Rossi-alpha Analysis of CURIE Experiment

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INTRODUCTION

Critical assembly measurement and operations are crucial to the development of benchmark data to support research into criticality safety, radiation-detection development, and the overall application of nuclear technologies. Accurate nuclear data are needed for accurate predictive simulations, and validation using critical experiments is an important part of the nuclear data pipeline. The accuracy of nuclear data are improved using more robust and targeted measurements. In particular, the intermediate energy range of uranium is of great interest. LANL has successfully performed the Zeus series of experiments on the Comet assembly [1] to investigate the intermediate energy range for HEU with various moderators [2–7]. A successor to these experiments is the benchmark for the Critical Unresolved Region Integral Experiment (CURIE), designed to be sensitive to the unresolved resonance region (URR). This experiment is designed using polytetrafluoroethylene, more commonly known as Teflon, moderators. The CURIE experiment was successfully conducted at the National Criticality Experiments Research Center (NCERC).

The Rossi-alpha method was used to evaluate the propensity of the CURIE configurations to sustain fission chains by estimating the prompt neutron decay constant α [8–10]. This work evaluates the α at delayed critical using Rossi-alpha for different Teflon moderator thicknesses in the CURIE experiment. These results will help improve understanding of the CURIE benchmark experiments.

Rossi-alpha

Rossi-alpha measurements utilize histograms of the time differences of neutron detections to evaluate the prompt neutron decay constant, α, from correlated (fission) and uncorrelated (background, room return, etc) neutron counting events. The prompt neutron decay constant is a property of a system's criticality that allows us to evaluate the reactivity, ρ, and effective multiplication factor, k_{eff} [8–11].

Figure 1 demonstrates how the histogram is fit to a single exponential equation,

$$f(t) = Ae^{-\alpha t} + B \tag{1}$$

where the t corresponds to the time-difference bins and α is one of the fit parameters. The value of α and the associated error were calculated for each corresponding configuration.

The prompt neutron decay constant, α_{DC}, was determined from several subcritical configurations. An extrapolation of α [12] as a function of inverse count rate is used to infer α_{DC} as shown in Figure 4. Where the value of α at an inverse count rate of zero corresponds to the α_{DC} because the count rate at critical approaches infinity.

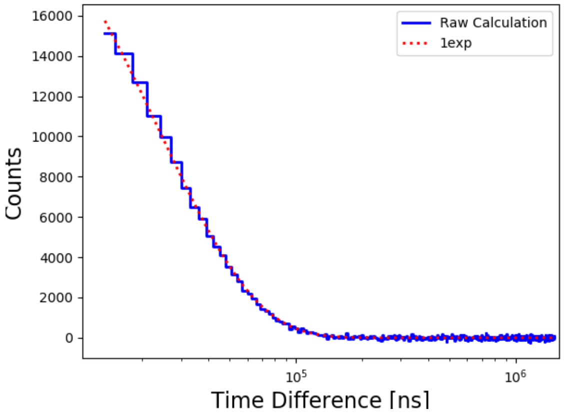

Fig. 1. Sample Rossi-alpha plot with single exponential fit

EXPERIMENT

The use of Teflon to target the URR was determined via a genetic algorithm using MCNP simulations to maximize sensitivity to U235 fission in the URR region [13]. The thicknesses of Teflon selected to target the URR include systems between 5/8" and 9/8" in 1/8" increments. Rossi-α measurements were taken on configurations with 5/8", 7/8", and 9/8" Teflon moderators. The experiment was split into two subcritical cylindrical portions. An upper stationary core and a lower moving portion. The lower portion of the core has a hollow aluminum alignment rod where the detectors to perform these measurements are placed. The upper portion of the core is surrounded by a thick copper reflector and contains a cylindrical void for the lower portion of the core to fill. When inserted, the lower portion approaches the stationary upper portion of the core, and becomes encased in the thick copper reflector. Each portion of the core consists of fissile material units surrounded by Teflon moderators. A unit consists of two Teflon plates sandwiching an HEU Jemima plate. To build the core, several units were stacked. A full-stack for the lower portion of the 7/8" CURIE core is shown in Figure 2

The temporal events were recorded with 4 bare ^{3}He detectors pressurized to 40 atm. The tubes were arranged inside the aluminum alignment tube as shown in figure 3, placing it very close to the center of the system. The detection system includes data acquisition using an Advanced List-Mode Module (ALMM). The ALMM, developed at LANL, produces a time-list and channel number of each recorded event with a precision of 100 ns (which is much faster than needed for all ^{3}He systems).

Rossi-α measurements were performed at three subcritical separation distances for each CURIE configuration. Each subcritical separation distance was measured five times, to-

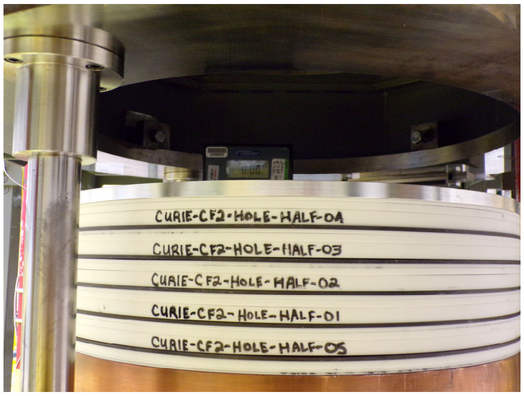

Fig. 2. Bottom portion of the core loaded with 7/8" Teflon

taling 15 measurements for each Teflon thickness. Delayed critical and super-critical scenarios were also measured, but will not be addressed in this work.

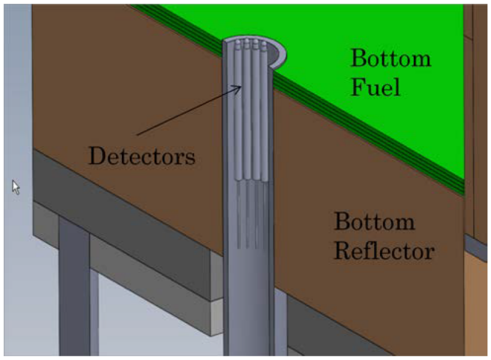

Fig. 3. CURIE configuration with four bare ^{3}He detectors placed inside the alignment tube [12]

PRELIMINARY RESULTS AND ANALYSIS

Rossi-alpha analysis is underway for each measurement. Preliminary results from the 5/8" configuration are shown here. The calculated alpha and inverse count rates were averaged for each configuration. Standard deviation was determined from the differences in a set of measurements. The averaged values for 5/8" Teflon were plotted as shown in Figure 4, where α is a function of inverse count rate, and α approaches delayed critical as the inverse count rate approaches zero. α_{DC} was determined from the y-intercept of the linear regression. Table I lists the experimentally determined values of α_{DC} as well as simulated in Monte Carlo N-Particle Transport Code (MCNP$^{®}$) Code Version 6.2[1] [14]. Note that further needs to be completed for configurations beyond 5/8". With further work, a more complete representation of the effects of Teflon as a moderator can be known.

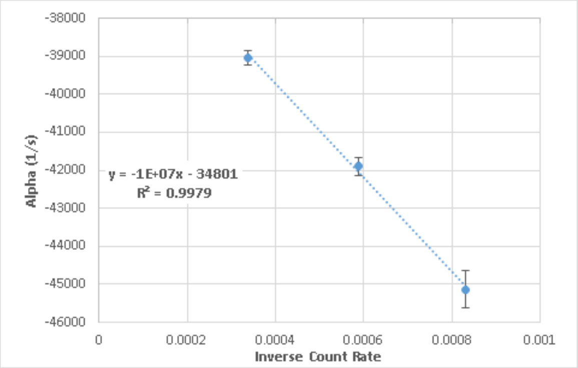

Fig. 4. Extrapolation to α_{DC} for 5/8" Teflon configuration

TABLE I. Comparison of simulated and experimental values of alpha at delayed critical

Configuration	**Simulated α_{DC} (s^{-1})**	**Experimental α_{DC} (s^{-1})**
5/8" Teflon	-41290.00 ± 87.02	-34801 ± 347.30
7/8" Teflon	-27739.70 ± 58.33	TBD
9/8" Teflon	-21977.90 ± 46.16	TBD

CONCLUSION

The CURIE integral experiment was conducted at NCERC to investigate the URR in uranium. Teflon was the moderator chosen to target the URR, determined via a genetic algorithm [13]. This work focused on the Rossi-α measurements of the assembly's approach to critical using ^{3}He detectors to evaluate the neutron population at various configurations to estimate the prompt neutron decay constant at delayed critical. The recorded events were analyzed using the time-dependent neutron noise technique Rossi-alpha to determine the prompt neutron decay constant α. The α values of several subcritical measurements were then used to predict the α value at delayed critical using linear regression. This was repeated for different configurations of the CURIE experiment.

This work builds on previous work demonstrating that the approach to delayed critical can predict the α_{DC} from more subcritical measurements. Specifically, this work provides validation for the need analyze gaps in our models for materials like Teflon. Simulations predicted a harder neutron spectrum than what was measured. Extrapolation allows dependable predictions while minimizing the threat of a criticality accident.

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