TW2-TTBC-002-D02

Task Title: MANUFACTURING AND TESTING OF MOCK-UPS: QUALIFICATION SAMPLES FOR HCLL AND HCPB TBMS

INTRODUCTION

This task deals with joining technology development, fabrication and testing of mock-ups to qualify manufacturing technologies for TBM assembly (figure 2). The demonstration of the integration of manufacturing technologies will be assessed through the fabrication of a TBM demonstrator: 6 cells mock-up. Joining technologies will be defined, developed and applied in the different stages of the task, in relation to welding tools and clamping devices developments. Cap to first wall joining has been processed by Electron Beam and Hybrid (MIG/Laser) welding processes.
Stiffening grid joining and stiffening grid joining to the first wall developments on Eurofer steel using the TIG and laser techniques, has been run out. The "T" joining development in extreme geometrical stress configuration for each cell has been conducted till demonstration fabrication of different mock-ups, including the material mock-up for neutron diffusion residual stress analysis for TW5-TTMS-004-D03 task (ENEA) and modelling instrumented mock-ups for TW5-TTMS-004-D04 task (CEA) and neutron mock-up have been successfully processed.

2006 ACTIVITIES

OBJECTIVES

For TBM manufacturing, three stages must be developed:
- Stiffening Grid joining and Stiffening / First Wall joining,
- First Wall / Cap joining.

The definition of the final 6 cells mock-up can be seen in figure 1:

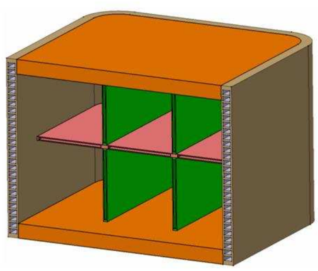

Figure 1: 6 cells mock-up

Two horizontal stiffening grids (with channels) slabs with continuous welds to FW and vertical stiffening grids. First Wall lateral slabs: 25 mm thickness (no available batch 40 mm in Eurofer).

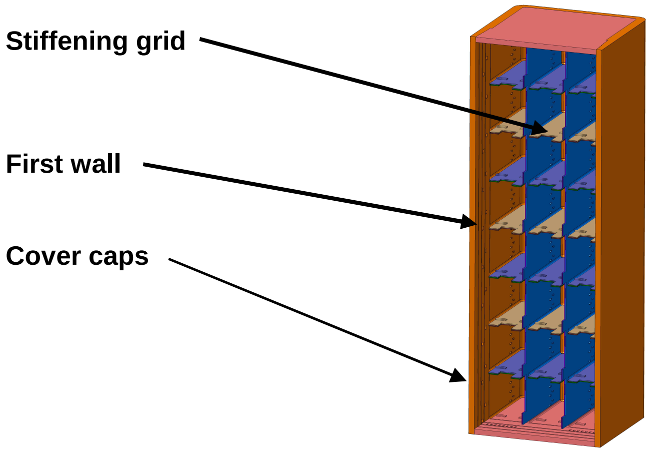

Figure 2: TBM module (HCLL concept)

COVER CAP / FIRST WALL JOINING

Two welding processes procuring minimum distortions such as Electron Beam and Hybrid MIG / Laser processes have been tested for performing the joint design (figure 3).

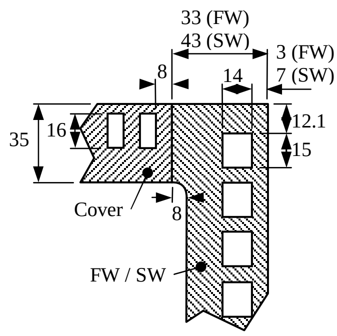

Figure 3: Cover Cap / First Wall joint design (HCLL concept)

Electron beam welding

The following welding parameters have been applied: High voltage: 150 kV, Welding current: 72 mA, Travel speed: 5 mm/s.

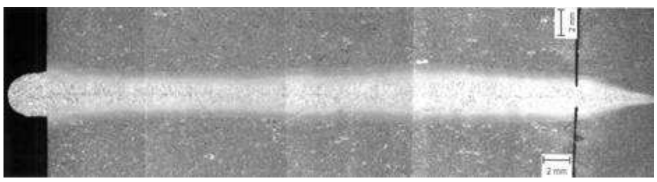

Figure 4: Electron Beam weld on 40 mm thickness Eurofer sample

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TW2-TTBC-002-D03

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

INTRODUCTION

The aim of this study is to validate the manufacturing process of HCLL blanket mock-up by means of thermomechanical tests in representative operating conditions of the breeder blanket module.

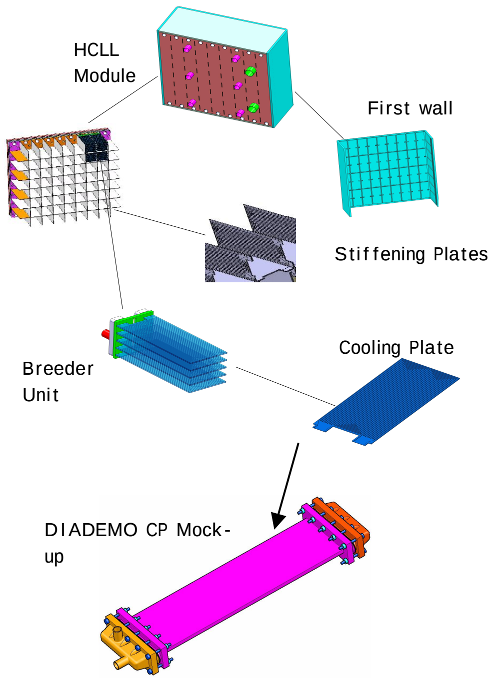


Figure 1: Composition of HCLL module – DIADEMO CP Mock- up

This manufacturing validation program will begin by the manufacturing process of the Cooling Plates (CP). For that a mock-up is manufactured in the task TW2-TTBC-002-D01. This mock-up manufacturing is relevant of the CP manufacturing, but its geometry is simplified (figure1):

- 8 straight channels of 4x4.5 mm² with 360 mm length,
- 1 U turn in a distribution box,
- The width the 2x 8 channels is 94.5 mm,
- The cooling plate, the He feeding and collector are made of EUROFER.

The principal program steps are:

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

2006 ACTIVITIES

The year 2006 was devoted to the preparation and the tests of the mock-up.

Due to the delay of the mock-up delivery (task TW2-TTBC-002-D01), these operations begun in the second part of the year, and only 3000 transient tests have been made in ITER relevant conditions.

The instrumentation, essentially thermocouples, was located with the help of calculations made in the frame of the tasks TW5-TTBC-001-D10 (figure 2).

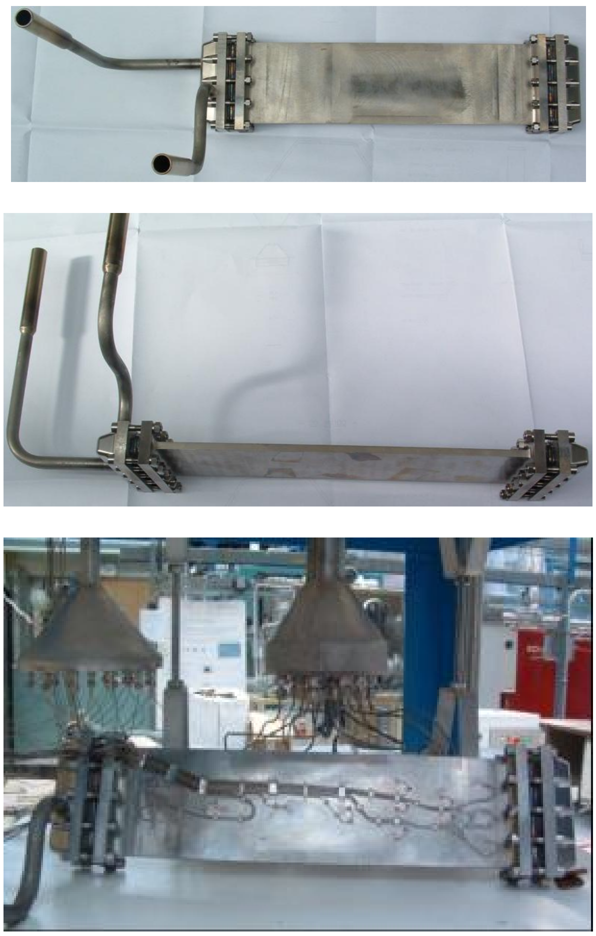


Figure 2: CP mock-up with its instrumentation

Then, the instrumented mock-up was mounted on the test section support, equipped with the heaters which allow the simulation of the thermal gradient in the CP length due to the plasma (figure 3).

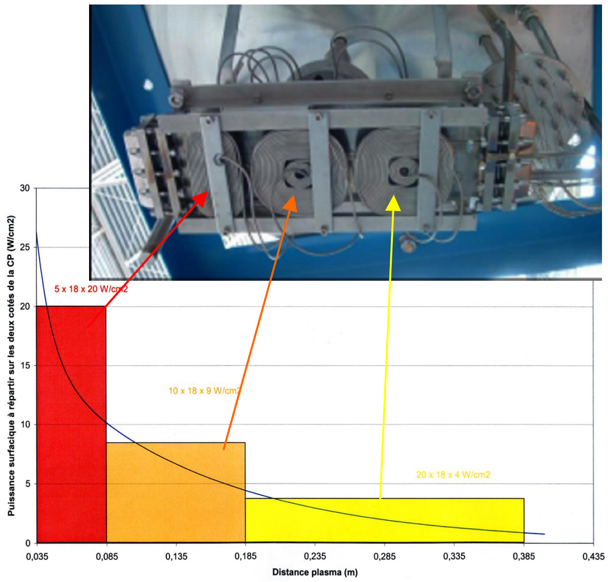
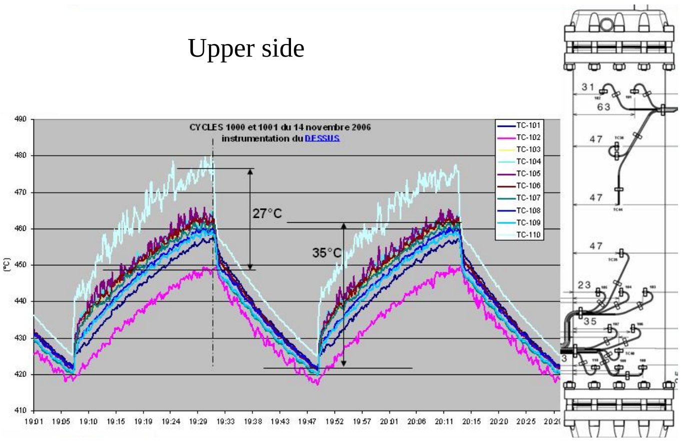


Figure 3: CP mock-up on its test section support with heaters

After that, the test section has been closed and the transient tests, in ITER relevant conditions began.

	DIADEMO Mock up
Plates dimensions	Width 88mm Length 368 mm Thick 6.5 mm
Channels dimensions	4x4,5 mm²
Average extracted power (kW)	1
Heat loading conditions (versus time)	Power on : 1400 s Power off : 1000 s 3000 cycles (≈3 months)
He flow (g/s)	8 g/s
He velocity (m/s)	10 m/s
He Tin/out (°C)	400/450 & 450/500

3000 cycles have been made in such conditions. The heat removal of the mock up, by the helium loop, was stable (about 1,2 KW when the power is on) all along the tests. The PbLi reached near the heaters a temperature up to 650°C during the power on phases.
The typical informations given by instrumentation are illustrated by the figure 4.



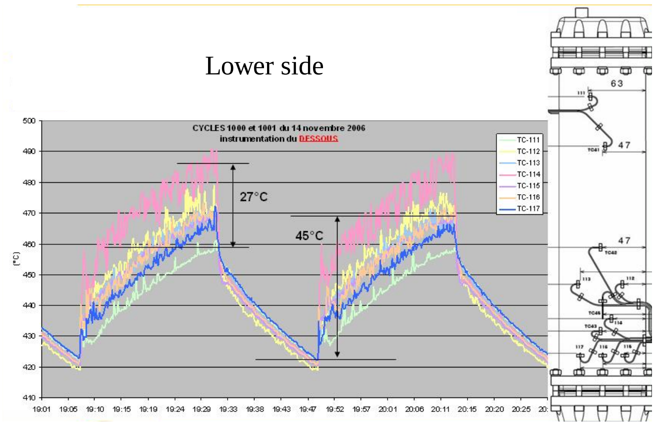


Figure 4: Typical information given by thermocouples during transient cycles

These results are the first obtained without post examination study and without expertise of the mock-up.
The main issue encountered during these tests is the corrosion of the stainless steel sheath of the thermocouples. The figure 5 shows the loss of thermocouples versus time.

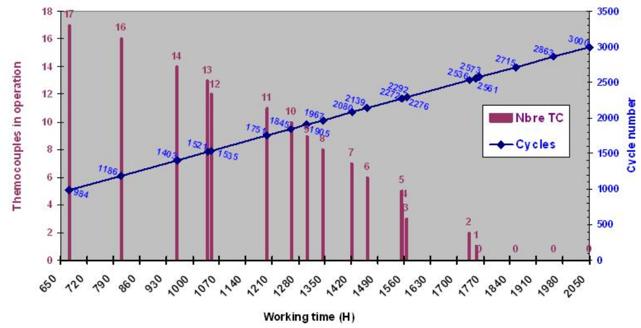


Figure 5: Loss of thermocouples due to corrosion vs time

This corrosion issue was pointed out before the tests but the lack of solutions, and also the lack of time to develop them, push us to go on with standard instrumentation.

CONCLUSIONS

After 3000 transient cycles made during 3 months showing a good functioning of the DIADEMO device, no leak occurred in the mock up.
So up to now, after the first investigations, manufacturing technologies seem to be qualified. Of course detailed expertises of the mock-up will have to be performed in order to confirm these first encouraging results.

For the next experimental manufacturing demonstrations, which could be done on a set of 3 CP (scale 1/TBM), corrosion issue in liquid metal of instrumentation will have to be solved.

REPORTS AND PUBLICATIONS

L. CACHON et al., "Blanket manufacturing technologies-Testing of small-scale mocks-ups to qualify manufacturing technologies" NT DTN/STPA/LTCG 2007-05.

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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. It is 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).

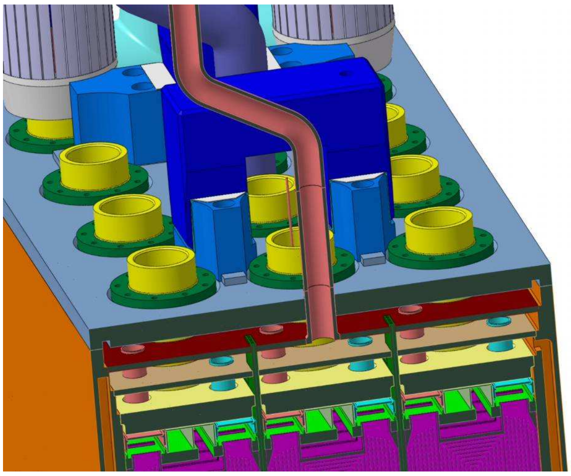

Figure 1: View of the HCLL EM-TBM with cut in the by-pass exit tube plane

2006 ACTIVITIES

The final report activity [2] has been written and is to be published. This report describes the specific features of the Helium-Cooled Lithium-Lead EM-TBM compared to the most demanding one, the In-TBM which will be tested in the high duty phase of D-T plasma in ITER. The document only focuses on dedicated testing programme, specific design features and particular thermal-hydraulics and hydrogen permeation calculations.

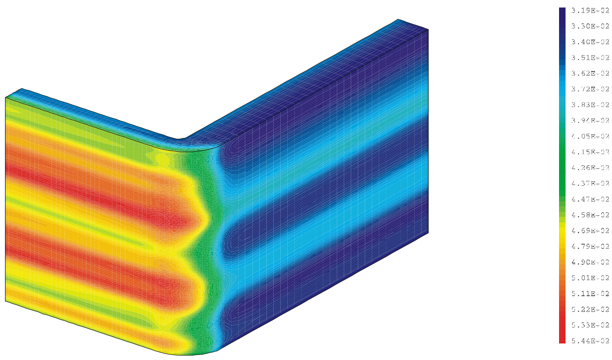

Figure 2: Temperature distribution (°C) in the FW (flux=0.30 MW/m^2, He mass flow=0.6 kg/s)

CONCLUSIONS

Because the EM-TBM shares the main design features of the In-TBM while it is tested in less demanding loads situations, critical dimensioning studies such as thermo-mechanical and mechanical calculations have not been repeated. It is therefore not necessary to circulate the whole He mass flow envisaged for the In-TBM in the first phase of ITER operation. Moreover, if heaters are used to heat the PbLi (because no neutronics power is deposited during the EM phase), an overcooling of the FW and the breeding zone is expected if circulating the same He mass flow. A by pass has therefore been situated at the exit of the FW, so that only one part of the He mass flow goes to the other subcomponents (figure 1). Nevertheless, some thermal-hydraulics calculations have been performed (figure 2) in order to assess the effect of the lower heat flux occurring in the HH phase. Main conclusion is that a He mass flow reduced to 0.6 kg/s is sufficient to ensure that temperature limits are not exceeded (in case of peak heat load) but leads to a He outlet temperature of 355°C when assuming the average flux value.

In order to be able to test permeation and internal structure behaviour under temperatures relevant for In-TBM, PbLi heaters will be necessary. A permeation study has also been performed. It is shown that even if PbLi entering the TBM is saturated with Hydrogen or Deuterium, the amount of permeated H/D towards He circuits will be very low and difficult to measure with classical equipments.
One solution in order to investigate permeation with the EM-TBM could be to dedicate some breeder units to permeation tests with specific low flow rate He purge circuit coming by dedicated feeding tubes (figure 3 and figure 4) instead of the main He coolant stream.
Moreover, some considerations on specific instrumentation needs have been given.

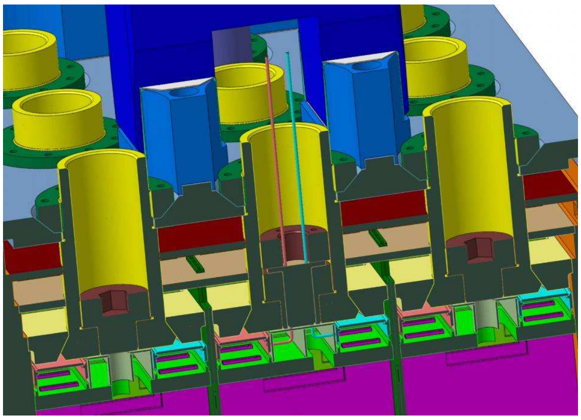

Figure 3: View of the HCLL EM TBM with dedicated He feeding tubes

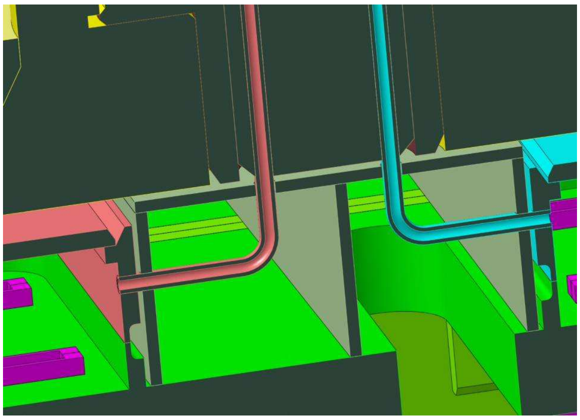

Figure 4: View of the HCLL EM-TBM with dedicated He feeding tubes (detail).

REFERENCES

[1] A. Li Puma et al., The Helium Cooled Lithium Lead blanket test proposal in ITER and requirements on Test Blanket Modules instrumentation, Fusion Engineering and Design 75-79 (2005) 951-955

REPORTS AND PUBLICATIONS

[2] G. Aiello, F. Gabriel, A. Li Puma, J-F. Salavy, Additional design and analyses for the HCLL TBM: testing programme and engineering design of the first TBM for ITER H-H phase, Report CEA, DM2S/SERMA/LCA/RT/06-4022/A

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TW5-TTBC-001-D01

Task Title: TBM DESIGN, INTEGRATION AND ANALYSIS: DESIGN AND ANALYSES OF THE HCLL TBM INCLUDING DESIGN OF SUPPORTING SYSTEM AND INSTRUMENTATION INTEGRATION

INTRODUCTION

The task aimed at completing the design and analyses for the HCLL Test Blanket Module, and for the EM-TBM (first TBM inserted in ITER) and the In-TBM (last and most complete TBM) versions. Based on an existing preliminary concept, various improvements were done in order to set fabrication issues, to introduce a possible access to instrumentation, and the attachment system. The specific features of the EM-TBM were also designed. Various analyses were performed aiming at demonstrating the withstanding of the structure under the main mechanical loads it is submitted to.

2006 ACTIVITIES

The activities related to this task were mostly achieved within the year 2005. However, a thermal hydraulic model of a TBM slice was developed within the year 2006, and used in order to update the thermal results produced for this task.

Thermal-Hydraulic Analyses

Finite Element thermal and thermal-hydraulic analyses have been performed to assess the thermal behaviour of the TBM. Previous analyses used 3 different simplified models (1 for the FW and 2 for the Breeding Zone) in order to calculate the fraction of the heat deposited in the Breeding Zone that was recovered by the FW. It was then necessary to iterate between model 1 and models 2 and 3 to obtain the final temperature distribution. In recent analyses, a new FE model comprising a whole Breeding Unit next to the Side Wall (figure 1) has been developed in order to obtain a more accurate estimate of temperature levels in the different cooling elements (FW, SPs, CPs) thus avoiding the iterative procedure and computing the thermal field in all the BU

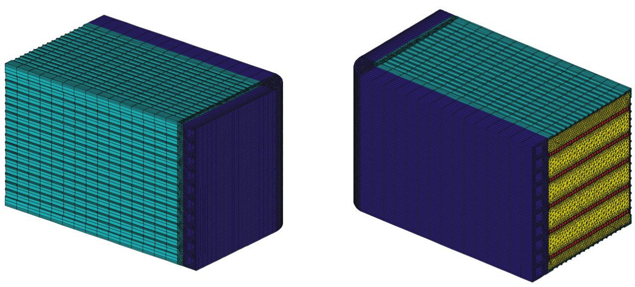

Figure 1: 3D FE model of one BU used for thermal analyses

Temperature Limits

According to the latest ITER specifications, the TBM has to withstand a surface Heat Flux of 0.5 MW/m^2 and a Neutron Wall Load of 0.78 MW/m^2 without exceeding the assumed temperature limits. Those limits derive from considerations on the DEMO reactor.
In particular, He inlet temperature is fixed by the embrittlement of Eurofer under irradiation. The increase of the DBTT (Ductile Brittle Transition Temperature) can become a concern if irradiation temperature is lower than 300 °C.
As far as the maximum steel temperature is concerned, thermodynamic considerations would suggest a He outlet T as high as possible; however, the strength of the steel drops sharply above 550 °C and its creep strength is sharply reduced for T > 600°C. As a compromise, 550°C has been fixed for the DEMO reactor on the basis of the S_t criterion (according to DISDC rules), assuming 10,000 h of operation time and a primary stress of 100 MPa. Although the TBM will not work at these conditions, the 550°C has been assumed as a temperature limit in order to keep the DEMO relevancy.
Besides, experimental campaigns have been carried out to estimate the compatibility between the lithium lead and FM steels at high temperatures. Available results suggest that the corrosion of Eurofer due to a Pb-Li flow appears acceptable up to a temperature of 550°C but more data are still needed.

Loads

The total power deposited in the TBM is summarized in table 1.

Table 1: Thermal power on the TBM (HF = 0.5 MWm^{-2}, NWL = 0.78MWm^{-2}

Regions	Deposited Power kW	
LiPb	406.5	
First wall	90.0	
Side wall	52.1	
Backplate	6.6	
Top Cap	12.0	
Bottom Cap	12.5	
Stiffening plate tor-rad	7.0	
Stiffening plate pol-rad	6.2	
Cooling plates	29.1	
Total Nuclear		622
TOTAL from FW HEAT FLUX (HF = 0.5 MW/m^2)		573
Total FW	663.4	
Total (Nuclear + heat flux)		1195

For the FE analyses, the following loads have been assumed:
- A heat flux on the FW = 0.5 MWm^{-2};
- A constant nuclear power density in the FW equal to

$$q^{III} = \frac{0.78}{0.75} \text{ x } 5.191 \qquad (MWm^{-3})$$

- A nuclear power density following, in the radial direction, a double exponential law of the type:

$$q^{III}(r) = \frac{0.78}{0.75} \cdot \left[a \cdot \exp(-b \cdot r) + c \cdot \exp(-d \cdot r) \right] \cdot \quad (MWm^{-3})$$

with r the distance (in m) from the plasma. The equation coefficients are summarized in the table 2 for the various materials components.

Table 2: Nuclear power density profile coefficients in the various TBM materials

	a	b	c	d
SW steel	2.7116	13.673	3.3047	5.425
hSP steel	3.2598	57.041	2.9611	10.218
vSP steel	7.4208	99.037	3.26645	11.610
CP steel	3.9592	58.0042	2.7493	10.316
LiPb	51.601	88.910	4.9510	8.0691

Boundary Conditions
A forced convection boundary conditions has been applied in the FW, SPs and CPs channels. For the Helium bulk temperature, the same hypotheses applied in [1] have been used, that is a linear temperature distribution varying between inlet and outlet values in each channel. The only exceptions are the Side Walls (SW) channels where the He temperature is constant. It should be noted that the heat recovering effect between adjacent channels is not, in this way, taken into account.
The He velocity, as well as the He physical parameters, are calculated as a function of its temperature.
The Nusselt number is estimated with the Dittus & Boelter correlation and the heat transfer coefficient calculated along the channel length.

Results
Figure 2 shows the obtained temperature distribution in the FW. The maximum value (560° C) is slightly higher than that obtained in previous analyses and also higher than the assumed limit. This difference can be explained by the more detailed modelling of the channel geometry near the bending FW/SW. In fact, the distance between the He channel and the plasma facing surface of the FW increases near the bending, which leads to higher FW temperatures. This effect could not be accounted for in previous FE models. However, the change in the He flow direction in the bending increases turbulence and thus the convection heat transfer coefficient. Since this phenomenon is not taken into account in the current model, the actual steel temperature should be lower. The temperature in the straight part of the channels remains within the assumed limits.

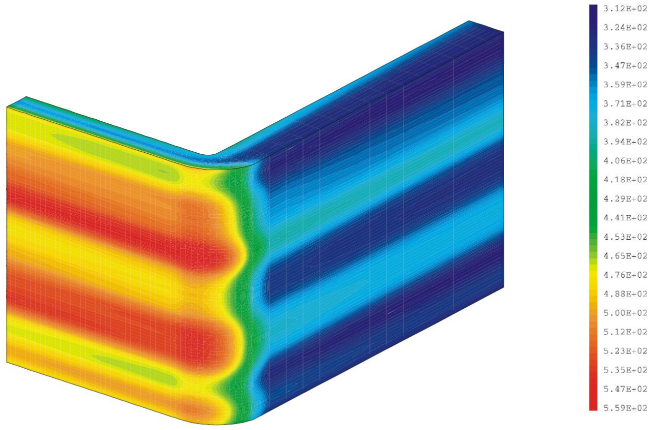

Figure 2: Temperature distribution in the FW

Figures 3 and 4 show the temperature levels in the SPs and CPs. For the CPs, the highest temperatures are located in the central one. All temperatures remain within the assumed limits.

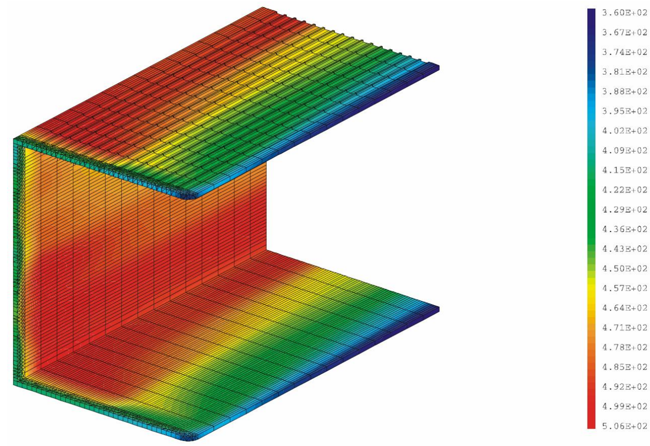

Figure 3: Temperature distribution in the SP

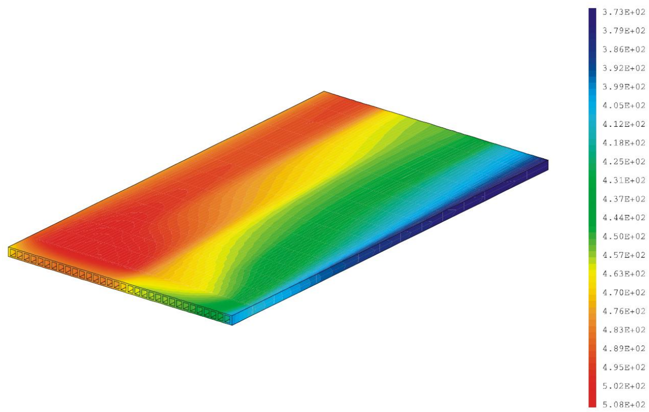

Figure 4: Temperature distribution in the central CP

CONCLUSIONS

The presented thermal hydraulics studies have completed the work that have been performed to modify, optimize, and validate the design of the HCLL Test Blanket Module. The final report [2] was achieved, including the review of the complete studies, detailed information for fabrication R&D, the assembly sequence and the whole set of 2D drawings.

REFERENCES

[1] A. Li Puma et al., "Helium Cooled Lithium Lead Test Blanket Module for ITER: engineering design, analyses and test programme and R&D needs", final report on TW2-TTBC-001-D01 deliverable, SERMA/LCA/RT/05-3568/A, December 2005

REPORTS AND PUBLICATIONS

[2] G. Rampal, "Design and analyses of the HCLL TBM including design of supporting system and instrumentation integration", final report of the EFDA task TW5-TTBC-001-D01, CEA report SEMT/BCCR/RT/06-004/A, September 2006

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TW5-TTBC-001-D02

Task Title: TBM DESIGN, INTEGRATION AND ANALYSIS FINALIZATION OF THE CONCEPTUAL DESIGN OF THE PROTOTYPICAL HCLL TBM MOCK-UP

INTRODUCTION

Within the framework of the development of Test Blanket Modules (TBM) for ITER, out-of-pile test campaigns are foreseen to qualify components, functionalities, and systems to guarantee that insertion of TBM in ITER will not affect its safety. This qualification program prior to ITER is foreseen in dedicated facilities and includes:
- The testing of the sub-components design and fabrication technology (First Wall, Breeder Units, Back Manifolds) from small to 1:1 mock-ups;
- In scale functional tests 1/4 TBM (PbLi loop with and without TBM, TBM structure, TBM structure and Breeder Units);
- 1/1 TBM mock up tests;
- Electro Magnetic TBM (EM-TBM, for ITER H-H phase) acceptance tests.

A relevant medium-scale Prototypical Mock-Up (PMU) is foreseen and will be tested in the European Breeding Blanket Testing Facility (EBBTF) in Brasimone, Italy.
The objective of this task is to finalize the conceptual design of this prototypical mock-up (preliminary design studied in the TW4 work-program) including the definition of operating parameters for test relevancy and instrumentation

2006 ACTIVITIES

Main activities for 2006 concerned the specification of measurement tools and the writing of the final report. A draft version of the final report is already written.
Previous works, presented in the last technofusion report presented the test objectives of the PMU, the mock up design and the design of the heaters simulating the heat production due to irradiation. A view of the PMU is presented figure 1.

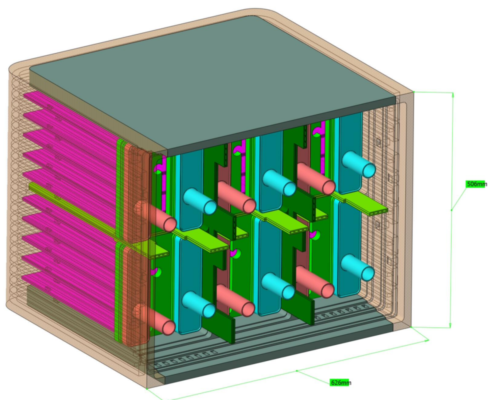

Figure 1: Conceptual design view of the TBM Prototypical Mock-Up

MEASUREMENT TOOLS

One of the PMU aims is to test the instrumentation and measurement procedure of the TBM. However, the more friendly environment (no electromagnetic fields neither neutron irradiation) as well as the possibility of acceding to the PMU from 5 sides and using more invasive tools will allow a wider choice on the off the shelves instrumentation and acquisition data chains, on the number of installed sensors and on their type.

Some measurements which could not be realized in the TBM, can furthermore be envisaged, e.g. the PbLi velocity (or mass flow) inside the TBM.

As too many measurement tools would have a major impact on the behaviour of the PMU, the number of measurements which can be carried out on a run is limited and having various test campaigns with different sets of installed instruments is so far retained.

A preliminary list of the needed measurements has been established. A distinction has to be made between the monitoring instrumentation and the experiments instrumentation. The former is supposed to be installed for the whole mock-up life duration; the latter can be dependent on the various experiments. This list is summarized in the table 1 and table 2.

CONCLUSIONS

The main functional data for the design of a HCLL TBM relevant Prototypical Mock-Up have been identified, and conceptual drawings have been produced. The next steps of the design are identified under the deliverable TW5-TTBC-001-D05, in which final drawings of the mock-up will be produced, and internal and external heating devices will be defined in more detail. The PMU design main requirement is the In-TBM for ITER relevancy [1] in terms both of thermal and mechanical behaviour and also in geometry and manufacturing procedures. That implies similar velocities and flow path for helium and PbLi, similar heat levels (First Wall, Cooling Plates), similar mechanical behaviour with regard to the pressure loads, similar manufacturing / manufacturing sequence. The main design characteristics are synthesized in table 3.

Table 1: List of possible fields of investigation for PMU monitoring

Field	***Data type***	***Location on PMU***	***Instrumentation type***
Structural response	• Structure temperatures	Box structure (internal)	Thermocouples, optical fibres
Helium thermal-hydraulics	• Temperature (inlet, outlet, by-pass) • Velocities / Mass flow (inlet) • Pressure (manifold stages, inlet and outlet, leak detection)	Inlet / outlet pipes Inlet pipe Box structure (internal)	Thermocouples, optical fibres Flow meters Pressure transducers
PbLi flow	• Temperature (inlet, outlet) • Mass flow • PbLi replenishment/draining • Pressure (leak detection)	Inlet / outlet pipes Inlet pipe Box structure (internal) Inlet / outlet pipes	Thermocouples, optical fibres Flow meters Level sensors Pressure transducers

Table 2: List of possible fields of investigation for dedicated experiments

Field	***Data type***	***Location on PMU***	***Instrumentation type***
Structural response	• Strains • Structure temperatures	Box structure (external) Box structure (internal)	Strain gauges Thermocouples, optical fibres
PbLi MHD	• Temperature field • Velocities / Mass flow distributions	In PbLi In PbLi	Thermocouples Potentiometers
H or D permeation	• Partial pressure / Gas analysis	Out of box	Permeation sensor
Corrosion by PbLi		Post-examination	

Table 3: Main data on the PMU design

Box structure				
FW thickness		25 mm		
Steel mass		480 kg		
Total mass		1250 kg		
FW max. temperature (°C)		533		
Helium scheme				
FW channels dimensions		14 x 15 mm2		
He mass flow		0.34 kg/s		
He inlet T		300°C		
He outlet T		#459°C		
Total pressure drop (bar)		1.97		
FW He velocity (min., ave., max. - m/s)		61,30	64,75	73,69
SP He velocity (min., ave., max. - m/s)		3,46	3,61	3,78
CP He velocity (min., ave., max. - m/s)		3,59	3,79	4,11
PbLi scheme				
PbLi number of recirculation per day		10	70	
PbLi mass flow (kg/s)		0.089	0.623	
Volumetric flow (m^3/h)	Mock-up	0.0327	0.229	
	Cells column	0.0109	0.0763	
PbLi velocity (mm/s)	Mock-up feeding pipe	5.7	40	
	BU cross section	0.09	0.65	
	FW opening	3	21	

REFERENCES

[1] G. Rampal et al., "Design and analyses of the HCLL TBM including design of supporting system/connections and instrumentation integration", final report on TW5-TTBC-001-D01 deliverable, to be issued.

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TW5-TTBC-001-D03

Task Title: TBM DESIGN, INTEGRATION AND ANALYSIS PIE AND HOT CELL REQUIREMENTS FOR THE HCLL TBM

INTRODUCTION

The definition of the ITER building and especially of the Hot Cell building features is a key issue that has been already extensively studied by the ITER Team. The impact of the TBM testing programme in ITER on the RH and Hot Cell facility has to be evaluated (operation schedule, storage, repairing, etc.). For that the hot cell needs for TBM maintenance operations (replacement, inspection, repairing, storage, PIE) have to be identified and compared to the ITER capabilities. Discrepancies have to be discussed with the ITER team for definition of common solution.

2006 ACTIVITIES

The bases of the HCLL TBM system Integration Description Document (IDD) have been produced by identifying main boundaries and guidelines, geometrical aspects, objects to be considered and preliminary maintenance sequence. In a future final version, this IDD should include procedures describing the mounting, dismounting and neutralisation operations specific to the HCLL-TBM. Moreover, the preliminary list of required PIE test (in-situ or external) has been described for a later evaluation with the ITER project and some recommendations for TBM cutting after operation have been derived. An assessment of the envisaged PIEs based on CEA/DMN/SEMI/LECI (Saclay hot cell operation) expertise has also been performed. It gives general informations on existing techniques and equipments potentially compatible with HCLL PIE needs. The final report for the task [1] has been edited.

OVERVIEW OF THE INTEGRATION PROBLEMATIC

The general guidelines identified in the study have been intended to be as general as possible. However in practice, they will be affected by ITER boundaries. TBM mounting and dismounting procedures will distinguish between operations in Interface-2 region (from the VV outer walls to the cryostat inner wall) and operations in Interface-3 region (behind the cryostat, i.e. in the Port Cell). These regions are illustrated on figure 1.
The boundaries of this integration study are related to Interface-2 & Interface-3 Zones, Port Cell Geometry & Available Space, Remote Handling System (RHS), and Testing Apparatus & Cables. The preliminary implantation of the HCLL TBM system in Port Cell #18, including piping, part of the He circuit components and PbLi ancillary system has been designed, taking into account geometrical and components considerations and identifying specific issues.

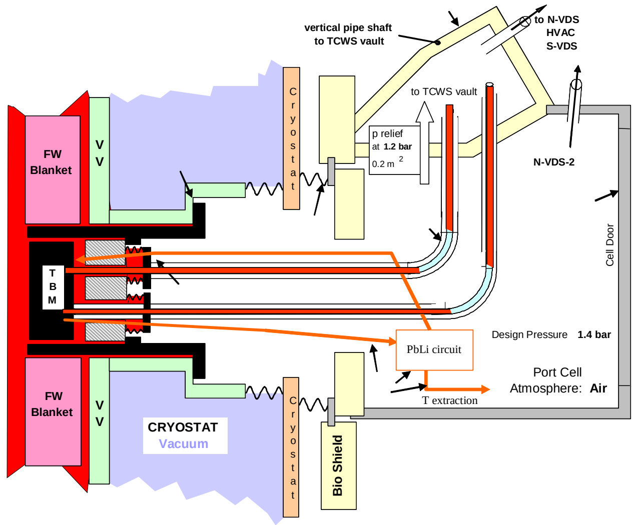

Figure 1: Schematised representation of the Port Cell region with TBM-pipes interfaces

An illustration of this implantation is given on figure 2. Then, general considerations on the TBM system integration and handling have been identified. Then concern the overall replacement strategy, the TBM Mounting sequences including the preliminary identification of operations, the circuits' maintenance, the dismounting and transfer to hot cell and the TBM replacement in hot cell possible strategy. Open points have been highlighted.

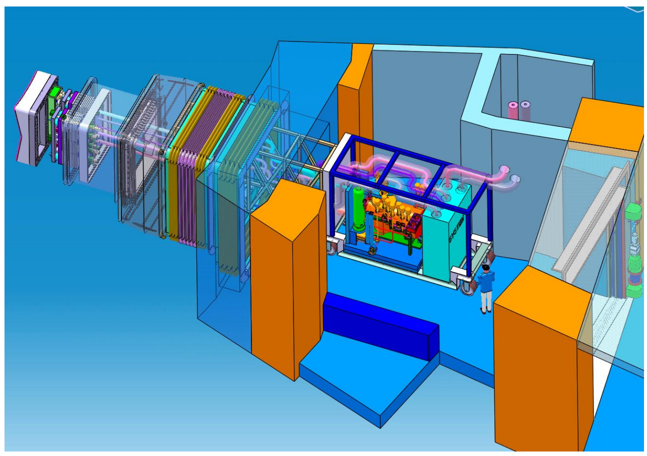

Figure 2: Implantation of the HCLL TBM system in Port Cell #18

PIE REQUIREMENTS

Based on the preliminary list of needed PIE already identified in the framework of this subtask, the estimation of needs in term of hot cell equipments have been derived.

To recover any PIE specimens/parts, the TBM PIE Hot Cell needs to be equipped with:

- Equipment and glove box tritium measurement facilities to recover and measure any potential tritium release while the TBM is still hot.
- Remote manipulators for handling the TBM, sections removed from the TBM, and specimen cassettes.
- Remote visual inspection and recording to examine and record the condition of the TBM and sections of a TBM. Such equipment is essential for guiding subsequent cutting operations.
- Ultrasonic and eddy current non destructive inspection of the TBM and sections removed from the TBM.
- Metrology to characterize dimensional changes with an accuracy of ±0.1 mm.
- Equipments (to be determined) to remove and store any residual liquid metals from liquid breeder TBMs.
- Computer controlled cutting tools such as laser and argon-arc torches, mechanical cropping equipment and electro discharge machining capability for careful sectioning of the TBM and subcomponents into more manageable pieces.
- The capability to perform simple mechanical tests such as tensile or Charpy impact testing of pre-machined specimens over a range of temperatures and possibly under vacuum or inert gas environment.
- RF or thermocouple monitoring to track the temperature of the TBM and TBM sections (from a rough estimation taking into account a starting state of TBM structures (PbLi-empty) at 300°C, afterheat sources and radiation of TBM external surfaces to 20°C, temperature of the steel structures is about 140°C after 1 day and 50°C after 3 days).
- Radiation monitoring for radioactive decay of the TBM, TBM sections, and test specimens.
- Provisions must be made to collect and pick-up any waste parts from the sectioning.
- The capability to load sections of a TBM and test specimens into appropriate activated material shipping casks for shipment.

Detailed technical parameters and corresponding spatial requirements will need to be specified in the future.

To conclude the work, an assessment of the envisaged PIEs based on CEA/DMN/SEMI/LECI (Saclay hot cell operation) expertise has been realized. It gives general informations on existing techniques and equipments potentially compatible with HCLL PIE needs. From a general point of view, due to the lack of space and the incompatibility between the various envisaged operations, it appears difficult to integrate in a single hot cell all the equipment necessary for the envisaged operations.
One first recommendation is to limit the operations in ITER hot cell to the minimum and transfer other ones in already existing facilities. Operations that could be realized in ITER TBM hot cell are the following:

- Global visual inspection;
- Global structure metrology;
- US control at the structure level;
- Cutting into elements compatible with existing transport cask;
- Intermediate elements (non transportable) metrology;
- Elements nuclear activity measurements;
- Transportable elements conditioning;
- Waste conditioning;
- Transport of elements to other hot cell facilities.

All types of hot cell envisaged operations have been analysed, giving for each of them some recommendations and references for existing tools already used in the CEA-Saclay hot cell facilities.

CONCLUSIONS

The final report of this task is a preliminary version of a HCLL-TBM Integration Description Document. It aims at defining guidelines and requirements in order to guarantee a high safety level for the HCLL-TBM integration into ITER. Integration of the TBM into ITER includes operations describing the scheduled mounting and dismounting and unscheduled neutralisation of the HCLL-TBM. It has sought to identify in the first place the issues that are specifically related to the liquid PbLi use. Many of the issues related to the HCLL-TBM integration are not determined yet although they have been identified in the document. Progressively, these issues will be completed and other new issues will certainly be identified. At one of the later stages, different TBM's Integration Description Documents should be normalised and interfacing subjects should be developed jointly. It also proposes first discussions on the possible Post Irradiation Examinations (PIEs) that can be envisaged for the HCLL-TBM after tests in ITER. From an expertise realised by CEA operators of Saclay hot cells laboratories, it appears that most of the envisaged hot cell operations are already performed in existing hot facilities. Nevertheless, operations are usually done for element size smaller that the TBM scale, while already necessitating substantial space. It is therefore recommended to limit as much as possible in-situ operations (essentially cutting TBM into small elements) and dispatch these elements in existing or dedicated hot cell facilities.

REPORTS AND PUBLICATIONS

[1] M. EID, N. JONQUERES, A. MORIN, J-F. SALAVY, P. MONGABURE, "Integration of the HCLL TBM system in ITER: Guidelines, PIE and Hot Cell requirements - Final Report for the EFDA Task TW5-TTBC-001-D03",CEAReport SERMA/LCA/RT/06-4009/A, December 2006

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TW5-TTBC-001-D05

Task Title: TBM DESIGN, INTEGRATION AND ANALYSIS FINALIZATION OF THE HCLL TBM PROTOTYPICAL MOCK-UP

INTRODUCTION

The objective of this task is the finalization of the design of a Prototypical Mock-Up (PMU), a relevant medium-scale (1/4) representative of the HCLL-TBM module for ITER and to be tested out-of-pile in the European Breeding Blanket Testing Facility (EBBTF)/Brasimone facility. This mock-up should allow prepare the manufacturing of the TBM, the monitoring of the TBM-systems and guarantee, as well as possible, that they will not affect the ITER safety.
After a conceptual step in the design process (TW5-TTBC-001-D02) [1], this deliverable will aim at finalizing the design of this under task with detailed drawings ready for manufacturing and consistent with operating parameters and specifications.

2006 ACTIVITIES

Main 2006 activities are related to the conceptual study of the external heater, including technical solution and thermo-mechanical dimensioning simulating the plasma heating of the first wall of the TBM (0.5 MW/m²).

Experimental device design

A relevant medium-scale (¼) prototypical mock-up is foreseen and will be tested out of beam in ENEA loops, in the European Breeding Blanket Testing Facility (EBBTF)/Brasimone for the PbLi loop and HEFUS3 for the He loop. The mock-up dimension will be obtained by divided the TBM height by 4: 2 cells in the poloidal axis and 3 cells in the toroidal axis, the radial dimension stays the same. A design proposal is made (figure 1).

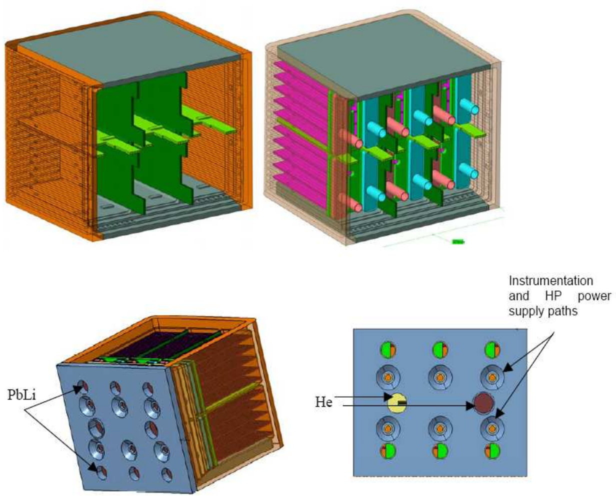

Figure 1: Design of the prototypical mock-up

The experimental device is based on a cylindrical vacuum vessel in which the TBM mock-up with the heaters would be located. This vacuum vessel is supported by a support frame (figure 2) which is designed to withstand 2000 kg.

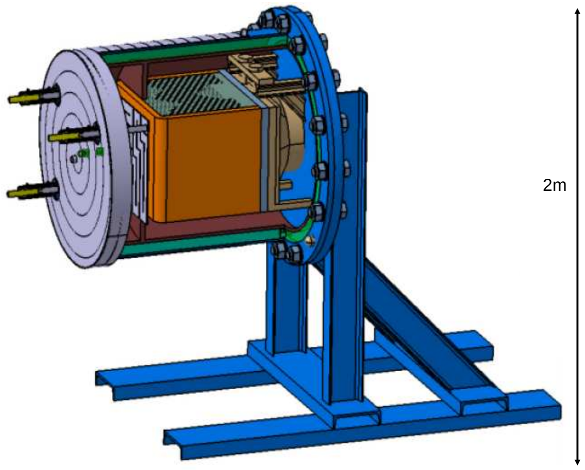

Figure 2: View of the prototypical mock-up in its vacuum vessel and support frame

Due to the high thermal flux, the first wall has to receive (0.5 MW/m²) and the induced temperature of the heater (about 1500°C), heater material has been chosen as carbide composite which keeps interesting physical and mechanical characteristics at high temperature. In order to optimise the radiative heat transfer, the heater is located in front of the first wall in a vacuum environment with an area similar to the one of the first wall (figure 3).

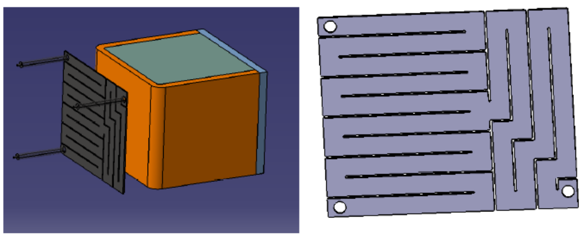

Figure 3: Electrical heater (620 x 500 mm²)

It is actively cooled by external water circulation.
Electrical paths have been designed to supply the electrical power to the heater (figure 4). These paths are also actively cooled.
Finite elements computations were performed to verify the mechanical design of the heater, the vacuum vessel, the electrical path and the support frame.

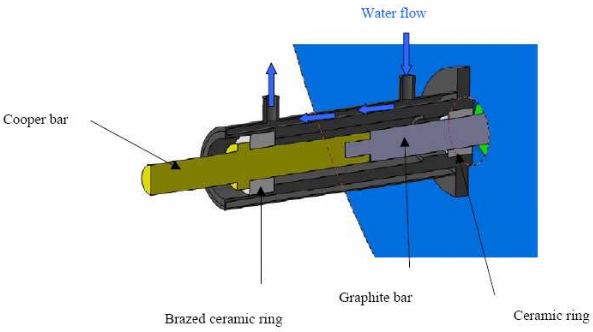

Figure 4: Electrical path

CONCLUSIONS

Heaters and electric paths have been designed in detail and the conceptual design of what could be the general test section has been proposed.

REFERENCES

A. Li Puma et al., Helium cooled Lithium Lead fusion power plant (PPCS model AB) design and integration of in-vessel components and associated systems, rapport CEA/DM2S/SERMA/LCA/RT/04-3543/A

REPORTS AND PUBLICATIONS

[1] G. Rampal et al., “Design and analyses of the HCLL TBM including design of supporting system/connections and instrumentation integration”, final report on TW5-TTBC-001-D01 deliverable, to be issued

[2] L. Cachon – External heater for the TBM mock-up – report CEA/DTN/STPA/LTCG/2006-022

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TW5-TTBC-001-D06

Task Title: TBM DESIGN, INTEGRATION AND ANALYSIS: FURTHER THERMAL-HYDRAULICS AND DESIGN STUDY RELATED TO THE CHOICE OF A REFERENCE He COOLING SCHEME

INTRODUCTION

In the current HCLL DEMO Blanket design, helium scheme is such as the First Wall (FW) and the Stiffening Plates (SPs) are cooled in parallel at first, then the He passes in the Cooling Plates (CPs). This schema allows cooling with "cold He" components having structural functions, while guaranteeing an He outlet temperature of 500 °C, as suitable to obtain interesting thermodynamic efficiency. Thanks to the fact that only one portion of the He mass flow circulating in the stiffening plates allows, furthermore, to reduce the SPs channels cross section and then the SPs thickness so increasing the breeder material (LiPb) content in the breeder zone.
The He mass flow distribution, i.e. the balance of the pressure drops between the FW and in the SPs, on the other hand, relies on the use of appropriate flow limiters in the SPs. In the 2003 HCLL DEMO blanket module design [1] 80% of the He mass flow circulates in the FW and the 20% in the SPs (figure 1).

The scope of this task is to assess series alternative He flow schemes avoiding any external control of the He mass flow and to define a reference He scheme for the HCLL DEMO blanket to be applied on the HCLL TBM for ITER.

2006 ACTIVITIES

2006 activities are dedicated to DEMO thermal analysis and estimations of the consequences on the TBM.

DEMO ANALYSIS

Three different configurations have been analysed and compared with the following criteria:

- Tmax < 550°C;
- Power ratio = $\dfrac{\text{Pumping power}}{\text{Deposited thermal power}}$ < 10%.

One, referred as the parallel configuration corresponds to the former helium flow path. The other two, referred as series 1 and series 2 correspond to a series scheme. Differences between series 1 and series 2 correspond to geometrical variations of the SPs. The main geometrical characteristics of the studied module components, FW, SP and CP are presented in table 1.

To calculate the pitch of the stiffening grid, 2 x 13 mm (13 mm each side) have to be spared in order to weld the stiffening plates. The obtained results show that cooling the FW, SPs and CPs in series is a viable solution. The lowest pressure drops configuration seems to be the series 1 configuration. Main results are presented hereafter.

Table 1: Studied configurations presentation

	configuration	Thickness	decomposition	channels	pitch	decomposition	inlets
First Wall	Parallel	25 mm	4 + 14 + 7	14 x 15.6	21.6	15.6 + 6	82
	Series 1	25 mm	3 + 15 + 7	15 x 16	21.9	16 + 5.9	82
	Series 2	25 mm	3 + 15 + 7	15 x 16	21.9	16 + 5.9	82
Stiffening Plates	Parallel	8 mm	2.5 + 3 + 2.5	3 x 10	11.46	10 + 1.46	4
	Series 1	11 mm	2.5 + 6 + 2.5	6 x 12	15.45	12 + 3.45	3
	Series 2	11 mm	2.5 + 6 + 2.5	6 x 9	11.53	9 + 2.53	4
Cooling plates	Parallel	6.5 mm	1 + 4.5 + 1	4.5 x 4.5	6.4	4.5 + 1.9	8
	Series 1	6.5 mm	1 + 4.5 + 1	4.5 x 4.5	6.4	4 + 1.9	8
	Series 2	6.5 mm	1 + 4.5 + 1	4.5 x 4.5	6.4	4 + 1.9	8

Table 2: Main hydraulic characteristics

Configuration	Dimensions (r x t x p) in m	Deposited power MW	Total mass flow kg s^{-1}	Pressure drop (MPa)	Power ratio
Series 1	0.8 x 2.02 x 1.811	10.50	10.125	0.347	6.1 %

The configuration flow is schematically represented in figure 1, where the He mass flows and temperatures in the various circuits are reported.

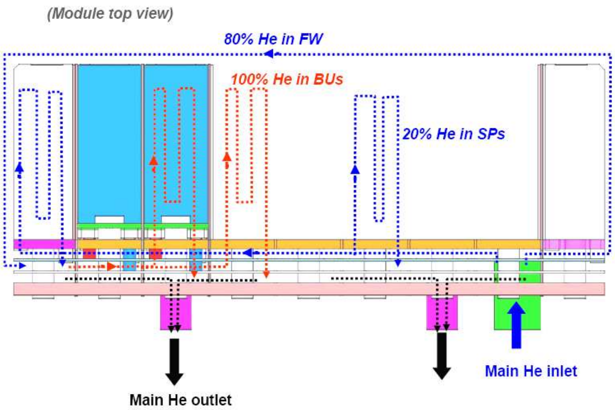

Figure 1: DEMO 2003 Helium flow scheme

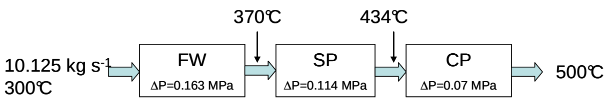

Figure 2: DEMO 2006 series He flow scheme

The hydraulic analysis has been completed by a thermal finite element analysis in order to verify that temperature limits are not exceeded. In this purpose, two different FE models are developed. The first model aims at computing the temperature in the FW using both counter-current and parallel flow whereas the second model is used to compute the temperature in SPs and CPs and to estimate the fraction of the heat deposited in the BZ that is recovered by the FW.

Numerical calculations have been performed using Cast3M. This is a multiphysics CEA finite elements code well adapted to solve thermal problems. The numerical algorithm which was developed for this study is an adaptation of the numerical algorithm developed in [2]. It basically follows the followings steps:

1. temperature initialisation
2. repeat
   a. calculation of the heat transfer coefficient using equation 7
   b. calculation of the temperature field in the structure
   c. calculation of the heat flux using equation 17
   d. calculation of physical properties of the He
   e. calculation of the fluid velocity
   f. calculation of the temperature in He
3. until $\left\| \frac{\Delta T_{Euro}}{T_{Euro}} \right\| \leq 10^{-4}$ and $\left\| \frac{\Delta Q}{Q_{tot}} \right\| \leq 10^{-2}$

Figure 3 shows the temperature distribution in the FW and the SW as illustration.

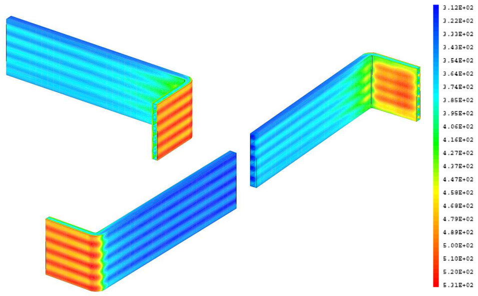

Figure 3: Temperature (°C) distribution in the first wall and the side walls

The main thermal characteristics of the serie1 configuration are presented in table 3.

A careful re-engineering of the geometry of the He channels in the cooling plates is needed to avoid hot spots in the steel and achieve a more uniform He outlet temperature. This result can mainly be explained by the heat recuperation effect taken place in side walls. In the first leg of the cooling plate near the side walls, He is firstly cooled so that in order to verify the global heat balance the highest He bulk temperature is higher than the average outlet temperature (figure 4), close to 540°C. Therefore, at this point a hot spot appears.

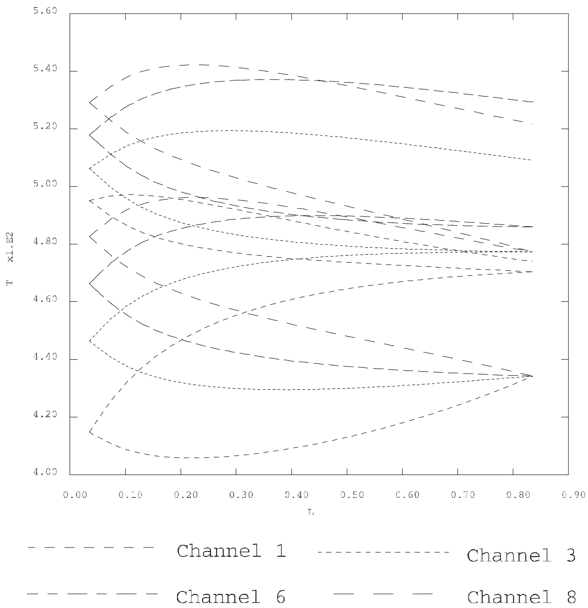

Figure 4: He bulk temperature distribution (°C) versus curvilinear (m) abscise in the central CP

Table 3: Main thermal components characteristics

Component	Recovered power (MW)	Pressure drops (MPa)	T_{in} (°C)	T_{out} (°C)	T_{max} (°C)	He average heat transfer coefficient (W m^{-2} K^{-1})
FW	3.89	0.163	300	370	532	5931.4
SP	3.56	0.114	370	434	517	4798.2
CP	3.13	0.069	434	500	590	3664.8

TBM CONSEQUENCES

To be DEMO relevant, the HCLL TBM should feature the in-series cooling path. Main consequences on the TBM design are:

- SPs and CPs should be feed in-series,
- SPs in the In-TBM should be 11 mm thick,
- A fifth back-plate need to be added.

These modifications will be introduced in the TBM design together with the modification of its overall dimensions due to the recent changes in the frame dimensions asked by the ITER team. Moreover, due to fabrication issues, it is foreseen to have the same thickness for FW and SW.

Due to these design modifications, thermal-hydraulics scheme of the in-TBM needs to be deeply reassessed. Nevertheless, with the same assumptions that the ones used in the previous thermal analyses, and in particular the same dimensions and a heat flux of 0.5 MW/m² on the whole surface, the heat to be recovered is (table 4):

T*able 4: Thermal power distribution in the In-TBM*

Component	FW	SP	CP
Thermal Power (kW)	772.8	221	194.6

With the further assumption to preserve the same increase of helium temperature in the TBM FW as in DEMO, the mass flow rate of helium for the TBM should be around 2.12 kg s^{-1}. To also keep a similarly behaviour in the SPs and the CPS, a bypass should be foreseen and around 71 % of the mass flow rate should be bypassed after the FW. A possible hydraulic scheme for the new In-TBM is presented in figure 5.

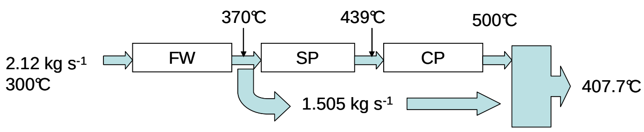

Figure 5: Example of possible Hydraulic scheme for the in “series” In-TBM

CONCLUSIONS

Final assessment of the HCLL TBM cooling scheme taking into account all the recent modifications will be performed in the framework of the task TW6-TTBC-001-D03. The scope of the present task was to assess series He flow schemes avoiding any external control of the He mass flow and to define a reference He scheme for the HCLL DEMO blanket to be applied on the HCLL TBM for ITER. Three different configurations have been analysed and compared using the following criteria.

- Tmax < 550°C;
- Power ratio < 10%.

The obtained results show that cooling the FW, SPs and CPs in series is a viable solution. However, a careful re-engineering of the geometry of the He channels in the cooling plates is needed to avoid hot spots in the steel and to achieve a more uniform He outlet temperature.

Regarding these results, the In-TBM should undergo some design modifications. First of all, stiffening plates should have the same thickness as those of DEMO series and in order to keep the temperature increase of the helium in the FW, the mass flow rate has to be 2.12 kg s^{-1}. Therefore, acting like DEMO in the SPs and the CPs, leads to bypass around 71 % of the mass flow after the FW.

REFERENCES

[1] A. Li Puma & al., Helium Cooled Lithium Lead Blanket Module for DEMO – Designs and Analysis, CEA report, DM2/SERMA/LCA/03-3297

[2] S. Gounand – Modélisation couplée Thermique 3D-Thermohydraulique 1D d’un cœur de réacteur à caloporteur gaz DM2S/SFME/LTMF/RT-03-012

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TW5-TTBC-001-D07

Task Title: TBM DESIGN, INTEGRATION AND ANALYSIS DETAILED TBM DEVELOPMENT WORKPLAN UP TO EM-TBM INSTALLATION IN ITER

INTRODUCTION

In order to be able to install a HCLL Test Blanket Module (TBM) in day 1 of ITER operation (~2015), as envisaged up to now in the testing strategy for EU concepts of breeding blankets, it is necessary to establish both a detailed HCLL TBM development workplan up to EM-TBM fabrication and installation in ITER and a Project technical specification document. These documents will be a basis to identify the activities (on R&D, analyses, needs of out-of-pile test, supplies and fabrication,…) to be launched, and will help to follow the project taking care of the critical path.

The objectives of the deliverable are:

i) to produce a detailed HCLL TBM development workplan (MS-Project) and,

ii) to produce a first version of a Project technical specification document.

2006 ACTIVITIES

The major part of activity performed in 2006 has been devoted to the technical follow-up of the main progresses realised in each field of the project, integrating the modifications of the overall project specifications coming from the ITER Organisation. In particular, these changes have concerned the available space in port cell for TBM installation (impact on TBM design and integration features) and the safety strategy (impact on safety analysis). In such a context, it has been difficult to freeze the overall technical specifications for the TBM project Nevertheless, the outline of the technical specification document [1] has been established, but still needs to be completed and finalized.

EUROPEAN TBM PROJECT

Based on the work produced in the framework of this subtask (and in parallel done by FZK for the HCPB concept), the EU technical plan over next ten years for TBMs has been detailed. table 1 shows the main milestones of the project and table 2 gives the evaluated cost scenario.

This study has been presented at the SOFT conference of Varsaw [2].

Table 1: Main milestones of the TBMs project up to installation of first TBMs in ITER

Project Milestones	**Target achievement date**
Qualification of fabrication technologies (as to be used in first TBMs) Qualification of thermal-hydraulic design	End 2008
1/4-1/3 TBM mock-ups fabrication	Mid 2010
1/4-1/3 TBM mock-ups tests (thermo-mechanics, thermal-hydraulics, H permeation & extraction, etc.)	End 2011
Prototypes fabrication (HCLL and HCPB)	Mid 2013
Prototypes tests (FW heat extraction, validation of fabrication procedures, He flow, permeation tests, etc.)	Beg.2014
Procurement package of first HCLL/HCPB TBMs	Mid 2014
HCLL and HCPB TBMs fabrication	End 2015
Ancillary systems fabrication	End 2015
TBM Systems installation and commissioning in ITER	End 2016
First TBM operation in ITER	2017

Table 2: Baseline cost scenario of the European TBMs Project (both HCLL and HCPB costs are included)

Period	Evaluated cost (*)
2007-2025 (4 TBMs for each HCPB and HCLL concepts)	212 M€
2007-2016 (HCPB and HCLL first TBMs installed in ITER)	127 M€
2007-2011 (TBM development within EU Framework Program VII)	49 M€

(*) € ref. year 2006

From a technical point of view, the synthesis of the last progresses for the TBMs project has been detailed and exposed in an oral presentation at the same conference (SOFT-24) [3]. A more dedicated presentation on the R&D status concerning the use of liquid metal in the HCLL TBM has been realised for the IEA Workshop meeting of St Petersburg, June 2006 [4].

REPORTS AND PUBLICATIONS

[1] J-F. Salavy, Detailed TBM development workplan up to EM-TBM installation in ITER, CEA report SERMA/RT/06-3816/A, to be issued (2007)

[2] Y. Poitevin, L.V. Boccaccini, G. Dell'Orco, E. Diegele, R. Lässer, J.-F. Salavy, J. Sundström, M. Zmitko, "The Test Blanket Modules project in Europe: From the strategy to the technical plan over next ten years", Poster presentation to SOFT 2006, to be published in Fusion Eng & Design

[3] J-F. Salavy, L.V. Boccaccini, R. Lässer, R. Meyder, H. Neuberger, Y. Poitevin, G. Rampal, E. Rigal, M. Zmitko, "Overview of the last progresses for the European Test Blanket Modules projects", Oral presentation to SOFT 2006, to be published in Fusion Eng & Design

[4] J-F. Salavy et al., "Overview of the R&D issues of the European Helium-Cooled Lithium-Lead breeder blanket concept", Oral presentation to the IEA International workshop on liquid breeder blankets, Saint-Petersburg, June 7-9, 2006

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TW5-TTBC-001-D08

Task Title: TBM DESIGN, INTEGRATION AND ANALYSIS HCLL STUDIES ANALYSES: ADDITIONAL ACCIDENTAL STUDIES TO TAKE INTO ACCOUNT ITER SAFETY REQUIREMENTS (FROM ITER TBWG)

INTRODUCTION

In parallel with the plasma behaviour study, ***ITER*** (***I***nternational ***T***hermonuclear ***E***xperimental ***R***eactor) will be also used to test some components which will be necessary to the operation of the reactor system. Among them, there is the ***B***lanket ***M***odule, which will be installed on the industrial prototype of electric-power reactor called ***DEMO***. The ***B***lanket ***M***odule facing the plasma will constitute the power conversion system and will produce in situ tritium. The partners envisage several concepts of Blanket Modules, therefore a ***TBM*** (***T***est ***B***lanket ***M***odule) programme in ***ITER*** has been setup. The objective of the ***TBM*** programme is to test under representative conditions the different ***B***lanket ***M***odule.

In this framework the ***CEA***-Euratom Association develops the **HCLL** concept (Helium Cooled Lithium Lead), which is designed by the ***DM2S/SERMA*** at ***CEA***/***SACLAY*** [1] [2] (see figure 1).

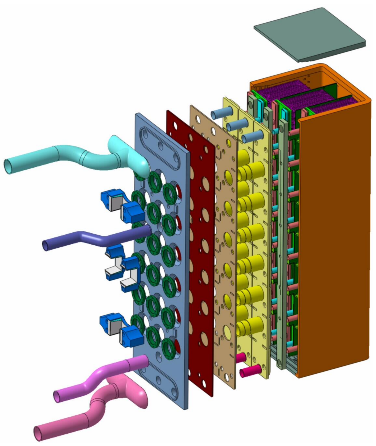


Figure 1: HCLL-TBM 3D view

The ***HCLL-TBM*** will be placed into ***ITER*** in 2016 when first plasma will be produced. But before, we have to determine its thermo-mechanical behaviour under normal, incidental and accidental operating conditions.

In the scope of the ***EFDA TW5-TTBC-001-D08*** task, the ***DER/SESI*** at CEA-Cadarache has to provide thermal and thermo-mechanical analysis of the ***HCLL-TBM*** under accidental conditions. This task is focused on one of the most severe accidental conditions expected, which is an ***in-TBM LOCA*** (internal ***L***oss ***O***f ***C***oolant ***A***ccident with pressurization of the blanket module box at the helium pressure of 8.0 MPa).

It is obvious that ***HCLL-TBM*** can not withstand such a loading for a long time if any plasma shutdown does not happen; the purpose of the calculation is to determine the time interval ***t0*** available during which the ***HCLL-TBM*** can withstand such thermal loading (due to loss of helium cooling capacity) combined with the internal pressure loading (due to in-***TBM LOCA***).

To complete this study, a plasma shutdown is modelled in order to check the ***HCLL-TBM*** capability to remove the decay heat by natural radiation.

2006 ACTIVITIES

The main characteristics of the computations are recalled hereafter. One model was carried out with the finite element code (***CAST3M***): the thermal and the stress fields are computed within the ***HCLL-TBM*** during the transient. The model is representative of one and a half ***BU*** (***B***reeder ***U***nit) in width (see figure 2).

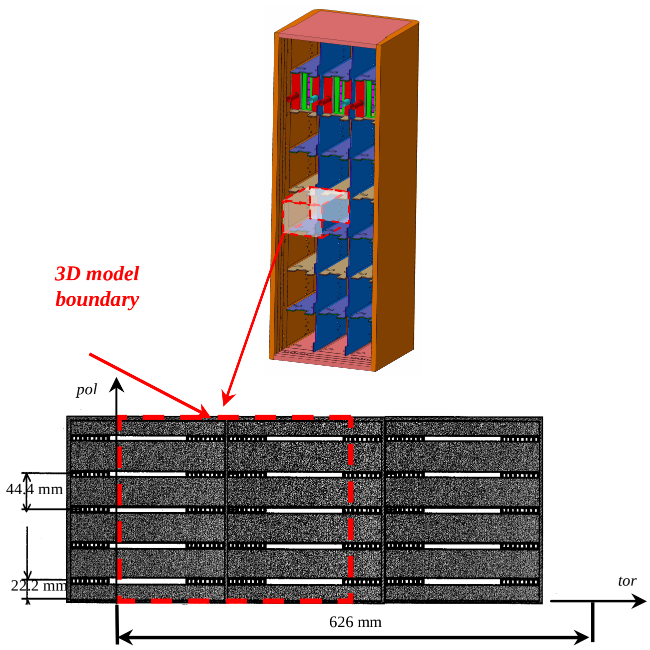


Figure 2: Positioning of the model into a TBM

The model is innovative as it describes beryllium layer and the exact geometry of the junction between the ***FW*** (***F***irst ***W***all) and the ***SW*** (***S***ide ***W***all). Out of concern for simplicity, the model doesn't account for horizontal stiffening plates and the ***BP*** (***B***ack ***P***lates), which are replaced at this step by mechanical boundary conditions. The comprehensive meshing is presented in figure 3.

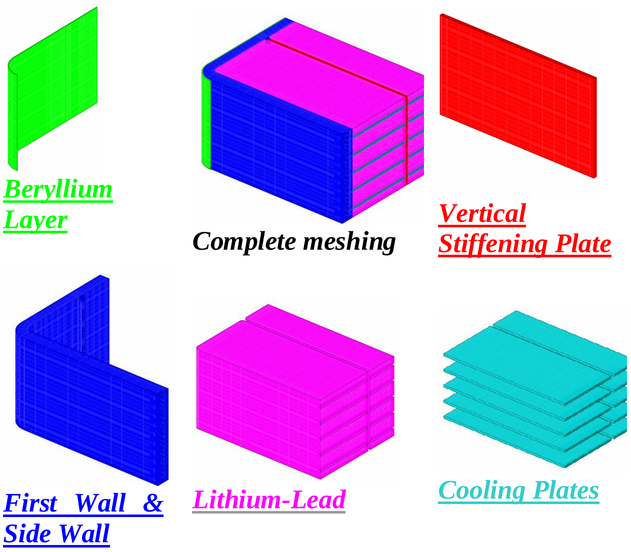


Figure 3: Exploded view of the 3D model

The thermal-hydraulic features taken into account are summarized in figure 4 [1]. That is the scheme with by-pass. The helium inlet temperature is 300°C whereas the outlet temperature is 454°C.

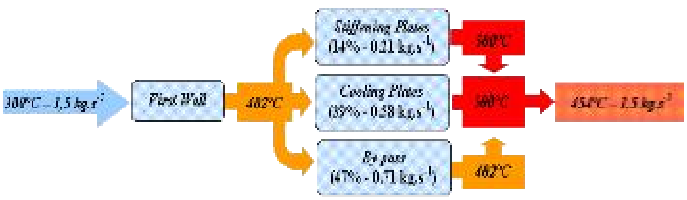


Figure 4: Helium flow scheme

The thermal loads considered in this study are [1]:

- ***H***eat ***F***lux (***HF***) on the ***FW*** of 0.5 MWm^{-2},
- Power density distribution related to a ***N***eutron ***W***all ***L***oading (***NWL***) of 0.78 MWm^{-2}.

The mechanical loading consists in an internal pressure of 8.0 MPa. This pressure is applied to the helium channels and to the surfaces in contact with Lithium-Lead to simulate an in-***TBM*** helium leak pressurization (see figure 5).

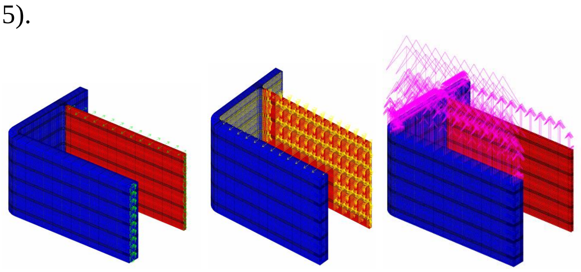


Figure 5: Mechanical loads

The time interval ***t0*** during which the ***HCLL-TBM*** can withstand without damaging the ***TBM*** box after an in-***TBM LOCA*** without plasma shutdown, is determined by using the following methodology:

- A thermal transient computation simulating the ***LOCA*** assuming plasma heating and no cooling from helium,
- A pure mechanical computation, simulating the 8.0 MPa pressurisation of the ***HCLL-TBM*** box.

The maximal mechanical stress is related to a maximal allowed temperature (from the table of maximal allowable stress as a function of temperature). It is then looked for in the results from the thermal transient when, at the same location, this maximal temperature is reached, this gives the time ***t1***.

The analysis is also performed for the mechanical stress obtained at the maximal temperature location, this stress is related to a maximal allowable temperature and from the thermal transient to a time ***t2*** when this temperature is reached.

- The minimum of ***t1*** and ***t2*** gives the time ***t0 = Min. (t1, t2)*** when the ***HCLL-TBM*** box will start to not fulfil the ***SDC-IC*** criteria (primary stress upper than the maximal allowable stress).

The simulation establishes, first, the permanent thermal field before the accidental transient is calculated (see figures 6, 7 and 8).

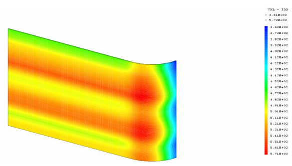


Figure 6: Temperature field **-** *Beryllium layer*

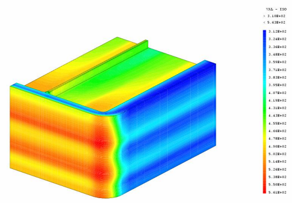


Figure 7: Temperature field **-** *EUROFER structures*

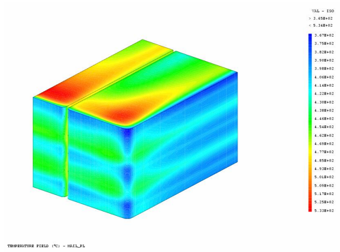


Figure 8: Temperature field - Lithium-Lead

The temperature is between 310°C and 563°C. The maximum of 563°C is reached in ***FW-SW*** structure at the junction level. The beryllium layer insulates slightly the ***FW***.

LOCA transient is now arbitrarily simulated for 100 seconds. The thermal field is calculated as a function of time. Figure 9 shows the thermal field evolution. As soon as the helium flow is stopped, the ***FW*** temperature tends toward an homogeneous thermal field The temperature exceeds 700°C, 15 seconds after the transient beginning then reaches some 1000°C at 50 seconds At the end simulation (100 seconds) the ***FW*** temperature is about 1300°C.

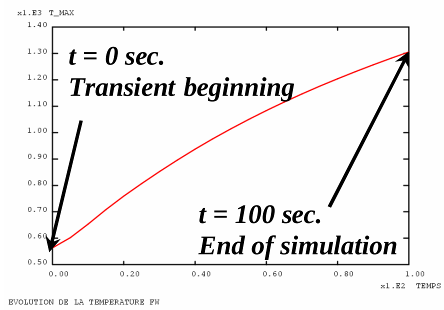


Figure 9: FW maximal temperature evolution during a LOCA transient up to 100 seconds

Then, thermal assessment of plasma shutdown with disruption effect is performed. The objective is to determine the magnitude of **FW** temperature during the plasma shutdown phase and to verify the capability to remove the decay heat by thermal radiation. In this study, the plasma shutdown creates a disruption (**H**eat **F**lux = 5.5 $MW.m^{-2}$ for 100 ms) adding an additional heat loading that must be taken into account in the analysis.

The thermal computation shows that the increment of temperature caused by the disruption is weak (only + 8°C). After the plasma shutdown, the thermal radiation allows the temperature to be decreased rapidly (figure 10).

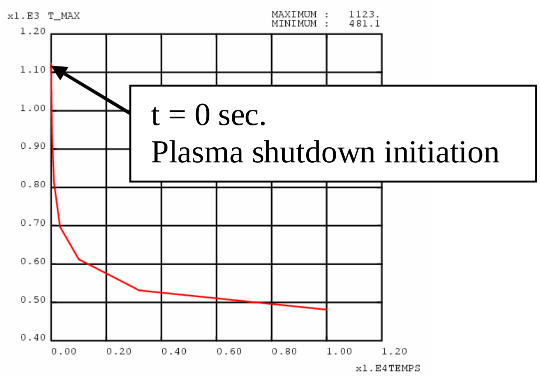


Figure 10: FW maximal temperature evolution after a plasma shutdown with disruption

At this stage the mechanical analysis is carried out. The analysis is performed at central part of the model where the stress concentration is observed with a maximum value of 298 MPa (see area of analysis in figure 11).

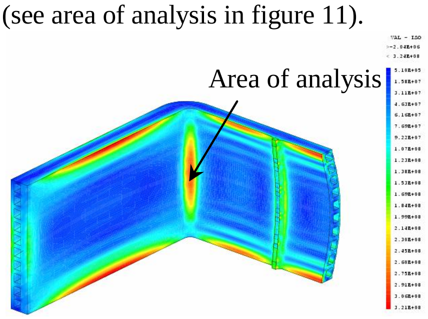
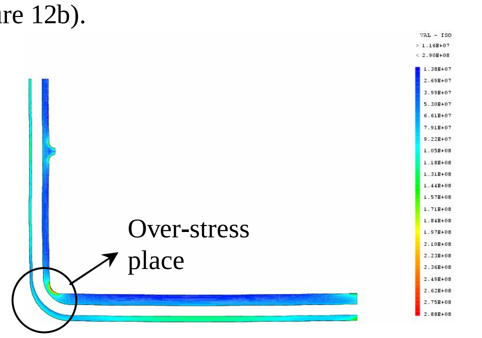


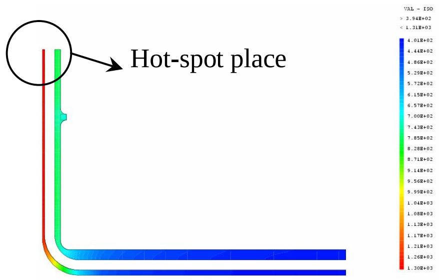
Figure 11: Equivalent primary stress field due to an in-TBM pressurisation (8.0 MPa)

The strength capability has been determined according to the ***S****tructural* ***D****esign* ***C****riteria for* ***ITER*** (***I-SDC***) [3] design rules level D criteria. The objective is to determine, during the ***LOCA*** transient, when the stresses become equal to the allowable stress intensity S_m^D [4]. Two different areas are analyzed:

- The over-stress place where the stress intensity is maximum (figure 12a),
- The hot-spot place where the temperature is maximum (figure 12b).



(a) Mechanical stress intensity field



(b) Thermal field

Figure 12: Analysed area positioning (cross section through a cooling channel)

Over-stress place analysis

The over-stress place is located at the junction between ***First Wall*** and ***Side Wall*** (on the corner). The calculations lead to a maximal stress intensity of 298 MPa. Several slices are analysed in order to determine accurately the supporting line segment corresponding to the lower resistance area. The lower resistance area is situated at the helium channel level. The stress analysis is performed along the supporting line segment indicated in figure 13 hereafter.

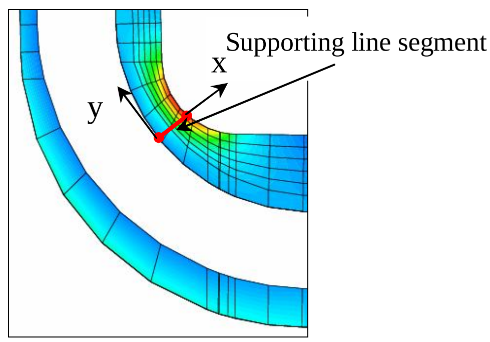


Figure 13: Supporting line segment at the over-stress place – Calculation index

The stress profiles along the supporting line segment are given in figure 14. The main results are:

- $\overline{P_m}$ = 120.4 MPa

- $\overline{P_L + P_b}$ = 239 MPa

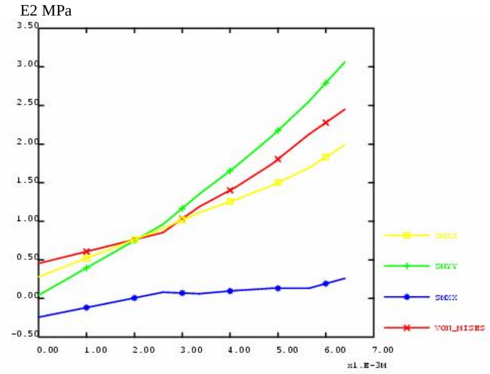


Figure 14: Primary stress intensity supporting line segment

Thus, the allowable stress intensity must be upper than:

$S_m^D(\theta_m) > \overline{P_m}$		$S_m^D(\theta_m) > 120$ MPa
and	⇨	and
K_{eff} x $S_m^D(\theta_m) > \overline{P_L + P_b}$ with $K_{eff} = 1.5$		$S_m^D(\theta_m) > 159$ MPa

This condition is fulfilled when θ_m is lower than 642°C (figure 15). Then, as long as the average temperature along the supporting line segment is lower than ***634°C***[1], the criteria are fulfilled even in case of shutdown with disruption. The time interval available, ***t1***, before criteria are not any longer fulfilled, is obtained by using the support line segment average temperature evolution during the transient (figure 16). For the over-stress place, we find ***t1*** equal to ***70 seconds*** from the beginning of ***LOCA*** accident.

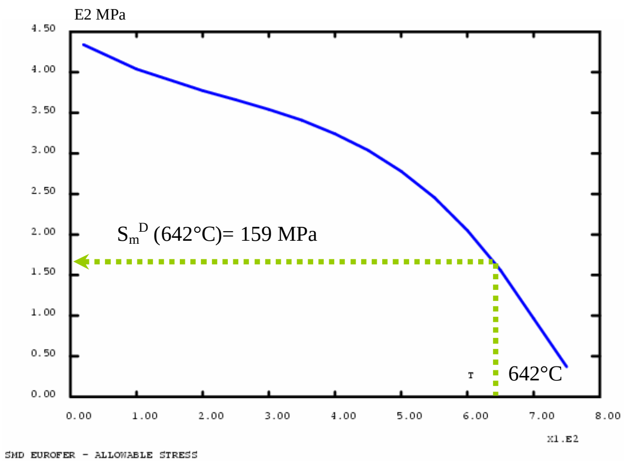


Figure 15: Sm ^{D} allowable stress intensity

[1] Corresponding to 642°C ***minus 8°C*** due to the additional heating created by the disruption phenomena

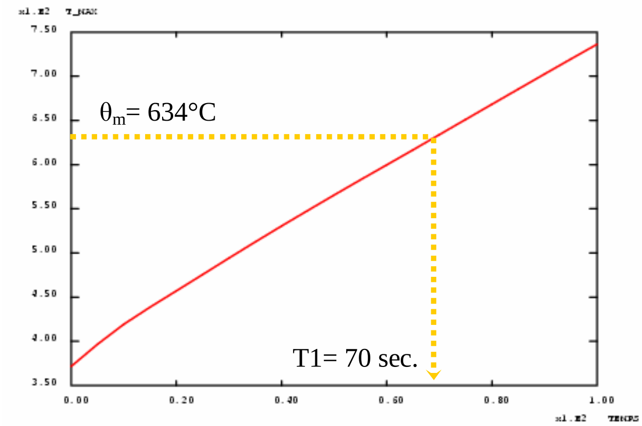


Figure 16: Supporting line segment – Average temperature during LOCA

Regarding the thermal creep a simplified assessment of the creep rupture usage fraction W_D has been computed for 70 seconds showing that W_D does not exceed 1.

Hot spot place analysis

This place is located on the ***First Wall*** and corresponds to the helium channel wall plasma side (supporting line segment indicated in figure 17).

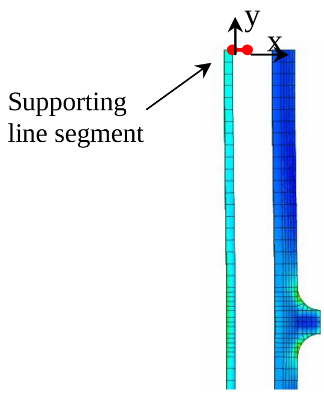


Figure 17: Supporting line segment at the hot-spot place

The stress profiles on the supporting line segment are given in figure 18. The main results are:

- $\overline{P_m}$ = 105 MPa

- $\overline{P_L + P_b}$ = 110 MPa

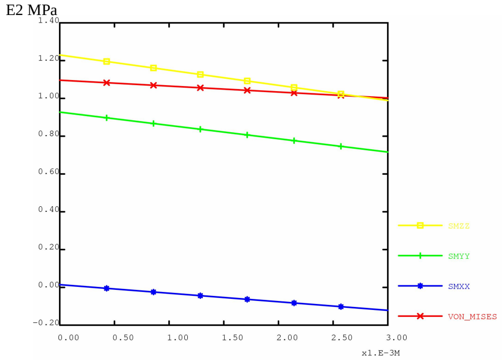


Figure 18: Primary stress intensity. Supporting line segment

Thus, the allowable stress intensity must be upper than:

$S_m^D(\theta_m) > \overline{P_m}$

and

$K_{eff} \times S_m^D(\theta_m) > \overline{P_L + P_b}$

with $K_{eff} = 1.5$

⇨

$S_m^D(\theta_m) > 105$ MPa

and

$S_m^D(\theta_m) > 73$ MPa

This condition is fulfilled when θ_m is lower than 692°C (figure 19). Then, as long as the average temperature along the supporting line segment is lower than ***684°C***[2], the criteria are fulfilled even in case of shutdown with disruption. The time interval available, ***t2***, before the criteria are not any longer fulfilled, is obtained by using the support line segment average temperature evolution during the transient (figure 20). For the hot-spot place we find ***t2*** equal to ***15 seconds*** from the beginning of ***LOCA*** accident.

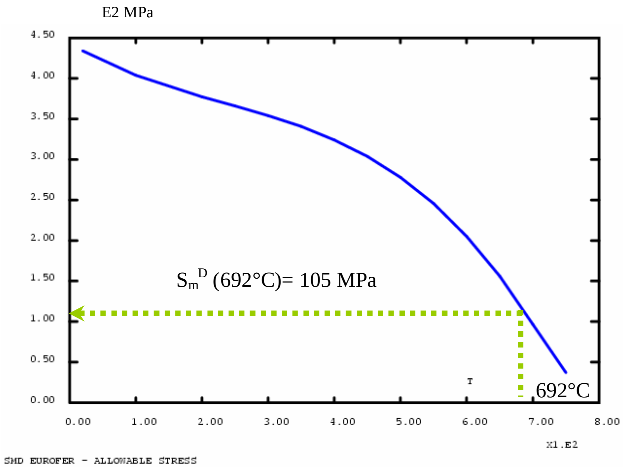


Figure 19: Sm ^{D} allowable stress intensity

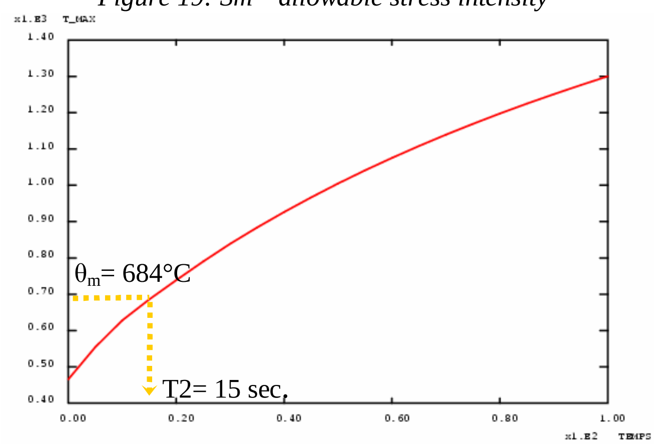


Figure 20: Supporting line segment – Average temperature during LOCA

Regarding the thermal creep if the plasma shutdown occurs 15 seconds after the beginning of the accidental transient, the creep rupture usage fractions W_D do not exceed 1.

t2 (15 sec.) is lower than ***t1*** (70 sec.), therefore the hot-spot place can be considered as the weak point of the ***HCLL-TBM*** for a total loss of heat exchange with helium combined with an in-***TBM*** pressurization (8.0 MPa).

CONCLUSIONS

The thermo-mechanical study performed at the ***CEA/DEN/DER/SESI*** is related to the ***HCLL-TBM*** behaviour under a severe in-***TBM LOCA*** event leading to:

- A total loss of helium cooling,
- ***HCLL-TBM*** box pressurization (8.0 MPa).

During the accidental transient, the time interval while the level D ***SDC-IC*** criteria are fulfilled have been determined. The analysis indicates:

- First, that the hot-spot place is the sizing point of ***HCLL-TBM.*** This point is located at the outer wall helium channel of the ***F***irst ***W***all.
- Second, within the framework approach followed, that the time interval available before the level D criteria are reached is equal to 15 seconds after the beginning of the transient.

With that in mind, this result does not demonstrate that, under very conservative assumptions there is a risk of ***HCLL-TBM*** rupture as soon as this time interval is exceeded. It only indicates that the conventional margin to the possible rupture will be not fulfilled at any point of the structure if the plasma is not shutdown. That does not mean an immediate Lithium-Lead leakage into the vacuum vessel. Indeed, if a rupture should occur, it will first involve the outer wall helium channel of the ***F***irst ***W***all. The consequential helium leakage would shutdown the plasma and probably prevents the failure propagation up to the Lithium-Lead. To determine such sequence a complementary study should have to be performed.

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] Report DM2S SEMT/BCCR/RT/06-004/A
Design and analyses of the HCLL TBM including design of supporting system and instrumentation integration
G. Rampal, G. Aiello

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

[2] Corresponding to 692°C ***minus 8°C*** due to the additional heating created by the disruption phenomena

[4] 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

REPORTS AND PUBLICATIONS

N. SCHMIDT - C. GIRARD, ITER – Helium Cooled Lithium Lead – Test Blanket Module (HCLL-TBM). Assessment of thermal-mechanical behavior under in-TBM LOCA CEA/DEN/CAD/DER/SESI/LESA/NT DO 29 26/10/06

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Task Title: TBM DESIGN, INTEGRATION AND ANALYSIS DETERMINATION OF RANGES OF TRITIUM INVENTORIES IN PbLi AND He CIRCUITS

INTRODUCTION

In the framework of the fusion technology development, management of tritium still constitutes an open issue. Indeed the question of fuel feeding in particular with tritium and its supplying routes must be studied in detail for the first future fusion demonstration reactor (DEMO), but before some tritium breeding systems must be tested in ITER. It is foreseen by the use of Test Blanket Module (TBM). This document presents the order of magnitude of tritium in the different circuits used in the TBM systems (PbLi loop and helium loop). The assessment is based on the geometric features of the circuits and the behaviour of tritium in term of diffusion in the operating conditions.

The calculations are using mass balances on each circuit taking into account the diffusible species and traducing their diffusion by fick's law and permeation using Sievert's constant in each metallic media.
The first part recalls the main data: geometry of HCLL (Helium cooled Lithium Lead) TBM.

2006 ACTIVITIES

DESCRIPTION OF HCLL TBM

The tritium-breeding blanket comprises a liquid metal (PbLi) and a helium circuit that acts as coolant in order to recover the heat produced. Channels in which the helium circulates therefore run through the entire blanket. The helium then releases its heat into a third circuit, the water circuit.
The power deposited in ITER is almost 0.5 $MW.m^{-2}$, the total flow rate of the coolant (He) in the internal channels of the TBM is 1.5 $kg.s^{-1}$. Figure 1 illustrates the division of the flow rates and temperature levels on the inlet and outlet of a module which are used for the calculations. The significant pressure drop of the gas due to the complex geometry of the parts may also be noted.

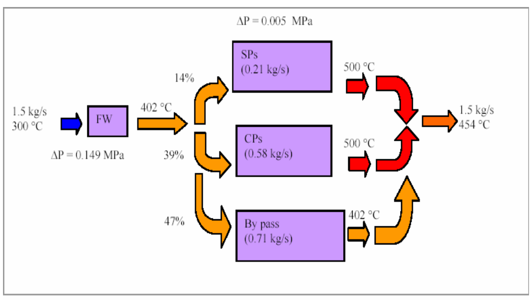


Figure 1: Flow rates and temperatures of secondary helium circulation in a module

Detail of the HCLL concept

The HCLL concept is characterised by a two-circuit architecture:

- Primary circuit contains the tritium-breeding material: lithium-lead eutectic.

- Secondary circuit in which pressurized helium (80 bar) flows, acting as coolant. It is this fluid that takes the power into a steam generator (GV) and is capable of creating a current-production cycle for example.

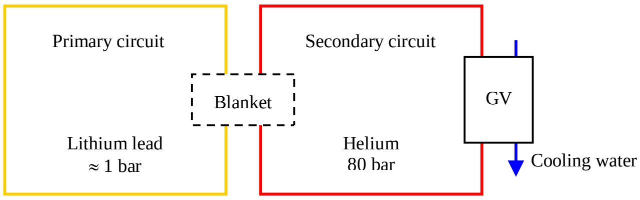


Figure 2: Block diagram of HCLL

In a TBM we can distinguish three zones:
- 1, the fluid distribution zone,
- 2, the zone where the exchanges take place (matter and heat),
- 3, a Breeder Unit, the zone where the PbLi produces the Tritium flows.

The 3 main components making up the blanket and acting as interface for tritium transfer from PbLi circuit to helium circuit are:
- The First Wall
- The Stiffening Plates
- The Cooling Plates

DATA REQUIRED FOR CALCULATIONS

This paragraph gives an overview of several important themes necessary for implementing the model.

Inventory of materials

The structural materials used in a fusion reactor must meet mechanical strength characteristics and give good containment of the matter. The solutions envisaged for metallic materials in DEMO are being re-used in ITER TBMs. These are structural materials described as having low activation. For TBMs, this is mainly Eurofer which is an RAFMS (Raw Activation Ferritic and Martensitic Steel).

The other materials present are eutectic PbLi and He, both of which are in circulation in the structure.

Choice of data

The physical magnitudes that play a major role in the diffusion of tritium in a reactor are Sievert constants and the diffusivity of tritium in lithium-lead and Eurofer for the HCLL concept. The different authors give varying values for these magnitudes in the literature.
We will take the Sievert's constant of tritium in PbLi as an example.
The type of equation giving this magnitude is as follows:

$$Ks_T = Ks°.\exp\left(-\frac{Ea}{R.T}\right)$$

But in the absorption or desorption experiments performed, the values for the constants differ.

- According to the experiments carried out on the SOLE installation:

$$Ks_T^{PbLi} = 0.237.e^{\left(-\frac{12844}{RT}\right)} \text{ (mol.m}^{-3}\text{.Pa}^{-1/2}\text{)}$$

- According to the REITER experiments:

$$Ks_T^{PbLi} = 1.17.10^{-3}.e^{\left(-\frac{1350}{RT}\right)} \text{ (mol.m}^{-3}\text{.Pa}^{-1/2}\text{)}$$

Figure 3 shows changes in Sievert's constants versus temperature and experimental module.

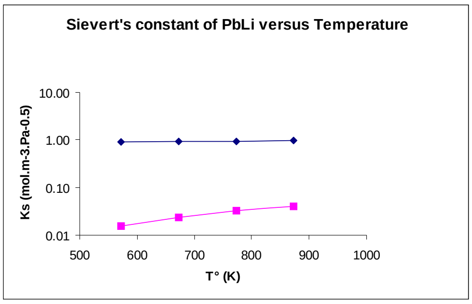


Figure 3: Changes in Sievert's constant of tritium in PbLi versus temperature and the module used

As these values are very different and as it is difficult to determine what the better one is, the calculations have therefore been performed using two sets of data:
- SOLE
- REITER

The changes relating to the permeability of Tritium in steel and the exchangers versus temperature are relatively important. Figure 4 shows an example of the behaviour of Sievert's constant for Tritium in Eurofer steel versus temperature and the experimental module.

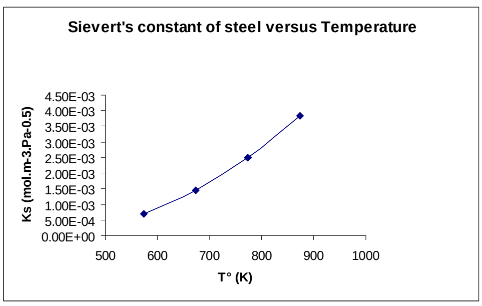


Figure 4: Changes in Sievert's constant of tritium in Eurofer versus temperature

Given the paucity of literature on Sievert's constants in Eurofer (one reference), these values may be compared with other experimental data (obtained on OPTIFER IVb, which has a very similar composition to that of EUROFER). The data is very similar.

- Justification of durations and test periods on ITER

The experimental phases on ITER will consist of pulses of varying duration. Two choices have been established:

- Pulses lasting 400 s (SP: short pulse)
- Pulses lasting 3 000 s (LP: long pulse)

Four distinct configurations can thus be studied:
- SP_SOLE
- SP_REITER
- LP_SOLE
- LP_REITER

MODELLING TRITIUM TRANSFERS

Block diagram

The diagram in figure 5 shows the succession of components that can be encountered in the various loops. The blanket is divided into units in order to differentiate the specific geometries as discussed above. Incoming and outgoing flows are represented by red arrows.

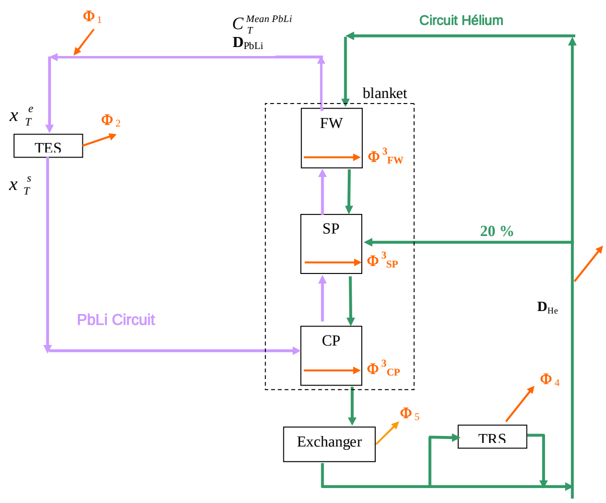


Figure 5: Block diagram of HCLL concept

Hypotheses

- The PbLi current is considered to be a uniform concentration and the effect of a limit layer at the transfer surface is not taken into account. Concentrations are therefore taken as uniform on both sides of the exchanger plate. In fact the concentrations operating in the flows transferred are uniform throughout a circuit because the outgoing flows from each component (by diffusive transfer or extraction) are slight compared with partial flow-rates. The same can be said for the He current.

- The extraction yield of Tritium from the PbLi circuit by TES is taken as equal to that considered for DEMO.

- Transfer is limited by diffusion.

- The concentration of Tritium in the exchanger water is considered to be nil: $c_T^{eau} = 0$.

- The transfer of Tritium from the reactor core to the PbLi circuit is negligible compared with the other terms.

- The Tritium is only in its T2 form in the Helium loop if the quantity of H is negligible compared to that of T: $n_T << n_H$ and hence: $n_T << n_{He}$.

N.B.: We thus have:

$$x_T^{He} = \frac{n_T^{He}}{n_{total}^{He}} = \frac{n_T}{n_{He}}$$

The Tritium may be in the form of T_2 or HT if H_2 is present in sufficient quantities or HTO if there are oxidising species or H_2O. The tritium fraction that can diffuse is thus defined as: $x_{T_{diffusible}}^{He} = 2x_{T_2} + x_{HT}$

Estimation of flows

Inventory of incoming and outgoing flows:
- Φ_1: Production of Tritium by neutron bombardment
- Φ_2: Extraction of Tritium from the PbLi circuit (TES)
- Φ_3: Transfer of Tritium to the Helium by permeation:
  - Φ^3_{FW}: transfer through the First Wall
  - Φ^3_{SP}: transfer through the Stiffening Plates
  - Φ^3_{CP}: transfer through the Cooling Plates
- Φ_4: Extraction of Tritium from the helium circuit (TRS)
- Φ_5:Transfer of Tritium to the exchanger (water circuit) by permeation

NB: We should also add:

- Release into the volumes surrounding the circuits through leakage
- Transfer of Tritium from the plasma to the PbLi circuit (= unconsumed Tritium)

The flow from the production of Tritium by neutron bombardment is a fundamental data item. This flow generated by the nuclear reaction is a constant fixed in the DDD on the tritium-breeding blankets of ITER at 76 mg/day, i.e.:

$$\phi_1 = 2.93 .10^{-7} \ mol .s^{-1}$$

It is assumed for the time being that this stationary inlet flow of 76 mg in one day before taking account of the actual results of future tests by modelling an inlet by pulses during the day, i.e. peaks at given intervals.

The other fluxes are expressed according diffusion laws and efficiency of extraction or purification systems. The complete equations are given in document [1].

Each exchange areas are evaluated according to the geometry of the different plates.

The mass balances on the different circuits are leading to the establishment of a system of non linear differential equations. The equation concerning the PbLi circuit is given hereafter as an example.

$$\frac{\phi^1}{V} + \frac{1}{V}\left[\frac{2\eta_{TES} D_{PbLi}}{(\eta_{TES}-2)} + (Q_{FW}+Q_{SP}+Q_{CP})\right] c_T^{PbLi} + \frac{1}{V}(Q_{FW} KU^{PbLi}_{T\_FW} + Q_{SP} KU^{PbLi}_{T\_SP} + Q_{CP} KU^{PbLi}_{T\_CP})(x_T^{He})^n = \frac{\partial c_T^{PbLi}}{\partial t}$$

Solving this system of differential equations requires the use of a powerful mathematical resolution engine based on suitable numerical methods. The engine used is the COMSOL Multiphysics software.

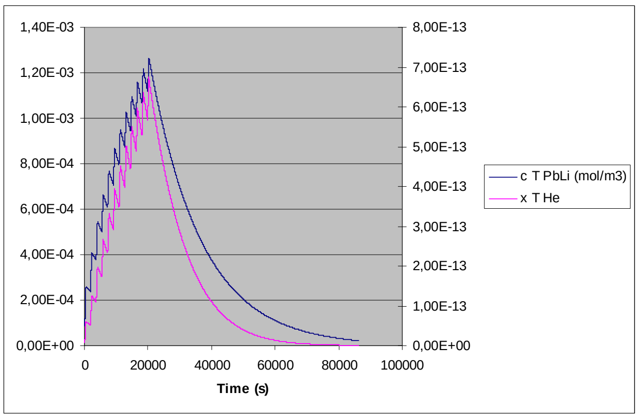
Comparison with steady state results is also done.

RESULTS

In this chapter is given one example of results obtained in the case of SP_SOLE with the following value for the different parameters:

- 90% as tritium extraction efficiency from LiPb circuit,
- 95% of purification efficiency in helium loop,
- 0,5% of the helium treated by the purification system,
- No permeation reduction factor.

The results obtained for tritium concentration in PbLi (mol/m^3) and in He (fraction) is given with the following graph.



CONCLUSIONS

As part of studies on ITER test tritium-breeding blankets (TBM), it was necessary to evaluate tritium inventories in the circuits associated with the blankets. An estimate of the potential release induced by permeation was necessary. These evaluations were carried out on one of the TBM concepts for which our Association is responsible: the HCLL (Helium Cooled Lithium Lead) concept.
In order to achieve this objective a model based on the laws of diffusion and permeation of tritium through a variety of materials was written. The search for the data necessary for simulation of the behaviour of tritium in the system (TBM + associated circuits) highlighted disparities in the physical data necessary according to the bibliographical sources. Extreme values were used for the calculations.

Solving the system of equations under transitory operating conditions showed that in all the situations studied (SP and LP), the tritium inventories both with the circuits and capable of flowing out of the system were very low. This enables us to guarantee that the HCLL TBM will have virtually no impact on either the tritium inventory or the release given off by ITER.

But this analysis is based on data such as extraction rates that need to be confirmed experimentally, as does the modeling used. Clearly given the margins obtained (several orders of magnitude), changes in the results following such confirmation should not undermine the conclusions of the present study.

REPORTS AND PUBLICATIONS

[1] O. Gastaldi, P. Aizes
Assessment of tritium inventory and transfer in HCLLTBM
Technical document DTN/STPA/LPC/2006/070

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TW5-TTBC-001-D10

Task Title: TBM DESIGN, INTEGRATION, AND ANALYSIS SUPPORT STUDIES FOR THE COOLING PLATE MOCK-UP TESTING IN DIADEMO

INTRODUCTION

The experimental program for the qualification of the cooling plate fabrication process is made on DIADEMO facility. To support this experimental study, thermo-mechanical calculations by FE tools have been performed in order to determine the most relevant test conditions and to precise the location of the maximum temperature on the mock-up structure, the temperature gradients and the associated stresses.
These results have been used to support:
- The choice of the best experimental parameters to be monitored and their location,
- The choice of most relevant temperature to drive transient cycles.

2006 ACTIVITIES

The goal of these calculations is to simulate theoretical transient to be produced in DIADEMO facility.

INPUT DATA – THERMO MECHANICAL LOADS

Table 1: Cooling Plate design and operating conditions in HCLL TBM and DEMO

	1 CP in TBM	1 CP in DEMO
Plates dimensions	Width 178 mm Length : 336 mm Thick.: 6.5 mm	Width 208 mm Length : ~550 mm Thick.: 6.5 mm
Channels dimensions	(4 x 4.5) mm2	(4.5 x 4.5)mm2
Average extracted power (kW)	2 kW	14 kW
Heat loading conditions (versus time)	400s power on 1400s power off typ. 6000 cycles	Steady-state
He flow (g/s)	7.5 g/s	30 g/s
He velocity (m/s)	10 m/s	35 m/s
He Tin/out (°C)	450/500	410/500

The main functioning data can be found in the table 1, depending if the CP is in TBM or in a DEMO module. Concerning the heat deposition in the TBM, the power profile can be expressed as:

$$\dot{q} = a \cdot e^{-b \cdot x} + c \cdot e^{-d \cdot x}$$

Where $\dot{q}$ is the power density in W/m^3 and χ is the distance from the plasma in meters.
Table 2 summarizes the coefficients of the equation for each TBM region.

To simulate the power deposition, electrical heaters are located around the two sides of the CP mock-up. The theoretical profile, calculated with table 2, is the blue curve in figure 1, and the experimental power deposition is represented by the 3 coloured areas.

Table 2: Coefficients of the equation describing the power density profile in the various TBM regions

	a	b	c	d
FW steel	5398628,19	0	0	0
SW steel	2820049,65	13,672789	3436905,99	5,4253952
CPs steel	4117528,69	58,004425	2859255,15	10,315923
Vert. SPs steel	7717621,7	99,036875	3397104,98	11,610371
Hor. SPs steel	3390235,06	57,041405	3079508,12	10,217708
Lithium Lead	53665089,9	88,910064	5149067,14	8,0690909

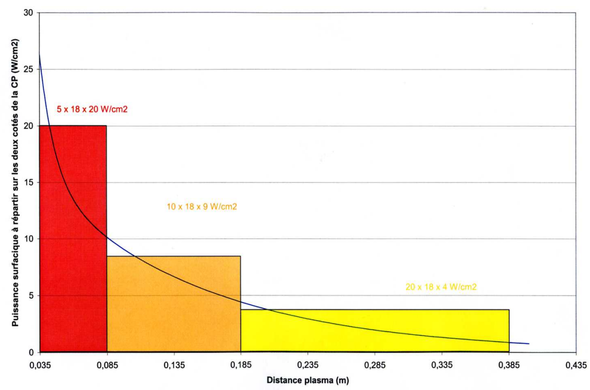

Figure 1: Power deposition profile

THERMOHYDRAULICAL ANALYTICAL CALCULATIONS

These calculations allow to feed the forced convection conditions in helium side at the F.E. model. To perform them, the model described in the figure 2 was used, assuming only thermal conduction in PbLi side.

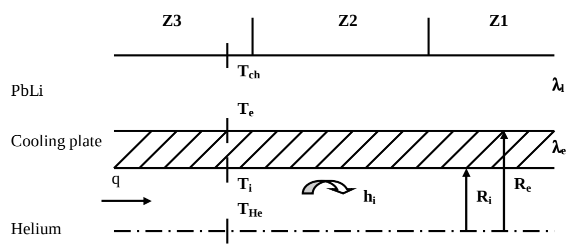

Figure 2: Thermal exchange model

On helium side, the forced convection is modelized using Gnielinski correlation. The main results obtained could be illustrated by the figure 3.

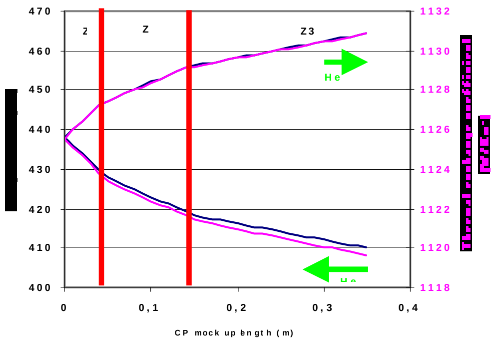

Figure 3: Helium temperature with exchange coefficient profiles along the CP mock up length for an helium inlet at 410°C

These results show that the working temperature for heaters is a few over limit for ITER conditions. So DEMO conditions, which need 30 g/s of He flow rate instead of 7 g/s, induce an increase of thermal flux and so an increase of heaters temperature. Calculations performed with DEMO conditions showed a maximum heater temperature around 900°C, which is not possible with current heaters.

F.E. THERMO MECHANICAL CALCULATIONS

The results show the thermal distribution and von Mises stresses in the CP mock-up (figure 4).
For an inlet helium temperature of 410°C (figure 4), the temperature of the CP mock-up goes up to 610°C on the massive parts of the “U turn cap”, due to the lack of He cooling. On the plate, the results are quite equivalent of those obtained with the analytical methodology, with a maximum temperature of about 550°C.
The stresses are equally maximum in the cap where the temperature is maximum. On the plate the maximum stresses are in the border in the higher flux heaters with a level of 130 MPa. The maximum deformation due to thermal dilatation is lower than 3 mm.

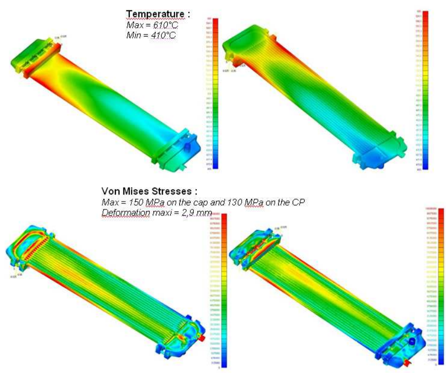

Figure 4: Results of 3 D simulation for ITER conditions and inlet He temperature of 410°C

For an increase of the inlet He temperature from 410°C to 450°C, the mean temperature level normally increases with a maximum temperature of 660°C located in the “U turn cap”, which induces a maximum stress of 150 MPa.

As for previous calculations, there is a good accordance with the analytical calculations concerning the structure temperature.

INSTRUMENTATION LOCATION

After previous simulations, all critical areas have been identified in order to locate instrumentation, composed by thermocouples. 25 tight paths are available and 8 thermocouples are needed for the DIADEMO control command: so 17 thermocouples are devoted for experimental test.

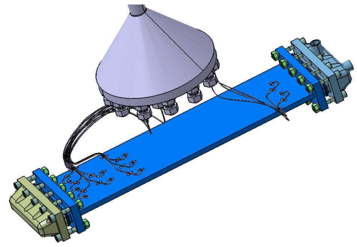

Figure 14: Thermocouples implantation

The maximum of thermocouples takes place in the area where the temperature is the highest.

CONCLUSIONS

This thermo-mechanical study has been performed in support to DIADEMO experimental program on the CP mock-up. The objective was to simulate the different test parameters schedule in order to estimate CP mock up behavior. The results allow to:
- Optimize the thermocouples location on the CP mock up,
- See that the thermal flux required to simulate DEMO conditions could not be simulate with the current heaters.

After the experimental program, made on DIADEMO device, these theoretical results will be compared to experimental data.

REPORTS AND PUBLICATIONS

- L. CACHON et al., "Support studies for the cooling plate mock-up testing in DIADEMO (TW5-TTBC-001-D10)" NT DTN/STPA/LTCG 2006-037

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TW5-TTBC-001-D11

Task Title: PRELIMINARY LAYOUT OF THE HCLL TBM PIPING IN THE ITER PORT CELL

INTRODUCTION

This task consisted in a preliminary definition of the piping between the Helium Cooled Lithium Lead Test Blanket Module (HCLL TBM) and the loops it is connected to in the ITER reactor, through the bioshield and the Port Cell up to the Vertical Shaft. The Helium and PbLi loops were concerned. This definition had to include the pipes organisation, geometries and positions, the type and locations of the connections between pipes sections, and the ways to handle the thermal expansions. The TBM shielding system, provided by ITER, has been represented in the piping paths design. The Port Cell equipments were taken into account, by using symbolic representations: the PbLi loop has been represented to figure out the piping connections; the constraints due to the space sharing with another system in the Port Cell was also taken into account; the Piping Integration Cask has also been taken into account as it involves strong limitations on space constraints.

As the auxiliary systems to be integrated are defined only at a preliminary level, the 2006 preliminary integration step mainly aimed at identifying some issues and some fields needing further investigation, and allowed choosing a design with maximum advantages. The presented design is not the result of mechanical calculations for the auxiliary systems part.

2006 ACTIVITIES

ENVIRONMENT OVERVIEW

The HCLL TBM and the auxiliary systems are mounted in the equatorial Port #18.

TBM systems include:
- Circuit and components of the primary heat transfer system (PHTS or helium loop)
- Secondary coolant circuits and components
- Tritium management components
- Liquid breeder PbLi loop
- Instrumentation packaging and control system, safety-relevant detection systems and valves
- Possibly, remote tools

Come of these systems (PbLi Loop and some Helium system components) are included in the Piping Integration Cask (PIC) that is a mobile assembly.

Figure 1 shows the auxiliary systems at their current state of definition. The TBM is linked with the shield. The interface 1 was defined as the attachment zone between the backside shield of the Frame and the TBM. The ensemble TBM + shield is placed into the Frame. The Frame is removable and is placed into a hole in the VV named the Port Plug. The feeding pipes of the TBM go through the Frame shield and reach the Port Cell.

1) TBM
2) Frame
3) Plug shield
4) PbLi inlet pipe
5) He inlet pipe
6) He by-pass pipe
7) He outlet pipe
8) PbLi outlet pipe
9) PIC bioshield
10) PbLi system
11) Cask
12) Auxiliary He system (by-pass valve, gas mixer,…) + measurement systems
13) Tritium extraction

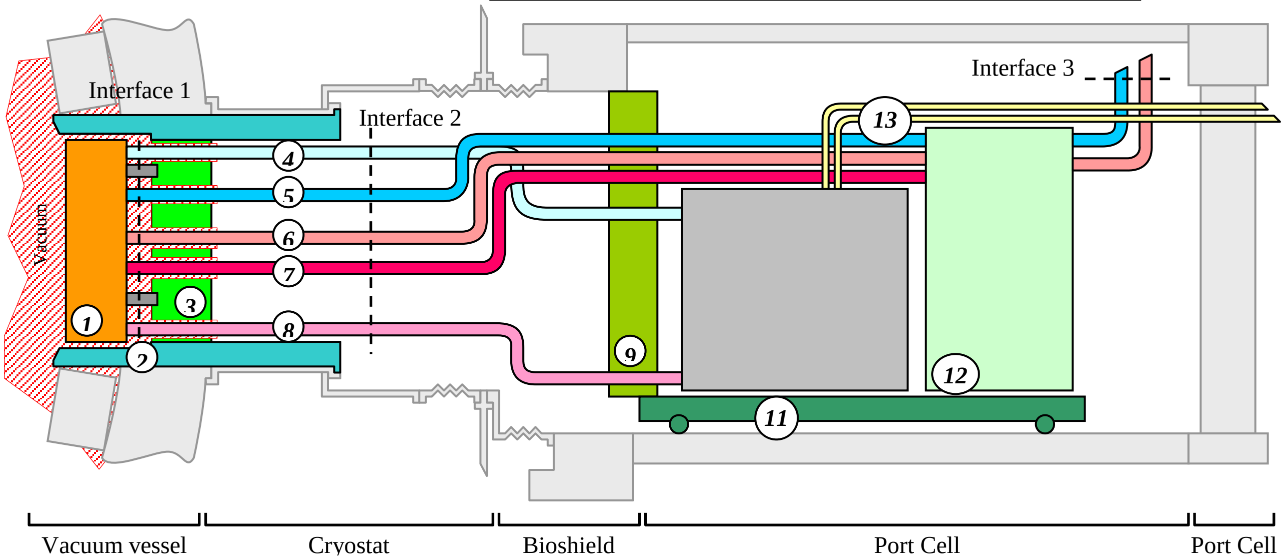

Figure 1: View of the whole systems with the interfaces

The vacuum is limited by the shield. After passing through the shield, the feeding pipes reach the interface 2 zone, were they will be connected to the pipes coming from the auxiliary systems. Then, the piping lines continue towards the Piping Integration Cask (PIC); some bends are foreseen to allow thermal dilatation. The PIC is situated in the rear part of the Port Cell. It is removed before doing operations on the TBM to allow access for the Transfer Cask (all these operations are largely described in. [1] Helium pipes go out of the PIC and are directed to the Vertical Shaft. Here is the interface 3 zone, where the connection between the pipes present in the Vertical Shaft and the pipes linked to the PIC is realised.

REQUIREMENTS

Various requirements apply to the TBM systems. The major challenge is to do all the changing operations of all the TBM in a limited time (now foreseen to be one month). This requirement implies to have enough space in hot cell to deal with all the operations of all the TBM. This leads to some standardization necessary around the assembly plug shield + TBM inserted in the Frame. The current option is to have a dismountable plug shield and to extract in hot cell the assembly plug shield + TBM. Then it has to be decided if shields are provisioned. In this case, the next assembly can be prepared previously to reactor shutdown, and to be replaced without waiting for the separation of the shield and the TBM. The available space, the feasibility of PIE operations and the schedule are the major constraints relative to the Hot Cell issue

Another strong constraint is the available space in the Port Cell. One Port Cell is occupied by the systems of two different TBM. In this study, it was assumed to limit the occupation for the HCLL system to only a half of the Port Cell, and, in addition, that no component could be shared between the two TBM.

The Frame must be removed and transported by a standardized device, the Transfert Cask [2].

The requirement for quality control during design and production of TBMs and especially for the out-of-vessel part of the TBM loop, will be similar to the SIC (Safety Important Class) components.

Due to radiological requirements, remote handling operations have to be studied. The exact list of operations to be done without human access has to be defined. This could be an important issue, because the cutting/welding operations could be difficult due to the space constraint

DESCRIPTION OF THE CURRENT INTEGRATION SOLUTION

The PIC has been designed with the help of the known dimensions of the current PbLi loop design, and by adding additional space for some He system components and data acquisition systems, in the limit of the allowable space and displacement constraints. A metallic frame is appended to the PIC for the supporting of the pipes between the PIC and the interface 2. The pipes are bended to compensate the thermal dilatations.

It has been checked that the maximal dimensions of the PIC would allow its displacement in the building, on the basis of the assumptions made for the Transfer Cask. An arbitrary thickness of 100mm has been taken for the thermal insulation on the pipes.

About the operations at interface 1, the main option is to connect / disconnect the TBM from the shield in hot cell after removing the assembly TBM + shield of the Frame. Then, the access to the interface 1 is possible either from the sides (space between TBM and shield) or from the rear of the shield. This option must be further studied along with the design of the shield. The devices to connect are pipes, mechanical attachments, and electrical connections

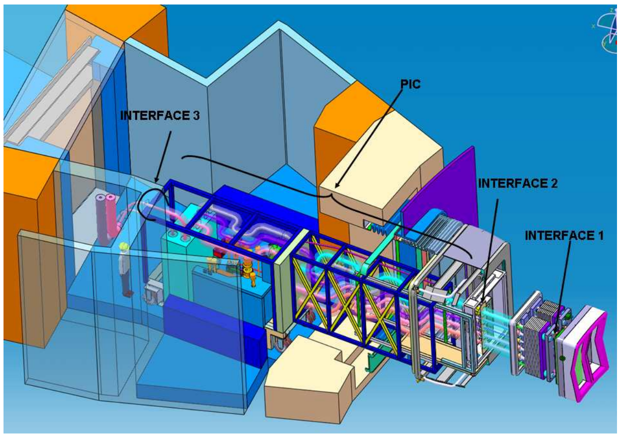

Figure 2: General overview of the whole TBM's systems mounted

At interface 2, it is still in debate if the operations are fully executed by remote tools. The operations consist in cutting/welding the feeding pipes. A preliminary design of a system that can be connected / disconnected remotely has been proposed. Positioning devices helps the remote tools and avoid developing efforts for aligning the pipes (figure 3 and 4).

In this first design, the welding tools are placed on a carriage that permits reaching the interface 2 without making the PIC structure too long.

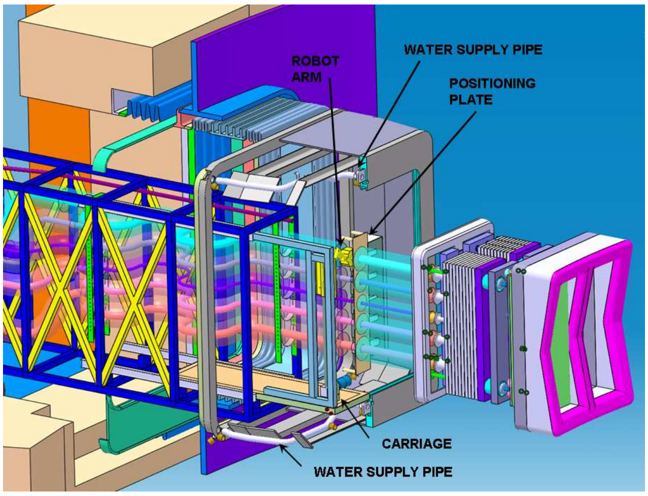

Figure 3: View of the cutting / welding systems

This allows an easier displacement of the PIC in the building. On this carriage, is placed an «elevator», on which a robot arm (in yellow figure 4) can be placed at the appropriate height. The robot arm can reach the pipes and place around them a cutting tool or a welding tool.

For the robot arm and the tools on it, dimensions from industrial applications have been taken. A space is left in the thermal insulator to allow the access of the tools. After finishing the operations, a piece of insulator placed on a moving system is moved by a pneumatic jack to surround the pipes.

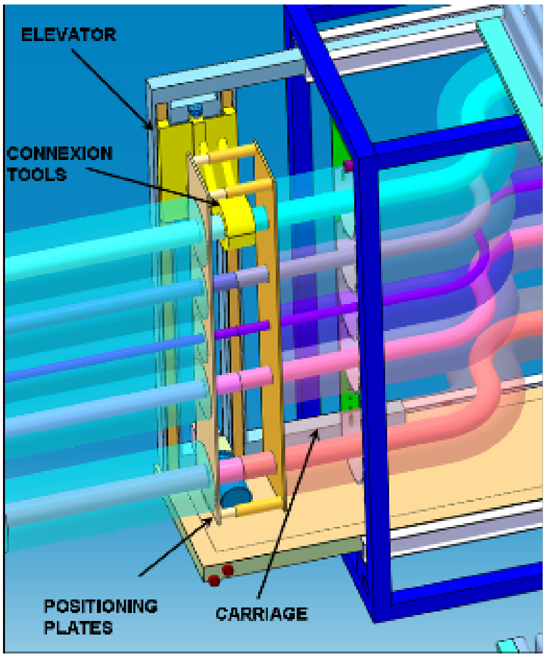

Figure 4: View of the interface 2 zone with cutting/welding tool, positioning plate

CONCLUSIONS

The main issue is the design of the shield and the connection operations at interface 2. Indeed, the design of the shield has an influence on many steps of the TBM changing operation. The operations at interface 2 have to be further detailed and studied in regard to the remote control operations. The PIC will also have to be more detailed while the systems inside will be defined.

A draft version of the final report has been issued [4].

REFERENCES

[1] "Report from the re-established Test Blanket Working Group (TBWG) for the period of the ITER transitional Arrangements (ITA)", September 2005

[2] ITER Technical Basis, ch 2.9 Remote Handling, www.iter.org

[3] M. Eid et al., "Integration of the HCLL TBM system in ITER: Guidelines, PIE and Hot Cell requirements. Task EFDA TW5-TTBC-001-D03", October 2006

REPORTS AND PUBLICATIONS

[4] N. Jonquères, "Integration of the HCLL TBM systems", final report of the EFDA task TW5-TTBC-001-D11, to be issued

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TW5-TTBC-005-D05

Task Title: PROCESS AND AUXILIARY COMPONENTS SENSITIVITY EFFECT OF Pb-Li VELOCITY PROFILE IN VARIOUS LOCATIONS OF THE BREEDER BLANKET STRUCTURE ON T PERMEATION

INTRODUCTION

The objective of this deliverable is to study the sensitivity of Pb-Li velocity profile on the estimation of the Tritium mass flow rate towards the He-coolant under DEMO and ITER TBM conditions for a Breeder Unit.

2006 ACTIVITIES

Main activities during 2006 have concerned the modelling of the permeation of T towards the He circuits for the DEMO 2003 mid-equatorial inboard and outboard HCLL blanket module. The HCLL blanket uses the eutectic metal liquid Pb-15.7Li as both breeder and neutron multiplier with 90% ^{6}Li enrichment. Main performances of the blankets can be found in [1]. The HCLL blanket is composed of modules whose dimensions are around 210 cm (toroidal) x 180 cm (poloidal) and consists of 72 breeder units (9 BU in poloidal direction and 8 in toroidal direction). The reference module has a radial thickness of almost 100 cm. Modules include a first wall (FW) facing the plasma, side walls, covers, stiffening plates to ensure module resistance in case of accidental internal pressurisation, breeding units in which Pb-15.7Li circulates along cooling plates (CP) and at the rear, back plates. There is around 2.1 m^3 of Pb-15.7Li in a module. The structures, made of EUROFER, low activation ferritic martensitic steel, are cooled by pressurized helium at 8 MPa and inlet outlet temperature 300/500°C. In this concept, the Pb-15.7Li is fed from the top of the blanket and distributed in parallel vertical channels among pairs of breeder unit, one BU for the radial movement towards the plasma, the other for the return (figure 1). Each breeder unit is a package of 5 CPs placed horizontally. The BU dimensions are 20.8 cm in both toroidal and poloidal directions and 80 cm in the radial. The liquid metal fills the in-box volume and is slowly re-circulated (few mm per second) to remove the produced T.
The T system components in a reactor can be divided in three main parts, the blanket itself within the vacuum vessel, the Pb-15.7Li circuits and components and the helium coolant circuits and components. The main T-flows are: Φ1: production rate, Φ2: extraction rate from Pb-15.7Li in the Tritium Extraction System (TES), Φ3: permeation rate towards He coolant, Φ4: extraction rate from the He coolant in the Cooling Purification System (CPS), Φ5: release rate to the environment from the He loop. A scheme is presented in figure 1.

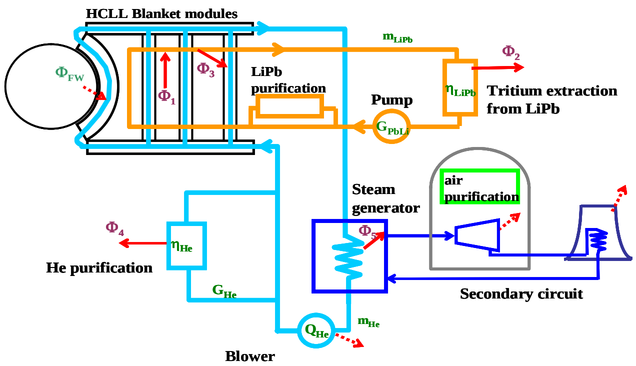

Figure 1: Main tritium flows in a fusion reactor

Ideally, the T produced by the reaction of the Li is transported outside the vacuum vessel to the TES. In practice, due to its fugacity, T is expected in the helium coolant circuits and a coolant purification system must be design in order to achieve the maximum authorized T releases (1 g/year). Many factors contribute to a very high expected T permeation rate such as:

- High T concentration due to the Pb-15.7Li limited flow rate, because of the MHD-induced pressure drops that prevents high liquid metal velocities,

- High T partial pressure due to its low solubility in Pb-15.7Li,

- Very large permeation surfaces between Pb-15.7Li and He with small walls thickness, necessary to ensure an efficient cooling of the Pb-15.7Li and a sufficient tritium breeding ratio,

- Quite high T diffusivity in the Eurofer structural material, especially at high temperature.

It was shown in [2] that taking into account forced convection and diffusion for the transport of T in the Pb-15.7Li can be compared to the benefit of a permeation barrier with a PRF equal to 50 (using an analytic velocity profile in an isothermal forced convection diffusion model). Indeed, the T is transported across the Pb-15.7Li by diffusion, by forced convection to ensure a given recycling rate and by buoyancy convection due to thermal gradient. So, in order to assess the effect of the velocity profile, a local finite element modeling of the T permeation rate through the HCLL breeder unit CPs has been developed.

MAIN PARAMETER VALUES

Tritium solubility in Pb-15.7Li is one of the more arguable characteristics. In order to compare our results from the already published results [2], we keep the Reiter's value for the solubility [3]. There are two kinds of parameters used for the description of the HCLL T cycle, those linked to the process and those linked to the design choices. In this study, we assume that the parameters associated to the helium circuits are such that the total partial pressure of the T gas is much smaller than 1. We also assume, in order to compare our results to [3] that the TES efficiency is 0.8 and that there are 10 recirculations per day. The main reactor parameters are given for the mid-equatorial inboard and outboard module. The heat production and the T production in the HCLL module have been predicted by three dimensional radiation transport calculations employing the MCNP Monte-Carlo code [4]. The distance from the FW to the beginning of the CP is 3.5 cm. For the inboard distribution, a correction factor should be applied, however in order to evaluate the influence of the magnetic field, the inboard permeation rate estimation have been performed with the same heat source and T source. We also implicitly assume that the two modules have the same geometrical characteristics. Magnetic toroidal field induction is set at 10 T for the inboard module and at 5 T for the outboard module.

PERMEATION MODELLING

The T concentration in the helium circuit and remaining in the lithium lead circuit are evaluated by solving partial differential equations governing the T concentration balance, the thermal field and the lithium lead velocity field. In the HCLL concept, the Pb-15.7Li is fed from the top of the blanket and distributed in parallel vertical channels among pairs of breeder units (one BU for the radial movement towards the plasma, the other for the return). So, as a first approach one can assume a radial/poloidal representation of breeder unit (figure 2).

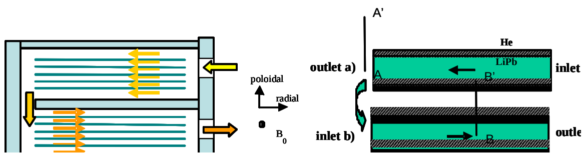

Figure 2: Geometrical model for the simulation

Moreover, results from [2] showed that more than 80% of T permeation occurs through the CP. Therefore, assuming that each CP in a breeder unit plays the same role, it is only necessary to simulate the permeation across two channels (figure 2). However, the upper channel and the lower channel are not independent, balances have to be verified between the outlet of upper channel (channel a) and the inlet of the lower channel (channel b). Moreover, the fluid velocity profile at the outlet could be modified regarding the outlet of the other channels.
The main assumptions used to establish the governing equations are the following:

- Laminar flow,
- Boussinesq approximation for the buoyancy force,
- Inductionless approximation (no induced magnetic field),
- Perfectly conductor side walls (internal walls act like perfectly conducting side walls in MHD flows [5]),
- The T concentration in He circuit is negligible (low partial pressure),
- Limited diffusion regime for the T,
- Steady state.

The main related dimensionless numbers for 10 T taken at the mean wall temperature (476°C) and mean Pb-15.7Li temperature (497°C) for:

- Reynolds number = 2.28,
- Magnetic Reynolds number = $1.5 \cdot 10^{-6}$,
- Hartmann number = 5069,
- Grashof number = $5.86 \cdot 10^{7}$,
- Thermal Peclet number = 0.029,
- Mass Peclet number = 259.3.

The dimensionless numbers are computed using 0.02 m as characteristic length and $\frac{\upsilon}{L}\frac{Gr}{Ha^2}$ as characteristic velocity. The temperature difference used to compute the Grashof is $\delta\theta = \frac{\bar{Q}_f L^2}{\lambda}$. One can see from Reynolds, Grashof and Harmann numbers that the laminar flow and inductionless assumptions are justified. According to Peclet numbers, heat is essentially transferred by diffusion and concentration is transferred by advection.

Because of the geometrical simplification, two kinds of boundary conditions could be applied at the outlet of the channels for the velocity field. The effect of the choice of the boundary is therefore analysed in this study in order to check the usefulness of the geometrical simplifications.
Details boundary conditions are presented in [7]. We only highlight here boundary conditions related to tritium transfer. Indeed, a special care is given to the T concentration boundary conditions because they are related to the T cycle functioning parameters. For instance, the bulk inlet concentration in the module is related to the bulk outlet concentration due to the efficiency of the TES.

Boundary conditions for the concentration

For the Pb-15.7Li

- Prescribed concentration at inlet a) set to (1 – η) times the bulk outlet concentration of the outlet b),
- Concentration at the inlet b) set to the bulk concentration at the outlet a),

For the Eurofer

- Concentration set to 0. at the boundary in contact with helium,
- Insulated conditions for the other wall,

At the interface between Pb-15.7Li and Eurofer

- Equality of the mass flow,
- Equality of the partial pressure ($\frac{C_f}{K_f} = \frac{C_w}{K_w}$).

ANALYSIS AND DISCUSSION

The presented equations are solved using the CEA finite elements code CAST3M. The two channels were meshed using 19200 four nodes elements with a fine meshing near the side walls so that at least 5 elements are in the boundary layer.

The interesting outputs allowing specifying the processing elements of the circuits are:

$$\phi_3 = \int_{\text{wall}} -D_w \frac{\partial C_w}{\partial y} dy \, , \qquad (1)$$

$$\bar{C}_f = \frac{\int_{\text{outlet b)}} u\, C_f \, dy}{\int_{\text{outlet b)}} u \, dy} \qquad (2)$$

$$\Phi 3/\Phi 1 \text{ where } \phi_1 = \frac{1}{r_{\max} - r_{\min}} \int_{r_{\min}}^{r_{\max}} Q_f(r) dr \qquad (3)$$

In this paper, we focussed our interest in the sensitivity of the velocity profile on these three outputs. Therefore, two (one for 5 T and one for 10 T) two levels factorial designs analysis are carried out considering the two factors, X_{CL} the outlet velocity boundary conditions and X_{NC} the natural convection. Setting X_{CL} to +1 if considering the prescribed constant velocity and -1 for the fully developed boundary and setting X_{NC} to +1 if considering the buoyancy force in the momentum equation and -1 if not, leads to the 4 numerical experiments presented in table 1.

Table 1: Numerical experiments for a 2 levels factorial design

	NE 1	NE 2	NE 3	NE 4
X_{CL}	+1	-1	+1	-1
X_{CV}	+1	+1	-1	-1

Figure 3 and 4 report the temperature and concentration fields for the numerical experiment 1 at 10 T. The temperature is higher near the FW and looks like a pure diffusion field. Near the outlet b), the temperature field is almost constant and follows the prescribed wall temperature. Tritium concentration gets enriched as it flows toward the FW. One can see the development of concentration boundary layer near the wall where the tritium concentration is lower than in the bulk. This layer should be regarded as a mass transfer coefficient around 1.12 x 10^{-6} m·s^{-1} for the tritium permeation and should be taken into account in the 1D model as $\frac{K_w D_w}{K_f t} \approx 3.26\,10^{-5}$ m·s^{-1} for the HCLL CP.

The permeation rate towards the helium should be written as:

$$\phi_3 = \frac{\bar{C}\, A}{\frac{1}{k} + \frac{PRF\; K_f\; t}{K_w\; D_w}} \qquad (4)$$

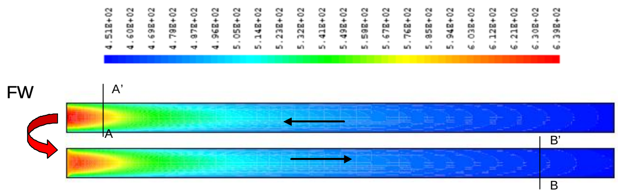

Figure 3: Field temperature (°C) for numerical experiment 1 – B = 10 T

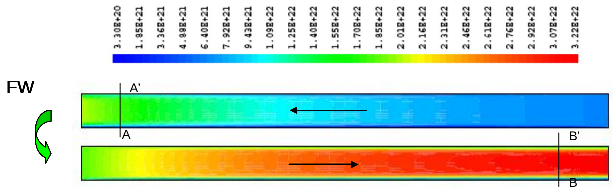

Figure 4: Tritium concentration field for numerical experiment 1 – B = 10 T

This mass transfer coefficient is equivalent to a PRF of 30 which is the order of magnitude found in [2].

The 4 performed numerical experiments of each two levels factorial design allow estimating the parameters of the following response surface:

$$y(X_{CL}, X_{CN}) = a_0 \;\; (1 + \frac{a_1}{a_0} X_{CL} + \frac{a_2}{a_0} X_{CN} + \frac{a_3}{a_0} X_{CL} X_{CN}) \qquad (5)$$

where y is any of the three considered outputs (Φ_3, $\bar{C}_f$ and Φ_3/Φ_1). It must be note that a_0 is the mean value of the 4th numerical results, a_1 expresses the effect of the velocity boundary conditions, a_2 expresses the effect of the natural convection and a_3 expresses the effect of the interaction between the boundary conditions and the natural convection. Table 2 gives the estimated values of these parameters.

Table 2: Parameters of the response surfaces

	a0	a1/a0	a2/a0	a3/a0
Φ3 (g/m²d) – 5 T	2.93 10^{-3}	-0.08 %	-0.66 %	-0.10 %
$\bar{C}_f$ (mol m^{-3}) - 5 T	0.0454	-0.10 %	0.26 %	-0.08 %
Φ3/Φ1 (%)– 5 T	21.16	-0.08 %	-0.66 %	-0.10 %
Φ3 (g/m²d) – 10 T	2.94 10^{-3}	0.015 %	-0.21 %	-0.005 %
$\bar{C}_f$ (mol m^{-3}) - 10 T	0.0453	- 0.023 %	0.066 %	-0.013 %
Φ3/Φ1 (%)– 10 T	21.25	0.014 %	-0.21 %	-0.005 %

The Φ3 quantity is divided by the wetted Pb-15.7Li surface (110 m²) in order to be useful for other studies. It appears that the outlet velocity boundary limit and the natural convection have no effect on the observed outputs. Indeed, the highest value is around 0.66 % and is to be compared to 1. This may be not the case for modules where gravity is parallel to the prescribed flow (top and bottom of the reactor). Moreover, mean values show that the observed outputs are not sensitive to the value of the magnetic field. This is valuable information as permeation experiments have to be performed.

CONCLUSIONS

The permeation rate through the helium circuit and remaining in the lithium lead circuit are evaluated by solving partial differential equations governing the tritium concentration balance, the thermal field and the lithium lead velocity field for a simplified 2D geometrical representation of the breeder units. It is shown, for the mid equatorial HCLL modules with the retained assumptions, that the permeation through the helium circuit, the mean outlet tritium concentration in Pb-15.7Li and the ratio between the permeation through the helium circuit and the production rate are insensitive to the magnetic field and the buoyancy effects. However, due to the flow, a concentration boundary layer exists and is to be regarded as an equivalent permeation reduction factor (PRF) of 30. Considering the difficulty encountered in the past years to obtain stable and reproducible high PRF with Al-based coating on Eurofer [6], an equivalent PRF of 30 is of great importance for the T inventory in the HCLL blanket and should relaxed the CP requirements.

REFERENCES

[1] A. Li Puma et al., Helium Cooled Lithium Lead Blanket Module for DEMO – Designs and Analysis, CEA report, DM2/SERMA/LCA/03-3297

[2] W. Farabolini et al.: “Tritium control modeling for helium cooled lithium-lead blanket of a fusion power reactor”, Fus. Eng. And Des. 81 (2006) pp 753-762

[3] F. Reiter, "Solubility and diffusivity of hydrogen isotopes in liquid Pb-17Li", Fus. Eng. and Des. 14 (1991), pp 207-211

[4] J. Jordanova et al., “Evaluation of nuclear heating, tritium breeding and shielding efficiency of the DEMO HCLL breeder blanket”, Fus. Eng. and Des 75-79 (2005) pp 963-967

[5] J. Reimann et al.: “Magneto-hydrodynamic issues of the HCLL blanket”, Fus. Eng. and Des 81 (2006) pp 625-629

[6] A. Aiello, A. Ciampichetti and G. Benamati: "an overview on tritium permeation barrier development for WCLL blanket concept”, J. Nuc. Mat. 329-333 (2004) pp 1398-1402

REPORTS AND PUBLICATIONS

[7] F. Gabriel et al., A 2D FINITE ELEMENT MODELLING OF TRITIUM PERMEATION FOR THE HCLL DEMO BLANKET MODULE – presented at the 24th SOFT conference

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TW6-TTBC-001-D03

Task Title: HCLL TBM DESIGN AND INTEGRATION ANALYSES

INTRODUCTION

In the Work Program 2006, the detailed engineering design of the HCLL Test Blanket Modules (in particular the IN-TBM and EM-TBM) and associated systems has to be further developed in particular with focus on integration of diagnostic and monitoring instrumentation, integration of fabrication R&D issues, ITER environmental and schedule constraints and performances optimization.

Thus, the objectives of this task are:
- The further development of the TBM design, and in particular the update of the TBM dimensions according the constraints of the last frame design update, the improvement and optimization of the He flow scheme according to the last DEMO studies, and the instrumentation integration;
- The evaluation of design margins regarding the design criteria, as they impact the manufacturing choices;
- The definition of the maintenance sequence of the TBM (installation, replacement, dismounting);
- The analysis and improvement of the Helium Cooling System of the TBM.

2006 ACTIVITIES

This work started in late 2006, and only preliminary results can be reported.

TBM design

The modifications of the Frame design for test blankets ports have led to the reduction of the dimensions of the internal space available for the TBM. The necessary reduction of the TBM poloidal and toroidal lengths has a strong impact on the HCLL TBM design, and its update, based on the previous existing design [1] requires:

- To re-define the number of breeding cells, taking into account the new TBM overall dimensions, without loosing the DEMO relevancy;
- To re-define consequently the First Wall design (channels section and pitch, thickness, number of passes,) with the following steps: analytical thermal-hydraulics optimisation, mechanical behaviour validation, thermal-hydraulics computation for final validation;
- To reconsider the back plates stiffening and the attachments system.

In addition, further improvements of the design can be made:
- According to the TW5-TTBC-001-D06 work on the reference Helium flow scheme for DEMO, the Helium flow scheme for the TBM has to be updated; the new scheme being serial, a forth stage has to be added in the back collector, and the cooling channels of the Stiffening Plates, Covers, and Cooling Plates has to be adapted, and the corresponding pressure drops assessed;
- The positions of the Covers feeding and by-pass pipe has to be consequently re-defined;
- The Covers cooling has to be assessed and optimised (circulation path, front channel in the First Wall).

These updates have been preliminarily performed on the In-TBM, which is the basis of design for the other TBM. They have led in particular to:
- The reduction to 2 vertical columns of breeding cells to keep dimensions similar to DEMO;
- The revision of the whole dimensioning of the TBM;
- An in-series Helium flow scheme, which allows a better flow control but requires an additional stage in the back manifold (5th back plate);
- The reduction of the channels sweeps in the FW (3 passes);
- The increase of the SP channels cross-section;
- The reduction to 3 CP per BU;
- A new positioning of the inlets/outlets in the back manifold;
- Attempt to solve back plates welding issues.

The new proposed He flow scheme and its main characteristics are presented in figure 1.

Some preliminary geometric data related to the sub-components dimensions are given in table 1.

Table 1: HCLL In-TBM preliminary updated dimension

External max. dimensions (t x p)		484 x 1660 mm^2
External dimensions (r x t x p)		573 x 484 x 1655 mm^3
Covers thickness		30 mm
FW/SW	Thickness Channels section (w x h) Number of channels passes Channels pitch Channel legs per BU	30 mm 11 x 12.5 mm^2 3 22.3 mm 9
BU	Breeding Cells dimensions (r x t x p) Number of Cooling Plates Cooling Plates pitch	372 x 206.5 x 189.7 mm^3 3 44.6 mm
CP	Thickness Number of channels Channels cross-section	6.5 mm 8 4.5 x 4.5 mm^2
SP	Thickness hSP channels cross-section hSP channels number / pitch vSP channels cross-section vSP channels number / pitch	11 mm 6 x 10 mm^2 3 / 15.5 mm 6 x 10 mm^2 3 / 14.5 mm

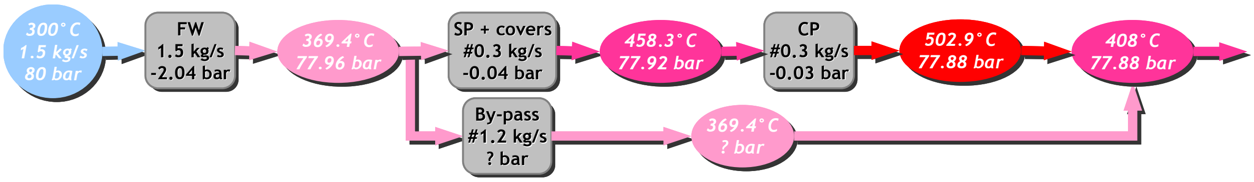

Figure 1: New He flow scheme for the HCLL In-TBM

A preview of the geometry based on dimensions presented in table 1 is given in figure 2.

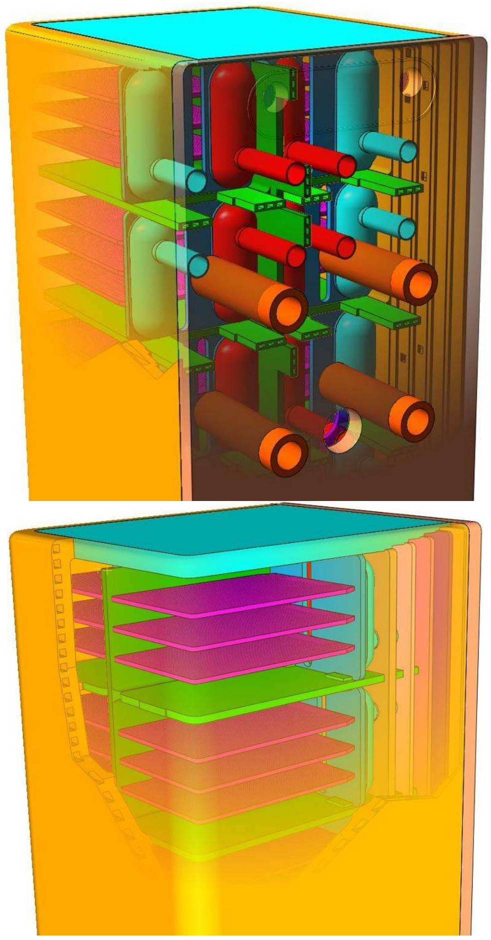

Figure 2: Details of the CAD model of the HCLL In-TBM

Definition of a design specification package for fabrication R&D

The methodology to follow has been defined:
- The studies will rely on the fabrication on the First Wall
- Variations of the nominal dimensions of the cross section will be assumed:
  - An ensemble of thermal 2D calculations of the cross section will be performed,
  - The variations of thermal performances of the FW will be assessed,
  - Those variations will be considered as acceptable according to 2 criteria: maximal temperature of the FW, and maximal height of the FW (e.g. TBM),
  - A range of acceptable tolerances will be deduced.

Design and integration analyses of the TBM HCS

Those analyses started by the evaluation of the space necessary for the implantation of the components in the TCWS. The possibility to put in common He circuits components for several TBM (in TCWS and Port Cell) has been assessed: If it leads to the diminution of the space constraints in the TCWS, it reports them in the Port Cell by adding new components (recuperator, heater, mixer, valves…) where space is already limited, in particular in the case of the HCLL system by the PbLi loop. In addition, and as main issue, a gas mixing is not possible for test objectives on tritium balance: measurements have to be done at the inlet/outlet of each TBM, but also integrated along the whole loop.

In conclusion, the circuits for TBM have to be kept independent (but standardization of technological choices for components should be required).

CONCLUSIONS

The update of the HCLL TBM design on the basis of its new Port Frame dimensions and on several optimisations has started. This new design will have to be confirmed in 2007, with the help of:

- Thermal computations
  - Determination of the parameters of the He flow scheme (pressure drop, channels sections,…),
  - Use of a coupled fluid/structure model, based on one breeding cell model (including SW), such as the one used in TW5-TTBC-001-D06, to determine the temperature field under several operating scenarios.

- Thermo-mechanical calculations
  - Use of the thermal results on the structure model,
  - Validation of geometrical choices (thicknesses,…).

- Covers cooling optimization

This work will be completed with solutions for the installation of measurement sensors inside the TBM, with the analysis of the maintenance sequence of the TBM (installation, replacement, dismounting), and with the further detailed analysis of the Helium Cooling System.

REFERENCES

[1] G. Rampal, "Design and analyses of the HCLL TBM including design of supporting system and instrumentation integration", final report of the EFDA task TW5-TTBC-001-D01, CEA report SEMT/BCCR/RT/06-004/A, September 2006

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