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Title: Correlated Neutron and Gamma-Ray Emissions in MCNP6

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Correlated Neutron and Gamma-ray Emissions in MCNP6

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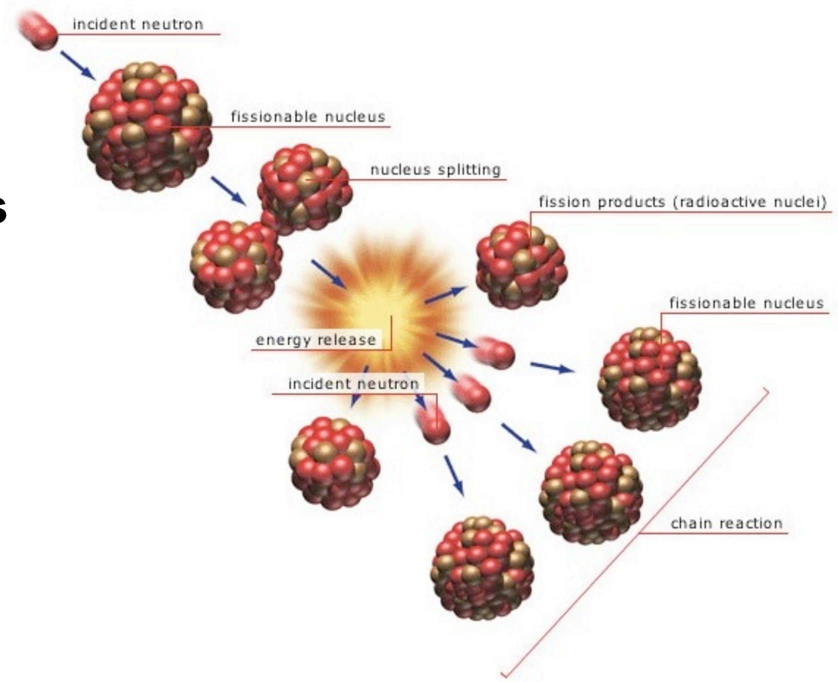
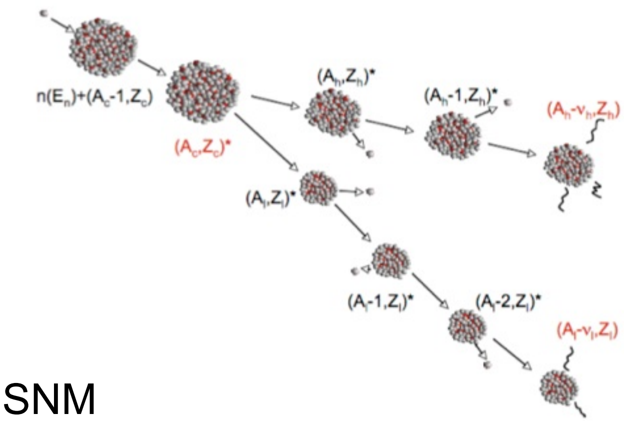


Introduction

- **Application of interest**
  - Global security and nuclear nonproliferation
  - Detection of special nuclear material (SNM)
  - Warhead measurement campaign (WMC)
  - Passive and active interrogation techniques
  - Coincident neutron and photon leakage



- **Key issues**
  - Average nuclear data quantities are insufficient
  - Cannot predict correlated signatures of shielded SNM
- **Approach to obtain predictive capability**
  - Use transport code MCNP for modeling neutrons and photons
  - Need microscopic fission event information
  - Fission event generators are under development
  - Implement in MCNP and compare to experiments

Background

- **In tabulated nuclear data libraries (i.e. ENDF/B-VII.1):**
  - Average secondary neutron and photon information can be available
    - Average multiplicity, $\bar{\nu}$
    - Average spectrum, $\chi(E)$
    - Average energy-angle spectrum, $\chi(E,\theta)$
  - Generally, high-dimensional distributions of secondary particles are unavailable
    - Multiplicity distribution, $P(\nu)$
    - Multiplicity-dependent emission spectra, $\chi(\nu,E)$
    - Multiplicity-dependent energy-angle emission spectra, $\chi(\nu,E,\theta)$
    - Neutron-neutron, neutron-photon and photon-photon correlations
    - Too much data to tabulate!
- **Default MCNP uses average quantities**
  - Consider this a nuclear data “variance reduction” technique
  - Good for integral quantities, like flux and effective multiplication
  - Bad for studying detailed particle emission physics

Secondary Particle Event Generators

MCNP6.1.1 contains two event generators:

- **LLNL Fission Library[1]**
  - Spontaneous, neutron-induced and photo-fission
  - Fission Reaction Event Yield Algorithm (FREYA)[2] isotopes:
    - Spontaneous: ^{238}U, ^{240}Pu, ^{244}Cm and ^{252}Cf
    - Neutron-induced: ^{233}U, ^{235}U and ^{239}Pu
  - When available, FREYA generates secondary neutrons and photons
- **Cascading Gamma-ray Multiplicity (CGM)[3] - LANL**
  - Generates secondary particles from a variety of reactions
  - No fission! (CGMF under active development)

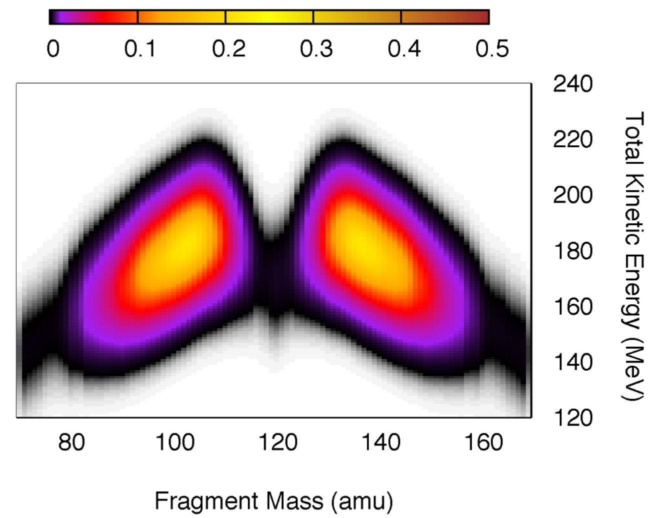
[1] J.M. Verbeke, C. Hagmann, and D. Wright, Lawrence Livermore National Laboratory, UCRL-AR-228518 (2014).

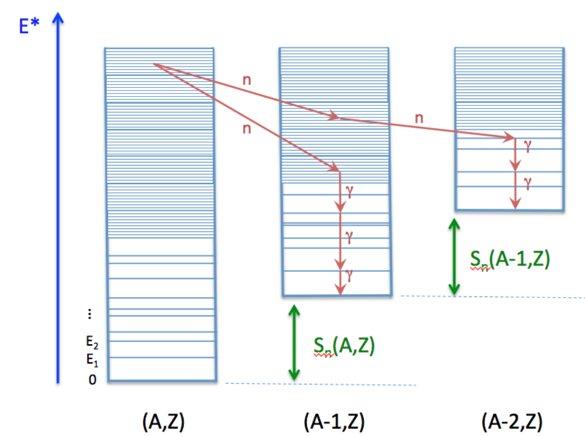
[2] R. Vogt and J. Randrup, *Phys. Rev. C*, vol. 84, pp. 044612-1-14 (2011).

[3] T. Kawano, P. Talou, M.B. Chadwick, and T. Watanabe, *J. Nucl. Sci. Tech.*, **47** (5), 462-69 (2010).

Secondary Particle Event Generators: CGMF

- CGMF is a superset of CGM with an added fission reaction capability
- Fission fragments are sampled from a joint probability distribution function of mass (A), charge (Z) and total kinetic energy (TKE)
- Uses Hauser-Feshbach statistical theory of nuclear reactions
- Neutron / photon competition is treated during evaporation from fission fragments
- Monte Carlo is used to sample each step in the de-excitation process

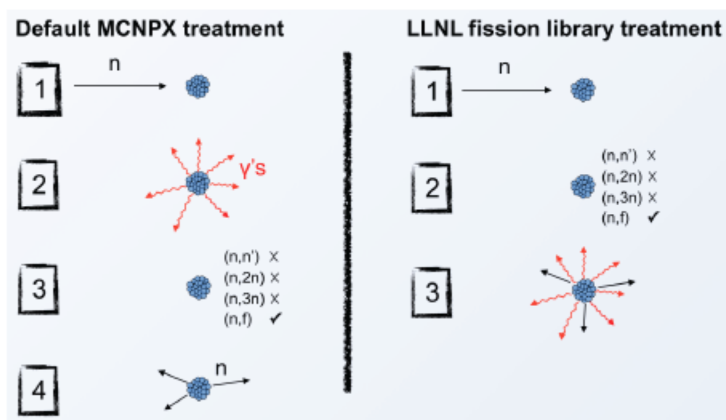




[4] B. Becker, P. Talou, T. Kawano, Y. Danon, and I. Stetcu, *Phys. Rev. C*, 87, 014617 (2013).

Secondary Particle Event Generators: FREYA

- **FREYA is LLNL's fission event generator**
- **In MCNP6, it is accessible through LLNL Fission Package**
- **The LLNL Fission Package includes more tabulated and fitted data used for lesser known isotopes FREYA can't presently handle**
- **FREYA uses a Monte Carlo Weisskopf approach**
  - Neutrons emitted by sampling from Weisskopf spectrum
  - After neutrons are done emitting, gamma rays are emitted from residual energy
- **Computationally more efficient than Monte Carlo Hauser-Feshbach**



Numerical Results

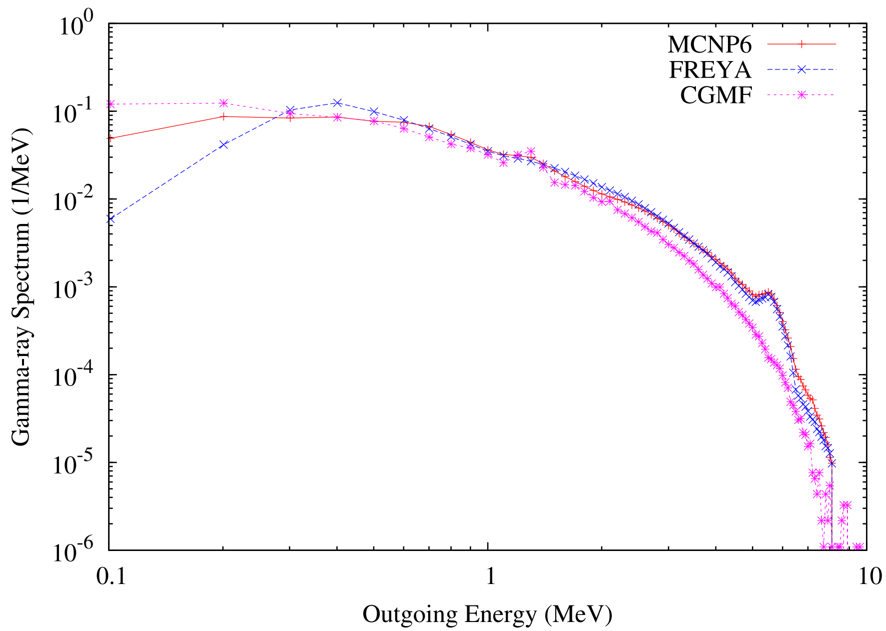
- **Implementation of CGMF into MCNP6 is underway**
- **Standalone and integrated code comparison needed for verification**
- **CGMF behavior is studied to understand trends and correlations**
- **Validation experiments will be needed to provide feedback to models**

- **For the following numerical results:**
  - CGMF results are based on standalone code
  - FREYA used through LLNL Fission Package in MCNP6
  - Default MCNP6 behavior is shown
- **Average energy, multiplicity and gamma ray spectrum**
- **Secondary gamma ray spectrum**

Numerical Results: Average Quantities

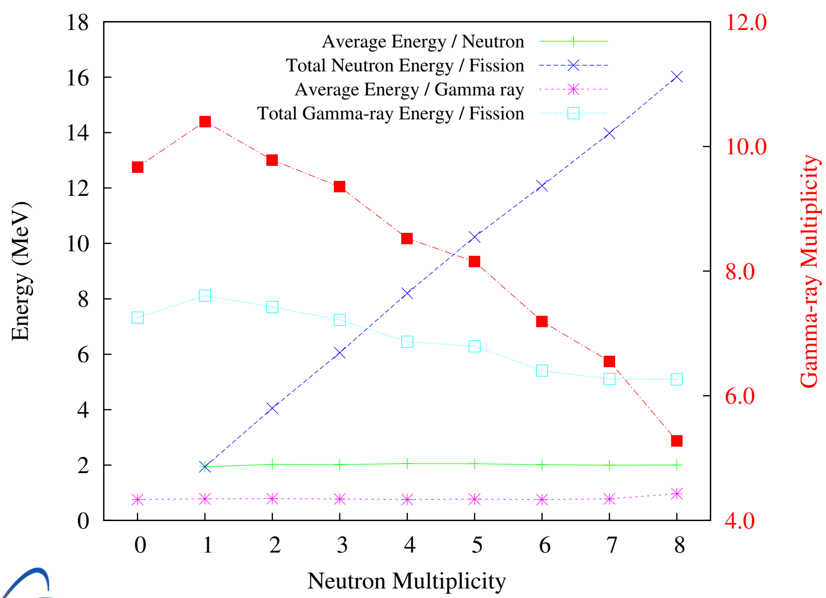
- **Thermal neutron incident on ^{239}Pu**
- **For MCNP6 and FREYA:**
  - Secondary neutrons from reaction (n,f)
  - Secondary gamma rays from (n,f), (n,γ), etc.
- **For CGMF (standalone):**
  - Secondary neutrons and gamma rays from (n,f) only
- **Discrepancies due to (n,γ):**
  - Multiplicity lower
  - Average energy higher
  - Peak at 5.5 MeV causes bump
- **Check again after integration**

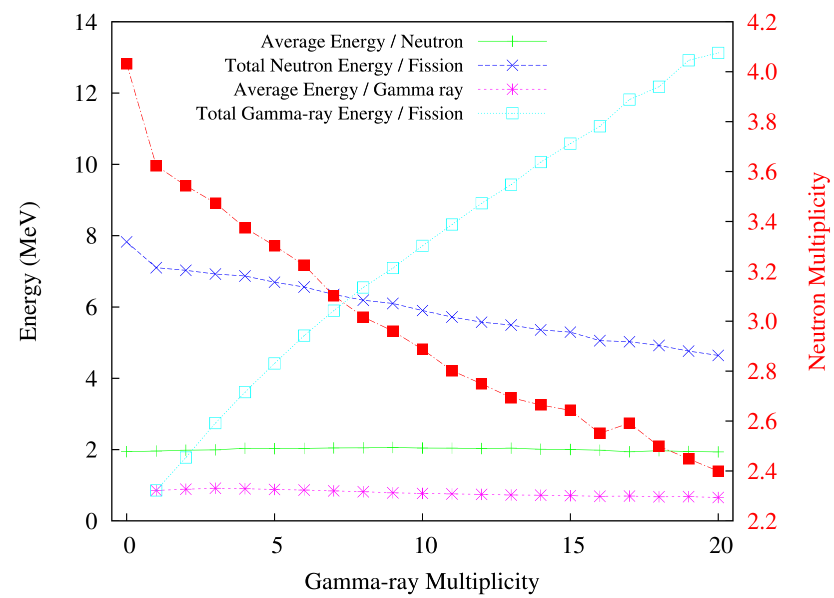
Quantity	MCNP6	FREYA	CGMF
$\bar{\nu}_N$	2.8725	2.8723	2.9764
$\bar{\nu}_\gamma$	2.0	7.2973	9.1797
$\langle E_N \rangle$ (MeV)	2.1034	2.0003	2.0327
$\langle E_\gamma \rangle$ (MeV)	0.9949	1.0327	0.7728



Numerical Results: Neutron and Gamma-ray Correlations

- **Neutron – gamma ray energy and multiplicity correlations**
- **Analyzing CGMF results for n(*th*)+^{239}Pu fission reaction**
- **Use to verify implementation into MCNP**
- **This physics needs to be validated with experiment**





Conclusions

- **Many applications are in need of high fidelity physics models**
- **Fission event generators are under active development**
- **When implemented in MCNP a predictive capability may be possible**
- **SNM signature detection with code validation will soon be possible**

- **Future work:**
  - Finish implementation and improvements to fission event generators in MCNP
  - Develop verification tests for all these new features
  - Need experimental measurements to compare against
  - Validate the new physics features with experiment
  - Compare against MCNP-PoliMi and other specialized codes

Questions?

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