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Correlation of Scaled Breeder Mock-ups toFull-Scale Using Multiphysics

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The efficient and accurate design of tritium breeder blankets is essential for the success of nuclear fusion reactors, playing a vital role in achieving optimal performance and safety. This study, developed within the LIBRTI programme funded by UK Atomic Energy Authority (UKAEA), introduces a comprehensive workflow that integrates parametric geometry generation, meshing, and multiphysics simulation to analyze tritium breeder blanket architectures, with particular emphasis on the methodology for correlating scaled mock-up results to full-size blanket performance.

The workflow begins with parametric geometry modeling using ParaBlank, an open-source Python tool developed by IDOM for the STEP programme. ParaBlank integrates CadQuery-based parametric geometry generation, high-quality conformal meshing with Gmsh, and geometry conversion to DAGMC for neutronics. Material properties, boundary conditions, and physical parameters are embedded directly during geometry creation, ensuring geometric consistency across disciplines by preserving face-level tags.

The SALAMANDER platform, developed by Idaho National Laboratory, serves as the core simulation framework, integrating key physics domains: neutronics via OpenMC, thermal-hydraulics and thermomechanics via MOOSE, and multiscale tritium transport via TMAP8 for predicting tritium release to the purge gas.

A key methodological contribution addresses the computational challenge of full-scale blanket simulation. At the mock-up scale, detailed multiphysics simulations produce data for global sensitivity analysis to identify parameters governing blanket performance. These parameters inform surrogate models that represent detailed pin-level physics at reduced computational cost. At full-size blanket scale, where detailed 3D simulations become computationally impractical, system-level analyses leverage these surrogate models combined with the MOOSE Thermal Hydraulics Module to efficiently capture essential local physics within each breeder unit.

The analysis focuses on critical performance metrics including neutronic heat deposition, Tritium Breeding Ratio, thermal performance, structural integrity, coolant behavior, and tritium release characteristics. The derived correlations between mock-up and full-scale behavior provide insights for experimental validation and their implications at fusion reactor level.

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