Transactions of the Korean Nuclear Society Autumn Meeting
Gyeongju, Korea, October 24-25, 2013

Investigation into the In-box LOCA consequence and structural integrity of the KO HCCR TBM in an ITER

D. W. Lee [a*], H. G. Jin[a], K. I. Shin [a], E. H. Lee [a], J. S. Yoon [a], S. K. Kim [a], M. Y. Ahn [b], S. Cho [b]
[a]*Korea Atomic Energy Research Institute, Republic of Korea*
[b]*National Fusion Research Institute, Republic of Korea*
[*]*Corresponding author: dwlee@kaeri.re.kr*

1. Introduction

Korea has developed a Helium Cooled Ceramic Reflector (HCCR) based Test Blanket System (TBS) for an ITER [1-5]. Using the current TBM System (TBS) design, accident analyses were performed on eight selected reference accidents. Among them, the in-box LOCA is introduced in the present paper. This accident starts with a rupture of the cooling plates in the Breeding Zone (BZ) pressurizing the BZ box structure, and thus the subsequent pressurization of the Tritium Extraction System (TES). In this paper, the consequences of an accident such as pressurization in the BZ and the integrity of the internal structure of the TBM by this pressurization were investigated using a safety analysis code (GAMMA-FR) and a commercial code, ANSYS, respectively [6-8].

2. Accident analysis with GAMMA-FR

For an accident analysis, the GAMMA-FR code is used, which is a system code to predict the thermo-hydraulic and chemical reaction phenomena expected to occur during thermo-fluid transients. In the GAMMA-FR code, a fluid flow and heat transport are solved unsteadily by the thermal non-equilibrium model, consisting of two sets of equations for two media, gas and solid parts.

The nodalization for the safety analysis is based on a schematic diagram of the Korea HCCR TBS shown in (Fig. 1), which has a typical TBS configuration including a PI (Port inter-space), PC (Port Cell), Tritium building etc. Precise sizing and pipe routing of the HCS (Helium Cooling System) and TES (Tritium Extraction System) will be determined. The conceptual design specifications of the HCCR TBS were used, and one-dimensional fluid connections and two-dimensional heat structures were adopted. This nodalization was designed to monitor the physical properties of the HCCR TBS during normal operation and accident condition including an in-vessel LOCA, ex-vessel LOCA, in-box LOCA, LOFA, and LOSA (Fig. 2).

For an in-box LOCA accident, the following scenario was considered; 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, a double-ended break of one pipe is assumed, which corresponds to 0.74% of the cooling pipes in one sub-module BZ. The acceptance criteria for this accident are as follows:

- Confinement integrity: purge pressure < design pressure of TES
- Max long term FW temperature < 550 °C
- Structural integrity: TBM box pressurization < design limit
- Accident doses << General Safety Objectives for ITER

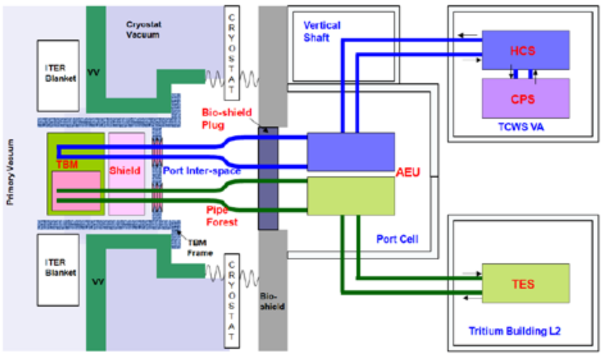

Fig. 1 HCCR TBS schematic diagram.

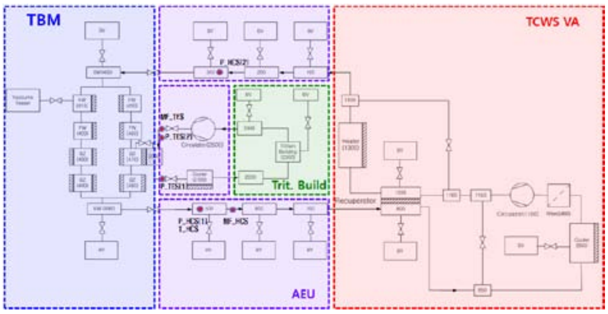

Fig. 2 Nodalization of HCCR TBS for accident analysis.

The accident is detected at 6.0 seconds as the TES internal pressure exceeds 0.5 MPa. Figure 3 shows the pressure transient at locations where the safety devices exist (isolated zone) and the other part of the TES (non-isolated zone). After detection of an in-box LOCA, isolation valves are closed, and an isolated TES zone is then pressurized. This is because the pressure of the helium coolant in the TBM is still higher than that of the purge gas in the TES, and the TES volume becomes smaller from isolation.

By the TES pressurization, the BZ box is expected to be broken since this box is not designed to endure the pressure, and the thickness is very thin (5 mm). The TBM outer box, which consists of the FW, SW, and

BM, will be pressurized as the TES pressurization, and therefore the integrity of the TBM outer box should be investigated.

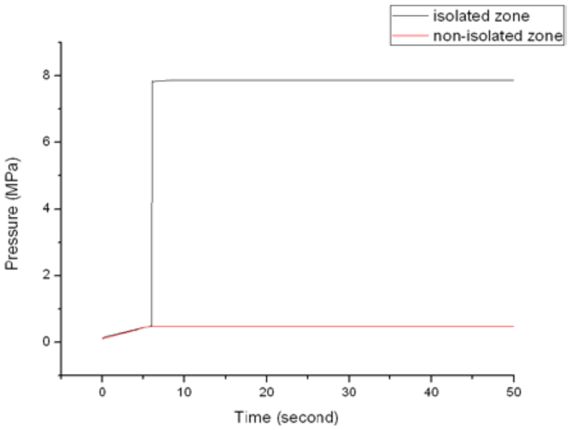

Fig. 3 Pressure transient in TES when in-box LOCA.

3. Integrity investigation of TBM

As shown in the previous chapter, the maximum pressure in the TBM box can be 8 MPa, which is the same as the coolant pressure by the in-box LOCA. In this accident, the pressurization at internal TBM box was investigated using the ANSYS code. To avoid the stress concentration in the right angle region of the TBM box, the curvature (*R*=2) was considered in the analysis, as shown in Fig. 5, which will be reflected in the fabrication procedure such as high pressure welding. In this figure, the boundary conditions such as internal pressure and fixing region were shown together with the generated meshes.

Figure 6 shows the von Mises stress distribution from an elastic-plastic analysis. 390 MPa of yield strength, 460 MPa of tensile strength, and the bilinear kinematic hardening were considered in the elastic plastic analysis. As shown in Fig. 6, the maximum von Mises stress is about 391 MPa and the over deformation occurred in the upper and lower regions in the TBM box, but the maximum stress is lower than the tensile strength. It can be noted that the plastic deformation will occur in the TBM box caused by in-box LOCA, but it will not lead to a rupture accident.

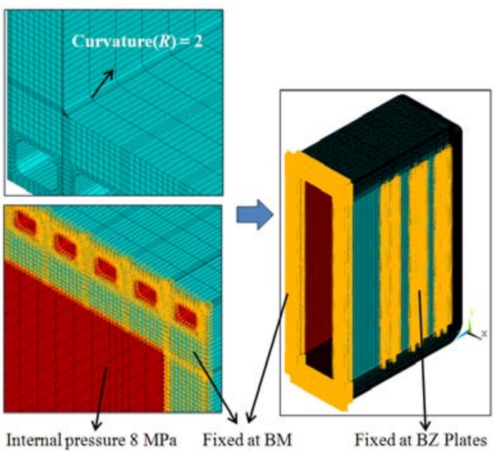

Fig. 4 Mesh and boundary conditions for ANSYS analysis.

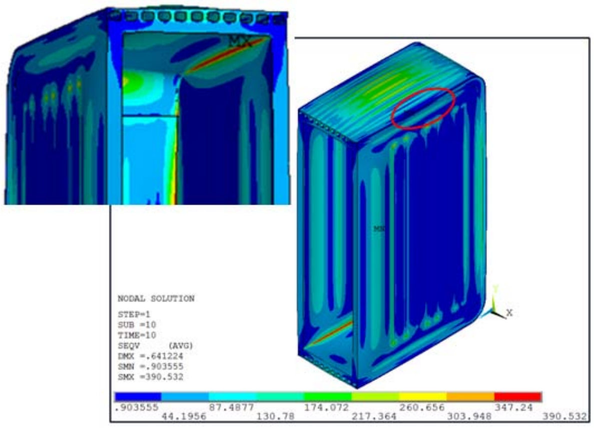

Fig. 5 Stress distribution by pressurization at in-box LOCA.

4. Conclusion

The accident sequence and internal integrity of the KO HCCR TBS in the case of in-box LOCA were investigated using the developed GAMMA-FR code and commercial FEM code. TES pressurization may cause TBM outer box pressurization with a short time. However, the TBM outer box seems able to endure this pressure.

References

[1] D.W. Lee, et. al., “Design and preliminary safety analysis of a helium cooled molten lithium test blanket module for the ITER in Korea,” Fusion Eng. Des. 83 (2008) 1217-1221.

[2] D.W. Lee, et. al., “Fabrication and High Heat Flux Test of the First Wall Mock-ups for the Korean He Cooled Test Blanket (KO HCML TBM),” Fusion Eng. Des., 84 (2009) 1164-1169.

[3] K. I. Shin, et. al., “Design and performance analysis of structural components for a Korean He cooled ceramic reflector TBM in ITER,” Fusion Eng. Des., accepted for publication.

[4] S. Cho, et. al., “Overview of helium cooled solid breeder test blanket module development in Korea,” Fusion Eng. Des., accepted for publication.

[5] M. Y. Ahn, et. al., “Design change of Korean HCCR TBM to vertical configuration,” Fusion Eng. Des., accepted for publication

[6] Hee Cheon No, Hong S. Lim, “GAMMA multidimensional multicomponent mixture analysis to predict air ingress phenomena in an HTGR.” Nucl. Sci. Eng.152 1, 2006.

[7] Hee Cheon No, Hong S. Lim, Jong Kim, Chang Oh, Larry Siefken, Cliff Davis, “Multi-component diffusion analysis and assessment of GAMMA code and improved RELAP5 code” Nucl. Eng. and Design, Volume 237, Pages 997-1008, 2007.

[8] ANSYS CFX-11, 2007, User Manual, ANSYS-CFX.