Title: Variance Reduction with Pulse-Height Tallies in MCNP

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Variance Reduction with Pulse-Height Tallies in MCNP

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Abstract

The forthcoming release of MCNP5 (version 1.50) will include an advanced implementation of T. E. Booth’s method for estimation of pulse-height tallies in the presence of variance reduction techniques, including DXTRAN. This presentation will provide a brief, heuristic introduction to the method and illustrate the technique with a calculational example.
Developers

• Tom Booth
  – Original theory and prototype implementation.

• John Hendricks and Gregg McKinney
  – First released implementation into MCNPX.

• Avneet Sood
  – General transport issues and implementation into MCNP5.
  – Analytic benchmarking.

• Jeff Bull
  – Further development, testing, and implementation for threading.
  – Implementation for MCNP5 and 6.
Variance Reduction Methods Supported

- Source biasing (was always allowed)
- Implicit capture and weight cutoff (CUT)
- Cell splitting/roulette (IMP)
- Cell-based weight windows (WWN, etc.)
- Weight window mesh (MESH)
- Forced collisions (FCL)
- Exponential transform (EXT)
- Energy splitting (ESPLT)
- Time splitting (TSPLT)
- DXTRAN (DXT, DD, DXC)
Algorithm before PHTVR

• During each history accumulate energy deposition by cell.
  – Add source weight*energy
  – Add entering weight*energy
  – Subtract exiting weight*energy
  – (Positrons: include 2×rest mass energy)

• After each history divide accumulation by source weight.
  – The resulting energy determines the pulse-height tally bin.
  – The source weight is the contribution to that bin.

• After transport divide tally by total source weight.

• Result is “fraction of source weight resulting in various amounts of energy deposition” *i.e.* “counts.”

• This algorithm works correctly only for analog problems.
  – (Except that source biasing is allowed.)
What does a pulse-height tally measure?

Contributions: $W_0$ in energy bin containing $E_2 - E_3$
$W_1$ in energy bin containing $E_4 - E_5 + E_6$
Why Ordinary Variance Reduction Fails

Analog

- \( \text{W E}_0 \), Bin with E gets W.
- \( \text{W E}_0 \), No score.
- \( \text{W E}_0 \), Bin with E gets W.
- \( \text{W E}_0 \), No score.

Cell Importance

- \( \text{W E}_0 \), Bin with \( \frac{1}{2} \text{E} \) gets W.
- \( \text{W E}_0 \), Bin with \( \frac{1}{2} \text{E} \) gets W.
- \( \text{W E}_0 \), Bin with \( \frac{1}{2} \text{E} \) gets W.
- \( \text{W E}_0 \), Bin with \( \frac{1}{2} \text{E} \) gets W.

<table>
<thead>
<tr>
<th>0.5</th>
<th>( \text{E} )</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.25</td>
<td>( \frac{1}{2} \text{E} )</td>
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</tbody>
</table>
Branches = Physically Realizable Tracks

Each branch weight = ½

W E₀ → E

Bin with E gets ½W.

2-for-1 splitting node creates 2 branches for each history.
View a history as a tree

Energy bin containing $\Delta_1 + \Delta_6 + \Delta_7$ gets $\frac{1}{4}W_0$
Energy bin containing $\Delta_1 + \Delta_6 + \Delta_8$ gets $\frac{1}{4}W_0$
Energy bin containing $\Delta_1 + \Delta_2 + \Delta_3 + \Delta_4$ gets 0
Energy bin containing $\Delta_1 + \Delta_2 + \Delta_3 + \Delta_4 + \Delta_5$ gets $W_0$
New Approach to History Tracking

- Selected pieces of entire history must be kept in memory.
- With PHTVR a single history becomes a collection of separate physically-realizable branches.
- Physical nodes are distinguished from variance-reduction nodes.
- Roulette introduces some potential complexity.
- DXTRAN (which includes roulette) introduces much greater complexity.
- PHTVR is a natural application of tree structures.
An Example with Variance Reduction

- PHT with weight windows.
- 1 21 -2.7 -11 12 imp:p = 1
- 2 22 -10.0 -12 imp:p = 1
- 3 0 11 imp:p = 0

- 11 RCC 0 0 0 0 120 0 50
- 12 SPH 0 100 0 1

- wwp:p j j j j -1
- mode p
- mesh geom=rzt ref 0 .1 0 axs 0 1 0 origin -.1 -.1 -.1 imesh 50.2 jints 5 jmesh 120.2 jints 12 kmesh 1
- m21 13000 1 $ aluminum
- m22 32000 1 $ germanium
- sdef erg 5 pos 0 .01 0
- f8:p 2
- e8 0 1.0e-06 .001 39ilog 10.
Results of an Analog Calculation

![Graph showing energy (MeV) vs. counts per MeV per source photon, with a logarithmic scale for both axes.](image-url)
Results with Weight Windows

Counts per MeV per source photon

Energy (MeV)

10^{-3} 10^{-2} 10^{-1} 10^{0}

10^{-9} 10^{-8} 10^{-7} 10^{-6} 10^{-5} 10^{-4} 10^{-3} 10^{-2} 10^{-1} 10^{0}
Testing

- Regression test set with 215 problems
  - Compare with analog results
  - Compare with MCNPX where applicable
  - Compare different VR techniques

- Internal structure tests
  - Valid tree structure
  - Array bounds checking

- Analytical test problems
  - Report by Avneet Sood forthcoming
Restrictions and/or Future Work

- No PHYS:E card variance reduction techniques
  - \( B_{\text{NUM}}, X_{\text{NUM}}, R_{\text{NOK}}, \) and \( E_{\text{NUM}} \)
    - Changed to unity unless set to zero by user
  - No \( \text{NUM}_B \) biasing

- Only one DXTRAN sphere

- Non-analog physics still not addressed (e.g. neutrons)