Introduction and Motivation

Neutron fingerprinting by neutron multiplicity measurement
- Proven technique to establish unique signatures for tight identification of nuclear fuel composition; accountability and control of nuclear material at every stage of the fuel cycle
- Modeling and simulation: complements experiments, provides predictive capability
- Project goal is to develop hierarchy of numerical solution approaches
  - Lump or point kinetic models for rapid scopeing and estimation: Monte Carlo and deterministic
  - Full phase deterministic methods for more refined solutions energy and angle correlations
  - Monte Carlo for highly refined solutions and benchmarking (MCNP6, PoliMi)

Mission Relevance

Mitigating proliferation pathways through modeling and simulation advances to support nuclear material detection
- Expanding and making accessible to the community advances in predictive science capabilities in the nuclear security space
- Preparing future experts in nuclear security through pedagogy, defining and solving innovative research problems, and developing advanced technical skills in theory, modeling and simulation

Technical Approach & Results

Background

- Neutron Multiplicity Counting (NMC) is based on observing the statistical fluctuations of emitted neutrons as deviation from a Poisson distribution. Analysis of these deviations provides information pertaining to the fissile nuclear material of interest.
- Point Kinetic Model was considered – Spatial and Energy dependence have been ignored.
- Joint probability distribution \( P_{n,m}(t) \) was defined to study the number of neutron counts.

\[ P_{n,m}(t) = \text{The probability of } n \text{ neutron existing at time } t \text{ with } m \text{ neutrons being detected up to that time.} \]

Forward Master Equation

- The forward master equation is formulated by conducting a probability balance of all independent mutually exclusive interaction a neutron may undergo in a system

\[ \frac{d}{dt} P_{n,m}(t) = -(S + n\lambda_f)P_{n,m}(t) + S \sum_{j=0}^{m} \left[ \alpha_j(n+1-j)P_{n+1,m-j}(t) + \lambda_n P_{n+1,m}(t) + \lambda_{n+1}P_{n+1,m-1}(t) - \lambda_n P_{n+1,m-1}(t) \right] \]

Stochastic Simulation Algorithm (SSA) Monte Carlo

- From the probability balance above, an algorithm is derived to simulate the state of a system.
- The state of the system at time \( t \) is defined as \( [n, m, f, \ldots] \)

Algorithm:
- \( t \) = Sample time to event while \( t < 1/\lambda_{\text{max}} \)
- Sample which event occurred
- Change the state of the system
- \( t \leftarrow \) Sample time to next event

Deterministic Method

- A deterministic solution for the neutron number PDF was produced

\[ \frac{d}{dt} P_n(t) = -(S + n\lambda_f)P_n(t) + S \sum_{j=0}^{m} \left[ \alpha_j(n+1-j)P_{n+1,m-j}(t) + \lambda_n P_{n+1,m}(t) + \lambda_{n+1}P_{n+1,m-1}(t) - \lambda_n P_{n+1,m-1}(t) \right] \]

Expected Impact

- Provide a deeper understanding of the statistical uncertainties of radiation signals from weak sources

MTV Impact

- Create linkages with MTV partner universities through workshop participation
- Strengthen national lab connections in nuclear security areas through joint research and internship opportunities for undergraduate and graduate students

Conclusion

- The Stochastic Simulation Algorithm (SSA) Monte Carlo: versatile, memory and performance efficient for multiplicity simulations in lumped geometry
- Deterministic methods: orders of magnitude speedup potential

Next Steps

- Simulate conditions under which overlapping chains are important
- Further expand understanding of SSA performance and capability
- Add multigroup neutron energy dependence to SSA – benchmarks for later deterministic solution
- Shift focus of deterministic approach to backward Master equation formulation for external neutron count distributions

This work was funded in part by the Consortium for Monitoring, Technology, and Verification under Department of Energy National Nuclear Security Administration award number DE-NA0003920