Analysis of Condensation Induced Steam Waterhammer in a BWR LPCI System

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Most of the Boiling Water Reactor (BWR) Plant Technical Specifications require Low Pressure Coolant Injection (LPCI) to be operable in Modes 1, 2 and 3, with the allowance that LPCI may still be considered operable while operating in Shutdown Cooling (SDC) if it is capable of being manually aligned to the LPCI mode. There is a concern that the alignment of the RHR system to the Torus (or suppression pool) to mitigate a Loss of Coolant Accident (LOCA) during SDC operation would cause steam void formation and collapse on the suction and discharge sides of the RHR pumps.

A study to characterize the steam waterhammer phenomena of a low pressure cooling injection (LPCI) system for a Mark 1 boiling water reactor (BWR) has been performed using RELAP5 during a transient event. The scenario of particular interest was a manual switchover from shutdown cooling mode 3 to low pressure injection due to a loss of coolant accident (LOCA). This transient was initiated by opening the isolation valves (MO-B1 and MO-D1) of the two trains on a LPCI system into the torus (see Figure 1).

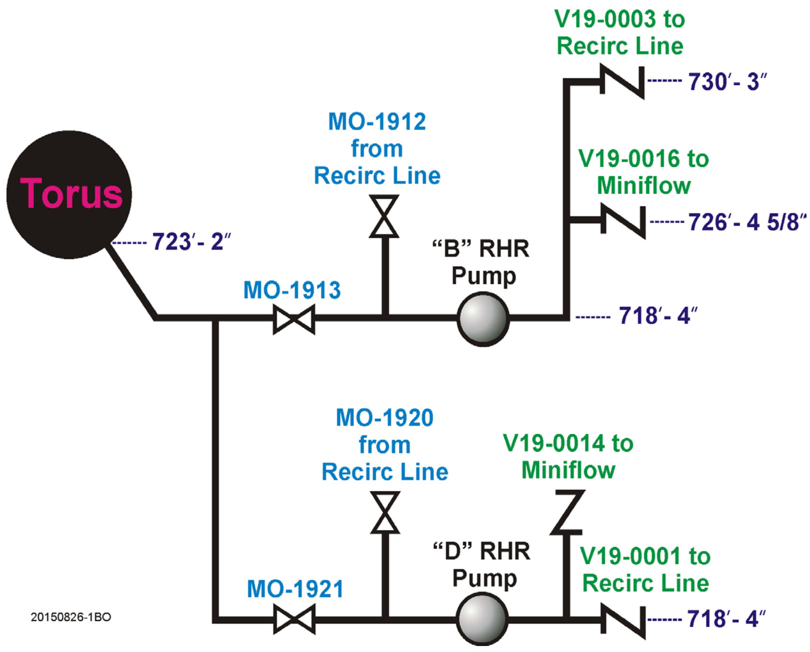

Figure 1 Simplified schematic of RHR Loop

The torus was considered to be at atmospheric pressure and 68°F. The initial condition of the problem was set up such that the liquid was stagnant in the system. The initial temperature and pressure of the liquid, which was between the torus and isolation valves, was considered to be the same as the torus conditions. On the other hand, the initial condition of the liquid upstream of the isolation valves was chosen to be at 150 psia and near saturation temperature. The analysis showed that the liquid in the system flashed into steam and discharged into the torus after the isolation valves started to open. Discharge of steam continued until the pressure in the LPCI system reached to a hydrostatic equilibrium with the torus. Following this, the cold liquid from the torus began to reflood the LPCI piping while condensing the steam at the liquid-steam interphase. Figure 2 provides a pictorial presentation of the phenomena. These series of events caused a mild steam waterhammer event when all of the steam condensed in the piping segments with closed ends as shown in Figure 3. A sensitivity analysis showed that the magnitude of the steam waterhammer predicted by RELAP5 was sensitive to the number of nodes selected to model the piping, where the steam waterhammer phenomena occurred. Technical basis was obtained from the available literature and used as a guide to choose the number of nodes for the models in both codes. Once the steam waterhammer and the hydrodynamic properties associated with this transient were predicted by RELAP5, the forces exerted on critical pipe components were calculated using a one-dimensional momentum equation. Figure 4 shows the force, which was calculated on "B" Shutdown Cooling Line.

Steam waterhammer phenomena have been of major concern to the nuclear industry. This is because of the fact that large waterhammer pressure and hydrodaynamic loads can potentially be generated that will challenge the integrity of various piping systems if a strong steam waterhammer occurs. As a result of this, the United States Nuclear Regulatory Commission (USNRC) issued a generic letter, GL 96-06 (1996). All licensees are required to perform evaluations on various systems that are susceptible to steam waterhammer.

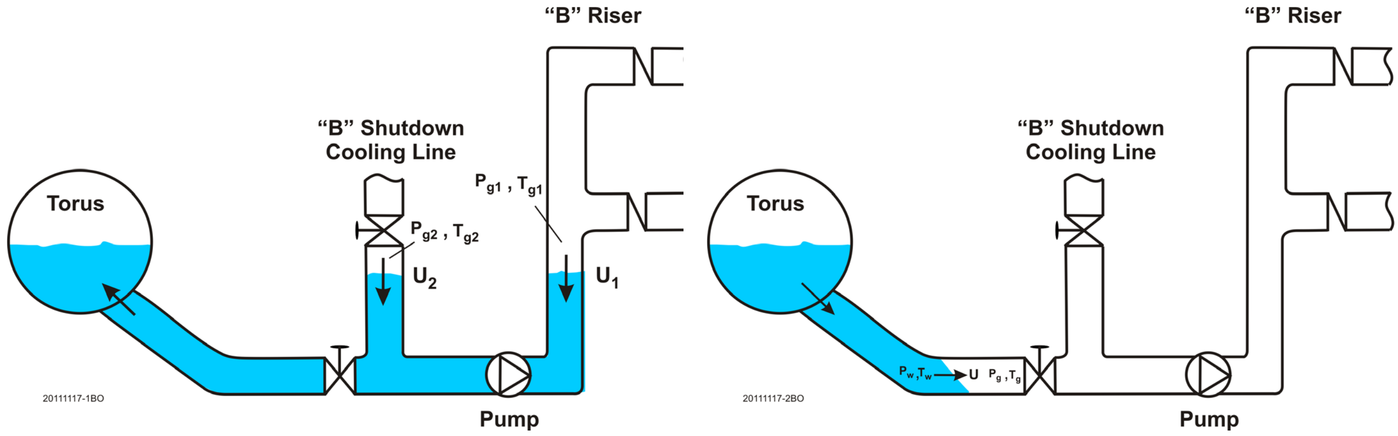

Figure 2 Schematic representations of blow-down and re-flooding

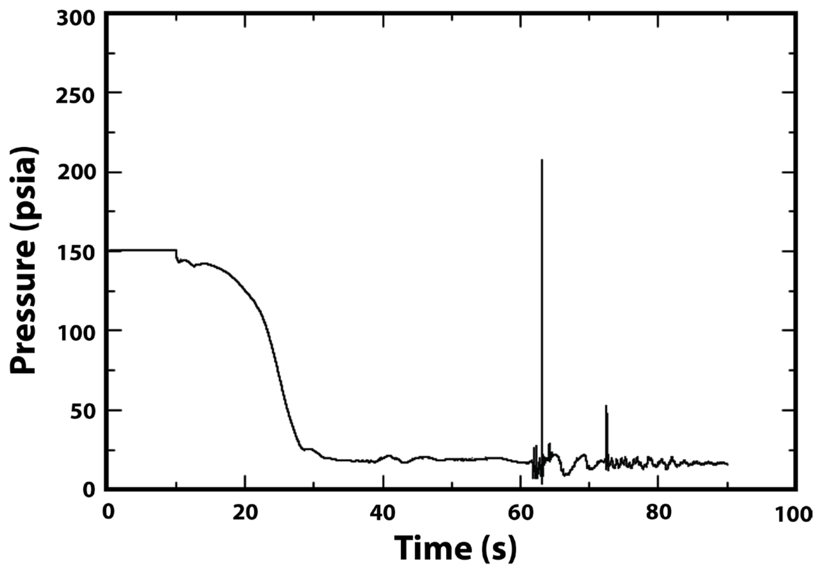

Figure 3 Pressure time history at the top of "B" Shutdown Cooling Line

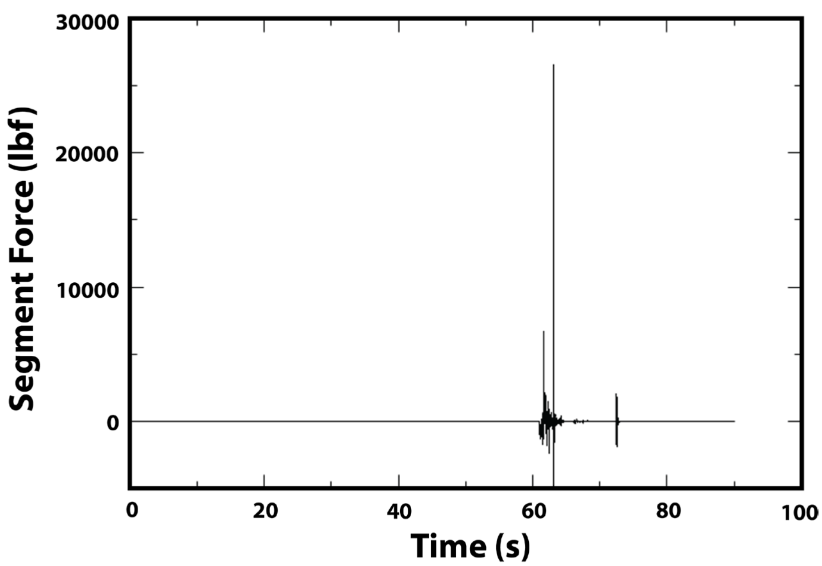

Figure 4 Force time history of the top of "B" Shutdown Cooling Line

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