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Highly Enriched Uranium Metal Cylinders Surrounded by Various Reflector Materials

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HIGHLY ENRICHED URANIUM METAL CYLINDERS SURROUNDED BY VARIOUS REFLECTOR MATERIALS

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1. Introduction

A series of experiments was performed at Los Alamos Scientific Laboratory in 1958 to determine critical masses of cylinders of Oralloy (Oy) reflected by a number of materials. The experiments were all performed on the Comet Universal Critical Assembly Machine, and consisted of discs of highly-enriched uranium (93.3 wt.% ^{235}U) reflected by 0.5-inch and 1-inch-thick cylindrical shells of various reflector materials. The experiments were performed by members of Group N-2, particularly K. W. Gallup, G. E. Hansen, H. C. Paxton, and R. H. White [1,2]. These experiments were intended to ascertain critical mass values for criticality safety purposes, as well as to compare neutron transport cross sections to those obtained from danger coefficient measurements with the Topsy Oralloy-Tuballoy reflected and Godiva unreflected critical assemblies.

The reflector materials examined in this series of experiments are as follows: magnesium, titanium, aluminum, graphite, mild steel, nickel, copper, cobalt, molybdenum, natural uranium, tungsten, beryllium, aluminum oxide, molybdenum carbide, and polythene (polyethylene). Also included are two special configurations with composite beryllium and iron reflectors.

The experiments were evaluated and found to be acceptable for use as criticality safety benchmarks. Complete evaluation of these experiments will be published in the 2007 Edition of the *International Handbook of Evaluated Criticality Safety Benchmark Experiments* [3]. A description of the experiments and evaluation of the experimental results are provided in this paper. Comparison of calculated k_{eff} values obtained by using ENDF/B-VI.6 and ENDF/B-VII neutron cross-section data libraries are also provided. The benchmarks are intended to be used by Criticality Safety specialists to validate their methods, codes, and nuclear data.

2. Description of Experiment

These experiments were all performed with cylindrical cores of HEU metal with a diameter of 5.25 inches, surrounded on all sides by either a 0.5-inch- or 1-inch-thick reflector. The Comet Assembly machine was comprised of two main parts: a hydraulic ram at the bottom and a steel diaphragm located above. An aluminum platen and platen adapter, used to hold the lower half of the cylindrical Oralloy core region, was located on the ram. The stainless steel diaphragm was 0.015-inches thick and was used to support the upper part of the sample. The Oralloy core region consisted of up to 10 discs, with thicknesses ranging from 0.0375-inch to 1.2-inch. A total of 39.96 kg of Oralloy were available for these experiments. The reflector material was composed of 0.5-inch-thick concentric cylindrical rings and rings with inner diameters of 5.25 and 6.25 inches were both available. The smaller size reflector parts fit tightly around the Oralloy discs, forming the 0.5-inch-thick reflector configuration. The larger size reflector parts fit tightly around the smaller reflector parts, forming the 1-inch-thick reflector configuration. Both cylinder ends were then capped with either 1-inch-thick or 0.5-inch-thick reflector plates, with diameters equal to the outer diameter of the reflector. The thickness of these end caps matched the thickness of the radial reflector. No information was reported for tolerances in reflector geometry or mass, Oralloy disc radius or mass, or gap size between the reflector and Oralloy.

Two special configurations were also described. The first configuration was a normal Oralloy cylinder surrounded by a 0.5-inch-thick Be reflector, which was then surrounded by a 0.5-inch-thick Fe reflector. The next was an Oralloy cylinder surrounded on the sides and top by a 0.5-inch-thick Be reflector, and on the bottom by a 1-inch-thick Be reflector. This was then surrounded by a 0.5-inch-thick Fe reflector.

The experimenters attempted to configure the Oralloy so that half of the mass rested on the platen and half rested on the diaphragm. A mock fission neutron source was placed in the plate containing a small source hole, and this plate formed the top of the lower assembly. When the active material was to be assembled, the hydraulic ram raised the lower half to meet the upper half. The lower cylinder was raised high enough to lift the upper cylinder and diaphragm from their supports, leaving them resting on the lower cylinder. In addition, weights were placed on top of the assembly to further compress the disks. This served to minimize any axial gaps that may have been present. A diagram of the experimental setup is shown in Figure 1.

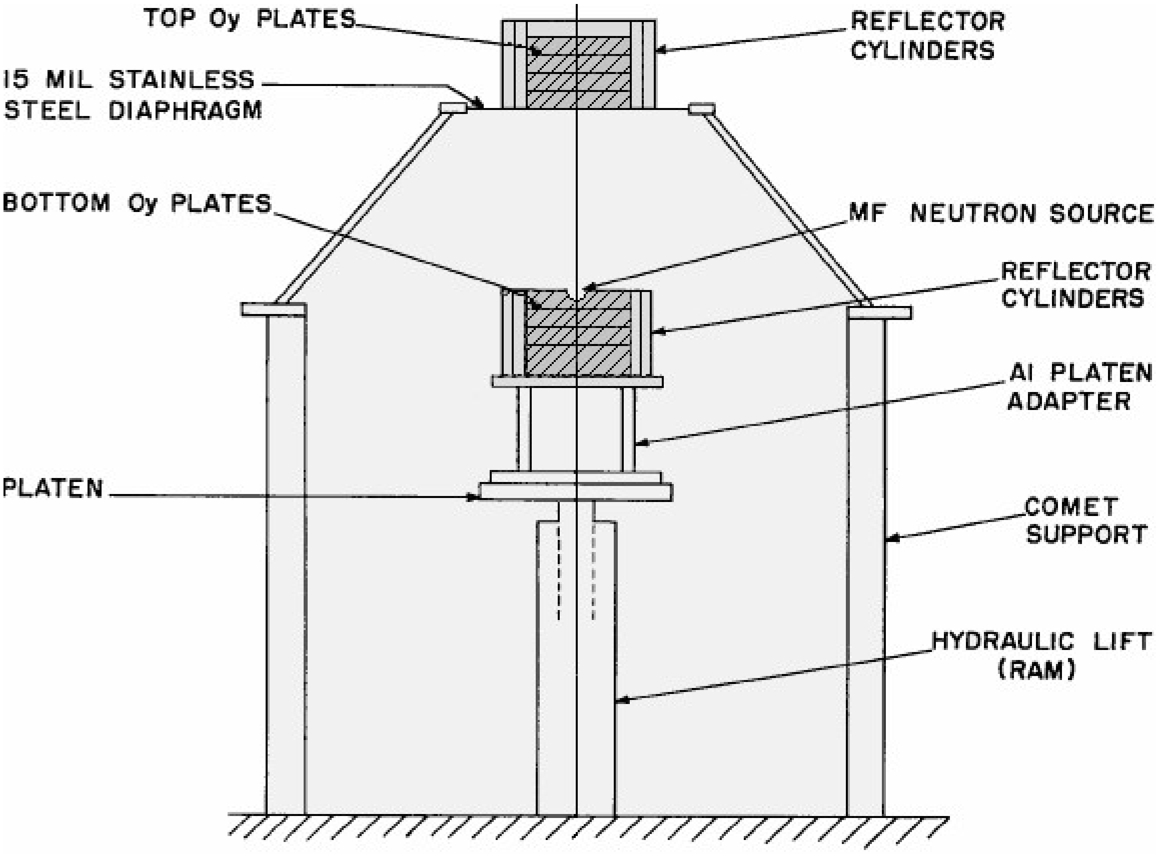

Figure 1: Experimental Setup.

The experiment was monitored by four boron-lined counters in long-counter geometry. To measure the unmultiplied counting rate, the Oralloy was replaced with Tuballoy (Tu), a term generally used to describe natural or depleted uranium. The actual isotopic composition of the Tuballoy used in these experiments is not known, but it can be assumed that the same Tu components were used for all configurations. The multiplied counting rates were then measured using the Oralloy components. The ratio of multiplied-to-unmultiplied rates gives a value for the multiplication. Oralloy discs were added to the top of the assembly to increase the reactivity in safe steps. A progressive plot of the inverse multiplications against the Oralloy mass was used to extrapolate to critical mass. All of the experiments listed were slightly subcritical.

Corrections were made by the experimenters to account for the effects of both the 0.015 inch steel diaphragm and the aluminum platen. This was accomplished by increasing the diaphragm and platen thickness and measuring the reactivity effect.

Critical masses for the configurations ranged from 31.25 kg Oy to 50.7 kg Oy with 1-inch-thick reflectors, and from 41.35 kg Oy to 57.6 kg Oy for the configurations with 0.5-inch-thick reflectors. The two Be/Fe configurations had critical masses comparable to the 1-inch-thick reflector configurations.

The experimenters used Oralloy plates enriched to 93.5 wt.% ^{235}U with a density of 18.75 g/cm^3. General composition information was given for the reflector materials; however, no specific isotopic composition was given. No information on Oralloy or reflector material impurities was reported.

3. Evaluation of Experimental Data

Uncertainties in six major parameters of the experimental configuration were examined; namely, extrapolation to the uranium critical mass, uranium density, ^{235}U enrichment, reflector density, reflector thickness, and reflector impurities. The experimenters did not report any information on probable error in any of these parameters apart from critical mass and uranium disc thickness. Uncertainties in these parameters were estimated by reviewing many comparable experiments performed during the same time period.

The density values quoted by the experimenters for the molybdenum and molybdenum carbide reflectors, 10.53 g/cm^3 and 9.57 g/cm^3, respectively, exceeded the theoretical densities for these materials, 10.22 g/cm^3 and 9.18 g/cm^3, respectively, and so these values were assumed to be in error. Internal Los Alamos National Lab documents show that, historically, densities of 10.228 g/cm3 and 9.102 g/cm3 have been used, and so these values were used for the benchmark model. Larger uncertainties in reflector density were used for the molybdenum reflected experiments, which resulted in larger uncertainties in benchmark k_{eff} values than were found for the other reflector materials.

In addition to the idealizations made by the experimenters (removal of the platen and diaphragm, Figure 1), two simplifications were also made to the benchmark models that resulted in a small bias and additional uncertainty. First of all, since impurities in core and reflector materials were only estimated, they were not included in the benchmark models. Secondly, the room, support structure, and other possible surrounding equipment were not included in the model. Bias values that result from these two simplifications were determined and associated uncertainty in the bias values were included in the overall uncertainty in benchmark k_{eff} values. Bias values were very small, ranging from 0.0004 to 0.0007 Δk low.

The effect on k_{eff} due to these uncertainties was calculated using the Monte Carlo code MCNP5 with ENDF/B-VI.6 cross sections. In most cases, the uncertainty studies were performed using six million active histories, leading to an MCNP uncertainty of approximately ±0.0003 in k_{eff}. In all cases, an effort was made to obtain a best estimate of the uncertainty at the 1-σ level. Often parameter variations were increased beyond the estimated 1-σ level in order to obtain statistically meaningful results. Calculated values were then scaled back to the 1-σ level. In cases where this was not possible, the number of active neutron histories was increased to 60 million, yielding an MCNP uncertainty of ±0.0001 in k_{eff}.

The overall benchmark-model uncertainty for each configuration was calculated by summing the effects of each individual uncertainty in quadrature. These values are given in Table 1 for each of the 32 configurations. The only configurations with uncertainty greater than ±0.0030 were those with large uncertainties arising from the molybdenum and molybdenum carbide densities.

The other configurations, with uncertainties between ±0.0018 and ±0.0029, were influenced mostly by uncertainties arising from uranium density and extrapolation to critical mass.

Table 1: Benchmark-Model Uncertainty.

Reflector Material	Thickness	Total (1-σ) Uncertainty	Thickness	Total (1-σ) Uncertainty
Al	**1 in**	**±0.0019**	**0.5 in**	**±0.0028**
Al_2O_3	**1 in**	**±0.0021**	**0.5 in**	**±0.0021**
Be	**1 in**	**±0.0021**	**0.5 in**	**±0.0020**
C	**1 in**	**±0.0020**	**0.5 in**	**±0.0020**
Co	**1 in**	**±0.0021**	**0.5 in**	**±0.0018**
Cu	**1 in**	**±0.0024**	**0.5 in**	**±0.0022**
Fe	**1 in**	**±0.0020**	**0.5 in**	**±0.0019**
Mg	**1 in**	**±0.0026**	**0.5 in**	**±0.0029**
Mo	**1 in**	**±0.0034**	**0.5 in**	**±0.0025**
Mo_2C	**1 in**	**±0.0054**	**0.5 in**	**±0.0045**
Ni	**1 in**	**±0.0022**	**0.5 in**	**±0.0020**
Polyethylene	**1 in**	**±0.0019**	**0.5 in**	**±0.0023**
Ti	**1 in**	**±0.0020**	**0.5 in**	**±0.0030**
U	**1 in**	**±0.0022**	**0.5 in**	**±0.0018**
W	**1 in**	**±0.0019**	**0.5 in**	**±0.0020**
Be/Fe(a)		**±0.0021**		
Be/Fe(b)		**±0.0020**		

(a) Configuration with 0.5-inch lower beryllium thickness.
(b) Configuration with 1-inch lower beryllium thickness.

4. Results and Conclusions

Sample calculations were performed using both MCNP5 and KENO-V.a Monte Carlo neutron transport codes to verify the results of the experiments. MCNP5 results were calculated for both ENDF/B-VI.6 and ENDF/B-VII cross-section data. KENO-V.a results were obtained using standard KENO 238-Group ENDF/B-V cross-section data.

Two deviations from the benchmark model were necessary. First, there are no ENDF/B-V or -VI cross section data available for zinc. For MCNP, ENDL92 cross section data were used. For KENO, zinc was replaced with copper, which has similar properties to that of zinc. Also, since ^{180}W and ^{18}O are not included in the ENDF/B-VI.6 or –VII beta 2 libraries, these atoms were replaced with void for all MCNP calculations.

The results of these sample calculations are shown in Figure 2, along with a graphical representation of the benchmark-model uncertainties. Calculated results using MCNP5 and ENDF/B-VI.6 show differences between calculated and benchmark-model k_{eff} values that exceeded three times the benchmark model uncertainty only for configurations with 1-inch-thick molybdenum and titanium reflectors. MCNP results using ENDF/B-VII and KENO results using 238-energy-group ENDF/B-V data were within three times the benchmark uncertainty for both titanium configurations. Differences are likely due to deficiencies in cross-section data.

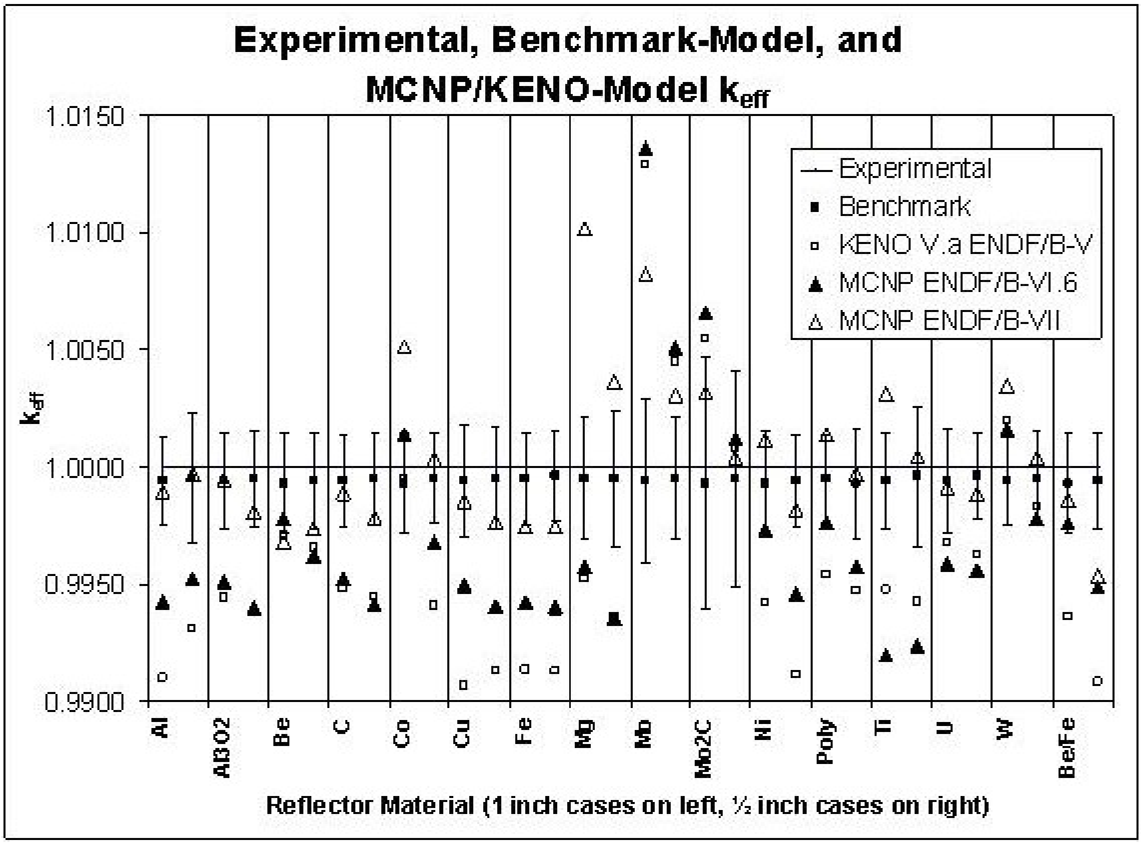

Figure 2: Results of Sample Calculations.

Calculated results using ENDF/B-VII are, in general, closer to the benchmark model k_{eff} than those calculated using ENDF/B-VI.6. This is likely a result of newer cross-section data for uranium. Other major differences between ENDF/B-VI.6 and ENDF/B-VII for materials considered in this evaluation include updated cross sections for molybdenum, magnesium, and titanium in ENDF/B-VII. As a result, those configurations with molybdenum calculated approximately 0.3% lower, those configurations with magnesium and titanium calculated approximately 1% higher, and the majority of the remaining cases calculated approximately 0.5% higher. The change in calculated k_{eff} between ENDF/B-VI.6 and ENDF/B-VII is shown in Figure 3.

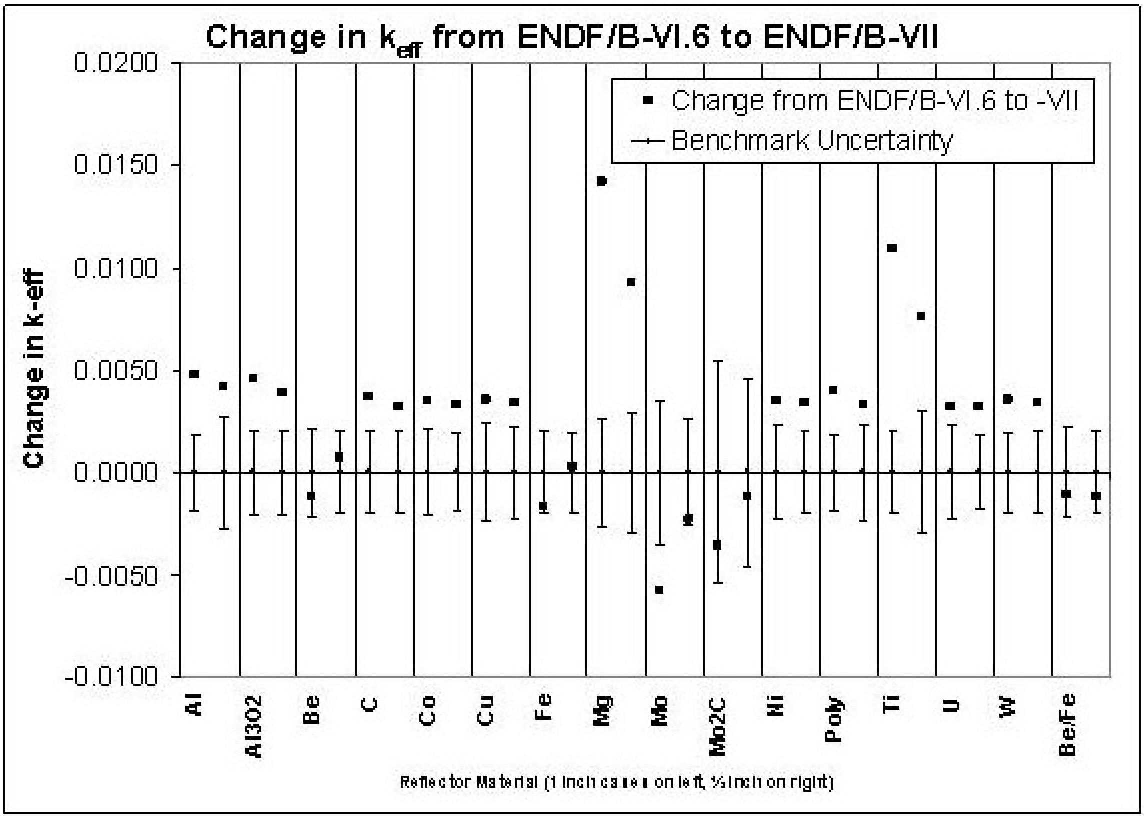

Figure 3: Difference in Calculated k_{eff} Values Obtained Using ENDF/B-VI.6 and ENDF/B–VII Data.

5. Acknowledgements

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6. References

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