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SHIELDING ANALYSES: THE RABBIT VS THE TURTLE?

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ABSTRACT

This paper compares solutions using Monte Carlo and discrete-ordinates methods applied to two actual shielding situations in order to make some general observations concerning the efficiency and advantages/disadvantages of the two approaches. The discrete-ordinates solutions are performed using two-dimensional geometries, while the Monte Carlo approaches utilize three-dimensional geometries with both multigroup and point cross-section data.

I. INTRODUCTION

Deep-penetration shielding analyses have in the past been largely dominated by one-dimensional (1-D) and two-dimensional (2-D) discrete-ordinate methods (a.k.a. the turtle). The popularity of these methods stemmed from their easy availability and proven application along with flexibility using biased quadrature sets. More recently three-dimensional (3-D) discrete-ordinates methods have been developed, but as of yet have not received widespread use due to their geometry limitations, difficulty of use, and computing time and storage requirements. With the improvement in automated Monte Carlo biasing schemes for various shielding codes, the stochastic methods have rapidly been gaining acceptance (a.k.a. the rabbit) in the shielding community. These advanced biasing schemes include a number of popular techniques such as path-length stretching, source spatial and energy biasing, importance region, Russian roulette particle splitting, weight windows, etc. The automated Monte Carlo biasing schemes have been based on multidimensional adjoint diffusion theory, 1-D adjoint discrete-ordinates theory, and various weight window generators. This paper will illustrate the advantages and disadvantages of both methods by looking at a variety of shielding problems. As always, the analyst is left with the choice of which method is the more appropriate for a given application.

II. "HEAT ONE"

The first problem that was solved using both discrete-ordinates and Monte Carlo methods consisted of a Criticality Accident Alarm System (CAAS) verification in an environmental remediation project.[1] This application is unique in that the criticality source of concern is well defined. The configuration analyzed consisted of a thin-walled, charcoal-bearing pipe containing approximately 2 kg of ^{233}U immersed in water.

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This entire configuration was 120 cm below the ground surface in a 300-cm-diameter pit. The pit was covered by a concrete shield plug 45 cm thick, located 45 cm below the ground surface. The desired result from this application was the suitability of a CAAS location inside the reactor building adjacent to the pit. The complex computational nature of this problem included the determination of the critical neutron leakage spectrum, followed by a coupled neutron/gamma deep penetration analysis through the 45 cm concrete shield plug, and finally a skyshine evaluation to determine the resulting dose rates in the neighboring building some 24 to 30 m away. The computational procedures used in this analysis were the MCNP 3-D Monte Carlo code[2] and the DORT 2-D discrete-ordinates code.[3] In both cases all portions of the problem (i.e., leakage, deep penetration, and skyshine) were solved simultaneously. The actual location of the fissile deposit was in an off-centered location in the pit; however, to facilitate the comparison, the deposit was modeled at the pit center, and the pit diameter narrowed resulting in a symmetric model. The pit diameter in this revised model was chosen to maintain the minimum distance from the fissile deposit to the pit wall. The assumed fission yield in all calculations was 10^{16} fissions in a one-second burst.

The DORT and MCNP results for this symmetric geometry model were within about 10% of each other at the proposed detector location, lending credence to the solutions for these very difficult problems. An interesting observation concerning the MCNP-vs-DORT solutions was the behavior of the solutions in the vicinity of the neighboring reactor building. Shown in Fig. 1 are the DORT results vs distance from the pipe center and results at four points from the MCNP calculation. All results correspond to locations 30 cm above the ground or floor and at the specified distance from the pipe center. The DORT results around 10 m from the pipe center indicate a near-direct radiation path from the top of the concrete shield plug. This direct component quickly attenuates as the amount of ground material between the shield plug and the dose location increases. The dose rate peak around 23 m is caused by secondary gamma rays produced in the building steel wall and is seen in both the DORT and MCNP results. However, the MCNP peak is not as pronounced as that predicted by DORT. This is due to the resolution of the MCNP "point" detectors. For this calculation, the MCNP point detectors were actually a spherical surface centered at the point indicated with a radius of 30 cm. The MCNP results in general appear to be about 30 to 40% lower than the DORT results. Differences of this order are expected based on point vs multigroup cross sections for similar problems. The good agreement seen at about 26 m is somewhat fortuitous since the DORT values are decreasing more than expected due to the lack of sufficient air in the model beyond the last detector.

Both computational methods solve this problem quite well. The advantages of the discrete-ordinates methods for this situation are largely in the amount of solution detail available in a single calculation; however, a geometric simplification was necessary to obtain a 2-D solution. The Monte Carlo method solves the problem in an efficient manner, utilizing the full 3-D model and with the benefit of point cross sections.

III. "HEAT TWO"

The second application in which both Monte Carlo and discrete-ordinates methods were utilized consisted of a problem in which measured dose rates around an actual spent-fuel-loaded storage cask were analyzed.[4] In the experiment, an actual MC-10 spent fuel storage cask[5] was loaded with 24 pressurized water reactor (PWR) spent fuel assemblies with burnups ranging from 24 to 35 GWd/MTU and cooling times from 4 to 10 years. The azimuthal dependence of the neutron and gamma-ray dose rates at the axial midplane of the cask were determined with the DORT and SAS4/MORSE-SGC[6] codes and compared with the measurements. The problem was analyzed by the 2-D discrete-ordinates DORT code using R-Θ

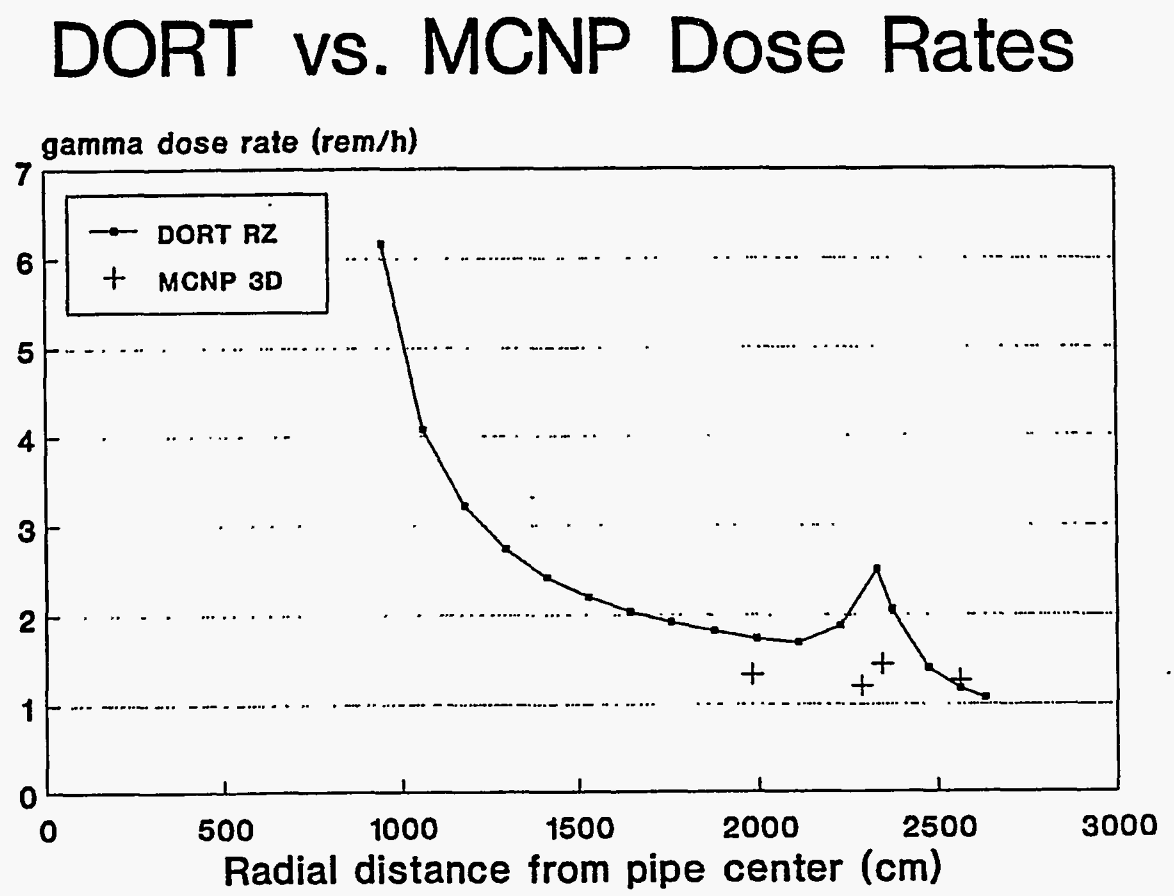

Fig. 1. DORT vs MCNP dose rates along the ground as a function of distance from pipe center.

geometry and with the 3-D Monte Carlo SAS4 module along with a post-processor[7] to obtain dose-rate profile information. The corresponding dose-rate profiles for the neutron dose rates are given in Figs. 2 and 3. The DORT results in Fig. 2 have been averaged over the azimuthal angles corresponding to the SAS4 calculations for ease of comparison. The large variations seen in Fig. 3 are caused by the external fins present on the MC-10 cask. From these plots a number of conclusions are evident: (1) both the DORT-averaged and SAS4 results agree very well with the experimental values, (2) the explicit DORT results show much more structure than is practical with the Monte Carlo results, and (3) the large variations seen in the DORT results can give rise to an understanding of the variations in the measurements themselves.

Figures 4 and 5 give similar results for the gamma-ray dose rates for various azimuthal angles at the MC-10 cask midplane. Again, good agreement is seen between the DORT and SAS4/MORSE-SGC results (the MARMER results are a point kernel solution); however, the predictions are a factor of 2 above the measurements. More recent results have lowered this overprediction to a factor of about 1.5, but the general trends remain. The variations caused by the fins are even more pronounced for the gamma-ray results.

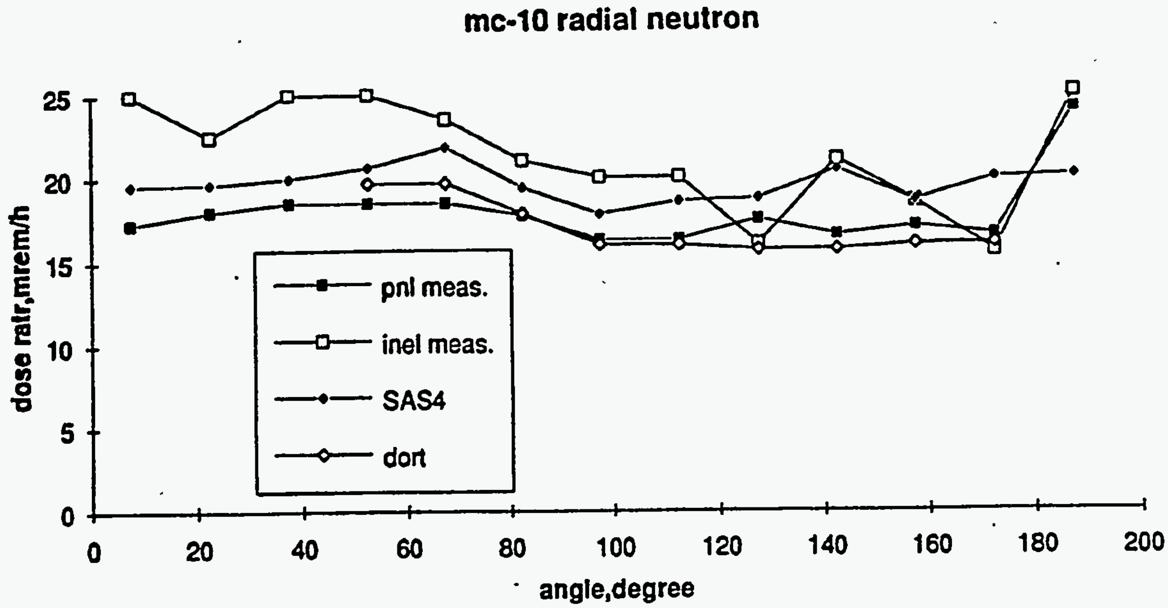

Fig. 2. MC-10 neutron dose-rate comparison for various azimuthal angles at cask axial midplane.

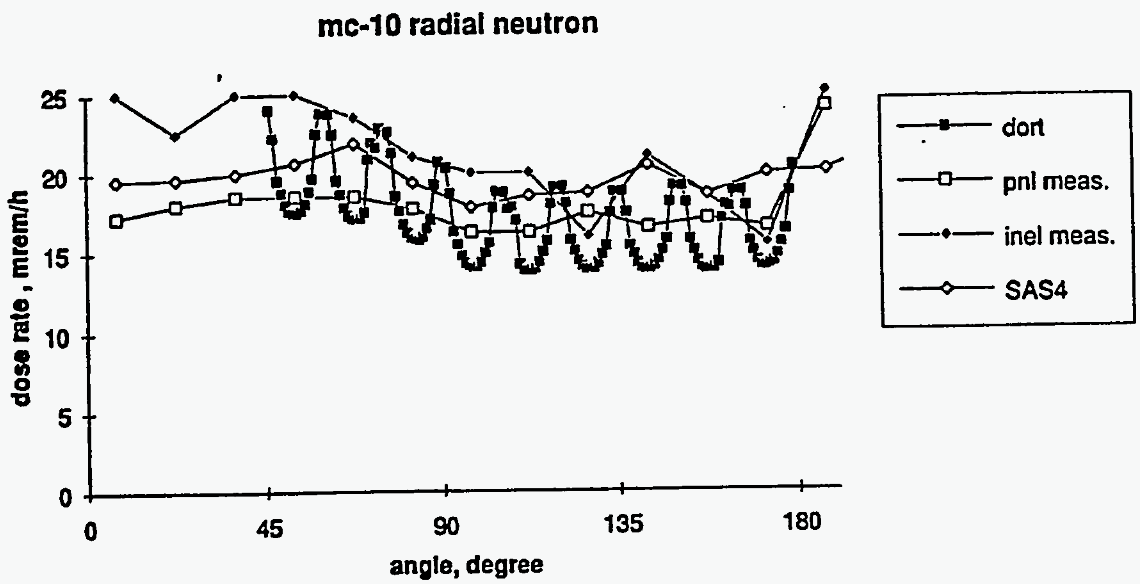

Fig. 3. MC-10 detailed dose-rate profiles for various azimuthal angles at cask axial midplane.

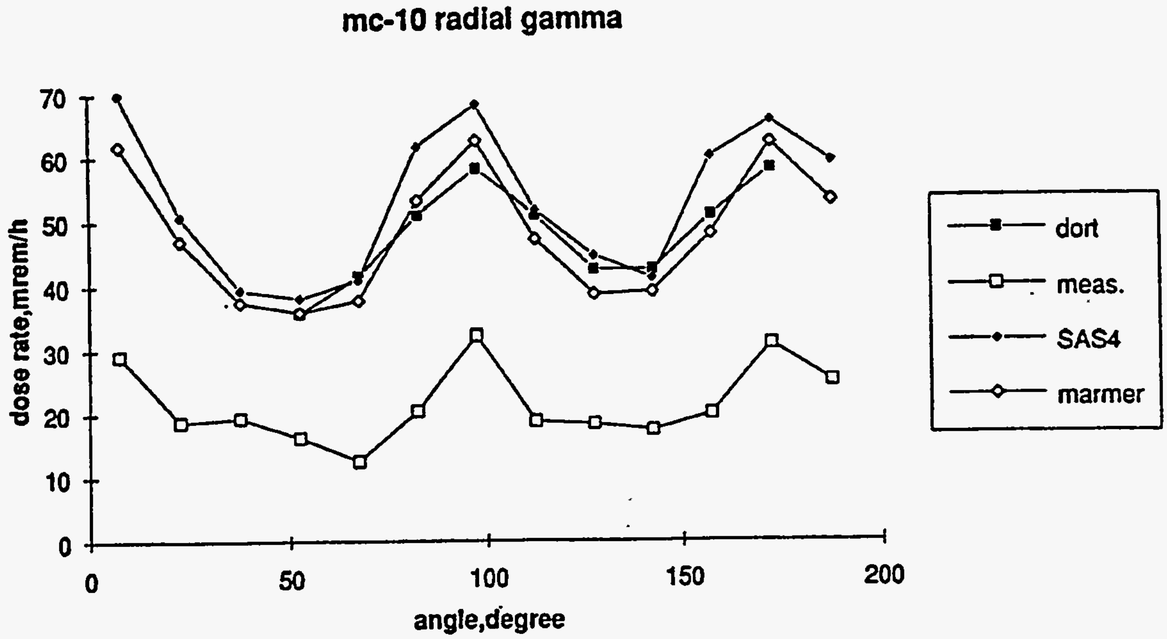

Fig. 4. MC-10 gamma-ray dose-rate comparison for various azimuthal angles at cask axial midplane.

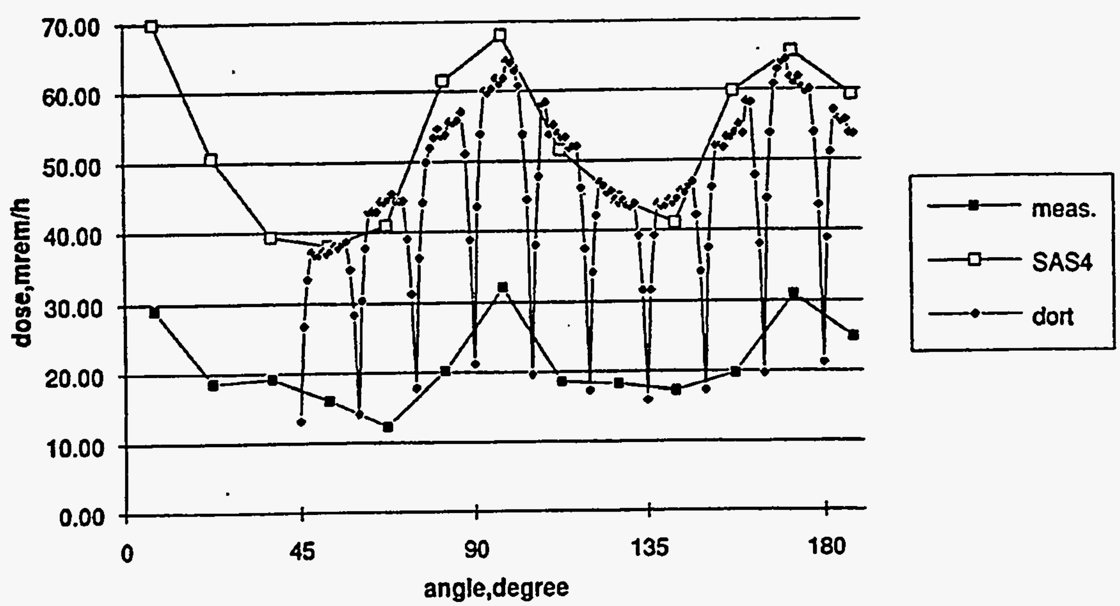

Fig. 5. MC-10 Detailed dose-rate profiles for various azimuthal angles at cask axial midplane.

IV. SUMMARY

The above two examples give a comparison of typical results that can be obtained using the discrete-ordinates and Monte Carlo methods. The results in general appear to be comparable, with the primary differences being the detail necessary in the problem solutions. For some cases the overriding concerns are the 3-D nature of the problem solution, while with others the detailed spatial resolution is the important result. This paper has not addressed the comparison of computing times, since for most realistic problems with current computing resources computing time is not usually the dominant parameter. The author's experience with most problems is that overnight turnaround for either Monte Carlo or discrete ordinates is the norm. Monte Carlo is becoming more popular due in part to its more advanced development, the availability of point-cross-section libraries, and ease-of-use in solving the actual geometry rather than two or three approximate pieces of the geometry.

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