

A Reliability-Based Framework for Prioritizing Nuclear Data Needs: Application to the Fusion Nuclear Science Facility

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Recent community discussions, including WANDA 2024, have highlighted the need for sensitivity studies to prioritize nuclear data improvement efforts for Fusion Energy Sciences. Yet nuclear data sensitivity analyses in fusion are still commonly performed one response at a time, such as tritium breeding ratio or activation, and one component at a time, such as the blanket, first wall, or vacuum vessel, producing competing prioritization lists of important nuclides and reactions. Because fusion power plants are tightly coupled systems that must satisfy multiple constraints simultaneously, a whole-reactor methodology is needed to connect nuclear data needs directly to reactor feasibility and reliability.

Here, we establish a systematic framework for prioritizing nuclear data needs in fusion energy by quantifying how nuclear data uncertainties affect the probability that a power plant design fails to meet key performance requirements. The central idea is to replace isolated, response-by-response prioritization with a reliability-based approach that integrates multiple reactor criteria into a single performance measure. Using Monte Carlo neutron transport with nuclear data uncertainty propagation, together with activation and cost-relevant modeling, the methodology identifies the nuclides and reaction channels that most strongly influence overall reactor viability.

As a first step, the framework is applied to a simplified 1D cylindrical radial build model of the Fusion Energy Systems Study Fusion Nuclear Science Facility (FESS–FNSF), derived from a detailed 3D reference design. The model represents the radial material layout with 85 zones and captures major blanket and shielding features in the inboard and outboard regions, including PbLi flow channels, SiC flow-channel inserts, and helium-cooled structural components. Nuclear data uncertainties are propagated by processing libraries with NJOY, sampling evaluated data with SANDY, and calculating neutronics responses with OpenMC.

The resulting workflow quantifies uncertainty in key responses and provides a baseline for subsequent sensitivity analysis and nuclear data prioritization. It is designed to extend across multiple fidelities, from 1D radial builds to conceptual and detailed 3D reactor models, ultimately enabling a whole-reactor view of nuclear data needs that is usable by both public-sector programs and private fusion enterprises. The long-term outcome is an open-source framework to guide high-impact, cost-effective nuclear data improvement for fusion energy development.

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