Quantitative Analysis of Radiation Interaction and Energy Degradation of TINT Cyclotron Facility for Enhanced Nuclear Physics Experiments

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EXTENDED ABSTRACT

The CC-30/15 cyclotron at the Thailand Institute of Nuclear Technology (TINT) accelerates protons within the 15–30 MeV range. Among its five beamline ports, Port 5 is dedicated to vacuum-based nuclear physics experiments, including PIXE and PIGE, which require proton energies of 2–3 MeV [1]. Since the cyclotron's minimum energy is 15 MeV, an energy degrader system is employed to reduce the beam energy accordingly.

This study utilizes GEANT4 Monte Carlo simulations to analyze radiation interactions during energy degradation and beam transport. The results provide key data on particle fluence, energy spread, and absorbed dose, supporting efforts to minimize radiation damage. Fig. 1 shows the simulation setup, including a vacuum tube, an energy degrader chamber with a degrader foil placed at 750 mm, and an energy measurement chamber with a proton detector (active area: 500 mm²) positioned at 1345 mm. A 15 MeV proton beam (5 mm diameter, 10^6 particles) was simulated passing through the degrader foil and reaching the detector. Foil materials made of aluminum, copper, and graphite, with respective thicknesses of 1.2 mm, 0.45 mm, and 1.2 mm, were studied. These thicknesses were determined based on SRIM calculations. Each simulation employed a single foil material to investigate the characteristics and effects of each material type. The simulation outputs include beam energy, energy spread, and normalized fluence, defined as the ratio of protons detected within the active area to the total number of particles within the field. The results are summarized in Table 1 and Fig. 2.

To investigate additional characteristics, the number of energy-degrading foils was increased. Two configurations were examined: (1) a single aluminum foil with a thickness of 1.2 mm positioned at 750 mm, and (2) two aluminum foils with a combined thickness of 1.2 mm, where the first foil (1.0 mm thick) was placed at 570 mm and the second foil (0.2 mm thick) at 750 mm. This arrangement was intended to enhance particle scattering [2]. Simulation results indicated that the energy spread was 20% in the single-foil configuration and 21% in the two-foil configuration, while the normalized fluence decreased from 18% to 13%, respectively.

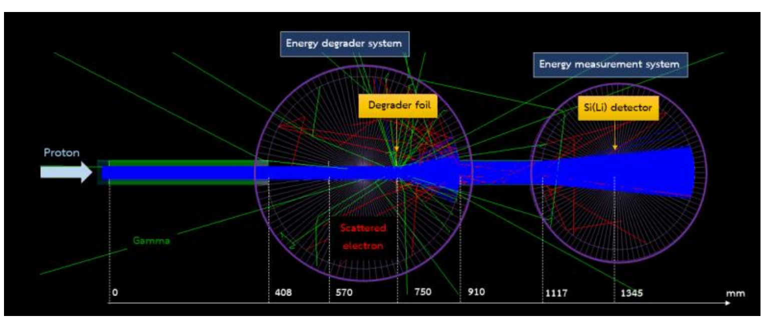

FIGURE 1. GEANT4 simulation setup illustrating the system components and particle tracks within the detection chambers: protons (blue), electrons (red) and gamma photons (green).

TABLE 1. Simulated output energy and energy spread of a 15 MeV proton beam after passing through three different degrader materials.

Degrader material	Output energy (MeV)	Energy spread (%)	Beam size (mm)	Normalized fluence (%)
No foil	14.98	1.02	5.09	100

Degrader material	Output energy (MeV)	Energy spread (%)	Beam size (mm)	Normalized fluence (%)
Aluminum	3.13	19.96	14.74	17.91
Copper	3.18	18.30	14.88	9.06
Graphite	3.35	17.94	14.33	37.79

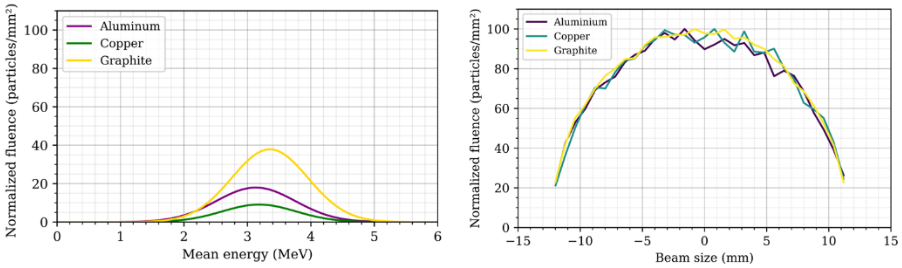

FIGURE 2. Beam characteristics after passing through three different degrader foils: energy spread (left) and beam profile (right).

The simulation results demonstrate that the proton energy was successfully reduced to the targeted value of 3 MeV. Among the tested materials, aluminum was found to be the most suitable option. Although graphite showed slightly better simulation outcomes, aluminum's higher atomic number and density offer superior stopping power, enabling more efficient proton energy loss and precise control of the beam energy. Furthermore, using a single aluminum foil produced the optimal results in terms of energy spread and normalized fluence.

In a simulation study of proton energy degradation within a room measuring 180 × 180 × 180 cm³, a proton beam with an initial energy of 15 MeV was simulated. The simulation revealed the production of secondary radiation, primarily gamma rays and electrons, with average energy depositions of 1.7×10^{-6} MeV/particle and 0.01 MeV/particle, respectively, throughout the simulated volume. Based on these energy deposition values, the maximum absorbed dose was estimated to be 4 mGy, occurring at the position of the aluminum foil at 750 mm from the beam source within the chamber, as illustrated in Fig. 3. In the next phase of the study, an analysis of the ambient dose will be conducted in parallel with the design of radiation shielding systems to improve radiation protection effectiveness within the operational area.

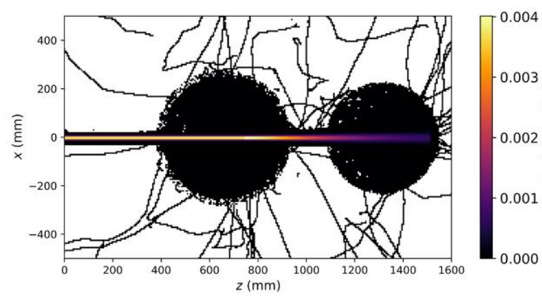

FIGURE 3. Absorbed dose distribution from a 15 MeV proton beam in a simulated room.

ACKNOWLEDGMENTS

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