REVIEW OF WESTINGHOUSE OWNERS GROUP (WOG) BOUNDING EVALUATION FOR PRESSURIZER SURGE LINE THERMAL STRATIFICATION WCAP-12277

INTRODUCTION

The pressurizer surge line (PSL) in the pressurized water reactors (PWRs), is a stainless steel pipe, connecting the bottom of the pressurizer vessel to the hot leg of the coolant loop. The out flow of the pressurizer water is generally warmer than the hot leg flow. Such temperature differential (ΔT) varies with plant operation activities and can be as high as 320° F during the initial plant heat up. Thermal stratification is the separation of cold flow stream in the horizontal portion of the PSL resulting in temperature difference at the top and bottom of the pipe. Since thermal stratification is the direct result of the differences in densities between the pressurizer water and the hot leg water, the potential for stratification is increased as system ΔT increases and as the insurge or outsurge flow decreases. Stratification in PSL was found recently and confirmed by data measured from several PWR plants.

Original design analyses did not include any stratified flow loading conditions. Instead it assumed complete sweep of fluid along the line during insurges or outsurges resulting in uniform thermal loading at any particular piping location. Such analyses did not reflect PSL actual thermal condition and potentially may overlook undesirable line deflection and its actual high stresses may exceed design limits. In addition, the striping phenomenon, which is the oscillation of the hot and cold stratified boundary, may induce high cycle fatigue to the inner pipe wall and needs also to be analyzed. Thus assessment of stratification effects on PSL is necessary to ensure piping integrity and ASME Code Section III conformance.

STAFF EVALUATION

Since stratification in PSL is a generic concern to all PWRs an NRC Information Notice No 88-80 was issued on October 7, 1988, and then an NRC Bulletin 88-11 for the same concern was also issued on December 20, 1988. Westinghouse, on behalf of the Westinghouse Owners Group (WOG), has performed a generic bounding evaluation report WCAP-12277 (Reference 1). This report provides the technical basis for the generic justification for continued operation (JCO), for each of the WOG plants and constitutes compliance with the requested action 1.b of Bulletin 88-11. Plants which have discovered any gross discernable distress during performance of the walkdown, as requested by Bulletin's action 1.a, should report findings and specify corrective actions in their JCO, in addition to that provided in this report. The following is the staff's evaluation of the Westinghouse's efforts and information provided in the report.

Prior to the issuance of the Bulletin, WOG implemented a program to address the issue of the surge line thermal stratification. The program consisted of plant-specific analysis covering five plants and a review of thermal monitoring data from eight plants. Westinghouse had instrumented PSLs and collected data for verifying stratification conditions. The thermal monitoring data obtained considered outside wall temperatures at different location around the pipe and along the axis of the pipe vs. time, vertical and lateral displacements at various locations along the pipe vs. time, and various plant parameters vs. time, from existing plant instrumentation and control sensors. In some cases the data were based not only on plant heatup but also on operation and plant cooldown conditions. The specific analyses included re-definition of revised thermal transients considering stratification effects and evaluation of pipe stress and fatigue usage factors. The overall analytical approach used in all these cases have been consistent and has been reviewed in detail by the NRC staff.

The evaluation concluded that a single bounding analysis was not feasible. Due to the variations in design, Westinghouse could not define a single envelope case to justify the 40 year life of the surge line, therefore a bounding evaluation was performed to justify continued operation for at least ten (10) additional heatup/cooldown cycles.

The bounding evaluation is essentially a demonstration of the applicability of the plant-specific and the monitoring results to the remaining WOG plants. All plant-specific analyses completed to-date, have demonstrated a 40 year life of the surge line

Two sets of parameters were defined.

a) Parameters which affect severity of thermal stratification (i.e thermal hydraulic and operational effects)
b) Parameters which affect PSL response to thermal stratification (i.e. structural effects).

The range of the parameters for the plants analyzed and/or monitored was used to establish the bounding criteria and to enable an individual plant by plant comparison.

To expand the data base for a wider range of PSL configurations, Westinghouse recommended additional plant monitoring based on plant similarities (grouping), and surge line physical, design and operational parameters of all 55 domestic Westinghouse plants. Plants with parameters not within the range of the current monitoring database were recommended for additional monitoring. Ten (10) different groups were identified for the 55 domestic Westinghouse plants for data collection, review and analysis of the pertinent thermal hydraulic, operational and structural parameters. Currently 22 separate monitoring programs are either completed, in process, or being planned. About 40% of the plants falling in one group with the remaining 60% of the Westinghouse PWR's divided among the nine groups. When this program is completed, it will provide sufficient monitoring data with at least one plant monitored in each group.

Parameters which have a significant effect from a thermal hydraulic stand point are pipe inside diameter and slope. Plants falling outside the resulting bounding criteria of pipe inside diameter of 7" to 15.4" and pipe average slope of 0^{o} to 1.44^{o} degrees, were recommended for monitoring. The range of the parameters was expanded by ± 20% in determining a bounding criteria to which other plants were compared. It was concluded that a bounding evaluation which is based on enveloping techniques, will not have a significant effect on the thermohydraulic behavior due to a ±20% change in pipe size and slope. The staff agrees with Westinghouse's efforts and methodology for monitoring, updating and assessing PSL for the stratification condition.

Thermal hydraulic evaluations using higher slope and smaller diameter pipe are expected to reduce the stratification effects. Eleven plants have an average slope higher and one plant has a pipe size smaller than that allowed by the criteria.

Some parameters judged to be relatively significant for the structural effects are:

Entrance angle to the hot leg nozzle
Mid line riser
Length of the longest straight run of pipe
Type of in-line component
Presence of whip restraints
Number of vertical rigid supports

Two plants have longest straight run lengths which are less than the minimum in the criteria, and four plants have welded lugs or trunnion attachments to PSL. Since none of the analysis to date has included evaluation of welded attachments, which may increase thermal stresses due to structural discontinuities, this condition falls outside the criteria and the following has been recommended.

a) Inspection of these welds during walkdown
b) Evaluation of these attachments on a plant-specific basis.

The five plant specific analysis consisted of three parts: (1) global effects on stresses, moments, displacements, and support reaction loads, based on both axial and radial variations in the pipe metal temperature, (2) local stresses due to thermal gradient, and (3) local stresses and effects to fatigue due to thermal striping. The global and local stresses in items (1) and (2) above were superimposed to obtain total stresses. In addition to the detailed plant specific analysis for the five plants, twelve (12) plants have completed interim evaluations of the surge line stratification which include Finite Element structural analysis of each specific configuration under stratified conditions.

The five plants for which detailed plant-specific analyses performed and evaluation reports submitted to NRC, are as follows:

Seabrook (see WCAP-12151 and Suppl. 1, and WCAP-12305)
South Texas Units 1 and 2 (see WCAP-12067 Rev 1 and Suppl. 1)
Vogle Unit 2 (see WCAP-12132, WCAP-12199 and WCAP-12218)
Beaver Valley Unit 2 (see WCAP-12093 and Suppl's 1 and 2)
Comanche Peak Unit 1 (see WCAP-12248 and Suppl. 1)

Based on these reviews Westinghouse concluded that a shorter horizontal length will result in lower loads since the the surge line will experience less vertical deflection and it will tend to to result in a more uniform distribution of the bending moment due to stratified loading. In addition middle line risers will also tend to reduce the stratification effects.

The stratification induced global bending of the surge line was calculated using ANSYS computer code. Although a 320° F step temperature change was assumed for stratification through out the surge line, the changes were linearized in ANSYS using conventional pipe element model. Finite Element models were used to calculate local stresses due to top-to-bottom non-linear thermal gradients in the PSL. Five (5) hot-to-cold interface locations were analyzed using eleven (11) cases of thermal stratification, to calculate piping response under all required loading conditions, reflecting temperatures differences up to 320° F. Other cases were obtained by interpolation. Westinghouse reported that their best estimate analytical results compared favorably with measured displacements data observed during monitoring.

In two of the analyses, a rigid vertical support was removed. In one case it was shown that the support was not required, and in the other case it was replaced with a snubber and a spring. The PSL was subsequently re-qualified and found acceptable.

Stress summary results from the five plant specific analyses performed to date indicates that the primary plus secondary stress intensity range ratio of equation 12 of ASME III section NB-3600, is less than 1.0. The critical location for stress is usually the safe end weld of the nozzle connecting the surge line to the primary loop hot leg. In one case only it was determined to be at the reducer. This seem to be a unique case since no other utility within the WOG has a mid line reducer in the PSL. Stresses were intensified by "K" factors, to account for the worst case concentration for all piping elements in the PSL. The staff agrees with the approaches used by the licensee for performing PSL reanalysis.

To account for the thermal striping effects to PSL, flow model test results, performed for the Liquid Metal Fast Breeder Reactor primary loop and for the Mitsubishi Heavy Industries Feedwater Line cracking, were reviewed to establish the boundary condition. These test results were used to define striping oscillation data, amplitude and frequencies, for evaluating high cycle fatigue. Portions of PSL which experience stratification and striping were defined based on measured results.

Westinghouse reported that considering ΔT attenuation with time, and a frequency of .30 HZ, a usage factor of less than .20 was determined as the worst case due to striping alone, even when the stresses were intensified by "K" factors. The worst case element was determined to be the butt weld. A surface film coefficient of 500 BTU/hr-sq. ft- ^oF was used and it was based on a flow rate of 90 gpm which was assumed to be constant throughout all stripping analysis. Although the data used in the assessment were obtained from scale test model which showed that the frequency can range from .10-10 HZ. the staff agreed that the stresses will be higher with the lower frequency and the .30 HZ. average frequency is justified. However the thermal stripping potential due to a film coefficient of 500 BTU/hr-sq. ft.- ^oF and attenuation of delta T is questionable, but at this time no other better number exists and therefore this represents the best judgement. If other information will be available, based on the ongoing efforts by EPRI or possible future NRC research work, it will be utilized and further assessments will be made for assessing the striping effects to PSL.

With the thermal transients redefined, new fatigue usage factors were calculated. To determine the new fatigue usage factors, the more detail techniques of ASME III NB-3200 were employed. Due to the non-axisymmetric nature of stratification loading, stresses due to all loadings were obtained from Finite Element analysis and then combined on a stress component basis. Five (5) levels of thermal stratification at five worst case points were calculated using the WECEVAL program. Stresses were intensified by "K" factors to account for worst case concentration in the piping elements.

Westinghouse reported that a cumulative usage factor (CUF) of 0.73 was determined to be the worst case at the hot leg nozzle safe end location for all but one case. For that case a 14x16 reducer existed in the surge line and the CUF at that location was determined to 0.94. The CUF included contributions from both global bending and local effects of stratification considering the nonlinear step change top to bottom temperature distribution and stripping.

Stresses resulting from primary loading such as pressure, dead weight, and seismic are not affected by thermal stratification loading and typically have a minor effect on the calculation of the fatigue usage factor. The contribution of seismic loadings to the cumulative usage factor from the plant specific analyses was reported to be 18%. All of the detailed plant specific analyses assumed the occurrence of twenty operational earthquakes.

The staff agrees with the approaches used by Westinghouse for calculating the usage factor.

Westinghouse reported that the PSL fatigue life is primarily depended upon the number of heatup and cooldown cycles rather than the years of operation. The worst case years of operation at any WOG plant is 28.5 years. The worst case number of heatup cooldown cycles is 75 and occurs at a different plant. Based on the combination of these two worst case values an "Operating Life Factor" (OLF) of 0.44 is obtained which indicates that no more than 50% of the operating life has been used at any Westinghouse plant to date. For the generic case of a CUF = 1.0 a 17% value was attributed to age and an 83% was attributed to fatigue with a 20% of the 83% value attributed to stripping.

CONCLUSIONS

Based on our review, we conclude that the information provided by Westinghouse in references 1 and 2, is comprehensive and acceptable. Westinghouse on behalf of the Owners Group had made acceptable efforts to provide technical basis for the licensee's JCO as indicated in the requested actions of the NRC Bulletin 88-11, item 1.b. The staff believes that there is no immediate or short term safety concerns associated with the stratification effects for 10 fuel cycles of continued plant operation. However, each of the WOG plants should submit a JCO using this report as the basis. We will assess if the surge line in each plant meet the code acceptance criteria for the 40 year plant life when additional generic analyses based on plant grouping is performed by Westinghouse for the Owners group.

REFERENCES

1. Westinghouse Report WCAP-12277 (Proprietary), and WCAP-12278 (Non-Proprietary). "Westinghouse Owners Group bounding evaluation for Pressurizer surge Line thermal stratification " June 15, 1988.

2. Viewgraphs by Westinghouse. Presentation to NRC on May 23 and 24.