FLUKA Beginners' Online Training

Answers to the questionnaire on Introduction to FLUKA and fundamentals of Monte Carlo simulations

Question 1

The most relevant quantity for estimating the probability of Single-Event Effects in electronics in a high-energy accelerator context is:

A. Thermal neutron fluence.

B. Energy deposition.

C. **High-energy hadron fluence**

D. X-ray fluence

In the high-energy accelerator context, Single-Event Effects (SEE) are typically induced by indirect energy deposition events from nuclear interactions between the hadrons in the radiation environment and the nuclei in the component sensitive area. Thus, the SEE-relevant radiation environment is mainly described through the so-called high-energy hadron fluence, where “high-energy” denotes here above 20 MeV (the cross section for nuclear interaction typically decreasing below this energy).

See: R. Garcia-Alia *et al.*, *Semicond. Sci. Technol.* **32** 034003 (2017).

A bit more on this during the Scoring II lecture, which will among other address topics concerning radiation effects on electronics.

Question 2

Which of the following statements is true?

A. Running a simulation with twice the number of histories will yield results with half the statistical uncertainty

B. Running the same simulation with different random seeds will produce identical results

C. **A sufficiently large number of contributions to a Monte Carlo estimator follows a normal distribution around the expectation value of the physical observable being estimated.**

D. Random number sequences produced during a Monte Carlo simulation cannot be exactly reproduced a second time

Note that the first answer cannot be: statistical uncertainty scales with $1/\sqrt{N}$, where N is the number of primary events. Thus, one would have to run a simulation with $4N$ primary events to halve the statistical uncertainty.

The second answer can of course not be: different seeds will produce different random-number sequences, and therefore different histories (their contributions to the desired physical observables of course converging to the expected mean value).

The third answer is true, as discussed at length in the lecture.

The fourth answer is of course false: a sequence of (pseudo-)random numbers can be reproduced by setting the same original seeds.

Question 3

How can you best estimate whether a simulation is sufficiently covering the phase-space of your problem ?

A. Running 1 cycle with 1,000,000 particles.

B. **Running 5 cycles with 200,000 particles each.**

C. Running 1 cycle with 1,000,000 particles, but with a very high random seed.

D. Running 1 cycle with 1,000,000 particles with energies following a normal distribution with known σ.

The situation suggested in the first answer would not allow FLUKA to evaluate the statistical uncertainty (done on the basis of results from various cycles or batches). In such a scenario, FLUKA would quote 100% uncertainty.

The second answer, instead, allows FLUKA to evaluate the statistical uncertainty (several cycles being available with considerable number of primary events).

The third and the fourth replies are obviously decoys.

Question 4

Which of the following statements is true?

A. Systematic errors contribute to the statistical uncertainty of Monte Carlo estimators.

B. The accuracy of a result is ensured by achieving low statistical uncertainty.

C. Cross-section uncertainties cancel each other out when running multiple cycles.

D. **The inclusion of trace elements in material definitions may be necessary to obtain accurate results.**

The first suggested answer option is invalid: whereas statistical uncertainty can be reduced by increasing the number of primary events in your simulation, systematic errors (*e.g.* in the experimental data from which employed interaction cross sections are extracted) cannot (being implicit and to the extent possible mitigated a priori).

The second answer is an elaboration of the previous: one can improve the *precision* of a result (*i.e.* how many significant/converged figures one obtains) by achieving low statistical uncertainty, but the *accuracy* is also a function of the employed interaction models. The latter is what intrinsically ensures the quality of the results; the former indicates how well these results are resolved with the dedicated simulation time.

The third option is a further elaboration of this train of thought: cross section uncertainties (systematic errors) are not reduced by improving the statistics (which will help to reduce only the statistical uncertainty).

The fourth option is the correct one: the inclusion of trace elements/isotopes can indeed be crucial to obtain accurate results.

Question 5

Which of the following statements is true?

A. A Monte Carlo simulation can follow the time-evolution of material degradation.

B. It is in general possible to solve the transport equation analytically.

C. Monte Carlo simulations of radiation transport can be run for primary energies of 50 eV regardless of the particle species.

D. **The particle step length in a Monte Carlo simulation is sampled from an exponential distribution.**

The first suggested answer is false: every new event in a Monte Carlo simulation of radiation transport sees the same clean pristine material as any previously simulated particle shower. Thus, an online description of material degradation is not accessible in such a simulation scheme.

The second answer is also not true: solutions for the transport equation exist in constrained situations, *i.e.* for a given particle type, simple geometry, and reduced number of interaction mechanisms. For instance, the Molière multiple scattering distribution is obtained from an (approximate) analytical solution of the transport equation for charged particles undergoing only elastic scattering in an infinite medium. Such solutions are not purely academic: complex transport algorithms employ them as building blocks!

The third answer is false: at low energies, the de-Broglie wavelength of particles increases, and it will eventually span several interatomic distances, therefore compromising a basic assumption of the Monte Carlo simulation approach for radiation transport problems, namely, that one can assume interactions with individual target atoms. Thus, there is a formal/natural low-energy limit at which a detailed particle transport simulation can be carried out in its standard form.

The fourth answer is true (see lecture backup slide for the derivation).