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TOTAL NEUTRON CROSS-SECTION OF U-238 AS MEASURED WITH FILTERED NEUTRONS OF 55 KEV AND 144 KEV

Pham Zuy Hien, Vuong Huu Tan, Nguyen Phuoc Xuan.
Dalat Nuclear Research Institute. Dalat, Vietnam.

ABSTRACT

In the piercing horizontal channel of the Dalat nuclear research reactor a 98cm long silicon filter has been installed for producing quasi-monoenergetic neutrons of 55 keV and 144keV . The flux intensities of the neutron beams are 4×10^{6} n/cm^{2}.s (55 keV) and 1.2×10^{7} n /cm^{2}.s (144 keV). Filtered neutron beams are being utilized for the measurements of the resonance-averaged nuclear parameters. In the first experiments aiming partly at testing the adequacy of the experimental conditions total neutron cross-sections have been measured by transmission technique for U-238 and C-12 target nuclei. The data for U-238 obtained with the accuracy of about 1% were compared with the evaluated ENDF/B-IV data and the results of recent experimental works.

1/ Introduction

Since the pioneer work of Sympson and his co-workers [1], neutron transmission filters have been successfully used to produce quasi-monoenergetic neutrons for nuclear physics experiments. These experiments yield information on the nuclear parameters averaged over a large number of neutron resonance states. It is these averaged values which are either of physical significance or needed as nuclear data for the various neutron physics applications.This advantage along with the simplicity of the experimental technique attracts the interest of nuclear physicists, and in some cases, filtered neutron technique is the best choice when dealing with the task of monochromatization of white neutron spectra.

At the Dalat nuclear research reactor (Dalat, Vietnam) the neutron flux at the piercing horizontal beam port is 6 $\times 10^{8}$ n/cm^{2}.s, and about one tenth of which are epithermal neutrons. A 98 cm long silicon single crystal installed in the channel provides a well collimated beam of thermal neutrons as well as of neutrons of 55 keV and 144 keV. The flux intensities and the quality of the filtered neutron beams are adequate for a number of experiments, enabling the Dalat Nuclear Research Center with very limited budgetary capability to enlarge the reactor utilization activities by embarking on the field of nuclear data research.

Another single crystal silicon filter has been installed also in the tangential beam tube to produce well collimated and high purity thermal neutron beam for prompt gamma-neutron activation analysis, neutron radiography and for calibration measurements by using thermal neutron data as references. A detailed description of that thermal neutron beam and its applications was given in Ref. [2].

2/ Filtered neutron beam characteristics.

Being abundant in fast and epithermal neutrons, the piercing horizontal beam tube is most suitable for producing quasi-monoenergetic neutron in tho intermediate-neutron energy region by using neutron filters. A silicon filter has been installed in the beam tube for this purpose (Fig.1). There are several reasons for starting our program with silicon filter: it is inexpensive, available with high purity as silicon single crystal and it can generate a beam with very little neutron background from other energies and little photon radiation. A 98cm long single crystal of silicon has been used, which transmits thermal neutrons as well as neutrons of 144keV and 55keV with the flux intensities and FWHM's shown in Table I

Table I.

Filtered neutron beam characteristics.

Neutron	Filter combination	Flux density (n/cm^2.s)	FWHM
Thermal	none	6×10^8	
Epithermal	none	7×10^7	
Thermal	98cmSi + 10cmTi + 50g/cm^{2}S	1.8×10^7	
144keV	98cmSi +10cmTi+ 0.4cm B_4C	1.2×10^7	22keV
55keV	98cmSi + 50g/cm^{2}S + 0.4cm B_4C	4×10^6	8keV

Fig.2 shows the pulse-height distribution of recoil protons measured with the hydrogen proportional counter SNM-38. The 764keV peak of the total energy of (n,p) reaction with thermal neutron on He-3 introduced into the counter as a gas component served as reference energy. The energy spectrum of the filtered neutron beam (Fig. 3) was obtained by differentiating the recoil proton energy distribution of Fig.2. The FWHM of the 144keV and 55keV lines are 24keV and 8keV respectively. To obtain single line spectra (quasi-monoenergetic neutrons), additional selective absorbers were used (Table I). The flux intensities of quasi-monoenergetic neutrons shown in Table I were measured at 25cm from the beam port outlet by activation of Au-foils.

3/ Total neutron cross-section measurements

Measurements of the averaged neutron cross-sections were the first experiments done with quasi-monoenergetic neutrons. U-238 and C-12 were chosen as targets in such experiments.The measurements with C-12 target were aimed at checking the adequacy of the experimental conditions by comparing the results with the literature data. In the case of U-238, although the accuracy of the experimental cross-sections in the energy range above 10keV were claimed to be 1-2%, the difference in the data measured by different authors is such that the actual uncertainty of these values would be higher (see e.g. Ref. [4]).

The averaged total neutron cross-sections were measured by neutron transmission technique. For a target of thickness x, the experimental total neutron cross-section is determined by the formula:

$$\sigma_x = -(1/\rho x)\ \mathrm{Ln}\ T \qquad (1)$$

where ρ is the concentration of target nuclei and T is the neutron transmission defined experimentally as :

$$T = \frac{(\phi - \phi b)}{(\phi o - \phi ob)} \qquad (2)$$

where ϕo and ϕ are the neutron count rates of the incident and transmitted beams, ϕ_{ob} and ϕ_b are the corresponding backgrounds. Mathematically, the neutron transmission T is given by the formula:

$$T = \frac{\int \exp\,[-\rho x\ \sigma_t(E)]\ f(E)\ d(E)}{\int f(E)\ dE} \qquad (4)$$

with $\sigma_t(E)$ - total neutron cross section at energy E, and

f(E) - energy distribution function of incident neutrons.

In the case of infinitely thin target ($x \rightarrow 0$), we have

$$\sigma_t \rightarrow \frac{\int \sigma_t(E)\ f(E)\ d(E)}{\int f(E)\ dE} \qquad (4)$$

As f(E) varies more slowly with E than $\sigma_t(E)$, the averaging in (4) can be further simplified as :

$$\sigma_t \rightarrow (1/\Delta E) \int_{\Delta E} \sigma_t (E)\, dE \ , \qquad (5)$$

i.e. when x -> 0 the experimental value σ_t will approach the averaged total neutron cross-section, $\sigma_t \rightarrow \langle\sigma_t\rangle$.

In the experiments, the incident and transmitted neutron fluxes ϕ_o and ϕ were determined by a detection system consisting of a cylindrical boron absorber (85% enriched in B-10) and a HpGe-detector counting the 480keV gamma rays from the $^{10}B(n,\alpha\gamma)$ reaction. The detector was properly shielded with lead and borated paraffin against scattered neutrons and prompt gamma-rays other than the above mentioned 480keV.

The backgrounds ϕ_b, ϕ_{ob} determined by intercepting the neutron beams by a 10cm long polyethylene absorber were approximately 1% of the neutron fluxes ϕ and ϕ_o. The target samples were prepared in the form of pellets or cylinders with diameter of 18mm (while the diameter of the incident neutron beam was 10 mm). Nuclear-grade graphite and metallic depleted uranium with 0,22% U-235 were used in preparing the target samples.

Results and discussions.

For a given target thickness the incident and transmitted neutron fluxes were measured alternatively in many cycles in order to minimize the influence of the reactor neutron flux fluctuation. The experimental errors were associated almost with the determination of the area under the 480keV photopeak.

For C-12 the 2.5mm thick graphite pellet could be regarded as thin target and the transmission experiments yield directly the total neutron cross-section. Our obtained results :

σ_t = 4.37 ± 0.15 b for 55keV neutrons
= 4.28 ± 0.013 b for 144keV neutrons

are in good agreement with the experimental data obtained by the same filtered neutron technique [3] ($\sigma_t = 4.497 \pm 0.089$ b (55keV) and 4.309 ± 0.018 b (144keV)).

In the case of U-238, the experimental cross-sections defined by Eq.(1) are not identical to the average total neutron cross-section and slightly vary with the thickness of the target due to the self-shielding effect. In Fig.4 the experimental cross-sections are presented versus the target thicknesses for 55keV and 144keV neutrons. At these energies the self-shielding effect is rather weak, and the thickness dependence of the experimental cross sections can be expressed by a linear function [3]:

$$\sigma_t = \langle\sigma_t\rangle - ax . \tag{6}$$

The averaged total neutron cross-sections $\langle\sigma_t\rangle$ can be obtained by extrapolating the experimental cross-sections to zero target thickness. The fitting procedure has yielded the results:

$\langle\sigma_t\rangle = (13.31 \pm 0.11)$b, $a = (0.026 \pm 0.002)$ b/mm for 55keV neutrons,
$\langle\sigma_t\rangle = (11.52 \pm 0.1)$b, $a = (0.0044 \pm 0.0005)$b/mm for 144keV neutrons,

which are in very good agreement with the results obtained in Ref.[3] (1mm of U- 238 is equivalent to 0.0473 nucl./barn). The experimental errors are about 1% and could be further reduced by increasing the number of measuring cycles. Table II shows the comparison of experimental and evaluated cross-sections. For 55 keV neutrons the result of this work and of Ref.[3] are higher than that of Ref [5] measured with neutrons from $T(p,n)^3He$ reaction as well as the ENDF/B-IV value. Meanwhile, at 144keV energy our result confirms the fact revealed in Ref [5] that in the energy region of 150 - 300 keV the experimental cross-sections are 2-3% higher than the ENDF/B-IV values.

Concerning the analysis of the experimental data for determining the averaged nuclear parameters (see e.g. Ref[6]), notice that the results would be more unambiguous if other experimental information, such as partial cross-sections, was taken into account. For such a purpose the measurement of the radiative capture cross-sections of U-238 has recently been initiated.

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Table II

Comparison of the total neutron cross-sections (in barns) of U-238

Energy	This work	Ref.[3]	Ref.[6]	ENDF/B-IV
55 keV	13.31 ± .11	13.343 ± .051	12.95 ± .2	12.9
144 keV	11.52 ± .11	11.55 ± .022	11.7 ± .15	11.14

References

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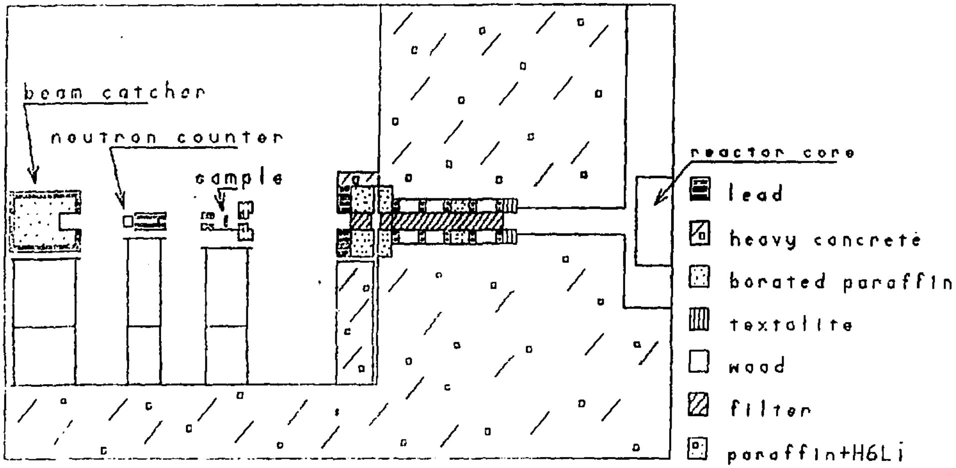

Fig. 1 Experimental set-up at the piercing beam port of the Dalat nuclear research reactor

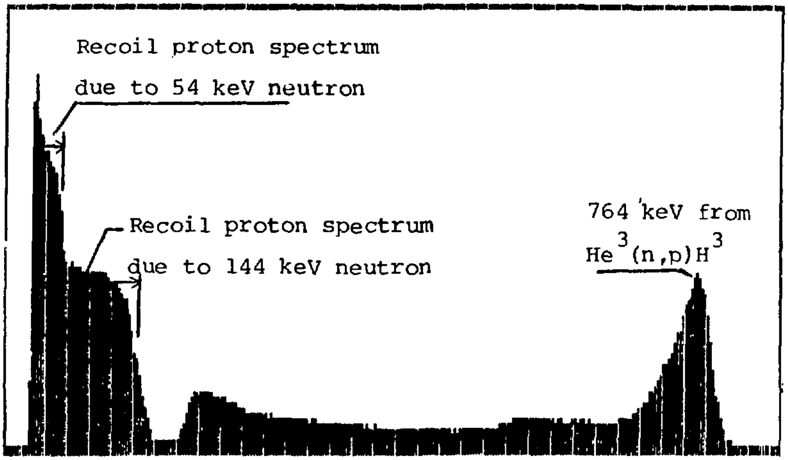

Fig. 2 . *Total energy spectrum from recoil proton detector.*

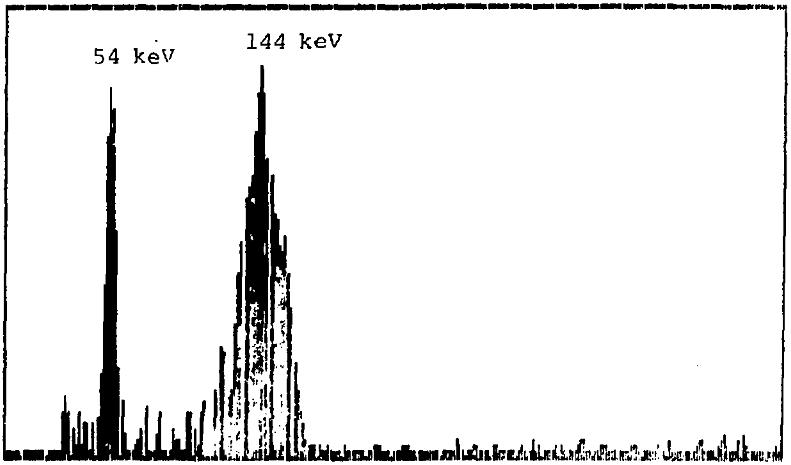

Fig. 3 . *Neutron beam differential spectrum.*

Fig. 4 Thickness dependence of the experimental cross-section
(1)- 55 keV, (2)- 144 keV