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Author(s):

David Loaiza and Rene Sanchez

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Benchmark Calculations for the Diluted Highly Enriched Uranium (HEU) and Aluminum Experiment

By
David Loaiza and Rene Sanchez
P.O. Box 1663, MS J562
Los Alamos National Laboratory
Los Alamos, NM 87545

1. Introduction

The HEU-Al experiment was performed using the Planet universal critical assembly at Los Alamos Critical Experiment Facility (LACEF) in Los Alamos National Laboratory. This experiment consisted of placing HEU foils interspersed with aluminum plates in a column stack. These uranium foils were moderated and reflected by polyethylene square plates. This experiment was performed to measure the prompt neutron decay constants in uranium systems diluted by matrix materials. This experimental set-up yielded a Al/^{235}U ratio of 60:1.[1] The experimental k_{eff} was 1.001 and the modeled MCNP k_{eff} was 1.0016±0.0004. This report summarizes the benchmark calculations performed to validate the experiment.

The experimental arrangement is depicted in Figure 1. As Figure 1 illustrates the stack is divided into two parts. The bottom half of the stack rest on an aluminum support plate which is 1 inch thick. The top half of the experiment rest on 0.75 inch thick polyethylene plate. Criticality is achieved by decreasing the gap between the top and bottom portions of the stack. To disassemble the configuration the bottom stack is dropped to its initial position. There are no other control or safety rods inside the assembly.[2]

2. Experiment Description

The experiment consists of laminated HEU foils, aluminum plates, and high density polyethylene moderator plates. The moderator in the experiment consists of 18 high density polyethylene plates with recesses built into them for the HEU foils and the aluminum plates. This is done in order to minimize axial leakage. The dimension for

Figure 1. HEU-Al experiment mounted on the Planet assembly

these moderating plates are 15.4 by 15.4 by 0.75 inches. This experiment also used 8 high density polyethylene reflectors. In total, 18 aluminum plates were used in the experiment. The foils used were 9-inch by 9-inch square and 0.003 inches thick before they were laminated. The lamination material was polyethylene. The final laminated foils had a dimension of 9.5-inches by 9.5-inches and 0.018-inches thick.

3. Experimental Procedure

The approach to critical was performed using the (1/M) technique. The HEU foils were placed between the aluminum and polyethylene plates. Once the handstacking limit was reached, the operators split the stack. The bottom part of the core, which contained approximately half of the critical mass, was placed on the movable platen of the Planet assembly. The top part of the core was placed on the top platform and typically contained two or three units. A unit is defined as two HEU foils. The lower portion of the assembly, which contained a Pu-Be source, was then raised remotely until it contacted the top portion of the assembly. The neutron leakage from the assembly was measured with four BF_3 detectors and (1/M) as a function of number of units was plotted. By extrapolating the last two point of the (1/M) values to zero, it was determined that 19.03 units were necessary to reach criticality. The assembly was delayed critical with 38 HEU foils or 19 units (set of 2 HEU foils). This experiment resulted in a positive period of 64.89 sec which yielded a positive reactor period of 13.8 cents. At this measurement the assembly was fully closed, i.e. top and bottom stacks are in direct contact.

4. Benchmark of the Experiment

A benchmark analysis was performed to validate the experimental results. The reactivity effects of many of the uncertainties discussed below were quantified using the MCNP model of the benchmark. The analysis was performed by employing a detailed three-dimensional MCNP model with continuous-energy cross sections from ENDF/B-VI neutron data. The MCNP calculations had 6,000,000 active histories. A total of 5,000 histories per generation were used and 1,250 generations of neutrons.

The uncertainties affecting the experiment have been divided into three broad categories. They are the uncertainties associated with 1) mass measurement techniques, 2) geometry, and 3) compositions. Each category is considered in turn and then the combined experimental uncertainty is presented. Each uncertainty estimate is one standard deviation.

A summary of the uncertainties are collected in Table I. From the uncertainties due to variations in mass, only the HEU mass uncertainty is important. Two of the uncertainties in the geometry category are important – uncertainties in the polyethylene plates and the uncertainty in the large plate. In fact, the uncertainty in the dimension from the large plate alone is almost as large as the uncertainty from all other plates. This is because of the neutronic importance of this plate with relation to the other plates. Of the composition uncertainties, only the component due to the impurities of aluminum is significant. Mass uncertainties dominate the overall experimental uncertainty in this benchmark.

Table I. Summary of Uncertainties.

Source of Uncertainty	Parameter Variation in Calculation	Calculated Effect (Δk_{eff}) of Variation	Standard Uncertainty of Parameter	Standard Uncertainty in Δk_{eff}
Material Mass				
HEU Mass	0.569 g/cm^3	± 0.0044	0.569/√38	± 0.0007
Enrichment in ^{235}U (wt%)	0.02 wt.%	± 0.0002	0.02/2	± 0.0001
Polyethylene Plate Mass	0.0015 g/cm^3	± 0.0010	0.015/√26	± 0.0002
Polyethylene Lamination Mass	0.0043 g/cm^3	± 0.0001	0.0043/√38	± 0.0001
Aluminum Plate Mass	0.0065 g/cm^3	± 0.0004	0.0065/√18	± 0.0001
Geometry Dimensions				
HEU	0.5 %	± 0.0003	0.005/√3	± 0.0002
Polyethylene Plates	0.1 in.	± 0.0015	0.1/√3	± 0.0009
Polyethylene Large Plate 48	0.1 in.	± 0.0011	0.1/√3	± 0.0006
Aluminum Plate	0.1 in.	± 0.0004	0.1/√3	± 0.0002
Axial Air Gap	0.002 in.	± 0.0027	0.002/√3	± 0.0016
Material Composition				
Impurity in Lamination	Included	- 0.0001	-	-
Impurity in Polyethylene Plates	Included	- 0.0001	-	-
Composition of Al Plates	Included	+ 0.0014	-	± 0.0007
Additional Calculations				
Support plates	Included	<0.0010	-	± 0.0010[(a)]
Room return	Included	<0.0010	-	
Total Uncertainty			Quadratic Total:	± 0.0027

(a) 0.0010 is estimated as the standard uncertainty from support plates and room returrn

5. References

1. Sanchez, R., Loaiza, D. and Brunson, G., "Prompt Neutron Decay Constants in Uranium Diluted with Matrix Material Systems," Trans. Am. Nucl. Soc. (2001)

2. LACEF, "Los Alamos Critical Experiments Facility Safety Analysis Report," Los Alamos National Laboratory, LA-CP-92-235 (1994).