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Measurements of isomeric yield ratios in the photo-production of ^{58m,g}Co from ^{nat}Co using 60-, 65-, and 70-MeV bremsstrahlung

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1. Introduction

Gamma-ray activation can be used for the various practical purposes such as activation analysis, isotopes production for medical purposes, material science investigations, and biological studies. The relative population of the metastable (*m*)- and ground (*g*)-state of a residual nuclide formed in a nuclear reaction, isomeric yield ratio (IR), becomes an important source of information on the structure and properties of the excited states of the atomic nuclei [1-4]. The excited states are produced via different nuclear reactions and de-excitation process populates the low-lying excited states that reflected in a simple nuclear structure [5]. Important information about the interaction mechanism and the properties of excited nuclear states in both continuous and discrete spectra is obtained from the investigations of the excited states, the characteristics and probability of excitations, the energy and spin distributions, and the different decay [6]. Using the isomeric yield data, both the nuclear reaction mechanism and statistical properties of the excited state of atomic nuclei can be investigated. Because the isomeric yield ratio highly depends on the input angular momentum of the projectile, the spin of target nuclei, and the de-excitation by the evaporation nucleon emission, the isomeric yield ratio is an ideal tool for studying the angular momentum effects in nuclear reactions and the spin dependence in nuclear level density, refining the gamma transition theories, and testing of the theoretical nuclear models [7-10]. However, the information regarding the formation of isomeric-states is rather scanty and some discrepancies are still observed among the literature values which might be attributed to variations in experimental methods and/or the nuclear constants [7,8]. Moreover, the experimental database is also outdated because of the improvement of the sensitivity of detection system and the refinement of the spectroscopic features. Therefore, the update of the measurement of the isomeric yield ratios has been reissued recently.

The isomeric yield ratios for the photonuclear reactions of $^{nat}Co(\gamma,n)^{58m,g}Co$ was measured in the 60-, 65-, 70-MeV end-point bremsstrahlung by using the activation and the off-line γ-ray spectrometric technique in the electron linac at Pohang Accelerator Laboratory (PAL), Korea. The aim of the present work is to measure the isomeric yield ratios of the ^{58m,g}Co with bremsstrahlung energy of 60- to 70-MeV with a step of ΔE = 5 MeV from natural Cobalt.

2. Methods and Results

2.1. *Bremsstrahlung production*

The experiment was performed by using the end-point bremsstrahlung energies of 60-, 65-, and 70-MeV at the electron linear accelerator (linac) which was designed for 100 MeV and can be operated from 40-, to 70-MeV [11]. The bremsstrahlung was produced when a pulsed electron hits a thin W-target with a size of 100 × 100 mm and a thickness of 0.1 mm . The W-target is located at 18 cm from the beam exit window. We simulated the bremsstrahlung photons generated by electrons with MCNPX [12] code as shown in Fig. 1.

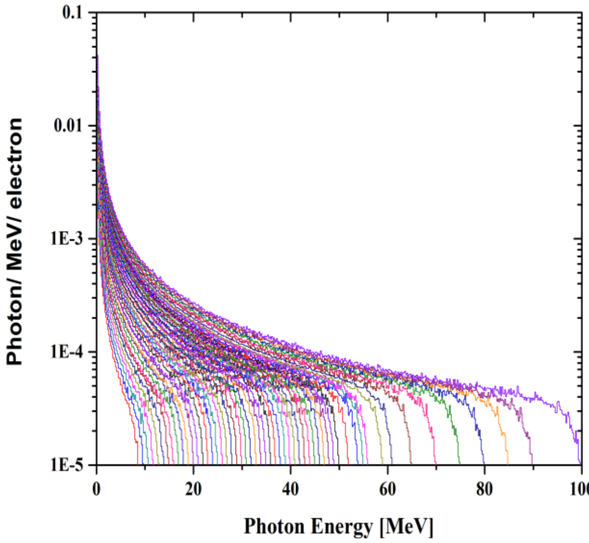

Fig. 1. Spectral yield of bremsstrahlung radiation emitted from 0.1 mm W converter struck by electron beam.

2.2. *Sample irradiation*

A high-purity(99.9%) natural cobalt(^{nat}Co) foil with a size of 10 × 10 mm and a thickness 0f 0.1 mm made by the Nilaco Co. (Japan) was fixed on a stand in air at 12 cm from the W-target. Thin Co foils were used for the irradiation which led to the strongly reduced or the negligible effect for a self-absorption of the measured γ-line. A simplified experimental arrangement is shown in Fig. 2.

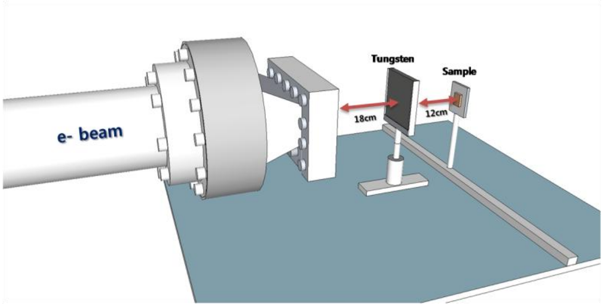

Fig. 2. Experimental set-up for sample irradiation

After an irradiation and an appropriate waiting time, the activated foils were taken out, and then the induced activities of the irradiated foils were measured by using a gamma spectrometer without any chemical purification. The gamma spectrometer used for the measurements was a n-type coaxial DSG high-purity germanium (HPGe) detector. The HPGe detector was connected to a PC-based multi-channel analyzer card system, which determined the photo-peak area of the γ-ray spectra by using the GAMMA-W. The energy resolution of the detector was 1.8 keV full width at half maximum (FWHM) at the 1332.5 keV peak of ^{60}Co. The detection efficiency was 80% at the 1332.5 keV relative to a 7.62 cm diameter × 7.62 cm length NaI(Tl) detector. The absolute photo peak efficiencies and total efficiencies of the HPGe detector were measured with the calibrated sources of ^{57}Co, ^{241}Am, ^{133}Ba, ^{137}Cs, and ^{152}Eu.

For the measurements, the cooling and the measuring times were chosen based on the activity and half-life of each radioactive isotope. In order to optimize the dead time and the coincidence summing effect we have also chosen the appropriate distance between the sample and the detector for each measurement. The activated foil was attached on a plastic sample holder and can be set at a distance from 5 mm to 100 mm from the surface of the HPGe detector. Generally, the dead times were kept below 1.0% during the measurement and the statistical errors below 7.0%. Each sample was counted several times in order to obtain decay curves for the photo-peaks as well as to observe the linearity of the experimental IR.

2.4. Results and discussion

The isomeric yield ratios for the ^{nat}Co(γ,n)^{58m,g}Co reaction at 60-, 65-, and 70-MeV bremsstrahung energies are 0.012 ± 0.055, 0.013 ± 0.053, and 0.014 ± 0.049, respectively. The uncertainties were calculated by using error propagation principle. The main sources of the uncertainties for the present results are due to statistical uncertainty, uncertainties in photo-peak efficiency calibration, nuclear data such as half-life, gamma intensity, IT, photo-peak area determination, coincidence summing, bremsstrahlung flux fluctuation, and others. There is no available data measured 60-, 65-, and 70-MeV bremsstrahlung energies.

3. Conclusion and future improvements

The isomeric yield ratio for the ^{nat}Co(γ,n)^{58m,g}Co reaction was measured with 60-, 65-, and 70-MeV end point bremsstrahlung energies by using the activation and the off-line γ-ray spectrometric technique in the electron linac Pohang Accelerator Laboratory(PAL). The reaction ^{nat}Co(γ,n)^{58m,g}Ce was studied for the first time which has no comparable literature data. The present experiment is based on (γ,n) reaction which is the first time measurement at intermediate energy bremsstrahlung 60-, 65-, and 70-MeV from ^{nat}Co target. From the reaction studied in present measurement, it is observable that isomeric ratio is dependent on the spin of the target nuclei. The present results are the first measurements at these energy points. The detailed data analysis and results of IRs for ^{58m,g}Co are available and will be given in a future publication.

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