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Characterization of Photoneutron Yields Produced from Cu Target by High Energy Electron Accelerators using Monte Carlo Simulation

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1. Introduction

Many countries use synchrotron light sources for advanced research in science and technology. Recently, more advanced synchrotron radiation facilities, with electron beam energies higher than 5 GeV have been in operation or under construction to increase the brightness of hard X-rays and incorporate advanced beamlines. The neutrons are produced through photonuclear reactions caused by the bremsstrahlung photons during electron interactions with some accelerator components. One of the main radiation safety issues at high-energy electron accelerators is the personnel exposure to induced radioactivity in beamline components and shielding materials due to these photoneutrons. 1].

In this study, the photoneutron energy spectra and differential yields produced from Cu target bombarded with 1.0, 2.5, and 10 GeV electrons were estimated using the MCNP6.2 [2], the PHITS3.32 [3], and the FLUKA [4] codes. The objective of this work is to gain a comprehensive understanding of high energy photonuclear reactions in terms of radiation safety of a synchrotron radiation facility. Additionally, the estimation results of the photoneutron yields and emission spectrum are very important information to operate high-energy electron accelerators safely and economically [5].

2. Methods and Results

2.1 Target Geometry

Fig.1 shows a schematic representation of the Monte Carlo simulation model of a copper cylindrical target irradiated by electron with the energy of 1.0, 2.5, and 10 GeV. The target features a cylindrical geometry with dimensions of 15 cm in length and 10 cm in diameter, chosen to optimize the yield of neutrons and high-energy photons. This corresponds to a length of about 10 radiation lengths and a radius of about 3 Moliere radii, as indicated in Table 1. This is also the approximate size of the transition piece at the entrance to an insertion device of synchrotron light sources. The tally was positioned 100 cm from the center of this geometry to score the neutrons emitted from the target. The tally's scoring angles were 0~5°, 30~45°, 80~100°, 135~150° with respect to the beam direction. Additionally, the tally encompassed all surfaces (4π) of the tally sphere to integrate the emitted neutrons.

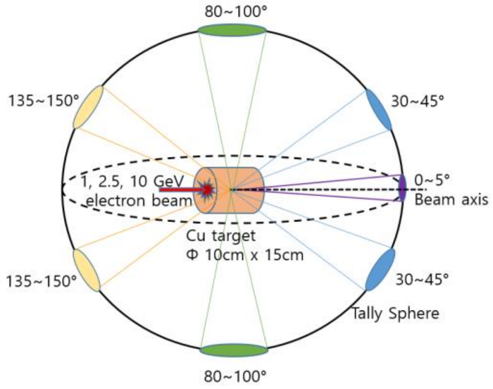

Fig. 1. Input geometry in the MCNP codes for calculating differential neutron yields emitted from the Cu target.

Table.1: Atomic and nuclear properties of copper

Quantity	Value [6]
Specific gravity(density)	8.960 g·cm^{-3}
Nuclear collision length	9.393 cm
Nuclear interaction length	15.32 cm
Radiation length	1.436 cm
Moliere radius	1.568 cm
Critical energy	19.42 MeV for e$^-$

2.2 Monte Carlo Calculations

Three Monte Carlo codes, which are MCNP6.2, PHITS3.32, and FLUKA, were used to estimate neutron production yields. The MCNP6.2 code is capable of simulating the photonuclear reactions by nuclear data libraries from the ENDF/B-VII.1 [7] and physics models when the experimental nuclear data are unavailable. Therefore the MCNP6 can calculate nuclear reactions with the energies higher than 10 GeV without energy restriction for electron or photon. Similarly, the PHITS3.32 code can simulate the photonuclear reactions using either theoretical models or nuclear data libraries from JENDL-4.0. FLUKA code can handle electromagnetic effects with good accuracy, even though it is best known for its hadron event generators because of historical reasons. This code can transport photons and electrons across an extensive energy range, over about 12 decades of 1 keV~1 PeV (i.e 10^{-3} MeV~10^{9} MeV).

3. Results and Discussions

3.1 Photoneutron Yields

The calculated integral photoneutron yields for 4π solid angle emitted by copper target per electron with energy of 1.0 GeV are shown in Fig.2, simulated using MCNP6.2. It shows that the maximum neutron energy is about 600 MeV. The electron energies of 2.5 GeV and 10 GeV are being simulated under the same target geometry.

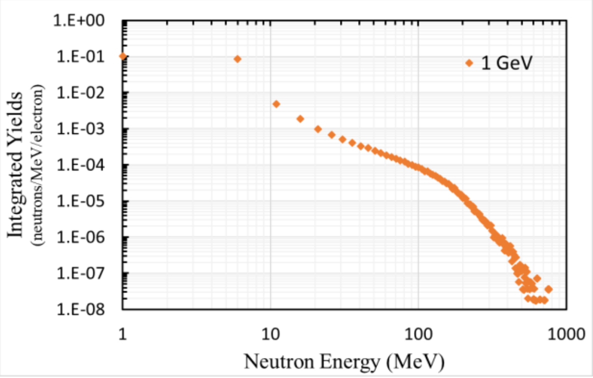

Fig. 2. Integrated photoneutron yields emitted by the copper target irradiated by 1.0 GeV electron, simulated with MCNP6.2

The differential photoneutron yields calculated for four kinds of scoring angles which were 0~5°, 30~45°, 80~100°, 135~150° with respect to the beam direction are shown in Fig.3. It seems that the differential yields and the maximum neutron energy decrease, respectively when the scoring angle increases.

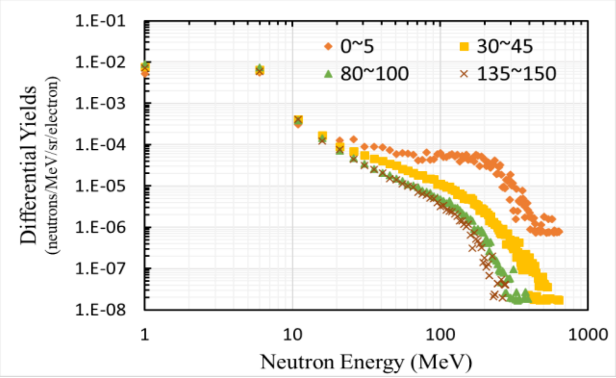

Fig. 3 Differential photoneutron yields for counting angles, simulated with MCNP6.2

3.2 Angular Distribution

Fig. 4 shows the angular distribution of the photoneutron emitted by copper target irradiated by 1.0 GeV electrons. The angular distribution of the photoneutron seems to be anisotropic with respect to 90° as its central axis. It seems to be due to target geometry effects caused by a relatively long length of the target.

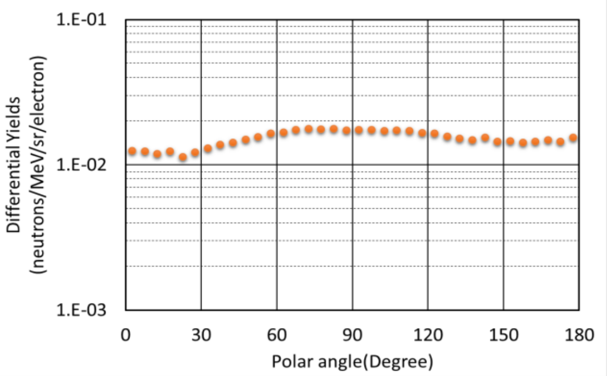

Fig. 4 Angular distribution of photoneutrons emitted by Cu target irradiated by 1.0 GeV electrons, simulated with MCNP6.2

4. Conclusions

Photoneutron yields emitted by copper target irradiated with 1.0 GeV electrons were calculated by Monte Carlo simulation. The maximum neutron energy is about 600 MeV. The differential yields and the maximum neutron energy decrease, respectively when the scoring angle increases. The angular distribution seems to be a little anisotropic. The electron energies of 2.5 GeV and 10 GeV are being simulated under the same target geometry and we have a plan to simulate the photoneutron yields using PHITS and FLUKA codes under the same condition. In conclusion, the findings of this study can be useful in the radiation safety of high energy electron accelerators.

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