

Proton Beam Monitoring by Activation Analysis for Medical Radioisotopes

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1. Introduction

For the production of medical radioisotopes, the monitoring of proton beam energy is needed to maximize the production yields along with minimizing the impurities. The production yields of radionuclides varying with the incident proton beam energies can be estimated from the cross-sections of proton-induced nuclear reactions. Thus, we measure the energies of the accelerated proton beams from MC50 cyclotron at KIRAMS, measuring the ratios of $^{63}\text{Cu}(p,2n)^{62}\text{Zn}$ and $^{65}\text{Cu}(p,n)^{65}\text{Zn}$ nuclear reactions in target, which is consisted of five Cu foils with 100 μm thickness. From the comparison of measured energy values and estimated ones, the activation method on thin metallic foil targets with natural isotopic composition can be used to calibrate proton beam energies where many medical applications can be employed in that ranges.

2. Methods and Results

2.1. Experimental Method

As a beam monitor, natural copper foils of 100 μm thickness are used as shown in Figure 1. A stack of five copper foils is irradiated at an angle of 45 degree to the proton beam having incident energy of 35 MeV with 2 μA beam current for 10mins. Using well-known stopping range calculation [1], the proton beam can be reached at the first copper foil with the energy of 27 MeV. The natural copper foil is the mixture of two isotopes of ^{63}Cu (69.17%) and ^{65}Cu (30.83%). The well-measured monitor reactions [2] of $^{63}\text{Cu}(p,2n)^{62}\text{Zn}$ ($T_{1/2}=9.26\text{h}$) and $^{65}\text{Cu}(p,n)^{65}\text{Zn}$ ($T_{1/2}=244.1\text{d}$) are used to estimate the energy degradation of protons along the Cu stacks.

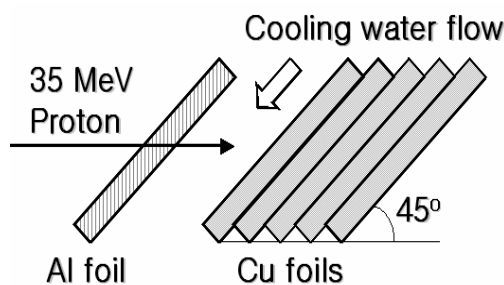


Figure 1. Schematic diagram of a stacked target (not scaled)

The energy assessment corresponding to the middle of each Cu foil is determined by the ratio of the

activities of two nuclides, ^{62}Zn and ^{65}Zn , measured with a high-resolution gamma-ray spectroscopy (see Figure 2). The characteristic gamma-ray lines in the samples are identified based on their emitted gamma-ray energies, intensities, and half lives. The detecting efficiency of the Ge detector is calibrated using known sources of ^{22}Na , ^{60}Co , and ^{137}Cs .

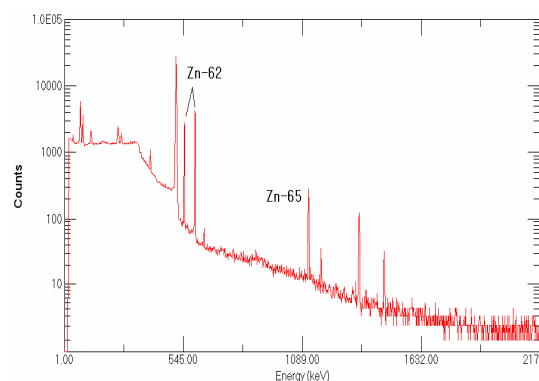


Figure 2. A typical measured gamma spectrum from the proton-irradiated natural copper foils. Characteristic gamma-ray lines of the nuclei Zn-62 (596.60 keV) and Zn-65 (1115.55 keV) are presented.

2.2. Calculation results

For the observed reactions Figure 3 shows the ratio of the cross section calculated for each reaction using published proton stopping range and cross section data [3] as a function of proton energies. The linearity for the energy ranges from 15 MeV to 27 MeV can be employed to estimate the proton energy.

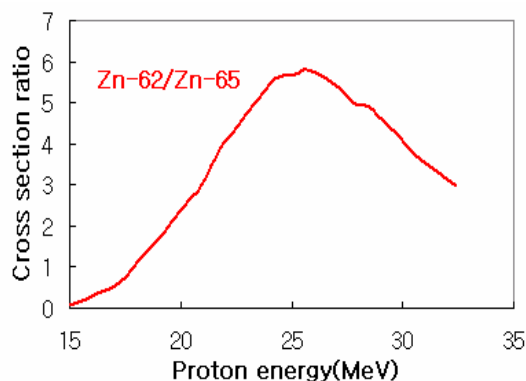


Figure 3. The cross section ratio of Zn-62 and Zn-65, measured from the corresponding gamma lines. The larger value in ratio indicates the higher energy of incident proton beam.

The calculated energy losses of proton beams are plotted in Figure 4 with three different Cu foil thicknesses. The proton spectra derived in this way indicating protons loss their energy as travel into the Cu foils. A thinner copper layer has a smaller impact on the proton beam, but as a monitor of proton, thinner copper also has a lower sensitivity. The Cu thickness should be optimized according to the energies of the protons and the affordable impact of the monitor on the proton application. For the five Cu foils with 100 μm thickness, the proton beam energy varies from 27 MeV to 15 MeV, which is the threshold for the nuclear reaction. With this reason, 100 μm Cu foils are preferred to use in this experiment.

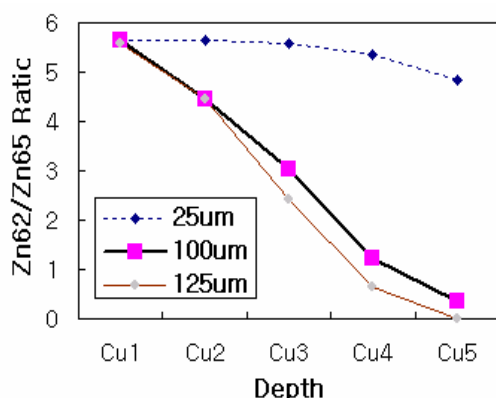


Figure 4. Dependence of the activity ratio versus penetration depth for the $^{63}\text{Cu}(p,2n)^{62}\text{Zn}$ and $^{65}\text{Cu}(p,n)^{65}\text{Zn}$ nuclear reaction processes calculated by the measured excitation functions.

2.3. Experimental Results and Comparison

As it can be seen in Fig. 5 the measured ratio of ^{62}Zn and ^{65}Zn shows a similar trend but lower values than the ones calculated from cross section data. The underestimation could be explained with many reasons, from the uncertainties of beam energy, detector efficiency, intensity, and statistical errors. The factors mentioned have to be investigated more details. With the proper calibration, it is suggested that the energy of the accelerated protons can be determined from a single thin copper foil with corresponding induced (p,xn) reactions.

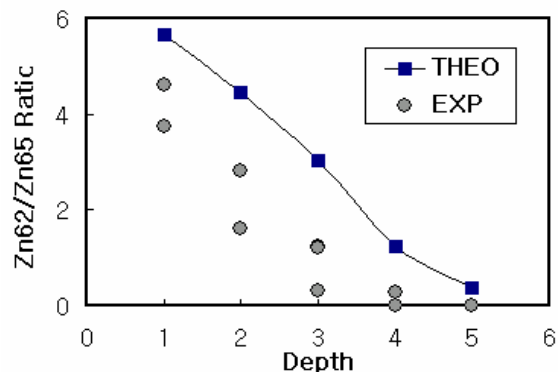


Figure 5. Comparison of the theoretical and experimental measurement from the stacked Cu target.

3. Conclusion

Proton beams generated from the cyclotron have been measured by irradiating the copper samples caused several induced nuclear reactions. Two different proton-induced reactions in copper have been measured and used to determine proton energies. From the cross section data, the observed proton-induced reactions in copper could be useful to determine the proton energy in range of 15-27 MeV. It is also suggested that measurable energy ranges can be extended using a composition of copper and other materials such as cobalt, zinc, and nickel in a single foil. This diagnostic technique for beam monitoring is useful to calibrate the beam energy of proton, producing medical radioisotopes using cyclotron.

REFERENCES

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