THE DUAL COOLANT LITHIUM LEAD BREEDING BLANKET: STATUS AND PERSPECTIVES

EUROfusion

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INTRODUCTION

During the last years CIEMAT has been leading the activities to develop an integral breeding blanket with advanced performances to work in a realistic DEMO scenario. This blanket is the Dual Coolant Lithium Lead (DCLL) working at a limited temperature in order to allow the use of conventional materials and technologies. The design of this blanket was finished, including the definition of the tritium extraction system and tritium simulations. Then, determined by the selection of other two concepts as driver blankets for DEMO, the focus was put on developing a DCLL which can work at higher temperatures, thus increasing the plant net efficiency. In this work, a summary of the status of the DCLL is presented, together with some ideas for developing an advanced DCLL in the near future

DEMO as a Component Test Facility

❑ High-level objectives of the European strategy, which considered DEMO as the only step between ITER and a fusion plant:

1. To supply a net electricity production of a few hundred megawatts to the grid
2. To reproduce the amount of tritium needed to complete the fuel cycle in the reactor
3. To demonstrate the feasibility of all technologies for the construction of a commercial fusion plant, including an adequate level of availability

G. Federici, Overview of the design approach and priorization of R&D activities towards an EU DEMO, FE&D (2015)

❑ New strategy: DEMO as a '**Component Test Facility**' for BB

- **Driver BB concept**: demonstrate T self-sufficiency and power extraction (80% of the segments)
- **Advanced BB (ABB) concept**: potentially attractive for commercial reactors

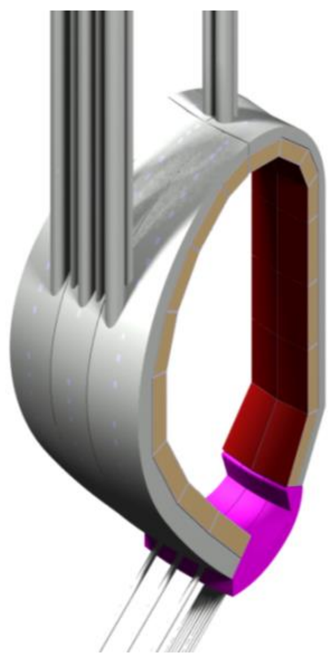
In particular the development of high temperatures structural materials to exploit more attractive concepts and make possible higher plant efficiency is recommended (WG TBM-BB)

❑ The designs for the 'driver' and ABB have to be developed at the same level (excepting BoP)

DCLL: Single Module Segmentation vs Multi-Module Segmentation

❑ From the point of view of the liquid metal, it seems favorable to have a segment consisting in an unique module (SMS)

- The SMS architecture presents several advantages:
  - Less turns in planes perpendicular to B, therefore less pressure drop due to 3D MHD effects is expected
  - FCI mostly necessary for poloidal channels, not quite complex configurations
  - Higher TBR due to the lower amount of steel
- However, due to the use of EUROFER as structural material → strong temperature limitation
  - Large route for the liquid metal, typically ~10 m
  - Temperatures: short operational window between 300 °C and 550 °C
  - This implies higher PbLi velocities → large corrosion rates, higher pressure drops (MHD)
  - Integration of heating systems? Structural integrity can be compromised



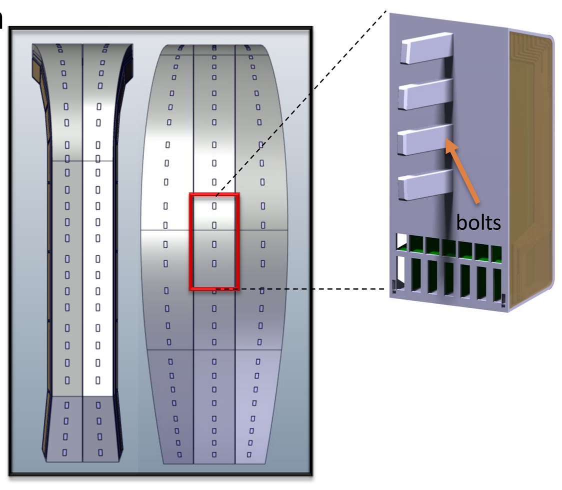
The LT-DCLL: present status

The adopted solution for the LT-DCLL was a MMS:

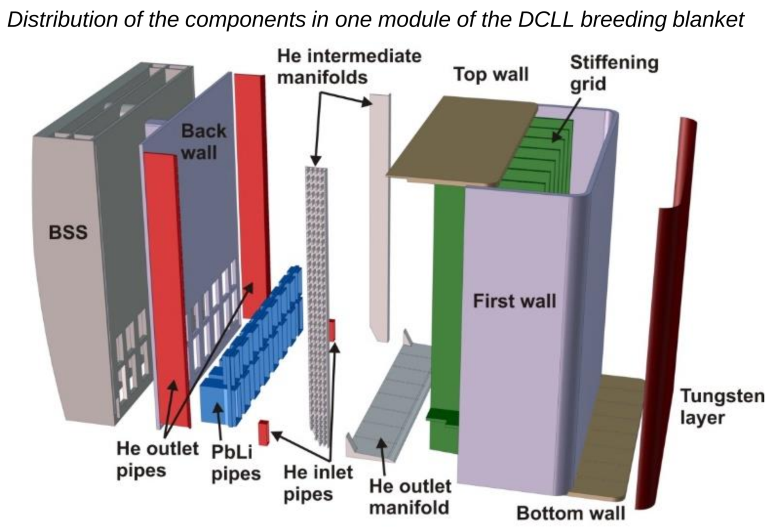
❑ A number of different blanket modules attached to a common Back Supporting Structure

❑ Disadvantages:
- More 3D complicated geometries, which can cause important pressure drop.
- Lower TBR is expected

❑ BUT:
- ✓ For the LT concept the outlet temperature is easily achieved at moderate velocities: around 2 cm/s in the poloidal channels
- ✓ Therefore MHD effects will not be quite important
- ✓ Corrosion is not a 'killing' issue
- ✓ The present DCLL design suggests a parallel cooling of the different modules → pressure loss is reduced to that for one BB module



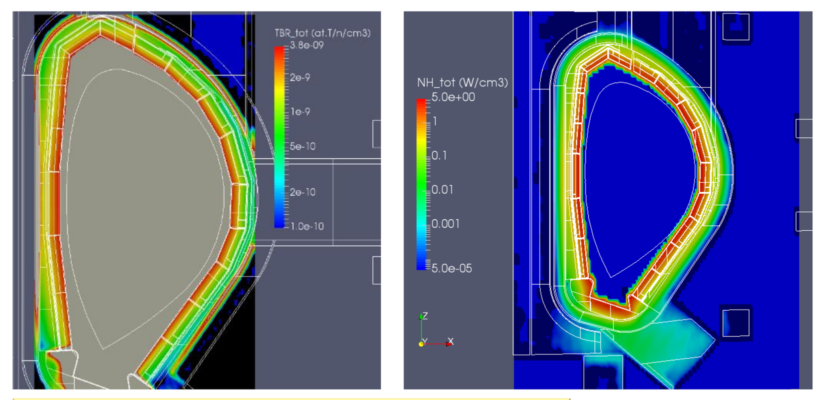
Distribution of the components in one module of the DCLL breeding blanket



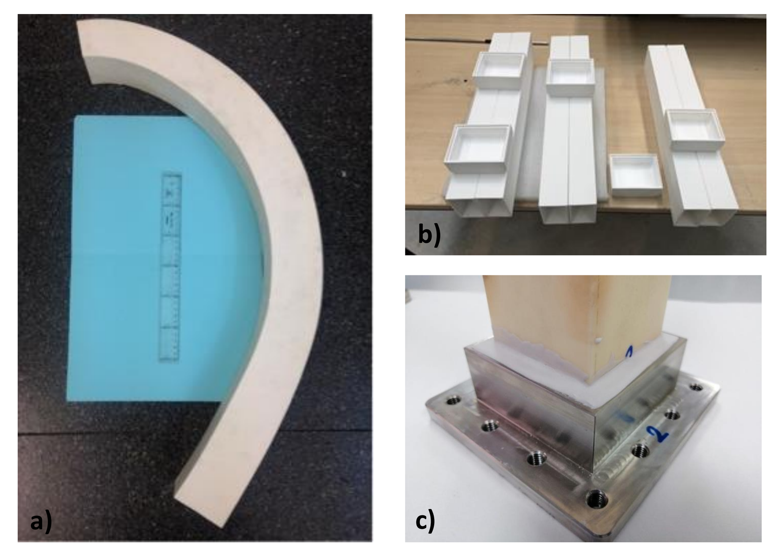
<u>Neutronics calculations</u>:
- ❖ TBR = 1.173
- ❖ M_E = 1.21

1. (left) Radial-poloidal distribution of the tritium generated

2. (right) radial-poloidal distribution of the nuclear heating



I. Fernández-Berceruelo et al., Fusion Eng. Des. 155 (2020) 111559

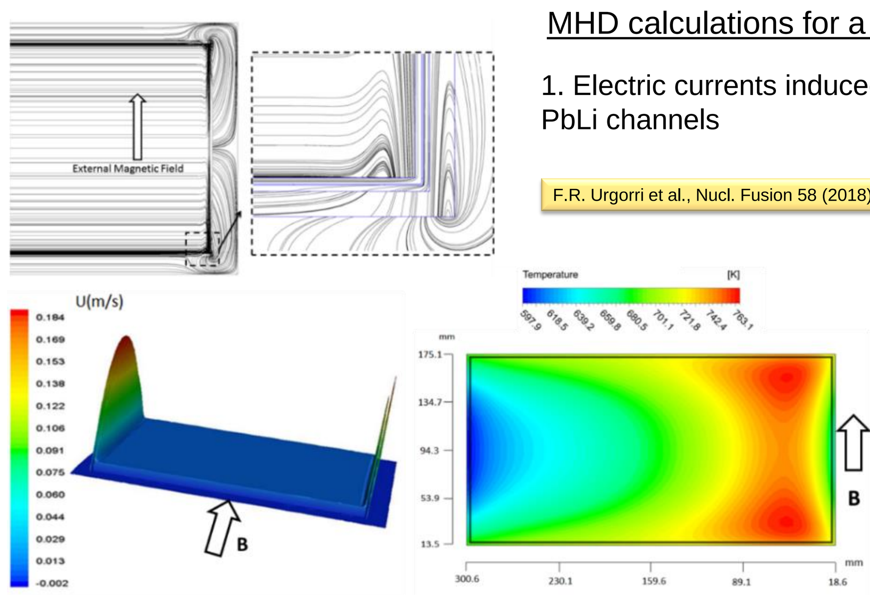


a) Final sintered banana-shaped FCI; b) longitudinal alumina mock-ups produced by casting; c) prototype assembly of the squared sectioned alumina tube and the steel flange with a white ceramic cement

<u>MHD calculations for a channel with FCI:</u>

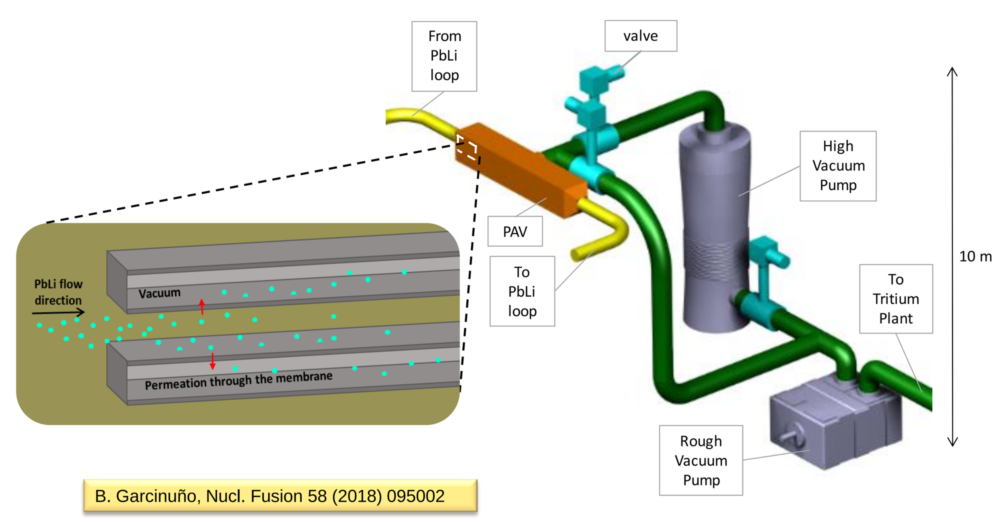
1. Electric currents induced in the PbLi channels

F.R. Urgorri et al., Nucl. Fusion 58 (2018) 106001



2. (left) MHD fully developed velocity profile in a frontal PbLi channel.

3. (right) Temperature distribution in the same channel considering the neutronic volumetric heating



B. Garcinuño, Nucl. Fusion 58 (2018) 095002

Schematic view of the PAV functioning and 3D design of the TERS

Perspectives: the HT-DCLL

<u>PROPOSAL FOR A HT-ABB</u>

❑ To produce an integral blanket design that is capable of achieving high plant efficiencies.

❑ How the efficiency can be increased?
- Concept working with a liquid metal which operates at higher temperatures (700-800 ºC)

❑ Development of an ABB working at high temperature
- This implies, in parallel, the development of auxiliaries
- Strong development in insulating components (electrical/thermal): FCI? Ceramic structures?

<u>IMPLICATIONS OF A HT-DCLL</u>:

❑ Higher requirements to the BB, but also to the auxiliaries

❑ Structural material? Usually, all the blanket designs consider the structural material as the container of the liquid metal → new approach is needed

❑ Corrosion of materials: anti corrosion barriers are mandatory

❑ High permeation problem due to large temperature gradients → BUT high PbLi velocvity, lower tritium concentration

❑ TERS, which now should operate at higher temperature. Positive impact on the extraction efficiency?

❑ The development of a heat exchanger for high temperature → there are studies for SiC heat exchanger

<u>SEGMENT DEFINITION</u>: SINGLE BOX WITH SIMPLE PbLi ROUTE

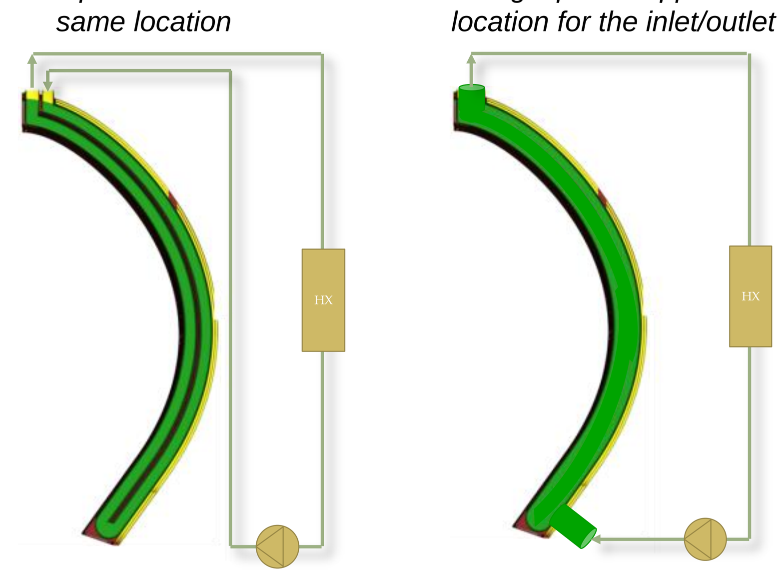
- Wider operational window (300-700º/800ºC?) → improvement in the plant net efficiency
- Moderate PbLi velocity for a step of 400 ºC
- Potential improvement of the TBR
- Only one turn in perpendicular direction to the B

(even none turns): reduction of MHD effects (3D)

- Electrical isolation in relatively simple geometry

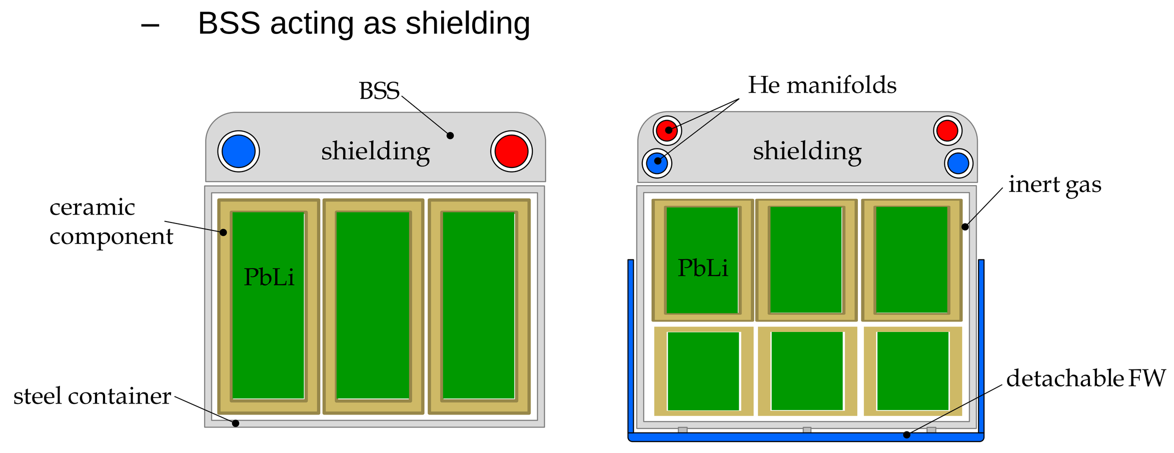
2 paths – inlet/outlet same location

1 single path – opposite location for the inlet/outlet



<u>CONCEPTUAL DESIGN BASED ON</u>:

- Segment is a unique box, with just one coolant pass
- Ceramic box as liquid metal container
- Steel box as structural-containment box → no inbox-LOCA
- Inert gas (Ar, He) in between ceramics and steel box
- Decoupled FW → toroidal cooling, common manifold in the BSS
- BSS acting as shielding



<u>ADVANTAGES OF THE HT-DCLL</u>

- ❖ In some way the in-box LOCA, which pressurizes the external box, can be avoided
- ❖ Much more simple route for the PbLi: less 3D-MHD effects
- ❖ Tritium losses to the secondary coolant (He) are practically discarded, thanks to the separation between the external and internal boxes
- ❖ EUROFER corrosion due to liquid metal is now excluded → requirements of the purification system are relaxed
- ❖ The FW could be mechanically and hydraulically decoupled from the segment, acting as a protection panel (to be studied)
- ❖ Issues related with the liquid metal velocity in IB segments are strongly reduced (much more radial space for allocating the breeder)
- ❖ In case of He nucleation in PbLi, the exit of the bubbles is assured

References

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