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Multiphysics Modeling of Fusion Energy Systems Using the Software for Advanced Large-scale Analysis of MAgnetic confinement for Numerical Design, Engineering & Research (SALAMANDER) Computational Tool

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Addressing the fusion science and technology development needs of the accelerating fusion energy deployment timeline requires a deep understanding of the interaction between materials and the complex physics and engineering processes in the extreme fusion environment. Plasma facing materials, for example, are subject to extreme thermal loads, repeated thermal shocks, and bombardment by 14 MeV neutrons, plasma ions, and neutral particles (deuterium, tritium, and helium), whose interactions with material and system performance are complex. Advanced multiphysics modeling and simulation capabilities offer great potential for accelerated scientific and engineering studies through a high-fidelity, multiscale approach resolving these convoluted interactions. The open-source Software for Advanced Large-scale Analysis of MAgnetic confinement for Numerical Design, Engineering & Research (SALAMANDER) framework addresses these needs by leveraging the Multiphysics Object-Oriented Simulation Environment (MOOSE) framework to model the environment and response of plasma facing materials. SALAMANDER integrates various MOOSE capabilities, including the heat transfer, solid mechanics, and thermal hydraulics modules, along with MOOSE-based applications such as Cardinal (neutronics and computational fluid dynamics) and TMAP8 (Tritium Migration Analysis Program, version 8). SALAMANDER also supports dedicated plasma edge modeling capabilities for plasma-material interaction simulations. By capturing these physics, SALAMANDER can accurately predict the fusion environment and simulate component and system performance.

We will introduce SALAMANDER as a MOOSE-based Multiphysics capability and present its current capabilities. We will describe an example case for a divertor monoblock focusing on interactions between its environment and component performance, as well as future plans focused on expanding ongoing TMAP8 efforts to higher fidelity through multiphysics simulations. This example will highlight SALAMANDER's modular design and how it enables collaborations for massively parallel multiphysics simulations. SALAMANDER is being developed following the INL Software Quality Assurance plan PLN-4005, ensuring rigorous verification, continuous integration and adequacy for purpose. Its open access, on the other hand, enables a community-driven development and wide usage. These features support SALAMANDER in advancing fusion research, design, and performance evaluation.

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