

Divertor Monoblock Multiphysics Analysis Using the SALAMANDER Code

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Advanced computational tools play a crucial role in ensuring the rapid deployment of fusion energy systems due to the multiphysics interactions occurring at the component level. For example, plasma-facing components (PFCs), such as the divertor, undergo thermal loads and stresses, nuclear heating from neutrons and ions, and conjugate heat transfer in the solid material regions and water-cooling channels. High-fidelity multiphysics computational tools allow scientists and engineers to better understand the complex physical phenomena occurring in these components, ensuring their appropriate operation within fusion energy systems. To address these challenges, the Multiphysics Object Oriented Simulation Environment (MOOSE) framework is being leveraged for fusion modeling and simulation through the MOOSE-based Software for Advanced Large-scale Analysis of MAGnetic confinement for Numerical Design, Engineering & Research (SALAMANDER) code. SALAMANDER is designed as a multiphysics and multiscale computational tool capable of 3D high-fidelity fusion system modeling, and it leverages modular MOOSE-based physics capabilities such as thermal mechanics, heat transfer, and fluid dynamics. In addition to MOOSE, the MOOSE-based application Cardinal is employed by SALAMANDER for neutronics capabilities and the MOOSE-based Tritium Migration Analysis Program, version 8 (TMAP8) is used for tritium transport and fuel cycle simulations. Finally, SALAMANDER also possesses capabilities for plasma edge modeling using particle-in-cell to perform high-fidelity PFC simulations.

This work aims to leverage SALAMANDER's capabilities to conduct a case study on an ITER-like divertor monoblock. The divertor is responsible for managing and removing excess heat and impurities from the plasma, protecting the tokamak's components, and maintaining plasma stability during operation. The developed model utilizes its multiphysics capabilities to simulate the neutron interaction from the plasma and the thermal-hydraulic effects from the cooling channel on the divertor monoblock. The neutronics analysis employs a quasi-static approach to calculate heating from a Monte Carlo neutron transport simulation, where a planar neutron source is defined at the top boundary of the divertor monoblock. The same pulsing function is then used to normalize the OpenMC tally results. The thermal-hydraulics analysis utilizes the Reynolds-Averaged Navier-Stokes (RANS) approach, implemented using the Navier-Stokes module in MOOSE, to model fluid flow through the divertor cooling channel. The heat transfer between the solid divertor monoblock and the water-cooling channel is handled using an interface kernel. Tritium is modeled using TMAP8 and accounts for diffusion, trapping, and solubility. By incorporating advanced modeling tools into a fully unified framework, SALAMANDER serves as a key resource for advancing the deployment of fusion energy.

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