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Options and methods for instrumentation of Test Blanket Systems for experiment control and scientific mission

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HIGHLIGHTS

- This work defined options and methods to instrument ITER TBSs based on functional categories: safety, interlock and control and scientific exploitation based on the ITER research program.
- Presented the general architecture of the HCLL and HCPB Test Blanket System Instrumentation and Control.
- Defined safety and interlock sensors count and technology selection based on preliminary safety analysis.
- Discussed the development status of scientific instrumentation, with focus on integration with design and fulfillment of TBM research program.

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ABSTRACT

Europe is currently developing two reference breeder blankets concepts for DEMO reactor specifications that will be tested in ITER under the form of Test Blanket Modules (TBMs): the Helium-Cooled Lithium-Lead (HCLL) concept which uses the eutectic Pb-16Li as both breeder and neutron multiplier; the Helium-Cooled Pebble-Bed (HCPB) concept which features lithiated ceramic pebbles as breeder and beryllium pebbles as neutron multiplier. Each TBM is associated with several sub-systems required for their operation; together they form the Test Blanket System (TBS). This paper presents the state of HCLL and HCPB TBS instrumentation design. The discussion is based on the systems functional analysis, from which three main categories of instrumentation are defined: those relevant to safety functions; those relevant to interlock functions; those designed for the control and scientific exploitation of the devices based on the TBM program objectives.

1. Introduction

ITER Test Blanket Systems have been the subject of research activity in European Fusion Laboratories for several years, first under the frame of the European Fusion Development Agreement (EFDA), and more recently under the Fusion for Energy (F4E) framework [1,2]. The Helium Cooled Lithium Lead (HCLL) Test Blanket Module (TBM) uses Pb-16Li eutectic (liquid at operating temperatures) both as tritium breeding material and neutron multiplier [3]. The Helium Cooled Pebble Bed (HCPB) TBM uses the Lithium orthosilicate Li_4SiO_4 or metatitanate Li_2TiO_3 as tritium breeding material and Beryllium as neutron multiplier, both in the form of pebbles [4]. The TBMs are equipped with a radiation shield, forming the TBM sets, both of which are housed in ITER Equatorial port #16 [5]. The TBM sets are then connected to several ancillary sub-systems, with which they form the Test Blanket Systems (TBS). They are essentially forced convection fluid loops, and for the purpose of this paper they can be classified as cooling and tritium systems, according to their main function. The HCLL TBS includes an additional sub-system to circulate the liquid metal breeder [6,7]. Component specific instrumentation will be defined by ongoing design activities and are not addressed in this paper, therefore the sub-systems design details are not essential for the analysis summarized in this work.

The HCLL and HCPB TBSs are completely independent from each other at the functional level, only sharing physical space and supporting structures. They will therefore be equipped with separate Instrumentation and Control (I&C) systems, and related sensors and actuators. The two I&C systems have not been designed in detail yet, but preliminary considerations following ITER guidelines [8] have been made in support of the preparation of the

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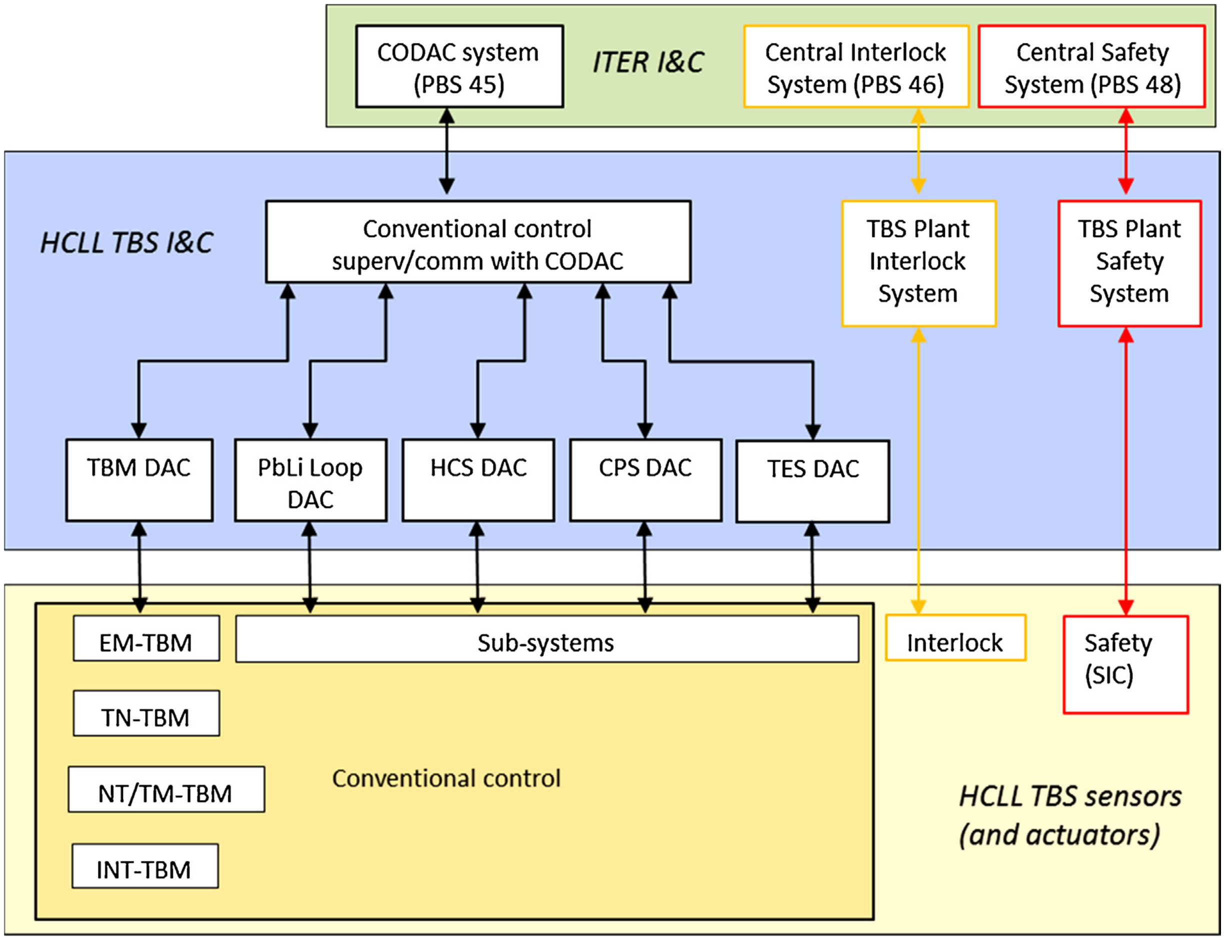

Fig. 1. HCLL TBS I&C architecture.

Preliminary Safety Report (PrSR) [9]. The I&C architecture of the HCLL TBS shown in Fig. 1 is the same as the HCPB TBS, and mirrors at the level of Plant the architecture of ITER I&C. Here the four sub-systems of the HCLL TBS are mentioned: the liquid metal loop (PbLi loop), the Helium Cooling System (HCS) and Coolant Purification System (CPS) (referred together as cooling systems in this paper) and the Tritium Extraction System (TES). Acronyms related to the four different TBM modules are described in Section 3.2. The sensors considered in the scheme are the subject of this analysis. Those directly connected to the Plant Safety System (PSS) and Plant Interlock System (PIS) are considered in Section 2, while the others in Section 3. All the results and conclusions presented in this paper are provided as an update of ongoing design activities and shall be considered as preliminary indications until the completion of the ITER Design Review process for the two TBSs, starting with the Conceptual Design Review (CDR) planned for 2014.

2. Safety and interlock instrumentation

TBS components contribute in the two fundamental ITER facility safety functions, which are radioactive material confinement and limitation of internal and external exposure to ionizing radiation [10]. In order to fulfill these general requirements three safety functions are identified specifically for the TBS, which are called upon detection of abnormal conditions by safety relevant instrumentation:

- the isolation of TBS sub-systems;
- the controlled release of gas in the event of over-pressurization of a sub-system;
- the call to the ITER Central Safety System (CSS) for plasma termination.

In general, the isolation of the TBS sub-systems is the first safety function foreseen in case abnormal conditions are detected. The combined result of such isolation is to contain the whole TBS inventory of tritium and mobile activated materials within the TBS primary confinement and to place it in its safest state by confining it as much as possible within components housed in Port Cell 16 and away from the interface with other ITER systems. The second safety function is the activation of the pressure suppression system for any loop in which a condition of abnormal over-pressure is detected. The third safety function is the call from the TBS Plant Safety System for the activation of the ITER Fusion Power Shutdown System trough CSS.

As part of the definition of the safety functions, trigger events have been identified as well as the sensors that are responsible for its measurement, most of which are deployed in the ancillary subsystems. The only exception is temperature sensors placed on the two TBMs first wall [3]. The sensors connected to the PSS and PIS are similar to those used for conventional control in terms of technology. The implication of the safety functional category is related to the more stringent requirements, because sensors participating in nuclear safety functions will have to be qualified according to ITER rules and applicable nuclear standards. However, at this stage of development the instruments identified in pre-conceptual design activities for sub-systems components also apply to safety