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The Dual Coolant Lithium Lead breeding blanket: status and perspectives

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The breeding blanket will be the component in charge of extracting and amplifying the neutronic power in future Fusion Power Plants. In addition, it has to warrant the reactor tritium self-sufficiency through efficient breeding and recovery. An additional function is the protection of the vacuum vessel (VV) and magnets against radiation [1.]. Various blanket concepts have been proposed along the years based on different breeder materials, neutron multipliers and power extraction methods (coolants). Within the EUROfusion Power Plant Physics and Technology (PPPT) Program (2014-2018) four breeding blankets have been investigated [1.], among them, the Dual Coolant Lead-Lithium (DCLL) blanket. This concept uses the eutectic alloy of lead-lithium (PbLi) as tritium breeder, neutron multiplier and tritium carrier. In addition, the PbLi acts as main coolant, being a quasi-self-cooled concept. The structural material is EUROFER, while the secondary coolant, mainly used to refrigerate the first wall (FW) and the blanket structures, is helium (He) at a pressure of 8 MPa. The proposed program considered a "low temperature"version of DCLL, i.e. with a maximum operational temperature of 550 ºC, in order to allow the use of conventional materials and technologies. One of the major consequences in this limitation was that the potential thermodynamic efficiency, which is the main advantage of this blanket technology, is reduced [2.].
Activities coordinated by CIEMAT on the DCLL development started with the definition of system specifications, leading to an overall design of the blanket, which included a series of engineering analyses needed to prove the feasibility of this concept. Intensive CAD work was focused on the adaptation of the DCLL geometry to the space allocated for the blanket in different reactor models. The result was a pre-conceptual design of DCLL based on a multi-module segment configuration, consisting on a number of different blanket modules attached to a common back supporting structure. The last DCLL design, produced during 2018 for a DEMO reactor with a fusion power about 2 GW, consisted of 16 sectors distributed every 22.5° and including 5 segments each, 3 outboard and 2 inboard. Calculations in different engineering fields were needed to prove the good performances of the blanket. Firstly, neutronics computations were required to calculate responses such as the tritium breeding ratio (TBR), the nuclear heating distribution and the energy multiplication factor. This version of DEMO included a critical reduction in the radial thickness of the OB segments, with a negative effect on the TBR. However, the required TBR target (>1.1) was still achieved, maintaining also adequate shielding performances on the VV and Toroidal Field Coils [3.].
The thermalhydraulics (TH) performances of the DCLL have to assure a proper power extraction looking for the highest reactor efficiency. In this sense, different activities related to the coolants (PbLi and He) were also conducted to maximize their outlet temperature and, at the same time, maintaining a low value for the pressure drop. The PLATOON 1D code, developed at CIEMAT [4.], was employed to characterize key parameters which affect the performance of the primary heat transfer system and the power conversion system. CFD calculations (Ansys FLUENT) were also used to study specific issues in the He cooling system, e.g. the mass flow distribution. A trade-off between several He channel dimensions was carried out to select the most suitable to work under different operational conditions. Temperatures resulting from the TH analyses were used as input for a thermomechanical analysis which also included internal pressure loads.
Due to the interaction between the intense magnetic field of the reactor and the liquid metal (an excellent electrical conductor), magnetohydrodynamics (MHD) effects can appear. MHD phenomena may produce important pressure drops in the PbLi flows, impacting the blanket functionality; thus, MHD analyses are of primary interest [5.]. Apart from pressure drop estimations, specific MHD calculations were conducted to estimate the heat transfer between the He and PbLi circuits. Special components, the Flow Channel Inserts (FCI), are used to mitigate MHD pressure drops, but introduce important effects on the PbLi velocity profile that were also investigated.
The associated blanket R&D includes the development and characterization of ceramic components to mitigate MHD effects. CIEMAT has developed an ambitious workplan to fabricate ceramic components made of alumina, with different arrangements and geometries [6.]. An extensive characterization, including effects of ionizing radiation, has been performed. Results are promising although some issues are still unsolved and will be addressed in upcoming activities. In addition to FCI/ceramics development, some other activities have been developed in support of the design. The tritium extraction and removal system, which is a key component in charge of the tritium recovery, has been deeply investigated (technologies, materials, transport models). A consolidated design able of extracting tritium with a minimum 80% efficiency has been produced to fit with the DCLL design specifications [7.]. Finally, specific tritium transport models were developed to investigate tritium migration to the coolants and expected inventories in the blanket [8.].

Recently, a working group supported by a panel of independent experts, made an extensive work to identify the best strategy to harmonize the ITER-TBM and the EU-DEMO BB programs, including their associated R&D. Thus, a 'driver'blanket will be installed in DEMO that should be in line with the ITER TBM Program, which now considers the HCPB and WCLL to cover all technologies (coolants, breeders) [9.]. It seems advisable to develop, in parallel, alternative concepts for the long term, aiming at higher efficiencies. In that sense, although the feasibility of the DCLL has been demonstrated (main issues are related to corrosion and unknown MHD phenomena), it has been suggested that activities will focus more on the R&D of the concept, excluding all the integration tasks. Among others, these activities could explore different configurations for the FW, operational windows of the coolants, strategies for TBR enhancement. At present, the efforts of the DCLL design team have been focused on exploring the adaptability of the low-temperature DCLL to the needs of more advanced breeding blankets, taking as basis the already developed DCLL concept. Thus, the activities are focused on optimizing the DCLL in terms of plant net efficiency, proposing solutions to solve the issues encountered during the period 2014-2018.

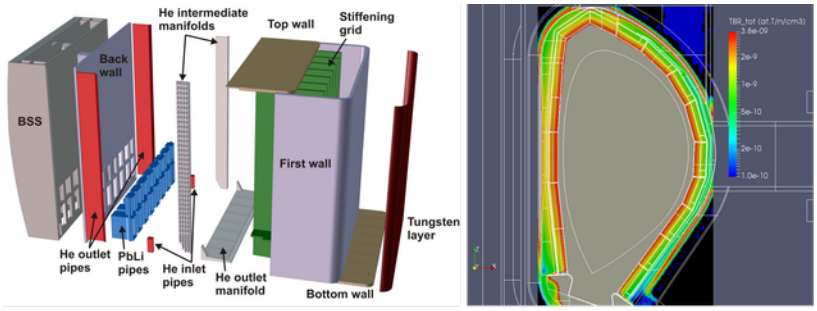

Fig. 1 Distribution of the components in one module of the DCLL breeder blanket.

Fig. 2 Radial-poloidal distribution of the tritium generated in the DCLL (at. T/n/cm3) calculated with MCNP.

Figure 1: Figs 1 and 2

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