Development of a Research Reactor Protocol for Neutron Multiplication Measurements

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INTRODUCTION

Establishing a protocol for measurements on research reactors is the next step in advanced subcritical neutron multiplication inference measurements. Such measurements can help identify deficiencies[1] and quantify uncertainties in nuclear data and validate predictive Monte Carlo radiation transport simulation capabilities related to subcritical neutron multiplication inference techniques. This work expands on previous benchmark-quality efforts [10] performed at the National Criticality Experiments Research Center (NCERC) located in Nevada, including subcritical experiments with a 4.5-kg α-phase plutonium sphere surrounded by copper [11], tungsten [12] and nickel [13]. Evaluations of the nickel and tungsten measurements have both been accepted into the International Criticality Safety Benchmark Evaluation Project (ICSBEP) Handbook [14]. The nickel benchmark was the first ICSBEP-accepted evaluation of measurements using the Feynman Variance-to-Mean method based on the Hage-Cifarelli formulism [15], and was the culmination of many years of subcritical experiment research.

To help establish a protocol for research reactor-based subcritical measurements, a series of Critical and Subcritical Ø-Power Experiments at Rensselaer (CaSPER) have been designed. This neutron multiplication measurement series will be executed at the Rensselaer Polytechnic Institute Walthousen Reactor Critical Facility (RPI-RCF) in upstate New York. The RPI reactor facility can provide benchmark-quality integral experimental configurations where different reactivity states can be achieved by varying the control rod height/water height in the reactor. The diversity of achievable configurations are also unique in contrast to previous subcritical benchmark measurements in that they are spatially complex, involve different materials (fuel, moderator), and are characterized by system-specific neutron cross section sensitivities (various energy ranges and neutron reaction contributions). It is worth noting that previous proof-of-concept subcritical measurements [16] have been performed on thermal systems at NCERC, at a variety of reactivity states by separation distance, yet it was not possible to know the reactivity of various configurations accurately for benchmarking (there are no control rod worth curves as there are no control rods).

[1] Deficiencies in quantities such as ^{239}Pu nubar have been widely reported to have an effect on inferred values from subcritical measurements [1-9].

EXPERIMENT DESIGN

The CaSPER measurements at the RPI-RCF have been designed to include five configurations at various reactivity states ranging from subcritical to above delayed critical. The configurations will be achieved by varying the control rod and water heights in the reactor core which is currently fueled with SPERT (F-1) fuel pins having 4.81 wt% enriched UO_2 pellets. The reactor tank has enough room to fit the standard LANL ^{3}He portable neutron multiplicity detector systems which were retrofitted for water submersion. A photograph of the reactor and a simplified rendering of the detector and experimental configuration is shown in Fig. 1.

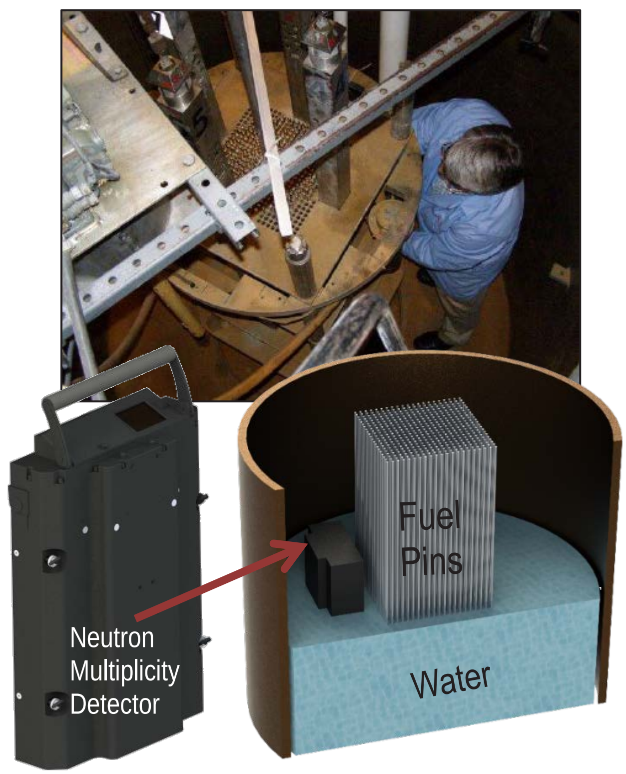

Fig. 1. Photograph of the RPI-RCF (*above*), and a Solidworks® simplified graphic rendering of the CaSPER measurement campaign at the RPI-RCF (*below*).

The final experiment design included Monte Carlo simulations of the full system: neutron multiplicity detector, ^{252}Cf starter source which is required to increase the number of fissions and associated count rate for statistical adequacy, and the reactor configuration (fuel/rods/water). The simulations were also adopted for the required experimental safety analysis.

RESULTS

The CaSPER experiments will include subcritical configurations with a measured multiplication of one, up to delayed critical. Fig. 2 and Fig. 3 show the results of preliminary simulations with MCNP®6 [17] calculating the reactivity worth curves of the RPI-RCF control rods.

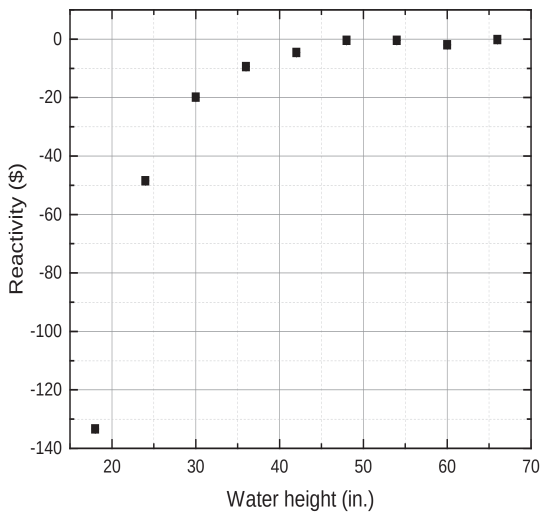

Fig. 2. Simulated reactivity worth curves for the RPI-RCF water height starting from the bottom of the fuel region.

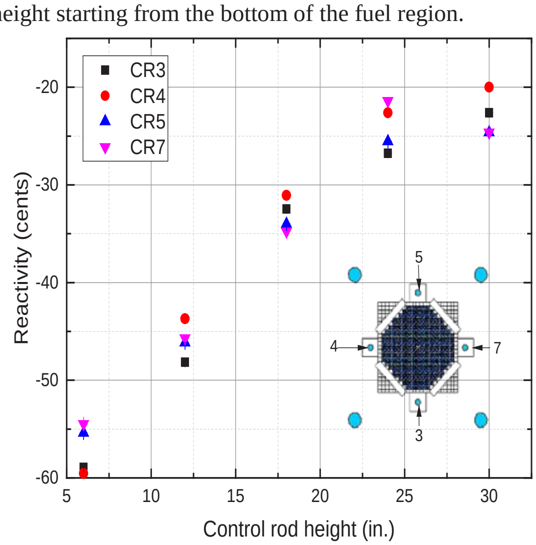

Fig. 3. Simulated reactivity worth curves for the RPI-RCF control rods. The simulation geometry is also included. The simulated curves will be compared to experimental control rod worth curves of the proposed configuration after the experiment is conducted.

MCNP®6 was also used to determine an optimal measurement configuration: neutron multiplicity detector placement, ^{252}Cf source strength, and ^{252}Cf source position. The neutron multiplicity detector employs a data acquisition system that produces time-correlated neutron list-mode data (timestamp of each registered event) which is binned into Feynman histograms to obtain "singles" (total detector count rate) and "doubles" (two detected neutrons from the same fission chain). The goal was to determine a configuration with a neutron singles rate of 10^3-10^5 s^{-1} and an acceptable fit of neutron doubles rate versus gate width as exemplified in Fig. 3. The final optimized CaSPER measurement configuration was determined to require a 10^5 n/s ^{252}Cf source at the center position with the portable neutron multiplicity detector positioned 35 cm away based on fits at various distances. Actual measurements will likely be performed at a slightly further distance due to the actual physical contraisnts within the reactor tank.

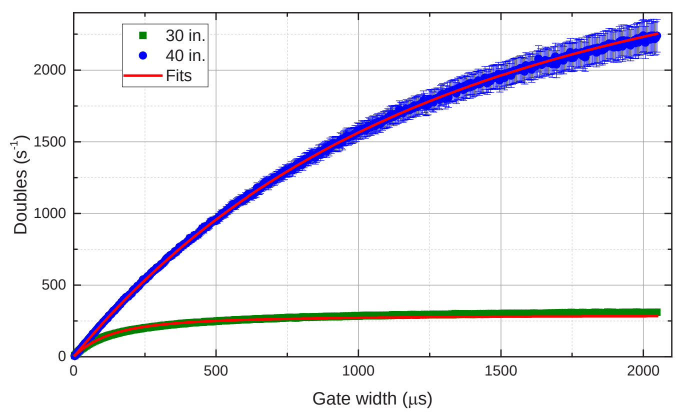

Fig. 4. Sample doubles fits from the LANL ^{3}He neutron multiplicity detector at different simulated water heights. Simulations were performed w/MCNP®6, and the fits were generated using Origin®.

FUTURE WORK

Execution, analysis and documentation of the measured configurations are planned. Similar to past work, the measured results will be compared to both control rod worth curves and Monte Carlo simulations for these uniquely diverse (mass, spatial, spectral) subcritical configurations.

Additional future work will explore fixed-source sensitivity and uncertainty radiation transport capabilities for subcritical measured and inferred quantities (singles, doubles, and multiplication), coupled with an attempt at performing full-scale nuclear data and physical uncertainty propagation.

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