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YIELD RATIOS OF ISOMERIC PAIRS ^{196m,g}Au, ^{186m,g}Ir, AND ^{183m,g}Os IN THE ^{197}Au$(\gamma,xnyp)$ REACTIONS WITH 2.5 GeV BREMSSTRAHLUNG

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Abstract. *The yield ratios of high to low spin states of the ^{196m,g}Au, ^{186m,g}Ir, and ^{183m,g}Os isomeric pairs produced by ^{197}Au$(\gamma,xnyp)$ reactions with a bremsstrahlung end-point energy of 2.5 GeV have been measured. Measurements were performed by the activation method in combination with off-line γ-ray spectrometry. The induced activity of the studied radionuclides was derived from the photo-peak area of the selected γ-ray after making the necessary corrections. The isomeric yield ratios obtained in this work are the first measurement. The relationships between the yield ratios of studied isomeric pairs with the value of high spin states, the spin difference between the high spin states and the target nucleus, and the number of nucleons emitted from the target nucleus are discussed.*

Keywords: isomeric yield ratio; ^{197}Au$(\gamma,xnyp)$; ^{196m,g}Au, ^{186m,g}Ir, ^{183m,g}Os; 2.5 GeV bremsstrahlung; activation method.

Classification numbers: 25.20.-x; 29.50.+v.

I. INTRODUCTION

The study of the cross section or the yield ratio of the nuclear reaction product existing in both metastable (isomer) and unstable ground states, so-called the nuclear isomer, is of fundamental interest for nuclear physics research and applications. The data obtained are useful for

various fields of study such as nuclear reaction mechanisms, nuclear structure, transfer of angular momentum, spin dependence of nuclear level density, refinements of gamma transition theories and testing theoretical nuclear models. So far, most of the studied nuclear isomers have been produced in nuclear reactions with low energy projectiles such as 14 MeV neutrons [1–3], charged particles [4–6], and bremsstrahlung radiations [7–9]. Investigations show that the isomeric cross section and/or the yield ratio depend on several factors, such as the incident energy of the projectile [7,10,11], the reaction channel leading to the nuclear isomer [12–14] and the spin of the target nucleus as well as that of the high spin state [15,16].

For nuclear reactions induced at relatively low energies, the compound reaction mechanism dominates and only one or two nucleons are released from the target nucleus. As there are few data on the yield/cross section ratio for isomeric pairs formed in high energy reactions, further studies are needed. At high energies, nuclear reactions proceed in different ways, releasing multiple nucleons and producing different isomers from the same target nucleus, which become the interesting objects of study. Balabekian et al. [17] measured the isomeric ratios for eight isomeric pairs ^{44m,g}Sc, ^{95m,g}Nb, ^{95m,g}Tc, ^{102m,g}Rh, ^{184m,g}Re, ^{193m,g}Hg, ^{196m,g}Au and ^{197m,g}Hg produced on a gold target by deuteron bombardment with an energy of 4 GeV. Zhuikov et al. [18] measured isomeric ratios of ^{178m,g}Ta, ^{180m,g}Hf, ^{179m,g}Lu, and ^{177m,g}Lu, produced from ^{181}Ta by proton bombardment with an energy in the range 100 to 500 MeV and found a trend of isomeric ratio dependence on isomer spin. Bachschi *et al.* [19] measured isomeric ratios of ^{44m,g}Sc and ^{52m,g}Sc isomeric pairs produced from ^{45}Sc, and ^{nat}Cu irradiated with 2 GeV bremsstrahlung. Recently, Do *et al.* [20] also measured yield ratios of the same isomeric pairs ^{44m,g}Sc formed in different reaction channels, namely: ^{45}Sc(γ,n), ^{nat}Ti(γ,pxn), ^{nat}Fe$(\gamma,5pxn)$ and ^{nat}Cu$(\gamma,8pxn)$ with 2.5 GeV bremsstrahlung and found an increasing trend of the isomeric yield ratios with an increasing mass difference between the target and the product nuclei.

In this work, we determined the yield ratios of nuclear isomers from gold foil irradiated with a bremsstrahlung end-point energy of 2.5 GeV. Among a number of reaction products formed in ^{197}Au$(\gamma,xnyp)$ spallation reactions, we found three isomeric pairs: ^{196m,g}Au, ^{186m,g}Ir, and ^{183m,g}Os, which are formed via the reactions: ^{197}Au$(\gamma,n)^{196m,g}$Au, ^{197}Au$(\gamma,9n2p)^{186m,g}$Ir, and ^{197}Au$(\gamma,11n3p)^{183m,g}$Os. The threshold energies of these reactions vary over a wide energy range, approximately from 8 MeV for the ^{197}Au$(\gamma,n)^{196m,g}$Au reactions to 98 MeV for the ^{197}Au$(\gamma,11n3p)^{183m,g}$Os reactions. The number of nucleons emitted from the gold target nucleus during the formation of the studied isomeric pairs varies in a wide range, a single nucleon (neutron) from the ^{197}Au$(\gamma,n)^{196m,g}$Au reaction up to 14 from the ^{197}Au$(\gamma,11n3p)^{183m,g}$Os reactions, including 11 neutrons and 3 protons. In addition, the values of the high spin states also vary considerably, from $9/2^+$ for ^{183g}Os to 12^- for ^{196m}Au, respectively. Thus, these isomeric pairs have interesting features to study. To our knowledge, several measurements have been made to date for the yield ratio of the ^{196m,g}Au isomeric pair. However, measurements were mainly made at bremstrahlung end-point energies in the range of 20-65 MeV [15,21–25], except that our measurements were made at bremsstrahlung end-point energy of 2.5 GeV [25,26]. In this work, we again measured the yield ratio of ^{196m,g}Au to compare with the previous results and thus also to confirm the stability of the experimental technique used. The yield ratio of the isomeric pair ^{186m,g}Ir has probably not been measured to date. For the ^{183m,g}Os isomeric pair, only one measurement was made by Sakar et al [27] at bremsstrahlung end-point energies in the range 195-1000 MeV. It is clear that the yield ratios of the isomeric pairs ^{196m,g}Au, ^{186m,g}Ir and ^{183m,g}Os generated from ^{197}Au via

spallation reactions at the GeV energy range are very rare. The lack of such nuclear data is one of the reasons for encouraging this study.

The aim of the present work was to measure the yield ratios of isomeric pairs ^{196m,g}Au, ^{186m,g}Ir, and ^{183m,g}Os produced on ^{197}Au via different nuclear reaction channels, namely ^{197}Au$(\gamma,n)^{196m,g}$Au, ^{197}Au$(\gamma,9n2p)^{186m,g}$Ir and ^{197}Au$(\gamma,11n3p)^{183m,g}$Os with bremsstrahlung end-point energy of 2.5 GeV and provide new nuclear data. In particular, we also pay attention to nuclear effects that can affect the yield ratio of the studied isomeric pairs.

The structure of the article consists of the Introduction and four Sections. The basic equations for determining the isomer yield ratio are contained in Sec. II, details of the experimental procedures are contained in Sec. III, the results and discussion are contained in Sec. IV, and finally, the concluding remarks are in Sec. V.

II. BASIC EQUATIONS FOR DETERMINING ISOMERIC YIELD RATIO

In general, the isomeric yield ratio (IYR) for a given isomeric pair produced via bremsstrahlung photons-induced reaction is expressed as:

$$IYR = Y_h/Y_l, \tag{1}$$

where Y_h and Y_l represent the yield of high and low spin states of the isomeric pair. Since the bremsstrahlung spectrum has a continuous energy distribution, the independent reaction yield can be expressed as:

$$Y_k = \int_{E_{th}}^{E_{\gamma\max}} \sigma_k(E)\phi_k(E)dE, \tag{2}$$

where $k(=m,g)$ represents the isomeric state (m) or the ground state (g) of an isomeric pair, $\sigma_k(E)$ is the energy dependent reaction cross-section, $\phi_k(E)$ is the bremsstrahlung flux, $E_{\gamma\max}$ and E_{th} are the bremsstrahlung end-point energy and the reaction threshold energy, respectively.

By taking into account the fact that, the sample has been irradiated with pulsed bremsstrahlung and the activity of the residual nuclide is measured by off-line gamma spectroscopy, the independent yield can be obtained as:

$$Y_k = \frac{S_k\lambda_k(1-e^{-\lambda_k T})}{N_0 I_k \varepsilon_k(1-e^{-\lambda_k\tau})(1-e^{-\lambda_k t_i})e^{-\lambda_k t_w}(1-e^{-\lambda_k t_c})}, \tag{3}$$

where S_k is the number of counts (or area) under the photo-peak of the measured γ-ray, N_0 is the number of target nuclei, I_k is the intensity of the measured γ-ray, ε_k is the detection efficiency of the detector at the γ-ray of interest, λ_k is the decay constant of the $k(=m,g)$ state, τ is the pulse width, T is the cycle period, t_i, t_w and t_c are the irradiation, waiting and counting times, respectively.

In general, the residual nuclide in the isomeric state formed directly from the reaction on a given stable isotope with a cross section of σ_m, then it decays to the unstable ground state with the so-called isomeric transition (IT) coefficient of P. Therefore, the yield of unstable ground state nuclide consists of two parts, one part comes directly from the reaction on a given stable isotope of cross section σ_g and the other part comes from the decay of the residual nuclide in the isomeric state. Therefore, the task of the experimental work is to determine the independent yield of both

the isomeric and unstable ground states. For this purpose, we establish the differential equation system describing the production rate and the decay process of the residual nuclide as follows [17]:

$$\frac{dN_m}{dt} = Y_m - \lambda_m N_m, \tag{4}$$

$$\frac{dN_g}{dt} = Y_g - \gamma_g N_g + p\gamma_m N_m, \tag{5}$$

where N_m and N_g are the number of residual nuclides in the isomeric and ground state, Y_m and Y_g are the yield of the residual nuclide in the isomeric and ground state, λ_m and λ_g are the decay constants of the two states, and P is the IT coefficient (branching ratio) for the decay from the metastable state to the unstable ground state.

It is known that, both the isomeric state and ground state of the isomeric pair are produced from the same target nuclide under the same irradiation conditions (bremsstrahlung beam, irradiation time and the irradiation geometry), the reaction yield of a given isomeric pair can be obtained by solving the two differential equations (4) and (5). Then, combined with the measured γ-activity, the isomeric yield ratio of the isomeric pair expressed by high to low spin states can be derived as follows [28]:

$$IYR \equiv \frac{Y_m}{Y_g} = \left[\frac{\lambda_g F_m}{\lambda_m F_g} \times \left(\frac{S_g}{S_m} \times \frac{\varepsilon_m I_m}{\varepsilon_g I_g} - \frac{P\lambda_g}{\lambda_g - \lambda_m}\right) + \frac{P\lambda_m}{\lambda_g - \lambda_m}\right]^{-1}, \tag{6}$$

where S_m and S_g are the photo-peak area of the measured γ-rays from the isomeric and the ground states, P is the IT coefficient (branching ratio) for the decay from the metastable state to the unstable ground state, and the factor F_k is expressed as:

$$F_{k=m,g} = \frac{\left(1 - e^{-\lambda_k \tau}\right) \times \left(1 - e^{-\lambda_k t_i}\right) \times e^{-\lambda_k t_w} \times \left(1 - e^{-\lambda_k t_c}\right)}{1 - e^{-\lambda_k t_w}} e^{-\lambda_k (T-\tau)}. \tag{7}$$

As we can see in Eq. (6), to obtain the yield ratio of a given isomeric pair, we need to measure the activity of the residual nuclide in both states and make interference corrections if necessary. Note that, in the case of an unstable ground state representing a high spin state, the yield ratio will be equal to the inverse of Eq. (6).

III. EXPERIMENT

III.1. Sample irradiation

Bremsstrahlung radiations were produced by bombarding a 50 mm $\times$ 50 mm $\times$ 0.2 mm tungsten (W) target with a 2.5 GeV electron beam from an accelerator at Pohang Accelerator Laboratory (PAL), POSTECH, Korea. In this experiment, the W target was fixed at 38.5 cm from the electron beam exit window, and the gold (Au) foil was placed 24 cm from the W target. Two gold foils with a purity of 99.95%, a thickness of 0.03 mm, and a diameter of $1/2$ inches were irradiated for 1 h and 4 h, respectively. During the irradiation period, the electron accelerator was operated with a repetition frequency of 10 Hz, a pulse width of 1 ns, and an electron beam energy of 2.5 GeV. The nuclear reactions to be investigated and the main nuclear decay data are given in Table 1 [29, 30].

Table 1. Production of nuclear isomers and their main decay data [29, 30].

Nuclear reaction	Threshold energy, E_{th} (MeV)	Half-life, $T_{1/2}$	Decay mode (%)	Spin & parity, J^{π}	Major γ-ray e energy, E_{γ} (keV)	γ-ray intensity, I_{γ} (%)
^{197}Au$(\gamma,n)^{196m2}$Au	8.67	9.6 h	IT: 100	12^-	147.8	43.5
^{197}Au$(\gamma,n)^{196g}$Au	8.07	6.183 d	ε: 93.0	2^-	333.03	22.9
					355.73	87.0
^{197}Au$(\gamma,9n2p)^{186m}$Ir	79.21	1.90 h	ε : 75.0	2^-	137.15	23
			IT:25		296.93	86.
					767.46	18.4
					773.24	11.7
^{197}Au$(\gamma,9n2p)^{186g}$Ir	79.21	16.64 h	ε+β+:	5^+	137.15	41
			100		296.90 4	62.3
					434.84	33.9
					773.28	8.9
^{197}Au$(\gamma,11n3p)^{183m}$Os	98.16	9.9 h	ε+β+: 85	$1/2^-$	1101.94	49.0
			IT:15		1107.92	22.36
^{197}Au$(\gamma,11n3p)^{183g}$Os	98.16	13.0 h	ε: 100	$9/2^+$	381.74	91.6

III.2. Activity measurement

The induced activity of the residual nuclides in the activated gold foil was measured with a γ-ray spectrometer based on a high-purity germanium detector (HPGe, CANBERRA) with a diameter of 59.2 mm and a length of 30 mm. The energy resolution of the detector was 1.80 keV for the 1332.5 keV γ-ray of ^{60}Co. The detection efficiency was 20% at 1332.5 keV compared to the 3" x 3" NaI(Tl) detector. The photo and total efficiencies of the HPGe detector were calibrated using a standard γ-sources. The detector was coupled to a computer-based multichannel analyzer card system, which can determine the photo-peak area of a particular γ-peak existing in the spectrum using the computer program GENIE2000 (Canberra). In some cases, the γ-spectrum was also analyzed using the FitzPeaks gamma analysis software for comparison.

For activity measurement, the sample was placed at least 10 cm from the detector surface to reduce dead time and coincidence summation effect. In general, the detector dead time was kept around 4-8% and the statistical error below 5%. Generally, high intensity, non-interfering or correctable gamma rays were chosen for the measurement. Since the half-lives of all studied radionuclides are relatively long, appropriate waiting and measurement times for each radioisotope were taken into account. The radioactive reaction product was identified based on the γ-ray energy and half-life. The major γ-rays of isomeric pairs ^{196m,g}Au, ^{186m,g}Ir and ^{183m,g}Os are shown in γ-spectrum plotted in Fig. 1.

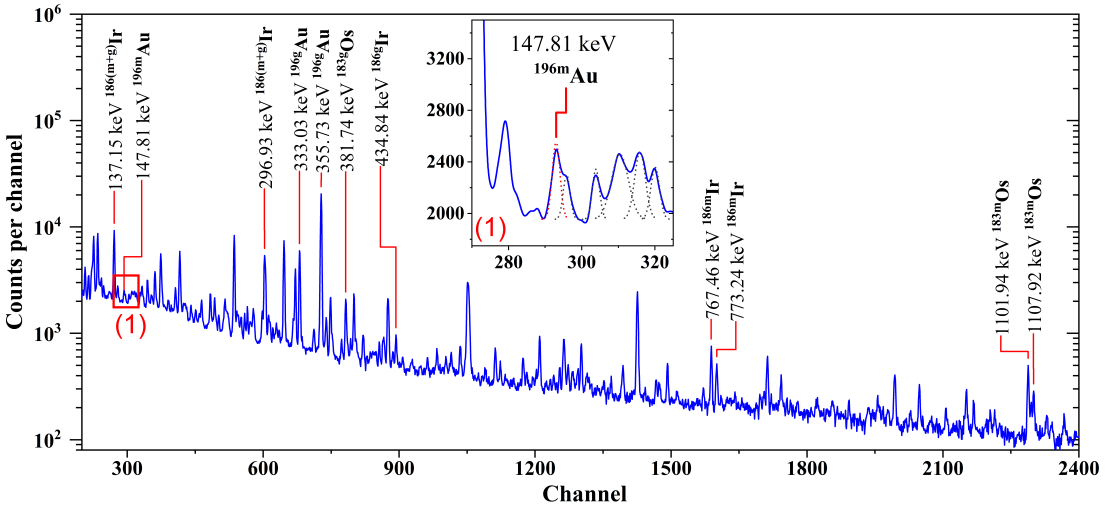

Fig. 1. Main γ-peaks of isomeric pairs ^{196m,g}Au, ^{186m,g}Ir and ^{183m,g}Os in the γ-spectrum of ^{197}Au irradiated by a bremsstrahlung end-point energy of 2.5 GeV with $t_i = 1$ h, $t_w = 3$ h and $t_c = 1$ h.

III.3. Determination of isomeric yield ratio

After the activity measurement, the yield ratios for the isomeric pairs were determined from Eqs. (6) and (7).

III.3.1. *Yield ratio for the ^{196m,g}Au isomeric pair*

For the purpose of comparison, we remeasured the yield ratio of the ^{196m,g}Au isomeric pair using the same method as the previous work [25, 26]. In this study, two gold foils were irradiated separately, one foil sample was irradiated for 1 h and the second was irradiated for 4 h. The result obtained is the average value of the two experiments.

As we know, the ^{196}Au radionuclide produced from the ^{197}Au(γ,n) reaction exists in three states, ^{196m1}Au $(T_{1/2} = 8.1$ sec, $J^\pi = 5^+)$, ^{196m2}Au $(T_{1/2} = 9.6$ h, $J^\pi = 12^-)$, and ^{196g}Au $(T_{1/2} = 6.1669$ d, $J^\pi = 2^-)$. The two metastable states ^{196m1}Au and ^{196m2}Au decay to the ground state ^{196g}Au by isomeric transition with a branching ratio of 100%. Since the half-life of the ^{196m1}Au is too short, its activity cannot be measured. In this study we only measured the activity of ^{196m2}Au and that of the ^{196g}Au ground state. The activity of ^{196m2}Au was measured using the γ-ray of 147.81 keV (43.5%). The activity of the ^{196g}Au was measured using the γ-ray of 355.73 keV (87%). Since ^{196g}Au is a long-lived radioisotope $(T_{1/2} = 6.183$ d), its activity was measured several days after the end of irradiation to allow most short-lived isotopes to decay and reduce the spectral background. The yield ratio of the high spin state to that of the low spin state of the ^{196m,g}Au isomeric pair was determined based on Eq. (6) to be $(1.01 \pm 0.12)10^{-3}$. Since it is impossible to measure the activity of ^{196m1}Au $(T_{1/2} = 8.1$ sec, $J^\pi = 5^+)$, it's activity contribution to the ground state of 196gAu cannot be subtracted either. Therefore, the current yield ratio of the high spin to the low spin states of ^{196m,g}Au radionuclide is known as the yield ratio of ^{196m2}Au to that of $^{196(m1+g)}$Au.

III.3.2. *Yield ratio for the ^{186m,g}Ir isomeric pair*

The yield ratio of the ^{186m,g}Ir isomeric pair was determined from the independent yield of ^{186g}Ir (the high spin state, $J^{\pi} = 5^{+}$) and that of ^{186m}Ir (the low spin state, $J^{\pi} = 2^{-}$). The activity of ^{186m}Ir was determined using the 767.46 keV (18.4%) γ-ray and that of the ^{186g}Ir was determined using the 434.84 keV (33.9%) γ-ray, respectively. The ^{186m}Ir was formed via the ^{197}Au$(\gamma, 9n2p)^{186m}$Ir reaction and the decay of radioactive nuclide ^{186}Pt ($T_{1/2} = 2.08$ h) by EC with a branching ratio of 100%, where the ^{186}Pt was formed via the ^{197}Au$(\gamma, 10n1p)^{186}$Pt reaction. The ^{186g}Ir was formed through two channels, from (1) the ^{197}Au$(\gamma, 9n2p)^{186g}$Ir reaction, and (2) the decay of the ^{186m}Ir with an IT coefficient of $P = 25\%$. Therefore, to obtain the independent yield of ^{186m}Ir and ^{186g}Ir residual nuclides, the contributions of radioactive precourse must be subtracted. The subtraction can be done in the same way as in our previous work [7,31]. Accordingly, to subtract ^{186}Pt activity, we need to measure its activity. Fortunately, the activity of ^{186}Pt can be measured with the 689.4 keV (70%) γ-ray, which is suitable for accurate measurements because it is well separated and has a relatively high intensity. After obtaining the independent activities, the yield ratio for the high to low spin states of the ^{186m,g}Ir isomeric pair was determined based on Eq. (6) to be $(4.51 \pm 0.59)10^{-2}$.

III.3.3. *Yield ratio for the ^{183m,g}Os isomeric pair*

The activity of the isomeric state ^{183m}Os (low spin state, $J^{\pi} = 1/2^{-}$) was measured using the 1101.94 keV (49.0%) γ-ray and that of the ground state ^{183g}Os (high spin state, $J^{\pi} = 9/2^{+}$) was measured using the 381.74 keV (91.6%) γ-ray. However, the ^{183}Ir radionuclide ($T_{1/2} = 58$ min) formed in the ^{197}Au$(\gamma, xnyp)$ reaction with a threshold energy of 102.41 MeV decays to ^{183m}Os ($T_{1/2} = 9.9$ h) with an EC decay coefficient of 100%. Therefore, to obtain the independent activity of ^{183m}Os and ^{183g}Os, the contribution of ^{183}Ir had to be subtracted. The subtraction can be done in the same way as in Refs. [7, 31]. The activity of ^{183}Ir can be measured with the γ-ray of 392.5 keV (9.8%). Fortunately, the 392.5 keV (9.8%) γ-ray is suitable for measurement because it is free from interference. Knowing that, the half-life of ^{183}Ir is relatively short compared to number of radionuclides, which are also formed in the ^{197}Au$(\gamma, xnyp)$ reactions. Therefore, activity measurements for ^{183}Ir should begin shortly after the end of irradiation. After activity measurement and making correction, the yield ratio for the high to low spin states of the ^{183m}Os isomeric pair was determined based on Eq. (6) to be $(5.66 \pm 0.75)10^{-1}$.

IV. RESULTS AND DISCUSSION

The experimental yield ratios for the isomeric pairs ^{196m,g}Au, ^{186m,g}Ir and ^{183m,g}Os produced via ^{197}Au$(\gamma, xnyp)$ reactions with 2.5 GeV bremsstrahlung endpoint energy are summarized in Table 2 along with the possible reference data. The uncertainties in the determination of isomeric yield ratios were estimated based on the uncertainties associated with the counting statistics ($\sim$ 2–4%), half-life of nuclear isomers ($\sim$ 4–5%), detector efficiency ($\sim$ 3–4%), photo-peak analysis ($\sim$ 4–5%), γ-ray intensity ($\sim$ 3–6%), bremsstrahlung flux fluctuation ($\sim$ 6–7%) and other errors (4–5%). The total uncertainties of the isomeric yield ratios were estimated at 10-14%.

As can be seen in Table 2, the present result for the ^{196m,g}Au isomeric pair agrees with the previously measured results [25, 26] within error limits. However, experimental data for the

^{186m,g}Ir and ^{183m,g}Os isomeric pairs are not available in the literature for comparison with the current results. Moreover, there is no theoretical data to compare with our results, probably because current nuclear codes such as TALYS and EMPIRE are only suitable for simulating nuclear reactions in the energy range up to several hundred MeV. Therefore, instead of a comparison, we analyze the relationship between isomeric yield ratios and associated nuclear parameters.

Table 2. Isomeric yield ratios of the ^{196m,g}Au, ^{186m,g}Ir, and ^{183m,g}Os isomeric pairs produced via ^{197}Au$(\gamma,xnyp)$ spallation reactions with a bremsstrahlung end-point energy of 2.5 GeV.

Isomeric pair	Emitted nucleons	J_{high}	$\lvert J_{high}-J_{target}\rvert$	Isomeric yield ratio (Y_h/Y_l)	
(1)	(2)	(3)	(4)	(5) Present result	(6) Reference
^{196m,g}Au	1	12^-	21/2	$(1.01\pm0.12)10^{-3}$	$(0.927\pm0.083)10^{-3}$ [25,26]
^{186m,g}Ir	11	5^+	7/2	$(4.51\pm0.59)10^{-2}$	–
^{183m,g}Os	14	$9/2^+$	6/2	$(5.66\pm0.75)10^{-1}$	–

As is known, three pairs of isomers ^{196m,g}Au, ^{186m,g}Ir and ^{183m,g}Os are formed from the same ^{197}Au nucleus by releasing different numbers of nucleons (see the second column in Table 2). The yield ratio of the three isomeric pairs shows an increasing trend with the number of nucleons released from three corresponding nuclear reactions. The ^{196m,g}Au isomeric pair is produced via the ^{197}Au(γ,n) reaction by releasing a single nucleon and its isomeric yield ratio being the smallest of the three values. On the other hand, the yield ratio for the ^{186m,g}Ir isomeric pair produced through the ^{197}Au$(\gamma,9n2p)^{186m,g}$Ir reaction by releasing 11 nucleons is higher than that of ^{196m,g}Au isomeric pair, but lower than the yield ratio for the ^{183m,g}Os isomeric pair, which is produced via the ^{197}Au$(\gamma,11n3p)^{183m}$Os reaction by releasing 14 nucleons. The relationship between the isomeric yield ratio and the number of nucleons emitted by the respective reactions discussed here is somewhat similar to the trend found in our previous research work [20].

We suggest that at high energy the ^{197}Au$(\gamma,n)^{196m,g}$Au reaction occurs mainly via the direct mechanism, so that most of the energy and momentum of the incident bremsstrahlung is carried away by the emitting neutron and only a small part is transferred to the target nuclide. As a result, the high spin state population of the ^{196m,g}Au isomeric pair is strongly suppressed, resulting in the low Y_h/Y_l value. Another interesting aspect worth considering is the relationship between the Y_h/Y_l ratio and the value of the high spin isomers. As seen in the first and third columns of Table 2, the high spin values of the three isomeric pairs ^{196m,g}Au, ^{186m,g}Ir and ^{183m,g}Os are 12^-, 5^+ and $9/2^+$, respectively. The yield ratios of the three isomeric pairs ^{196m,g}Au, ^{186m,g}Ir and ^{183m,g}Os showed a decreasing trend with increasing value of the high spin state.

Finally, we consider the relationship between the Y_h/Y_l ratio of the ^{196m,g}Au, ^{186m,g}Ir and ^{183m,g}Os isomeric pairs and the spin difference between the value of high-spin isomer and that of the target nuclide, $|J_{high}-J_{target}|$. As seen in the fourth column of Table 2, the $|J_{high}-J_{target}|$ values are 21/2, 7/2, and 6/2, corresponding to the isomeric pairs ^{196m,g}Au, ^{186m,g}Ir and ^{183m,g}Os. It is suggested that the Y_h/Y_l ratio favors low values of $|J_{high}-J_{target}|$, or in other words for a pair of isomers whose high spin state value is closer to that of the target nuclide.

V. SUMMARY AND CONCLUSION

Three isomeric pairs of ^{196m,g}Au, ^{186m,g}Ir and ^{183m,g}Os produced in ^{197}Au$(\gamma,xnyp)$ reactions with a bremsstrahlung endpoint energy of 2.5 GeV were identified and their yield ratios were measured based on the method of induced activity in combination with offline γ-spectroscopy. The current measured yield ratio for the ^{196m,g}Au isomeric pair agrees with previously measured results within error limits. The yield ratios of the two isomeric pairs ^{186m,g}Ir and ^{183m,g}Os are measured for the first time, so comparison with other measurements cannot be made. However, by analyzing the yield ratios obtained from the isomeric pairs ^{196m,g}Au, ^{186m,g}Ir and ^{183m,g}Os we can observe some trends between the Y_h/Y_l values and the associated nuclear parameters. The Y_h/Y_l values show an increasing trend with increasing number of nucleons emitted by ^{197}Au$(\gamma,xnyp)$ reactions. Moreover, the Y_h/Y_l values also show an increasing trend with decreasing values of high spin states, J_{high}, and with isomers having a high spin state value closer to that of the target nuclide. Current results on yield ratios of studied isomeric pairs formed on ^{197}Au$(\gamma,xnyp)$ reactions are useful in the analysis of reaction mechanisms and can help verify the nuclear model in the GeV energy range .

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