Preliminary Performance Analysis on Passive Containment Cooling System of i-SMR Using MARS-KS

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1. Introduction

In the domestic nuclear power industry, nowadays the development of the innovative Small Modular Reactor (i-SMR) is in progress [1]. The i-SMR will be equipped with the following three passive safety systems to replace the active safety systems of existing commercial nuclear power plants: Passive Emergency Core Cooling System (PECCS), Passive Auxiliary Feedwater System (PAFS), and Passive Containment Cooling System (PCCS) (see Fig. 1). The PECCS performs the core makeup/cooling function, the PAFS removes residual heat by steam generator (SG) cooling, and the PCCS conducts the heat removal from the containment vessel (CV) atmosphere. Since the passive safety system can perform safety functions by natural forces without continuous power supply or any operator action, it is expected to dramatically improve the safety of nuclear power plants (NPP).

In this paper, we present the results of performance analysis for PCCS among the above-mentioned passive safety systems using MARS-KS [2]. The main variables of interest are CV peak pressure, PCCS heat removal rate, and natural circulation flow (or tube inlet velocity).

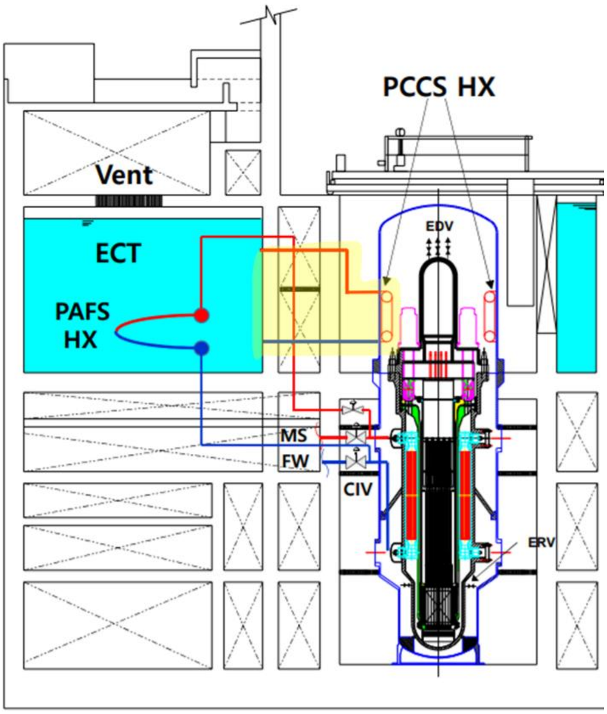

Fig. 1. Schematic of i-SMR [1]

2. Development of i-SMR input model for MARS-KS

For the reliable design and performance analysis of the PCCS, we developed the i-SMR input model for MARS-KS (see Fig. 2). It includes main components and systems such as reactor pressure vessel (including core, pressurizer, reactor coolant pump, and SG), PECCS (with emergency depressurization valve (EDV) and emergency recirculation valve (ERV)), PAFS, PCCS, CV (with containment passive heat sink), and emergency cooling tank (ECT).

For the PCCS, the main components are modeled as follows. The PIPE components C800 and C802 are used to model two trains of PCCS heat exchanger (HX) tube bundle. PIPE components C400 and C402 are used to model the ECT. They are connected by the multiple junction, MJ-401, to simulate the natural convection in the pool. TDV-470 is connected to the pool for pressure control. PCCS HX is connected with the ECT through the HX inlet pipings (C001/C004 and C501/C504) and HX outlet pipings (C008/C010 and C 508/C510). The heat structure of PCCS HX is used to calculate the heat removal rate from the containment.

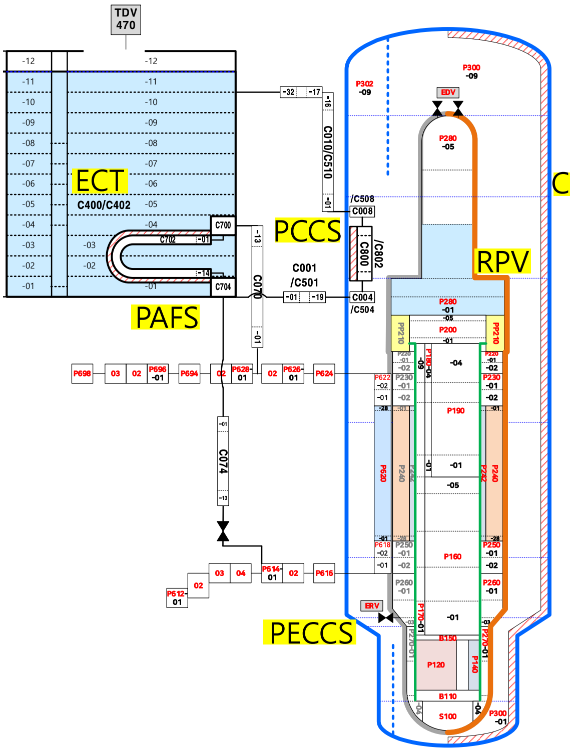

Fig. 2. MARS-KS nodalization of i-SMR

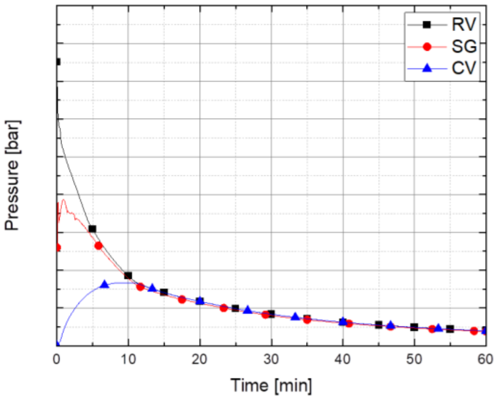

Fig. 3. Containment pressure

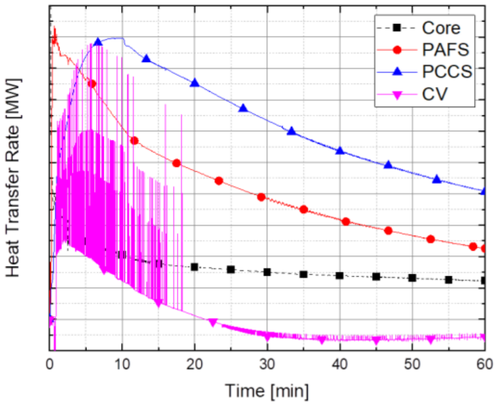

Fig. 4. PCCS heat removal rate

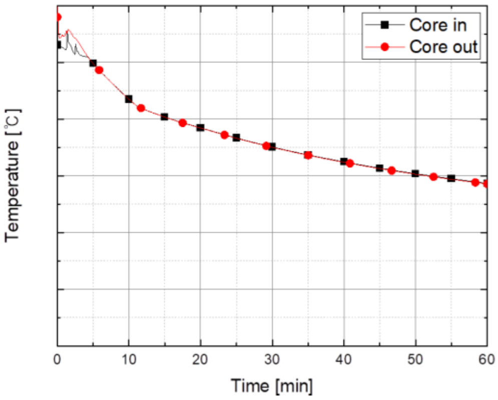

Fig. 5. Core temperature

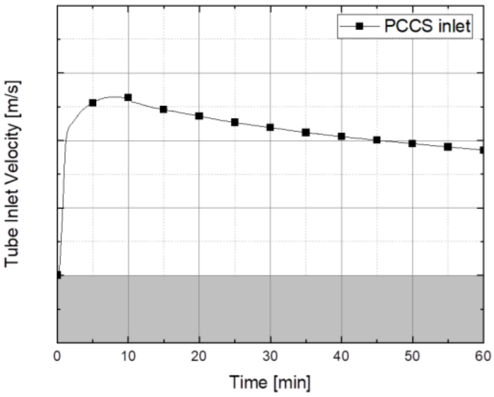

Fig. 6.PCCS tube inlet velocity

3. Performance analysis of i-SMR PCCS

In this study, the postulated EDV-LOCA scenario was simulated, where one of the EDVs is suddenly opened. Figures 3 to 6 show the results of EDV-LOCA simulation during 1 hour. (Since the i-SMR design is in progress, specific values are not presented in this paper.)

During an ED-VLOCA event, the high-pressure and high-temperature steam is released from the primary system into the CV. Due to the break flow, the CV pressure increases (see Fig. 3). However, as the PCCS operates and removes heat from the CV atmosphere, CV pressure start to decrease after about 10 minutes. For this simulation case, it is predicted that the PCCS reduces the containment pressure to half of the peak pressure within 24 hours along with other safety systems (such as PAFS).

Fig. 4 shows the PCCS heat removal rate. The PCCS heat removal rate is predicted to be higher than the core power. Similarly to PAFS, the PCCS heat removal rate was also predicted stably.

Fig. 5 shows the core inlet and outlet temperatures. The core is rapidly cooled by the PAFS operation along with the mass-energy release through the break.

Figure 6 shows the water velocity at the PCCS heat exchanger tube inlet. The steam is condensed on PCCS HX and transfer heat into the tube-side of PCCS HX, which is connected to the ECT. Water temperature inside the HX increases and due to change in density and height difference between HX and ECT, natural circulation is established. It can be confirmed that the natural circulation flow is stably formed.

4. Conclusions

To evaluate the PCCS performance, the i-SMR input model was developed for MARS-KS and EDV-LOCA scenario simulated. From the preliminary simulation results, it is confirmed that the PCCS can sufficiently remove the heat from the containment with the natural circulation flow. Although continuous improvement of the input model is required, the results of this study will be helpful in the PCCS development process.

Acknowledgment

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