Fusion Engineering and Design 87 (2012) 395–402

Contents lists available at SciVerse ScienceDirect

Fusion Engineering and Design

journal homepage: www.elsevier.com/locate/fusengdes

Overview of the ITER TBM Program

L.M. Giancarli[a,*], M. Abdou[b], D.J. Campbell[a], V.A. Chuyanov[a], M.Y. Ahn[c], M. Enoeda[d], C. Pan[e], Y. Poitevin[f], E. Rajendra Kumar[g], I. Ricapito[f], Y. Strebkov[h], S. Suzuki[d], P.C. Wong[i], M. Zmitko[f]

[a] ITER Organization, Route de Vinon sur Verdon, 13115 Saint Paul Lez Durance, France
[b] UCLA, Engineering IV 44-114, Los Angeles, CA 90095-1597, United States
[c] National Fusion Research Institute (NFRI), Gwahangno 169-148, Yuseong-gu, Daejeon 305-806, Republic of Korea
[d] JAEA, Division of Fusion Energy Technology, Mukoyama 801-1, Naka-shi, Ibaraki-ken 311-0193, Japan
[e] Southwestern Institute of Physics (SWIP), P.O. Box 432, Chengdu, Sichuan 610041, PR China
[f] Fusion For Energy (F4E), Josep Pla, 2; Torres Diagonal Litoral B3, Barcelona E-08019, Spain
[g] Institute for Plasma Research, Bhat, Gandhinagar, Gujarat 382428, India
[h] NIKIET, P.O. Box 788, Malaya Krasnoselskaya 2/8, 101000 Moscow, Russian Federation
[i] General Atomics, P.O. Box 85608, San Diego, CA 92186-5608, United States

ARTICLE INFO

Article history:
Available online 6 May 2012

Keywords:
Breeding blanket
TBM
ITER
DEMO

ABSTRACT

The objective of the ITER TBM Program is to provide the first experimental data on the performance of the breeding blankets in the integrated fusion nuclear environment. Such information is essential to design and predict the performance of DEMO and future fusion reactors. It foresees to test six mock-ups of breeding blankets, called Test Blanket Module (TBM), in three dedicated ITER equatorial ports from the beginning of the ITER operation. The TBM and its associated ancillary systems, including cooling system and tritium extraction system, forms the Test Blanket System (TBS) that will be fully integrated in the ITER machine and buildings. This paper describes the main features of the six TBSs that are presently planned for installation and operation in ITER, the main interfaces with other ITER systems and the main aspects of the TBM Program management.

1. Introduction

A tritium breeding blanket (BB) ensuring tritium breeding self-sufficiency is a compulsory component for demonstration power reactor (DEMO), the next-step after ITER, although is not present in ITER. Mock-ups of DEMO BB, called Test Blanket Modules (TBMs), will be inserted and tested in ITER in three dedicated equatorial ports directly facing the plasma. They are the principal means by which ITER will provide the first experimental data on the performance of the BBs that is still an open issue on the path to commercial fusion power. These activities correspond to the so-called "TBM Program". A successful ITER TBM Program represents an essential step on the path to DEMO for any fusion power development plan [1].

All ITER Members contribute to the TBM Program. A testing strategy has been developed for the first ten years of ITER operation. In fact, six mock-ups of six whole DEMO-BB systems will be tested in ITER, which means that the TBMs are connected with several ancillary systems, such as cooling systems, tritium extraction systems, coolant purification systems, and instrumentation and control (I&C) systems. TBMs and associated systems are called Test Blanket Systems (TBSs).

The TBSs functional characteristics are dictated by the operational conditions and requirements expected in a DEMO-BB system and, in this sense, they differ from the other ITER components that are designed in compliance with only ITER requirements. However, they must be fully integrated in ITER; therefore they must be compatible with the systems and operational procedures of ITER and the ITER operating plan. Moreover, TBS testing must not endanger ITER performances, safety and availability.

The following sections describe the major technical aspects of the TBM Program including the description of the main features of the presently selected TBSs and of the main interfaces with ITER machine and buildings. Moreover, the last section describes the main aspects of the TBM Program management [2] and main short-term official steps that will be required in order to perform the TBM Program in an efficient and timely manner.

2. Overall objectives of the TBM Program

In order to proceed to DEMO construction, the TBM Program is essential to answering two critical questions about fusion as an energy source: "Can tritium be produced in the blanket and extracted from the blanket at a rate equal to tritium consumption

* Corresponding author. Tel.: +33 442176504; fax: +33 442257366.
E-mail address: luciano.giancarli@iter.org (L.M. Giancarli).

0920-3796/$ – see front matter © 2012 Published by Elsevier B.V.
doi:10.1016/j.fusengdes.2011.11.005

in the plasma plus losses by radioactive decay from tritium inventories in reactor components?" and "Can heat be extracted from the blanket, simultaneously with tritium breeding, at temperatures high enough for efficient electricity generation?".

These questions directly involve the main functions of a DEMO-BB system. However, direct testing of DEMO-BB in ITER is not possible since ITER operating conditions are different from the expected DEMO ones. The most important differences are the lower neutron wall load on the ITER FW (~30% of the DEMO values) and the much lower neutron fluence on the ITER-FW. Moreover, ITER features pulsed operations with relatively short pulses compared to the quasi-continuous or steady state operation expected in DEMO.

Despite these differences, several studies done by ITER Members have shown that most required data can be obtained by the testing of TBSs at ITER, provided the TBMs use the same structural and breeding materials as in the DEMO-BB [3] and the TBMs are designed using proper engineering scaling [4]. For instance, reference neutron, thermal mechanics and thermal hydraulic codes (and their possible coupling) and tritium control modeling can be validated during these tests.

Therefore, the overall objective of the TBM Program is to acquire all relevant data and information concerning a given breeding blanket in order to validate the applied codes for the relevant analyses and to be able to design, to manufacture and to operate a BB-system in DEMO and in following fusion power reactors, provided that data on long-term irradiation effects and failure modes are obtained in parallel in other facilities. Since several BB designs are tested simultaneously in ITER, the TBM Program could also determine the figure of merit of the various designs prior the DEMO-BB design and manufacturing.

In particular, the major testing objectives are: (i) validation of the theoretical predictions of the breeding blankets structural integrity under combined and relevant thermal, mechanical and electromagnetic loads; (ii) validation of tritium breeding predictions; (iii) validation of tritium recovery process efficiency and T-inventories in the different blanket materials; (iv) validation of thermal predictions for strongly heterogeneous breeding blanket concepts with volumetric heat sources and magnetic fields; and (v) demonstration of the integral performance of the BB systems.

3. TBS testing strategy and planning

The TBMs will be installed in 3 dedicated equatorial ports of ITER (ports no. 2, 18, and 16) directly facing the plasma. The TBMs First Wall (FW) is therefore acting as a plasma facing-component, although it will be recessed of 120 mm compared to the ITER shield modules FW, in order to avoid major heat loads transients which are expected in ITER but should not to be present in DEMO. TBMs are inserted in a 20 cm-thick water-cooled stainless steel frames [5] that act as the unique interface with shield modules and vacuum vessel from thermal, mechanical and neutronic point of view. Each TBM is attached to a shield block to form a TBM-Set. Each port can accommodate 2 TBM-Sets, therefore 6 TBMs and associated independent systems can be simultaneously tested in ITER. The TBM frames also provide a separation wall between the 2 neighboring TBM-Sets. The mechanical system formed by a TBM frame and 2 TBM-Sets is called the "TBM Port Plug (PP)".

The TBS testing strategy for each BB design is to test different design versions of the corresponding TBM concept, each of them adapted to the operational plan of ITER that foresees different plasma phases with very different operating conditions, from the initial H/He-pulses (without neutrons) to a high-duty D-T phase after several years of operations (long pulses up to about 3000 s and back-to-back pulses for several days), passing through the D-phase and the low-duty D–T phase.

Depending on the considered version and operating conditions, it will be possible to perform specific experiments in the different fields such as neutronics, thermo-mechanics, magneto-hydrodynamics (MHD) and electromagnetic (EM), tritium control and management.

Typically, at present, up to four TBMs versions are expected for each TBS, to be used throughout the various plasma phases, corresponding to four experimental campaigns. Each campaign is connected with the ITER experimental program and its duration corresponds to the operation time between each ITER long-term maintenance shutdown (resulting in ~16 months of operations). The possibility to extend the scope of tests associated with a given version of TBM or to combine 2 TBM versions into a single one is not precluded at this stage of the planning.

It is assumed that all four TBM versions will share the same basic architecture, in particular their structural part, whose design will be qualified during the testing program in laboratory facilities before TBM commissioning and checked/monitored step-by-step during the different phases of ITER operation. This strategy ensures a relatively stable interface between the TBM and ITER during the whole operation time, facilitating the licensing aspects.

An important difference in the design of each version will concern the integration of the specific instrumentation and the design of internals; in particular of the breeding zone that could be modified for testing optimized design variants or to achieve the required testing conditions. For instance, the thickness of the breeder material could be increased to achieve DEMO-relevant temperatures, and the ^{6}Li enrichment could be modified to obtain the desired test conditions. Therefore, different versions of the TBMs will operate at different operating conditions; however, the DEMO-relevant values will have to be reached in some time-periods of the experimental campaigns.

The TBSs are expected to be installed in ITER during the second assembly phase that is expected to start in 2021. If one (or more) TBM-Set is not ready for installation, it will be replaced by a dummy TBM [5].

4. Selected Test Blanket Systems

At present, the following six independent TBSs are used for the integration and interfaces definition in ITER:

- the Helium Cooled Lithium Lead (HCLL) TBS and the Helium Cooled Pebble Bed (HCPB) TBS for installation in Equatorial Port #16;
- the Water Cooled Ceramic Breeder (WCCB) TBS and the Dual Coolant Lithium Lead (DCLL) TBS for installation in Equatorial Port #18;
- the Helium Cooled Ceramic Breeder (HCCB) TBS and the Lithium Lead Ceramic Breeder (LLCB) TBS for installation in Equatorial Port #02.

The typical dimensions of each TBM are: 1.66 m (poloidal) × 48 cm (toroidal) × 50/70 cm (radial). The structural material for all TBMs is Reduced-Activation Ferritic/Martensitic (RAFM) steel [6], which is a ferromagnetic material and has, therefore, an impact on the magnetic field close to the corresponding equatorial ports. Such an impact is discussed in Section 5.1 below. The lithium-lead-based concepts use the liquid metal eutectic Pb–16Li with melting temperature of 235 °C. The ceramic-based concepts use pebble-beds of either Li_4SiO_4 or Li_2TiO_3.

It should be noted that the above list of TBSs could require modifications as a function of the results of the on-going R&D on breeding