PGE Portland General Electric Company

David W. Cockfield Vice President, Nuclear

December 20, 1989

Trojan Nuclear Plant
Docket 50-344
License NPF-1

U.S. Nuclear Regulatory Commission
Attn: Document Control Desk
Washington DC 20555

Dear Sir:

Pressurizer Pressure Transmitters Failure Analysis

During May 1986, Portland General Electric Company (PGE) replaced each of the four pressurizer pressure transmitters (PTs) which provide signals to the reactor protection system with a new model of transmitter. A number of subsequent failures of the PTs resulted in the replacement of the PTs with another type of transmitter during the 1989 Refueling Outage.

Although PGE determined that the failures were not reportable under Title 10, Code of Federal Regulations, Part 21 (10 CFR 21), the attached report is submitted for your information because the failure of these PTs in applications at other plants could potentially create a substantial safety hazard. The report discusses how hydrogen embrittlement of the Bourdon tube was determined to be the failure mechanism and how a manufacturing change contributed to the failure.

Sincerely,

TTnwalt for

Attachment

c: Mr. John B. Martin
Regional Administrator, Region V
U.S. Nuclear Regulatory Commission

Mr. David Stewart-Smith
State of Oregon
Department of Energy

Mr. R. C. Barr
NRC Resident Inspector
Trojan Nuclear Plant

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121 S.W. Salmon Street, Portland, Oregon 97204

FAILURE ANALYSIS OF MODEL 763A ITT BARTON PRESSURE TRANSMITTERS

Summary

Due to equipment qualification concerns, Portland General Electric Company (PGE) replaced each of the four pressurizer pressure transmitters (PTs) which provide signals to the reactor protection system with Model 763A ITT Barton PTs in May 1986. These Model 763As performed satisfactorily until the first failure occurred in September 1987. Approximately 17 transmitters failed at locations PT455, PT456, PT457, and PT458 before they were replaced with another type of transmitter during the 1989 Refueling Outage. The failures were characterized by the transmitters drifting off scale high.

A detailed failure analysis was performed to determine the root cause and any contributing factors. The failure analysis considered changes in system configuration, changes in the manufacturing process, and process service conditions. Three potential failure mechanisms were identified and investigated. These mechanisms were overpressurization, high-cycle fatigue, and hydrogen embrittlement. Overpressurization and fatigue have been discounted as a result of field and laboratory testing followed by metallurgical evaluation. Hydrogen embrittlement of the Bourdon tube was confirmed to be the prime cause of transmitter failure. This conclusion was confirmed by field sampling of sensing line fluid, calculation, laboratory induced failure, and metallurgical evaluation.

Analysis of Potential Failure Mechanisms

Overpressurization

The PT failures were initially ascribed to a substantial one-time overpressure transient. Metallurgical examination of the early tube failures showed that this was not the case. Furthermore, a continuous pressurizer pressure monitoring program revealed that no large pressure transients were occurring. Additionally, the following failure scenarios were hypothesized and then rejected because they either contradict established engineering principles or contradict observed data and facts:

1. Large rapid pressure fluctuations in the pressurizer resulting in fatigue failure.

2. Water hammer inside the reactor coolant system (RCS) resulting in overload failures.

3. Overpressurization of the Bourdon tube caused by hydraulic lock with the instrument root valve shut.

High-Cycle Fatigue

In order to evaluate the fatigue mechanism, fast response pressure transducers were connected by tubing to the pressurizer pressure sensing lines. Spectral analysis was performed and high-speed recording mechanisms were used to monitor pressurizer pressure fluctuations over a period of several months. During the course of the monitoring, no significant forcing functions were identified.

Hydrogen Embrittlement

Metallurgical evaluations of the early failures led to the hypothesis that fatigue was the most probable mechanism. Failure Prevention, Incorporated was contracted to provide an independent evaluation. Their analysis, which is provided as Enclosure 1, suggested that hydrogen embrittlement was the primary cause.

Failure Prevention, Incorporated also identified that the PT vendor changed the wall thickness of the Bourdon tube from 19 mils to 22 mils. This increase in wall thickness led to a much greater tendency toward bending induced buckling on the inside flank of the flattened tube. The increased level of residual stress would aggravate either of the two proposed failure mechanisms.

The nature of the cracking (transgranular cracks originating on the sharp radius inside flank of the tube) was nominally compatible with either suggested mechanism. It was, therefore, decided to compare the Trojan failures with known fatigue failures and a known hydrogen embrittlement failure.

Two fatigue failure samples were provided by the Georgia Power Company Vogtle Plant. The failures were caused by the exposure of 22-mil-wall Bourdon tubes to a cyclic pressure fluctuation from vortex shedding in the Vogtle reactor coolant system. The $\pm$ 210 pounds per square inch (psi) pressure fluctuation would, according to Failure Prevention, Incorporated's finite element analysis, have led to a $\pm$ 15,000 psi cyclic stress on the inside sharp radius flank of the tube. Failures were occurring about every six days after about 13×10^6 cycles and were 100 percent through-wall.

A known hydrogen embrittlement failure sample was provided from testing conducted by PGE. A test apparatus was created to evaluate the effects of hydrogen on the Bourdon tubes. It included one Barton 763 with a 22-mil-wall tube identical to those used in Barton 763As, a Barton 763 with a 19-mil-wall Bourdon tube and a Payne pressure transducer. These were connected to data loggers and strip chart recorders. The test apparatus was first pressurized with nitrogen to check for system leakage and to provide for calibration. After a soak period of approximately 24 hours, the test apparatus was depressurized, evacuated, and repressurized with pure hydrogen gas. The Barton 763 22-mil-wall Bourdon tube pressure transmitter failed after approximately 41 hours of continuous hydrogen service. The cracks in the test sample and the in-service failures at Trojan were 10 to 50 percent through-wall. The Barton 763 19-mil-wall Bourdon tube continued to track the reference pressure transducer for a continuous 30-day period without incident at which point the hydrogen test was terminated.

Comparison of the various samples is made in the metallurgical report provided as Enclosure 2. The results of the comparison indicate that the Trojan failures were due primarily to hydrogen embrittlement. Investigation has shown the processing of the Bourdon tubes places them in a vulnerable condition because of the high level of cold work and heat treatment in the wrong temperature range. This process produces high residual stresses at the inside flank of the tube as well as a micro-structure highly susceptible to hydrogen embrittlement. The occurrence of bending induced buckling in the 22-mil-wall tube exacerbates the stress situation as compared to the 19-mil-wall tube.

At Trojan a hydrogen blanket is maintained in the volume control tank so a concentration of 25 to 35 cubic centimeters of hydrogen gas at standard temperature and pressure per kilogram of reactor coolant [cc/kg(STP)] is maintained in the RCS for oxygen scavenging. At the elevated pressurizer temperature, the solubility limit for hydrogen drops to zero at the liquid vapor interface. The resultant escape of hydrogen gas from the RCS water reaches an equilibrium concentration in the top of the pressurizer pressure vapor space. The upper pressurizer sensing lines connect to the pressurizer vapor space. As the fluid in the sensing lines is at a lower temperature than the pressurizer vapor space, the hydrogen gas returns to solution. Samples of the pressurizer pressure sensing line fluid contained 1,800 cc/kg(STP) of hydrogen. Calculations performed by PGE indicate that the maximum dissolved hydrogen could reach 2,300 cc/kg(STP). During a replacement of PT-456 in September 1988, it was discovered that the sensing line was dry and contained pure hydrogen gas (by sample analysis).

Conclusions

The testing program and metallurgical evaluation have demonstrated that the failure of the Barton 763A 22-mil-wall Bourdon tubes is due to hydrogen embrittlement. These tubes are placed in service in a highly cold worked condition after a heat treatment that produces considerable vulnerability to hydrogen embrittlement. The increase in wall thickness from 19 mils to 22 mils heightens the total stress level on the inside flank of the tube to the point where hydrogen cracks initiate and grow to near midwall, at which time the transmitters drift off scale high. Much of the increase in total stress is due to higher residual stress associated with bending induced buckling on the inside flank of the flattened 22-mil-wall tube.

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