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Measurement of isomeric yield ratio for the ^{nat}Lu(γ,xn)^{174m,g}Lu reaction measured at 55-, 60-, and 65-MeV bremsstrahlung energies

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1. Introduction

Studies of isomeric ratios are of considerable importance 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 detailed 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 photo-nuclear data will be one of the useful data for the designing of such system.

In this work, the isomeric yield ratio of ^{174m,g}Lu produced in the ^{nat}Lu(*γ,xn*) reactions with end-point bremsstrahlung energies of 55-, 60-, and 65-MeV have been determined by using activation and off-line *γ*-ray spectrometric technique at Pohang Accelerator Laboratory (PAL), Pohang, Korea. The present work is a part of the systematic studies of the isomeric yield ratio in the Pohang Accelerator Laboratory.

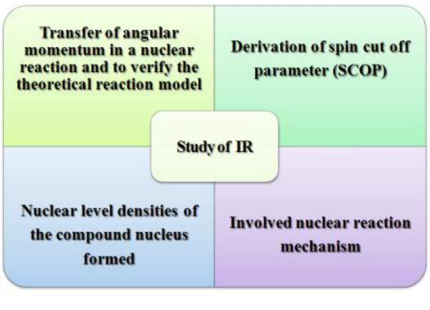

Fig. 1. A study related to isomeric yield ratio

2. Materials and Methods

2.1. *Sample irradiation*

The experiment was performed at the 100 MeV electron linac of PAL, which was operated in the energy range of 40-70 MeV [5]. The bremsstrahlung was generated when pulsed electrons hits a thin tungsten(W) foil with a size of 10.0 × 10.0 cm and a thickness of 0.1 mm. The W-target is located at 18.0 cm from the electron beam exit window. Even though we used very thin W target to avoid or minimize neutrons during bremsstrahlung production, some electrons could be produced or passed through the thin tungsten along with the bremsstrahlung.

The High-purity(99.9 %) natural Lu foils in square shape, size of 1.25 × 1.25 cm 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.

2.2. *Radioactivity measurements*

The induced activities of the activated samples were measured by a *γ*-spectrometer without any chemical purification. The gamma spectrometer used for the measurements was a p-type coaxial Canberra (Detector System Gmbh) high-purity germanium (HPGe) detector with an energy resolution of 1.8 keV and relative efficiency of 40 % at the 1.332 keV *γ*-peak of ^{60}Co. The detector was coupled to a computer-based multichannel analyzer system, which could determine the photopeak area of the γ-ray spectrum with the GENIE 2000 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 pile-up effect.

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}Lu(*γ,xn*)^{174m,g}Lu 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 ^{174m,g}Lu isomeric pair were identified based on their characteristic γ-ray energies and half-lives. The isomeric-state ^{174m}Lu (high-spin state, 6^-) with a half-life of 142 d decays directly to the unstable ground-state (low-spin state, 2^-) by emitting the 76.47-keV γ -rays with a branching ratio 99.38 %.

3. Results and future improvements

The isomeric yield ratios for the ^{nat}Lu(*γ,xn*)^{174m,g}Lu reaction measured at 55-, 60-, and 65-MeV bremsstrahlung energies are 1.035±0.08, 0.951±0.09 and 0.930±0.08, 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 ^{174m,g}Lu are listed in Table 1, and illustrated graphically in Fig. 2.

Table 1 : Isomeric yield ratios of ^{174m,g}Lu via photonuclear reactions with ^{nat}Lu

Nuclear reaction	Threshold energy (MeV)	Photon Energy (MeV)	IR ($Y_{high\text{-}spin}$ / $Y_{low\text{-}spin}$)
^{nat}*Li(γ,xn)*^{174m,g}*Lu*	14.04	55	1.035±0.08
		60	0.951±0.09
		65	0.930±0.08

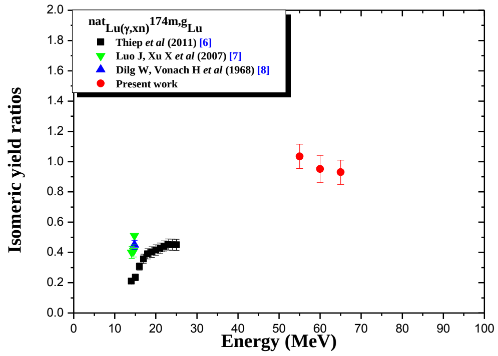

Fig. 2. Dependence of isomeric yield ratios of ^{174mg}Lu on the incident bremsstrahlung energy via (*γ,xn*) reactions.

The present experiment is based on (*γ,xn*) reactions which is the first time measurement at intermediate energy bremsstrahlung 55-, 60-, and 65-MeV from ^{nat}Lu target. The results provide complete data for this region and could contribute to the Nuclear Data. The detailed results of IRs for ^{174m,g}Lu is available and will be given in a future publication.

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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] Tran Duc Thiep • Truong Thi An • Phan Viet Cuong • Nguyen The Vinh • A. G. Belov, J Radioanal Nucl Chem (2011) 290:515–524
[7] Luo J, Xu X et al. (2007) Nuclear Instruments and Methods in Physics Research B 265:453
[8] Dilg W, Vonach H et al (1968) Nucl Phys A118:9