INL/CON-06-11913
PREPRINT

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American Nuclear Society

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June 2007

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INTRODUCTION

A series of neutron transport experiments was performed in 1989 and 1990 at NIST (National Institute of Standards and Technology) using a spherical stainless steel container and fission chambers. These experiments were performed to help understand errors observed in criticality calculations for arrays of individually subcritical components, particularly solution arrays [1-3]. They were supported by the U.S. Department of Energy, Environment and Health, Nuclear Criticality Technology and Safety Project. The intent was to evaluate the possibility that the criticality prediction errors stem from errors in the calculation of neutron leakage from individual components of the array. Thus, the explicit product of the experiments was the measurement of the leakage flux, as characterized by various Cd-shielded and unshielded fission rates. Because the various fission rates have different neutron-energy sensitivities, collectively they give an indication of the energy dependence of the leakage flux. Leakage and moderation were varied systematically through the use of different diameter spheres, with and without water. Some of these experiments with bare fission chambers have been evaluated by the International Criticality Safety Benchmark Evaluation Project (ICSBEP)[4].

MCNP Modeling

A lightly encapsulated Cf-252 neutron source was placed at the center of the spherical shell of stainless steel, and absolute fission rates of U-235, Pu-239, U-238, and Np-237 deposits in fission chambers positioned outside the spherical container were measured (see Figure 1). The measurements were performed for spherical containers of three different diameters; 3-in., 4-in. and 5-in., with and without water in the spherical container. Experiments were performed with bare fission chambers and cadmium-covered fission chambers. Detailed 3-D MCNP5 [5] models were set up consisting of the neutron source, stainless steel container, and two fission chambers for three different sphere sizes, fission chambers with and without cadmium cover, and dry and wet cases.

No fissionable deposit materials are in the model explicitly. Rather, the surface neutron flux at each deposit location was multiplied by each infinitely dilute fission cross section separately (F2 tally with FM multipliers). The top and bottom fission rates (per fissionable atom and per source neutron) were multiplied by their respective values of $4\pi R^2$ (0.7% different) and then the results were averaged. This parallels the processing of the experimental data.

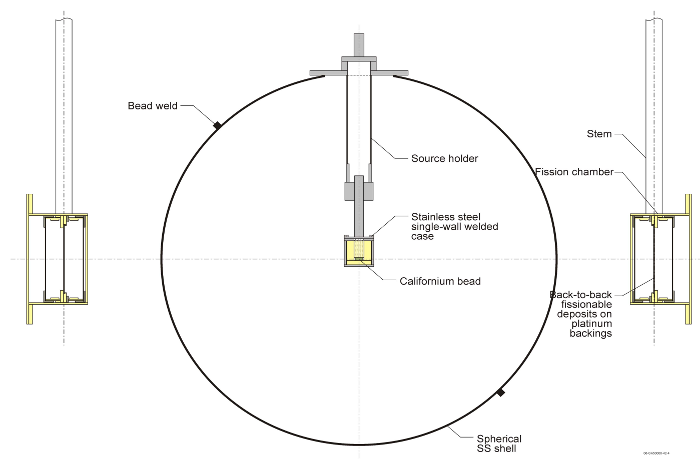

Fig. 1. A Typical Experimental Arrangement.

RESULTS

Forty experiment cases were calculated using MCNP5 and ENDF/B-VI cross section data, and results are presented in Table 1. The dry experimental results for the 5-in. diameter sphere were not reported. The Cf-252 emission spectrum was represented as a Watt spectrum with constants recommended by F. H. Froehner [6]. The fission rates are identified using a designation of the form fnm, where n is the last digit of the isotope's atomic number and m is the last digit of the isotope's atomic weight.

Significant C/E discrepancies are evident in Table 1. The fission rates that are sensitive to high energy neutrons, f28 and f37, tend to have C/E values that are low, ranging from 0.93 to 0.96. The fission rates that are sensitive to thermal neutrons, f25 and f49, have C/E values that range from 0.95 to 1.03. The C/Es tend to be closer to unity for f25 than for f49, perhaps because of the Pu-239 fission resonance near 0.3 eV. The C/Es for wet f25 and f49 are lower when the Cd covers were on the detectors. Under most conditions, there is no clear C/E trend with the size of the sphere. The calculated fission rates are sensitive to the representation of the Cf-252 emission spectrum. Thus, the C/E results suggest that there are still significant errors in ENDF/B-VI cross section data and/or the Cf-252 emission spectrum. The complete documentation of the evaluation through the ICSBEP project provides valuable information for criticality safety code and cross section data validation. Plans to evaluate C/Es further, using the upcoming ENDF/B-VII cross section data, are under way.

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Table 1
Comparison of Measured and Calculated Fission Rates

Condition	Sphere Diameter (inches)	C/E	f25	f49	f28	f37
Dry	3	E	1.273 ± 1.6%[a]	1.916 ± 1.5%	0.332 ± 1.7%	1.419 ± 1.8%
		C	1.263 ± 0.11%[b]	1.849 ± 0.10%	0.315 ± 0.13%	1.361 ± 0.11%
		C/E	**0.992 ± 1.6%[c]**	**0.965 ± 1.5%**	**0.949 ± 1.7%**	**0.959 ± 1.8%**
	4	E	1.279 ± 1.6%	1.924 ± 1.5%	0.334 ± 1.7%	1.420 ± 1.8%
		C	1.264 ± 0.11%	1.850 ± 0.10%	0.315 ± 0.13%	1.361 ± 0.11%
		C/E	**0.988 ± 1.6%**	**0.962 ± 1.5%**	**0.943 ± 1.7%**	**0.958 ± 1.8%**
Dry + Cd	3	E	1.288 ± 1.8%	1.946 ± 1.8%	0.333 ± 1.8%	1.433 ± 1.9%
		C	1.269 ± 0.11%	1.856 ± 0.11%	0.314 ± 0.13%	1.361 ± 0.11%
		C/E	**0.985 ± 1.8%**	**0.954 ± 1.8%**	**0.943 ± 1.8%**	**0.950 ± 1.9%**
	4	E	1.291 ± 1.8%	1.931 ± 1.8%	0.334 ± 1.8%	1.427 ± 1.9%
		C	1.270 ± 0.11%	1.857 ± 0.11%	0.314 ± 0.13%	1.362 ± 0.11%
		C/E	**0.984 ± 1.8%**	**0.962 ± 1.8%**	**0.940 ± 1.8%**	**0.954 ± 1.9%**
Wet	3	E	19.6 ± 1.7%	36.7 ± 1.5%	0.228 ± 1.8%	0.987 ± 1.8%
		C	20.2 ± 0.29%	37.0 ± 0.36%	0.215 ± 0.10%	0.942 ± 0.08%
		C/E	**1.031 ± 1.7%**	**1.008 ± 1.5%**	**0.943 ± 1.8%**	**0.954 ± 1.8%**
	4	E	45.7 ± 1.7%	82.3 ± 1.5%	0.199 ± 1.8%	0.873 ± 1.8%
		C	46.3 ± 0.21%	82.1 ± 0.24%	0.187 ± 0.11%	0.819 ± 0.09%
		C/E	**1.013 ± 1.7%**	**0.998 ± 1.5%**	**0.940 ± 1.8%**	**0.938 ± 1.8%**
	5	E	72.2 ± 1.7%	125.5 ± 1.5%	0.172 ± 1.8%	0.761 ± 1.8%
		C	72.6 ± 0.23%	124.5 ± 0.26%	0.162 ± 0.16%	0.704 ± 0.13%
		C/E	**1.006 ± 1.7%**	**0.992 ± 1.5%**	**0.942 ± 1.8%**	**0.925 ± 1.8%**
Wet + Cd	3	E	4.18 ± 1.7%	5.34 ± 1.9%	0.228 ± 1.9%	1.011 ± 1.9%
		C	4.20 ± 0.31%	5.21 ± 0.31%	0.214 ± 0.10%	0.942 ± 0.08%
		C/E	**1.005 ± 1.7%**	**0.976 ± 1.9%**	**0.939 ± 1.9%**	**0.932 ± 1.9%**
	4	E	5.51 ± 1.7%	7.04 ± 1.9%	0.199 ± 1.9%	0.877 ± 1.9%
		C	5.52 ± 0.30%	6.90 ± 0.55%	0.187 ± 0.11%	0.818 ± 0.09%
		C/E	**1.002 ± 1.7%**	**0.980 ± 2.0%**	**0.940 ± 1.9%**	**0.933 ± 1.9%**
	5	E	5.86 ± 1.7%	7.74 ± 1.9%	0.171 ± 1.9%	0.748 ± 1.9%
		C	5.89 ± 0.39%	7.37 ± 0.66%	0.161 ± 0.16%	0.702 ± 0.14%
		C/E	**1.005 ± 1.7%**	**0.952 ± 2.0%**	**0.942 ± 1.9%**	**0.939 ± 1.9%**

[a]The combined uncertainty for all known factors.
[b]The statistical uncertainty only.
[c]Root-sum-of squares combination for C and E.