Simulation of crash cooling during SBO transient in CANDU-6 plants

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1. Introduction

An analysis model for the SBO accident in a CANDU-6 plant [1] has been developed using the MARS-KS code [2]. The procedure of the crash cooling, which is one of the operator's measures to mitigate accidents, is to mechanically fix the main steam safety valves (MSSVs) in an open state according to the emergency operating procedure [3]. It has a positive effect of delaying the deterioration of heat removal from the shell side of steam generators (SGs) by abruptly reducing the SGs' pressure, but the SG inventory may be depleted more quickly. In this study, therefore, the effect of the crash cooling on the system behavior was investigated.

2. Modelling for simulating crash cooling

A total of 16 MSSVs, equipped on the main steam pipe, 4 per SG, perform two functions: overpressure protection for the main steam system and rapid cooling through the SGs. When the main steam pressure reaches the range of the MSSV opening set-point, the MSSVs are opened, and when it decreases, the valves are automatically closed by spring force. In this study, the maximum value of the set-point range was set as an opening set-point, taking into account some uncertainty, and 8 out of 16 valves were modelled to be opened when the main steam pressure exceeded this value. Crash cooling is to mechanically fix the MSSVs in an open state so as to reduce the consumption of auxiliary control air due to frequent opening and closing for relieving the overpressure. Conservatively, 7 out of 16 valves were modelled to be opened in this study. The initiation time of the crash cooling was also assumed to be 30 minutes after the transient began. Because the available number of MSSVs was considered differently depending on the function, as shown in Fig. 1, two valves with different flow cross-sectional areas were modelled to avoid operating at the same time.

When the SG pressure becomes less than 345 kPa(g) due to the crash cooling, the emergency water inside the dousing tank can be supplied to the SG shell by gravity with a maximum flow rate of about 34 kg/s [3,4]. In this study, when the SG pressure fell below the above set-point, the SG water level, reduced by repetitive opening-closing of the MSSVs and crash cooling, was modelled to be recovered and maintained the value of the normal operation with the emergency water of the dousing tank.

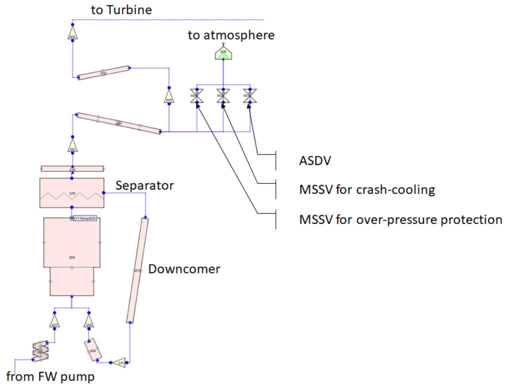

Fig. 1. SG model for simulating crash cooling.

3. Results and Discussions

Figure 2 shows the reactor header pressure. The pressure slightly increased immediately after the transient initiation, but rapidly decreased as the reactor tripped. As the primary coolant of high temperature and high pressure leaked through the PHT pump sealing, the pressure gradually decreased. However, the pressure began to decrease rapidly due to the increase in PHTS heat removal by the crash-cooling procedure. At about 2,800 s, a high-pressure safety injection signal was generated, and the pressure increased again as the emergency coolant of the accumulator was injected into the PHTS. The PHTS, after reaching to the accumulator pressure, gradually decreased during the transient period. The emergency coolant amount, filled with PHTS by high-pressure safety injection for 8 hr, was estimated to be about 82.8 ton.

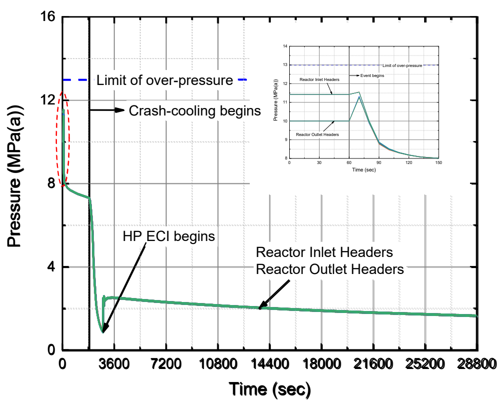

Fig. 2. Pressure of reactor headers.

Figure 3 shows the steam discharging flow through the MSSVs. Before the crash cooling began, the MSSVs opened and closed repetitively to prevent SG overpressure. However, after the manual opening of the MSSVs, the amount of discharge increased rapidly, after which the SG inventory and the pressure decreased, leading to decreasing in the amount of steam discharge. Afterward, the SG inventory was recovered by gravity water supply from the dousing tank, and the decay heat was removed through the SG u-tube.

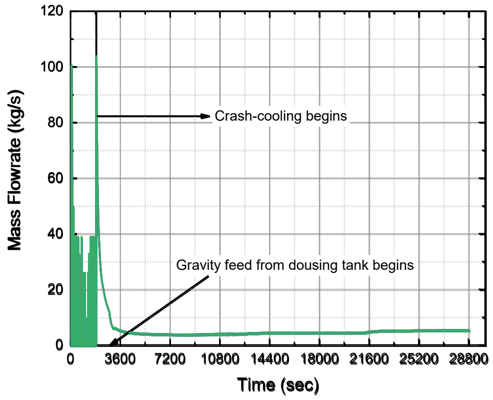

Fig. 3. Steam discharge flow through MSSVs.

As a result of the calculation, the water supply from the dousing tank was estimated to begin at about 2,850.0 s. As the cooling water from the dousing tank was supplied to the SG shell, and the water level of SGs was recovered with the level of the normal operating condition in about 11,480.0 s. It was also estimated that the cooling water in the dousing tank was depleted in about 21,310.4 s, and then the SG water level decreased again, as shown in Fig. 4.

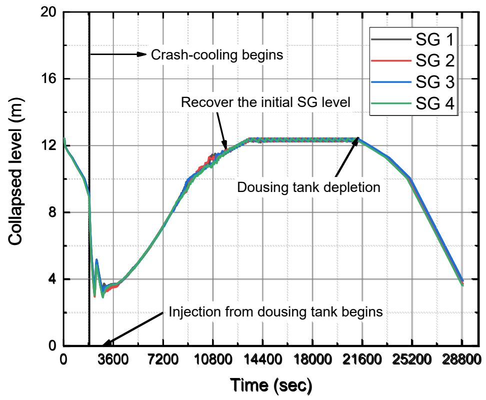

Fig. 4. Collapsed water level of SGs.

Figure 5 shows the maximum temperature of the fuel cladding and pressure tube. It was evaluated that due to the cooling water supplied from the dousing tank to the secondary-side shell, the SGs functioned as a heat sink, and the fuel cladding and pressure tube were maintained below the failure criteria.

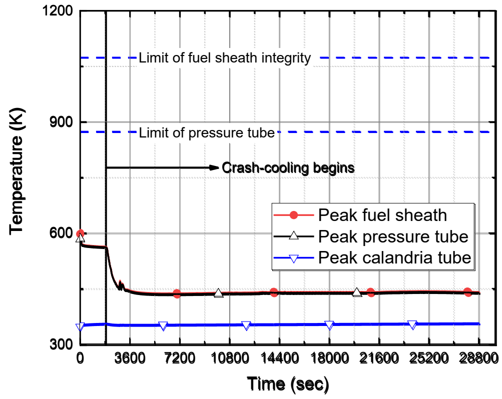

Fig. 5. Maximum temperature of fuel sheath and PT.

4. Conclusions

Based on the system model for simulating the SBO transient in a CANDU-6 reactor, the logic controllers of crash cooling using SGs, water injection from the dousing tank, and PHT pump seal leakage were developed. After confirming that the transient conditions were adequately applied, the overall behavior of the primary/secondary parameters such as pressure, water level, and flow rate during the transient period was analyzed. Through examining the system responses induced by crash cooling and water injection from the dousing tank, it was found that the calculation results by the improved model were reasonable in the present given conditions. Besides, under the given conditions of this study, it was evaluated that the integrity of fuel and fuel channels was maintained by the combined effect of SG depressurization, water supply from the dousing tank, and high-pressure emergency coolant injection.

Acknowledgments

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