A Low Order Transport Method Based on the Dynamic Truncation of the Integral Transport Matrix Method (ITMM) that Converges to the S_N Solution with Increasing Cell Optical Thickness

PI: Yousry Y. Azmy, NC State University

Program: M&S-3

Collaborators:
Changho Lee, Argonne National Laboratory
Scott Palmtag, NC State University

ABSTRACT:

Modeling reactor cores under depletion or transient scenarios requires solving the neutron transport equation at each time step within the modeled time span. The repeated solution of the full transport equation at every step is computationally intractable, so low-order approximations have been developed to enhance computational efficiency. Equivalence theories utilize Monte Carlo (MC) solutions at representative configurations to calibrate the low-order operator and replicate the MC results throughout the time-dependent calculation. However, changes in isotopics and temperature distributions during the depletion and transient, respectively, cause the low-order operator, hence its solution to become inaccurate with increasing time as the configuration deviates further from the MC configurations used in the calibration. Repeated MC calculations to improve the calibration defeats the purpose of the low-order approximation altogether, calling for a new approach that does not require calibration.

We propose a low-order operator that is truncated from a fully discretized Discrete Ordinates (S_N) transport (dense matrix) operator whose elements can be computed readily from analytical expressions or numerically on the fly. Elements of the high-order operator are truncated automatically based on cells' optical thickness, thus yielding a low-order operator whose solutions accurately approximate the high-order operator's solution, itself designed to replicate MC results. Since the low-order operator is transport based, it naturally contains transport (streaming) modes, does not need to be calibrated via equivalence factors, and should be applicable broadly, i.e. changing core configurations. For the sake of computational efficiency, we will adopt as the high-order operator the Integral Transport Matrix Method (ITMM) that was developed and tested to accelerate transport source iterations. The ITMM is a dense matrix dimensioned by the number of computational elements per group, i.e. integrated over angle. For each time step ITMM matrix elements will be computed and retained if their magnitude is larger than a user-defined threshold or truncated dynamically otherwise. Computation of the ITMM matrix elements analytically (on-the-fly) has been demonstrated earlier in the context of iterative acceleration (block Jacobi iterative solution) for the transport equation. We will establish the proof of principle of this novel idea on Cartesian meshes, then we will implement the proven method in the NEAMS unstructured mesh transport code Griffin followed by rigorous verification exercises.

Existing experience with equivalence factors is mostly limited to thermal reactors with relatively optically thick regions, and some of the basic assumptions in deriving them may not be accurately applicable to all advanced reactor concepts. For example, most low-order transport methods utilize a diffusion-like operator that is typically valid in the thermal energy range but not in groups where the flux is highly anisotropic. This effect is prominent in fast groups due to the high down-scattering probability that effectively constitutes removal events causing strong dependence on angle. Clearly streaming effects that are representable by the high-order operator cannot be represented accurately and generally by the diffusion operator. Success of this project will enable Griffin to accurately model the diverse advanced reactor concepts with a great reduction in execution time, without the need for pre-calculated equivalence factors. The reduced computational load is a direct consequence of the low-order operator's sparse nature.