Neutron Transmission Calculations for Several Moderated Plutonium Systems

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INTRODUCTION

We are interested in the calculation and inference of subcritical multiplication. In particular, we wish to compare fixed-source (FS) Monte Carlo calculations with MCNP™ criticality (KCODE) simulations that assume, by definition, the system is in the fundamental mode. In previous comparisons, we considered a bare plutonium source fabricated at Los Alamos National Laboratory (LANL) for criticality experiments; we also examined this source in an aluminum heat sink [1]. Since then, our codes have improved and criticality measurements have been published on the plutonium sphere with a variety of hydrogenous and metallic reflectors [2-3].

Such experiments become increasingly valuable for code benchmarking efforts. Working with special nuclear material (SNM) is difficult in today's regulatory environment and simulations are more heavily relied upon for applications like radiation detector development and, ironically, planning for criticality experiments.

The Feynman Variance-to-Mean (FVM) technique is an experimental method used to infer subcritical system multiplication. Like FVM, the californium source-driven noise analysis (CSDNA) technique used in [2] has also been synthesized. In this work, we model one of the acrylic-reflected geometries from [2] and infer system multiplication using the FVM technique on simulated "list mode", or time-tagged pulse-train neutron data. We are interested in how materials like polyethylene or acrylic compare with other hydrogenous moderators under KCODE and FS assumptions.

In this work we use MCNP6, the merged version of two widely used Los Alamos Monte Carlo codes (MCNP and MCNPX) to study neutron transport characteristics for several moderated plutonium systems. Public release of this new code is planned for the summer of 2010 and internal testing is ongoing at Los Alamos [4].

DESCRIPTION OF THE ACTUAL WORK

We used MCNP6 to model a simple spherical geometry (Fig. 1) in which several moderators of varied thickness surround a steel-clad 4.4 kg alpha-phase plutonium sphere. Shell thickness was varied in 0.5 cm increments from 4-10 cm, 1 cm increments from 10-20 cm, 2 cm increments from 20-30 cm, and 5 cm increments from 30-50 cm radii. A small air gap exists between 3.8558 and 4 cm radii, the region between cladding and first moderator shell; the source is described in [1].

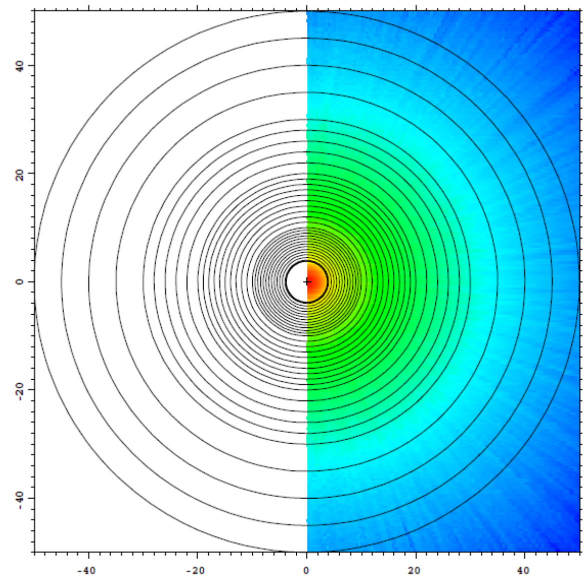

Fig. 1. MCNP6 cross-sectional plot of the geometry

In addition to water, polyethylene, and acrylic, five high-explosive (HE) related moderators were considered in this work: two commercially available HE surrogate materials, referred to here as mock1 and mock2, Composition B, a ubiquitous explosive known simply as "comp-b", and two plastic bonded explosives (PBX) employed in nuclear ordnance, 9501 and 9502. The three HE materials were selected to represent a range of hydrogen content [5].

Moderator material composition and density are shown in Table I. The density ranged from 1.6 to 1.9 g/cc while H atom fraction varied from 0.20228 to 0.31558.

Table I. Atom fractions for several HE moderators

	Mock HE1	Mock HE 2	Comp B	PBX 9501	PBX 9502
g/cc	1.60	1.89	1.73	1.83	1.90
H	0.31558	0.20228	0.26639	0.29008	0.24264
C	0.22682	0.21492	0.21926	0.14599	0.25275
N	0.29586	0.17699	0.22848	0.28053	0.24236
O	0.15779	0.27813	0.28586	0.28340	0.24207
F	-	0.05057	-	-	0.01484
Mg	-	0.02528	-	-	-
Si	-	0.03793	-	-	-
Cl	0.00394	0.01391	-	-	0.00534

Atom fractions for the HE were taken from [6] and it is important to note these compositions are not unique; multiple references may report slightly different values. Moreover, conversion between atom and weight fractions and inclusion or omission of trace materials and impurities may introduce errors. The mock explosive fractions are from [7].

For each moderator, we made 31 KCODE simulations; 1000 cycles were tracked at 10,000 neutrons per cycle and the first 100 cycles were inactive, or skipped. Of these 186 (31x6) calculations, several were repeated in a fixed-source mode and a smaller subset was modeled in FS mode to obtain list-mode data for FVM analysis.

Approximating the subcritical multiplication factor in a FS calculation can be done by manipulation of MCNP output (e.g. average value of ν is found by dividing the fission neutrons gained by the fission neutrons lost in the physical event weight balance table); this factor is obtained directly in the eigenvalue calculations.

RESULTS

Portions of our results are shown in Figs. 2-4. KCODE results are shown in Fig. 2 and neutron transmission, defined as the ratio of neutrons exiting the moderator to those entering, is shown in Fig. 3. In terms of subcritical multiplication, water behaves like the HE-related moderators and is quite similar to comp-b. The cases considered here, save beryllium, are well subcritical. For transmission, proper normalization or scaling of the tally results from a KCODE simulation is not an issue because we are interested in the ratio of two tallies. We find good agreement between KCODE and FS results.

The average neutron energy causing fission is shown in Fig. 4. While the HE-related moderators are similar, the average fission-producing neutron energy in those cases is higher than that in water. Limited data for acrylic, polyethylene, and beryllium is also shown [3].

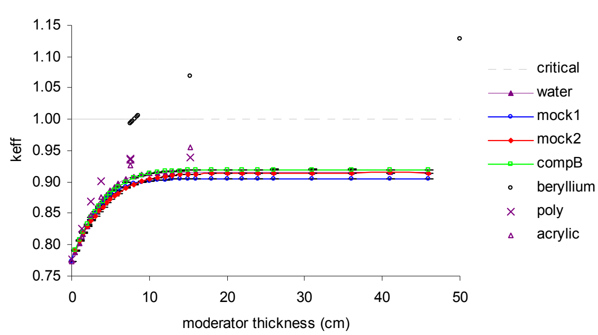

Fig. 2. KCODE criticality results from several moderators

Results from the other two moderators (PBX 9501 and PBX 9502), the FVM analysis, as well as conclusions drawn from the simulations, are discussed in our full paper.

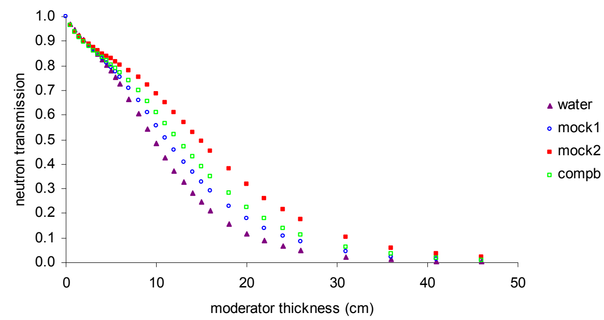

Fig. 3. Neutron transmission from several moderators

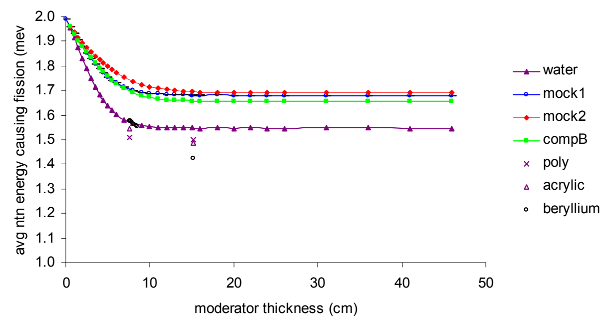

Fig. 4. Average neutron energy causing fission

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