Study of photon production by 30 MeV electrons in a Tungsten converter target

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1. Introduction

Radioactive ion beams (RIBs) are a powerful tool in nuclear physics research, allowing the study of nuclei far from stability. These beams consist of ions of radioactive isotopes, which are produced either by fragmenting heavier stable nuclei or by using nuclear reactions that produce unstable nuclei. RIBs open new avenues in understanding nuclear structure, astrophysical processes, and fundamental interactions [1]. There are two primary methods for producing Radioactive Ion Beams (RIBs): the In-Flight Fragmentation method and the Isotope Separation On-Line (ISOL) method.

In the In-Flight Fragmentation method, a stable, high-intensity beam of heavy particles (such as uranium, oxygen, or carbon) is accelerated to high energies, typically hundreds of MeV per nucleon. This accelerated beam then collides with a thin target made of materials like beryllium or carbon. During the collision, the stable nuclei break apart, producing a variety of lighter, unstable radioactive isotopes. These radioactive nuclei retain their high momentum in the forward direction and can be quickly mass-separated in-flight using magnetic or electrostatic separators. The selected radioactive ion beam can then be delivered at high energies for experiments.

In contrast, the ISOL method involves bombarding a thick target (such as uranium carbide) with high-intensity beams of light particles. This bombardment induces nuclear reactions, resulting in the production of a wide range of radioactive isotopes within the target. The target is then heated to allow the generated nuclei to release, facilitating their extraction for further use. These isotopes are ionized using techniques like surface ionization, laser ionization, or electron impact ionization. The ionized radioactive species are passed through a mass separator to select the desired isotope based on its mass-to-charge ratio. The radioactive ions can then be further accelerated to the desired beam energy for experiments.

Alternatively, a high-energy electron beam (typically 30-50 MeV) is directed at a high atomic number converter target, such as tungsten to produce bremsstrahlung photons. These photons can reach energies up to the initial electron energy. The high-energy bremsstrahlung photons are then directed on to a secondary target typically made of heavy actinides to induce photonuclear reactions mainly photo-fission.These reactions produce a wide range of neutron-rich radioactive fragments which then can be used for RIB production [2].

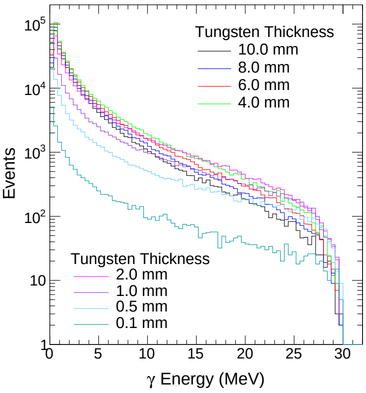

FIG. 1: Photon energy spectrum for different thickness of Tungsten converter target for 100000 incident electrons with 30 MeV energy. The electron strikes perpendicularly at the center of YZ plane from -X direction.

A 30 MeV high current electron accelerator is being developed at BARC-Vizag. Generation of RIB via photo-fission will be one on the main utilization of this accelerator. The Research and development activities for the production of radioactive ions are currently underway at the Nuclear Physics Division (NPD) of BARC. In this study, we investigated the interaction of 30 MeV electrons with tungsten (W) targets of varying thickness using the latest version of the GEANT4 framework [3, 4]. The photons produced during these interactions were characterized, and the photon multiplicity was extracted for all the produced photons, as well as for high energy photons with energies above 10 MeV.

2. photon production by 30 MeV electrons in Tungsten target

GEANT4 (Geometry and Tracking) is a Monte Carlo-based simulation tool widely used for modeling nuclear and electromagnetic processes [3, 4]. In this study, we use the latest version of GEANT4 (geant4-11-02-patch-02) to optimize the thickness of a tungsten (W) converter target for maximum photon production. All simulations were performed using the Quasi-elastic Bertini Binary Cascade (QBBC) Reference Physics List, which includes comprehensive electromagnetic models to simulate processes such as Compton scattering, the photoelectric effect, bremsstrahlung, and pair

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We defined a simple geometry consisting of tungsten (W) and uranium dicarbide (UC_2) blocks. The Y and Z dimensions of these blocks were fixed at 10 cm, while the thickness of the W block (X dimension) was varied from 0.1 mm to 10 mm. The thickness of the UC_2 block was kept negligibly small in this set of simulations to prevent photon absorption within the UC_2 block. A 30 MeV electron beam perpendicularly strikes the center of the YZ plane from the -X direction, initiating particle production as described by the QBBC physics list in GEANT4. The produced photons were tracked outside the W target, and their energy and position were recorded for each event. These data were then used to determine the photon multiplicity (i.e., the number of photons produced per incident electron) for all W thicknesses.

Figure 1 presents the photon energy spectrum for different thicknesses of the W converter target, based on 100,000 incident electrons. For all thicknesses, the maximum energy of the produced photons remains below the 30 MeV cutoff. Photon production is minimal for very thin targets, such as 0.1 mm and 0.5 mm, and increases as the thickness reaches 1 mm. This is expected, as electrons do not lose a significant amount of energy in such thin converters. The maximum number of low-energy photons is produced at a thickness of around 4 mm. These spectra were then integrated to determine the total number of produced photons, from which the photon multiplicity was extracted.

Figure 2 shows the photon multiplicity as a function of tungsten thickness. Figure 2(a) displays the photon multiplicity for all produced photons, while Figure 2(b) focuses on the photon multiplicity for high-energy photons ($E_\gamma > 10$ MeV). The photon spectrum above $E_\gamma > 10$ MeV, the giant dipole region, is the focus of the present study as the photo-fission in actinide targets mainly comes from this part. For both cases, photon multiplicity is very low for thin targets, such as 0.1 mm and 0.5 mm, but increases with thickness, reaching a maximum value. A steady decline in photon multiplicity is observed beyond this point. While the overall trend is similar for both cases, the photon multiplicity for high-energy photons shows a more pronounced decline after the peak compared to the total photon multiplicity. The maximum photon multiplicity for all photons occurs at a thickness of 4.2 mm, whereas the maximum photon multiplicity for high-energy photons is observed at 2.3 mm.

3. Conclusion

We have investigated photon production within a tungsten converter target using the GEANT4 simulation package. A simple geometry consisting of tungsten (W) and uranium dicarbide (UC_2) blocks was defined, with monoenergetic 30 MeV electrons incident perpendicularly on the setup. The energy spectrum of the produced photons was analyzed to extract photon multiplicity for both all photons and photons with energies above 10 MeV. The maximum photon multiplicity for all photons was observed at a tungsten thickness of 4.2 mm, while the maximum multiplicity for high-energy photons occurred at 2.3 mm. Future simulations will extend this study to evaluate photon absorption inside the UC_2 block and, ultimately, to include photon-induced fission reactions.

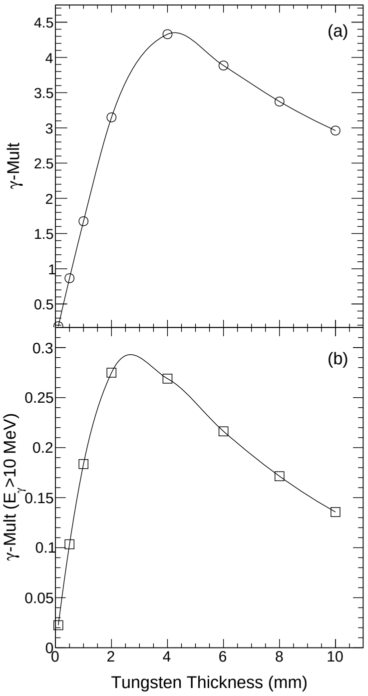

FIG. 2: The photon multiplicity as a function of Tungsten thickness for all the produced photons (a) and for high energy $E_\gamma > 10$ MeV) photons (b).

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