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In-box LOCA sensitivity analysis for PD-2 HCCR-TBS

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1. Introduction

This paper presents sensitivity analysis results of the in-box LOCA (Loss of Coolant Accident) for the PD-2 phase design of a Helium Cooled Ceramic Reflector (HCCR) Test Blanket System (TBS). In-box LOCA is a significant safety concern, where helium coolant leakage into the breeding zone (BZ) can lead to pressurization of the TBM box structure and the Tritium Extraction System (TES). This study focuses on the sensitivity analysis of in-box LOCA for CASE I, where the relief tank is in the isolated zone with the Helium Cooling System (HCS) loop. Specifically, this paper examines the effects of varying crack size and isolation valve closing time on the system's behavior during an in-box LOCA event to contribute design optimization of the HCCR-TBS. [1-3]

2. Safety Analysis Code

For accident analysis, the GAMMA-FR (General Analyzer for Multi-component and Multi-dimensional Transient Application – Fusion Reactor) code, which has been developed in KAERI (Korea Atomic Anergy Research Institute) [4] was used. The GAMMA-FR code is a system code to predict thermo-hydraulic and chemical reaction phenomena expected to occur during thermo-fluid transients and it has been used extensively for the safety assessment of the HCCR TBS.

3. Parameters and nodalization

If the cooling plates in the BZ are broken, the helium coolant flows into the BZ and then pressurizes the BZ box structure and the TES. In this analysis, double-ended break of one pipe is assumed, which corresponds to 0.74 % of cooling pipes in one sub-module BZ. The objectives of this analysis are to show that the accidental over-pressure in the TBM box and TES will be safely accommodated, the post-accident cooling is established to remove decay heat, and radioactive release is adequately confined. Break area is 0.001 m^2, TBM frame temperature is 135 ℃ and the emissivity of TBM frame is 0.3.

Figure 1 shows nodalization of the PD-2 phase in-box LOCA analysis. The TBM-TES volume is 0.735 m^3 and TBM-HCS volume is 4.311 m^3. Isolation valve is located between PI in TES and TBM, which is between nodalization number FB200 and FB232.

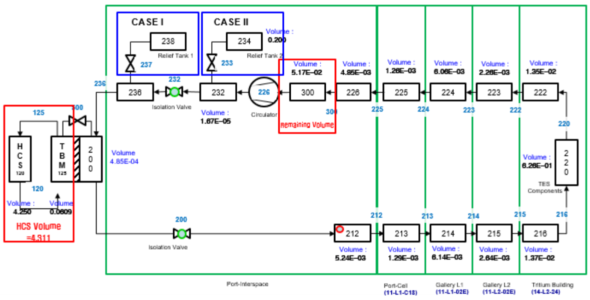

Fig. 1. Nodalization of the analysis

To analyze the effect on the location of the relief valve, the following two cases were investigated. Case I is that the relief valve is located in isolated zone with HCS loop. Case II is that the relief valve is located in non-isolated zone with TES loop. Operation pressure is 8 MPa for HCS loop, and 0.1 MPa (atmospheric pressure) for TES loop. The HCS loop temperature is assumed to be 400 ℃. TES loop temperature is 450 ℃ from TBM to Port Interspace, while from the Port Cell to other loop is 25 ℃ (room temperature).

In this analysis, the cases is assorted to four regarded to the isolation time, which starts when more than 0.4 MPa pressure occurs on TES loop. Relief valve opens when pressure of PI is more than 0.2 MPa.

Table I: Parameters for in-box LOCA

Test Index	Relief Tank location	Crack size	detection	Isolation time (second)
01vs0401	01	very small	0.4 MPa	1
01vs0403	01	very small	0.4 MPa	3
01vs0405	01	very small	0.4 MPa	5
01vs0410	01	very small	0.4 MPa	10
01sm0401	01	small	0.4 MPa	1
01sm0403	01	small	0.4 MPa	3
01sm0405	01	small	0.4 MPa	5
01sm0410	01	small	0.4 MPa	10
01lg0401	01	large	0.4 MPa	1
01lg0403	01	large	0.4 MPa	3
01lg0405	01	large	0.4 MPa	5
01lg0410	01	large	0.4 MPa	10
01vl0401	01	very large	0.4 MPa	1
01vl0403	01	very large	0.4 MPa	3
01vl0405	01	very large	0.4 MPa	5
01vl0410	01	very large	0.4 MPa	10

4. Results

Figures 2 shows the pressure of non-isolated zone. As the time for the relief valve closing time increases, the pressure in the non-isolated zone increases. This is because an increased isolation valve operation time prolongs the duration of high-pressure ingress from the HCS into the TES.

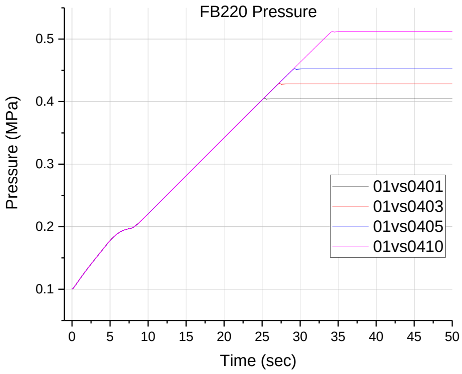

Fig. 2. Pressure of non-isolated zone in TES s

Figure 3 shows mass flow rate of leak path at every closing time for different isolation valve operating scenarios (01sm0401, 01sm0403, 01sm0405, and 01sm0410). It can be observed that as the isolation valve operation time increases, the duration of mass flow from the HCS into the TES also extends accordingly.

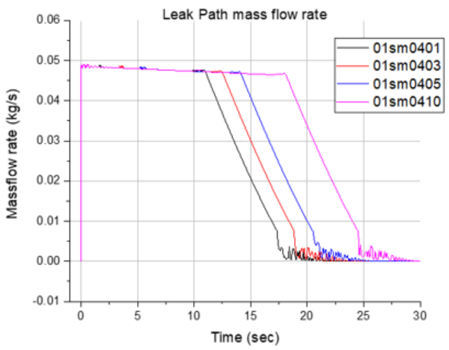

Fig. 3. Mass flow rate of leak path

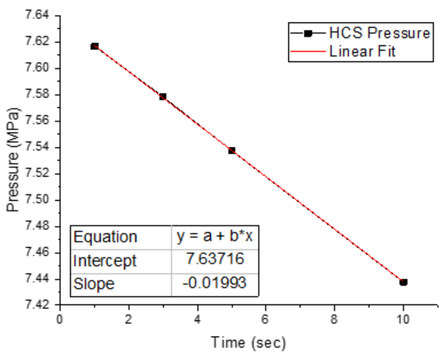

Fig. 4. HCS pressure vs. Closing time

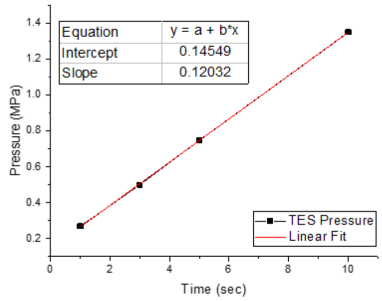

Fig. 5. TES pressure vs. Closing time

Figure 4 and 5 show convergence pressure of HCS and TES by change of closing time. HCS pressure drops and TES pressure surges as closing time gets longer. Since both two graphs show linear trends as closing time changes, convergence pressure of other closing time can be estimated.

5. Conclusion

Consequently, these findings can be instrumental in defining appropriate detection thresholds for accident conditions. By understanding the relationship between crack size and the rate of pressure increase, it is possible to design and specify the requirements for safety functions and diagnostic instruments.

This study provides critical insights into the sensitivity of in-box LOCA scenarios for the PD-2 HCCR, emphasizing the impact on safety systems design and operational guidelines in nuclear fusion reactors.

REFERENCES

[1] M.-Y. Ahn et al., Current status of accident analysis for Korean HCCR TBS, Fusion Eng. Des. 89 (2014) 1289-1293.
[2] H. G. Jin et al., Sensitivity study on in-box LOCA for a Korean HCCR TBM in ITER, Fusion Eng. Des. 89 (2014) 2024-2027.
[3] H. G. Jin et al., Scoping study on in-vessel LOCA of a Korean TBS in ITER, IEEE Transaction on plasma science vol. 42 no 3 (2014) 671-674.
[4] H. S. Lim et al., GAMMA multidimensional multicomponent mixture analysis to predict air ingress phenomena in an HTGR, Nucl. Sci. Eng. 152 (2006)