International Atomic Energy Agency

INDC(VN)-011
Distr. L0

INDC INTERNATIONAL NUCLEAR DATA COMMITTEE

Neutron Capture Cross Section Measurements of ^{109}Ag, ^{186}W and ^{158}Gd on Filtered Neutron Beams of 55 and 144 keV

Vuong Huu Tan
Vietnam Atomic Energy Commission (VAEC)
Hanoi, Vietnam

Nguyen Canh Hai, Pham Ngoc Son, Tran Tuan Anh
Nuclear Research Institute
Dalat, Vietnam

December 2004

IAEA NUCLEAR DATA SECTION, WAGRAMER STRASSE 5, A-1400 VIENNA

Reproduced by the IAEA in Austria
December 2004

INDC(VN)-011
Distr. L0

Neutron Capture Cross Section Measurements of ^{109}Ag, ^{186}W and ^{158}Gd on Filtered Neutron Beams of 55 and 144 keV

Vuong Huu Tan
Vietnam Atomic Energy Commission (VAEC)
Hanoi, Vietnam

Nguyen Canh Hai, Pham Ngoc Son, Tran Tuan Anh
Nuclear Research Institute
Dalat, Vietnam

Abstract

The neutron capture cross sections of the ^{109}Ag(n, γ)^{110m}Ag, ^{186}W(n, γ)^{187}W and ^{158}Gd(n, γ)^{159}Gd have been measured at 55 and 144 keV by the activation method with filtered neutron beams of the Dalat nuclear research reactor. The cross sections were determined relative to the standard capture cross sections of ^{197}Au using highly purity metallic foils of Ag, W, Gd and Au. The high efficient HPGe detector was used for the gamma rays measurement from the samples, and absolute efficiency calibration was performed by using a set of standard radioisotope sources and a multi-nuclides standard solution. The present results were compared with the previous measurements listed in EXFOR-CINDA, and the evaluated data of ENDF/B-VI.

December 2004

CONTENTS

Neutron Capture Cross Section Measurements of ^{109}Ag, ^{186}W and ^{158}Gd on Filtered Neutron Beams of 55 and 144 keV

Vuong Huu Tan, Vietnam Atomic Energy Commission (VAEC)
Nguyen Canh Hai, Pham Ngoc Son, Tran Tuan Anh, Nuclear Research Institute, Dalat Vietnam

I. Introduction

Average radiactive neutron capture cross sections in the keV energy region are important in the calculation and design of reactors as well as in the studies of nuclear physics, the s-process for nucleosynthesis in astrophysics [6] and safety analysis. At present, the published experimental data is quite discrepant in different experiments, and it is still not satisfied in quality and quantity. That is the reason why new experimental data, theoretical predictions for more accurate parameters and improvement of theoretical description of neutron radiactive capture reaction are always necessary. In the current study, the radiactive neutron capture cross section for the reactions of ^{109}Ag(n, γ)^{110m}Ag, ^{186}W(n, γ)^{187}W and ^{158}Gd(n, γ)^{159}Gd at energy regions of 55 and 144 keV have been measured by the activation method with the filtered neutron beams, whose characteristics are shown in Table 1, at the Dalat nuclear research reactor. A system of gamma spectroscopy, ORTEC DSPEC^{Js}, with a high relative efficiency of 58% as well as high resolution HPGe detector was used to measure gamma rays from the irradiated samples. The capture cross sections were obtained relative to the standard capture cross sections of ^{197}Au, and the results have been compared with the previous experimental data in EXFOR computer program and the evaluated cross sections in ENDF/B-VI.

II. Experimental Procedure

The experimental arrangements were performed on the horizontal channel of the Dalat 500 kW research reactor. The structures of the filter for 55 keV neutron beam are 98 cm Si + 35 g/cm^2 S + 0.2 g/cm^2 B^{10}, and those for 144 keV neutron beam are 98 cm Si + 1 cm Ti + 0.2 g/cm^2 B^{10}. The neutron and gamma rays collimators in diameter of 3 cm were composed of Cd, B_4C, Pb and borated paraffin. In this work, the samples in disk form of Ag, W and Gd were made of naturally high pure metallic foils with 2.54 cm and 0.05 mm in diameter and thickness, respectively, and the gold foils, 2.54 cm in diameter and 0.01 mm in thickness, were used as the neutron flux monitors. Each sample was sandwiched between two gold foils; the sample groups were wrapped in Cd covers of 0.5 mm in thickness to reject most of thermal neutron background. The duration of irradiations for each energy region were about 24 hours for W and Gd, and 70 hours for Ag samples. The activities of samples and gold foils were measured with the high resolution and efficiency calibrated HPGe detector, and the samples were placed on the surface of the detector because of their weak activities. In order, the efficiency calibration of the detector has been performed by using a set of standard radioisotope sources and a multi-nuclides standard solution; a computer program, called ETNA (**E**fficiency **T**ransfer for **N**uclide **A**ctivity measurements), was employed to calculate the correction of geometric differences between the samples and the standard sources, and generate the absolute efficiency curve.

Table 1. *Filtered neutron beam characteristics*

Neutron energy (keV)	Filter combination	Flux density (n/cm^2/s)	FWHM
55	98 cm Si + 35 g/cm^2 S + 0.2 g/cm^2 B^{10}	5.61 x 10^5	8 keV
144	98 cm Si + 1 cm Ti + 0.2 g/cm^2 B^{10}	2.14 x 10^6	22 keV

III. Data Processing

During irradiation, the activated reaction rate, R, of samples in the filtered neutron beam with energy spectrum ϕ(E) is defined as following [1]:

$$R = S\int_{E_1}^{E_2}\int_0^l \phi(E)N_{nucl}\exp\{-[N_{nucl}\sigma_t(E)x]\}\sigma_a(E)dxdE \qquad (1)$$

Where S, l and N_{nucl} are the area (cm^2), the thickness (cm) and the density (number of nuclei per cm^3), respectively, of sample, ϕ(E) the neutron energy spectrum of the beams, σ_a(E) and σ_t(E) the capture cross section (barn) and total cross section (barn), respectively, and E_1, E_2 the lower and upper limits of energy range of neutron beams. In the experiment, the thickness of samples and gold foils are thin enough for neglecting the multiple-scattering and γ-self absorption corrections in the samples, and applying the following expression [1]:

$$\exp(-N_0\sigma_t(E)) = 1 - N_0\sigma_t(E) + \frac{(N_0\sigma_t(E))^2}{2} \qquad (2)$$

where N_0=N_{nucl}.x is thickness of the sample (number of nuclei per cm^2). Let define $<\sigma_a>$ and $<\sigma_t>$ as the average cross section on the spectrum of the filtered neutron beam, and suppose that $<\sigma_a.\sigma_t> = <\sigma_a>.<\sigma_t>$. The integrating equation (1) can be rewritten as:

$$R = N<\sigma_a>\left[1-\frac{N_0<\sigma_t>}{2}\right]<\Phi> \qquad (3)$$

where N = SN_0 ;

$$<\Phi> = \int_{E_1}^{E_2}\phi(E)dE \;;\; <\sigma_a> = \frac{\int_{E_1}^{E_2}\sigma_a(E)\phi(E)dE}{\int_{E_1}^{E_2}\phi(E)dE} \;;\; <\sigma_t> = \frac{\int_{E_1}^{E_2}\sigma_t(E)\phi(E)dE}{\int_{E_1}^{E_2}\phi(E)dE}$$

The radioactivity, A, of the activated sample at the end of neutron irradiation has related with the activated reaction rate as well as the number of count, C, obtained from the measurement of gamma rays, by following expressions:

$$A = R(1-\exp(-\lambda t_1)) \qquad (4)$$

$$A = \frac{C(1-L_m)(1+L_n)\lambda}{\varepsilon_\gamma I_\gamma \exp(-\lambda t_2)(1-\exp(-\lambda t_3))} \qquad (5)$$

Where t_1, t_2 and t_3 are irradiating, cooling and measuring times, respectively, λ the decay constant of activated nuclide, ε_γ the detection efficiency of detector, I_γ the branching ratio of interesting γ-ray radiation, L_m and L_n the correction factors for multiple-scattering and γ-self absorption. Finally, from Eqs. (3), (4) and (5) the average capture cross sections, $<\sigma_a>^x$, for the samples at energy E can be obtained relative to that of ^{197}Au standard by using the following relations:

$$<\sigma_a>^x = \frac{C^x f(\lambda,t)^x I_\gamma^{Au} \varepsilon_\gamma^{Au} N^{Au} (1 - N_0^{Au} <\sigma_t>^{Au}/2) <\sigma_a>^{Au}}{C^{Au} f(\lambda,t)^{Au} I_\gamma^x \varepsilon_\gamma^x N^x (1 - N_0^x <\sigma_t>^x/2)} \quad (6)$$

$$f(\lambda,t) = \frac{\lambda}{(1-\exp(-\lambda t_1))\exp(-\lambda t_2)(1-\exp(-\lambda t_3))} \quad (7)$$

Where the superscript 'x' means the nucleus of sample, and as above-mentioned the thickness of samples and gold foils, in the present work, are thin enough for neglecting the multiple-scattering and γ-self absorption effects, so that the L_m and L_n factors in Eq. (5) can be omitted. The standard cross sections of gold are given in Table 2, and the relevant decay data of ^{198}Au, ^{110m}Ag, ^{187}W and ^{159}Gd are listed in Table 3.

Table 2. *Standard cross sections of* ^{197}*Au [8]*

Neutron energy (keV)	$<\sigma_a>^{Au-197}$ (mb)	$<\sigma_t>^{Au-197}$ (b)
55 keV	414.61 ± 12.44	11.52 ± 0.35
144 keV	277.21 ± 8.32	9.51 ± 0.29

Table 3. *Decay data of products [4]*

Product nucleus	$T_{1/2}$	E_γ (keV)	Iγ (%)
^{198}Au	2.69d	411.7	95.5
^{187}W	23.72h	479.5	21.8
^{159}Gd	33.6d	364.2	11.0
^{110m}Ag	249.8d	657.7	94.37

IV. Results and Discussion

The average neutron capture cross sections for the reactions of ^{109}Ag(n, γ)^{110m}Ag, ^{186}W(n, γ)^{187}W and ^{158}Gd(n, γ)^{159}Gd at incident neutron energies of 55 and 144 keV from the filtered neutron beams have been measured by the activation method. The results, obtained relative to the standard cross section values of ^{197}Au(n, γ)^{198}Au reaction, recommended in ENDF/B-6 library, are given in Table 4. The previous measurements, EXFOR, and the evaluated data of ENDF/B-6, together with the current results, are plotted in Fig. 1, 2 and 3. In the energy regions of 55 and 144 keV, it can be seen from the figures that, in the case of ^{109}Ag(n, γ)^{110m}Ag reaction, no experimental data of cross section have been reported before, and in the case of ^{158}Gd(n, γ)^{159}Gd reaction, the current measurements are in good agreement with previous measurements and the evaluated data within the uncertainties, but in the case of ^{186}W(n, γ)^{187}W reaction, the current measurements are higher by 8 - 30% than the previous measurements and the evaluated data.

In addition, the experimental uncertainties of the current measurements are 5 to 10%, which are mainly due to the statistical errors (0.1 - 10%), the uncertainties of γ-ray detection efficiency (2.0%) and the reference cross section value (3.0%).

Table 4. *The radiactive capture cross sections of ^{109}Ag, ^{186}W and ^{158}Gd measured in this work*

Neutron beams	**$<\sigma_a>^W$ (mb)**	**$<\sigma_a>^{Gd}$ (mb)**	**$<\sigma_a>^{Ag}$ (mb)**
55 keV	178.71 ± 10.3	199.42 ± 11.5	21.4 ± 2.35
144 keV	139.78 ± 5.3	114.85 ± 5.26	20.7 ± 3.47

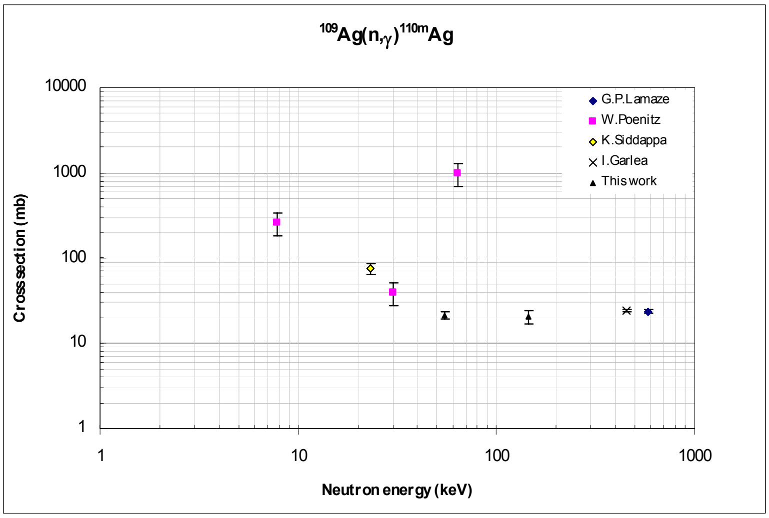

Fig. 1. Comparison of the previous experimental data with the present measurement for ^{109}Ag(n, γ)^{110m}Ag reaction.

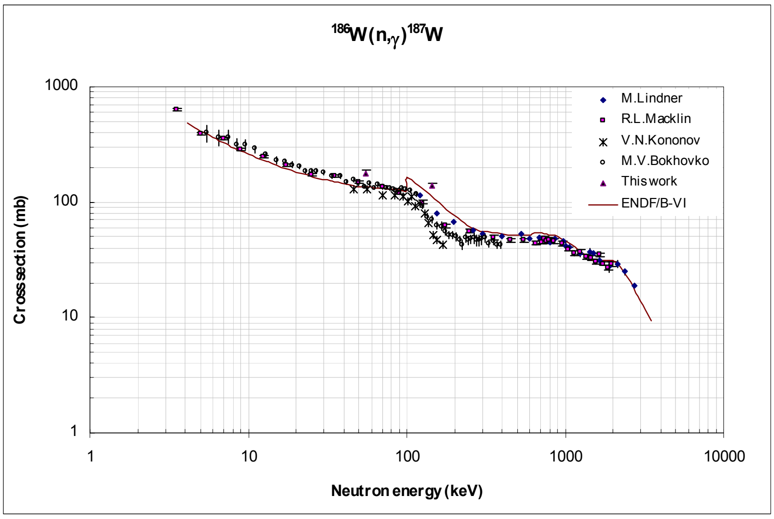

Fig. 2. Comparison of the previous experimental data and the evaluated cross sections with the present measurement for ^{186}W(n, γ)^{187}W reaction.

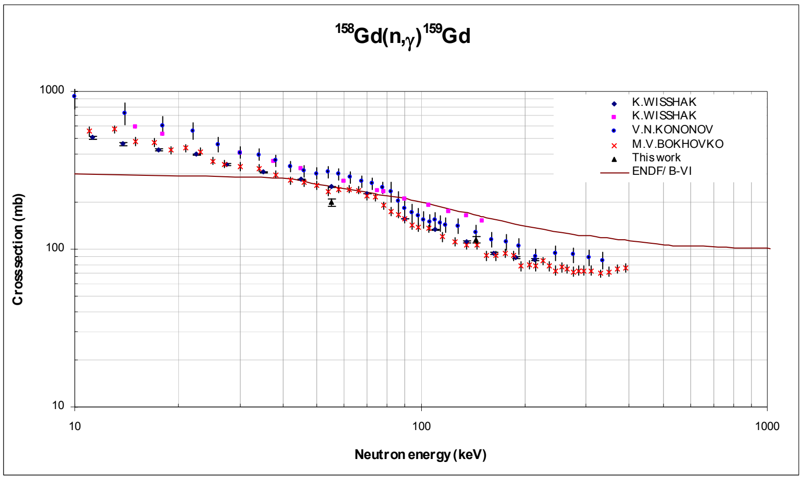

Fig. 3. Comparison of the previous experimental data and the evaluated cross sections with the present measurement for $^{158}Gd(n, \gamma)^{159}Gd$ reaction.

Acknowledgment

The authors would like to express their thanks to the Vietnam Atomic Energy Commission (VAEC) and the Nuclear Research Institute, Dalat, for the financial support and making it possible to carry out the current experiments under the fundamental research contract N^0. 430604.

References

1. P.Z. Hien, V.H. Tan, N.C. Hai. Radiactive capture cross section measurements for U-238 on the 55 and 144 keV filtered neutron beams, KC-09-08, Dalat-1995, pp. 117-121.
2. V.H. Tan, N.C. Hai. Corrections for multiple neutron scattering and γ-self absorption effects by the Monte-Carlo method, Proceedings of the National Conference on Nuclear Physics and Technology, VAEC, 2000, pp. 43-48.
3. V.H. Tan, N.C. Hai, T.T. Anh, N.X. Trong. Average neutron capture cross section measurements of Te, Ba and Sb on Filtered Neutron Beams of 55 and 144 keV**,** Proceedings of the National Conference on Nuclear Physics and Technology, VAEC, 2000, pp. 49-53.
4. Handbook on Nuclear Activation Data. International Atomic Energy Agency, Vienna, 1997, pp. 68 – 71, pp. 206 - 247.
5. J. Kopecky. Atlas of Neutron Capture Cross Sections. International Nuclear Data Committee
6. S. Goriely. Nuclear Reaction Data Relevant to Nuclear Astrophysics. Journal of Nuclear Science and Technology, Supplement 2, pp. 536 – 541.
7. LIU Jianfeng. Calculations of Cross Sections and Energy Spectra for Neutron Induced γ-ray of ^{181}Ta, ^{197}Au and Natural Ag. Communication of Nuclear Data Progress No.28 (2002).
8. ENDF/B-VI data file for ^{197}Au (MAT=7925), P.G. Young and E.D. Arthur, NDS, IAEA.

Nuclear Data Section
International Atomic Energy Agency
P.O. Box 100
A-1400 Vienna
Austria

e-mail: services@iaeand.iaea.org
fax: (43-1) 26007
telephone: (43-1) 2600-21710

Online: TELNET or FTP: iaeand.iaea.org
username: IAEANDS for interactive Nuclear Data Information System
usernames: ANONYMOUS for FTP file transfer;
FENDL2 for FTP file transfer of FENDL-2.0;
RIPL for FTP file transfer of RIPL.
NDSONL for FTP access to files sent to NDIS "open" area.
Web: http://www-nds.iaea.org