Comparison of the Performance of Various Correlated Fission Multiplicity Monte Carlo Codes

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Outline

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II. **Methods**
III. **Results**
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    B. Code comparisons
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INTRODUCTION

Motivation

- **Accurate prediction of special nuclear material (SNM) measurements**
  - Using Monte Carlo (MC) radiation transport codes
- **Historically: uncorrelated fission emissions**
- **Reality: correlations in time, energy, and multiplicity [1]**
- **This work: investigates the performance of various current MC codes with correlated physics of fission**

Fission multiplicity distributions

- **P(ν) have large impact on correlated neutron results**
  - Probability of emission of ν neutrons in a single fission

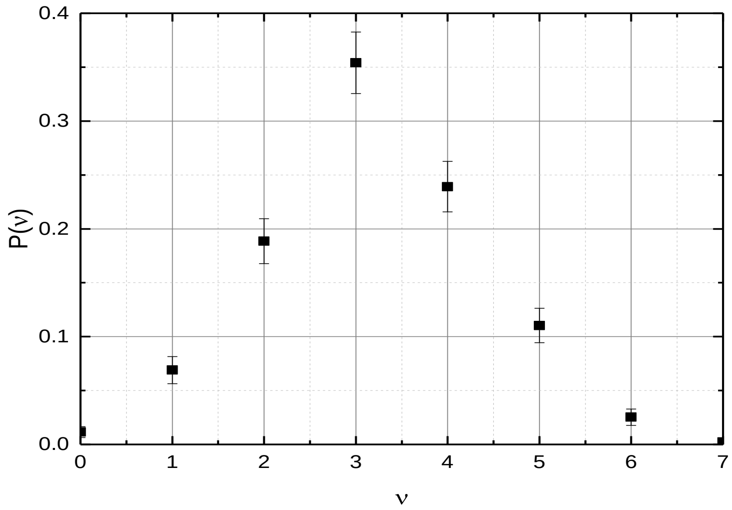

Fig. 1. Example multiplicity distribution.

MC codes

- **Monte Carlo N-Particle Transport code (MCNP)**
- **MCNP®6 [2]**
  - Default: bounded integer treatment
  - Optional: FMULT card to input multiplicity distributions/parameters
- **MCNP®6/FREYA [3,4]**
  - FREYA fission event generator produces neutrons and gives to MCNP for transport
- **MCNPX-PoliMi [5]**
  - Choose from a few different built-in multiplicity distributions

Fission event generator (FEG)

- **Uses:**
  - Fission fragment mass and kinetic energy distributions
  - Unbounded statistical evaporation models
  - Conservation of energy and momentum
- **Generates number, energy, and direction of neutrons released by each fission event [3]**

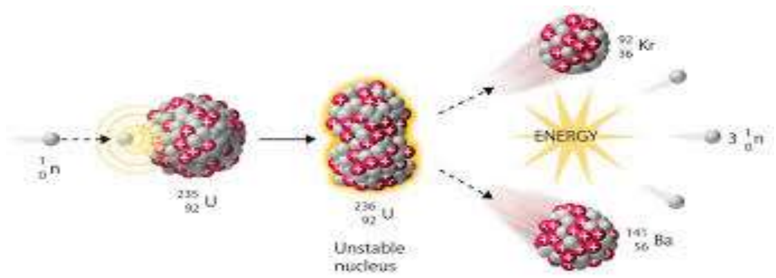

Fig. 2. Representation of a fission event.

LANL BeRP benchmark

- Los Alamos National Laboratory (LANL) bare plutonium metal (BeRP ball) benchmark measurement
- 4.5 kg sphere of α-phase Pu [6]
- Original MCNP input file adjusted t

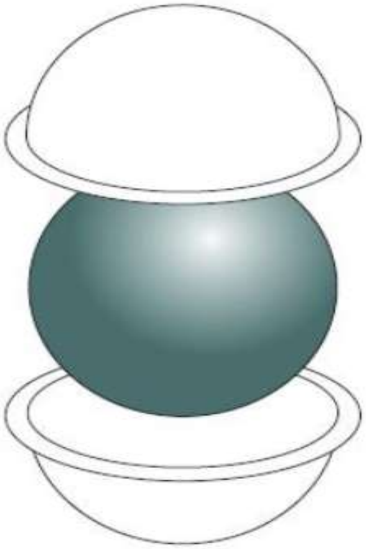

Fig. 3. BeRP ball

METHODS

Simulation geometry

- **Bare BeRP ball (bare configuration only) with NPOD detectors**
  - LANL ^{3}He multiplicity detector
  - 15 ^{3}He neutron detectors in polyethylene moderator
- **50 cm detector distance**

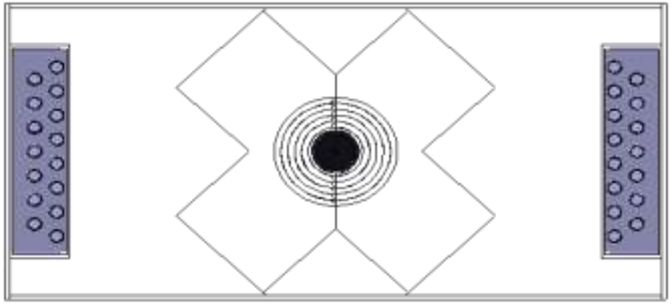

Fig. 4. BeRP benchmark bare case geometry (VisEd)

This model came from the evaluation FUND-NCERC-PU-HE3-MULT-001

List-mode data

- **Only time and detector of interaction**
  - MCNP®6 and MCNP®6/FREYA: obtained from particle track (PTRAC) output files
  - MCNPX-PoliMi: obtained from collision data file
- **Feynman histogram: list-mode data binned into multiplets according to specified time widths (Momentum [7])**
- **Singles rate (R_1): detector count rate**
- **Doubles rate (R_2): frequency of detection of two neutrons from the same fission chain**

Data processing

Table I. Variable definitions [8].

τ	**Specified time width**
	n^{th} order reduced factorial moment

P(ν) comparisons

- **Differences in Feynman histograms, R_1, and R_2 are expected to be sensitive to differences in underlying multiplicity distributions**

- **MCNP®6 and MCNPX-Polimi: Lestone [9], Santi [10], Terrell [11]**
  - Specified as CDF or Gaussian mean and width
  - Induced fission means taken from ENDF/B-VII.1
- **MCNP®6/FREYA: FEG**
  - Extracted from PTRAC file
  - Frequency distribution of ν

Multiplicity distributions

RESULTS

Induced fission

- **2 MeV incident neutron energy**
  - Average energy of neutrons causing fission in the bare BeRP is 1.98 MeV
- **MCNP®6/FREYA: simulated 2 MeV neutron source hitting a thin film of pure ^{239}Pu**

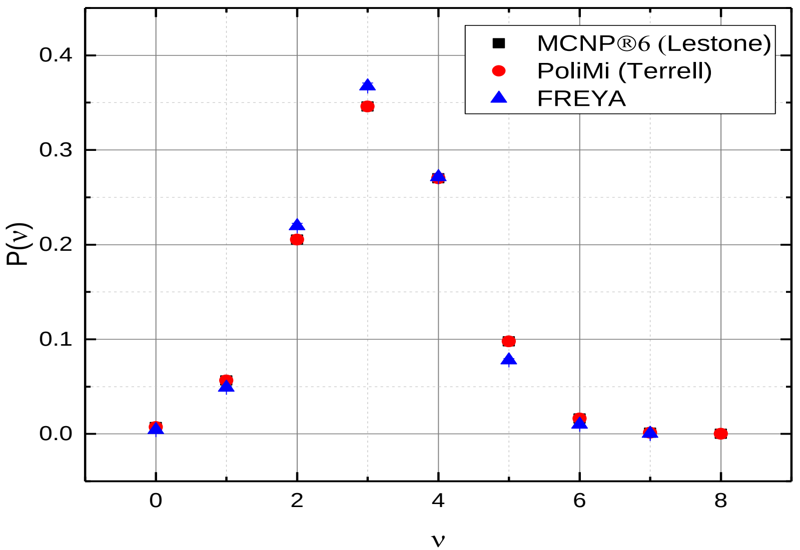

Fig. 5. Induced fission multiplicity distributions (at 2 MeV) incident neutron energy.

Table II. Induced fission multiplicity distribution parameters.

Code	MCNP®6	MCNPX-PoliMi	MCNP®6/FREYA
$\bar{\nu}$	3.178[4]	3.178[4]	3.128
σ	1.140[1]	1.140[3]	1.057

[1]Lestone [3]Terrell [4]ENDF

Spontaneous fission

- In general:
- R_1 expected to change only with mean of $P(\nu)$
- R_2 and Feynman histogram expected to change with both mean and width

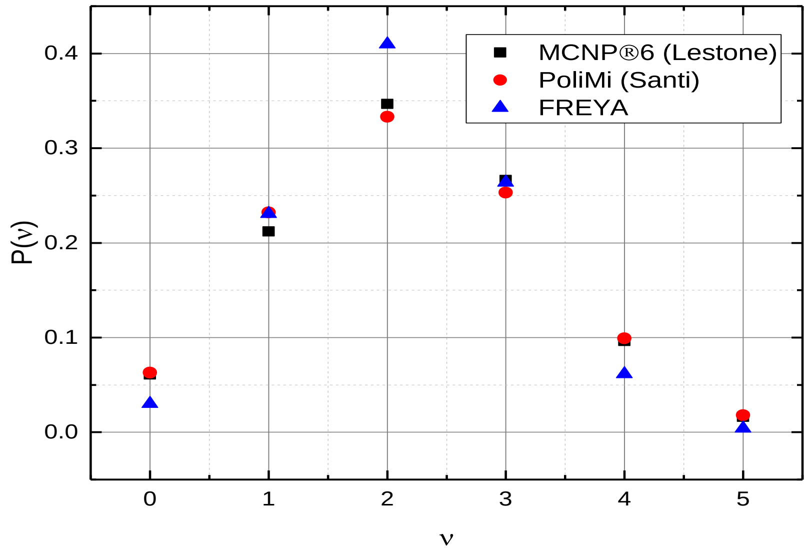

Fig. 6. Spontaneous fission multiplicity distributions.

Table III. Spontaneous fission multiplicity distribution parameters.

Code	MCNP®6	MCNPX-PoliMi	MCNP®6/FREYA
$\bar{\nu}$	2.151[1]	2.093[2]	2.109
$\bar{\nu}$	1.151[1]	1.199[2]	0.942

[1]Lestone [2]Santi

Code comparisons

RESULTS

Feynman histogram

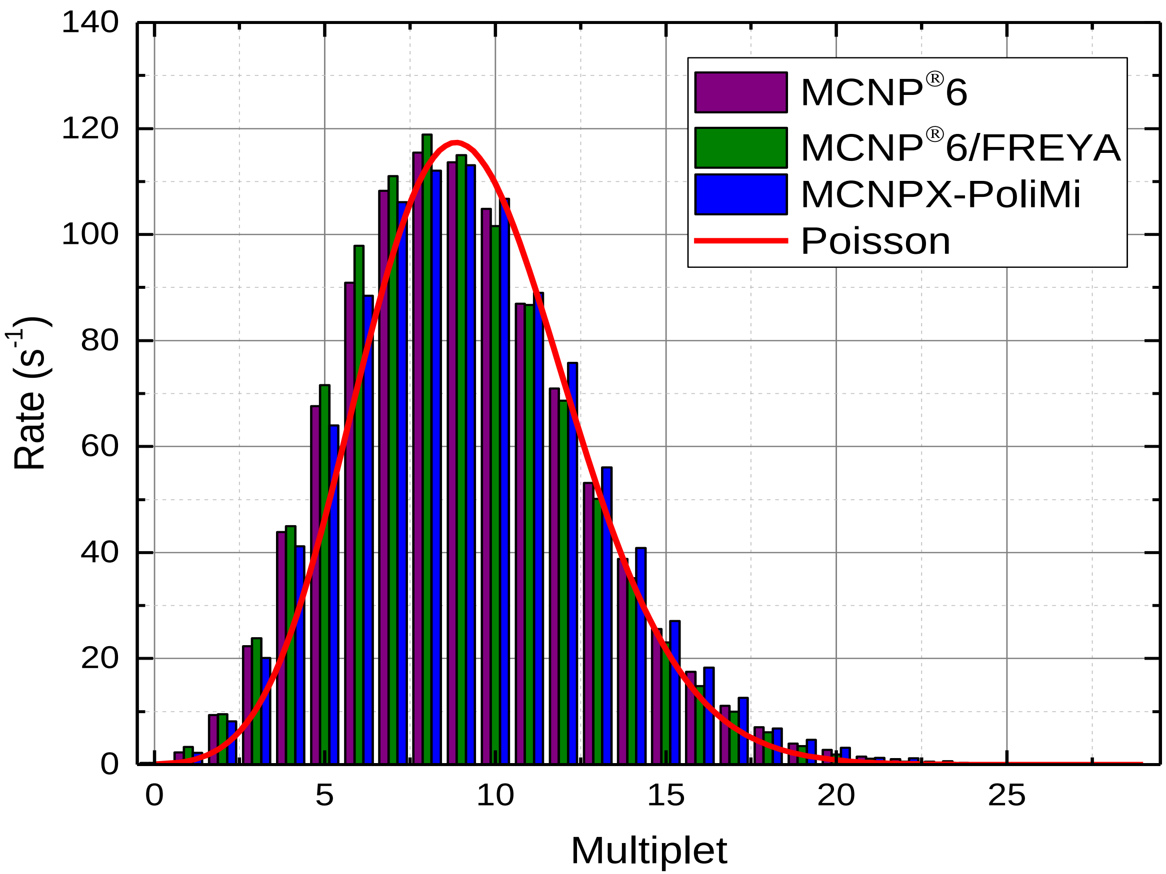

Fig. 7. Comparison of Feynman histograms at 1000 μs time width.

Singles/doubles rates

- R_1 and R_2 from MCNP®6 and MCNPX-PoliMi are within 2-4% of the measured results
- MCNP®6/FREYA R_1 show <1% deviation
  - Doubles show 10% deviation.

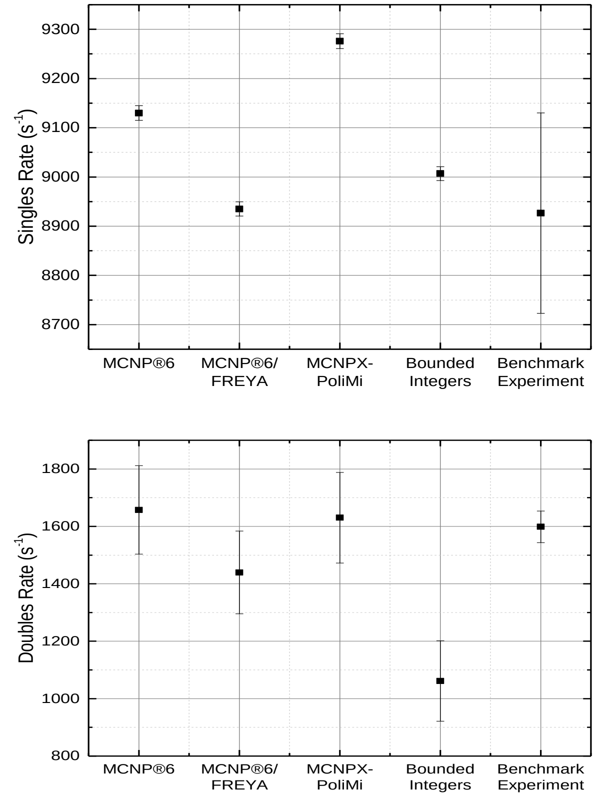

Fig. 5. Singles and doubles rates at 1000 μs plotted alongside both the benchmark measured results and MCNP®6 default bounded integer treatment.

CONCLUSIONS

Comparisons

Conclusions

- **Preliminary comparisons of correlated physics Monte Carlo codes show similar performance**
- **Discrepancies in correlated neutron results are more pronounced when discrepancies exist in the multiplicity distributions used**
- **Future work:**
  - Investigate other MC codes with correlated physics of fission (CGMF)
  - Input multiplicity distributions from other codes into MCNP®6

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References

1. C. WAGEMANS, *The Nuclear Fission Process*, CRC Press, Boca Raton (1991).
2. J.T. GOORLEY et. al., “Initial MCNP6 Release Overview,” *Nuclear Technology*, 180, 298-315 (2012).
3. C. HAGMANN et. al., “FREYA—A New Monte Carlo Code for Improved Modeling of Fission Chains,” *IEEE Transactions on Nucl. Sci.*, 60, 545-549 (2013).
4. M.E. RISING et. al., “Correlated Neutron and Gamma-Ray Emissions in MCNP6,” LA-UR-14-24979 (2014).
5. S. A. POZZI et. al., “MCNPX-PoliMi for Nuclear Nonproliferation Applications,” *Nuclear Instruments and Methods in Physics Research Section A*, 694, 119-125 (2012).
6. B. RICHARD et. al., “Nickel-Reflected Plutonium-Metal-Sphere Subcritical Measurements,” International Handbook of Evaluated Criticality Safety Benchmark Experiments, NEA/NSC/DOC/(95)03/I, FUND-NCERC-PU-HE3-MULT-001.
7. M. SMITH-NELSON, “Momentum: version 0.36.3,” LANL Software, March 29, 2015.
8. J. HUTCHINSON et. al., “Estimation of Uncertainties for Subcritical Benchmark Measurements,” ICNC 2015, Charlotte NC, 2015.
9. J.P. LESTONE, “Energy and Isotope Dependence of Neutron Multiplicity Distributions,” LA-UR-05-0288.
10. P. SANTI, M. MILLER, “Reevaluation of Prompt Neutron Emission Multiplicity Distributions for Spontaneous Fission,” *Nucl. Sci. and Eng.,* 160, 190-199 (2008).
11. J. TERRELL, “Distributions of Fission Neutron Numbers,” *Physical Review,* 108, 783-789 (1957).