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SAFETY EVALUATION BY THE OFFICE OF NUCLEAR REACTOR REGULATION

COMBUSTION ENGINEERING OWNERS GROUP

PROGRAM FOR EVALUATION OF PRESSURIZER SURGE LINE

THERMAL STRATIFICATION

NRC BULLETIN 88-11

INTRODUCTION

By reports CEN-387-P, Revisions 0 and 1, "Pressurizer Surge Line Flow Stratification Evaluation," the Combustion Engineering Owners' Group (CEOG) demonstrated the integrity of the pressurizer surge line (PSL) in view of the occurrence of thermal stratification during the 40-year service life as described in NRC Bulletin 88-11. The reports responded generically to the NRC concern for the following 15 Combustion Engineering (CE) plants:

50-528/50-529/50-530	Palo Verde, Units 1, 2, and 3
50-368	Arkansas Nuclear One, Unit 2
50-317/50-318	Calvert Cliffs, Units 1 and 2
50-255	Palisades
50-335/50-389	St. Lucie, Units 1 and 2
50-382	Waterford, Unit 3
50-309	Maine Yankee
50-336	Millstone, Unit 2
50-285	Fort Calhoun
50-361/50-362	San Onofre, Units 2 and 3

EVALUATION

NRC Bulletin 88-11 required all licensees for pressurized water reactor (PWR) Operating Plants to take the following actions to demonstrate that the integrity of PSLs is maintained for the 40-year design life of these piping systems.

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

1.b Perform a plant-specific or generic-bounding analysis to demonstrate that the surge line meets applicable design codes and other Final Safety Analysis Report (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.

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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 through collective efforts, demonstrate similarity in geometry and operation.

1.d Perform detailed stress and fatigue analyses of the surge line to ensure compliance with applicable code requirements incorporating any observations from 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 description of corrective actions for effecting long-term resolution.

Although not required by the Bulletin, licensees were encouraged to work collectively to address the technical concerns associated with this issue, as well as to share the PSL data and operational experience. The CEOG implemented a series of programs to address the issue of surge line stratification in CE plants.

The visual inspections of the surge lines, Action 1.a, have been addressed by each of the 15 CE plants. The walkdown results are included in CEOG report CEN-387-P. The inspections did not reveal indications of discernable distress or structural damage in any of the 15 CE plants.

The CEOG implemented a series of programs to satisfy the requirements of 1.b through 1.d. It was established that all CE plants have similar PSL arrangements and loading conditions, hence, bounding analyses were used to generically evaluate the adequacy of the PSL design in all CE operating plants with consideration of the effect of thermal stratification and thermal striping during its 40-year service life. These results were reported in the CEOG publication CEN-387-P, Revisions 0 and 1. Comparing the PSL thermal stratification data collected from three plants, the CEOG found that all large surge line top-to-bottom temperature differentials are caused by either an insurge or outsurge of the pressurizer. These fluid surges can result from a number of plant operations including spray initiation, energizing heaters, or the mismatch of charging/letdown flow. The data were tabulated and summarized to identify the numbers of transients measured at different ranges of ΔT. These results were used as the basis for developing new design-basis transients.

Since the data on thermal stratification was based on outside wall temperature, two different assumptions of the inside fluid conditions were modeled to evaluate the outside wall temperatures. The first was a stratified flow model defined by hot fluid (pressurizer temperature) in the upper portion of the pipe and cold fluid (hot leg temperature) in the lower half with a sharp interface in between. The second model was a uniform temperature gradient model in which the pipe cross section was divided into a finite number of water layers to approximate a continuous top-to-bottom temperature fatigue gradient. Using the CE-Marc code, a number of heat transfer calculations were performed on these two models. It was determined that the second assumed fluid condition yielded results somewhat consistent with the measured in-plant data. However, the first model (stratified flow) provides for more conservatism in the stress and fatigue analyses, and was chosen to be used for analytic purposes. This application is acceptable. The original design basis transients used in the design and analysis of the NSSS including the PSL did not include any stratified flow loading conditions. CE developed a revised set of design-basis transients based on the thermal stratification test data collected as a part of this program. The revised transient data assumed 500 heatup-cooldown cycles, the same as the original assumption, but, in addition, accounted for the number of stratification cycles that occur during each heatup-cooldown. Additional conservative assumptions included: the entire horizontal section of the surge line was assumed to be uniformly stratified, the maximum pressurizer-to-hot leg ΔT was assumed to be 340°F, and the total number of transients is greater than the expected number based on test data.

To satisfy the Bulletin concern regarding thermal striping, CE developed a one-dimensional finite element model to evaluate thermal striping at the inside of the pipe wall. Experimental data had shown that the amplitude of fluid temperature fluctuation near the pipe wall is smaller than the maximum temperature difference, and that the oscillation frequency varies and can cover a wide range. CE considered four load cases with a fluid temperature range of 8% and 41% of the maximum temperature differential and a period of 1 second and 4 seconds. The local stresses due to each temperature gradient as a function of time were determined following the formulas in ASME Code Section III. To determine the striping contribution to fatigue, each striping transient stress range was combined with the corresponding numbers of cycles of the stratified flow stress ranges resulting in an alternating stress range for which an allowable number of cycles was determined. CE also performed fracture mechanics analysis, which concluded that existing cracks will not propagate appreciably into the surge line wall.

To satisfy Bulletin Action 1.d, and to verify that the revised design-basis transients were in compliance with ASME Code stress and fatigue requirements, CE performed a stress evaluation of the PSLs. The results of the elastic analyses exceeded the limit of 3Sm in all of the surge lines. Therefore, CE proceeded to use elastic-plastic analyses to demonstrate the adequacy of the PSLs. A review of the CE evaluation raised two issues. The first issue involved an acceptable value for the deformation limit. To accommodate the small deformation theory, which is the analytic basis, and minimize the distortion interference with the neighboring components, CE selected the Code-case-permitted 5% as the limiting value. The elastic-plastic analysis demonstrated the maximum-accumulated strain at approximately half this limiting value. The second issue involved whether the austenitic stainless steel will strain harden with cyclic loading, resulting in an increase in the yield surface. CE concluded that the intent of the expansion stress criterion was satisfied by demonstrating that at shakedown, the strain range of the material, based on isotropic hardening and an increase in the yield surface, will be elastic in nature.

As a confirmatory action, CE initiated two ASME Code inquiries to obtain Code Committee concurrence on the approach and on the use of the isotropic strain hardening model discussed above. The Code Committee responses indicated that (1) when shakedown is demonstrated in accordance with NB-3228.4(b), the expansion stress criterion of NB-3222.3 need not be satisfied, and (2) in performing a plastic shakedown analysis, NB-3228.4 does not prohibit the use of either kinematic hardening or isotropic hardening to represent the motion of the yield surface due to strain hardening. Therefore the requirements to satisfy NB-3200 are demonstrated by showing the accumulated usage factor is less than one.

CONCLUSION

Brookhaven National Laboratory (BNL) has performed a review of the CEOG Reports CEN-387-P, Revisions 0 and 1, "Pressurizer Surge Line Flow Stratification Evaluation." BNL's evaluation is documented in a Technical Evaluation Report (TER) A-3869. The NRC has reviewed the TER and concurs with BNL that the methodology used to analyze the effects of thermal stratification and striping in the PSL is acceptable. Accordingly, we conclude that the results of the CEOG analysis may be used as the basis for CEOG licensees to update their plant-specific Code stress reports to demonstrate compliance with applicable Code requirements as requested in Bulletin 88-11.

However, due to the fact that elastic-plastic analysis was necessary in performing the PSL stress evaluation, the staff concurs with BNL's recommendation for performing enhanced inservice inspections to provide additional confidence in the structural integrity of the surge lines. The staff recommends that licensees perform volumetric examination of critical elbow components as part of future ASME Section XI inservice examinations. Examinations of elbow bodies, as well as elbow welds, should be performed to ensure that the most highly-stressed areas have not sustained damage.

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