Kasetsart J. (Nat. Sci.) 43 : 817 - 821 (2009)

A Simulation of Neutron Scattering via Geant4

Rachanee Rujiwarodom[1]*, Burin Asavapibhop[2] and Pat Sangpeng[1]

ABSTRACT

Geant4 is a program developed by The European Organization for Particle Physics (CERN). This research applied Geant4 in a simulation of neutron scattering in a collimator, and subsequently for the modification of a collimator design for use with a nuclear research reactor. Six different materials were used in the simulation: concrete, iron, lead, bismuth, graphite and boron carbide. Trajectories of neutron particles produced during the reaction could be visualized through the simulation. The effects of the six materials on the kinetic energy of neutrons and the neutron scattering angle were studied. The results showed that iron was the most suitable material for fabrication of the collimator pile for a neutron reactor source with an energy level at 0.025 eV, due to its good neutron-reflecting ability. Boron carbide was not suitable, owing to its ability to absorb neutron particles.

Key words: simulation, neutron scattering, collimator, material, Geant4

INTRODUCTION

Neutrons are attenuated by three major interactions; nuclear collision, elastic scattering and absorption. At high energy (>20 MeV), nuclear collision with high atomic nuclei is a major concern. In this case, another new product is produced through the inelastic collision. The energy of a neutron at 0.025 eV (thermal neutron) was used in the simulation to achieve elastic collision conditions.

Geant4 (Geometry and tracking) is a toolkit for the simulation of the passage of particles through matter. This is supported and has a center at CERN.Geant4 (or G4) is the fourth version and is based on the C^{++} language, which supports object oriented programming; the function enables further development and easy design. The scope of this work was to study the effects of six different materials on the kinetic energy of neutrons and the neutron scattering angle. The results from the simulation were then to be used to identify the most suitable material for making a collimator.

MATERIALS AND METHODS

Neutron scattering

Consider a non-relativistic, elastic collision between a neutron (mass m_1), with energy E_{1i} and speed $\vec{v}_{1i}$ on a target nucleus (mass m_2) initially at rest. This event is illustrated in Figure 1(a) for the laboratory (lab) frame and in figure 1(b) for the center-of-mass (cm) frame (Marion and Thornton, 1995).

From Figure 1, the relationship between E_{1i} and E_{1f} is shown in Equation 1:

$$E_{1f} = E_{1i}\left(\frac{m_1^2 + m_2^2 + 2m_1m_2\cos\theta_c}{(m_1 + m_2)^2}\right) \qquad (1)$$

[1] Department of Physics, Faculty of Science, Kasetsart University, Bangkok 10900, Thailand.
[2] Department of Physics, Faculty of Science, Chulalongkorn University, Bangkok 10330, Thailand.
* Corresponding author, e-mail: fscirnr@ku.ac.th

Received date : 28/04/09 Accepted date : 22/06/09

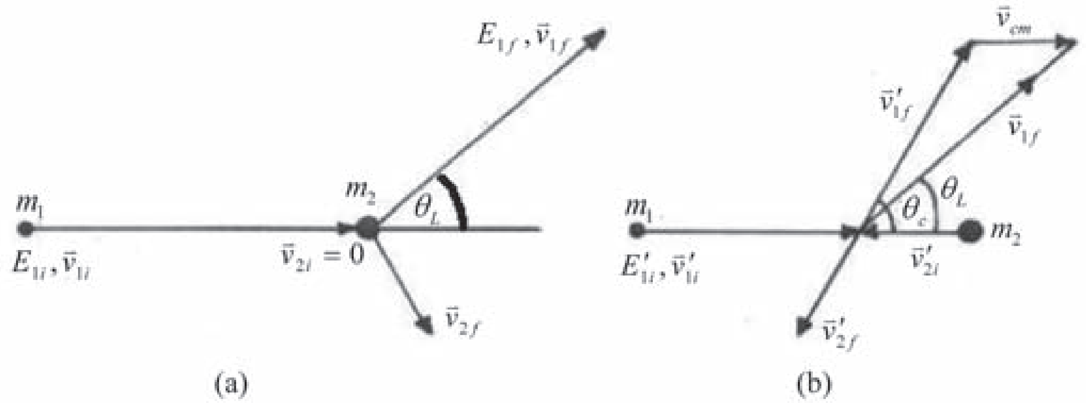

Figure 1 Elastic scattering kinematics for an incident particle of mass m_1, initial energy, E_{1i} and speed $\vec{v}_{1i}$, colliding with a particle of mass m_2 (target) in (a) the laboratory (lab) frame and (b) the center-of-mass (cm) frame.

where: E_{1i} = the pre-kinetic energy in the lab frame,

E_{1f} = the post-kinetic energy in the lab frame,

θ_c = the scattering angle in the cm frame.

The pre-kinetic energy is the energy of a neutron particle before a collision, the post-kinetic energy is the energy of a neutron particle after a collision. θ_c is given by Equation 2:

$$\tan\theta_L = \frac{\sin\theta_c}{\left(m_1/m_2\right) + \cos\theta_c} \qquad (2)$$

where: θ_L = the scattering angle in the lab frame. The value of θ_c can be obtained using θ_L measured from the simulation in Equation 2, and E_{1f} can be calculated from θ_c and E_{1i} = 0.025 eV according to the relationship in Equation 1. E_{1f} from Equation 1 was compared with E_{1f} measured from the Geant4 simulation. In the initial simulation, bismuth was used in order to obtain an accurate estimation of $\theta_L = \theta_c$, due to the condition given that $m_2 >> m_1$.

The result from the simulation was found to correspond with the calculated data (Table 1). Therefore, Geant4 was used in the simulation to demonstrate the effect of various materials on the kinetic energy of a neutron and the neutron scattering angle.

Table 1 Post-kinetic energy in the simulation compared with post-kinetic energy from calculations derived using bismuth as a target.

Scattering angle in lab frame (θ_L) (degree)	Post-kinetic energy in the simulation (E_{1f}) (eV)	Post-kinetic energy from calculation (E_{1f}) (eV)
24.2838	0.024814	0.024948
40.0793	0.024934	0.024862
81.2160	0.024881	0.024502
92.9697	0.024024	0.024382
125.816	0.022064	0.024068
164.283	0.021537	0.023851

Geant4

In order to carry out a simulation, the main program must be executed. The contents of the main program will vary according to the needs of a given simulation application that must be supplied by the user. The Geant4 toolkit does not provide a main program, so the user has to build one by including the subprograms needed to run the application. The main program is implemented by two toolkit classes, G4RunManager and G4UImanager. The G4RunManager consists of five subprograms: DetectorConstruction, PhysicsList, PrimaryGeneratorAction, SteppingAction and TrackingAction. The G4UImanager creates a pointer to the interface manager. This manager class is created when the run manager is created. The pointer UI is created in order for the user to issue commands to the program (Colonna and Altieri, 2002; Incerti *et al.*, 2003; Anonymous, 2004).

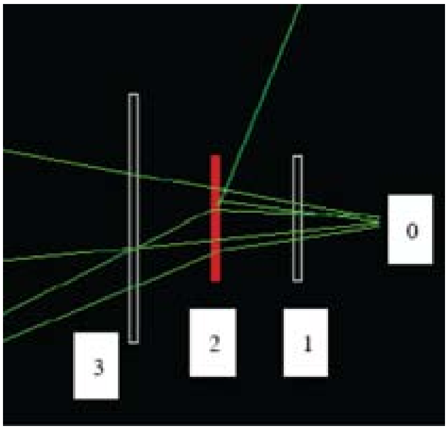

Figure 2 Illustration of the simulation of neutron scattering using Geant4.
Point 0 represents a generator; point 2 represents a target, which is one of the six different materials; point 1 represents a vacuum measuring the number of neutrons from a generation; and point 3 represents a vacuum measuring the number of neutrons scattering from a target.

Root analysis

ROOT is an object-oriented framework designed to solve the data analysis of particle physics. The benefits of this framework include histogram analysis (filling and fitting) and graphics (Anonymous, 2005).

RESULTS AND DISCUSSION

The neutron trajectory, post-kinetic energy of the neutron and the angle of neutron scattering were simulated. Figures 4, 5 and 6 show these three results for iron (thickness 5 cm), and Figures 7, 8 and 9 show these three results for boron carbide (thickness 5 cm), respectively. In this simulation, the number of neutrons emitted from the generator was 10,000 particles and the pre-kinetic energy of the neutron was 0.025 eV.

From a comparison of Figures 4 and 7, the trajectories of the neutrons illustrates that iron has a good ability to reflect neutrons, while boron carbide does not, owing to its ability to absorb neutron particles.

Figures 5 and 6 show that the 3,030 neutron particles scattering from iron had post-kinetic energy between 0.00 to 0.05 eV and underwent total reflection (scattering angle from 90° to 180°).

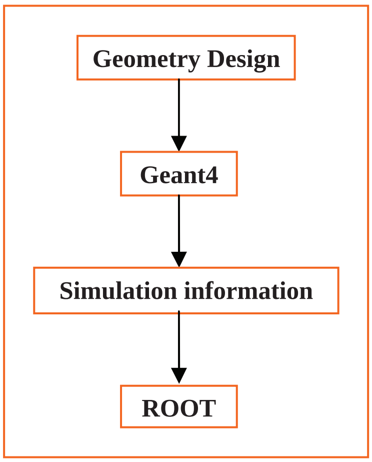

Figure 3 Diagram of root analysis.

Figures 8 and 9 show that the six neutron particles scattering from boron carbide had post-kinetic energy between 0.00 to 0.05 eV and underwent total reflection (scattering angle from 90° to 180°).

The results of the other four materials (concrete, lead, bismuth and graphite) were similar; they had the ability to both scatter and totally reflect neutrons, but the number of neutrons that underwent total reflection was less than 3,030 particles.

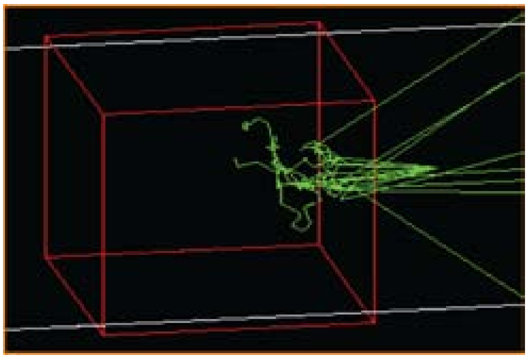

Figure 4 Neutron trajectories in iron.

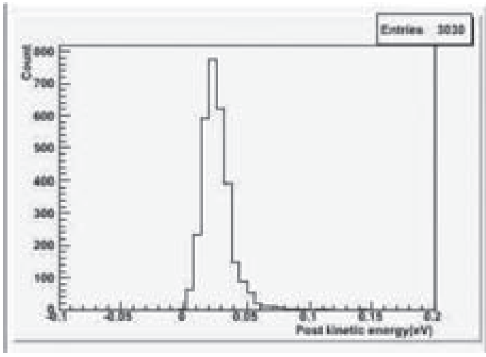

Figure 5 Post-kinetic energy of neutrons from iron.

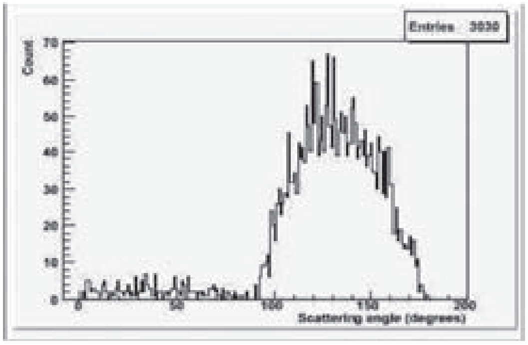

Figure 6 Angle of neutrons scattering from iron.

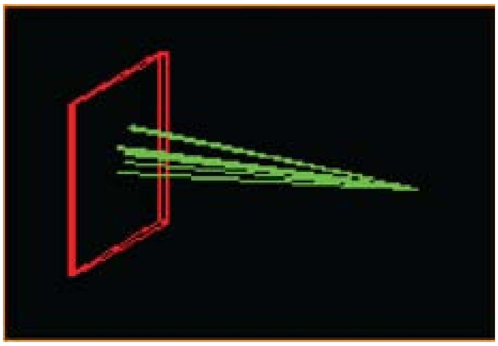

Figure 7 Neutron trajectories in boron carbide.

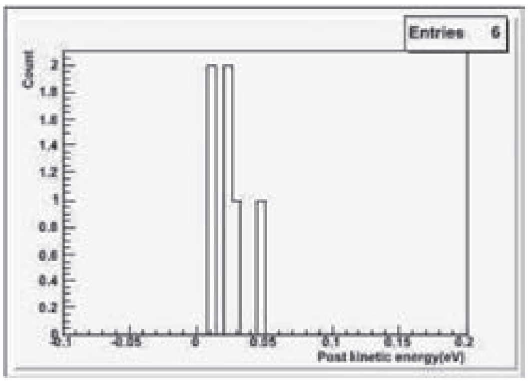

Figure 8 Post-kinetic energy of neutrons from boron carbide.

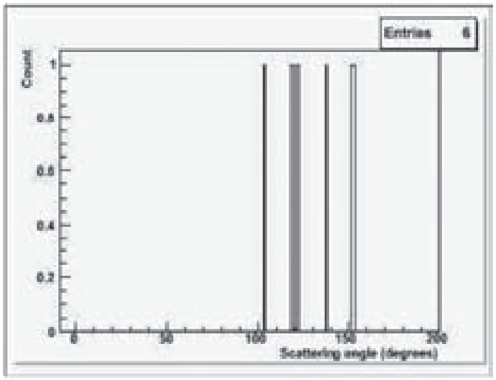

Figure 9 Angle of neutrons scattering from boron carbide.

Therefore, iron was the most suitable material for fabrication of the collimator pile, due to its good neutron-reflecting ability, which is a requirement for a good collimator.

CONCLUSION

The results showed that iron was the most suitable material for fabrication of the collimator pile for a neutron reactor source with an energy level at 0.025 eV, due to iron having good neutron-reflecting ability. Boron carbide was not suitable, owing to its ability to absorb neutron particles.

ACKNOWLEDGEMENTS

This work was financially supported by the Kasetsart University Research and Development Institute (KURDI) and partially supported by the Science, Research Fund, ScRF of the Faculty of Science at Kasetsart University.

LITERATURE CITED

Anonymous. 2004. **Geant4 Program.** Decagon Devices, Pullman., WA, USA.

Anonymous. 2005. **ROOT Program.** Decagon Devices, Pullman., WA, USA.

Colonna, N. and S. Altieri. 2002. Simulations of Neutron Transport at Low Energy: A Comparison between GEANT and MCNP. **Health Phys**. 82: 840-846.

Incerti, Ph. S., B. Barberet, C. Courtois, Michelet-Habchi and Ph. Moretto. 2003. Simulation of Ion Propagation in The Microbeam Line of CENBG using GEANT4. **Nucl. Instrum. Methods Phys. Res., Sect. B.** 210: 92-97.

Marion, J.B. and S.T. Thornton. 1995. **Classical Dynamics of Particles and Systems**. 4^{th} ed. harcourt Brace & Company, U.S.A. 638 p.