to go to 1/2 operating status

Raising steam generator levels for hot soak (at 532F and at 400F to 300F)

Adjusting turbine bypass valve positions for desired cooling rate (turbine bypass valves in manual)

Spraying down pressurizer

Holding reactor coolant system temperature for placing reactor protection system in shutdown bypass

Tripping reactor coolant pump to go to 0/2 operating pump status

Performing core flood tank valve tests (at reactor coolant pressure 750 to 700 psig)

Performing power-operated relief valve cycle tests (at reactor coolant pressure 725 to 675 psig)

Decreasing pressurizer level setpoint to 60 inches (prior to tripping reactor coolant pumps)

Opening letdown orifice manual bypass

Holding for steam generator chemistry, continuing fill, soak, and drain operations

Holding reactor coolant system temperature at 280F (adjusting turbine bypass valve positions)

Table 4-3. Events Affecting Surge Line Flow for Plant Heatup and Cooldown

(cont.)

Valving in the low-pressure injection system

Adjusting low-pressure injection cooler outlet temperature to cold leg temperature

Raising steam generator level for natural circulation cooldown

Tripping last two reactor coolant pumps (average temperature increases)

Establishing 25"/hr increase in pressurizer level

Raising and lowering pressurizer level when on decay heat removal

Open decay heat removal Aux spray valve and set to ensure surge line net flow from reactor coolant system to pressurizer

Spraying down to final pressurizer pressure

Filling steam generators to wet layup level (at less than 200F)

Securing reactor coolant pump seal injection/return flows

Shutting down makeup and purification system (at less than 75 psig)

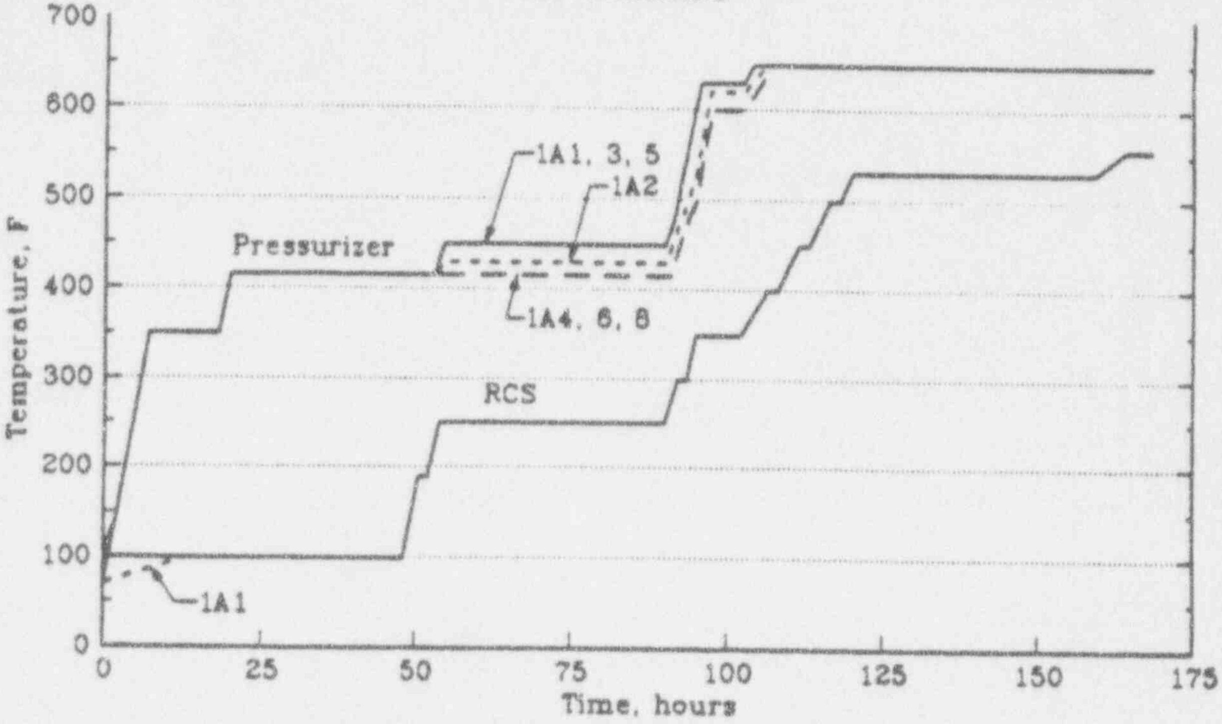
Table 4-4
Summary of Results for Thermal Transient Parameters
(for lower horizontal section of surge line piping)

Transient	Max delta T Reversal	Cumulative Number of Significant Reversals at > ΔT								Max Signif. Striping delta T	
		50/	100/	150/	200/	250/	300/	350/	400	Past	Future
HU1A1	298	96/	68/	26/	15/	8/	-	-	-	260	NA
HU1A2	295	94/	63/	25/	15/	8/	-	-	-	197	NA
HU1A3	295	92/	63/	26/	13/	8/	-	-	-	203	NA
HU1A4	295	90/	57/	23/	16/	8/	-	-	-	197	NA
HU1A5	295	88/	57/	27/	14/	8/	-	-	-	201	NA
HU1A6	295	84/	52/	22/	15/	8/	-	-	-	198	NA
HU1A8	295	90/	57/	23/	13/	8/	-	-	-	197	NA
HU1A9	298	96/	65/	29/	14/	8/	-	-	-	260	260
HU1A10	262	96/	61/	27/	13/	3/	-	-	-	180	180
CD1B1	218	56/	39/	18/	2/	-	-	-	-	196	NA
CD1B2	218	52/	36/	17/	2/	-	-	-	-	196	NA
CD1B3	218	54/	38/	17/	2/	-	-	-	-	196	NA
CD1B4	218	48/	34/	15/	2/	-	-	-	-	196	NA
CD1B5	<------------------ (same as CD1B3) ------------------>										
CD1B6	<------------------ (same as CD1B4) ------------------>										
CD1B8	<------------------ (same as CD1B4) ------------------>										
CD1B9	223	54/	38/	19/	2/	-	-	-	-	199	199
CD1B10	223	54/	39/	19/	2/	-	-	-	-	199	199
HU1C1	310	28/	20/	19/	12/	9/	1/	-	-	154	154
TRAN2A	142	2/	2/	-	-	-	-	-	-	137	-
TRAN2B	165	2/	2/	2/	-	-	-	-	-	142	-
TRAN3	115	2/	2/	-	-	-	-	-	-	154	98
TRAN4	137	2/	2/	-	-	-	-	-	-	149	-
TRAN5	72	2/	-	-	-	-	-	-	-	119	-
TRAN6	-	-	-	-	-	-	-	-	-	127	-
TRAN7	138	2/	2/	-	-	-	-	-	-	139	-
TRAN8A	135	4/	2/	-	-	-	-	-	-	108	-
TRAN8B	158	2/	2/	2/	-	-	-	-	-	113	-
TRAN8C	129	2/	2/	-	-	-	-	-	-	118	-
TRAN9	64	2/	-	-	-	-	-	-	-	-	-
TRAN10	72	2/	-	-	-	-	-	-	-	119	-
TRAN13	-	-	-	-	-	-	-	-	-	-	-
TRAN14	81	2/	-	-	-	-	-	-	-	125	-

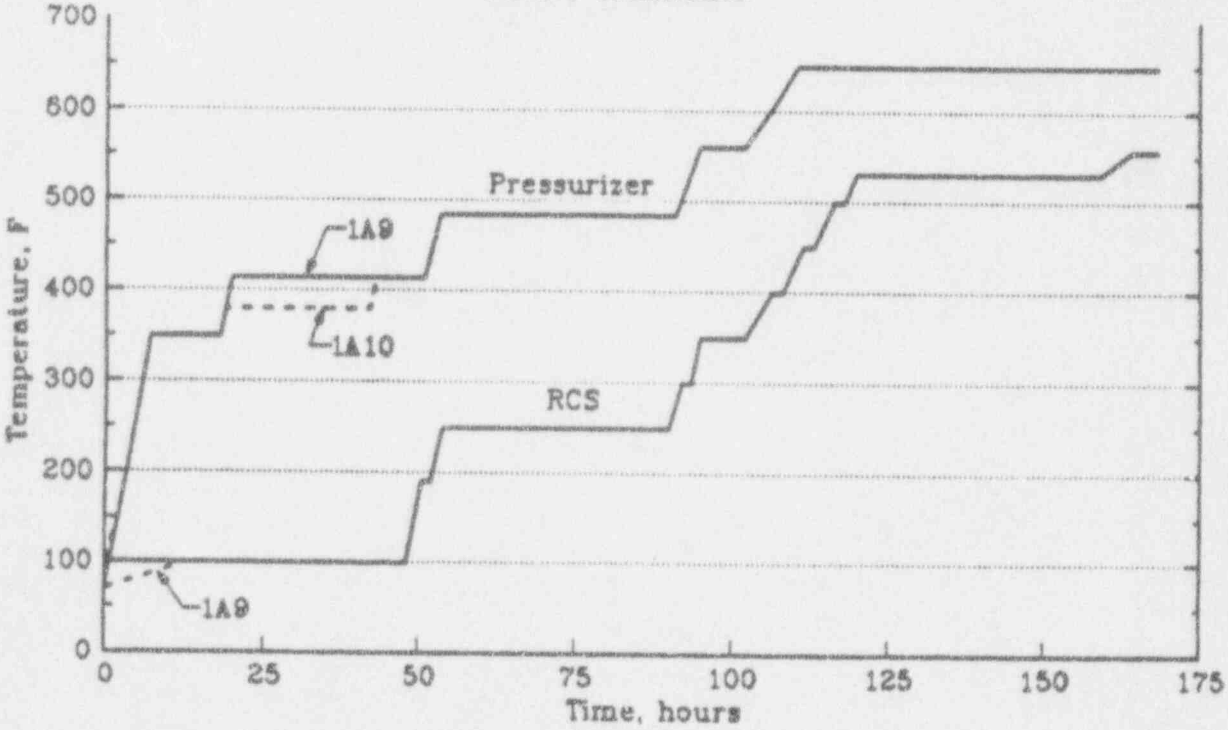
Table 4-4
Summary of Results for Thermal Transient Parameters
(cont.)

Transient	Max delta T Reversal	Cumulative Number of Significant Reversals at > ΔT								Max Signif. Striping delta T	
		50/	100/	150/	200/	250/	300/	350/	400	Past	Future
TRAN19	62	4/	-	-	-	-	-	-	-	-	-
TRAN20A	51	2/	-	-	-	-	-	-	-	-	-
TRAN20C	-	-	-	-	-	-	-	-	-	-	-
TRAN20D2	82	2/	-	-	-	-	-	-	-	99	-
TRAN20E	59	2/	-	-	-	-	-	-	-	-	-
TRAN22E	141	2/	2/	-	-	-	-	-	-	101	101

Figure 4-1. Design Heatup Transient Temperatures



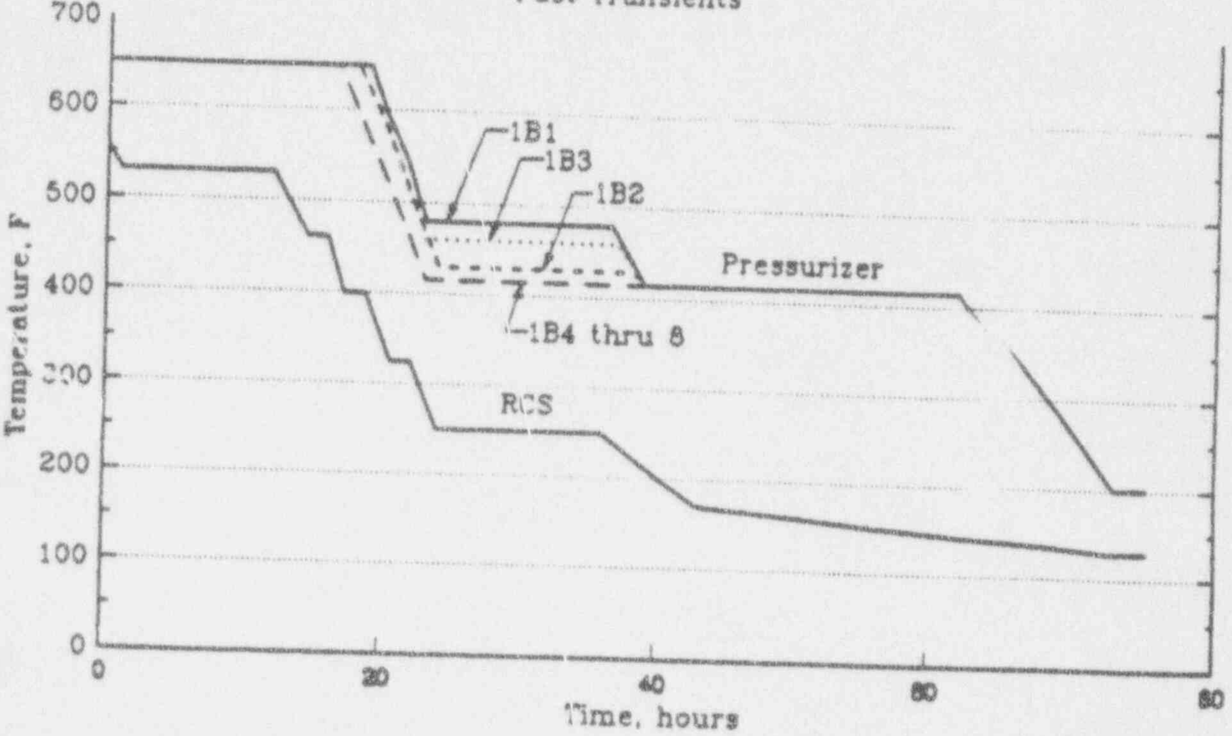
Past Transients



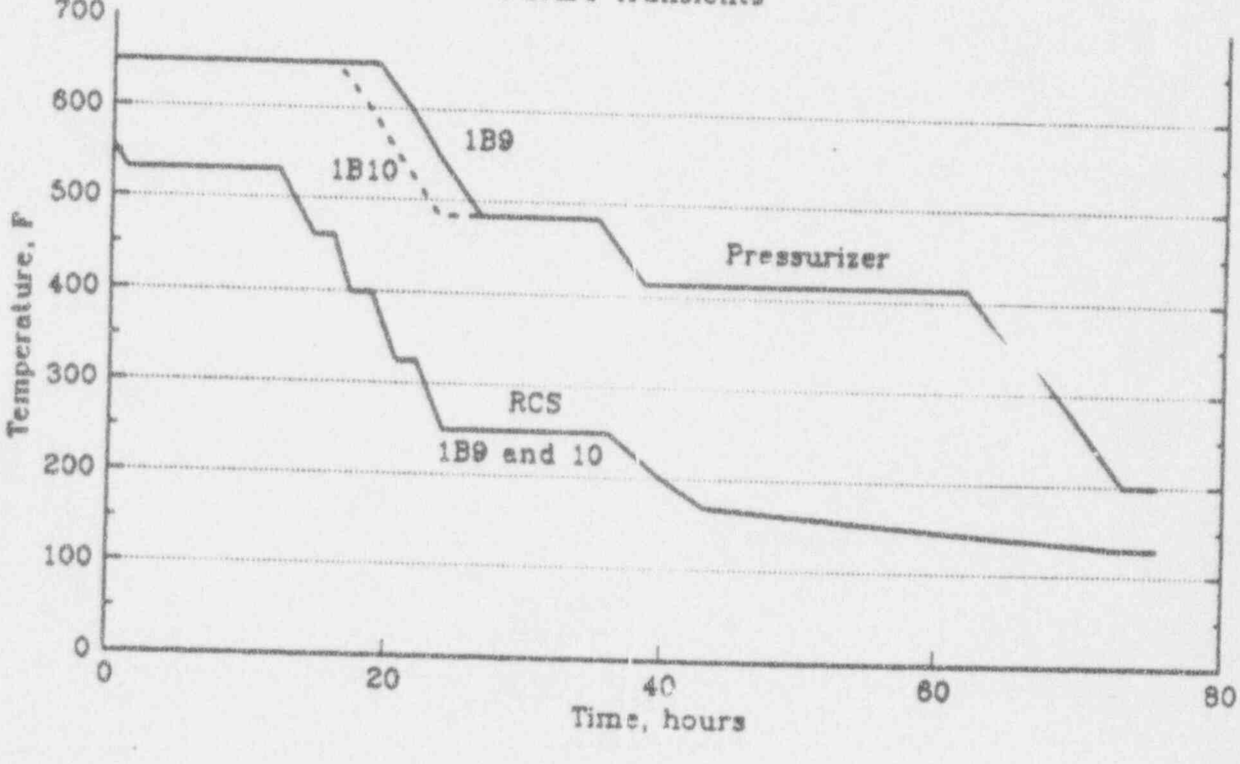
Future Transients

Figure 4-2. Design Cooldown Transient Temperatures

Past Transients



Future Transients



5. PIPING ANALYSIS

5.1 Structural Loading Analysis

The structural loading analysis which generates the internal forces and moments in the surge line for the thermal stratification conditions defined in the design basis transients is essentially the same for Davis-Besse Unit 1 as that performed for the lowered-loop plants, with the exception of the gapped whip restraints for Davis-Besse Unit 1. The structural loading analysis of the surge line for Davis-Besse Unit 1 was performed using the computer program ANSYS (Reference 5).

5.1.1 Mathematical Model

An "extended" mathematical model was built consisting of the pressurizer, surge line, hot leg, reactor vessel, and steam generator. The mathematical model of the Davis-Besse Unit 1 surge line is shown in Figure 5-1.

Gap elements were used to model the whip restraints at the following locations:

joint 48	SL#1	(upper horizontal)
joint 44	SL#2	(upper horizontal)
joint 41	SL#3	(upper horizontal)
joint 37	SL#4	(upper horizontal)
joint 30	SL#5	(riser)
joint 22	SL#6	(lower horizontal)
joint 18	SL#7	(lower horizontal)
joint 15	SL#8	(lower horizontal)

The deadweight support, PSU-H1 originally located in the upper horizontal pipe at joint 36, has been redesigned and will be relocated to the lower horizontal pipe at joint 21 during the 9th refueling outage. This Grinnell Type F spring support was modeled as a gap element and a spring element. If conditions cause the spring support travel to be exceeded, the spring support will bottom out and become rigid, thereby, supporting the pipe in a compressive mode from below. In addition, the past experiences of snubber PSU-R1 interference at joint 36 were modeled as a gap element. Before 1984, there were two snubbers located where PSU-R1 is currently positioned, one on each side of the surge line. In 1984, the snubber closest to the wall was found to be broken and both snubbers were replaced with one snubber, the current PSU-R1, located on the side of the surge line farthest from the wall. The stanchion (3/8" x 4" x 4" structural tubing) closest to the wall was also removed. The bottomed out spring support and snubber interference were considered in the analysis.

5.1.2 Non-Linear Temperature Profile

As for the lowered-loop plants, the temperature profile on the pipe cross-section for the Davis-Besse Unit 1 plant is non-linear in the horizontal portion of the surge line.. A study of the non-linear temperature profile was repeated for Davis-Besse Unit 1 in the same manner as performed for the lowered-loop plants in order to find an "equivalent linear temperature profile". Four non-linear measured temperature profiles at the outside surface were selected for the lower horizontal and another four for the upper horizontal. These selections exhibited the most non-linear temperature profiles as described in Subsection 5.1.3 of the main report. A non-linearity coefficient was calculated for each of these profiles, using a piece-wise integration of the actual temperature profile on the pipe cross-section. The non-linearity coefficient is used to obtain an equivalent linear top-to-bottom temperature profile which produces the same rotation as the non-linear temperature profile. Therefore, the non-linearity coefficient is actually the ratio of the rotation produced using the actual top-to-bottom temperature profile and a linear temperature profile with the actual top and bottom temperatures.

Finite element conduction runs were used in an iterative process to match the calculated outside temperature profiles to the outside measured profiles and subsequently to obtain an average temperature profile. Thus, an equivalent linear temperature profile with an average modulus of elasticity and an average coefficient of thermal expansion was obtained for each non-linear measured temperature profile with the modulus of elasticity and the coefficient of thermal expansion varying on the pipe cross-section. Using the non-linearity coefficients from the piece-wise integration for each profile, the mathematical formula developed for the non-linearity coefficient for the lowered-loop plants was modified to obtain a worst case profile for the lower horizontal and a worst case profile for the upper horizontal of the Davis-Besse Unit 1 surge line.

Toledo Edison has committed to making modifications to the surge line insulation in order to eliminate excessive heat losses in the surge line. These modifications are expected to result in stratification temperature differences in the surge line comparable to the Oconee measurements. Therefore, the more conservative formula for the non-linearity coefficient which was developed for the lowered-loop plants was used for future transients.

5.1.3 Verification Run for Displacements

During the Davis-Besse Unit 1 June 1990 heatup, the temperatures and the displacements of the surge line were recorded. The instrumentation locations are shown in Figure A-2 in Appendix A. This data was used to verify the Davis-Besse Unit 1 mathematical model using the methodology from the lowered-loop analysis. Table 5.1 gives the temperature measurement locations with the measured top and bottom temperatures, as well as the top and bottom temperatures adjusted by the non-linearity coefficient to obtain the equivalent linear temperature profile. The non-linearity coefficient for these profiles were calculated using the piece-wise integration described in Section 5.1.2. The adjusted temperatures were given as input into the surge line ANSYS mathematical model shown in Figure 5-1. The displacements obtained from the ANSYS computer run were compared to the measured displacements and are in good agreement as shown in Figures 5-2 through 5-4.

5.1.4 Structural Loading Analysis for the Thermal Stratification Conditions

The thermal stratification conditions were defined in the design basis transients documented in Section 4.5. The structural loading analysis for the Davis-Besse Unit 1 surge line included the pressurizer, the hot leg, the steam generator, the reactor vessel, the surge line, and the surge line supports and restraints. This analysis was performed using the non-linear effects of the gap whip restraints, the restricted hanger travel, and the snubber/stanchion interference with the wall (corrected in 1984). The surge line and other reactor coolant system components were represented linearly. Running the ANSYS model with the gaps for all gap and temperature conditions would have been prohibitive; therefore, base cases were executed. These base cases were utilized to develop an iterative interpolation scheme to obtain the forces and moments in the surge line. This method was verified by comparing ANSYS results to the results of the iterative scheme for the same gaps and temperature conditions. Thus, using a nominal number of ANSYS non-linear base cases, the resulting loads were determined for all the temperature and gap conditions.

5.2 Verification of NB-3600 Equations (Equations 12 and 13, and Thermal Stress Ratcheting)

The Primary Plus Secondary Stress Intensity Range, Equation 10 of NB-3653 (Reference 6), exceeded the 3*Sm limit for the most critical thermal stratification cycles. The excessive stress intensity range occurred most typically for the thermal stratification cycles associated with very high top-to-bottom temperature differences in the surge line linked with high temperature flushing events. For the load sets which did not satisfy Equation 10, it was necessary to verify Equations 12 and 13 of NB-3653.6 and the Thermal Stress Ratcheting Equation of NB-3653.7. These verifications were performed using the method applied to the lowered-loop plants as described in Subsection 5.3 of the main report and Subsection 2.5 of supplement 2 (Reference 9).

Equation 12 requires the calculation of the secondary stress range due to thermal expansion and a comparison of the secondary stress range to the 3*Sm allowable. The secondary stress range of the Davis-Besse Unit 1 surge line was calculated from the thermally adjusted internal forces and moments associated with the most severe range of thermal stratification conditions. The thermally adjusted internal forces and moments were the internal forces and moments from the thermal stratification structural loading analysis multiplied by the ratio E_{cold}/E_{hot}. This was performed in accordance with NB-3672.5. The ratio E_{cold}/E_{hot}, where E_{cold} was taken at the ambient temperature of 70°F, was always greater than 1.0.

Equation 12 secondary stress was verified at every surge line location in supplement 2 (Reference 9) by assuring shakedown.

Equation 13 involves the calculation of the primary plus secondary membrane plus bending stress intensity, excluding thermal expansion, and comparing the total resulting stress with the 3*Sm limit. Equation 13 stress is due to dead weight, operating pressure and Operating Basis Earthquake (OBE). The surge line does not contain any material or thickness discontinuity. Therefore, the third term of Equation 13 stress was equal to zero (no variation of modulus of elasticity and no abrupt variation of average temperature in the axial direction of the piping). Equation 13 stress was shown to be acceptable at every surge line location for Davis-Besse Unit 1. The maximum Equation 13 stress ratio to allowable was 55%. The maximum Equation 13 stress occurred at the beginning of the riser elbow in the lower horizontal section of the surge line.

The verification of Thermal Stress Ratcheting consisted of comparing the highest occurring Delta T_1 range with an allowable value to be calculated in accordance with NB-3653.7, where Delta T_1 range is the range of the linear through-wall temperature gradients. The verification of Thermal Stress Ratcheting was performed in the fatigue analysis of the surge line described in Section 5.4 and was found to be acceptable (by at least 15%).

5.3 Development of Peak Stresses

The development of the peak stresses due to fluid flow, thermal striping, and the non-linearity of the temperature profile was discussed in detail in Section 5.4 of the main report. The development of the peak stresses for the Davis-Besse Unit 1 surge line was accomplished with the same method utilized for the lowered-loop plants.

5.3.1 Peak Stresses Due to Fluid Flow

The peak stresses due to fluid flow were calculated as described in Section 5.4.1 of the main report. These stresses are due only to the through-wall temperature gradients. If the peak stresses due to fluid flow were greater than the maximum thermal striping peak stresses, they were added to the peak stresses due to thermal stratification induced bending moments in the fatigue analysis of the surge line as explained in Section 5.5 of the main report. The water temperature ramp rates and fluid flow rates were used internal to the code which calculated the through wall gradients in order to obtain an appropriate film coefficient per B&W standard film coefficient correlations.

5.3.2 Peak Stresses Due to Thermal Striping

From the lowered-loop surge line analysis, a striping period of 4.0 seconds for as-welded locations and 0.5 seconds for locations remote from welds was found to result in the maximum possible peak stress intensity range due to thermal striping. These critical striping periods were used to determine the maximum possible peak stress intensity ranges for the Davis-Besse Unit 1 surge line. The temperature variations on the pipe thickness as a result of thermal striping were calculated through ANSYS finite element analysis. Given the inside metal temperature variations on the pipe thickness, the linear and non-linear temperature gradients were calculated using the equations given in NB-3653.2, leading to the maximum peak stress values due to thermal striping. Film coefficients were built into the striping correlations. The "cut-sawtooth" pattern used for the calculation of the stress intensity ranges was compared with the wave-forms from the Battelle-Karlsruhe experiments. (See Section 2 of Appendix C of the main report.) The comparison showed that the analyzed "cut-sawtooth" patterns are representative of the measured wave forms.

5.3.3 Peak Stresses Due to the Non-Linearity of the Temperature Profile

The peak stresses due to the non-linearity of the temperature profile were calculated as described in Section 5.4.3 of the main report. This peak stress reflects the non-linearity of the top-to-bottom temperature profile, usually referred to as the delta T_4 peak stress. The ABAQUS finite element model used for this analysis was the same as the model used in the lowered-loop analysis.

The model consisted of 27 rows of elements in the axial direction with each row containing 24 elements going from the bottom to the top of the pipe, covering an angle of 180 degrees. Boundary conditions were applied so that only half of the pipe required analysis. The peak stress intensity was calculated using the top-to-bottom delta-T, the elevation of the fluid interface centerline and the maximum difference between the actual temperature profile and the equivalent linear top-to-bottom temperature profile, delta T_4.

5.4 Fatigue Analysis of the Surge Line

A Code reconciliation was performed for the Davis-Besse Unit 1 surge line analysis and the results are identical to those listed in Section 5.5 of the main report. The Code of record for the Davis-Besse Unit 1 plant is B-31.7 USA Standards (1968).

The fatigue usage factors for the Davis-Besse Unit 1 surge line were calculated using the methods described in Section 5.5 of the main report. The thermal stratification peaks and valleys were combined into pairs for each joint of the surge line model. In calculating the main fatigue, the assumption was made that all of the cycles in the transients that produce thermal stratification can occur at any time. Using that methodology, the different stress states were ranged using the following pattern:

- the highest possible state of stress (Peak) with the lowest possible state of stress (Valley),
- the second highest state of stress (Peak) with the second lowest state of stress (Valley), etc...

This procedure was used for the total number of occurrences of each peak and valley.

The main fatigue usage is the usage factor due to all the thermal stratification conditions which are characterized by a top-to-bottom temperature difference (thermal stratification PV's). These top-to-bottom temperature differences induce bending moments in the surge line. For the calculation of the main fatigue usage, the absolute values of the peak stress ranges from the following contributions were conservatively added:

1. moment loading range due to thermal stratification,
2. moment loading range due to OBE (for 30 future cycles),
3. internal pressure range in the surge line,
4. non-linearity of the top-to-bottom temperature profile,
5. maximum of the peak stress due to thermal striping or the peak stress due to fluid flow.

The calculation of the main fatigue usage of the elbows included the shakedown and post-shakedown fatigue as described in section 3 of supplement 2 (Reference 9). The addition of the contributions listed above is very conservative, because the assumption was made that the different peak stress ranges occur at the same location on the pipe cross-section.

The peak stress due to fluid flow and the additional peak stress due to the non-linearity of the top-to-bottom temperature profile were both directly considered in the calculation of the main fatigue usage. These two peak stress contributions are not highly cyclic in nature and generally occur with moment peaks or valleys. No additional fatigue usage was considered for the delta T_4 stress. However, there are fluid flow conditions, involving a complete or partial flushing of the surge line, which are not in concert with moment peaks or valleys. These fluid flow conditions were considered in a separate fatigue analysis and the fatigue usage was added to the main fatigue.

Thermal striping is a highly cyclic phenomenon which also induces an additional fatigue usage. This additional fatigue usage was calculated and was simply added to the main fatigue usage. Again, these two contributions to the total fatigue usage probably do not occur at the same location in the pipe cross-section.

The moment loading due to OBE was considered in the calculation of the main fatigue usage. The OBE moments at each surge line location were conservatively added to the thermal stratification moments for the 30 most critical future thermal stratification ranges, assuming that one OBE cycle will occur exactly at the time of that most critical thermal stratification range. This procedure was done for the future only, as it is known that an OBE has not occurred in the past at Davis-Besse Unit 1, and 30 occurrences of an OBE have to be assumed for the 40-year plant life.

In addition, a total number of 650 OBE cycles must be assumed for the 40-year plant life. As 30 of these cycles were considered in the main fatigue usage, an additional fatigue for 620 independently occurring OBE cycles was added to the sum of the main fatigue usage and the fatigue usage due to the thermal striping cycles.

5.5 Fatigue Analysis Results for the Surge Line

The total fatigue usage factors for a 40-year plant life (including past and future fatigue) are listed in Table 5-2. All total fatigue usage factors were less than the allowable of 1.0. The highest cumulative fatigue usage factor was 0.76 and occurs in the straight pipe in the lower horizontal run at the beginning of the second elbow from the pressurizer (elbow B on Figure 5-1). The highest usage factor for an elbow was 0.64 and occurs in the first elbow (A) from the pressurizer. The fatigue usage factor for the stanchion was 0.26.

Table 5-1. Measured and Equivalent Linear Temperature Profiles

TEMPERATURE MEASUREMENT LOCATION (SEE FIGURE A-2)	MEASURED TEMPERATURE (F)		NODE RANGE (SEE FIGURE 5-1)	EQUIVALENT LINEAR TEMPERATURE (F)	
	Ttop	Tbottom		Ttop	Tbottom
HOT LEG	131	131	HOT LEG	131	131
LOCATION 2	146	126	50-53	136	136
LOCATION 3	149	129	45-50	149	126
LOCATION 5	149	129	42-45	150	128
LOCATION 6	149	130	36-42	150	131
			32-36	139	139
LOCATION 9	195	126	30-32	172	172
			24-30	194	194
			21-24	185	115
LOCATION 10	197	124	18-21	187	114
LOCATION 12	199	127	13-18	187	116
LOCATION 14	201	126	11-13	189	117
			9-11	189	117
			4-9	201	201
PRESSURIZER	380	380	PRESSURIZER	380	380

Table 5-2. Total Fatigue Usage Factors for the Davis-Besse Unit 1 Surge Line

Surge Line Locations	Maximum Usage Factor
Most Critical Straight	0.76
Most Critical Elbow	0.64
Drain Nozzle Branch	0.17
Stanchion	0.26

Figure 5-1 Surge Line Mathematical Model

NSSS	PLANT
14	DB 1

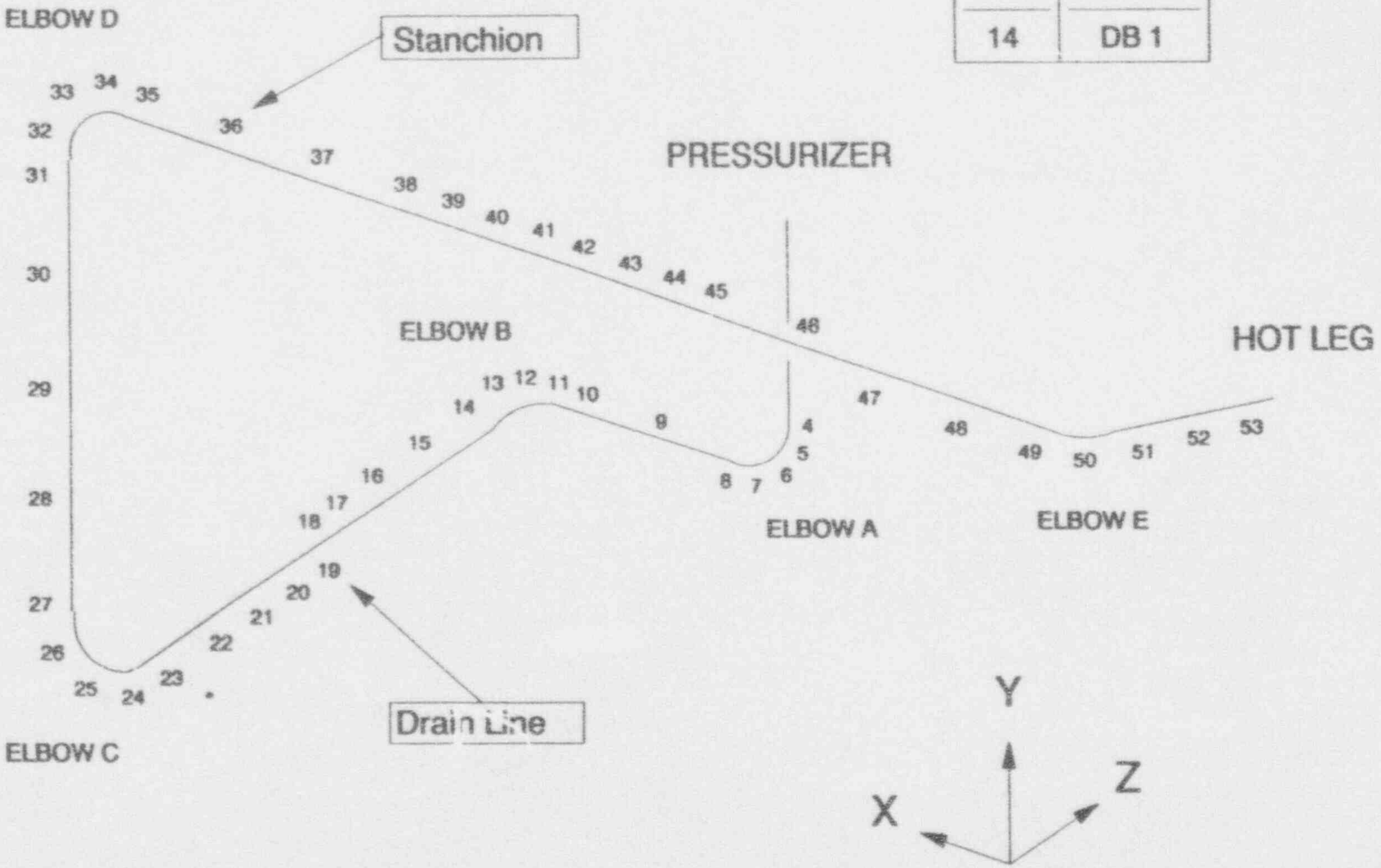


FIGURE 5-2

Comparison of Surge Line Displacements

For 6/13/90 at 03:29:59.9 hrs.

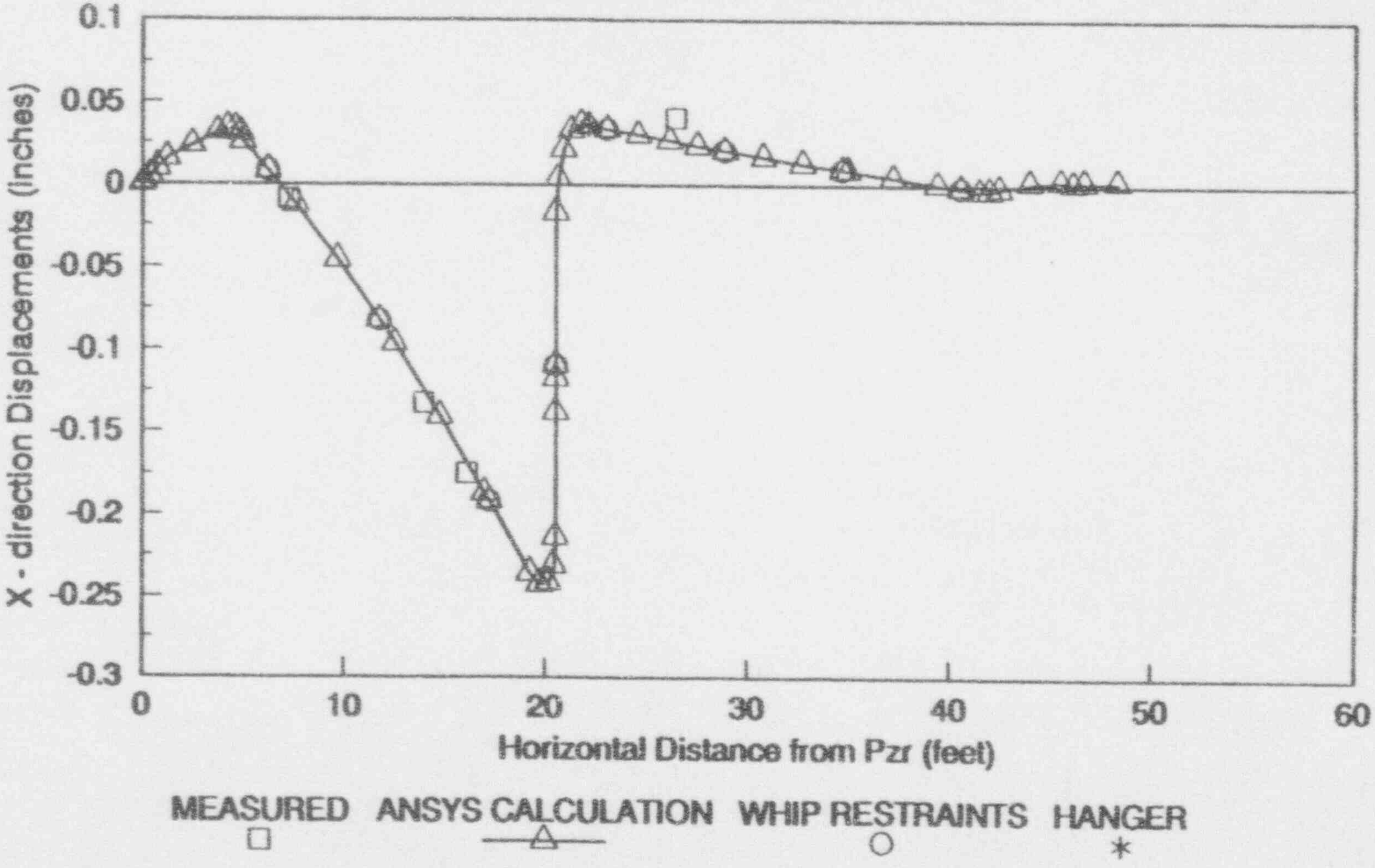


FIGURE 5-3

Comparison of Surge Line Displacements

For 6/13/90 at 03:29:59.9 hrs.

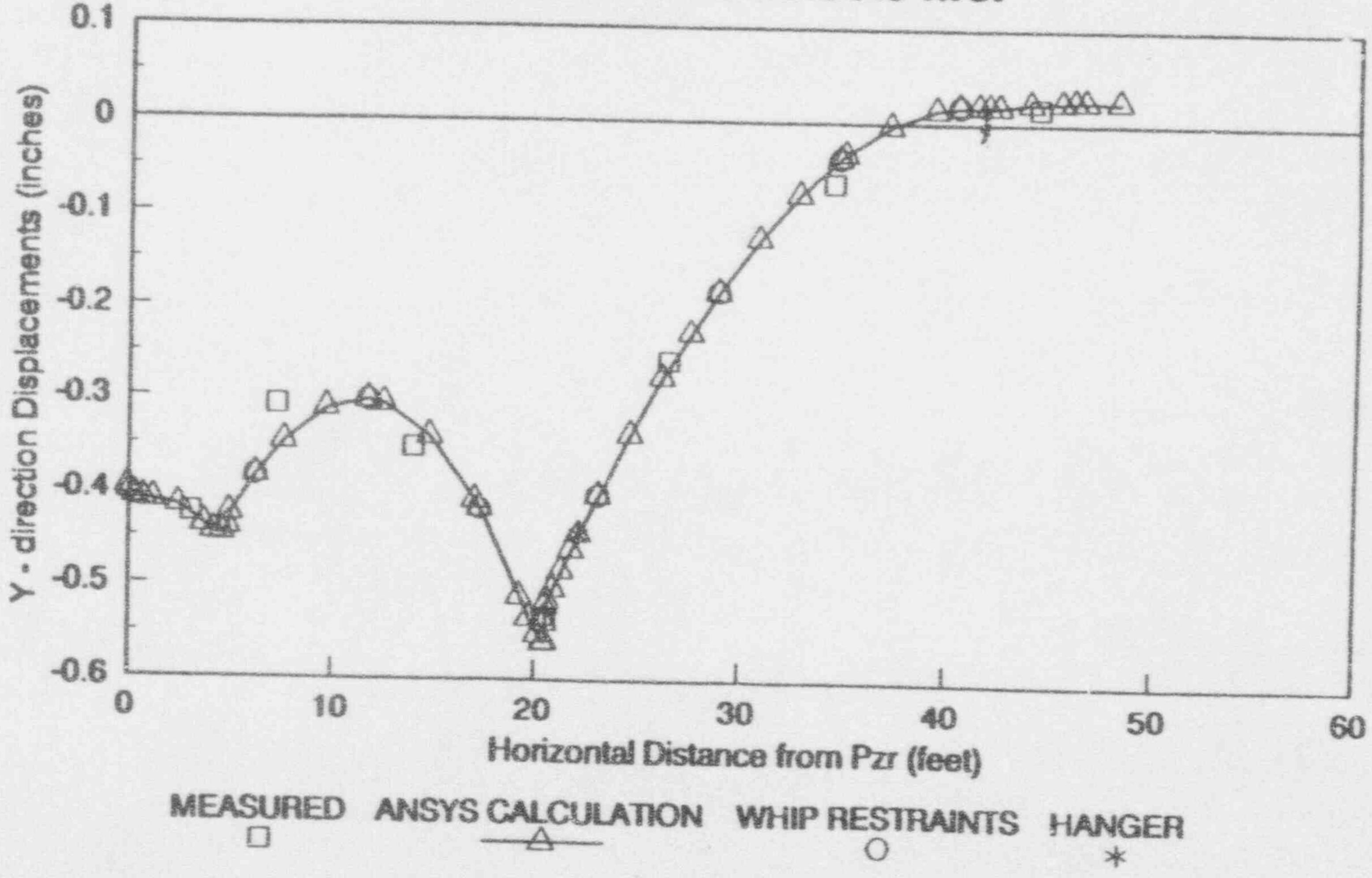
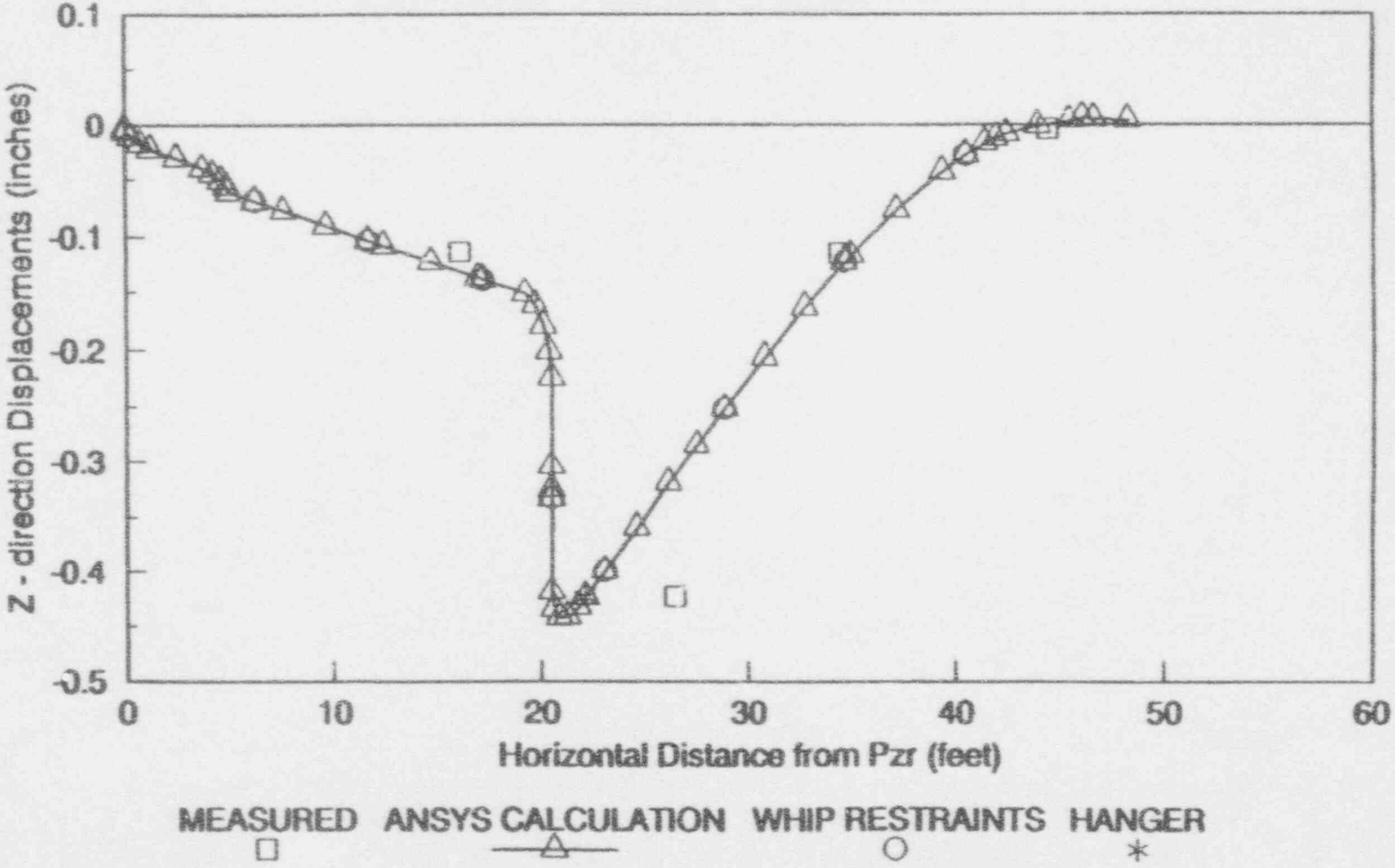


FIGURE 5-4

Comparison of Surge Line Displacements

For 6/13/90 at 03:29:59.9 hrs.



6. NOZZLE ANALYSES

In addition to the structural analysis of the surge line described in Section 5, detailed stress analyses of the pressurizer and hot leg nozzles have been performed to demonstrate compliance with the requirements of the ASME Code, Section III. The thermal and pressure parameters for each nozzle are described in the design basis transients of Section 4.5. In addition, each nozzle is subjected to piping loads from the surge line itself. These loads have been taken from the piping analysis described in Section 5 and the resulting stresses have been combined with those from pressure and thermal loadings.

Detailed descriptions of the analyses of the pressurizer surge nozzle and of the surge line to hot leg nozzle are contained in the following sections. The analysis of the surge drain nozzle is part of the surge line structural analysis described in Section 5 (Table 5-2 gives the total fatigue usage for the surge drain nozzle of Davis-Besse Unit 1).

6.1 Pressurizer Surge Nozzle

6.1.1 Methodology Modifications from Lowered-Loop Analysis

The purpose of this supplemental report is to describe the evaluation of the raised-loop pressurizer surge nozzle of Toledo Edison's Davis-Besse Unit 1 (DB-1). The method used for the analysis of the Davis-Besse Unit 1 nozzle was basically the same as that outlined in Section 6.1 (main report) for the lowered-loop surge nozzle evaluation. However, because of differences in transient thermal data, resulting external loads, and the experience gained from the lowered loop evaluation, some modifications to the analytical method were made. This supplemental report describes those modifications and summarizes the results of the Davis-Besse Unit 1 nozzle evaluation.

1. The geometry of the Davis-Besse Unit 1 nozzle is identical to that of the lowered-loop plants shown in Figure 6-1 (main report). Therefore, the finite element model used for the lowered loop nozzle evaluation (shown in Figures 6-1, 6-2, 6-4, 6-5, 6-6, and 6-7, main report) is applicable to the Davis-Besse Unit 1 nozzle.

2. New transient thermal and pressure conditions were defined for the Davis-Besse nozzle; the Davis-Besse data are discussed in Section 4.5. In addition to containing a larger number of peaks and valleys, the Davis-Besse data include ramp rates much greater than those specified for the lowered-loop plants. Because of these higher ramp rates, additional base case runs were made to insure that all transient ramps would be bounded by a base case.

3. In the lowered-loop evaluation, the thermal stresses for the chosen base case were used directly. For the Davis-Besse Unit 1 evaluation, the base case thermal stresses were adjusted by the ratio of the transient ΔT-to-base case ΔT.

4. For the lowered-loop evaluation, the moments used were based on the moment set occurring at the time closest to that of the transient pv. For the Davis-Besse Unit 1 evaluation, the external loads at the exact time of the transient pv are defined and used. This allows for a more accurate time phasing of loads than was used (available) in the lowered-loop evaluation.

5. The ramp rates used to define the pv base case in the lowered-loop evaluation were based on the maximum rate at any time throughout the transient pv. The ramp rate used for the Davis-Besse Unit 1 evaluation was based on the change-weighting technique discussed in Section 4.2 under "Correlation."

6. In the calculation of the fatigue usage factor for the lowered-loop plants, two separate usage factors were determined and then added together. One value was the transient-to-transient usage factor which was determined from the absolute maximum and minimum stresses from each

transient. The second value was the transient internal usage factor which was determined for each transient based on all other transient stresses.

For the calculation of the Davis-Besse Unit 1 usage factors, all pvs are conservatively used in the transient-to-transient approach to determine one complete usage factor.

7. The evaluations of the safe end and safe end-to-elbow weld for the lowered-loop evaluation were conservatively combined into one evaluation. The analysis conservatively used the stress indices from NB-3600 (piping, radial gradient stress is peak) for the as-welded condition and applied them to the stresses as classified in NB-3200 (components, radial gradient is secondary).

   For the Davis-Besse Unit 1 evaluation, the safe end and safe end-to-elbow weld were evaluated separately; this is in accordance with ASME Section III, NB-1131, which states that the connecting weld shall be considered part of the piping. The safe end was evaluated using the requirements of NB-3200 (radial gradient is secondary) without the stress indices of the as-welded condition. The safe end-to-elbow weld was evaluated using the requirements of NB-3600 (radial gradient is peak) with the stress indices of the as-welded condition.

The items listed above provide a summary of the differences between the evaluations of the Davis-Besse Unit 1 pressurizer surge nozzle and the lowered-loop surge nozzle of Section 6.1 (main report) and retain a conservative basis for the stress and fatigue evaluations. It should be noted that other assumptions as listed in Section 6.1.4 (main report) remain valid for the Davis-Besse analysis. These original assumptions, when combined with the differences noted above, result in a conservative estimate of the fatigue usage.

6.1.2 Summary of Results and Conclusions

The following table provides a summary of the results for the Davis-Besse Unit 1 pressurizer surge nozzle.

SUMMARY OF RESULTS

LOCATION	FATIGUE USAGE FACTOR	
	ACTUAL	ALLOWABLE
SAFE END-TO-ELBOW WELD (STAINLESS STEEL)	0.51 max	1.0
SAFE END (STAINLESS STEEL)	0.30 max	1.0
NOZZLE-TO-HEAD CORNER (CARBON STEEL)	0.93 max	1.0

In summary, the pressurizer surge nozzle, safe end, and safe end-to-elbow weld meet the requirements for Class 1 components of the ASME code, Section III, 1986 Edition with no Addenda for the loading conditions identified in the Transient Specification for the surge line.

6.2 Hot Leg Surge Nozzle

This section completely replaces Section 6.2 in the main report. The purpose of this section is to describe the evaluation of the hot leg surge nozzle for Davis-Besse Unit 1. Due to the differences (geometry and loadings) between the lowered-loop and raised-loop hot leg surge nozzle, an independent analysis for the raised-loop nozzle was performed. The stress analysis of the nozzle and nozzle-to-surge line weld has been performed using the finite element method as implemented by the "ANSYS" computer code, Reference 5. The loads used for evaluation were the thermal and pressure loads identified in the design basis transients for the surge line stratification (see Section 4.5). The acceptance criteria for the evaluation were the requirements for Class 1 components of the ASME B&PV code, Section III, 1986 edition with no Addenda, Reference 6. The nozzle and nozzle-to-surge line weld were evaluated using the detailed requirements of Subsection NB-3200 as permitted by NB-3600.

6.2.1 Geometry

An axisymmetrical representation of a small segment of the surge line, hot leg surge nozzle, and hot leg is shown in Figure 6-8 with an effective radius for the sphere (hot leg) equal to 3.2 times the hot leg pipe radius. The 3.2 : 1 equivalent spherical vessel is a modeling technique recommended by Reference 7. Using the 3.2 factor instead of the more common 2.0, assures that the maximum pressure stress at the critical location in the nozzle is adequately predicted by the axisymmetric model. This modeling technique is conservative for predicting the membrane stress, but is accurate for predicting the maximum stress in the critical locations for use in a fatigue analysis. This piping junction consists of a carbon steel nozzle welded to the carbon steel hot leg. Both the nozzle and hot leg are clad with stainless steel to prevent reactor coolant fluid from contacting the carbon steel base metal.

6.2.2 Description of Loadings

The loadings on the hot leg surge nozzle consist of thermal gradients, internal pressure, and external piping loads.

The thermal gradients are caused by the various fluid temperature swings (peaks and valleys) associated with the in- and out- surges of fluid between the pressurizer (hot) and the hot leg pipe (cold). The surge line fluid thermal stratification can extend into the hot leg nozzle producing circumferential temperature gradients and thermal striping which are in addition to the axisymmetric (radial and longitudinal) temperature gradients produced by the transient. Also, the temperature differential between the surge line fluid and the hot leg fluid contributes to these temperature gradients. The temperature swings for the surge nozzle and hot leg fluids are defined in the design basis for the surge line. The thermal gradients and stresses due to these temperature swings are determined using the ANSYS finite element code.

The RCS pressure is applied to the internal surfaces of the nozzle and hot leg pipe. The pressures are defined in the design basis and the resulting stresses are determined using the ANSYS finite element code.

There are significant external loads developed due to the heating and cooling of the surge line as well as the stratification in the surge line. The external loads, forces and moments, for each peak and valley are given in the documentation of the surge line analysis. The stresses due to these moments and forces are calculated using the ANSYS finite element code.

6.2.3 Discussion of Analysis

In a typical fluid temperature spike, the top fluid in the nozzle will have a larger temperature change than the bottom fluid. Thus, for the determination of the radial and longitudinal temperature gradients and the associated thermal stress, it is conservative to use an axisymmetric analysis with the top fluid as the fluid boundary. An axisymmetric thermal and thermal stress analysis has been performed using the ANSYS finite element computer code. The transient thermal analysis consists of imposing time dependent boundary conditions (bulk fluid temperatures and heat transfer coefficients) on the finite element model. Nodal temperatures from the thermal analysis were stored on magnetic tape for each iteration (time step) of the transient. The ANSYS postprocessor "POST 26" uses the nodal temperatures to calculate Delta-T's between various locations in the structure. Tables of the Delta-T's versus time for each transient were used to determine when the maximum and minimum stresses are likely to occur. The nodal temperatures for each critical time step were input to the ANSYS stress routine for the determination of stresses. The ANSYS postprocessor, "POST 11", was used to linearize the stresses at critical sections of the structure. Stresses due to pressure and resultant external force (along the nozzle axis) were also determined at the critical sections using ANSYS and POST11.

Due to the large number of temperature swings (peaks and valleys) associated with the thermal stratification transients, it was not practical to evaluate each peak and valley as an individual case. Instead, a few "base cases" were created to envelop the large number of identified peaks and valleys. The base cases were chosen using the following parameters; the hot leg fluid temperature, the maximum instantaneous ramp rate for the top fluid temperature excursion in the stratified nozzle, the top fluid starting temperature, the top fluid temperature change (Delta-T) between a peak and valley in the nozzle and whether or not the RC pumps are on or off. The temperature distribution and resulting thermal stresses for each of the base cases were determined using the procedure described above. Parameters describing the actual transients identified in the design basis were used to determine a representative base case for each peak and valley which will now approximate the actual transient. The linearized and maximum thermal stresses from the chosen "base case" were used directly for combining with stresses due to pressure, resultant external force, and non-axisymmetric load stresses.

Pressure stresses for a base case with an internal pressure of 1000 psi were determined using ANSYS. The pressure stresses for each peak and valley were determined by multiplying the stresses from the base case by the ratio of the actual pressure for the peak or valley from the design bases to the pressure used in the pressure base case.

The stresses due to a axial load of 10^5 lbs were determined using ANSYS. The axial load stresses for each peak and valley were determined by multiplying the stresses from the base case by the ratio of the resultant force for the peak or valley from the surge line evaluation to the force used in the base case.

As described above, the thermal analysis performed is axisymmetric in that it is assumes that the top fluid completely fills the nozzle and creates the two-dimensional axisymmetrical temperature fields in the nozzle for the various thermal transients. The next task was to determine the additional stresses due to circumferential temperature gradients produced by the fluid stratification in the nozzle. The stresses due to this fluid stratification were conservatively assumed to occur at the time of maximum thermal stresses due to the radial and longitudinal temperature gradients.

The stresses due to thermal stratification were determined for six base cases by use of the ANSYS harmonic element STIF 25. This element is used for two-dimensional modeling of an axisymmetric structure with non-axisymmetric loading. In the case being considered, the non-axisymmetric loading is the temperature field in the nozzle which varies in the circumferential direction as well as in the radial and axial directions. The stresses due to a circumferential temperature gradient are independent of the radial and axial gradients. These stresses are primarily a function of the temperature difference between the top and bottom fluid and the transition zone between the two fluid temperatures.

The circumferential temperature gradient was approximated by assuming the top and bottom of the nozzle is at a steady state condition for a thermal peak and valley, respectively. The transition between these two temperature fields was assumed to be linear over the same 1" height of nozzle that contains the fluid interface zone between the hot and cold fluid. From the design basis, the centerline elevation of this interface zone in the hot leg nozzle, relative to the centerline of the nozzle, varies from +2" to -3" in steps of -1" during the various PV temperature excursions. Thus, six thermal stratification load base cases were required.

The six stratification base cases used a 200°F temperature differential between the hot and cold fluid. Therefore, the stress due to the base case circumferential temperature gradient could be determined by subtracting the steady state stress due to the radial and axial temperature gradients from the combined stress due to radial, axial, and circumferential temperature gradients (from harmonic element results which included the same steady-state temperatures as were used in the axisymmetric load).

The thermal stratification stresses due to the circumferential temperature gradient for each peak and valley were determined by multiplying the stresses from the appropriate circumferential temperature gradient base case by the ratio of the actual stratification Delta-T for the peak or valley from the design basis to the Delta-T used in the stratification base case (200°F).

Stresses for two base case nozzle bending moments of 10^6 in-lbs (MY and MZ) were also determined by using the ANSYS harmonic element, STIF 25. The bending moment stresses for each peak and valley were determined by multiplying the stresses from the base case by the ratio of the moment for the peak or valley from the surge line evaluation to the moment used in the base case.

Shear stresses for a base case nozzle torsion load (MX) were calculated by hand for a unit load of 10^6 in-lbs. The shear stresses for each peak and valley were determined by multiplying the stresses from the base case by the ratio of the torque for the peak or valley from the surge line evaluation to the torque used in the base case.

The thermal, stratification, pressure, and external load stresses were multiplied by the appropriate stress indices (Table NB-3681(a)-1) or stress concentration factors and then combined for determination of maximum stress and fatigue usage. The results are given in Section 6.2.9.

6.2.4 List of Assumptions/Inputs Used in Analysis

1. The surge line nozzle to hot leg junction is a 3D structure and the thermal stratification in the nozzle produces non-axisymmetric loads. Two significant assumptions are necessary in order to analyze this nozzle using a 2D finite element model.
    a. The 3D structure can be approximated as a nozzle attached to a sphere whose radius is 3.2 times the radius of the hot leg. This assures that the pressure stress in the model will be equivalent to the maximum pressure stress in the actual structure at the critical location. The thermal stress from the model due to temperature gradients is approximately equal to those in the actual structure since thermal stress is not a strong function of the radius of the sphere.
    b. The circumferential temperature gradient is approximated by assuming the top and bottom of the nozzle is at a steady state condition for a thermal peak and valley, respectively. The transition between these two temperature fields is assumed to occur over the same 1" height of nozzle that contains the fluid interface zone between the hot and cold fluid. This is a conservative assumption since heat conduction in the circumferential direction of the nozzle will increase the height of the transition zone in the metal which would tend to reduce the thermal stresses.
2. The outside of surge line nozzle and hot leg are assumed to be fully insulated (no heat loss).
3. The surge line nozzle and hot leg are assumed to be at a steady state condition at the beginning of each up ramp (peak) or down ramp (valley). This is a conservative assumption since it maximizes the radial and axial gradients in the structure for each peak or valley.
4. The fluid temperature ramp rate (°F/Hr) used in the analysis in determining the applicable base case is the maximum ramp rate at any time throughout the temperature change (PV) as defined in the design basis.

5. The transition between the nozzle and hot leg fluid temperatures is assumed to be a step change occurring at the intersection of the nozzle and hot leg pipe. This is a conservative assumption as a more gradual transition will actually occur which would reduce the thermal stresses in this region of the nozzle.

6. Fluid stratification is assumed to occur over the entire nozzle length (i.e., there is no mixing at the entrance to the hot leg).

7. The outside nozzle surface temperature and maximum rate of change for each PV, as predicted in the design basis, is also assumed to be representative of the nozzle fluid temperature and ramp rate. This is an appropriate assumption for the majority of the PVs, however, it is slightly unconservative for some short duration transients (i.e., the outside metal temperature would not see the total fluid temperature change).

8. The transient stresses are conservatively assumed to apply to all angles around the nozzle and not just to the regions in contact with the top (hot) fluid.

9. The temperature excursions predicted for the surge line upper horizontal run are assumed to be applicable for the hot leg nozzle.

10. The OBE seismic events are assumed to occur at steady state conditions and not at the point of maximum or minimum transient stress. Even if an event were to occur during a time of maximum transient stress, the effect on fatigue usage for only one occurrence of OBE would be minimal.

6.2.5 Thermal Analysis of Axisymmetric Loads

An axisymmetric heat transfer analysis using the finite element code ANSYS was performed to obtain the temperature distributions in the surge line nozzle and hot leg. The thermal transients evaluated are those specified in the design basis and discussed in Section 6.2.5.1. The resulting nodal temperatures from the thermal analysis will be used as input to the stress analysis.

The finite element model of a small segment of the surge line, surge nozzle, and hot leg is shown in Figure 6-9. These components are represented by isoparametric quadrilateral thermal elements, STIF 55. The required inputs for this element are four nodal points and material properties: thermal conductivity, density, and specific heat.

6.2.5.1 Selection of Transients

The operating transients for the surge line (and nozzles) are identified in the design basis for the surge line and discussed in Section 4.5. A review of the transients revealed a significant number of temperature fluctuations during each transient. The temperature fluctuations involved 50 to 60 different peaks or valleys per heatup or cooldown transient. The fluctuations include temperature changes (Delta-T) with magnitudes ranging from approximately 40 to 400 degrees F. As previously stated, an evaluation of each peak and valley was not practical, therefore only a few cases were considered. These cases are referred to as "base cases" and were selected to insure all peaks and valleys are enveloped.

6.2.5.2 Thermal Boundary Conditions

The thermal boundary conditions consist of convective heat transfer at the inside surfaces of the model. Depending on the flow velocity in the nozzle and hot leg, either free or forced convection may be the predominant mode of heat transfer between the fluid and metal surfaces. For natural convection, the heat transfer is caused, primarily, by the difference in temperature between the metal surface and the reactor coolant fluid. The film coefficient versus Delta-T is input in tabular form to the ANSYS thermal runs. ANSYS uses the actual surface-to-fluid Delta-T at each time step (iteration) to determine the appropriate film coefficient. For forced convection, the film coefficient is constant for a given fluid velocity, temperature, and geometry. The film coefficient used in the analysis is the maximum of the coefficients for free or forced convection. Free convection film coefficients for the nozzle are not used in any of the base cases since the calculated force convection coefficient is larger. A sample of the film coefficients for the two regions of the model is given below.

REGION	FILM COEFFICIENT (BTU/HR-FT^2-F)	
	FREE	FORCED
NOZZLE	140	400
HOT LEG	115	3000

The outside surfaces of the model are assumed to be fully insulated. In addition, for symmetry, the ends of the model are assumed to be adiabatic surfaces.

The transition between the nozzle and hot leg fluid temperatures is conservatively assumed to be a step change at the intersection of the nozzle and hot leg pipe.

6.2.5.3 Results of Thermal Analysis

The results of the thermal analysis are in the form of nodal temperatures. These nodal temperatures were read into the thermal stress analysis and provided the model with the axial and radial thermal gradients that produce the thermal stress. The times at which the maximum gradients occur were used for the thermal stress analysis since they were likely to produce the maximum stresses. To determine when the maximum gradients occur the ANSYS postprocessor, POST 26, was used. POST 26 provides a time history of the gradients at defined locations for the duration of the transient. For the surge nozzle evaluation fifteen pairs of nodes were used to examine the thermal response (Delta-T) of the structure. The locations of these 15 node pairs are shown in Figure 6-11. Figure 6-12 shows the temperature contours at an extreme Delta-T time point of a typical fluid temperature spike.

6.2.6 Stress Analysis of Axisymmetric Loads

An axisymmetric stress analysis using the finite element code ANSYS has been performed to obtain the stress distribution in the model for the base case axisymmetric loadings. The loadings for the analysis are the nodal temperatures from the thermal analysis (Section 6.2.5), a unit pressure load (1000 psi), and a unit axial force (10^5 lbs).

6.2.6.1 Description of Finite Element Model

The finite element model used for the thermal analysis was also used for the stress analysis. The only difference between the two models is the element type designation. The STIF 55 thermal element was replaced with a isoparametric quadrilateral stress elements, STIF 42. The required inputs for this element are four nodal points and material properties: coefficient of thermal expansion, modulus of elasticity, and Poisson's ratio.

6.2.6.2 Structural Boundary Conditions

The structural boundary conditions applied were required to simulate those portions of the structure that were not modeled. The end of the model representing the hot leg was restrained from motion in the meridional direction (UY displacement = 0.0). This restraint simulates the restraint of the adjacent hot leg pipe material. The end of the surge line segment was assumed to be free. The location of this free boundary condition is sufficiently remote from the nozzle-to-surge line weld such that any stress induced by the assumed boundary condition will have attenuated to a negligible value at this critical section.

6.2.6.3 Selection of Transient Times

As stated in Section 6.2.5.3, the selection of transient times for use in the stress analysis was dependent upon the thermal gradients through the structure. The thermal gradients cause differential growth between adjacent material which results in thermal stresses. The times at which the maximum radial and axial gradients (Delta-T) occur were evaluated for stress.

6.2.6.4 Finite Element Stress Results

The results from the ANSYS stress runs are not in a format which can be directly compared to ASME code allowables. In order to get stresses compatible with the ASME code requirements it was necessary to use the ANSYS postprocessor POST 11. POST 11 performs stress linearization by converting the non-linear through-wall stress distributions into the stress components required for an ASME code evaluation: membrane stress, bending stress, and peak stress. The pertinent information about the linearization methods and detailed input is given in Section 6.31 of the ANSYS users manual. Twelve stress classification lines (SCL) were selected to evaluate stresses in the various regions of the model. The line locations are shown in Figure 6-13. The sum of the linearized stresses for a given load set was used to compare to the ASME code limit for the range of primary-plus-secondary stress intensities (3Sm limit).

In addition to the linearized stresses each "base case" also contains maximum stresses. The maximum stresses represent the stresses at the surface of the component and are given in the ANSYS element stress printout as the element surface stress. The sum of the maximum stresses for a given load set was used in the evaluation for fatigue usage.

6.2.7 Stress Analysis of Non-Axisymmetric Loads

A non-axisymmetric stress analysis using the finite element code ANSYS was performed to obtain the stress distribution in the model for the base case non-axisymmetric loadings. The loadings for the analysis were the circumferential nodal temperature gradients for six stratification cases and two nozzle bending moments as described in Section 6.2.3.

6.2.7.1 Description of Finite Element Model

The finite element stress model used for the axisymmetric loads was also used for the stress model for the non-axisymmetric loads. The only difference between the two models is the element type designation. The STIF 42 element was replaced with a harmonic element, STIF 25. The required inputs for this element are four nodal points and constant material properties: coefficient of thermal expansion, modulus of elasticity, and Poisson's ratio.

6.2.7.2 Structural Boundary Conditions

The structural boundary conditions are the same as was used for the axisymmetric loads in Section 6.2.6.2.

6.2.7.3 ANSYS Load Step Data

A harmonic element model requires the load to be input as a series of harmonic functions (Fourier series). The ANSYS preprocessor PREP6 was used to generate the Fourier series for the stratification temperature fields described in Section 6.2.3. Stresses were obtained for all the modes up through mode number 20. These stress modes were then combined using the ANSYS postprocessor POST29. The unit (10^6 in-lb) nozzle bending moment was applied as described in Section 2.25, Case C of the ANSYS user's manual. This bending moment was represented by applying peak axial (nozzle) force values at the end of the nozzle. The load varies as a first harmonic wave (MODE =1) with a cosine symmetry condition (ISYM = 1).

6.2.7.4 Finite Element Stress Results

The stresses output from POST29 were linearized at critical sections of the model. The results were then combined with linearized stresses from other loads and compared to the ASME code allowables as described in Section 6.2.8.

6.2.8 ASME Code Calculations

The linearized thermal, stratification, pressure, and external load stresses for each peak and valley were combined to obtain the total linearized stress. The linearized stresses for all peaks and valleys were tabulated and the difference between the maximum and minimum linearized stresses was used for comparison to the ASME code limit of 3Sm. When the 3Sm limit was exceeded, NB-3228.5 "Simplified Elastic-Plastic Analysis" was used to justify the stress conditions. The maximum thermal, stratification, pressure, and external load stresses for each peak and valley were multiplied by the appropriate stress indices or stress concentration factor and combined to obtain the total maximum stress. The maximum stresses for all peaks and valleys were tabulated for evaluation of fatigue. A sample of the linearized and maximum stresses at the end of nozzle taper with the associated fatigue usage for a typical PV is given in Table 6-5. The fatigue evaluation took into account the number of cycles for each peak and valley, the maximum stress ranges, the linearized stress range associated with the maximum stress range, and the resulting Ke factor for the maximum stress range when the linearized stress range exceeds the 3Sm allowable. Fatigue usage due to thermal striping on the stainless steel regions of the nozzle was conservatively assumed to be equal to that calculated for the surge line. The maximum linearized stress and fatigue usage factor for both the stainless steel and carbon steel portions of the surge nozzle are given in Section 6.2.9. All requirements of the ASME code are met.

6.2.9 Summary of Results and Conclusion

A summary of results for the hot leg surge nozzle evaluation is given in the following table. Although the 3Sm limit is exceeded for both the carbon steel and inconel, the requirements of the ASME code were satisfied by performing a "Simplified Elastic-Plastic Analysis" as defined in Subsection, NB-3228.5 of the code.

SUMMARY OF RESULTS, HOT LEG SURGE NOZZLE

LOCATION	FATIGUE USAGE FACTORS	
	ACTUAL	ALLOWABLE
NOZZLE-TO-SURGE LINE WELD (STAINLESS STEEL)	0.62	1.0
NOZZLE-TO-SURGE LINE WELD (INCONEL)	0.32	1.0
END OF NOZZLE TAPER (CARBON STEEL)	0.81	1.0
NOZZLE-TO-HOT LEG CORNER (CARBON STEEL)	0.77	1.0

In conclusion, the hot leg surge nozzle and nozzle-to-surge line weld meet the requirements for Class 1 components of the ASME Code, Section III, 1986 Edition with no Addenda for the revised design basis transients discussed in Section 4.5.

Table 6-5. Stresses and Fatigue for a Typical PV at the End of the Nozzle Taper

```
SECTION NO.  7 AT THETA =    83. DEGREES FOR THE OUTSIDE SURFACE

 TMAX  TMIN  3*SM     SY        E          ALPHA       SN       SP     KE      SA      NACTUAL    NALLOW       U       USUM
  (F)   (F)  (PSI)  (PSI)     (PSI)     (IN/IN/F)   (PSI)    (PSI)          (PSI)

  417.  116.  65208.  30511. 0.2763E+08 0.6791E-05  76745.  117314.  1.354   86219.        5.  0.89389E+03  0.0056  0.0056

TRANSIENT HU1A10, PV NO. 22, FOR THE YEARS RF09 -       . THE TOTAL NUMBER OF OCCURRENCES FOR THIS TRANSIENT IS     158.

LOAD               COMPUTER RUN NAME  ----------------OUTSIDE SURFACE STRESSES (PSI)---------------   INSIDE SURFACE STRESSES (PSI)
                                      -------  LINEARIZED-----------  -----------SURFACE------------  ---------LINEARIZED-----------
                                       SX      SY       SZ      SYZ     SX      SY      SZ      SYZ       SX      SY      SZ      SYZ

FORCES                      GAQB       0.     -89.     -28.      0.      0.    -136.    -30.     0.        0.     -33.    -12.      0.
PRESSURE                    GAQB       0.     225.     316.      0.      0.     287.    340.     0.     -300.     572.    547.      0.
MOMENTS             GOAV    GOAV       0.    7845.    2882.   1143.      0.   12523.   2789.  1143.        0.    1733.    867.    813.
STRATIFICATION      GPPL    GBYM       0.   30371.   10132.  -3553.      0.   41102.   1671. -3359.        0.   10406. -11446.  -5650.
TRANSIENT           GJVT    GAPQ       0.   26285.   22087.      0.      0.   29100.  14187.     0.        0.  -28826. -20215.      0.
MINUS RADIAL GRADIENT, DT = -85.5 F       -11454.  -11454.                                                       11454.  11454.

TOTAL                                  0.   53183.   23934.  -2410.      0.   82876.  18957. -2216.


TRANSIENT CD1B4 , PV NO. 25, FOR THE YEARS 1980 - 1982.  THE TOTAL NUMBER OF OCCURRENCES FOR THIS TRANSIENT IS        5.

LOAD               COMPUTER RUN NAME  ----------------OUTSIDE SURFACE STRESSES (PSI)---------------   INSIDE SURFACE STRESSES (PSI)
                                      ---------LINEARIZED-----------  -----------SURFACE------------  ---------LINEARIZED-----------
                                       SX      SY       SZ      SYZ     SX      SY      SZ      SYZ       SX      SY      SZ      SYZ

FORCES                      GAQB       0.    -148.     -47.      0.      0.    -225.    -50.     0.        0.     -55.    -20.      0.
PRESSURE                    GAQB       0.     212.     297.      0.      0.     270.    320.     0.     -282.     538.    514.      0.
MOMENTS             GOAV    GOAV       0.    -821.    -302.   2958.      0.   -1312.   -292.  2958.        0.    -182.    -91.   2459.
STRATIFICATION              GBYM       0.  -29630.  -10088.  -2985.      0.  -42661.  -4288. -2985.        0.  -12622.   6896.  -4725.
TRANSIENT                   GAPL       0.   13075.   11452.      0.      0.   13042.   6619.     0.        0.  -14341. -10239.      0.
MINUS RADIAL GRADIENT, DT = -29.1 F        -3906.   -3906.                                                        3906.   3906.

TOTAL                                  0.  -21218.   -2595.    -27.      0.  -30887.   2308.   -27.

THE FOLLOWING STRESS RANGES INCLUDE 1.25 TIMES THE  ABOVE MOMENT AND FORCE STRESS RANGES.

COMPONENT STRESS RANGE                 0.   76582.   27329.  -2836.      0.  117244.  17424. -2642.
PRINCIPAL STRESS RANGE                 0.   76745.   27166.              0.  117314.  17355.
STRESS DIFFERENCES                -76745.   49579.   27166.        -117314.   99960.  17355.
PL + PB + Q - THERMAL BENDING =    47261. PSI
ALLOWABLE THERMAL STRESS RANGE AS PERMITTED BY RATCHETING RULES = 1012401. PSI
ACTUAL THERMAL STRESS RANGE =    13210. PSI
STRESS RANGE DUE TO RESTRAINT OF FREE END DISPLACEMENT, PE =     11585. PSI
```

Figure 6-8. Geometry of Hot Leg Surge Nozzle

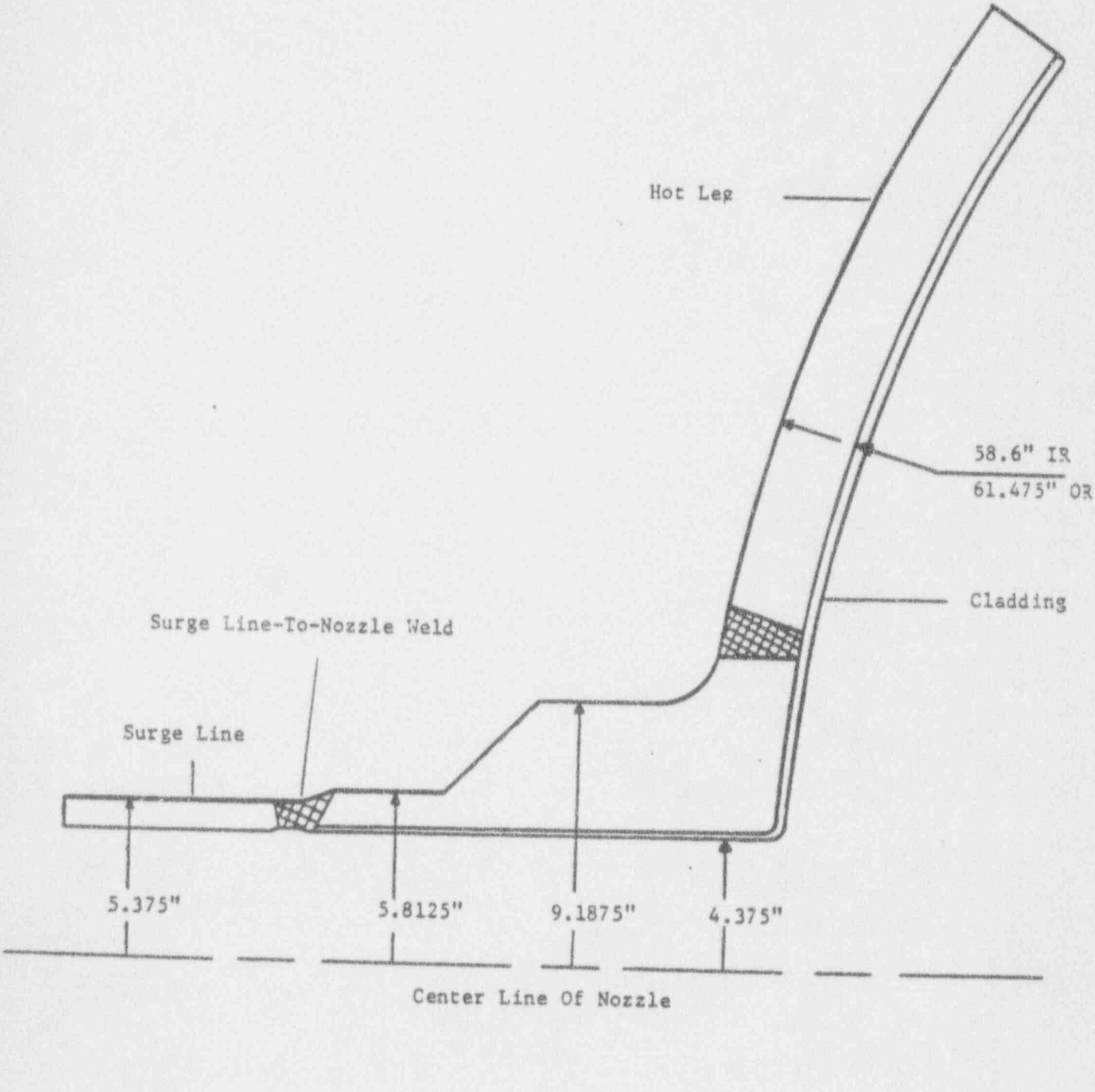


Figure 6-9. Finite Element Model of Hot Leg Surge Nozzle

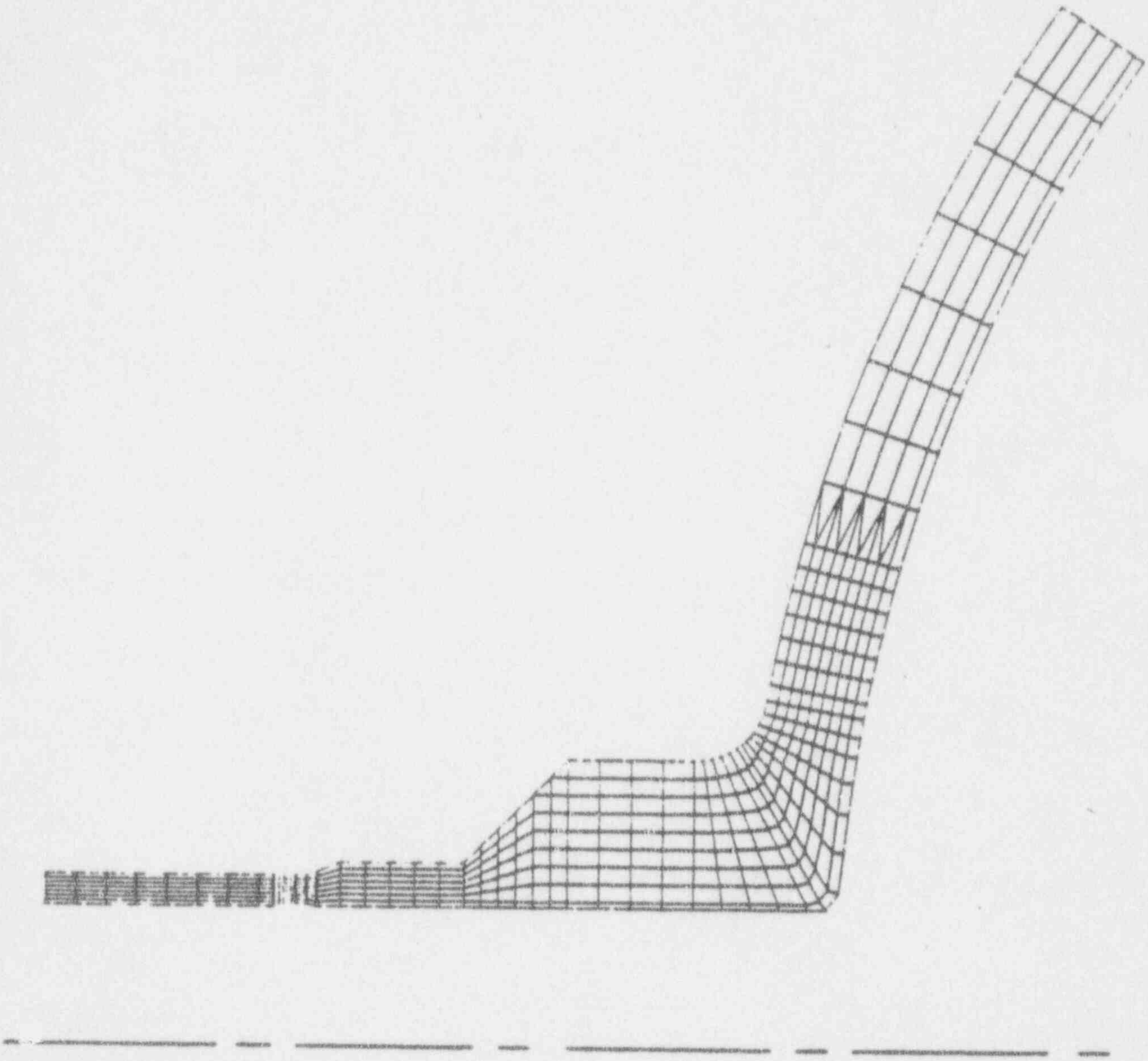
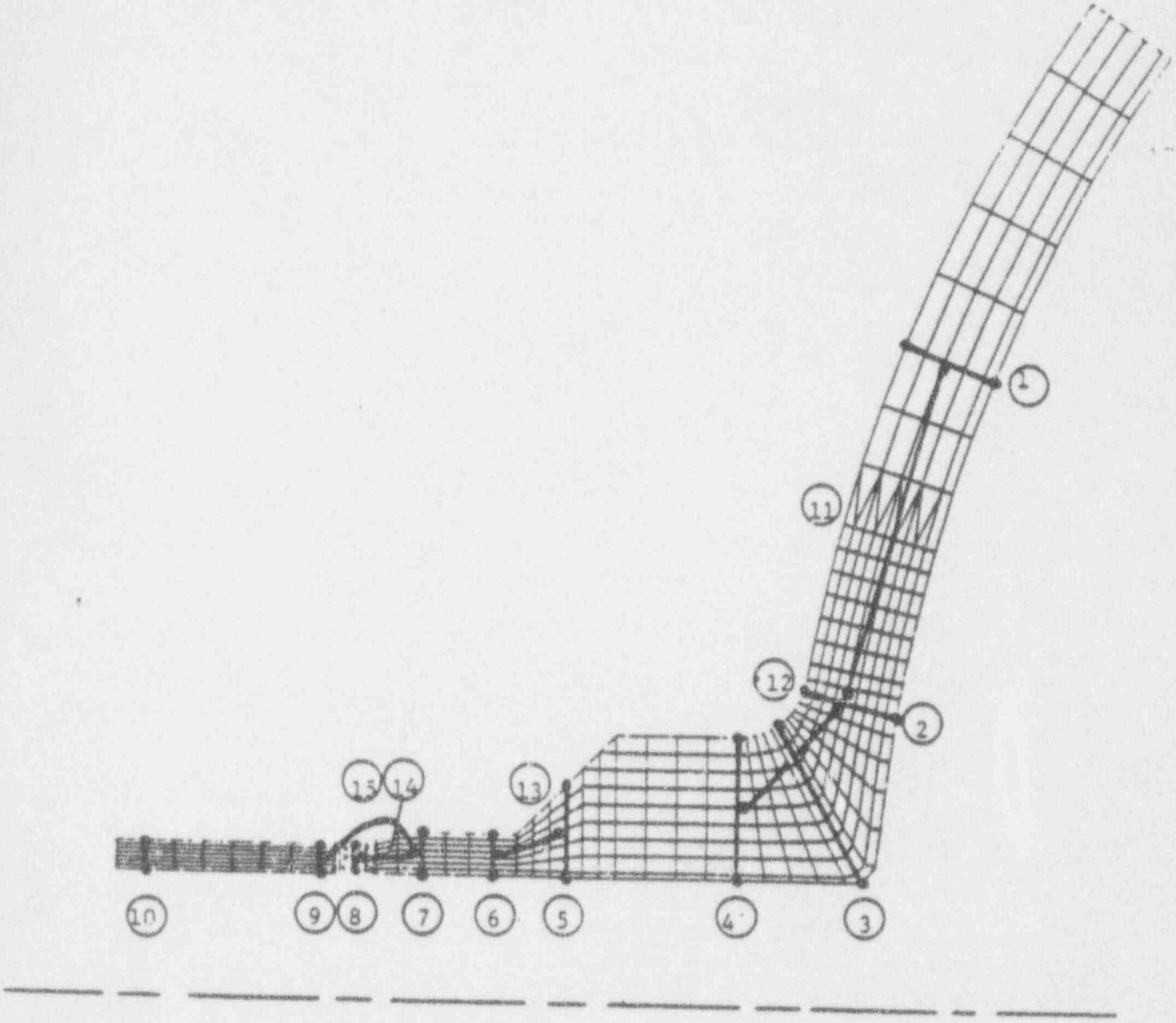


Figure 6-11. Location of Delta-T Values

(Hot Leg Surge Nozzle)



- DELTA-T LOCATIONS

1 to 10 are radial Delta-T

11 to 15 are axial Delta-T

Figure 6-12. Hot Leg Surge Nozzle Temperature Contours (F) for a Typical PV

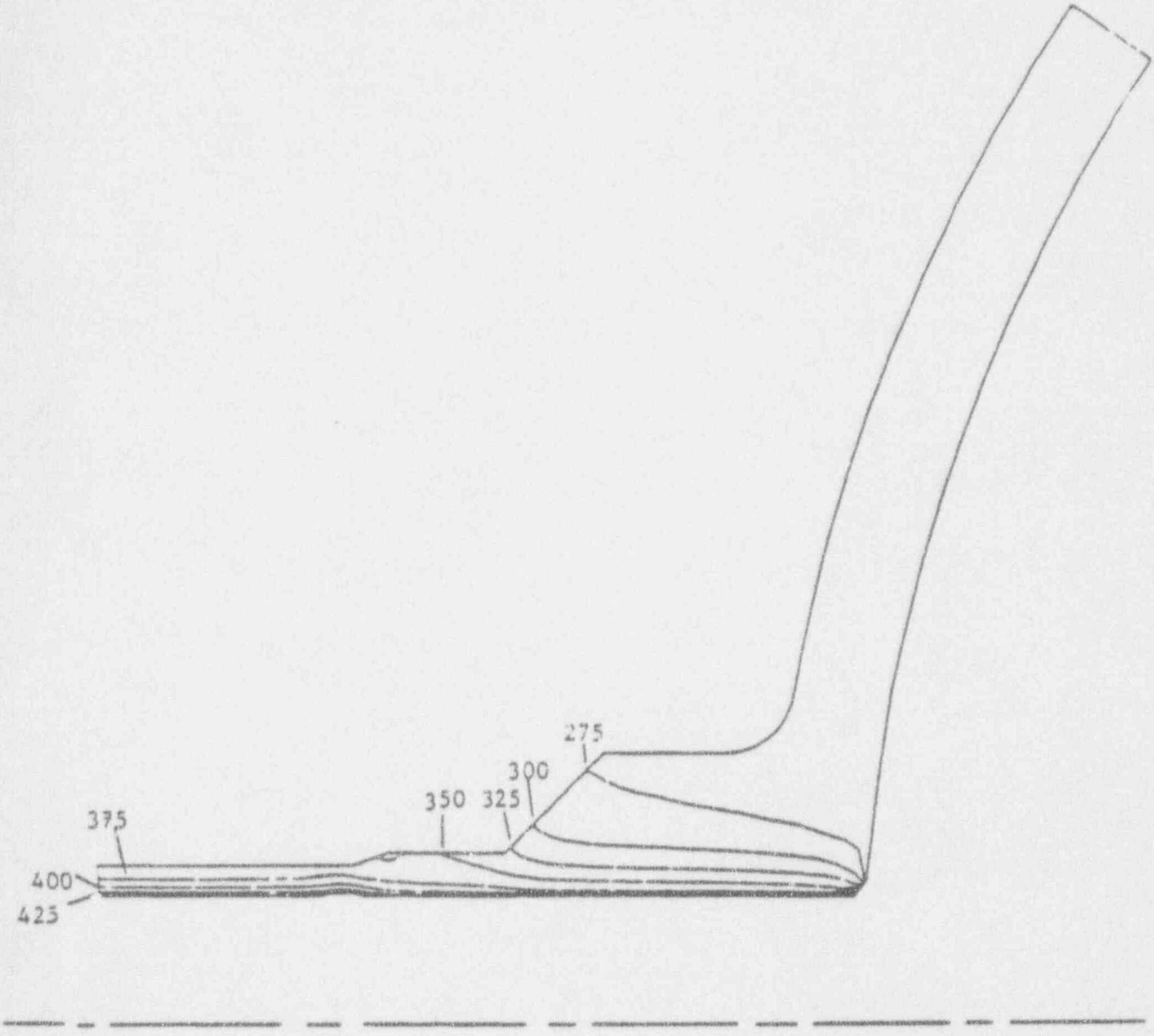
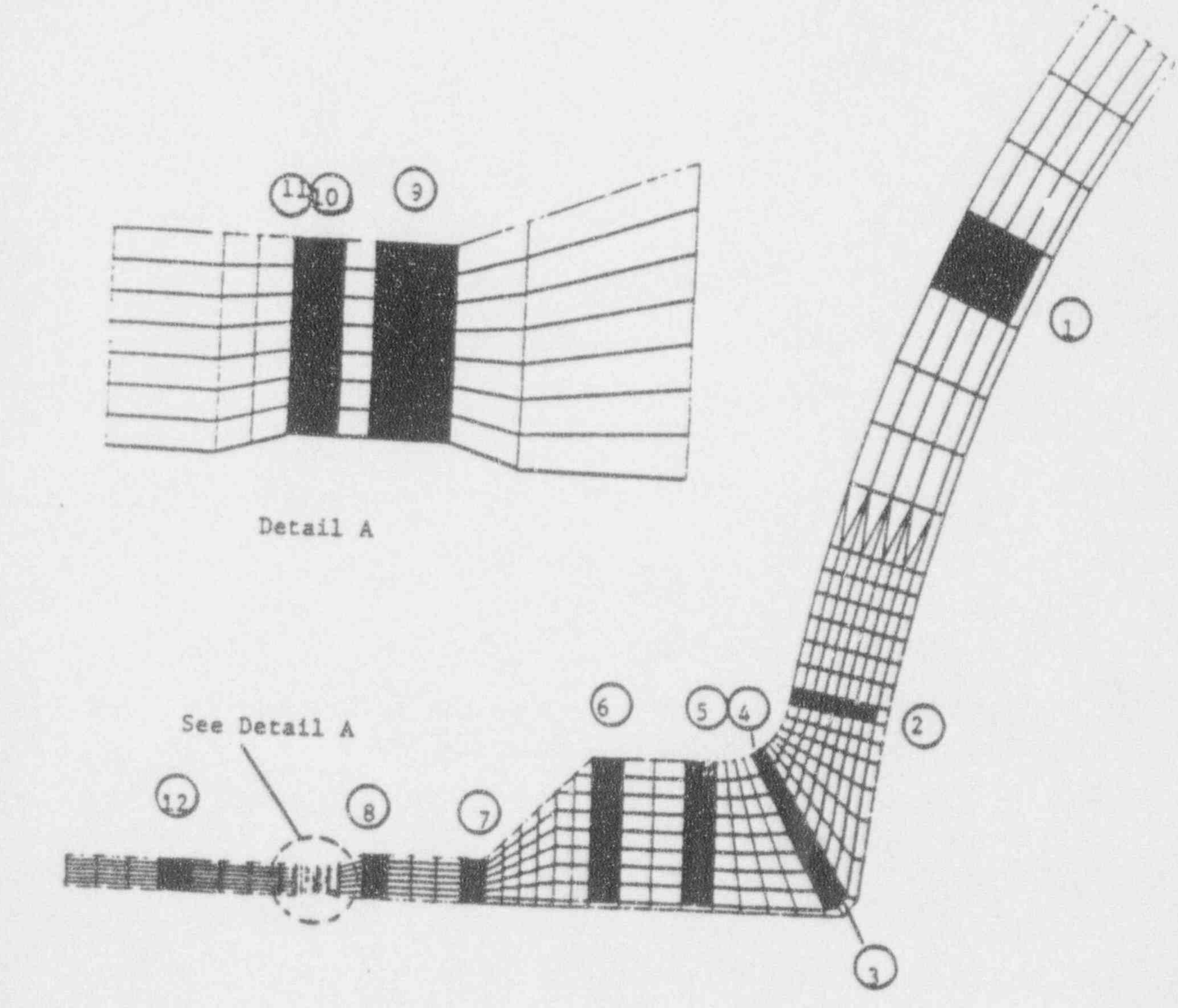


Figure 6-13. Location of Stress Classification Lines

(Hot Leg Surge Nozzle)



7. SUMMARY OF RESULTS

The B&W Owners Group developed a program to comprehensively address the requirements of NRC Bulletin 88-11, "Pressurizer Surge Line Thermal Stratification." The Owners collected the necessary information required to evaluate the surge line. In addition to operational records and plant design information, plant thermal stratification data and thermal striping test data were obtained.

It was determined that the lowered-loop plant configuration and plant operations are sufficiently similar for a generic development of the design basis transient. The subsequent analysis and results for the lowered-loop plants was documented in BAW-2127 of December 1990.

However, Davis-Besse Unit 1 (DB-1), a raised-loop plant required its own instrumentation and a separate, plant-specific, set of design basis transients because of inherent differences in its design. These differences are discussed in Section 3 of both the main report (BAW-2127) and this supplement. The Davis-Besse Unit 1 analysis has been addressed in this supplement to the main report.

Revised surge line design basis transients accounting for plant evolutions affecting the surge line for the 40 year design life of Davis-Besse Unit 1 were developed. The plant heatup and cooldown transients were the most significant contributor to the fatigue usage factor for surge line components.

A structural loading analysis of the surge line was performed to take into account the global effects due to thermal stratification. The resulting internal forces and moments were applied for the fatigue stress analysis of the surge line and the associated nozzles.

The fatigue stress analysis considered the stress ranges for the global effects due to thermal stratification, the localized effects due to thermal stratification, the pressure ranges, the Operating Basis Earthquake, the thermal striping and the fluid flow conditions. All resulting stress intensities were shown to be within their allowable limits. As a result of the fatigue analyses, the cumulative usage factor is less than 1.0 at all locations of the surge line and its nozzles.

In summary, the following is a tabulation of the highest usage factor for the most important surge line components of Davis-Besse Unit 1.

Surge Line Component	Usage Factor (40 year Life)
Surge Line Elbow	0.64
Straight Pipe Section	0.76
Drain Nozzle Branch Connection	0.17
Stanchion	0.26
Pressurizer Nozzle	0.93
Hot Leg Nozzle	0.81

In view of the conservatism accumulated in the synthesis of the design transients and in the analysis of resultant stresses, these fatigue usage values provide assurance that the 40 year licensed life of Davis-Besse Unit 1 will be met with acceptable margin to accommodate normal variations in operations.

8. BASES FOR THE DAVIS-BESSE 1 ANALYSIS

The generation of the revised Design Basis transients and the thermal stratification fatigue stress analysis of the surge line for Davis-Besse Unit 1 were based on conditions stated in this section.

The thermal stratification fatigue stress analysis was based on the following:

For past operations, limitations to motion from supports, restraints, and snubbers were identified and taken into account. The following were included in the analyses:

External Loadings

- Restraint clearances with the restraint structures and the secondary concrete wall were taken into account throughout the history of operation. These restraint clearances were evaluated and extended unchanged from the last measurements until the 9th Refueling Outage (9RFO). After 9RFO, the analysis assumes that no interference with other structures will occur.

- An interference between snubber PSU-R1 stanchion and the D-ring wall resulting in failure of the snubber occurred in 1984. The interference dimensions were taken into account in limiting surge line displacement for all heatups and cooldowns until redesign of the snubber and elimination of this potential interference in 1984.

- Apart from the interference resulting in failure of snubber PSU-R1 in 1984, both past and future transients are based upon the amplitudes of surge line displacements within the free travel range of each snubber.

- Limitations on surge line downward displacement by reaching the hard stop limit of spring support PSU-H1 were taken into account for all transients to the 9RFO. After 9RFO, modifications to the spring support will eliminate this limit to displacement. This will be performed by moving the hanger position from the current location, upper horizontal near the riser, to a location near the riser elbow in the lower horizontal piping run where there is more working area. The new location will use a spring hanger which will accommodate the worst case thermal displacement of the line at this point.

- Branch moments at the surge line drain nozzle connection within their respective maximum allowable (for deadweight, Operating Basis Earthquake, and thermal stratification) were assumed for past and future transients.

Thermal Response

Surge line thermal response on Davis-Besse Unit 1 differs from the lowered-loop plants and the measurements in Oconee 1 in two respects:

1. The surge line insulation and restraint impact collars result in increased heat loss, particularly noticeable in the lower horizontal run of the surge line as the plant temperature increases.

2. The makeup pumps during the heatup following the 6RFO were placed under automatic control immediately prior to initiating reactor coolant pump operations. The resultant makeup flow was cyclic, varying around the pressurizer water level setpoint and resulting in periodic reversals of flow in the surge line during most of the heatup.

The results of these observations were taken into account in the analysis in the following manner:

- The thermal responses due to makeup valve cycling measured following the 6RFO were conservatively taken into account although it is known that in some past heatups the valve was maintained in manual and the significant cycling during the heatup did not occur.

- Similarly, the measured temperatures representing the heat losses through the thermal insulation in addition to potential cooling effects from the PORV inlet drain were taken into account extending through the 9RFO.

- Also, for transients following the 9RFO, the stratification temperature differences in the piping during steady reactor operation will be reduced to values approximating those measured in Oconee 1 and used in the analyses for the lowered-loop plants. The improvement will be accomplished through upgrading in the thermal insulation at the time of modifications of the whip restraints to ensure freedom from interference.

- The top-to-bottom temperature profiles on the Davis-Besse surge line have been more nearly linear than those observed during the instrumented heatups at Oconee 1. With the improvements in insulation, the conditions in the Davis-Besse surge line will more nearly resemble those at Oconee 1. Hence, the non-linear profile developed for Oconee 1 was conservatively applied to the Davis-Besse analytical model for the operations following the 9RFO.

Toledo Edison has committed to making the plant modifications necessary to ensure the validity of the bases stated above for future transients in terms of structural and support interferences and insulation.

Toledo Edison will monitor the surge line temperature following the restraint and insulation modification to confirm that surge line thermal response adequately supports the conclusion that striping fatigue does not challenge the full 40-year licensed lifetime of Davis-Besse Unit 1.

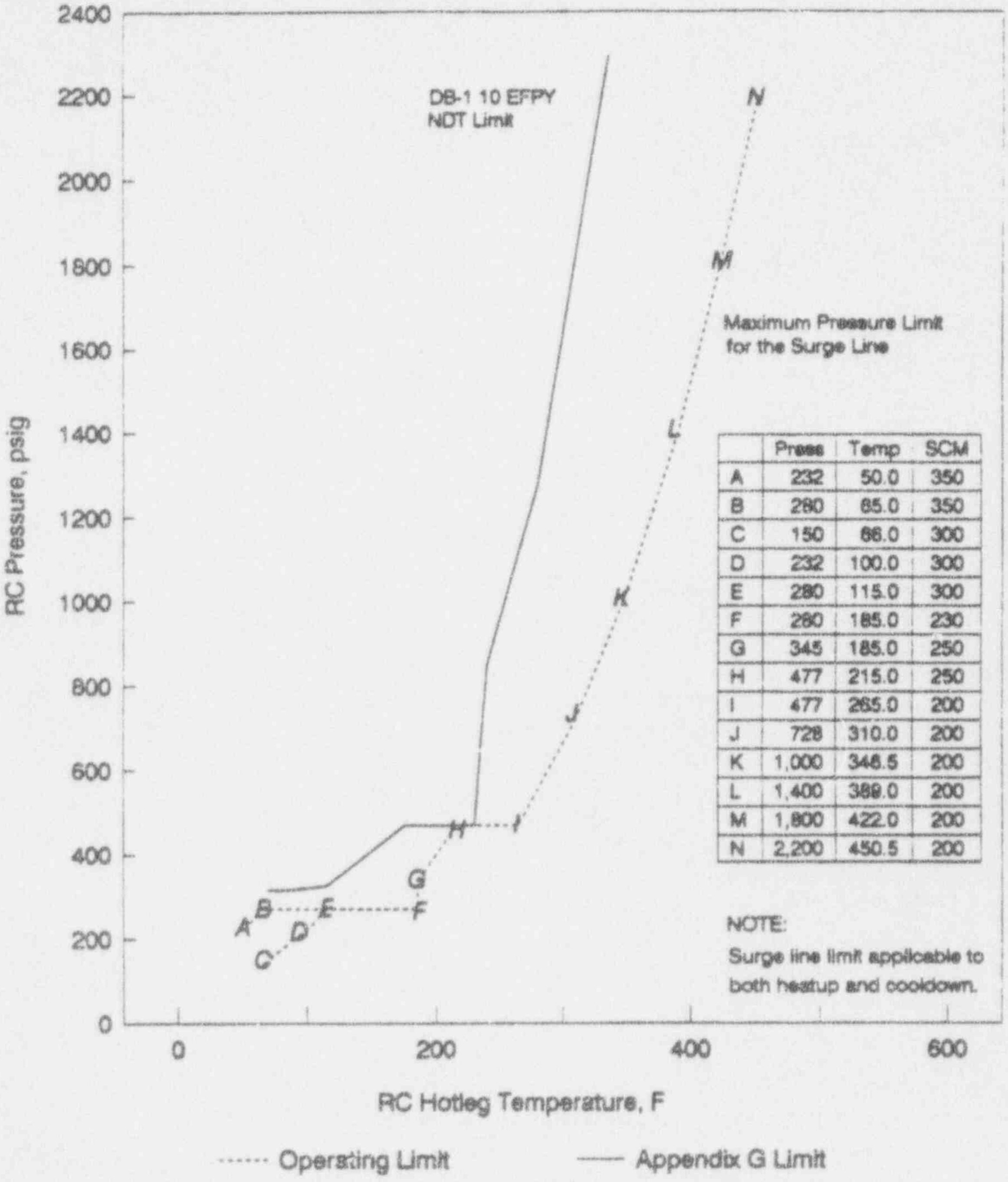
Operating Limits

The generation of the revised Design Basis Transients (for future events) was based on operating guidelines that limit the pressurizer to RCS temperature difference during plant heatups and cooldowns (imposed with RCS pressure/temperature limits).

The heatup and cooldown Design Basis transients defined for future operation will remain conservative if the RCS pressure is limited in accordance with Figure 8-1. The curve shown in Figure 8-1 is a composite of various subcooling limit curves that vary over the range of RCS temperatures. The operating procedures at Davis-Besse have been revised to maintain pressure and temperature during heatup and cooldown operation to the right of the selected maximum allowed subcooling limits. (The curve shown is similar to that developed for the lowered-loop plants except that a somewhat more restrictive limit of 280 psig has been placed on the pressurizer pressure when the RCS temperature is below 185F. This limit is consistent with the normal plant operations since the pressure is normally limited in this range of temperatures to avoid lifting the Decay Heat Removal relief valves, which provide protection against overpressure at low RCS temperatures.)

To meet the pressure limit specific for heatup in the temperature range 70F to 150F, preheating the RCS has been recommended. This may be accomplished by throttling back on the decay heat system cooling water (i.e., component cooling water) and/or bypassing reactor coolant flow around the decay heat removal heat exchanger. The availability of decay heat and the requirements of the heatup schedule will dictate the capability of maintaining the recommended P/T profile prior to achieving the conditions necessary for starting an RC pump. The fatigue evaluation was performed on the basis that 85% of the heatups for the remainder of the plant life can meet the recommended limit shown by path CDEN in Figure 8-1. For those heatups involving pressurization at an RC temperature of 70F to 120F, a less restrictive limit is included in order to permit RC pump operation at lower RCS temperatures (path ABEN in Figure 8-1) when core decay heat is not adequate for raising RC temperature. The fatigue evaluation was performed on the basis that 15% of the heatups for the remainder of the plant life will follow this heatup path. In summary, future heatups were divided into path CDEN (85%) and path ABEN (15%).

Figure 8-1. Surge Line Operational Limit



	Press	Temp	SCM
A	232	50.0	350
B	280	65.0	350
C	150	66.0	300
D	232	100.0	300
E	280	115.0	300
F	280	185.0	230
G	345	185.0	250
H	477	215.0	250
I	477	265.0	200
J	728	310.0	200
K	1,000	348.5	200
L	1,400	389.0	200
M	1,800	422.0	200
N	2,200	450.5	200

NOTE:
Surge line limit applicable to both heatup and cooldown.

9. REFERENCES

1. BAW-2127, Final Submittal for Nuclear Regulatory Commission Bulletin 88-11 "Pressurizer Surge Line Thermal Stratification," December 1990.

2. NRC Bulletin 88-11, "Pressurizer Surge Line Thermal Stratification," December 20, 1988.

3. BAW-2085, "Submittal in Response to NRC Bulletin 88-11, Pressurizer Surge Line Thermal Stratification," May 1989.

4. NRC Letter dated May 18, 1990, J. T. Larkins to M. A. Haghi, "Evaluation of Babcock and Wilcox Owners Group Bounding Analysis Regarding NRC Bulletin 88-11."

5. "ANSYS" Computer Code, Versions 4.1c and 4.3. Engineering Analysis System, User's Manual Volumes I and II, Swanson Analysis Systems, Inc.

6. "ASME Boiler and Pressure Vessel Code," Section III, 1986 Edition with no Addenda.

7. J. B. Truitt and P. P. Raju, "Three-Dimensional Versus Axisymmetric Finite-Element Analysis of a Cylindrical Vessel Inlet Nozzle Subject to Internal Pressure -- A Comparative Study," ASME Pressure Vessel and Piping Division, Paper No. 78-PVP-6.

8. BAW-2127, Supplement 1, Plant-Specific Analysis in Response to Nuclear Regulatory Commission Bulletin 88-11 "Pressurizer Surge Line Thermal Stratification" Davis-Besse Nuclear Power Station Unit 1, September 1991, B&W Owners Group letter number OG-970.

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APPENDIX I.

A. Surge Line Data Acquisition at Davis-Besse Unit 1

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1. Thermocouple Fabrication and Qualification A-2
2. Displacement Transducer Description A-3
3. Data Acquisition System Description and Operation A-3
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Davis-Besse Unit 1 was instrumented extending the B&WOG program data as discussed in Section 3.1. This appendix supplements Section 3.1 with additional detail on the data acquisition.

1. Thermocouple Fabrication and Qualification

The thermocouple assemblies and associated extension wire assemblies required for instrumenting Davis-Besse Unit 1 were fabricated by B&W Nuclear Service Company. Thermocouple assemblies were fabricated from ANSI Type K, 20 gage solid Chromel-Alumel commercial grade assembly wire having parallel conductors individually insulated with ceramic fiber braid, an overall jacket of ceramic fiber braid and stainless steel protective overbraid. The thermocouple junction was mechanically formed and then spot welded to a band which was later strapped around the surge line. Standard 2-pole connector plugs with integral cable clamp were attached to the ends of the thermocouple wires opposite the hot junction. Thermocouple extension cable assemblies were fabricated from ANSI Type K, 20-gage solid Chromel-Alumel commercial grade extension wire having twisted connectors individually insulated with Tefzel, Mylar-backed aluminum foil shielding with drain wire, and an overall extruded Tefzel insulation jacket.

Qualifying the commercial grade thermocouples fabricated for the safety-related pressurizer surge line temperature measurement application was accomplished by the standard practice of "type" testing. In this approach, duplicate thermocouple assemblies prepared from the same materials and following the same procedures that applied to fabricating the thermocouples installed at Davis-Besse were placed in a furnace (Jofra Temperature Calibrator) with certified Platinum Resistance Thermometers (RTDs) and heated. Comparison between the temperature registered by these qualification test thermocouples and the reference temperature monitored by the RTDs provided a means of qualifying the surge line thermocouples. The furnace was set to ramp to a new level at a rate of 10 F or 20 F per minute to temperatures levels between 75F and 700F. At each test level, the temperature was allowed to stabilize within 1F for 3 minutes. The test setup was then allowed to equilibrate for at least 5 minutes before the reference and test specimen temperatures were recorded.

Comparison of thermocouple data and the RTD reference indications demonstrated that thermocouple readings were consistently within 1.5F of the reference temperature. This agreement was well within the established acceptance criteria at all test conditions for qualifying surge line thermocouples.

2. Displacement Transducer Description

The displacement transducers manufactured by Celesco Transducer Products, Inc., (Model PT101) provide an electrical signal proportional to the linear extension of a stainless steel cable. Displacement was measured by attaching the cable to the surge line and the body of the transducer to a fixed surface. Retraction is effected by means of a constant tension spring motor which maintains uniform tension on the cable. The manufacturer specified the accuracy to be within 0.25% for the expected range of surge line displacements.

3. Data Acquisition System Description and Operation

The schematic in Figure A-1 depicts the general interface of components which make up the data acquisition system. The system included a Fluke Helios mainframe controlled by a host Compaq computer utilizing LabTech Notebook software which was configured to receive the desired data. The computer and Helios mainframe, which were located in the Davis-Besse Unit 1 control room, interfaced with a remote Helios extender chassis housed in an instrumentation cabinet located in the reactor containment building near the pressurizer surge line. This instrument cabinet also contained the power supply, signal conditioning and other interfacing equipment required for the surge line thermocouples and displacement transducers.

With the system installation complete, the integrity of each instrument and acquisition component was checked. Proper electrical loop resistances for the thermocouples, lead wires, and extension cables were verified. A polarity test and a complete checkout were then performed for all instrument channels. Data collection was started before the pressurizer heaters were turned on and continued until the plant had reached power and remained there for several days. There were only short time periods in which data collection was interrupted in order to download the data from the host computer.

BWNS and Toledo Edison personnel monitored the data acquisition system to ensure proper operation. In addition, plant operations were monitored closely and the events which affected the surge line were noted. The operator and unit logs have been obtained to assist in associating plant operations to surge line transients.

4. General Description of Data

The temperature and displacement of the surge line were monitored, as well as the reactor coolant system (RCS) conditions. A list of recorded parameters is contained in Table A-1. To record surge line temperature, thermocouples were placed at eight different axial locations (shown in Figure A-2). There are two or seven thermocouples at each location as given in Figure A-2. All locations contain a thermocouple at the top (T1) and bottom (T7) of the surge line. Where seven thermocouples are used, they are spaced with equal elevation differences between thermocouples as shown in Figure A-3. The thermocouples are identified by axial location and relative position as follows: "10T7" means the thermocouple at location 10 and thermocouple position 7 as given in Figures A-2 and A-3. The displacement of the surge line was monitored with position transducers (string potentiometers) at locations noted in Figure A-2. Position transducers are identified by axial location and the measurement direction as follows: 01ZY denotes the potentiometer which indicates the Y direction movement at location 1.

Plant data have been recorded for two heatups, one cooldown and during periods of power operation. The data were stored at sampling interval times of 20 seconds. The large quantity of data (more than 200 Megabytes of disk space) was stored in ASCII format and transferred to the BWNS HP9000 Series 800 computer where the data was processed into functional information (plots, calculations, etc.).

Table A.1. Signal Identification

IDNTFR/UNITS	DESCRIPTION
02T1 F	Location 2 Position 1
02T2 F	" 2 " 2
02T3 F	" 2 " 3
02T4 F	" 2 " 4
02T5 F	" 2 " 5
02T6 F	" 2 " 6
02T7 F	" 2 " 7
03T1 F	" 3 " 1
03T2 F	" 3 " 2
03T3 F	etc.
03T4 F	
03T5 F	
03T6 F	
03T7 F	
06T1 F	
06T2 F	
06T3 F	
06T4 F	
06T5 F	
06T6 F	
06T7 F	
09T1 F	Location 9 Position 1
09T2 F	" 9 " 2
09T3 F	" 9 " 3
09T4 F	" 9 " 4
09T5 F	" 9 " 5
09T6 F	" 9 " 6
09T7 F	" 9 " 7
12T1 F	" 12 " 1
12T2 F	" 12 " 2
12T3 F	etc.
12T4 F	
12T5 F	
12T6 F	
12T7 F	
14T1 F	
14T2 F	
14T3 F	
14T4 F	
14T5 F	
14T6 F	
14T7 F	
05T1 F	Location 5 Position 1
05T7 F	" 5 " 7
10T1 F	" 10 " 1
10T7 F	" 10 " /
M1T4 F	Mirror Insulation Temperature Location 1, Thermocouple Pos.4
M2T4 F	Mirror Insulation Temperature Location 2, Thermocouple Pos.4

Table A.1. Signal Identification (cont.)

IDNTFR/UNITS		DESCRIPTION
D1T1	F	Decay Heat Drop Line Location 1, Thermocouple Pos. 1
D1T2	F	Decay Heat Drop Line Location 1, Thermocouple Pos. 2
D1T3	F	Decay Heat Drop Line Location 1, Thermocouple Pos. 3
D2T1	F	Decay Heat Drop Line Location 2, Thermocouple Pos. 1
D3T1	F	Decay Heat Drop Line Location 3, Thermocouple Pos. 1
D3T2	F	Decay Heat Drop Line Location 3, Thermocouple Pos. 2
D3T3	F	Decay Heat Drop Line Location 3, Thermocouple Pos. 3
D4T1	F	Decay Heat Drop Line Location 4, Thermocouple Pos. 1
01ZY	Inches	Location 1 Direction Y
01ZZ	Inches	" 1 " Z
04ZY	Inches	" 4 " Y
04ZZ	Inches	etc.
07ZX	Inches	
07ZY	Inches	
07ZZ	Inches	
08ZX	Inches	
08ZY	Inches	
08ZZ	Inches	
11ZX	Inches	
11ZY	Inches	
13ZX	Inches	
13ZY	Inches	
15ZY	Inches	
RS46	Percent	Auctioneered Average Power
QS85	Tripped	Turbine Trip Signal Master
T358	F	DH CLR 1 Out Temp
T361	F	DH CLR 2 Out Temp
F461g	GPM	HP INJ 1-1 Flow
F464g	GPM	HP INJ 1-2 Flow
F467g	GPM	HP INJ 2-1 Flow
F470g	GPM	HP INJ 2-2 Flow
F592	GPM	LP INJ 2 Flow
F593	GPM	LP INJ 1 Flow
LS52	Inches	Pressurizer Compensated Level
T776	F	RC PRZR Temp, RC15-1
ZS76	Position	RC PRZR Spray Line VLV, RC2
PS57	Psig	RC Loop 1 HLG WR Press
P721	Psig	RC Loop 1 HLG NR Press, RPS CH1
T753	F	RC Loop 1 HLG WR Temp, CH1
TS63	F	Tcold Wide Range, Loop 1
J788	MW	RCP 1-1 MTR PWR
J808	MW	RCP 1-2 MTR PWR
J828	MW	RCP 2-1 MTR PWR
J848	MW	RCP 2-2 MTR PWR
F722	MPPH	RC Loop 1 HLG Flow, RPS CH1
F728	MPPH	RC Loop 2 HLG Flow, RPS CH2
F719	Inches	RC Letdown Flow
F738	GPM	RC MU Flow, Low Range

Table A.1. Signal Identification (cont.)

IDNTFR/UNITS		DESCRIPTION
F740	GPM	RC MU Flow, High Range
L881	Percent	SG 1 Operate Level, 9B1
L883	Inches	SG 1 SU Range, 9B3
L891	Percent	SG 2 Operate Level, 9A1
L893	Inches	SG 2 SU Range, 9A3
T671	F	MN FW Temp to ICS,TT1-1
P931	Psig	SG 1 Out STM Press, PT12B1
TS83	F	SG 1 Out STM Temp
P936	Psig	SG 2 Out STM Press, PT12A1
TS84	F	SG 2 Out STM Temp
HXTI	F	Fluke Helios Extension Chassis inside I/O cabinet External Heat Exchanger Inlet Temperature
HXTO	F	Fluke Helios Extension Chassis inside I/O cabinet External Heat Exchanger Outlet Temperature
HITI	F	Fluke Helios Extension Chassis inside I/O cabinet Internal Heat Exchanger Inlet Temperature
HITO	F	Fluke Helios Extension Chassis inside I/O cabinet External Heat Exchanger Outlet Temperature
TP01	F	Ambient Temperature near Displacement Location 1
TP13	F	Ambient Temperature near Displacement Location 13
TR01	F	Ref Temperature in PZR room - 595′ elv
TR02	F	Ref Temperature in hallway outside D-ring - 595′ elv
TR03	F	Ref Temperature above PZR - 640′ elv
TR04	F	Ref Temperature at bottom elevation - 575′ elv
PSE1	Volts DC	20 Volt Power Supply
PSE2	Volts DC	Backup 20 Volt Power Supply
CIT1	F	Internal I/O Cabinet Temperature
CIH1	%RH	Internal I/O Cabinet Relative Humidity
REZY	Inches	Reference String Potentiometer
CXT1	F	External I/O Cabinet Temperature
CXH1	RH	External I/O Cabinet Relative Humidity
C913	Percent	Core Power
F210	MPPH	Core RC Flow
F460	GPM	HP INJ 1-1 Flow
F488	GPM	HP INJ 2-1 Flow
F489	GPM	HP INJ 2-2 Flow
F490	GPM	HP INJ 1-2 Flow
F712	MPPH	RC Loop 1 HLG Flow
F713	MPPH	RC Loop 2 HLG Flow
F717	GPM	RC Letdown Flow
F782	GPM	RCP Seal In Flow
F783	GPM	RCP Seal Ret Flow
L769	Inches	RC PRZR AVG LVL
P732	Psig	RC LOOP 2 HLG WR Press, SFAS CH 2
Q613		MFPT 1 (Main Feed Pump #1 Trip)
Q634		MFPT 2 (Main Feed Pump #2 Trip)
Q764		RC PRZR HTR SOURCE
Q810		RPS CH 1 TRIP

Table A.1. Signal Identification (cont.)

IDNTFR/UNITS		DESCRIPTION
Q818		RPS CH 2 TRIP
Q826		RPS CH 3 TRIP
Q834		RPS CH 4 TRIP
T713	F	RC AVG TEMP (120/920)
T724	F	RC Loop 1 CLG Temp (0/700)
T733	F	RC Loop 2 CLG Temp (0/700)
T753	F	RC Loop 1 HLG WR Temp, CH 1
T773	F	RC PRZR PWR RLF Out Temp, RC12-1
T774	F	RC PRZR Spray Line Temp
T775	F	RC PRZR Surge Line Temp
T777	F	RC PRZR Temp, RC15-2
T783	F	RC Loop 2 HLG WR Temp, CH 2
T885	F	SG 1 Out STM Temp
T901	F	SG 2 Out STM Temp
X038		T-G Master Turb Trip
Z768	Position	RC PRZR PWR RLF VLV
Z769	Position	RC PRZR PWR RLF Shutoff VLV
Z771	Position	RC PRZR Spray Line VLV, RC-10
L768	Inches	Pressurizer Level
F738	GPM	RC MU FLOW, Low Range
F740	GPM	RC MU FLOW, High Range
P725	Psig	RC Loop 1 HLG WR Press, SFAS CH3
R790	Mwt	Auctioneered NI Linear Power
T781	F	RCP 1-1 Dschrg CLG WR Temp, RC4B2
Z772	Position	RC PRZR Spray Line VLV, RC2
Z750	% Open	RC MU CTRL VLV
L768	Inches	Pressurizer Level

Figure A-1. Davis-Besse Data Acquisition Hardware Configuration

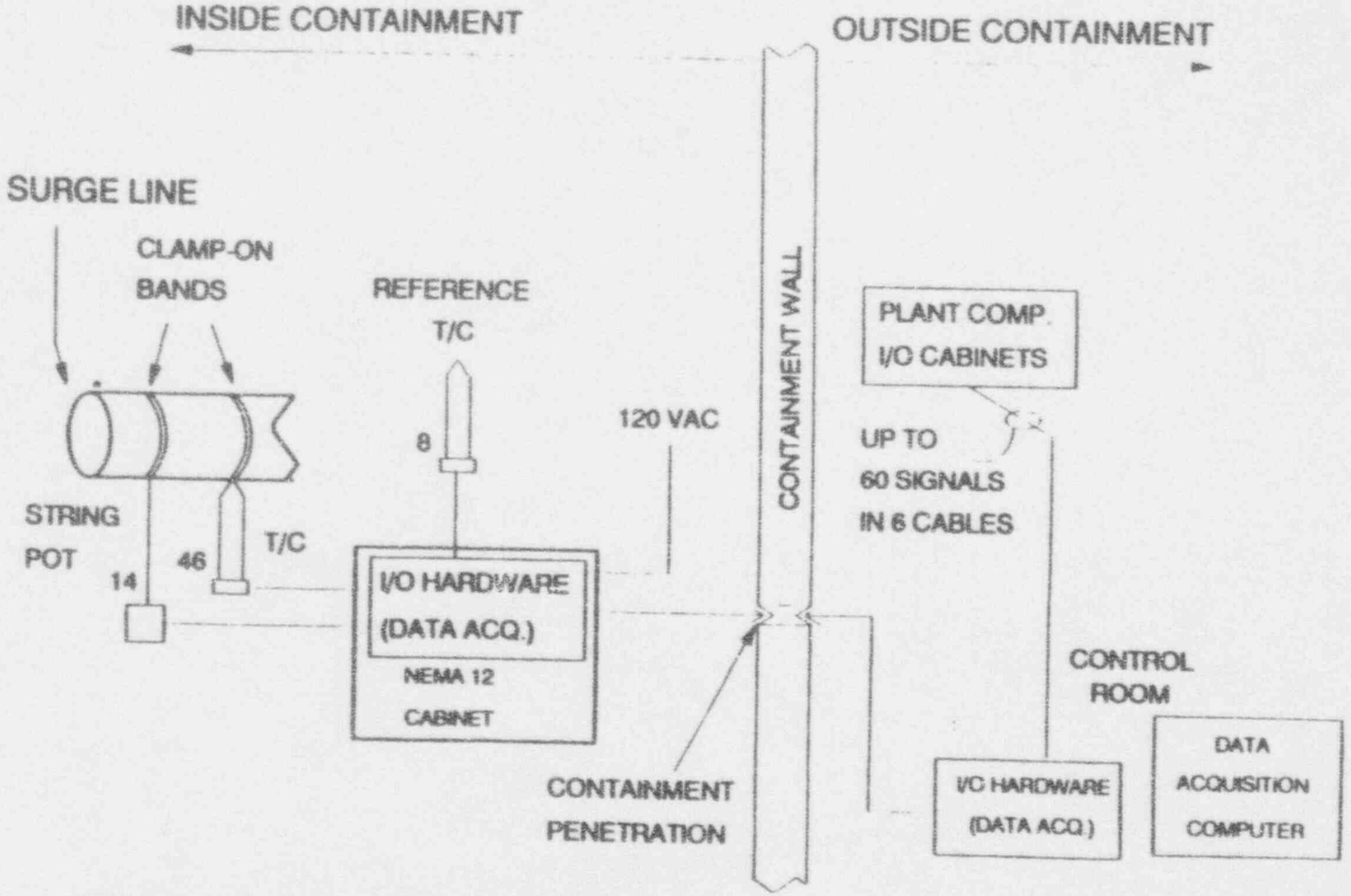
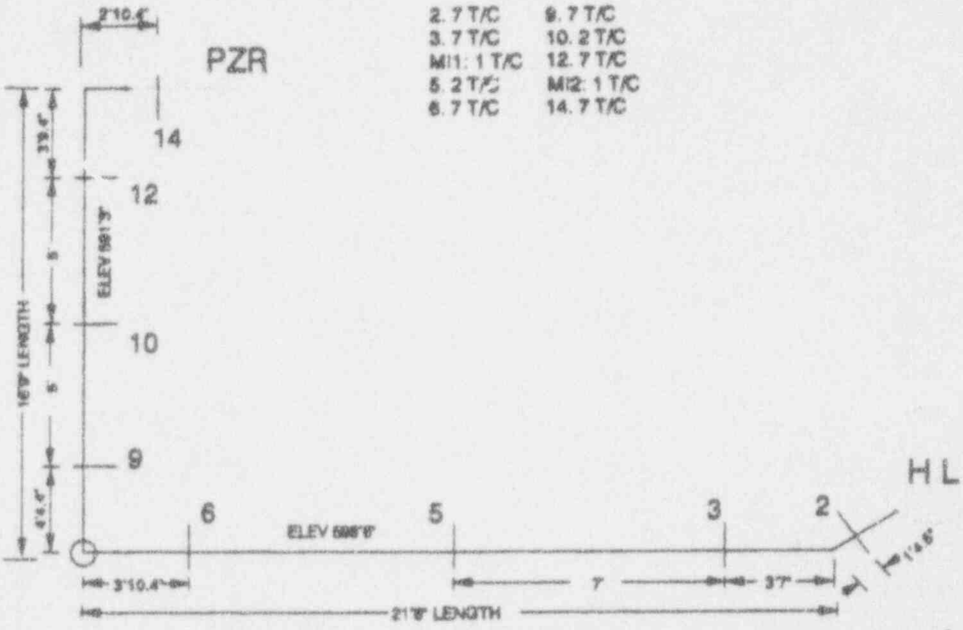
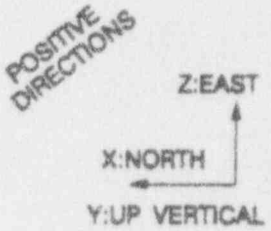
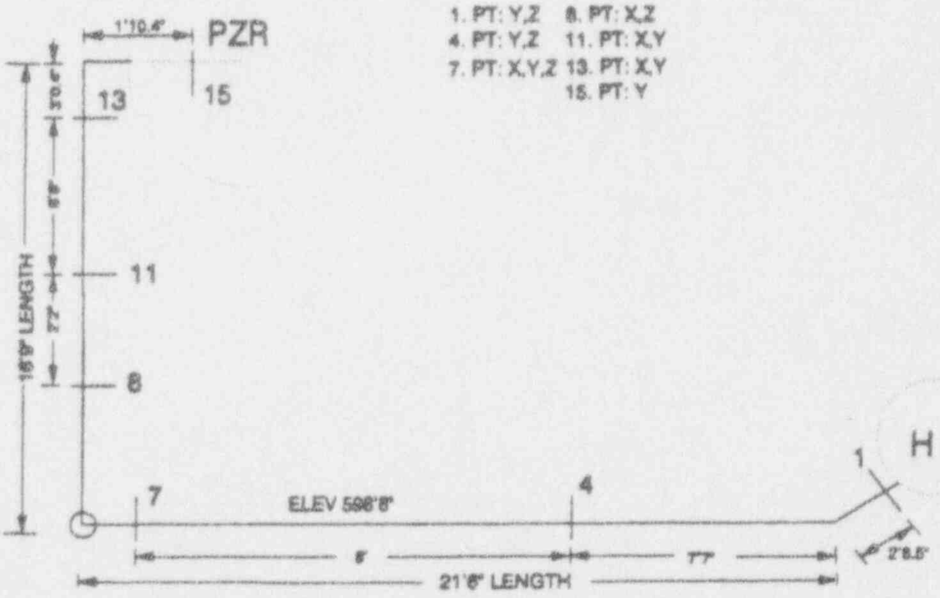


FIGURE A-2. Instrumentation Locations at Davis-Besse Unit 1



Thermocouple Locations

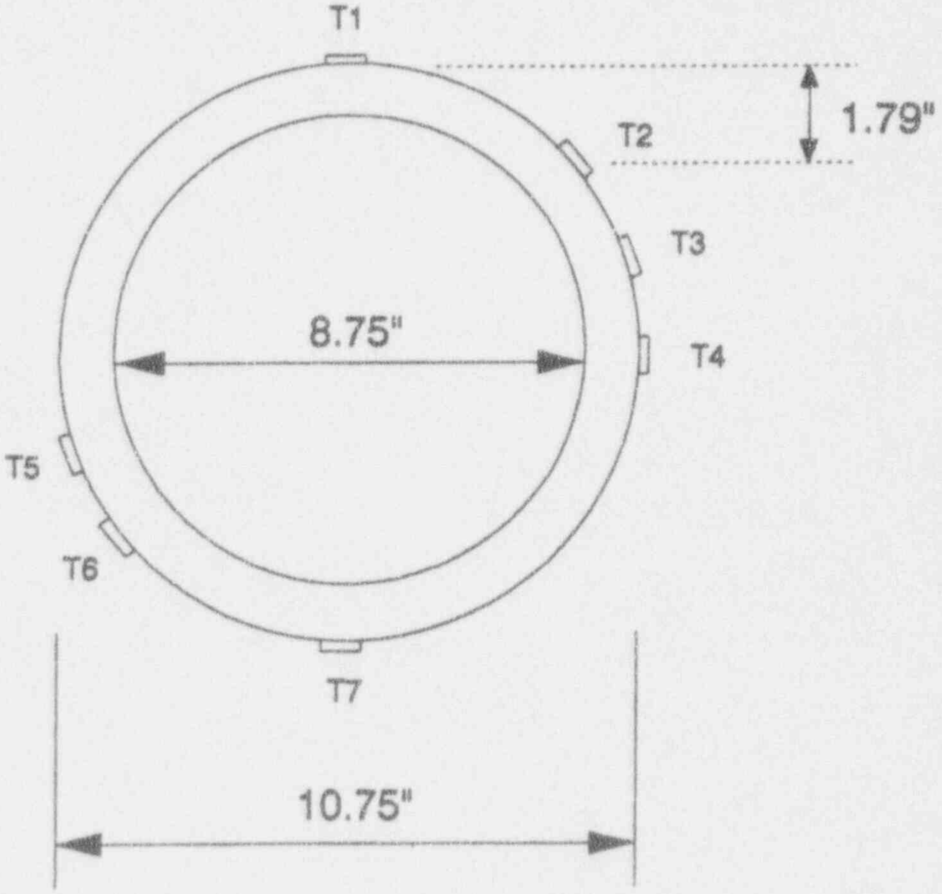




Displacement Transducer Locations

Figure A-3

Thermocouple Positions



Note: Distance between adjacent thermocouples (T1-T2, T2-T3, etc.) is 1.79".