"NEUTRONIC DESIGN AND ASSESSMENTS OF A DCLL BB: ADAPTATION FROM DEMO TOKAMAK TO HELIAS STELLARATOR"

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ABSTRACT

Towards the conceptualization of a mature Helical-Axis Advanced Stellarator (HELIAS) power reactor, different engineering and technological aspects must be studied, improved and solved. To this end, starting from a very preliminary reactor design called "HELIAS 5-B" (5-field-period) with a fusion power of 3000 MW, neutronic models have been developed and analyzed introducing in the baseline the relevant components of Breeding Blankets (BB). 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 elaborated in the frame of the WPBB Programme of EUROfusion/PPPT, to the HELIAS configuration. Preliminary neutronic assessments have been performed focusing on neutron wall loading, tritium production, power density distributions and damage/shielding responses as nuclear heating, neutron fluence, dpa and helium production. Particle transport calculations have been performed with MCNP5v1.6 Monte Carlo code.

BACKGROUND

As possible long-term alternative to a tokamak fusion power plant, the stellarator concept offers salient physics features.

Very little in the way of conceptual design studies has been performed compared to tokamaks and enhancement of engineering aspects should follow.

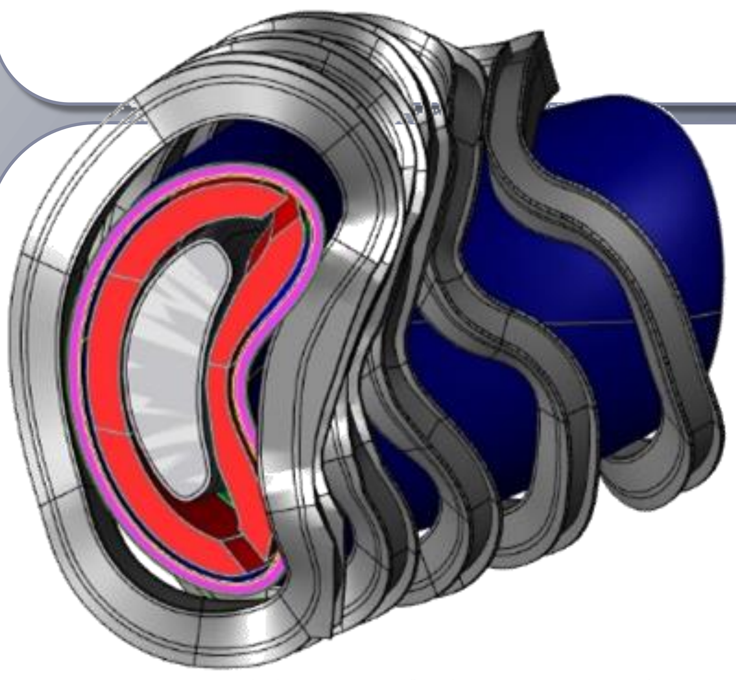
With the recent start of operation of Wendelstein 7-X, the HELIAS line has raised again interest among the scientific and technologic EUROfusion Programme.

The main aim at present is showing that stellarators (particularly helical axis stellarators) are viable as potential fusion power reactors.

CHALLENGES

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 both for modelling than for assessments. 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.

Differently from neutronics for tokamaks, the state of the art of the neutronics for stellarator is quite limited and still primitive. Despite the three-dimensional freedom of stellarators, only a limited number of conceptual stellarator reactor designs are under assessments in the world, and as a consequence there is not an established procedure for the development of 3D neutronic designs, a standard approach for 3D neutronic assessments and a common methodology for visualization of such complex results. Therefore, unique developments and results are described.



METHODS / IMPLEMENTATION

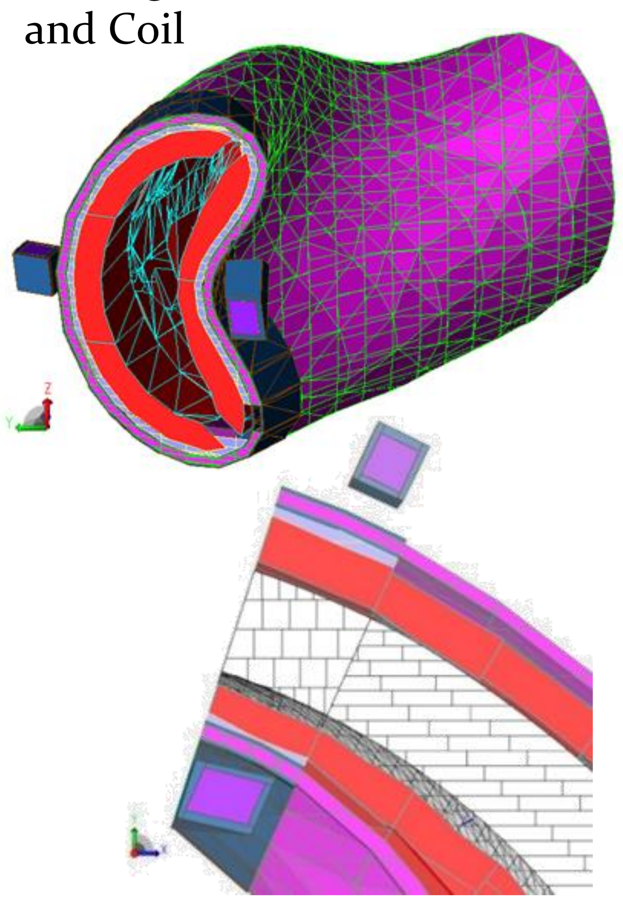
The development of an apparently simple neutronic design starting from the CAD model of an HELIAS stellarator, in which most of the components are homogenized, is a very hard and time-consuming process. This is due to the inherent complexity of the stellarator original CAD design which is fully made by splines. This bottleneck will also be addressed in future developments by studying better CAD modelling solutions.

Main problems of the original model: Splines, big components, 36º sector, no separate FW surface; high number of cells in neutronic model, complex and high nº of void cells.

Due to all these difficulties different procedures has been implemented with different degree of accuracy (faceted process to approximate splines). To overcome these complications, 3 different models have been finally developed, focusing on the specific analyses to be performed with each one: model 1 for simplified TBR and shielding analyses, model 2 for detailed TBR and dpa assessments at the FW, and model 3 for NWL studies.

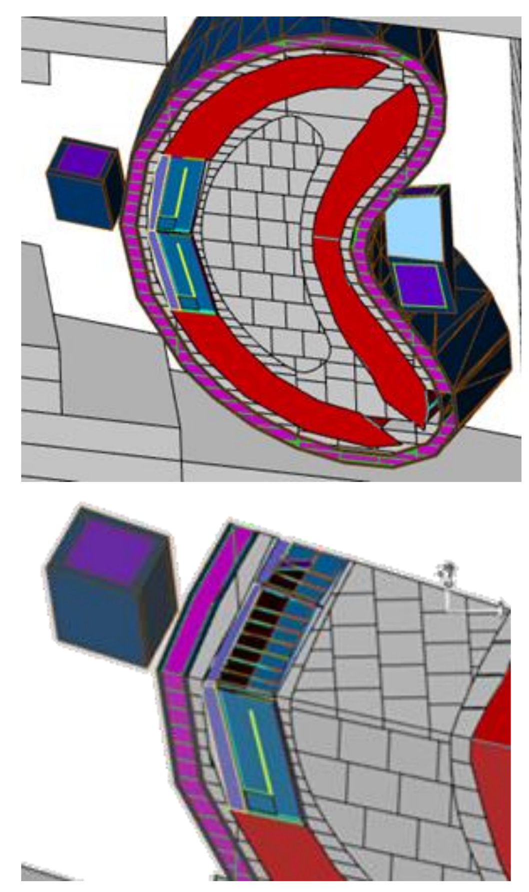
model 1

Homogenized BB, detailed VV and Coil



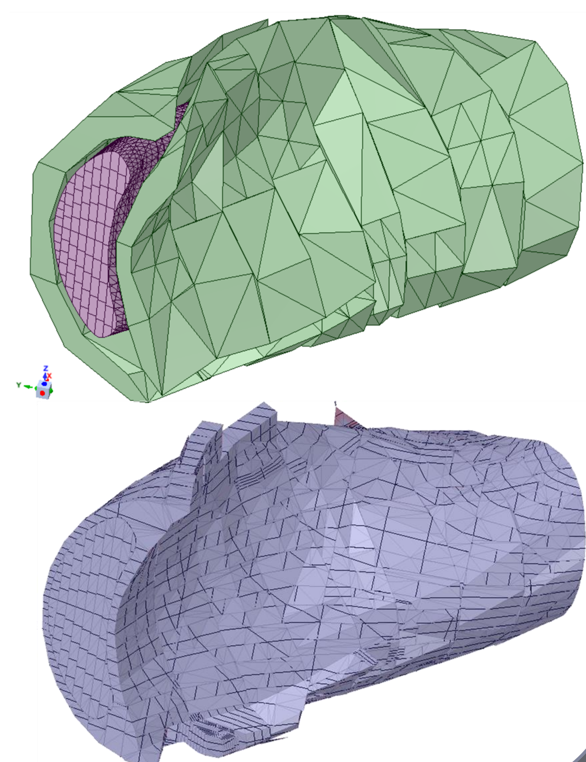
model 2

Detailed DCLL BB in Ring 8



model 3

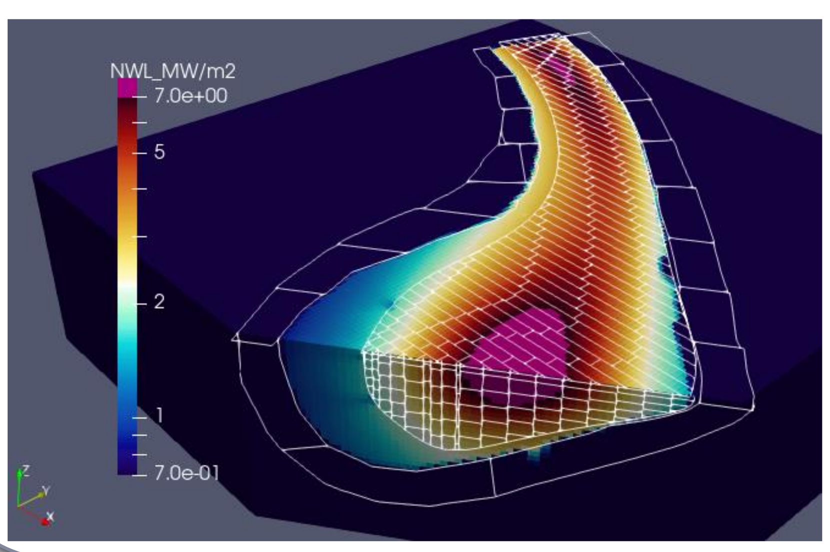
Development of a different void structure delimiting the FW surface

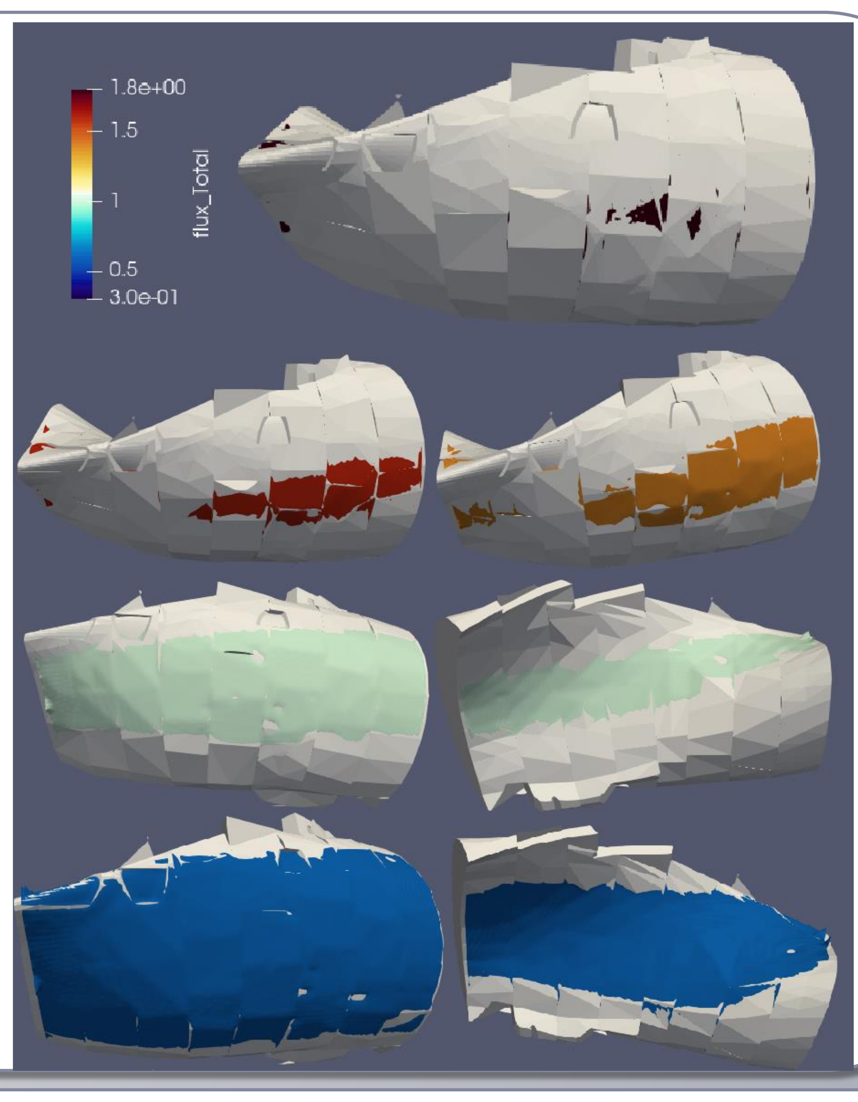


NEUTRONIC ANALYSES

Neutron Wall Loading

Different plots have been produced to give a comprehensive representation of the 3D NWL variation. A NWL slightly higher than the range 0.3-1.8 MW/m² is obtained for this HELIAS configuration.





Tritium Breeding

The space in red is devoted to the Blanket or Blanket+Back Supporting Structure (BSS) components depending on the achieved T production capabilities. Two homogenized compositions have been tested as extracted from DCLL BB of DEMO:

- 24.5% Eurofer, 70.5% PbLi, 4.4% He, 0.5% W, 0.16% Al_2O_3 – representing the BB structures, and
- 41.696% Eurofer, 52.485% PbLi, 5.477% He, 0.255% W, 0.087%Al_2O_3- representing both BB and BSS.

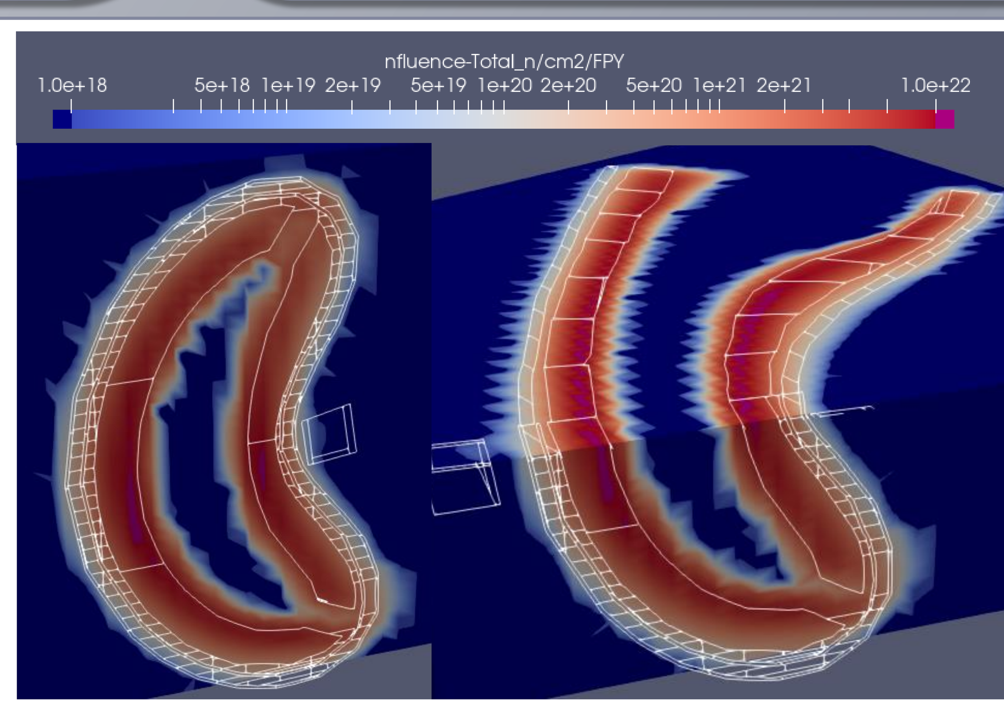
TBR values around 1.27 and 1.1 have been obtained in the two homogenized configurations, BB vs. BB+BSS, respectively, fulfilling in both cases the 1.1 TBR target. Values of 1.24 and 1.077 would be the correspondent ones in case in which the *intermediate layer* between BB and VV would be left to shielding purposes instead than to PbLi collecting (breeding also Tritium). Higher values (+6%) around 1.31-1.14 could be expected, as they have been extrapolated, by using the detailed description of the DCLL BB modules and BSS (*model 2*) instead of the homogenized one (*model 1*).

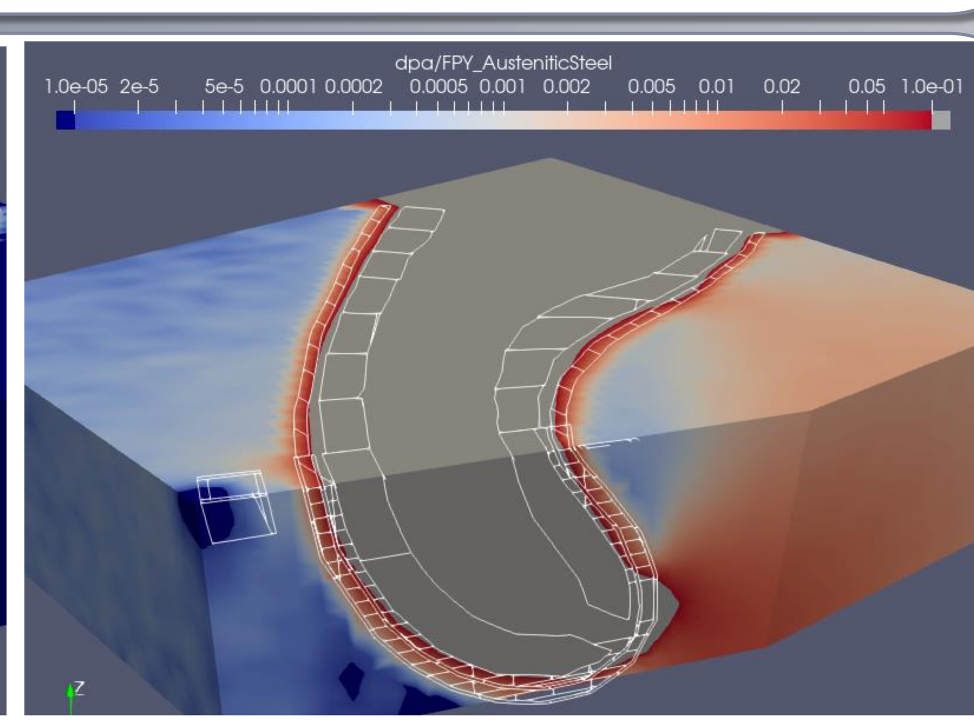
Shielding/Damage Responses

The analyses have involved the shielding responses on the Vacuum Vessel (VV) and on the Coil located around the bean-shaped Ring number 8 (*model 1*), namely, neutron fluence, nuclear heating, dpa and helium production. Local accumulated results inside cells as well as 3D distribution maps have been produced to represent adequately the 3D variation of the stellarator configuration. The nuclear heating values inside the winding pack are about 1 order of magnitude (~2-6 x 10^{-4} W/cm³) higher than the limit, depending on IB/OB zones and the kind of BB representation: BB vs. BB+BSS inside the BB space.

Regarding the neutron fluence, if the same lifetime than the adopted for DEMO is considered for HELIAS (6 Full Power Years (FPY)), it has been observed that the values inside the winding pack are fully accomplished adopting BB+BSS composition or very near to be fulfilled when adopting only BB composition inside the blanket region. Nevertheless the dpa at such locations is 3-5 times higher than the quench limit.

More precise dpa results have been provided for the FW of 4 detailed BB modules taken from *model 2*. Values between 13 and 15 dpa/FPY are obtained implying a slight increase of the values obtained with the homogenized blanket modules. This would compromise a bit the foresee operation since the 1.57 FPY at 20 dpa would be overpassed.





CONCLUSIONS & FUTURE WORK

Nuclear models and analyses of a test HELIAS reactor have been developed with the aim of having a preliminary idea of the nuclear performances and viability of the DCLL concept for a stellarator device. The encouraging TBR values will allow important improvements on the lacking shielding performance of such preliminary DCLL HELIAS design. In the next future, the crucial step will be to develop a dedicated DCLL BB that takes the essence of the DCLL DEMO and adapts and improves it considering the peculiarities and needs of HELIAS. Novel activities addressing these issues will be developed among the Prospective R&D (PRD) FP9 EUROfusion Programme for the period 2021-2025.

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