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Project Title

Perturbation theory based data assimilation applied to neutron multiplicity counting experiments.

Project Objective

Perform perturbation theory based sensitivity analysis, uncertainty quantification, and parameter estimation applied to neutron multiplicity counting experiments to update prior estimates of the mean and uncertainty of nuclear cross sections.

Project Description

Data assimilation of nuclear cross sections is the process of updating prior estimates of their mean and uncertainty with new information. Data assimilation is currently performed using gross neutron counting experiments which has resulted in artificially inflated covariances and biases in expected values of some nuclear parameters, such as Pu-239 $\bar{\nu}$ [1]. Neutron multiplicity counting (NMC) experiments would be useful for data assimilation because each moment of the distribution is a function of the cross sections raised to a power denoted by that moment; consequently, calculations of higher order multiplicity moments are more sensitive to the nuclear parameters than the mean, which is equivalent to gross counting. Performing data assimilation using higher order moments of the NMC distribution would therefore lead to more precise estimates of cross sections mean and uncertainty.

Previous work by O'Brien developed perturbation theory-based sensitivity analysis (SA) derived from the stochastic neutron transport equation (STE) [2]. My research will extend O'Brien's SA into data assimilation utilizing uncertainty quantification (UQ) and parameter estimation (PE) of nuclear cross sections applied to NMC experiments. The data assimilation will be implemented by iterating over the SA, UQ, and PE steps and utilizing Bayesian inference to obtain a best estimate of the mean and uncertainty in the nuclear cross sections. Of interest is Kalman filtering because it is a natural application of Bayesian inference to data assimilation.

Project Relevance to Nuclear Nonproliferation

Mattingly et al [1] demonstrated that simulations of NMC experiments with a highly multiplicative source consistently over predict the measured NMC distribution
mean and variance. Inverse analysis methods that utilize the NMC distribution, such as the Feynman variance to mean technique, would therefore provide inaccurate estimates of source properties (e.g. neutron multiplication). A small (~1%) decrease in the nominal ENDF-B/VII Pu-239 $\bar{\nu}$ value resulted in better agreement between simulated and measured NMC distributions. Perturbation theory-based data assimilation will provide a novel method of adjusting the mean and reducing the uncertainty in nuclear cross sections, which will result in more accurate estimates of source properties.

Products and Outcomes of Project

My research will provide a novel method for data assimilation that utilizes NMC experiments to obtain more precise estimates of cross sections mean and uncertainty, which will improve agreement between simulated and measured NMC distributions. Consequently, estimates of source properties from inverse analysis
(e.g. neutron multiplication) will be more accurate.

Presentations

A. Clark, J. Mattingly and S. O. Brien, “Using Nonlinear Regression Analysis to Estimate Point Kinetic Parameters from Neutron Multiplicity Counting Experiments,” *Poster presentation, UITI*, Raleigh, 2016.

A. Clark, J. Mattingly and S. O. Brien, “Perturbation theory-based parameter estimation applied to neutron multiplicity counting experiments,” *Poster presentation, UPR*, Walnut Creek, 2017.

References

[1] J. Mattingly, "Polyethylene-Reflected Plutonium Metal Sphere: Subcritical Neutron and Gamma Measurements," SAND2009-5804, Albuquerque, 2009.

[2] S. O'Brien, "Sensitivity Analysis of Neutron Multiplicity Counting Statistics of a Subcritical Plutonium Benchmark using First-Order Perturbation Theory," Ph. D. thesis, North Carolina State University, Raleigh, 2016.