Loss of Flow Accident Analysis for PD-2 HCCR-TBS

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1. Introduction

This paper presents sensitivity analysis results of the LOFA (Loss of Flow Accident) for the PD-2 phase design of a Helium Cooled Ceramic Reflector (HCCR) Test Blanket System (TBS). A circulator seizure in the Helium Cooling System (HCS) is one of the reference accidents for the HCCR-TBS. Flow rundown can raise first-wall (FW) and breeder-zone (BZ) temperatures and alter loop mass flow rate. This paper evaluates the PD-2 HCCR-TBS LOFA response by varying two operational parameters: the low-flow detection threshold and the isolation-valve full-closure time to contribute design optimization of the HCCR-TBS. [1-3]

2. Safety Analysis Code

Accident transients are computed using GAMMA-FR (General Analyzer for Multi-component and Multi-dimensional Transient Application—Fusion Reactor), developed at KAERI. 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

Plant state. HCS design pressure 8 MPa; initial loop mass flow 1.14 kg s^{-1}; representative temperatures consistent with PD-2 operation. The TBM–non-isolated loop control volume is 0.735 m^3 and the TBM–HCS volume is 4.311 m^3. Isolation & detection points. The isolation valve is located between FB200 and FB232; the low-flow detection is taken at JB20150. These are the reference points for the LOFA matrix below. (Figure 1 illustrates the PD-2 nodalization as used for the LOFA study.)

- Detection threshold: 50/70/80% of the initial 1.14 kg s^{-1}, i.e., 0.57 / 0.798 / 0.912 kg s^{-1}.
- Valve full-closure time: 1 / 3 / 5 / 10 s. The twelve cases are denoted LOFA5001…8010 using the (threshold, closure) convention.

Figure 1 shows nodalization of the PD-2 phase LOFA analysis. The TBM-HCS volume is 4.311 m^3. Isolation valve is located between Port Cell in HCS, which is between nodalization number FB200 and FB150, FB600 and FB700.

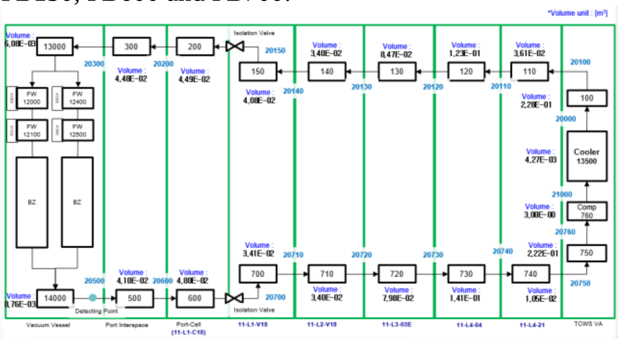

Fig. 1. Nodalization of the analysis

Table I: LOFA test matrix

Test Index.	Accident	Flow detection	Isolation time (second)
LOFA5001	LOFA	50%	1
LOFA5003	LOFA	50%	3
LOFA5005	LOFA	50%	5
LOFA5010	LOFA	50%	10
LOFA7001	LOFA	70%	1
LOFA7003	LOFA	70%	3
LOFA7005	LOFA	70%	5
LOFA7010	LOFA	70%	10
LOFA8001	LOFA	80%	1
LOFA8003	LOFA	80%	3
LOFA8005	LOFA	80%	5
LOFA8010	LOFA	80%	10

4. Results

Figure 2 overlays LOFA5001/5003/5005/5010. Following circulator trip, the mass flow at JB20150 drops promptly with small oscillations and decays to zero exactly at the case-specific full-closure time. The 70%/80% threshold cases show the same shape shifted earlier in time (earlier detection → earlier start of valve motion), confirming that the closure time—not the threshold—governs the moment of complete flow cessation.

In Figure 3, the temperature rises after an accident, the additional disruption load of 0.3 GW/m², acting for 0.001 seconds, causes the temperature of the FW to soar up to about 650 ℃ and then drop off. Subsequently, after an additional disruption load of 0.3 MW/m² is applied for one second, the temperature of the FW decreases due to the radiational heat release.

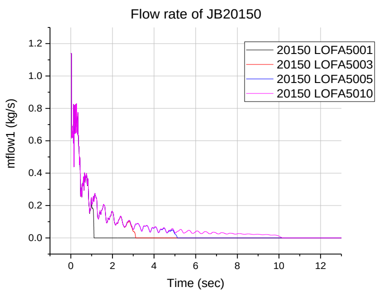

Fig. 2. Flow rate of JB20150 (isolation valve located)

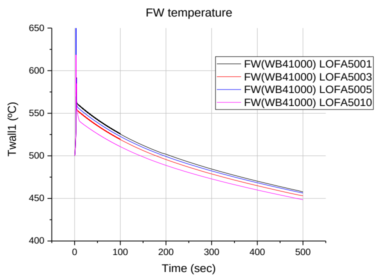

Fig. 3. FW temperature transient when LOFA

Figure 4 depicts a trend line for the FW temperature per detecting flow rate at 500 s. As the detecting flow rate increases, the temperature of the FW tends to increase slightly by about 0.5 ℃. An earlier detection triggered by a higher flow-rate threshold results in faster isolation of the coolant flow, which in turn causes the first-wall temperature to increase slightly.

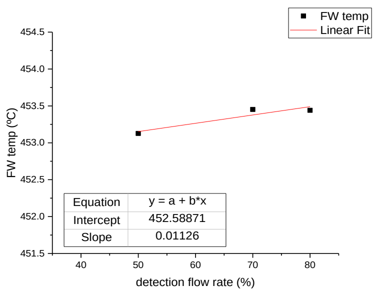

Fig. 4. FW temperature by increasing detection flow rate

The incident detection flow rate is fixed at 80% (0.912 kg/s) of the initial value and the sensitivity according to the change of the closing time was checked. Figure 5 shows a trend line for the isolated zone pressure per closing time at 500 s. With increasing isolation valve closing time, the HCS is allowed more time to reach internal pressure uniformity, leading to a reduction in the isolated-zone pressure. Nevertheless, because LOFA entails no coolant leakage, the pressure variations associated with the actuation of safety functions are negligible.

In Figure 5, as the closing time increases, the temperature of the FW decreases. During a LOFA, the system pressure shows insignificant variation, but the flow rate decreases rapidly. As a result, the FW temperature becomes sensitive to the isolation valve closing time, and a slower closing time tends to reduce the FW temperature. This behavior is attributed to the residual cooling effect provided by the remaining internal flow after the accident, indicating that immediate actuation of the isolation valve is not necessarily favorable from the perspective of post-accident cooling.

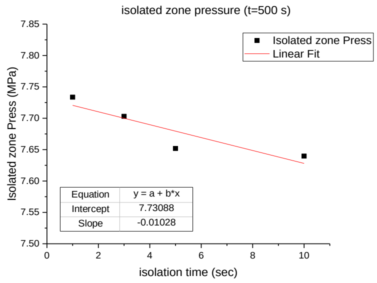

Fig. 5. Pressure of isolated zone by increasing closing time

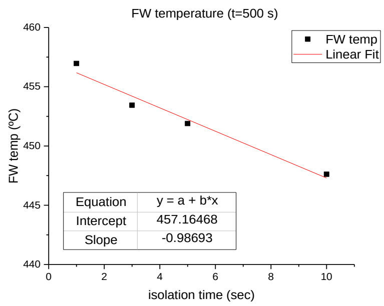

Fig. 6. HCS pressure vs. Closing time

5. Conclusion

This study provides critical insights into the sensitivity of LOFA scenarios for the PD-2 HCCR, emphasizing the impact on safety systems design and operational guidelines in nuclear fusion reactors. In this accident analysis, it is assumed that the circulator stops instantaneously at the onset of the event; however, an immediate stop is practically impossible. Therefore, to achieve a more accurate sensitivity study, the analysis should incorporate the transient rundown characteristics of the circulator and explicitly model how the flow rate decreases over time until it comes to a complete stop.

REFERENCES

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