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Author(s):

Russell D. Mosteller
David J. Loaiza

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Creation of a Simplified Benchmark Model for the Neptunium Sphere Experiment

Russell D. Mosteller* and David J. Loaiza**

**Applied Physics Division, Los Alamos National Laboratory, Los Alamos, NM, 87545, mosteller@lanl.gov*
***Nonproliferation and International Security Division, Los Alamos National Laboratory, Los Alamos, NM, 87545, dloaiza@lanl.gov*

INTRODUCTION

Although neptunium is produced in significant amounts by nuclear power reactors, its critical mass is not well known. In addition, sizeable uncertainties exist for its cross sections. As an important step toward resolution of these issues, a critical experiment was conducted in 2002 at the Los Alamos Critical Experiments Facility (LACEF). In the experiment, a 6-kg sphere of ^{237}Np was surrounded by nested hemispherical shells of highly enriched uranium (HEU).[1,2,3] The HEU shells were required in order to reach a critical condition.

Subsequently, a detailed benchmark model of the experiment was developed.[3] This model faithfully reproduces the components of the experiment, but it is geometrically complex. The objective of the study reported herein was to produce a simplified benchmark model that removes the geometric complexity but retains all the important aspects of its neutronic behavior.

DESCRIPTION OF EXPERIMENT

The experiment was performed on the Planet vertical assembly at LACEF. The Planet assembly has two primary components: a stationary platform that supports a stainless-steel membrane to hold the upper portion of the experimental assembly in place, and a vertical drive that lifts the lower portion of the assembly upward. In this particular experiment, the upper portion of the assembly contained 14 hemispherical HEU shells, while the lower portion contained 15 hemispherical HEU shells and the Np sphere. An aluminum spacer was placed on top of the lower HEU shells to prevent a configuration that would exceed operating limits. A slightly idealized schematic of the experimental configuration is shown in Fig. 1.

The Np sphere was enclosed in a tungsten shell to reduce the radiological hazard. That shell, in turn, was coated with two separate layers of nickel cladding.

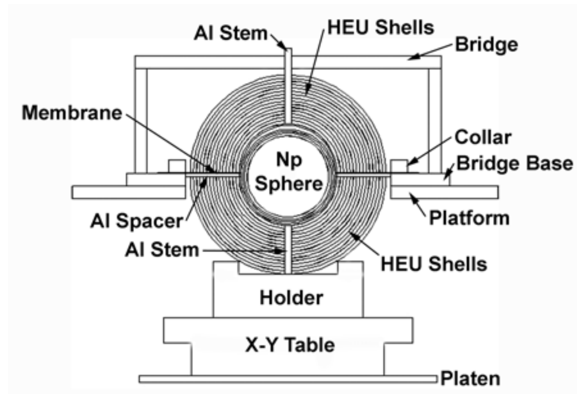

Fig. 1. Schematic of the Experiment.

SIMPLIFICATIONS AND RESULTS

A series of sensitivity calculations was performed with the objective of reducing the geometric complexity of the benchmark specifications. The calculations were performed with the MCNP5™ Monte Carlo code[4] and its associated ENDF66 continuous-energy nuclear data library.[5] ENDF66 is based on release 6 of ENDF/B-VI.[6]

Each calculation employed 1,250 generations of 5,000 neutron histories. The first 50 generations were excluded from the statistics, and therefore the results reported herein are based on 6,000,000 active histories. The calculations were performed in sequential order, with each model retaining all of the previous simplifications. Consequently, the statistical uncertainties associated with the intermediate and final models are not compounded.

The reactivity change associated with each of the simplifications is summarized in Table I. None of the individual changes exceed a quarter of a percent, and most of them are less than a tenth of a percent. Furthermore, they tend to offset each other, and the net change in k_{eff} is only -0.0008 ± 0.0004.

Some structural components and the Al spacer were retained because their removal produced a reactivity change that was considered unacceptably

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large. Removal of the spacer, for example, increased reactivity by approximately 1 percent.

After the simplified benchmark model had been determined, the MCNP input file was revised to make it as simple as possible while retaining complete consistency with the simplified benchmark model. The results from that model are compared with those from the original benchmark model in Table II. The comparison clearly demonstrates the equivalence of the two benchmarks. Furthermore, the simplified benchmark consumes only about ⅓ as much CPU time as the original. In addition, the observed deficiency in the calculated values for k_{eff} provides support for the suspicion that better cross sections are needed for ^{237}Np.

TABLE I. Reactivity Impact of Geometric Simplifications.

Change	Δk
Remove bridge	-0.0011 ± 0.0004
Remove platen	-0.0001 ± 0.0004
Remove X-Y alignment table	-0.0021 ± 0.0003
Convert bridge base, collar, and platform into cylindrical ring	0.0010 ± 0.0004
Remove Al stems and caps	-0.0008 ± 0.0004
Remove diaphragm	0.0019 ± 0.0004
Homogenize HEU shells and enclosed voids	0.0005 ± 0.0004
Homogenize tungsten and nickel cladding with enclosed voids	-0.0001 ± 0.0003
Cumulative change	-0.0008 ± 0.0004

TABLE II. Comparison of Results.

Parameter		SPEC-MET-FAST-008	Simplified Benchmark
k_{eff}		0.9882 ± 0.0003	0.9870 ± 0.0003
Fission Distribution, by Energy	Fast	0.9476	0.9483
	Intermediate	0.0524	0.0517
	Thermal	0.0	0.0
Fission, by Material	Np	0.1251	0.1260
	^{235}U	0.8583	0.8575
Average Energy of Neutrons Causing Fission (MeV)		1.517	1.524
Average Number of Neutrons Produced per Fission		2.636	2.637
Execution Time (Minutes)*		61.84	21.60

*Calculations were performed on an 800 MHz PC running Windows 2000 Professional

SUMMARY AND CONCLUSIONS

A set of simplified benchmark specifications has been constructed for the Np sphere experiment. The simplified benchmark model retains all of the important neutronic aspects of the original, and it substantially reduces the computer resources required for the calculation.

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