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ADVANCED VARIANCE REDUCTION STRATEGIES FOR OPTIMIZING MESH TALLIES IN MAVRIC

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INTRODUCTION

More often than in the past, Monte Carlo methods are being used to compute fluxes or doses over large areas using mesh tallies (a set of region tallies defined on a mesh that overlays the geometry). For problems that demand that the uncertainty in each mesh cell be less than some set maximum, computation time is controlled by the cell with the largest uncertainty. This issue becomes quite troublesome in deep-penetration problems, and advanced variance reduction techniques are required to obtain reasonable uncertainties over large areas.

The CADIS (Consistent Adjoint Driven Importance Sampling) methodology [1,2] has been shown to very efficiently optimize the calculation of a response (flux or dose) for a single point or a small region using weight windows and a biased source based on the adjoint of that response. This has been incorporated into codes such as ADVANTG [3] (based on MCNP) and the new sequence MAVRIC [4], which will be available in the next release of SCALE.

In an effort to compute lower uncertainties everywhere in the problem, Larsen's group has also developed several methods to help distribute particles more evenly, based on forward estimates of flux [5,6].

This paper focuses on the use of a forward estimate to weight the placement of the source in the adjoint calculation used by CADIS, which we refer to as a forward-weighted CADIS (FW-CADIS) [7].

COMPARISON OF POSSIBLE METHODS

To optimize a response over a large region of a Monte Carlo problem, such as a mesh tally, several methods were devised. These include the following:

1. Use CADIS with the adjoint source placed all around the exterior boundary of the mesh volume—to force particles outward.
2. Define everywhere in the mesh to be equally important and thus distribute the adjoint source uniformly across the mesh tally volume. This method may prove to be equivalent to analog sampling, since all cells are equally important.
3. Distribute the adjoint source across the mesh tally volume, weighted inversely by the approximate forward response in each cell. This method would require two discrete-ordinates calculations (FW-CADIS).

These methods were tested on a small sample problem, which modeled a small building consisting of several rooms separated by concrete walls. Spent fuel is stored in one room (square on left side of both plots in Fig. 1) and the desired response is the neutron dose in all of the other rooms. Fig. 1 shows the analog calculation in which particles have trouble getting through the third wall.

The method that used CADIS with the adjoint source at the boundary of the problem performed much better but with large uncertainties and an underestimation of the response between the source and boundary. This finding is somewhat expected since particles are important only at the boundary.

Using a uniformly weighted adjoint source over the entire problem performed only slightly better than the analog calculation, probably as a result of the use of a biased source. The weight windows did not vary much, since every part of the problem was made equally important.

Figure 2 shows the results of a calculation in which the weight windows were set by the result of an FW-CADIS calculation. Areas with low forward estimates of dose rate were given more adjoint source, while areas with high estimates of forward dose rate were given less adjoint source. Note that uncertainties are low for all

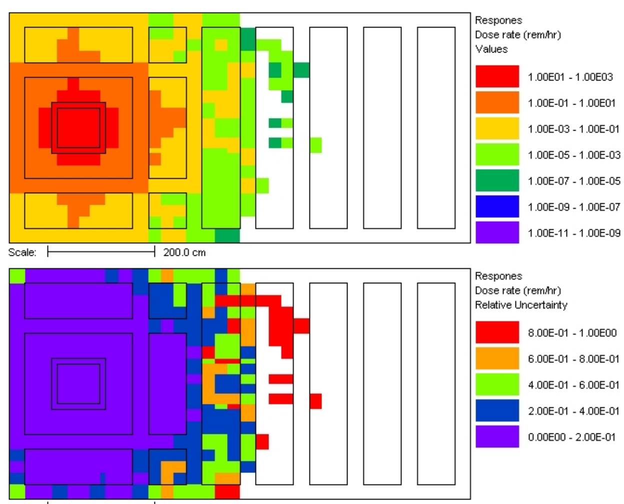

Fig. 1. Sample problem analog calculation: dose rates (top) and relative uncertainties (bottom).

mesh cells. The total calculation time, including both discrete-ordinates calculations, was the same as the analog case.

APPLICATION OF THE FW-CADIS METHOD TO STORAGE CASK ARRAY

For an array of storage casks, shown in Fig. 3, the objective is to calculate the dose rates everywhere in the vicinity of the array to determine the controlled area. It is not required to determine the dose rate with vanishingly small uncertainties anywhere but rather to calculate dose rates with reasonably small uncertainties everywhere.

The neutron dose rates were calculated using the MAVRIC sequence with both analog transport and the FW-CADIS method. For the analog calculation, the Monte Carlo engine Monaco ran for 300 minutes. For the new method, the forward TORT took 25 minutes; the adjoint TORT, 25 minutes; and Monaco, 250 minutes. The mesh tallies for each method are shown in Fig. 4.

To compare the uncertainties of the resulting mesh tallies, a cumulative histogram was created for each method, showing what fraction of mesh cells had relative uncertainties below a given uncertainty. These values are shown in Fig. 5. The analog calculation does not register any dose in most cells of the mesh tally but the relative uncertainty for 7% of the cells were 1% or less. The FW-CADIS method calculates doses in every mesh cell, with 90% of the cells having less than 20% relative uncertainty.

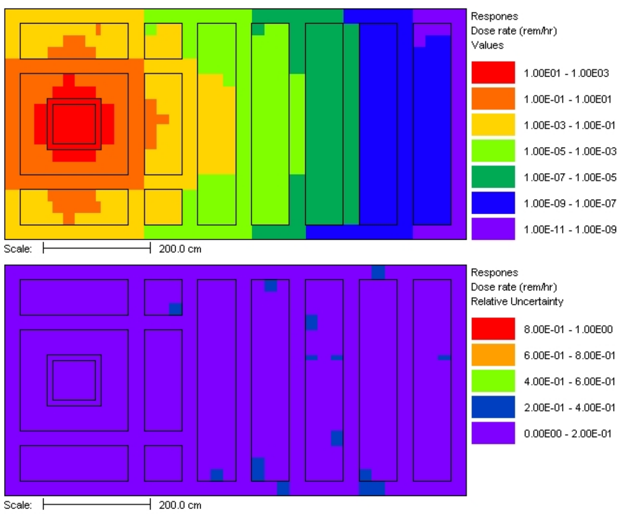

Fig. 2. Sample problem computed using a forward-weighted adjoint source over the entire volume of the problem (top—dose rate; bottom—relative uncertainties).

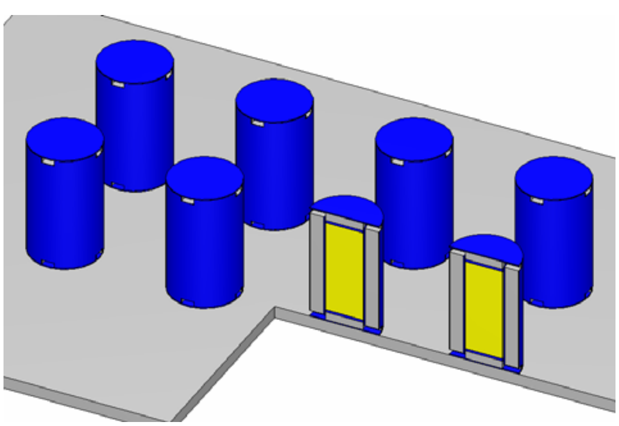

Figure 3. Cutaway view of an array of storage casks.

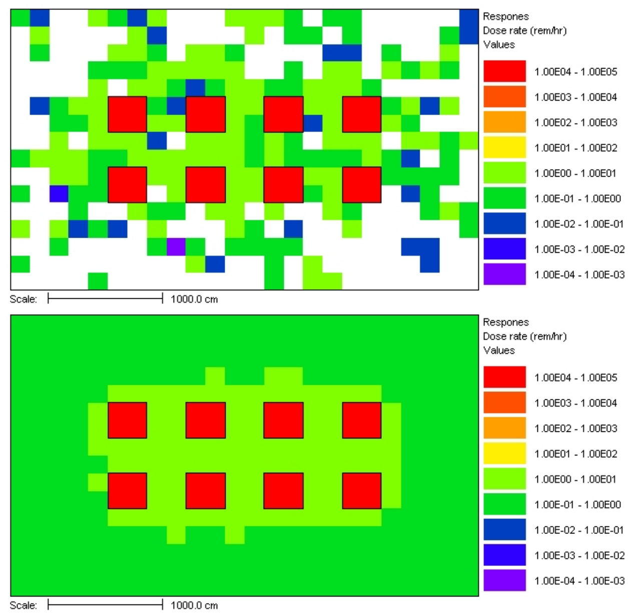

Fig. 4. Neutron dose rates calculated for an array of storage casks using analog transport (top) and the forward-weighted adjoint method (bottom).

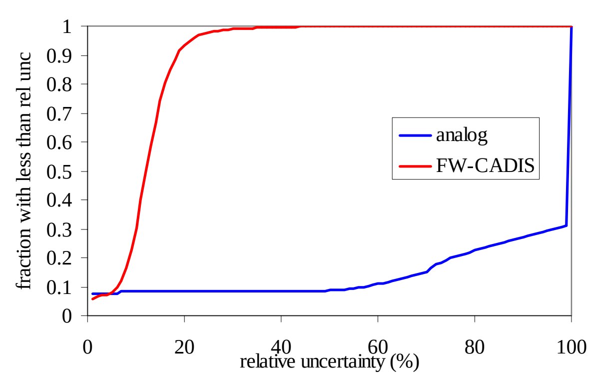

Fig. 5. Relative uncertainty histograms for the cask array problem, comparing the fraction of mesh tally cells that have uncertainties below a given relative uncertainty.

SUMMARY

Using two discrete-ordinates calculations, one forward and one adjoint, to construct the weight windows for Monte Carlo can produce low uncertainties over a large volume of the problem. The FW-CADIS method was tested on two practical models and showed a great reduction in the computational time required to obtain reasonable answers. This method should be suitable for a wide range of practical shielding problems.

The FW-CADIS capability has been added to the MAVRIC sequence. With one extra keyword in the input, the forward response can be estimated and used to weight the distribution of adjoint sources in the adjoint calculation.

ACKNOWLEDGEMENTS

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