SAND2008-3384C

Synthesis of the Feynman-Y Neutron Multiplicity Metric using Deterministic Transport

John Mattingly and Eric S. Varley
Sandia National Laboratories

American Nuclear Society 2008 Annual Meeting
June 8 – 12, 2008

Sandia is a multiprogram laboratory operated by Sandia Corporation, a Lockheed Martin Company, for the United States Department of Energy's National Nuclear Security Administration under contract DE-AC04-94AL85000.

Objective

- Infer configuration of an unknown radiation source from its measured radiation signatures

- Source features
  - Isotopic composition
  - Fissile mass & multiplication
  - Geometric arrangement of radiating and shielding materials

- Signatures
  - Gamma spectrometry
  - Neutron time-correlation and multiplicity counting

- Applications
  - Nonproliferation
  - Counterterrorism
  - Emergency Response

Technical Approach

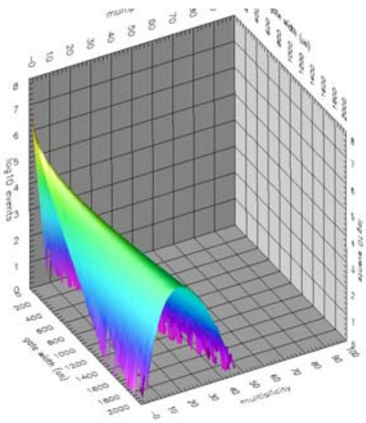
- Compute radiation signatures using radiation transport
- Iteratively modify model parameters to minimize error between predicted and measured signatures

- Method is fairly mature using gamma spectral signatures
- Gamma spectrum primarily sensitive to outer surface of source
- Solution based on gamma spectrometry alone is weakly constrained

- Neutron multiplicity sensitive to entire source volume
- Simultaneous solution based on gamma spectral and neutron multiplicity signatures is better constrained
- Sandia developed fast method to accurately compute neutron multiplicity signatures – based on original work by Muñoz-Cobo, Perez, and Verdú

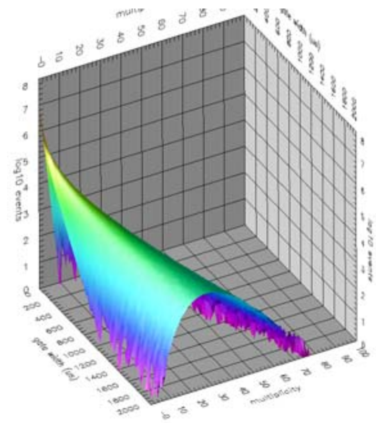
Neutron Multiplicity Distribution

Multiplication ~ 4.5
Generation Time ~ 3 ns



LANL BeRP Ball / Bare

Multiplication ~ 15.5
Generation Time ~ 9 μs



LANL BeRP Ball / 3” Poly Reflector

NNSA

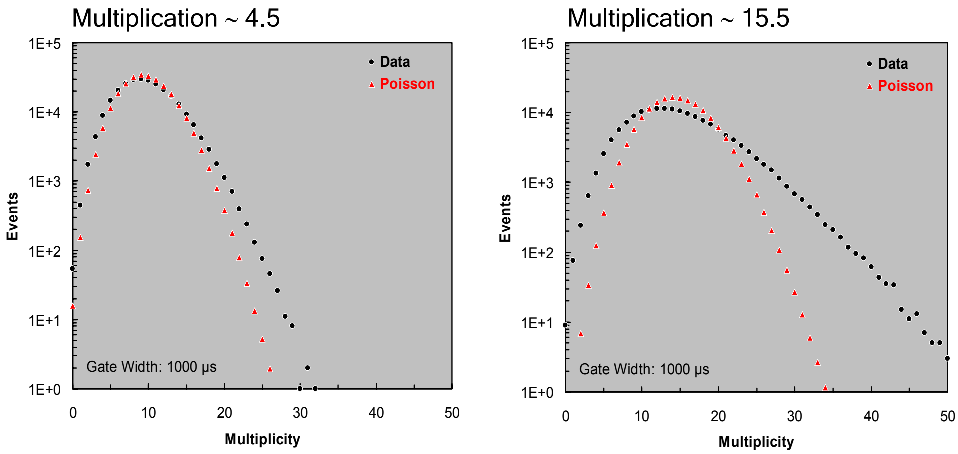
Sandia National Laboratories

•Los Alamos BeRP ball is an unclassified 4.5 kg sphere of alpha-phase weapons-grade plutonium metal

•Constructed for critical and subcritical experiments using various reflecting materials

•All measurements shown in this presentation use polyethylene reflectors varying in thickness from 0 (bare) to 6”

Multiplication Induces Excess Variance



LANL BeRP Ball / Bare

LANL BeRP Ball / 3” Poly Reflector

Feynman-Y: Excess Relative Variance

- Feynman-Y measures excess variance relative to Poisson process

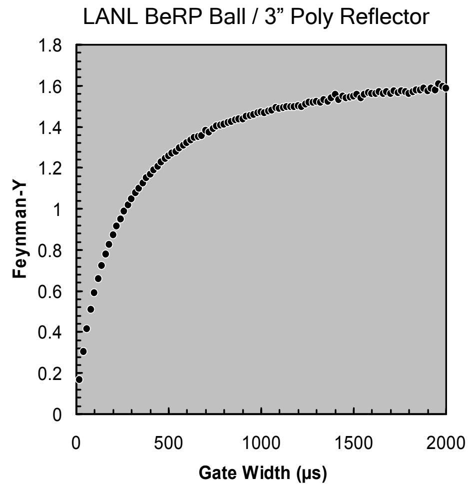
$$\frac{\sigma^2}{\mu} = 1 + Y$$

$$\sigma^2 : variance$$

$$\mu : mean$$

- Y vanishes if counting distribution is purely Poisson
- Y tends to increase with neutron multiplication

- Usually measured vs. coincidence gate width (counting time)



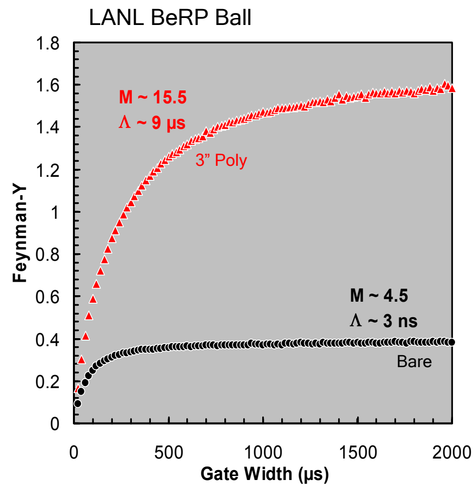
NNSA

Sandia National Laboratories

Effect of Multiplication and Generation Time

- Y is a measure of the second moment of the counting distribution
- Asymptotic value tends to increase with square of neutron multiplication

- Y is a measure of the system's dynamic response
- Shape vs. gate width tends to evolve more slowly with increasing neutron generation time



Computation of Feynman-Y from Deterministic Transport

- Feynman-Y exhibits two notional features
  - Asymptotic value
  - Shape dependent on coincidence gate width

- Asymptote
  - Computed from static forward and adjoint transport solution
  - Accounts for relative contribution of source and induced fission neutrons
  - Source term for adjoint problem is detection efficiency – adjoint flux "weighting function" represents importance to detection

- Shape
  - Computed from solution to dynamic step response problem
  - Forward source term is instantaneously stepped
  - Leakage current is folded with detector cross-section & impulse response
  - Detector response is integrated over gate width

Computation of Feynman-Y Asymptote

- Excess variance comes from source and induced fission

$$\frac{\sigma^2}{\mu} = 1 + Y \qquad \sigma^2 = \mu + {}_2S_0 + {}_2S$$

- Variance of source neutron production Q

$${}_2S_0 = \int d^3r \int dE \, \frac{\overline{\nu_0(\nu_0 - 1)}}{\overline{\nu_0}} Q(\vec{r},E)\, I_0^2(\vec{r}) \qquad I_0(\vec{r}) = \int dE' \frac{\chi_0(\vec{r},E')}{4\pi} \varphi^\dagger(\vec{r},E')$$

- Variance of fission neutron production $\nu\Sigma_f\varphi$

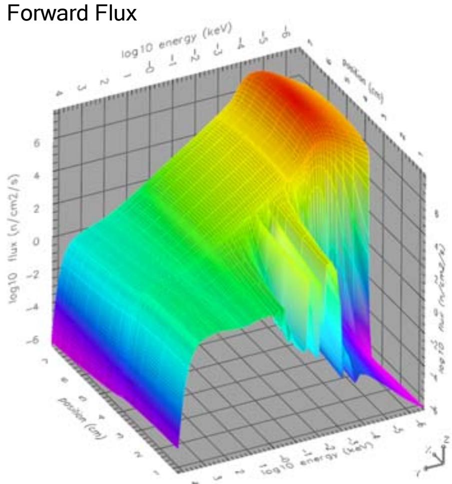
$${}_2S = \int d^3r \int dE \; \overline{\nu(\nu-1)}\Sigma_f(\vec{r},E)\, \varphi(\vec{r},E)\, I^2(\vec{r}) \qquad I(\vec{r}) = \int dE' \frac{\chi(\vec{r},E')}{4\pi} \varphi^\dagger(\vec{r},E)$$

- Importances I_0 and I weighted by adjoint flux $\varphi^\dagger$

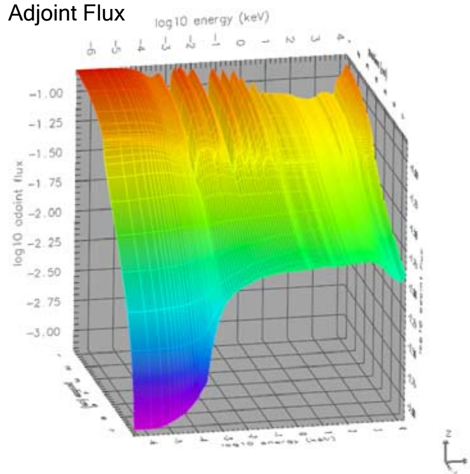
Static Forward and Adjoint Solutions

LANL BeRP Ball / 1.5” Poly Reflector

Forward Flux



Adjoint Flux



Computation of Feynman-Y Shape

- Feynman-Y shape computed from solution to forward dynamic step response problem

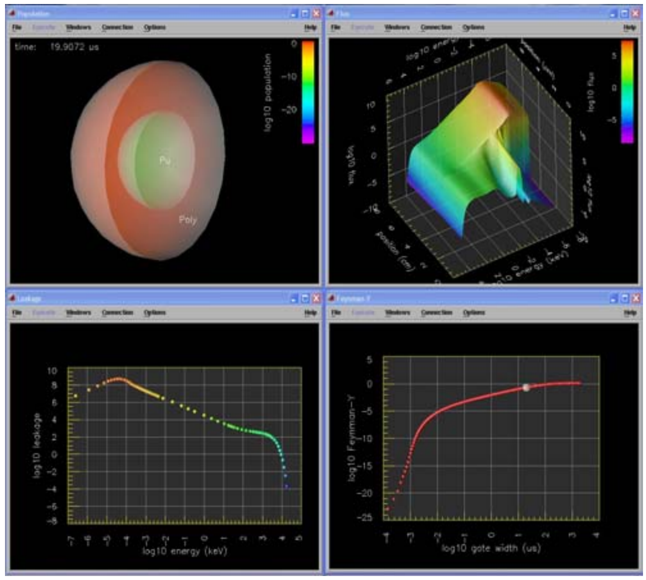
$$Y(T) \quad \propto \quad \frac{1}{T}\int_0^T dt \int_0^t dt' \, h(t-t')\,\Sigma_d(\vec{r},E)\,\varphi(\vec{r},E,t')$$

- Uses LANL transport solver PARTISN to compute flux φ in response to instantaneous step in forward source term Q

- Time-dependent flux folded with detector cross-section Σ_d and impulse response h

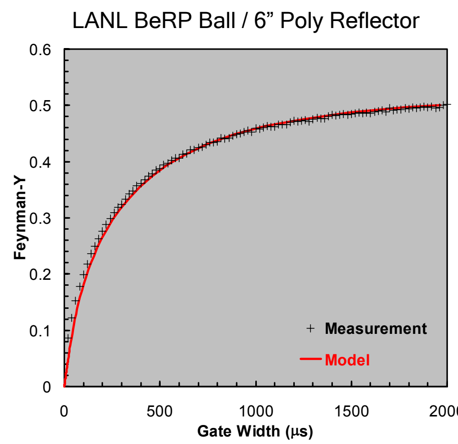
- Integrated over coincidence gate width T

Computation of Dynamic Response



Test Results

- Neutron multiplicity calculations tested against six measurements of LANL BeRP ball
  - Bare
  - Reflected by polyethylene 0.5”, 1”, 1.5”, 3”, and 6” thick
- Calculations match measurements within measured uncertainty
- Computational time between 1 and 15 seconds on standard laptop
- Total computational time dominated by dynamic calculation, primarily dictated by neutron lifetime



Conclusions

- Possible to infer configuration of an unknown radiation source from its radiation signatures

- Solutions based on multiple complementary signatures are better constrained

- Sandia is developing methods to solve for source configuration using gamma spectrometry and neutron multiplicity signatures

- Sandia developed fast method to accurately compute Feynman-Y
- Based on original work by Muñoz-Cobo, Perez, and Verdú
- Implementation uses LANL-developed, time-dependent transport solver PARTISN

- Initial test results confirm method's accuracy and potential speed

Future Work

- Increase speed of calculations
  - Explore alternative cross-section libraries
  - Explore different solver options
  - Resolve slow convergence of adjoint solution (maybe)

- Benchmark accuracy of calculations
  - Some measurements used for initial testing exhibited large systematic variations
  - Planning to collect new measurements according to benchmark standards

Acknowledgments

- This work was sponsored by the Simulation, Algorithms, and Modeling Program of the NNSA's Office of Nonproliferation Research and Development

- Thanks to Rafael Perez, Prof. Emeritus at University of Tennessee for his help in understanding the method to compute Feynman-Y

- Thanks to Randy Baker and Jeff Favorite of Los Alamos for their help with PARTISN