SAFETY EVALUATION BY THE OFFICE OF NUCLEAR REACTOR REGULATION

RELATED TO THE WESTINGHOUSE OWNERS GROUP PRESSUR ZER SURGE LINE

THERMAL STRATIFICATION GENERIC DETAILED ANALYSIS

WCAP-12639

1.0 INTRODUCTION

NRC Bulletin No. 88-11 requested all PWR licensees to establish and implement a program to confirm pressurizer surge line integrity in view of the occurrence of thermal stratification and inform the staff of the actions taken to resolve this issue. Licensees of operating PWR's were requested to take the following actions:

Action 1.a - Perform a visual inspection walkdown (ASME Section XI, VT-3) at the first available cold shutdown which exceeds 7 days.

Action 1.b - Perform a plant-specific or generic bounding analysis to demonstrate that the surge line meets applicable design codes and other FSAR and regulatory commitments for the design life of the plant. The analysis is requested within 4 months for plants in operation over 10 years and within 1 year for plants in operation less than 10 years. If the analysis does not demonstrate compliance with these requirements, submit a justification for continued operation (JCO) and implement actions 1.c and 1.d below.

Action 1.c - Obtain data on thermal stratification, thermal striping, and line deflections either by plant-specific monitoring or through collective efforts among plants with a similar surge line design. If data is acquired through collective efforts, demonstrate similarity in geometry and operation.

Action 1.d - Perform detailed stress and fatigue analyses of the surge line to ensure compliance with applicable code requirements incorporating any observations from Action Item 1.a. The analysis should be based on the applicable plant-specific or referenced data and should be completed within 2 years. If the detailed analysis is unable to show compliance, submit a JCO and a description of corrective actions for effecting long-term resolution.

Although not required by Bulletin 88-11, licensees were encouraged to work collectively to address the technical concerns associated with this issue. In response, the Westinghouse Owners Group (WOG) implemented two programs to address the issue of surge line stratification in Westinghouse plants. In the first program, a generic bounding evaluation was performed to satisfy Bulletin Action Item 1.b. Since the results of this evaluation did not provide verification of safe operation for the design life of the affected plants, this report was used later by each of the WOG plants as the technical basis for justifying continued operation. Based on this evaluation, it was deemed acceptable for all WOG plants to continue power operation for at least ten additional heatup/cooldown cycles. The bounding analysis methods and results were summarized in a Westinghouse topical report, WCAP-12277, which was submitted to the staff in June 1989. The staff reviewed the report and concluded that the bounding evaluation provided a sound technical basis for justifying continued operation until completion of action Item 1 d of Bulletin 88-11 by the end of 1990. This report, combined with acceptable plant-specific visual inspections, satisfied Bulletin Actions 1.a and 1.b for all Westinghouse plants.

The second WOG program was implemented to develop a detailed analysis of the surge line to demonstrate ASME Code compliance for the design life of plants and to satisfy Bulletin Actions 1.c and 1.d. The program provided stress and fatigue evaluations in accordance with the ASME Code based on individual detailed analyses of groups of plants. The methodology and results of the generic detailed analysis were summarized in WCAP-12639 which was submitted to the NRC in June 1990. The staff reviewed the WOG report and conducted an audit at Westinghouse in November 1990. The following section summarizes the NRC staff evaluation of the program.

2.0 NRC STAFF EVALUATION

The WOG generic detailed analysis was applicable to 43 of the 55 Westinghouse plants. Plant-specific analyses had been previously performed for the other 12 plants. In order to reduce the analytical efforts, the 43 plants were categorized into 17 analysis groups based on their similarity of response to thermal stratification. The WOG program involved the development of updated design transients to account for stratification and striping, and the analysis of each structural group for global and local stresses for verifying ASME Code compliance in calculating stress and fatigue. Individual licensees are responsible for demonstrating applicability of the WOG generic analysis to their specific plants. The major areas of staff review and evaluation are summarized below.

2.1 Update of Design Transients

Westinghouse updated their design transients for the pressurizer surge line to reflect stratification effects. Two major categories of transients were considered: heatup and cooldown transients and normal and upset transients. For each design transient, the original assumption of a uniform temperature distribution was modified to represent a stratified temperature distribution with a corresponding number of cycles. In addition, Westinghouse developed a new set of transients for thermal striping.

The development of updated transients used information from an operational study and the results from several plant monitoring programs. In the operational study, Westinghouse reviewed heatup and cooldown procedures as well as historical records from several plants. Heatup and cooldown operation was of primary concern because the maximum temperature difference between the pressurizer and the hot leg occur during these modes. In addition, Westinghouse conducted interviews with reactor operators and shift supervisors at a representative sample of plants to gain additional insight into the variation of operating methods.

Based on a review of the plant geometries at a number of Westinghouse plants and earlier monitoring experience gained in plant-specific programs, Westinghouse provided recommendations to the affected licensees regarding the need for additional monitoring data to cover all variations of WOG plants. Westinghouse received surge line monitoring data from a total of 21 domestic plants. Typical monitoring programs involved the installation of temporary sensors on the surge line piping. Externally mounted resistance temperature detectors (RTDs) or thermocouples were attached to the outside surface of the surge line at various circumferential and axial locations. These sensors provided data on the top to bottom temperature distribution along the longitudinal axis of the pipe. Several plants also installed sensors to detect vertical and horizontal movements at locations along the pipe axis. Data was typically collected at frequent intervals during heatups and cooldowns when the system differential temperatures were high. Data was also collected during steady-state operation but at a reduced frequency. In addition, existing plant instrumentation was used to record various system parameters for correlation of plant operation actions with thermal stratification in the surge line. The data was typically provided to Westinghouse in tabular form or in time history plots.

In updating the analysis of heatup and cooldown transients, the total assumed number of heatup-cooldown cycles remained unchanged (200). However, sub-events and the associated number of occurrences were redefined based on historical records and monitoring data. Westinghouse reviewed operating records from 10 plants to determine a conservative estimate of the range of differential temperatures to be used over the design life of the affected plants. Monitoring data from 10 plants was analyzed to develop a bounding distribution of cycles at various ranges of relative strength of stratification (ratio of pipe ΔT to system ΔT). The information was used to develop a table of numbers of cycles at various maximum stratification ΔT values for heatup/cooldown cycles for the design life of the plants.

In updating the normal and upset transients, Westinghouse redefined the fluid conditions based on the existing design transient system parameters and the knowledge gained from the monitoring programs. The redefined fluid conditions conservatively accounted for thermal stratification. The result of this effort was a table of maximum stratification ΔT values and corresponding cycles for all normal and upset transients. Westinghouse reviewed the monitoring data to verify that all recorded normal or upset transient data was enveloped by the updated design transients.

Westinghouse developed a new set of transients for thermal striping. The frequency of fluid oscillation was conservatively derived from various experimental studies referenced in WCAP-12639. Westinghouse assumed that each stratification transient would initiate striping oscillations. The differential temperature was assumed to be the full ΔT which would decrease with time because of conduction between the hot and cold layers of fluid. The attenuation of thermal striping was factored into the assumption regarding the amount of time that each level of ΔT would exist. The end result was a table of striping transients correlating the number of initiation cycles with several ΔT levels.

The staff reviewed the methodology and raised several questions which were discussed during the November 1990 audit at Westinghouse. During the audit, the staff also reviewed some of the monitoring data and other related documentation. Based on the review of the information provided during the audit, all NRC staff concerns were adequately resolved. The staff found the methodology used by Westinghouse to update design transients to be acceptable. Westinghouse used conservative methods and assumptions to incorporate thermal stratification into their normal and upset transients. To the extent possible, monitoring data was used to confirm the conservatism of the revised normal and upset transients. The definition of thermal striping transients was based on the conservative application of experimental data and anticipated stratification conditions in the surge line. The development of updated heatup and cooldown transients relied heavily on plant monitoring data, procedural limits and historical data. By considering distributions of maximum system ΔT and relative strengths of stratification observed in several plants, Westinghouse developed a reasonably conservative correlation of the cf number of cycles at corresponding maximum stratification ΔT values for heatups and cooldowns during the life of a plant. To provide additional confidence, each licensee will be required to review their operating records and procedures to verify that the input and assumptions of the generic analysis are applicable to their specific plant.

2.2 Pipe Stress Analysis

In order to minimize the number of analyses, Westinghouse divided the 43 plants into 17 analysis groups based on the similarity of plant design and the response to stratification as noted above. The three major parameters considered in establishing the groups were structural layout and support design, axial temperature profile distributions, and thermal transients from plant operation. During the audit, the staff reviewed the guidelines for defining enveloping design configurations and found them to be conservative.

For thermal stratification loading, the piping analysis was divided into two parts. The global piping system analysis addressed the restraint effects from pipe supports on the piping system. The local thermal stress analysis considered the effects of the non-linear temperature gradient in the pipe at several locations, including structural discontinuities. In the global analysis, a piping model which typically included pipe, elbow, linear and non-linear support elements was prepared for each of the 17 analysis groups. Bounding thermal stratification loadings were defined and applied. The results provided maximum pipe loads at critical locations for each group.

The local thermal stress analysis determined the local axial stresses which result from the step change in temperature that occurs at the hot-to-cold interface along the pipe including the structural discontinuity stresses in the nozzle transition region. Westinghouse developed detailed finite element models of the surge line piping and hot leg nozzles to calculate these local thermal stresses. A number of thermal stratification load cases were defined and analyzed to determine temperature and thermal stress distribution. The results of the global and local stress analyses were combined as needed to perform the ASME Code evaluation.

Stresses and fatigue usage due to thermal striping were evaluated separately. The fluid ΔT and corresponding number of cycles of striping initiation transients were developed from design transients and plant monitoring data. Initially, the striping differential temperature was assumed to be the full ΔT which decreased with time because of conduction between the hot and cold layers of fluid. A striping attenuation curve was developed, and for each striping initiation cycle, the ΔT was assumed to follow this curve in five degree temperature steps. The total number of striping cycles at each five degree step were determined by multiplying the number of striping initiation cycles which have a temperature step at that level, by the frequency of striping oscillation and amount of time that the ΔT existed at that step. The frequency of oscillation was based on values observed in water model flow tests performed for the Liquid Metal Fast Breeder Reactor and in experimental studies of thermal striping which were performed in Japan by Mitsubishi Heavy Industries. Thermal striping stresses were determined by finite element analysis and by a Westinghouse computer program, STRFAT2. Stresses were intensified by the appropriate ASME Code stress indices for peak stress.

During the NRC audit at Westinghouse, the staff reviewed sample calculations covering key analysis methods and assumptions. This included the methodology for heat transfer and stress analysis, calculations for determining heat transfer film coefficients for thermal stratification and striping conditions, the models used in the striping analysis, and the technical basis for the attenuation curve used in the striping analysis. The staff found the methodology and assumptions to be reasonably conservative, and therefore, acceptable.

2.3 ASME Code Evaluation and Results

The stress and fatigue evaluation was based on the ASME Code, Section III, 1986 Edition. Westinghouse generally applied the methods of NB-3200 to evaluate the surge line components and reported the results in terms of the NB-3650 piping stress equations. Stresses were classified in accordance with Code guidelines using stress indices from NB-3680 where appropriate. Stresses due to pressure, bending moments, and thermal loads were combined when checking against the limits of Code Equations 12 and 13, cumulative fatigue usage and thermal stress ratchet requirements.

The results of the evaluation were presented in WCAP-12639. Westinghouse concluded that all analysis groups met the thermal stress ratchet requirements.

However, only 15 plants in five groups met the Equation 12 and cumulative fatigue usage factor limits. For Equation 13 qualification, Westinghouse determined limiting values for the resultant moments due to deadweight and the operating basis earthquake (OBE) for the plant groups that met the other limits. Therefore, each of these 15 plants must demonstrate that their plant-specific OBE and deadweight moments in the surge line are enveloped by values used by Westinghouse.

The staff reviewed the Code evaluation results and agreed that they provide an acceptable basis for qualification of the surge lines for the 15 plants, subject to plant-specific verification of the applicability of the generic analysis and completion of additional plant-specific evaluations needed to address items not covered by the generic analysis.

2.4 Applicability Demonstration

For the 15 plants which were found acceptable by the WOG generic detailed analysis, Westinghouse provided guidelines regarding additional work that licensees should perform to verify applicability of the generic analysis for their specific plant and to complete additional evaluations which were outside of the scope of the WOG generic analysis. These guidelines are summarized below.

Licensees should review past operating records to verify that system ΔT values for their individual plants have not exceeded the maximum system ΔT used in the Westinghouse analysis. They should also verify that the operational methods used in the WOG generic analysis is applicable to their plant. It is expected that the system ΔT will be controlled in the future by plant operating procedures to minimize the possibility of exceeding the ΔT values assumed in the analysis. In this regard, WCAP-12639 provided a list of operational recommendations to minimize the chances for exceeding these system ΔT values in the future.

Each plant must demonstrate adequacy of its pipe supports and the acceptability of calculated piping displacements. Additional plant-specific piping analysis may be needed to determine these loads and displacements. Licensees must verify that seismic OBE moments assumed in the Westinghouse fatigue analysis are applicable to their plants or are conservative. Allowable resultant moment values for combined deadweight and OBE loadings at the hot leg nozzle safe end weld must be checked.

The WOG generic detailed analysis did not address the effects of thermal stratification on the evaluation of stress and fatigue at integral welded attachments (e.g., lugs, plates) or on the pressurizer nozzle. Plant-specific evaluations of these areas are needed to complete the surge line qualification.

Plant-specific detailed analysis must be performed for all plants that were not shown acceptable under the generic analysis. For some plants, modifications may be necessary.

The staff reviewed the above plant-specific applicability requirements and agreed with the Westinghouse recommendations.

3.0 CONCLUSIONS

Based on the review of the WCAP-12639 and additional information provided by Westinghouse during the November 1990 audit, the staff concludes that the WOG methodology for evaluation of stress and fatigue effects on the surge line due to thermal stratification and thermal striping is acceptable. The WOG generic detailed analysis demonstrated acceptable compliance with stress and fatigue usage as determined by Equation 12 of Code Case NB-3650 of Section III of the ASME Code in the surge line and the reactor coolant loop nozzle for the following 15 plants:

Zion 1 & 2	Haddam Neck
Salem 1 & 2	Millstone 3
McGuire 1 & 2	Ginna
Catawba 1 & 2	San Onofre 1
Prairie Island 2	Wolf Creek
Callaway	

For these plants, the WOG generic detailed analysis program results can be used to satisfy the requirements of Action Items 1.c and 1.d of NRC Bulletin 88-11, provided that plant-specific applicability is demonstrated and additional evaluations which were not included as part of the WOG program are performed.

Applicability requirements include:

- o A review of operating records to ensure that system ΔT limits assumed in the Westinghouse analysis were not exceeded
- o A verification of operational methods to ensure that they are consistent with the methods assumed in the Westinghouse analysis. Limits on system ΔT are recommended for future plant operation.
- o A verification of the applicability of the seismic OBE bending moments used in the Westinghouse fatigue analysis, including a verification that the combined deadweight and OBE moments at the hot leg nozzle for the individual plants do not exceed the values used in the Westinghouse analysis.

Additional plant specific evaluations to be performed include:

- o An evaluation of the adequacy of pipe support loads and pipe displacements.
- o An evaluation of the effects of thermal stratification on the stress and fatigue usage at integral welded attachments (e.g., lugs, plates).
- o An evaluation of the effects of thermal stratification on the stress and fatigue usage of the pressurizer nozzle.

A total of 28 Westinghouse plants could not be shown acceptable by the WOG generic analysis. They include the following plants:

D.C. Cook 1 & 2	Indian Point 2 & 3
Farley 1 & 2	Turkey Point 3 & 4
H.B. Robinson 2	Kewaunee
Shearon Harris	Yankee Rowe
Byron 1 & 2	V.C. Summer
Braidwood 1 & 2	Sequoyah 1 & 2
Watts Bar 1 & 2	North Anna 1 & 2
Surry 1 & 2	Point Beach 1 & 2
Prairie Island 1	

This group of plants will require plant-specific analysis to demonstrate compliance with the applicable ASME Code. It is anticipated that some of these plants can be shown to be acceptable by removing some of the conservatisms inherent in the generic approach. It is likely, however, that some of these plants will require modifications.