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TW2-TTBC-001-D01

Task Title: HELIUM COOLED LITHIUM LEAD - TBM DESIGN, INTEGRATION AND ANALYSIS Blanket system design and analysis - Integration and testing in ITER

INTRODUCTION

In 2002, EU has endorsed the decision to concentrate the work on blanket modules for testing in ITER on a single coolant, helium.

Up to that time, two different coolants were envisaged for the EU Breeding Blankets: i) pressurized water for the Water Cooled Lithium Lead (WCLL) concept and ii) pressurized He for the HCPB concept (Helium-Cooled pebble-Bed).

In this frame, the general objective of the EU Task TW2-TTBC-001-D01 is to develop and optimize (with regard to tritium breeding, heat removal and shielding capability) a Helium Cooled Lithium Lead (HCLL) breeding blanket concept for DEMO and its corresponding Test Blanket Module (TBM) to be tested in ITER.

2004 ACTIVITIES

2004 activities mainly concerned the improvement and completion of the TBM engineering design.

After a first design step in which the main structure, its functional features, its mounting sequence and manufacturing characteristics were defined, the second step, relied on the optimization of the design and manufacturing of the module as well as its integration to the supporting frame.

A planning and list of test requirements for the qualification of the HCLL TBM prior to ITER was defined. A preliminary testing programme for the HCLL TBMs in ITER has been proposed on the basis of the foreseen ITER scenario and of the TBM testing strategy and mock-ups test objectives.

THE HELIUM COOLED LITHIUM LEAD (HCLL) INTEGRAL TBM (IN-TBM): DESIGN AND ANALYSES

The In-TBM looks alike a generic HCLL breeder blanket module for DEMO. It features a steel box cooled by horizontal multi-passes rectangular cross section channels and closed by top and bottom cooled covers and, in the rear, by 4 steel plates acting also as distributing/collecting chambers for the He coolant. An exploded view of the TBM is shown in the figure 1.

The box is stiffened by poloidal radial and toroidal radial cooled plates (vertical and horizontal stiffening plates, SPs) in order to withstand the internal pressurization at 8 MPa in case of accident (loss of coolant inside the TBM). The grid also stiffens the box against the torques acting on it during disruptions.

The grid forms radial cells in which circulates the multiplier/breeder Pb-Li, so allowing external tritium extraction. In each cell is inserted a breeder cooling unit (BU), ensuring the heat recovering from the breeding zone. Each BU consists of five radial toroidal plates (Cooling Plates, CPs) cooled by internal double U rectangular channels and welded to the BU back plate. Two BU collectors located behind the BU back plate distribute/collect the He circulating in the CPs.

The manifolding back plate is reinforced by stiffening steel rods for pressure withstanding. In the present reference design the rods has a tubular cross-section with larger overall diameter compared to the equivalent full rods. This new design allows either to use the rods as an access to the module body for the instrumentation connections, or to use some of them as thread for the bolts of the attachment system. This tubular rod design presents also the great advantage that structural function (relying on threads and conical surfaces) and tightening function (relying on welding) are dicoupled.

One He circuit is envisaged to cool both the FW and the breeder zone. In the DEMO blanket module the “cold” He (Tinl = 300°) cools in parallel the FW and the SPs, recovering all the power deposited as heat flux (HF) on the FW and a small percentage of the nuclear power deposited in the breeder zone (BZ). Then the He passes in the CPs in which it recovers the largest part of the nuclear power deposited in the BZ and finally it exits at 500°C.

This cooling scheme was adopted also in the first TBM 0, in which the ratio between the thermal power deposited on the FW and the one deposited on the BZ (0.27/0.78) was of the same order as the DEMO one (0.5/2.2). Recently, because of uncertainties on plasma control, ITER Team has requested TBMs to be designed to withstand a surface heat flux of 0.5 MWm^{-2}. The He cooling scheme has then been modified in a way that the FW is cooled at first and then the SPs and the CPs are cooled in parallel. This allows to reduce the He temperature at the FW outlet and then the thermal sink temperature so guaranteeing the recovering of the high heat flux on the FW with moderate total He mass flow (see later § Structural and thermo-mechanical analyses).

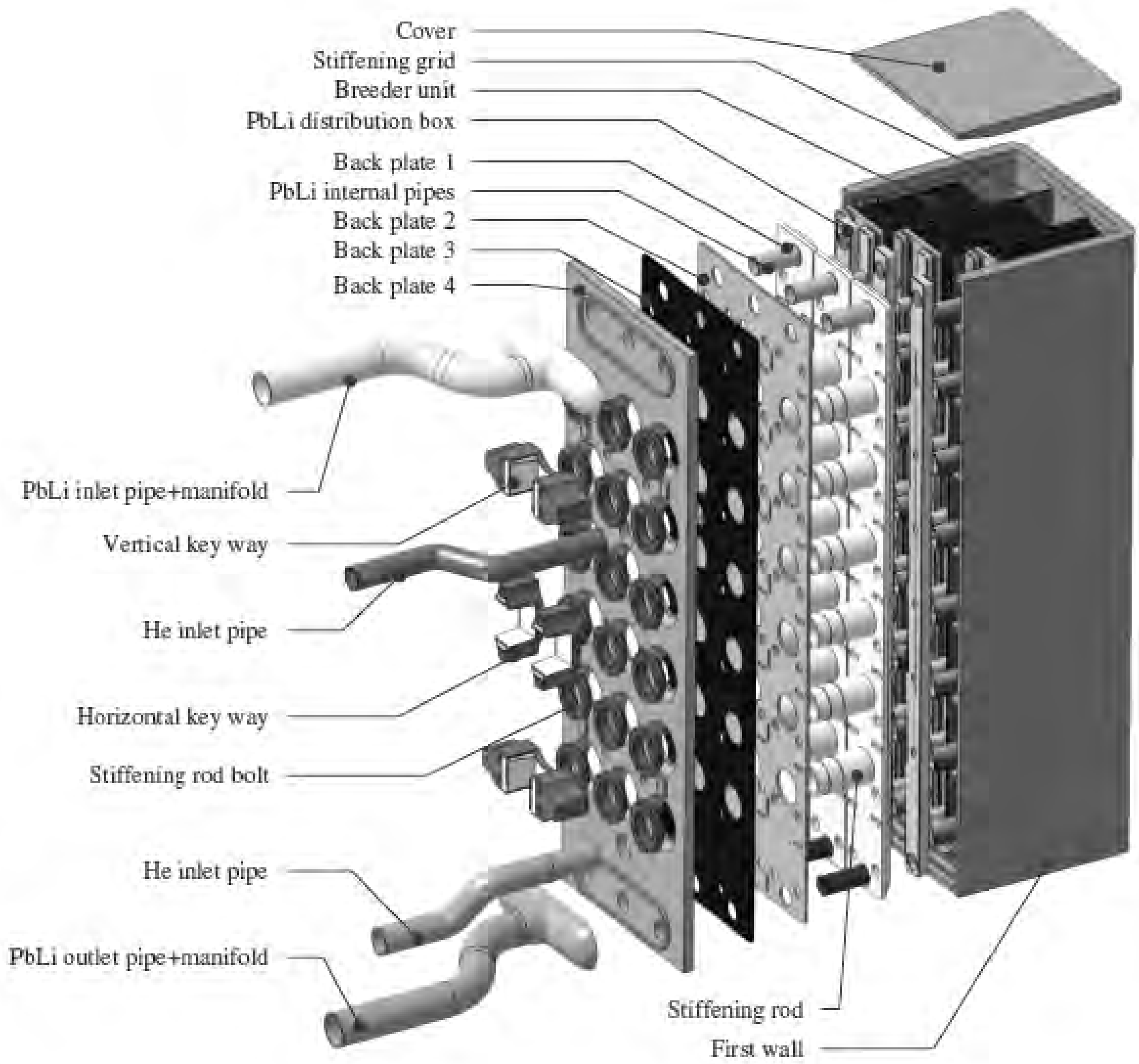

Figure 1 : Exploded view of the HCLL TBM

Recent studies carried out in the frame of the Power Plant Conceptual Study have shown that the configuration previously foreseen for the HCLL DEMO generic blanket module in which the Pb-Li passes in series through all BU of a vertical column meandering between one BU and the one immediately below would lead to too high liquid metal velocities and MHD pressure drops.

As a consequence, an improved liquid metal flow path has been envisaged which allows higher re-circulation rates avoiding excessive LiPb velocities.

The liquid metal enters from the external collector and then it is distributed in some intermediate vertical distributing boxes located behind the BU. It enters in a BU and exits from the one below, feeding in this way the BU in parallel (par couple). The vertical collectors have been integrated in the TBM design as vertical parallelepiped chambers located behind the BU, between the BU He collectors and separated to form the inlet and outlet legs by an oblique internal wall.

The Pb-Li draining is realized from the TBM bottom, to allow the draining by gravity so improving safety.

When draining PbLi from the module, it is necessary to insure that, in case of residual Pb-Li, its solidification does not lead to wall failures. This has lead to lower as much as possible the exit pipes used for the draining, and to suppress the lowest cooling plate of the bottom BUs, in order to avoid its potential interaction with residual Pb-Li.

Being the Pb-Li mass flow rate lower than in previous version, the dimensions of Pb-Li external feeding pipes and consequently of the external collectors have been reduced, so increasing the available place for the mechanical attachments on the last back plate.

Integration into the frame

The number of the TBM pipes leaving the TBM from the rear has been fixed to four, two for the cooling helium (inlet pipe having ∅in = 60 mm, outlet pipe having ∅in = 70 mm) and two for the liquid metal (∅in = 87 mm). That allows to reduce the time for connection/disconnection and the number of passing through the frame. The pipes are curved in the crossing of the frame in order to limit the neutron streaming.

For the connection of the TBM to the frame, mechanical attachments of the same type as those used for the ITER outboard shielding modules are foreseen, consisting of:

- A flexible fixation (flexible cartridges) on 4 points to recover the radial mechanical loads while authorizing the thermal expansion in the poloidal and toroidal directions.

- A gliding shear keys system along a cross-shaped key way on the external back plate, to lock up the module displacements in poloidal and toroidal directions during the disruption loads, the thermal expansion in these directions being free; it also contributes to bear the weight of the module.

The whole system is positioned on the external plate of the module’s back collector. The bolts of the system of flexible cartridges are screwed in four of the stiffening rods of the back collector (the cartridges being screwed in the frame). The key ways are laid out on the back plate according to a cross centred on the module, the shear keys being fixed on the frame.

The attachments have been dimensioned to resist to a maximum torque of 1.5 MNm, value estimated considering a safety factor of three on the resulting forces obtained for the HCPB-TBM. A detail of the TBM in its frame with a cut of the attachment system is shown in figure 2.

In-TBM Manufacturing sequence

A preliminary TBM manufacturing sequence has been defined: the main mounting steps for the assembly of the basic components (First Wall, Stiffening Plates, Cooling Plates) have been identified with their specific requirements (tightness, mechanical resistance, etc.) and illustrated with 3D drawings. This proposal has been submitted to industry expertise intended to evaluate its feasibility and the sequence has then been updated, on the basis of the industry suggestions. A complete set of drawings has been issued showing the manufacturing sequence steps and indicating the operation to be accomplished. The possible main concerns and key points have been also noticed. All welding preparations have been indicated in the drawings, taking into account the chamfrain, where needed, in accord with the envisaged welding technique.

The TBM design has been furthermore modified adopting the following design guidelines:

- Avoid welding triple points.
- Avoid sharp points on some welding trajectories.
- Avoid thickness variations along some welding trajectories.
- Avoid possible interference between welding beams and welded parts.
- Avoid welding of thick to thin components.
- Separate mechanical and tightening function.

Structural and thermo-mechanical analyses

The first In-TBM was designed to resist to a surface Heat Flux (HF) = 0.27 MW/m^2 and to a Neutron Wall Loading (NWL) = 0.78 MW/m^2. Recently, ITER Team has requested TBMs to be designed to withstand a surface heat flux of 0.5 MWm^{-2}, even if most of the time the real heat flux will be lower so the previous design has been modified.

Steady state analyses, thermal, thermal-hydraulic and mechanical, have been performed to adapt the outline design to these new “dimensioning loading conditions”.

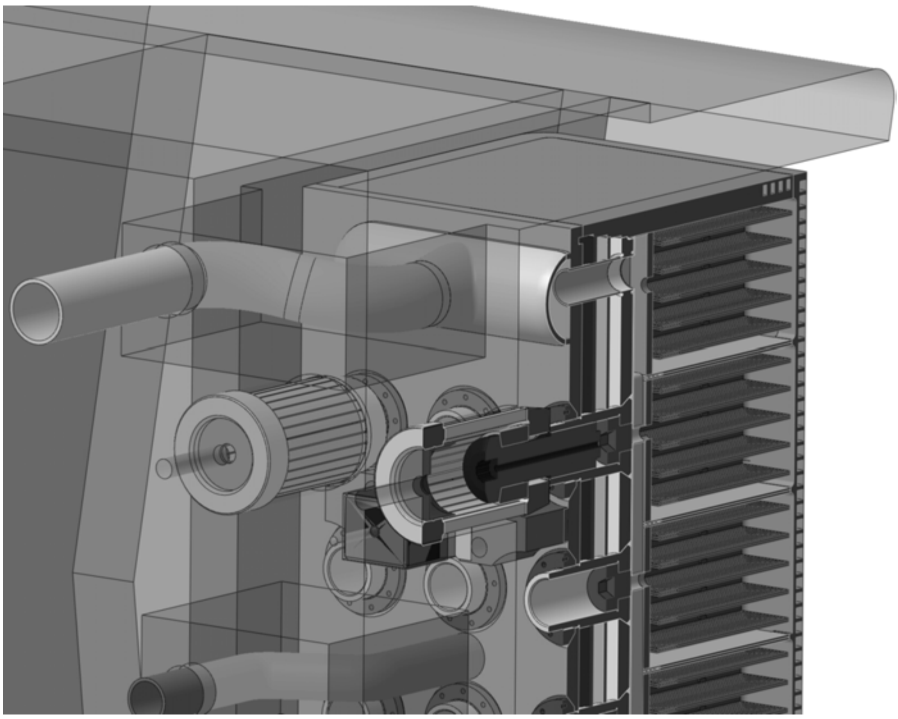

Figure 2 : Detail of the TBM inserted in the ITER frame, with the attachment system

1.2 MW are deposited on the TBM of which about 0.7 MW on the FW and 0.5 MW on the breeder zone (CPs, SPs and liquid metal). Due to higher ratio between the HF and the NWL (0.5/0.78 against 0.5/2.4 in DEMO) neither the cooling schema nor the He parameters adopted in DEMO are fully suitable for the TBM.

In order to recover the 0.5 MW/m^2 impacting on the FW without exceed 550°C in the steel, a He velocity of about 70 m/s is needed with a He maximum temperature of 413°C. Taking into account this requirement, the He flow schema and mass flow and the FW channels cross section have then been modified and optimised with regard to the pumping power in the He circuit.

In the optimised configuration the FW channels have a cross section of 15x10.5 mm^2 (poloidal x radial) and 1.3 kg/s of He circulates in the TBM. The He enters in the FW at 300°C, then passes in the SPs, the covers and the CPs which are cooled in parallel. The percentage of the He circulating in the CPs (37%) is chosen in a way that the He temperature at the exit of the CP channels is 500°C. That will allow to obtain in the CPs steel temperatures of the same order of magnitude as those obtained in DEMO so guarantying a good relevance in terms of T permeation. He exits from the TBMs between 440-460 °C (depending on the derivation scheme).

Pressure drops are evaluated at 0.222 MPa in the FW, 0.0040 MPa in the parallel CPs//SPs//covers (in particular it is in the SPs that take place max pressure drops), and 0.9 MPa in the region between the TBM and the ITER Heat Recovery System (HRS). 200 m of 100 mm ∅in pipes have been assumed between the TBM and the HRS with ten 90° corners. The total pressure drops (including those in the back plate region) amount to 0.38 MPa, leading to a pumping power of about 100 KW.

Mechanical analyses have been furthermore carried out to evaluate the resistance of the module in accidental conditions. It has been assumed that the rupture either of a CP or a SP would imply the pressurization of the entire box to the He pressure (8 MPa).

Analyses showed that (see figure 3), according to the IISDC criteria, the box will be able to withstand this type of load.

Transient analyses have then been carried out considering an ITER pulse with a duty cycle of 400 s / 1800 s and showed that in terms of thermo-mechanical behaviour, stationary conditions would be reached in the TBM front regions, where maximum temperatures and stresses are located, after some tens of seconds (60 in the FW).

PLANNING FOR THE TBM DESIGN AND R&D

A planning and list of test requirements for the qualification of the HCLL TBM prior to ITER has been defined.

It is based on a progressive qualification of the TBM, from the qualification of the fabrication techniques and technology of the basic sub-components (FW, CPs, SPs), to the functional qualification of the systems at different scale until a 1:1 scale mock-up.

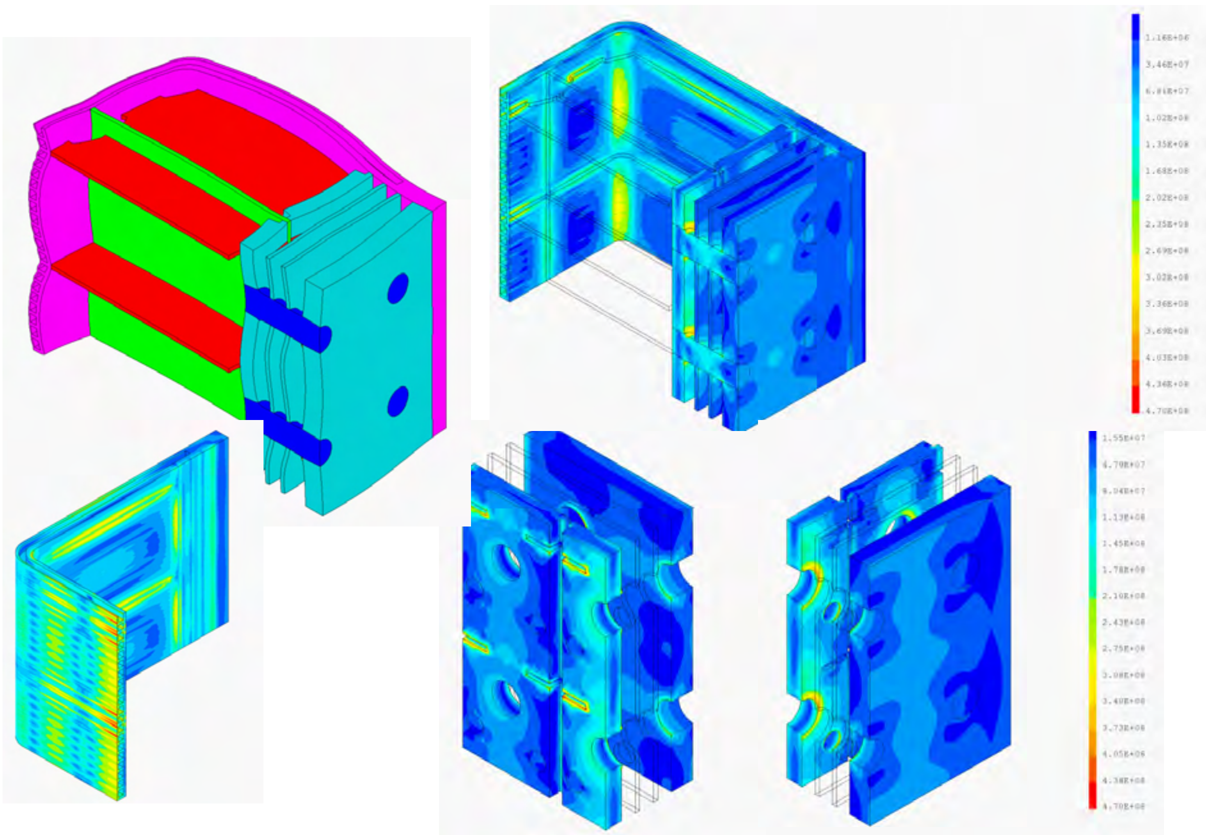

Figure 3 : Von Mises stresses distribution (MPa) in faulted conditions

This planning allows to highlight the need for future He test facilities and will be used within the HCLL/HCPB projects to better define the R&D timeschedule.

On the other hand, some interactions with fabrication R&D have initiated complementary design analyses. The foreseen manufacturing sequence is indeed featured by the assembly of basic components the fabrication of which assumes, thus, a fundamental role in the fabrication feasibility. Various techniques are actually retained for further development for the fabrication of the FW, the CPs and the SPs. The applicability of some of these requires small modifications of the design (i.e. increase of the rib between the CPs channels), the impact of which on the TBM behaviour is under assessment.

Being the Eurofer especially developed for the use in fusion device, the material data base is still under completion. In particular, the data on its weldability with various techniques (EB, laser, TIG), comprising the mechanical behaviour of the welded regions and the post welding treatment needs should be investigated with an appropriate R&D campaign.

TESTING PROGRAMME IN ITER

A preliminary testing program to test and validate the Helium Cooled Lithium Lead breeder blanket concept in the ITER machine has been defined, taking into account the chosen testing strategy, the TBMs objectives and the ITER operating scenario during the first 10 years of ITER operation.

The proposal envisages four different test mock-ups or modules, adapted for qualifying single or combined effects and whose design makes large use of engineering scaling for compensating the differences between the testing conditions and those expected in DEMO (e.g., neutron wall load, heat flux, pulsed operating conditions):

- EM-TBM: Electromagnetic TBM (plasma H-H).
- NT-TBM: Neutronic TBM (plasma D-D and first period of the D-T low cycle phase).
- TT-TBM: Thermo-mechanic & Tritium Control TBM (last period of the D-T low cycle and first period of the D-T high duty cycle phase).
- IN-TBM: Integral TBM (last period of the high duty cycle D-T phase).

With the first two types of modules, useful information can be obtained about the impact of the TBM on the plasma stability, as well as on the TBM structural integrity and system functionality. The provisional capability of the calculation tools (neutronic, EM, MHD) can be furthermore validated and sources can be calibrated for the following phases.

The two others types of modules will allow to complete the code validation (thermo-mechanic), the tritium control, up to the integral qualification of the HCLL blanket and of PbLi and He coolant circuit components under DEMO relevant conditions.

The He parameters can be varied to achieve the DEMO relevancy under different loading conditions, compatibly with the response time of the system regulators. Therefore, the meaningfulness of most of the tests in the D-T phase, in particular for the TT-TBM and for the In-TBM, will depend on the capability to predict the actual surface heat load with sufficient advance and to keep it constant for a sufficient long time.

The feasibility of the tests foreseen for the various envisaged TBMs will depend from the possibility of measure the meaningful physical properties (temperature in the material structure, in the He and in the liquid metal, He pressure, lithium lead velocity in the various regions of the TBM, deformations in the structure and in the attachments, etc.) with required accuracy, sensibility, response time, etc.

The characteristics of available measurement tools have been explored paying special attention to their adaptability to the ITER working conditions, as well as to their installation in the TBM.

A part from some instruments specifically developed in the frame of this work programme (tritium concentration measure in the LiPb), most of the needed instruments tools are available on shell. Their installation and use in the TBM is not, however, always obvious. The installation of thermocouples or deformation gauges in the FW, p.i. could not be compatible with the TBM manufacturing sequence, in the sense that if the sensor are installed before the welding of the manifolding back plate, they should be undamaged by post thermal treatment. Another issue could be the signal transmission to the treatment system, which could be perturbed by the varying magnetic field.

REFERENCES

[1] A. Li Puma et al. - HCLL TBM for ITER – Status of the design, analyses and test programme in ITER - CEA report SERMA/RT/04-3350/A, 10/2004.

REPORTS AND PUBLICATIONS

G. Rampal et al. - Helium Cooled Lithium-Lead test blanket module for ITER - reference document for a mounting sequence - CEA Report, SEMT/BCCR/RT/04-016/A, April 2004.

Y. Poitevin et al. - He testing requirement and planning for the development and qualification of HCLL TBM - CEA report SERMA/04-3470/A, 09/2004.

A. Li Puma et al. - Helium Cooled Lithium Lead Test Blanket Module for ITER Engineering design, analyses and test programme & needs - Task EFDA TW2-TTBC001-D01 - Final Report on sub deliverables 1d, 1e, 1g and 1h, CEA report SERMA/RT/05-3568/A, 03/2005.

A. Li Puma, Y. Poitevin, L. Giancarli - The Helium Cooled Lithium Lead blanket test proposal in ITER and requirements on Test Blanket Modules instrumentation - to be published in Fus Eng Des.

G. Rampal, A. Li Puma, Y. Poitevin, E. Rigal, J. Szczepanski, C. Boudot - HCLL TBM for ITER - Design studies", to be published in Fus Eng Des.

Y. Poitevin, L. Boccaccini, A. Cardella et al. - The EU Breeding Blankets development and the test strategy in ITER - to be published in Fus Eng Des.

L.V. Boccaccini, J-F. Salavy, R. Lässer, A. Li Puma, R. Meyder, H. Neuberger, Y. Poitevin, G. Rampal - The european test blanket module systems: design and integration in ITER - Proceeding ISFNT-7 (invited paper) - to be published in Fus Eng Des.

G.Rampal, D. Gatelet, L. Giancarli, G. Laffont, A. Li-Puma, J.F. Salavy, E. Rigal - Design approach for the main ITER Test Blanket Modules for the EU Helium Cooled Lithium-Lead blankets - Proceeding ISFNT-7 - to be published in Fus Eng Des.

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TW2-TTBC-002-D03

Task Title: TESTING OF SMALL-SCALE MOCKS-UPS TO QUALIFY MANUFACTURING TECHNOLOGIES

INTRODUCTION

The aim of this study is to validate the manufacturing of HCLL blanket mocks-up, made in the frame of the action TW2-TTBC-002-D01&D02, by means of thermo-mechanical loads, representative of blanket running conditions.

The principal program steps are:

- Design of the He cooling loop of DIADEMO.
- Design of the PbLi test section.
- Manufacturing.
- Thermomechanical tests.
- Endurance tests.

2004 ACTIVITIES

After the design of the helium loop during 2003, the manufacturing has been launched and it will be ended at the beginning of 2005.

Figure 1 : Exchangers of He loop

During the manufacturing of the helium loop, the conceptual design of the PbLi test section have been carried out until the phase of tendering for manufacturing.

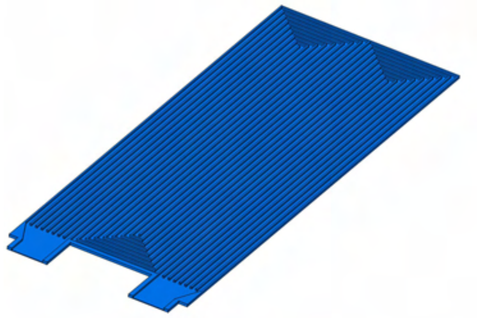

Figure 2 : ½ cooling plate

DESIGN DATA

The conceptual design of the PbLi test section has been made taking into account that one cooling plate of the HCLL blanket concept was the DIADEMO test mock-up:

- Object tested: 1 CP of typical TBM dimensions and operating conditions.
- CP orientation: horizontal.
- PbLi container: in order to limit the PbLi inventory in the test section, it is accepted to use a rectangular steel container. The upper and lower plates of this container shall be at a distance of the CP of the same order of magnitude of the pitch between two cooling plates.
- Possibility to test several cooling plates: Even if only CP is tested here, it is recommended to design an external vessel compatible with the test of at least a group of 3 CPs separated by the reference pitch.
- Heat loading: A relevant power deposition on the CP (via PbLi by conduction) is expected.
- Instrumentation: thermocouples shall be instrumented on the plate external surface to follow the temperature evolution along tests; Tin/out He and Q He shall be measured.
- CP fixing: the CP shall be fixed on the container box in the same way as in the TBM.

PBLI TEST SECTION

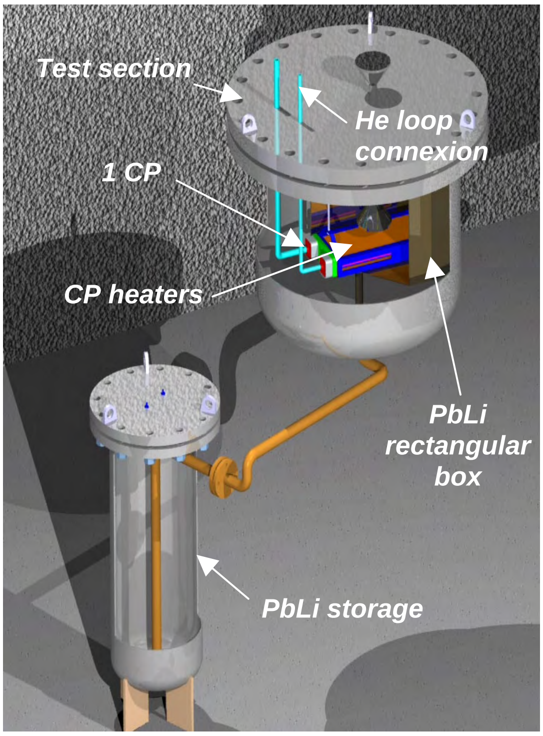

Figure 3 : PbLi test section

PbLi test section is composed of 2 pressure vessels (figure 3):

- The PbLi storage.
- Test section, where is located the cooling plate.

To limit the PbLi inventory in the test section, a rectangular steel container is put in the test section. The level of PbLi is controlled by means of differential pressure regulation between storage and test section. The fixation of CP has been designed in the same way than TBM fixations.

A relevant power deposition on the CP is made by means of electrical heaters how it is shown in figure 4.

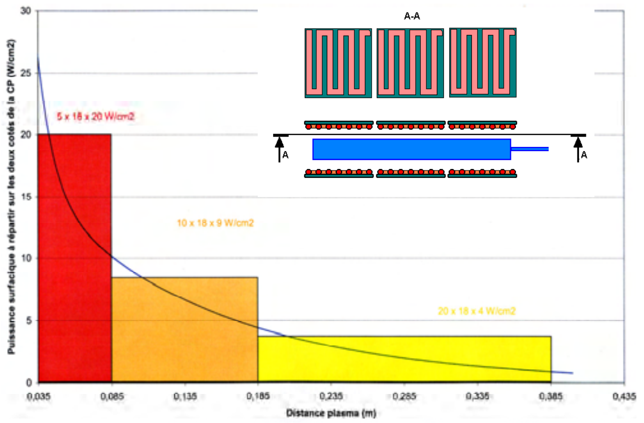

Figure 4 : Illustration of the CP heaters

CONCLUSIONS

After, this conceptual design phase, a call for tender for "detailed design and manufacturing" has been launched at the end of 2004. The test section will be available at the middle of 2005. Taking in account a CP mock-up available in July 2005 (TW2-TTBC-002-D02a), the experimental program will can begin in September 2005 to be continued up to Marsh 2006.

REPORTS AND PUBLICATIONS

F. DELASSALLE et al - APS d'une section d'essais en PbLi pour CP sur DIADEMO HCLL - NT DTN/STPA/LTCG 04-028.

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TW2-TTBC-005-D01

Task Title: HELIUM COOLED LITHIUM LEAD - SAFETY AND LICENSING Test Blanket Module (TBM) accidental safety study

INTRODUCTION

Within the framework of investigations foreseen in the International Thermonuclear Experimental Reactor (ITER), a Test Blanket Module (TBM) program is scheduled.

Several types of TBM are developed in parallel and, among them, the CEA (Commissariat à l'Energie Atomique) has proposed a concept called HCLL-TBM (Helium Cooled Lithium Lead-TBM). The TBM design is based on the DEMOnstration reactor (DEMO) blanket module. Besides the HCLL-TBM design stage performed in DM2S/SERMA at CEA/SACLAY [1], the DER/SESI at CADARACHE has to provide thermal and thermal-mechanical analysis of the HCLL-TBM under accidental conditions.

In 2004, the HCLL-TBM behaviour under Loss Of Coolant Accident (LOCA) operating conditions has been assessed in one of its worst scenario: the ex-vessel LOCA with active plasma shutdown after delayed accident detection with disruption. More precisely, the HCLL-TBM mechanical integrity is assessed in two steps. Firstly, the mechanical stresses generated during the accidental transient have been computed. Then, secondly, a comparison with the allowable stress intensity according to the Structural Design Criteria for ITER (I-SDC) [2] has been carried out.

2004 ACTIVITIES

In order to determine the thermal-mechanical behaviour of the whole HCLL-TBM (figure 1), three models have been carried out with the finite elements method (CAST3M). These models allow to compute the thermal and the stress fields within the HCLL-TBM during the transient.

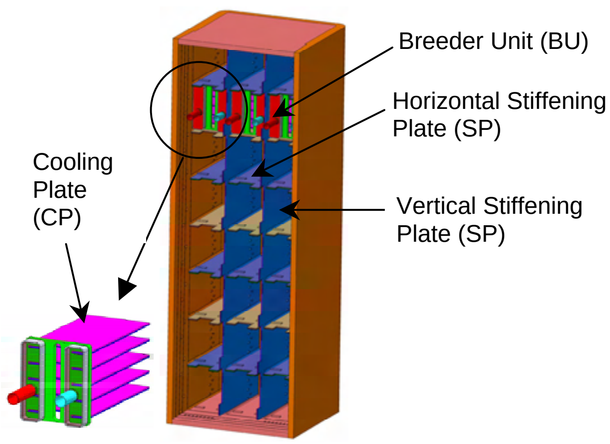

Figure 1 : HCLL-TBM 3D view

By design, all structures are actively cooled with helium. The helium flow, at 8.0 MPa, allows to maintain the steel temperature below a critical temperature. The section of helium channels is rectangular:

- First Wall (FW) helium channel section:
  * 10.5 x 15.0 mm^2
- Stiffening Plate (SP) helium channel section:
  * 10. x 3.0 mm^2
- Cooling Plate (CP) helium channel section:
  * 4. x 4.5 mm^2

Each model is representative of a specific part of the HCLL-TBM (figure 2):

- model Nr 1: lower part of a Breeder Unit (BU) with a horizontal SP completely welded to the FW,
- model Nr 2: middle part of the cell without horizontal SP,
- model Nr 3: upper part of the cell with lithium-lead opening between the horizontal SP and the rear of the FW.

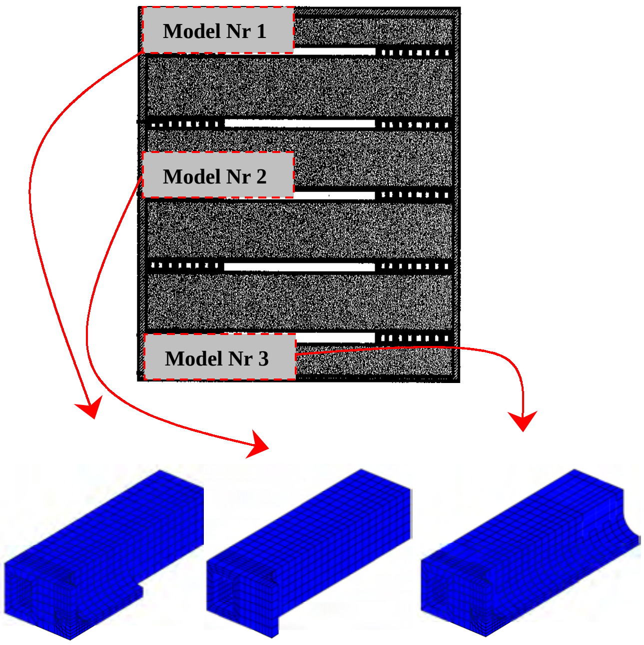

Figure 2 : Positioning of the three models into a BU – FW meshing of Nr 1, 2 and 3 models respectively

The originality of these models is to describe the exact geometry of the connection between the SPs and the FW.

An example of complete meshing is given in figure 3 to figure 6, relative to the model Nr 1.

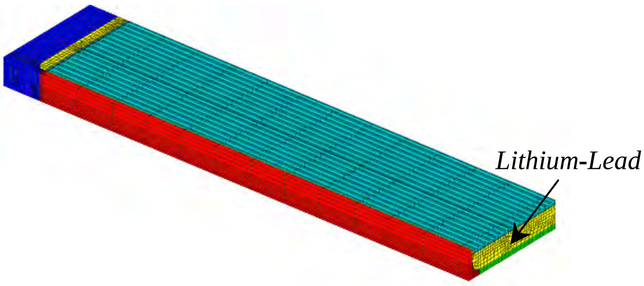

Figure 3 : Example of 3D model - Model Nr 3

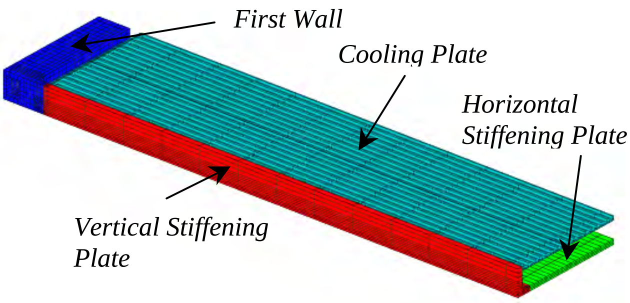

Figure 4 : Representative of steel structures (EUROFER)

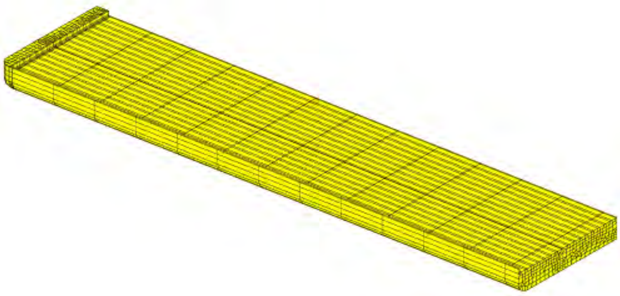

Figure 5 : Representation of the coolant (Lithium-Lead)

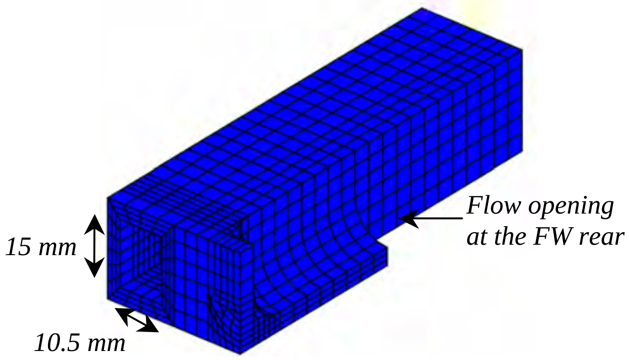

Figure 6 : Representation of the FW

The geometrical data come from the designer (DM2S/SERMA), the physical properties of helium [3] and Lithium-Lead [4] from literature and the thermal-mechanical characteristics of the steel structure, EUROFER, come from the up to date appendix A of I-SDC, December 2004 [5].

The thermal-hydraulic features taken into account are summarized in figure 7.

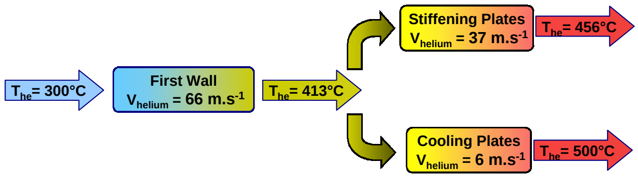

Figure 7 : Helium flow scheme

The thermal loads considered in this study are:

- Heat Flux (HF) on the FW of 0.5 MWm^{-2}.
- Power density distribution related to a Neutron Wall Loading (NWL) of 0.78 MWm^{-2}.

The simulation establishes, first, the permanent thermal field under normal operating conditions, and then assesses the accidental transient. The transient consists of the total loss of helium flow after one second. This event occurs everywhere in the helium channels of the HCLL-TBM.

The sequence is therefore the following:

- t = 0 s - Loss of coolant beginning
- t = 1 s - Complete loss of coolant
- t = 3 s - Detection of accident
- t = 13 s - Shutdown with disruption during 100 ms
- t = 13.1 s - Effective shutdown.

Throughout the disruption, the HF reaches 5.5 MW.m^{-2} [6] (see figure 8). The simulation is extended up to 120 seconds in order to represent the cooldown phase.

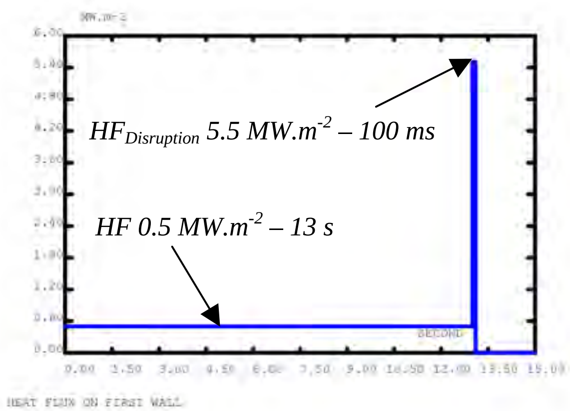

Figure 8 : Heat Flux (HF) on FW - Plasma shutdown after delayed accident detection with disruption

The FW temperature is dominated by HF magnitude. At the beginning of the transient, the FW maximum temperature is 558°C facing the plasma. The beginning temperature is the same for the three models. During the transient, the temperature increases. The maximum temperature is reached at the middle part of the BU (model Nr 2):

576 °C at t = 1 s (complete loss of coolant),
634 °C at t = 3 s (effective detection of accident),
823 °C at t = 13 s (shutdown with beginning of disruption),
951 °C at t = 13.1 s (end of disruption),
578°C at t = 120 s (end of simulation).

Figure 9 shows FW temperature evolution.

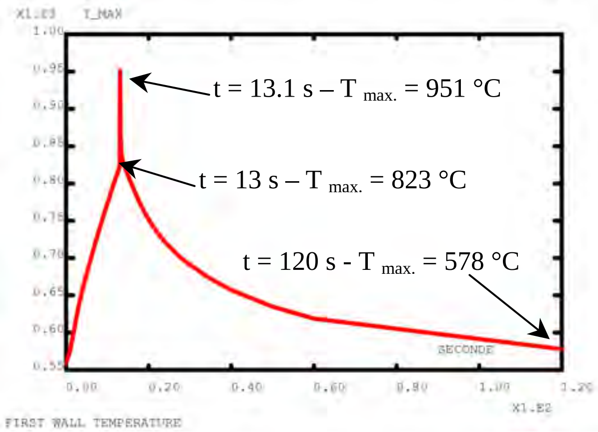

Figure 9 : Model Nr 2 - FW temperature evolution during the transient

Figure 10 gives the FW thermal field when the temperature is maximum (t = 13.1 s), just at the end of the disruption event. The temperature is quite homogeneous in front of the helium channel. The FW rear zone remains relatively cool at 500°C.

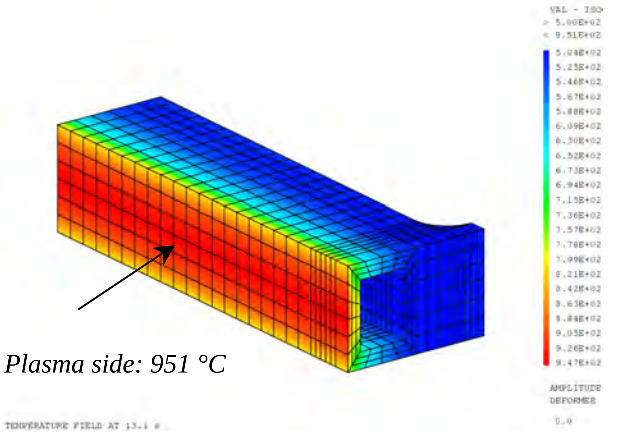

Figure 10 : Model Nr 2 at t = 13.1 s – FW thermal field

The corresponding CP temperatures range between 557 °C and 467 °C (figure 11).

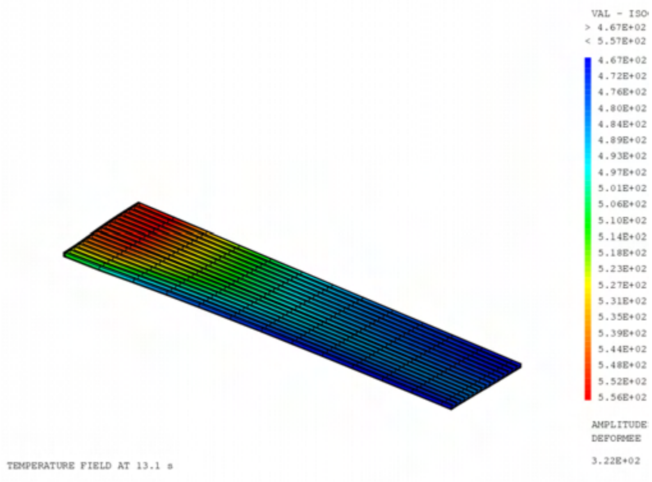

Figure 11 : Model Nr 2 at t = 13.1 s – CP thermal field

From the point of view of mechanical loads, the internal pressure of 8.0 MPa is applied in the FW helium channel (figure 12). The mechanical analysis is carried out at 13.1 seconds.

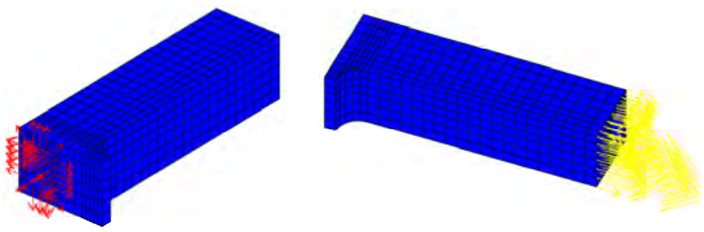

Figure 12 : Model Nr2 – Mechanical loads including end effect (yellow arrows)

The equivalent primary stresses (Von Misès) are computed and displayed in the FW meshing (figure 13).

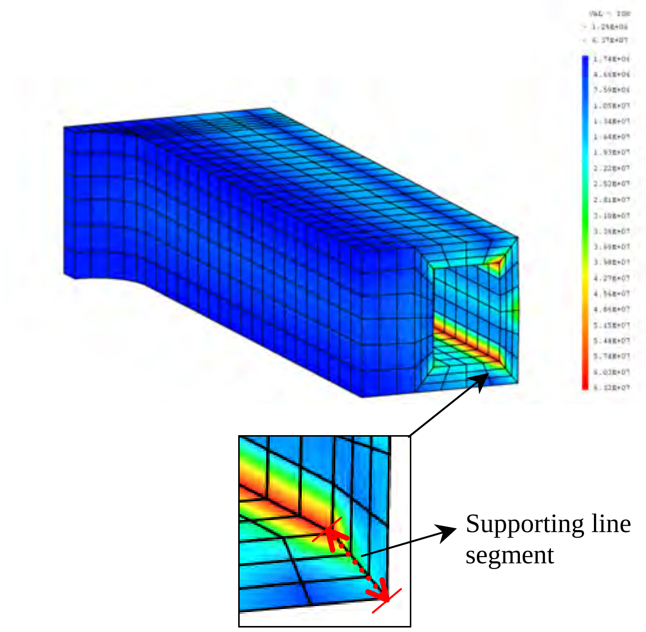

Figure 13 : Model Nr 2 – Equivalent primary stress (Von Misès) at 13.1 s

The stress intensity is 63.7 MPa. The maximum stress area is located at the corner of the helium channel. Hence, the mechanical analysis is performed at this location (see supporting line segment in figure 13). The main thermal-mechanical features are:

- average temperature θ_m,
- primary membrane stress intensity P_m,
- primary local membrane plus bending stress intensity $L_m + P_b$.

The results obtained on the three models are summarized in table 1.

Table 1 : Thermal-mechanical results

	Model Nr 1	Model Nr 2	Model Nr 3
θ_m	735 °C	739 °C	735 °C
P_m	31.4 MPa	31.4 MPa	31.3 MPa
$L_m + P_b$	62.7 MPa	62.7 MPa	62.6 MPa

The P_m and L_m+P_b stresses are compared to the allowable stress intensity function of the event classification. For the LOCA event, the level D criteria of I-SDC are applied:

- $P_m \leq$ Min {2.4 S_m (θ_m) ; 0.7 $S_{u\ min.}$ (θ_m)} (1)
- $L_m+P_b \leq K_{eff.}$ x Min {2.4 S_m (θ_m) ; 0.7 $S_{u\ min.}$ (θ_m)} (2) where K_{eff} = 1.5 in this case

S_m is a temperature dependent allowable stress intensity and $S_{u\ min.}$ the minimal value of the ultimate tensile strength. At the supporting line segment average temperature, the allowable stress intensities are (see figure 14 and table 2):

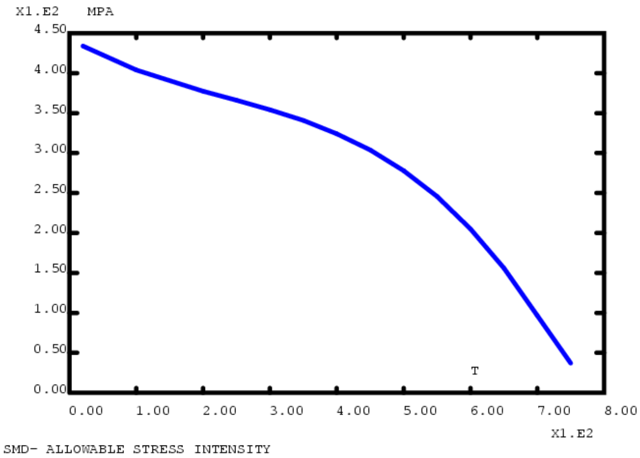

Figure 14 : EUROFER - Min {2.4 S_m ; 0.7 $S_{u\ min.}$ } versus temperature

Table 2 : Allowable stress intensities at average temperature of the supporting line segments

	Models Nr 1 & 3	Model Nr 2
θ_m	735 °C	739 °C
Limit on P_m (1)	55.0 MPa	50.5 MPa
Limit on $L_m + P_b$ (2)	82.6 MPa	75.8 MPa

The primary stress intensities do not exceed the allowable values. So, the level D criteria are verified, demonstrating that there is no risk of FW break.

CONCLUSIONS

The thermal-mechanical study performed in 2004 at the CEA/DEN/CAD/DER/SESI deals with the HCLL-TBM behaviour under a severe LOCA event:

- complete loss of helium flow,
- shutdown delayed (HF of 0.5 MW.m^{-2} during 13 s),
- disruption occurrence (HF of 5.5 MW.m^{-2} during 100 ms).

In this case, the results obtained show that there is no risk of FW break. The criteria level D of I-SDC are verified with margins.

REFERENCES

[1] Report DM2S SERMA/LCA/RT/03-3350 - Helium Cooled Lithium Lead Test Blanket Module for ITER outline design and manufacturing sequence (EFDA TASK TW2-TTBC-001-D01) A. Li Puma et al.

[2] ITER G 74 MA 8 01-05-28 W0.2 - ITER Structural Design Criteria for in-vessel components (SDC-IC).

[3] Helium characteristics - Rapport CEA R 3791 DEP/EMT/T/68-216.

[4] Coolant made of Pb-17Li Note CEA STRA/DIR 86/17 Généralités sur le lithium - J. Trove.

[5] DMN Technical Report DMN.DIR/NT/2004-02/A - Fusion Demo Interim Structural Design Criteria - Appendix A Material Design Limit Data A3.S18E Eurofer Steel - (EFDA TASK TW4-TTMS-005-D01) - F. Tavassoli.

[6] Interface of blanket testing and ITER design - V. Chuyanov and ITER international team.

REPORTS AND PUBLICATIONS

N. Schmidt - ITER - Outlines of the TBM for ITER calculations -CEA/DEN/CAD/DER/SESI/LESA/NT D0 14.

N. Schmidt - ITER - Evaluation of HCLL-TBM thermal-mechanical behaviour in case of LOCA - CEA/DEN/CAD/DER/SESI/LESA/NT in progress.

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TW4-TTBC-001-D01

Task Title: TBM DESIGN, INTEGRATION AND ANALYSIS Testing programme and engineering design of the first HCLL TBM for ITER H-H phase

INTRODUCTION

The objective of this activity is the development of the design and testing programme of the first TBM (Test Blanket Module) to be inserted in ITER during the H-H plasma phase.

Is it focused on the TBM itself and therefore the design of the associated systems and components is only very preliminary.

In fact, the main part of the TBM design activities have been performed under another subtask [1] and are oriented towards the definition of a TBM design directly derived from the corresponding DEMO modules. These activities will permit to define the design of the TBM required for a fully integrated test program under D-T plasma after several years of operation (the so-called Integral TBM", IN-TBM). In parallel to this activity, it is essential to define the design and the testing program of the first TBM to be inserted in ITER during H-H plasma (from the first day of ITER operation).

The objective of the present subtask is to define a testing program and to develop a design, including instrumentation, for the first TBM able to take advantage of the ITER H-H phase to progressively qualify and optimise the TBM behaviour before D-D and D-T plasma operations. This TBM is often called "Electro-Magnetic TBM" (EM-TBM).

2004 ACTIVITIES

The activities for this subtask efficiently start only after having made some progress on the design of the IN-TBM and after the first definition of a relevant instrumentation. Therefore, the 2004 work on the EM-TBM has addressed only the test objectives during the H-H phase and the assessment of the main expected differences between the IN-TBM and the EM-TBM. The finalisation of the subtask is expected in 2005.

PROPOSAL FOR A TESTING PROGRAMME DURING H-H PLASMA; KEY POINTS FOR CODE AND TECHNOLOGY QUALIFICATION

From the preliminary global list of test objectives to be achieved during ITER program, some fields of test activities have been identified as relevant to be started during the HH phase, on the bases of the following criteria:

- to gain earlier confidence in the TBM before DT phase (ex: structural robustness, compatibility of the module with ITER operations),

- to develop experimental skills on sensitive activities in real ITER environment (ex: T management using safe D equivalent),

- opportunity to use the specific ITER environmental conditions not easily available out of this facility (ex: high magnetic fields, stress induced by plasma disruptions),

- interest to host extensive or intrusive instrumentation before encountering more stressing conditions due to neutron load (validation of MHD codes for LiPb circulation with numerous flow-meters).

Based on these criteria, the main objectives of test during the H-H phase can be summarized as follows:

- Verify the need of Be coating on the First Wall (FW) due to the compatibility with ITER plasma operation.

- Assess the impact of RAFM (Reduced Activation Ferro Magnetic) steel on plasma stability. Ferromagnetic materials cause a deformation of magnetic fields also in static conditions; in ITER the magnetized structures (e.g. of the TBM's) produce a non-axisymmetrical magnetic field in the plasma region which can affect plasma stability and lead to disruption.

- Develop and validate computational tools suitable for design calculation of reactors components based on RAFM structures.

- Validate the structural integrity of the box and of the attachment system (especially during disruption and Vertical Displacement Event). This validation is of extreme importance for the safety dossier for the acceptability of similar TBMs in the D-T phase.

- Measure the Magneto-Hydro-Dynamic (MHD) pressure drops as a function of PbLi flow-rate.

- Assess the tritium diffusion in the PbLi and permeation into the cooling He and qualify the tritium extraction system and the He purification system. The tritium will be simulated using H/D diluted in the PbLi circuit which has to be tested up to relevant DEMO temperatures. Tests should be performed for different DEMO-relevant H/D-partial pressures such as 100 Pa, 500 Pa, and 1000 Pa.

- Evaluate the H/D inventory in the TBM and external circuits for different DEMO-relevant D-partial pressures such as 100 Pa, 500 Pa, and 1000 Pa.

- Assess the overall functionality of the HCLL System, both in the TBM (e.g., heaters if needed, measurement devices such as thermo-couples, sensors, etc.) and in the ancillary equipment for He-circuits (pumps, heat exchanger, flow-meters, thermocouples, etc.) and PbLi circuit (pumps, valves, tritium extractor, etc.).

- Verify the safety-relevant functions (e.g., required time for valves opening and closing, etc.) implemented in the TBM system.

- Confirm the heat losses, kinetics for heating and cooling of the circuits, draining of the PbLi.

- Validate the capability of heat extraction from the First Wall (FW), taking into account the deposited surface heat and thermocouples measurements in structures and FW cooling circuit.

During commissioning, the tightness of the various HCLL system components (including external circuits) will be tested with gas (cold and hot) leak tests. The validity of the remote repair procedure will be checked. The PbLi filling procedure, requiring the previous structure heating with circulating He and eventually with appropriate heaters (in order to avoid PbLi freezing) will be moreover validated.

TBM DESIGN PROPOSAL AND ANALYSES

New concepts allowing easily insertion of the instrumentation have been designed (ex: annular columns between BPs and gloves finger penetration inside BUs), which will be used also in the following TBMs until the IN-TBM.

Innovative sensors offering high potential in term of installation facility and insensitivity to nuclear fusion environment could be tested (ex: optic fibre engraved with Bragg grazes for temperature measurement or even for other physical data).

Analytical and FEM computations have been performed to assess the possibility to use externally D-saturated LiPb in order to evaluate T-permeation and T-control in the absence of T bulk production by neutron. The expected very low concentration of D in He coolant has led to design a dedicated purge gas circuit in the EM-TBM.

Another driving factor for the EM-TBM design is the fabrication constraints that could beneficiate of some relief during H-H phase due to the lower heat load (ex: thicker CPs), according to the recommendations of the manufacturer.

These considerations will be integrated in the EM-TBM drawings at the beginning of 2005.

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