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Overview of the ITER TBM Program

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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

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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

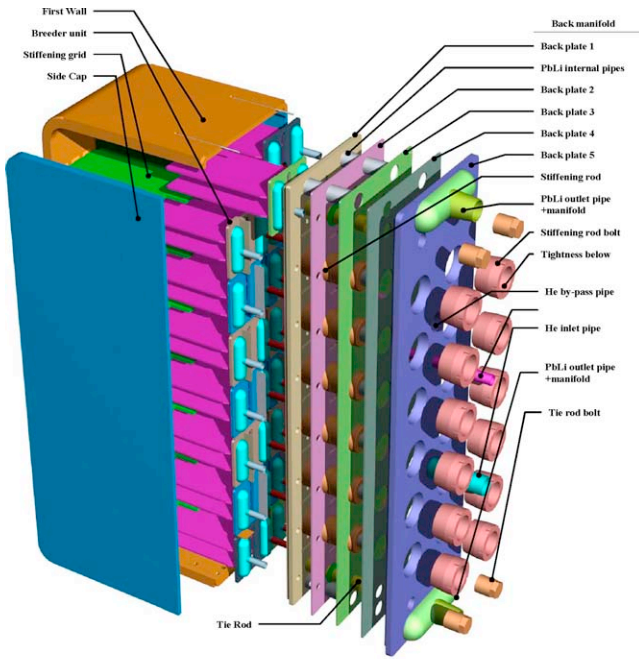

Fig. 1. Exploded view of the HCLL-TBM.

blankets, which will continue throughout the ITER construction phase.

4.1. The HCLL TBS

The DEMO HCLL-BB system, proposed by the European Union, uses the liquid metal Pb–16Li as tritium breeder and neutron multiplier and Eurofer steel [6] as structural material. The Li is enriched at 90% in ^{6}Li. The Pb–16Li slowly flows from the TBM to the port cell in order to extract the produced tritium in the port cell and send it to the tritium plant. It is cooled by helium at a pressure of 8 MPa and inlet/outlet temperatures of 300 °C/500 °C.

The corresponding HCLL-TBM [7] features a Eurofer steel box cooled by vertical multi-passes rectangular cross section channels and closed by side cooled covers and in the rear, by 5 steel plates delimiting distributing/collecting chambers for the He coolant (see Fig. 1). Poloidal-radial and toroidal-radial He-cooled plates stiffen the TBM box in order to withstand the accidental internal pressurization at the coolant pressure. The corresponding stiffening grid forms several radial cells in which the Pb–16Li circulates at few mm/s for external tritium extraction purposes. In each cell are inserted various radial-toroidal cooling plates welded to a common back plate. A single He circuit is envisaged, the He cooling at first the FW and then the breeder zone.

The TBM structures temperatures range between 350 °C and 550 °C. The maximum LiPb/steel interface temperature is about 520 °C. In order to facilitate T-management and control, in view of DEMO operation, the use of T-permeation barriers might be envisaged.

The HCLL-TBS includes several ancillary systems, namely the helium cooling system, the Pb–16Li system, the tritium removal system (from Pb–16Li), the coolant purification system and the I&C system. Part of the components of these systems are located in the port cell #16, the remaining components are located in level 3 of the Tokamak building and in level 2 of the Tritium building. Corresponding process flow diagrams are under finalization. In total, these systems feature more than 65 components (excluding I&C system).

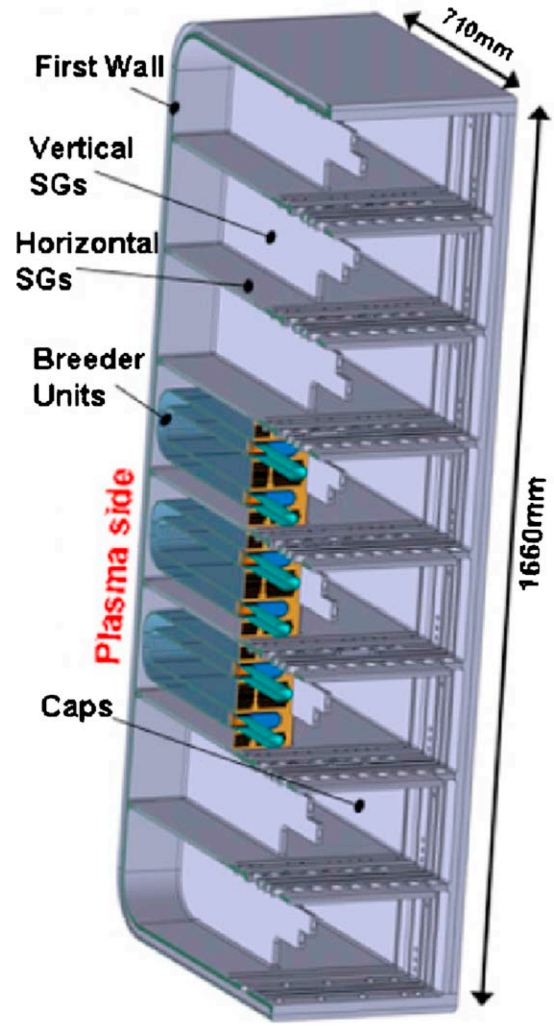

Fig. 2. Internal view of the HCPB-TBM.

4.2. The HCPB TBS

The DEMO HCPB-BB, proposed by the European Union, uses either Li_4SiO_4 or Li_2TiO_3 pebble beds as tritium breeder, beryllium pebble beds as neutron multiplier and Eurofer steel [6] as structural material. Li is enriched 30% in ^{6}Li in case of Li_4SiO_4 breeder and 60% in case of Li_2TiO_3 breeder. Maximum temperatures are 920 °C in ceramic, 650 °C in Be, and 550 °C in steel. It is cooled by helium at a pressure of 8 MPa and inlet/outlet temperatures of 300 °C/500 °C.

The corresponding HCPB-TBM [7] is essentially a He-cooled box reinforced by a He-cooled steel grid and able to withstand the full pressure of the He-coolant in accidental conditions and it features vertical cooling of the first wall with high pressure manifolds integrated in the back plate structure (see Fig. 2). Breeder units are inserted in the grid and several cooling plates ensure the heat-extraction from the breeder/multiplier. Ceramic and Be pebbles are purged by a low pressure He-stream for T-extraction that flows at first in the Be-beds and then through the ceramic-beds from the front region to the back manifolds.

The HCPB-TBS includes several ancillary systems, namely the helium cooling system, the tritium extraction system (i.e., the purge gas system), the coolant purification system and the I&C system. Part of the components of these systems are located in the port cell #16, the remaining components are located in level 3 of the Tokamak building and in level 2 of the tritium building. Corresponding

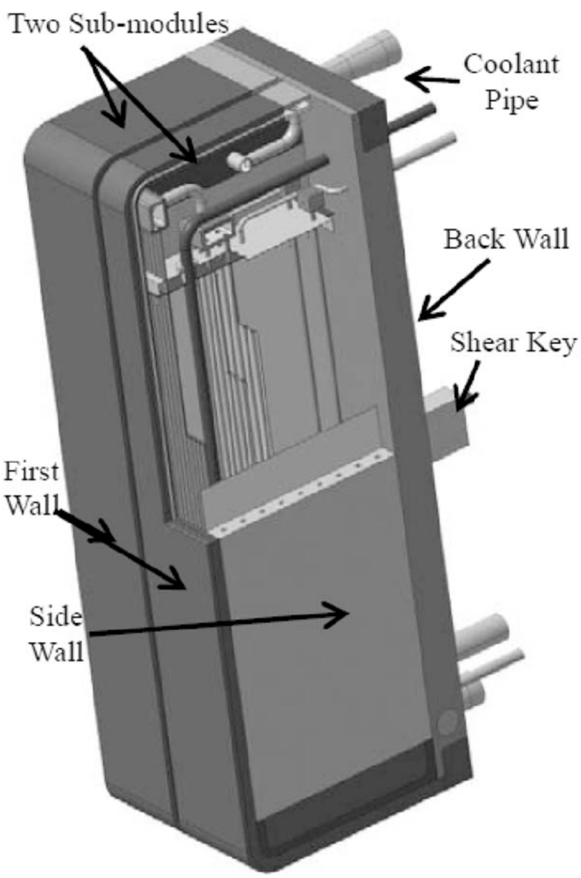

Fig. 3. View of the WCCB-TBM.

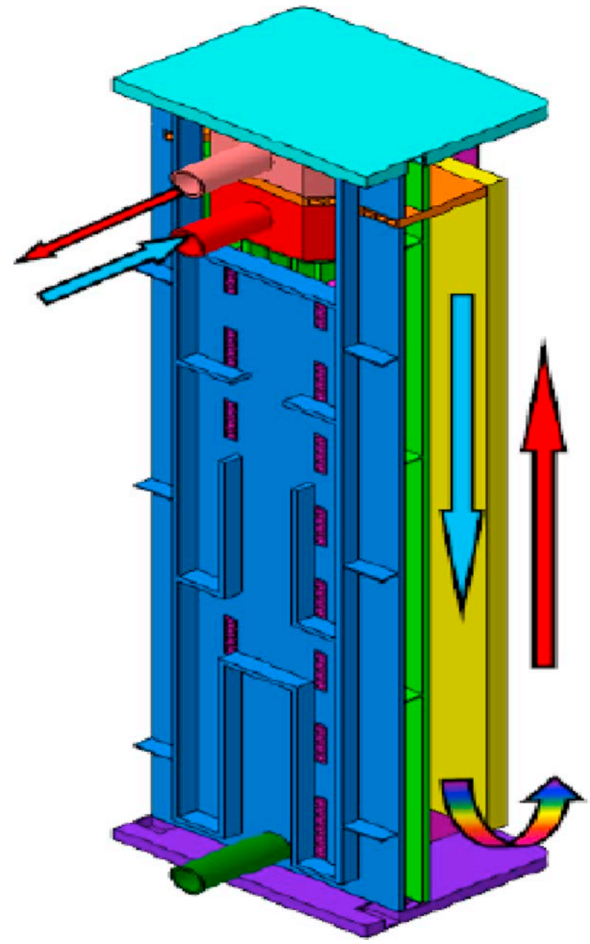

Fig. 4. Details of the Pb–16Li path in the DCLL-TBM.

process flow diagrams are under finalization. In total, these systems feature more than 55 components (excluding I&C system).

4.3. The WCCB TBS

The DEMO WCCB-BB, proposed by the Japan, uses Li_2TiO_3 pebble beds as tritium breeder, beryllium pebble beds as neutron multiplier and F82H steel [6] as structural material. Li is enriched 30% in ^{6}Li. Maximum temperatures are 900 °C in the ceramic, 600 °C in the Be, and 550 °C in the steel. It is cooled by water at pressurized water reactor conditions ($T_{inlet/outlet}$ 280 °C/325 °C).

The WCCB-TBM [8] is formed by 2 sub-modules having the same box structures and the same internal structures (see Fig. 3). The FW has built-in rectangular cooling channels. As for internal structure, it has multi-layer pebble beds structure similar to that of the DEMO-BB. Ceramic and beryllium pebble-beds are packed separately and divided into four layers by cooling panels. The cooling panel consists of F82H tubes and thin plates connecting adjacent tubes. The inner box structure is welded to the first wall and to the back plate. The thickness of each layer and pitches between tubes in each cooling panel have been optimized in order to feature similar levels of temperatures and possibly similar stresses to those present in a DEMO-BB. In order to reduce T-permeation from the breeder zone towards the water-coolant, the use of T-permeation barriers is envisaged.

The WCCB-TBS includes several ancillary systems, namely the water cooling system, the tritium extraction system (i.e., the purge gas system), and the I&C system. Part of the components of these systems are located in the port cell #18, the remaining components are located in level 4 and in level 2 of the tritium building. Corresponding process flow diagrams are under finalization. In total, these systems feature more than 50 components (excluding I&C system).

4.4. The DCLL TBS

The DEMO DCLL-BB system, proposed by the United States with support for interface coordination by Korea, uses Helium for cooling FW and structures, Pb–16Li as second coolant at $T_{inlet/outlet}$ of 460/650 °C, and F82H steel [6] as structural material. The Pb–16Li acts also as tritium breeder and neutron multiplier. The Li is enriched at 90% in ^{6}Li. The helium is at a pressure of 8 MPa and inlet/outlet temperatures of 300/500 °C.

The DCLL-TBM [9] is formed by a box stiffened by a vertical grid of He-cooled steel plate that has also the function of LiPb flow separator (see Fig. 4). The LiPb flows upwards in the front row and downwards in the back row at a velocity of about 10 cm/s. The steel structures are electrically and thermally insulated from the Pb–16Li by means of flow channel inserts (FCIs) that follow the contours of the channels formed by the grid leaving a gap of few mm. Helium inlet/outlet temperatures are 350/410 °C. Maximum temperature in the structures is 550 °C while in the SiC/SiC is about 600 °C.

The DCLL-TBS includes several ancillary systems, namely the FW helium cooling system, the Pb–16Li system, the secondary He-coolant system (for Pb–16Li), the coolant purification system and the I&C system. Part of the components of these systems are located in the port cell #18, the remaining components are located either in level 4 and in level 2 of the tritium building. Corresponding process

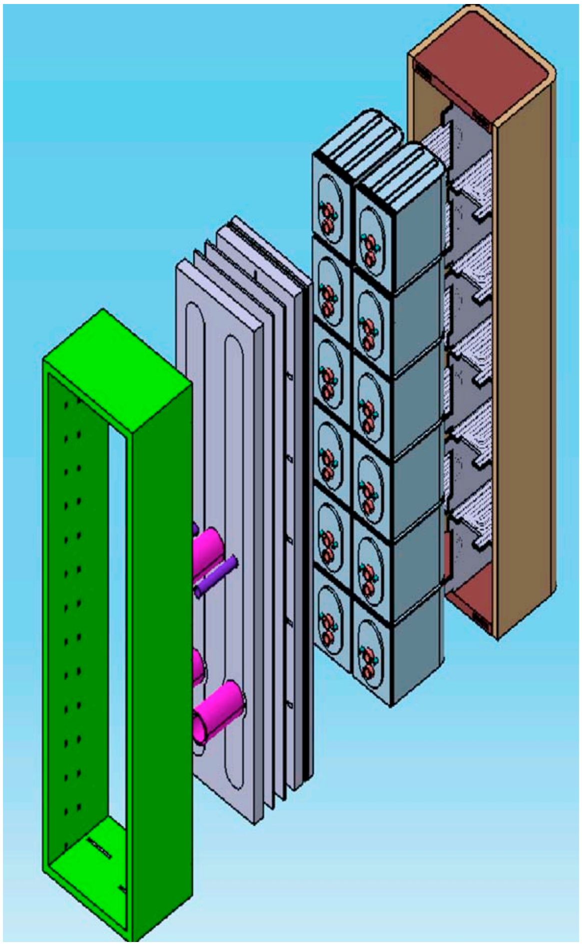

Fig. 5. Exploded view of the HCCB-TBM.

flow diagrams are under finalization. In total, these systems feature more than 65 components (excluding I&C system).

4.5. The HCCB TBS

The DEMO HCCB-BB, proposed by China, uses Li_4SiO_4 pebble beds as tritium breeder, beryllium pebble beds as neutron multiplier and RAFM steel as structural material. Li is enriched 80% in ^{6}Li. Maximum temperatures are 900 °C in the ceramic, 600 °C in the Be, and 550 °C in the steel.

The corresponding HCCB-TBM [10] has a U-shaped plate first wall with toroidal coolant channels, reinforced by He-cooled stiffening ribs to provide required strength in abnormal operation conditions (see Fig. 5). The internal space between the first wall module and back plate is used for breeding zone arrangement. The breeding zone contains a sequence of poloidal rows of circular coolant channels, of Li_4SiO_4 pebbles, and of Be pebbles. The Li_4SiO_4 pebbles are single-size pebbles (38% porosity) while Be is used as binary pebble-bed (20% porosity) with diameters of 0.5 and 1 mm. The structure of TBM consists of the following main components: first wall, caps, grids, manifolds, attachments, cooling pipes, purge gas pipes and sub-modules.

The HCCB-TBS includes several ancillary systems, namely the helium cooling system, the tritium extraction system (i.e., the purge gas system), the coolant purification system and the control/measurement system. Part of the components of these systems are located in the port cell #02, the remaining components are located in level 4 of and in level 2 of the tritium building. Corresponding process flow diagrams are under finalization. In total, these systems feature more than 55 components (excluding I&C system).

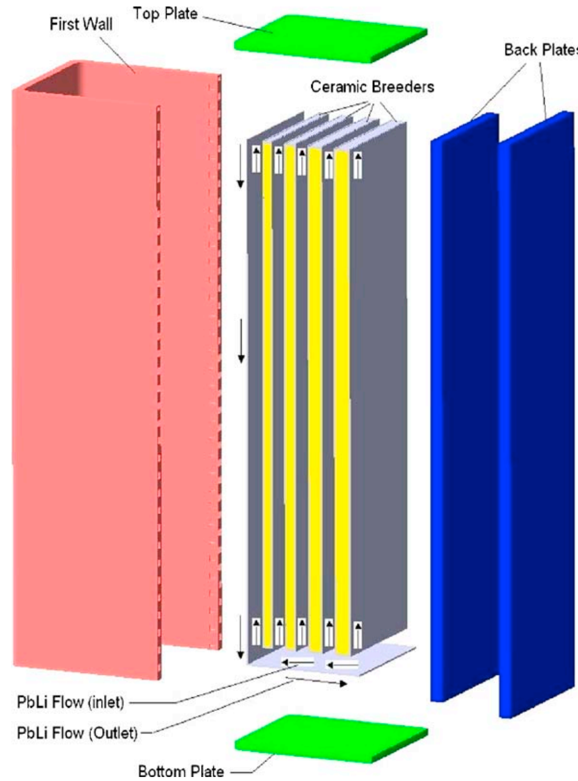

Fig. 6. Exploded view of the LLCB-TBM.

4.6. The LLCB TBS

The DEMO LLCB-BB system, proposed by India and supported by the Russian Federation, has both features of solid breeder and liquid breeder blankets. In fact, it uses Li_2TiO_3 pebble beds and Pb–16Li as tritium breeder and RAFM steel as structural material. Li enrichment in ^{6}Li is 30–60% in pebbles and 90% in Pb–16Li. There are two coolants: the Helium coolant for the FW and the external box structure (pressure 8 MPa, $T_{inlet/outlet}$ 300–350 °C) and the Pb–16Li coolant for ceramic breeder packed beds ($T_{inlet/outlet}$ 300–480 °C). The Pb–16Li acts also as additional breeder and as neutron multiplier. To avoid too large MHD-pressure drops, the Pb–16Li is isolated from the steel channel walls by means of electrical insulating coatings.

The LLCB-TBM [11] has the same features of the DEMO LLCB-BB (see Fig. 6). In particular, the molten Pb–16Li eutectic, flows separately around the ceramic pebble bed compartments to extract heat produced in the ceramic and in the Pb–16Li itself. Tritium produced in the ceramic breeder zones is extracted by low-pressure helium purge gas. The tritium produced in the Pb–16Li circuit is extracted separately by an external detritiation system.

The LLCB-TBS includes several ancillary systems, namely the FW helium cooling system, the Pb–16Li system, the secondary He-coolant system (for Pb–16Li), the tritium removal system (from Pb–16Li), the tritium extraction system (i.e., the purge gas system), the coolant purification system and the I&C system. Part of the components of these systems are located in the port cell #02, the remaining components are located in level 4 and in level 2 of the tritium building. Corresponding process flow diagrams are under finalization. In total, these systems feature more than 90 components (excluding I&C system).

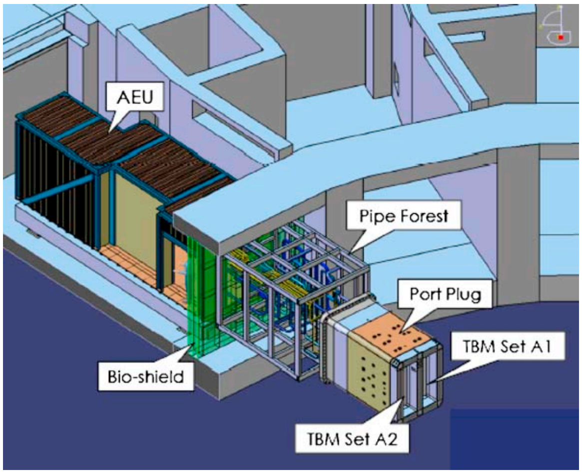

Fig. 7. View of the TBM port cell area.

5. TBS integration in ITER

This section describes the TBS main integration aspects in ITER, including both physical integration and operational aspects.

5.1. TBM impact on plasma performances

The structures of the TBMs are made of RAFM steel, which is ferromagnetic material. The TBM-induced magnetic field creates additional ripples in the toroidal and poloidal magnetic field. The present theoretical assessments and experimental results [12,13] shows that the impacts during the initial H-phase are negligible but could become significant during the plasma high-performance phases; however, they are not yet fully understood. Both theoretical and experimental efforts in plasma physics are on-going to obtain a more reliable prediction of the effects on the plasma performance of the magnetic field perturbations. The present recommended strategy is to minimize the TBM ferromagnetic mass (below 1.3 tons), and take advantage of the initial ITER H-phase to better understand the possible TBM-induced disturbances and implement any appropriate countermeasure for the following ITER phases.

5.2. Equatorial port cell arrangement

In each port, several pipes (e.g., He or water coolant, He purge gas, LiPb) and various I&C cables cross the VV boundary and the biological shield plug to reach the area of the port cell where the Ancillary Equipment Unit (AEU) is located. The corresponding bundle of pipes between the back of the PP and the biological shield (corresponding to the port interspace) is called the Pipe Forest (PF). A view of a TBM port cell arrangement is given in Fig. 7 [14,15].

Each PF includes all the pipes feeding the two TBMs and a cantilevered supporting structure attached to two vertical metallic beams which are themselves attached to the concrete of the bioshield. The temperature of the pipes ranges between 280 and 500 °C and, therefore, pipes are surrounded by thermal insulator layers up to 14 cm-thick. Despite the insulator, the heat release in the PF area could reach about 10 kW. Each pipe has several bends in order to reduce thermal stresses. Most pipes will contain tritiated fluid and therefore, could potentially release tritium through permeation.

Each AEU includes: (i) part of the tritium circuits; (ii) some cooling circuits (CC) components; (iii) the LiPb loop of the LiPb-based TBMs; (iv) some I&C systems; and (v) shield (as needed). Each AEU is expected to have a closed self-sustained structure with the same external dimensions of a Transfer Cask (2.6 m × 3.7 m × 8.5 m) and to make use of the same Cask Transfer System (CTS) for the transfer to the Hot Cell Facility (HCF). The AEU is supported by six pads fixed to embedded plates present in the floor. The supports have been designed taking into account the appropriate seismic loads.

Several connection pipes and cables leave the AEUs and pass either through the corresponding shaft or through the Tokamak corridor to reach the main CC and tritium circuit (TC) components and the I&C cubicles located up to 40 m far away.

The arrangement of the AEU internals is on-going and it depends on which couple of TBS is considered. In any case, as for the PF, heat and tritium releases will occur from pipes and components present in the AEU. The heat release will be dealt with the installation of Local Air Coolers (LAC) in some corners of the port cell taking into account that the air temperature in the port cell has to be limited to 40 °C. The assessment of the countermeasures able to deal with the tritium releases is still on-going. In fact, personnel access is required in the PF area during the planned long-term shutdown (e.g., 8 months) and in the AEU area also during the short-term shutdowns (e.g., 3–4 days). To allow personnel access, the tritium concentration in the port cell air has to be controlled.

5.3. TBM port plug replacement strategy

A large effort has been devoted to the establishment of the TBM PPs refurbishment procedure and to the definition of the space and equipment requirements in the Hot Cell Facility (HCF).

The adopted TBM replacement strategy is to replace the whole TBM PPs with new ones prepared and stored in advance in the HCF and to perform off-line maintenance. This strategy requires the availability of six TBM-PP frames, three of them installed and operating in the TBM Ports and other three ones stored in the HCF. The refurbishment of the TBMs will occur off-line. For each TBM-Set, it is expected to have up to three replacements in the first ten years of ITER operation.

The TBM-Sets will be replaced in pairs for each port; therefore, a strict coordination of the testing plan is necessary for the two TBMs located in the same port. To replace the 2 TBM-Sets, each TBM PP will be removed from the vacuum vessel using the ITER Equatorial Cask Transport System (ECTS) and delivered to the appropriated area of the HCF. A new TBM PP, containing two new TBM-Sets, has to be available for immediate installation in the TBM port. TBM-PP pre-installation tests have to be performed in the PP Test Facility. Typical dimensions of a TBM PP are 2.2 m × 1.8 m × 3.6 m.

In order to reuse the TBM-frames, the 2 irradiated TBM-Sets will be remotely extracted from the PP and replaced with two new ones (off-line operations). Each irradiated TBM-Set will then be further remotely dismantled, the shield block will be treated as radio-waste, and the TBMs will be stored in a dedicated buffer storage for specific further treatment in order to be, at least partially, packaged and shipped to the ITER Member owner for Post-Irradiation Examinations. Appropriate equipment and tools will be installed to perform these operations.

Prior to the replacement of the TBM PP, the corresponding AEU and PF will have to be disconnected and transferred in the HCF in this order.

The AEU will be disconnected and transferred in a specific HCF area dedicated to AEU maintenance (using the same pathway as the ECTS). In the HCF, it will be maintained on-line and, after testing, sent back to the corresponding port cell after the installation of the new TBM PP and of the new PF. Required equipment in the HCF includes: inspection equipment, preparation equipment for re-installation in the port cell, and testing equipment.

The PF (including the bio-shield plug) has also to be disconnected and transferred in the HCF where it will be treated as type-A waste. Therefore, a new Pipe Forest will have to be available for installation. This strategy will allow minimizing the dose received by the workers during the PF reinstallation.

5.4. TBS ancillary systems outside the port cells

Most cooling circuit (CC) components are located in a room at level 3 of the Tokamak building for the TBS of port cell #16, and in a room at level 4 of the tritium building for the TBSs of port cells #18 and #02. To reach these locations, connecting pipes will use the corresponding port cell shaft and cross several Tokamak building rooms where other ITER systems are present. Such high-temperatures pipes require thermal insulation and several bends for thermal stresses release. They will have their own supports (about one each 2 m) designed against appropriate loads including seismic loads and attached to embedded plates installed in the building structures. Because of the high-temperature and the high pressure vessels, these pipes have to be segregated from the other ITER systems.

Most of the components (including glove boxes) of the six TBS TCs are located in a room in level 2 of the tritium building. Connecting pipes are expected to be at room temperatures and run from the port cell areas to this room passing through corridors. They also have their own supports. It is recalled that, after accountancy, the extracted tritium will be released to the ITER tritium plant.

5.5. Main TBS services

The main services required by each TBS are the following: (i) secondary water coolant, (ii) steady-state electrical power supply, (iii) helium gas distribution, (iv) liquid nitrogen distribution, (v) demineralized water distribution, (vi) compressed air distribution, and (vii) breathing air distribution.

For each TBS, a secondary water coolant is required at the level of the heat exchanger for extracting the heat deposited in the TBM (about 800 kW) and for the cooling of several other TBS components (e.g., pumps, blowers).

Steady-state electrical power supply is needed for operating the various TBS components (e.g., pumps, blowers, heaters). The required power for all six TBS is about 12 MW that gives an average of 2 MW per TBS. The peak for both water flow-rate and power supply requirements occurs during the TBS operation, with strong reduction during the long-term shutdowns.

Helium supply is necessary for He-cooled TBSs to compensate helium leakages during operation and perform the initial filling of the circuits and their potential partial refilling after long-term maintenance shutdowns. Demineralized water is necessary for the initial filling of the water-cooled TBS and its possible refilling. Compressed air is necessary to actuate the numerous valves that are necessary for all TBS ancillary systems. In particular it is needed for the isolation valves that are required to isolate, in case of accident, all the pipes feeding the TBMs since they correspond to a direct access to the vacuum vessel.

5.6. TBS components classifications

Each TBS includes a variety of components that are submitted to various classifications such as safety classification, ESP/ESPN classification (valid for respectively pressure equipment and nuclear pressure equipment), quality classification, seismic classification, and tritium classification. These classifications apply differently to different TBS components although the component classification strategy has to be the same for the 6 TBSs since the six TBSs feature the same functionalities.

For instance, TBMs have to be considered nuclear pressure equipment but, since they have no safety function they are classified as non-SIC components. However, since they require high reliability they are classified as quality-one component. On the contrary, the TBM feeding pipes, since they are an extension of the vacuum vessel primary barrier for radio-isotope confinement, they are classified as SIC components.

The classifications have a significant impact on the design, manufacturing and testing of each component. For instance, for a component classified as ESPN, the design, manufacturing and testing have to be certified by an Agreed Notifying Body (ANB).

5.7. Main safety and quality aspects

Because of the high-level of integration of the TBSs in ITER, the TBSs licensing is requested at the same time as the ITER licensing. For this reason, they have been included in the ITER Preliminary Safety Report (RPrS) released to the French Safety Authority.

The main implications are that all detailed TBS safety analyses and relevant operational data have to be defined in due time in coherence with the schedule of the ITER licensing documentation. One particularly important aspect is the estimation of the weight and the type of rad-waste that will be generated by the performance of the TBM Program. A further issue is to define the rad-waste treatment strategy that will have to be applied for each TBS.

An important aspect related with both safety and quality is the strategy to be applied to each TBS to avoid major safety concerns and to protect the investment (both of the TBS itself and of other ITER components). In particular, it is necessary to determine which actions have to be performed to mitigate the consequences of the most severe accidental events such as Loss-Of-Coolant or Loss-Of-Flow accidents. Current studies address the definition of the number and type of measurements for detecting such events and the actions required to other ITER systems via the Central Safety System (CSS) and to the Central Interlock System (CIS).

Quality Assurance (QA) procedure and Quality Plan (QP) will have to be prepared by the TBM Teams in agreement with IO. It is recalled that the QP has to include the following information: (i) the specific allocation of resources, duties, responsibilities and authority; (ii) details of all suppliers/subcontractors and how interfaces are managed; (iii) the specific procedures, methods and work instructions to be applied; (iv) the specific methods of communication, both formal and informal, to be established between working groups; and (v) any access restrictions for IO representatives.

6. Management of the TBM Program

In November 2008 the ITER Council agreed that the TBM Program is undertaken under the framework of the ITER Agreement [2]; nevertheless, TBMs and associated systems are not part of the procurement identified for the ITER construction, but are responsibility of ITER Members.

In 2009, the ITER Council has created a specific high level advisory body, the TBM Program Committee [2]. The TBM-PC is formed by a member and up to three experts from each of the seven IMs and chaired by a representative of the IMs. It is charged with the governance of the TBM Program to ensure, in particular, that the selected TBSs will be delivered on time on the ITER site and to establish a credible R&D validation program to guarantee a sufficient TBS reliability.

The ITER Organization (IO) has responsibility for preparing the necessary interfaces required for the installation of the TBSs based on input data given by the TBM Teams, and, after positive results from appropriate TBS acceptance tests guaranteeing their safety and reliability performance, has the responsibility of operating the TBSs. The ITER Members are in charge of the design, manufacturing and delivery of the TBSs to the ITER site. Additional IO responsibilities cover the TBSs integration into ITER facility, providing space and utilities, design of interfaces, procurement of TBM frames, dummy TBMs and standardized maintenance tools and equipment.

Each TBS has a responsible ITER Member (IM), denoted TBM Leader that could be associated with other IMs that are denoted TBM Partners. Each TBM Port includes two TBSs and therefore one of the two TBM Leaders, called Port Master, ensures the coordinated installation and operation in the port, in particular for the common components.

At present, there is no official commitment by ITER Members to deliver the planned TBSs. Therefore, a specific arrangement, called TBM Arrangement (TBMA), will have to be signed between IO and each of the IM TBM Leaders, in order to establish the formal framework of the TBM Program, including the IM commitment of delivering the TBS on due time, the IO commitment of integrating it in the ITER facility, and other important aspects such as intellectual property rights, rad-waste management and liability. Moreover, each TBMA will specify the framework for the main governing, legal and administrative requirements related to the TBM Program, will define the management specifications, accepted sound project management practices, safety and QA requirements, and will establish the TBS technical specifications and milestones, including the delivery date.

At present, a generic TBMA is under preparation in order to be used as template for each specific TBMA. Each specific TBMA will have to be proposed by each IM TBM Leader to IO and, after consultation, will have to be signed as soon as possible. It is expected to sign most of the TBMAs in 2013. After each TBMA signature, the corresponding TBS conceptual design review will take place to identify all possible technical issues still present and to define the action plan for solving them.

7. Conclusions

The ITER TBM Program is the answer to the ITER mission of testing tritium breeding module concepts that would lead in a future reactor to tritium self-sufficiency, the extraction of high grade heat and electricity production.

The pre-conceptual design of the six TBSs to be tested in ITER is available and their integration in the ITER facility is currently on-going. For each TBS, the most important next step is the signature of the corresponding TBM Arrangement that will allow performing the TBS conceptual design review shortly after.

Disclaimer

The views and opinions expressed herein do not necessarily reflect those of the ITER Organization.

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