Simulation of PWR Turbine Trip Transient in ROSA-IV Large Scale Test Facility

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As a part of tests for commissioning the ROSA-IV Program’s Large Scale Test Facility (LSTF), an experimental simulation of the pressurized water reactor (PWR) turbine trip transient was conducted. This test (AT-LT-01) was the first test conducted in the LSTF on a PWR operational transient, and has provided test data useful for code assessment.

1. Test Facility and Procedure

The LSTF (Fig. 1) is a 1/48-scale simulation of a Westinghouse type 4-loops (3,423 MWt) PWR. The elevations of major components are preserved full-scale to properly represent the natural circulation phenomena important to the core cooling during and after small break loss-of-coolant accidents (LOCAs) and operational transients. The PWR 4-loops are represented by 2 equal-volume loops. Thus, the secondary volume and heat transfer area in each steam generator (SG) are scaled at 1/24 of those in the reference PWR.

![Fig. 1 Schematic of ROSA-IV Large Scale Test Facility (LSTF)](image)

The test was initiated from a pressurizer pressure of 15.6 MPa and hot and cold leg temperatures of 598 and 564 K, respectively. These pressure and temperatures are typical of the reference PWR’s rated operating conditions. The maximum core power (10 MW) is 14% of the scaled PWR rated power (3,423/48=71.3 MW) and the initial core flow also reduced to be 14% of the scaled PWR core flow to obtain prototypical hot and cold leg temperatures. Also the initial secondary temperature and pressure were higher than those in the reference PWR to limit the primary-to-secondary heat transfer to 10 MW.

The test was initiated by quickly closing a simulated turbine throttle valve. The valve closure caused automatically a core power trip and also caused the main feedwater flow to stop as the main steam flow stopped. The core power was programmed to maintain its initial level (10 MW) until 2.7 s after the core power trip, when the scaled PWR core power became 14% of the initial value, i.e. 10 MW. Then, the LSTF core power was controlled to follow a scaled PWR core power decay curve. The reactor was...
coolant pumps were operated at a constant speed of \(\sim 800\) rpm.

The core power trip signal activated the simulated turbine bypass system. Thus, the secondary steam was relieved to cool the primary system and SG secondaries.

The PWR turbine bypass system (valves connecting the main steam header and condenser) was simulated using the SG atmospheric relief valves (Fig. 2). The simulated turbine bypass valves (one on each SG) were programmed to open when the primary mean temperature (PMT: the average of the hot leg and cold leg temperatures) exceeded a set point of 566.4 K and to close when PMT was less than 566.3 K. The discharge flow from each valve was limited by a 19.4-mm I.D. orifice.

![Diagram of PWR and LSTF turbine bypass system](image)

**Fig. 2** Schematic of turbine bypass system in PWR and LSTF

**2. Test Results and Discussions**

Shown in **Fig. 3** are the LSTF test results and the predictions with the RELAP5/Mod1 CY=18 computer code\(^{(2)}\). The turbine bypass valves opened twice during the test duration of 400 s and caused the PMT to decrease toward the setpoint of 566.4 K. Thus, the system was led to approach the reference PWR hot standby conditions.

The reactor coolant system (RCS) pressure first increased slightly and the gradually decreased as the fluid temperatures decreased due to the core power trip and the operation of the turbine bypass system. The depressurization was affected by the simulated pressure control system which consists of pressurizer proportional heater and backup heater. The pressurizer proportional heater was powered full (7.0 kW) when the pressurizer pressure was less than 15.41 MPa. Also, the pressurizer backup heater (74.7 kW) was on when the pressurizer pressure was less than 15.34 MPa. These heaters slowed the RCS depressurization, and caused the RCS to repressurize when the simulated turbine bypass valves closed.

The secondary pressure initially increased as the turbine throttle valve was closed. Thereafter, the secondary pressure decreased when the relief valves were opened and increased when the relief valves were closed.
The average temperature (PMT) of primary loops decreased due to the heat removal from SG when the relief valves were opened.

A post-test analysis of the present test was conducted using the RELAP5/Mod1 code. The LSTF was represented using 195 volumes, 200 junctions and 73 heat slabs. A discharge coefficient of 0.6 was assumed for the turbine bypass valve orifices. The calculated RCS pressure and PMT agreed well with the test data as shown in Fig. 3. The timings of the closure and opening of the simulated turbine bypass valves were also predicted reasonably well.

The PMT behavior calculated for the reference PWR is compared to the LSTF data also in Fig. 3. The PWR system was represented using 189 volumes, 196 junctions and 82 heat slabs. It is considered that the difference between the PWR and LSTF transients resulted primarily from the smaller core flow to the power ratio in the LSTF compared to the reference PWR. In the LSTF, the core flow remained ~14% of the scaled PWR core flow, whereas the core power became 100% of the scaled PWR power after 2.7 s. The PWR hot leg temperature decreased after the core power trip more rapidly than the LSTF, so that the PMT rapidly became lower than the turbine bypass setpoint. This suggests that the LSTF will better simulate the temperature behavior, if the core flow is increased after the core power trip. Such test procedure will be considered for the future tests.

The LSTF behavior was also affected by the simplified simulation of the turbine bypass system. The PWR turbine bypass system consists of several banks of control valves which are programmed to provide flow area proportional to the temperature deviation from the setpoint (~565 K). However, this was simulated in the LSTF by on-off valves (one on each SG) with a total flow area (19.4 mm I.D. x 2 orifices) which was 30% of the scaled maximum PWR turbine bypass flow area. Thus, the LSTF turbine bypass system provided smaller-than-scaled bypass flows during the early portion of the test where the PMT was higher than that corresponding to 30% of the full bypass flow in the reference PWR (~571 K).

3. Conclusion

(1) The PWR turbine trip transient was successfully simulated with the LSTF. The RELAP5/Mod1 CY=18 code predicted well the behaviors of transient parameters during the LSTF test.

(2) The LSTF test results qualitatively agreed with the predicted PWR transient. However, because of the smaller core flow to power ratio, the decrease of RCS temperature following the core power trip was slower than that in the reference PWR.

REFERENCES
