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High-fidelity, data science-informed pebble-bed reactor simulation

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Abstract:

Detailed high-fidelity simulation of Pebble Bed Reactors (PBRs) with depletion and pebble re-circulation is currently not possible. Conventional neutronics calculation approaches (VSOP, TINTE, …) rely on homogenized spectral zones (SZ). Enabling much higher-fidelity calculations than the traditional approach requires the ability (i) to track individual pebbles, (ii) to discretize neutronics and thermal-hydraulics models at the full core-level without smearing pebbles into SZ, and (iii) to provide closure relations to such models. While (i) and (ii) and currently feasible (including in the recently developed Griffin's Pebble Tracking Transport (PTT) algorithm developed at INL), (iii) remains challenging.

Our proposed work aims at providing accurate multigroup cross sections for arbitrary spectral zone definitions (up to the level of individual pebbles). One of the target applications for the cross-section generation is their subsequent use within the PTT algorithm of INL, where the pebbles are modeled explicitly, thus reducing the assumptions needed to perform depletion and equilibrium core calculations. In our proposed approach, an iterative global/local approach is proposed to dynamically homogenize cross sections for the Griffin/PTT tool. The advantages of our approach are that each pebble can be treated individually: Griffin/PTT can be employed for full-core level simulations and a Monte Carlo simulation is performed in each pebble allowing for the use of continuous nuclear data. Additionally, the pebble burnup during the operational cycle will be computed using Griffin, pebble motion will be tracked using the Discrete Element Method (DEM) available in Griffin's MAMMOTH tool, and thermal feedback will be evaluated using a multiscale reconstruction of the pebbles' temperature via Pronghorn. The extensive use of INL's tools ensure the immediate integration of our results in INL's simulation tools.

Machine learning methods, including pebble clustering into representative types and feedforward neutral network to learn multigroup cross sections from Monte Carlo reference simulations will be used for accelerating the generation of cross sections via Serpent, thus making the problem tractable. Our goal is to demonstrate the ability of the approach to compute full-core PBRs with high-accuracy in a reasonable wall-clock time using the Griffin tool and its PTT algorithm, including depletion, pebble motion, and thermal feedback. This demonstration will include equilibrium cores but also "running-ins" phases (using HTR-10, PBMR-400 and FHR-Mark-1 data).