Three-Dimensional Modeling of Complex Fusion Devices Using CAD-MCNP Interface

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For a commercial power plant fusion device, many engineering design concepts were evaluated and a design based on the compact stellarator (CS) concept has been recently developed by the ARIES team. Nuclear analysis is needed to obtain some key neutronics parameters, such as the neutron wall loading level, tritium breeding ratio, and radiation damage to structural components. These nuclear analyses give guidance and recommendations on radiation protection for the TF magnet, the size of a breeding blanket, and the selection of an optimal shield.

A three-dimensional Monte Carlo analysis is often needed by the MCNP code to generate the neutron wall loading profile and estimate the overall design parameters such as the tritium breeding ratio and energy multiplication. However, the present MCNP code only provides limited geometry modeling capabilities, particularly for complex geometries. A limited number of geometric primitives are difficult to use when constructing complex models. ARIES-CS involves complicated geometries that can not be modeled with the present version of MCNP. If we use an approximation of the actual geometry configuration, the accuracy of Monte Carlo calculation results will be inevitably hurt by an inaccurate geometry model.

To improve the modeling capability of MCNP, we used CAD software as the geometry engine. The radiation transport is directly performed through the CAD geometry. We use the Common Geometry Module (CGM), which is based on ACIS, as the CAD geometry engine. The MCNP/CGM code can perform simulations on any CAD geometry model. Because complex models are usually designed with CAD systems, the CAD model of complicated geometry usually exists before the Monte Carlo simulation. Therefore, we can also save the time of modeling the complicated geometry for the Monte Carlo calculation.

The first application of the CAD-MCNP coupling approach for the ARIES-CS design is to calculate the neutron wall loading distribution (□) in the poloidal and toroidal directions. Variations of the neutron source profile within the plasma boundary have been examined. These include a uniform source across the plasma, a line source at the geometric or magnetic axes, and the actual source profile that peaks at the geometric magnetic axis. It is found that the change to the peak □ due to the neutron source distribution is about 20%.

The results of this analysis will have a major impact on the ARIES-CS design. The poloidal/toroidal □ distribution helps determine the exact size of the shield needed to protect the magnet and thus could solve a potential interference problem that has been identified for the field-period maintenance scheme when the blanket is moved toroidally out for replacement at the end of its service lifetime.