MCNP Report
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1 Result

For the following exercise all parts are created using the ENDL92 library (which is the most recently updated library available), and ran on the phymat server of University of Birmingham School of Physics and Astronomy, which is a Scientific Linux 7.3 (Nitrogen) system with 16 CPU's (Intel(R) Xeon(R) CPU E5-2630 v3 @ 2.40GHz) (though it is important to note that only 1 CPU is used at a time because this version of MCNP does not support parallel computing). Note that there is no delayed neutron cross section data available in ENDL92 (or any other nuclear databases available on phymat), so the simulation may deviate from reality slightly.

1.1 Exercise 1 Simple Neutron Source in a Bucket of Water

1.1.1 Input file

Energy cut-off is not applied so that very slow (thermalized) neutrons to interact and let further reactions take place.
Therefore the lower bound of the 1^{st} bin is 0.
The temperature of the cross-section data in databse 42(ENDL92, acquired by Lawrence Livermore National Laboratory) were acrquired at T=300K, as shown in 91-99, and is subsequently adjusted down to 20.4 C^o (2.53×10^{-8}MeV). Either way, thermal effects should significantly affect that falls into the first 3 energy bins. (0-10^{-9}MeV, 10^{-9}-10^{-8}MeV,10^{-8}-10^{-7}MeV respectively).
Insert the pictures of the cross sections of the geometry here, caption with cell number and material number

1.1.2 Output file

By examining the first 50 particles(using `PRINT 110`), the source was confirmed to be a point souce 2cm above the centre of the bottom of the tank's internal surface; and the majority of the particles have initial energy $E < 4$ MeV as expected when they are distributed according to the Watt spectrum for neutron generated by ^{235}U+n(thermal).
Insert Watt Spectrum .png
Note from the Watt spectrum above that there is a small but non-zero probability of getting neutrons of very high energy. This leads to some warning messages when the occassional particle scores above the upper limit of the largest tallying bin.
plot variation of VoV, fom, , as nps increases to 20000

1. These results are not reliable because the statistical checks (
   insert number of them not passed) are not passed, meaning that some reactions are not sampled enough for us to be confidence about the frequencies of their occurance.
   Additionally, some bins in the PDF are empty (seen table 161 of tally 22) suggesting that insufficient number of neutrons is sampled to approximate a continuous distribution.

2. The total fluences Φ are simplay calculated by formula $NA\sum_i(\Psi_i)$
   where each Ψ_i refers to the flux calculated for the ith energy bin *per history.*

A = Effective area for surface flux tallying, where the particle passing through still had non-zero weight.
N = number of histories
Giving
create table

3. The neutron spectra
(insert logx histograms using pandas, [dividing by the difference in upper and lower class boundaries so that it gives number density instead?].)
Copy and modify table above to show their respective means
The average standard flux ϕ i.e. number of neutrons passing through each unit surface area of interest, and the implication (fewer gets their because of the inverse square law)
The hardness of neutron spectrum decreases as follows: hardness at base (Tally 32)>long side (Tally 12)>short side (Tally 22), because distance of them increases in that order.
More neutrons can penetrate the base at the energy its creation energy without being moderated by the water; therefore the 1^{st} bin of tally 32is more filled than that of tally 12.
The ratio of neutron flux in the slow/Cadmium region (<0.01 MeV) to neutron flux in the resonance regions (>0.01MeV) builds up since the latter gets slowed down/captured by the resonance peaks much faster than the rate of consumption of the former, as they travel through the material.

Note that the 1^{st} bin (0 to 1×10^{-9} MeV) is below the thermal energy of room temperature; neutrons of these energies are strongly affected by the free gas thermal treatment of the interaction cross sections; additionally due to the large cross section in the thermal region which increases as the neutron slows, very few neutrons of these energies can travel far enough to be counted by these surface flux tallies. Therefore this bin always have the largest relative errors among all bins.

To ensure that no bins have relative error larger than 0.10 to ensure that the results are reasonable, enough histories must be ran to allow this energy bin in all 3 tallies to be filled sufficiently, in addition to passing all 10 statistical checks.

The tally probability distributions (histograms shown in table 161's) all show reasonably Gaussian distributions (and the cumulative probability distributions all show reasonably sigmoidal distributions) without the majority of the counts falling into a particular bin; therefore there is no inherent reason for using a finer spacing; but for the purpose of visualizing the spectrum with a higher resolution, a finer group structure with trifolded bin density (still logarithmically spaced, 3 bins per decade) was used.
Even when the spacing of energy groups is trisected in this manner, the 1^{st} bin (0 to 1×10^{-9} MeV) is still the bin that receives the least counts. In a real problem this would've been merged with the 2^{nd} bin to form a single, larger bin to tally up all the completely thermalized neutrons, increasing its count so that it converges to a precise enough value in a shorter CPU time; but according to the constraint of the problem, there must be one bin with 10^{-9} MeV as the upper limit. Therefore the only option left is to increase the number of histories such that the results of this bin converges.
Even after running 500000 histories, the relative error for this bin remains high (0.2599, 0.4236, 0.3681, for tally 12, 22, and 32, respectively) despite the fact that all other statistical checks were passed and the fom has alreay converged to a stable asymptotic limit.

If one does not care for the accuracy of the 1^{st} bin, then running 2800000 histories is sufficient, as it passess all statistical test, such as the figure of merit having stablized enough by the 2800000 history, in a reasonable computing time of 1.98 minutes. However, 16000000 histories are required for the convergence of the 1^{st} bin, requiring 12.79 minutes of coputing

time, which is quite long for a simple problem.
Additionally, the statistics of tally 22 is poor, leading to a fluctuating Figure of Merit being recorded, leading to what appears to be a decreasing trend in FoM the last half of the simulation, missing the fom statistical check. Therefore it is less reliable than the other two (tally 12 and tally 32) tally's statistics.

1.2 Exercise 3: Criticality

1.2.1 Input file

Geometry definition It is easier geometry to define the geometry if a sphere was used to define the graveyard (void) outside; but a cuboidal geometry was chosen instead to allow the surface flux detectors (F2) to tally particles passing through lateral surfaces separately from particles passing through horizontal surfaces.
All components except the concrete floor had the same neutron importance. Neutron importance in concrete started off at 1 but was subsequently reduced to 0.1 such that the simulation runs faster by ignoring particles that enter the concrete, since they will otherwise undergo a lot of collision (each requiring a lot of CPU time) to slow down, without causing multiplication.
If the mean free path to absorption λ_{abs} is known, the dimension of the concrete floor can be chosen to extend from the stainless steel tank by $N\lambda_{\text{abs}}$ where N is some arbitrary threshold factor (e.g. 3).
However only the mean free path to collision for neutron is found on a Cell particle activity table (using `PRINT 126`). Since concrete is only a weakly neutron-absorbing medium, this cannot be used as the proxy for λ_{abs}.
Instead the fraction of neutrons escaping the concrete block into the void was calculated. This was done by comparing the number of neutrons travelling from the concrete to the void region (where neutron importance = 0) to the neutron population in the concrete. The quantity "population" instead of "tracks entering" was used because the latter re-counts particles re-entering the same cell, thus the former is a more accurate measurement of how many distinct neutrons have been present in the concrete cell. The simulation is considered accurate when the ratio of these two numbers is less than 1%, i.e. $< 1\%$ of the neutrons entering the concrete were "killed" (by entering the void region) instead of being absorbed in the concrete/reflected back towards the tank. The dimension of the concrete block was increased until this ratio is lower than 1%.
This resulted in a concrete floor block of 160.4cm in the x- and y-directions and 50 cm in the z-direction, resulting in 0.21621209% and 0.04494092% of neutrons escaping through the lateral planes and the horizontal plane (plane separating the concrete block from the void below) respectively. This was used as the final dimension for the concrete block.

Source definition Using the `KSRC` card a "generic Watt spectrum"(
Quote MCNP manaul p.2-160) of neutrons was created at the center points of each cylinder.
This allowed for very fast convergence of the results, where the k_{eff} value settled down to a stable value in less than 10 generations. The k_{eff} estimation started after that.
The alternatives of using an `SDEF` card with a cookie cutter(`CCC`) rejection/`CEL` rejection OR 5 uniform cylindrical sources overlayed onto cell 11-15 (all the uranium cylinder cells) were attempted, but were not applied in the end because it is likely to distribute neutrons close to the non-re-entrant surfaces where they can escape.
Quote MCNP p.4-30

1.2.2 Questions

- Examine and report upon the estimate of
  k_{eff} with cycle number given in the output.

- The final results of $\mathrm{k}_{\text{eff}} =$
  is fairly reliable, considering the following items, as suggested by [
  Quote p.2-180]:

  - all cells with fissile isotopes (i.e. all U cylinders) were sampled
  - the average combined k_{eff} appeared to be varying randomly about the average k_{eff} for the average cycles
  - no noticable trend was present in the later stage of the average combined k_{eff}
  - the confidence intervals from the batched combined k_{eff} does not appear to differ significantly from the final result, meaning there are no cyclic variations
  - the Figure of Merit for combined k_{eff} is stable.

  and lastly,

  - the lack of delayed neutron cross section library should only make an insignificant difference to the final k_{eff} because they shouldn't care

- In addition to Monte Carlo stochastic uncertainties what other uncertainties may need to be considered in a criticality safety assessment?