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MCNP6 Print Table 199

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1 Objective

The objective of this report is to document MCNP6's print table 199 that provides some additional accounting information when particle weights are above the top of a weight window. Some examples are provided.

2 Introduction

Variance reduction in MCNP6 [1] can be accomplished using weight windows (WW) where each region in phase space (space and energy) is assigned a target weight range – a window with lower and upper weight bounds. Particles with weight outside of the window are split or rouletted to maintain the required particle weight. If a particle were to transport to a region of phase space with WW bounds orders of magnitude smaller than its own weight, it would split into particles of smaller weight. By default, a maximum 1-to-5 split occurs when the WW game is played (i.e., when the weight is checked at collisions and/or geometry surfaces or every mean free path if mesh-based windows are used). If any of "these daughter particles" fail to transport out of this region, they will in turn be split again under the WW checking until either all particles have weight within the window, transport out of the region, or otherwise terminate.

Whether with MCNP6's built-in stochastic generator or an external deterministic generator such as ADVANTG [2], WW bounds are usually set according to some average quantity such as (inversely proportional to) the adjoint flux. Sometimes, infrequently sampled events can produce histories that strongly deviate from that average weight; this leads to excess splitting. Such events may include a high weight particle entering a streaming path and arriving in a region of much lower expected weight. This has been observed in practice [3, 4, 5].

The presence of such "long histories" (abbreviated LH) have been observed when running MCNP models representing the ITER device [3, 4]. These long histories occur very rarely, but can take a long time (hours, days) to complete and are detrimental to the efficient use of large-scale, parallel processing computers. The ITER model contains a mixture of heavily shielded regions and small (< 1 cm) streaming paths, along with a spatially distributed neutron source. Where a streaming particle produces such a LH, the effect of streaming has clearly not been adequately captured in the WW generation process. An improved WW estimate with increased space and energy resolution may alleviate this effect. However, it is often impractical to obtain an *ideal* WW in a large and complex geometrical model since computer memory limitations prevent the use of the high space and energy resolutions necessary to resolve the streaming path effects. Assessing the degree and frequency with which this occurs in a calculation has been difficult. An additional diagnostic table to help with this is discussed next.

3 Print Table 199

Understanding how bad the LH problem is for any particular calculation is difficult when the code provides little relevant information in this regard. To meet this need a new print table, Print Table 199, was added starting with MCNP Version 6.2 that provides cell-based accounting information for the WW that can be used for either cell-based or mesh-based WWs. This table is broken into sections by energy group and particle type in the calculation. Details follow and there are samples provided.

For this print table to appear in the output file, WW's must be present in the problem and the value 199 entered on the PRINT card.

Each energy group section of the table contains large weight summary information by particle type on the WW. It is a binning of the particle track weights above the WW upper bound. That is, the accounting occurs when the track's weight is above the top of the WW. NOTE: everything is referenced from the WW lower bound. The binning occurs by order of magnitude with 10 bins ordered in the table from 10 times the lower bound to 10^{10} times the lower bound. Higher bins do not include information from lower bins. The first bin covers weights from the upper bound to 10 times the lower bound. The second bin covers weights from 10 times the lower bound to 100 times the lower bound, likewise for the remaining bins. When there is a non-zero value for any of the 10 bins for any cell, a row is added to this section of the table.

As experience is gained in analyzing these types of problems with print table 199, the print table may be modified in the future.

4 Sample Problems

Two sample problems are described in this section for which calculations were performed and print table 199 generated.

4.1 Solid Slab Geometry

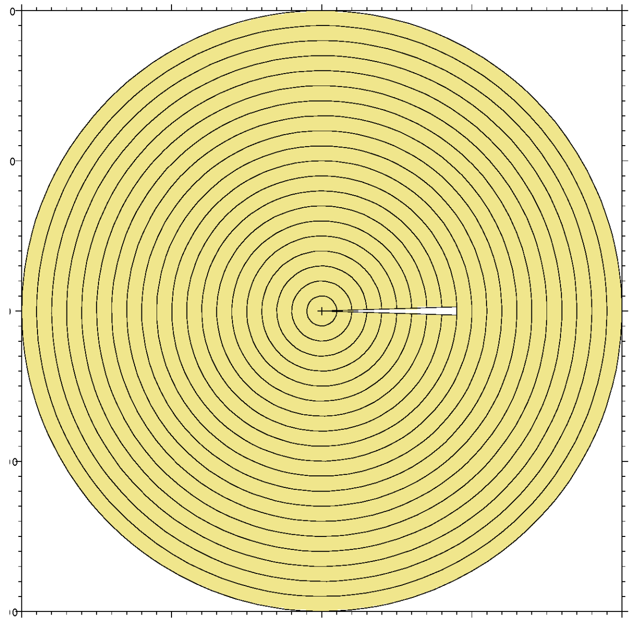
This problem was taken form the MCNP6 class variance reduction section. It consists of an 100 cm thick cylindrical slab broken into 10 disks each with a thickness of 10 cm and with radius 100 cm. The material is a pseudo-concrete (2 w/o hydrogen, 60 w/o oxygen, 38 w/o silicon) with density 2.03 gm/cm^3. Cell-based weight windows were generated with MCNP6's stochastic weight window generator. Listing 1 shows print table 199 that is generated when the WW is used in a calculation with 1 million histories.

Listing 2 shows print table 199 when the the WW is scaled by a factor of 1/100 so that the particles' weights are always well above the window – a malformed WW for all histories.

4.2 Spherical Geometry

This problem was intentionally designed, Reference 3, to produce long histories and run in a reasonable amount of time. The test geometry consists of a sphere with a radius of 200 cm and a material composition set to a steel (80 a/o iron) and water (20 a/o hydrogen) mix. The sphere was divided into 20 spherical shells for variance reduction purposes upon which a cell-based WW was generated

Figure 1: Spherical geometry with conical penetration



to achieve accurate flux estimates throughout the sphere. This was a fixed source problem with 14 MeV neutrons emanating isotropically at the sphere's center.

After constructing the WW, a conical penetration was added to provide a streaming path of known solid angle. The streaming path terminated in material so that any particle traveling along the penetration would be subsequently split by the WW when it hit the end. Since the streaming path was not included when the WW was generated, high weight particles near the source will transport along the path with a weight in excess of the WW range and lead to a long history when they exit the path. This artificial LH scenario is equivalent to a streaming path which was not adequately sampled during the WW production.

Listing 3 shows print table 199 for a 1 million history calculation with this problem.

4.3 Some Insights

4.3.1 Solid Slab Problem

Listing 1 provides print table 199 from an 1 million history calculation for the unaltered case of slab geometry. Notice that there is no entry for the first cell in the problem. This is the cell in which the mono-energetic source resides where all of the source weights are within the window. There are roughly 1.1 million tracks (over the rest of the cells) with weights in the 1e2 x LB bin. This is probably a good indication that the WW needs to be refined in space and/or energy. However, this WW did produce acceptable results.

Listing 2 provides print table 199 from an 1 million history calculation when the WW was scaled by a factor of 1/100 so that particle weights are always above the window. Notice that there are now tracks (6.111e6) with weights in the 1e3 x LB bin and the total number of tracks above the first bin have increased substantially – ~ 100 times the number before. It should be no surprise that the efficiency of this calculation suffered from excessive splitting (FOM of 331 vs 1732 for the 2 slab problems discussed here).

4.3.2 Sphere Problem

Listing 3 provides print table 199 from an 1 million history calculation on the sphere problem that was designed to produce LH's. It can be seen in the table that in those cells beyond the conical penetration there are a substantial number of tracks well above the WW – 1.226e4 in bin 1e5 x LB alone.

5 Conclusions

As a means of understanding if a LH problem may occur and how bad that problem might be, Print Table 199 was added to MCNP6. From monitoring this table users may be able to determine if refinement of their WW's is warranted. Even though the information is provided by cell, this print table can help in assessing mesh-based WW's. Since this is a new feature, few problems have been analyzed with the print table.

Listing 1: Sample Print Table 199 for Slab Penetration Problem – Unaltered WW

```
1weight window diagnostics of high weight particles                                                   print table 199

  Number of high weight neutron tracks above weight window upper bound.

  Weight Window Energy Group:    1    Upper bound:  1.00000E+36

              Cells   1e1 x LB   1e2 x LB   1e3 x LB   1e4 x LB   1e5 x LB   1e6 x LB   1e7 x LB   1e8 x LB   1e9 x LB   1e10 x LB
        2       20   2.327E+05  1.330E+05  0.000E+00  0.000E+00  0.000E+00  0.000E+00  0.000E+00  0.000E+00  0.000E+00  0.000E+00
        3       30   1.575E+05  1.233E+05  0.000E+00  0.000E+00  0.000E+00  0.000E+00  0.000E+00  0.000E+00  0.000E+00  0.000E+00
        4       40   3.286E+05  4.393E+03  0.000E+00  0.000E+00  0.000E+00  0.000E+00  0.000E+00  0.000E+00  0.000E+00  0.000E+00
        5       50   2.563E+05  7.157E+04  0.000E+00  0.000E+00  0.000E+00  0.000E+00  0.000E+00  0.000E+00  0.000E+00  0.000E+00
        6       60   2.478E+05  8.318E+04  0.000E+00  0.000E+00  0.000E+00  0.000E+00  0.000E+00  0.000E+00  0.000E+00  0.000E+00
        7       70   2.222E+05  1.154E+05  0.000E+00  0.000E+00  0.000E+00  0.000E+00  0.000E+00  0.000E+00  0.000E+00  0.000E+00
        8       80   1.875E+05  1.671E+05  0.000E+00  0.000E+00  0.000E+00  0.000E+00  0.000E+00  0.000E+00  0.000E+00  0.000E+00
        9       90   1.672E+05  2.067E+05  0.000E+00  0.000E+00  0.000E+00  0.000E+00  0.000E+00  0.000E+00  0.000E+00  0.000E+00
       10      100   1.655E+05  1.927E+05  0.000E+00  0.000E+00  0.000E+00  0.000E+00  0.000E+00  0.000E+00  0.000E+00  0.000E+00

                     1.965E+06  1.097E+06  0.000E+00  0.000E+00  0.000E+00  0.000E+00  0.000E+00  0.000E+00  0.000E+00  0.000E+00
```

Listing 2: Sample Print Table 199 for Slab Penetration Problem – Scaled WW

```
1weight window diagnostics of high weight particles                                                    print table 199

  Number of high weight neutron tracks above weight window upper bound.

  Weight Window Energy Group:    1    Upper bound:  1.00000E+36

              Cells   1e1 x LB   1e2 x LB   1e3 x LB   1e4 x LB   1e5 x LB   1e6 x LB   1e7 x LB   1e8 x LB   1e9 x LB   1e10 x LB
        1        10   9.428E+06  2.386E+06  1.000E+06  0.000E+00  0.000E+00  0.000E+00  0.000E+00  0.000E+00  0.000E+00  0.000E+00
        2        20   8.014E+06  2.219E+07  1.110E+05  0.000E+00  0.000E+00  0.000E+00  0.000E+00  0.000E+00  0.000E+00  0.000E+00
        3        30   1.985E+07  8.602E+06  0.000E+00  0.000E+00  0.000E+00  0.000E+00  0.000E+00  0.000E+00  0.000E+00  0.000E+00
        4        40   2.848E+07  4.344E+06  0.000E+00  0.000E+00  0.000E+00  0.000E+00  0.000E+00  0.000E+00  0.000E+00  0.000E+00
        5        50   2.709E+07  7.124E+06  0.000E+00  0.000E+00  0.000E+00  0.000E+00  0.000E+00  0.000E+00  0.000E+00  0.000E+00
        6        60   2.558E+07  8.291E+06  0.000E+00  0.000E+00  0.000E+00  0.000E+00  0.000E+00  0.000E+00  0.000E+00  0.000E+00
        7        70   2.236E+07  1.154E+07  0.000E+00  0.000E+00  0.000E+00  0.000E+00  0.000E+00  0.000E+00  0.000E+00  0.000E+00
        8        80   1.889E+07  1.684E+07  0.000E+00  0.000E+00  0.000E+00  0.000E+00  0.000E+00  0.000E+00  0.000E+00  0.000E+00
        9        90   1.693E+07  2.108E+07  0.000E+00  0.000E+00  0.000E+00  0.000E+00  0.000E+00  0.000E+00  0.000E+00  0.000E+00
       10       100   1.690E+07  1.967E+07  0.000E+00  0.000E+00  0.000E+00  0.000E+00  0.000E+00  0.000E+00  0.000E+00  0.000E+00

                      1.935E+08  1.221E+08  1.111E+06  0.000E+00  0.000E+00  0.000E+00  0.000E+00  0.000E+00  0.000E+00  0.000E+00
```

Listing 3: Sample Print Table 199 for Sphere Problem

```
1weight window diagnostics of high weight particles                                                  print table 199

  Number of high weight neutron tracks above weight window upper bound.

  Weight Window Energy Group:    1    Upper bound:  1.00000E+36

              Cells   1e1 x LB   1e2 x LB   1e3 x LB   1e4 x LB   1e5 x LB   1e6 x LB   1e7 x LB   1e8 x LB   1e9 x LB   1e10 x LB
         2        2  6.625E+06  1.207E+06  0.000E+00  0.000E+00  0.000E+00  0.000E+00  0.000E+00  0.000E+00  0.000E+00  0.000E+00
         3        3  1.901E+06  1.069E+07  0.000E+00  0.000E+00  0.000E+00  0.000E+00  0.000E+00  0.000E+00  0.000E+00  0.000E+00
         4        4  4.211E+06  2.092E+07  0.000E+00  0.000E+00  0.000E+00  0.000E+00  0.000E+00  0.000E+00  0.000E+00  0.000E+00
         5        5  7.740E+06  3.480E+07  3.700E+01  0.000E+00  0.000E+00  0.000E+00  0.000E+00  0.000E+00  0.000E+00  0.000E+00
         6        6  1.259E+07  5.250E+07  1.370E+02  0.000E+00  0.000E+00  0.000E+00  0.000E+00  0.000E+00  0.000E+00  0.000E+00
         7        7  1.916E+07  7.365E+07  2.530E+02  0.000E+00  0.000E+00  0.000E+00  0.000E+00  0.000E+00  0.000E+00  0.000E+00
         8        8  2.786E+07  9.806E+07  4.690E+02  9.000E+00  0.000E+00  0.000E+00  0.000E+00  0.000E+00  0.000E+00  0.000E+00
         9        9  4.443E+07  1.211E+08  2.458E+04  3.500E+01  0.000E+00  0.000E+00  0.000E+00  0.000E+00  0.000E+00  0.000E+00
        10       10  5.136E+07  1.589E+08  9.648E+04  2.341E+04  7.356E+03  0.000E+00  0.000E+00  0.000E+00  0.000E+00  0.000E+00
        11       11  6.942E+07  2.015E+08  3.681E+05  8.383E+04  1.409E+03  0.000E+00  0.000E+00  0.000E+00  0.000E+00  0.000E+00
        12       12  1.192E+08  2.313E+08  9.388E+05  1.971E+04  1.628E+03  0.000E+00  0.000E+00  0.000E+00  0.000E+00  0.000E+00
        13       13  1.263E+08  2.909E+08  2.362E+05  2.666E+04  1.863E+03  0.000E+00  0.000E+00  0.000E+00  0.000E+00  0.000E+00
        14       14  1.608E+08  3.500E+08  3.634E+05  3.851E+04  0.000E+00  0.000E+00  0.000E+00  0.000E+00  0.000E+00  0.000E+00
        15       15  1.772E+08  4.368E+08  5.730E+05  2.785E+03  0.000E+00  0.000E+00  0.000E+00  0.000E+00  0.000E+00  0.000E+00
        16       16  2.442E+08  4.835E+08  6.612E+04  2.947E+03  0.000E+00  0.000E+00  0.000E+00  0.000E+00  0.000E+00  0.000E+00
        17       17  2.808E+08  5.657E+08  8.325E+04  3.345E+03  0.000E+00  0.000E+00  0.000E+00  0.000E+00  0.000E+00  0.000E+00
        18       18  3.422E+08  6.338E+08  1.050E+05  0.000E+00  0.000E+00  0.000E+00  0.000E+00  0.000E+00  0.000E+00  0.000E+00
        19       19  3.734E+08  7.345E+08  4.308E+03  0.000E+00  0.000E+00  0.000E+00  0.000E+00  0.000E+00  0.000E+00  0.000E+00
        20       20  2.302E+08  1.048E+09  4.714E+03  0.000E+00  0.000E+00  0.000E+00  0.000E+00  0.000E+00  0.000E+00  0.000E+00

                     2.300E+09  5.548E+09  2.865E+06  2.012E+05  1.226E+04  0.000E+00  0.000E+00  0.000E+00  0.000E+00  0.000E+00
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