NEUP Nuclear Energy University Program
U.S. Department of Energy

# Unstructured Adaptive Mesh Algorithms for Monte Carlo Transport

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**Program**: Topic 8: Modeling and Simulation

**ABSTRACT:**

Recent growth in computing now permits large-scale multiphysics modeling using Monte Carlo methods, considered state-of-the-art for particle transport. The Monte Carlo method is well-suited for benchmarking lower-fidelity tools, guiding multigroup cross section library development, and aspects of reactor design. However, Monte Carlo methods remain expensive, especially in multiphysics workflows where simulations are performed iteratively. Significant expertise is also needed to pre-divide phase space for scoring tallies, taking into account competing effects including spatial detail, runtime, memory usage, and propagation of truncation/statistical errors to coupled physics solvers. Adaptive mesh refinement (AMR) is a technique which adaptively refines (or coarsens) a mesh to preferentially add Degrees of Freedom (DOFs) where the error is highest, and remove DOFs where the solution is already well-captured. Despite the remarkable success of AMR in other fields, there has been very limited use of AMR for Monte Carlo tally meshes, especially in the context of multiphysics or in combination with h- and p-refinement. This proposal will **develop the fundamental methods and techniques for unstructured mesh AMR with Monte Carlo tallies to enable a transformative leap forward in speed, accuracy, and robustness of Monte Carlo methods for advanced simulation**.

We structure this research in three Thrusts. In Thrust 1, AMR algorithms from the libMesh mesh library will be integrated with OpenMC's unstructured mesh tallies via Cardinal. We focus on algorithmic strategy for selection of refinement/coarsening criteria and incorporation of statistical criteria specialized to Monte Carlo simulation. Theoretical developments for new techniques in element amalgamation (grouping mesh elements together into a tally bin) and element-wise local functional expansion tallies shall be integrated with these AMR capabilities to provide a powerful combination of h- and p-refinement that balances runtime, accuracy, and memory consumption. A series of "open" and "blind" benchmarks shall be performed to assess the AMR Figure of Merit (FOM) and formulate a robust AMR strategy. In Thrust 2, the AMR algorithms are extended to incorporate new refinement criteria customized to multiphysics scenarios, with fundamental research in the application of AMR to acceleration and stabilization of Picard-type multiphysics iteration. Finally, AMR is an enabling technology for simulations where the Quantities of Interest (QOIs) change location in time. In Thrust 3, our multiphysics AMR platform is deployed on a realistic challenge problem for cascading heat pipe failure in a heat pipe microreactor to test algorithmic efficacy for scenarios where the QOIs change location in time.

Project outcomes will include algorithms to enhance the speed, accuracy, and robustness of high-fidelity Monte Carlo modeling. Enhanced solution verification and a reduced barrier-to-entry will increase the contribution of Monte Carlo multiphysics to reactor design and deployment. Education and training of the next generation of nuclear engineers is targeted through a holistic research experience and integration of an undergraduate summer Fellowship program.