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Impact of Higher Fidelity Design Iterations on Critical System Criteria

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20 – 25 Minutes
Application and Experimental Design

Nuclear criticality experiments are effective at informing the performance of nuclear data libraries across many applications. This work explores the implications of refining critical experiment MCNP [1] models from their low fidelity optimization phase to penultimate neutronic models. Specifically, this work is focused on two series of plutonium fueled experiments funded through internal programs at Los Alamos National Laboratory building off previous efforts under the EUCLID (Experiments Underpinned by Computational Learning for Improvements in Nuclear Data) [2] collaboration. Thales, the first of the two collaborations, is a fast spectrum Ta-reflected plutonium experiment to support operations at PF-4. The second experiment are twin configurations designed to target the intermediate energy cross sections in ^{239}Pu. Motivation for this experiment stems from the PARallel Approach of Differential and InteGral Measurements (PARADIGM) collaboration which hopes to achieve a significant reduction in ^{239}Pu cross section uncertainties in the intermediate region.

Both experiment campaigns were initially optimized with low fidelity models. PARADIGM employed a genetic algorithm built in Python [3] and Thales used an expert-in-the-loop design process with Bayesian D-Optimization [4]. These were set to find material and geometric configurations that would yield high sensitivities to the desired application as well as being near critical. From this stage, higher fidelity geometries for fuel forms, reflectors, and membranes are added to the low fidelity models. Normally, the transition from low to high fidelity model involves a lower k_{eff} than initially started with. This can be compensated for by providing additional fuel layers if they are still within the confines of the experimental assemblies, if not then a redesign may be necessary. After sufficient reactivity has been added to the system again, incorporation of engineering fixtures and air gaps for machining tolerances are included. The sensitivities of the experimental design to a given cross section tend to stay relatively constant when the ratio of material to fuel is maintained. If higher fidelity models deviated significantly from the low fidelity in terms of moderator-to-fuel or reflector-to-fuel ratios then the sensitivities changed on the order of 10% or more.

In all, the work highlights both the strength of low-fidelity optimization as a tool for designing application specific experiments as well as the need for high-fidelity iterations to incorporate mechanical engineering aspects.

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Thompson, S. Vander Wiel, and N. Wynne, "EUCLID: A New Approach to Constrain Nuclear Data via Optimized Validation Experiments using Machine Learning," EPJ Web of Conf., 284, 15006 (2023).
[3] N. Kleedtke, M. Hua, and S. Pozzi, "Genetic algorithm optimization of tin–copper graded shielding for improved plutonium safeguards measurements," Nuclear Instruments and Methods in Physics Research Section A: Accelerators, Spectrometers, Detectors and Associated Equipment, 988, 164877 (2021)
[4] I. Michaud, M. Grosskopf, J. Hutchinson, and S. Vander Wiel, "Expert-in-the-loop design of integral nuclear data experiments", Stat. Anal. Data Min.: ASA DataSci. J. 17 (2024), e11677. https://doi.org/10.1002/sam.1167719321872, 2024,