Measurement of RFT-30 Cyclotron Proton Beam Energy

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1. Introduction

RFT-30 cyclotron has been developed for not only the production of radioisotopes (RIs) and their applications, but also proton beam utilization to various research fields including material science, bio science, and so on. RFT-30 Cyclotron has been designed in which proton beam energy can be controlled from 15 to 30 MeV by adjusting the position of a stripper carbon foil, which steals two electrons from accelerated negative hydrogen ions, and therefore results in the conversion of negative hydrogen ions to protons. Unfortunately, the proton beam energy of RFT-30 has not yet been precisely measured although it has been operated for many years for the production of various RIs. For the measurement of proton beam energy, several methods have been published [1-4], and among them, a stacked foil technique has been widely used to measure the proton beam energy. In this technique, metal foils such as aluminum (Al) or copper (Cu) are irradiated and the radioactivity of some monitoring nuclear reactions induced by the irradiation was measured for the estimation of the beam energy. Particularly, Cu is commonly used as a target material because many products from nuclear reactions induced by the irradiation can be determined easily by gamma spectroscopy [5]. In this research, we performed the energy measurement of the proton beam from RFT-30 cyclotron by means of the stacked foil technique. Stacked Cu foils were irradiated by the proton beam, and then each foil's radioactivity, which resulted from ^{65}Zn produced from ^{65}Cu atoms via ^{65}Cu(p, n)^{65}Zn reaction, was measured. By comparing theoretically calculated and measured activities, we could obtain the value of proton beam energy. Measured beam energy can be useful information for the accurate estimation of the radioactivity when producing RIs.

2. Methods and Results

2.1 Materials and Irradiation Condition

High purity copper (Cu) foils with a diameter of 30 mm and a thickness of 0.1 mm (Cu >99.99%, Goodfellow Cambridge Limited) were used as irradiation targets. A stack of nine Cu foils were installed at the end of the beamline (Fig. 1), and then irradiated at normal incidence with a proton beam generated from RFT-30 cyclotron of Korea Atomic Energy Research Institute (KAERI). Accelerated proton beam, of which the energy determined by the position of the stripper foil was assumed to be 28.4 MeV, penetrated an aluminum (Al) degrader with a thickness of 2.2 mm, and then collided with the stacked Cu foils. Average proton beam current was 10 μA and irradiation time was 360 s. The Cu foils were water-cooled during the proton irradiation process.

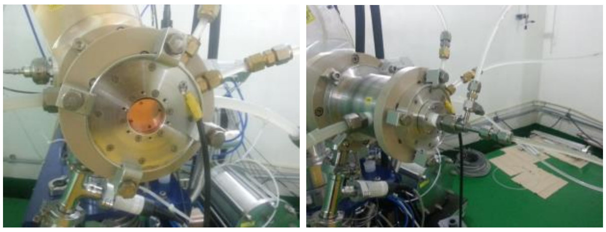

Fig. 1. Cu foils installed at the end of the beamline.

2.2 Measurement of the Activity of Irradiated Cu foils and Beam Energy Analysis

After the irradiation, Cu foils were kept at ambient air condition for one week. Natural Cu consists of two stable isotopes ^{63}Cu (69.15%) and ^{65}Cu (30.85%), so that short-lived radioisotopes such as ^{63}Zn ($T_{1/2}$ = 38.47 min) and ^{62}Zn ($T_{1/2}$ = 9.193 h) would be produced by ^{63}Cu(p, n)^{63}Zn and ^{63}Cu(p, 2n)^{62}Zn reactions in addition to ^{65}Zn produced by ^{65}Cu(p, n)^{65}Zn reaction, which is the monitoring reaction of this research. Because ^{65}Zn has relatively long half-life of 243.93 days, short-lived radioisotopes including ^{63}Zn and ^{62}Zn almost completely decayed and only ^{65}Zn survived after one week.

Because the activity of the produced radioisotope is determined by the factors including incident beam energy and penetration depth, the beam energy can be estimated by measuring the activity of a certain nuclear reaction induced by the irradiation of a target material. Using a high purity Ge (HPGe) detector (GEM20P4, ORTEC) and multichannel analyzer (MCA) system (ORTEC), the gamma spectrum of each Cu foil was measured for 600 s. The activity of ^{65}Zn was counted from its characteristic photopeak centered at 1115.5 keV. Background counts and correction for deadtime were automatically dealt with by the software. Deadtime for each measurement was kept less than 5%. Measured activities of each foil and normalized ratio are shown in Table I. For comparison, activities of ^{65}Zn were also theoretically calculated with the procedure described by Burrage et al [2].

Table I: Measured and calculated activity of ^{65}Zn produced in each Cu foil from bombardment by 18.046 MeV proton beam. Foil 1 is the first to encounter the proton beam.

Foil	1	2	3	4	5	6	7	8	9
Count	49430	82641	138849	250249	309130	224111	76225	1713	0
Ratio (Measured)	0.156	0.267	0.449	0.810	1.000	0.725	0.247	0.006	0
Ratio (Calculated)	0.332	0.547	0.865	1.000	0.617	0.188	0.002	0	0

Stopping power data were obtained from the National Institute of Standards and Technology (NIST) [6] (Fig. 2) and curves were fitted to these data which enables stopping power to be dealt as a continuous function of proton energy. The curve equations were obtained using the curve fitting application CurveExpert [7]. Cross section data for $^{65}Cu(p, n)^{65}Zn$ reaction were obtained from papers by Collé and Grütter [5,8] (Fig. 3) and curves were also fitted using CurveExpert which allows the cross section for $^{65}Cu(p, n)^{65}Zn$ reaction to be considered as a continuous function of proton energy.

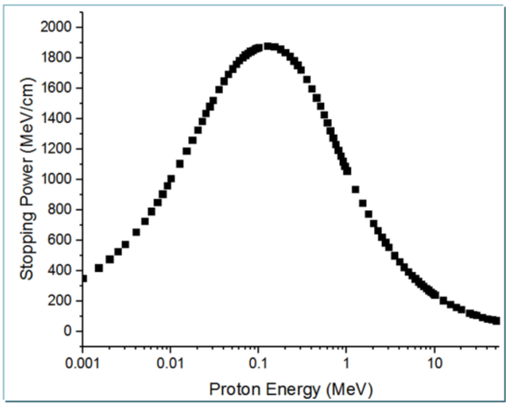

Fig. 2. Stopping power data of natural Cu as a function of proton energy obtained from NIST.

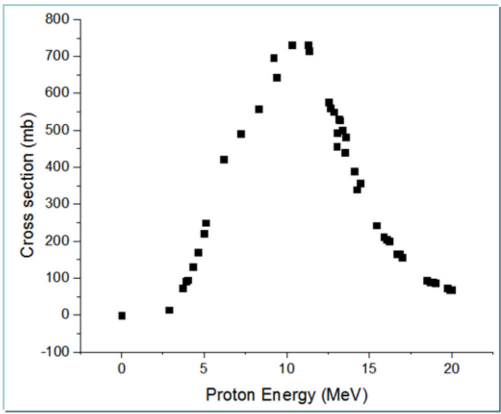

Fig. 3. Cross section data of $^{65}Cu(p, n)^{65}Zn$ reaction as a function of proton energy obtained from Ref 7 and 8.

Using these data, the ^{65}Zn radioactivity of each Cu foil produced by 18.046 MeV proton beam was calculated because the proton beam energy would be reduced from 28.4 to 18.046 MeV by the Al degrader with the thickness of 2.2 mm according to ELOSS code calculation [9]. Ratio of calculated activities of ^{65}Zn is also shown in Table 1.

To estimate the proton beam energy, the measured activity ratio was compared to the theoretically calculated activity ratio. Activities were normalized to the activity of the most active Cu foil. By analyzing the data, we can conclude that the real proton beam energy should be higher than the assumed incident beam energy of 18.046 MeV because the measured activity showed the maximum value at 5th foil while the calculated activity showed the maximum value at 4th foil. For each Cu foil, the difference between the measured and calculated activity ratio was calculated, squared, and then summed over 9 foils. The incident beam energy used in the calculation was continually adjusted until the sum of the squares of differences was minimized in order to accurately estimate the incident beam energy. When we initially assumed the energy of incident proton beam to be 18.046 MeV, the sum of the squares of differences was 0.81226. By continuous calculation, we found that the value was minimized to 0.01821 when the incident proton beam energy was set to be 19.54 MeV. Then we could reversely calculate the proton beam energy before entering the Al degrader. According to the ELOSS code calculation, the proton beam energy extracted from the RFT-30 cyclotron was determined to be 29.45 MeV.

3. Conclusions

In this research, the proton beam energy of RFT-30 cyclotron was measured for the first time using a simple stacked foil method. Before the measurement it was assumed to be 28.4 MeV, but it was proved that the actual proton beam energy was 29.45 MeV. Measured beam energy can be used for the determination of degrader and target conditions in radioisotope production experiments, and the precise radioactivity estimation of the RIs produced by the proton beam of RFT-30 cyclotron. In addition, the production of unwanted RIs, which is regarded as impurities, can be effectively controlled. In order to make the measured proton beam energy reliable, several other beam energy measurement techniques should be applied, and then measured beam energy values have to be compared and confirmed.

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