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Simulation of Recirculation between Reactor Coolant System and Containment with MARS-KS using Simple SMR Input

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1. Introduction

Recently, newly developed small modular reactors (SMRs) have proposed various designs for fully passive safety injection system. There is a concept of safety injection by hydraulic head of condensed coolant in the containment building after break accident. Reactor coolant system and containment are connected by recirculation valve for passive safety injection in this design. There is a relief valve on the pressurizer (PZR) which is an upper part of integral type reactor coolant system in SMR. It is used to depressurize the reactor coolant system for safety injection by hydraulic head of condensed coolant.

This study used MARS-KS [1] code with an input data connecting a reactor coolant system of simple integral type SMR and containment to confirm the recirculation phenomenon depending on the break number of recirculation valve. It is a conceptual study of recirculation phenomenon and does not reflect the design of specific reactor.

2. Modelling of Recirculation System

In this section modelling of recirculation system for calculation with MARS-KS [1] is described. The recirculation system includes reactor coolant system, containment and valves as shown in Fig. 1.

2.1 Reactor Coolant System

The reactor coolant system consists of a mixing header, a core, an annulus flow path and a pressurizer (PZR) as shown in Fig. 1. It was referred from SMART-ITL input data [2]. Recirculation between reactor coolant system and containment was simulated assuming an accident which is an inadvertent opening of recirculation valve.

2.2 Containment

The containment is a simple large pipe as shown in Fig. 1. The volume of containment is more than five times larger than reactor coolant system. It is initially assumed to be filled of steam and linked to reactor coolant system with recirculation valve and relief valve. Heat exchanger in the containment was not considered yet.

2.3 Valves

There are two types of connecting valves between reactor coolant system and containment. The recirculation valve is connected from tenth cell of containment to branch cell of reactor coolant system placed after core outlet. The relief valve is connected from the top of pressurizer to twenty-fourth cell of containment. The containment cell number is counted from the bottom. The connecting sizes are following a break size of small break loss of coolant accident (SBLOCA) in SMART-ITL [3].

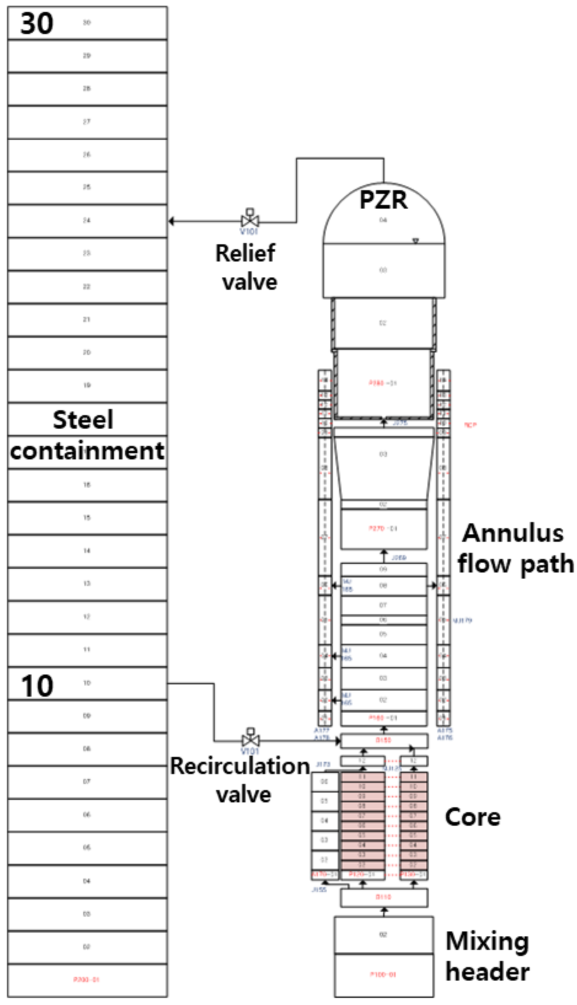

Fig. 1. Modelling of reactor coolant system and containment with MARS-KS using simple SMR input

3. Simulation Results

Simulation of an inadvertent opening of recirculation valve was conducted after steady-state calculation for 2,000 s to maintain stability of reactor coolant system. Transient simulation started with inadvertent opening of recirculation valve at 0 s in Figs. 2~5. Table I shows the calculation conditions in this study. Case1 is single break of recirculation valve and case2 is twin breaks of recirculation valves.

Table I: Calculation Conditions

	Operation time (s)	
	Case1	Case2
Recirculation valve #1	0	0
Recirculation valve #2	-	0
Relief valve	700	700

3.1 Case1: Single Recirculation Valve

Fig. 2 shows pressure behavior of case1. Pressure of reactor vessel (Pressure_RV in legend) decreased and pressure of containment (Pressure_CV in legend) increased after inadvertent opening of recirculation valve #1. Pressure equilibrium was achieved after opening of relief valve at 700 s. The pressures decreased after equilibrium because of decay heat simulation in the core.

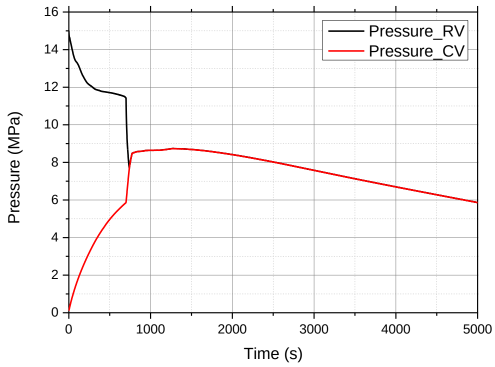

Fig. 2. Pressure behavior with single recirculation valve.

Fig. 3 shows water level behavior of case1. Water level of reactor vessel (Level_RV in legend) decreased and water level of containment (Level_CV in legend) increased after inadvertent opening of recirculation valve #1. The water level of reactor vessel was sharply increased at 700 s because the relief valve opened. Dynamic pressure due to relief valve opening affected the increase of water level in the reactor vessel. The water level of containment did not exceed one of reactor vessel as shown in Fig. 3. It means that the recirculation was not observed in the case1.

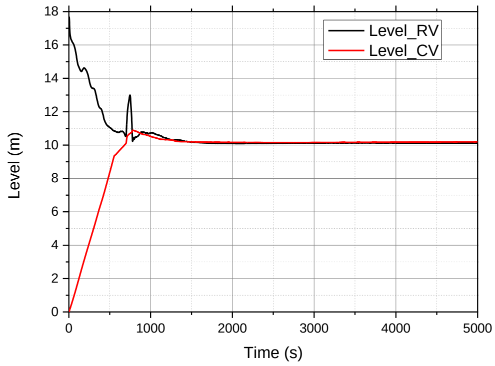

Fig. 3. Water level behavior with single recirculation valve.

3.2 Case2: Twin Recirculation Valves

Fig. 4 shows pressure behavior of case2. The break area doubled because the two recirculation valves were opened. Pressure equilibrium was achieved faster than case1 and it was near to the opening time of relief valve at 700 s.

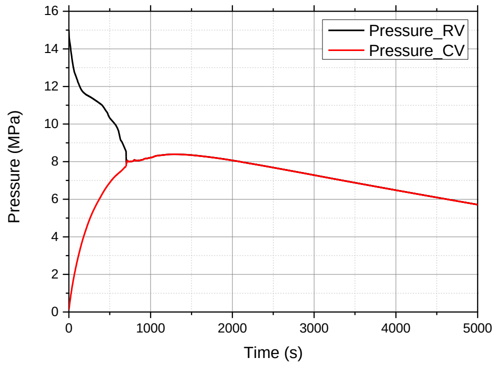

Fig. 4. Pressure behavior with twin recirculation valves.

Fig. 5 shows water level behavior of case2. Water level of containment was much higher than one of reactor vessel as break mass flow rate increased. The recirculation could be observed in the case2 because the hydraulic head between containment and reactor coolant system was enough for coolant injection.

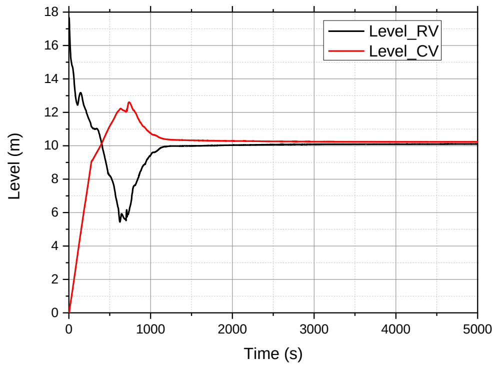

Fig. 5. Water level behavior with twin recirculation valves.

4. Conclusions

Recirculation between reactor coolant system and containment was simulated depending on the break number of recirculation valve with MARS-KS code. The recirculation phenomenon could not be observed when a single recirculation valve was opened, but when two recirculation valves were opened, it could be observed. The water level distribution in the reactor coolant system and containment before the pressure equilibrium is significant parameter of passive safety injection in the recirculation system. The effect of condensation by heat exchanger in the containment will be considered in future study.

REFERENCES

[1] Korea Atomic Energy Research Institute, MARS Code Manual Volume I: Code Structure, System Models, and Solution Methods, KAERI/TR-2812 /2004, KAERI, 2007.

[2] J. H. Yang, et al., Analysis of SMART-ITL PRHRS Performance Test with MARS-KS, Transactions of the Korean Nuclear Society Autumn Meeting, Yeosu, Korea, October 25-26, 2018.

[3] J. H. Yang, et al., Comparison of Two Different Sized Small-Break LOCAs on the Passive Safety Injection Line Using SMART-ITL Data, *Nuclear Technology*, Vol. 206, pp. 1421–1435, Sep. 2020.