

Study on the Effect of Heat Removal Ratio of PAFS and PCCS on Core Level in i-SMR using Simplified Model

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1. Introduction

The Korean nuclear industry is developing i-SMR (Innovative Small Modular Reactor). The i-SMR has passive safety systems including PECCS (Passive Emergency Core Cooling System). The PECCS consists of EDVs (Emergency Depressurization Valve) and ERVs (Emergency Recirculation Valve). In case of LOCA (Loss of Coolant Accident), EDVs open to depressurize the RCS. The steam vented through EDVs condense in the PCCS (Passive Containment Cooling System) heat exchangers. The condensate fall to the bottom of containment vessel to form pool of water. This water returns to the reactor vessel downcomer region through ERVs. The water flow through the ERVs is determined by elevation head of water pool in the containment vessel and pressure difference of reactor vessel and containment vessel. The pressure of reactor vessel and containment vessel are affected by heat removal rate of PAFS (Passive Auxiliary Feedwater System) and PCCS respectively. In this paper, the effect of heat removal ratio of PAFS and PCCS on core water level is studied using SPACE code and simplified input model.

2. Analysis Methods

2.1 Description of i-SMR Safety Systems

The i-SMR uses 3 passive safety systems: PAFS, PCCS and PECCS. The PAFS remove heat from the RCS through steam generator tubes and reject heat to ECT (Emergency Cooling Tank). Steam is generated in steam generator tubes and the steam is condensed in PAFS heat exchanger located in the ECT. The condensate is returned to steam generator by natural circulation. The PCCS removes heat from the containment through PCCS heat exchangers located inside the containment. The water from ECT is circulated to the PCCS heat exchanger by natural circulation. During normal operation, the containment pressure is near vacuum and heat removal through PCCS is kept to a minimum. In case of LOCA or steam line break inside containment, a lot of steam is released to the containment. The PCCS heat exchangers remove heat from the containment to limit maximum pressure of the containment vessel. The steam will condense on

the PCCS heat exchanger surface and fall to the bottom of containment vessel to form pool of water. In case of LOCA, this pool of water is sent back to the reactor vessel through ERVs. The PECCS consists of EDVs and ERVs. The PECCS has no pumps or safety injection tanks to actively inject water to the core. It relies on natural circulation to keep the core submerged in water. The EDVs depressurize the RCS to minimize or stop the flow through the break. Pool of water is formed at the bottom of containment by water from break flow and steam condensation from PCCS heat exchangers. When the height of water pool becomes high enough, water will flow to the reactor vessel through ERVs. The flow path for the water is containment vessel → reactor vessel downcomer → reactor vessel core+riser section. The ratio of heat removal between PAFS and PCCS also affect the core water level by changing reactor vessel and containment vessel pressure.

2.2 Computer Code Used in the Analysis

The Korean nuclear industry developed a thermal-hydraulic analysis code for the safety analysis of PWRs, named SPACE (Safety and Performance Analysis Code for Nuclear Power Plant). The SPACE code is an advanced thermal hydraulic analysis code capable of two-fluid, three-field analysis. The SPACE code has many component models required for modeling a PWR, such as reactor coolant pump, safety injection tank, etc. The SPACE code can be used in LBLOCA, SBLOCA and Non-LOCA analysis of PWRs. The SPACE code is used in this study.

2.3 Nodalization Model

Since the core water level and ERV water flowrate is determined by water levels in the containment vessel and downcomer, a simplified model is developed using three pipes. Each pipe represents core+riser+pressurizer, steam generator+downcomer and containment vessel. In each pipe, sections with similar cross section area were merged into several large cells. Each pipe has 6~7 cells. The volume and height of each cells were preserved. The core, PAFS, PCCS are modeled using heat structure and heat flux boundary conditions. The pipe height and heat structure height is same as i-SMR design. The core power approximately follow

ANS73+20% decay heat curve. The total heat removal rate of PAFS+PCCS is assumed to be 10MWt. The actual heat transfer rate of PAFS and PCCS depends on thermal hydraulic conditions of RCS and containment vessel. The PAFS is designed to cooldown the reactor to safe shutdown temperature within 36 hours after reactor trip. The PCCS design to reduce containment pressure to half of peak pressure in 24 hours. LOCA break is not modeled. Instead, all EDVs and ERVs open at $t=0$ sec. The reference point for elevation is the bottom of reactor vessel (inner surface). Calculations were performed for 10000 sec. The collapsed water level at the end of calculation were compared.

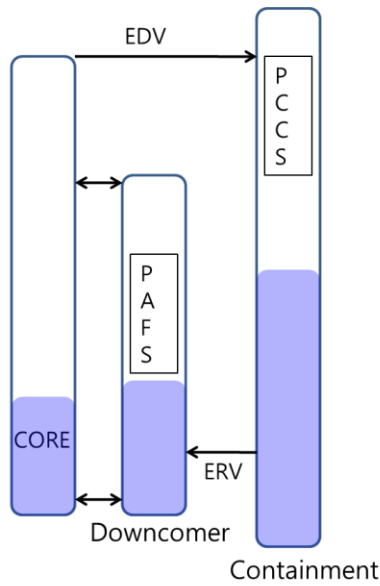


Fig. 1. Nodalization for simple model.

3. Results

The cases analyzed are shown in Table 1. The water level shown are level at $t=10000$ sec. The water level show slight oscillation even at $t=10000$ sec. The results from case01~05 show that the core level increases at PAFS heat removal rate is increased(Fig. 2). This is because more power is removed from the reactor vessel region and the resulting pressure is lower. Also, higher PAFS heat removal results in more condensation occurring in SG/downcomer region than PCCS heat exchanger. Case06 shows lower core level because there is a lot of oscillation and $t=10000$ sec happens to show lower value of oscillating level. Case07 is same as case03 with failure of one ERV. Case08 is same as case03 with failure of one EDV. The valve failure cases show lower core level as expected. All cases show sufficient margin of the core water level to prevent core damage.

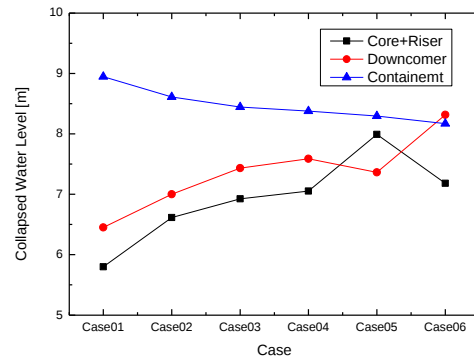


Fig. 2. Water Level for Cases 1~6

Table I: Calculated Cases and Results

Case	Heat Tr[MW]		Water Level[m]		
	PAFS	PCCS	Core	Down	CV
Case01	0	10	5.80	6.45	8.95
Case02	2	8	6.62	7.00	8.61
Case03	4	6	6.92	7.43	8.44
Case04	6	4	7.05	7.59	8.38
Case05	8	2	7.99	7.36	8.29
Case06	10	0	7.18	8.32	8.17
Case07	4	6	6.62	7.23	8.54
Case08	4	6	6.39	7.01	8.50

4. Conclusions

The core water level during PECCS operation were studied as function of heat removal ratio of PAFS and PCCS. The results show that higher PAFS heat removal rate compared to PCCS results in higher core level due to lower reactor vessel pressure. Also more condensation occurring in SG/downcomer region contributes to higher core level. The insight obtained from this simple model can help understand the thermal hydraulics response of i-SMR in various conditions.

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