Implementation of Control Logic for PHTS Pressure and Inventory to mSGTR analysis model of MARS-KS code in CANDU-6 Plants

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1. Introduction

A steam generator tube rupture is one of the reactor building bypass events that lead to a release of fission products (FPs) into the environment. The high temperature, high pressure primary coolant can be leaked or discharged to the secondary system through the ruptured SG u-tubes (mSGTR) and then directly reach the atmosphere and general public through the damaged SG or other possible release paths in the secondary system.

This study aimed to develop an advanced evaluation technology for assessing CANDU-6 safety. For this purpose, the operation logic models for the pressurizer heaters and feed system were implemented in the analysis model to evaluate the plant responses using the MARS-KS ver.1.5 [1], a best-estimate computer code for the design-basis accident analyses.

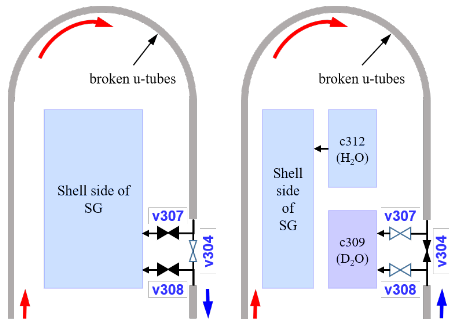
2. Methods and Results

2.1 Faulted SG Modelling

To simulate the rupture of the u-tubes, the SG #4 was separated into intact u-tubes and broken u-tubes. When the u-tubes rupture, the primary coolant of D_2O discharges to the SG shell and mixes with the secondary coolant of H_2O. Although their physical properties are similar, the code recognizes them as different fluids, so that there are limits to simulating mixing the two different liquids in the calculation. In order to simulate the discharge of the D_2O coolant to the SG shell through the ruptured u-tubes, some imaginary components such as a valve (v304) between the broken u-tubes and the SG outlet plenum, two valves (v307, v308) for simulating the ruptures, and two time-dependent volumes (c309, c312) as imaginary boundary conditions were used, as shown in Fig. 1.

The rupture of the u-tubes was expressed by opening the v307 and v308 valves at the same time as the v304 valve was closed. Henry-Fauske's choking model [1] was applied to both valves to calculate the critical flow rate through the ruptured u-tubes. Then, the primary coolant discharged through the broken u-tubes to the imaginary volume (c309) was set as the pressure condition of the ruptured part, while the secondary coolant with the same flow rate from the imaginary volume (c312) was injected into the SG shell at the same time.

Since the u-tubes' rupture was assumed to be a guillotine break, the total break flow rate is the sum of the flow rates from the SG inlet (v307) and the SG outlet (v308).



(a) Normal operation (b) transient

Fig. 1. Modelling for coolant discharge through ruptured u-tubes.

2.2 PHTS Pressure and Inventory Modelling

The primary heat transport system (PHTS) pressure is controlled by spray or/and steam relief valves for depressurization and electric heaters inside the pressurizer for pressurization. In the case of mSGTR, the PHTS is not expected to be over-pressured, so that the operating logic of the pressurizer heaters is modelled. The heaters consist of one variable heater and four on/off heaters. As shown in Fig. 2, when the maximum pressure of the reactor outlet header (ROH) becomes lower than an operational set value, the variable heater actuates according to the increasing output demand. However, if the pressure is not recovered, the four on/off heaters automatically operate. In addition, all heaters become unavailable when the pressurizer's water level is below the set value to prevent exposure to steam. The proposed analysis model includes the afore-mentioned operating logic of the pressurizer heaters.

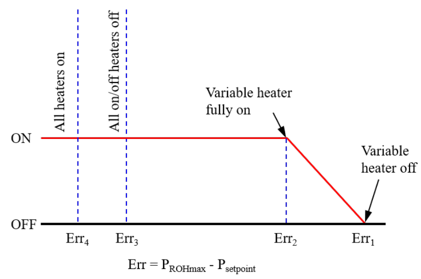


Fig. 2. Logic of the pressurizer heaters' operation.

The coolant inventory in the PHTS decreases along with the pressure decrease during the mSGTR transient, causing the water level of the pressurizer connected to the two loops via ROHs to drop. The control logic for the PHTS inventory was developed using the water level changes in the pressurizer to compensate for the coolant loss. In other words, when the water level starts to decrease, the coolant feeds immediately from the D_2O storage tank modelled as a boundary condition. The tank was assumed to be depleted if it became less than 10% of its initial amount and the feed stopped.

2.3 Effect of Control Logic Implemented on Plant Responses

The control logic was modeled to realistically simulate the behavior of the PHTS pressure and inventory affected by the mSGTR. As shown in Fig. 3 and Fig. 4, comparing the header pressure and the coolant discharge flowrate through the ruptured u-tubes, the implemented control logic reasonably affected the transient behaviors, and the reactor shutdown was delayed about 342 s or about 97%, which was similar to the result of the CATHENA code [2].

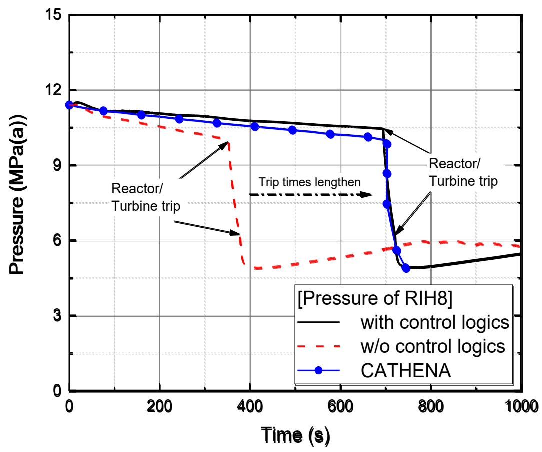


Fig. 3. Comparison of header pressures.

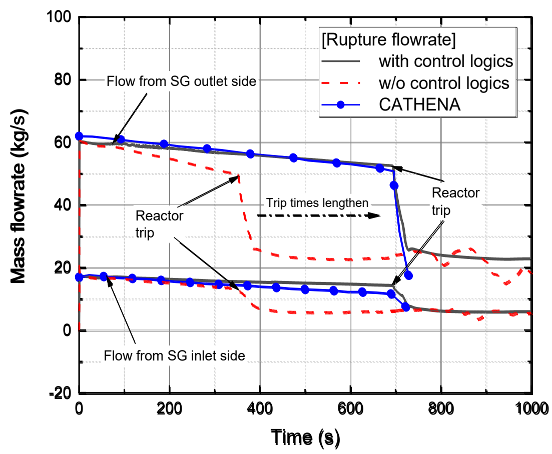


Fig. 4. Comparison of discharge flowrates.

Fig. 5 shows the water level behaviors of the damaged SG. Due to the coolant inflow, the water level increased to the upper part of the SG separator, and even when the main feedwater pump was tripped due to the power loss assumed in this study, coolant continued to flow in and the SG became full. These behaviors were similar regardless of whether the control logic was implemented or not, except the time of when the SG water level started to increase above the upper part of the separator.

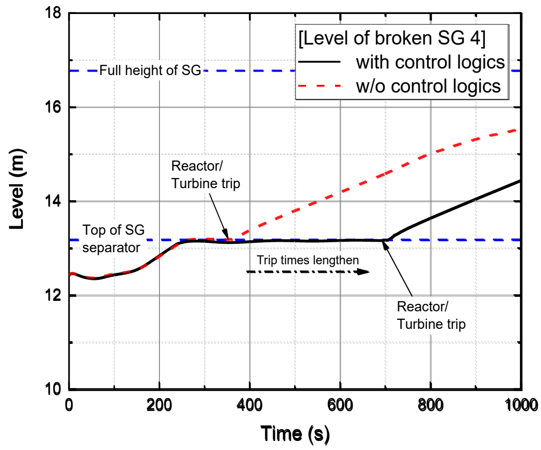


Fig. 5 Comparison of SG levels.

3. Conclusions

In this study, for mSGTR simulation, the u-tubes of SG 4 were divided into intact and broken ones, and the operation logic models for the pressurizer heaters and feed system were implemented in the analysis model to evaluate the plant responses using the MARS-KS code.

From the physically reasonable behaviors of the thermal hydraulic parameters and the comparison with other codes, the operation of the PHTS pressure and inventory control logic implemented in the present analysis model is appropriate, and it was evaluated that the system responses can be more realistically simulated in the accident analyses.

REFERENCES

[1] KINS, MARS-KS Code Manual, Korea Institute of Nuclear Safety, Daejeon, KINS/RR-1822, 2020.
[2] KHNP, Final Safety Assessment Report of Wolsong 3,4 units, Korea Hydro & Nuclear Power Co., Ltd., 2020.