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EXPERIMENTAL MEASUREMENT OF THE RATIO OF THE REACTION CROSS SECTION (n,2n) FOR THE NATURAL MIXTURES OF LEAD AND IRON ISOTOPES WITH 14 MeV NEUTRONS BY THE METHOD OF MODERATED NEUTRON-NEUTRON COINCIDENCES

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INTRODUCTION

Neutron data are widely applied in nuclei physics and into practice as well. Data obtained by means of different measurement methods are of interest for increasing the accuracy and reliability of the recommended values for the cross sections of neutron interactions with substance.

The activation analysis method gives a possibility to obtain data about cross section interactions of 14 MeV neutrons with the nuclei σ (n,2n), σ(n,p), σ(n,pn), σ(n,α), etc. A serious shortcoming of this measuring method is the necessity of applying express methods of analysis of induced activities - restrictions connected with the life-times of the reaction products. It is also necessary to comply with the requirements for high accuracy in the data about the decay schemes and the absolute intensities of the γ -transitions in the investigated nuclei.

The investigations directly measuring the output of the reaction products from the targets', placed into the neutron beam, do not possess the shortcomings of the activation method but require serious demands toward the detecting apparatuses (ionization chambers, semiconducting and scintillation detectors, proportional counters, etc.). These demands are connected with the heavy background conditions of work at the beams for measurements of whatever partial cross sections.

During the experimental measurements of the reactions by neutron emission for registration, it is necessary to slow them down to thermal energies, since only in this energy interval there exist sufficiently effective without threshold detectors. We have elaborated the experimental set-up allowing to measure the neutron multiplicity in an interaction. In the present work we have also used it for a relative measure-

ment the the reaction cross section σ (n,2n) for Fe and Pb nuclei in their natural isotope mixtures. As it is known, this reaction has an important application for the blanket materials of thermonuclear reactors and for tritium fuel regeneration problem.

The measurements were carried out on a neutron generator of the type SAMES-150 D.

II. DESCRIPTION OF THE EXPERIMENTAL SET-UP

Our method is based on the principle of moderated neutron-netron coincidences. The principle scheme of the set-up is presented in Fig.1.

Twelve neutron detectors of CHM-17 type, working in corona regime, are placed in the moderator - polyethylene cube of 35 cm side. Along the central axis of the cube, a through orifice is made of diameter 70 mm, where a thin plexiglass container with the sample is placed. The sample diameter is equal to the diameter of the neutron collimator and is 22 mm. The position of the detectors in the moderator is seen in the figure. The cube with the detectors is situated behind a shielding of thickness 130 cm made of polyethylene granules and iron grains. A collimator of monolith block of iron of diameter 100 mm and light aperture of 22 mm is installed on the wall. The detector block position is so adjusted that ensures full streamflow of the sample by the collimated neutron beam. Data on the characteristics of the investigated samples are given in Table 1. It follows that the samples are "thin", therefore corrections of changing the neutron flux in them are not necessary. Measurements were carried out at accelerating voltage of the generator 140 kV.

E l e c t r o n a p p a r a t u s

The principle scheme of the used electronics is presented in Fig. 1. The outgoing pulses of every detector come to the entrance of the corresponding preamplifiers, ensuring constant and equal duration of outgoing signals for all detectors. Temporary shapers also discriminate the neutron signals against noises and allow to level the intensity of the charges from every separate detector. Signals are summed by a linear summator and by means of a cascade of four dis-

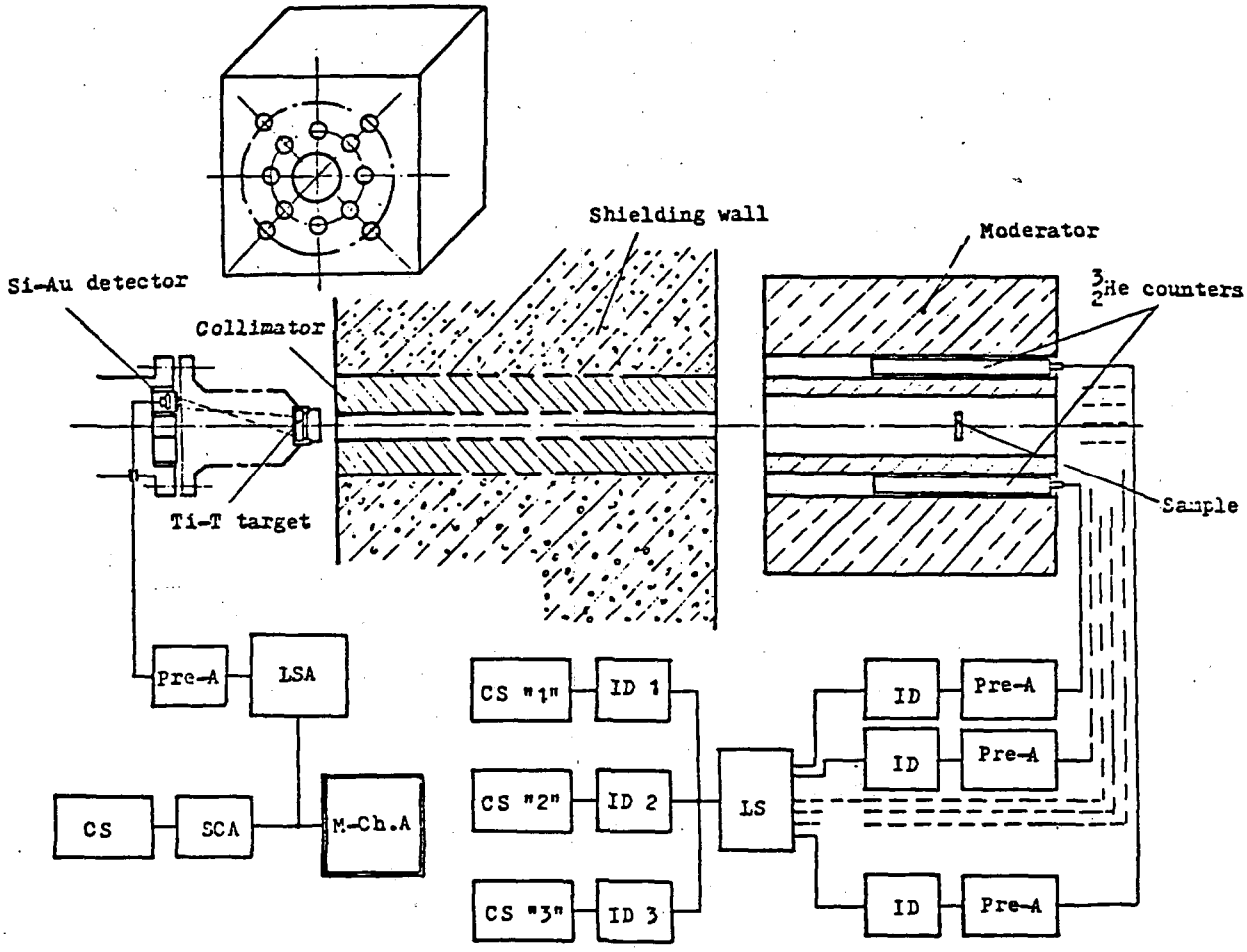

Fig. 1 Principle scheme of the experimental set up. The upper part of the figure shows the position of the detectors in the moderator.on a scale.

Pre-A - charge sensitive preamplifier
LSA - linear spectroscopic amplifier
SCA - monochannel analyzer
CS - count scheme
ID - integral discriminator
LS - linear summator
M-Ch.A- multichannel amplitude analyzer

criminators signals are obtained,corresponding to the appearance of one or overlapping of two, three and more pulses from the neutron detectors. Every one of these events is registered in a corresponding scaling circuit.

For selection of the moderated neutron-neutron coincidences we chose resolution of τ = 30 nsec. Special measurements of the life-times and the neutron thermalization have not been made in our moderat-

TABLE 1

Nuclear physical characteristics of the investigated samples

Samples	Quantity of nuclei x cm^{-2}	σ_{tot} (Barns)	$N_s \sigma_{tot}$	$\sigma(n,2n)$ (barns)			
		/9/		/3/	/4/	/5/,/6/	/7/
Fe	$2,212.10^{22}$	2,587	0,054	0,470±0,036 R = 4,27±0,66	0,472 R=4,265	0,45	
Pb	$0,565.10^{22}$	5,3823	0,030	2,006±0,156	2,01		2,13±0,25

or, so the choice of τ is rather arbitrary. We used only this measurement of the neutron emission with scintillation tanks where the resolution times are of the same order.

III. NUTRON FLUX MONITORING

The purpose of the experiments is to obtain nuclear data, so the main task consists in correct monitoring the number of particles passing through the sample. For fulfilment of this condition we prepared a target attachement to the neutron generator (Fig. 2). In front of the attachement a cooling diaphragm is placed, limiting the deutron beam up to the dimensions of the working spot in the Ti-T target. Behind the diaphragm a holder is put in which five surface-barrier Si-Au detectors can be mounted which registrate the alpha-particles accompanying the appearance of neutrons in the reaction $D(T,n)^4He$. An analogous attachement is described in the work/2/.

When adjusting the attachment we use simultaneously both detectors the first one is screened against reverse scattered deutrons by an aluminium foil with thickness ~1 mg/cm^2, and the second one is unscreened. In practice, the detectors showed equal spectrometric properties. The measurements were carried out by a thick ^{243}Am alfa-source which was put in the place of the Ti-T target. Results showed that the loss at counting alfa-particles in the screened detector is less than 0,1 %.

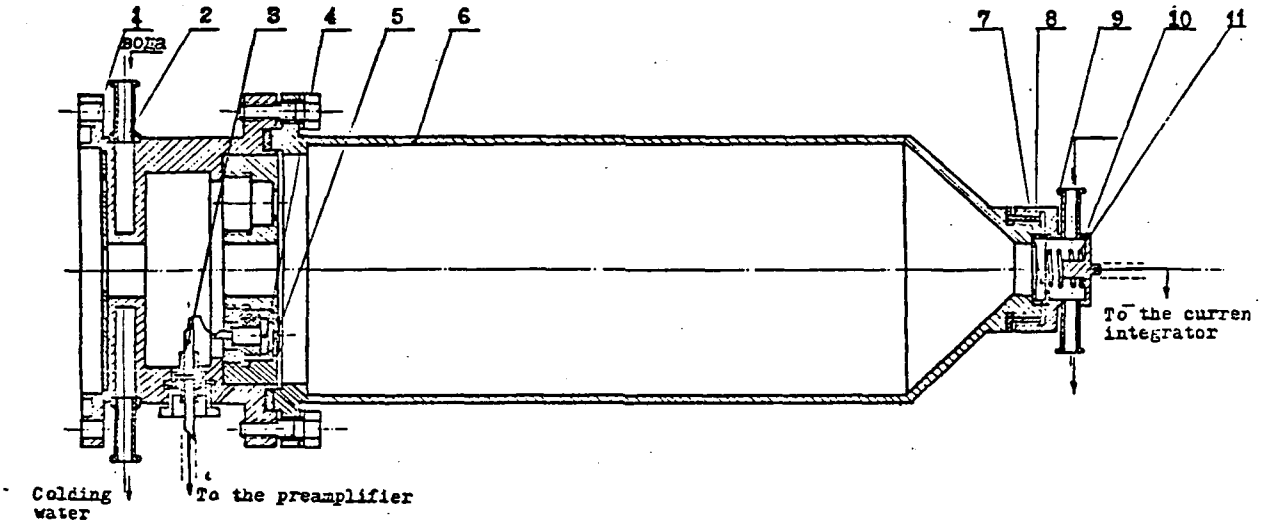

Fig. 2 General type of the -attachment to the neutron generator

1,6 - the attachment corpus
2 - copper diaphragm
3 - signal outlet of the detector
4 - Si-Au surface barrier detector
5 - aluminium foil (1 m^2/m^2)
7 - Ti-T target
8 - isolation garniture
9 - teflon vacuum tight substrate of the target
10 - pressing corpus
11 - contact spring

The results from the measurements of the α-spectra directly in the deutron beam (Fig. 3) showed that the ratio between the peak areas from screened and unscreened detectors differs with less than 0.3%. Therefore, the shielding of the detector from scattered deutrons does not insert distortions in the number of registered α-particles. In working conditions, the monitoringof the neutron beam was done by a screened detector with active surface limited to 0,8mm^2. Continuous measurements of the alfo particles have been carried out for controlling the target state. As it is seen in Table 2, the process of target burn up increases more and more the influence of the $D(D,n)^3He$ reaction resulting, on its part, in decreasing the ratio of the monitor record to the record of single neutron pulses ("Σ"-

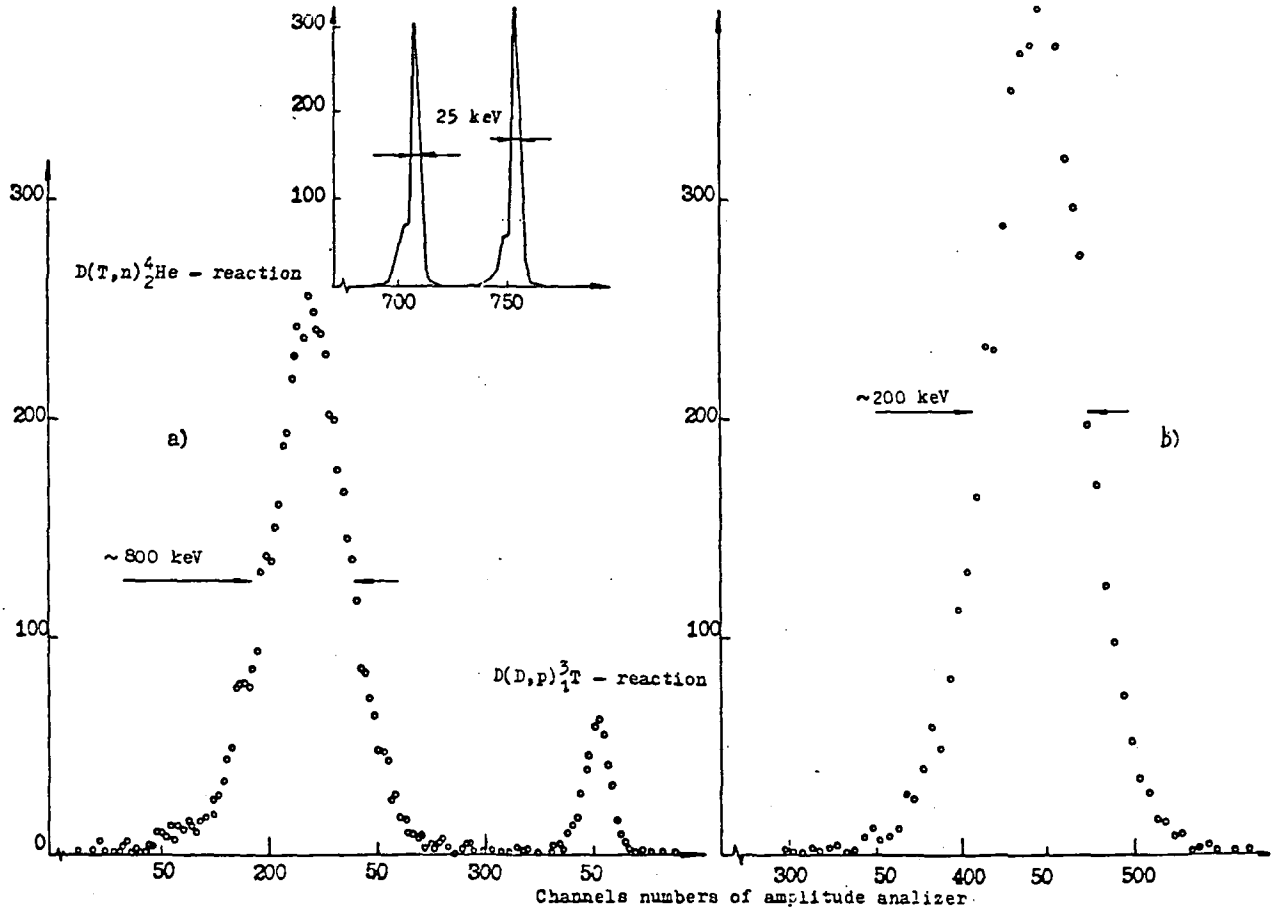

Fig. 3 Amplitude spectrum of α-particles from shielded (a) and unshielded detectors (b). The spectroscopic properties of Si-Au surface-barrier detectors are shown in the upper part.

TABLE 2

Numerical Data of the Measurable Values of an Iron Sample in the Course of Work of a Target

No.	Monitor		Monitor	"2"	"3"	effect	background
1	492664	72960	6,752	241	0	96,0	31,1
2	445203	69782	6,387	227	0	94,2	29,4
3	404227	66891	6,035	197	1	75,0	27,3
4	291612	52421	5,563	133	0	58,0	19,9
5	216006	41313	5,228	96	1	50,5	15,6

channel). As the energy of ^{3}He nucleus is insufficient for overcoming the protection of the Si-Au -detector, this ratio should drop.

The monitoring of the neutron beam was also carried out by one-channel analyzer in whose window was the α -peak. The results from the record of the one-channel analyzer and the peak area measured by the amplitude analyzer (bacground defined by the trapezium method) showed great stability toward the record in single neutron pulses. That is why we consider that monitoring can be done only by an one-channel analyzer.

In the monitor's channel we used surface-barrier detectors and standard electronic blocks from the firms CANBERRA and ORTEC and a multichannel amplitude analyzer CANBERRA-40.

IV. MEASUREMENTS AND DISCUSSION

The experimental measurements were carried out in 1000-sec time intervals. This is dictated by the necessity of stability and repeatedness of results. Series of 24 measuring intervals for iron samples and 17 for lead samples were carried out.

Experimentally measured values are the numbers of registered single neutron pulses N_Σ, double and triple coincidences $N^{(2,3)}$ and the quantity of monitoring pulses M_x. Among all calculated values, the number of double coincidences is the most correct and simply connected with the channel of reaction (n,2n):

$$(1) \qquad N_{eff}^{(2)} = c \cdot \sigma(n,2n) \cdot N_s \cdot \Phi_n$$

where: $N_{eff}^{(2)}$ - real number of registered double coincidences obtained by counting the background;

c - proportionality coefficient expressing the registration efficiency of the double coincidences;

N_s - number of nuclei in the sample;

Φ_n - neutron flux passing through the sample. In our experiment this value is simply expressed by the pulse number M_x registered by the monitor during the measuring time.

The number of registered triple coincidences $N^{(3)}$ for the conditions of our experiment is put before all by the emission effect of two neutrons in the reaction (n, 2n) and the incident coincidence of a single neutron scattering. For this reason, in spite of the somewhat small number $N^{(3)}$, we add them directly to $N^{(2)}$.

It should be noted that the dependence (1) is true if we suggest that the detector efficiency does not depend on the reaction neutron spectra and on their angular distribution. The geometry of the detecting system, as well as the moderating properties of polyethylene, allow us to consider these suppositions filfilled.

Table 2 represents numerical data of the values measured for a cycle out of five measuring intervals of the iron sample for the different extents of a target burn up. These data illustrate the order of magnitudes obtained in our experiment.

The number of double coincidences measured in our experiment, $N^{(2)}$, includes the true coincidences $N^{(2)}_{eff}$ as well as the background events. The nature of the background coincidences could be different. If the source is uncorrelated, i.e. the neutron emission goes on by one and is uniformly distributed in the time, then for a system of 12 detectors (outgoing signals equal in intensity) the following formula holds

$$(2) \qquad N^{(2)}_{b,nc} = n_{\Sigma}^{2} \cdot \frac{11}{12} T \tau$$

where $N^{(2)}_{b,nc}$ - the number of uncorrelated background double coincidences registered by a system of detectors for measuring time T;

n_{Σ} - charge intensity of the summarized channel (one-act events);

τ - resolution of the coincidence scheme.

For checking the validity of formula (2), we carried out a measuring with the neutron source (Pu-Be, 10^4 $nsec^{-1}$). The check data are given in Fig. 4 where along the abscissa axis the charge intensity I are placed in the channel of one-act events n_{Σ}, and along the ordinate axis - the record of intensity of incident

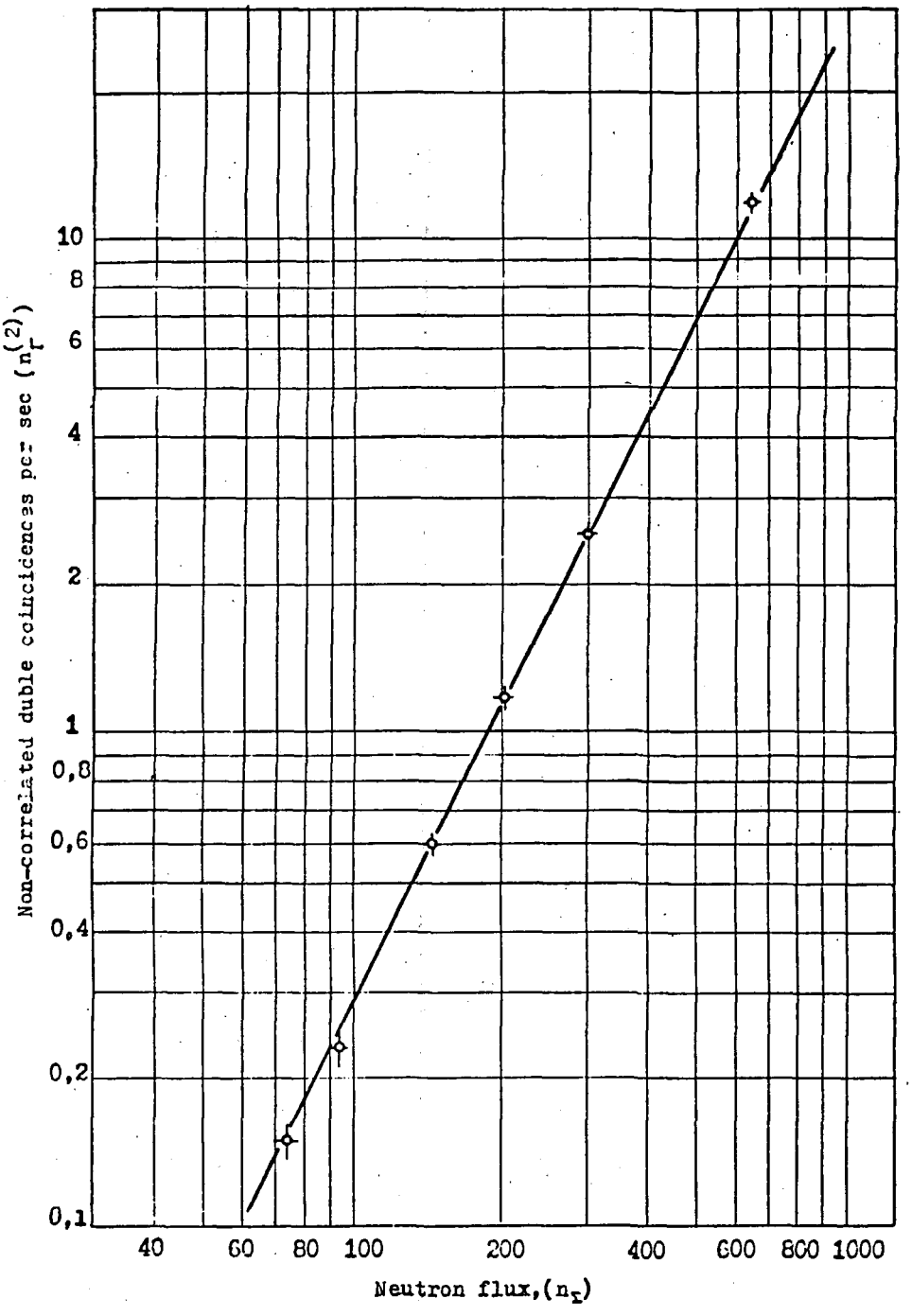

Fig. 4 Theoretical dependence and experimental measuring points of non-correlated incident double coincidences as an intensity function of registered one-act events.

coincidences $n_r^{(2)}$ The theoretical straight line is in good agreement with the measured values.

The presence of metal cases of the neutron detectors, cadmium shielding of the polyethylene cube and the construction materials around it can be a source of correlated background

from the reaction (n,2n) of these materials. Here the spectrum of scattering sample neutrons as well as the final scattering effects of the collimator neutrons appear determining. We conducted a series of experiments by irradiating imitating samples of graphite and polyethylene with beam of 14 MeV neutrons. The results of these measurements showed that the difference between the number of registered double coincidences $N^{(2)}$, calculated by the formula (2) and the number of uncorrelated incident coincidences with regard to $N^{(2)}$ is less than 1%. For this reason we neglected the uncorrelated background.

Error calculation

The errors of our experiment due to lack of correlated background is thoroughly determined by the sum of the statistical errors of the number of registered double coincidences $\sqrt{N^{(2)}}$ in every measuring interval and the error from calculating the number of incident coincidences.

The estimation and the exact expressions for calculating the depositions of the different factors participating in the experiment in the summarized value are obtained by the differentiation formula (2).

1. The differential formulas (2) for the n_Σ variable gives the following dependence of of the partial error $\Delta N_\Sigma^{(2)}$ of the measurement related to the errors of the measurements in the channel of single events:

$$\Delta N_\Sigma^{(2)} = 2 n_\Sigma \cdot \left[\frac{11}{12} T \tau \right] \qquad (3)$$

It is very important to note that the value Δn_Σ has a complex character. It is a result of the summing from purely statistical and systematical errors ($= \frac{\sqrt{N_\Sigma}}{T}$) determined by the neutron flux stability during measuring. Taking all necessary measures we achieved in maintaining the count stability n_Σ in the limits of 10 %. At that, it proved that both - statistical and systematical errors - are approximately equal.

2. The magnitude of indefiniteness of the scheme of coincidences of the resolving time $\Delta\tau \simeq 0{,}01\tau$. According to the procedure of differentiation, the calculated value $\Delta N^{(2)}$ should be systematically increased to 1%.

3. The longitude indefiniteness of the time interval is significantly less than 0,001 T that is why we neglected its influence over the value.

4. The sample weight and their chemical purity can also be sources of systematical errors. As far as we worked with precisely measured ($\sim 0{,}01\%$) substances of peculiar chemical purity, we consider that the contribution of these sources of errors is negligibly small.

As a result of the serial measurement carried out taking into account the influence of the recalculated above sources of errors, we registered the following numbers of true double coincidences for both samples correspondingly:

for Fe - 2 251±202

for Pb - 2 412±208.

In processing the data for lead, we did not record the influence of reaction (n, 3n). The neutron energy in our experiment is in the region of the threshold of this reaction and besides that it appears as a function of the extent of target burn-up, which would significantly complicate the records of its influence on the obtained results.

The ratio cross section value of (n,2n)-reaction for both nuclei which is the ultimate goal of the investigations carried out, is expressed in the following form:

$$(4) \quad R = \frac{N_{eff}^{(n)}(Pb)}{N_{eff}^{(n)}(Fe)} \cdot \frac{M_{Fe} \cdot N_s^{Fe}}{M_{Pb} \cdot N_s^{Pb}} = 4.23 \pm 0.74$$

where $M_{Fe,\,Pb}$ - is the summed monitoring count during the measuring time of lead and iron correspondingly.

The comparison of the result obtained by us with the data from other authors become complicated due to the relative character of our measurements. Most suitable for comparison are the data publish-

ed in the paper by Frehaut et al.[3] (see Table 2), who measured the cross sections of (n,2n)- reaction for natural isotope mixtures of lead and iron by the same method in the limits of the same neutron energy region. It is in good agreement with these data. Table 2 shows the comparison with the tabulated data presented in paper [4]. It should be noted that our results are in good agreement with the calculated values of σ (n,2n) with the cited papers [4,5,] for iron and with the paper by Iwasaki et al[7] for lead, and do not agree with the data in [8] for ^{56}Fe appearing as a basic isotope component.

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