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Analysis of the reference accidental sequence for safety assessment of LLCB TBM system

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ABSTRACT

Safety analysis of the reference accidental sequence has been carried out for Lead Lithium cooled Ceramic Breeder (LLCB) Test Blanket Module (TBM) system; India's prototype of DEMO blanket concept for testing in International Thermonuclear Experimental Reactor (ITER). The accidental event analyzed starts with a Postulated Initiating Event (PIE) of ex-vessel loss of first wall helium coolant due to guillotine rupture of coolant pipe with simultaneous assumed failure of plasma shutdown system. Three different variants of the sequences analyzed include simultaneous additional failures of TBM and ITER first wall, failure of TBM box resulting in to spilling of lead lithium liquid metal in to vacuum vessel and reactor trip on Loss of Coolant Accident (LOCA) signal from TBM system. The analysis address specific reactor safety concerns, such as pressurization of confinement buildings, vacuum vessel pressurization, release of activated products and tritium during these accidental events and hydrogen production from chemical reactions between lead–lithium liquid metal and beryllium with water. An in-house customized computer code is developed and through these deterministic safety analyses the prescribed safety limits are shown to be well within limits for Indian LLCB-TBM design and it also meets overall safety goal for ITER. This paper reports transient analysis results of the safety assessment.

1. Introduction

One of the key missions of the International Thermonuclear Experimental Reactor (ITER) is to validate the design concepts of tritium breeding blankets relevant to a power-producing reactor like DEMO. ITER should demonstrate the feasibility of the breeding blanket concepts that would lead to tritium self-sufficiency and the extraction of a high-grade heat, which are necessary goals for the DEMO. India has proposed a Lead Lithium cooled Ceramic Breeder (LLCB) blanket as one of the feasible options for a DEMO relevant blanket concept. The LLCB blanket concept [1] consists of lithium titanate as ceramic breeder material in the form of packed pebble beds. The structural material is ferritic steel and is cooled by helium gas. In LLCB, the Pb–Li eutectic acts as multiplier, breeder and coolant. The Pb–Li flow velocity is moderate enough such that the heat generated within and the heat transferred from ceramic breeder zone is extracted effectively.

Safety considerations are important part of the design process. 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 [3]. A set of four reference accidents is identified for LLCB TBS. Each accidental sequence begins with a Postulated Initiating Event (PIE) identified through Failure Modes and Effects Analysis (FMEA) at component level. The frequency category of each PIE is decided from the failure rate data of the components. When a PIE occurs, such as the burst of a cooling pipe, the sequence of events that could follow include aggravating failures, each of which may be a consequential failure, such as further damage caused by the plasma disruption as steam rushes into the plasma chamber, or an independent failure, such as loss of power supplies, reducing the capability of active systems to cope with the event. The reference event includes both the Design Basis Accident (DBA), which put specific requirement on the design and Beyond Design Basis Accidents (BDBA), to show the robustness of the design and demonstrate an ultimate safety margin. For each of the reference accidents, there may be one or more safety analysis objective. The common safety analysis objective is to demonstrate that the releases from TBS would not exceed the release prescribed limits in any case. Analysis of one of the reference accidental sequence called ex-vessel loss of coolant is reported here.

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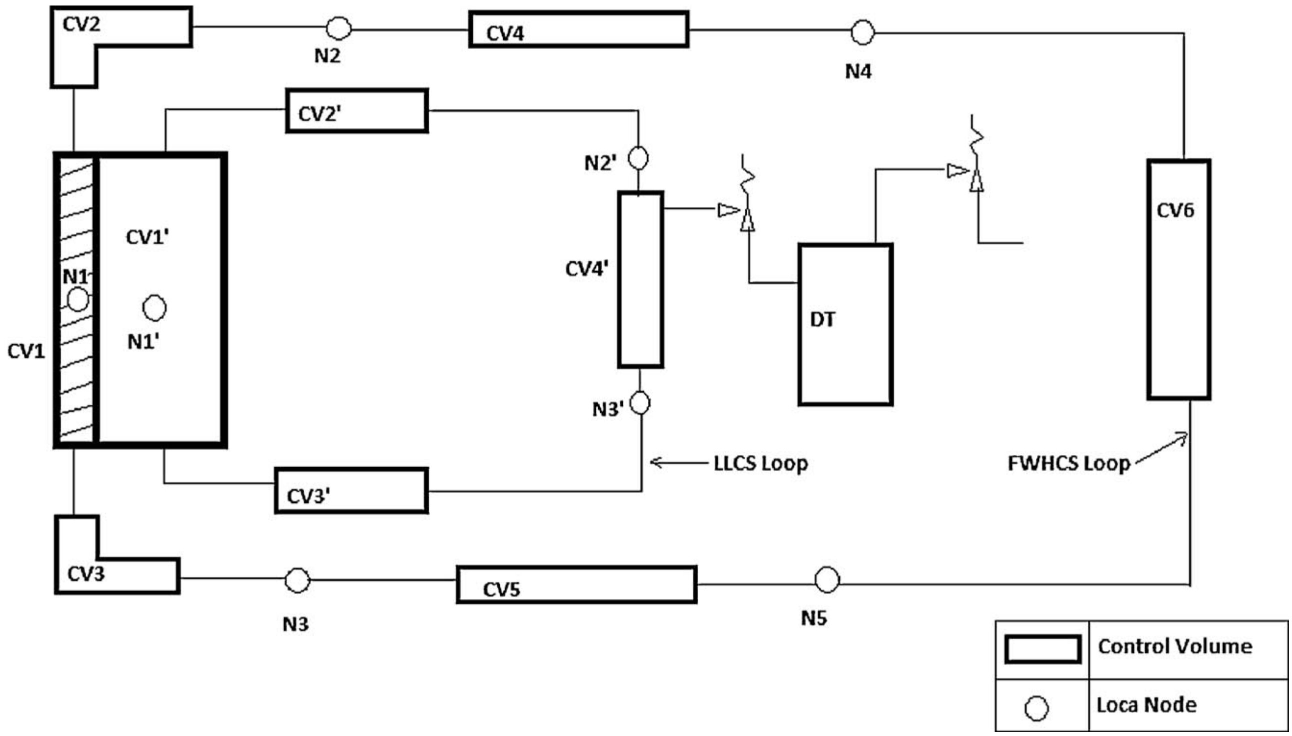

Fig. 1. Control volumes and LOCA nodes of FWHCS and LLCS modeled for safety analysis.

2. Method of analysis

An in-house customized computer code is developed for the deterministic safety analysis. The mathematical formulation of the code is developed for the calculation of dynamic modes of LLCB TBS ancillary loops with gas compensation for pressure variations. The development allows performing calculations of all main specified normal and emergency operational modes and associated variations of parameters of primary and secondary circuits. This is achieved by the choice of calculation scheme and calculation methods. The mathematical models are based on known principles and generally accepted assumptions as homogenization of node parameters, lumped model, thermodynamic equilibrium of phases, etc.

A nodalization scheme is developed for the analysis with 6 control volumes of for First Wall Helium Cooling System (FWHCS) and 4 control volumes for Lead Lithium Cooling System (LLCS) as shown in Fig. 1. For Loss of Coolant Accident (LOCA) analysis 5 nodes for FWHCS and 3 nodes for LLCS are modeled. A list of different control volumes and LOCA nodes modeled for safety analysis is given in Table 1. For this simplified model of the safety analysis code following assumptions are made:

(a) Lumped parameter model is considered for the equipment and piping.
(b) No spatial temperature variation within the equipment using lumped parameter framework.
(c) Homogeneous property exists within a control volume.
(d) For gas system the behavior of gas is considered as incompressible as the line pressure drop is less than 10% of system pressure drop.
(e) Heat loss to surrounding from different control volumes is considered as a function of temperature and data obtained from heat loss calculations are fed as inputs.

Table 1
List of control volumes and LOCA nodes of FWHCS and LLCS modeled for safety analysis.

Control volume	Description	LOCA node	Description
CV1	LLCB TBM in FWHCS loop	N1	Break in TBM First Wall (FW) with coolant ingress in Vacuum Vessel (VV)
CV2	Hot path of FWHCS from TBM to Port Cell	N2	Break in hot path of FWHCS in Port Cell
CV3	Cold path of FWHCS from Port Cell to TBM	N3	Break in cold path of FWHCS in Port Cell
CV4	Hot path of FWHCS from Port Cell to Tokamak Cooling Water System (TCWS) building	N4	Break in hot path of FWHCS in TCWS building
CV5	Cold path of FWHCS from TCWS building to Port Cell	N5	Break in cold path of FWHCS in TCWS building
CV6	FWHCS in TCWS building		
CV1′	LLCB TBM in LLCS loop	N1′	Failure of TBM First Wall (FW) with liquid metal ingress in VV
CV2′	Hot path of LLCS from TBM to Port Cell	N2′	Break in hot path of LLCS in Port Cell
CV3′	Cold path of LLCS from Port Cell to TBM	N3′	Break in cold path of LLCS in Port Cell
CV4′	LLCS in Port Cell		