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A Machine Learning approach to Breeder Blanket optimisation for Fusion Tokamaks

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Neutronics plays a vital role in the design, operation, and decommissioning of nuclear facilities, requiring accurate assessments of neutron energy distributions, activation calculations, and gamma decay fields. Transport codes, either deterministic or Monte Carlo-based, are used for these assessments. Deterministic methods are faster but less detailed, while Monte Carlo-based methods, though more resource-intensive, provide higher accuracy and are widely adopted.

Machine learning (ML) models have recently emerged as a promising tool to reduce computational resources in various fields, including neutronics. By applying ML algorithms to datasets generated from Monte Carlo neutronics simulations (e.g. OpenMC [1]), faster design iterations can be achieved.

This presentation will explore the application of Monte Carlo-informed neural network models to optimise tritium generation in a Tokamak breeder blanket design, a critical but underdeveloped component due to tritium scarcity [2]. The model predicts neutron energy distribution throughout the system and utilises a volume-analogous approach, dividing the breeder blanket into layers with varying breeding, multiplier, coolant, and structural materials. It calculates the effect of each material choice on neutron energy distribution and sequentially predicts subsequent layers, accounting for neutron multiplication and reflection.

The neutron flux spectrum and nuclear cross-sectional data can used to determine reaction rates, such as the tritium breeding ratio, enabling rapid development of blanket designs. These designs can later be verified by traditional Monte Carlo calculations. The output neutron energy spectrum can also be used to inform activation calculations and reactor shutdown dose rates. Due to the flexibility of the ML model, any blanket geometry can be predicted; therefore, providing an efficient design loop especially in the initial down selection phase.

References

[1] P. K. Romano, N. E. Horelik, B. R. Herman, A. G. Nelson, B. Forget, K. Smith, Openmc: A state-of-the-art monte carlo code for research and development, Annals of Nuclear Energy 82 (2015) 90–97.

[2] M. Sawan, M. Abdou, Physics and technology conditions for attaining tritium self-sufficiency for the dt fuel cycle, Fusion Engineering and Design 81 (2006) 1131–1144.

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