Development of a Passive Residual Heat Removal System with an Air Cooling Component of the ATOM system

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1. Introduction

Development of a Small Modular Reactor (SMR) has been steadily paid attention over the past few decades for excellent siting flexibility, lower construction cost, or improved safety [1]. Recently, a research team in Korea has focused on the development of a new SMR that aims at a naturally-safe and autonomous operation, called the Autonomous Transportable One-demand reactor Module (ATOM) project. Moreover, the ATOM system pursues further advanced safety and deployment in extreme environments where there is the lack of cooling water.

In this study, as a starting step, a simple feasibility assessment of the ATOM safety system is carried out. A passive residual heat removal system (PRHRS) with an air cooling component is discussed using the MARS code, the one-dimensional (1D) system analysis code developed at KAERI in Korea.

2. MARS Simulation of the PRHRS with an Air Cooling Component

At the design stage, the ATOM system mainly adopts passive safety systems during an accident. Figure 1 shows a schematic of the overall ATOM system.

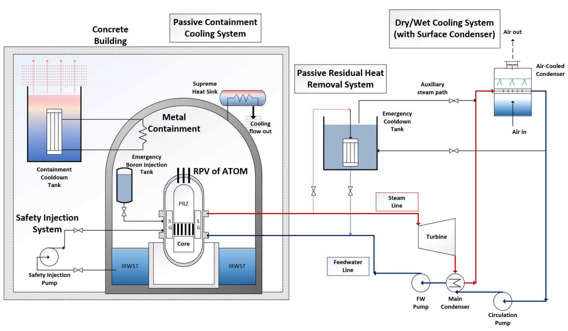

Fig. 1. Schematic of the overall ATOM system.

The passive residual heat removal system (PRHRS) and passive containment cooling system (PCCS) are represented, and the dry air cooling system (DACS) is suggested for an ultimate heat sink with an air cooling process and an auxiliary feature of the safety systems. More detailed descriptions can be found in the previous study [2].

In order to assess a cooling capability of the ATOM safety system, the MARS code was employed to simulate the PRHRS with an air cooling component. Figure 2 shows a schematic of the PRHRS nodalization of the MARS model. The system mainly consists of three parts: the primary part, the PRHRS part, and the DACS part. The primary part is a decay heat source. The PRHRS part is composed of two major components, which are the PRHRS loop and emergency cooldown tank (ECT). The PRHRS loop connects the primary part to the ECT. The generated decay heat is transferred to the ECT, and, as a result, natural circulation occurs at the PRHRS loop. The ECT removes the transferred decay heat as the cooling water in the ECT evaporates. Moreover, the DACS part consists of a coolant loop and the air cooling component. The coolant loop connects the ECT to the air cooling component, which removes the heat transferred from the ECT as a final heat sink.

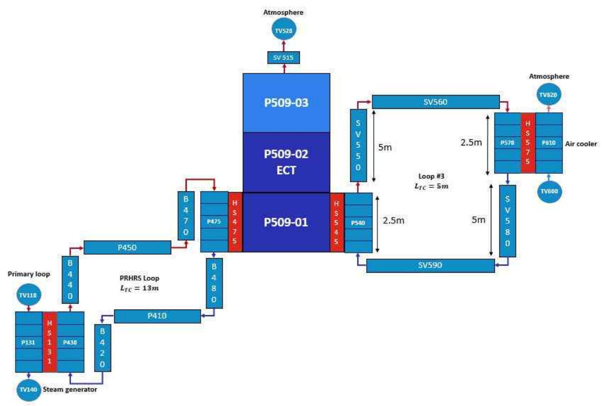

Fig. 2. PRHRS nodalization of the ATOM system.

The steam generator (volume 430) and heat exchanger (volume 475) in the PRHRS loop were modeled as the pipe component, and the ECT (volume 509) was also modeled as the pipe component. The heat exchanger (volume 540) and final heat sink (volume 610) present components of DACS.

3. Results and Discussion

For a simple comparison with the MARS simulation, mass of the remaining water in the ECT was calculated. During the PRHRS operation, the decay heat in the primary part is transferred to the ECT, the sensible heat and latent heat of the water pool can be expressed by

$$Q = C \cdot m \cdot \Delta T \qquad (1)$$

$$Q = m \cdot r \qquad (2)$$

Here, C and r are the specific heat and latent heat, respectively [3].

Figure 3 shows changes of the remaining water in the ECT with the theoretical and MARS calculations until 36,000 seconds. At first, the heat of 6.5 MW from the primary part is removed by the sensible heat of the water pool until 4,487 seconds, and the temperature of water increases to the saturation condition. After that, the heat generated from the primary part is removed by the latent heat of the water pool. During the water evaporation, the amount of remaining water gradually decreases. The comparison work shows a reasonable agreement with the analytical calculation.

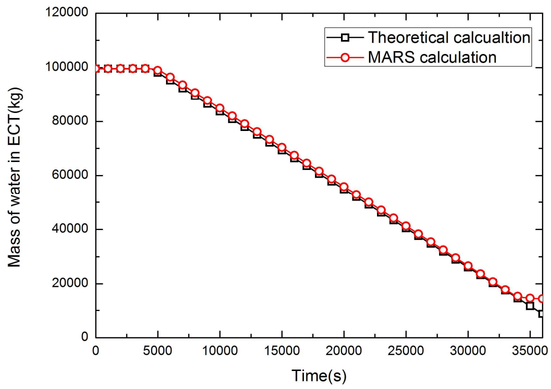

Fig. 3. The mass of remaining water in the ECT.

Figure 4 shows the amount of heat removed in 10 hrs by the ECT and DACS parts, respectively. The heat transferred to ECT is constantly about 6.5 MW. On the other hand, the amount of heat transferred to the DACS, the air cooling component, is 0.612 MW. As compared to the ECT, since the DACS adopts dry air as the coolant, the amount of heat removal is relatively small value.

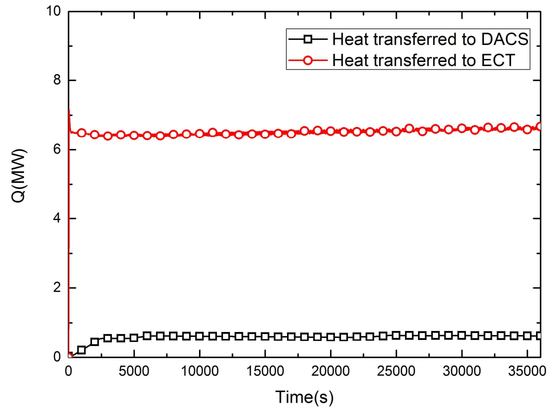

Fig. 4. Amount of heat transferred to the ECT and DACS.

Figure 5 shows the mass flow rates of steam/water in the PRHRS loop. The mass flow rates from the steam generator to the heat exchanger were defined at the junction (junction 451) after the pipe 450, and The mass flow rates from heat exchanger to steam generator were defined at the junction (junction 415) after the pipe 410. The steam generated from the steam generator flows to the heat exchanger, and the condensed water by heat transfer of the ECT flows back to the steam generator. The MARS calculation shows that the hot steam before the heat exchanger is completely condensed by the ECT, and the stable natural circulation occurs in the loop.

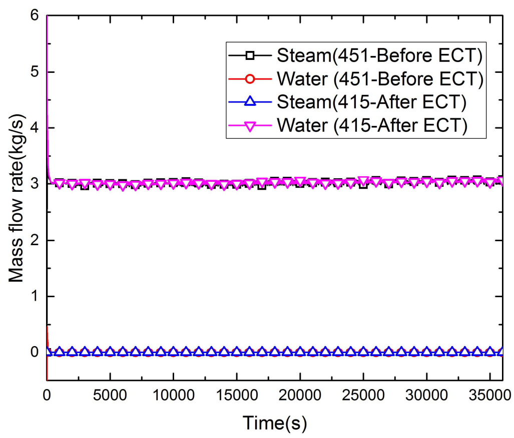

Fig. 5. Mass flow rates before and after the heat exchanger in the PRHRS loop.

Figure 6 shows the mass flow rates in the PRHRS and DACS loops, the stable natural circulations are observed at both the loops. This indicates the gradual heat removal was achieved without any pumps.

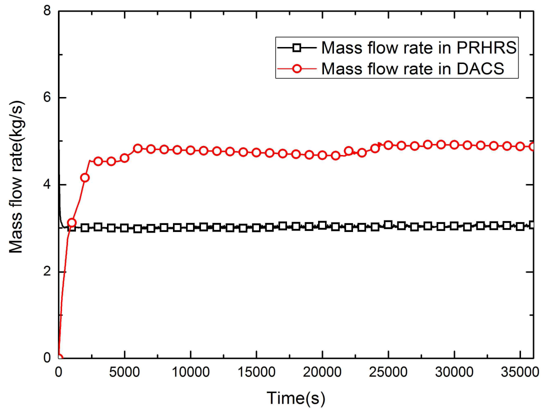

Fig. 6. Mass flow rates of natural circulation in the PRHRS and DACS loops.

Figure 7 shows mass changes of the remaining water in the ECT. There two cases in the calculations, and One case represents the PRHRS operation with the ECT only. The other case indicates the PRHRS operation with the DACS cooling process together. As a result, the improved heat removal is achieved, and the water evaporation is delayed with the help of DACS for the second case.

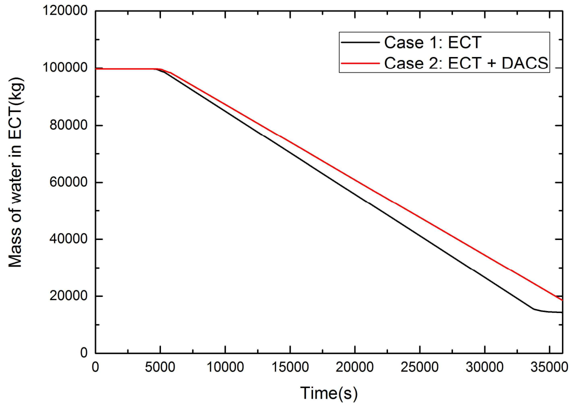

Fig. 7. Mass of remaining water in the ECT.

5. Conclusions

In this study, a feasibility assessment of the ATOM PRHRS with the air cooling component was discussed using the MARS code. Major outcomes of this study are summarized as follows:

(1) The natural circulations were stably established in the PRHRS and DACS loops, removing the decay heat generated from the primary part.

(2) the MARS simulation implies that the PRHRS with the air cooling system showed the improved cooling capability for 10 hrs as compared to the conventional PRHRS.

For further study, to assess the feasibility of the overall ATOM safety systems, more extensive evaluations are essentially needed, including various accident scenarios.

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