SAFETY EVALUATION REPORT
ACCUMULATOR FILL LINE FAILURES
TROJAN NUCLEAR PLANT
Docket No. 50-344

1.0 Description of Event

During the 1987 refueling outage, two failures of the "A" safety injection accumulator fill line occurred. On May 12, 1987 while transferring water from the "A" accumulator to the "D" accumulator by sluicing through the fill lines, a rupture of the "A" fill line at the accumulator nozzle-to-pipe weld occurred. The differential pressure between the accumulators at the time was 583 psid. A metallurgical evaluation indicated that a low-cycle fatigue failure had occurred.

The failed weld was repaired and the system was hydrostatically tested on May 23, 1987. The pressure was then reduced to 650 psig and the sluicing operation was repeated. A loud banging noise was heard, and the operation was stopped. A second attempt was made and the loud banging noise continued. Following a valve line-up check, the operation was started again, and a rupture of the fill line at the line nozzle weld location occurred.

2.0 The Licensee's Efforts

2.1 Root Cause Evaluations

Metallurgical evaluations were performed after the first and the second failures with the determination that failures were caused by low-cycle fatigue. The Licensee then conducted investigations to determine the cause of the failure and the source of the banging noise.

Through vendor and industry experience, the Licensee determined that the Kerotest Y-pattern packless metal diaphragm (PMD) manual valves which are used in the accumulator fill line are subject to chattering when exposed to excessive back-flow. The sluicing flow will cause reverse flow through the PMD valve. Because the PMD valve's globe is held open by a spring, when reverse flow through this valve reaches a specific velocity and the fluid closing force exceeds the spring force, the disk will be forced down, shutting the valve. The the valve will open and close repeatedly due to pressure oscillations. Industry data suggests that backflow rates exceed 55 gallons per minute (gpm) can result in valve chatter and violent pressure surges in the attached piping system.

The Licensee conducted a test to determine the backflow rate at which the Kerotest valve becomes unstable and "chatters". A section of piping which replicated the geometry of a section of accumulator fill line piping was fabricated for the tests. When the steady state backflow rate exceeded 68 gpm, chatter was noted. Pipe motion was violent and loud noises were heard. The piping failed at the locations corresponding to the accumulator connection. The number of cycles to failure was estimated at approximately 100.

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The Licensee performed calculations to determine the expected backflow rates from the "A" to "D" accumulators when transferring water via the fill and sample lines assuming a 600 psi differential pressure. The results indicated that the backflow rate via the fill line was 95 gpm. The backflow rate through the sample line was 45 gpm and the backflow rate to the CVCS holdup tank was 26 gpm. Based on these results, the Licensee concluded that valve chatter would be expected during a transfer operation via the accumulator fill line since the flow rate exceeds the critical flow rate. Valve chatter would not be expected in the other two cases.

To verify that the valve chatter was the cause of the piping failure, the Licensee had Bechtel perform a water hammer analysis to predict the pipe stress during the event. In order to generate hydraulic forcing functions for structural evaluations, a thermal hydraulic analysis of the piping between the accumulators was performed. The model assumed a differential pressure of 580 psi, a backflow rate of 56 gpm and an assumed closure time of 5 milliseconds for the PMD valve (based on engineering judgement). The analysis indicated that significant pressure pulses would be generated due to valve closure, water column separation and void collapse. Sensitivity studies with longer valve closure time and lower flow rate also indicated that high pressure pulses would be expected.

The force time history generated from the hydraulic analysis was applied to the piping system in a linear elastic dynamic time history analysis. The calculated stress at the pipe junction with the accumulator nozzle indicates that significant plastic deformation would occur. The calculation also indicated that the piping was in resonance with the hydraulic force time history. Thus the analysis provided additional evidence that the hydraulic transient resulting from the valve chattering could cause a low cycle fatigue failure.

2.2 Inspection of Accumulator Fill Lines

The Licensee repaired the nozzle-to-pipe weld and conducted a number of inspections to assure the integrity of piping and components of the affected line and similar safety injection lines. The inspection included the following:

a. Surface examinations on (1) all nozzle-to-pipe welds; (2) fill line pipe welds from accumulator to second support upstream of control valve, and (3) sample line pipe welds about 10 feet on either side of packless diaphragm globe valves.

b. Ultrasonic examinations on nozzle to vessel weld on "A" accumulator.

c. Visual examinations on (1) pipe supports of fill lines for all accumulators; (2) control valves and packless diaphragm globe valves on sample and fill lines, and (3) small piping in containment with packless diaphragm globe valves.

The inspection results indicated that all piping and nozzle-to-pipe welds were satisfactory. All pipe supports were found to be satisfactory. Some damage was observed on the "A" fill line control valve and PMD valve. These valves were repaired.

2.3 Accumulator Nozzle Evaluation

In the course of the two failures of the "A" fill line at the pipe-to-nozzle weld, the nozzle was exposed to higher then normal loading. In order to verify the adequacy of the nozzle for continuing service, the Licensee performed additional evaluations to estimate the stress and the fatigue usage factors due to the pipe failure events. The nozzle loads were calculated based on the moment range required to produce bending stress equal to twice the yield stress at the junction of the pipe and the socket weld. Using the methodology described in Welding Research Council (WRC) Bulletin No. 207, the combined membrane and bending stress intensities were determined to be 1,484 psi at the vessel and 31,303 psi at the nozzle.

Since the vessel stress was significantly below the fatigue endurance limit of 14,000 psi, it was concluded that there was no loss in fatigue life. For the nozzle, fatigue usage factors were calculated at two locations. The first location was at the bottom of the socket and the second at the base of the nozzle at the interface with the vessel weld. The usage factors were conservatively based on 2500 cycles at the calculated load. The resultant fatigue usage factors were 0.01 for the first location and 0.004 for the second. A sensitivity check was performed using bending moments of double and half the calculated value. The usage factors for double the bending moment were 0.009 and 0.001, and for half the bending moment were 0.071 and 0.003, respectively. All of these values are well below the limit of 1.0, indicating that the effect on the fatigue life on the nozzle is negligible.

2.4 Corrective Actions

The Licensee has made the necessary repairs on pipe-to-nozzle connection welds to make the system operational. To prevent future recurrence of the PMD valve chatter-induced water hammer, Operating Procedure OI-5-2 was revised to prohibit sluicing between accumulators through the fill or sample lines.

3.0 Staff Evaluations

The staff reviewed the summary and results of the Licensee flow calculations (Attachment A to Reference 1) which indicated that during the sluicing operation which resulted in the pipe failure, the backflow rate through the PMD valve was 95 gpm. The staff also reviewed the test report on the PMD valve flow test (Reference 2) which demonstrated that valve chatter at high backflow rates can be expected when backflow exceeds a critical rate of approximately 70 gpm. The test simulated the piping geometry of the accumulator fill line that failed. At the critical flow rate, violent pipe motion was observed and the test piping failed at the location corresponding to the accumulator nozzle connection. Based on these reviews, the staff concludes that the Licensee has adequately demonstrated that valve chatter and water hammer loads were a direct result of the sluicing operation through the "A" to "D" fill lines.

The staff reviewed Bechtel's report (Attachment B to Reference 1) on the thermal hydraulic analysis and stress analysis of the piping due to rapid closure of the PMD valve. The analysis indicated that the loads associated with the water hammer would result in stresses of sufficient intensity to cause a low cycle fatigue piping failure at the nozzle connection. Based on these results and the test results, the staff concludes that the Licensee has properly identified the root cause of the piping failure. The staff also concurs with the Licensee's corrective action in revising procedures to prohibit the sluicing operations in order to prevent recurrence of this type of failure.

The Licensee performed several inspections and a stress analysis of the "A" vessel nozzle to verify the structural integrity of the system. The inspections included surface examinations of welds, ultrasonic examinations of the nozzle-to-vessel weld, and visual inspection of pipe supports, valves and other piping. All inspection results showed the system to be satisfactory except for some valve damage. The valves were subsequently repaired. The staff finds the inspections acceptable.

The staff reviewed the Licensee's accumulator nozzle stress evaluation (Attachment A to Reference 1). The staff concurs with the Licensee's conclusion that the calculated fatigue usage factors would have a negligible effect on the fatigue life of the nozzle.

4.0 Conclusion

The staff evaluation concludes that the Licensee has properly identified the cause of the accumulator fill line failures and has taken appropriate corrective actions to prevent future recurrences. The inspections have demonstrated the adequacy of the system in its present condition.

References

1. PGE letter, C. P. Yundt to USNRC, "Accumulator F 11 Line Failure Engineering Analyses" dated June 12, 1987.

2. PGE Subtask Report, "Kerotest Valve Flow Tes. Action Plan Item No. A.2.i, Accumulator Fill Line Failure, dated June 4, 1987.

3. PGE letter, D.W. Cockfield to USNRC, dated September 4, 1987