Fast and Rigorous Methods for Multiphysics SPn Transport in Advanced Reactors

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ABSTRACT:

Over the past decade the U.S. Department of Energy has made significant investments into advancing the modeling and simulation tools used for nuclear reactor analysis. During this time, development efforts focused on enhancing capabilities of 3D deterministic transport (or the associated 2D/1D approximation) which resulted in significant advances in this area. The tools that have grown out of these programs demonstrate a significant leap in capability, fidelity, and computational requirements. However, there is a need for a low-order transport method that permits the running of 10,000's of whole-core calculations required for the design process.

For a neutronics capability enabling routine reactor design in NEAMS, **we propose to perform rigorous theoretical and numerical analysis of the SPn method and underlying cross section models to enable a fast and robust multiphysics low-order transport capability for advanced reactors.** Our approach will be to (i) focus first on the discretization and solution of the SPn equations to obtain a provably efficient method that easily integrates with the existing infrastructure in Griffin; (ii) then perform numerical error analysis of the coefficients from the cross section (XS) case matrix and evaluation to enhance the accuracy and efficiency of ISOXML in multiphysics calculations; (iii) consider the nuances of equivalence factors and potentially develop new ones; (iv) address the challenges of efficiently computing few group constants from continuous energy Monte Carlo transport; and (v) verify and validate our methodology against the most relevant benchmark problems available (e.g. HTR-10, EBR-II, MSRE, etc).

We propose a new discretization of the recently developed *Generalized SPn* (GSPn) equations that combines the best qualities of traditional nodal methods (e.g. higher order convergence) and finite element methods (extension to unstructured mesh and multiple dimensions). Further, this discretization will be developed to be robust in the presence of voids through the use of techniques that preserve the uncollided flux in these regions. Then we will look to develop and apply the recent Hierarchical Poincaré-Steklov solution algorithm; a direct method with nearly linear complexity for sparse linear systems.

In multiphysics calculations, determining good homogenized few-group constants is non-trivial. Therefore, we will apply error analysis to the ISOXML interpolation models to optimize XS functionalization. Additionally, as Monte Carlo XS generation becomes increasingly used, we will address some challenges here by implementing the highly efficiently kernel density estimators in the NEAMS Monte Carlo code Shift for tallying the few-group constants. The statistical uncertainty of Monte Carlo XS will also be treated through the error analysis of the XS interpolation. Finally, with clear understandings of the GSPn theory and numerical methods for its solution, proper equivalence factors can be developed that only account for those differences that they should—and not be generally correcting for discretization errors, XS errors or homogenization all at once.

By developing a fast and rigorous SPn methodology, NEAMS will gain a new capability for advanced reactor design and analysis with sufficient accuracy (e.g. < 200pcm on reactivity, and < 1% RMS and <5% max difference on relative fission rate distributions) at an order of magnitude less computational resources (e.g. minutes with 10's of cores instead of hours with 100's of cores). This capability will enable NEAMS users to more quickly iterate on core designs to produce optimized results that can be verified by the existing high-fidelity capabilities. Through a rigorous approach we expect to be able to fully characterize the numerical errors from each choice made in the development of the method—this will provide guarantees on accuracy and guidance on any future improvements.