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Advancing Neutronics Modeling of Stellarators Using Mesh-based Serpent2 Workflow

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The development of next-generation stellarators is rapidly advancing, driven by recent progress in stellarator optimization that enables enhanced MHD stability and reduced turbulence [1]. Alongside public research initiatives, private companies are also pursuing pilot power plant concepts based on these designs. For a fusion reactor to operate sustainably, it must include a breeding blanket and a closed tritium cycle to ensure that tritium production exceeds its consumption. Beyond tritium breeding, the breeding blanket plays a vital role in converting the kinetic energy of fusion neutrons into heat for electricity generation and in shielding the vacuum vessel and superconducting coils from neutron damage. Its design is driven by the selection of viable materials that can withstand intense neutron irradiation and thermo-mechanical loads, while maintaining sufficient tritium breeding performance. In stellarators, additional constraints arise from the complex three-dimensional geometry—particularly the limited space between the plasma and coil systems—and the divertor configuration. These impose geometric and integration constraints that must be addressed without compromising blanket coverage, remote maintenance access, or reactor longevity.

This work presents a comprehensive overview of stellarator neutronics activities conducted using the Serpent2 [2] Monte Carlo code. The modeling workflow takes the last closed flux surface (LCFS) and coil filament current lines from the stellarator optimization as inputs, fitting the reactor layers within the space defined by the LCFS and coil system. The model also includes a layered island divertor with homogenized material composition. The geometry generation produces CAD-based STL triangle meshes that are directly compatible with Serpent's transport routine. Tritium breeding performance is evaluated for the HELIAS 5B [3] stellarator design with different non-uniform thickness blanket configurations that balance coil shielding and breeding performance by maximizing the breeding zone volume while accommodating an additional shielding layer to peak flux regions. In addition, the impact of various divertor configurations—such as placement, area, coolants, and material composition—is assessed through a dedicated parameter study, expanding on Ref. [4] to cover the new non-uniform blanket thickness configurations. While achieving both sufficient tritium breeding and effective coil shielding is challenging with uniform-thickness layers, the tools presented in this work for generating non-uniform reactor layer thicknesses provide a promising path to meeting these requirements simultaneously.

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