A Moment-Preserving Nonanalog Method for Charged Particle Transport

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Extremely short collision mean free paths and near-singular elastic and inelastic differential cross sections (DCS) make analog Monte Carlo simulation an impractical tool for charged particle transport. The widely used alternative, the condensed history method, while efficient, also suffers from several limitations arising from the use of precomputed smooth distributions for sampling. There is much interest in developing computationally efficient algorithms that implement the correct transport mechanics. Here we present a nonanalog transport-based method that incorporates the correct transport mechanics and is computationally efficient for implementation in single event Monte Carlo codes. Our method systematically preserves important physics and is mathematically rigorous. It builds on higher order Fokker-Planck and Boltzmann Fokker-Planck representations of the scattering and energy-loss process, and we accordingly refer to it as a Generalized Boltzmann Fokker-Planck (GBFP) approach.

We postulate the existence of nonanalog single collision scattering and energy-loss distributions (differential cross sections) and impose the constraint that the first few momentum transfer and energy-loss moments be identical to corresponding analog values. This is effected through a decomposition or hybridizing scheme wherein the singular forward peaked, small energy-transfer collisions are isolated and de-singularized using different moment-preserving strategies, while the large angle, large energy-transfer collisions are described by the exact (analog) DCS or approximated to a high degree of accuracy. The inclusion of the latter component allows the higher angle and energy-loss moments to be accurately captured. This procedure yields a regularized transport model characterized by longer mean free paths and smoother scattering and energy transfer kernels than analog. In practice, acceptable accuracy is achieved with two rigorously preserved moments, but accuracy can be systematically increased to analog level by preserving successively higher moments with almost no change to the algorithm. Details of specific moment-preserving strategies will be described and results presented for dose in heterogeneous media due to a pencil beam and a line source of monoenergetic electrons. Error and runtimes of our nonanalog formulations will be contrasted against condensed history implementations.