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^{155,157}Gd neutron capture cross sections measured at n_TOF (CERN)

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Summary. — The accurate knowledge of the neutron capture cross sections of ^{155}Gd and ^{157}Gd plays an important in many fields of science. Despite of its importance, only few experimental data are available on these two isotopes in the low energy region. For this purpose, a measurement of the neutron capture cross-sections of the two odd Gd isotopes was carried out at the experimental area (EAR1) of the n_TOF facility at CERN. In this work, the main results obtained in the thermal region as well as in the resolved resonance region, will be presented.

1. – Introduction

In the field of the nuclear energy, the so-called "burnable neutron poisons" are those isotopes characterized by a neutron capture cross section at thermal energy comparable or higher than the one of neutron-induced fission on ^{235}U, so to compete with the latter in the absorption of thermal neutrons. In this way burnable poisons can compensate a higher initial amount of fissile material that would not be otherwise allowed for safety reasons. Among these elements the most common is gadolinium, whose odd isotopes, ^{155}Gd and ^{157}Gd, are characterized by the largest neutron capture cross section below 1 eV.

For these reasons, accurate values of the neutron capture cross section of odd gadolinium isotopes play an important role for the neutron balance and safety features of current thermal reactors [1]. Moreover the proper knowledge of these cross sections is important in the context of nucleosynthesis of elements beyond the iron in stars [2], in the neutron capture therapy of cancer [3] and in the development of neutrino detectors [4].

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TABLE I. – *The* ^{155,157}*Gd(n, γ) thermal cross section (in kb) as reported in experiments* [6-8], *compilation* [5] *and evaluations. The uncertainty is not explicitly quoted in* [6].

Reference	^{155}Gd	^{157}Gd
Moller [7]	58.9(5)	254(2)
Ohno [8]	61.9(6)	248(4)
Leinweber [6]	60.2	226
Mughabgab [5]	60.9(5)	254.0(8)
JENDL-4.0 [9]	60.735	253.25
JEFF-3.3 [10]	60.89	254.5
ENDF/B-VIII.0 [11]	60.89	253.32

Despite of their importance, the state of the art of experimental and theoretical data is not satisfactory; concerning neutron capture on ^{155}Gd, although the values reported in literature at thermal energy (see Table I) are in agreement among each other within 5%, at higher energies up to 180 eV (where evaluated resonances stop) large deviations are present among data. A worse situation concerns the ^{157}Gd isotope: while nuclear data libraries for the thermal cross section adopt the value reported in a compilation by Mughabgab [5], the experimental data are in disagreement up to 12% (as shown in Table I). Also in this case, large discrepancies are present among evaluations and between evaluated and experimental data up to 300 eV.

All these inconsistencies prompted an substantial improvement of the Resolved Resonances Region (RRR) by measuring the ^{155,157}Gd(n, γ) cross section at the CERN neutron time-of-flight facility, n_TOF; in the following the main results from thermal neutron energy 25.3 meV up to 1 keV are reported.

2. – The experimental setup

At the n_TOF facility, featuring two beam lines, neutrons are produced by spallation induced by a 20 GeV/c protons pulse (7 x 10^{12} protons per pulse, 7 ns rms) impinging on a massive lead target. The initially fast neutrons are moderated by a first layer of 1 cm of demineralized water plus a second layer of 4 cm of borated water, resulting in a neutron flux spanning from thermal up to some GeV; for more details on the n_TOF facility see [12]. Because of the better resolving power ($\Delta E_n/E_n$ < 5 x 10^{-4} for E_n < 1 keV), the ^{155}Gd(n, γ) and ^{157}Gd(n, γ) capture measurements were carried out at experimental area 1 (EAR1), located at 185-m distance from the spallation target.

An array of four deuterated benzene (C_6D_6) liquid scintillation detectors has been used for detection of gamma radiation emitted after a neutron capture event. These detectors, optimized in order to reduce the neutron sensitivity [13], are particularly suited for capture measurements [14, 15]. The total energy detection principle was used by combining the detection system with the so called Pulse Height Weighting Technique (PHWT). The detectors were placed face to face at 90° with respect to the neutron beam and about at 10 cm distance from the isotope sample. As the total ^{155,157}Gd yield below 1 eV is capture dominated, to avoid saturation and in order to study the whole interest energy range, two samples, one thin and one thick were used for each element. Moreover, a gold (^{197}Au) and a lead sample were used for normaliztion and background measurements. Samples were cilindrycal in shape with 2 cm diameter.

3. – Data analysis and assessment

To obtain accurate evaluation of the cross-sections, the experimental setup as well as data quality have been carefully characterized and checked.

From the experimental point of view, the stability of the detectors has been periodically verified by measurements of standard γ-ray sources; the recorded energy spectra were in agreement among them within 0.7% for the whole Gd campaign. By means of standard γ-ray sources (^{137}Cs, ^{88}Y, Am-Be and Cm-C) reliable channel to energy conversion was also obtained.

A very important check concerns the data analysis of the thick samples. At thermal energies, the total yield is dominated by the capture and its saturated value should be $\simeq 1$. Due to the variations at energies < 1 eV of the neutrons beam fraction intercepted by the sample (BIF), large deviations are present between the extracted yield and the expected one based on ENDF/B-VIII.0 data. Taking advantage of such deviations a correction factor has been extracted; the comparison using the ^{197}Au neutron standard between the BIF corrected data and the ENDF/B-VIII.0 evaluations reported an agreement better than 1.5%.

The capture yield were analyzed with the R-Matrix code SAMMY in the Reich-Moore approximations and taking into account the several experimental conditions: Doppler broadening, self shielding and multiple scattering in the sample. The starting point of the resonance parameters was assumed by ENDF/B-VIII.0 library. For energies below 1 eV, the resonance shape analysis (RSA) has been performed with data obtained with the thin samples. The present RSA has observed and analyzed resonance structures well above the RRR limits reported by main nuclear data libraries, such as ENDF/B-VIII.0, JENDL-4.0 and JEFF-3.3.

4. – Resuls and conclusions

4·1. ^{155}*Gd*. – Regarding the thermal ^{155}Gd(n, γ) cross section, a slightly higher value compared with the one reported in the libraries (see Table I) has been obtained. In the resolved resonance region, large differences are present between the n_TOF data and the evaluations as shown in Figure 1. A comparison in terms of kernel residuals as a function of the resonance energy shows on average a good agreement with the ENDF/B-VIII.0 and JEFF-3.3 evaluations, as well as with the results reported by Baramsai et al. [16].

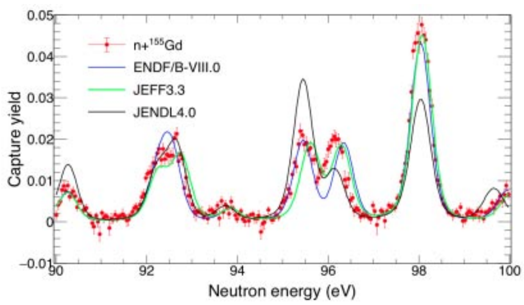

Fig. 1. – (Color online) ^{155}Gd(n, γ) yield from the present work compared to the expected capture yields, calculated on the basis of the cross sections in ENDF/B-VIII.0, JEFF-3.3 and JENDL-4.0 nuclear data libraries.

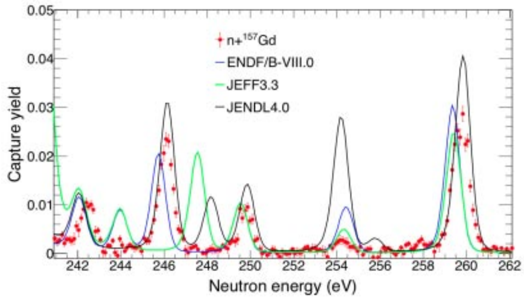

Fig. 2. – (Color online) ^{157}Gd(n, γ) yield from the present work and comparison with the expected capture yield, calculated on the basis of the cross sections in ENDF/B-VIII.0, JEFF-3.3 and JENDL-4.0 libraries

4·2. ^{157}*Gd*. – The weighted yield of the present data was compared with the main evaluations and the one reported by Leinweber *et al.* [6]. The present data settle the thermal cross section in the middle of the two groups of expected value risulting in a thermal value lower than the one suggested by nuclear data libraries. A worse situation concerns the resolved region (see Figure 2) where largest discrepancies between libraries and n_TOF data are present. However an analysis of the kernel residuals, reports on average a good agreement with ENDF/B-VIII.0 and JEFF-3.3 evaluations.

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