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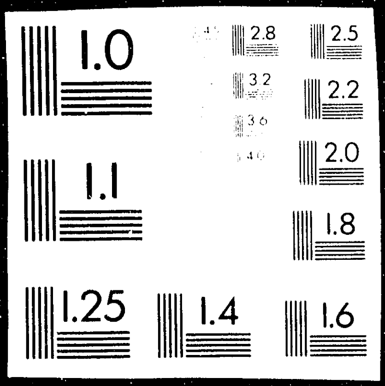

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TITLE: MCNP NEUTRON BENCHMARKS

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Over 50 neutron benchmark calculations have recently been completed as part of an ongoing program to validate the MCNP Monte Carlo radiation transport code.[1] The new and significant aspects of this work are as follows:

1. These calculations are the first attempt at a validation program for MCNP and the first official benchmarking of version 4 of the code.
2. We believe the chosen set of benchmarks is a comprehensive set that may be useful for benchmarking other radiation transport codes and data libraries.
3. These calculations provide insight into how well neutron transport calculations can be expected to model a wide variety of problems.

I. THE BENCHMARKING PROJECT

The benchmark calculations reported here are part of an ongoing multi-year, multi-person effort to benchmark version 4 of the MCNP code. MCNP is a Monte Carlo three-dimensional, general purpose, continuous-energy neutron, photon, and electron transport code. It is used around the world for many applications including aerospace, oil-well logging, physics experiments, criticality safety, reactor analysis, medical imaging, defense applications, accelerator design, radiation hardening, radiation shielding, health physics, fusion research, and education.[2] The first phase of the benchmark project consisted of analytic and photon problems.[3,4] The second phase consists of the ENDF/B-V neutron problems reported here and in more detail in our comprehensive report.[5] A cooperative program being carried out at General Electric, San Jose, consists of light water reactor benchmark problems.[6,7] A subsequent phase focusing on electron problems is planned.

The photon and neutron benchmarks in the first two phases were selected from the benchmark set used by Wilcox and Lent to benchmark the Livermore COG Monte Carlo code.[8] Our selection of problems differed from Wilcox and Lent in that we chose a subset of their problems and in some cases we substituted experimental problems for purely calculational ones. We believe that the photon and neutron benchmarks we have chosen (largely to the credit of Wilcox and Lent) represent a large class of transport problems, and we would recommend them for the benchmarking of other radiation transport codes and data libraries.

II. LIVERMORE PULSED SPHERES

The neutron benchmarks fall into three major categories of problems. The first is the Livermore pulsed spheres.[9,10] These utilize a 14-MeV neutron source and measure penetration of a wide variety of materials of various thicknesses at several angles. The results for 28 spheres are tabulated in Table I. The MCNP agreement with experiment is generally very good. Where it is not good, the disagreement appears to be due to cross section uncertainty as demonstrated by comparisons using ENDF/B-VI.

III. OAK RIDGE FUSION SHIELDING BENCHMARKS

The second family of neutron benchmarks are nine of the fusion shielding problems of Santoro at Oak Ridge National Laboratory.[11,12] These problems involve streaming, deep penetration, and generation of neutron-induced photons. Fourteen-Mev neutrons are emitted isotropically and stream down an iron pipe embedded in concrete before penetrating either a 30.5 cm iron shield or a 46 cm iron and 10 cm of borated polyethylene shield. Neutrons and secondary photons are then measured at points on and off axis beyond the shield. Considering the deep penetration of up to 25 mean free paths, both neutron and photon results are good as indicated in Table I.

IV. CRITICALITY PROBLEMS

The third family of neutron benchmarks are 9 criticality problems.[13] The critical assemblies and their calculated k_{eff} values are reported in Table I. In all cases MCNP agreed with the measured value of $k_{eff} = 1$. Although it is our experience that Monte Carlo calculations of the k_{eff} eigenvalue can be very accurate, the corresponding calculation of the flux distribution, or eigenfunction, can at the same time be inaccurate with large flux tilts for larger systems.

V. SUMMARY

We have calculated and reported over fifty benchmark problems in three major categories. These calculations demonstrate the accuracy of the Monte Carlo method and the MCNP code in particular. They provide a comprehensive set of benchmark problems for other codes or data sets. And they indicate the degree to which we can rely on calculational results.

TABLE I

NEUTRON BENCHMARKS

Livermore Pulsed Sphere Benchmarks:

Material	mfp	calc/exp 12-16 MeV	calc/exp 2-16 MeV
^{6}Li	0.5	.981	.981
	1.6	1.019	1.030
^{7}Li	0.5	.990	.985
	1.6	1.017	1.008
Be	0.8	.937	.997
C	0.5	.974	.990
	2.9	.950	.973
N	1.1	.866	.950
	3.1	.812	.972
	7.7	.713	.931
N (ENDF/B-VI)	1.1	.910	.975
	3.1	899	1.009
	7.7	.868	.973
O	0.7	.921	.988
Mg	0.7	1.046	1.033
	1.9	.994	.960
Al	0.9	.940	.948
	2.6	.786	.839
Ti	1.2	1.069	.992
	3.5	1.077	.930
Fe	0.9	1.006	1.006
	4.8	.937	.948
Pb	1.4	.873	.851
H_2O	1.1	.881	.946
	1.9	.961	1.066
D_2O	1.2	.865	.914
	2.1	.983	1.025
CH_2	0.8	.973	.999
	3.5	.884	.969
CF_2	0.9	.957	.976
	2.9	.766	.782
Concrete	2.0	.987	1.041

TABLE I (cont.)

Fusion Shielding Benchmarks:

Shield thickness	detector location	particle type	calc/ experiment
0	on-axis	neutron	1.12
30.5	on-axis	neutron	1.00
30.5	off-axis	neutron	1.28
46 + 10	on-axis	neutron	1.00
46 + 10	off-axis	neutron	0.89
30.5	on-axis	photon	0.85
30.5	off-axis	photon	0.85
46 + 10	on-axis	photon	0.78
46 + 10	off-axis	photon	0.77

Criticality Benchmarks:

Assembly	keff
Godiva (94.7% U-235)	.9976
Jezebel (95.5% Pu-239)	.9986
Jezebel (80.0% Pu-239)	1.0075
Uranium Cylinder (10.9% U-235)	1.0024
Uranium Cylinder (14.11% U-235)	1.0003
Graphite-Tamped 93.5% U-235 Sphere	.9981
Water-Reflected 97.7% U-235 Sphere	.9956
Three Uranium Cylinders	.9991
3x3 Array of Plutonium Fuel Rods	1.0000

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