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AUTOMATED VARIANCE REDUCTION FOR SCALE SHIELDING CALCULATIONS

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INTRODUCTION

Monte Carlo particle transport calculations for thick shielding problems can require very long run times in order to achieve an acceptable level of uncertainty (variance) in the final answers. Discrete ordinates codes can be faster but have limitations relative to the geometry modeling. Monte Carlo calculations can be modified (biased) to produce results with the same variance in less time if an approximate answer or some other additional information is already known about the problem. If an importance can be assigned to different particles based on how much they will contribute to the final answer, then more time can be spent on important particles and less time devoted to unimportant particles. One of the best ways to bias a Monte Carlo code is to form an importance map from the adjoint flux, which, unfortunately, could be just as difficult to compute as the original problem itself. Fortunately, an approximate adjoint can still be very useful in biasing the Monte Carlo solution.[1] Discrete ordinates can be used to quickly compute an approximate adjoint. Together, Monte Carlo and discrete ordinates can be used to find solutions to thick shielding problems in reasonable times.

SHIELDING CALCULATIONS IN SCALE

A new sequence is being written for Monaco,[2] which has been developed to become the new multi-group shielding code for SCALE. This new sequence, called MAVRIC (Monaco with Automated Variance Reduction using Importance Calculations), is based on the CADIS (Consistent Adjoint Driven Importance Sampling) methodology.[3] MAVRIC will automatically perform a quick three-dimensional, discrete ordinates calculation using TORT to find the adjoint flux as a function of position and energy. This adjoint flux information is then taken by Monaco to construct an importance map to be used for biasing during particle transport and to create a biased source distribution. The particle weight is compared with the importance map at each particle interaction and at each crossing of a regular geometry boundary.

SAMPLE PROBLEM

A rectangular-shaped shipping cask was used for a sample problem. (The rectangular shape was selected so that the TORT model would match exactly.) An inner region made of leaded glass with dimensions 1.7×1.7×4.6 m served as the source region. The source was modeled with a fission product gamma emission distribution. This was surrounded by a 5-cm stainless steel lining, 60-cm of concrete and a 2-cm outer layer of stainless steel. Total photon dose rates were calculated using flux-to-dose conversion factors applied to point detectors at the midplane, along the axis, and at the corner, 10 cm and 1 m from the outer surfaces. Locations are shown in Fig. 1.

RESULTS

Calculations with analog Monaco and MCNP using continuous energy cross sections showed poor uncertainties after 64 h. In these analog simulations, it is expected that the calculated results could underestimate the true results since most of the contributions to the detectors come from scatters near the outside edge of the cask. Examination of the point detector results as the simulations progressed showed that the results were not converging, changing from batch to batch more than the indicated uncertainties.

For each detector location, a separate MAVRIC sequence was calculated. Each combined a 90-min TORT adjoint calculation with a 12-h Monaco calculation. Results from the biased Monte Carlo showed much better uncertainties and the batch-to-batch changes were much smaller, indicating that the results were well converged. Ratios of the figures of merit (FOM, defined as FOM = 1/[time $(\text{rel err})^2$]) of the MAVRIC sequences to the analog Monaco were three to four orders of magnitude for the different detector positions.

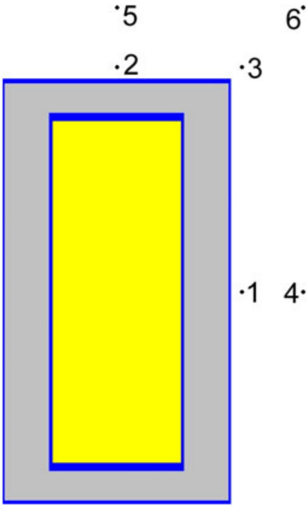

Fig. 1. Location of the point detectors.

TABLE I. Results of Sample Problem

Point Detector Position	Monaco 3840 min Dec Alpha dose (rem/hr)	MCNP 3840 min Linux PC dose (rem/hr)	MAVRIC 720 min Dec Alpha dose (rem/hr)	FOM ratio MAVRIC/ analog Monaco
1	1.12e-1 ± 39%	2.23e-1 ± 66%	2.18e-1 ± 3.3%	651
2	9.76e-3 ± 19%	3.21e-2 ± 40%	5.47e-2 ± 1.9%	487
3	2.12e-3 ± 81%	9.42e-4 ± 33%	2.60e-3 ± 1.1%	28029
4	1.51e-1 ± 37%	1.49e-1 ± 10%	1.52e-1 ± 0.7%	14033
5	3.36e-2 ± 55%	2.79e-2 ± 14%	3.37e-2 ± 0.6%	44919
6	5.89e-3 ± 52%	5.76e-3 ± 24%	4.36e-3 ± 0.8%	22328

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