An approach for the pathway towards the development of high performance breeding blankets

Iván Fernández-Berceruelo, David Rapisarda

Fusion Technology Division
National Fusion Laboratory
CIEMAT

This work has been carried out within the framework of the EUROfusion Consortium, funded by the European Union via the Euratom Research and Training Programme (Grant Agreement No 101052200 — EUROfusion). Views and opinions expressed are however those of the author(s) only and do not necessarily reflect those of the European Union or the European Commission. Neither the European Union nor the European Commission can be held responsible for them.

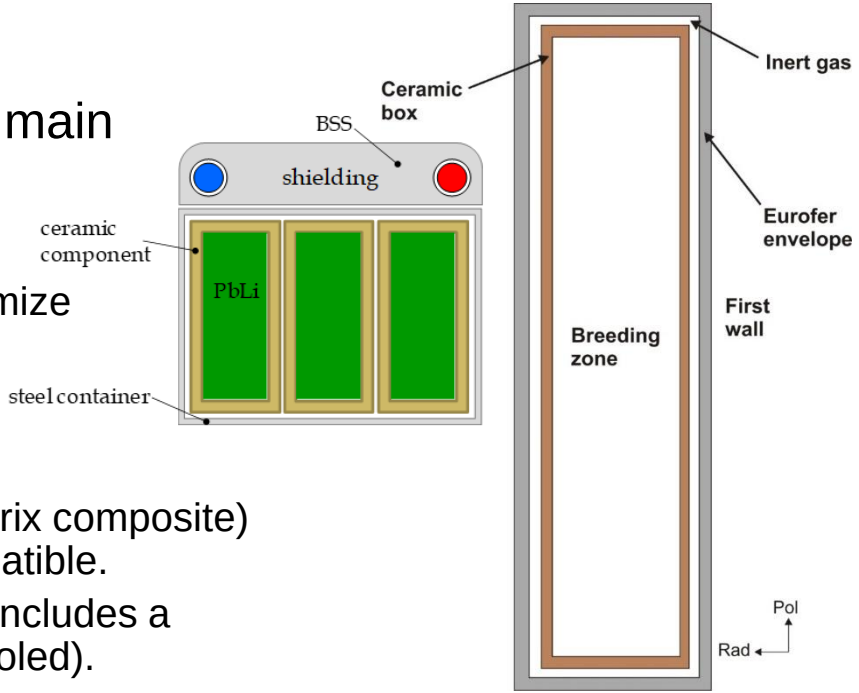
Introduction

DEMO → ?... → FPP

- Interest of achieving as fast as possible the capability to build and operate high performance reactors which finally allow competing in the electricity market.
- Breeding blanket → Need to maximize the reliability, availability and energy recovery efficiency (cycle and electric).
- Use of an incompressible self-cooled liquid breeder (PbLi, molten salt) and high temperature materials.
- Simple design (easy paths, few components, few welds/joints). Single Module Segment architecture (SMS).

Dual Coolant Lithium Lead (DCLL) SMS

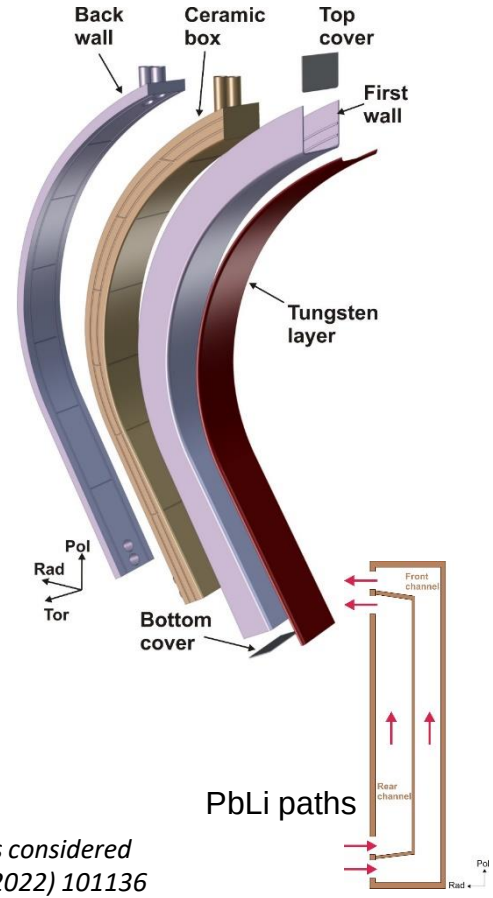
- Self-cooled eutectic PbLi as breeder & main coolant.
- Key issues:
  - electrical insulation of breeder circuit to minimize magnetohydrodynamic (MHD) effects.
  - Corrosion/erosion.
- **Solution 1**:
  - Electrically resistive ceramic (or ceramic matrix composite) box enclosing the breeder circuit. PbLi-compatible.
  - Protected by a EUROFER steel case which includes a continuous First Wall (FW) panel (Helium-cooled).
  - Separated by a gap to accommodate the different thermal expansion of dissimilar materials. Gap filled with a low pressure inert gas.



D. Rapisarda, I. Fernández-Berceruelo, et al., "The European Dual Coolant Lithium Lead breeding blanket for DEMO: status and perspectives", Nucl. Fusion 61 (2021) 115001

DCLL SMS

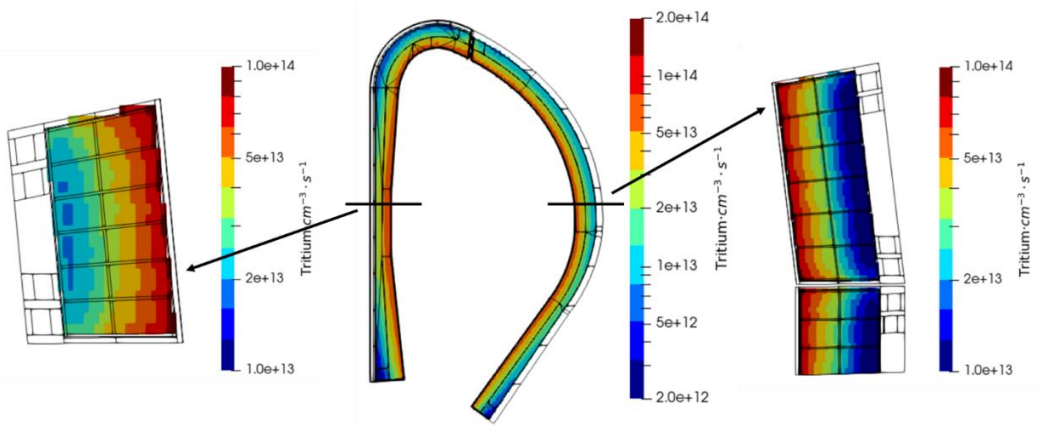
- Two thermal levels: 300-550 ºC (FW), 300-700 ºC (breeding zone).
- Relevant challenges linked to the behaviour of brittle materials.
- Development of ceramic-metallic pipe connections: ongoing activity.
- Effect of double-wall on Tritium Breeding Ratio (TBR).
- Important advantages from the point of view of electromagnetic forces and MHD.
- Ceramics under evaluation: ZrO_2, SiO_2, $MgAl_2O_4$. Previously assessed: Al_2O_3, SiC.



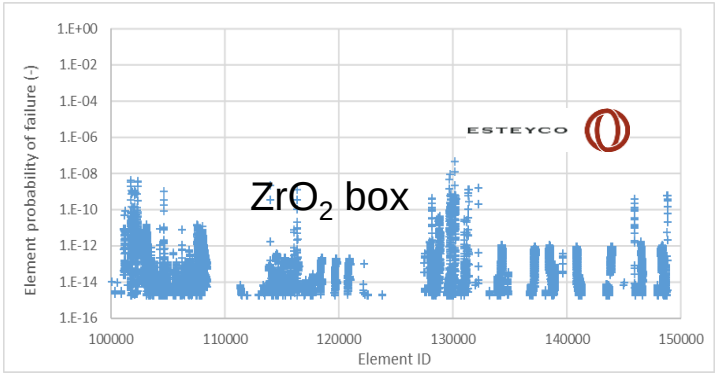
I. Palermo et al., "Radiological characterization of ceramic materials considered for the HT-DCLL DEMO reactor", Nuclear Materials and Energy 30 (2022) 101136

DCLL SMS

- Interface ceramic box-steel case: need to keep equilibrium between robustness and freedom.
- Solution based on a roller support + a hinged support. Very promising initial results.
- 12.5 mm ceramic thickness. TBR=1.14.



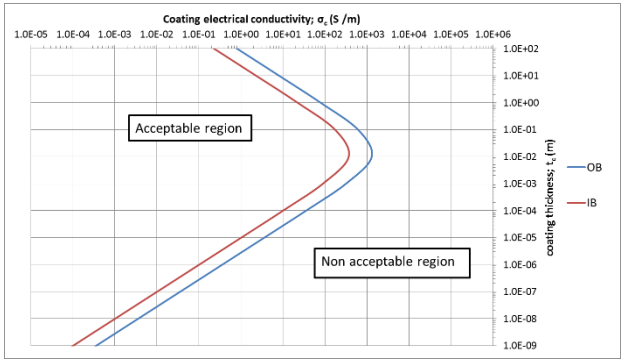
I. Fernández-Berceruelo, et al., "Alternatives for upgrading the EU DCLL breeding blanket from MMS to SMS", Fusion Eng. Des. 167 (2021) 112380



Element probability of failure (numerical model with temperatures, self-weight and PbLi hydrostatic pressure as loads)

DCLL SMS

- **Solution 2**: Ceramic coated channels would simplify the requirements of the DCLL channel walls in comparison with other alternatives.
- Advanced steel (e.g. ODS or RAFM 9%Cr steel with improved high temperature strength, creep and creep fatigue properties), capable to operate at 650 °C.



Required coating thickness vs electrical conductivity (MHD pressure drop)

- Compatibility PbLi-coating: still challenging.
- Common activity to solutions 1 and 2: adaptation of liquid metal divertor concepts for the FW. Capillary Porous Systems (CPS).

Summary

- Ongoing activity (EUROfusion Prospective R&D) focused on the design of high performance breeding blankets (coolant outlet temperature up to 650-700 ºC).
- Proposed solutions under development:
  - 1: ceramic box (breeding zone) + RAFM steel envelope (including the FW).
  - 2: coating + advanced RAFM steel.