# SIMULATION OF AN AP1000 INADVERTENT PASSIVE RESIDUAL HEAT REMOVAL HEAT EXCHANGER ACTUATION IN THE APEX TEST FACILITY

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## ABSTRACT

The AP1000 passive safety systems are designed to mitigate against design basis accidents without the need for AC power. A key component of the passive core cooling system (PXS) is the passive residual heat removal (PRHR) heat exchanger which is the safety grade component designed to remove decay heat from the reactor coolant system (RCS) following an accident. The PRHR heat exchanger is located in the in-containment refueling water storage tank (IRWST) at an elevation above the reactor core. The inlet to the heat exchanger is connected to one of the two hot legs while the outlet is connected to the outlet plenum on one of the two steam generators. The inlet is open to the RCS pressure, and the outlet pipe is normally closed by two isolation valves in parallel to assure that the system is single failure proof. During normal operation, the water in the heat exchanger tubes is in thermal equilibrium with the IRWST. When a safety injection signal is generated following an accident, these isolation valves are opened and natural circulation is established in the heat exchanger which is sized to remove the decay heat from the RCS. To enhance natural circulation, the reactor coolant pumps are tripped on a safety injection signal.

A unique accident sequence for AP1000 is the inadvertent opening of the PRHR isolation valves when the reactor is operating at full power. Cold water from the PRHR heat exchanger tubes is discharged into the steam generator channel head where it mixes with the RCS loop flow as it exits from the steam generator tubes. The outlet plenum feeds the inlets of two reactor coolant pumps which pump the flow into the two cold legs. Either the two cold legs will be close to the same temperature if the water in the plenum is well-mixed, or one cold leg temperature could be significantly colder than the other if it is not well-mixed.

For a well-mixed plenum, two of the four cold legs will be moderately colder than the two attached to the steam generator without the PRHR return line. For a non-well-mixed plenum, one of the four cold legs will be significantly colder than the other three. The four cold legs enter the reactor vessel downcomer at 90-degree increments around the vessel. The flow turns downward and can mix with flow from the other cold legs. In the limit where there is no mixing in the steam generator plenum and no mixing in the downcomer, flow could enter one quadrant of the core at a much lower temperature leading to a local power excursion due to a positive reactivity insertion from the colder, denser reactor coolant. Thus, it is useful to determine the degree of mixing to guide the safety analysis assumptions for this accident.

The APEX facility is a one-fourth pressure, one-fourth height scale model of the AP1000 passive core cooling system. The facility has been used to simulate design basis accidents in support of the AP1000 design certification. The facility is extensively instrumented to provide pressure, temperatures and flow rates throughout the RCS and PXS. In addition, there is a large number of thermocouples in the downcomer to determine the extent of mixing between the four cold leg streams before they enter the reactor vessel lower plenum. The inadvertent PRHR actuation accident was simulated at APEX to determine the degree of mixing in the steam generator outlet plenum and the reactor vessel downcomer. The results of these tests were then used to guide the safety analysis assumptions on mixing.