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Title: Analysis of the Np Sphere Experiment with MCNP5 and ENDF/B-VI

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Analysis of the Np Sphere Experiment with MCNP5™ and ENDF/B-VI

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ABSTRACT

Although neptunium is produced in significant quantities in 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. In the experiment, a 6-kg sphere of ^{237}Np was surrounded by nested hemispherical shells of highly enriched uranium to produce a critical configuration.

Subsequently, a detailed analysis of that experiment has been performed using the MCNP5 Monte Carlo code in conjunction with a nuclear data library based on ENDF/B-VI. The results of that analysis are presented herein. It is found that a relatively small fraction (~12%) of the fissions occur in the 237Np sphere and that criticality is underpredicted by ~0.01 Δk. This is approximately three times the size of the underprediction for a bare sphere of highly enriched uranium. Consequently, it is concluded that better cross sections are needed for ^{237}Np.

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ANALYSIS OF THE NP SPHERE EXPERIMENT WITH MCNP5™ AND ENDF/B-VI

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BACKGROUND

Power reactors produce substantial quantities of ^{237}Np and ^{239}Np

^{239}Np decays quickly ($t_{½}$ = 2.355 d), but ^{237}Np has a very long half life ($t_{½}$ = 2.14 x 10^{6} yr)

^{237}Np is produced by

- (n,2n) reactions on ^{238}U
- (n,γ) reactions on ^{236}U followed by β^- decay of ^{237}U

^{237}Np has an effective threshold for fission at ~550 keV

Critical mass of ^{237}Np is not well known, and neither are its cross sections

Previous estimates of the critical mass for ^{237}Np have been based primarily on replacement measurements (tens of grams)

NP SPHERE EXPERIMENT

Experiment was performed in 2002 on the Planet vertical assembly machine at the Los Alamos Critical Experiments Facility

6.0704 kg sphere of nearly pure ^{237}Np was surrounded by hemispherical shells of highly enriched uranium (HEU) to achieve criticality

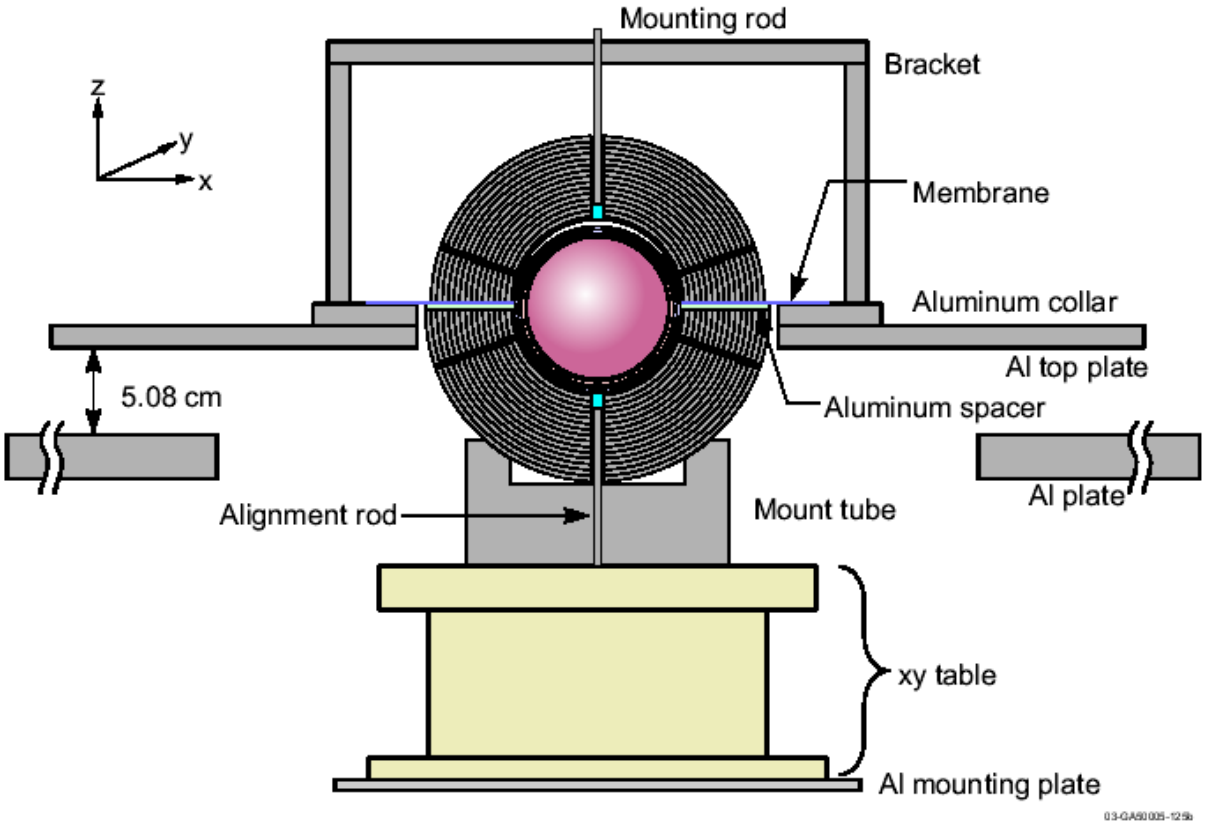
Radius of Np sphere was 1.6335 inches (implied density is 20.289 g/cm^3)

Sphere was enclosed in tungsten and two layers of nickel to reduce radiological dose from 310 keV γ rays from ^{233}Pa

Total mass of HEU shells was 62.555 kg

Benchmark k_{eff} for detailed model of experiment is 1.0026 ± 0.0034

SCHEMATIC OF NP SPHERE EXPERIMENT



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COMPOSITION OF NP SPHERE

Element	wt.%
Np (100% ^{237}Np)	98.8
U (78.7 wt.% ^{235}U)	0.035
Pu (88.2 wt.% ^{239}Pu)	0.036
Am (99.6 wt.% ^{243}Am)	0.183
Total	99.054

Sample assay did not dissolve completely, leaving 0.946 wt.% of the mass of the sphere unaccounted for

MCNP5 CALCULATIONS

MCNP5 calculations were performed to assess the impact of the “missing” mass of the sphere and to estimate k_{eff} for the experiment

Calculations employed a combination of the ACTI and ENDF66 continuous-energy nuclear data libraries, corresponding to ENDF/B-VI.8

Each calculation employed 650 generations of 10,000 neutrons each

First 50 generations were excluded from the statistics

Results therefore are based on 6,000,000 active neutron histories

REACTIVITY IMPACT OF "MISSING" MASS

Missing mass represented as	Δk	Fission Fraction	
		^{237}Np	^{235}U
Void	—	0.1264	0.8570
Carbon	-0.0005 ± 0.0004	0.1257	0.8577
Iron	-0.0002 ± 0.0004	0.1257	0.8576
Europium	-0.0011 ± 0.0004	0.1258	0.8576
Erbium	-0.0004 ± 0.0004	0.1259	0.8574
^{237}Np	0.0012 ± 0.0004	0.1278	0.8556

Reactivity impact of missing mass is ~ ± 0.0012 Δk

Benchmark k_{eff} for detailed model of experiment with "missing" mass represented as void becomes 1.0026 ± 0.0036

RESULTS FOR DETAILED MODEL OF EXPERIMENT

Parameter		Value
k_{eff}		0.9900 ± 0.0002
Fission Fraction, by Energy	Fast	0.9474
	Intermediate	0.0526
	Thermal	0.0
Fission Fraction, by Material	^{237}Np	0.1247
	^{235}U	0.8587

For comparison, k_{eff} for Godiva (bare HEU sphere) is 0.9965 ± 0.0002 (-0.0035 Δk relative to benchmark value)

^{237}Np, with 1 fission in 8, therefore produces an underprediction of ~ 0.009 Δk

Based on these results, T-16 estimates critical mass of ^{237}Np as ~ 57 kg

CONCLUSIONS

Reactivity impact of “missing” mass in Np sphere is small and can be accounted for by a slight increase in the uncertainty associated with k_{eff}

Relatively small fraction of fissions occurs in Np sphere (~ 1 in 8)

Critical mass of ^{237}Np is estimated to be ~ 57 kg

Based on ENDF/B-VI, calculated k_{eff} for this experiment is ~ 0.0125 Δk low

^{237}Np cross sections need to be improved