Neutronic analysis for a compact negative-triangularity based spherical tokamak fusion power plant

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High-field Spherical Tokamaks (STs) offer an attractive path to compact Fusion Power Plants (FPP). Extreme nuclear heating and power exhaust levels pose, however, severe engineering challenges due to their tight divertor wetted area and center columns. Negative Triangularity (NT) emerges as a promising solution for an integrated scenario with high fusion performance, minimal plasma-wall interaction and larger centre columns. eSMART [1] is the first attempt to integrate and exploit, in an FPP design, a high-field ST with NT-shaped plasma. Based on positive triangularity scaling laws, ASTRA simulations, and neutronic analysis, the most compact and economic eSMART design has been obtained.

This work will present a complete neutronic analysis for the eSMART tokamak carried out with the AFSI [2] and Serpent2 [3] codes. AFSI allows us to generate realistic neutron sources consistent with magnetic equilibria and kinetic profiles, thus ensuring the accuracy of the model. Serpent2 capability to work with unstructured meshes enables direct communication and iteration with CAD models, facilitating the optimisation process. Combining both codes, the AFSI-Serpent2 toolchain is used to estimate the neutron flux and its impact and interactions with the materials of the most relevant geometry components. Key optimisation criteria include a Tritium Breeding Ratio (TBR) greater than 1.15 and a sufficient High-Temperature Superconducting (HTS) coil lifetime.

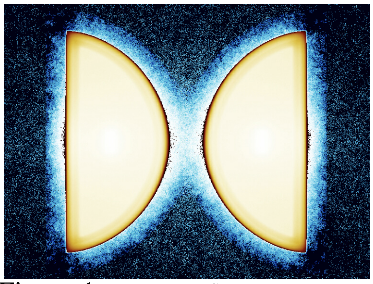

Figure 1: *Neutron flux in eSMART.*

Preliminary results of the neutron flux are shown in figure 1 in a poloidal cross section of eSMART using a simplified model of the vessel that includes a LiPb Tritium Breeding Blanket (TBB), 3 layers of neutron shields made of Steel-Water, B4C and WC, and the HTS coils. This analysis will be done for different neutron-shield and TBB configurations varying the material composition and the thickness of the layers to assist the design optimisation.

References

[1] D. J. Cruz-Zabala et al., Poster at 22*nd* ISTW, 2024.

[2] P. Sirén et al., Nucl. Fusion **58**, (2018) 016023

[3] J. Leppänen et al Ann. Nucl. Energy, **82** (2015) 142-150.