Simulating neutron propagations with FLUKA, GEANT4 and MCNP

Yung-Shun Yeh, Chung-Hsiang Wang, Hong-Ming Liu, Tsung-Che Liu, and Guey-Lin Lin

Abstract—**We perform simulations on neutron transport properties for neutrons with energies less than 500 MeV. The simulation packages FLUKA, GEANT4 and MCNP are used. The neutron energy distributions and attenuation lengths, which are resulted from a mono-energetic initial neutron beam traversing a given thickness of medium, are presented.**

I. INTRODUCTION

NEUTRONS play important roles in various areas. For radiation safety and neutron therapy, neutrons are research objects[5]. For dark matter search and neutrino detection experiments, the neutrons induced by cosmic muons can be important backgrounds in these experiments[4]. The Monte Carlo simulations are helpful to determine the detector parameters before starting an experiment. There are several simulation toolkits capable of simulating neutron transport behaviors. MCNP[3] is frequently used to deal with the neutron dose in radiation safety and neutron therapy; FLUKA[1] and GEANT4[2] are frequently used in particle physics.

We perform simulations on neutron transport properties for neutrons with energies less than 500 MeV. The simulation packages FLUKA, GEANT4 and MCNP are used. The neutron energy distributions and attenuation lengths, which are resulted from a mono-energetic initial neutron beam traversing a given thickness of medium, are presented.

II. SIMULATION CONFIGURATION

The version of GEANT4 used in this study is GEANT4 9.0 with neutron data library G4NDL 3.11. The following neutron models are applied,

- For neutron energy greater than 20 MeV, G4HadraonElastic, G4NeutronInelastic, G4LFission and G4Lcapture are employed to simulate neutron propagations.
- For neutron energy less than 20 MeV, Neutron High Precision Models are used.
- For neutron energy less than 4 eV, thermal neutron scattering from chemical bound atoms are considered.

The version of MCNP is MCNP4C with neutron data library ENDF/B-VI.6. Continuous-energy neutron interaction data from 10^{-11} MeV to 150 MeV is available. Thermal neutron $S(\alpha, \beta)$ tables were used for neutron energy less than 4 eV by considering the molecular binding effects.

The version of FLUKA is FLUKA 2006.3. For neutron energy greater than 19.6 MeV, default settings are used. For neutron energy less than that, low energy neutron models are turned on.

We design the detector geometry as a sphere filled with either water or concrete for comparing the neutron propagation behaviors given by the above three simulation toolkits. The outside region of the detector is set to be vacuum to avoid the back scattering effects. Mono-energetic neutrons are generated in the center of the sphere. The concrete in this study is Tiara concrete[6] (density ρ = 2.4 g/cm^3) with composition listed in Table I.

TABLE I: The Concrete Composition

Elecment	Mass fraction(%)
H	1.09
O	48.17
Si	22.42
Al	6.06
Fe	5.67
Mg	1.08
Ca	12.39
Na	2.04
K	1.08

III. ANALYSIS

The outgoing neutron spectra and yields are studied. Those neutrons which penetrate through the detector will be recorded. There is no energy cut for outgoing neutrons.

We also deterimine the neutron attenuation lengths. To calculate the attenuation length, we count numbers of neutrons which penetrate the concrete spheres with various radii. We then fit the results to an exponential function,

$$N = A \cdot \exp\left(-x/\lambda\right),$$

where N is the number of outgoing neutrons, and λ is the neutron mean free path. The attenuation length L_{att} is the product of mean free path and the concrete density,

$$L_{\text{att}} = \rho \cdot \lambda.$$

The neutron needs to travel some distance for developing the cascade. Hence we choose the radii sufficiently large for developing the cascade.

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IV. RESULTS

Fig. 1 shows the outgoing neutron yields per incident neutron penetrating through 10 cm water. For incident neutron with energy below 100 MeV, GEANT4 gives similar result as FLUKA. For incident neutron with energy above 100 MeV, the result by GEANT4 is approaching to that given by MCNP. These three simulation toolkits agree within 20% for the outgoing neutron yields.

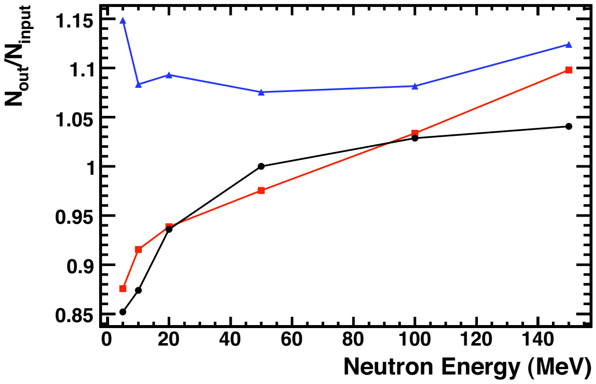


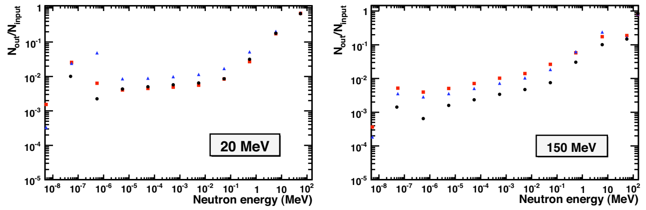
Fig. 1: Neutron yields arising from an incident neutron which penetrate through a 10-cm-radius sphere filled with water. The results given by FLUKA are shown as black circular points; the results given by GEANT4 are shown as red square points; the results given by MCNP are shown as blue triangular points.

From the studies of energy spectra, the differences of outgoing neutron yields mainly come from the low energy region (see Fig. 2). Fig. 2 shows the outgoing neutron energy spectra corresponding to different incident neutron energies. In the thermal neutron region, these three toolkits give different estimations. In the energy region $(10^{-5} - 1)$ MeV, the result of GEANT4 agrees with that of FLUKA. As the energy of incident neutron increases, the energy spectrum obtained by GEANT4 is approaching to that given by MCNP. The differences between three toolkits on total neutron yield are within 20%.

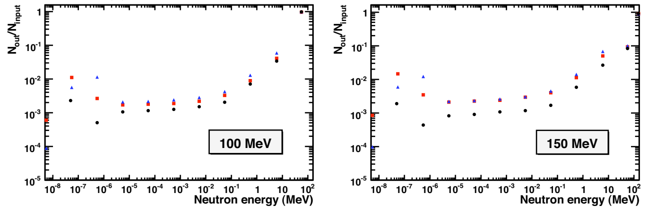
For concrete with a 10 cm radius, we obtain similar results. Fig. 3 shows the the total neutron yields after 10 cm concrete as a function of the incident neutron energy. Fig. 4 shows the outgoing neutron energy spectra with 10 MeV and 150 MeV incident neutrons.

Fig. 5 shows the neutron attenuation lengths as a function of incident neutron energy. It is seen that three simulation toolkits and the PDG curve[7] give similar results for incident neutron energy below 100 MeV. As the incident neutron energy increases, the curves of GEANT4 and FLUKA keep rising. However PDG's curve stays flat. There is no data from MCNP simulation for incident neutrons with energies above 150 MeV.

Although the attenuation lengths given by three simulation toolkits are similar, the total neutron yields are quite different. For example, Fig. 6 shows the total neutron yields with 100 MeV incident neutrons as a function of the concrete thickness. As we can see, differences between results obtained by three toolkits increase as the concrete thickness becomes larger. For 200-cm-thick concrete, the estimation of MCNP is about 2 times larger than that of GEANT4. The slopes of curves obtained by these toolkits remain similar. Therefore the attenuation lengths obtained by these toolkits agree with one other. Fig. 7 shows the neutron energy spectrum resulted from 100 MeV neutrons penetrating through a 200-cm-thick concrete. It shows that the differences on neutron yields as predicted by three simulation packages occur at all outgoing neutron energies.



(a) 20 MeV (b) 50 MeV



(c) 100 MeV (d) 150 MeV

Fig. 2: Outgoing neutron spectra corresponding to incident neutrons with different energies. The incident neutrons penetrate through a 10-cm-radius sphere filled with water. The results given by FLUKA are shown as black circular points; the results given by GEANT4 are shown as red square points; the results given by MCNP are shown as blue triangular points.

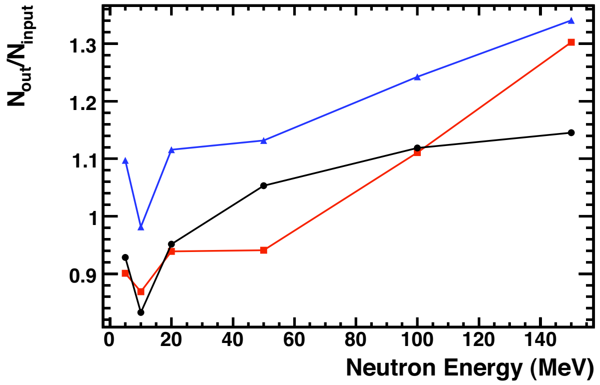
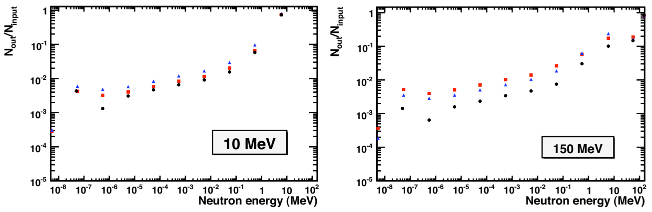


Fig. 3: Neutron yields arising from an incident neutron which penetrate through a 10-cm-radius sphere filled with concrete. The results given by FLUKA are shown as black circular points; the results given by GEANT4 are shown as red square points; the results given by MCNP are shown as blue triangular points.



(a) 10 MeV (b) 150 MeV

Fig. 4: Outgoing neutron spectra corresponding to incident neutrons with different energies. The incident neutrons penetrate through a 10-cm-radius sphere filled with concrete. The results given by FLUKA are shown as black circular points; the results given by GEANT4 are shown as red square points; the results given by MCNP are shown as blue triangular points.

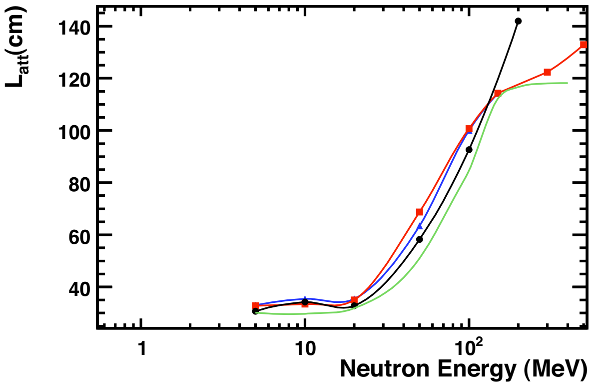


Fig. 5: The neutron attenuation length as a function of incident neutron energy. The result given by FLUKA is shown as the black curve; the result given by GEANT4 is shown as the red curve; the result given by MCNP is shown as the blue curve; the PDG curve is shown as the light green curve.

V. CONCLUSION

We have made comparisons of neutron transport properties as predicted by FLUKA, GEANT4, and MCNP. For neutron energy spectrum in the thin media, the reult given by MCNP is about 2 times lager than that given by FLUKA in the energy tail region(10 eV∼1 MeV). For incident neutron energy less than 100 MeV, GEANT4 and FLUKA agree well; for neutron energy greater than 100 MeV, the result given by GEANT4 approaches to that given by MCNP. Concerning the total neutron yield, these three toolkits agree within 20%.

In the studies of neutron attenuation lengths, all three packages obtain similar results for the incident neutron energy less than 150 MeV. When the neutron energy is larger than 150 MeV, the attenuation lengths given by GEANT4 and FLUKA keep rising with energies, while PDG curve stays flat.

As the materials become thicker, the differences on total neutron yields become larger.

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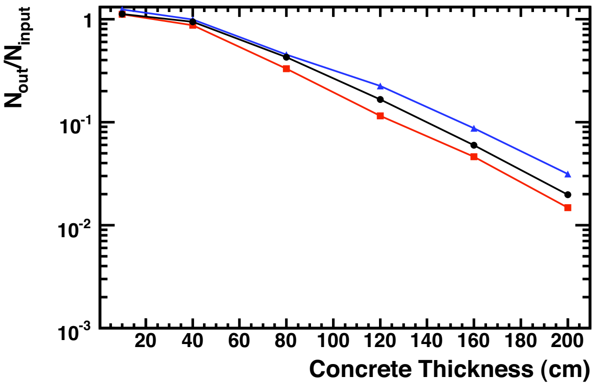

Fig. 6: Neutron yield per 100 MeV incident neutron as a function of the concrete thickness. The results given by FLUKA are shown as black circular points; the results given by GEANT4 are shown as red square points; the results given by MCNP are shown as blue triangular points.

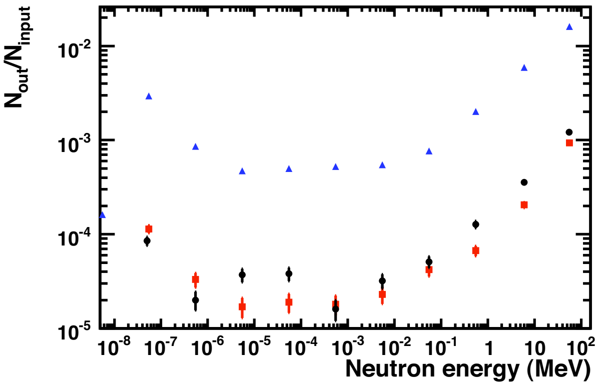

Fig. 7: Outgoing neutron specta resulted from 100 MeV incident neutrons which penetrate through a 200-cm-radius concrete. The results given by FLUKA are shown as black circular points; the results given by GEANT4 are shown as red square points; the results given by MCNP are shown as blue triangular points.

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