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YIELD RATIOS OF THE ISOMERIC PAIR ^{179m,g}W PRODUCED IN THE ^{nat}W$(\gamma,xn)^{179m,g}$W REACTIONS WITH 50-65 MeV BREMSSTRAHLUNG

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Abstract. *In this work we present the yield ratios of the* ^{179m,g}*W isomeric pair produced in the photonuclear reactions* ^{nat}*W*$(\gamma,xn)^{179m,g}$*W with bremsstrahlung end-point energies of 50-, 55-, 60-, and 65-MeV. The measurements were carried out by the induced activity method in combination with direct* γ*-ray spectrometry. The measured activities were corrected for overlapping* γ*-ray peaks, self-absorption of low energy* γ*-rays and true coincidence-summing effects. The present results are measured for the first time with bremsstrahlung end-point energies beyond the giant dipole resonance region. The obtained results are discussed with respect to the incident bremsstrahlung energies and reaction channel effect.*

Keywords: isomeric yield ratio; Photonuclear reaction; ^{nat}W$(\gamma$,xn$)^{179m,g}$W; γ-spectrometry.

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I. INTRODUCTION

There are a number of nuclear reactions that populate both the meta-stable (isomeric) state and the ground state of the daughter nucleus. The knowledge regarding the formation cross sections of these two states, so-called the isomeric cross section ratio has been subjected to various studies related to the nuclear reactions and nuclear structure [1]. The isomeric cross section ratio (*IR*) differs in spins, therefore it is commonly represented as a ratio of the cross-section for the production of high and low spin states, namely $IR = \sigma_{high-spin}/\sigma_{low-spin}$. For the photonuclear reactions produced by non-monoenergetic bremsstrahlung radiations, the isomeric cross section ratio is replaced by the isomeric yield ratio, namely $IR = Y_{high-spin}/Y_{low-spin}$.

So far, most of the measurements have been carried out for the isomeric pairs in the nuclear reactions produced with mono-energetic neutrons and/or charged particles. The nuclear data existing in literature for the isomeric pairs produced in photonuclear reactions are still scanty. In addition, most of the experimental measurements were performed with relatively low bremsstrahlung end-point energies, usually from the threshold energy of photonuclear reaction up to about 30 MeV, so-called the Giant Dipole Resonance (GDR) energy region. The main reason for these restrictions is possibly due to the lack of the intense high energy photon sources. Within the GDR energy region only simple photonuclear reactions such as (γ,n), $(\gamma,2n)$, and (γ,np) with relatively low threshold energies are occurred [2]. However, exceeding the GDR energy region the production of complexity photonuclear reactions with multi-particle emission becomes energetically possible.

We have chosen the isomeric pair ^{179m,g}W produced on natural tungsten (^{nat}W) target via the ^{nat}W(γ,xn)^{179m,g}W photonuclear reactions with the emission of one to seven neutrons ($x = 1 \div 7$) for the studies. According to our knowledge, there are no reference data for the ^{179m,g}W isomeric pair produced in the ^{nat}W(γ,xn)^{179m,g}W reactions with bremsstrahlung end-point energies in the region above the GDR. In literature we have found only three yield ratio values for the ^{179m,g}W isomeric pair produced in the $^{180}W(\gamma,n)^{179m,g}$W reaction with bremsstrahlung end-point energies in the range 20-40 MeV [3,4]. As we have known, naturally occuring tungsten consists of five stable isotopes with mass numbers A = 180-186, namely: ^{180}W (0.120%), ^{182}W (26.498%), ^{183}W (14.314%), ^{184}W (30.642%), and ^{186}W (28.428%). All these isotopes can participate in the $^{nat}W(\gamma,xn)^{179m,g}$W reactions with threshold energies varying from about 8 to 50 MeV. As the photonuclear reactions are characterized by pure electromagnetic interaction, the excitation of a nucleus is completely determined by the energy of the absorbed photons. This is the main reason why although the bremsstrahlung photons carry only a relatively small momentum, but they are still a good tool for studying the energy dependence of the isomeric yield ratios.

This work is aimed to measure the yield ratio of the ^{179m,g}W isomeric pair produced in the ^{nat}W(γ,xn)^{179m,g}W reactions. The measurements were carried out with bremsstrahlung end-point energies of 50-, 55-, 60-, and 65-MeV. The present results help to extend our understanding of how the isomeric yield ratios depend on the incident bremsstrahlung end-point energies in the region just above the GDR. In addition, due to the lack of the photonuclear data in the medium and high bremsstrahlung energy regions, the new nuclear data obtained in this work can also be used for testing theoretical nuclear models in the energy region beyond the GDR.

II. EXPERIMENTAL

II.1. Sample irradiation

The experiments were performed at the 100 MeV electron linac of the Pohang Accelerator Laboratory (PAL), Pohang, Korea. As we have known, the interaction of high energy electrons with high Z target produces the flux of gamma quanta, called bremsstrahlung radiations. The bremsstrahlung radiations used in this work were produced by bombarding a pulsed electron beam into a thin tungsten (W) target with a size of 100 mm × 100 mm and a thickness of 0.1 mm. The

W target was positioned in the air, and at 15 cm from the electron beam exit window. The details of the electron linac and the bremsstrahlung production were described elsewhere [5, 6].

In this experiment, high purity (99.95%) tungsten samples in the form of metallic foil with a thickness of 0.05 mm, size of 15 mm × 15 mm, and weight in the range of 0.1921 to 0.2145 g were used. The tungsten foils were irradiated separately with bremsstrahlung end-point energies of 50-, 55-, 60-, and 65-MeV. The foils to be irradiated were placed in the same position of the sample holder, and fixed at 90 degrees with respect to the direction of the electron beam. The distance between the irradiated foil and the W target was 12 cm. During the irradiation time, the electron linac was operated with a repetition rate of 30 Hz, a pulse width of 1.6 μs, and beam current of 20 mA. The irradiation time for each sample was about 60 min. In order to follow the changes of the electron beam current during the irradiation time, the integrator counts were recorded in multichannel scaling mode for the correction of the bremsstrahlung photon flux fluctuation when it is necessary.

It seems that the irradiation time applied in this experiment is longer than necessary for the production of the relatively short-lived radioactive isotope^{179m}W. In some cases the long irradiation would cause disadvantages for the activity measurement of short-lived isotopes due to increased background and γ-ray interference. Fortunately, in our case these effects are not obvious. Instead, a large number of radio-nuclides produced in the ^{nat}W(γ,xnyp) reactions can also be used for research and other applications.

II.2. Activity measurement

The induced activities of the radio-nuclides produced in the irradiated tungsten foils were measured by using a well calibrated γ-spectrometer. It consisted of a coaxial high-purity germanium (HPGe) gamma detector (ORTEC, GEM-2018-p) coupled to a PC-based 4K channel analyzer. The energy resolution of the detector system was 1.8 keV full width at half maximum (FWHM) at the 1332.5 keV photo-peak of ^{60}Co source. The detection efficiency is 20% at 1332.5 keV relative to a 3 inch × 3 inch NaI(Tl) detector. The detector efficiency and energy calibrations were made with the standard γ-sources. The details of the detector calibration were illustrated elsewhere [7]. The measured γ-ray spectra were analyzed by using the GammaVision software, version 5.10 (EG&G ORTEC). The spectrum analysis can give energies and areas of the photo-peaks. The radionuclides of interest can be identified based on their characteristic γ-ray energies and half-lives.

The nuclear reactions leading to the formation of the ^{179m}W and ^{179g}W radio-nuclides and their main decay data are given in Table 1. The nuclear decay data of these reaction products were taken from ref. [8]. From the experimental point of view we can say that the nuclear data given in Table 1 are feasible for the activity measurements by using an off-line γ-ray spectrometric technique. As usually, the activities of the reaction products of interest here were determined from the number of counts under the photo-peak of the γ-rays with relatively high intensity, well separated and low background. In order to perform the accurate γ-ray activity measurements, considerations were made in choosing appropriate distances between the sample and detector as well as the length of the waiting and measuring times.

As can be seen in Table 1, the half-life of the ^{179m}W is rather short (6.40 min), so its activity measurement should be started as soon as possible after the end of the irradiation. Usually, the counting time for the ^{179m}W was about 4-5 min depending on the activity strength of each irradiated foil. For the short-lived isotope ^{179m}W we accepted a statistical error of up to 3%. The half-life of the ^{179g}W (37.05 min) is longer than that of the ^{179m}W therefore several γ-ray spectra were taken. The statistical error for the activity measurement of the ^{179g}W isotope was kept less than 2.5%.

Table 1. Nuclear reactions leading to the formation of ^{179m,g}W and main decay data.

Radionuclide	Half-life	Used γ-ray, E_γ (keV)	γ−ray intensity, I_γ (%)	Contributing reactions	Threshold energy (MeV)
^{179m}W	6.40 min	221.5	8.8	$^{180}W(\gamma,n)^{179m}W$	8.634
Spin: 1/2-				$^{182}W(\gamma,3n)^{179m}W$	23.281
				$^{183}W(\gamma,4n)^{179m}W$	29.573
				$^{184}W(\gamma,5n)^{179m}W$	36.986
				$^{186}W(\gamma,7n)^{179m}W$	49.934
^{179g}W	37.05min	133.9	0.106	$^{180}W(\gamma,n)^{179g}W$	8.412
Spin: 7/2-				$^{182}W(\gamma,3n)^{179g}W$	23.159
				$^{183}W(\gamma,4n)^{179g}W$	29.351
				$^{184}W(\gamma,5n)^{179g}W$	36.764
				$^{186}W(\gamma,7n)^{179g}W$	49.712

III. DATA ANALYSIS

III.1. Basic equations used in the computation of isomeric yield ratio

The aim of this study was to obtain the experimental yield ratios for the isomeric pair ^{179m,g}W produced from the $^{nat}W(\gamma,xn)^{179m,g}W$ reactions in the energy region 50-65 MeV bremsstrahlung end-point energies. The relative population of the meta-stable and unstable ground states of this isomeric pair produced in these multi-particle photonuclear reactions is determined based on the yields of the two states of the reaction product instead of the cross-sections. The independent yield of the photonuclear reaction induced by non-monoenergetic bremstrahlung photons can be expressed by the following integral:

$$Y_k = N_0 \int_{E_{th}}^{E_{\gamma\max}} \sigma_k(E)\phi(E)dE \tag{1}$$

where character $k(=m,g)$ represents the metastable (m) state and the ground (g) state of the reaction product nuclei, N is the number of target nuclei, E_{th} and $E_{\gamma max}$ are the reaction threshold and bremsstrahlung end-point energies, $\phi(E)$ and $\sigma_k(E)$ are the bremsstrahlung flux and the reaction cross-section as a function of photon energies, respectively.

In this work, the photonuclear reactions were produced by the irradiation of tungsten foils with pulsed bremsstrahlung beam. Therefore the relation between the reaction yield and the measured activity of the reaction product can be expressed as follows [9]:

$$Y_k = \frac{S_{k,\gamma}\lambda_k(1-e^{-\lambda_k T})}{N_0 I_{k,\gamma}\varepsilon_{k,\gamma}(1-e^{-\lambda_k \tau})(1-e^{-\lambda_k t_i})e^{-\lambda_k t_w}(1-e^{-\lambda_k t_c})} \tag{2}$$

where $S_{k,\gamma}$ is the photo-peak area of the detected γ-ray of the metastable state or the ground state nuclei, $I_{k,\gamma}$ and $\varepsilon_{k,\gamma}$are the intensity and detection efficiency for the γ-ray of interest, $\lambda_k$is the decay constant of the metastable state or the unstable ground state nuclei, τ is the pulse width, T is the cycle period and t_i, t_w, and t_c are the times of irradiation, waiting and measurement, respectively.

The isomeric yield ratio can be computed from the measured activities of the meta-stable and ground states of the product nuclei. For the ^{179m,g}W isomeric pair, the meta-stable state nuclei ^{179m}W were formed directly from the ^{nat}W(γ,xn)^{179m}W reactions. However, the unstable ground state nuclei ^{179g}W were produced from two ways, firstly from the direct reactions ^{nat}W(γ,xn)^{179g}W, and secondly from the decay of the meta-stable state nuclei ^{179m}W with the branching ratio P = 99.72%. Therefore, the production of the isomeric pair and its decay during the activation time can be described by the following differential equation system:

$$\frac{dN_m}{dt} = Y_m - \lambda_m N_m \tag{3}$$

$$\frac{dN_g}{dt} = Y_g - \lambda_g N_g + P\lambda_m N_m \tag{4}$$

where N_k is the number of nuclei for $k(=m,g)$ states, λ_m and λ_g are the decay constants of the meta-stable and unstable ground state nuclei.

By solving the equations (3) and (4) in this equation system we can obtain the yield ratio of the investigated isomeric pair as follow [10]:

$$IR = \frac{Y_m}{Y_g} = \left[\frac{\lambda_g F_m}{\lambda_m F_g} \times \left(\frac{S_{g,\gamma}}{S_{m,\gamma}} \times \frac{\varepsilon_{m,\gamma} I_{m,\gamma}}{\varepsilon_{g,\gamma} I_{g,\gamma}} - \frac{P\lambda_g}{\lambda_g - \lambda_m}\right) + \frac{P\lambda_m}{\lambda_g - \lambda_m}\right]^{-1} \tag{5}$$

where the factor F_k is related as:

$$F_k = \frac{(1-e^{-\lambda_k \tau}) \times (1-e^{-\lambda_k t_i}) \times e^{-\lambda_k t_w} \times (1-e^{-\lambda_k t_c})}{1-e^{-\lambda_k T}} e^{-\lambda_k (T-\tau)} \tag{6}$$

III.2. Determination of yield ratio of the ^{179m,g}W isomeric pair

The simplified decay scheme of the ^{179m,g}W is given in Fig. 1. The examples of typical γ-ray spectra from the irradiated natural tungsten are shown in Fig. 2 (a,b). The measurements were started at different waiting times for the purpose of obtaining the γ-rays of both the short-lived ^{179m}W and long-lived ^{179g}W isotopes, respectively. As can be seen in Fig. 2 (a,b), these γ-spectra seem rather complex. Beside the 221.5 keV γ-ray of the ^{179m}W and 1339.9 keV γ-ray of the ^{179g}W we can also see a number of γ-rays emitted from other radio-nuclides, which have been produced on the natural tungsten foil through the ^{nat}W(γ,xnyp) reactions

From the decay scheme in Fig. 1 indicates that the activities of the ^{179m}W and ^{179g}W isotopes can be determined from the γ-rays of 221.5 keV (8.8%) and 133.9 keV (0.106%), respectively. These γ-peaks are well observed in two γ-spectra. However, the natural tungsten target activated with medium or high energy bremsstrahlungs can produce a large number of radioactive products. As usually, a large number of γ-rays emitted from these isotopes would cause difficulties in data processing due to γ-rays interference and/or overlap each other. At the present experimental conditions we have identified more than ten radioisotopes formed via the ^{nat}W(γ,xnyp) reactions. Some of their γ-rays having energies close to those of the ^{179m}W and ^{179g}W isotopes, and they cannot be separated by using the HPGe detector with high energy resolution. Therefore in order to obtain the accurate activities of the ^{179m}W and ^{179g}W isotopes it is necessary to check the possible interferences and make corrections for the overlapping γ-rays and/or interferences in data processing based on the data taken from the γ-ray spectra analysis

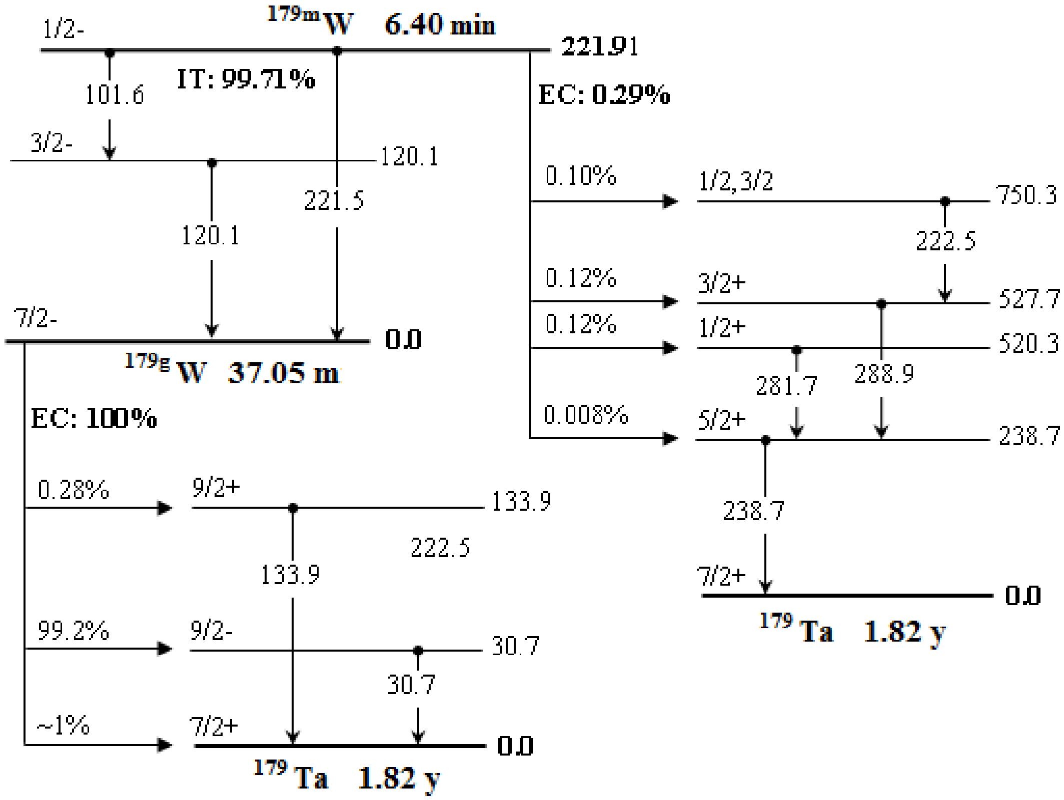

Fig. 1. Simplified decay scheme of ^{179m,g}W. The nuclear level energies are given in keV.

In this work, the yield ratio for the ^{179m,g}W isomeric pair produced in the $^{nat}W(\gamma,xn)^{179m,g}$W reactions was determined from the yield of the unstable ground state nuclei, ^{179g}W (high-spin state, 7/2-) relative to that of the meta-stable state nuclei, ^{179m}W (low-spin state, 1/2-). In order to obtain the activity of ^{179m}W we have to subtract the contribution from the overlapping γ-ray of 223.23 keV (2.05%) that was emitted from the ^{177}W ($T_{1/2}$=132 min) radionuclide produced in the multi-channel reactions $^{nat}W(\gamma,xn)^{177}$W. Fortunately, the ^{177}W is the multi-gamma ray emitter, therefore in practice, the activity contribution from the γ-ray of 223.23 keV can be approximated from other

γ-ray of ^{177}W [11, 12]. In this work, the activity from the 223.23 keV γ-ray was computed from the photo-peak area of the γ-ray of 426.98 keV (12.3%). The presence of the 426.98 keV γ-ray from the ^{177}W radionuclide can be seen in Fig. 2(b). The 426.98 keV γ-ray was selected because it is well separated from other γ-ray peaks and its intensity is relatively high. The photo-peak area of the 223.23 keV γ-ray was obtained from that of the 426.98 keV γ-ray based on the following fundamental relationship [11, 12]:

$$\frac{S_\gamma(223.23)}{I_\gamma(223.23)\times\varepsilon_\gamma(223.23)}=\frac{S_\gamma(426.98)}{I_\gamma(426.98)\times\varepsilon_\gamma(426.98)} \tag{7}$$

where S_γ, I_γ and ε_γ represent the number of counts in the photo-peak, the γ-ray intensity and the detection efficiency for the γ-rays of 223.23 keV and 426.98 keV, respectively.

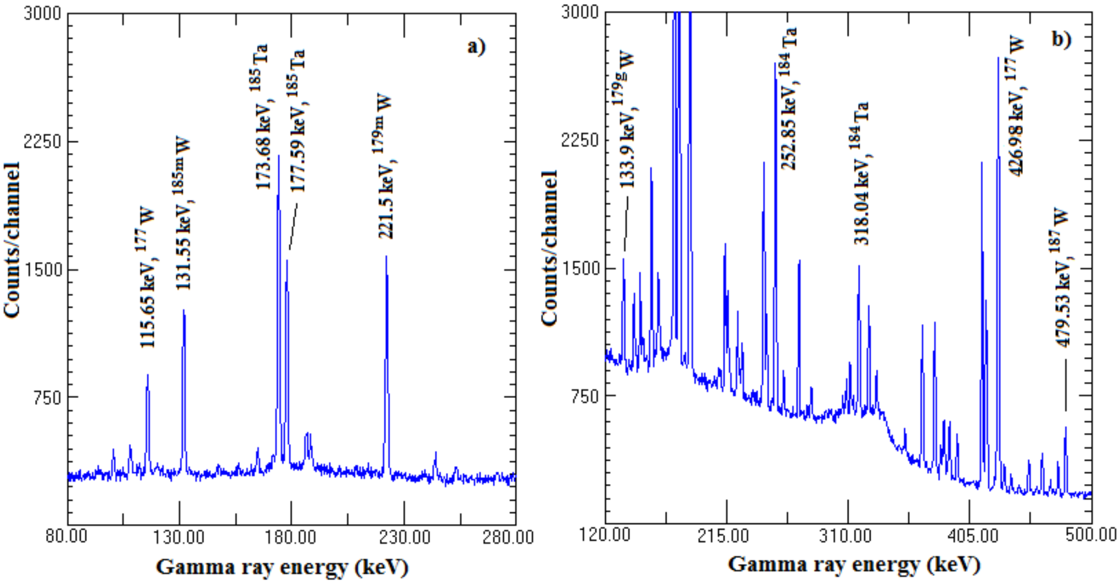

Fig. 2. Parts of typical γ-ray spectra from natural tungsten foil irradiated with 60 MeV bremsstrahlung. The measurements were started (a) 4 min and (b) 40 min after the end of the irradiation.

After making correction for the overlapping γ-rays, the counting losses due to self-absorption and coincidence summing for the 221.5 keV γ-ray were also calculated [13-15]. The attenuation factor, F_{att}, for the γ-ray of interest can be approximated based on the formula:

$$F_{att}=\frac{t}{(1-e^{-\mu t})} \tag{8}$$

where μ is the linear attenuation coefficient and t is the sample thickness.

In our case, the attenuation factor for the 221.5 keV γ-ray was estimated to be 0.971. The measured activity then corrected to zero attenuation by dividing with factor F_{att}. The γ-ray of 221.5 keV is in coincidence with two γ-rays of 101.6 keV and 120.1 keV (summing-in). At the present measuring condition the summing correction factor was estimated to be 0.999. In this case, the number of counting loss due to the summing-in is very small and neglected.

For the activity measurement of the ^{179g}W isotope by using the γ-ray of 133.9 keV we also have a problem with the overlapping γ-ray of the 134.25 keV. This γ-ray was emitted from the ^{187}W radioactive isotope, which is produced in the so-called secondary reaction ^{186}W(n,γ)^{187}W. The 133.9 keV photo-peak of the ^{179g}W and that of the 134.25 keV (10.36%) of the ^{187}W ($T_{1/2}$= 24 h) cannot be separated by using the HPGe detector. Therefore, in order to obtain the activity of the ^{179g}W isotope we also have to subtract the contribution from the overlapping γ-ray of 134.25 keV from the ^{187}W by the same way as applied for the activity processing of the ^{179m}W isotope. Fortunately, the contribution of the 134.25 keV γ-ray peak can be approximated from the photo-peak area of the 479.53 keV (21.8%) γ-ray peak that was also emitted from the multi-gamma ray emitter ^{187}W. The presence of the 479.53 keV γ-ray peak from the radionuclide ^{187}W can be seen in Fig. 2 (b). The photo-peak area of the 134.25 keV γ-ray was calculated from that of the 479.53 keV γ-ray by applying the relationship (7). The attenuation factor for the 133.9 keV γ-rays was estimated based on Eq. (8) to be 0.904.

After making appropriate corrections, the yield ratio of the ^{179m,g}W isomeric pair was computed based on Eq. (5) under the condition of P = 99.72 %.

IV. RESULTS AND DISCUSSION

The present yield ratios of the ^{197m,g}W isomeric pair produced in multi-particle photonuclear reactions ^{nat}W(γ,xn)^{197m,g}W with bremsstrahlung end-point energies of 50-, 55-, 60-, and 65-MeV are given in Table 2. The uncertainties of the present experimental results were determined based on the error propagation principle that contained both statistical and systematic errors. The random error in the observed activity is primarily due to counting statistics, which is estimated to be (2.5-3.0%) for the ^{179m}W and (2.0-2.5%) for the ^{179g}W, respectively. The systematic errors are due to uncertainties in the irradiation time (0.3%), the half-life of the reaction products and the γ-ray intensities (8.2-9.6%) and the detection efficiency (2.5%), which arises from the fitting error. Thus, the total systematic error is about (8.5-10 %). In addition, the error from other unknown sources was also added and expected to be 1-3%. Finally, the combined uncertainties from both statistical and systematic error lie within 9-11%.

In Table 2 we also give some available yield/cross section ratios of the same isomeric pair ^{197m,g}W produced in different types of nuclear reaction such as the simple photonuclear reaction ^{180}W(γ,n)^{179m,g}W [3,4] and 14 MeV neutrons induced reaction ^{180}W(n,2n)^{179m,g}W [16,17]. It is remarkable, however that the nuclear reaction ^{180}W(n,2n)^{179m,g}W does not give the yield ratio for the ^{179m,g}W isomeric pair, but the cross section ratio, therefore the comparison here should be regarded as a qualitative comparison.

As can be seen in Table 2, there are no such data in literature, which can be directly compared with the present results. Therefore, only a qualitative discussion on the experimental results can be made. As we have seen, the isomeric ratios in Table 2, including the present results can be formed into three groups by magnitudes. The data for the ^{179m,g}W isomeric pair produced in the ^{180}W(n,2n)^{179m,g}W reaction with 14 MeV neutrons are larger compared to those for the same isomeric pairs produced in photonuclear reactions^{180}W(γ,n)^{179m,g}W and ^{nat}W(γ,xn)^{179m,g}W. This can be understood qualitatively due to the momentum of incident neutrons transformed to the target nucleus is larger than that of photons. This observation provides an additional confirmation of

Table 2. Isomeric ratios for the ^{179m,g}W isomeric pair.

Nuclear reaction	$E_{\gamma max}$(MeV)	$IR = Y_{high-spin}/Y_{low-spin}$	
		This work	Reference
^{180}W(n,2n)^{179m,g}W	13.5 14.1		2.498 [16,17] 2.400 [16,17]
^{180}W(γ,n)^{179m,g}W	20		1.45 [3]
^{180}W(γ,n)^{179m,g}W	30		1.72 [3] 1.93 ± 0.02 [4]
^{180}W(γ,n)^{179m,g}W	40		1.82 [3]
^{nat}W(γ,xn)^{179m,g}W	50	1.90 ± 0.21	
^{nat}W(γ,xn)^{179m,g}W	55	1.89 ± 0.20	
^{nat}W(γ,xn)^{179m,g}W	60	1.96 ± 0.19	
^{nat}W(γ,xn)^{179m,g}W	65	2.03 ± 0.19	

the role of the angular momentum in the entrance channel of the reaction as indicated previously [18-21].

Further comparison of the experimental data in Table 2 we can also observe that the isomeric yield ratios for the ^{179m,g}W isomeric pairs produced in different types of photonuclear reactions ^{180}W(γ,n)^{179m,g}W and ^{nat}W(γ,xn)^{179m,g}W are difference in the magnitude and certain difference in the energy-dependent tendency. Of course, the difference between two groups of data for these two types of photonuclear reaction does not cause a strong impact by the magnitude.

For the ^{180}W(γ,n)^{179m,g}W reaction, the change of the isomeric yield ratios for the ^{179m,g}W isomeric pair as a function of the excitation energies is obvious. In the energy region 20-30 MeV the yield ratios for the ^{179m,g}W isomeric pair produced in the ^{180}W(γ,n)^{179m,g}W reaction increased relatively fast (about 20%), however in the energy region 30-40 MeV the increasing tendency is not observed. It is shown that the tendency of the energy-dependent for the isomeric pair ^{179m,g}W produced in the ^{180}W(γ,n)^{179m,g}W reaction in the energy region 30-40 MeV and that of the isomeric pair ^{179m,g}W produced in the ^{nat}W(γ,xn)^{179m,g}W reactions in the energy region 50-65 MeV have nearly the same saturated tendency. The changing trend of the isomeric yield ratios for the ^{179m,g}W isomeric pair in the simple photonuclear reaction ^{180}W(γ,n)^{179m,g}W can be explained due to the role of the excitation energy [18-21]. According to this role, at low excitation energies, below about 30 MeV, the formation of compound nucleus is dominant. In this case the formation of the isomeric state ^{179m}W with spin (1/2-) closer to that of the target nucleus (0+) would be favored. However, at higher energies, approximately from about 25-30 MeV the newly opening reaction channels such as direct and multi-particle reactions are increased and that would lead to an increase in the yield of the initially unfavorable isomeric state, the ^{179g}W [18-21].

For the ^{nat}W(γ,xn)^{179m,g}W multi-channel reactions, the yield ratios for the ^{179m,g}W isomeric pair seem to be unchanged, namely the variation is only from 1.89±0.20 to 2.03±0.19 in whole investigated energy region, from 50 to 65 MeV bremsstrahlung end-point energies. The saturated tendency of this group data is understandable, because in this energy region, the contributions of direct reactions become increasingly important. For the direct reactions, the directly emitted particles carry away a relatively large angular momentum, therefore only a fraction of the energy and angular momentum of the incident bremsstrahlung photons are transformed to the target nucleus. Consequently, the population of states with higher spin more or less was suppressed, leading to the yield ratio of high to low-spin isomers might not continue its increasing trend, and instead it would level off or cease to change.

V. CONCLUSION

We have measured the yield ratios of the ^{197m,g}W isomeric pair produced in the ^{nat}W(γ,xn)^{179m,g}W reactions with bremsstrahlung end-point energies of 50-, 55-, 60-, and 65-MeV, where there is still a lack of data. The present results were expressed in terms of the fraction of the yield that populates the high-spin isomer. The present results have been measured for the first time. In order to improve the accuracy of the experimental results, the efforts were made in making corrections for the counting losses due to the γ-ray attenuation and true coincidence summing effect. In addition, the contributions of the overlapping γ-rays to the analytical peaks were also corrected.

By comparison of the available experimental data for the ^{179m,g}W isomeric pairs produced in several types of nuclear reactions we would say that the isomeric ratio for the isomeric pair can be affected by different factors. In case of the ^{179m,g}W isomeric pair produced in the photonuclear reactions ^{nat}W(γ,xn)^{179m,g}W with bremsstrahlung end-point energies above the giant dipole resonance region the yield ratio is also affected by many factors, but among them the excitation energy and the reaction channel effect are probably most pronounced. In addition, we have also observed that the yield ratios for the ^{179m,g}W isomeric pair produced in the multi-particle photonuclear reactions ^{nat}W(γ,xn)^{179m,g}W seem to be saturated within the whole investigated energy region.

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