CAPTURE CROSS SECTION MEASUREMENTS OF ^{161}Dy, ^{162}Dy, ^{163}Dy, AND ^{164}Dy IN THE NEUTRON ENERGY REGION BETWEEN 10 AND 90 KEV

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ABSTRACT

The neutron capture cross sections of Dy isotopes (^{161}Dy, ^{162}Dy, ^{163}Dy, and ^{164}Dy) have been measured in the neutron energy region of 10 to 90 keV using the 3-MV Pelletron accelerator of the Research Laboratory for Nuclear Reactors at the Tokyo Institute of Technology. Pulsed keV neutrons were produced from the ^{7}Li(p,n)^{7}Be reaction by bombarding the lithium target with the 1.5-ns bunched proton beam from the Pelletron accelerator. The incident neutron spectrum on a capture sample was measured by means of a TOF method with a ^{6}Li-glass detector. Capture γ-rays were detected with a large anti-Compton NaI(Tl) spectrometer, employing a TOF method. A pulse-height weighting technique was applied to observed capture γ-ray pulse-height spectra to derive capture yields. The capture cross sections were obtained by using the standard capture cross sections of ^{197}Au. The present results were compared with the previous measurements and the evaluated values of ENDF/B-VI.

1. INTRODUCTION

Capture cross-sections in the keV-neutron energy region are important in the design of reactors as well as in the studies of the nuclear physics and astrophysics. The published experimental data are poor in both quality and quantity. One of the reasons is the difficulty of preparing pure enriched isotopes enough to perform keV-neutron capture cross-section measurement. An anti-Compton NaI(Tl) spectrometer[1] developed by the Research Laboratory for Nuclear Reactors at the Tokyo Institute of Technology (Titech) made this

measurement possible with a small amount of sample.
We have measured the capture cross-sections of Dy isotopes in the neutron energy region from 10 to 90 keV with the high efficient capture γ-ray spectrometer. Pulsed keV neutrons were produced from the $^{7}Li(p,n)^{7}Be$ reaction by bombarding a lithium target with the 1.5-ns bunched proton beam from the Pelletron accelerator. This is the first experiment to use metal foils instead of the dysprosium oxide (Dy_2O_3). Since dysprosium oxide powder is generally hygroscopic, the effect of the water on the sample in the previous measurements was taken into account in the analysis of experimental data. We have compared the present results with the previous ones and the evaluated values of ENDF/B-VI.

2. EXPERIMENT

The neutron capture cross sections of the enriched dysprosium isotopes have been measured in the energy range from 10 to 90 keV using gold as a standard. Since the experimental method has been published previously[2,3], only a general description is given here. Pulsed keV-neutrons were produced via $^{7}Li(p,n)^{7}Be$ reaction by bombarding metallic lithium target with the 1.5 ns bunched proton beam from the 3-MV Pelletron accelerator in Titech. The lithium target was made by evaporating metallic lithium on a copper disk with a diameter of 3 cm and a thickness of 0.4 mm. The diameter of lithium layer was about 2 cm. The lithium target was cooled by water to prevent lithium from being scattered and lost. The temperature of lithium target has been kept less than 27˚C. The proton energy was set to 1.903 MeV, which is 22 keV above the threshold energy of the $^{7}Li(p,n)^{7}Be$ reaction. This yields continuous neutron spectra in the energy range from 2 to 90 keV emitted within about 50 degrees with respect to the proton beam direction. The pulse repetition rate was 4 MHz and the average proton beam current was about 9 □. The experimental arrangement, which is similar to the previous one[2,3], is shown in Figure 1.

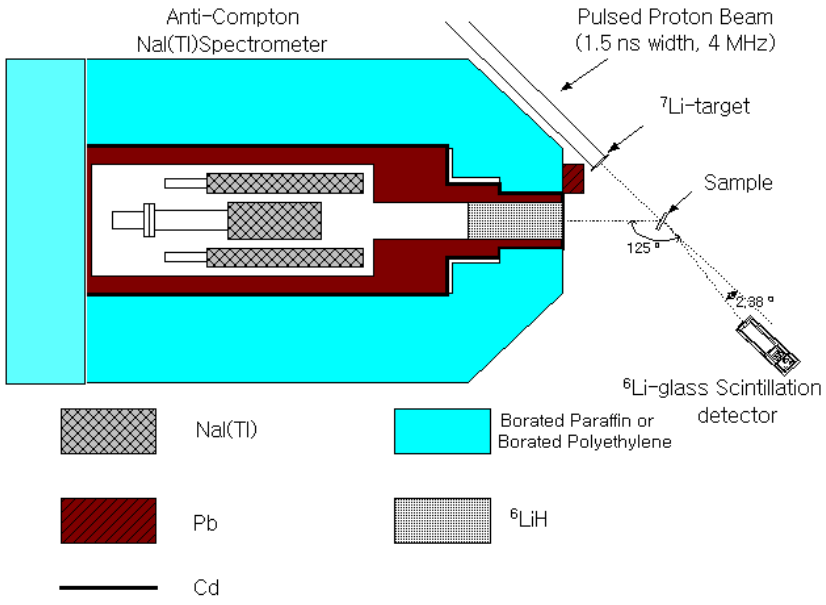

Figure 1. The experimental arrangement for cross section measurement

The dysprosium samples are enriched metallic disk of 20 mm or 15 mm in diameter and 0.2 mm in thickness. Two gold plates with 20 and 15 mm in diameter and 1.0 mm in thickness have been used as a standard. The characteristics of the samples are summarized in Table I. The capture sample was aligned at zero degree with respect to the proton beam direction. The distance between the lithium target and the sample was 12 cm.

Table I. Characteristics of samples

Sample	^{161}Dy	^{162}Dy	^{163}Dy	^{164}Dy	^{197}Au	
Weight (g)	0.536	0.310	0.556	0.327	6.014	3.427
Chemical purity (%)	100	100	100	100	99.99	99.99
Isotopic composition (%)						
^{156}Dy	<0.02	<0.01	<0.01	<0.01		
^{158}Dy	<0.02	<0.01	<0.01	<0.01		
^{160}Dy	0.35	0.08	0.03	0.02		
^{161}Dy	95.66	1.24	0.36	0.15		
^{162}Dy	2.53	96.17	1.23	0.35		
^{163}Dy	0.90	1.79	96.86	1.03		
^{164}Dy	0.56	0.72	1.52	98.45		
Thickness (mm)	0.2	0.2	0.2	0.2	0.98	1.01
Diameter (mm)	20.0	15.0	20.0	15.0	20.10	14.95

The incident neutron spectrum on the capture sample was measured by means of the TOF method with a ^{6}Li-glass scintillation detector. A 5.0 mm diameter and 5.0 mm thick ^{6}Li-glass scintillator mounted on the 12.7 mm diameter photomultiplier was located at 30.0 cm from the lithium target and at 2.4 degrees with respect to the proton beam direction. The applied high voltage for the photomultiplier was 1 kV. The anode output was used as the timing signal for the neutron TOF spectrum, while the dynode output was used as the pulse height signal for the n-γ discrimination. The stop signal for the TOF analysis with a time-to-amplitude converter (TAC) was taken from a time pick-off unit at about 2 m upstream from the lithium target. The neutron TOF spectrum was stored into a personal computer.

The γ-rays emitted from the sample were detected by a large anti-Compton NaI(Tl) spectrometer located at 86.0 cm from the sample with an angle of 125 degrees with respect to the proton beam direction. The distance between the face of NaI(Tl) spectrometer and the sample was 86.0 cm. The main detector of the spectrometer was made by a 15.2 cm diameter and 20.3 cm long NaI(Tl) scintillator, and was located in the center of a 33.0 cm outer diameter and 35.6 cm long NaI(Tl) detector. A ^{6}LiH shield that absorbed effectively the neutrons scattered by the sample was added in the collimator of the spectrometer shield [4]. The pulse height signals of main detector were taken from the 12th dynode of photomultiplier, while the timing signals were taken from the anode. The stop signal for a TAC was taken from the time pick-off unit. The pulse height signals of Compton-suppression detectors were obtained by summing up the anode outputs from ten photomultipliers, and a discriminator level was set to 30 keV. The high voltage for each of the ten photomultipliers was adjusted so as to generate the same pulse height outputs for an ^{241}Am source at the center of detector.

The runs with and without sample (sample run and blank run) and the run with standard gold

sample (gold run) were made cyclically in each measurement to average changes in experimental conditions such as the incident neutron spectrum. Since the measurements were carried out cyclically, systematic changes in experimental conditions could be corrected. The blank run was performed in order to determine the background, and also to monitor any changes in the incident neutron energy and the thickness of the ^{7}Li neutron-target. The three runs were normalized with the neutron counts of the ^{6}Li-glass detector. The total measuring times were about 31, 92, 32, and 132 hours for ^{161}Dy, ^{162}Dy, ^{163}Dy, and ^{164}Dy respectively.

3. DATA ANALYSIS

The detailed description of the data analysis was given in elsewhere[2,3], so a short summary is given in the present paper.
The incident neutron energy spectra on the sample were obtained from the ^{6}Li-glass detector by the neutron TOF method. The incident neutron energy spectrum for the blank run as an example is shown in Figure 2, where the incident neutron energy is in the laboratory system. The cut-off energy was set to 10 keV, because the signal-to-noise ratios of the corresponding TOF spectrum were not so good below 10 keV.

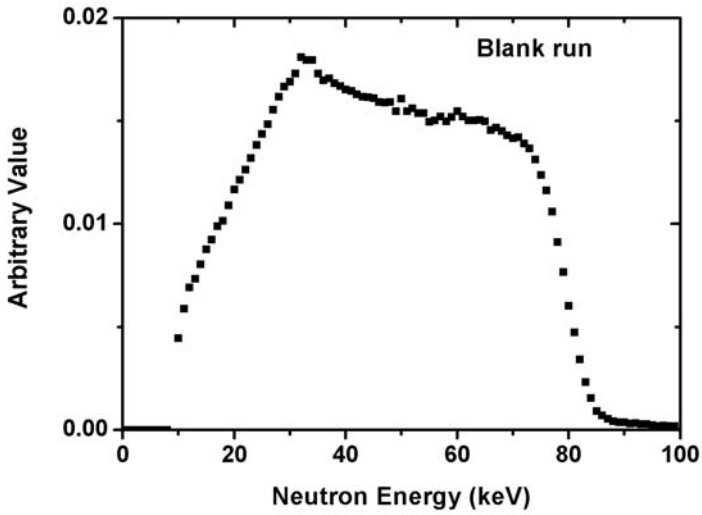

Figure 2. Incident neutron energy spectra for the blank run.

The observed TOF spectra with the γ-ray spectrometer for the (a) blank, (b) gold, and (c) ^{163}Dy sample runs are shown in Figure 3 as an example. The sharp and intense peak around 630 channel is due to the γ rays from the ^{7}Li(p, γ)^{8}Be reaction, and the bump below 500 channel is due to the neutron capture γ rays from the ^{163}Dy or ^{197}Au sample. In order to obtain foreground and background pulse height spectra, digital gates were set in the foreground and background regions of the TOF spectra measured for the sample, gold, and blank runs, as shown in Figure 3. The background level around 200 channels is identical to that around 900 channels within the statistical error. The background level in Figure 3 (a) is constant over the whole region except for the (p,γ) peak. Thus, the net capture γ-ray pulse height spectra were obtained by subtracting the background pulse height spectrum normalized with the ratio of gate widths from the foreground pulse height spectra. Figure 4 shows the net capture γ-ray PH spectrum of ^{163}Dy in the incident neutron energy region from 15 to 75 keV.

The horizontal axis in the figure was calibrated by using γ-rays from standard γ-ray sources and the background γ-rays from the $^{1}H(n, \gamma)^{2}H$ and $^{56}Fe(n, \gamma)^{57}Fe$ reactions by thermal neutrons.

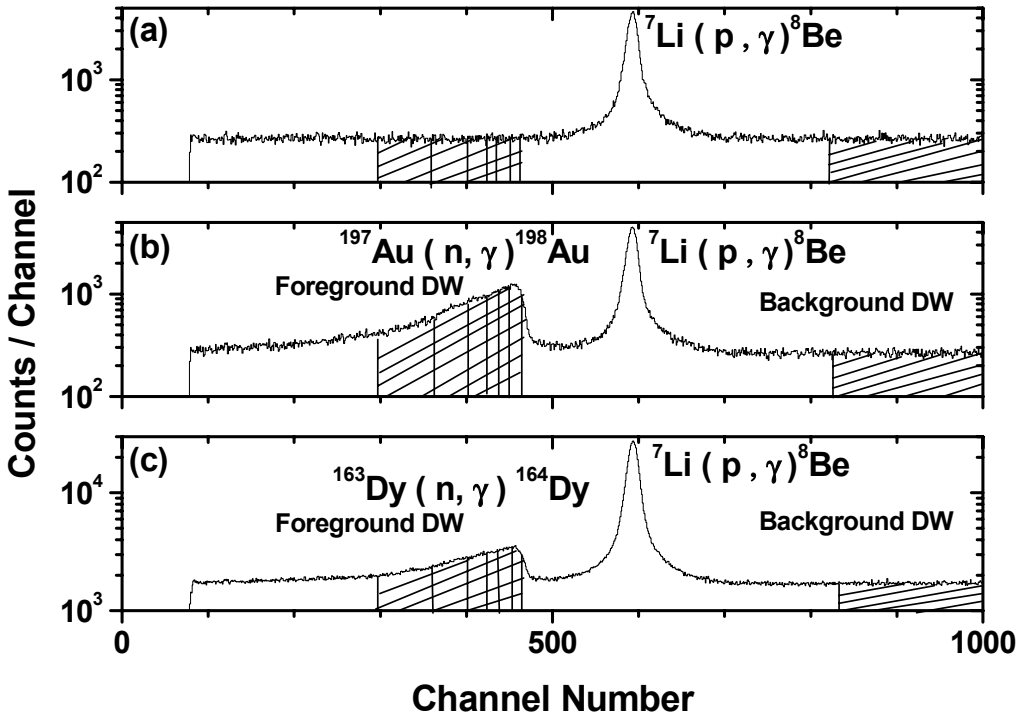

Figure 3. TOF spectra observed with γ-ray spectrometer for (a) blank, (b) gold, and (c) ^{163}Dy sample runs.

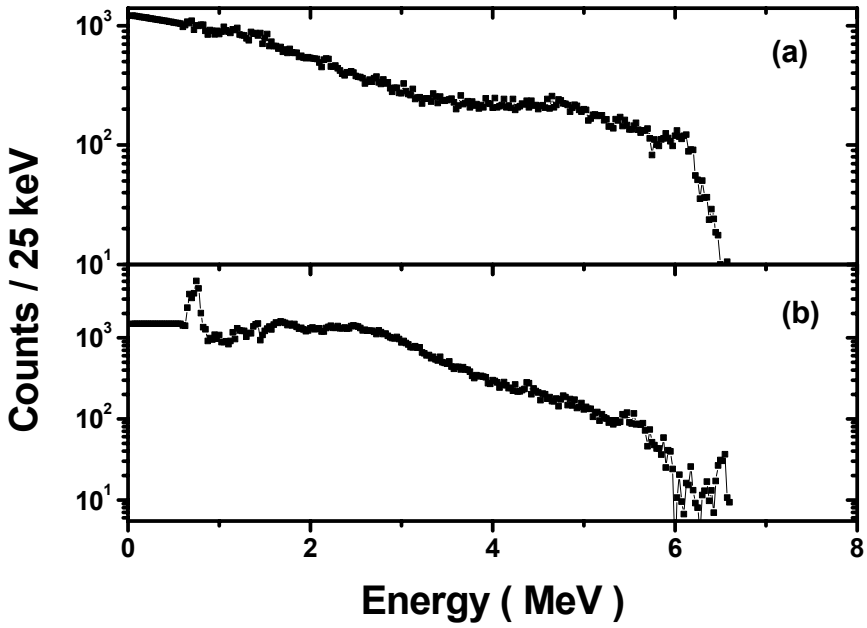

Figure 4. Observed capture γ-ray pulse height spectra of (a) ^{197}Au and (b) ^{163}Dy in the incident neutron energy region from 15 to 75 keV. The γ-ray energy bin width is 25 keV.

A pulse-height weighting technique with the weighting function of the γ-ray spectrometer[2,5] was applied to each of the net capture γ-ray pulse-height spectra and the capture yields, i.e., the number of capture events, of the Dy isotopes and ^{197}Au samples for each digital window (DW) were obtained. The number of incident neutrons for each DW of the Au run was derived from the corresponding capture yield and the averaged capture cross sections of ^{197}Au for the DW which was calculated from the evaluated values of ^{197}Au in ENDF/B-VI[6] and the incident neutron spectrum. Then, the number of incident neutrons for the corresponding DW of each sample was obtained by using the neutron monitor counts of the ^{6}Li-glass detector for the sample and Au runs. Finally, the average capture cross section of the sample for each DW was derived from the corresponding capture yield of the sample and the number of incident neutrons.

In addition to the statistical error (about 1-10 %), the following errors were taken into account for those of capture cross sections of Dy isotopes: the errors due to the number of target nuclei (<1%), the standard capture cross sections of ^{197}Au (3 %), the weighting function of the γ-ray spectrometer (1 %), the extrapolation of net capture γ-ray pulse-height spectrum below the discrimination level (0.6 MeV) in deriving the capture yield with the pulse-height weighting technique (2 %), and the estimation of correction factor (1-2 %).

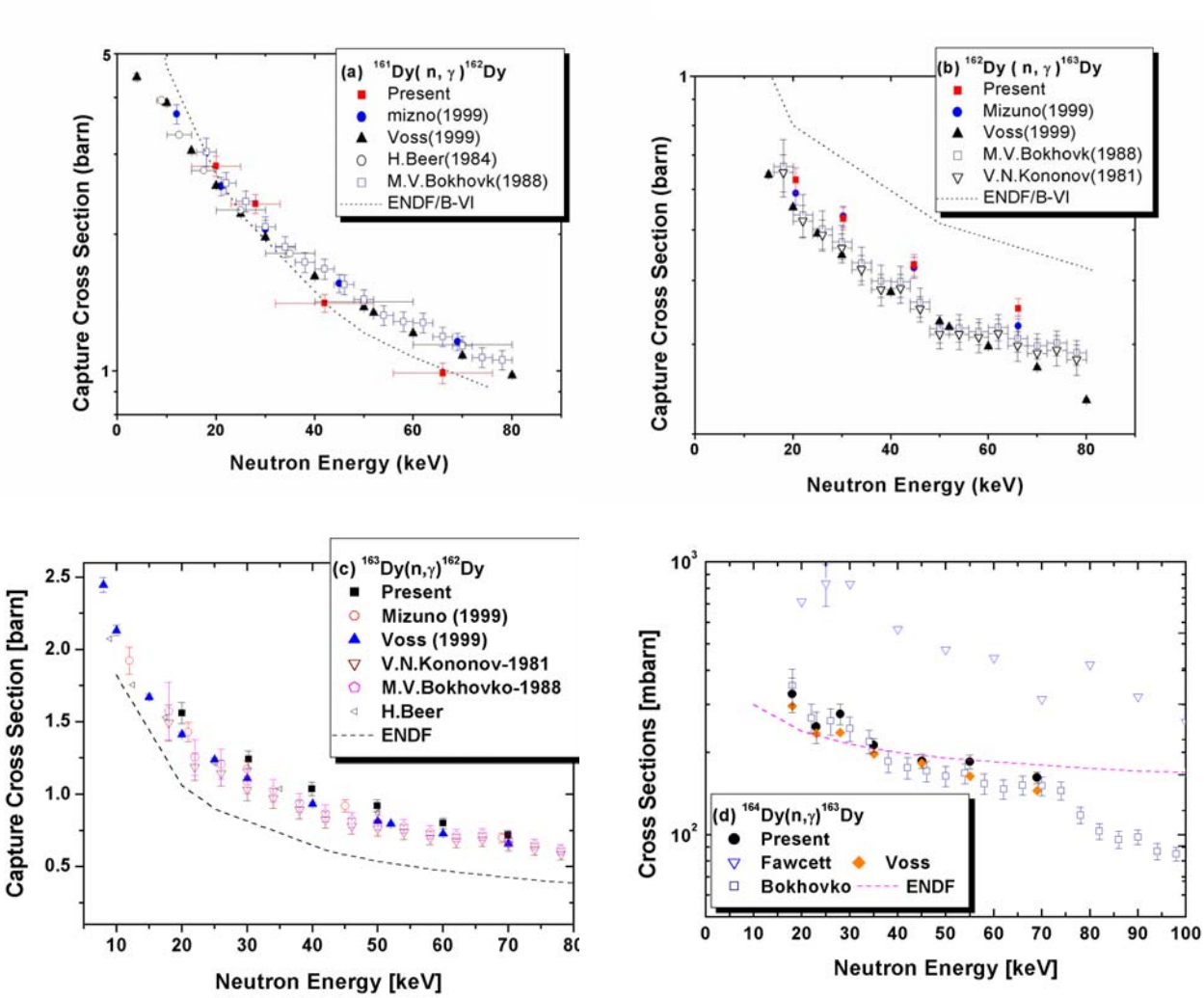

Figure 5. Neutron capture cross sections of (a) ^{161}Dy, (b) ^{162}Dy, (c) ^{163}Dy and (d) ^{164}Dy in the keV region.

4. RESULTS AND DISCUSSION

The capture cross sections of ^{161}Dy, ^{162}Dy, ^{163}Dy, and ^{164}Dy were measured with errors of about 5 - 12 % in the incident neutron energy region from 10 to 90 keV. The present results are shown in Figure 5 and compared with the previous measurements[2,7-13] and the evaluations of ENDF/B-VI[14].

The present measurement of ^{161}Dy is consistent with the previous measurements[2,7,8,9] in the neutron energy region below 40 keV, but considerably lower than the previous ones above 40 keV. However, the present values are in good agreement with the ENDF/B-VI[14] evaluations. For the capture cross section of ^{162}Dy, the present measurements are higher than other measurements[7,9,12] except for Mizuno *et al.*[2]. The ENDF/B-VI values[14] are higher than any other measurements as shown in Figure 5 (b). The present result of ^{163}Dy is a little bit higher than other measurements[7,10,11,12] except for Mizuno *et al*.[2]. However, both the present and the previous results are different from the evaluated values in the ENDF/B-VI[6]. In case of ^{164}Dy, the present results are in good agreement with both the previous measurements done by Voss *et al.*[7] and Bokhovko *et al.*[10] and the evaluated values in the ENDF/B-VI. However, the data measured by Fawcett *et al*.[13] were higher than any other results. Beer *et al.*[8] and Voss *et al.*[7] used the capture cross sections of ^{197}Au measured by Macklin. The value by Macklin is smaller by 3 - 5 % than ENDF/B-VI[6] used for the present study in the region from 10 to 90 keV.

5. CONCLUSIONS

The neutron capture cross sections of ^{161}Dy, ^{162}Dy, ^{163}Dy and ^{164}Dy have been measured with errors of about 5-12 % in the incident neutron energy region from 10 to 90 keV using an anti-Compton NaI(Tl) γ–ray spectrometer and a 1.5-ns pulsed neutron source generated by the ^{7}Li(p,n)^{7}Be reaction.

The present results are in good agreement with the previous measurements carried out by different experimental methods where they used dysprosium oxide powder instead of metal plate. There are some differences between the present measurements and the previous cross sections of ^{161}Dy in the neutron energy region above 40 keV. There are big differences between the experimental cross sections and the evaluated values of ENDF/B-VI in case of ^{162}Dy and ^{163}Dy.

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