OVERVIEW OF THE DCLL BREEDING BLANKET FOR HELIAS 5-B AND FURTHER STEPS TOWARDS A NOVEL QI DEVICE

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As part of the ambitious EUROfusion mission of "bring(ing) the stellarator line to technological maturity," the Stellarator Power Plant Studies (SPPS) Prospective R&D Work Package (WPPRD) started in 2021, covering the engineering activities for the development of a Helical-Axis Advanced Stellarator (HELIAS) power plant.

In alignment with this objective and leveraging previous expertise in Breeding Blanket (BB) designs for the European DEMO tokamak, activities devoted to develop a Dual Coolant Liquid Lead Lithium (DCLL) BB HELIAS design started in Europe [1]. The DCLL BB concept relies on a liquid breeder (PbLi) and has decoupled First wall (FW) and breeder cooling circuits based on helium and PbLi, respectively. These two features could inherently address the specific challenges posed by the complex HELIAS configuration and have been empowered and further exploited to simplify the remote maintenance and integration of the BB segments: i) by adopting a fully detached FW based on a Capillary Porous System (CPS) and ii) by adapting the PbLi path and BB shape to the stellarator's intricate morphology and varying magnetic field. As a result, a quasi-toroidal configuration of the BB segments (QTS) in which the PbLi flows predominantly parallel to the magnetic field has been proposed (Fig. 1), as a measure to minimize the magnetohydrodynamic component of pressure drop due to the induced currents in the PbLi flow (in up to two orders of magnitude according to preliminary calculations). Such scheme would drastically simplify the blanket design in a stellarator configuration eliminating the need for of electrical isolation systems (Flow Channel Inserts, coatings, etc).

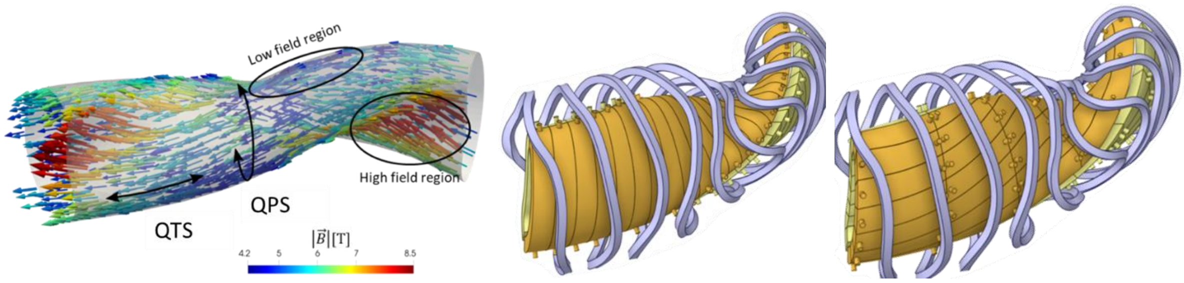

Fig.1. B-field vector field (left), Quasi Poloidal (center) and Quasi Toroidal (right) Segmentations [1]

One of the primary concerns with the QTS is related to the Remote Handling (RH) of the BB segments traditionally planned to be performed through vertical ports. This tokamak-oriented approach has been reconsidered and tailored specifically to 3D stellarator machines in which the segments within a period rotate, and what is vertical may become horizontal, and what is concave/inboard/down can switch to convex/outboard/upper, and so on. Other solutions - to some extent disruptive - have been explored as splittable magnets or repositioning the coils to temporarily attach larger ports (Fig. 2 left). Another previously suggested, yet controversial, approach involves considering detachable periods or half-periods. While this could provide access to the blanket by splitting the vacuum vessel, it raises concerns related to containment, safety, interfaces, and time constraints.

Another different strategy involves using a detached FW to transfer the maintenance burden primarily to smaller FW panels manageable through standard ports. In other words, the blanket segments would be replaced less frequently (or never) as the FW would be the primary component damaged by neutron radiation and would undergo regular replacements. Specifically, a CPS concept for a decoupled FW of the DCLL BB has been defined (Figure 2 right). Thermal-hydraulic simulations have been carried-out to establish preliminary parameters and cooling solutions using liquid metals as Li or Sn embedded in a Tungsten matrix within the CPS. Additionally, studies on capillary flow and liquid metal spreadability have been carried out to determine the necessary porosity and pore size. Neutronic analyses have also been performed to explore ways to reduce the damage (in terms of displacements per atom, or dpa) to the blanket, thereby enhancing machine availability, while maintaining a viable Tritium Breeding Ratio (TBR), i.e. including in the FW design a specific material substrate. These analyses suggest that, while strong neutron absorbers - such as tungsten-boron (WB) mixtures, tungsten carbide (WC), and tungsten - reduce dpa significantly but also the TBR, moderators based on beryllium not only reduce the dpa in the back BB Eurofer structure, but also increase the TBR, providing additional margin for further improvements.

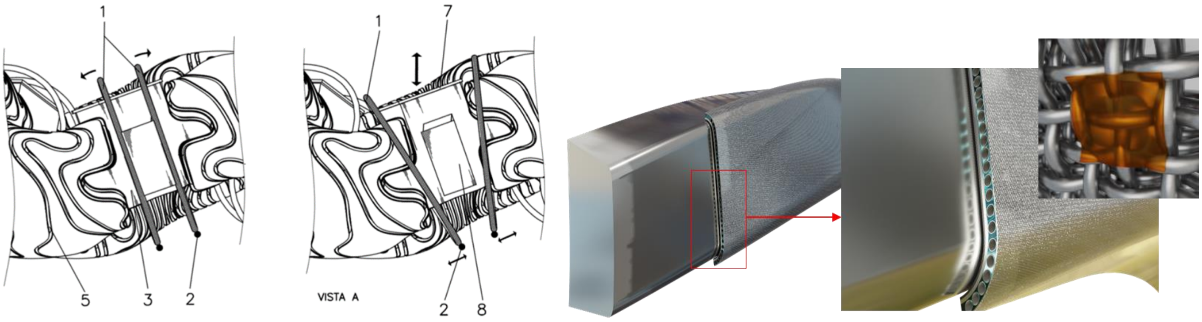

Fig. 2. Rotation or translation of coils to allow wider ports for BB toroidal segment extraction (left); Capillary Porous System: the liquid metal flows through channels embedded in the surface of a metallic matrix (right)[2]

To accelerate the DCLL HELIAS design and overcome the bottlenecks identified during the initial phases of the project, regarding the lack of tools to represent quickly and realistically 3D complex geometries, two *ad-hoc* tools have been developed (Figure 3) for the parametrization of the models and the convergence towards a viable design, speeding-up the coupling of the CAD modelling with the neutronic and thermal-hydraulic analyses.

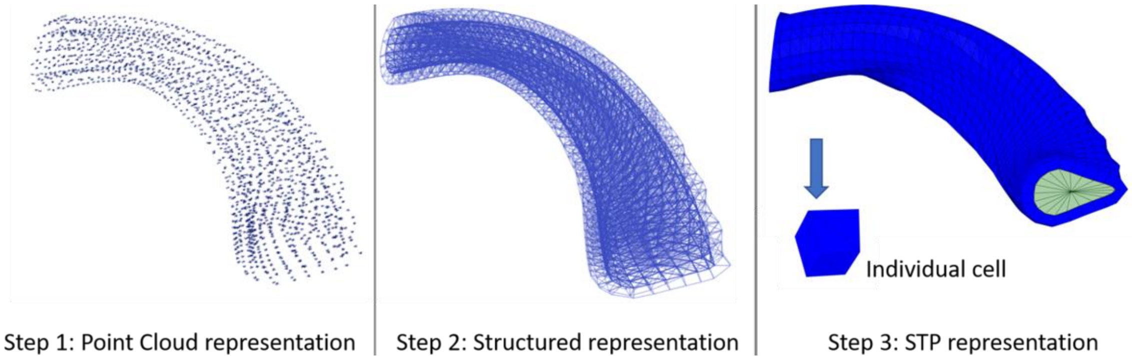

Fig. 3. Sequence employed by SHANE and HeliasGeom tools to get tetrahedralized STP model [1]

For the preliminary DCLL BB model, 3D analyses have begun, including detailed neutronic studies to optimize the radial build as a function of the toroidal and poloidal angles; 3D MHD assessments in non-uniform magnetic field and with HELIAS-relevant Hartmann numbers using the open code GridapMHD; and 3D thermal-hydraulic calculations coupled with the thermo-mechanical one through a multi-scale approach.

Finally, as novel *quasi-isodynamic (QI)* magnetic configurations emerged in recent years [3], improving the performances of the W7-X and HELIAS-class devices in terms of confinement of fast ions and turbulent transport, the activities performed so far for the HELIAS 5-B are being readapted to one of the new stellarator configurations of the CIEMAT-QI family. Advancements in the field will be also presented.

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REFERENCES

[1] Iole Palermo et al., Challenges towards an acceleration in stellarator reactors engineering: The Dual Coolant Lithium-Lead Breeding Blanket Helical-axis advanced stellarator case, Energy (Volume 289, 15 February 2024, 129970) https://doi.org/10.1016/j.energy.2023.129970

[2] Zong-Biao Ye et al., Compatibility investigation of liquid tin and tungsten-based capillary porous system under high-density plasma environment, Tungsten 2, 94–100 (2020). https://doi.org/10.1007/s42864-020-00044-8

[3] E. Sánchez et al., A quasi-isodynamic configuration with good confinement of fast ions at low plasma β, 2023 Nucl. Fusion 63 066037 https://doi.org/10.1088/1741-4326/accd82