Chapter 9

IMPORTANCE SAMPLING IN MCNP

Importance sampling means to sample (or at least attempt to sample) in such a fashion that the number of particles sampled is an region is proportional to its importance to the tally of interest. This is a biasing process that must be compensated for in the scoring process and should result in a variance reduction, within a reasonable execution time. Biasing can occur at the source, during the random walk and at scoring. Source biasing was discussed in Section 6.7, while biasing during scoring is dealt with in subsection 10.2.3. Variance reduction can also be achieved by the cut-off parameters, discussed in Chapter 8. We discuses here importance sampling during the random walk process.

9.1 Splitting and Russian Roulette

MCNP allows splitting and Russian roulette in geometry and energy or both. The ESPLT card allows for splitting and Russian roulette in energy, and the IMP card allows or the same in geometry. For energy however, the use of energy-dependent weight-cut off , through the CUT card, is generally preferred. Splitting is applied in regions or energies that are expected to significantly contribute to the quantity of interest but is unlikely to reach there; the opposite is true for Russian roulette. In splitting, the incoming particle is split into two or more particles, assigned new weights totaling the original weight.

Geometry splitting is applied when a particle passed from a cell of lower importance to a cell of higher importance, as assigned by the IMP card, while Russian roulette applies if the particles passes to a cell of lower importance. When splitting occurs, one of the created particles is followed, while the other is stored in a bank for latter tracking. Geometry splitting with Russian roulette is very reliable. It is important however to keep the ratio of adjacent importance small (4 or less) to avoid unnecessary creating too many particles. Note that MCNP never splits in a void, there is no need to.

Russian roulette takes a particle of weight W_0 and turns it into a particle of weight $W_1 > W_0$ with probability W_0/W_1 and kills it with probability $(1 - W_0/W_1)$. In general, Russian roulette increases the history variance but decreases the time per history, while splitting achieves the opposite effect.

Energy splitting and Russian roulette through the ESPLT card are independent of spatial cell. They are typically used together, but the user can specify one only of desired.

Space-energy-dependent splitting and Russian roulette is allowed through Weight Windows (WWE, WWN, WWP, WWG, WWGE and Cards). Here a weight-window is defined in space and energy by a lower and an upper weight. Splitting occurs if the particle's weight exceed the upper value, while Russian roulette is performed if the particle weight is lower than the lower value. Note that weight windows can be applied at surface, collision site or both, while energy splitting is only applied at the surface between cells. An automatic weight window generator exists in MCNP (WWG and WWGE cards). This is done, with little book keeping, by calculating the ratio of the total score of particles in a cell or within an energy range to the total number of particles. The generator uses however statistical estimates that are subject to error and should be used with caution.

9.2 Exponential Transformation

The exponential transformation is simply a path-length stretcher/shrinker, by artificially reducing the macroscopic cross section in the preferred direction and increasing it in the opposite direction. The fictitious cross section, Σ^* related to the actual cross section, Σ as $\Sigma^* = \Sigma_t(1 - p\mu)$, where μ is the cosine of the angle between the preferred direction and the particle's direction and p is biasing parameter, $|p| < 1$, and is a constant or equal to Σ_a/Σ_t. The preferred direction is specified by a VECT card, while p is specified through the EXT weight. The particle weight is accordingly adjusted.

Exponential transformation works best on highly absorbing media and very poorly on highly scattering media. It should be used in conjunction with a weight window to stratify the particle weight and provide better statistics. A value of $p = 0.7$ is recommended for neutron penetration in concrete or earth, while $p = 0.9$ is recommended for photons in high-Z material. Note that for $p = \Sigma_a/\Sigma_t$ and $\mu + 1$, $\Sigma^* = \Sigma_s$ and the particle path is sampled from the distance to scatter, rather than the distance to collision, or the mean-free-path $(1/\Sigma_t)$ .This is useful in a highly absorbing media and the weight is adjusted by a factor of $\exp(\Sigma d)$, where d is the distance of travel. This is equivalent to implicit capture (non-analog capture) performed along the flight path.

9.3 Deterministic Transport (DXTRAN)

DXTRAN is used when a small region is being adequately sampled because particles have a very small chance of reaching that region. Then the user can specify a DXTRAN sphere that encloses the small region. Upon collision outside the sphere, DXTRAN creates a special DXTRAN particle and deterministically scatters it toward the DXTRAN sphere and deterministically transports it without collision to the surface of the sphere. The original random walk is continued as usual with its original weight, but it is killed if it enters the sphere. This killing process, on average, compensates for the creation of the pseudo-particle for DXTRAN. The latter particle is given a weight adjusted for its probability of creation and transport to the sphere and then stored in a bank for tracking randomly, as a real particle. However, inside the DXTRAN sphere, the particles are not subject to normal cutoffs. The DXTRAN card (DXT) allows however the setting of its own weight cutoff. The DXC card assigns probability of cell contribution to the DXTRAN (similar to the PD card for detectors). Similarly, low weight particles can be killed by Russian roulette using the DD card for a DXTRAN sphere.

9.4 Forced Collisions

Forced collisions, the FCL card, is useful to generate more collisions that may be needed for DXTRAN or the next-event estimator of point and ring detectors. Particles are split into collided and uncollided parts. The collided part is forced to collide within the current cell and the uncollided part exists the cell without collision and is stored in a bank, until later when its track is continued to the cell boundary. The uncollided particle is given a weight equal to the original particle's weight times the probability of exiting the cell without collision, the colliding particle is given the remaining value of the original weight. The collided part may be sampled only a fraction of the time. The collision distance for the collided particle is sampled such that the particle does not leave the cell. With the FCL card, the user can specify that forced collision be applied only to the particles entering the cell, and not to subsequent collisions. This option can eliminate the production of too many particles with small weight.

9.5 Bremsstrahling Biasing

Bremsstrahling produces may now-energy photons, but the higher energy photons are often of more interest. The BREMS card allows the generation of more high-energy photon tracks by biasing each sampling of Bremsstrahling toward a larger fraction of available electron energy.

9.6 Correlated Sampling

Correlated sampling estimates the change in a quantity due to a small perturbation of any type in the problem. MCNP correlates two runs by each new history in the unperturbed and perturbed problem by the same initial pseudo-random number. The same sequence of subsequent numbers is used until a perturbation causes the sequences to diverge. This sequencing is done by incrementing the random number generator at the beginning of each history by a stride S of random numbers from the beginning of the previous history. The default value of S is 151917. If a history requires more than S random numbers, a message is printed in the problem summary; the maximum number of random numbers requited for a history is always printed in the problem summary. The default value of S can be changed by the X_{13} parameter in the BCN card.

The user must compare manually the results provided by the two runs. The code does not provide an estimates of the error in the difference, but a post processor can be used to relate the error, using the relationship:

$$\sigma^2 = \left\{\frac{C_1}{C_1 + C_2}\right\}^2 \sigma_1^2 + \left\{\frac{C_2}{C_1 + C_2}\right\}^2 \sigma_2^2$$

where C refers to the number histories and σ is the standard deviation (mean $\times$ fsd), and the subscript refers to the two runs; usually $C_1 = C_2$ in correlated sampling.

9.7 Work Problems

Explain each parameter in the following MCNP cards:

1. IMP:n 1 2 2m 0 1 20R
2. EXT: N 0 0.7V2 S -SV2 -.6V9 0 .5V9 SZ -.4X VECT V9 0 0 0 V2 1 1 1
3. WWN1:P 0.2 0.7 0.9
4. BREM 1. 1. 46I 10. 888 999