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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.

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.

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.[4] In the first problem, an isotropic photon point source is in an infinite medium, with scattering accounting for 90% of the total photon interaction cross section. In the second problem, scattering accounts for 30% of the total cross section. In addition, MCNP was run with a pure absorption (0% scattering) interaction cross section. The one-group interaction cross section in each case is normalized to 1 cm^{-1}. In the 0% case, one expects the number of particles existing a distance r from the source to decrease as e^{-r}.

Figure 1 shows the results of both analytic and Monte Carlo modeling of the case with 90% scattering. This information is also in Fig. 2, which shows (as a function of distance from the source) the difference between MCNP and the analytical result. This difference is scaled to the Monte Carlo statistical deviation. If numerical and analytical models agree, this scaled difference should be between +1 and -1 approximately 67% of the time. As both MCNP and COG produce this agreement at least 67% of the time, these Monte Carlo codes accurately model the analytic benchmark.

Similar comparisons have been obtained for the 30% and 0% scattering benchmarks. Due to the reduced scattering cross section in both of these cases, there is no local maximum photon current away from the source (as there is at 1.5 cm in the 90% scattering case). As expected, the Monte Carlo models agree (within one standard deviation) with the analytic results 67% of the time, and thus we conclude that the Monte Carlo codes accurately model these analytic benchmarks.

HUPMOBILE THERMOLUMINESCENT DOSIMETER EXPERIMENTS

The Hupmobile thermoluminescent dosimeter (TLD) 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 nonimbedded reference TLD were measured from six photon sources ranging from 39.9 keV to 1.33 Mev. To date, MCNP has been used to model three of these six photon sources: ^{60}Co (1.33 and 1.17 MeV), ^{137}Cs (661 keV), and ^{198}Au (412 keV).

A sample result of such modeling is shown in Fig. 3. Agreement between Monte Carlo model and experiment is actually better than shown in Fig. 3, as the experimental values are only accurate to somewhere between a few percent and 10%. For the ^{60}Co, ^{137}Cs, and ^{198}Au sources, the MCNP results always agree (within a standard deviation) with the experimental results (within experimental uncertainty) at all seventeen detector locations. Thus, the Monte Carlo technique models the experimental benchmark, within the uncertainty of the Monte Carlo and the experimental method.

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

In the ^{60}Co air-over-ground benchmark problem, the dose build-up factor is determined for a person standing in a field upon which ^{60}Co fallout has been uniformly spread. The person is represented by a detector three feet above the ground, and the build-up factor is the ratio of the total dose to the dose from uncollided radiation. This benchmark also includes the determination of the angular dependence of the kerma rate at the detector. In the standard field experiment, results for an infinite ^{60}Co source are extrapolated from a finite set of ^{60}Co point sources. This verification problem is number 4.0 in the American Nuclear Society ANS-6 Standards Committee compilation of reference shielding problems.[7]

The Monte Carlo models of this problem find a dose build-up factor of 1.19±.01 (MCNP point detector), 1.20±.01 (MCNP surface tally), and 1.18±.0.02 (COG point detector). The experimental determinations of this factor range from 1.15 to 1.38, and other numerical/analytical determinations range from 1.16 to 1.23.[7] Thus, the MCNP and COG models agree with experiments and other models, within the uncertainty and variation of these experiments and other models.

Figure 4 contains the results of models and an experiment that approximates the angular dependence of radiation from the uniform ^{60}Co layer. Considering the uncertainty in the experimental measurements of the kerma rate, and the experimental approximations that exist from utilizing discrete point radiation sources, the MCNP and COG models provide a reasonable match to experiment. This match is best at large kerma rates, where experimental and statistical uncertainty are the smallest.

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 difficulties in numerically modeling the actual experimental set-up include an imprecise knowledge of the radiation pattern of the cobalt source, and an imprecise knowledge of the terrain (which is known not to be flat) of the experimental field.

Results of the MCNP and COG models and the experiment are shown in Fig. 5. The dose (per source Curie) is plotted as a function of detector distance (atmospheric column density) from the source. Because of uncertainties in the source pattern and the terrain (numerically modeled as flat), further quantitative comparison of MCNP and experiment does not appear valuable. It should be noted that the worst agreement between numerical model and experiment typically occurs at distances with known experimental terrain anomalies. With these considerations, it can be seen that the Monte Carlo models provide a reasonable determination of skyshine dose.

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.

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.

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).

Figure 1. The Number of Photons (per Initial Photon) Surviving at Given Distance From the Source is Shown for Material With a 1 cm^{-1} Interaction Cross Section. Scattering Accounts for 90% of This Cross Section.

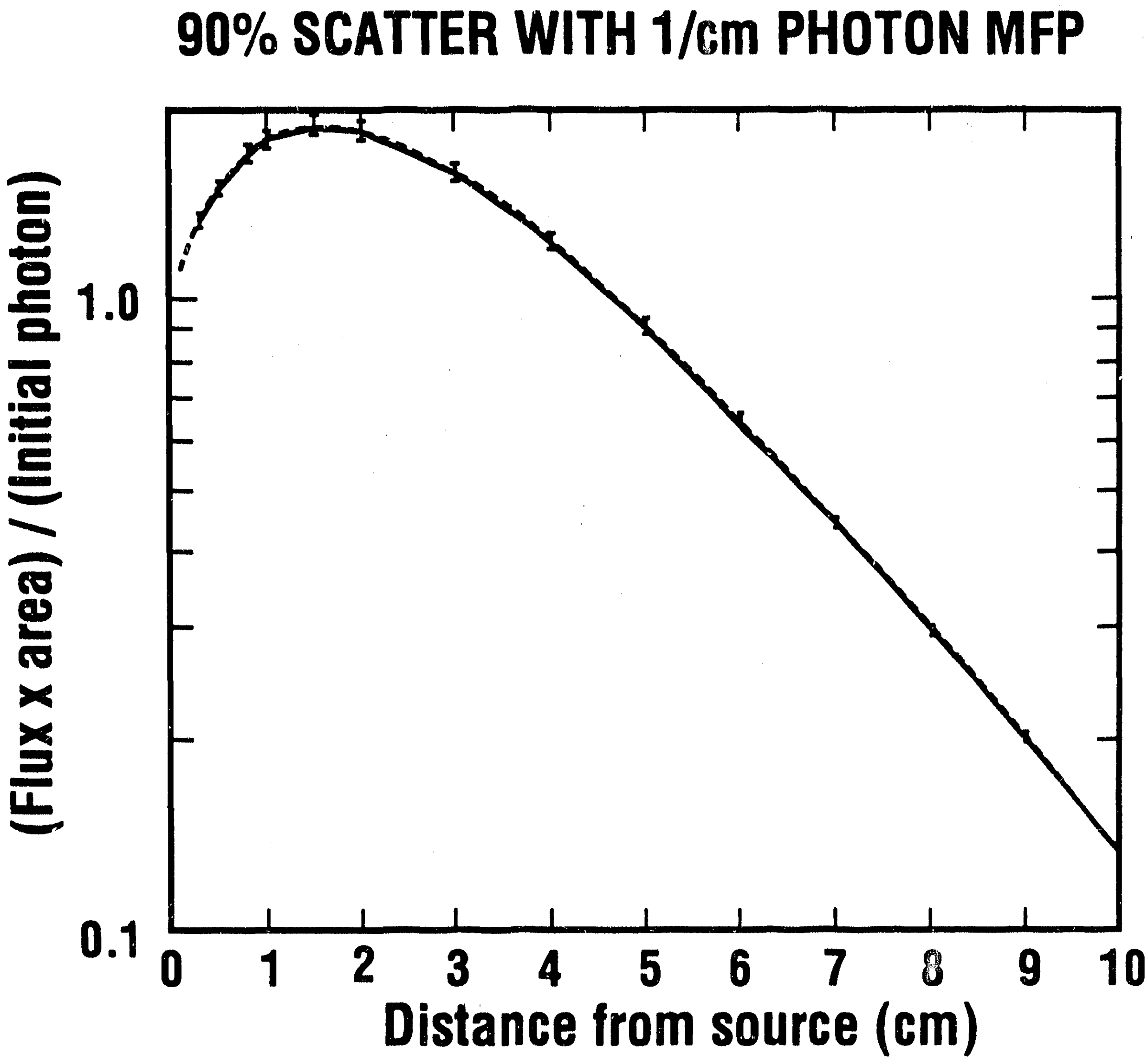


Figure 2. The Ordinate of This Plot Shows the Difference Between the Analytic Solution and the Monte Carlo Model, as Scaled to the Monte Carlo Standard Deviation. Statistically, the two Solutions Agree if the Ordinate Value is Between +1 and -1 Approximately 67% of the Time.

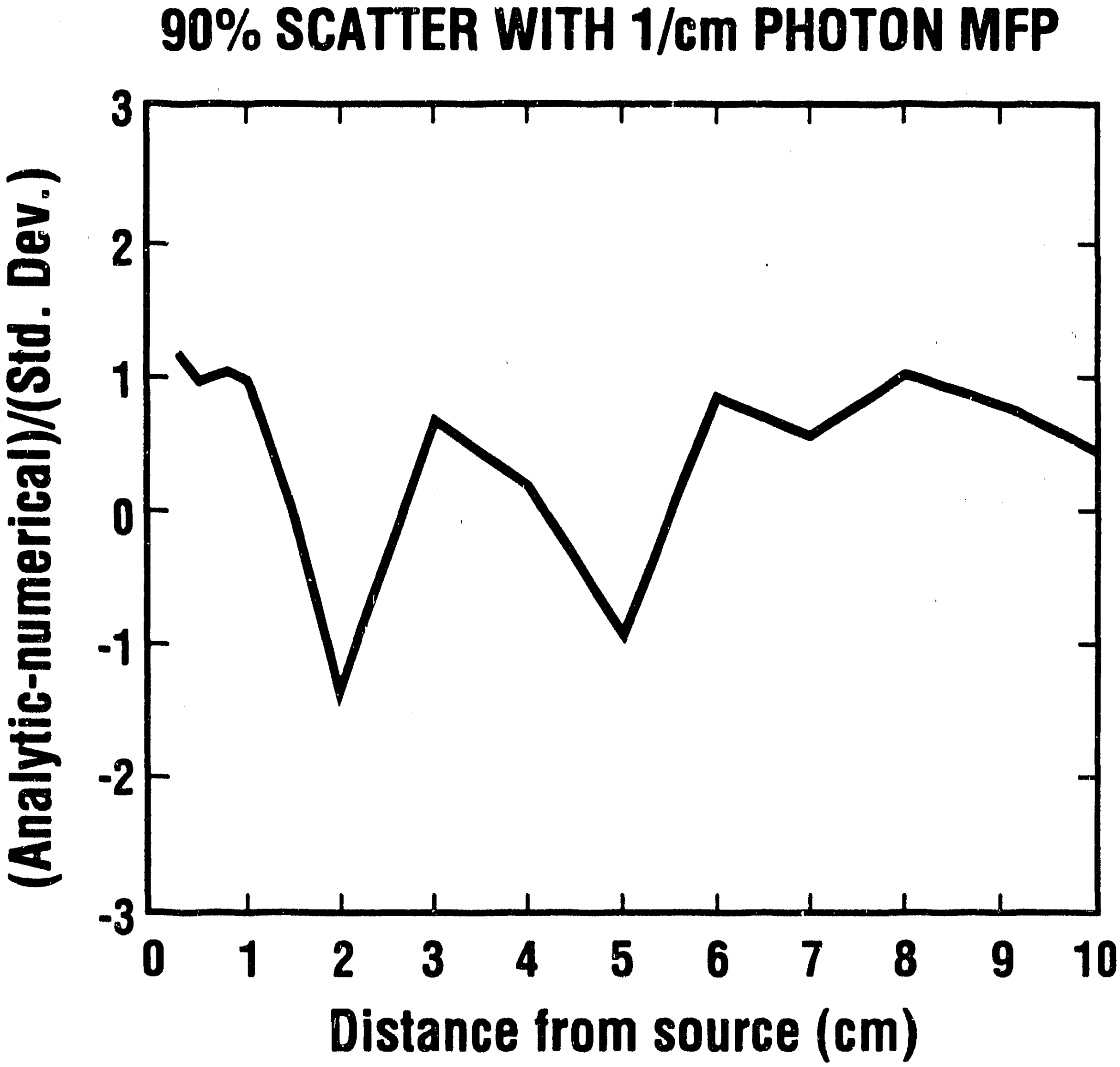


Figure 3. Hupmobile TLD Results for Cesium X-rays (661 keV). The Lines Represent MCNP, COG, and Measured Results.

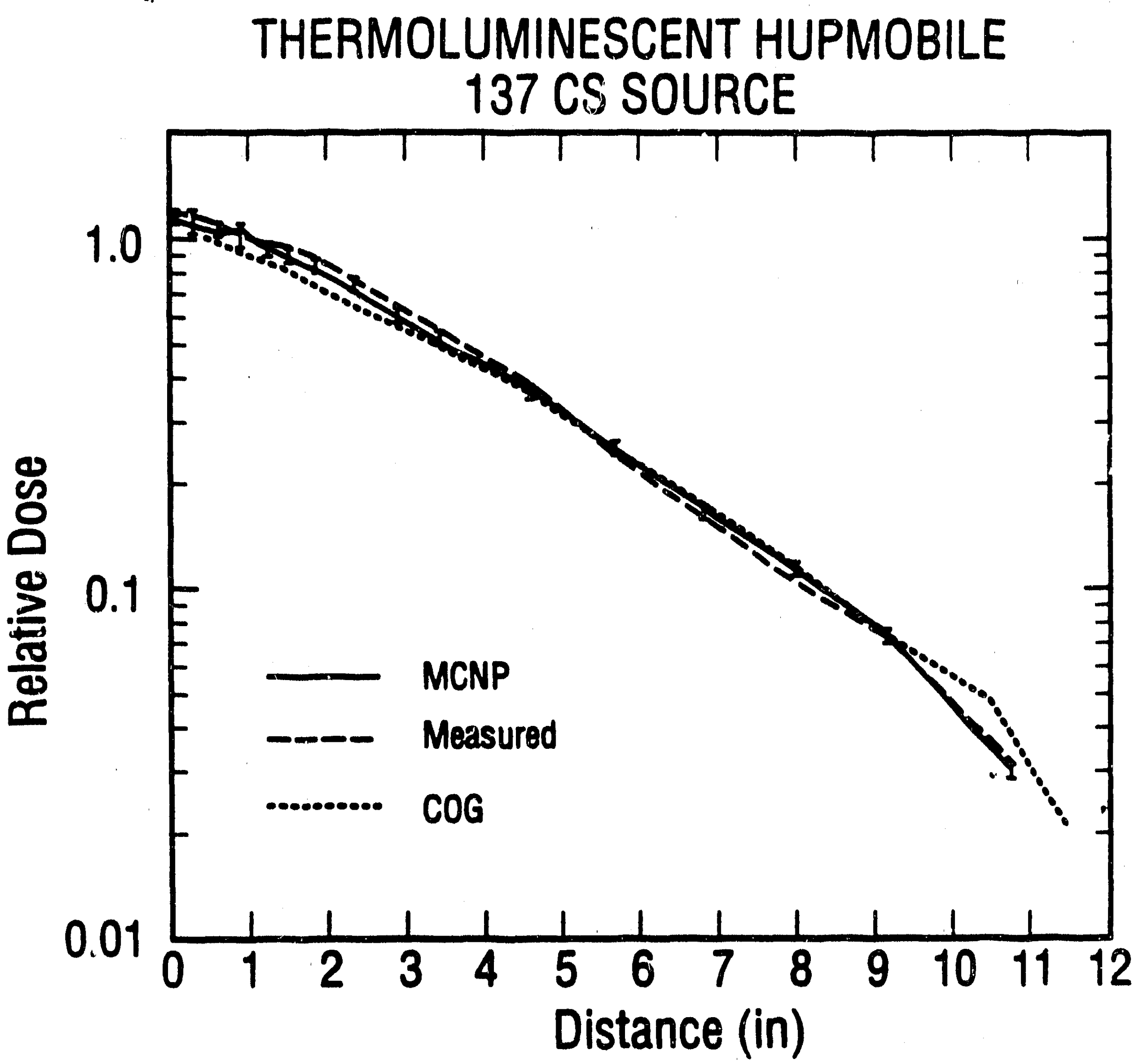


Figure. 4. Kerma Angular Distribution at Detector for ^{60}Co Problem. The Histograms Represent MCNP and COG Calculations. The Points Represent the Experimental Measurement. Cos $\theta = 1.0$ When Looking Directly Toward the Ground From the Detector Location.

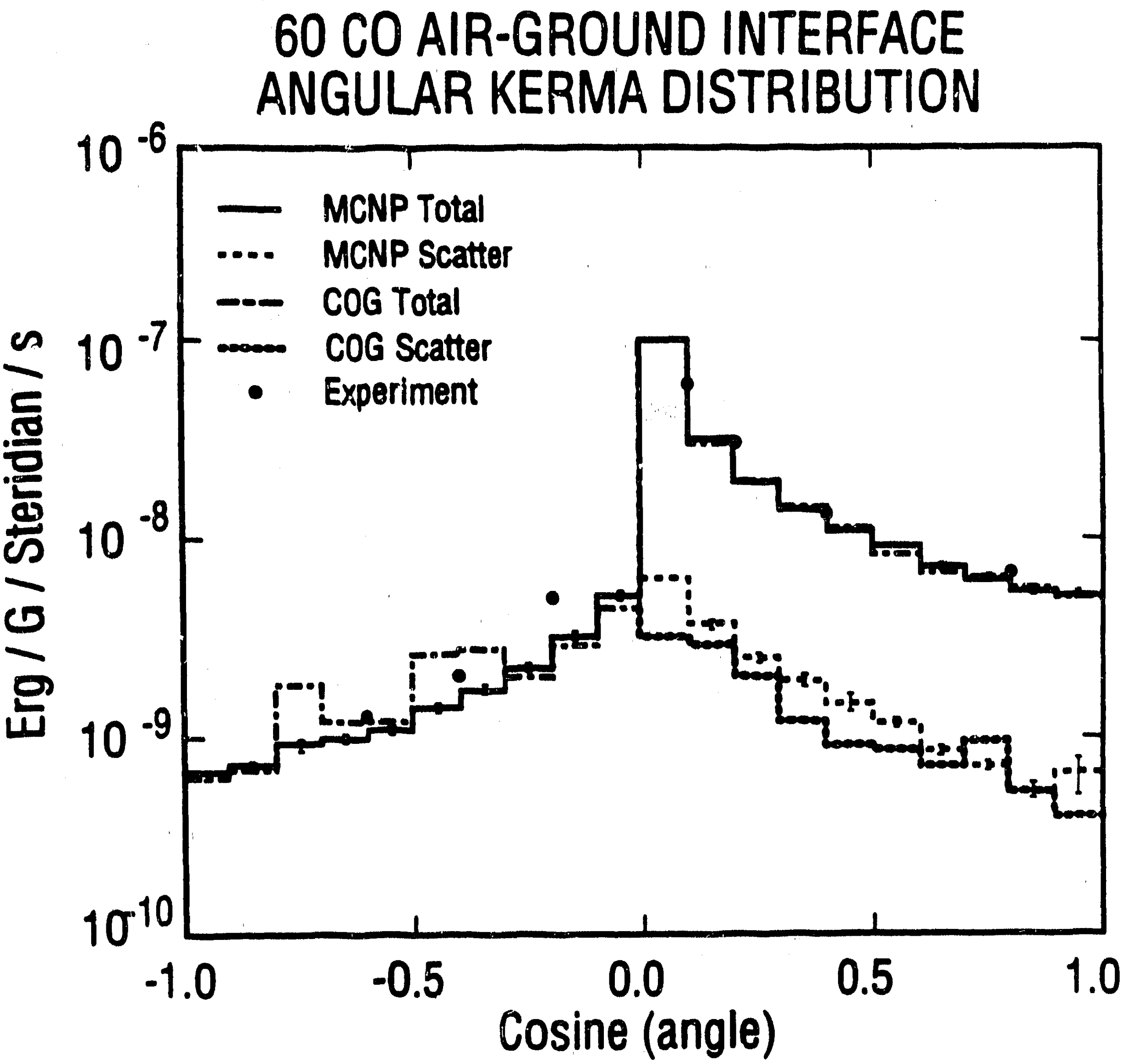
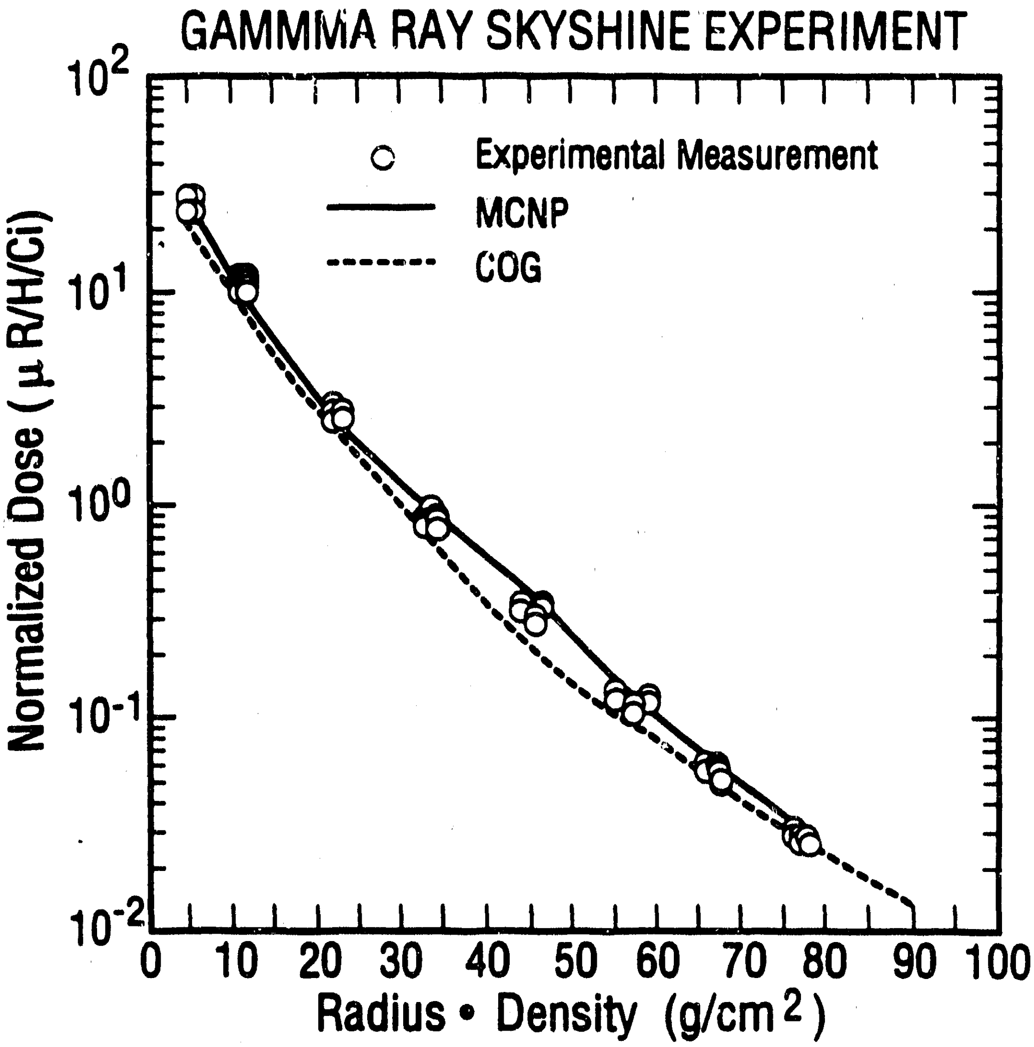


Figure. 5. Gamma-ray Skyshine Experiment Results. The Values of Flux as a Function of Distance are Shown for MCNP, COG, and the Experimental Measurement.



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