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学位論文要旨

Abstract

The yields of tungsten isotopes were measured for the reactions ^{181}Ta(γ, π^-xn)$^{181-x}$W for x = 3, 4, 5, 6, 7, 8 and 9 at bremsstrahlung maximum end-point energies, E_0 = 60 - 1100 MeV and for ^{181}Hf from the reaction ^{181}Ta(γ, π^+)^{181}Hf at E_0 = 60 - 1000 MeV with the aid of radiochemical separation followed by γ-ray spectrometry. The attention was focused on tungsten yield measurements in order to check the agreement of the yield values with the systematics obtained from previous studies. The results are discussed in terms of their variations with photon energy, the neutron multiplicity (x) and the neutron-to-proton ratio of the target, $(N/Z)_t$. The yields of tungsten for the ^{181}Ta(γ, π^-xn) reactions were found to agree with the systematics except for x = 4, which was lower by a factor of about 2. The present results were also compared with the results of the photon-induced cascade-evaporation calculations using the PICA code developed by Gabriel and Alsmiller.

1. Introduction

A target of ^{181}Ta is newly used here in our series of photopion reactions because of its monoisotopic nature and its position in the periodic table. It is also of interest to investigate whether the (γ,π^-xn) reaction yields of ^{181}Ta are similar to the other targets such as ^{175}Lu, ^{197}Au and ^{209}Bi interms of the (N/Z) ratio of the targets, which systematics was constructed in the previuos study. The main purpose of the present study is to determine the yields with x = 8 and x = 9. It is also important to determine the multiple x data for the (γ, π^-xn) reactions with x≧1 to investigate the even-odd effect. We report here on the yields for the ^{181}Ta(γ, π^-xn)$^{181-x}$W (x = 3 - 9) reactions and the data are compared with the $(N/Z)_t$ -systematics [3]. The yields of the ^{181}Ta(γ, π^+)^{181}Hf reaction are also measured in this work and are compared with the values reported by Oura [5] in order to check A_t -independence of the (γ, π^+)

reaction. The present experimental results have also been compared with the results of theoretical calculations with the PICA code by Gabriel and Alsmiller [7].

2. Experimental

Commercial metallic Ta plates of high purity (99.95% up) were irradiated with bremsstrahlung beam from the 300 MeV electron linac of the Laboratory of Nuclear Science (LNS), Tohoku University and the 1.3 GeV electron Synchrotron of the Institute for Nuclear Study (INS), The University of Tokyo (now the High Energy Accelerator Research Organization, KEK, Japan). The γ-ray spectrometry of radionuclides of W and Hf was performed after their radiochemical separations from the matrix activity Ta target. In the yield calculation the photon intensity was monitored by $^{27}Al(\gamma, 2pn)^{24}Na$ reaction for $E_0 \geqq 100$ MeV. The photon flux was deduced to be 10^8 to 10^9 equivalent quanta per second (eq.q./s). The photon intensity was also determined from the $^{197}Au(\gamma, n)^{196}Au$ reaction for $E_0 \leqq 100$ MeV. The beam intensity ranged from 10^{11} to 10^{13} eq.q./s. Since the measurement of ^{173}W (x = 8) and ^{172}W (x = 9) yields are very significant for the present work, we developed a rapid radiochemical procedure to determine x= 8 and 9 product yields of the ^{181}Ta target for the first time. The chemical yield of tungsten was determined graviametrically as tungsten. For Hf, the yields were determined incomparison with the data by nondestructive gamma-ray spectrometry.

3. Results and Discussion

A. Yield Curves

The relative yields are plotted for x = 8 and 9 as closed squares in Figs. 2a and 2b. We have drawn E_0-dependent yield curves of x = 8 as well as x = 9 for the first time on the targets of a

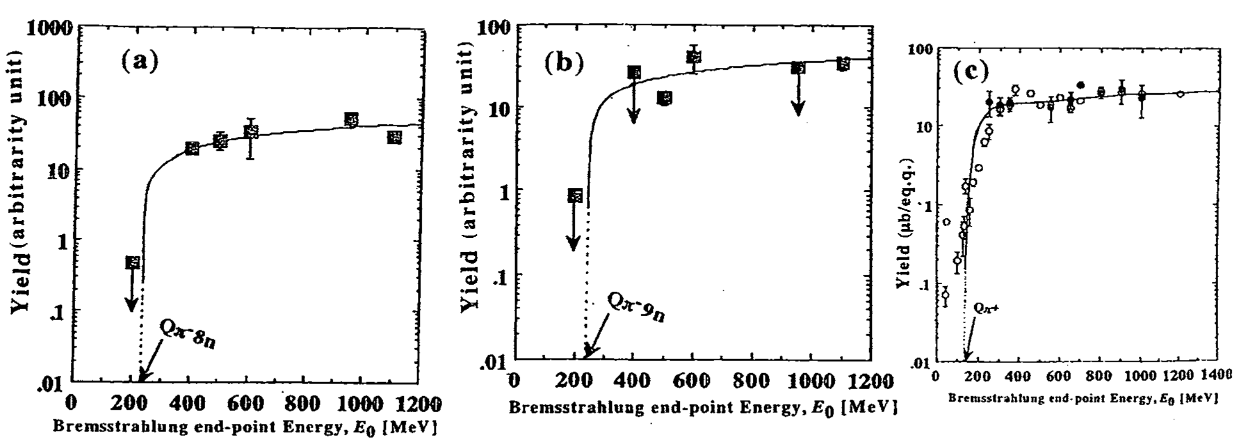


Fig. 1. Observed yields of W and Hf isotopes from ^{181}Ta as a function of maximum end-point energy. (a) - (b): Closed squares indicate observed the relative W yields. (c): Closed and open circles represent the present and previous (Ref.5) data for ^{181}Hf. Curves are drawn to guide the eye. Arrows on the E_0-axes show the Q-values for the relevant photopion reactions.

wide range of mass number. On the E_0-dependent yield curves, it was observed that the relative yields for ^{173}W (x = 8) and ^{172}W (x = 9) are almost similar to the absolute yield curves [6]. In the present work, radiochemical separation of Hf from Ta was performed by solvent extarction to measure the radioactivity of ^{181}Hf. From the comparison between the present and the previous data, it is described that the present yields of the $^{181}Ta(\gamma, \pi^+)^{181}Hf$ reaction are in good agreement with the previous results which demonstrated the A_t-independence in the (γ, π^+) reaction.

B. Mass Yield Curves

The yields of $^{181-x}W$ from ^{181}Ta $(\gamma, \pi^- xn)$ reactions plotted against the number of emitted neutrons (x) at 400 MeV are compared with the systematics yields [3] and the yields calculated by Gabriel and Alsmiller [7] using the PICA code on the photon-induced cascade-evaporation. The calculated values for the $(\gamma, \pi^- xn)$ reactions for $x \geqq 1$ show an even-odd effect for products ; higher for the even mass (odd x) than for the odd mass (even x). The zig-zag feature is more evident at lower E_0 [1 - 3]. However, any even-odd variation is not seen in the experimental results.The calculated yields for x = 3 are comparable with the experimental values within the limits of errors. However, for x = 4, 5, 6, and 7 at E_0 = 400 MeV the values are higher by a factor of 1 - 4 than the experimental values. The yield for x = 4 was found to be lower by a factor of about 2 than the predicted systematics. One of the possible reasons of the descrepancy may be the odd-even effect. The emission probability of γ-rays of ^{177}W (x = 4) could be suspected for its complexity of nuclear decay diagram.

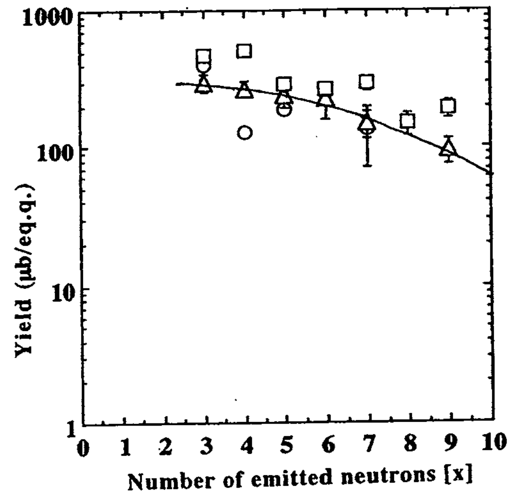
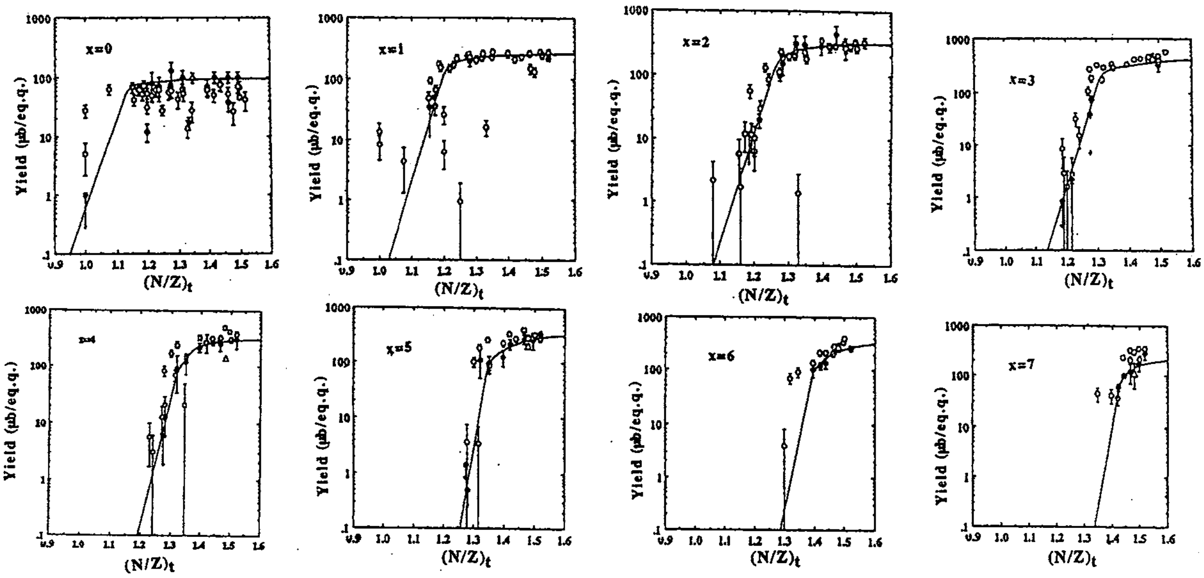


Fig. 2. Measured and calculated (PICA code) mass yield curves for the $^{181}Ta(\gamma, \pi^- xn)^{181-x}W$ (x = 3 , 4, 5, 6, and 7) reactions at E_0 = 400 MeV. The present data and the predicted yield from systematics are represented by open circles and open triangles, respectively. Open squares are from the PICA prediction.

C. $(N/Z)_t$-dependence of mass yield curves:

In order to observe target-dependence of yields for the (γ, π^-xn) reactions (x = 0 - 7), the yields at 400 MeV are plotted with the systematics yields and the yields calculated by the PICA code against $(N/Z)_t$ in Fig. 3. The yields change systematically with respect to *x* and $(N/Z)_t$. Both the observed and calculated yields for the individual reactions begin at a certain value of $(N/Z)_t$, increase rapidly with an increasing $(N/Z)_t$ and reach a plateau at 400 MeV. The present yields at 400 MeV for ^{181}Ta(γ, π^-xn)$^{181-x}$W (x = 3, 5, 6, 7) reactions are almost consistent with the $(N/Z)_t$-systematics. But the yield for the ^{181}Ta(γ, π^-xn)$^{181-x}$W (x= 4) reaction is lower by a factor of 2 than the $(N/Z)_t$-systematics. The lower observed yield for x = 4 implies that there is a high possibility of lowering of the γ-ray intensities of ^{177}W (115 keV) than the reported values. The PICA results underestimate the (γ, π^-) yields by 35% as noted previously, but overestimate the (γ, π^-xn) reaction yields for x≧3 by factors of 1.5 - 2.0.



● Systematics [3]
△ Present results
○ PICA calculations [7]

Fig. 3. Variations of the (γ, π^-xn) reaction yields with $(N/Z)_t$ for x = 0 - 7 at E_0 = 400 MeV. Open triangles indicate the present data together with the experimental yield values (closed circles) for various targets in the reference [3]. The PICA calculation results are shown by open circles.

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学位論文審査結果の要旨

本提出論文について，各審査委員において参考論文等も含めて個別に審査した後，審査員全員が集まって提出者に対する詳細な予聴・質疑を行った上で協議を行った。次いで，8 月 12 日に公開口頭発表会を開催し，その後審査員全員が集まって最終協議を行い，以下の判定に至った。

本論文提出者は，光核反応で生成する核種の生成収率の系統性を放射化学的手法によって研究してきたグループに所属して，ターゲットからの生成物の化学分離が容易でなく研究が遅れていたタンタル (Ta) をターゲットする系について，それまでの系統性研究の空白を埋めるための研究を行った。本論文では，とくに ^{181}Ta（γ，π^-xn）$^{181-x}$W 反応（x=3，4，5，6，7，8，9）と ^{181}Ta（γ，π^+）^{181}Hf 反応について，それらの反応による生成核の収率を光量子の最大エネルギー60～1100MeV の範囲（75～350MeV のステップ）で調べ，既報の結果及び光子誘導核内カスケード蒸発モデルによる計算（PICA）と比較しながら，核反応収率と光量子最大エネルギー・放出中性子数（x）・ターゲット核の‘中性子数／陽子数’比との関係で系統性について重点的に論じている。本研究の新規性は，核反応ターゲットとして比較的多量（約 5g）の金属 Ta を用いて，そこから核反応で生成した極微量（放射能も微弱）のタングステン（W）同位体とハフニウム（Hf）同位体を化学分離して定量することに成功した点にある。本研究で得られたデータは，結果的には従来の研究から導かれた系統性に合うものであることが分かり，また以前から未解明である PICA 計算との不一致の問題は本研究においても同様に認められて，系統性研究としての新規性は少ない。しかし本研究の結果は，将来的に光核反応の反応機構の解明を進める上で，未確認部分を実験的に明らかにしたことに意義があり，よって本論文は，博士（学術）の学位を授与するに値すると判定した。