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Modern Neutronics Workflows in The Evaluation Of Tritium Production Performance For Fusion Concepts

Fusion power plants that rely on D-T fuel must achieve tritium self-sufficiency, assessed at concept design stages through an evaluation of the tritium breeding ratio (TBR)—the ratio of tritium produced in the breeding blanket to that consumed in the plasma. In developing a concept it is essential to set a design target TBR, for determining the viability of a given design against a risk appetite for that design in meeting the required TBR, as discussed by Fischer et al. (Fus. Eng. Des. 155, 2020) in the context of EU DEMO. The design target takes into account a range of factors, including physics and technological considerations, as well as the uncertainties associated with them. Additionally, there are uncertainties stemming from "incomplete" neutronics models, where initial design assumptions—such as the size, shape or material composition of components or structures—may vary. The modelling fidelity varies at different design stages; early stages exhibit simplifications, which can lead to an overestimation of the TBR due to missing geometry features. As designs mature, more detailed modelling using CAD and advanced tools becomes essential for accurate TBR predictions and a revision of the design target, appropriate to its maturity, is made.

Neutronics analysis and underlying nuclear data libraries, such as the IAEA's FENDL evaluation, and modes for validation is vital throughout the design process to predict TBR against a target. Different fusion approaches—tokamaks, stellarators, inertial confinement—are developing concurrently in the public and private space, each facing unique challenges and utilising various neutronics workflows in order to do this. Established radiation transport codes such as MCNP are widely used, while promising open source codes, notably OpenMC, are also being utilised and increasingly validated against computational and experimental benchmarks. In this paper, we present the advanced suite of neutronics analysis workflows adopted at UKAEA, discuss their validation and provide example case studies for various fusion concepts. We will also discuss approaches in uncertainty quantification in tackling the factors comprising the target TBR, growth of tritium in breeders, impact on extraction and implications on waste classification.

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