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Data-Driven Surrogate Models for Multiphysics Tritium Breeding Blanket Performance Prediction

This work presents a data-driven surrogate modeling framework developed within the LIBRTI project to enable computationally tractable full-scale tritium breeder blanket analysis. High fidelity multiphysics simulations coupling neutronics, thermal-hydraulics, and tritium transport are prohibitively expensive for system-level parametric studies due to the computational burden of resolving 3D transport phenomena across engineering-scale domains.

To address this challenge, we employ machine learning surrogates trained on a structured dataset generated through coupled SALAMANDER simulations of parametrically varied geometries produced by ParaBlank. The primary methodological focus is managing the curse of dimensionality inherent to tritium transport modeling, where the parameter space exceeds 20 dimensions spanning material properties, geometric configurations, and operational conditions. We conduct a rigorous comparative evaluation of surrogate architectures, including Gaussian Process Regression with various covariance kernels and deep Artificial Neural Networks with optimized layer topologies, to identify optimal mappings from high-dimensional input spaces to critical Quantities of Interest (QoIs) such as spatially-resolved tritium production rates, inventory distributions, and permeation fluxes.

Performance metrics including prediction accuracy, extrapolation capability, and computational efficiency are systematically benchmarked against held-out validation sets. This surrogate accelerated workflow enables sensitivity analysis, and inverse design optimization at the blanket scale, facilitating the upscaling of mock-up experimental data to inform design decisions with quantified predictive confidence

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