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REGISTRATION OF CONVERSION ELECTRONS IN A WIDE ENERGY RANGE BY THE DETECTING SYSTEM "Si PLANAR DETECTOR – METAL Gd CONVERTER"

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The possibility of conversion electrons registration in a wide energy range by the detecting system "planar uncooled silicon detector – metal gadolinium converter" is studied. Research samples of detecting modules have been developed and manufactured. The spectrometric system for registration the energy levels of conversion electrons has been modernized. For the first time all levels of conversion electrons were experimentally registered in the energy range 30…200 keV by the detection system "silicon planar detector – metal gadolinium converter".

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INTRODUCTION

Gadolinium is a powerful neutron absorber that converts the incident radiation into a set of products of cascade reactions, which directly (electrons) or indirectly (photons) ionize the recording medium, which is used as silicon planar detectors.

Table 1 lists the energies of conversion electrons, Auger electrons, and gadolinium gamma quanta after the capture of Gd (n, γ), which are given in [1].

Prominent internal conversion electrons, X-rays and Auger electrons after Gd (n,γ) capture

Energy of reaction product, keV	Emission rate, nc^{-1}	Nature of reaction product
4.8	0.207	Ae^-(L-shell)
6.1	0.053	XR($L_{\alpha1}$)
6.7	0.033	XR($L_{\beta1}$)
7.1	0.011	XR($L_{\beta2,15}$)
7.8	0.006	XR($L_{\gamma1}$)
29.3	0.166	Ice^-(Gd-157)
34.9	0.077	Ae^-(K-shell)
38.73	0.044	Ice^-(Gd-155)
42.3	0.264	XR($K_{\alpha2}$)
43.0	0.476	XR($K_{\alpha1}$)
48.7	0.147	XR($K_{\beta1}$)
50.0	0.042	XR($K_{\beta2}$)
71.9	0.248	Ice^-(Gd-157)
77.9	0.059	Ice^-(Gd-157)
81.3	0.051	Ice^-(Gd-155)
131.7	0.030	Ice^-(Gd-157)
149.0	0.006	Ice^-(Gd-155)
174.1	0.011	Ice^-(Gd-157)
180.1	0.003	Ice^-(Gd-157)

Registration of thermal neutrons, which is of great importance for modern medicine and experimental physics, is used in the world's leading scientific centers. The prospect of detecting thermal neutrons using a system based on metal converters with a large thermal neutron capture cross section, which are located close to the surface of a semiconductor silicon detector, is shown in [1–4]. Gadolinium is used as a converter due to the fact that it has the largest thermal neutron capture cross section (up to 300,000 barns).

This work continues research on the registration of thermal neutrons using planar silicon detectors with a neutron converter made of metallic gadolinium, the results of which are presented in [5–9].

In [5], using a single-channel silicon planar uncooled detector (SPD), the possibility of creating a sealed detecting module for the simultaneous detection of X-rays and low-energy conversion electrons formed in metallic gadolinium during the capture of thermal neutrons was shown.

In [8], a block diagram of a two-channel spectrometric detection system for detecting thermal neutrons is presented. In the first channel of the spectrometric system, the detecting module contains only a silicon detector with an active area size of 5×5 mm and a thickness of 0.3 mm. In the second channel, the detecting module contains a silicon detector with a metal Gd converter. The paper also describes a method for determining the thermal neutron flux density by a spectrometric detection system based on uncooled silicon detectors and a metal gadolinium converter.

This paper presents the results of registration of conversion electrons in a wide energy range with the possibility of eliminating background radiation using a two-channel spectrometric system under complex background conditions. For this, a silicon detector and a metal Gd converter with a polyethylene spacer between them are used in the second system channel, which is used to absorb conversion electrons.

1. DESIGN OF DETECTING MODULES

For research purposes, detecting modules with SPD active region area of 4 mm^2 were designed and manufactured.

The design of the modules is similar to that described in [5, 6] and consists of a hermetically sealed metal housing containing a detector holder, a detector, and a metal gadolinium converter mounted above the detector. The converter is located in close proximity to the detector, but without electrical and mechanical contact. The gap between the detector and the converter is 10…30 μm.

During the research, a two-channel thermal neutron registration system was used. This system uses two detecting modules with converters, while in the design of one of the modules between the detector and the converter there is a gasket that absorbs conversion electrons.

Schematic representations of the design of detector modules with a conditionally cut case are shown in Figs. 1, 2. The figures also conditionally show tear-outs on the detector and gasket, explaining the location of the converter and the absorbing gasket.

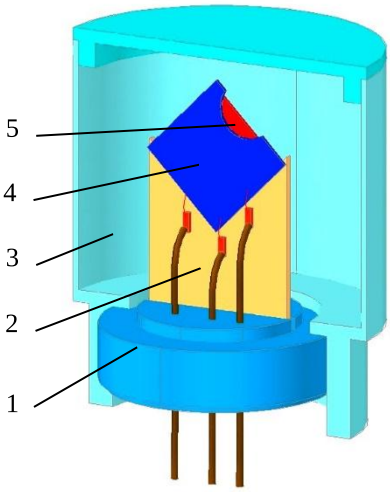

Fig. 1. Detecting module with a converter located on the rear side of the detector: 1 – base; 2 – detector holder; 3 – housing; 4 – detector; 5 – gadolinium converter

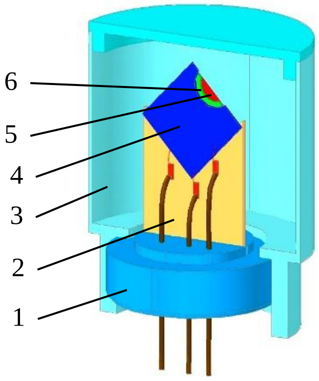

Fig. 2. Detecting module with converter and absorbing gasket: 1 – base; 2 – detector holder; 3 – housing; 4 – detector; 5 – gadolinium converter; 6 – absorbing gasket

All detectors and gadolinium converters are square in shape. To increase the registration efficiency, the gadolinium converters were polished.

A photograph of a research sample of the detecting modules without a housing with a 2×2 mm detector, a gadolinium converter and an absorbing gasket is shown in Fig. 3.

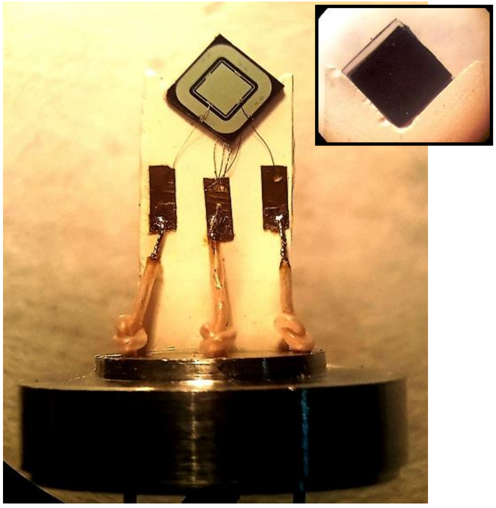

Fig. 3. Detecting module 2×2 mm with a converter and an absorbing gasket, in the upper right corner – a view of the detector from the back side

2. OPTIMIZATION OF THE ELECTRONICS OF THE SPECTROMETRIC CHANNEL

To detect conversion electrons, a two-channel spectrometric system described in [8] has optirnized. This system consists of two detecting modules, two charge-sensitive amplifiers (CSA), two shaping amplifiers, a converter unit for powering the path, powered by USB, and two spectrometric ADCs connected to a computer.

The block diagram of the two-channel spectrometric system is shown in Fig. 4.

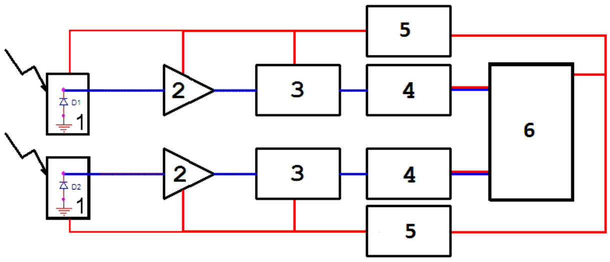

Fig. 4. Block diagram of a two-channel spectrometric system [8]: 1 – detecting modules; 2 – charge-sensitive amplifiers; 3 – spectrometric amplifiers; 4 – spectrometric ADCs; 5 – DC/DC converters; 6 – computer or laptop

In order to improve energy resolution the optimization of the CSA was carried out in two stages. At the first stage, computer modeling of electronic components was carried out, at the second stage, prototyping and testing of the modules included in the spectrometer were carried out.

The change in the energy resolution of the detector along the 60 keV line (^{241}Am) depending on the number of transistors at the input of the CSA is shown in Figs. 5, 6.

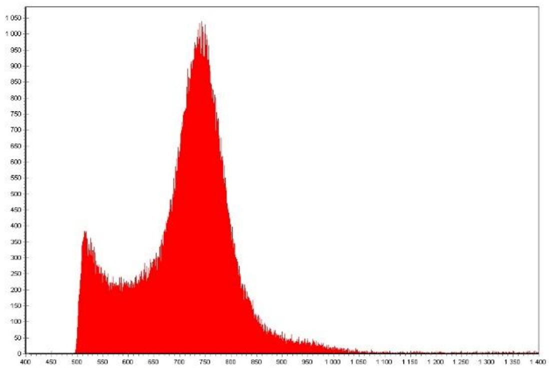

Fig. 5. One transistor at the input of the CSA. Energy resolution 8.36 keV

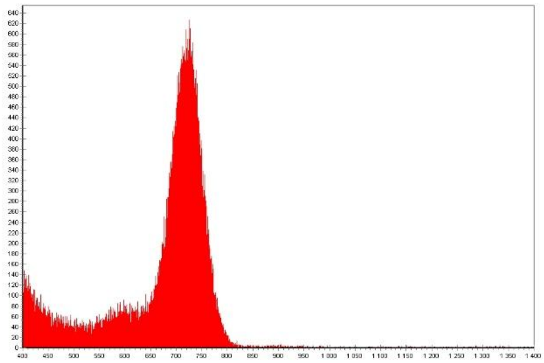

Fig. 6. Two transistors at the input of the CSA. Energy resolution 5.66 keV

A simplified diagram of CSA is shown on Fig. 7.

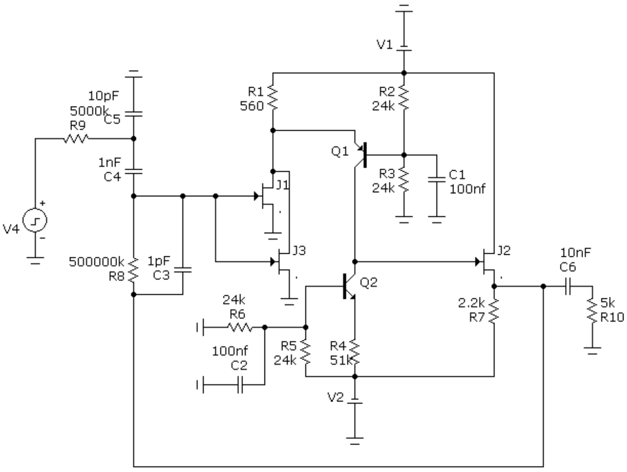

Fig. 7. Simplified circuit of CSA

Transistors J1, J3 are low noise JFETs with low capacitance Cgs < 8 pF and low gate current Ig < 1 pA. The signal from the detector is fed directly to the gate of transistors J1, J3. Fig. 8. shows the shape of the pulse at the output of the CSA obtained as a result of modeling, and Fig. 9 shows an oscillogram of the response of the CSA to the charge coming from the detector connected to the input of the amplifier.

The USB interface is used as the primary power source. To implement all the necessary supply voltages in the spectrometric device, a DC/DC converter was used.

The software of the two-channel spectrometric system implements the simultaneous measurement of two spectra and their processing.

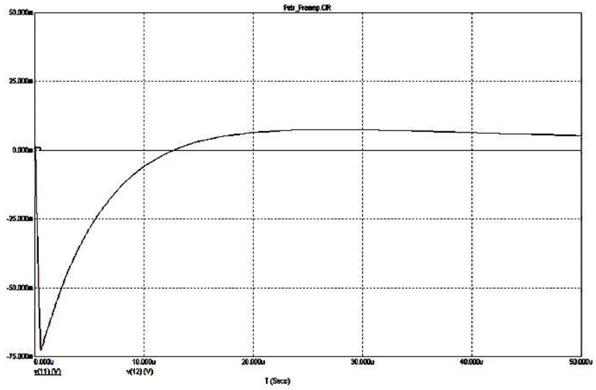

Fig. 8. The shape of the pulse at the output of the CSA obtained during the simulation

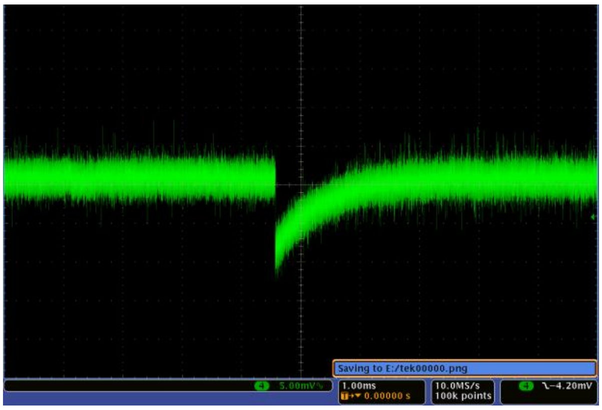

Fig. 9. A typical oscillogram of the pulse at the output of the CSA

When the program is started, a number of parameters for the program operation are loaded from the configuration file.

The program in the computer controls the setting of response thresholds, starting and stopping the accumulation of the spectrum, clearing the internal memory of the ADC. The spectra are periodically read from the internal memory of the ADC, processed and displayed on the monitor screen in the specified form.

It is possible to process the obtained spectra and correct the distortions of the spectra caused by differences in the measurement channels.

The obtained spectra are saved to files on a computer disk; previously recorded spectra can be loaded into the program for viewing and processing.

3. REGISTRATION OF CONVERSION ELECTRONS IN A WIDE RANGE OF ENERGIES

Experimental measurements of conversion electrons in a wide energy range were performed using the developed two-channel spectrometric system and manufactured detection modules based on planar silicon uncooled detectors using an IBN-21 fast neutron source. The measurement results were displayed on the screen of the control computer of the spectrometric system.

Fig. 10 shows a photograph of the stand with the spectrometric system for measuring the energy levels of conversion electrons (the control computer is not shown in the photograph).

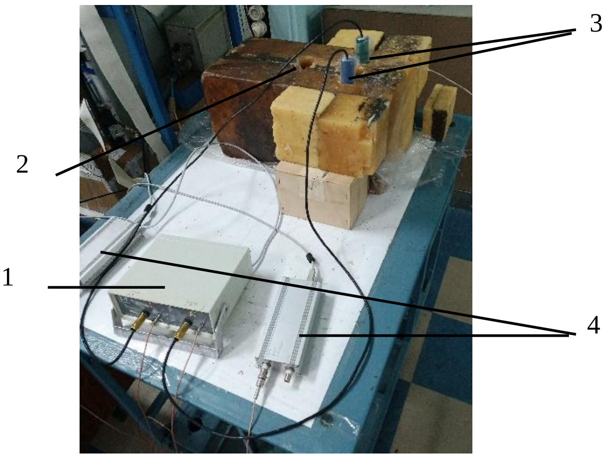

Fig. 10. Two-channel spectrometric system for registering the energy levels of conversion electrons: 1 – main block of the spectrometric system; 2 – neutron source IBN-21 in the middle of the paraffin block; 3 – detector modules with remote preamplifiers; 4 – ADC of the first and second channels

The spectra during the registration of conversion electrons in a wide energy range by planar silicon detectors 2×2 mm in size are shown on Fig. 11.

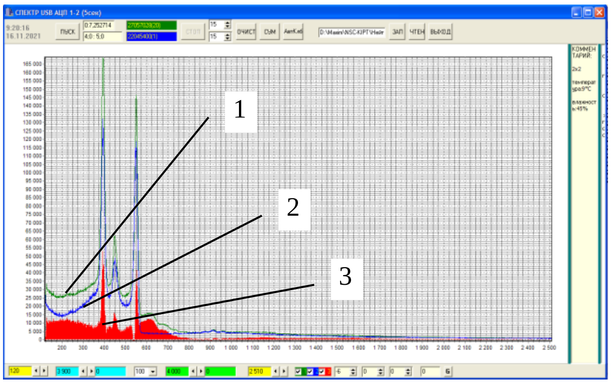

Fig. 11. General view of the control computer screen during conversion electron registration in the wide energy range by 2×2 mm detectors

Curve 1 in Fig. 11 shows spectrum of the detecting module, in which the metal Gd converter is placed close to the silicon detector without a polyethylene gasket. Curve 2 is the spectrum of the detecting module, in which the metal Gd converter is placed close to the silicon detector and in which there is a polyethylene gasket between the detector and the converter. The spectrum of conversion electrons (curve 3) was taken by automatic selection of the values of two spectra.

The peaks of gadolinium CXR were observed in the spectrum of conversion electrons, because of using fast neutrons source IBN-21. In addition to the spectrum of conversion electrons gadolinium CXR peaks are observed, which is caused by the emission of gamma quanta from the source Pu-Be and the peak with energy 59.6 keV (^{241}Am line). Figs. 12, 13 shows the emission spectrum with indication of peak energies.

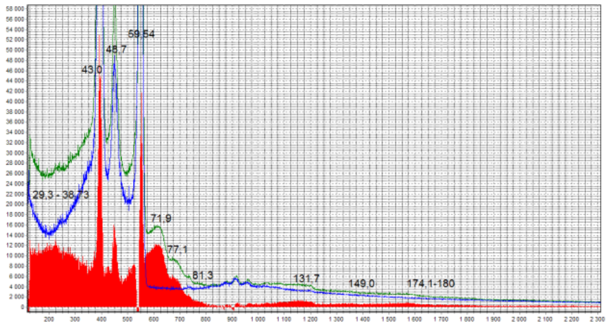

Fig. 12. Registered emission spectrum with indication of peak energies

Fig. 13 shows a plot of conversion electrons spectrum on a larger scale.

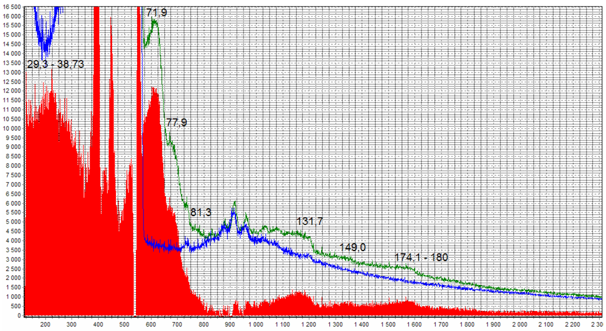

Fig. 13. Zoomed section of the conversion electrons spectrum

An analysis of the spectra of conversion electrons and the comparison of the conversion electrons peak energies with the data of Table shows a good agreement between the experimental data and the data of the paper [1].

CONCLUSIONS

Research samples of detecting modules for thermal neutrons detecting based on silicon uncooled planar detectors and metal gadolinium converters have been developed and manufactured.

The spectrometric system for registering the energy levels of conversion electrons has been modernized.

For the first time, all levels of conversion electrons in the energy range of 30…200 keV were experimentally registered by the detection system «silicon planar detector – metal gadolinium converter». A good agreement between the obtained experimental results and the literature data was obtained.

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РЕЄСТРАЦІЯ КОНВЕРСІЙНИХ ЕЛЕКТРОНІВ У ШИРОКОМУ ДІАПАЗОНІ ЕНЕРГІЙ ДЕТЕКТУЮЧОЮ СИСТЕМОЮ «Si-ПЛАНАРНИЙ ДЕТЕКТОР – МЕТАЛЕВИЙ Gd-КОНВЕРТЕР»

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Досліджено можливість реєстрації конверсійних електронів у широкому діапазоні енергій детектуючою системою «планарний кремнієвий неохолоджуваний детектор – металевий гадолінієвий конвертер». Розроблено та виготовлено дослідницькі зразки детектуючих модулів. Модернізовано спектрометричну систему для реєстрації енергетичних рівнів конверсійних електронів. Вперше експериментально зареєстровані всі рівні конверсійних електронів у діапазоні енергій 30…200 кеВ детектуючою системою «кремнієвий планарний детектор – металевий гадолінієвий конвертер».