Time Dependent Hybrid Variance Reduction for a Time-of-Flight Benchmark Problem

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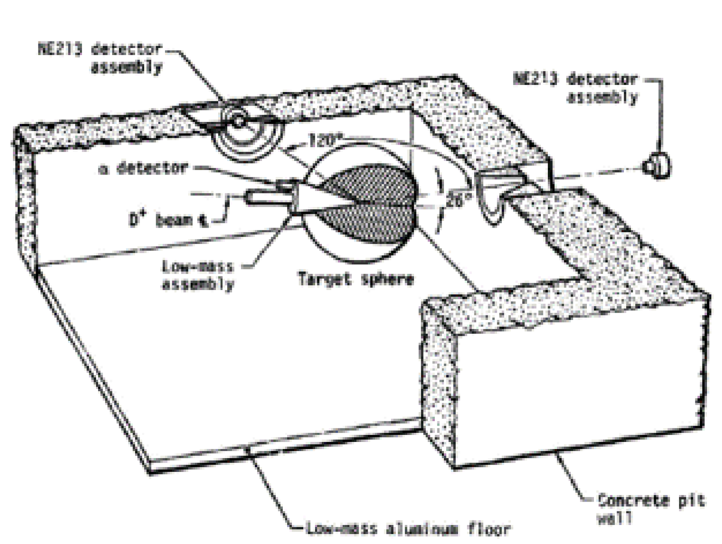
Introduction

Neutron Transport is all about understanding the distributions of neutrons. A good model of the radiation fields is necessary for estimating reaction rates, which is useful for many difference applications.

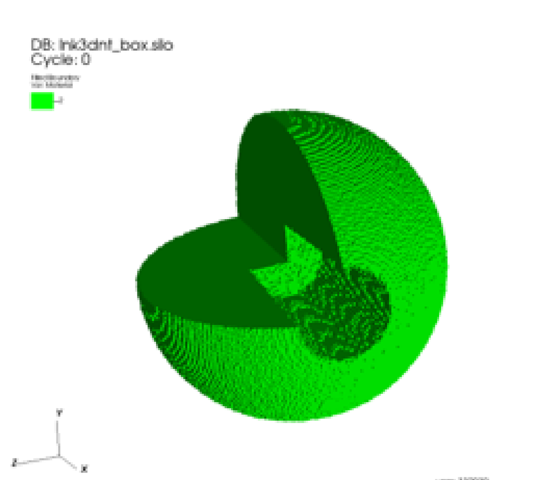
Neutron Transport Codes use either Deterministic Methods, where Physics are approximated to Differential Equations which are then solved, or Stochastic/Monte Carlo Method, where codes simulate particles with exact physics and use statistics to tally the results. Hybrid methods can gain benefits from both solution methods. A common hybrid method is to use a Deterministic solution to create Weight Windows that are then used by the Monte Carlo Solver.

Geometry of Benchmark Problem

- Iron sphere at center of room with radius of 0.9 mean free path
- NE-213 scintillators located between 7 – 10 m at fixed angles
- Short pulse of 14 MeV D-T neutrons is produced in sphere
- Detection in 2 ns time bins from 130 to 500 ns



Geometry of LLNL Pulsed Sphere Experiment



Discretized Target Sphere

PAVR and MCATK

PAVR is a tool that interfaces with PARTISN to create deterministic solutions to the forward and/or adjoint problem. The deterministic adjoint solution is used to create time, energy, and space dependent weight windows.

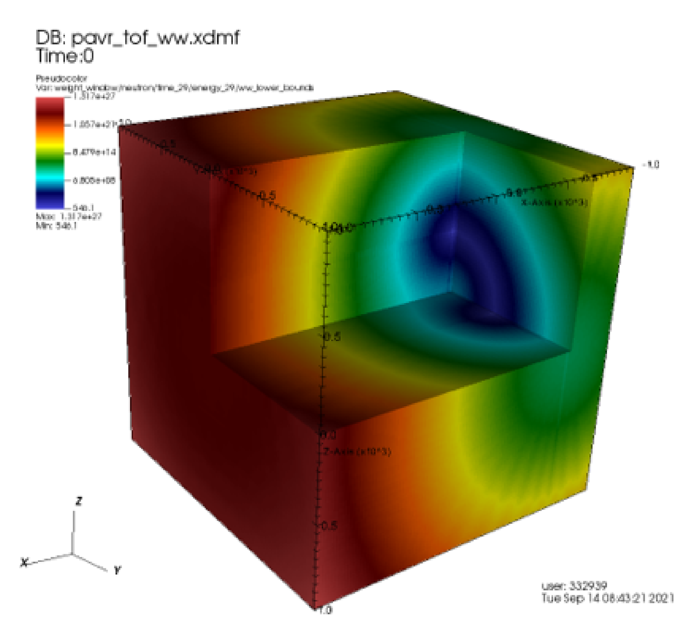
The Monte Carlo Applications Toolkit (MCATK) includes many functions to be able to model Monte Carlo applications.

Geometry, Materials, Sources, Monte Carlo Simulation, Weight Windows

Weight Windows

Weight Windows (WW) are a method for Variance Reduction of Monte Carlo Codes. The Adjoint Flux is used as an approximation of the relative importance as a function of space, energy, and time. Weight Windows are generated as the reciprocal of the computed Adjoint Flux.

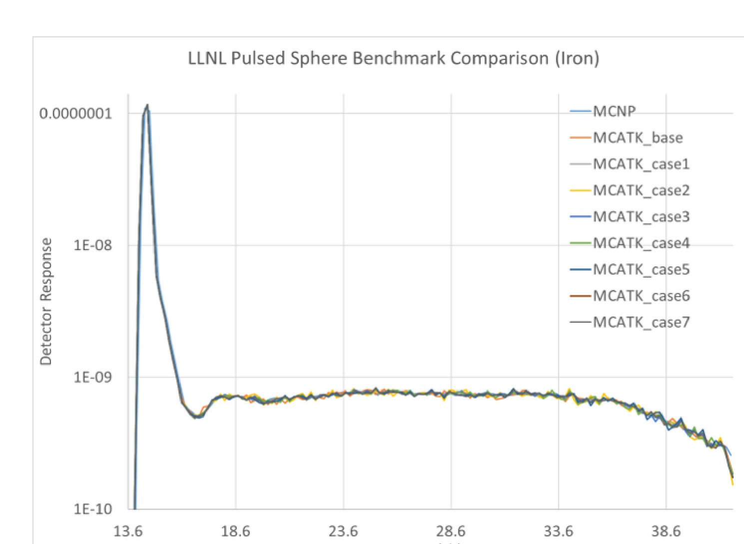
- Particles are given weights to represent any number of neutrons.
- Particle splitting occurs when entering an area with a lower WW to decrease variance locally.
- Russian Roulette can be used when a particle moves to a higher WW to limit computational cost in less important regions.



Weight Windows for Highest Energy Group, Last Time Step

Results

- All MCATK solutions agree with the MCNP Benchmark solution within uncertainty
- Average relative error over all time steps is less than 3%
- Relative error at peak of less than 0.2%.
- Solution bias is significantly smaller than the Monte Carlo uncertainty



Time-Dependent Detector Response from MCNP, MCATK, and MCATK+PAVR cases

Cases

Seven initial cases were constructed using coarse and fine resolutions for spatial mesh, angular quadrature, scattering order, energy groups, and time steps. The 8th case was added with even more refined angular quadrature and time steps. These parameters had the most impact for increasing the figure of merit, so Case 8 is expected to perform better than Case 7.

All cases simulated 400 million particle histories over 576 cores.

Table: FOMs and Runtimes for all cases

	FOM	True FOM	MC Runtime (s)	SN Runtime (s)
Base	1	1	152	0
Case 1	2.27	2.21	102	2.64
Case 2	2.14	1.67	70.1	19.4
Case 3	2.21	2.02	174	16.8
Case 4	2.25	2.20	107	2.86
Case 5	2.34	2.21	95.6	5.75
Case 6	2.61	2.46	101	6.47
Case 7	2.73	0.54	172	703
Case 8	2.70	1.66	158	98.8

Conclusions

Figures-of-Merit improved by 2-3x for all test cases of this problem. With problems that have higher optical thicknesses, higher FOM improvements are expected; observing FOM improvements for optically thin problems is an indicator of a good method.

PAVR successfully generated Weight Windows that reduced the variance for all cases. This supports that the PAVR implementation is working as intended.

The greatest True Figure-Of-Merits improvements came from the most inexpensive Weight Window cases. As the Monte Carlo simulation time increases, finer resolved Weight Windows can be justified. However, Coarse Weight Windows can also be sufficient for significant Figure-of-Merit improvements.

Acknowledgements

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