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MASS-SPECTROMETER METHOD OF DETERMINATION OF NEUTRONS CROSS - SECTIONS IN MATERIALS

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For precision measurements of effective cross-sections of neutrons capture by the nuclei of the investigated samples the new method of measurement was developed. The method is based on the registration of heavy fragments of fission reaction of nuclei under the action of the reactor neutrons with the help of the mass-spectrometer. The method allows to measure of neutron cross-sections with the relative accuracy less than 1 %.

Keywords: *neutrons, mass-spectrometer, cross-sections, fission products.*

INTRODUCTION

Known methods of measurement of effective capture cross-sections of neutrons by nuclei of investigated materials at small energies, involving passage of a neutron flux through these materials and further measurement, either the beam attenuation, or induced activity, have noticeable dispersion on the accuracy of measurements. So the accuracy of measurements by neutron-activation analysis averages 5-10 %, and by registration of attenuation of the neutron flux ~ 5 % [1,2].

In the present work aiming at more precise measurements of effective capture cross-sections of neutrons the nuclei of test materials offer to use a technique, in which one registers the heavy fragments of a fission reaction instead of neutrons.

For this purpose the precision mass-spectrometer recording system of fission products (FP) of nuclei used by us in physical researches at the reactor of the Institute of Nuclear Physics of the Academy of Sciences, Republic of Uzbekistan is applied [3].

THE FP MASS-SPECTROMETER SCHEME

The mass-spectrometer of unslow FP of nuclei is arranged on an exploratory horizontal channel of the reactor (Figure 1.). The device includes sequentially arranged electrostatic (2) and magnetic analyzers (3) and provides a separation of FP according masses M, kinetic energies E_k and ionic charges q. In an input arm of a mass-spectrometer in a flow of reactor neutrons the target (1) of fission material is placed. The registration of FP is implemented by semi-conducting detectors (4), arranged for the electrostatic analyzer and in a focal plane of the mass-spectrometer.

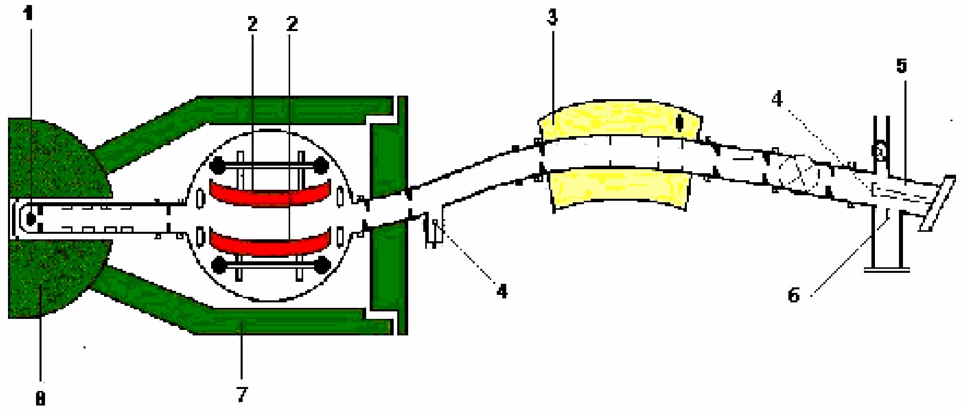


Figure 1. The scheme of a mass-spectrometer of unslowed FP of nuclei.

1 – Target;	2 - Electrostatic analyzer;
3 - Magnetic analyzer;	4 – Semi-conducting detectors;
5 – Detection chamber;	6 - Track detector;
7 - Biological protection;	8 – Nuclear reactor.

Resolving power of the mass-spectrometer on masses is $m/\Delta m \approx 800\text{-}900$. The illumination power of the device at width of the diaphragm in front of the electrostatic analyzer on 1.0 cm is $1.2 \cdot 10^{-6}$ sr. The measurement accuracy of FP masses is 0.06 %, and kinetic energy 0.02 %. The aperture of the device allows to make measurements of a position spectrum from 6-7 series of masses in the focal plane of the device.

METHOD AND OBJECTIVE

Let's obtain a connection between the neutron flux change on passing out of the fission target and reacting with the investigated material with a cross-section of neutrons capture σ_c. By the definition of speed of the FP in the focal plane of the mass-spectrometer from the fission target (Figure 1.), containing N_f nuclei, under the action of neutrons flux Φ_0, is equal [1]

$$A_f = \Phi_0 \cdot N_f \cdot \sigma_f \cdot \Omega \cdot \varepsilon \quad (1)$$

Here σ_f is cross-section of fission of target material, Ω is illumination power of the spectrometer, and ε is efficiency of the semi-conducting detector. If the sample under investigation is placed before target (1) it is clear, that the density change of neutron flux Φ_0, caused by acquisition of neutrons by nuclei of the material on their way, will cause other fluency of neutrons Φ on the target 1 i.e.

$$\Phi = \Phi_0\, e^{-\sigma_c n x}, \quad (2)$$

where σ_c is the capture cross-section, n is number of nuclei in unit volume (in 1 cm^3) of the investigated material, and x is depth of the investigated material in cm.

Thus the count rate of FP of nuclei in the focal plane of the mass spectrometer will change and will be equal to

$$\tilde{A}_f = \Phi_0 \cdot e^{-\sigma_c n x} \cdot N_f \cdot \sigma_f \cdot \Omega \cdot \varepsilon \quad (3)$$

From expressions (1) and (3) it is clear, that

$$\sigma_c = (1/(n \cdot x)) \cdot \ln (A_f / \tilde{A}_f) \quad (4)$$

EXPERIMENTAL EXAMINATION OF THE METHOD

In Figure 2. part of the scheme of the trial type tangent changes is shown in the field of the target concerning Figure1.

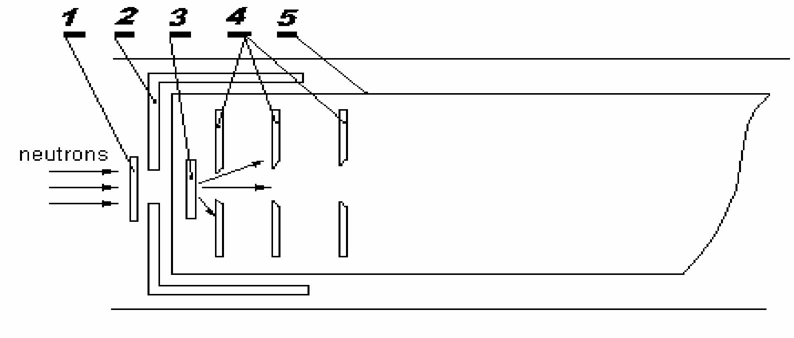


Figure 2. The scheme of an input part of the trial type with a sample.

1- Samarium sample; 2 - Cadmium sleeve;
3 - ^{239}Pu target; 4 - Collimators;
5 -Input arm of the mass-spectrometer.

As investigated material a sample of samarium of natural isotopic composition of thickness x = 0.0139 ± 0.0001 cm was selected. Here we underline two important aspects. At first, we will establish the features of the mass distribution of ^{239}Pu FP in accordance to the expression (4). Second, using observed data, we shall determine the value of capture cross-section σ_c, which for samarium is known with a high accuracy.

Pursuant to Figure 2. in neutron flux $\Phi_0 = 8\cdot 10^{12}$ neutrons / cm$^2\cdot$s was set the target of ^{239}Pu of thickness 50 µg/cm^2. The area of target location was closed by the cadmium sleeve of thickness 0.1 cm, with the rectangular form 1.5 x 4.0 cm^2 vice-versa targets. During measurements of FP yield of nuclei under the action of neutrons this form was replaced by an investigated sample - samarium metal foil of the indicated thickness. FP in the focal plane of the mass -spectrometer were counted by the semi-conducting detector with efficiency $\varepsilon = 1$. The measurements were carried out in the field of mass numbers A = 135 -150 of FP for fixed values of their kinetic energies $E_к$ in the interval from 66 up to 75 MeV with steps of 1 MeV.

The measured spectra are shown in Figure 3. as relative masses of the FP yields in the ^{239}Pu fission with the reactor neutrons (●) and under-samarium neutrons (▲) at $E_к$ = 66.5, 68.0, 71.5 and 75 MeV [4]. Normalization of mass yields of FP was conducted on the total number of the detected events in all peaks (from A=135 up to À=150): $A = \frac{N_A}{\sum_i^A N_i}$, where N_A - number of the detected events in peak.

As follows from Figure 3., the nature of distribution of FP mass spectra slightly depends on the value of their kinetic energy. The greatest difference is found for the least value of the kinetic energy FP (66 MeV). With ascending energy of registered fragments the difference decreases and at $E_к$ =71.5 MeV the identity of mass distributions of FP is shown for fission by neutrons of a reactor spectrum and using samarium neutrons. Therefore it is reasonable to consider, that, since these $E_к$ values, the mass-spectrometer measurements of FP ^{239}Pu with a test- sample and without it, can be utilized for the determination of effective neutron cross-sections of investigated materials with the help of expression (4). In other words, for determination of neutron capture cross-sections on investigated materials there is no necessity for direct measurement of neutrons, passing through the sample, as they can be exchanged by more precise measurements of FP yields of fission nuclei, for example ^{239}Pu [4] or ^{235}U [5].

For determination of the value of the effective capture cross-section of neutrons σ_c within the sample from samarium of natural isotopic composition (A = 150.35; ρ = 7.536 g/cм^3 [6]) the mass spectra of FP from ^{239}Pu with a kinetic energy E_k = 72 MeV

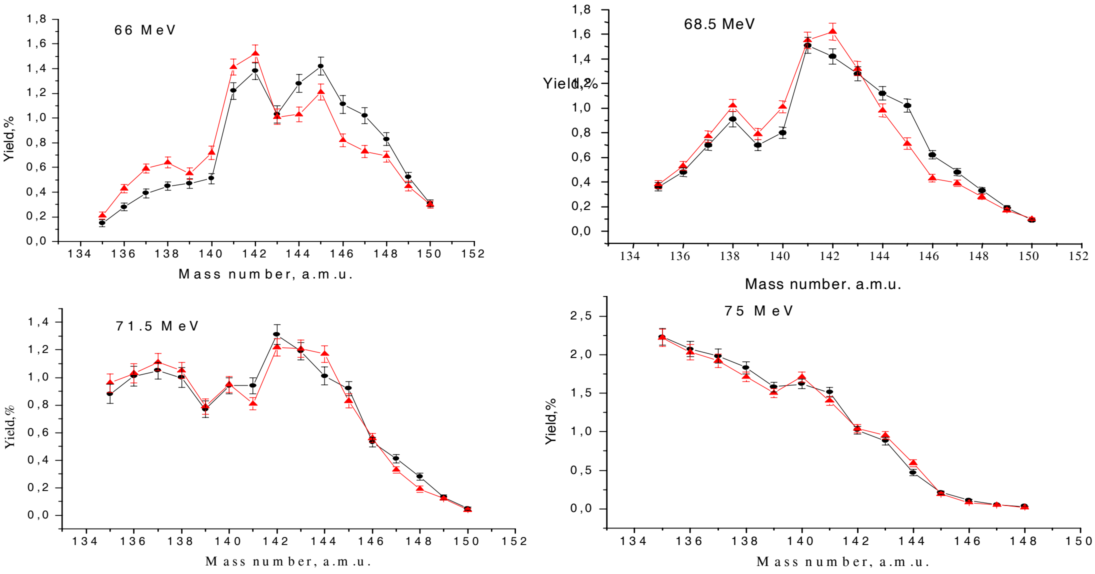
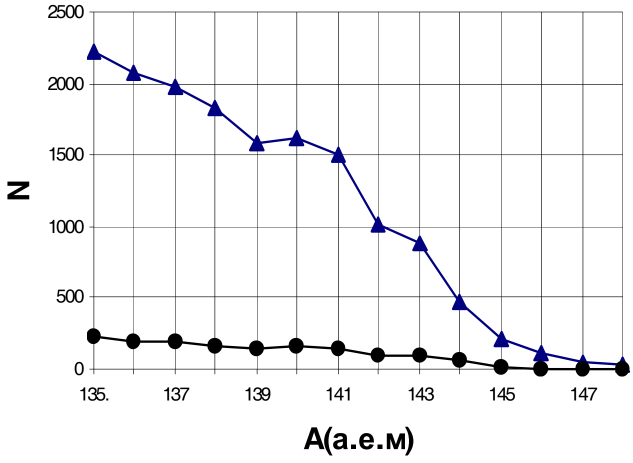


Figure 3. Relative yields of FP from ^{239}Pu, formed by reactor neutrons (●) and samarium neutrons (▲) at E_k = 66.5, 68.0, 71.5 and 75 MeV.

were calibrated at an identical temporary exposition both without the sample, and with the sample. The observed data are shown in Figure 4., where the upper curve corresponds to observed data without a sample (▲), and lower curve, with a sample (●).



▲ - $A_f = \sum_{A=135}^{148} N_A = 16592$ – without Sm

● – $\tilde{A}_f = \sum_{A=135}^{148} (N_A)_s = 1441$

with Sm sample

Figure 4. Spectral distribution of FP with kinetic energy E_k = 72 MeV, derived by fission ^{239}Pu by reactor neutrons (▲) and by samarium neutrons (●), in the region of FP mass numbers from A =138 up to A = 146.

Determination of the capture cross-section of neutrons σ_c in the samarium sample by the formula (4) gives the value: $\sigma_c = 5824$ barns

Thus an error estimated by the formula [1]

$$\Delta \sigma_c = \sigma_c \cdot \{ (1/ A_f + 1/ \tilde{A}_f) \}^{1/2} / \ln (A_f / \tilde{A}_f),$$

is equal to $\Delta \sigma_c = \pm 65$.

The obtained result $\sigma_c = 5824 \pm 65$ barn is in good agreement with the reference data (Table 41.1 [7]), namely with the value of neutron capture cross-section, equal to 5828 ± 30 barn.

The main contribution to error of measurement comes from the statistical error. This error can be decreased, if to conduct FP registration before the magnetic analyzer, where the quantity of FP is approximately 10 times more. So on measurement within 10 minutes, the amplitude spectrum (Figure 5.) quantity of FP ($\Sigma N_A = 18860$) is a little bit more reduced than above (Figure 4.), which was obtained for the hour exposition. On usage of thin metal foils of investigated materials the error of the determination of thickness of a film (g / cm^2) will be added, which should be the same as the statistical error or less.

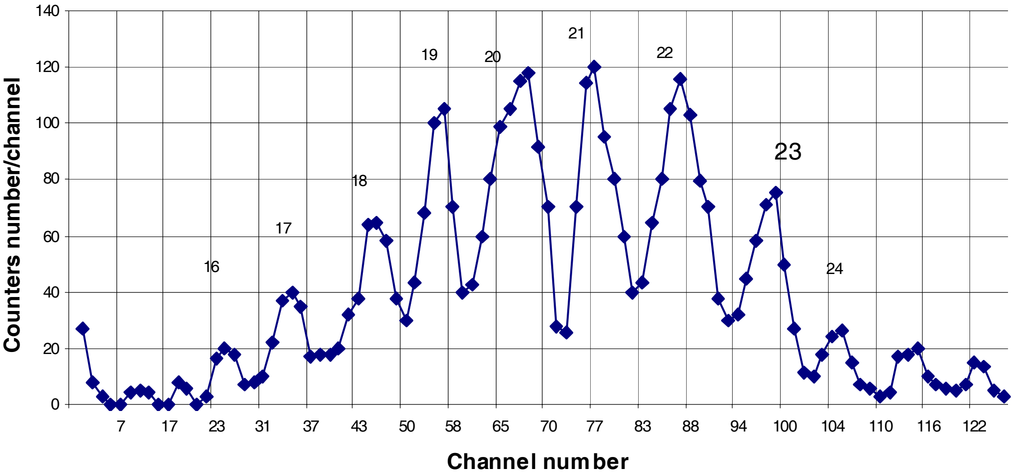


Figure 5. The amplitude spectrum of FP after the electrostatic analyzer, numbers for spikes - values of ionic charges registered FP.

Thus, with the help of a mass spectrometer it is possible to determine the statistically ensured measurements FP from the fission target without samples and with samples from investigated materials using the expression (4), effective capture cross-sections of neutrons in these materials have relative accuracy ≤ 1%.

Let us mark also, that, if before an investigated material to place filters detaining neutrons of definite energies, the given technique can be applied to measurement of relation of cross-section from energy of a neutron. Using this or filter or filter banks [8], it is possible from a flux of reactor neutrons to form before an investigated sample the neutron flux of a definite power spectrum for realization of such measurements.

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تعيين المقطع المستعرض في المعادن بطريقة مطياف الكتلة

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تم تطوير طريقة حديثة لإجراء القياسات الدقيقة لقيم المقطع المستعرض الفعال لاصطياد النيوترونات بواسطة أنووية العينات المدروسة. وتتأسس الطريقة علي قياس الشظايا الثقيلة لتفاعل إنشطار الأنوية بتأثير نيوترونات المفاعل بواسطة مطياف الكتلة. وتسمح الطريقة بقياس المقطع المستعرض للنيوترونات بدقة نسبية أقل من ١%.