

Advancing SPARC Design Through Deterministic Methods: An Overview

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The design of fusion energy devices poses great challenges to the neutronics modeling community. Fusion devices, such as Commonwealth Fusion Systems's (CFS) SPARC, are extremely complex devices characterized by a large number of components, streaming paths, and a spatially heterogeneous distribution of materials. In addition, the building that houses these fusion devices is characterized by thick walls of shielding with small diagnostics penetrations needed to allow neutrons to reach detectors and sensitive equipment. All these features make the estimation of particle flux and doses for shielding and detector design in fusion facilities very challenging, especially if quick design iterations are needed.

Deterministic methods have been used for decades in neutronics modeling of engineering systems. Unlike stochastic Monte Carlo approaches, deterministic solvers rely on discretization of phase space to directly solve the Boltzmann transport equation, enabling rapid evaluations over large geometries and broad flux changes. This makes them particularly effective for parametric studies, sensitivity analyses and iteration design processes for commercial fusion device design where engineering and computational speed is essential. As such, deterministic transport simulations have become a key tool in shielding and neutron detector design activities at CFS.

In this work, we present an overview of the application of deterministic methods for shielding and detector design analysis for SPARC. CFS utilizes the Attila deterministic solver to design shielding and estimate radiation doses in areas of the SPARC facility where neutron fluxes need to be attenuated by 6-10 orders of magnitude. These areas include the basement, buildings around the Tokamak Hall, and at the site boundary. Deterministic simulations have also been used to design shielding for the Diagnostics Hall wall, which is characterized by small penetrations that house different diagnostics systems. Furthermore, tools based on Attila deterministic simulations have been developed to support the design and calibration of neutron diagnostics systems. These tools leverage the adjoint flux and contribution concept to determine the source or scattering contribution to a detector response. When verified against Monte Carlo simulations and experimental benchmarks, we have found that deterministic approaches offer both speed and sufficient accuracy, making them an indispensable part of the design framework for advancing SPARC design. This presentation will showcase examples from different workflows and neutronics analyses, and discuss plans for future developments.

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