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Experimental verification of neutron inelastic scattering cross section for iron

B.V. Zhuravlev*, N.N. Titarenko

JSC «SSC RF-IPPE n.a. A.I. Leypunsky», 1 Bondarenko sq., Obninsk, Kaluga reg. 249033, Russia

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Abstract

Results of experimental verification of results on neutron inelastic scattering cross section for iron obtained in measurements of spectra of neutrons undergoing inelastic scattering at incident neutron energies of 6.0, 7.0 and 8.0 MeV and their calculations within the framework of statistical theory of nuclear reactions and direct interactions are presented. Description is given of the methodology of measurements and simulation calculations. Spectra of neutrons undergoing inelastic scattering obtained for iron in the process of experiments are analyzed in comparison with calculated data. New measurements of neutron inelastic scattering spectra and their analysis within the framework of contemporary modeling understanding allowed formulating proposal on introduction of corrections in the indigenous BROND-2.2 library of recommended evaluated neutron data and insignificant corrections in the most recent version of the library BROND-3.

Keywords: Inelastic neutron scattering; Neutron spectra; Time-of-flight method; Verification of evaluated neutron data.

Introduction

Iron is the main structural material for different nuclear installations, it is regarded as well as the standard of cross-section of emission of γ-quanta with 847-keV energy in ^{56}Fe (n, n′γ) reaction. Because of equivalence with inelastic scattering these data also serve as the verification of values of inelastic scattering cross-section. Experimental data on neutron inelastic scattering within the range of incident neutron energies from 5 MeV to 15 MeV are extremely scarce [1–6] and precision of determination of cross-section of emission of γ-quanta with 847-keV energy does not meet the requirements imposed on standards [7] which is clearly evident from Figs. 1 and 2. Agreement between the measured results is unsatisfactory, and different evaluations reflect the uncertainties of the data (Table 1).

While neutron cross-sections for standards tend to one-percent precision the best obtained precision for γ-quanta emission cross-sections at 847-keV energy ranges for iron from 5% to 10% with two relatively recent evaluations [10,11] differing from each other by 26% and, notably, with declared precision for both evaluations within the range from 5% to 10%. Results of measurements performed in Los-Alamos [7] and experiments performed by the authors of the present study at incident neutron energy equal to 9.1 MeV [3] indicate the necessity of increasing the value of inelastic scattering cross-section as compared with evaluations in ENDF/B-VI and BROND-2. Previously obtained experimental data [14] were processed and analyzed in order to prove this necessity and new calculations of neutron inelastic scattering spectra were performed for iron at incident neutron energies equal to 6, 7 and 8 MeV.

Experiment

Spectra of neutrons undergoing inelastic scattering on iron were measured at incident neutron energies of 6, 7 and 8 MeV. Time-of-flight measurements of spectra were performed using neutron spectrometer on the basis of EGP-10M pulsed tandem

* Corresponding author.
E-mail addresses: zhurav@ippe.ru, bvzhuravlev@iate.obninsk.ru (B.V. Zhuravlev), titan@ippe.ru (N.N. Titarenko).

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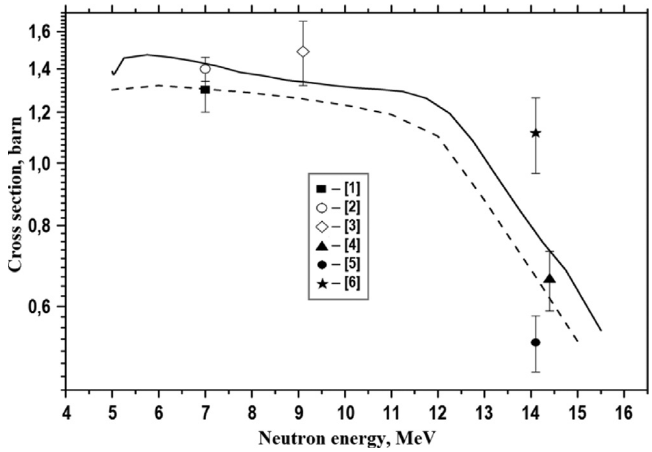

Fig. 1. Neutron inelastic scattering cross-section for iron: solid curve—ENDF/B-VI-8; dashed curve—BROND 2.2.

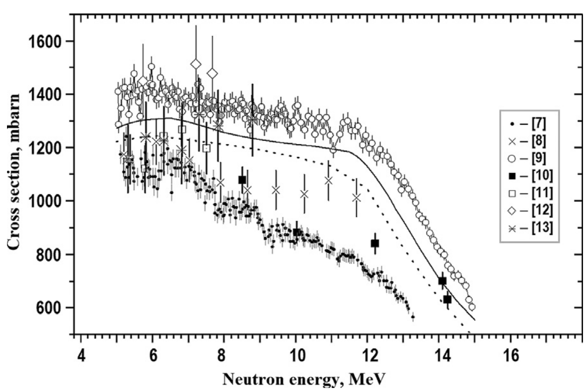

Fig. 2. Cross-section of emission of γ-quanta with 847-keV energy in ^{nat}Fe(n, n$'\gamma$) reaction: solid curve—ENDF/B-VI-8; dashed curve—BROND-2.2 [8,9,12,13].

Table 1
Evaluated neutron inelastic scattering cross-sections for ^{56}Fe at incident neutron energy of 14.5 MeV.

Library	Cross-section, mbarn	Discrepancy against ENDF/B-VI data, %
ENDF/B-VI	681	0.0
BROND-2	610	–10.4
JEFF-3	724	6.3
JENDL-3.3	672	1.3

accelerator at the SSC RF-IPPE. General layout of the experiment is presented in Fig. 3.

D(d, n)^{3}He reaction was used for generation of neutrons with energies from 6 MeV to 8 MeV. At the energies under investigation cross-section of accompanying D(d, np)D reaction and maximum energies of neutrons emitted from this reaction are small—at incident neutron energy of 8 MeV neutron yield (Y) amounts for the accompanying reaction to 0.3% with maximum energy of these neutrons equal to 1.2 MeV. Gaseous target with 10-mm diameter and 40-mm length was used. Inlet window of the target was made of molybdenum foil with 50-μm thickness. Platinum disc with 0.5 mm thickness was used as the bottom of the target where the beam of accel-

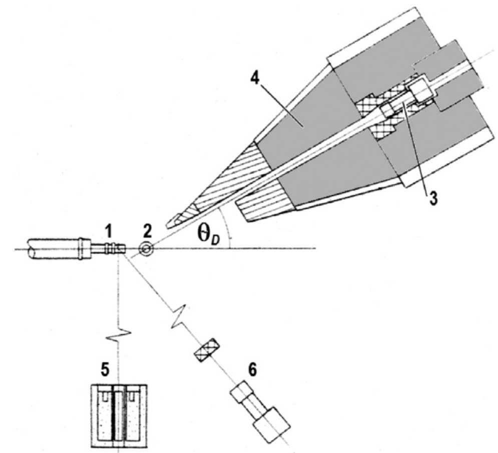

Fig. 3. General layout of the experiment for measurement of fast neutron inelastic scattering cross-section: 1—target; 2—sample; 3—neutron detector (θ_D—scattering angle); 4—detector shielding; 5—long counter; 6—monitor detector.

Table 2
Relative yields of neutrons from the target structure.

E_{d}, MeV	Y, %	$E_{\mathrm{n}}(0°)$ from D(d, n) reaction, MeV
3.17	0.8	6.0
4.08	1.7	7.0
5.06	3.2	8.0

erated deuterons is stopped. Deuterium pressure in the target amounted to 760 mm Hg. Relative yields of neutrons from the target structure carrying energy equal to 0.5 MeV at scattering angle equal to 0° relative to the accelerated deuteron direction are presented in Fig. 2.

It is evident from the data presented in Table 2 that contributions of background neutrons in the spectra of inelastically-scattered neutrons under investigation at energies equal to 6 MeV and 8 MeV are negligibly small and the resulting spectra were obtained as the difference between the measurements performed with and without the sample. Additional measurements were performed at incident energy equal to 8 MeV with evacuated target with and without the sample.

Investigated sample of iron was installed at the distance of 16 cm from the target along the direction of impinging deuterons. The sample is the hollow cylinder with the following dimensions: $d_{\mathrm{out}} = 45$ mm, $d_{\mathrm{in}} = 30$ mm, $h = 45$ mm. Sample of polyethylene ($d = 10$ mm, $h = 50$ mm) intended for the determination of absolute normalization of neutron inelastic scattering cross-sections for iron relative to the (n, p)-scattering cross-section was also used in the experiment.

Neutrons were registered by scintillation detector with stilbene crystal ($d = 40$ mm, $h = 40$ mm) and photomultiplier FEU-143. In order to suppress background, the detector was placed inside massive shielding and electronic discrimination of gamma-rays was applied. Detector efficiency was determined as follows: initially spectrum of prompt neutrons of ^{252}Cf spontaneous fission was determined by the time-of-flight method using dedicated fast fission ionization chamber specially designed for the purpose in the same experimental