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

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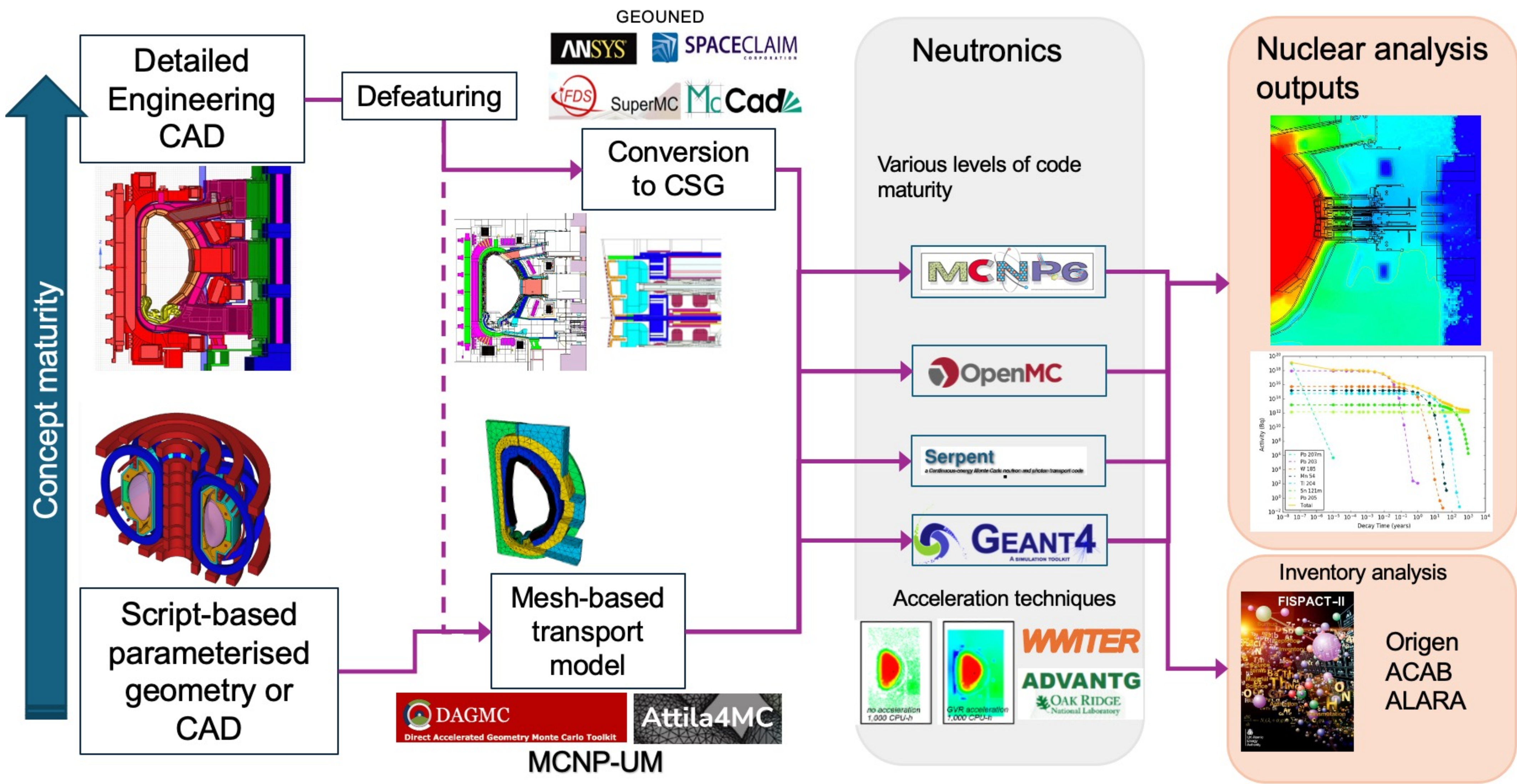
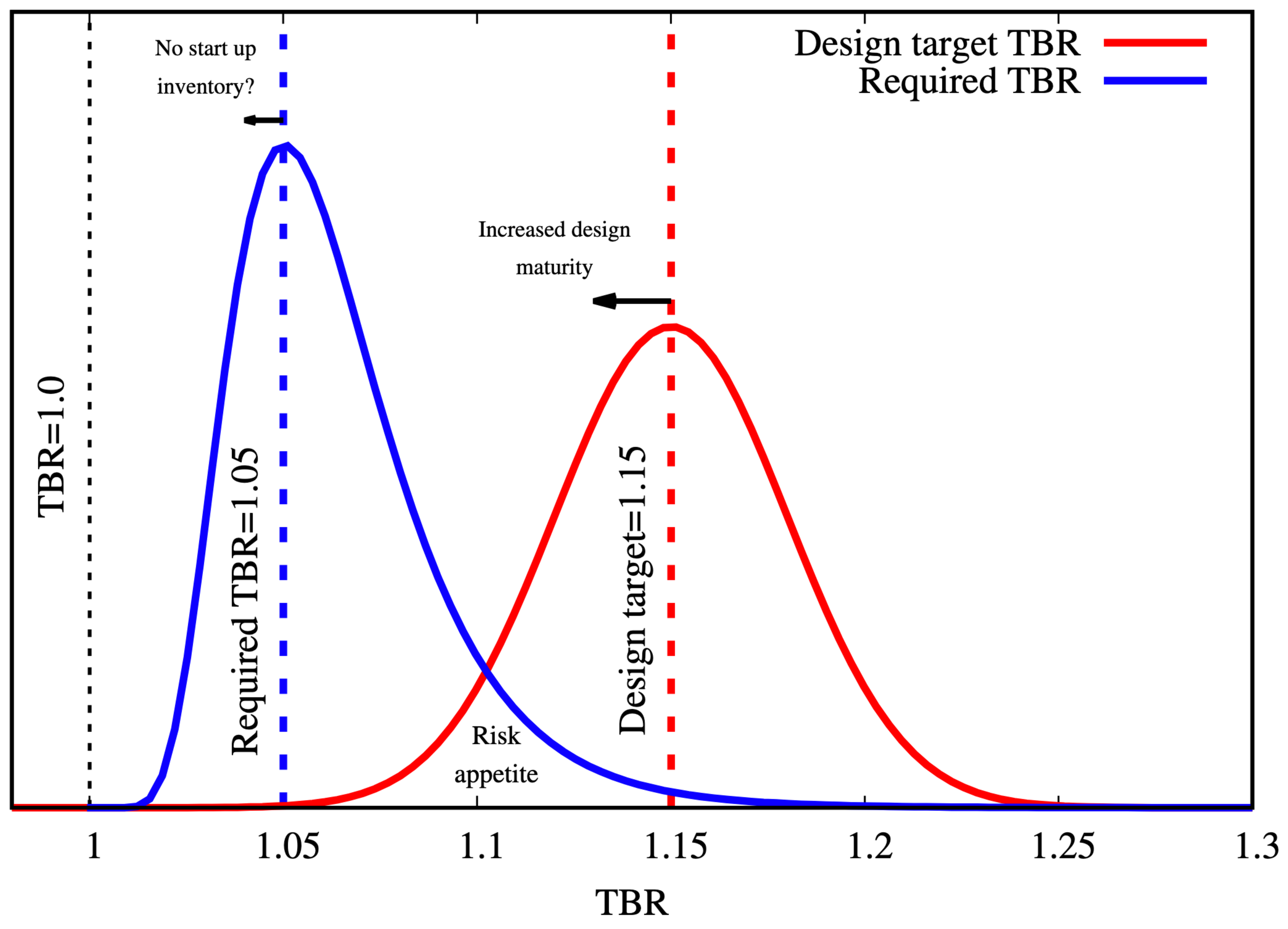
Background

Fusion power plants using DT fuel must achieve tritium self-sufficiency in operation. Developing a viable design requires evaluating and defining a target tritium breeding ratio, which is influenced by a range of physics and technological factors governing the fuel cycle, as well as modelling and associated uncertainties. Neutronics analysis, underpinned by nuclear data libraries such as the IAEA's *FENDL* library and radiation transport codes such as *MCNP* and *OpenMC*, is essential for guiding the design at different stages. This work presents aspects of UKAEA's advanced neutronics workflows, validation efforts, and highlights a case study which demonstrates capability across various fusion concepts.



Overview of UKAEA neutronics workflows.



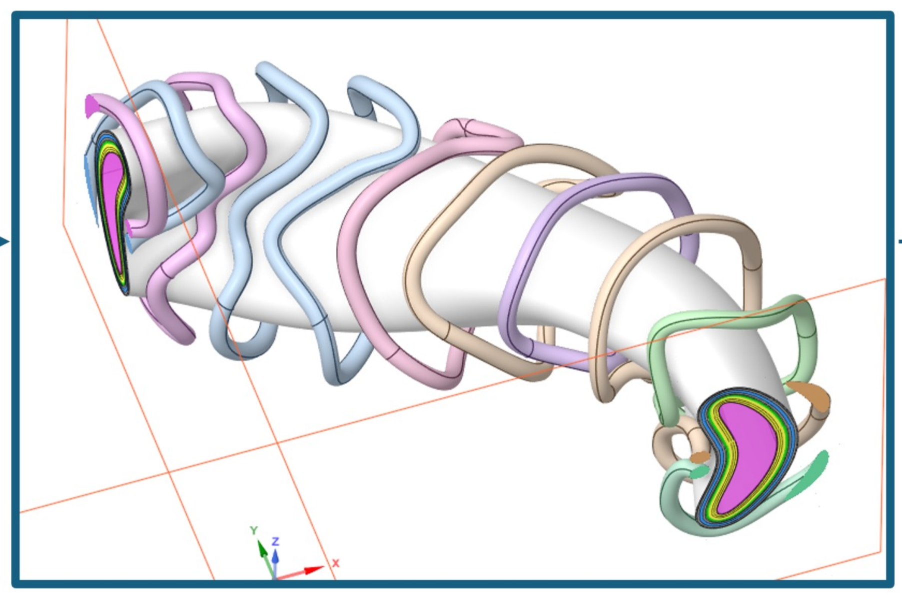
Designing with Uncertainty*: concepts of required and design target TBR for a hypothetical case (discussed in detail in Fischer FED* ***155*** *2020). The mean values, width and shape of these distributions are illustrative in this conceptual figure. The* ***required TBR****, here set to be 1.05 in this example, depends on several factors which are well-documented e.g. Sawan et al., FED* ***81*** *(2006); Abdou et al., Nuclear Fusion,* ***61*** *(2020), which include extraction, plasma fuel burn up performance, technological & temporal aspects of the fuel cycle and need for start-up inventory. The* ***design target TBR****, here set to be 1.15 is an additional margin to the required TBR, accounting for incomplete elements of a computational model.*

Case study: UKAEA undertakes extensive R&D in support of both domestic and international fusion design programmes. Through its simulation expertise, UKAEA has delivered analysis for private sector initiatives including Gauss Fusion (shown below), General Fusion, and First Light Fusion (some reports available online).

Parastell

WISCONSIN UNIVERSITY OF WISCONSIN–MADISON

The open source Parastell code [1] was used to generate a concept level CAD geometry

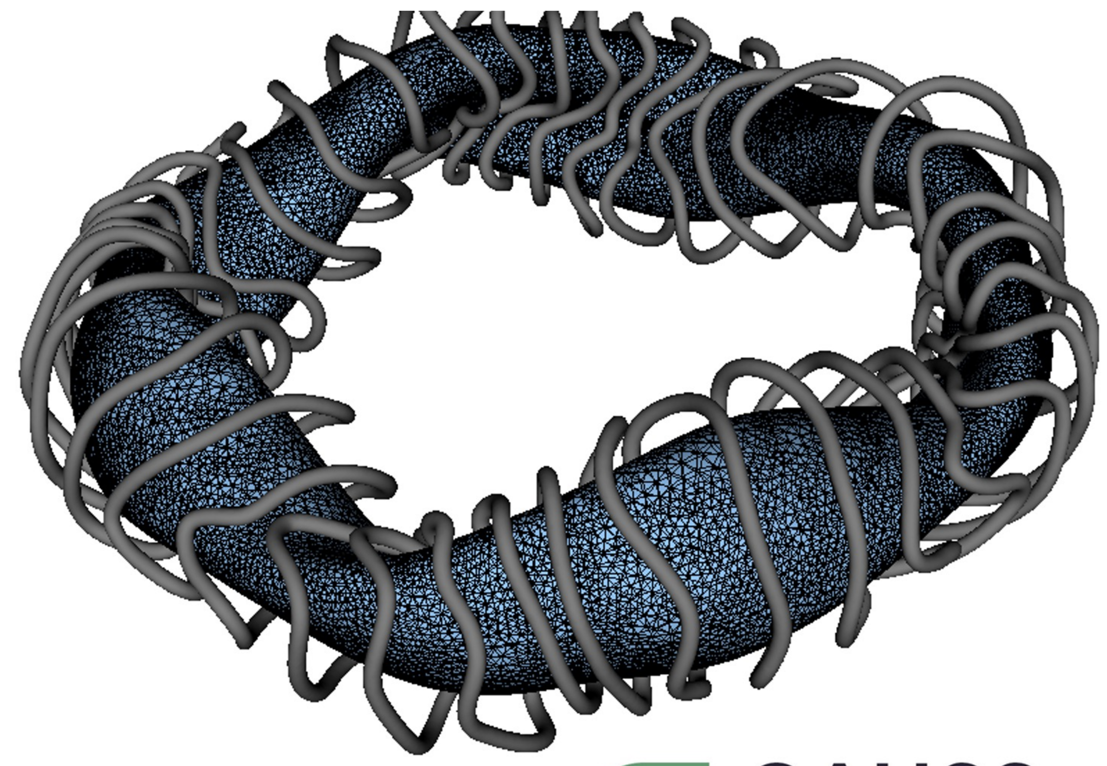


[1] *Moreno C, Bader A and Wilson P (2024) ParaStell: parametric modeling and neutronics support for stellarator fusion power plants. Front. Nucl. Eng. 3:1384788. doi: 10.3389/fnuen.2024.1384788*

ATTILA4MC

Silver Fir SOFTWARE

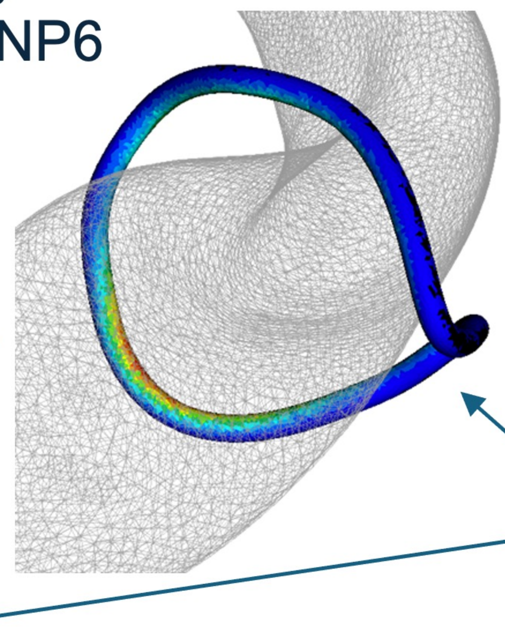
Attila4MC was used to mesh the geometry for analysis using MCNP6



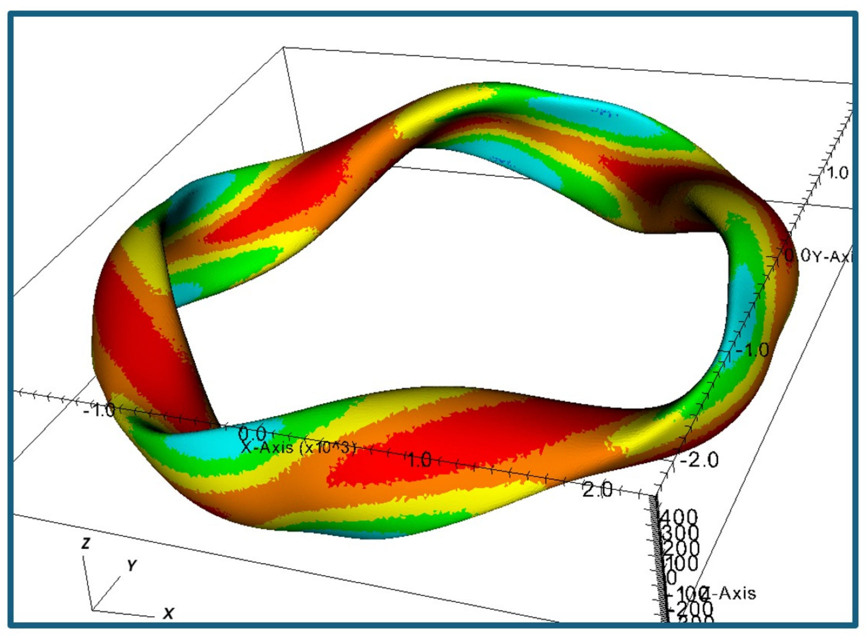
GAUSS FUSION

MCNP6

Heat maps in superconducting coils



Tritium production rate map



Conclusions

Neutronics workflows are essential to assess the tritium self-sufficiency for fusion concepts during their design. Design target TBR values must be evaluated and may need to adapt as designs mature. Advances in codes (incl. open-source), validation, and uncertainty quantification underpin confidence in predictions. UKAEA's integrated modelling approach enable an evaluation method that is agnostic to fusion technology pathways, supporting the development of viable fusion power plants.

Find out more about the Applied Radiation Technology group at UKAEA

The UK Atomic Energy Authority's mission is to lead the delivery of sustainable fusion energy and maximise scientific and economic benefit

Find out more
www.gov.uk/ukaea

UKRI Engineering and Physical Sciences Research Council

This work has been funded by the EPSRC Energy Programme [grant number EP/W006839/1]