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Abstract:

In order to reduce the user's time and the computer time needed to solve deep penetration problems, an automated variance reduction capability has been developed for the MCNP Monte Carlo transport code. This new variance reduction capability developed for MCNP5 employs the PARTISN multigroup discrete-ordinates code to generate mesh based weight windows. The technique of using deterministic methods to generate importance maps has been widely used to increase the efficiency of deep penetration Monte Carlo calculations. The application of this method in MCNP uses the existing mesh based weight window feature to translate the MCNP geometry into geometry suitable for PARTISN. The adjoint flux, which is calculated with PARTISN, is used to generate mesh based weight windows for MCNP. Additionally, the MCNP source energy spectrum can be biased, based on the adjoint energy spectrum at the source location. This method can also use angle-dependent weight windows.

INTRODUCTION

The generation of useful cell importances, or weight windows, is often difficult for novice MCNP[1] users. The MCNP weight window generator[2] (WWG) provides a method of generating weight windows, but requires some experience to generate useful results. Additionally the weight window generator can take considerable computational time to produce good results. The purpose of this work is to provide an easy method of generating weight windows for MCNP using deterministic adjoint methods, termed the deterministic adjoint weight window generator (DAWWG). This feature will allow novice MCNP users to quickly generate useful weight windows. Additionally, this deterministic adjoint method will provide a computationally faster alternative to the MCNP weight window generator.

The basis of this method is that the adjoint particle flux is proportional to the particle importance. This technique is employed by several Monte Carlo radiation transport codes including MCBEND[3] and MORSE[4]. MCBEND uses a diffusion solver that calculates the adjoint flux and MORSE/SAS4 uses a one-dimensional discrete ordinates solver to calculate the adjoint flux.

This method of generating importance functions has also been previously demonstrated for MCNP. AVATAR[5], developed at Los Alamos, used THREEDANT to generate weight windows for MCNP. Another effort ADVANTG[6], developed by John Wagner at Oak Ridge, uses TORT to generate weight windows for MCNP. However, until now these efforts have not resulted in such a feature being permanently added to MCNP and as a result these previous efforts have found limited use. Therefore, the purpose of this work is to develop a weight window generator using deterministic methods that will be a standard feature in MCNP.

METHOD

The adjoint flux for this method of automated variance reduction is calculated using the discrete ordinates code PARTISN[7], developed at Los Alamos. In order to perform the adjoint flux calculation with PARTISN the geometry and adjoint source (or Monte Carlo tally) information must be translated from MCNP to PARTISN. The MCNP geometry is translated by using the user defined weight window generator mesh[8]. MCNP determines the material at the center of each WWG mesh cell and uses that material in the PARTISN mesh cell. The user must provide a WWG mesh that adequately describes the problem when converted to PARTISN geometry. The MCNP materials must also be converted to material for PARTISN. This conversion is performed by mapping the MCNP ZAID's to the materials in the multi-group library.

The tally that will be optimized by the deterministic adjoint generated weight windows is used to construct the adjoint source. Spatial and energy dependent information about the tally is used in generating the adjoint source. To determine the spatial distribution of the adjoint source the WWG mesh is searched to identify the mesh cells that contain the tally cells. The energy dependent adjoint source is the energy dependent response of the tally. This energy dependent tally response can be defined as:

$$R_i = \int_{E_{i-1}}^{E_i} \phi(E)\sigma(E)dE, i = 1,..,N \qquad (1)$$

where R_i is the response of the tally for energy group i, E_i is the energy of the upper limit of group i, $\phi(E)$ is the energy dependent flux, and $\sigma(E)$ is the energy dependent response of the tally.

Since the energy dependent flux at the tally cell is unknown the energy dependent flux must be estimated. To do this several options are available to the user. The default option for neutrons assumes the flux to have a 1/E energy distribution. The energy dependent response of the tally is supplied by the user as energy multipliers (FM cards), reaction rate multipliers, or dose function multipliers. For the default option of a 1/E neutron fluence Equation (1) becomes: (2)

$$R_i = \int_{E_{i-1}}^{E_i} \frac{\sigma(E)}{E} dE$$

Another option for estimating the energy dependent adjoint source is by using a set of user supplied energy dependent fluxes, ϕ_i, as a guess. The energy dependent flux entered by the user must have the same energy group structure as the multi-group library. The energy dependent flux within each group is assumed to have a 1/E shape. For this option Equation (1) becomes:

$$R_i = \phi_i \frac{\int_{E_{i-1}}^{E_i} \frac{\sigma(E)}{E} dE}{\int_{E_{i-1}}^{E_i} \frac{1}{E} dE} \tag{3}$$

In the third option for estimating the energy dependent adjoint source is by using a set of energy dependent response, R_i, supplied by the user.

The adjoint fluxes from PARTISN are converted to weight windows for MCNP by taking the inverse of the adjoint flux, normalizing the weight windows to the weight window in the reference mesh, and then placing an upper limit on the weight windows. The weight windows can also used to provide source energy biasing. The source energy biasing ensures that the source particles are born within the weight window.

PARTISN also supplies the adjoint currents for each mesh cell. These adjoint currents can be used to provide angular weight windows for MCNP. The angular weight window concept is taken from AVATAR.

TEST CASES

Three test cases are presented to demonstrate the use of the deterministic adjoint weight window generator for MCNP. The first case is from the MCNP regression test suite, problem inp12. This problem simulates a neutron porosity tool used in the oil-well logging field. This problem consists of two detectors placed in a cylindrical borehole that is filled with water, and the borehole is surrounded by a limestone formation. The source for this problem is a 241AmBe source that is represented in MCNP as a neutron source with an defined energy distribution. This problem has been widely used to test various variance reduction techniques for MCNP, including testing of the weight window generator and other deterministically generated weight window methods[6,8,9].

The test problem geometry was converted to PARTISN geometry by overlaying a weight window mesh over the geometry. The mesh was defined fine enough to adequately represent the geometry. The energy dependence of the adjoint source was estimated by assuming a 1/E shape to the neutron flux at the far detector and by using the reaction multiplier to multiply the flux by the (n,p) reaction cross section for ^{3}H. PARTISN was then run using the SAILOR 47-neutron group cross section library. The PARTISN adjoint flux calculation was converted to weight windows for MCNP, during which the weight window lower bounds were limited to 100 times the weight window lower bound of the reference cell, which was chosen as the source location. A 10-minute MCNP run was then performed to evaluate the effectiveness of the weight windows calculated with deterministic adjoint weight window generator. The effectiveness was judged based on the figure of merit (FOM). The FOM is defined as:

$$FOM \equiv \frac{1}{R^2T}$$

where R is the estimated relative error and T is the computer time.

For the oil well logging problem PARTISN ran for 2.64 minutes on a 2.4 GHz Pentium IV and produced a figure of merit of 380. An analog MCNP run for this problem produced a FOM of 4.7. To compare the deterministic adjoint weight window generator with the standard MCNP weight window generator a series of weight window generation runs were performed. The weight windows were generated from multiple successive runs. Each run used the weight windows generated by the previous run. Two series of runs were performed, one with 1 hour iterations, and the other with two hour iterations. The FOM results of the 2-hour runs are presented in Figure 1 as a function of CPU time along with the results of the deterministic adjoint weight window generator and the results of the analog MCNP run. Figure 1 shows the WWG to produce FOM's that fluctuate widely and do not improve after the third iteration. The results of the 1-hour runs are listed in Table 1 along with the DAWWG results and the analog results. For this sample problem the DAWWG produces comparable results to the WWG in a fraction of the time.

The second problem used to test the DAWWG was a model of an experiment used to test shielding effectiveness of a polyethylene shield. A ^{252}Cf neutron source was modeled in a paraffin collimator. The paraffin collimator directed neutrons onto a 100-cm polyethylene shield. Behind the shield the neutron dose was tallied. The source, collimator, and shield are modeled inside of a room with 61-cm thick concrete walls and the room is filled with air to model neutron air scatter and room-return. Again the

SAILOR multigroup cross section set was used in PARTISN. The FOM from the DAWWG was 5.7, as compared to a FOM of 3.3 for analog MCNP. Successive 2-hour runs of the standard WWG were stable after the first iteration and produced a FOM of 10.6±8.1. The weight windows calculated with the DAWWG and the standard WWG for the 1-MeV group are plotted overlaying the MCNP geometry in Figure 2. The standard WWG plot is shown to have many areas where the weight window lower bound is zero and the values vary by a factor of 5×10^6. In contrast the DAWWG generated weight windows are smooth and vary by a factor of 2×10^3.

The third problem tested consists of a 3 leg cylindrical duct through a concrete wall. The source for the problem was a ^{252}Cf neutron source at one end of the duct. At the other end of the duct was a tally of neutron dose. Again the WWG mesh was overlaid on the problem for conversion to PARTISN geometry and again the SAILOR multi-group cross section was used. The resulting FOM was 20, as compared to a FOM of 16 for analog MCNP. The WWG with successive 1-hour runs produced a FOM of 429±82. The results of this problem are also listed in Table 1. For this problem the DAWWG does not perform as well as the WWG. The discrete angular nature of PARTISN is not well suited this angular dependent problem.

CONCLUSIONS

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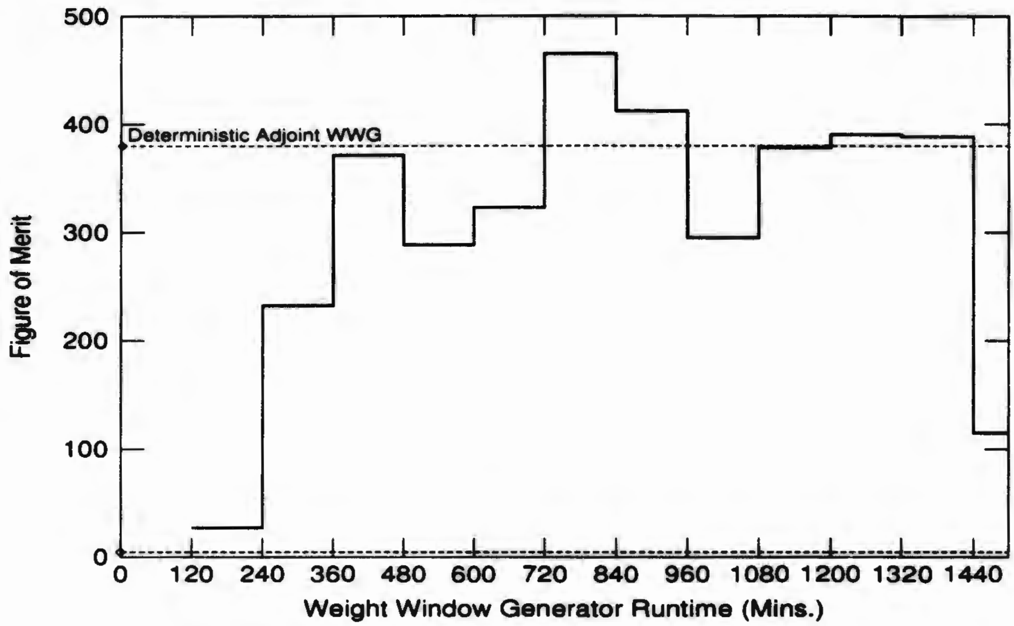
CAPTIONS

Figure 1: FOM verses WWG CPU time for the oil well logging problem (regression test problem inp12). — Solid Line: Standard MCNP WWG 2-hour interations; ♦ Deterministic adjoint weight window Generator; ◊ Analog MCNP.

Figure 2: Weight window lower bounds for the 1-MeV energy group shaded in color for the 100-cm polyethylene neutron shield problem. The color map is a log scale. Above: Weight windows generated with 12 2-hour iterations of the standard WWG. Below: Weight windows generated with the deterministic adjoint weight window generator.

Table 1: FOM's and CPU times are listed for the three test cases. The FOM's are evaluated using 10-min runs. The CPU times listed for the standard MCNP WWG are the minimum times need to produce a stable FOM.

Figure 1



500
400
300
200
100
0
Deterministic Adjoint WWG
Figure of Merit
0
120
240
360
480
600
720
840
960
1080
1200
1320
1440
Weight Window Generator Runtime (Mins.)

Figure 2

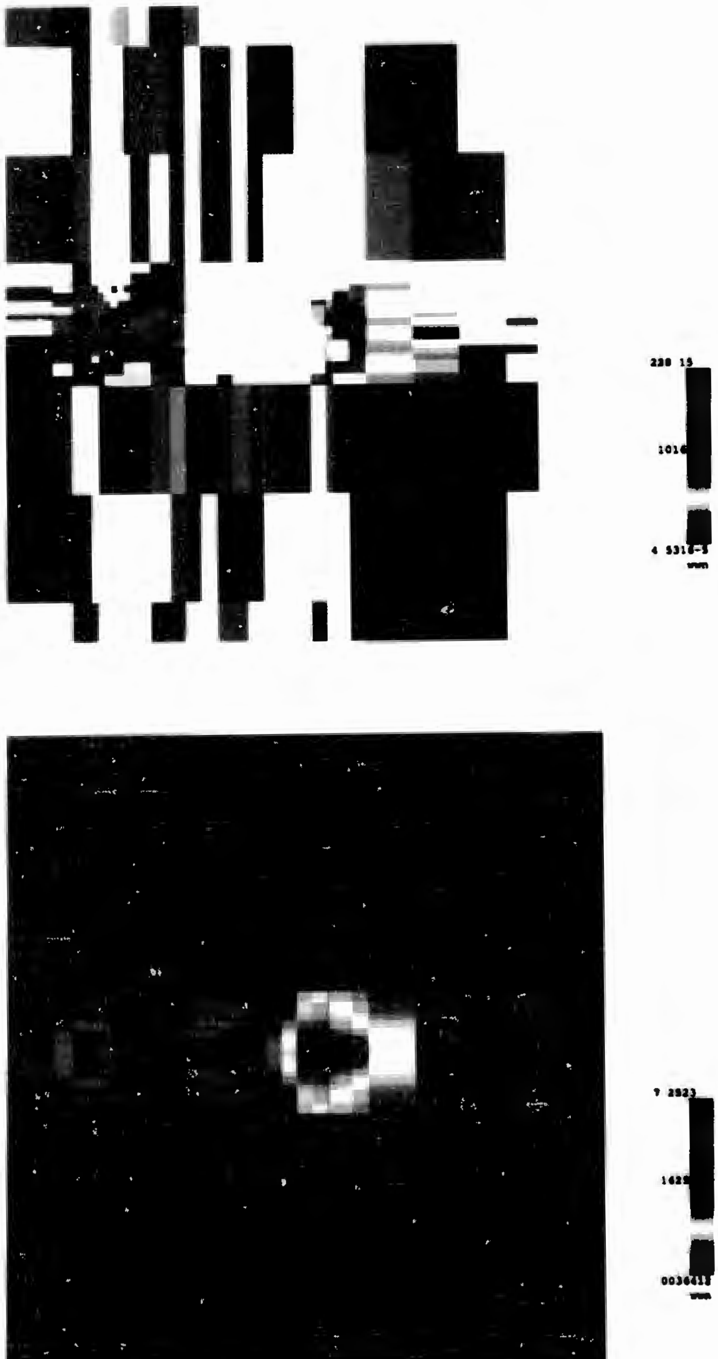


Table 1

Problem	Standard MCNP	MCNP WWG		Deterministic WWG	
	FOM	Time (min)	FOM	Time (min)	FOM
Oil Well Logging	4.7	180	415±66	2.64	380
Dogleg	1.6	180	429±82	1.58	20
Polyethylene Shield	3.3	120	10.6±8.1	8.15	5.7