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Title: BENCHMARK CALCULATIONS FOR SOME LOS ALAMOS ORALLOY CRITICAL EXPERIMENTS

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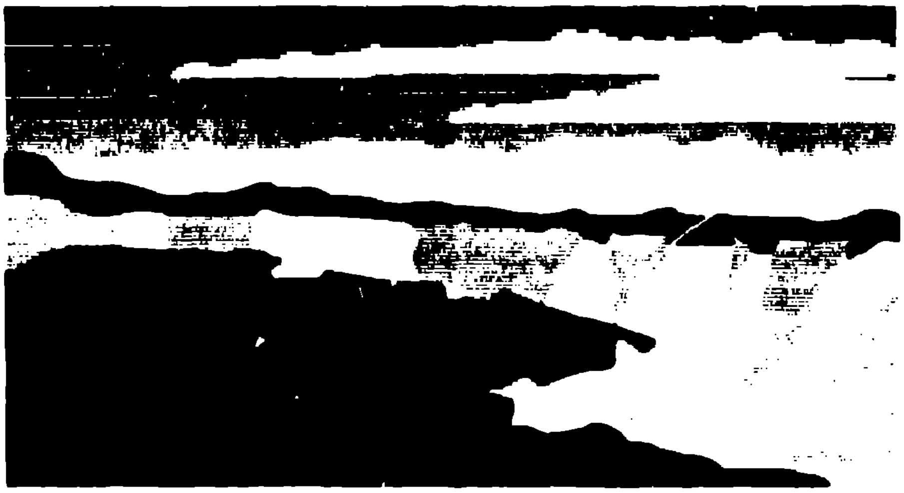

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DETAILED REANALYSIS OF A BENCHMARK CRITICAL EXPERIMENT:

WATER-REFLECTED ENRICHED-URANIUM SPHERE

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In late 1976, staff members at Los Alamos National Laboratory performed a very accurate measurement to determine the critical mass of a sphere of highly enriched uranium (oralloy) when reflected by water.[1] This experiment has been used previously to benchmark[2,3] the MCNP[4] and KENO[5] Monte Carlo codes. However, these benchmark calculations were performed for idealizations of the experiment and involved significant approximations. In contrast, the analysis reported herein is based on a detailed representation of the actual experiment and a set of recently published isotopic specifications for the sphere.[6] Differences between the results from this study and those from the earlier benchmark calculations are related to specific aspects of those calculations.

In the experiment, an oralloy sphere was placed on the beveled edge of a lucite stand inside an aluminum tank containing water. The sphere was comprised of two hemispheres and a small pin to hold them in place. The enrichment of the pin and of one of the hemispheres was 97.67 w/o, while the enrichment of the other hemisphere was 97.68 w/o. In addition, there were slightly larger variations in the concentrations of other uranium isotopes among the three pieces of oralloy. The radius of the sphere was 6.5537 cm, and the tank had a radius of 30 cm and was between 60 and 70 cm high.

The water level was raised until the configuration was slightly supercritical, and the excess reactivity was measured as a function of the height of the water above the surface of the oralloy sphere. In particular, the excess reactivity for a water level 16.5 cm above the sphere was reported to be 30.8 ± 0.2 cents, which corresponds to a k_{eff} of 1.0020. Unfortunately, because the geometric details of the stand were not formally documented, the depth of the water beneath the sphere is not known precisely. Furthermore, two different benchmark calculations for this experiment using the same code (MCNP) and the same cross-section library report values for k_{eff} that differ by several standard deviations.

We were able to estimate the dimensions of the three-legged stand from pictures and drawings provided by some of the original experimenters.[7,8] Those estimates are presented in Table I.

An outstanding feature of this experiment is that the results are insensitive to so many aspects of its design. In particular, the impurities in the oralloy (including a trace amount of ^{233}U), the presence of the tank, the presence of naturally occurring D_2O in the water, and the choice of the scattering law for the stand each were found to change the eigenvalue by 0.001 Δk or less. Furthermore, uncertainties in a number of other components of the experiment were shown to have a negligible impact on the eigenvalue. Included in this category are the enrichment of the oralloy, the density of the lucite, the width of the seat of the stand, the depth of the water below the sphere, and the density of the water. The only item that significantly affects the eigenvalue is the presence of the stand. Replacing the stand with water was found to reduce k_{eff} by 0.0024 ± 0.0007 Δk.

MCNP calculations for a detailed representation of this experiment, with the tank and the entire stand explicitly included, produced eigenvalues of 0.9993 ± 0.0004 and 0.9988 ± 0.0006, depending upon whether the composition with the higher enrichment was assigned to the upper or lower hemisphere. This difference is not considered significant, and additional calculations that used a single, averaged set of isotopic concentrations for both hemispheres and for the pin produced an eigenvalue of 0.9993 ± 0.0004. These calculations, like all the others in this study, employed continuous-energy cross sections derived from ENDF/B-V.

The analysis in the MCNP neutron benchmark report[2] idealized this experiment as simply an oralloy sphere inside a large cylinder of water and produced a k_{eff} of 0.9956 ±0.0022. When we removed the aluminum tank from our model, replaced the lucite stand with water and homogenized the oralloy into a sphere, we obtained an eigenvalue of 0.9974 ± 0.0005. This result is in good agreement with the eigenvalue from the report and represents a reactivity change of -0.0019 ± 0.0006 relative to the detailed representation of the experiment. Because this change is not statistically different from the reactivity worth of the stand by itself, the low eigenvalue reported in the neutron benchmark report can be attributed primarily to its omission of the lucite stand.

The analysis in the MCNP criticality-safety benchmark report[3] adopted the representation of this experiment given in KENO sample problem 15: the oralloy sphere rests on a flattened, hollow cylinder of lucite inside a cylinder of water. The document reports an eigenvalue of 1.0016 ± 0.0011 for this configuration. This value differs from ours by nearly two standard deviations (0.0023 ± 0.0012 Δk).

The difference was found to be due to a combination of three effects, none of which individually amounts to more than approximately 0.001 Δk: (1) slightly different isotopic concentrations in the oralloy, (2) the combination of other idealizations in KENO problem 15, and (3) a slightly high estimate of the eigenvalue in the criticality-safety benchmark report. The basis for the isotopics in the KENO sample problem is not known.

We performed a series of sensitivity studies in order to assess the reactivity effects of the differences between the two representations. The difference in the isotopic concentrations was found to contribute 0.0005 ± 0.0008 Δk, while the net effect of the other idealizations in the representation in KENO sample problem 15 was 0.0007 ± 0.0008 Δk.

We then investigated the effect of extending the number of histories used in the calculation in the criticality-safety benchmark report. Although we replicated the eigenvalue from this report when we used its input deck, we obtained a somewhat lower value, 1.0007 ± 0.0006, when we extended that calculation from 540,000 to 2,000,000 active neutron histories. Therefore, a better estimate of the difference in k_{eff} between the representation employed in the criticality-safety benchmark report and that in our detailed analysis of the experiment is 0.0014 ± 0.0008. That difference is well within the range attributable to the combination of isotopic differences and other idealizations.

Our detailed analysis of this experiment has produced an eigenvalue that is in good agreement with the experimental measurement. In addition, differences between our result and those obtained in previous benchmark calculations have been traced to specific aspects of those calculations.

Table I.

Estimated Dimensions of Lucite Stand

Item	Dimension (cm)	Dimension (inches)
Thickness of Seat	2.54	1.0
Outer Radius of Seat	12.7	5.0
Inner Radius of Seat (Beveled Edge)	3.0	2.36
Inner Radius of Seat (Flat Edge)	4.27	3.36
Height of Beveled Edge	1.27	0.5
Height of Stand (to Top of Seat)	27.29	10.75
Inset of Legs from Outer Edge of Seat	1.75	0.67
Radius of Legs	1.27	0.50
Length of Legs	33.0	13.0

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