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ROSSI-ALPHA FOR A THERMAL SYSTEM: COMPARISON OF EXPERIMENT AND CALCULATION

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INTRODUCTION

The measurement of subcritical reactivity has become an expanding area of research in the past several years. This interest is due in part to the desire to build accelerator driven reactor systems that operate below critical using the neutron multiplication of the system to increase the total neutron flux from the accelerator. Measuring the reactivity of this type of system presents some challenges because it falls between reactor measurements and conventional subcritical measurements.

Reactivity for operating reactor systems is measured by calibrations performed above delayed critical and extrapolated to the region below critical. Only values near critical are accurate. Conventional subcritical techniques, on the other hand, rely on assumptions that render them inaccurate for measurements near critical. As the system nears critical, the associated uncertainty rapidly increases.

The Rossi-α measurement technique works well near critical, and this paper attempts to examine the extent of its applicability in the subcritical regime. This study experimentally determines α for a thermal system of polyethylene and HEU and compares it to the value calculated by the MCNP®[1] kopts card. Polyethylene and uranium systems are often used to represent a solution of uranium dissolved in acid. The neutron lifetime and average neutron energies are similar. The fuel foils consist of thin highly enriched uranium (93 wt% ^{235}U) metal foils laminated in plastic. Each foil weighs approximately 68 grams. The fuel is interleaved with polyethylene plates to attain a critical configuration. The system, commonly referred to as the "class foils," is shown in Fig. 1.[1] The critical configuration requires ~ 14.5 fuel foils.

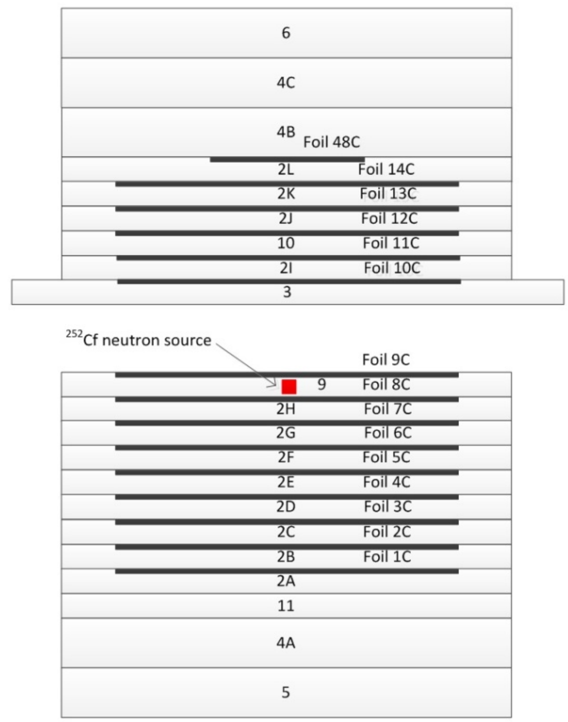

Fig. 1. Polyethylene class foils experiment.

ROSSI ALPHA TECHNIQUE

The Rossi-α measurement technique directly determines the prompt neutron decay constant in a fissioning system at or near delayed critical [2]. The Rossi-α measurement technique utilizes the fact that neutrons in a fission system occur in chains and not as random emissions.

The performance of the Rossi-α measurement technique relies heavily on the distinction between correlated and uncorrelated neutrons [4]. Correlated neutrons are those that occur as a result of fissions in a single chain. Uncorrelated neutrons consist of all other random sources of neutrons including neutrons from other fission chains or other sources. Additionally, it is important to make the distinction between prompt and delayed neutrons. Prompt neutrons are those released as a direct result of fission, and can be measured approximately a few nanoseconds after the start of the fission process. Delayed neutrons are released on the order of milliseconds to seconds after a fission event as a result of fission fragments decaying. Because delayed neutrons

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provide little insight into the time-dependent behavior of the fission process, they are lumped into the uncorrelated random source term.

The experiment is designed to measure the time correlation between neutron counting events. A time tagging system such as the LANL custom designed List-mode module is used to record the time a pulse occurred [3]. The system consists of standard NIM equipment and was built using the schematic shown in Fig. 2.

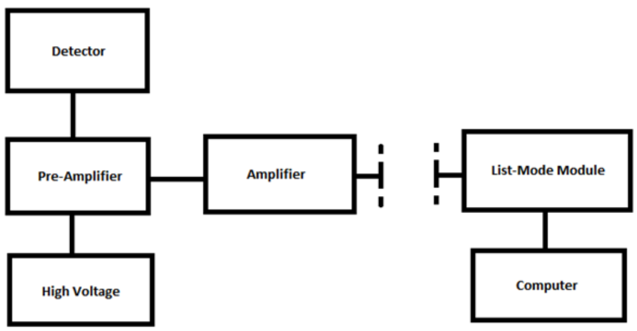

Fig. 2. Rossi-α detection system schematic.

The Rossi-α technique assumes a fission occurred at some time t_0, and produced a neutron pulse detected by the measurement system at time t_1 [4], often referred to as the initiating event. Then, the probability that another neutron will be incident on the detector in a given Δt after the initiating event is considered. The probability that a second neutron pulse occurs can be given as the sum of the probability that a random neutron pulse is incident on the detection system and the probability that a correlated neutron is incident on the detection system. This probability is given by,

$$p(t)\Delta t = A\Delta t + Be^{\alpha t}\Delta t$$

where the first term $A\Delta t$ consists of all uncorrelated potential sources for the origin of the neutron and the second term $Be^{\alpha t}\Delta t$ consists of only correlated neutrons [2]. The prompt neutron population in a subcritical system decays exponentially on average, so the probability of detecting a correlated event also decays exponentially with time. The prompt neutron decay constant defines the rate of this exponential decline in a subcritical system; the behavior is modeled by $e^{\alpha t}$ [4]. Thus the probability of the second neutron pulse being a correlated prompt neutron can then be written as $Be^{\alpha t}$ [2]. B is the maximum correlated neutron count and α is the prompt neutron decay constant. During the analysis of the data, the time between individual neutron pulses is determined and used to generate a histogram. This histogram is then fit to determine the prompt neutron decay constant.

The Rossi-α measurement technique is a convenient and precise method to calibrate reactivity without the use of the Inhour relation. The technique requires that several measurements are performed at different subcritical levels. These subcritical measurements are plotted against the inverse of the system count rate during the respective measurements. The value of the prompt neutron decay constant at DC, Rossi-α, is given by the y-intercept of a linear fit of the plot of subcritical data.

Plotting the value of alpha at delayed critical (reactivity=0) and plotting a point for prompt critical (alpha = 0 at reactivity = $1 allows a line to be drawn that can be extrapolated to determine the reactivity of any subcritical case. Using these definitions, the reactivity of other positions can be calculated using linear interpolation [5]. An example of this his method is shown for the Godiva IV assembly in Fig. 3.

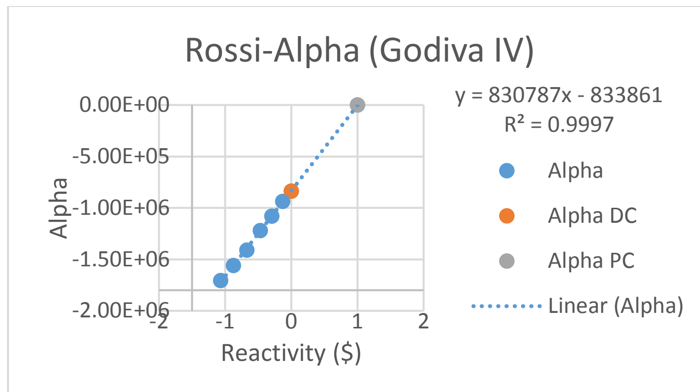

Fig. 3. Extrapolation of the Rossi-alpha for Godiva IV created using simulations.

The prompt neutron decay constant measured at DC is often used for comparison purposes to classify the hardness of the neutron spectrum produced in an assembly. For example, SHEBA II, an aqueous, homogeneous, solution reactor, with an extremely thermal neutron spectrum had a measured prompt neutron decay constant of $\alpha = -200\ s^{-1}$ at DC [6]. Alternatively, a fast system such as Lady Godiva, a spherical metal uranium system, had a measured prompt neutron decay constant of $\alpha = -1.1 \times 10^6\ s^{-1}$ at DC [6]. The polyethylene moderated class foils system is expected to have a prompt neutron decay constant that falls between Lady Godiva and SHEBA II, but much closer to the SHEBA II value.

ROSSI ALPHA SIMULATIONS

Simulations of the experiment were performed using the MCNP® neutronics code to obtain computational results of the Rossi-α. These simulations were performed using the MCNP® deck used to design the class foils experiment. This deck assumes the critical configuration to be 14 foils. This deck is subcritical when calculated by the code, but is very close to critical and therefore assumed to be a good comparison to the measured critical configuration of 14.5 foils. Two nuclear data libraries are used for the calculations compared to the experimental data. These libraries are ENDF/BVI (.66c) and ENDF/BVII (.80c).

In addition to obtaining estimates of the Rossi-α, a full reactivity worth study was performed in MCNP® to estimate how much additional material would be needed to complete the experiment [7]. These simulations estimated that 15.5 foils would need to be used to counteract the absorption occurring in the ^{3}He detector.

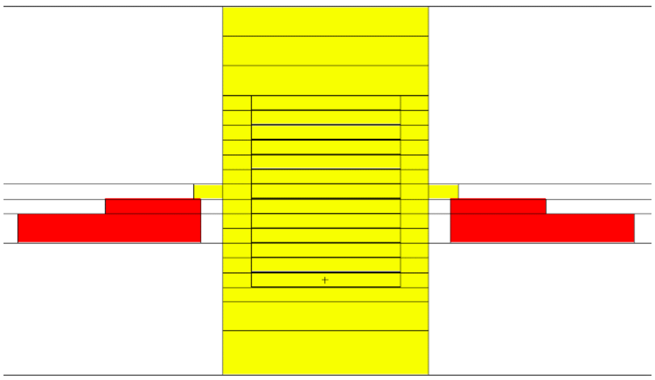

Fig. 4. VisEd portrayal of MCNP deck for the class foils.

ROSSI ALPHA EXPERIMENT

For the Rossi-α experiment, a special moderator plate was designed to hold four detectors as shown in Fig 5. Because the original system is at the optimal H/^{235}U ratio, any configuration change should result in more material needed to attain a critical configuration.

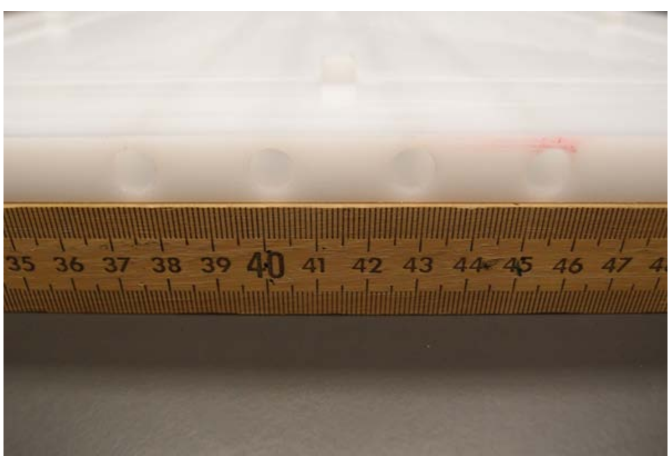

Fig. 5. Holes in a specially designed plate.

Rossi-α measurements can be performed with a wide range of neutron detectors, Helium-3 (^{3}He) detectors were selected in this case. The detectors are manufactured by Reuter-Stokes (RS-P4-0203-201), with a 0.25" inch diameter, an active length of approximately 3" inches, and a ^{3}He pressure of 40 atm [8, 9]. One of the ^{3}He detectors is shown in Fig. 6.

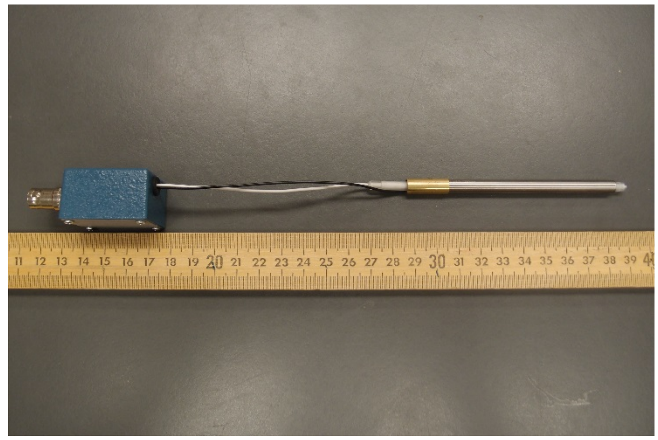

Fig. 6. He-3 detector used in the experiment.

The model of the detectors used in this study contains idealized versions of the ^{3}He detectors and an assumed stainless steel thickness of 5 mils. This study found that all four of the detectors together are worth approximately -3.5 dollars (β_{eff}=650 pcm) relative to the same assembly with no detectors [7].

RESULTS

MCNP® was used to estimate values for the prompt neutron decay constant at delayed critical. The values obtained using MCNP® for Rossi-alpha were -220±15.2 s^{-1} and -204±13.6 s^{-1} for EDNF/BVI and ENDF/BVII cross-section sets, respectively.

In Fig. 7, a graph of the experimentally determined alpha value is plotted with the x-axis being the inverse of the count rate measured during the experiment. As the system approaches delayed critical the count rate would approach infinity and therefore its inverse approaches zero. The value of alpha at delayed critical is determined by finding the y-intercept. For the class foils experiment the value of alpha at DC is experimentally determined to be -198±4 s^{-1} at DC.

Table 1. Experimentally determined values of alpha.

Alpha (s^{-1})	Reactivity ($)	Inverse Count Rate (s/c)
-198.21	0.00	N/A
-258.24	-0.31	7.809E-06
-286.87	-0.46	1.209E-05
-346.66	-0.76	1.966E-05

Plotting the value of alpha at delayed critical along with a point at prompt critical as described in Fig. 3 provides a line that can be used to determine the reactivity of each subcritical alpha. This method is shown in Fig. 8. The prompt critical point is not visible.

The MCNP® calculation (using the most current cross section library) of Rossi-α for this thermal system agrees well with the measured values as well as with historical data from similar systems. This lends confidence in the use of calculated kinetics parameters such as Rossi-alpha and beta-effective for estimating the reactivity of slightly subcritical systems.

Table 2. Comparison of Experimental and Simulated Results.

	Rossi-α (s^{-1})	Difference to Experiment
Experimental	-198.2±4	N/A
ENDF/BVI	-220±15.2	10.9%
ENDF/BVII	-204±13.6	2.7%

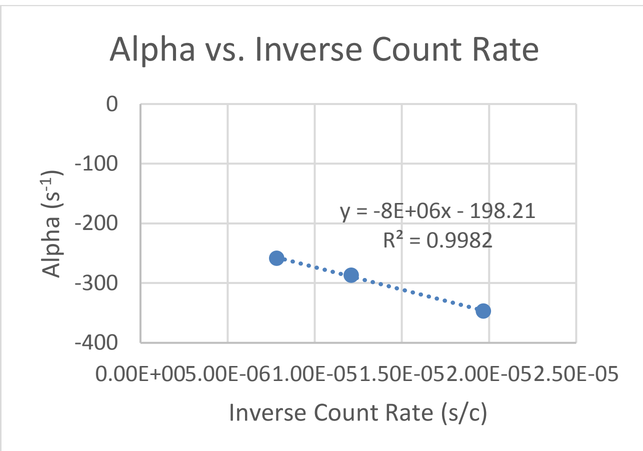

Fig. 7. Alpha versus inverse count rate.

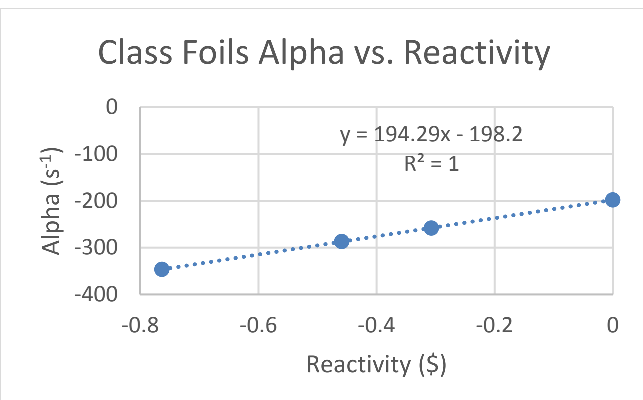

Fig. 8. Alpha versus reactivity.

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