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Prompt Neutron Decay Constants and Subcritical Measurements for Material Control & Accountability in SHEBA

By

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Introduction

Rossi-Alpha measurements were performed on the SHEBA assembly to determine the prompt neutron decay constants. These prompt neutron decay constants represent an eigenvalue characteristic of this particular assembly, which can be used to infer the amount of fissile material in the assembly. In addition, subcritical measurements using Rossi-Alpha and the source-jerk techniques were also performed on the SHEBA assembly. These measurements were compared against TWODANT calculations and agreed quite well. The subcritical measurements were also used to obtain a unique signature that represented the amount of material associated with the degree of subcriticality of the SHEBA assembly. Finally, the Feynman variance-to-mean technique in conjunction with TWODANT, were used to determine the effective delayed neutron fraction for the SHEBA assembly.

Description of the Experiment and the Subcriticality Techniques

The SHEBA assembly is fueled with uranyl flouride, UO_2F_2 (5% ^{235}U).[1] The fuel is pumped from four storage tanks into the critical assembly vessel (CAV). The dimensions of the CAV are approximately 48.9 cm in diameter and 76.2 cm in height. The isotopic composition of the fuel is given in Ref. 1.

The Rossi-Alpha[2] technique consists of detecting neutrons by counters located in or near the critical assembly. This neutron count is used to activate a time analyzer, which records any other neutrons detected by this or other counters. Assuming that the random event rate is small, it is possible to detect pairs of neutrons that come from the same prompt fission chain. Thus, it is feasible to measure the chain's decay constant from the exponential decrease in the number of prompt neutrons from the same fission chain.

The Feynman variance-to-mean[3] method consists of detecting the deviations in the time domain of the counting data from what are expected to be random events. It is known that for a purely random source, the ratio of the variance to the mean is equal to one. On the other hand, for a multiplying system, the ratio of the variance to the mean is greater than one. Thus, this ratio could easily be used to infer a fissile material mass, especially when the system is near delayed critical. The Feynman variance-to-mean technique can also be used to estimate the amount of material needed so that the system can reach prompt criticality.

The source-jerk[4] technique consists of introducing a neutron source into a subcritical assembly until the neutron population reaches equilibrium. The source is then rapidly ejected and the observed transient analyzed. The reactivity of the system is inferred from the transient data. Once again, the reactivity could be used to infer the fissile material mass in the system. For the experiments presented in this paper, we used a pulse neutron source to simulate the neutron source in the system. After the neutron flux reached equilibrium (typically five or six minutes), we proceeded to turn the pulse neutron source off and analyzed the transient data.

The Rossi-Alpha and Feynman variance measurements were performed using four He-3 neutron detectors. These detectors were placed in the center of the SHEBA assembly. The He-3 detectors were approximately 1.27 cm in diameter and 15 cm long. For the source-jerk measurements, BF_3 neutron detectors were placed on the side of the CAV. The pulse neutron source was located on the top of the CAV a few centimeters off the axial center line.

Results

Table I shows the prompt neutron decay constants (α) at different fuel heights. Because of the high neutron background, the α at delayed critical (DC) was obtained by plotting the alpha at a particular fuel height as a function of the inverse count rate and then extrapolating linearly to an inverse count rate of zero. The reactivity at each fuel height was calculated using Eq. 1.

$$\text{Reactivity (\$)} = \alpha/\alpha_{DC} - 1 \qquad [1]$$

Thus, for each fuel height, there is an associated volume, a U-235 mass, a prompt decay constant, and a degree of subcriticality, which constitute a unique signature. The density of the fuel used to calculate the amount of U-235 associated with each volume was 2.143 g/cc. The U-235 weight percent fraction was 4.9379 and the uranium content was 0.464 gU/g-solution.

The source-jerk results are also presented in Table I. A slightly higher fuel density (2.147 g/cc) is used to determine the amount of U-235 at a particular height because of the lower temperature of the fuel. These results were obtained by fitting the measured data to a point kinetics model, which assumes a system in equilibrium when suddenly a transient is induced. The parameter that is varied is the reactivity of the system so that the fit can be optimized. The experimental reactivity results from Rossi-Alpha and source-jerk are presented in Fig. 1. As seen in Fig. 1, these reactivities compared quite well with calculations performed with TWODANT[5] and the 16-group Hansen-Roach[6] cross sections.

The Feynman variance-to-mean technique was also used to provide a signature for the amount of U-235 in the SHEBA assembly as well as to determine the fuel height at which

SHEBA will go prompt critical. Figure 2 shows the plot of $Y^{-1/2}$ as a function of fuel height. $Y^{-1/2}$ is proportional to the prompt reactivity of the system. For equal fuel height increments, $Y^{-1/2}$ should be linear (see Fig. 2) with an intercept at prompt critical. Thus, from Fig.2, the difference in fuel height between delayed critical and prompt critical was estimated to be 2.29 cm. Two calculations were performed with TWODANT to estimate the effective delayed neutron fraction, β_{eff}. One calculation was at delayed critical, namely at 47.13 cm. The other one was at prompt critical or 49.42 cm in height. The difference in k_{eff} was the effective delayed neutron fraction for SHEBA, which was used to covert the keff from TWODANT into reactivity in dollars (see Fig. 1). The effective delayed neutron fraction for SHEBA, β_{eff}, was estimated to be 0.00938754.

Conclusion

We have shown that is possible to use the Rossi Alpha, Feynman variance-to-mean, and source-jerk techniques to provide signatures for the amount of U-235 in the system, especially when the assembly is operated near delayed critical. Finally, it was also shown that measured reactivities by these techniques compared quite well with calculational models.

table I. Prompt neutron decay constants and reactivities below delayed critical for a bare solution assembly (SHEBA).

Rossi-Alpha measurements at 23.7 °C

Fuel Height	α (sec^{-1})	Reactivity below DC ($)	Mass (g of U-235)
44.0 cm	481.9 ± 8.6	-1.51 ± 0.05	3,988
45.0 cm	377.8 ± 6.2	-0.97 ± 0.03	4,079
46.0 cm	288.2 ± 5.3	-0.51 ± 0.02	4,169
46.54 cm	242.0 ± 4.2	-0.27 ± 0.02	4,218
47.13 cm (DC)	191.3 ± 3.6	-0.0 ± 0.017	4,272

Source-Jerk Measurements at 20.3 °C

Fuel Height	Reactivity below DC ($)	Mass (g of U-235)
41.0 cm	-2.91 ± 0.03	3,723
42.0 cm	-2.48 ± 0.13	3,814
43.0 cm	-1.76 ± 0.04	3,905
44.0 cm	-1.26 ± 0.03	3,996
45.0 cm	-0.77 ± 0.02	4,086
46.0 cm	-0.31 ± 0.01	4,177
46.7 cm (DC)	0.0	4,241

Feynman Variance-to-mean Measurements at 23.7 °C

Fuel Height	$Y = (\overline{C^2} - \overline{C}^2)/\overline{C} - 1$	Mass (g of U-235)
44.0 cm	13.88 ± 0.34	3,988
45.0 cm	21.45 ± 0.78	4,079
46.0 cm	34.65 ± 1.94	4,169

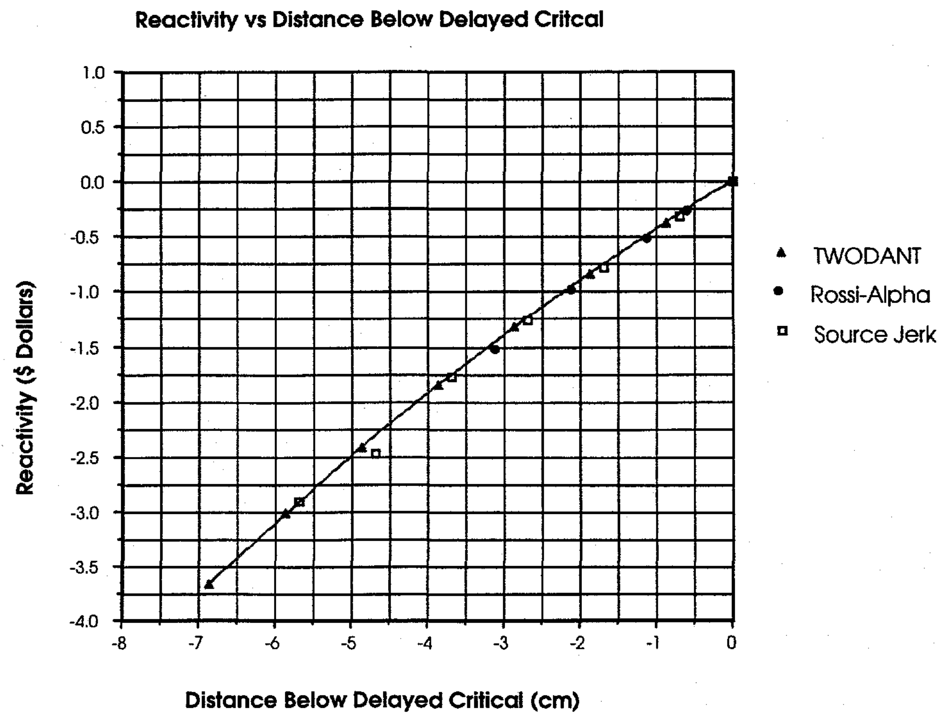

Figure 1. Comparison of subcritical measurement techniques.

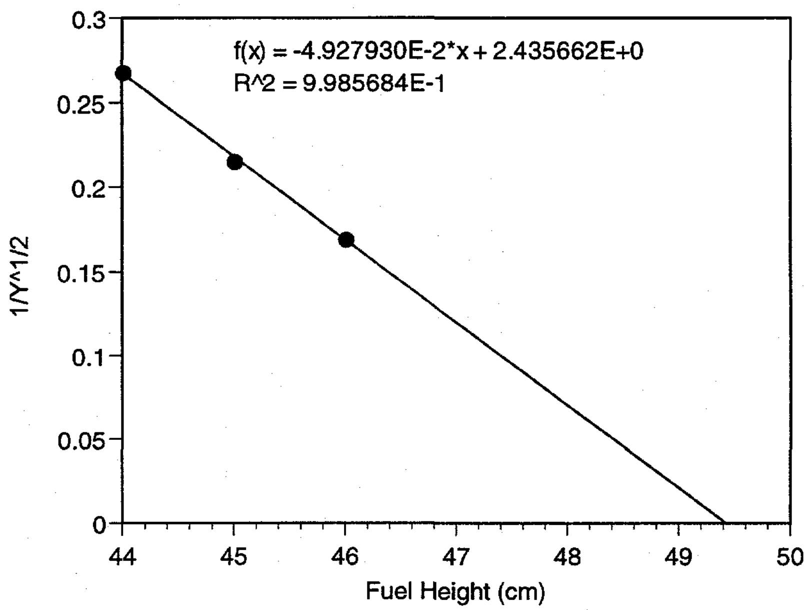

Figure 2. Plot of $Y^{-1/2}$ vs. fuel height on SHEBA.

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