LEGIBILITY NOTICE

A major purpose of the Technical Information Center is to provide the broadest dissemination possible of information contained in DOE's Research and Development Reports to business, industry, the academic community, and federal, state and local governments.

Although a small portion of this report is not reproducible, it is being made available to expedite the availability of information on the research discussed herein.

1

LA-UR -90-2860

LA-UR--90-2860

DE90 016445

SEP 0 7 1990

Los Alamos National Laboratory is operated by the University of California for the United States Department of Energy under contract W-7405-ENG-36

TITLE: MONTE CARLO PHOTON BENCHMARK PROBLEMS

AUTHOR(S): Daniel J. Whalen, David E. Hollowell, and John S. Hendricks

SUBMITTED TO: International Topical Meeting on Advances in Mathetmatics, Computations, and Reactor Physics, April 28 - May 1, 1991, Pittsburgh, PA.

Los Alamos National Laboratory
Los Alamos, New Mexico 87545

FORM NO 836 R4
ST NO 2629 5/81

DISTRIBUTION OF THIS DOCUMENT IS UNLIMITED

MONTE CARLO PHOTON BENCHMARK PROBLEMS

by

Daniel J. Whalen
University of California, Los Angeles, CA 90024

David E. Hollowell and John S. Hendricks
Los Alamos National Laboratory, Los Alamos, NM 87545

ABSTRACT

Photon benchmark calculations have been performed to validate the MCNP Monte Carlo computer code. These are compared to both the COG Monte Carlo computer code and either experimental or analytic results. The calculated solutions indicate that the Monte Carlo method, and MCNP and COG in particular, can accurately model a wide range of physical problems.

I. INTRODUCTION

The importance of accurate radiation transport modeling codes has dramatically increased in recent years. Faster and better computers along with great improvements in calculational techniques have made greater reliance upon calculations feasible. Meanwhile, the cost of experiments has risen making calculational approaches even more attractive. Calculations also provide greater insight into physical processes and are safer for problems in hazardous environments.

Requirements for increased quality assurance in design have also increased. Not only are more calculations with greater detail being performed, but more assurance of the accuracy of these calculations is being demanded. Regulatory agencies are insisting upon better code validation, and code quality control can even become a legal issue in tort law cases.

To ensure that the predictive results of a computer code are accurate, validation of the code by comparison to known results, either analytic or measured, is crucial. We report here, for the first time, a series of MCNP photon benchmark calculations. MCNP[1,2] is a general purpose Monte Carlo radiation transport code for three-dimensional, continuous energy, time-dependent neutron, photon, and electron transport. It is used at many installations around the world and is increasingly relied upon by the aerospace, medical, oil well logging, reactor analysis, criticality safety, fusion, and other communities. The benchmark comparisons are a series of nine families of neutron and photon benchmarks used to validate the COG Monte Carlo code developed at Lawrence Livermore National Laboratory.[3] The COG benchmarks are a carefully documented set of problems covering a wide range of radiation transport problems. Thus, the comparison presented here is to both COG and experimental or analytical results.

At this time four of the nine families of COG benchmarks have been calculated. These four problems are all photon problems; we plan to do the neutron problems soon. The results show excellent agreement between MCNP, COG, and the measured or analytical results. Thus, they increase our confidence in the codes and further define the degree of validity of such calculations. These calculations also demonstrate the applicability of the Monte Carlo method to the tested classes of problems.

We will now summarize the benchmark problems and display our results.

II. SPHERICAL PROBLEM WITH A CONSTANT CROSS SECTION AND ISOTROPIC SCATTERING

The spherical benchmark with a constant cross section and isotropic scattering is a family of problems with analytic solutions.

In the first problem, an isotropic point source is in an infinite medium, with the scattering being 30% of the total cross section. In the second problem, scattering is 90% of the total cross section. Both MCNP and COG agree with the analytic solution.[4] In addition, MCNP was run with scattering being 0% of the cross section (pure absorption). As expected, at a distance r the number of particles surviving per source particle was e^{-r}.

III. HUPMOBILE THERMOLUMINESCENT SPECTROMETER EXPERIMENTS

The Hupmobile thermoluminescent dosimeter experiments[5,6] were conducted to benchmark the LBL SORS-G Monte Carlo radiation transport code. Six experiments were performed in which a point source of gamma rays or x rays was placed in air one meter from one end of a teflon cylinder along its axis. Seventeen LiF TLDs were imbedded at specified locations inside the cylinder along its axis. The ratios of the dose at these TLDs to a non-imbedded reference TLD were measured from six photon sources ranging from 39.9 keV to 1.33 Mev. Typical results are shown in Fig. 1 indicating that MCNP and COG both agree with the measurements.

IV. UNIFORM ^{60}CO SOURCE ON AN INFINITE AIR-GROUND INTERFACE EXPERIMENT

In the ^{60}Co air-over-ground problem, the radiation dose that a person standing in a field upon which cobolt-60 fallout has been uniformly spread is determined. There have been at least three measurements of this setup and several calculational efforts. This problem is number 4.0 in the American Nuclear Society ANS-6 Standards Committee compilation of reference shielding problems.[7] The person is represented by a detector three feet above the ground and the kerma angular distribution is measured and calculated at that point as illustrated in Fig. 2.

V. GAMMA-RAY SKYSHINE EXPERIMENT

The gamma-ray skyshine problem consists of a collimated source two meters above ground directed into a 150.5° cone into the air. Dose rates at detectors one meter above ground at 100 meter intervals (out to 700 meters) were measured.[8] The MCNP results are compared to the experimental results in Fig. 3 and are shown to have excellent agreement.

VI. DISCUSSION

Although all of the benchmarks are simple conceptually, they are very challenging numerically. All involve deep penetration. Two have a difficult air-ground interface. All require a wide range and careful use of variance reduction techniques.

VII. SUMMARY

Radiation transport computer code validation by comparison to analytical or experimental benchmarks calculations is more important than ever. Four families of photon benchmarks from the COG benchmark set have been calculated with MCNP. Results show excellent agreement between both codes and the measured/analytical answers, thus validating these codes, their data bases, and the Monte Carlo method for these classes of problems.

VIII. REFERENCES

1. Judith F. Briesmeister, Editor, "MCNP - A General Monte Carlo Code for Neutron and Photon Transport, Version 3A," Los Alamos National Laboratory Report LA-7396-M, Rev. 2 (1986).

2. Judith F. Briesmeister, "MCNP - A General Monte Carlo Radiation Transport Code, Version 4," Los Alamos National Laboratory Report (1991) in preparation.

3. Thomas P. Wilcox, Jr., and Edward M. Lent, "COG - A Particle Transport Code Designed to Solve the Boltzmann Equation for Deep-Penetration (Shielding) Problems," Volume 4, "Benchmark Problems," Lawrence Livermore National Laboratory Report M-221-4 (12/2/88)

4. K. N. Case, F. deHoffman, and G. Placzek, *Introduction to the Theory of Neutron Diffusion,* Vol. 1, U. S. Government Printing Office, Washington, D.C. (1953)

5. E. Goldberg, D. J. Groves, D. E. Jones, H. F. Lutz, K. F. Petrock, G. A. Pohl, and D. H. White, "Experiments to Test Validity of SORS-G Monte Carlo Code: I. Au-198 and Cs-137," Lawrence Livermore National Laboratory, Livermore, CA, UCID-121 (1967)

6. E. Goldberg, D. J. Groves, D. E. Jones, H. F. Lutz, K. F. Petrock, G. A. Pohl, D. H. White and R. Worley, "Experiments to Test Validity of SORS-G Monte Carlo Code," Lawrence Livermore National Laboratory, Livermore, CA, UCID-368 (1969)

7. A. E. Profio, "Shielding Benchmark Problems," Radiation Shielding Information Center, Oak Ridge, TN, ORNL-RSIC-25, (ANS-SD-9)(1969)

8. R. R. Nason, J. K. Shultis, R. E. Faw, and C. E. Clifford, "A Benchmark Gamma-Ray Skyshine Experiment," *Nuclear Science and Engineering,* **79**, 404-416 (1981)

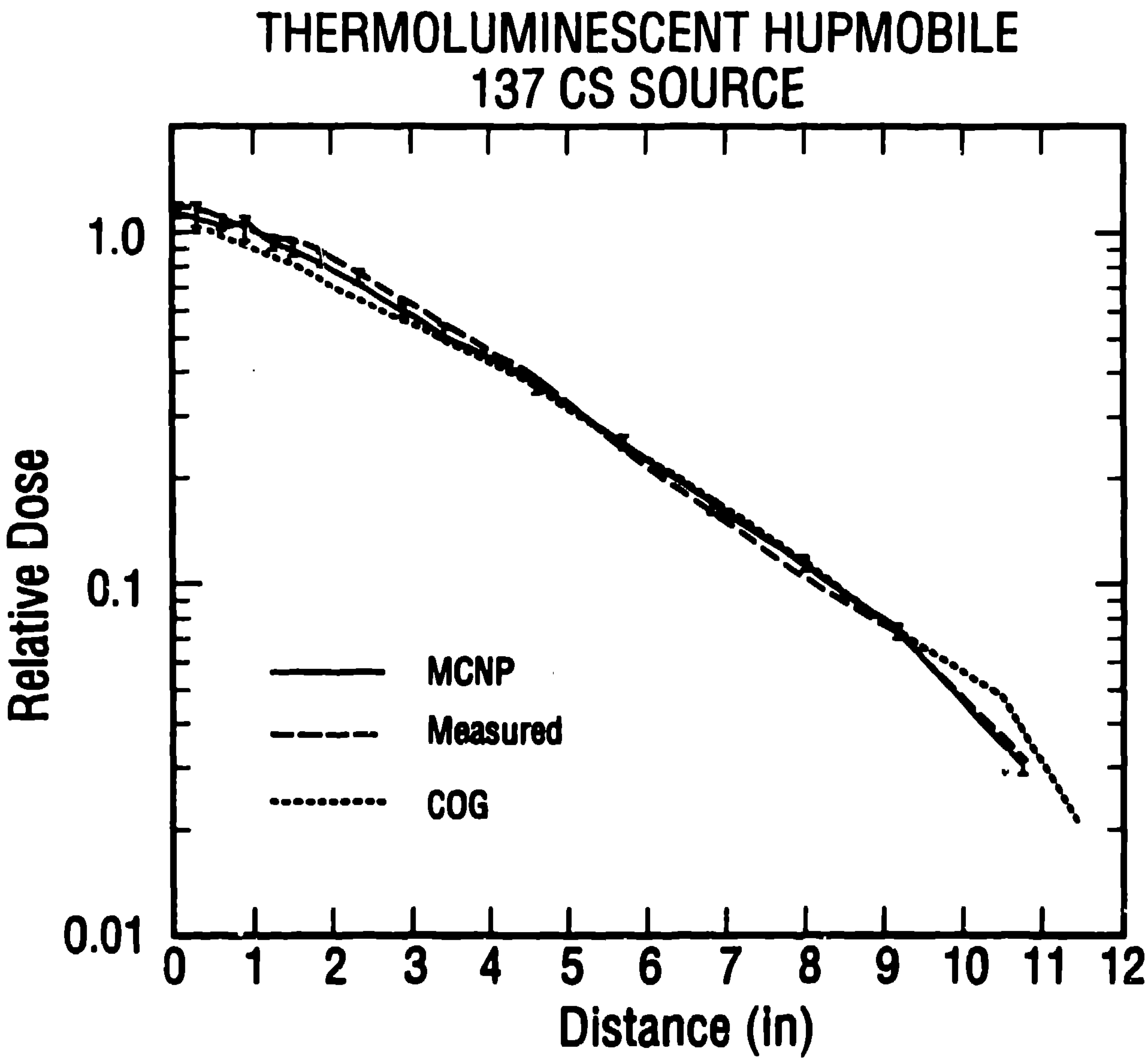

Fig. 1. Hupmobile TLD results for cesium x-rays (661 KeV). The lines represent MCNP, COG, and measured results.

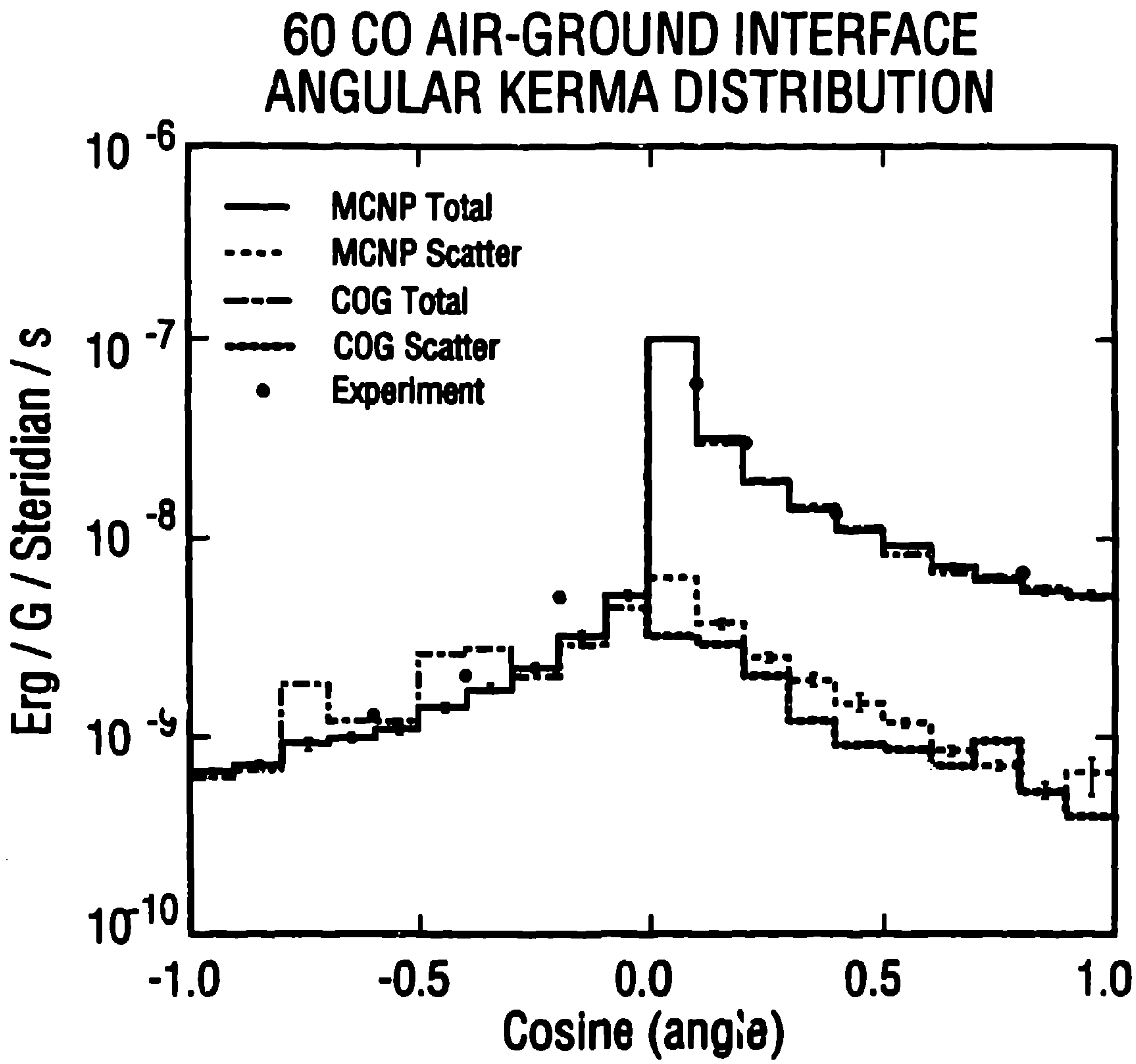

Fig. 2. Kerma angular distribution at detector for ^{60}Co problem. The histograms represent MCNP and COG calculations. The points represent the experimental measurement. Cos θ = 1.0 when looking directly toward the ground from the detector location.

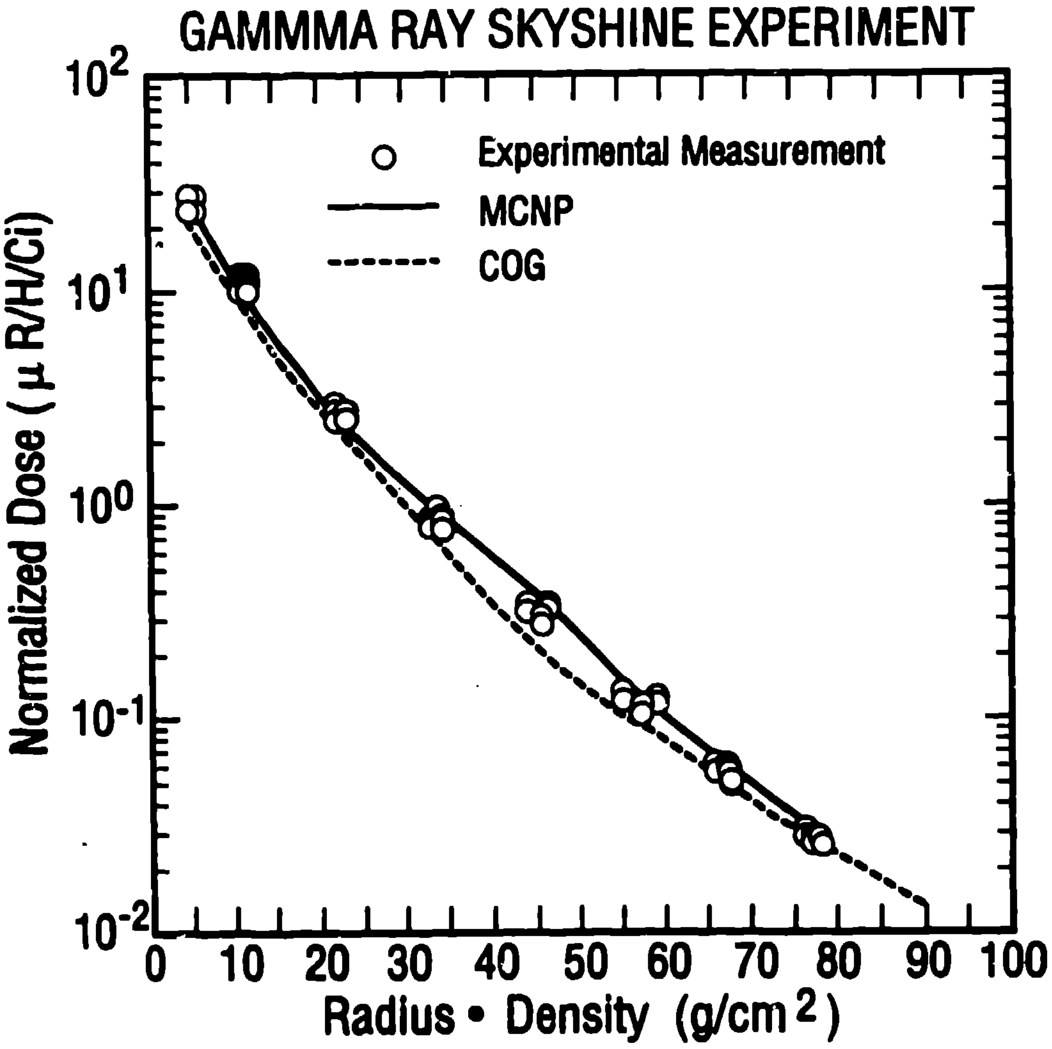

Fig. 3. Gamma-ray skyshine experiment results. The values of flux as a function of distance are shown for MCNP, COG, and the experimental measurement.