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Analysis of Ex-Vessel Coolability on Passive Molten Core Cooling System in iPOWER

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1. Introduction

In Korea, an innovatively safe nuclear power plant, so-called iPOWER, is being developed to significantly enhance the safety, taking advantage of passive safety systems which are designed to operate without external power supply. As one of the safety systems, Passive Molten Core Cooling System (PMCCS) is being developed to mitigate a severe accident, reach a safe state, and finally maintain the containment integrity [1].

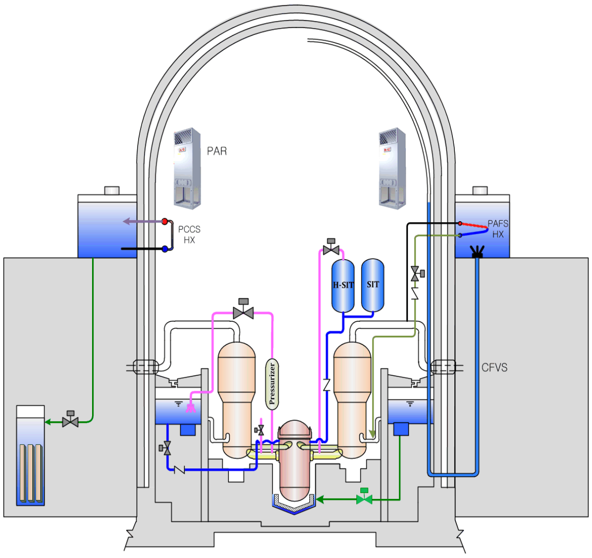

Fig.1. Conceptual Diagram for iPOWER

The configuration of PMCCS is assumed to have a hemisphere shape as shown in Fig. 2.

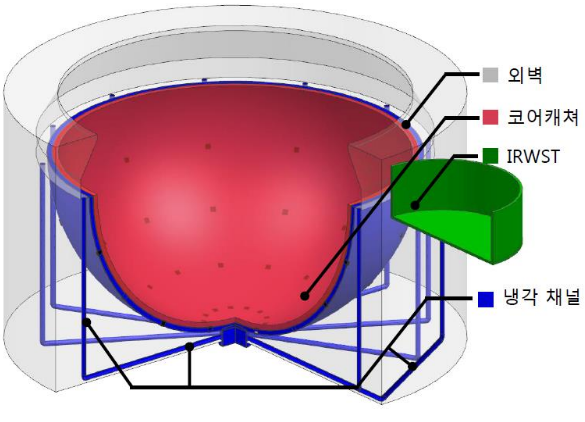

Fig.2. Configuration of PMCCS

Based on the conceptual cooling strategy of iPOWER against severe accidents, ex-vessel cooling by PMCCS is assumed in case of dry cavity condition in which cooling water is not provided for In-Vessel Retention and Eternal Reactor Vessel Cooling (IVR-ERVC).

In this paper, the analysis of ex-vessel coolability on PMCCS located under Reactor Vessel (RV) was performed based on the estimated properties for iPOWER.

2. Initial Conditions for Analysis

2.1 Overview of Analysis

In order to check the ex-vessel cooling ability of PMCCS, the analysis was conducted for 7,200 seconds (2 hours), focusing on the natural circulation of water in the cooling channel of PMCCS. At the beginning of analysis, it was assumed that the PMCCS and reactor cavity area are already filled with water while the heat load of corium has affected on the surface of PMCCS after RV failure.

The analysis was performed using SPACE (Safety and Performance Analysis Code for Nuclear Power Plant) code (version 3.0) developed by domestic research and industrial organizations.

2.2 Design Parameters

As the iPOWER is being developed and its design is still in progress, most of design parameters for iPOWER and PMCCS have been decided through engineering judgment or the estimation from existing design parameters in reference plants such as APR1400 and OPR1000.

Table 1. Design Parameters for iPOWER and PMCCS

Parameter	Value	Remark
Thermal Power	3,600 MW	Current design target
Electric Power	1,250 MW	Assumed thermal efficiency: 34.7%
Reactor Diameter	4.96 m (Outer dia.)	Estimated from APR1400 and OPR1000
Cavity Diameter	6.6 m	RV support column to be removed
PMCCS Diameter	6.8 m (Outer dia.)	Hemisphere configuration assumed

2.3 Heat Load on PMCCS

The heat load on PMCCS as an initial condition was calculated with the assumption that the RV is failed after 2 hours of a severe accident (LBLOCA) due to the failure of cooing water injection for IVR-ERVC. Generally, the PMCCS located under the RV covers downward heat load, and the downward heat load ratio was estimated as 70% conservatively.

The evaluation model for the heat load with a hemisphere shape was determined based on the VEssel Statistical Thermal Analysis (VESTA) code developed by Idaho National Engineering and Environmental Laboratory (INEEL) for the assessment of IVR in AP600 as shown in Fig. 3 [2].

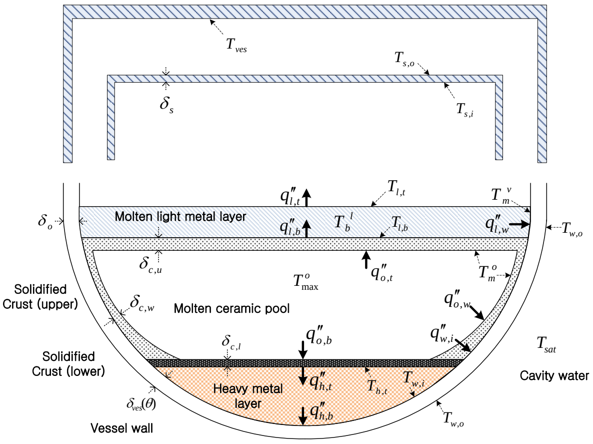

Fig.3. Heat load evaluation model developed by INEEL

The heat load on PMCCS was calculated in consideration of mixture volume for both corium and sacrificial material because the heat transfer area depends on the mixture volume in PMCCS.

The result of heat load on PMCCS is shown in Fig. 4 according to angles from 0 degree, the bottom of lower hemisphere to 90 degrees, the top of it.

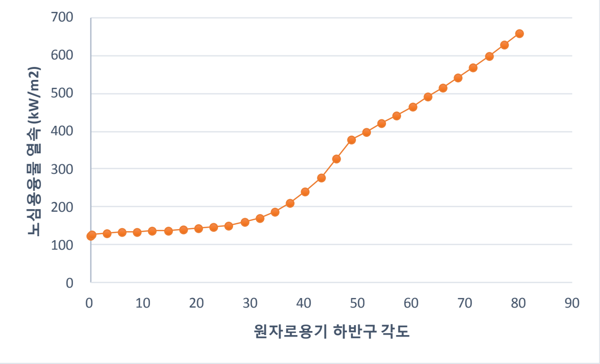

Fig.4. Heat load on PMCCS according to angles

2.4 SPACE nodalization for PMCCS analysis

Fig. 5 shows the SPACE nodalization for PMCCS analysis. Four annulus volumes (C210-C240) simulate cooling channels to remove downward heat flux as cooling water flow rate from IRWST to PMCCS is controlled as flow boundary condition with Temporal Face Boundary Condition (TFBC, C115).

The annulus volume (C320) represents reactor cavity area and the TBFC (C325) does containment free volume as pressure boundary.

The heat load is applied with four heat structures attached to the annulus volumes of cooling channels according to angles from 0 degree to 90 degrees.

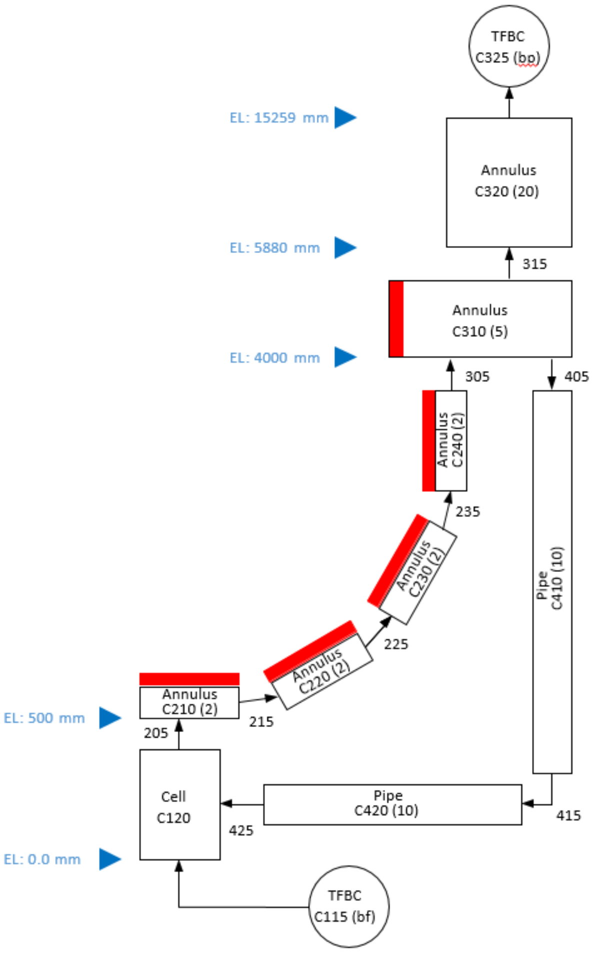

Fig. 5. SPACE nodalization for PMCCS

3. Results of Analysis

Fig. 6 shows the pressure trend of cooling channel inlet (C210), outlet (C240), and reactor cavity (C320). The pressure in cooling channel reaches steady state after some time while the pressure in reactor cavity maintains the steady state from the beginning.

Fig. 7 shows water temperature of cooling channel in PMCCS. In the early phase, water reaches the saturation temperature and wall boiling starts on the outer surface of PMCCS.

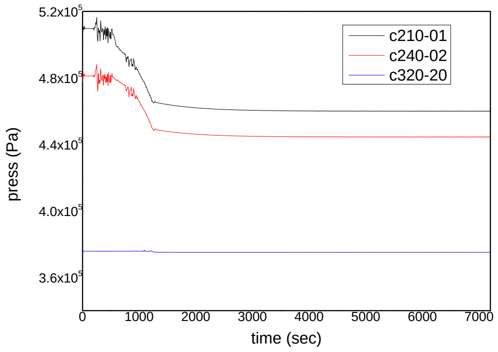

Fig.6. Pressure in cooling channel and reactor cavity

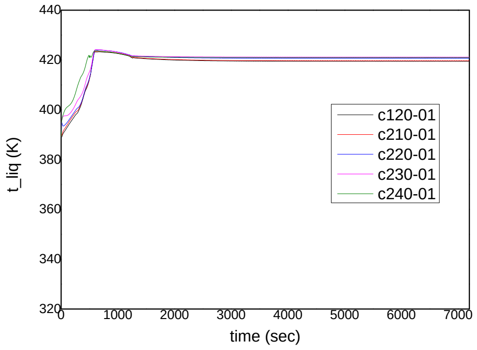

Fig.7. Water temperature in cooling channel

Fig. 8 shows natural circulation flow rate of water entering cooling channel in PMCCS. It shows fluctuation in the early phase until water circulation flow is stably maintained, and then the flow rate reaches equilibrium.

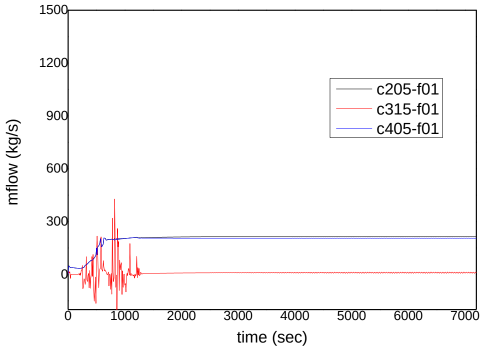

Fig.8. Water flow rate

Fig. 9 shows heat transfer mode near the outlet region of cooling channel in PMCCS. It is judged that the volume (C240) with the highest downward heat flux is maintained in the nucleate boiling heat transfer region.

Fig. 10 shows flow region index in cooling channel of PMCCS. The lower part of cooling channel remains in bubbly flow region and the upper part of it moves into slug flow region as heat flux increases from lower part to upper one.

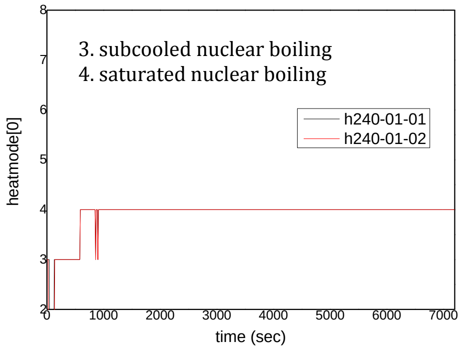

Fig.9. Heat transfer mode index

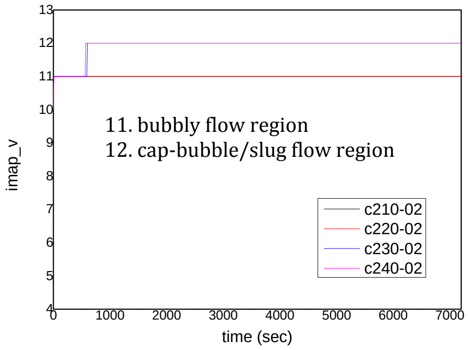

Fig.10. Flow region index

4. Conclusions

In this paper, the analysis of ex-vessel coolability on PMCCS in iPOWER.

The results of analysis show that the water in the cooling channel in PMCCS with hemisphere shape, forms stable natural circulation flow and its heat transfer between corium and cooling water is maintained in the nucleate boiling for 7,200 seconds, the analysis duration in case that corium is relocated in the PMCCS after two hours of a severe accident, LBLOCA.

In conclusion, it is proved that the PMCCS secures ex-vessel coolability against the heat load of corium in iPOWER.

Acknowledgement

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