Transactions of the Korean Nuclear Society Autumn Meeting
Gyeongju, Korea, October 29-30, 2015

Isomeric yield ratios for the ^{nat}Ni(γ,xn1p)^{58m,g}Co reaction measured at 60-, 65-, 70-, and 75-MeV bremsstrahlung energies

H. J. Kim[ab], S. J. Noh[a], H. Kim[ab], M. W. Lee[a], D. H. Jeong[a], K. M. Yang[a], T. I. Ro[b], S. G. Shin [c], Y. U. Kye [c], G. N. Kim[d], Y. R. Kang[a*]
[a]*Research Center, Dongnam Inst. of Radiological & Medical Sciences, Busan 619-953, Korea*
[b]*Department of Physics, Dong-A University, Busan 604-714, Korea*
[c] *Department of Advanced Nuclear Engineering , POSTECH, Pohang 790-784, Korea*
[d] *Kyungpook National University, Daegu 702-701, Korea*
[*]*Corresponding author: yeongrok@dirams.re.kr*

1. Introduction

The relative probabilities of occupying metastable (*m*)- and ground (*g*)-state of a final nucleus in a nuclear reactions, so-called isomeric ratio (IR), are of considerable important for both basic nuclear physics research and applications. The isomeric ratio depends on the spin distribution of the compound nuclei, the angular momentum carried away by the emitted particles, the character of the γ-cascade, and the spins of the isomeric states [1]. So far, most experimental results for the isomeric ratios have been measured for the nuclear reactions induced by neutrons [2], charged particles [3]. The measurements for the nuclear reactions induced by photons are rare and carried out mainly in the energy region of the giant dipole resonance (GDR), from reaction threshold to about 30 MeV, where the detail information about the reaction mechanism and the multi-pole nature of the photon absorption process is generally not available. During the last few years the essential progress is observable in the development of new and upgrading existing theoretical models for the reactions considered in this energy region. Some new pre-equilibrium models have been developed to define a multi-particle emission and to enhance a quasi-deuteron model [4]. Since the interest of accelerator driven sub-critical system (ADSs) is rapidly growing, a photonuclear data will be one of the useful data for the designing of such system.

The energy dependent isomeric yield ratios for the ^{58m,g}Co were performed using the activation method at Pohang Accelerator Laboratory (PAL). The aim of the present work is to measure the isomeric yield ratios of the ^{58m,g}Co with bremsstrahlung energy of 60- to 75-MeV with a step of ΔE = 5 MeV from natural Nickel.

2. Materials and Methods

2.1. *Sample irradiation*

The experiment was performed by using the end-point bremsstrahlung energies of 60-, 65-, 70-, and 75-MeV at the electron linear accelerator [5]. The beam condition and sample condition are summarized in Table 1.

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. The High-purity(99.9 %) natural nickel foils in square shape, size of 10 × 10 mm and a thickness of 0.1 mm made by the Alfa Aesar Inc. (USA) was placed in air at 12 cm from the W-target and they were positioned at zero degree with the direction of the electron beam.

Table 1: Characteristics of the ^{nat}Ni activation foils

Energy(MeV)		60	65	70	75
Beam Condition	Pulse width (μs)	1.2	1.2	1.2	1.2
	Repetition rate(Hz)	30	30	30	30
	Irradiation time (h)	2	2	2	2
	Waiting time (s)	11235	10811	10766	10768
	Counts time (s)	36000	36000	36000	8700
Sample Condition	Purity (%)	99.9	99.9	99.9	99.9
	Size (cm^2)	1	1	1	1
	Thickness (mm)	0.1	0.1	0.1	0.1

2.2. *Radioactivity measurements*

After an irradiation and an appropriate waiting time, the activated foils were take off, and then the induced gamma 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 (Detector System Gmbh) high-purity germanium (HPGe) crystal with a diameter of 74.5 mm, a length of 74.4 mm. The pre-amplifier type was RFB-DSG 51C while the main amplifier was TC 244. Amplified pulses from detector were analyzed in an 8 K channel analog to digital converter and recorder in a personal computer. The measurements were carried out to obtain statistically significant main peaks in the spectra that are recorded and processed by win-TMCA32 software made by ICx Technologies. Measured spectrum was saved as spectrum ORTEC files, which determined the photopeak area of the γ-ray spectra by using the GAMMA VISION (Ortec) data acquisition software. The dead time of detector system was kept below 1% by placing the sample at a suitable distance from the end-cap of the detector to avoid the pileup effect. The energy resolution of the detector was 2.3 keV full width at half maximum (FWHM) at the 1332.5 keV peak of ^{60}Co. The relative detection efficiency was 80% at the 1332.5 keV relative to a 7.62 cm diameter × 7.62 cm length NaI(Tl) detector. The photopeak efficiency is calculated with simple relationship [6] with a set of γ-ray standard sources : ^{57}Co, ^{241}Am, ^{133}Ba, and ^{152}Eu.

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.

2.3. *Determination of isomeric-yield ratios*

The photo-activation method was used to determine the isomeric yield ratios of the ^{nat}Ni($\gamma,xn1p$)^{58m,g}Co reaction. The produced nuclides in the irradiated foil together with reaction predecessors were identified based on the known spectroscopic data, such as energy and half-lives. The isomeric yield ratios were calculated from the measured activities of the high-spin state and the low-spin state of the produced radioisotope.

The ^{58m,g}Co isomeric pair were identified based on their characteristic γ-ray energies and half-lives. The simplified level and the decay scheme of the ^{58m,g}Co is given in Fig. 1. The isomeric-state ^{58m}Co (high-spin state, 5^{+}) with a half-life of 9.1 h decays directly to the unstable ground-state (low-spin state, 2+) by emitting the 24.9-keV γ -rays with a branching ratio 100%.

The unstable ground-state ^{58g}Co (J^{π}=2+) with a half-life of 70.86d decays to the 810.76 keV state of ^{58}Fe(J^{π}=0+) by EC + β^{+} processes with a branching ratio of 98.8%.

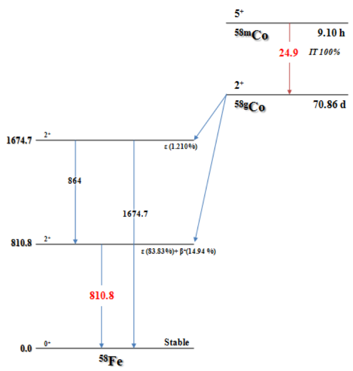

Fig. 1. Simplified decay scheme of the isomeric nuclide for ^{58m,g}Co . The nuclear level energies are in keV.

3. Results and future improvements

The isomeric yield ratios for the ^{nat}Ni($\gamma,xn1p$)^{58m,g}Co reaction measured at 60-, 65-, 70-, and 75 MeV bremsstrahlung energies are 2.278±0.05, 2.204±0.05, 1.510 ±0.05, and 1.090±0.06, 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. The measured values of IR of ^{58m,g}Co are listed in Table 2, and illustrated graphically in Fig. 2.

Table 2 : Isomeric yield ratios of ^{58mg}Co via photonuclear reactions with ^{nat}Ni

Nuclear reaction	Threshold energy (MeV)	Photon Energy (MeV)	IR ($Y_{high-spin}/Y_{low-spin}$)	TALYS
^{nat}Ni($\gamma,xn1p$)^{58m,g}Co	10.479	60	2.278±0.05	0.988
		65	2.204±0.05	0.988
		70	1.510±0.05	0.988
		75	1.090±0.06	0.988

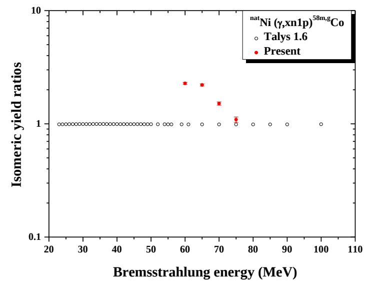

Fig. 2. Dependence of isomeric yield ratios of ^{58mg}Co on the incident bremsstrahlung energy via ($\gamma,xn1p$) reactions.

Studies of ^{nat}Ni($\gamma,xn1p$)^{58m,g}Co isomeric pair in the literature is based on ^{58}Ni(n,p)^{58}Co reactions in the low energy region [7-9]. The present experiment is based on ($\gamma,xn1p$) reactions which is the first time measurement at intermediate energy bremsstrahlung 60-, 65-, 70-, and 75-MeV from ^{nat}Ni 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 results of IRs for ^{58m,g}Co is available and will be given in a future publication.

Acknowledgment

This research was supported by National R&D Program through the Dongnam Inst. of Radiological & Medical Sciences funded by the Ministry of Science, ICT & Future Planning (50496-2015)

REFERENCES

[1] J.R. Huizenga, R. Vandenbosch, Phys. Rev. 120 (1960) 1305.
[2] I.G. Birn, B. Strohmaier, H. Freiesleben, S.M. Qaim, Phys. Rev. C 52 (1995) 2546.
[3] S.M. Qaim, A. Mushtaq, M. Uhl, Phys. Rev. C 38 (1988) 645.
[4] M. Herman, P. Oblozinsky, R. Capote, M. Sin, A. Trkov, A. Ventura, V. Zerkin, International conference of nuclear data for science and technology-ND2004, AIP Conf. Proc. 769, Melville (2005) 1184.
[5] G. N. Kim, Y. S. Lee, V. Skoy, V. Kovalchuck, M. H. Cho, I. S. Ko, W. Namkung, D.W. Lee, H. D. Kim, T. I Ro, Y. G. Min, J. Korean Phys. Soc. 38, 14 (2001).
[6] G. L. Monar, Zs. Revay, T. Belgye, Nucl. Instr. Meth A. 489 (2002) 140
[7]Cs.M.Buczko, J.Csikai, S.Sudar, A.Grallert, S.A.Jonah, B.W.Jimba, T.Chimoye, M.Wagner, Nucl.Phys. C52 (1995) 1940.
[8]P.Raics, F.Paszti, S.Daroczy, S.Nagy, J.Atomki Koezle-menyek, 23(1981)45
[9] J.W.Meadows, J.F.Whalen, Phys. Rev. 130 (1963) 2022