Development of Computational Methods for Neutron Noise Analysis: Improving Modeling and Understanding of Perturbations in Light Water Reactors

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ABSTRACT:

The term neutron noise is used to describe the small time-dependent fluctuations around the average static flux in a nuclear reactor. Such time-dependent perturbations can arise due to a variety of perturbations, such as the vibrations of fuel and control rods, vibrations of the pressure vessel, and perturbations in the coolant temperature and density. These perturbations can pose hazards to reactor operation. One example would be fuel pin and assembly vibrations, which can cause fretting and potentially lead to failure of the cladding. Neutron noise can be observed in the signal of ex-core detector responses. In some cases, these perturbations in detector signals have forced plants to reduce power to avoid activation of the automatic scram system. Incidents such as these reduce reactor availability and can even force prolonged shutdowns for repairs. To maximize plant availability and prevent damage to the fuel, it is essential to be able to identify potentially problematic neutron noise signals. In order to solve this inverse problem, using the detector signals to isolate the type and location of the perturbation inducing the noise, it is necessary to be able to accurately simulate the spatial and energetic effects of the perturbation on the static neutron flux. As such, the objective of this project is to perform a multifaceted exploration of the current theoretical models of neutron noise, advancing the current state of the art for Monte Carlo simulations of neutron noise. The project will include the treatment of the following topics:

- Development of formulas and algorithms to sample the noise source for different types of perturbations in Monte Carlo solvers. This includes translational, cantilever, and bowing vibrations of fuel rods, vibrations of the pressure vessel, and perturbations in coolant temperature and density.
- Analysis of weight cancellation as a variance reduction technique for Monte Carlo neutron noise simulations. This will include the development of methods to define a cancellation mesh, to ensure the bias imposed by approximate weight cancellation has a minimal effect on simulation results.
- Verification of the validity of the canonical neutron noise equations in the frequency domain. Performing simulations of various perturbations in both the frequency and time domains, it is possible to evaluate the applicability of the approximations in the canonical noise equation. An analysis of the effects of thermohydraulic feedback on noise signals will be examined through simulations of vibrations in the time domain.
- Evaluation of the energy dependence of neutron noise, examining the effects of various perturbations in a continuous energy context.

The results of the project will improve the fidelity of the modeling of neutron noise in power reactors and will transform our understanding of various types of perturbations in light water reactors. The methods and tools which are developed in the project will help in the future detection of anomalous and problematic neutron noise signals, bettering reactor safety and reliability.