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OpenMC-based Parametric Neutronic Assessment of Fusion Breeding Blankets for Compact D-T Reactor Configurations

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The choice of breeding blanket configuration represents one of the most critical design aspects for the viability of future D-T fusion power plants. POLITO and Eni have investigated and compared different breeding blanket concepts by evaluating their neutronic performance under consistent reactor boundary conditions. The objective is to provide a systematic assessment of the impact of blanket design choices on key nuclear parameters relevant for tritium self-sufficiency, structural integrity, and component lifetime.
To achieve this, a fully open-source and reproducible workflow was developed based on the OpenMC Monte Carlo code, employing Constructive Solid Geometry (CSG) models to enable parametric analyses of breeding blanket configurations for compact fusion reactors. The use of CSG has been found effective during the parametric studies, even if it shows some limitations when more realistic CADs are used. The plasma chamber and external shielding dimensions are kept constant across all configurations, while varying the internal blanket design within the vacuum vessel according to the investigated configurations. Both liquid and solid blanket concepts were analyzed, specifically FLiBe, CLiF, WCLL and DCLL liquid blankets, as well as HCPB as solid breeder designs.
For each configuration, key neutronic metrics were evaluated, including tritium breeding ratio (TBR), deposited power density, neutron flux distributions, energy spectra, and material activation. Furthermore, preliminary estimations of neutron-induced structural damage (displacements per atom, dpa) were performed as a function of the blanket concept. Additionally, a performance assessment of the computational codes is presented, emphasizing the efficiency and scalability of different modeling approaches. Uncertainty quantification (UQ) is carried out to evaluate the impact of nuclear data uncertainties on simulation results, providing insights into how cross-section uncertainties propagate through the calculations and affect final design metrics.
This work supports early design decisions for fusion power plant-class reactors by enabling comparisons across breeding strategies. within an open and reproducible computational environment.

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