Transactions of the Korean Nuclear Society Spring Meeting
Jeju, Korea, May 16-18, 2018

Preliminary Evaluation for External Reactor Vessel Cooling in the SMART

Hyung Seok Kang*, Hyoung Tae Kim, and Rae-Joon Park
Korea Atomic Energy Research Institute, 989-111, Daedeok-daero, Yuseong, Daejeon, 34057, Republic of Korea
**Corresponding author: hskang3@kaeri.re.kr*

1. Introduction

KAERI (Korea Atomic Energy Research Institute) is developing the SMART (System-Integrated Modular Advanced Reactor) 365 MW_{th} in which the IVR (In-Vessel corium Retention) through ERVC (External Reactor Vessel Cooling) is adopted as a severe accident mitigation system to maintain the integrity of the reactor vessel [1]. It is necessary to evaluate that the ERVC can sufficiently remove the thermal load from the corium to the outer reactor vessel during the severe accident. The preliminary evaluation can be performed by predicting a two phase natural circulation flow through the annular gap between the outer reactor vessel wall and the insulation of the reactor vessel with assuming the severe accident conditions.

2. Design Features of the IVR-ERVC

The ERVC of the SMART consists of the safety depressurization system, the reactor CFS (Cavity Flooding System), and the reactor vessel insulator with a coolant injection path, coolant circulation path and a steam discharge path (Fig. 1) [2,3]. The operator decides to use the ERVC for preventing damage to the reactor vessel when the core outlet temperature exceeds 650 ℃ during the severe accident. The operator opens the isolation valve of the CFS so that the IRWST water is injected into the reactor cavity by gravity. The coolant is injected into the annulus gap between the outer wall and insulator through the coolant injection path installed in the reactor vessel insulation. The steam generated from the outer wall of the reactor vessel is discharged into the annulus outside the reactor vessel insulator through the steam discharger installed in the insulator. The coolant is circulated through the coolant circulation tube installed in the reactor vessel.

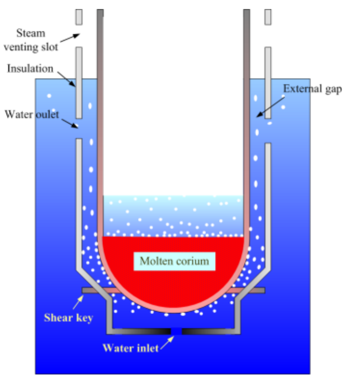


Fig. 1. IVR-ERVC Concept of the SMART

3. SPACE Analysis

This calculation was performed as a transient case by using the SPACE 2.19a code [4].

3.1 Input Models and Calculation Assumptions

Input models and calculation assumptions (Fig. 2 and Table 1) were developed based on the current design parameters of the ERVC in the SMART. The coolant supplied by the IRWST (TFBC106) circulates from the cavity water pool (Node C100) through the gap between the outer reactor vessel and insulation (Nodes. C30 - C90). The water inlet is a single face 11. The cross flow faces of No. 63 and 93 are the water circulation outlet and steam outlet, respectively. The spherical and cylindrical reactor vessels are simulated using the heat structure numbers 100 and 200, respectively. The thermal power of the corium [3] is simulated as boundary condition of the heat flux at the left side of spherical heat structure. The generated steam is vented into the containment atmosphere (TFBC 104). In all calculations, the initial conditions are assumed to be ambient pressure with no coolant mass flow rate. In addition, a sensitivity calculation by changing the heat flux was conducted because the calculated the corium thermal power is only 0.56% of the thermal power of the SMART [2].

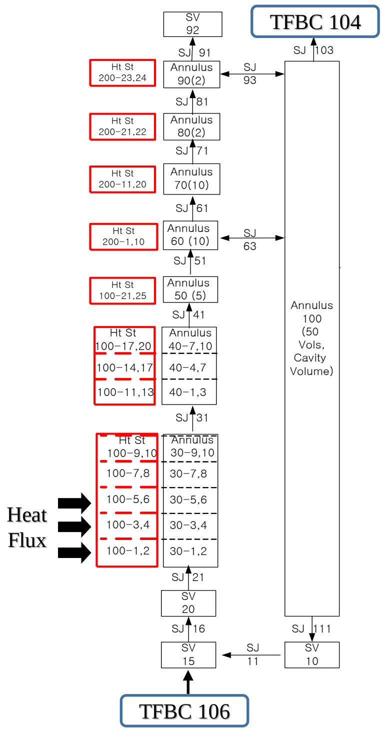


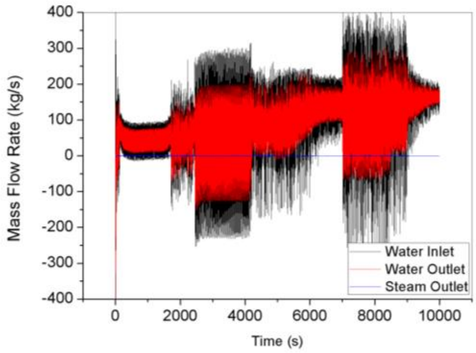
Fig. 2. Nodalization for the SPACE Analysis

Table 1. Basic Analysis Conditions

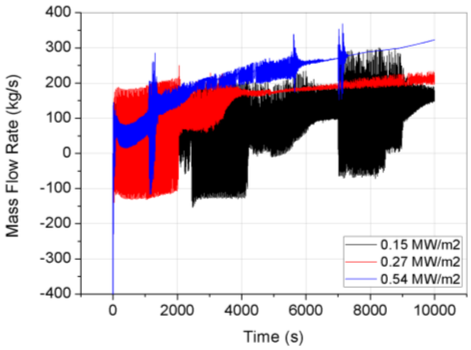
- Coolant injection area : 0.5 m^2
- Steam exit area : 0.5 m^2
- Coolant circulation port area : 0.5 m^2
- Steam exit level : 9.8 m from bottom head
- Coolant circulation port level : 4.8 m from bottom head
- Gap between external wall and insulation : 0.1 m
- Heat flux on the external wall : 0.153 MW/m^2
- Water level : 4.9 m from bottom head
- Injected coolant temperature : 50 ℃

3.2 Discussion on the Calculation Results

The predicted natural circulation flows through the annular gab are shown in Fig. 3. Fig. 3(a) shows that the natural circulation flow of approximately 190 kg/s is developed at 10,000 s through the annulus gap at the wall heat flux 0.15 MW/m^2 after passing the period of an oscillating flow. Fig. 3(b) shows that the calculated natural circulation flows at 10,000 s are also developed to approximately 200 kg/s and 290 kg/s at the wall heat flux of 0.27 MW/m^2 and 0.54 MW/m^2, respectively. According to the CHF test results regarding the IVR-ERVC [2], the calculated natural circulation flow rates at the various wall heat fluxes can sufficiently cool down the reactor vessel without the CHF occurrence. Therefore, we can know that the integrity of the reactor vessel can be assured if the IVR-ERVC properly operates during the severe accident of the SMART.



(a) Natural Circulation Flow Rate at Heat Flux 0.15 MW/m^2



(b) Natural Circulation Flow Rate at the Water Outlet according to Various Heat Fluxes

Fig. 3. SPACE Analysis Results

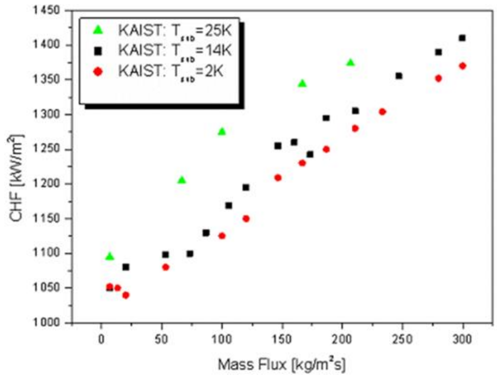


Fig. 4. KAIST Test Results of CHF on Outer Wall [2]

4. Conclusions and Further Work

KAERI performed a preliminary evaluation for the IVR-ERVC of the SMART on the basis of the current design parameters using the SPACE 2.19a. Through SPACE analysis results for predicting the natural circulation flow through the annular gap between the outer reactor vessel wall and the insulation of the reactor vessel, we can conclude that the reactor vessel integrity can be maintained by the operation of the IVR-ERVC system during the severe accident. However, the final evaluation for the design concept of the IVR-ERVC will be conducted on the basis of the CINEMA code [5] calculation results with using the final design parameters of the IVR-ERVC in the SMART.

ACKNOWLEDGMENTS

This work was supported by the National Research Foundation of Korea (NRF) grant funded by the Korea government (Ministry of Science, ICT, and Future Planning) (No. 2012M2A8A4025889)

REFERENCES

[1] Han Ok Kang, SMART Pre-Project Engineering between KAERI and K.A.CARE, Proceedings of KNS Autumn Meeting, October 29-30, 2015, Jeju, Republic of Korea.

[2] R.-J. Park, S.-B. Kim, and Y.-H. Jing, Evaluation of External Reactor Vessel Cooling, Technical Report, 916-NS301-113, KAERI, 2011.

[3] Rae-Joon Park, Kwang-Soon Ha, and Hwan-Yeol Kim, Detailed Evaluation of Natural Circulation Mass Flow Rate in the Annular Gap between the Outer Reactor Vessel Wall and Insulation under IVR-ERVC, Annals of Nuclear Energy, 89, pp. 50-55, 2016.

[4] KHNP, KEPCO E&C, and KAERI, SPACE 2.19a User Manual, 2016.

[5] KHNP, KAERI, FNC, and KEPCO E&C, CINEMA User Manual, S11NJ16-2-E-TR-7.4, Rev.0, 2017.