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Thermal-Mechanic Modeling of Fusion Components Using The MOOSE Framework

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Changing the World's Energy Future

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Idaho National Laboratory

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Introduction

The open-source codes Multiphysics Object Oriented Simulation Environment (MOOSE)[1], Tritium Migration Analysis Program Version 8 (TMAP8)[2], and Fusion ENergy Integrated Multiphysi-X (FENIX)[3] are being used for thermal-mechanic analysis of fusion components.

Methodology

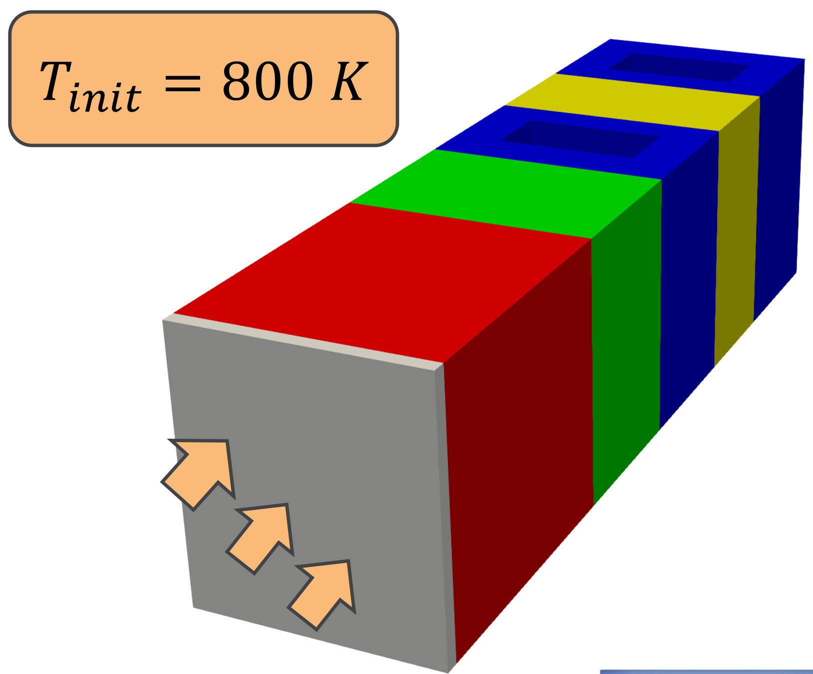
In this work, MOOSE was used for a multiphysics analysis on various fusion components. FENIX pulls together MOOSE with existing codes such as TMAP8 and OpenMC[4].

- MOOSE modules used – Heat Conduction, Thermal Hydraulics, Magnetics, and Mechanics.

Results

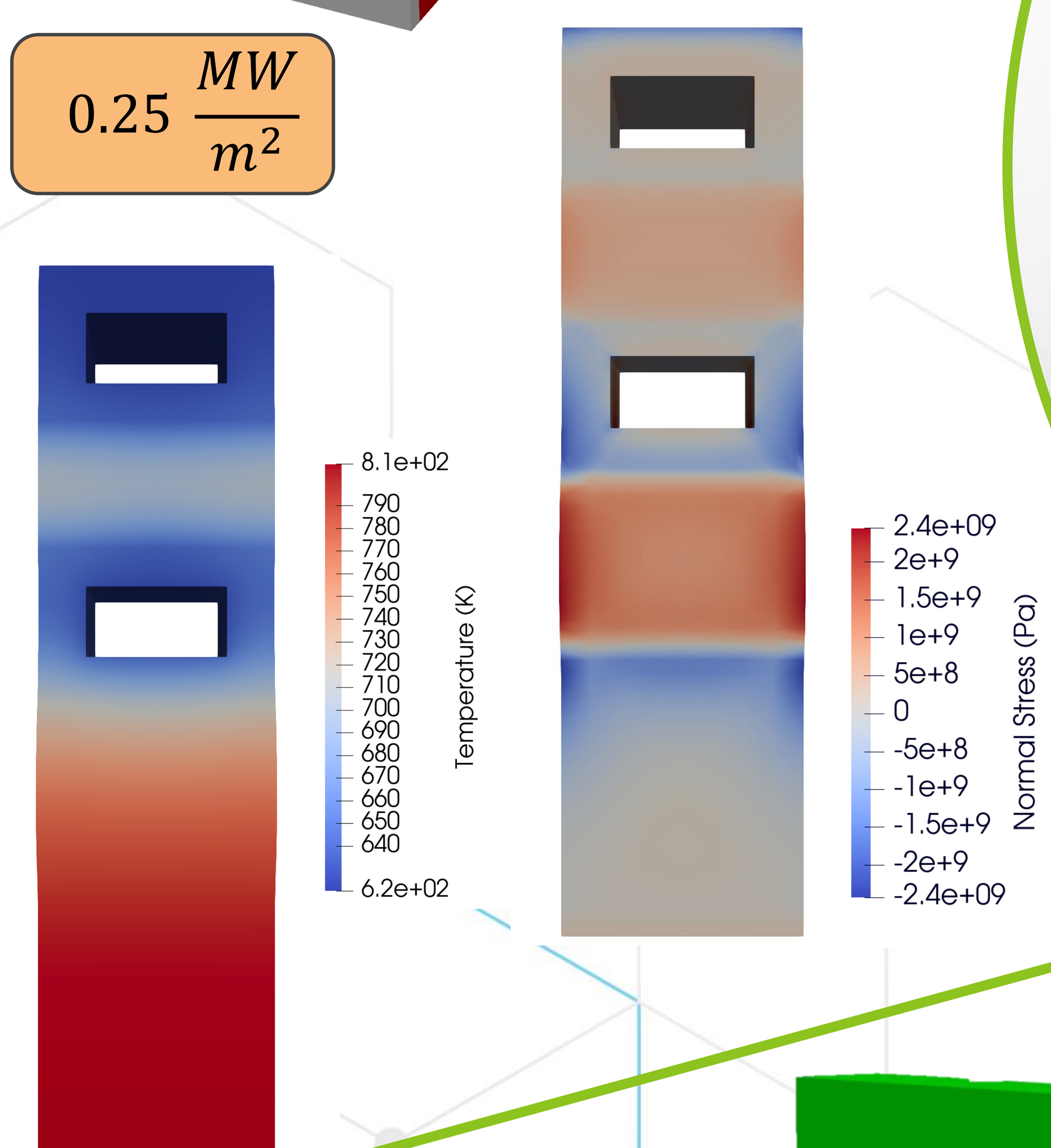
Fusion Blanket

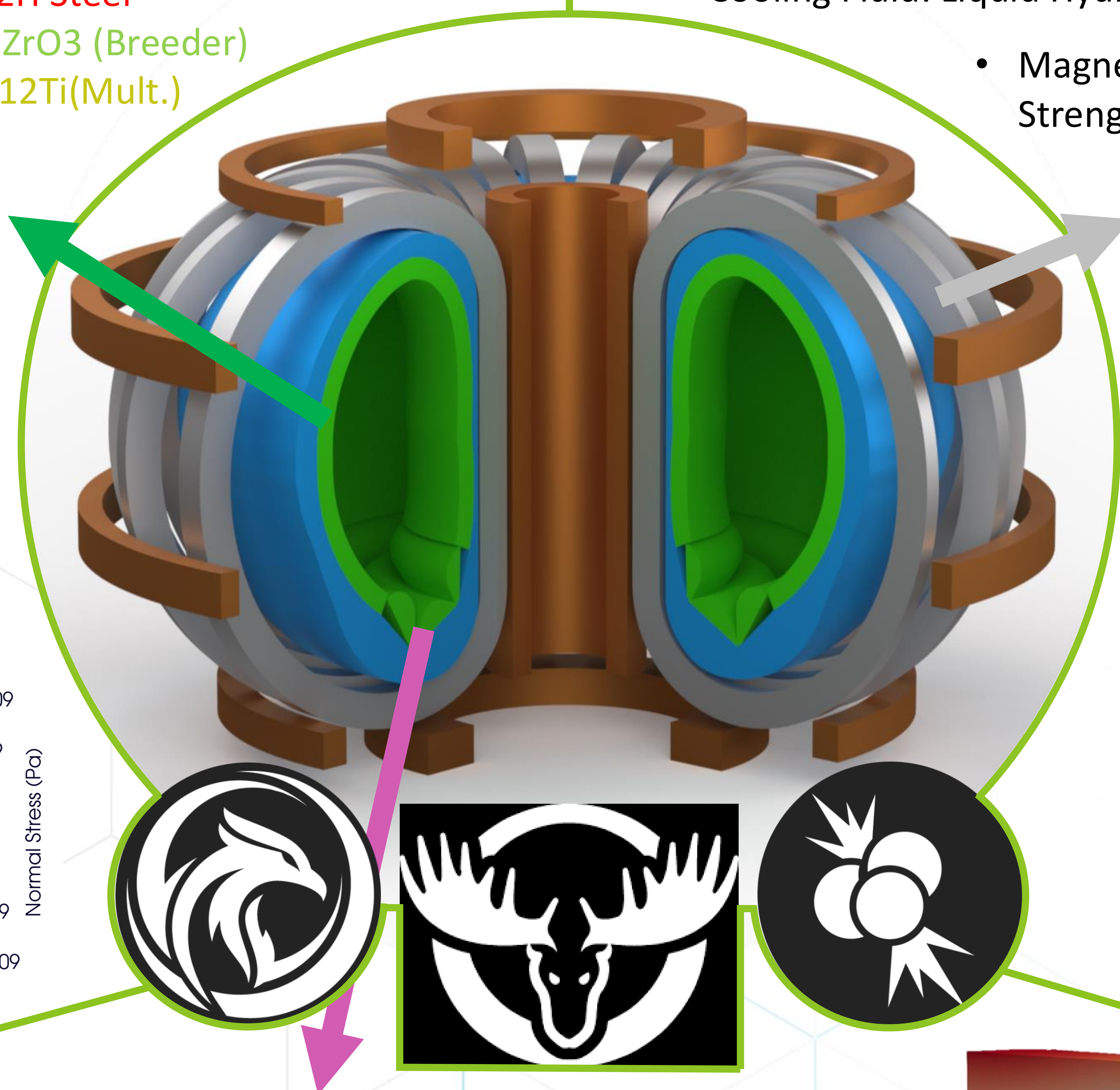
Fusion blankets are responsible for extracting heat from the tokamak for power conversion and producing tritium to fuel the device. To model these components, heat transfer, thermal hydraulics, neutronics, tritium generation and transport, and mechanics analysis are needed to understand how components will behave in tokamaks.



Materials

- Tungsten Armor
- F82H Steel
- Li2ZrO3 (Breeder)
- Be12Ti(Mult.)



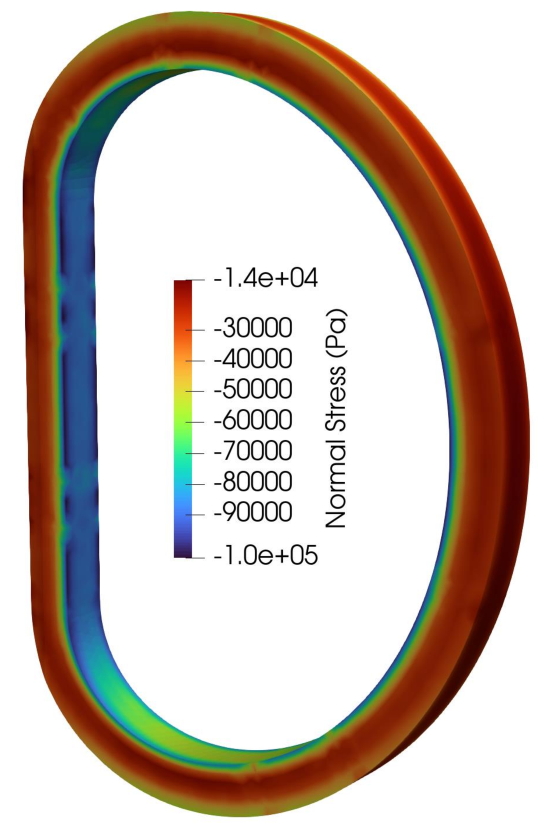


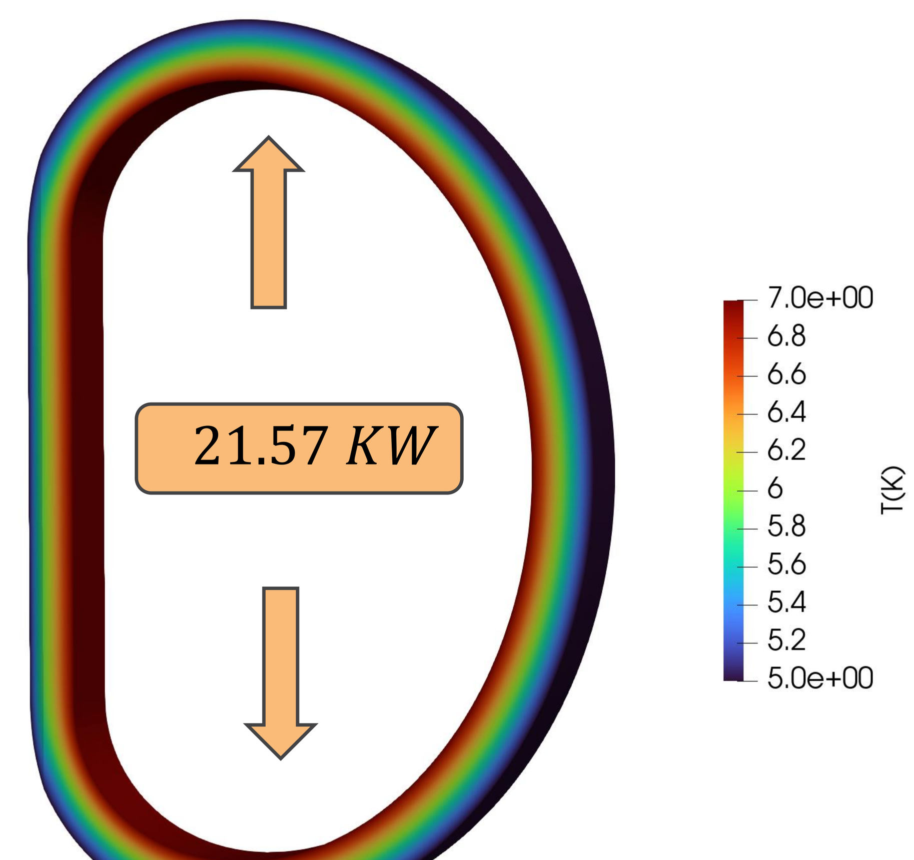
Toroidal Magnets

Toroidal magnets are the D-shaped magnets that keep the plasma confined in the toroidal direction. They are made up of an array of superconducting and structural material and are cooled by liquid hydrogen.

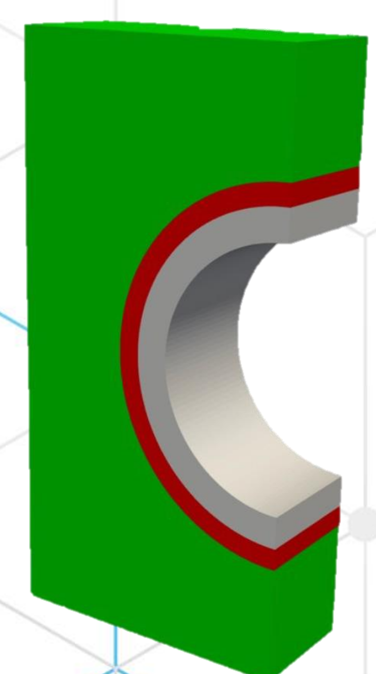
Parameters

- Average heat flux: 21.57KW
- Superconducting material: NiSn
- Cooling Fluid: Liquid Hydrogen
- Magnetic Field Strength: 12T





Divertor Monoblock

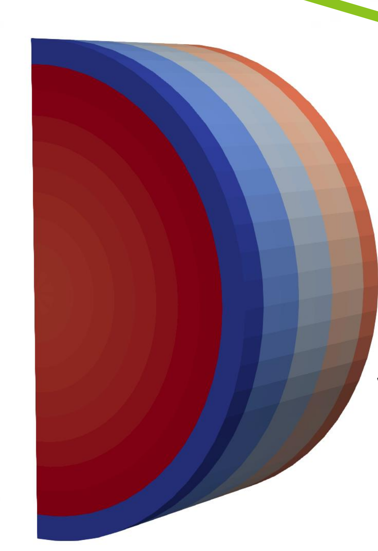


Materials

- Tungsten
- Copper (piping layer)
- CuCrZr (barrier)
- Water Cooling Channel

The Divertor Monoblock is responsible for shielding the area with the highest heat flux inside the tokamak. It is important to model neutronics, thermal hydraulics, and tritium deposition into the tungsten material when analyzing these components.

Temperature Profile



Velocity Profile

Conclusions

The work presented demonstrates the capabilities of modeling fusion components using the FENIX software and MOOSE framework on a fusion blanket, magnet, and divertor monoblock.

Impacts

- Contribution to FENIX, a new opensource tool
- Highlighted as part of a DOE office of technology transition presentation
- Invited presentation at TOFE

Acknowledgments

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[1]A.D.LINDSAY ET AL., "2.0 – MOOSE: Enabling massively parallel Multiohysics simulation," SoftwareX, 20, 101202 (2022).
[2]Tritium Migration Analysis Program, Version 8 (TMAP8) GitHub repository: https://github.com/idaholab/TMAP8, Idaho Falls, 2023.
[3]Fusion ENergy Muliphysi-X (FENIX) Github repository: https://github.com/idaholab/fenix.git
[4]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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