Analytical peak separation method for two isotopes ^{67}Cu and ^{67}Ga

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1. Introduction

^{67}Cu, one of the important copper radioisotopes, has been proposed as an excellent theranostic agent in clinical nuclear medicine. Recently, we developed an analytical separation method for the two isotopes ^{67}Cu and ^{67}Ga [1], from which we obtained the cross sections for the ^{nat}Zn(*p, x*)^{67}Cu and ^{nat}Zn(*p, x*)^{67}Ga reactions. The data were in good agreement with the previous literature. However, we found the method may give a substantial error, as the half-life difference between two isotopes becomes grow. In this work, we have further developed an analytical separation method for the overlapping gamma-ray spectra of the two isotopes ^{67}Cu and ^{67}Ga. Although the two isotopes of ^{67}Cu and ^{67}Ga have similar half-lives then less yielding errors in the separation results, the newly developed method in the present work may provide more exact cross-section data, thanks to a concrete formalism with fully considered variables.

2. Experiments

Cross section measurements of proton-induced reactions on natural Zn foils were carried out using the stacked-foil method with incident proton energy of 100 MeV. The experiments were performed using a 100 MeV proton accelerator installed at KOMAC, Gyeongju, Korea. Figure 1 show a typical γ-ray spectrum obtained from a measurement of an activated Zn foil using a high purity germanium (HPGe) detector. A large quantity of ^{67}Ga (half-life 3.2617 d) together with ^{67}Cu at the same γ-ray energies is co-produced by proton beam irradiation of a Zn target, and ^{67}Cu dacays into the stable daughter nuclei ^{67}Zn.

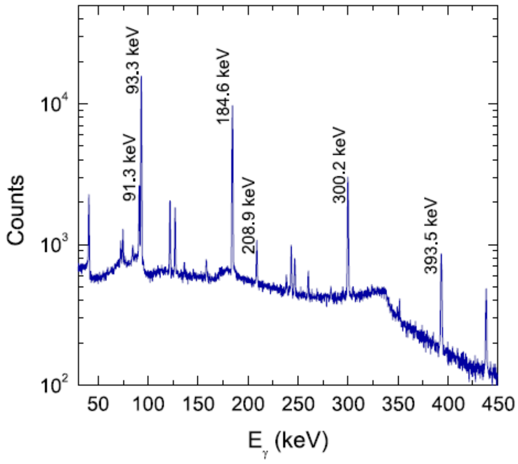

Figure 1 Typical **γ** –ray spectrum from measurements of the activated Zn foils using an HPGe detector. The respective transition peaks are labeled. The spectrum was obtained under the following conditions: E_p=97.4 MeV, t_i= 36.7 min, t_w=42.26 h, and t_m=60 min.

3. Analytical peak separation for ^{67}Cu and ^{67}Ga

The dominant γ-lines of ^{67}Cu and ^{67}Ga are the same in energy, and have close-lying half-lives for ^{67}Cu ($T_{1/2}$=61.9 h) and ^{67}Ga ($T_{1/2}$=78.3 h), so that determining the peak separation with an analytical method is essential in achieving an accurate cross section. The overlapped γ-ray spectrum is a mix of the two radionuclides ^{67}Cu and ^{67}Ga. Thus, we could sum the counts from each nuclide considering the timing factor θ, then it can be written,

$$C_{i,tot} = A_i + B_i, \qquad i = 0, 1, 2, \ldots, n, \tag{1}$$

where A_i and B_i denote the corrected count numbers for nuclides A and B, respectively, and $C_{i,tot}$ is the corrected count numbers of a total γ-peak area (S_i) for each γ-ray peak i, i.e., $C_{i,tot} = S_i/\epsilon_{\gamma,i}$. The ratio of γ-ray absolute intensities between any two peaks of the ^{67}Cu nuclide, e.g., $I_{93.3\,keV}/I_{184.4\,keV}$, does not show the time dependence, and is given by

$$\frac{A_i}{A_0} = \frac{I_{A,\gamma_i}}{I_{A,\gamma_0}}\frac{\theta_A}{\theta_A+\theta_B}, \quad \frac{B_i}{B_0} = \frac{I_{B,\gamma_i}}{I_{B,\gamma_0}}\frac{\theta_B}{\theta_A+\theta_B},$$

$$i = 1, 2, 3, \ldots, n, \tag{2}$$

where I_{A,γ_i} and I_{B,γ_i} denote the absolute γ-ray intensity for nuclides A and B, respectively. The θ_i denotes a timing factor and can be written,

$$\theta_i \equiv \left(1 - e^{-\lambda_i t_i}\right)\cdot e^{-\lambda_i t_w}\cdot\left(1 - e^{-\lambda_i t_m}\right),\ i = A, B. \tag{3}$$

Combining Eqs. (1) and (2) for *i*=0, 1 gives

$$A_0 = \frac{I_{A,\gamma_0}\{C_{1,tot}I_{B,\gamma_0}(\theta_A+\theta_B) - C_{0,tot}I_{B,\gamma_0}\theta_B\}}{\theta_A I_{A,\gamma_1}\cdot I_{B,\gamma_0} - \theta_B I_{A,\gamma_0}\cdot I_{B,\gamma_1}},$$

$$B_0 = \frac{I_{B,\gamma_0}\{C_{0,tot}I_{A,\gamma_1}\theta_A - C_{1,tot}I_{A,\gamma_0}(\theta_A+\theta_B)\}}{\theta_A I_{A,\gamma_1}\cdot I_{B,\gamma_0} - \theta_B I_{A,\gamma_0}\cdot I_{B,\gamma_1}}. \quad (4)$$

Figure 2 shows the timing factor θ_i as a function of waiting time. Due to the difference between the half-lives of the two isotopes, the θ_i shows different values. The shorter the waiting time is, the greater difference the θ_i is. The measurements were typically carried out after 1 day, thus the difference for θ_i cannot be negligible for the calculation of cross section.

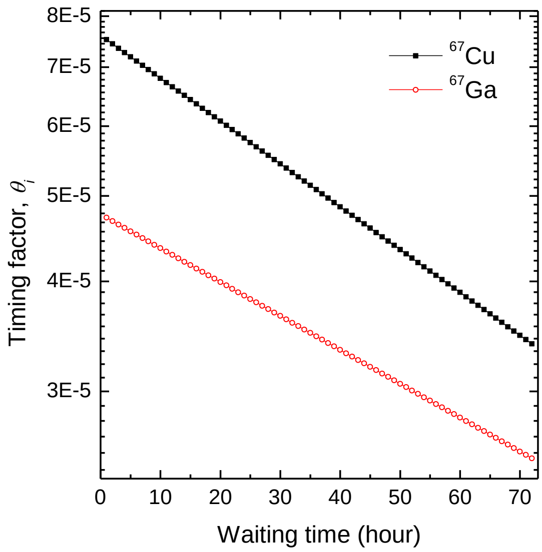

Figure 2 The timing factor θ_i for ^{67}Cu and ^{67}Ga as a function of waiting time.

4. Conclusions

We have developed an analytical peak separation method for the two isotopes ^{67}Cu and ^{67}Ga. Due to the exact same γ-ray energies for these two isotopes, the separation for the peaks is essential to find each cross section. The time factor introduced in the separation process gives more exact cross section data, which is considered for the first time in this work.

REFERENCES

[1] J. K. Park, M.-H. Jung, Y. S. Hwang, C. Kim, W.-J. Cho, S.-C. Yang, Measurement of cross sections for proton-induced reactions on natural Zn, Nucl. Instrum. Methods Phys. Res. B, Vol. 415, pp. 41-47, 2018.