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New Developments and Verification of the Fusion Blanket Simulation Capabilities in the MOOSE Framework

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Changing the World's Energy Future

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Introduction

A framework based on the open-source Multiphysics Object-Oriented Simulation Environment (MOOSE) is currently being developed for fusion device modeling and simulation (Fig. 1).

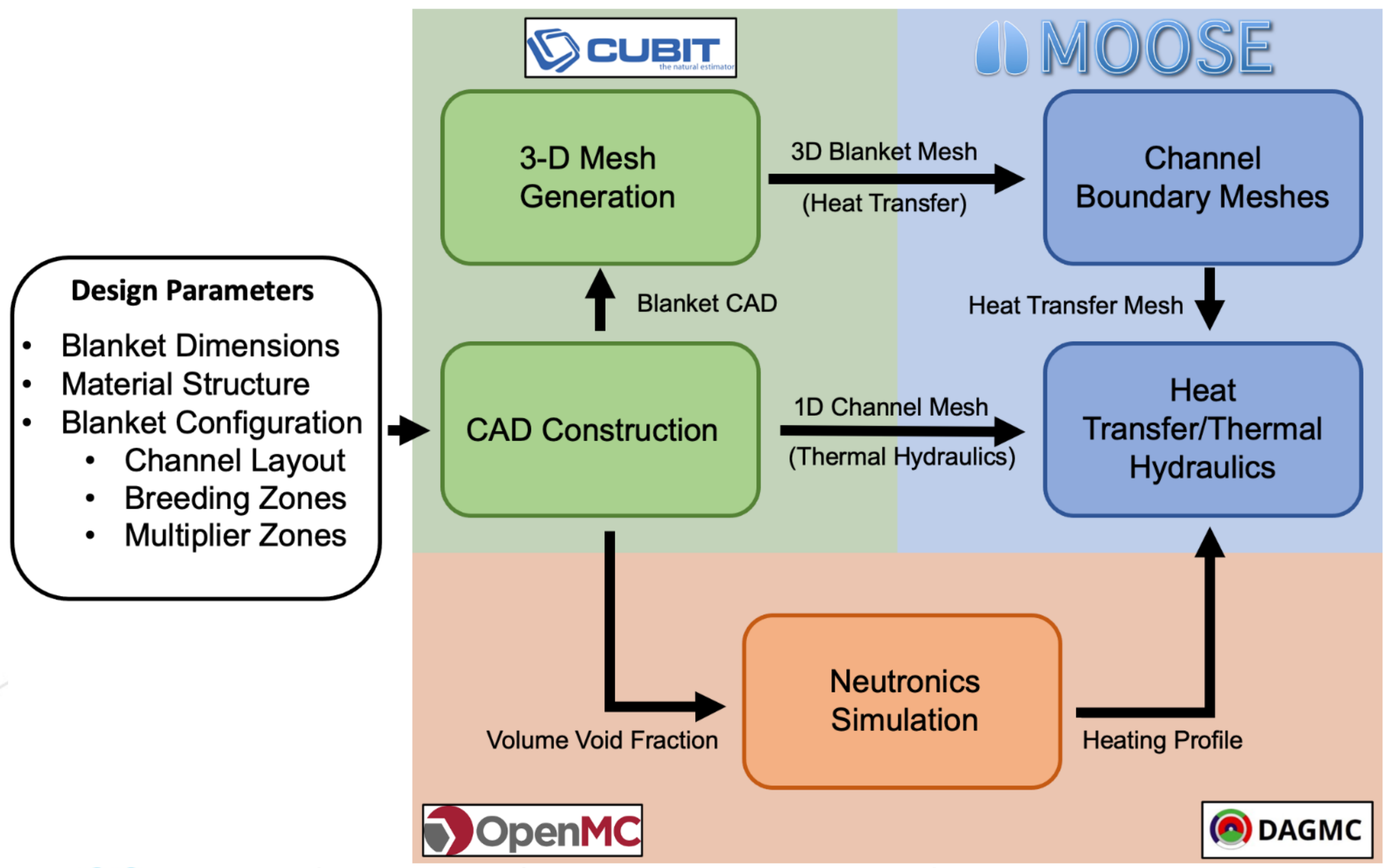

Fig. 1. Simulation workflow.

Methodology

The fusion modeling framework consists of four physics models:

- Neutronics (OpenMC [1])
- One dimensional (1D) system level thermal hydraulics for helium (MOOSE [2])
- 3D heat conduction (MOOSE)
- Tritium transport (TMAP8 [3])

The framework's capabilities were demonstrated using a section of a Fusion Nuclear Science Facility solid blanket design near the first wall at the midplane of the blanket (Fig. 2). The nuclear heating profile was adapted from Kong et al. [4] and assumed constant in the poloidal direction.

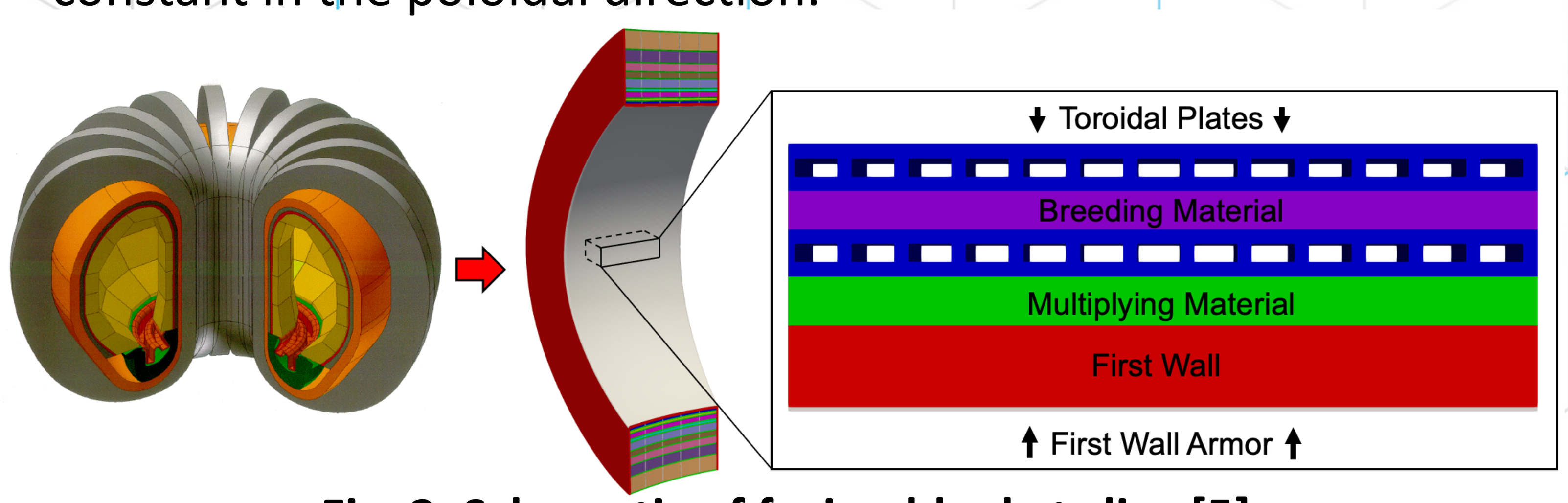

Fig. 2. Schematic of fusion blanket slice [5]

Results

Figs. 3a and 3b show the temperature map through the blanket slice and cooling channels. Fig. 3c shows the tritium concentration in the blanket slice. Most of the tritium is contained inside the breeding section where it is generated.

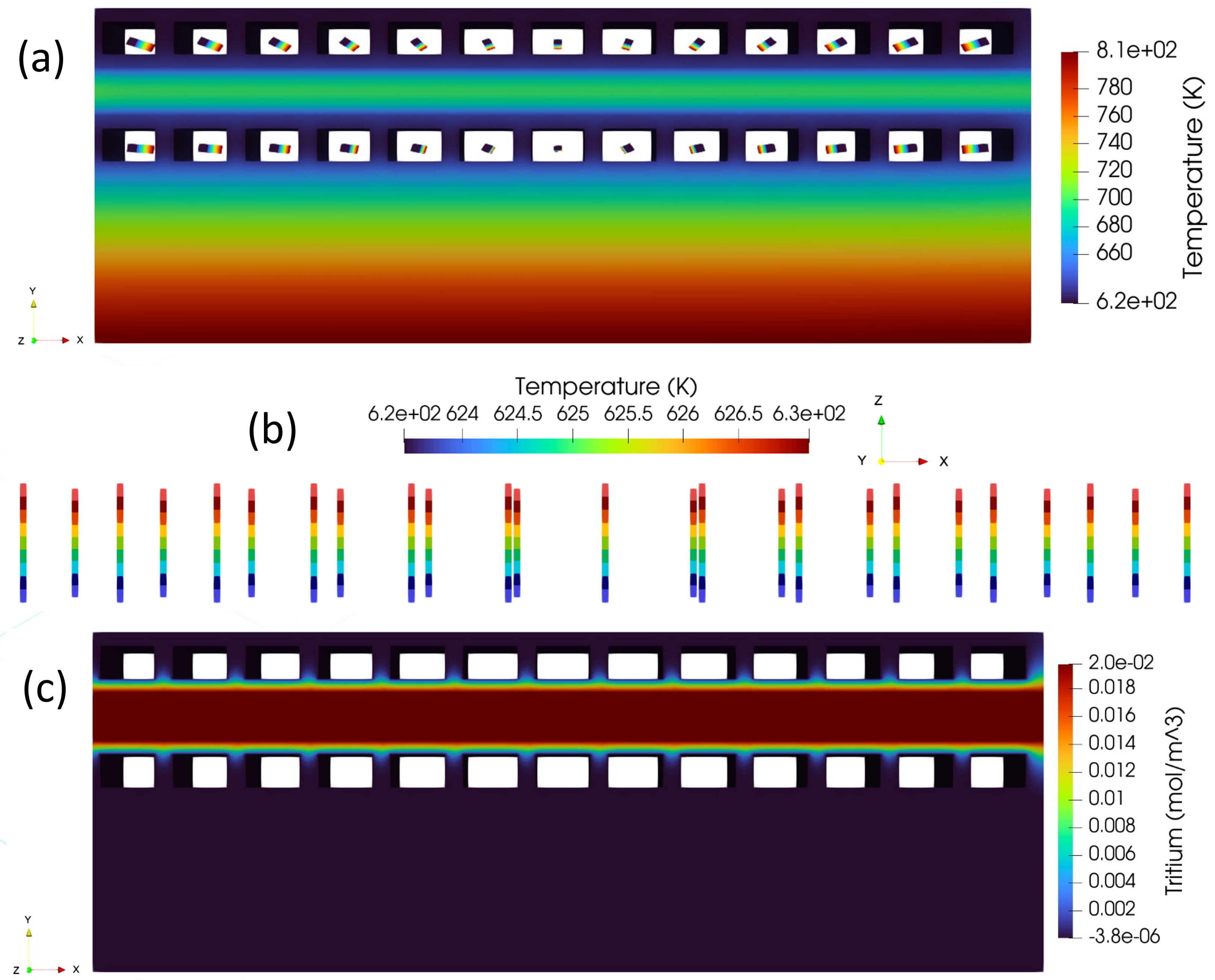

Fig. 3. Heat map (a), helium temperature (b), and tritium concentration (c)

Scan QR codes for 3D results!

Heat Conduction | Tritium Concentration | 1D Thermal Hydraulics

Software Quality and Testing

Enhanced testing for interfaces and the overall coupling strategy has been undertaken. Proper testing ensures that new developments to the fusion modeling framework continue to function as desired. When creating tests, it is important to create smaller computational testing domains to keep simulation run time at a minimum (Fig. 4).

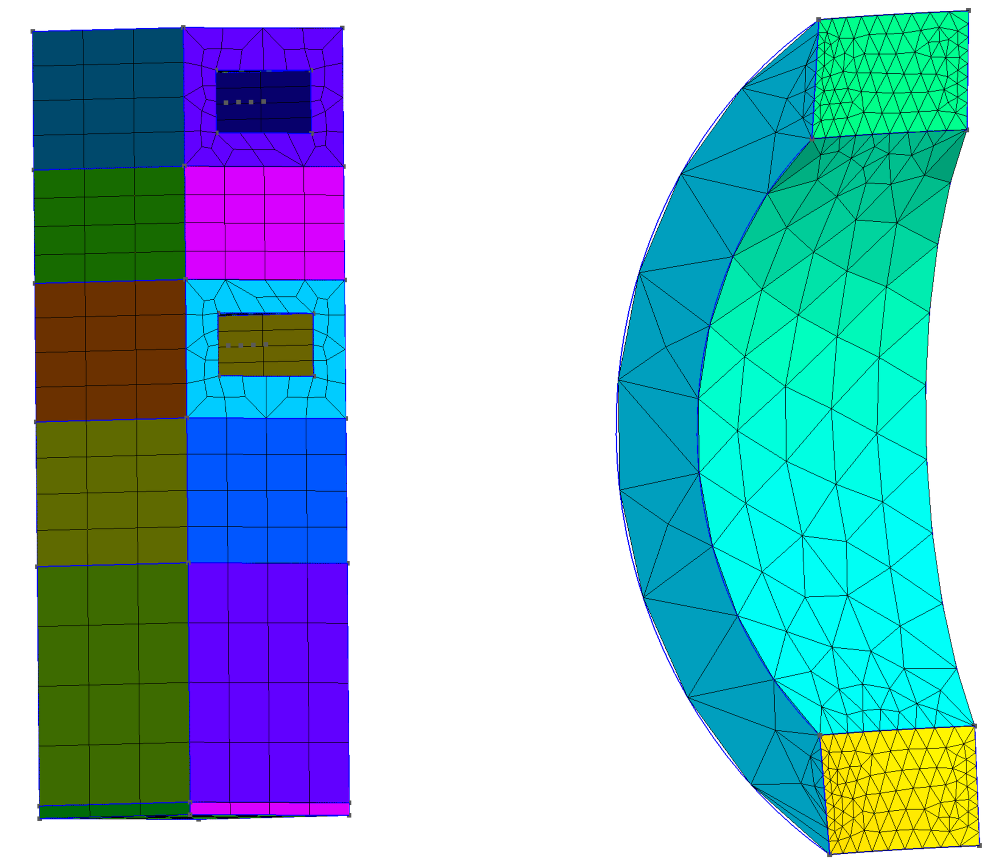

Fig. 4. Smaller meshes for testing

Conclusions and Future Work

The cooling channels kept temperatures in the blanket under the material limits. Tritium was contained in the breeding section, making tritium extraction possible. In the future, a neutronics profile that varies in the poloidal and toroidal direction will be added to the framework using DAGMC and tritium extraction will be added by modeling purge gas flow through the breeder section. This effort forms the basis of a MOOSE-based framework for fusion modeling and simulation at Idaho National Laboratory

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[1]P.K. ROMANO ET AL., "OpenMC: A state-of-the-art Monte Carlo code for research and development," Annals of Nuclear Energy, 82, 90-97 (2015).
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[3]Tritium Migration Analysis Program, Version 8 (TMAP8) GitHub repository: https://github.com/idaholab/TMAP8, Idaho Falls, 2023.
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[5]Bühler, Leo & Norajitra, Prachai. (2023). Magnetohydrodynamic flow in the Dual Coolant Blanket.

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