ENCLOSURE 1

REVIEW OF COMBUSTION ENGINEERING OWNERS GROUP (CEOG) PRESSURIZER SURGE LINE FLOW STRATIFICATION EVALUATION CEN 387-P JULY 1989

INTRODUCTION

The pressurizer surge line (PSL) in the pressurized water reactors (PWRs), is a stainless steel pipe, connecting the bottom of the pressurizer vessel of 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 (delta T) varies with plant operational activities and can be as high as 320°F during the initial plant heatup. Thermal stratification is the separation of the hot/cold flow stream in the horizontal portion of the PSL resulting in temperature differences at the top and bottom of the pipe. Since thermal stratification is the direct result of the difference in densities between the pressurizer and the hot leg water, the potential for stratification is increased as system delta T increases and as the insurge or outsurge flow decreases. Stratification in PSLs 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 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, needs also to be analyzed. Thus assessment of stratification effects on PSLs 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 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. Combustion Engineering on behalf of the Combustion Engineering Owners Group (CEOG), has performed a generic bounding evaluation report, CEN 387-P (Reference 1), which documents the results of the PSL stratification effects. The following is the staff's evaluation of the Combustion Engineering efforts and information provided in the report.

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A) Plant monitoring and update of design transients.

As a result of the INPO Safety Evaluation Report, which was issued in September 1987 and identified concerns associated with the stratified flow in the PSL, the CEOG initiated surge line temperature collection data at [ ]. Concurrently with this effort, [ ] initiated efforts also for the collection of temperature data on PSL at [ ]. This was later folded into the CEOG effort. In addition, [ ] also collected similar data for [ ], after the CEOG Task "Reduction and analysis of Pressurizer Surge Line data collected from CEOG plants" had commenced, and submitted them to Combustion Engineering for review and comparison with the data already collected from the first two CEOG plants.

With the exception of [ ], which was able to retain the temperature distribution data only after the bubble was formed in the pressurizer, the other two plants were able to retain the temperature distribution data during heatup and until normal operation. [ ] obtained displacement readings also, in addition to temperature.

The Owners Group is going to decide on a proposed task to collect data during the next cooldown at both [ ] and [ ]. The staff requests that monitoring should continue for a full cycle. Data should be obtained and evaluated to determine whether the observed thermal transients are bounded by the transients assumed.

Due to similar design features of all the CEOG plants (10 plants, 15 units), the data obtained were deemed adequate and CEOG met with NRC staff on February 13, 1989, to discuss the scope of the "Task" and how the Bulletin's requirements will be addressed.

All CEOG PSLs are similar in layout. They consist of a 12" (except for [ ] which is a 10") stainless steel schedule 160 pipe, with a vertical drop from the pressurizer to the horizontal run of pipe and a vertical drop to the hot leg nozzle (except for [ ] which is at a 60° vertical angle drop).

A review of the data, which measures pipe wall outside temperature variation with time, indicated that the largest surge line top-to-bottom temperature differentials were similar for the three plants and caused either by an insurge or an outsurge of the pressurizer. Therefore emphasis was given to these transients for evaluation. Surge line movements in [ ], were calculated and compared to actual pipe movements measured at three locations.

The deflections predicted by the analysis model were based on a stratified flow model with a pipe top-to-bottom delta T=320°F. The actual measured data collected at [ ], were obtained during a pipe top-to-bottom delta T=181°F and when the fluid inside the pipe approximated a uniform temperature distribution model. Even though the

analysis model predicted the same general shape as the measured data, the fluid conditions inside the pipe were not similar. The staff feels that further investigation and/or comparisons are required to predict PSL displacement behavior.

The data obtained from all three plants recorded outside pipe wall surface temperature distribution about the longitudinal and circumferential axis of the pipe. In order to determine fluid conditions for the design basis events at the inside surface of the pipe wall, a 2-D finite element heat transfer analysis of the pipe cross section was performed.

Two bounding analytical heat transfer models with various inside fluid conditions were developed, with an attempt to reproduce the recorded outside pipe wall surface temperature distribution.

1) A stratified flow model
2) A uniform temperature gradient model

The stratified flow model assumed the hot (pressurizer temperature) fluid in the upper half of the pipe, and the cold (hot leg temperature) fluid in the lower half of the pipe, with a sharp interface in between. During the outsurge it was assumed that flow occurred in the upper portion of the pipe only, while during the insurge it was assumed that flow occurred in the lower portion of the pipe only. For a given transient, a flow rate was calculated based on the pressurizer level change vs. time plots, and a heat transfer coefficient was then determined.

For the uniform temperature gradient model, the pipe cross sectional area was divided into a finite number of water layers to approximate a continuous temperature gradient. The uppermost layer was considered the hot fluid (pressurizer temperature), and the lowest layer was considered the cold fluid (hot leg temperature), with the intermediate layers having a uniform temperature gradient. It was assumed that flow occurs at the full pipe cross section during an outsurge or an insurge. During a given transient, a flow rate was calculated based on the pressurizer level change vs. time plots and a heat transfer coefficient was then determined.

Based on the above coefficients, and using the in-house CEMARC computer code, a 2-D finite element model was developed to determine the inside pipe wall temperature distribution for both the stratified flow and the uniform temperature gradient models. The temperatures at selected nodes were calculated and compared with the thermocouple data. The uniform temperature distribution model more closely approximated the measured results. This indicates that it does not appear to be a sharp hot/cold interface, and it is more likely that there is some mixing of the hot and cold fluids with a uniform temperature gradient from top to bottom of pipe. Changes were made to the stratified flow model to better match the measured data. These changes tended to better match the measured data for the outside pipe wall temperature distribution, but CE could not explain why these would be valid assumptions. Since a unique solution could not be derived, assumptions were used for the thermal striping, stress and fatigue evaluations utilizing the stratified flow model.

B) ASME Code compliance for Stress and Fatigue.

1) Code Compliance in Stress (Inelastic Analysis).

Each plant specific surge line was reanalyzed by the SUPERPIPE computer code using a bounding generic stratified flow loading.

Elastic analyses were performed on the plant specific piping layout and support configuration for each plant, considering that the maximum delta T for a given transient, occurs along the entire horizontal length of pipe. These results were used to choose a specific surge line for the bounding inelastic analysis. The elastic analyses predicted stress intensity levels in excess of the $3S_m$ allowable limit of the ASME Code Section III, NB-3600, equation 12. Thus an inelastic shakedown analysis was performed as per NB-3228.4 to determine if after a few cycles of load application, racheting and progressive inelastic deformation ceases. However, the PSL nozzle moments were calculated from the SUPERPIPE elastic analysis.

ASME Code stress indices were used for each pipe component for the plant specific elastic analyses. The bounding inelastic analysis was based on a Finite Element shell model and, therefore, the stress indices were inherently included in the analysis.

The SUPERPIPE computer code was used to performed the initial elastic analysis, which considered thermal effects of the stratified flow over the entire horizontal length of pipe, for delta T=32°F, delta T=90°F and delta T=320°F. For each structural model, a uniform fluid temperature loading and a stratified flow loading were applied. Three types of stratified flow effects were investigated.

a) Local stress due to temperature gradient in the pipe wall.

b) Thermal gradient stress across pipe wall due to transient condition.

c) Thermal pipe bending moment generated by the restraining effects of supports.

Actual support stiffnesses were used considering a ± 2" limit of spring motion, beyond which springs will act as rigids. The maximum movement based on delta T=320°F, pipe top to bottom stratified flow, was calculated for [ ] and [ ], both at location H2.

The staff feels that since no plant specific support data and displacement limitations were considered, further evaluations are required to justify the [ ] inelastic analysis as the worst case. In addition, it is the staff's opinion that the assumption on spring motion may not be conservative, in that, upward movement of a spring which exceeds it's travel range will cause the spring to unload and redistribution of stresses will occur.

The [ ] PSL configuration was chosen for the inelastic evaluation, since it predicted the highest stress levels under the elastic analysis. While each line will behave differently under a given stratified flow loading, it was concluded that the surge line with the highest elastic stresses will provide an upper bound for all other lines. This was verified by the fact that the most highly stressed region is the same location for both the elastic and the inelastic evaluation. For this line, the elbow under the pressurizer was determined to be the most critical location.

Material properties as T=650°F were used considering the strain hardening behavior of the material. The stress strain curve used was developed by Combustion Engineering based on the ASME code minimum yield stress value and plastic strain.

Three complete cycles of heatup, steady state and cooldown were analyzed. For fatigue evaluations, the maximum principal strain range values were calculated from the maximum and minimum principal strains. The maximum positive principal strain was calculated for three cycles and extrapolated to be less than 2% after 500 heatup/cooldown cycles, based on the decreasing rate of strain increases with additional cycles. The analysis results demonstrated that the first cycle undergoes significant permanent strain with subsequent cycles having smaller accumulation. The strain range from the first two cycles was considered in the fatigue analysis with the strain range from the third cycle used for the remaining 498 cycles.

Review of Fig. 3.6.2-8 and Fig. 3.6.2-9 of the report could not clearly demonstrate that strains were stabilized after the three heatup/cooldown cycles and that progressive distortion does not exist.

Changes in plastic strains showed some decrease with each cycle but the staff concluded that additional investigation was required to demonstrate that the decreasing rate of plastic strain will approach zero. Since there are no maximum strain limits prescribed in the ASME Section III code, the value of 2% was obtained from the High Temperature Code Case N47 and it was used as a guide for the maximum positive principal strain limit. The staff concluded that the use of 2% strain limit in this case needs further justification.

2) Code Compliance in Fatigue.

To determine stresses at the inside face of the pipe wall due to fluid oscillation at the interface of the hot to cold boundary (strping), a 1-D finite element analysis was performed. The input assumptions used in this analysis were based on the measured data from the CEOG plants, and other information available in the public domain. The thermal striping

model considered the hot fluid at the Pressurizer temperature, the cold fluid at the Hot Leg temperature, and a sharp interface with no mixing of the hot and cold fluid. A sawtooth fluid oscillation was assumed to occur across the interface region.

Results indicated that fatigue damage due to striping is insignificant when compared to all the other causes of fatigue damage. (i.e. static thermal stratification, thermal transients etc.). The CE report indicated that based on the stress levels calculated, an infinite number of allowable cycles exist, and thermal striping is not a concern. Since maximum stress due to striping occurs at the hot/cold interface, which is near the horizontal axis of the pipe, and maximum stress due to fatigue occurs at the top and bottom of the pipe, these stresses do not occur at the same location and are not additive. The staff feels that further investigation should be provided for the use of a fraction of the striping amplitude. In addition, data based on measurement outside the pipe may be inconclusive for the purpose of defining the striping phenomena.

Analysis for cyclic operation (fatigue) was performed, in addition to the shakedown analysis. Using the results of the inelastic analysis, the maximum principal total strain range which occurs from shakedown analysis was multiplied by one half the elastic modulus to determine the equivalent alternating stress, as per NB-3228.4 (c). This maximum strain range occurs after cycle 3, and this value was assumed for the remaining cycles. For the first two heatup-cooldown cycles, the larger of cycle 1 and 2 strain range was used.

The cumulative usage factor for this generic bounding analysis was determined to be 0.21 for [ ]. The maximum cumulative usage factor, when the effect of the ± 2" displacement limitation was considered, was 0.36 for [ ]. The staff feels that further evaluation is required to justify the [ ] inelastic analysis is the worst case.

CONCLUSION

Based on our review, we conclude that the information provided by Combustion Engineering in References 1 and 2 is not adequate to justify continued operation for the 40 year plant life. However, the staff believes that there is no immediate or short term safety concerns associated with the stratification effects for continued plant operation until final resolution of the Bulletin 88-11 is issued. This is scheduled to be completed by the end of 1990 and should also address the Code acceptance criteria of ASME NB-3600.

Concerns that the staff has are the following:

a) The ASME code acceptance criteria of Section NB-3600 Equations 9-14 need to be satisfied as applicable.

b) All supports, including pipe ship restraints, be considered for the effects of providing any additional constraints to the Surge Line, in the plant specific or the bounding pipe stress evaluation.

c) All supports, including pipe whip restraints, require plant specific confirmation of their capabilities, including clearances, and that they fall within the bounds of the analysis.

d) Justify the [ ] inelastic analysis as the worst case for stress and fatigue for all CEOG plants, including [ ].

e) Justify PSL displacement bahavior predicted by the analysis model and the use of a fraction of the striping amplitude.

REFERENCES

1. Combustion Engineering Report CEN 387-P (Proprietary). "Combustion Engineering Owners Group pressurizer surge line flow stratification evaluation." July 1989.

2. Draft meeting minutes of the NRC audit on September 25 and 26, 1989 regarding the CEOG Report CEN 387-P MPS-89-1048, dated October 17, 1989.

ENCLOSURE 2

Staff review of the CE responses regarding the NRC Audit
on September 25 and 26, 1989
Ref: CEOG Report CEN-387-P MPS-89-1048
dated October 17, 1989.

Section 2.0

1) The staff requests that monitoring should continue for a full fuel cycle. Data should be obtained and evaluated to determine whether the observed thermal transients are bounded by the transients assumed.

2) The staff feels that further investigation is required to predict PSL displacement behavior, considering the stratification effects. The deflection predicted by the analysis model were based on a stratified flow model with a pipe top-to-bottom delta T=320°F. The actual measured data collected at [ ] were obtained during a pipe top-to-bottom delta T=181°F and when the fluid inside the pipe approximated a uniform temperature distribution model. Even though the analysis model predicted the same general shape as the measured data, the fluid conditions inside the pipe were not similar.

3) Closed.

4) Closed.

5) Closed.

6) Closed.

7) Closed.

8) The staff requests that further investigation is required to demonstrate that strains were stabilized after the three heatup/cooldown cycles and that progressive distortion does not exist. It is required to demonstrate that the decreasing rate of plastic strain will approach zero and the peak value will not exceed a maximum strain acceptance criteria of 2. The staff feels that the inelastic analysis will be accepted as Justification for Continued Operation and that the ASME Code acceptance criteria of section NB-3600 equations 9-14 need to be satisfied, as required by the Bulletin.

9). Closed.

10) Closed.

11) The staff feels that all supports, including pipe whip restraints, be considered for the effects of providing additional constraints in the plant specific or the bounding evaluation.

12) The staff feels that all supports, including pipe whip restraints, require plant specific confirmation of their capabilities, including clearances, and that they fall within the bounds of the analysis.

Section 3.0

1) Closed.

2) Closed.

3) Closed.

4) Closed.

5) Closed.

6) Closed.

Table 2.7-1. Closed

Table 3.2.2-4. See response of Section 2.0 Item 2.

Table 3.4.3-2. Closed.

Table 3.6.2-1. Closed.

Table 3.6.3-2. The staff feels that further evaluation is required to justify the [ ] inelastic analysis as the worst case. The maximum cumulative usage factor for [ ] is 0.36 when the effects of the 2" displacement limitations are considered.

Figure 3.1.2-5. Closed.

Section 4.0

1) No specific review was performed.

2) See response of Section 2.0 Item 8.

3) No specific review was performed.

Questions during meeting.

Closed