Reliability of prompt γ-ray intensities for the measurement of neutron capture cross sections.

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We verified a new measuring method of cross sections for the thermal neutron capture detecting prompt γ-rays (the prompt-γ method). There was a tendency for measured cross section values by using the prompt-γ method to be smaller than those by using the activation method. The ratios, of measured cross section values by the prompt-γ method to those by used the activation method, are lower systematically from 1.0 ($\sigma_{prompt}=\sigma_{decay}$). It is considered the disagreement is caused by inaccuracy of the emission probabilities of prompt γ-rays. Because precision of emission probabilities is not enough, the new method cannot determine cross sections within 10%. It is necessary to measure precise emission probabilities of prompt γ-rays in (n, γ) reactions when we use the method.

1. Introduction

Cross sections for the neutron capture of long-lived fission products are needed for a nuclear transmutation technology. When we want to determine the cross sections, we utilize the activation method [1]. This method uses γ-rays following β-decay. If produced nuclei have too long half-lives or are stable, the utilization of the activation method is difficult or impossible. A measuring method by detecting prompt γ-rays (the prompt-γ method) is expected to solve this problem. The method doesn't depend on half-lives.

It is considered that the comparison of the prompt-γ method with the activation method, which has reliable actual results, can verify the new method. Therefore we measured the cross sections by using the prompt- γ method and the activation method. Then, these two measured cross section values were compared.

2. Experiment

Thermal neutron irradiations were carried out by the supermirror neutron guide tube (neutron flux 5×10^7 n/cm^2·s) at the Kyoto University Reactor [2]. Used detectors were 22, 38 and 90% HPGe detectors and a 90% GAMMA-X HPGe detector. The distance from a sample to the detector was 5 cm. Target nuclides were ^{23}Na, ^{27}Al, ^{51}V, ^{55}Mn, ^{64}Ni, ^{65}Cu, ^{141}Pr, ^{186}W and ^{197}Au. (Table 1) Measured reactions were selected by following five points; (1)Induced activities for the neutron capture have short half-lives enough to measure efficiently. (2)The emission probability of that γ-ray is large. (3)The cross section for the neutron capture is large, 0.2 to 1 b. (4)Abundance of the isotope of interest is large. Those points are important for an efficient measurement of cross section. (5)Lists of prompt γ-rays from the (n, γ) reactions are well known.

The schematic view of measuring processes was shown in Fig. 1. When the sample was irradiated, first γ-ray measurement was carried out simultaneously. The measurement was detecting prompt and β-decay γ-rays. Then, the irradiation stopped and the second measurement was carried out. The measurement was only detecting β-decay γ-rays. A box and plates made of a lithium fluoride (^{6}LiF) were used for shielding from neutrons. (Fig. 2) Because of those shields, the neutrons were activated surrounding materials including the detectors. A shutter made of a lithium fluoride stopped the irradiation. (Fig. 3) During no irradiation, leak of neutrons was smaller than 0.6%. (Fig. 4)

3. Results

For nine reactions, ratios of measured cross section values by the prompt-γ method to those by used the activation method were evaluated. The ratio is

$$Ratio = \frac{\sigma_{prompt}}{\sigma_{decay}} = \frac{Count_{prompt} \Big/ I_{prompt} \cdot \varepsilon_{prompt}}{Count_{decay} \Big/ I_{decay} \cdot \varepsilon_{decay}}$$

σ is measured values of cross sections. I is an emission probability. The emission probabilities are taken from ref. [3-8]. ε is efficiency of a γ-ray of interest. A subscript shows a measuring method. It is clearly seen that the ratios are lower systematically than 1.0 ($\sigma_{prompt}=\sigma_{decay}$) in Fig. 5. The ratios of ^{65}Cu and ^{186}W are -10% and –25% away from the others, respectively. Those of the other seven reactions were in agreement within 5%. Additionally, the ratios are scattered. It is considered the disagreement of the results is caused inaccuracy of the each emission probability of prompt γ-rays. Because their values are published for nuclear structure studies, it is thought that each value of them was not desired high accuracy.

4. Conclusion

We have concluded that the prompt-γ method cannot determine (n, γ) cross section within 10% because precise emission probabilities are not well known at present. Additionally, using more precise emission probabilities of γ-rays following β-decay, those of prompt γ-rays can be determined.

Using the prompt-γ method, we will determine the cross section of ^{104}Pd(n, γ) reaction which cannot be measured by using the activation method. We are going to construct the precise level scheme of ^{104}Pd(n, γ)^{105}Pd. We will gain the emission probabilities of the prompt γ-rays by balancing intensity of γ-rays at each level.

Acknowledgements

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Table 1 List of reactions and samples

Reaction	Abundance	Chemical form	$T_{1/2}$	E_γ (Decay)	I_γ
$^{23}Na(n, \gamma)^{24}Na$	100	NaF	14.95h	1368.6	1
$^{27}Al(n, \gamma)^{28}Al$	100	Al	2.241min	1779.0	1
$^{51}V(n, \gamma)^{52}V$	99.8	V_2O_5	3.743min	1434.1	1
$^{55}Mn(n, \gamma)^{56}Mn$	100	Mn	2.578h	846.8	0.9887
$^{64}Ni(n, \gamma)^{65}Ni$	97.9(SI)	Ni	2.517h	1481.8	1
$^{65}Cu(n, \gamma)^{66}Cu$	99.6(SI)	CuO	5.088min	1039.3	1
$^{141}Pr(n, \gamma)^{142}Pr$	100	Pr_6O_{11}	19.12h	1575.9	0.037
$^{186}W(n, \gamma)^{187}W$	97.5(SI)	WO_3	23.72h	479.5	0.218
$^{197}Au(n, \gamma)^{198}Au$	100	Au	2.695d	411.8	0.9558

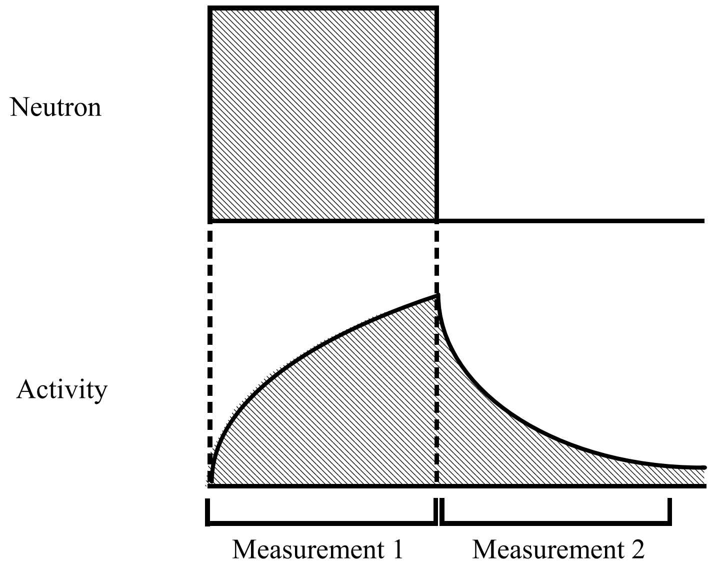

Fig. 1 The schematic view of the measuring process. "Measurement 1" was detecting prompt γ-rays including decay γ-rays. "Measurement 2" was detecting only decay γ-rays.

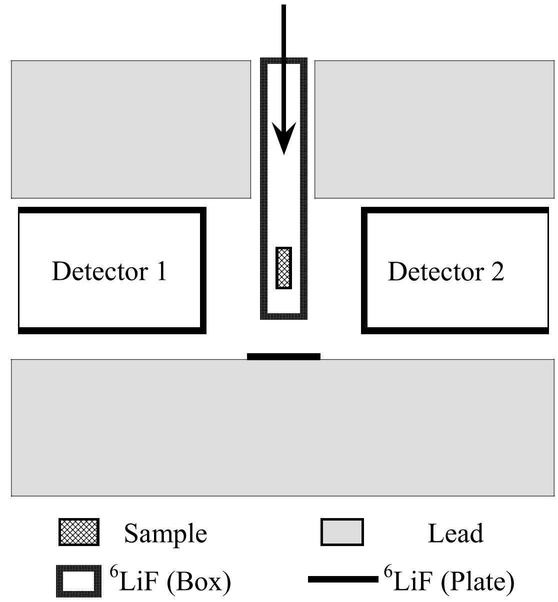

Fig. 2 The schematic view of the present experiment arrangement. The combination of “Detector 1” and “Detector 2” were 22% and 38% HPGe, or 90% HPGe and 90% GAMMA-X HPGe. Distance from sample to each detector was 5 cm.

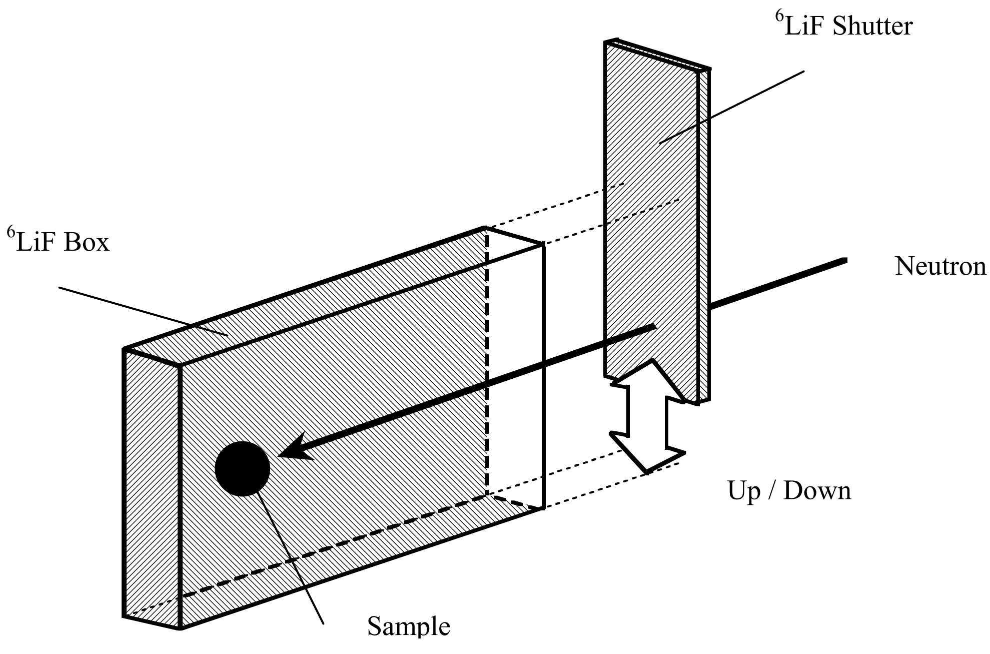

Fig. 3 The schematic view of the beam shutter and the target Box. The shutter moving down made the irradiation stop.

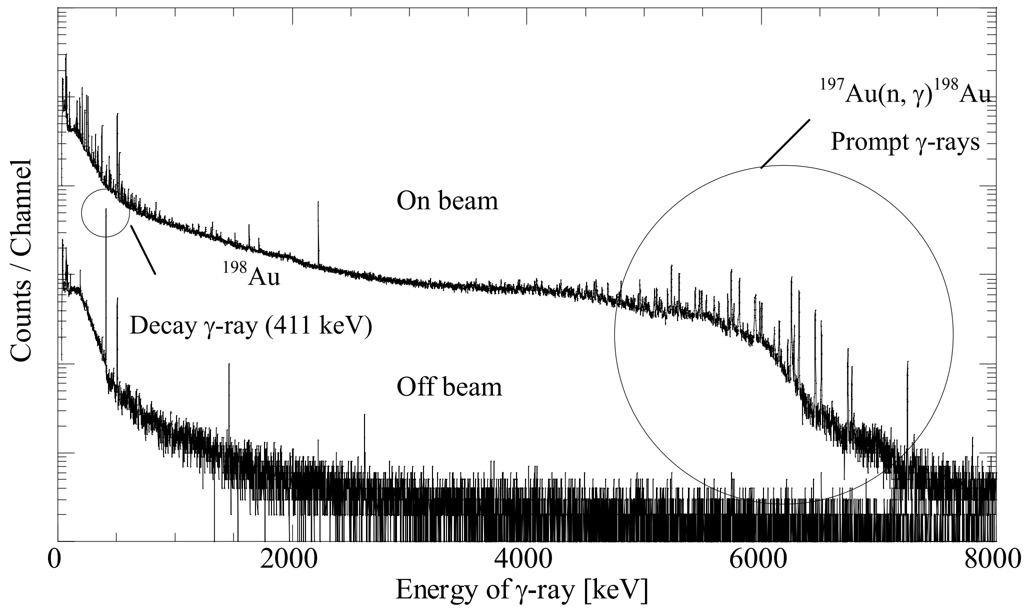

Fig. 4 Spectra for capture of thermal neutron in ^{197}Au. "On beam" and "Off beam" were switched by using a shutter made of ^{6}LiF. It is clearly seen that the γ-rays from the ^{197}Au(n, γ)^{198}Au reaction can be observed at "On beam" and cannot at "Off beam". It is considered that effects of the leaking neutrons are <0.6% at "Off beam".

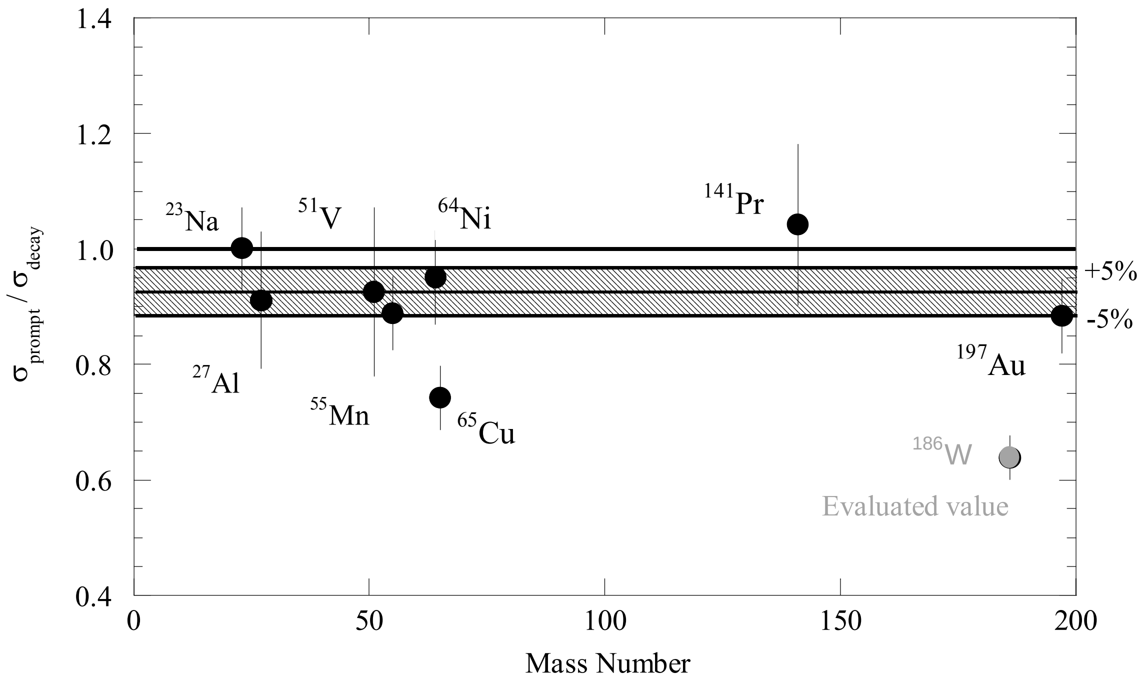

Fig. 5 The ratio of σ used prompt γ-rays to σ used β-decay γ-rays. Used detector was the 22% HPGe detector. It is clearly seen that the ratios are lower systematically than 1.0 ($\sigma_{prompt}=\sigma_{decay}$). The plot of ^{186}W are differentiated from the others because the values of emission probabilities of ^{186}W(n, γ)^{187}W is evaluated values.