ENCLOSURE A

SAFETY EVALUATION REPORT
MAIN FEEDWATER LINE RESTRAINT FAILURE
TROJAN NUCLEAR PLANT
DOCKET NO. 50-344

1.0 Description of Event

During the 1987 Refueling outage, a seismic restraint (SR8) on the Loop B feedwater piping inside containment was found to have a failed structural attachment to the concrete. The restraint had been inspected during the 1986 outage and was found to be intact at that time. The restraint is located on the first vertical run of piping inside containment. The design loadings for SR8 are 0.642 kips (thermal), 5.246 kips (OBE) and 8.761 (SSE). The restraint is oriented in the east-west direction and consists of a pipe clamp, a rigid sway strut (Bergen-Paterson RSSA-10), and end attachment, a supplementary steel frame structure (W6x20 vertical member, W4x13 knee brace) with two 1/2" base plates each attached to the concrete with 4-5/8" phillips red head concrete expansion anchor bolts and 2.5" embedment lengths. The failure consisted of pullout in one irregular shaped cone of the concrete under the baseplate for the knee brace and broken concrete under the vertical member baseplate.

2.0 Licensee's Efforts

2.1 Root Cause Evaluation

A. Evaluation of possible events

The Bechtel report enclosed in Reference 1 evaluated a number of possible events which could have contributed to a significant load on the feedwater system. Bechtel performed several analyses which demonstrated that normal operating loads in conjunction with postulated snubber malfunction, excessive strut preload, and constraint expansion due to the Integrated Leak Rate Testing could not have generated forces large enough to cause the damage observed. The load required to cause support failure was estimated to be not less than 40 kips. Bechtel concluded that the damage to SR8 most likely occurred as a result of a water hammer. Bechtel also determined that thermal bowing of the long run of horizontal piping due to low flow thermal stratification could have been a contributing factor that could coexist with a postulated water hammer resulting in additional loads to the pipe supports.

B. Verification of Stresses in Design Conditions

The portion of feedwater piping inside containment was reanalyzed. The calculated piping and support loads were confirmed to be within design allowables. Calculations also found that loads remain within allowables even without SR8.

C. Post Event Inspection

The inspections included visual, radiographic and ultrasonic examinations of the B loop feedwater piping, valves and supports, similar but less extensive examinations of the A loop and visual and surface examinations of the C and D feedwater lines. With the exception of the damaged support, only chatter and scrape marks on three B loop hangers were the only other observed abnormal indications considered to be associated with the failure of SR8. Piping integrity was maintained after the SR8 damage.

D. Calculations for a hypothetical water hammer loads

A hydraulic analysis was performed to establish water hammer forces resulting from normal plant trip with valve closures, and with a possible stuck open check valve or inadvertent delays in control valve and isolation valve closures. Water hammer forces resulting from condensation of postulated steam bubbles in the feedwater line steam generator feed ring were also calculated.

E. Piping analysis for response to hypothetical water hammer loads

A linear elastic time history analysis was performed to evaluate the feedwater piping and support response to the hypothetical water hammer loads. Piping with and without SR8 support were both evaluated. The dynamic response and maximum stress values were similar for both cases. The analysis verified that SR8 would be expected to be the first to fail due to lower anchorage capacity and being the only rigid support in the system. The failures of SR8 indicates that the occurrence of a water hammer was likely.

In summary, the above evaluations concluded that the damage to SR8 likely occurred as a result of water hammer and possibly in conjunction with thermal stratification loads, and the anchorage of SR8 was the limiting component of the system. However, the damage of SR8 did not affect the integrity of the feedwater system, and system integrity remains even without SR8.

2.2 Corrective Actions

A. Support modifications

Repairs to SR8 have been completed. The modified SR8 has a new anchorage system consisting of stronger bolts passing through the whole thickness of the slab, which is over 30 inches instead of 2.5 inches embedment in the original design. Thus capacity of SR8 is much enhanced.

B. System operation changes

By modification of system operating procedures, flow rate in feedwater line and steam generator water level can be better controlled to minimize the possible occurrences of the condensation induced water hammer event.

C. System maintenance testing

The main and auxiliary feedwater check valves will be checked for back leakage during startups from each refueling outage, and a maintenance inspection of these valves will be performed once every two years.

D. Dynamic load monitoring

Instrumented monitoring for possible occurrences of water hammer type dynamic loads to the feedwater system will be implemented. Pressure transducers, pressure indicator alarm, recorder to pipe movement, and thermocouples will be used to ensure data collections for any major transient.

E. Third party reviews

The licensee retained Impell Corporation to perform an independent review of the issues pertaining to SR8 damage, including thermal hydraulic analysis, piping analysis and support evaluations performed by Bechtel. The Impell review concurred with the Bechtel conclusions on the cause of SR8 damage with minor recommendations (Reference 3).

3.0 Staff Evaluation

The staff reviewed all of the reports and calculation summaries provided by the licensee in submittals dated June 12, 1987 (Reference 1), June 16, 1987 (Reference 2) and July 27, 1987 (Reference 3). These submittals included a Bechtel report on the evaluation of the support failure, a PGE report on the evaluation of the failure, and an Impell report on their independent review of the evaluation.

Judging from differences in magnitudes of loads caused by various events to piping and supports as shown in the Bechtel report (Reference 1), the staff agrees with the primary conclusion in the Bechtel report that the damage to SR8 most likely occurred as a result of an unanticipated water hammer. The staff considers the review effort as described in the PGE report (Reference 2) to be comprehensive. The action plan appears complete and its implementation has provided positive bases to support the conclusion that water hammer was the most probable cause of failure of SR8. Specifically the staff considers that the evaluations and analyses performed have adequately demonstrated that bubble collapse in the feedwater line near the steam generator nozzle can generate severe transient loads to cause the failure and that the prerequisite initiators of feedwater line drain back and high refill rate existed in the time periods when failure occurred.

The staff has reviewed the post-event inspection and repair performed by the licensee and considers that the inspection was extensive enough to reveal any measurable damage caused by the SR8 failure. The staff had conducted an on site inspection of the main feedwater line. Based on evidence of actual damage observed, the staff concurs with the scope of repair. By reinstalling the undamaged SR8 support with a strengthened anchorage system, SR8 will have ample capacity to sustain much greater loads than the design intended.

The staff accepts the licensee's corrective actions of instituting operating procedure changes to minimize feedwater line drain back which should minimize the formation of steam bubbles in the feedwater line following a plant trip and reduce the chance of future water hammer.

The staff considers that the licensee's monitoring program has provided a sufficient, though limited, amount of instrumentation to monitor future dynamic events. Instrumentation consisting of rapid response and alarmed pressure transducers on the feedwater lines, linear potentometer displacement monitors on spring supports H9 and H13 and thermocouples on the top and bottom of the steam generator nozzles have been installed. This instrumentation will be useful to monitor temperatures and peak system pressures during normal operations and will provide time history plots of the monitored pressures and system displacements when system pressures exceed 100 psi above steady state values. In this regard the staff feels that the addition of some acclerometers mounted in locations where peak accelerations would be expected would greatly enhance the monitoring effort.

The staff reviewed the July 27, 1987 PGE Report (Reference 3) which consisted of Appendices A and B. Appendix A provided a description of the water slug motion analyses performed by Bechtel as part of the Action Plan. As noted above the staff regards these analyses and the others as an adequate basis to support the licensee's root cause determination. The staff recommends that the table be expanded to include columns listing estimates of pipe displacements at the hanger locations and pipe stresses at key locations. This data could prove useful in corroborating the estimates of failure loads against the observed hanger displacements and in providing a basis for fatigue usage estimates. Appendix B is a summary of the independent review of Action Plan items performed by Impell Corporation. The staff has reviewed the Impell report and concurs with its findings and recommendations. The staff requires that the licensee comply with all the Impell proposed actions.

Although the staff considers the Licensee's Action Plan to be well conceived and comprehensive, it has identified the following two concerns.

A. The feedwater system was subjected to dynamic loads which were great enough to fail the anchorage of SR8. These loads may also have caused permanent, although invisible and unmeasureable damage to the feedwater piping and its components, possibly reducing their serviceable life. This issue does not seem to have been addressed in the Action Plan.

B. It is stated in Appendix B to the PGE report (Reference 3) that the allowable load for the strut in SR8 is 20 kips under faulted conditions and the inspections of SR8 revealed no signs of distress. Assuming that the other structural members of SR8 were also designed to meet a load of 20 kips with a comparable margin, it is questionable to expect that all these members could be subjected to an estimated failure load of 40 kips without showing any definite indications of distress. A verification to ensure consistency between the estimated failure load of SR8 and the extent of the observed damage is needed.

4.0 Conclusions

The staff concludes that the licensee has identified the most probable cause of failure of the seismic restraint SR8 and has taken appropriate actions to minimize the possibility of future recurrences. The inspections demonstrated that the feedwater piping and other support structures had not undergone measurable damage during the failure and, with the repair of the SR8 restraint, the system will be returned to an operable configuration with greater capacity to resist similar events in the future. The maintenance testing and inspection of main and auxiliary feedwater check valves will enhance their operability and minimize unanticipated transients induced by the malfunctioning of these valves.

The monitoring program will verify the effectiveness of changes in system operation procedures and get better understanding about the characteristics of severe transients should it recur. However, the licensee should confirm the following:

A. To ensure that the failure of restraint SR8 has not reduced the fatigue life of the feedwater piping systems to unacceptable levels for continuing service.

B. To ensure consistency between the estimated failure load of SR8 and the extent of damage observed.

C. To ensure that the proposed feedwater check valve maintenance and testing program is not inconsistent with the IST program for all valves in the Trojan plant.

References

1. Letter, PGE to NRC, "Main Feedwater Restraint Failure Engineering Analyses", June 12, 1987.

2. Letter, PGE to NRC Region V, "Main Feedwater Restraint Failure", June 16, 1987.

3. Letter, PGE to NRC, "Main Feedwater Restraint Failure Engineering Analyses", July 27, 1987.