Thermal Hydraulic Analysis of in-Vessel Loss of Coolant Accident and Loss of Flow Accident of First Wall Helium Cooling System of Generalized LLCB TBS in ITER Using Modified RELAP/SCDAPSIM MOD4.0 Code

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Abstract: *India has proposed Lead-Lithium cooled Ceramic Breeder (LLCB) Test Blanket Module (TBM) concept for testing in ITER. The First Wall of TBM (TBM FW) directly faces the plasma and is cooled by First Wall Helium Cooling System (FWHCS), it is considered as a critical component from ITER safety point of view. The scope of this work comprises of thermal hydraulic analysis of the Indian LLCB Test Blanket System (TBS) and the assessment of In-Vacuum Vessel (VV) Loss of Coolant Accident (In-Vessel LOCA) and Loss of Flow Accident (LOFA) in FWHCS on the ITER safety with the help of thermal-hydraulic code RELAP/SCDAPSIM/MOD4.0.*

Keywords: Safety analysis, ITER, Thermal hydraulics, RELAP/SCADAPSIM, TBM

1. INTRODUCTION

.ITER is a fusion based research reactor which uses tritium as a fuel and will provide a large amount of energy. The key feature of TBM is to develop the design technology for DEMO and future power producing fusion reactor. ITER provides an opportunity to test the blanket concept and collect DEMO relevant experimental data and has provided dedicated ports for testing of TBMs in the machine; India has proposed LLCB TBM as the blanket concept.There is always crisis of energy around the world and in future energy requirement will be much more. Conventional sources of energy are not capable to fulfill the demand and are also dangerous for the environment. Non-conventional energy resources are an alternative. ITER ("The Way" in Latin) is one of the most ambitious energy projects in the world today The objective of the safety analysis are to demonstrate that, the Test Blanket System (TBS) design has sufficient provisions to withstand accident sequences without violating the release guidelines and other safety principles established for ITER and documented in the Safety Guidelines for Test Blanket Systems [1]. The purpose of this safety analysis is to analyze the reference event sequences in an organized fashion for demonstrating that the system design has sufficient features to sustain under these sequences.

1.1 System Description and Components

The Indian LLCB blanket concept consists of lithium titanate as ceramic breeder (CB) material in the form of packed pebble beds, Lead-Lithium (Pb-Li) is acting as a coolant for ceramic breeder beds and in addition acts as tritium breeder and multiplier. The outer box and the FW are cooled by high pressure helium [2]. The high-pressure helium gas cools the box structure of the blanket module such as First wall, top plate, bottom plate and back side plate. The First Wall Helium Cooling System (FWHCS) transports the heat from the FW and the outer box structure. The TBM first wall is cooled by high pressure primary helium, which rejects heat to ITER water cooling system. The FWHCS is designed to remove the peak heat load of 300 kW [3]. The block diagram of FWHCS of LLCB TBM is documented in reference [3]. The TBM FW composed of a 28 mm thick U-shaped RAFMS structure, having internal cooling channels of 20 mm × 20 mm cross section. The coolant channels are designed to allow multiple passes of helium coolant across the FW in order to maximize the heat removal. The number of helium passes has been optimized such that the maximum temperature in the RAFMS remains below the design limit of 550 °C. The FW structure is having 64 helium coolant channels [4].

2. ANALYSIS AND RESULTS

2.1. In-vessel TBM Coolant Leak

2.1.1. Identification and causes of accident

The Postulate Initiating Event (PIE) is a small leak of TBM FW helium coolant into ITER VV, caused by TBM weld failure. The accident is assumed to begin at the end of the flat top of a 500 MW pulse, a 20% power excursion for 10 sec before PIE is considered to guarantee peak TBM temperatures at the time of the accident. Helium gas ingress into plasma induces intense plasma disruption and deposits plasma stored thermal energy of 1.8 MJ/m^2 over a period of time, assumed to be 1 sec in duration, which leads to the multiple TBM FW cooling tube failure within a 10 cm high toroidal strip [5]. The size of the break has been defined as the double ended rupture of all coolant channels within this toroidal strip around the entire reactor and for the TBM, this represents 4 FW channels (break size 0.0032 cm^2).

2.1.2. Results and discussions

Figure 1 and 2 shows the TBM FW temperature evolution during accident and during 10 days (with decay heat) respectively. Because of the 20 % power excursion for 10 sec before FW leak [6], average FW temperature rise from 450 ^{o}C to 475 ^{o}C and thereafter a peak temperature of ~564^{o}C is observed at 1 sec, due to the deposition of plasma disruption heat load (1.8 MJ for a second). The temperature initially reduces rapidly because of high helium mass flow rate from the FW break. After few seconds of accident the FW active cooling is completely lost and the decay heat is removed through radiation loss and conduction to colder structure causing slow decrease in temperature with time as shown in the Figure 2, the temperature reaches to 250 ^{o}C after 10 days of the accident. Figure 3 shows pressure profile of TBM FW and VV during accident case, FW helium pressure of 8MPa is rapidly decreases because of loss of helium into VV and 15 sec after LOCA equalizes to VV pressure.

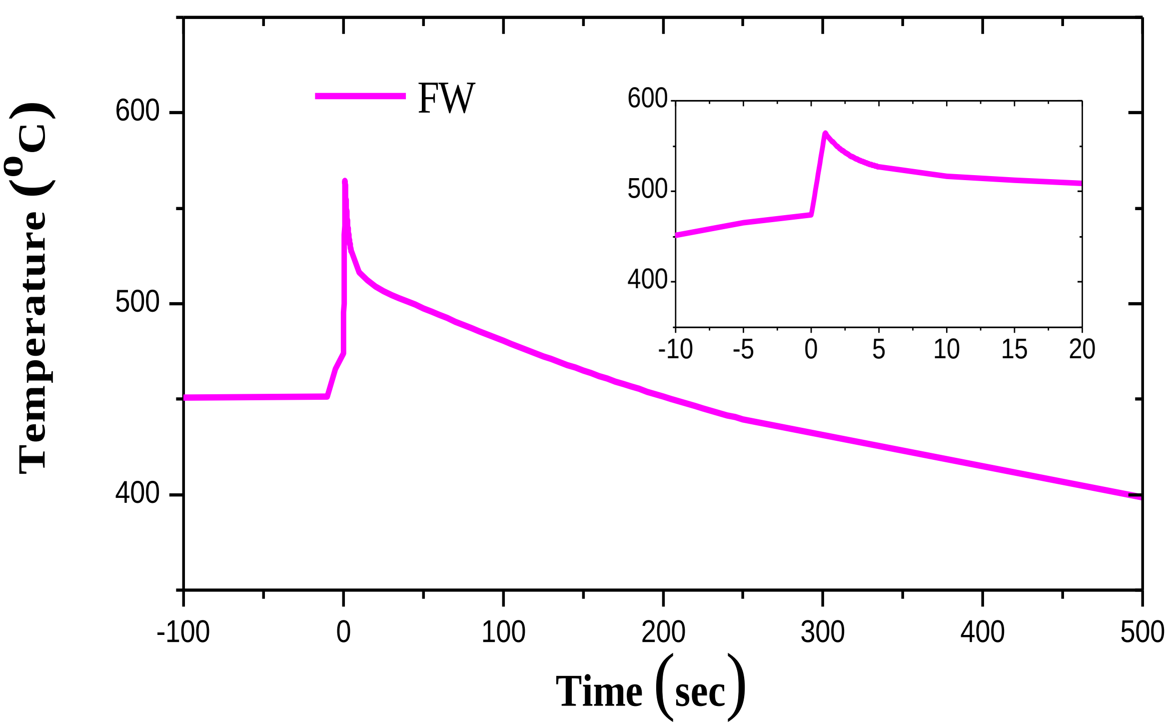

Figure 1 TBM FW temperature evolution during In-vessel TBM Coolant Leak

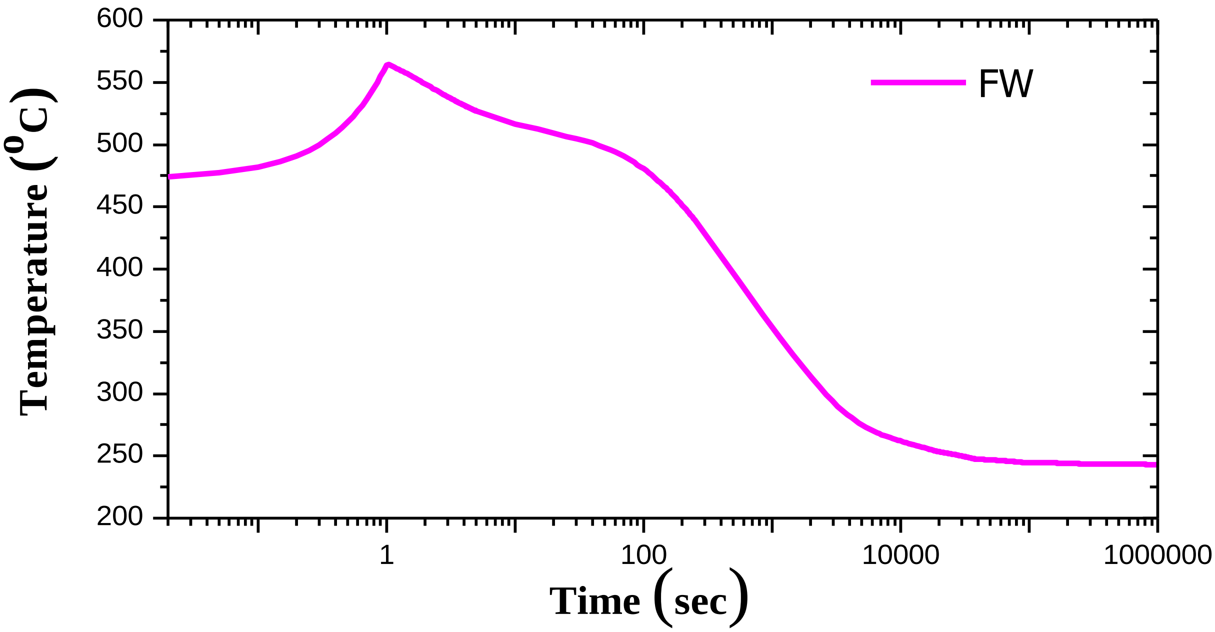

Figure 2 TBM FW temperature evolution for 10 days during In-vessel TBM Coolant Leak (with decay heat)

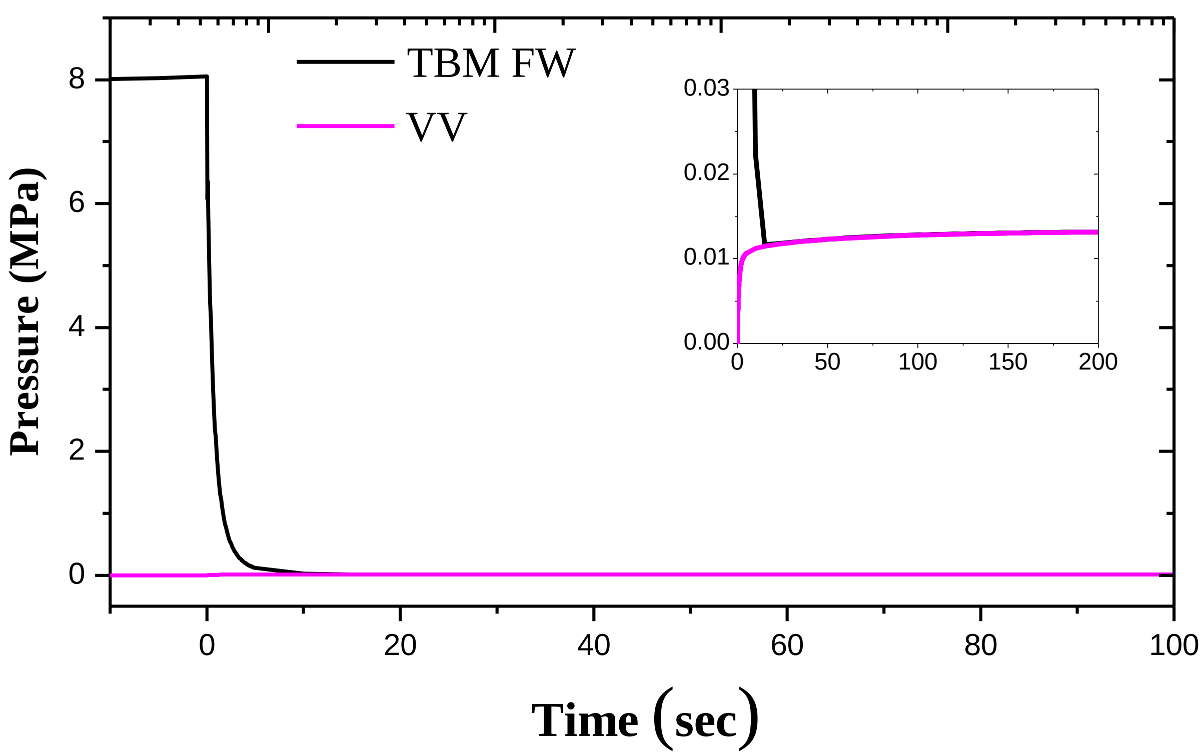

Figure 3 Pressure profiles of TBM FW and VV during In-vessel TBM Coolant Leak

2.2 Loss of flow accident

2.2.1. Identification and causes of accident

The trip of helium circulator of FWHCS loop is considered as PIE of this event. The mass flow rate in the TBM FW is reduced, as the mass flow rate in FWHCS reduces to 70 % of its normal operation value, FPSS trips the reactor on the low flow signal from the system.

2.2.2. Results and analysis

The transient starts with circulator trip at the end of the flat top of a 500 MW pulse. Figure 4 shows the mass flow rate at the inlet of TBM, after 2sec the mass flow in FWHCS loop reduces to 70 % and FPSS trips the reactor. Fig 5 shows the temperature evolution during LOFA with and without FPSS activation. The FW temperature increases rapidly without FPSS activation because of continuous heat deposition from plasma which may subsequently lead to FW failure. In case of LOFA with FPSS signal the temperature initially increases followed by disruption loads with subsequent decrease due to plasma shut down as shown in the Figure, a peak temperature of 598 ^{o}C is observed at 3.1 sec.

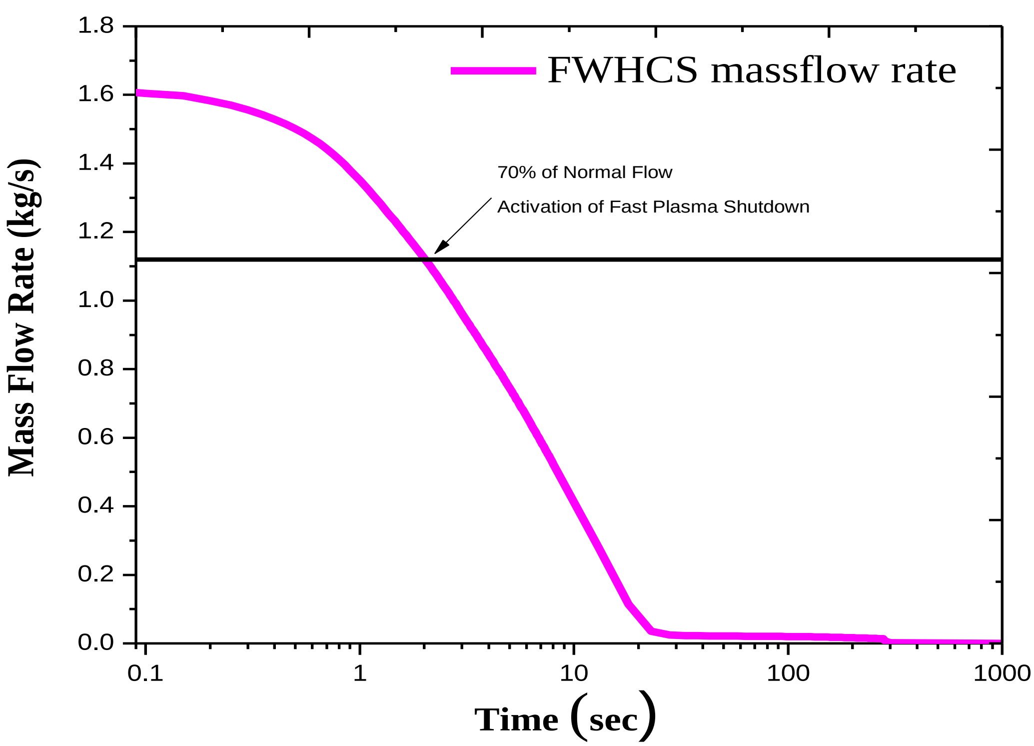

Figure 4 Mass flow rate at the Inlet of TBM during LOFA

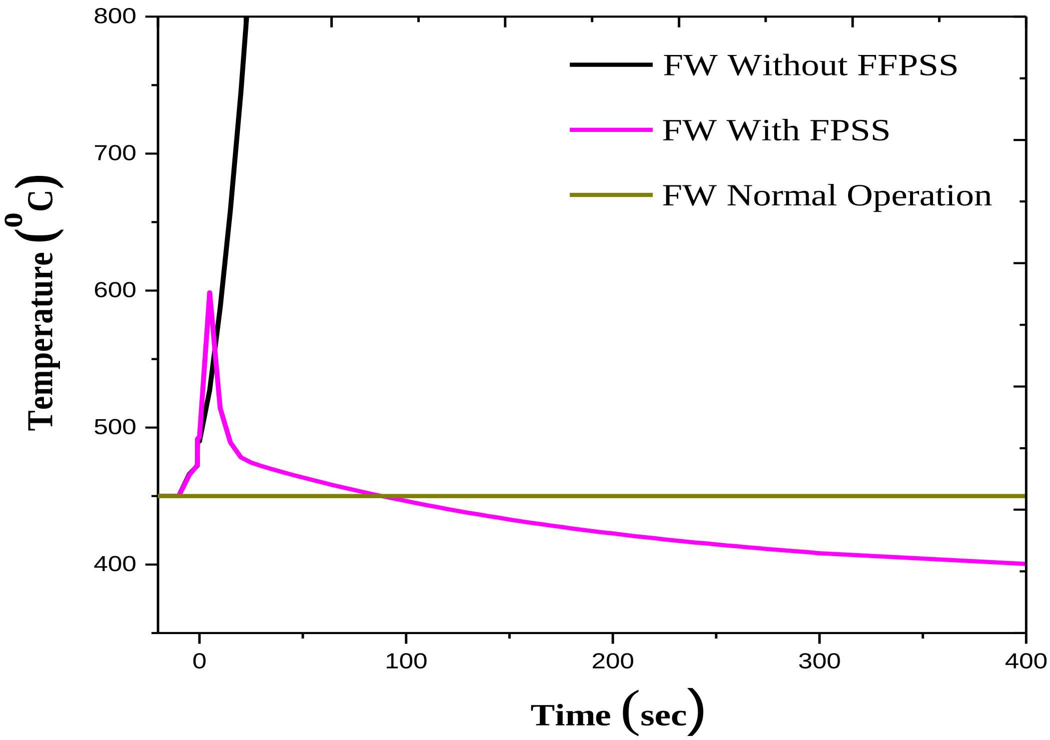

Figure 5 TBM FW temperature evolution during normal operation, with and without FPSS

3. CONCLUSION

The analysis shows that in case of TBM FW coolant leak into the VV, the total helium inventory of the FWHCS running loop does not cause over pressurization of VV and VV pressure remains well below design limit (0.2 MPa). The total helium ingress into VV is 17.5 Kg which is well within ITER prescribed limit of 45 Kg. The analysis also shows passive heat removal capability of TBM structure. Analysis of LOFA in FWHCS shows that activation of FPSS following the event is necessary in order to prevent TBM FW failure.

4. SYMBOLS

FW	First Wall
FWHCS	First wall helium cooling system
FPSS	Fast Plasma Shutdown System
ITER	"The Way" in Latin
LOCA	Loss of Coolant Accident
LOFA	Loss of flow accident
PIE	Postulated initiating Event
ST	Suppression Tank
TBM/TBS	Test Blanket Module/Test Blanket System

VV Vacuum Vessel

VVPSS Vacuum Vessel Pressure Suppression System

5. REFERENCES

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