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In-vessel LOCA crack size sensitivity analysis for HCCR-TBS

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1. Introduction

This paper presents accident analysis results of the in-vessel LOCA for the PD-2 phase design of a Helium Cooled Ceramic Reflector (HCCR) Test Blanket System (TBS). In-vessel LOCA occurs when one or more cooling channels in the first wall (FW) are damaged or ruptured. In this analysis, double-ended break of one channel is assumed, which corresponds to 9.1% of cooling channels of one sub-module. The objective of this analysis is how crack size area affects the progress of the accident.

2. Assumptions

In conducting the accident analysis within the scope of this study, a set of critical assumptions has been established to frame the simulation parameters and operational conditions. The following assumptions were utilized:

- Plant Safety System (PSS) is activated if two safety devices among three of them detects accidents.
- If PSS is activated, safety devices response immediately.
- Fusion Power Shutdown System (FPSS) is activated at three seconds after accident detection.
- Plasma disruption load is 0.3 GW/m^2 during 0.001 sec and 0.3 MW/m^2 for 1 second 100% nuclear power density and surface heat flux are applied for the HCCR TBM until plasma shutdown is completed.
- After plasma shutdown completed, decay heat by activation analysis for SA2 scenario is cooled by radiation heat transfer.

3. 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) [2] 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.

4. Parameters and nodalization

In Table I, main parameters for the accident are shown. The main parameters for the accident are these. Break area is 0.00033 m^2, free volume of VV is 1715 m^3, design pressure of VV is 200 kPa, and initial pressure of VV is 1 kPa.

Table I: Parameters for in-vessel LOCA

Parameter	Value
Break area	0.00033 m^2
VV free volume, design pressure	1715 m^3, 200 kPa
VV pressure, temperature	1 Pa, 135 °C
TBM Frame emissivity	0.3
TBM Frame temperature	135 °C

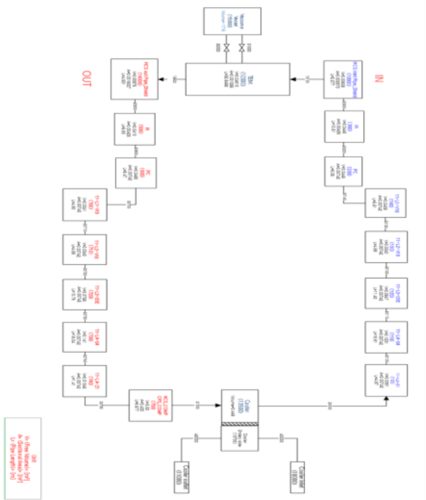

Fig. 1. Nodalization of the analysis

Figure 1. shows nodalization for the PD-2 phase. There is connection status between nodes, ID number, and material properties of free volume, section area, and length about each node. Moreover, to show that the cooling channel becomes double ended break, two junctions are connected between TBM and VV. As a result, it can be avoided that flow in one direction only in accident analysis.

5. Results

Figures 2 and 3 show the sensitivity analysis results based on crack sizes. The graph presents the pressure as a function of time in four different scenarios, each denoting a case with varying crack sizes.

This plot comprises four series, each representing a different case labeled "Case 0," "Case 1 (x0.5)," "Case 2 (x1.5)," and "Case 3 (x2)," likely indicative of varying crack sizes through which helium coolant is entering into the VV. All cases show a steep increase in pressure during the first 50 seconds, indicating a rapid ingress of gas into the VV.

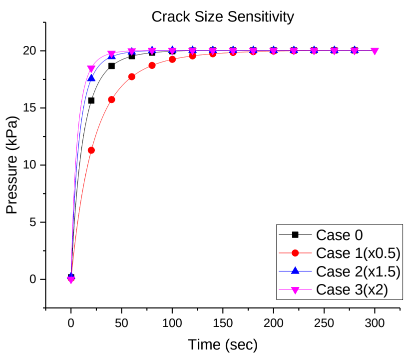

Fig. 2. VV Pressure according to crack size Pipes

This graph demonstrates a clear relationship between the size of the cracks in the vacuum vessel (VV) and the rate at which helium is introduced into the system, as well as the subsequent rate of pressure build-up within the VV. As it is evident that as the crack size increases (1.5 times, 2 times, or larger than that of the reference case "Case 0"), the mass flow rate of helium entering through these cracks correspondingly increases. This, in turn, accelerates the pressure build-up within the vessel.

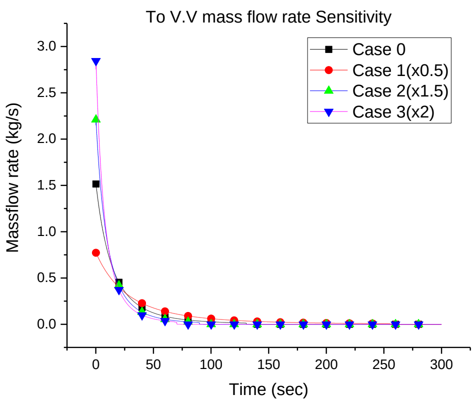

Fig. 2. Mass flow to VV according to crack size

Figure 2 depicts the mass flow rate into the vacuum vessel (VV) as a function of time. The data presented in the graphs effectively illustrate a trend where larger crack sizes result in higher initial mass flow rates at the onset of an accident, with a steep decline in the flow rate thereafter. This tendency is indicative of the significant influence that crack dimensions have on the system's behavior during the accident.

The bigger the crack size, the faster the release of helium occurs, and VV pressure increases. VV pressure converges on 20.04 kPa, and mass flow of helium to VV is 28.956 kg.

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.

Furthermore, the equipment specifications can be tailored to the sensitivities required for detecting the flow rates corresponding to the smallest cracks that are considered significant for safety analysis. By doing so, it is feasible to optimize the response time of safety mechanisms, allowing for a prompt and efficient intervention to maintain the integrity of the VV and prevent any potential escalation of the accident scenario.

In conclusion, the data provided by these pressure and mass flow rate analyses are crucial for informing the engineering decisions regarding the design and implementation of safety measures in nuclear fusion systems. These measures are essential to ensure that the systems operate within safe parameters.

REFERENCES

[1] H. S. Lim et al., GAMMA multidimensional multicomponent mixture analysis to predict air ingress phenomena in an HTGR, Nucl. Sci. Eng. 152 (2006)