Objectives and Progress of the ITER Test Blanket Working Group Activities

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Abstract. The ITER Test Blanket Working Group (TBWG) has restarted its activity in October 2003. Its objectives are to define the test program of the breeding blankets in ITER, to verify its feasibility and compatibility with ITER operation, and to identify the necessary collaboration on R&D taking into account the needs of the six ITER Parties and the progress of breeding blanket technology. Despite the large required extrapolations to be made from the ITER conditions to those of a potential DEMO reactor, all parties agree on the extreme importance of breeding blanket tests in ITER. The main expected outcomes of the work of the TBWG are the establishment of a meaningful and coordinated testing program and a complete definition of the interfaces between the three equatorial ports devoted to the testing and the ITER machine and buildings.

1 – Introduction

The ITER Test Blanket Working Group (TBWG) made a preliminary assessment of ITER breeding blanket testing capabilities in July 2001 [1]. The group has restarted its activity in October 2003 with an enlarged official membership. It includes now representatives of the ITER Team and of the six ITER parties (China, EU, Japan, Russian Federation, South Korea, and USA). The corresponding revised charter is aiming to: i) provide the Design Description Document (DDD) of the Test Blanket Modules (TBMs) systems proposed by parties including the description of the interfaces with the main ITER machine, ii) promote co-operation among parties on the associated R&D programs, iii) verify the integration of TBM testing in ITER site safety and environmental evaluations, and, finally, iv) develop and propose coordinated TBMs test programs taking into account ITER operation planning.

This paper presents the status of these activities, with special focus on the testing conditions and objectives and on the type of blanket lines that are envisaged to be tested in ITER by the different parties during the first 10 years of operation.

2 – Expected operating testing conditions in ITER

ITER as an experimental machine will have a rather broad domain of operation around Q=10, with fusion powers between 300 and 600 MW, depending on achievable confinement, density and maximum pressure. Three equatorial ports (1.75 m wide x 2.2 m high) have been allocated for TBM testing. The ITER operational plan has been discussed up to now for the first 10 years. It includes 1 year of integration of the sub-system level and in-vessel components baking, 2.5 years of initial H-H operation, a brief D-D-phase and a long D-T phase (*see FIG. 1*). During the D-T phase, in the hybrid mode of operation (inductive + partial current drive) the reference operating conditions for TBMs include a surface heat flux up to 0.25 MW/m^2, a neutron wall load up to 0.78 MW/m^2, a pulse length of 400 s with a duty cycle of 25%. Pulse lengths up to 3000 s are possible in CD regime. Longer burn times (>3000s) will probably be possible with some equipment up-grade.

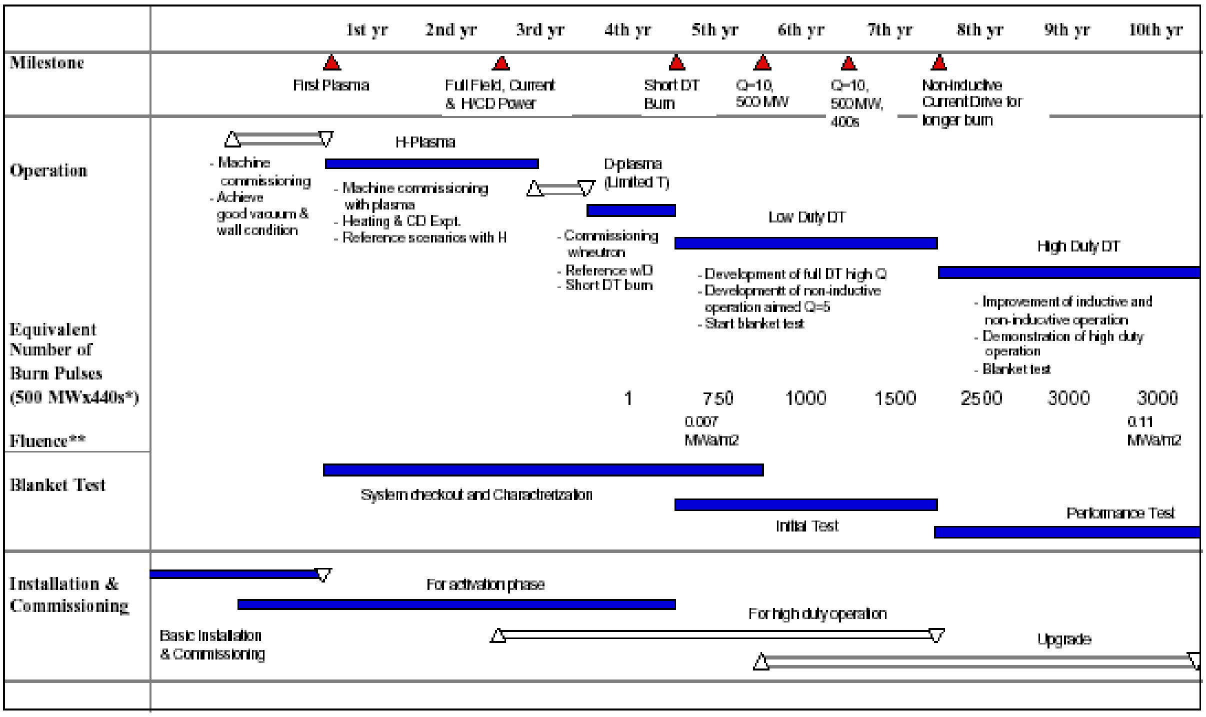

FIG. 1 : First 10 y of ITER Operational Plan and Test Blanket Plan

In the first 10 years of operations, the expected neutron fluence is of about 1.1 dpa (eq. Fe). TBMs are expected to be recessed of 50 mm from the nominal surface of the ITER shielding blanket first wall in order to reduce plasma-wall interaction effects, with a max disruption energy load of 0.55 MJ/m^2 (1ms-10ms). The schematic view of a TBM installed in an ITER test port is shown in *FIG. 2*. In fact, from recent ITER estimation, TBM FW may require to be designed for a heat load of 0.5 MW/m^2 because heat loads up to this value are expected during some pulses without possibility of predicting them in advance. Design value for the surface heat flux for the H-H phase should be 0.3 MW/m^2.

The location of the circuits and components associated with the TBM (TBM system) is of extreme important for testing. Outside the bioshield in front of each port there is a space (the port cell) available for placing a movable container (cask) with the interfacing equipment. The systems to be placed near the ports are primarily the Tritium interface and the primary coolant loop components. For the cases where the space inside the cask is found insufficient, the heat transfer components (or some of them) may be placed in the Tokamak Cooling Water System (TCWS) vault and inside the Tritium building. For each TBM type, a detailed assessment is under way for evaluating the possibility of placing at least part of the TBMs ancillary equipment in the port cell.

3 – Interest and objectives of TBMs testing

Breeding blankets and their integrated first wall for DEMO reactors have several feasibility issues which require large R&D efforts. The capability of reaching Tritium breeding self-sufficiency, which is one of the most demanding requirements for making use of Fusion as a future energy source, has yet to be demonstrated. ITER may be the only opportunity for testing breeding blankets mock-ups (TBMs) in a real fusion environment before the construction of a DEMO reactor ensuring: i) in the initial H-H phase, relevant magnetic fields, surface heat fluxes, and disruption-induced loads, and, ii) in the following D-T phase, an additional relevant neutron flux, volumetric heat, and Tritium production with corresponding T-management capabilities.

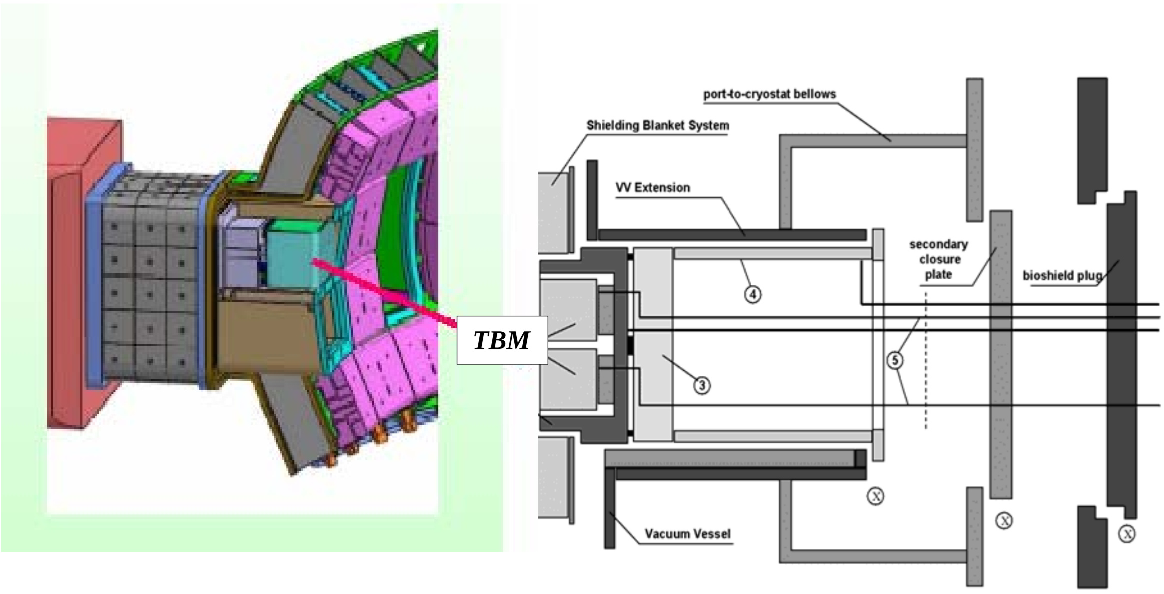

FIG. 2 : Schematic view of TBMs installed in a ITER Test Port

The most important restriction for blanket testing is that in ITER the magnitude of neutron flux, neutron fluence and volumetric power density is considerably lower than what expected in a DEMO reactor. As a consequence, in most cases, for each selected blanket concept, several TBMs have to be developed making use of “engineering scaling” for testing specific “act-alike” TBMs during the different ITER-phases for addressing the different aspects of the TBM performances (neutronics, thermo-mechanics, thermo-hydraulics, etc…). A “look-alike” TBM can be envisaged for integral tests of the whole TBM system.

Taking into account these limitations, the major overall testing objectives are the following:

i) validation of structural integrity theoretical predictions 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 blanket materials,
iv) validation of thermal predictions for strongly heterogeneous breeding blanket concepts with volumetric heat sources,
v) demonstration of the integral performance of the blankets systems.

It must be pointed out that Tritium-related performances generally need longer pulses (>3000 s) than the ITER reference one and, therefore, they are expected to be achieved only at a later stage.

Maximum expected neutron damage is about 3 dpa (eq. Fe) even after 20 years of operation, while dpa levels required for DEMO are greater than 70 dpa. Therefore, ITER cannot give answers to long term irradiation effects on blanket performances, failures, functional and structural materials and interfaces, synergistic effects. These should be addressed in other facilities, e.g. IFMIF.

On the other end very important data can be obtained during the H-H phase which requires for all parties to be ready to install TBMs since the beginning of ITER operation. The main results expected in this phase are the following:

i) demonstration of the structural integrity of the TBM structures and attachment during disruption and Vertical Displacement Events (VDE);
ii) assessment of the impact on Ferritic/Martensitic steel, used as a structure for most TBMs, on magnetic fields deformation in static conditions;
iii) verification of the need of Be-coating on the TBM FW.

For TBMs using liquid metals, additional data can be obtained for the validation of the MHD pressure drops estimations and for the T-control and management simulated with addition of H/D in the flowing liquid.

3 – Selected breeding blankets to be tested

The interest of the different parties can vary depending on breeding blanket domestic assessment, on the different kind and levels of performed R&D, and on historical reasons. All Parties have identified at least two kinds of DEMO-relevant blanket lines which need to be tested in ITER in support of their breeding blankets development programs. As shown below there is a general agreement on some choices, while some other proposals are more controversial.

In particular, all ITER Parties are interested in developing Helium-Cooled Ceramic Breeder (HCCB) blankets. The proposals are either to test independent TBMs based on different blanket concepts or to collaborate with other parties on a common TBM concept. This kind of blankets requires Beryllium as neutron multiplier, and Ferritic/Martensitic Steel (FMS) structures. Ceramic breeder is a Li-based compound such as Li_2TiO_3, Li_4SiO_4, and Li_2O (depending on the Parties domestic experience and performed R&D) and is used in pebbles-bed form.

The other selected breeding blankets lines and the corresponding testing approaches differ from Party to Party. Japan has selected a pressurized Water-Cooled Ceramic Breeder (WCCB) blanket, which is a water-cooled version of the HCCB blanket, therefore using Be-multiplier and FMS structures. All other Parties consider a liquid breeder option. In particular, EU has selected a Helium-Cooled Lithium-Lead (HCLL) blanket, using Lithium-Lead as breeder and neutron multiplier, and FMS structures. RF has selected a self-cooled Lithium blanket using a Vanadium-alloy as structures. China is performing comparative studies to reach a selection between a HCLL blanket and the Dual Coolant version of it, using both He and LiPb as coolant (DCLL). It is recalled that in DC blankets, He cools FW and structures while the liquid breeder acts also as a coolant for the breeder zone. South Korea is performing a selection between a DCLL and a Helium-Cooled Lithium (HCLi) blankets. Finally, USA is performing studies for selecting a TBM option between two Dual-Coolant blankets using different liquid breeders, one with Lithium-Lead (DCLL) and one with Molten Salts (DCMS).

This list has been limited to the breeding blankets which are candidate for TBM testing in the first few years of ITER operation. More advanced blankets and corresponding TBMs could be envisaged at a later stage.

It must be pointed out that significant R&D is still required for all the breeding blankets, although at a different level, before being able to demonstrate their feasibility, performances and reliabilities. The corresponding tests in ITER represent therefore a significant part of the planned R&D. These uncertainties justify the tests of various blankets lines needing different TBM systems.

However, at least the following general steps need to be performed prior to the TBMs installation in ITER:

- i) selection of materials grades and fabrication routes,
- ii) characterization of materials in fission reactors irradiations,
- iii) confirmation tests for components performances and reliability,
- iv) out-of-pile tests of TBM mock-ups up to the test of prototypical TBMs,
- v) validation of remote handling equipment and procedures.

4 – Present testing proposals and strategy

Resulting from the above parties' proposals, it can be seen that many different TBMs are envisaged to be tested in the 3 available ITER test ports. Being the typical size for most TBMs equal to half a port, the room available for testing is therefore quite limited and must be shared in the most reasonable way. In particular, taking into account that blanket performances will have to be determined and/or demonstrated in future R&D prior to installation in ITER, some uncertainties are still present in the definition on which blankets will actually be ready for being tested in ITER.

Therefore, from the technical point of view, the general interest is to keep some flexibility on the interfaces design for allowing a final TBMs selection as close as possible to the TBM installation time in ITER. The limitation here is that ITER project need to know all the interfaces between TBMs and ITER machine and buildings as soon as ITER construction is decided in order to establish the final construction plans.

In particular, it is compulsory to know which pipes have to be available in the port cells and in the vertical shaft for connecting the TBM system with the TCWS vault and the Tritium Building. It is therefore necessary to define the connecting coolant lines while keeping as much as possible open the choice of the kind of TBMs that will be tested in ITER throughout the various plasma operation phases.

As a consequence, it is very important to launch collaborative actions between the parties in order to share, at least partially, R&D program and results in order to converge to a reduced number of blanket concepts with the corresponding reduction of the number of feeding lines.

This optimization will permit to increase the number of tests for a single blanket line with an increased confidence on the obtained results and on the extrapolation to DEMO.

In order to promote collaboration between parties, taking into account their proposals, five major blanket lines have been identified, namely:

1) He-cooled ceramic/Be blankets using FMS structures, pebble-beds of Li-based ceramics and pebble-beds or porous Be,
2) He-cooled or Dual-coolant (He) Lithium-Lead blankets with FMS structures,
3) Water-cooled pebble-beds ceramic/Be blankets with FMS structures,
4) Self-cooled Li blankets with V-alloys structures,
5) Self-cooled or Dual-coolant (He) Molten Salts blankets using FMS structures.

For each blanket line, a specific Working Sub-Group (WSG), including members from each interested party, have been settled for identifying common TMB test requirements and for defining, as far as possible, the design of TBM and associated systems and a coordinated testing plan. Moreover, the WSGs are also charged to discuss the main design and R&D issues for the corresponding blanket lines, to assess the obtained R&D results and to identify the main R&D still required prior the installation in ITER in order to suggest to the TBWG potential collaboration between parties. These WSGs are therefore open to the participation of experts in the relevant fields in order to use in the most efficient way the parties R&D interest and capabilities.

For each blanket line a preliminary assessment has shown that a series of TBMs have to be tested. TBMs have to be installed and commissioned before the first day of ITER operation in order to demonstrate their integrity capability and their compatibility with all ITER aspects and performances since the start of the ITER operation, long in advance to the D-T phase and the consequent activation of the structures which will limit the access to the vacuum vessel components; other specific TBMs will then follow in order to achieve all the other testing objectives described above. TBM instrumentation and coordinated replacement strategy have to be taken into account.

In order to define the interfaces TBM/ITER buildings, a preliminary design and dimensioning of the whole TBM systems have to be performed for establishing which components can be placed in the port cell. A preliminary evaluation has already shown that, because of the limited space available in the port vertical shafts, only few connections with the TCWS vault can be accepted. This limitation excludes, in particular, the possibility for each party to test independently and simultaneously two TBMs.

5 – Main interfaces with ITER machine

The testing of TBMs must not interfere with ITER operation, decrease ITER reliability, and spoil operation safety. The testing operation must use as much as possible available resources such as the ITER heat rejection system and the infrastructure of the ITER tritium plant, the ITER remote handling equipment and the ITER hot cells.

TBMs have to be inserted in standard equatorial ports using standard ITER equipment for installation and removal. In particular, TBMs are surrounded by a water-cooled steel frame which is removed together with TBMs and port plug. TBM systems may be located either just behind the port between port plug and the bioshield (i.e. liquid-breeder circuits' components) or in the TCWS vaults (He and water circuits components).

TBM replacement occurs in the allocated hot cell, where the whole TBMs/shield plug system is remotely transported. The weight of the integrated structure consisting of TBM/frame/shield plug to be taken by a transfer cask is limited to 40 tons. The ITER hot cell may be used to replace irradiated TBMs, but it is not designed to allow TBM repair and/or post-irradiation examinations. This choice is a significant limitation with respect to the number of possible TBM replacements and to the obtainable information from the TBM testing and has to be assessed in details in a near future. The presence of hot-cell facilities on the site selected for construction has also to be taken into account in such an assessment.

6 – Recommendation and conclusions

Breeding blankets testing is extremely important for DEMO breeding blanket development. Collaborative activities between parties are necessary in order to optimize the R&D efforts, costs and the use of the limited space available for TBM testing in the ITER port, which limits the number of TBMs, but also to optimize the use of the limited space available in the hot cell, which limits the number of possible TBMs replacements.

References

[1] V.A. Chuyanov and the ITER Test Blanket Working Group, ITER Test Blanket Working Group Activities: a summary, recommendations and conclusions, Fus. Eng. & Design 61-62 (2002) 273-281.