Investigation of Application Specific k_{eff} Sensitivities to Existing and New Subcritical and Critical Experiments

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INTRODUCTION

Integral subcritical and critical experiments are essential in providing validation of computational codes which improve confidence in the predicted k_{eff} results of specific applications. This work discusses the relevance of existing integral subcritical and critical experiments to applications far reaching across the nuclear complex. These applications include Travelling Wave Reactors (TWR), Kilopower Reactor Using Stirling Technology (KRUSTY), and plutonium reflected by tantalum. The primary goal of this work is to improve knowledge of energy-dependent cross-section sensitivities for specific applications, identify nuclear data gaps in existing experiments, enable an optimized design of new experiments to address these gaps, and design practical new experiments that could be executed at the National Criticality Experiments Research Center (NCERC) that have a high-value to these applications.

BACKGROUND

NCERC constructs hundreds of subcritical and critical configurations each year for a variety of sponsors. NCERC has four critical assembly machines. Planet and Comet are general purpose vertical assembly machines. Recent Planet and Comet experiments include uranium and plutonium systems with fast, intermediate, and thermal spectra. Flat Top is a fixed-geometry machine with an HEU or Pu core reflected by natural uranium, and Godiva-IV is a fast-pulse critical assembly machine.

The subcritical and critical experiments that are conducted at NCERC and other facilities across the United States and international nuclear complex may be included as benchmarks for validation purposes. If these experiments are recommended for benchmark inclusion, then they are documented in the International Criticality Safety Benchmark Evaluation Project (ICSBEP) and the International Reactor Physics Experiment Evaluation Project (IRPhEP).

In nuclear criticality safety, the Upper Subcritical Limit (USL) is used as the upper value of k_{eff} during the analysis of the normal and abnormal process conditions. In order to determine this USL value, LANL has developed Whisper[1]. This program compares an application's k_{eff} sensitivity/uncertainty and nuclear covariance data to that of the 1101 benchmark critical experiments from the ICSBEP. The emphasis of this work is not on the USL capabilities of Whisper, but rather utilizing Whisper's ability to determine which benchmarks, from a large suite of benchmarks, are highly correlated (C_k) to a specific application.

PROCESS

The standard Whisper 1101 benchmark suite taken from the ICSBEP was expanded to include recent subcritical experiments conducted at NCERC and IRPhEP experiments that do not have an ICSBEP counterpart. Additionally, potential new experiments, determined via Bayesian optimization, that were postulated to have a high correlation to the specific applications were added to the Whisper benchmark suite in an iterative process. The focus of this work is on specific applications that show high energy-dependent k_{eff} cross-section sensitivities in a regime where there are known nuclear data gaps in existing experiments.

Data processing and manipulation scripts were created to process and interpret the k_{eff} sensitivity/uncertainty data produced from MCNP®6.2 calculations using ENDF/B-VII.I[2] cross-sections of the specific applications and highly correlated existing and new-postulated experiments.

RESULTS

The TWR specific application utilizes a sodium coolant channel and has a high positive k_{eff} sensitivity to elastic scattering of ^{23}Na in the intermediate and fast spectrum of which only ^{235}U and ^{238}U have a higher positive k_{eff} sensitivity. Few benchmarks sensitive to ^{23}Na exist in the default Whisper benchmark suite. The addition of IEU-COMP-FAST-004-001[3] and BFS2-FUND-EXP-001-001[4] to the benchmark suite show a C_k obtained using Whisper of 0.9924 and 0.9847, an increase of 0.0657 and 0.058, respectively, over the highest correlated benchmark experiment from the default Whisper benchmark suite. IEU-COMP-FAST-004-001[3] is ZPR-3 Assembly 12 which contains similar ^{235}U and ^{238}U k_{eff} sensitivities to that of the TWR application. BFS2-FUND-EXP-001-001[4] being the BFS-31 critical configuration performed on BFS-2 contains combinations of plutonium metal and depleted uranium dioxide with sodium pellets and contains similar ^{23}Na elastic scatter k_{eff} sensitivities in the intermediate and fast spectrum

The Kilopower specific application utilizes enriched uranium surrounded by beryllium-oxide of which there are few benchmarks in the default suite that contains beryllium-oxide. This application has a high positive k_{eff} sensitivity to elastic scattering of ^{9}Be in the intermediate and fast spectrum and n,2n of ^{9}Be in the fast spectrum. The KRUSTY critical experiment was recently conducted at

NCERC as a proof of concept test of the Kilopower reactor. The KRUSTY critical experiment was added to the benchmark suite and showed a high C_k of 0.9976 to the Kilopower reactor, which was as expected.

Plutonium reflected by tantalum shows a high k_{eff} sensitivity to elastic and inelastic scattering of ^{181}Ta, however the default benchmark suite doesn't provide adequate benchmark coverage for this configuration. However, the inclusion of multiple experiments to the benchmark suite still showed a distinct lack of experiments that have a similar k_{eff} sensitivity to ^{181}Ta. Therefore, for future work, this specific application will be a candidate for designing a potentially new experiment determined via Bayesian optimization to have similar k_{eff} sensitivity to ^{181}Ta.

It has been shown that expansion of the 1101 default criticality benchmark suite utilized by Whisper and obtained from ICSBEP can improve the knowledge of energy-dependent cross-section sensitivities for specific applications and emphasize nuclear data gaps in existing experiments.

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