SAFETY EVALUATION BY OFFICE OF NUCLEAR REACTOR REGULATION
MECHANICAL ENGINEERING BRANCH
STEAM GENERATOR TUBE INTEGRITY UNDER COMBINED ACCIDENT CONDITIONS
PORTLAND GENERAL ELECTRIC COMPANY
TROJAN NUCLEAR PLANT

INTRODUCTION

Combined accident condition loadings such as LOCA plus SSE could result in yielding at a tube support plate (TSP) with subsequent deformation of the tubes. If significant tube deformation should occur, primary flow area could be reduced and postulated cracks in tubes could propagate through-wall resulting in the potential for in-leakage under LOCA conditions. In-leakage is a potential concern as leakage through several severed tubes may inhibit the core refill/reflood process and cause an unacceptable increase in the core peak clad temperature (PCT).

DISCUSSION

The most limiting accident conditions from tube deformation considerations are seismic (SSE) plus loss of coolant accident (LOCA). The seismic excitation defined for steam generators is in the form of acceleration response spectra at the steam generator supports. In the seismic analysis, the licensee has used generic response spectra which envelope the Trojan specific response spectra. The El Centro earthquake motions were utilized in developing the generic response spectra. A finite element model of the Series 51 steam generator was developed and the analysis was performed using the WECAN computer program. The mathematical model consisted of three dimensional lumped mass, beam, and pipe elements as well as general matrix input to represent the piping and support stiffness.

Interactions at the TSP/shell and wrapper/shell connections were represented by concentric spring-gap dynamic elements. Impact damping was used to account for energy dissipation at these locations.

LOCA loads developed as a result of transient flow following a postulated primary coolant pipe break, were calculated for five different pipe break locations. These included three large and two minor pipe breaks. The large pipe break locations evaluated were the steam generator inlet and outlet lines and the reactor coolant pump outlet line, while the minor pipe breaks analyzed were the pressurizer surge line and the accumulator line breaks. Prior qualification of the Trojan primary piping for leak before break requirements resulted in the limiting LOCA event being either the accumulator line break or the pressurizer surge line break. The licensee has however used the loads for the primary piping break as a conservative approximation.

The principal tube loading during a LOCA is caused by the rarefaction wave in the primary fluid. This wave initiates at the postulated break location and travels around the tube U-bends. A differential pressure is created across the two legs of the tube which causes an inplane horizontal motion of the U-bends and induces significant lateral loads on the tube. The pressure time histories needed for creating the differential pressure across the tube are obtained from transient thermal-hydraulic analyses using the MULTIFLEX computer code. For the rarefaction wave induced loadings, the predominant motion of the U-bends is in the plane of the U-bend. Thus the individual tube motions are not coupled by the anti-vibration bars and the structural analysis is performed using single tube models limited to the U-bend and the straight leg region over the top two TSP's.

In addition to the rarefaction wave loading discussed above, the tube bundle is subjected to bending loads during a LOCA. These loads are due to the shaking of the steam generator caused by the break hydraulics and reactor coolant loop motion. However, the resulting TSP loads from this motion are small compared to those due to the rarefaction wave induced motion.

To obtain the LOCA induced hydraulic forcing functions, a dynamic blowdown analysis is performed to obtain the system hydraulic forcing functions assuming an instantaneous (1.0 msec break opening time) double-ended guillotine break. The hydraulic forcing functions are then applied, along with the displacement time-history of the reactor pressure vessel (obtained from a separate reactor vessel blowdown analysis), to a system structural model, which includes the steam generator, the reactor coolant pump and the primary piping. This analysis yields the time history displacements of the steam generator at its upper lateral and lower support nodes. These time-history displacements formulate the forcing functions for obtaining the tube stresses due to LOCA shaking of the steam generator.

In calculating a combined TSP load, the LOCA rarefaction and LOCA shaking loads are combined directly, while the LOCA and SSE loads are combined using the square root of the sum of the squares. The overall TSP load is transferred to the steam generator shell through wedge groups located at discrete locations around the plate circumference.

The radial loads due to combined LOCA and SSE could potentially result in yielding in the TSP at the wedge support. Some tubes in the vicinity of the wedge supports could partially deform and subsequently collapse during a LOCA. The reduction in flow area increases the resistance to flow of steam from the

core which in turn may potentially increase PCT. In addition there is a potential concern that tubes with partial through-wall cracks could progress to through-wall cracks during tube deformation. The resulting in-leakage is a potential concern since the cumulative leakage may cause an increase in the core PCT.

Utilizing results from recent tests and analysis programs the licensee has shown that tubes will undergo permanent deformation if the change in diameter exceeds 0.025 inch. This threshold for tube deformation is related to the concern for tubes with pre-existing tight cracks that could potentially open during a combined LOCA plus SSE event. For the Trojan plant the LOCA plus SSE loads were determined to be of such magnitude that none of the tubes are predicted to exceed this deformation limit and therefore will not lead to significant tube leakage.

The licensee has assessed the effect of SSE bending stresses on the burst strength of tubes with axial cracks. Tensile stress in the tube wall would tend to close the cracks while compressive stress would tend to open the cracks. On the basis of previously performed tests the licensee has concluded that bending stress on the order of yield stress of the tube material is necessary before the burst strength of the tube is affected to any significant degree. The maximum bending stress on the tube wall calculated to occur during a seismic event is substantially less than the yield stress of the tube material. Thus it is concluded that the burst strength of tubes with through-wall cracking is not affected by an SSE event.

CONCLUSION

Based on a review of the information provided by the licensee it is concluded that at Trojan no significant tube leakage is likely to occur during an SSE plus LOCA event which has been identified as the most limiting condition from tube deformation considerations.