A Simulation for PHTS Response in PHWR Severe SGTR Accident

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1. Introduction

This paper evaluates the analysis results for the steam generator tube rupture scenarios especially for primary heat transport system (PHTS) response with ISAAC (Integrated Severe Accident Analysis code for CANDU plants)[1]. The analyzed cases include the Wolsong1-specific scenarios selected based on PSA results [2].

2. ISAAC Simulation

During steam generator tube rupture (SGTR) event, the initiating event (time = 0 s) is multiple (=10) SGTR, with a coincident loss of long term ECC (e.g., loss of ECC heat exchanger at least) and important safety-related systems (e.g., losses of the moderator cooling, shield cooling, shutdown cooling and steam generator (SG) main feed water). For the ISAAC simulation of the Wolsong plants, 18 representative fuel channels for 190 actual channels each loop (9 channels between steam generators) are defined for the core configuration.

The simulations are performed using ISAAC 4.03. The simulations were run up to 500,000 s (139 h) and the maximum ISAAC time step before first pressure tube (PT) and calandria tube (CT) rupture in (broken) loop 1 (L1) is limited to 0.1 second in order to prevent overshoot (i.e., potential numerical instability of flow rates between the SG steam headers) in the results. In the simulation, the timing of significant events and quantities of radioactive fission products, which would be released to the environment in the course of the severe core damage accident, is determined and reported in the following analysis part.

SGTR is a transient sequence initiated by the rupture of several steam generator tubes, allowing PHTS coolant to discharge into the secondary side of the SG. A total break area of 10 tubes is assumed to occur at the bottom of the cold tube side in L1. The exact location of the break was "cold" SG leg, at the top of the SG tube sheet in order to get highest break discharge rate. This break elevation even permits more water in a broken SG to flow into the primary loop in the case of flow reversal. When severe core damage occurs during a SGTR, fission products released from the core will be delivered to the broken SG, to the secondary side of SG, and finally to the environment. This RB (reactor building) failure mode is called a RB bypass sequence, resulting in a large and direct release of fission products. The accident progression depends on the availability of safety systems.

3. PHTS Response

The postulated initiating event for the SGTR accident scenario is imposed at the start of the run by the rupture of ten steam generator tubes in PHTS L1 allows PHTS coolant to discharge into the secondary side of the SG. The total break area was equivalent to one-sided 2.222 x 10^{-3} m^2 (corresponding to about 0.4% RIH break size) which leads to average break flow of about 80 kg/sec until reactor trip time. This area corresponds to the total break flow of two-sided blow down of ten SG tubes in WS1 FSAR [3].

According to ISAAC calculation, (1) the first trip signal is low pressurizer water level (~6.66 m occurred at 466 s), and (2) the second trip signal is low PHT pressure (~8.8 MPa(a) occurred at 971 s). In FSAR, the first and second trip signals are also low pressurizer water level (occurred at 375 s) and low PHT pressure (occurred at 430 s) respectively, and the second one of low PHT pressure is credited. As more detailed logic and model of the PHTS such as that of DBA code (=CATHENA) are used for WS1 FSAR trip coverage (for multiple SGTR), the time of 430 s is used for reactor shutdown here. This time delay due to high PHT signal neglect would mean a larger loss of coolant from the PHTS via the broken SG1 U-tube in ISAAC simulation, which would affect the early stage accident progression and the final environmental ST in a conservative way.

Figure 1 shows the mass inventory behavior in the two PHTS loops. The initial inventories in PHTS loops and in the pressurizer decrease rapidly and such a decrease in inventory is mainly due to the following reasons: (1) break flow in L1 SG U-tubes, (2) the loss of fission power from the reactor core, (3) the core decay heat is transferred via PHTS coolant to the steam generators, and (4) LRVs (Liquid Relief Valves) opening cause the PHTS (L1/L2) inventory to be released to the degasser condenser tank (then to the RB).

After reactor shut down occurs at 430 s, the PHTS pressure drops rapidly. When the pressure in PHTS loops reaches 5.5 MPa, a LOCA (loss of coolant accident) signal is generated at 471 s and the isolation valves are closed to isolate the pressurizer from both loops (i.e., L1 separation from loop 2 (L2) occurs with 20 seconds delay after a LOCA signal) at 491 s. Figure 2 shows a continuous loss of inventory in PHTS L1 due to the SG U-tubes rupture until first PT/CT rupture. This causes the PHTS pressure to drop to just above

(~5.3 MPa(a)) the MSSV opening/closing set point (5.11~5.24 MPa(a)) at about 700 s as shown in Figure 3. After that, the PHTS loops 1&2 (including pressurizer) pressure stays relatively constant at that pressure until about 4,000 s. In the mean time, PHTS pumps in L1 trip at 1,865 s when the pump inlet water void reached 50% which is assumed in ISAAC calculations, and the forced flow through the PHTS becomes zero. But break gas flow rate in L1 is immediately resumed, because phase separation is assumed at above 50% of void fraction in ISAAC code and natural circulation works under this condition. At 4,374 s (1.22 h), L1 first PT/CT fail by ballooning since the (hottest bundle) PT temperature reaches ~900 K at high PT pressure of ~5.3 MPa (a). Further rapid pressure decrease occurs in PHTS L1 after the rupture of pressure and calandria tubes in L1 (Figure 3).

4. Results

The very important accident from the perspective of severe accident progression and environmental source term (ST) is a steam generator tube rupture (SGTR) as a severe accident. This SGTR beyond design basis accidents is typically caused by multiple tube ruptures with simultaneous loss of emergency safety features and/or important safety-related systems. The reference SGTR chosen here can be postulated as a combination of a multiple SGTR and a SBO (station blackout) because only basic (i.e., reactor trip) and passive (i.e., containment dousing sprays and PARs) features are available without any active heat sinks or operations available. When compared with a simple SBO, the reference SGTR shows faster accident progression with an earlier RB failure because some part (= about one third) of primary coolant is lost through ruptured tubes before reactor shutdown.

ACKNOWLEDGMENTS

This project has been carried out under the Nuclear R&D Program by MEST (Ministry of Education, Science and Technology) of Korea.

REFERENCES

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[3] KHNP, Wolsong 1 FSAR, Chapter 15: Accident Analysis.

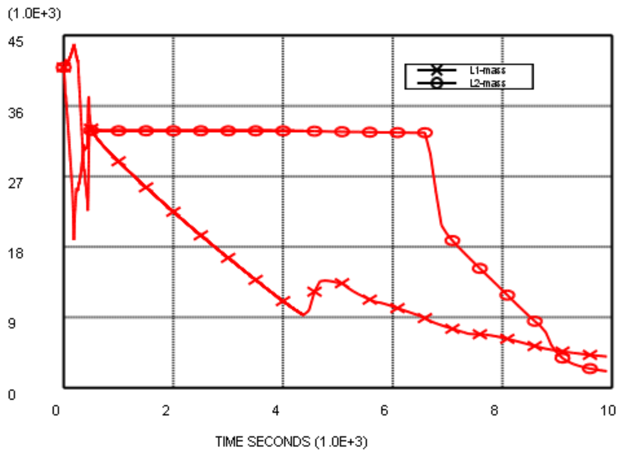

Figure.1 Mass of Coolant in PHTS L1 & L2

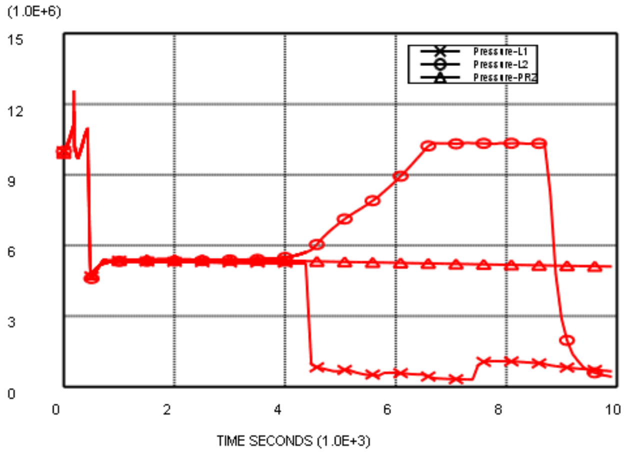

Figure.2 PHTS Pressure

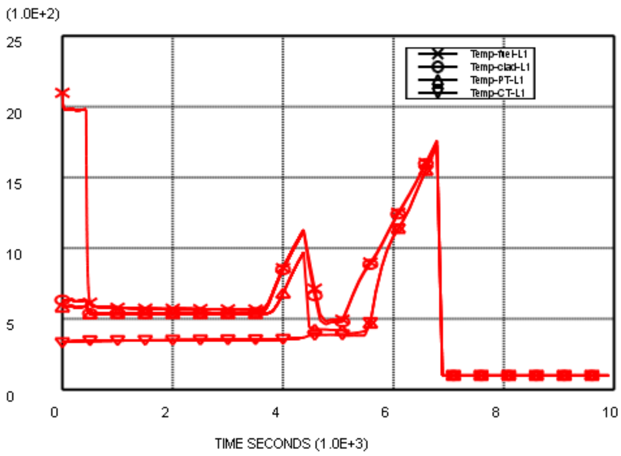

Figure.3 PT, CT and Fuel (fuel/clad) Temperature in L1 hottest bundle