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MEASUREMENT OF TOTAL NEUTRON CROSS SECTION FOR Sm, Gd AND Dy IN THE THERMAL ENERGY REGION

Kouichi Higurashi, Otohiko Aizawa and Tetsuo Matsumoto

Atomic Energy Research Laboratory
Musashi Institute of Technology
Ozenji 971, Asao-ku, Kawasaki, Japan

Hiroyuki Kadotani

Century Research Center Corporation
3-6-2 Nihonbashi, Hon-cho, Chuo-ku, Tokyo, Japan

Abstract: The method to measure total neutron cross sections in the thermal energy region was established with the chopper and time-of-flight facility installed at the Musashi reactor (TRIGA-II, 100kW). To date, the facility was used primarily for measuring samples which were essentially scatterers. The method successfully developed in this research was newly applied to samples having very large absorption cross section. Cross sections were measured for natural Sm, Gd and Dy by using the Al powder dilution method. Comparison of the measured cross sections with published data showed satisfactory agreement, but the results obtained for Sm and Gd at 0.0253 eV showed slightly lower values than the data published in BNL-325 3rd ed. The g-factors obtained by Westcott for these absorbers, however, were independently evaluated based on the result of this research, and found to be in good agreement with the published figures.

(total neutron cross section, time-of-flight, Westcott g-factor, natural Sm, Gd, Dy, dilution method)

Introduction

In the past, the chopper and time-of-flight (TOF) facility installed at the Musashi reactor has been successfully used to measure the total neutron cross section of several materials in the thermal energy region. The method of measurement was almost completely established for the samples having weak absorption cross section[1]. In the present paper, we conducted the measurement of total neutron cross section for samples having very strong absorption cross section.

The total neutron cross sections for elements with large absorption cross sections were conducted mostly before the 1970's, and are compiled in the famous BNL-325. Although the measured cross section values for Sm, Gd and Dy were well established, we conducted our own experiment to independently measure the total cross section of these elements. The reason was to expand the category of samples whose total cross sections can be measured with the Musashi facility. The measured cross sections were compared with those of the published data. As the g-factor of Westcott is still widely used to evaluate the reaction rate induced by the thermal neutron flux, we independently calculated the g-factors for these three elements.

Measurement of Total Neutron Cross Section with TOF Method

TOF Facility

The experiment was performed with the chopper and time-of-flight (TOF) facility of the Musashi reactor (TRIGA-II, 100kW). The cross-sectional view of the reactor and the facility arrangement are shown in Fig. 1. A Si-rod consisting of 30cm long nearly-perfect single crystal was used as a very effective thermal neutron bandpass filter. The neutron energy spectra of core and Si-filter beam are shown in Fig. 2.

The BN(boron-nitride) rotor of the chopper was 12cm in diameter and 12cm in height and had nine slits of 0.4cm × 7.0cm and was connected with a driving motor. In the present experiment the rotation frequency was 2,000rpm where the neutron burst width (FWHM) was 275μsec. The length of a neutron flight path was 6.77m with energy resolution of 18% for 0.0253eV neutrons. The neutron beam was collimated to 4cm in diameter. Three BF_3 counters were set at the end of flight path.

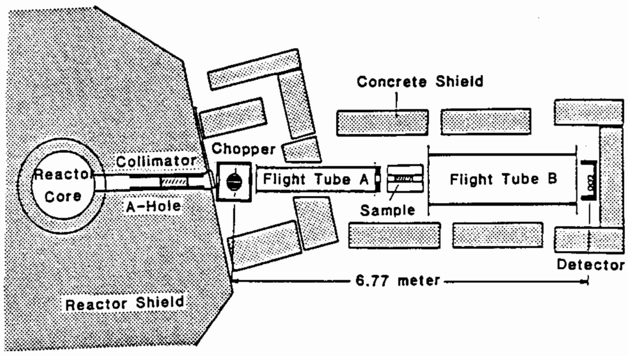

Fig. 1 Arrangement of TOF Facility

Preparation of Samples and Sample Holders

The measurement was performed for three samples: Sm, Gd and Dy. Samples of 99.9% purity Sm_2O_3, Gd_2O_3 and Dy_2O_3 were used. The oxide powder was diluted with Al metal powder of 99.98% purity. The sample holder was a cylinder type 64mm in dia. and 20mm thick, and made of Al. The diameter of the collimated neutron beam was 40mm. The homogeneity of the mixture of the oxide sample and Al powder was checked by the neutron radiography technique (see Fig. 3). The number density of the oxide sample was adjusted to obtain 20% transmission for 0.0253eV neutrons (see Table 1).

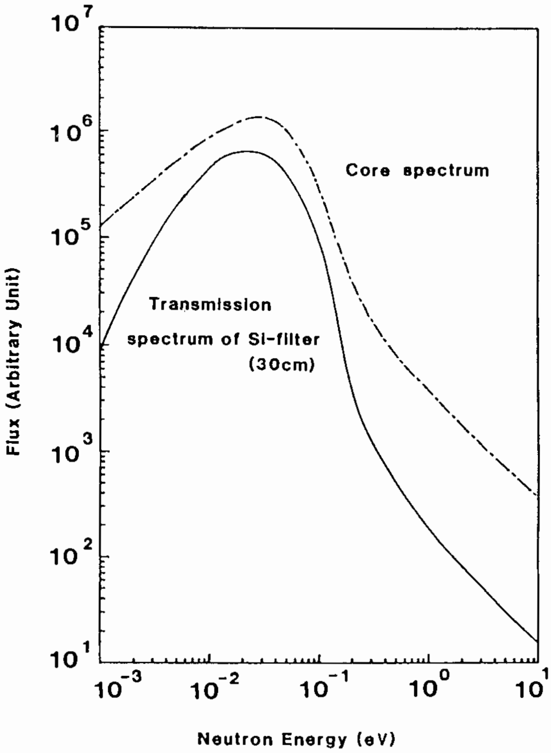

Fig. 2 Neutron Energy Spectra of Core and Si-filter Beam

Table 1. Samples

Chemical Form (powder)	Purity (%)	Number Density N ($barn^{-1}$ cm^{-1})	Transmission Rate (0.0253eV) (%)
Sm_2O_3	99.9	1.293×10^{-4}	20
Gd_2O_3	99.9	1.534×10^{-5}	20
Dy_2O_3	99.9	7.291×10^{-4}	20
Al	99.98	3.088×10^{-2}	90

Treatment of Data

Treatment of Data

Conceptual flow of data treatment is shown in Fig. 4. The total cross section can be obtained by dividing the open beam spectrum by the transmitted neutron spectrum:

$$\sigma(E) = \frac{1}{N\ d} \ln \frac{\phi_o(E)}{\phi_s(E)}$$

where N is the atomic number density of absorber, and d is the thickness of the sample. The transmitted neutron spectrum through the sample $\phi_s(E)$ was corrected by measuring time, the number of the chopper rotation, the monitored reactor power and the background neutron counts.

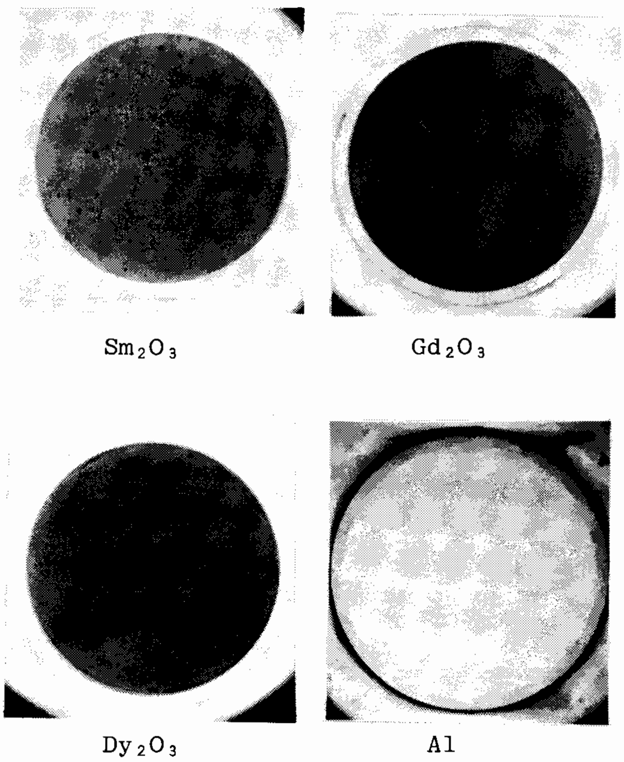

Fig. 3 Neutron Radiograph of Samples (Check of homogeneity)

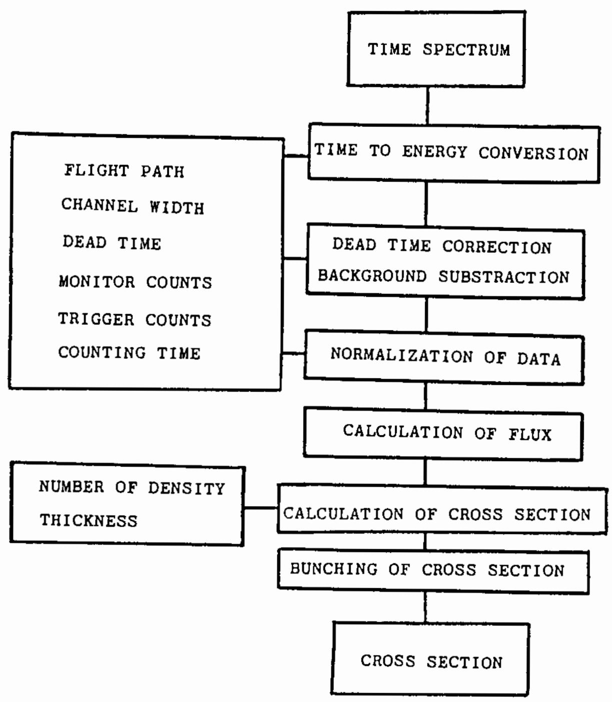

Fig. 4 Flow Chart of Data Treatment

The background was measured by covering the sample holder with a Cd plate of 1.3mm thickness. The time spectra of $\phi_s(E)$ and its background are shown in Fig. 5-1. In this figure Sm was used as the sample. The same correction procedure was applied to the neutron spectrum $\phi_o(E)$ through the sample holder containing only Al powder. The time spectra of neutrons of Al powder and its background are shown in Fig. 5-2.

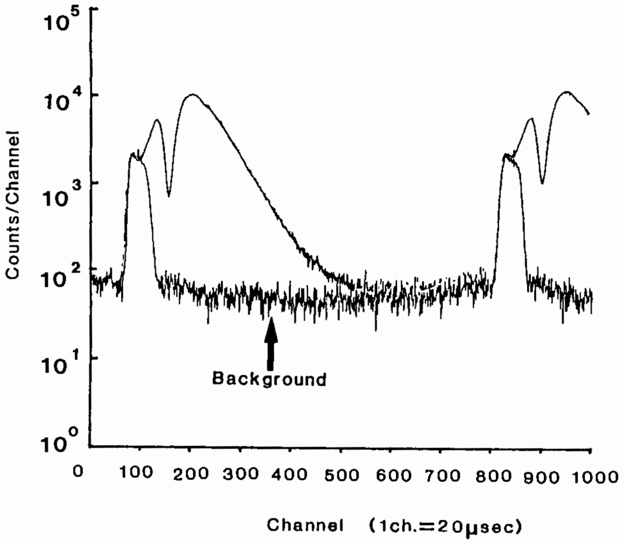

Fig. 5-1 Transmission Time Spectrum of Sm Sample

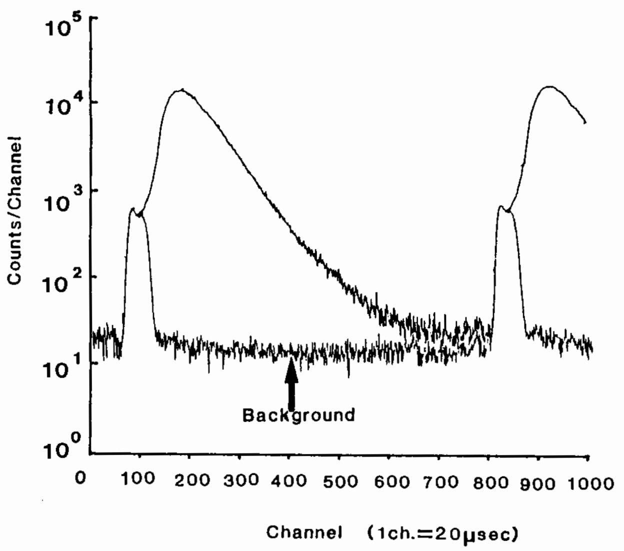

Fig. 5-2 Time Spectrum of Open Beam (Al Powder only)

Estimation of Error

The relation between the energy resolution and time resolution is:

$$\frac{\Delta E}{E} = 2 \times \frac{\Delta t}{t}$$

where E is the energy corresponding to the flight time t. In the present experimental condition, Δt was measured to be 275μsec. The energy resolution of the experiment can thus be easily estimated.

The error of the total cross section was influenced by the following factors: density of the sample, thickness of the sample, statistical error of signal neutron counting and monitor neutron counting by BF_3 counters. The density and the thickness of the sample, however, were negligible in comparison with the statistical error.

Experimental Results

The measured cross sections for natural Sm, Gd and Dy are shown in Figs. 6-1, 6-2 and 6-3, respectively, and these are compared with values obtained in other experiments[2,3,4]. Agreement is quite satisfactory, although the present data has relatively poor energy resolution. The cross sections obtained at 0.0253eV are shown in Table 2, and compared with the values from BNL-325 3rd ed.[5] As can be seen, the measured results for Sm and Gd show slightly lower values than the BNL-325 3rd ed. data.

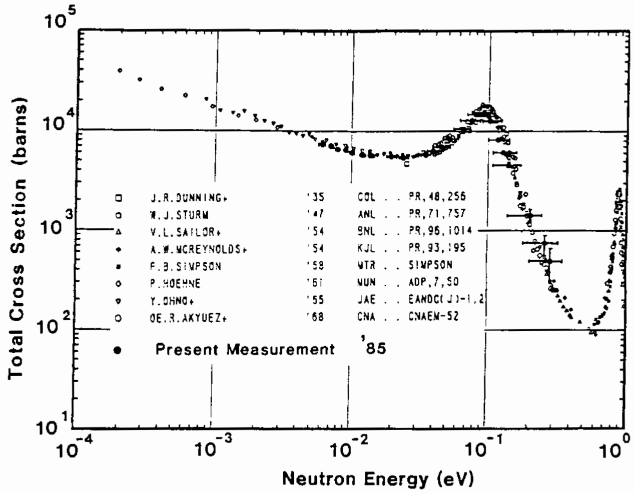

Fig. 6-1 Total Neutron Cross Section of Sm

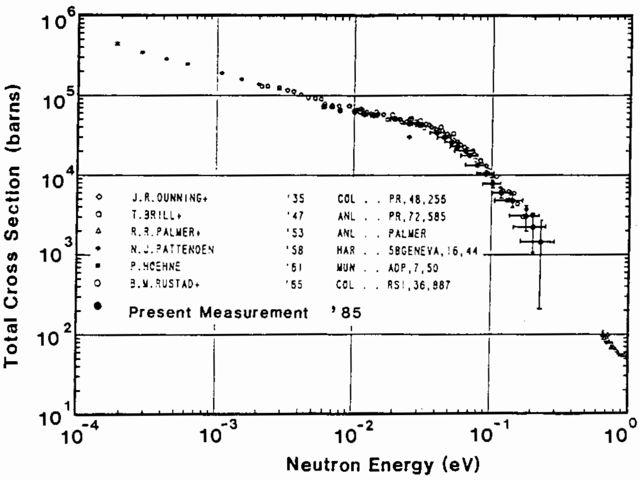

Fig. 6-2 Total Neutron Cross Section of Gd

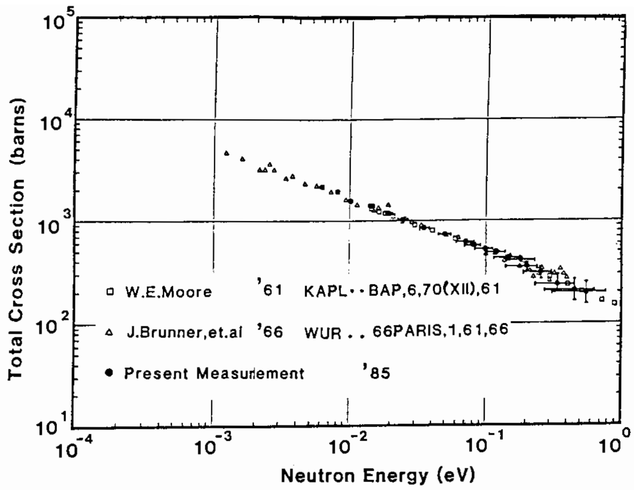

Fig. 6-3 Total Neutron Cross Section of Dy

Table 2 Total Neutron Cross Sections (barns)

	Sm	Gd	Dy
Present Results (at 0.0253 ±0.0023eV)	5428±87	44450±701	1041±21
BNL-325 3rd ed. (at 0.0253eV)	5800±100	49000±1000	1030±25

Parameters of Westcott Convention

As is well known, the reaction rate R for an element having 1/v type cross section is calculated as

$$R=nv_0 N\sigma_0$$

where the neutron flux has the form of the Maxwell distribution, σ_0 is the cross section at the neutron velocity v_0 (2200m/s), n is the energy integrated neutron density and N is the atomic number density of the element. This reaction rate equation must be corrected for non-1/v cross section, and the correction factor is known as the g-factor defined by Westcott[6]:

$$g(T)=\frac{2}{\sqrt{\pi}\sqrt{E_0}\sigma_0}\int_0^\infty \sqrt{E}\sigma(E)\sqrt{E/E_T}\exp(-E/E_T)dE/E_T$$

where $E_T=E_0T/T_0$, $E_0=0.0253$eV and $T_0=293.6$K.

In this research, the g-factor for Sm, Gd and Dy at several neutron temperatures were evaluated using the measured cross sections. These are shown in Tables 3-1, 3-2 and 3-3, respectively. The agreement of the previously published data[7,8] and the present results is fairly good for Sm and Gd. The g-factors for Dy were evaluated for the first time.

Table 3-1 $g(T_n)$-factors of Sm(=Sm^{149})

Tn(°C)	Present Values	C.H. Westcott [7]	E.M. Gryntakis et al. [8]
20	1.6349	1.6170	1.5860
100	1.9380	1.8874	1.8461
200	2.1756	2.0903	2.0457
300	2.2879	2.1768	2.1333
600	2.2343	2.0852	2.0533
800	2.0761	1.9246	1.8990
1000	1.9014	1.7568	1.7358

Table 3-2

$g(T_n)$-factors of Gd

Tn(°C)	Present Values	C.H. Westcott [7]
20	0.8042	0.8541
100	0.7664	0.7975
200	0.7108	0.7263
300	0.6559	0.6607
600	0.5175	0.5063
800	0.4472	0.4325
1000	0.3905	0.3749

Table 3-3

$g(T_n)$-factors of Dy

Tn(°C)	Present Values
20	0.9187
100	0.9381
200	0.9512
300	0.9538
600	0.9135
800	0.8632
1000	0.8064

Conclusion

The total neutron cross sections in the energy range of 0.006-0.2eV for natural Sm, Gd and Dy were successfully measured with the chopper and TOF facility installed at the Musashi reactor (TRIGA-II, 100kW). The measured cross sections show good agreement with the existing data, but the results obtained for Sm and Gd at 0.0253eV show slightly lower values than the data published in BNL-325 3rd ed. When we calculated the constants of Westcott g-factors from the present data, however, we found the constants of Sm and Gd to be in good agreement with the values published by Westcott and by E. M. Gryntakis et al. The constants for Dy are evaluated for the first time.

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