INNOVATIVE THREE-DIMENSIONAL NEUTRONICS ANALYSES DIRECTLY COUPLED WITH CAD MODELS OF GEOMETRICALLY COMPLEX FUSION SYSTEMS

Mohamed Sawan, P. Wilson, T. Tautges‡, L. El-Guebaly, D. Henderson, G. Sviatoslavsky, T. Bohm, B. Kiedrowski, A. Ibrahim, B. Smith, R. Slaybaugh
University of Wisconsin-Madison, 1500 Engineering Dr., Madison, WI 53706, USA
‡Argonne National Laboratory, Argonne, IL 60439, USA
E-mail: *sawan@engr.wisc.edu*

ABSTRACT

Fusion systems are, in general, geometrically complex requiring detailed three-dimensional (3-D) nuclear analysis. This analysis is required to address tritium self-sufficiency, nuclear heating, radiation damage, shielding, and radiation streaming issues. To facilitate such calculations, we developed an innovative computational tool that is based on the continuous energy Monte Carlo code MCNP and permits the direct use of CAD-based solid models in the ray-tracing. This allows performing the neutronics calculations in a model that preserves the geometrical details without any simplification, eliminates possible human error in modeling the geometry for MCNP, and allows faster design iterations. In addition to improving the workflow for simulating complex 3-D geometries, it allows a richer representation of the geometry compared to the standard 2nd order polynomial representation. This newly developed tool has been successfully tested for a detailed 40° sector benchmark of the International Thermonuclear Experimental Reactor (ITER). The calculations included determining the poloidal variation of the neutron wall loading, flux and nuclear heating in the divertor components, nuclear heating in toroidal field coils, and radiation streaming in the mid-plane port.

The tool has been applied to perform 3-D nuclear analysis for several fusion designs including the ARIES Compact Stellarator (ARIES-CS), the High Average Power Laser (HAPL) inertial fusion power plant, and ITER first wall/shield (FWS) modules. The ARIES-CS stellarator has a first wall shape and a plasma profile that varies toroidally within each field period compared to the uniform toroidal shape in tokamaks. Such variation cannot be modeled analytically in the standard MCNP code. The impact of the complex helical geometry and the non-uniform blanket and divertor on the overall tritium breeding ratio and total nuclear heating was determined. In addition, we calculated the neutron wall loading variation in both the poloidal and toroidal directions. The final optics system of the HAPL power plant includes several metallic and dielectric mirrors that are sensitive to radiation. Although some of these mirrors are not in the direct line-of-sight of the neutron source, radiation scattering and streaming through the laser beam ports requires an assessment of the nuclear environment at the final optics to predict their lifetime. Detailed CAD models of the ITER FWS modules were analyzed to produce high resolution maps of nuclear heating, radiation damage and helium production. These clearly show the impact of the design heterogeneity details with the many coolant channels embedded in the module. In addition, hot spots produced in the vacuum vessel behind the module as a result of streaming through these coolant channels were evaluated. These examples will be presented to demonstrate the applicability of the tool to nuclear analysis of complex fusion systems.