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Neutronic design and assessments of a DCLL BB: adaptation from DEMO tokamak to HELIAS stellarator

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On the way toward the realization of a commercial fusion power plant, following the ITER line, the DEMOstration tokamak reactor design has centralized the most of the research and development European efforts over the last decade. However, with the recent start of operation of Wendelstein 7-X, the Helical-Axis Advanced Stellarator (HELIAS) [1] line has raised again interest among the scientific and technologic EUROfusion Programme.

Substantial progress has been made in understanding stellarator plasmas and important advancements have been already obtained on the physics aspects. Hence, from the technology research side, the main aim at present is showing that stellarators (particularly helical axis stellarators) are viable as potential fusion reactors. To follow on the conceptualization of a mature HELIAS reactor different engineering and technological aspects have to be studied, improved and solved.

Guiding onto the conceptual design process, a neutronic design of the reactor has been developed [2] starting from a very preliminary design called "HELIAS 5-B"(5-field-period) with a fusion power of 3000 MW [3]. A simplified neutronic model has been constructed introducing in the baseline CAD model the relevant components of Breeding Blankets (BB) inside a simplistic model of Vacuum Vessel and superconductive Coils. In fact, the future stellarator reactor must be equipped with a breeding blanket system in order to guarantee the fuel (tritium) self-sufficiency of the reactor.

The large experience achieved at CIEMAT in BB designs for DEMO tokamak has been exploited, adapting the Dual coolant Lithium-Lead Breeding Blanket (DCLL BB) design [4][5], which was elaborated in the frame of the WPBB Programme of EUROfusion/PPPT, to the HELIAS configuration. To answer the required duties of a BB - tritium breeding, heat recovery and shielding - the DCLL uses LiPb as tritium breeder, neutron multiplier and primary coolant, and Eurofer as structural material.

The specific challenges of a stellarator, that are different from the ones that presents a tokamak, have been addressed starting with the crucial differences in the neutronic approach. In fact, due to the more complicated nature of stellarator neutronics analyses, simplified approaches to fusion neutronics, already developed for tokamaks, have been even more important for designing a conceptual stellarator reactor. Most of the neutronic requirements [6] adopted in DEMO seem to be reasonably applicable to stellarator devices. Such requirements as well as the codes, the inputs, and the geometries constraints are discussed, emphasizing the differences between DEMO and HELIAS. For example, the need for 3D neutron distributions - instead of tokamak 2D analyses- to adequately represent the variation of the neutronic responses also in the toroidal direction in complex geometries as the stellarator one is highlighted.

The activities performed at CIEMAT for the nuclear assessment of a DCLL BB concept for HELIAS have focused on a preliminary adaptation of the DCLL BB modules from DEMO to the stellarator structure giving sequential approximations for preliminary assessments of the main nuclear responses.

The neutrons coming from the fusion plasma of large machines, like HELIAS, could severely affect the stability and the lifetime of the components that constitute the reactor. Nevertheless, neutrons are fundamental to allow the reactor to reach the tritium self-sufficiency and to generate and extract enough nuclear power. This means that in the nuclear design of this kind of facilities it is essential to achieve and keep the delicate balance among fuel sustainability and power efficiency vs. radiation shielding.

Thus, starting from the plasma specifications [7] and the generic HELIAS design [3], a DCLL HELIAS model has been developed and preliminary neutronic assessments (Figure 1) have been performed focusing on:
- Tritium production, in terms of Tritium Breeding Ratio (TBR) and 3D maps distributions;
- power density 3D distributions and
- damage/shielding responses, as 3D maps for nuclear heating, dpa and fluences.

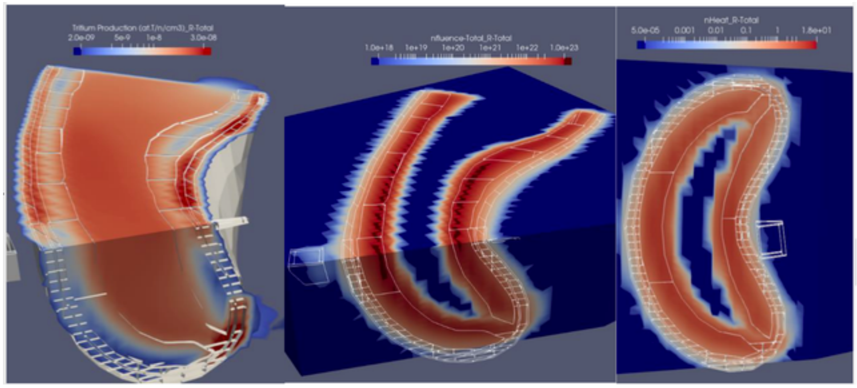

Figure 1: "Mesh tally"3D maps for the Tritium production, neutron fluence and nuclear heating in the preliminary DCLL breeding blanket model for HELIAS reactor.

The DCLL HELIAS neutronic model has been developed through the MCAM (Monte Carlo Modeling Interface Program) tool SuperMC_MCAM 5.2 Professional Version [8], an integrated interface program between commercial CAD software (here CATIAv5) and Monte Carlo radiation transport simulation codes. Using the MCAM tools, the simplification of the CAD model has been pursued and it has been adapted to the MCNP code in terms of spline approximation to faceted surfaces, void creation and decomposition, gluing of pieces of the same component, and splitting of others.

Particle transport calculations have been performed with MCNP5v1.6 Monte Carlo code [9] using JEFF 3.2 nuclear data library [10]. The achieved high TBR values, around 1.2 depending on the adopted BB configuration, will allow making important improvements on the lacking shielding performance of such initial DCLL HELIAS design. In fact, it has to be emphasized that the current analyses are on very preliminary designs developed with the aim of having an idea of the nuclear performances and viability of the DCLL concept for a stellarator device. In the next future, the crucial step will be to develop a dedicated DCLL BB design that takes the essence of the DCLL DEMO and adapts and improves it considering the peculiarities and needs of HELIAS.

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