September 16, 1991

Docket Nos. 50-335
and 50-389

DISTRIBUTION
Docket File
NRC & Local PDRs
PD22 Rdg
S. Varga
G. Lainas
H. Berkow
J. Norris
D. Miller
OGC
E. Jordan, MNBB 3701
J. Shea
S. Hou
J. Norberg
ACRS (10)
M. Sinkule, RII

Mr. J. H. Goldberg
President - Nuclear Division
Florida Power and Light Company
Post Office Box 14000
Juno Beach, Florida 33408-0420

Dear Mr. Goldberg:

SUBJECT: PRESSURIZER SURGE LINE THERMAL STRATIFICATION, BULLETIN 88-11, ST. LUCIE PLANT, UNITS 1 AND 2 (TAC NOS. 72169 AND 72170)

The NRC staff and its consultant, Brookhaven National Laboratory, conducted an audit on May 7 and 8, 1991, of the Combustion Engineering Owner's Group (CEOG) Pressurizer Surge Line Thermal Stratification Evaluation Program as related to Bulletin 88-11. During the audit, representatives of Combustion Engineering (CE) and the CEOG gave a presentation on the progress of the CEOG program, analytical methods used and results obtained, and provided responses to staff comments and questions. A copy of the May 7 and 8, 1991, audit report and a copy of the May 1990 staff review of CEN-387-P are enclosed for your information.

As a result of this audit, the staff concluded that CE has made progress in addressing some earlier staff concerns. However, several open issues remained and needed to be resolved. On August 14, 1991, a conference call was held between CE, Brookhaven National Laboratory and the NRC to discuss proposed solutions to these open issues. In that discussion, CE proposed a schedule for the completion of all action items related to Bulletin 88-11. Pursuant to that schedule, a final report from each licensee, detailing the completion of all Bulletin requirements, is expected by December 31, 1991.

If the completion of Bulletin action items, including any hardware modifications that may be required, is to be delayed beyond December 31, 1991, you should submit a justification for continued operation.

Sincerely,

/S/

Jan A. Norris, Sr. Project Manager
Project Directorate II-2
Division of Reactor Projects - I/II
Office of Nuclear Reactor Regulation

Enclosures:
1. Audit Trip Report
2. Staff Review of CEN-387-P

cc w/enclosures:
See next page

DOC NAME: LTR GOLDBERG/88-11 LTR

LA:PD22	PM:PD22	D:PD22
DMiller	JNorris	HBerkow
9/16/91	9/16/91	9/16/91

DF01 1/1

21

cc:
Jack Shreve, Public Counsel
Office of the Public Counsel
c/o The Florida Legislature
111 West Madison Avenue, Room 812
Tallahassee, Florida 32399-1400

Senior Resident Inspector
St. Lucie Plant
U.S. Nuclear Regulatory Commission
7585 S. Hwy A1A
Jensen Beach, Florida 33457

Mr. Gordon Guthrie, Director
Emergency Management
Department of Community Affairs
2740 Centerview Drive
Tallahassee, Florida 32399-2100

Harold F. Reis, Esq.
Newman & Holtzinger
1615 L Street, N.W.
Washington, DC 20036

John T. Butler, Esq.
Steel, Hector and Davis
4000 Southeast Financial Center
Miami, Florida 33131-2398

Administrator
Department of Environmental Regulation
Power Plant Siting Section
State of Florida
2600 Blair Stone Road
Tallahassee, Florida 32301

Mr. James V. Chisholm, County Administrator
St. Lucie County
2300 Virginia Avenue
Fort Pierce, Florida 34982

Mr. Charles B. Brinkman, Manager
Washington Nuclear Operations
ABB Combustion Engineering, Inc.
12300 Twinbrook Parkway, Suite 330
Rockville, Maryland 20852

Mr. Jacob Daniel Nash
Office of Radiation Control
Department of Health and Rehabilitative Services
1317 Winewood Blvd.
Tallahassee, Florida 32399-0700

Regional Administrator, Region II
U.S. Nuclear Regulatory Commission
101 Marietta Street N.W., Suite 2900
Atlanta, Georgia 30323

Mr. R. E. Grazio
Director, Nuclear Licensing
Florida Power and Light Company
P.O. Box 14000
Juno Beach, Florida 33408-0420

AUDIT TRIP REPORT

PURPOSE: Audit of Combustion Engineering Owner's Group (CEOG) Pressurizer Surge Line Thermal Stratification Evaluation Program to Address NRC Bulletin 88-11 Issues

LOCATION: ABB/Combustion Engineering Nuclear Power, Windsor, CT

DATES: May 7 and 8, 1991

NRC PERSONNEL: S. Hou (NRC), G. DeGrassi (BNL)

CEOG PERSONNEL: D. Sibiga, D.J. Ayres, and others (see Attachment 1)

The staff of the Mechanical Engineering Branch and its consultant from Brookhaven National Laboratory conducted an audit at ABB/Combustion Engineering. The purpose of this audit was to review the current status of the CEOG program on pressurizer surge line thermal stratification.

CE had submitted an evaluation report on this subject (Ref. 1) in June 1989. The report described the program which included data collection, defining new thermal loads, and performing an ASME Code stress and fatigue analysis and evaluation. Based on the program results, CE concluded that a 40 year fatigue life of the surge line was demonstrated. The staff reviewed the report and disagreed with this conclusion. The staff evaluation identified a number of concerns and concluded that the information provided by the CEOG report was inadequate to justify meeting all appropriate limits for the 40 year plant life. Major concerns were that stresses did not meet all ASME Code limits, striping was inadequately addressed and the bounding analysis did not represent the worse case in CE plants. The staff, however, accepted the report as sufficient basis to justify interim operation until a final analysis is completed.

CEOG has since performed additional work and submitted additional information to the staff (Ref. 2, 3, 4). During a plant specific audit at Palo Verde last February, additional questions and open items on the generic program were identified (see Attachment 2). CE representatives committed to provide responses at this audit. In addition, the staff wanted to audit sample calculations. A summary of the information presented during this audit and the staff evaluation is provided below.

I. CEOG PROGRAM STATUS

CE has redone the elastic-plastic shakedown analysis of the limiting surge line elbow. The finite element model was revised and incorporated 3-D solid elements instead of 2-D shell elements. A total of seven cycles were applied to demonstrate shakedown. Final results were not available for the audit due to computer problems. However, CE expects to complete the work and issue a draft report to the member utilities by mid-May. CE will be holding workshops for the CEOG in June to instruct utilities on how to apply the generic report in responding to the Bulletin. The final report will be submitted to NRC by the end of July. Each owner will then submit a plant specific response to Bulletin 88-11 in accordance with their own commitments.

II. CEOG RESPONSES TO NRC QUESTIONS

CE provided responses to the NRC questions listed in Attachment 2. The following is a summary of the responses and discussions.

1. Expansion Stress Intensity Evaluation

The original CE bounding analysis concluded that the surge line exceeded the 3 S_m elastic stress limit of ASME Section III Code NB-3600 equation 12. In the reevaluation, CE performed a finite element analysis of the elbow and concluded that the alternate thermal expansion stress limit of 3 S_m of NB-3222.3 is met. CE provided an explanation of how the thermal expansion stress (P_e) was determined from the finite element stress results. As indicated in Attachment 3, the finite element analysis provided axial stresses at the inside and outside surfaces of the pipe. The surface stresses were averaged through the wall thickness and the maximum and minimum values of these average stresses were used to calculate membrane and bending stresses in the pipe cross section. CE claimed that the combination of the averaged membrane and bending stresses equals the thermal expansion stress, P_e.

The audit team questioned the adequacy of using the average mid-thickness stress since it ignores the through-wall local bending stress which is significant. In addition, the stresses reported were axial stresses only and not stress intensities. CE agreed that stress intensities should be considered and claimed that the 3 S_m limit would still be met. However, since additional discussions could not resolve the question of using average instead of maximum stress, the audit team recommended that CE initiate a Code Inquiry to determine whether the ASME Code Committee concurs with the CE interpretation of P_e stress. CE explained that this had not been pursued since it would take at least a year to obtain such concurrence. Since the 3 S_m limit on P_e stress is believed to be conservative, the audit team agreed to leave this item as a confirmatory issue pending resolution of the Code Inquiry. If the issue cannot be resolved by June 30, 1992, CEOG must take appropriate corrective actions. CE agreed to initiate a Code Inquiry on this question and the staff will review the contents of the Code Inquiry before it is submitted to the Code Committee.

2. Code Case N47 Strain Limits

In previous discussions, the staff had questioned the use of high temperature Code Case N47 strain limits in the surge line evaluation. CE explained that these limits (1% on membrane strain, 2% on bending strain and 5% on peak strain) are only being used to support the validity of the analysis. They reviewed the Code Case and judged that no other requirements of N47 are relevant to the surge line. The audit team found their response acceptable, but requests clarification of the definition of the calculated strain to be compared to these limits (i.e. is it the accumulated strain at end of life or the largest value of strain at any point in time?).

3. Thermal Striping Loads Development

CE gave a presentation on the striping analysis methodology. A copy of the presentation slides is included in Attachment 4. CE reviewed the published test data in the open literature and developed what they believe is a conservative model. The available data on striping is primarily related to striping in feedwater lines. CE developed a model with two homogenous temperature layers separated by a thin interface. The critical parameters are frequency, amplitude and heat transfer coefficient. CE's objective was to select realistic but conservative values of these parameters. Based on the data published by Hu, Fujimoto, Wolf, and Woodward, CE considered a minimum frequency of 0.25 Hz and a maximum amplitude of 40% of the total pipe top to bottom ΔT. For heat transfer coefficient, CE used a high value of 3500 Btu/hr-ft$^{2\circ}$F.

The audit team found the model and the selection of key parameters reasonable but raised questions regarding the application of the model. See item 4 below.

4. Thermal Striping Fatigue Analysis

CE used a 1-D finite element model to evaluate stress and fatigue due to striping. Four load cases were analyzed with frequencies of 0.25Hz and 1.0Hz and amplitudes of approximately 10% and 40% of the pipe ΔT of 320°F. For all cases except low frequency (.25Hz) and high amplitude (40%), stresses were below the endurance limit with infinite allowable cycles. The case with low frequency and high amplitude had stresses which exceeded the endurance limit but CE judged this case to be too conservative and did not use these results. The thermal striping stresses were not combined with stratification stresses because they occur at different locations within the pipe.

The audit team questioned the basis for disregarding the low frequency/high amplitude load case and for not combining striping stress with stratification bending stress. CE agreed to provide either stronger justification for disregarding the most severe load case or incorporate it into the evaluation. CE also agreed to address the combination of stratification and striping stresses in the evaluation.

5. Design Basis Transients Development

CE discussed the development of the design basis transients in Table 3.5.1-1 of CEN 387-P which were used in the fatigue evaluation. The transients are based on the original design basis with stratification effects included. Heatup and cooldown transients are of particular interest since they contribute the most significant fatigue usage. CE assumes 500 heatup and cooldown cycles over the life of the plant with 2 cycles of 320°F ΔT stratification per heatup and cooldown. The audit team questioned the adequacy of assuming only 2 cycles of maximum stratification per heatup or cooldown. CE was asked to confirm that this assumption was reasonable and conservative based on plant monitoring data taken during heatups and cooldown. CE agreed to review the data and confirm this assumption.

6. Surge Line Slope Effects

In the review of the Palo Verde analysis, it was noted that the horizontal portion of the surge line had a slope which was not considered in the analysis. CE explained that their models assume zero slope because this is the most conservative assumption. The interface is assumed to be at the elevation of the centerline for the entire horizontal length of the line. The audit team agreed that this assumption is conservative and found the CE response acceptable.

7. Use of SUPERPIPE Program

CE had been previously asked to explain how the SUPERPIPE program had been used in the stratification analysis since the program does not have the capability to apply a transverse temperature gradient across the pipe. CE explained that SUPERPIPE was primarily used to identify the most highly stressed surge line of all CE plants for which the inelastic bounding analysis would be performed. The analyses were recently rerun with higher ΔT values of 340°F for Palo Verde, 340°F for Maine Yankee and 350°F for Arkansas. The results show that Palo Verde is the bounding CE plant.

In performing the SUPERPIPE analysis, the free end thermal expansion displacements were first calculated by hand. The pressurizer end of the pipe was fixed and the rest of the pipe was allowed to displace. The section rotations needed to calculate the displacements were determined from a two dimensional MARC heat transfer and stress analysis. Once the displacement profile was determined, the displacements and rotations at the hot leg nozzle and displacements at supports were applied in the opposite direction to the SUPERPIPE model. This provided the appropriate moments and bending stress due to stratification in the pipe. The audit team found this methodology acceptable.

8. Anchor Movements

CE had been asked to demonstrate how anchor movements were considered in the SUPERPIPE analysis. CE explained that anchor movements from the pressurizer and hot leg were applied in a separate SUPERPIPE analysis. In addition to the anchor movements, the load case also applied the appropriate average temperature along the horizontal portion of the pipe, the pressurizer temperature at the vertical pipe near the pressurizer, and the hot leg temperature at the vertical pipe near the hot leg. The moments and stresses from this load case were then superimposed with the moments and stresses for the stratification load case to give the total moments and stresses. The audit team found this procedure acceptable.

9. Nozzle Evaluation

CE provided a calculation on the ASME Code evaluation for the surge line pressurizer and hot leg nozzles and discussed the methodology and results. CE pointed out that the calculations will be redone with the higher stratification ΔT's but the methodology will be the same. The nozzle calculation used the loads from the SUPERPIPE analysis and the loads from the original nozzle evaluation. It assumed that the difference between these loads is the stratification induced load. Two cases were considered: (1) stratification stresses alone for 300 cycles, and (2) stratification plus OBE stresses for 200 cycles. By combining the stresses of these two cases with the stresses from the original nozzle stress report, a new stress range and fatigue usage factor with stratification was calculated. Nozzle stresses were calculated by formulas using bending moments and forces from the SUPERPIPE analysis. Local stratification effects were not applicable since all CE nozzles are vertical and not affected by local stratification.

The audit team questioned whether the calculation accounted for all stratification cycles. There was only one stratification cycle considered per heatup/cooldown. The revised design basis transients in Table 3.5.1-1 of CEN 387-P shows two 320°F ΔT transients for each heatup and cooldown as well as a number of lower ΔT transients which should be considered in the fatigue evaluation. CE was asked to investigate and determine whether the appropriate number of cycles were considered in the fatigue evaluation.

10. RTD and Sample Line Connection

During the recent NRC audit of Palo Verde, a review of the original surgeline stress report indicated high fatigue usage at the RTD and sample line connections. These areas were not addressed in the CEN 387-P report. As a result, CE was asked to provide information on the fatigue usage factors in these areas. CE stated that as part of the final evaluation, they will provide each plant with appropriate stress and displacement information in these areas. CE will conduct workshops in June to explain how the results should be used in plant specific evaluations. The audit team found this response acceptable.

III. SURGE LINE FATIGUE AND SHAKEDOWN ANALYSIS

CE provided additional information on the fatigue and shakedown analyses which are being redone. Based on additional SUPERPIPE analyses, CE confirmed that Palo Verde is the bounding plant. The elbow below the pressurizer is the critical component. CE developed a MARC elastic/plastic model of the surge line similar to the one shown in Figure 3.6.2-1 of CEN 387-P. Beam elements were used to model straight pipes. Elastic/plastic 20 node solid elements with two elements through the thickness were used to model the elbows. This is a refinement over the original model which used shell elements at the elbows. The shakedown analysis used the same load history that had been previously developed for a heatup/cooldown cycle with the exception that the maximum ΔT was increased to 340°F instead of the original 320°F.

CE did not yet have the final stress results but showed some preliminary data on elbow forces, moments, and strains. The preliminary results showed evidence that after seven heatup/cooldown cycles, the cyclic response is repeatable indicating that shakedown will occur.

CE also discussed the fatigue analysis methodology. The analysis will be redone for the higher ΔT but the methodology will be the same. CE considered a total of 35 load states plus OBE and full flow transients which resulted in 595 load sets for the fatigue analysis. Alternating stress intensities were determined from the strains of the inelastic shakedown analysis. Strain levels for events which were not inelastically analyzed were predicted by interpolating the strain from the analyzed events. In order to account for uncertainties, a 10% margin was applied to all stresses. The cumulative usage factor for the bounding plant was 0.21. The highest contribution to fatigue was from a load set which ranges between a non-stratified load state and a 320°F ΔT

stratified load state. When the analysis is redone for the 340°F ΔT, the usage factor will be expected to increase.

The audit team reviewed selected fatigue usage results and questioned why OBE seismic was not combined with the 320°F ΔT stratified flow as a load state. CE stated that, by definition, an OBE does not occur during a heatup or cooldown. They performed a quick review of various FSARs and noted that Section 3.9 defines an OBE as an earthquake load which occurs while the plant is at 100% power. The audit team asked CE to further review licensing documents to better justify the basis for this assumption.

IV. PALO VERDE DIFFERENTIAL TEMPERATURE CONTROL

During the recent NRC audit of Palo Verde, a review of operating procedures indicated that there are no limits on the differential temperature between the pressurizer and the hot leg to ensure that the 320°F ΔT assumed in the analysis is not exceeded. The licensee stated that several options were being considered and committed to inform the staff of the final decision by the CE audit.

During this audit, the Palo Verde representative notified the audit team that two actions are being taken to address the issue. The licensee is having CE redo the analysis to a higher ΔT (340°F) and an administrative limit is being established to ensure that this differential temperature will not be exceeded in the future. The audit team found these actions acceptable to close out this open item from the Palo Verde audit.

V. CONCLUSIONS

The audit team found that CE had made progress in addressing the earlier staff concerns on the bounding analysis. CE confirmed that Palo Verde is the bounding plant. The shakedown analysis is being redone for a larger number of cycles. Higher stratification ΔTs are being considered in the reanalysis. The revised analysis is nearly complete and preliminary results indicate a favorable outcome. However, the audit team identified a number of additional concerns which must be resolved expeditiously and described in the final report. They include the following:

1. The staff disagreed with the CE interpretation of expansion stress (P_e) in an elbow. The CE approach determined P_e on the basis of average stresses through the wall. Surface stresses resulting from local circumferential bending of the elbow wall were neglected. The staff recommends that CE initiate an ASME Code Inquiry to obtain a Code Committee interpretation of the definition of this stress. This will be treated as a confirmatory item pending resolution of the Code Inquiry and should be closed out no later than June 30, 1992.

2. CE must clarify its definition of calculated strain for comparison with Code Case N47 strain limits. Is it the accumulated strain at end of life or maximum strain at any point in time?

3. CE must address the issue of combining thermal striping stresses with thermal stratification stresses in the fatigue evaluation.

4. CE must either provide stronger justification for disregarding the results of the low frequency (0.25 Hz)/high amplitude (40% ΔT) load case in the striping fatigue evaluation or include these results in the fatigue evaluation.

5. CE must confirm the adequacy of their revised design basis transients for fatigue evaluation (Table 3.5.1-1 of CEN 387-P) based on data collected in the monitoring programs. An item of particular concern is the assumption of only two maximum ΔT stratification cycles during each heatup and cooldown.

6. CE must confirm and justify the number of stratification cycles used in the nozzle fatigue evaluation. Only one maximum ΔT stratification cycle per heatup/cooldown was used.

7. CE must provide additional justification for excluding a combined OBE and maximum ΔT stratification as a load state in the fatigue evaluation.

VI. REFERENCES

1. CEN 387-P, "Pressurizer Surge Line Flow Stratification Evaluation," prepared for CE Owners Group, Combustion Engineering, Inc. July 1989.

2. ABB/CE letter MPS-90-903, D. Sibiga to S. Hou, "CEOG Response to NRC Request for Further Information on the Pressurizer Surge Line Fatigue Analysis," September 21, 1990.

3. ABB/CE letter MPS-90-970, D. Sibiga to S. Hou, "CEOG Response to NRC Questions on Application of Plastic Analysis," October 11, 1990.

4. ABB/CE letter MPS-91-362, D. Sibiga to S. Hou, "CEOG Response to BNL Comments/Questions on Application of Plastic Analysis to the CEOG Surge Line Evaluation," March 28, 1991.

ENCLOSURE 2

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.

A) <u>Plant monitoring and update of design transients.</u>

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) <u>Code Compliance in Fatigue.</u>

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.

<u>Section 3.0</u>

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