Nuclear Instruments and Methods in Physics Research A 739 (2014) 68–74

Contents lists available at ScienceDirect

Nuclear Instruments and Methods in Physics Research A

journal homepage: www.elsevier.com/locate/nima

Determination of the default curve for the unfolding procedure in the measurement of threshold neutron excitation functions

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ARTICLE INFO

Article history:
Received 12 September 2013
Received in revised form
4 December 2013
Accepted 5 December 2013
Available online 17 December 2013

Keywords:
Spectrum unfolding
Default function
Neutron fluence spectrometry
Neutron-induced reaction
Excitation function

ABSTRACT

In this study we have improved the technique for measuring the neutron activation cross-section using wide energy neutron beams (NAXSUN). We propose a method for the determination of the default function for the unfolding procedure, which is an important and critical part for extracting reaction cross-sections from this type of measurements. The new method was tested on the measurement of the excitation function from the threshold energy up to 5.6 MeV for the ^{113}In(n,n′)^{113m}In and ^{115}In(n,n′)^{115m}In reactions.

1. Introduction

The measurement of accurate neutron activation cross-section data is very important for various research activities, such as astrophysics, geophysics, environmental protection, for fission and fusion reactor installations, for the production of medical isotopes, for the modeling of nuclear reaction cross-sections and for benchmarking the predictive power of those models etc. Up to now, many neutron activation cross-section measurements were carried out at research centres worldwide and several international data bases were established [1]. In general those data were measured pointwise at well-defined incident neutron energies. An overview of the data libraries shows that for many isotopes exist wide disagreements between the data obtained in different experiments [2]. For a considerable number of isotopes, none or only a few experimental data exist on neutron activation cross-sections. Moreover, different model calculations may show different trends to the same set of experimental data. These were some of the reasons to come up with a new experimental technique for the determination of activation cross-section data in neutron-induced reactions.

At IRMM (Institute for References Materials and Measurements), a new method was recently developed for obtaining neutron excitation functions in a wide energy range. By this method, as described in Ref. [3], it is possible to determine a neutron excitation function by irradiating identical disks, containing the studied isotope, in energy overlapping neutron beams and using the unfolding spectrum procedure to extract the reaction cross-section [4]. In the study reported in Ref. [3], the few channel spectrum-unfolding technique, which starts with an initial guess excitation function was used. A-priori information, necessary for the construction of the initial guess excitation function, can be obtained from the available experimental or calculated data. However, the problem is that the final results can be dependent on the initial guess function. Moreover, it is questionable which data can be taken in consideration for the initial guess curve if there are large discrepancies between the existing results or if there is no data at all.

In the demonstrator work reported in Ref. [3], the initial guess function was practically obtained from the large and concise data set existing in literature. Then, of course, the default function is already close to the real excitation function and convergence of the unfolding routine may be expected. This approach is not possible when no or discrepant data exist. Therefore, in this study we analyzed this problem and propose a new method for the determination of the guess function which enters the unfolding procedure. By this method, it is possible to obtain the new neutron excitation function that will be practically independent form other measurements or calculations. This new approach was tested on the previous experimental data for the ^{113}In(n,n′) ^{113m}In and ^{115}In(n,n′)^{115m}In reactions reported in Ref. [3].

2. Method

The method developed at IRMM for the determination of the neutron excitation function [3] and used in this study, is based on the irradiation of some number of identical disks containing the

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http://dx.doi.org/10.1016/j.nima.2013.12.017

studied isotopes in a series of well known, but different and energy overlapping neutron fields. The gamma-activity in the disks induced by the different neutron fields were measured by means of high-resolution gamma-ray spectroscopy systems. The induced saturation gamma activity of the disk is proportional to the product of the cross-section for a certain reaction and the corresponding neutron flux

$$C_k = \sum_i \Phi_{ki}\sigma_i, \quad k = 1, ..., m, \ i = 1, ..., c \tag{1}$$

where Φ_{ki} are the values of neutron fluxes for different energy E_i in the case of irradiation of disk k, σ_i are the values of the neutron excitation function, which correspond to the energy E_i, m is the number of irradiated identical disks and c is the number of bins in the neutron spectra and the excitation function curve. In this study, the following values were used $m = 10$ and $c = 140$.

The system of Eq. (1) is undetermined with an infinite number of solutions ($m \ll c$). However, it is possible to obtain the σ_i values when the values Φ_{ki} are well known, by the measurement of C_k using a technique for the few channel spectrum unfolding. In this work, the maximum entropy code MAXED [5] is applied for this purpose. The MAXED code starts with a guess excitation function and, from all the curves that fit the measured saturation gamma activity (1), the curve that maximizes the relative entropy is chosen

$$S = -\int \left\{ \sigma(E) \ln\left(\frac{\sigma(E)}{\sigma^{def}(E)}\right) + \sigma^{def}(E) - \sigma(E) \right\} dE \tag{2}$$

where $\sigma^{def}(E)$ is the guess excitation function or usually called default excitation function curve. The standard procedure is that the default curve can be chosen from the corresponding evaluated activation cross-section data file [6,7] or from other existing experimental data.

The problem apparently is what can be chosen as default excitation function, if the measurement data do not exist or the disagreement between different experimental and calculation data is large. In order to solve this problem, we made several simple approximations by which we transform the undetermined system of Eq. (1) into a determined system ($c = m$). By solving this determined system of equations, we obtained the default guess function for the start of the unfolding procedure.

For each irradiation and different neutron fields, the average value of the cross-section is defined by

$$\langle\sigma\rangle_k = \frac{\sum_i \Phi_{ki}\sigma_k}{\sum_i \Phi_{ki}} \tag{3}$$

Combining the above equation with (1) gives

$$\langle\sigma\rangle_k \approx \frac{C_k}{\Phi_k} \tag{4}$$

where $\Phi_k = \sum_i \Phi_{ki}$ is the integral neutron flux during the irradiation of disk k. By this approximation, the undetermined system (1) is transformed into a determined system (4). This means that for each irradiation it is possible to calculate one value of $\langle\sigma\rangle_k$, if the total neutron fluence and the detected specific gamma activities (C_k) are well known.

The standard way of presentation in the neutron dosimetry files is that for the average cross-section value $\langle\sigma\rangle_k$, the corresponding average neutron energy is given as

$$\langle E\rangle_k = \frac{\sum_i \sigma_i \Phi_{ki} E_i}{\sum_i \sigma_i \Phi_{ki}} \tag{5}$$

where E_i is the energy of the excitation function or neutron fluence bin. Since here the values σ_i are unknown, we make the following simplification:

$$\langle E\rangle_k \approx \frac{\sum_i \Phi_{ki} E_i}{\Phi_k} \tag{6}$$

Based on the above expression, we can calculate the average neutron energy $\langle E\rangle_k$, which corresponds to the average values of the cross-sections $\langle\sigma\rangle_k$. The performed analysis shows that the approximation made in Eq. (6) gives valuable results due to the specific and energy well defined neutron fluence. The details about the neutron fluence used for the disks irradiation are presented in the next chapter.

The k values of $\langle\sigma\rangle_k$ from Eq. (4), which correspond to the k energy values $\langle E\rangle_k$ from Eq. (6), are used as a starting point for obtaining the default guess function. The next step in this procedure is the linear interpolation of the energy dependence of the obtained cross-section values $\langle\sigma\rangle_k$ on energy E_k. This interpolated function was used as the default excitation function $\sigma^{def}(E)$ for the unfolding procedure. In this way, the obtained shape of the default neutron excitation function is obtained from the experiment itself and therefore, independent from any other experimental or calculated data set.

3. Measurement

3.1. Materials

The applicability of the method and its advantages are demonstrated on the determination of the excitation functions for the reactions ^{113}In(n,n′)^{113m}In and ^{115}In(n,n′)^{115m}In. A sufficient number of measurements has been done up to now on the cross-sections for those two reactions [7].

The IRMM method for obtaining the neutron excitation function of the ^{115}In(n,n′)^{115m}In and ^{113}In(n,n′)^{113m}In reactions was used Ref. [3]. In that case the default excitation functions were determined by fitting a 9th-order polynomial to the existing experimental data [7]. That means that guess functions were already well defined and close to real values at the beginning of the unfolding procedure. The obtained final unfolded excitation function is in very good agreement with the existing experimental data and it is presented in Figs. 1 and 2.

In this work, we used the spectroscopic data from Ref. [3] for obtaining the cross-section function of the ^{115}In(n,n′)^{115m}In and ^{113}In(n,n′)^{113m}In reactions. However, instead of fitting the existing experimental data as it was done in Ref. [3], we defined the default neutron excitation function by the new method described above. In this way, we can prove the applicability of our new method by comparing the results of the two approaches to the unfolding procedure on the same data set.

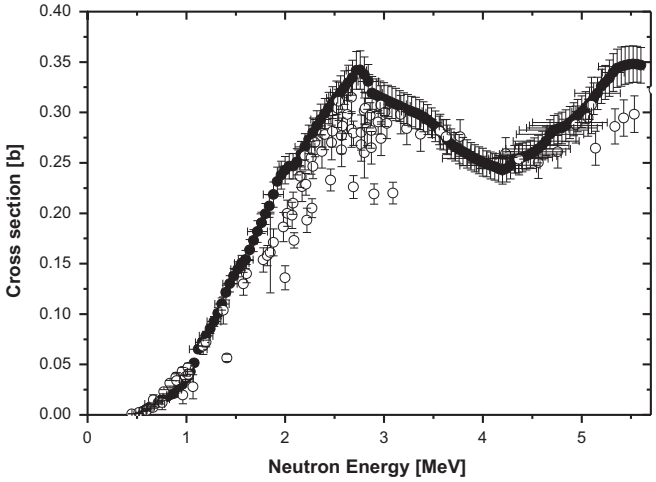

Fig. 1. The excitation function for the ^{113}In(n,n′)^{113m}In reaction. Open dots: EXFOR experimental data file for the [7]; black dots: unfolded data from [3].