Sensitivity Analysis of Neutron Multiplicity Counting Statistics Using First Order Perturbation Theory for a Subcritical Plutonium Benchmark

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Abstract:

Neutron multiplicity counting measurements are a valuable tool for nonproliferation initiatives by enabling nondestructive detection of special nuclear material. It is important to estimate the uncertainty and sensitivity of measured and simulated detector responses of the neutron multiplicity counting distribution. These uncertainties arise from the physical construction of the experiment, from uncertainties in the transport parameters and from counting uncertainties. In particular, in subcritical experiments the detector response is geometrically sensitive to the fission neutron yield distribution. The detector response is an integral quantity and therefore perturbation theory is used to perform a complete sensitivity analysis and uncertainty quantification (SA/UQ) on the moments of the neutron multiplicity counting distribution. Current SA/UQ methods have only existed for the mean of the distribution. We apply perturbation theory to compute the sensitivity of neutron multiplicity counting moments to arbitrarily high order. Each moment is determined by solving an adjoint transport equation with a source term that is a function of the adjoint solutions for lower order moments. This enables moments of arbitrarily high order to be sequentially determined and shows that each moment is sensitive to the uncertainties of all lower order moments. We derive SA/UQ moment closing equations that are forward transport equations that are a function of the forward flux and lower order moment adjoint fluxes. We verify our calculations for the first two moments by comparison with multiplicity measurements of a subcritical plutonium metal sphere. We compute the first four moments of the multiplicity distribution and rank the sensitivity of the moments to nuclear data parameters. This work will enable a new method to adjust the evaluated values of nuclear parameters using subcritical neutron multiplicity counting experiments, and it enables a more detailed sensitivity and uncertainty analysis of subcritical multiplicity counting measurements of fissionable material.