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Bologna, Italy
8 - 10 October 2007

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Variance Reduction with Pulse-Height Tallies in MCNP

H. Grady Hughes
Los Alamos National Laboratory

Uncertainty Assessment in Computational Dosimetry

Bologna, Italy
October 8–10, 2007

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.
    - *Monte Carlo Variance Reduction Approaches for Non-Boltzmann Tallies* LA–12433 (1992).
    - *Pulse Height Tally Variance Reduction in MCNP* LA–13955 (2004).
- 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.)

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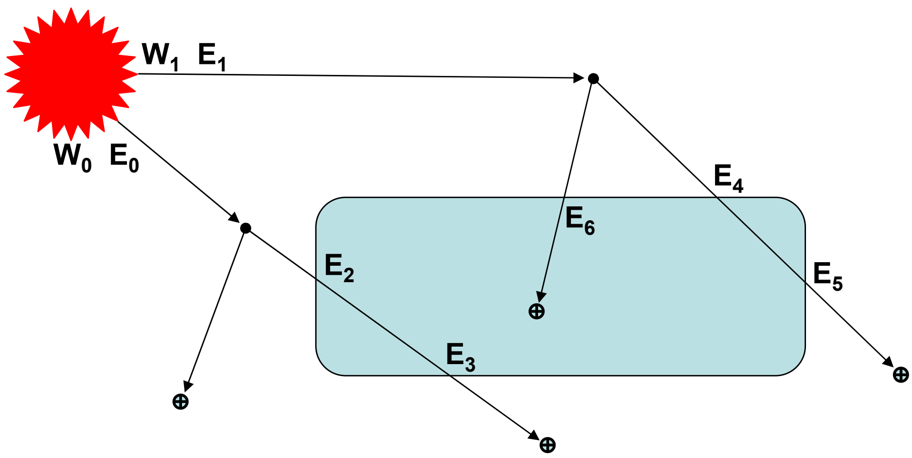
What does a pulse-height tally measure?



Contributions: W_0 in energy bin containing $E_2 - E_3$
W_1 in energy bin containing $E_4 - E_5 + E_6$

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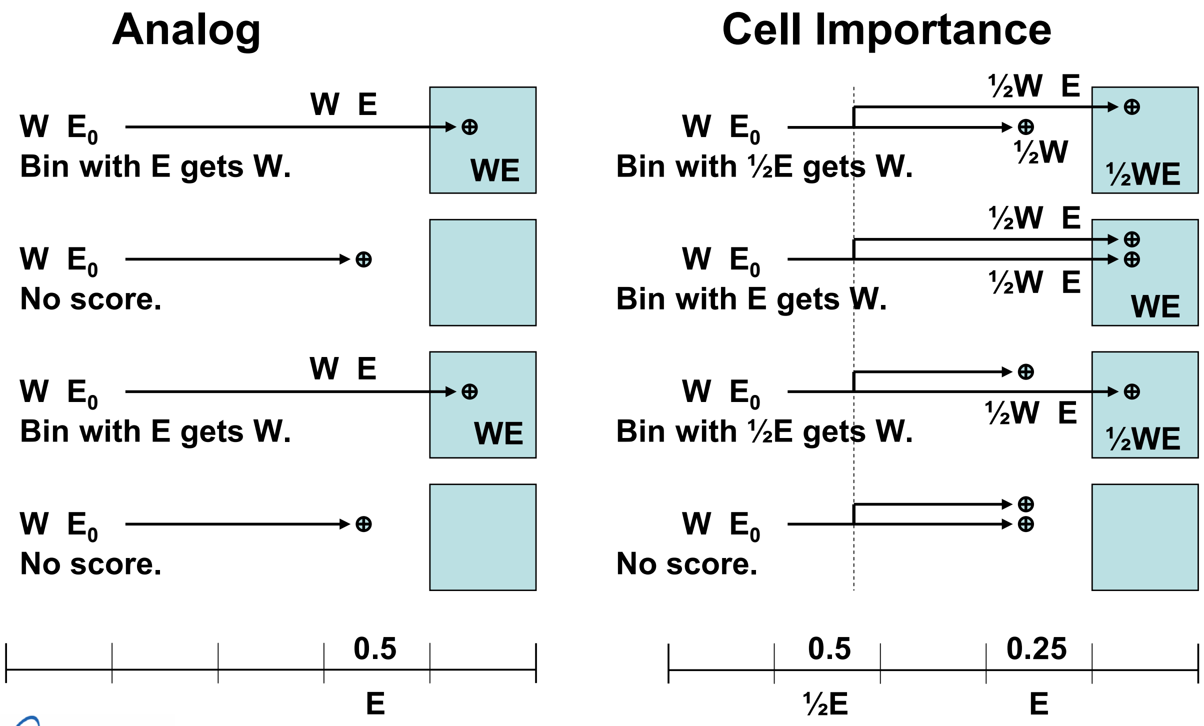
Why Ordinary Variance Reduction Fails



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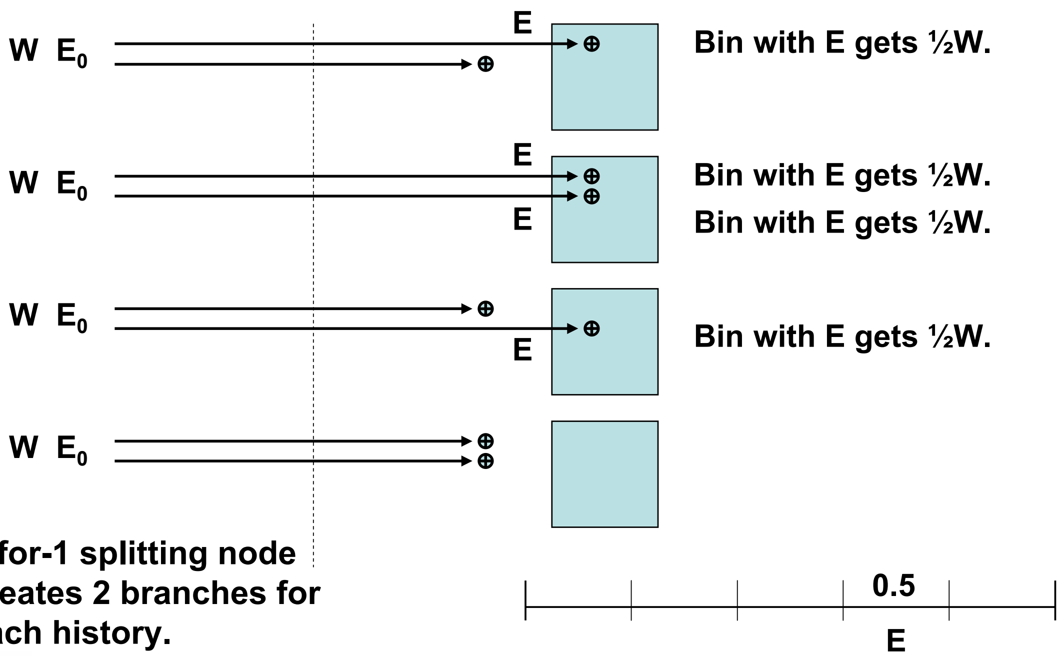
Branches = Physically Realizable Tracks

Each branch weight = ½



2-for-1 splitting node creates 2 branches for each history.

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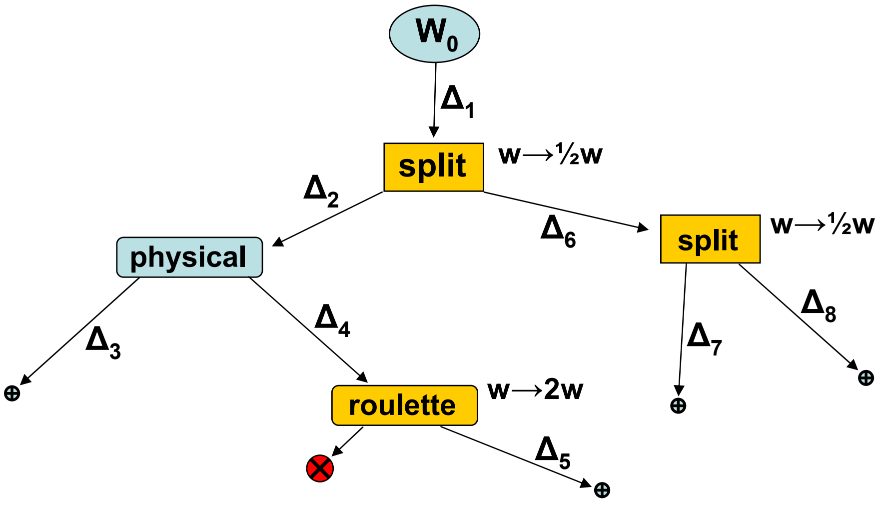
View a history as a tree



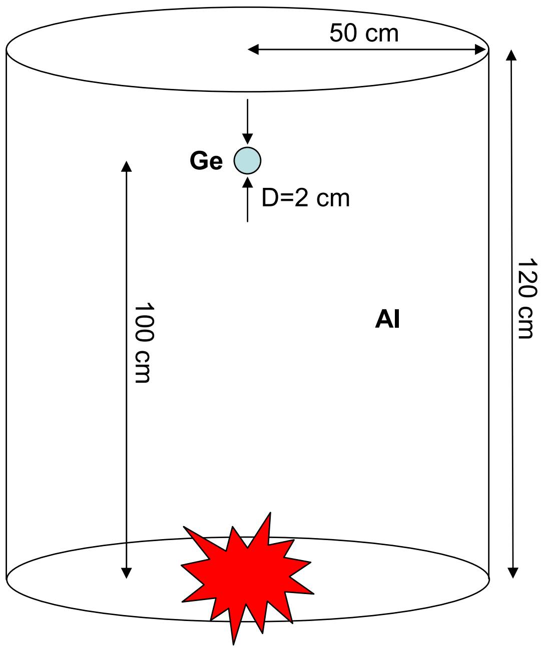
Energy bin containing $\Delta_1 + \Delta_6 + \Delta_7$	gets ¼W_0
Energy bin containing $\Delta_1 + \Delta_6 + \Delta_8$	gets ¼W_0
Energy bin containing $\Delta_1 + \Delta_2 + \Delta_3 + \Delta_4$	gets 0
Energy bin containing $\Delta_1 + \Delta_2 + \Delta_3 + \Delta_4 + \Delta_5$	gets W_0

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.

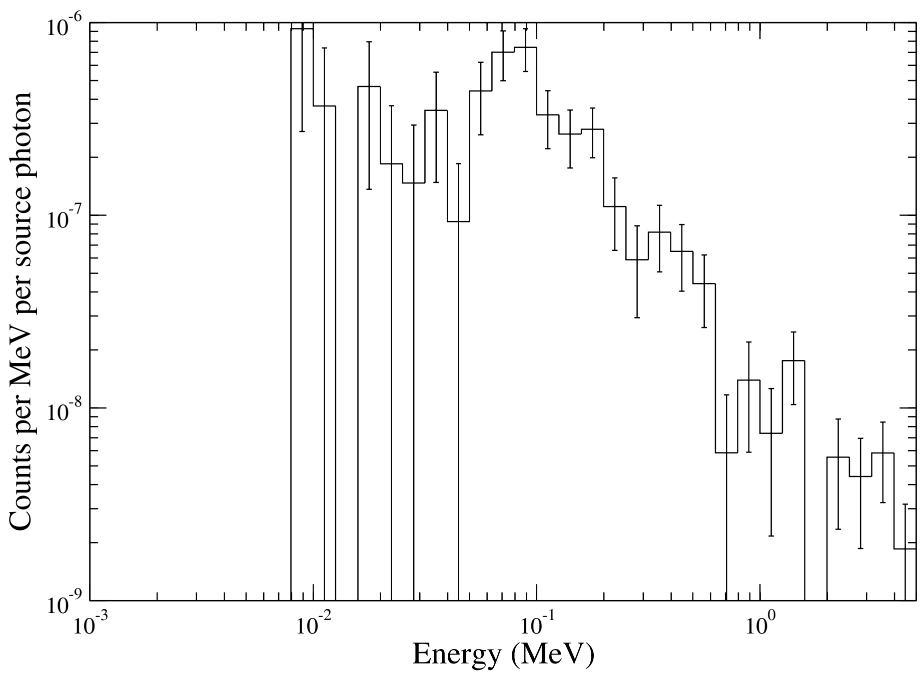
An Example with Variance Reduction

- 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 iints 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.

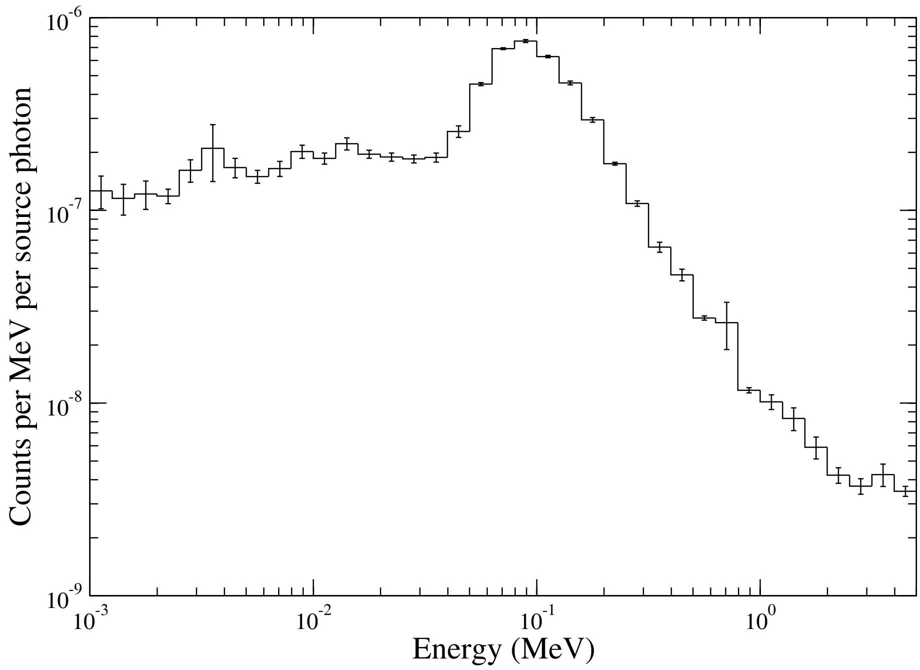


Point isotropic source
5-MeV photons

Results of an Analog Calculation



Results with Weight Windows



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

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Restrictions and/or Future Work

- No PHYS:E card variance reduction techniques
  - B_{NUM}, X_{NUM}, R_{NOK}, and E_{NUM}
    - Changed to unity unless set to zero by user
  - No NUM_B biasing
- Only one DXTRAN sphere
- Non-analog physics still not addressed (e.g. neutrons)