Parameters of extracted neutron beams of the IREN resonance neutron source at the FLNP, JINR

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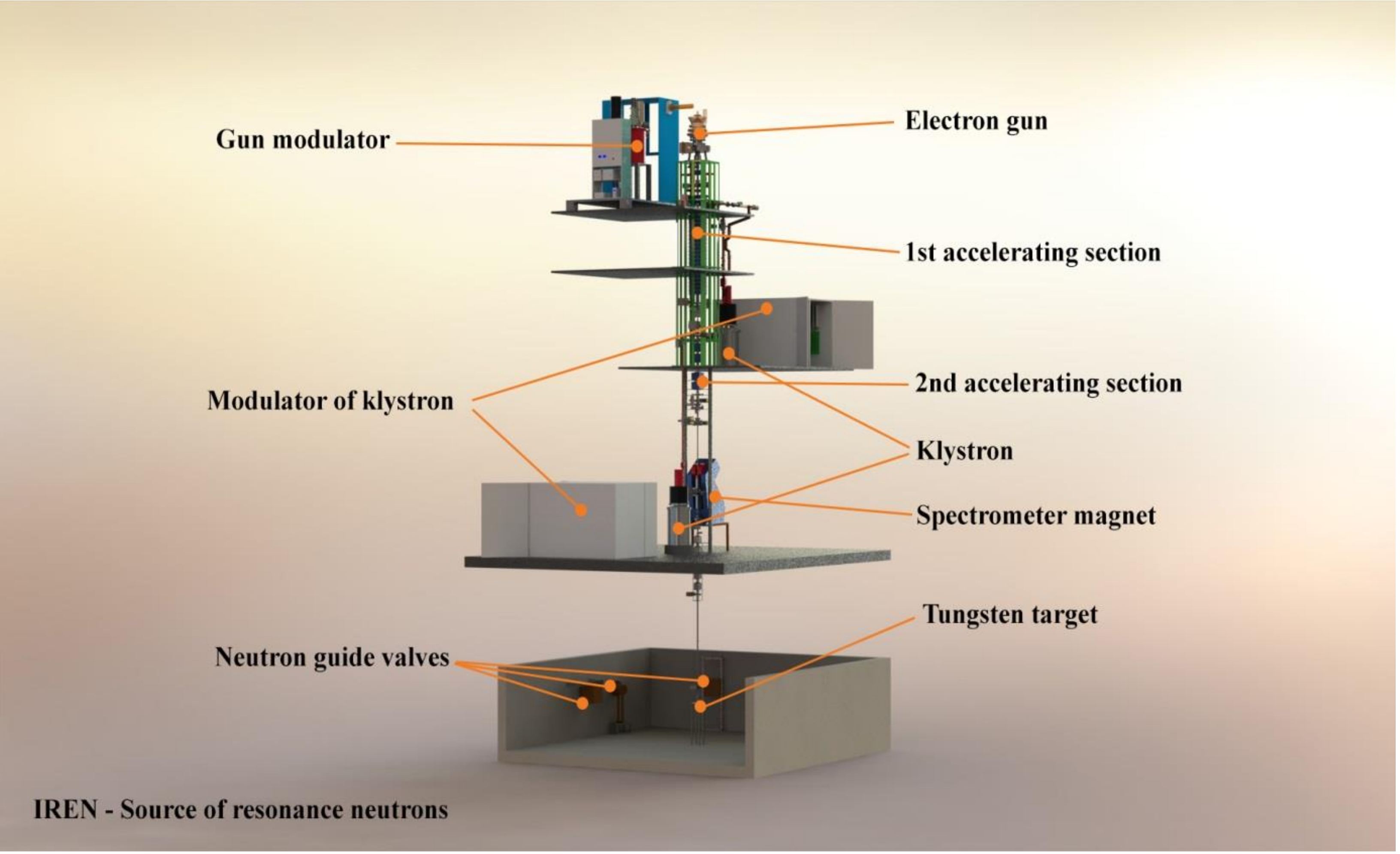
IREN (Intense Resonance Neutron Source) facility



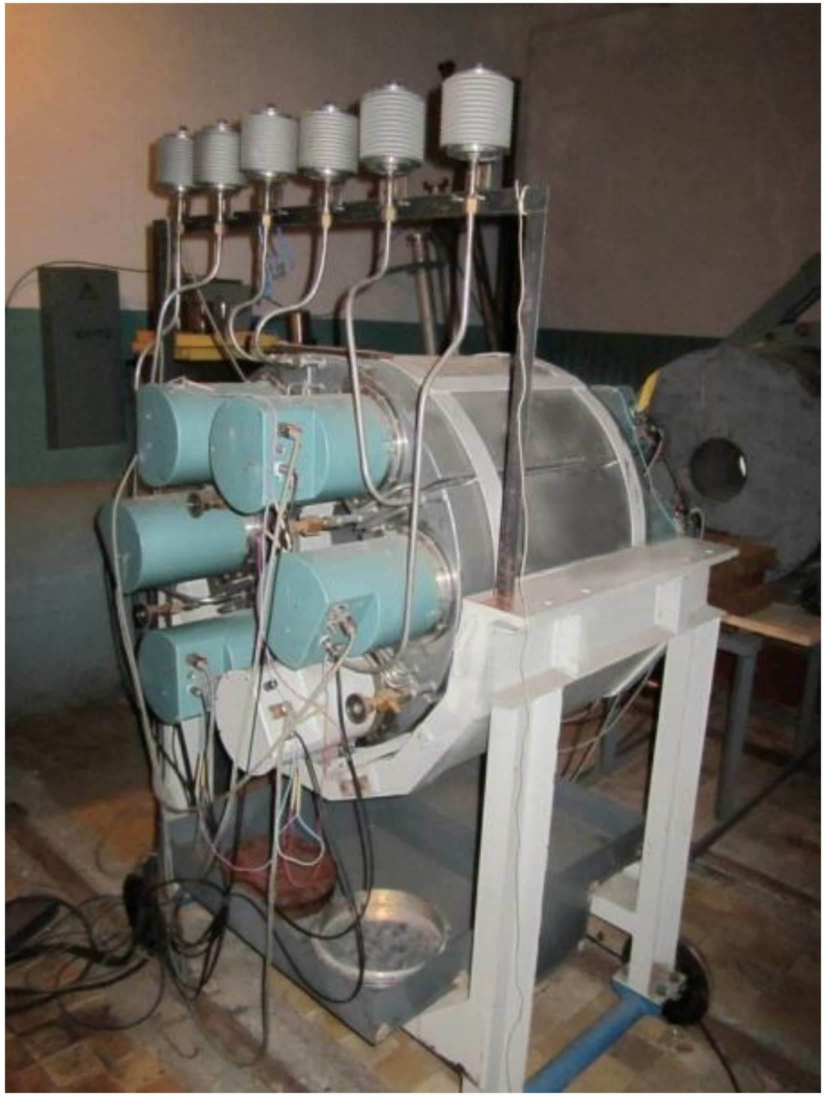
Target Material W: 90%, Ni: 7%, Fe: 1.5%, Co: 1%

Maximum emission current (A)	1.8
Repetition rate (Hz)	25, 50
Electronic pulse duration (ns)	100
Electron energy (MeV)	110
Beam power (kW)	1.2
Neutron yield (n/s)	$2 \cdot 10^{12}$

There are several instruments located on bases of the IREN facility, which are used to carry out measurements on the transmission, capture and scattering of neutrons by samples.

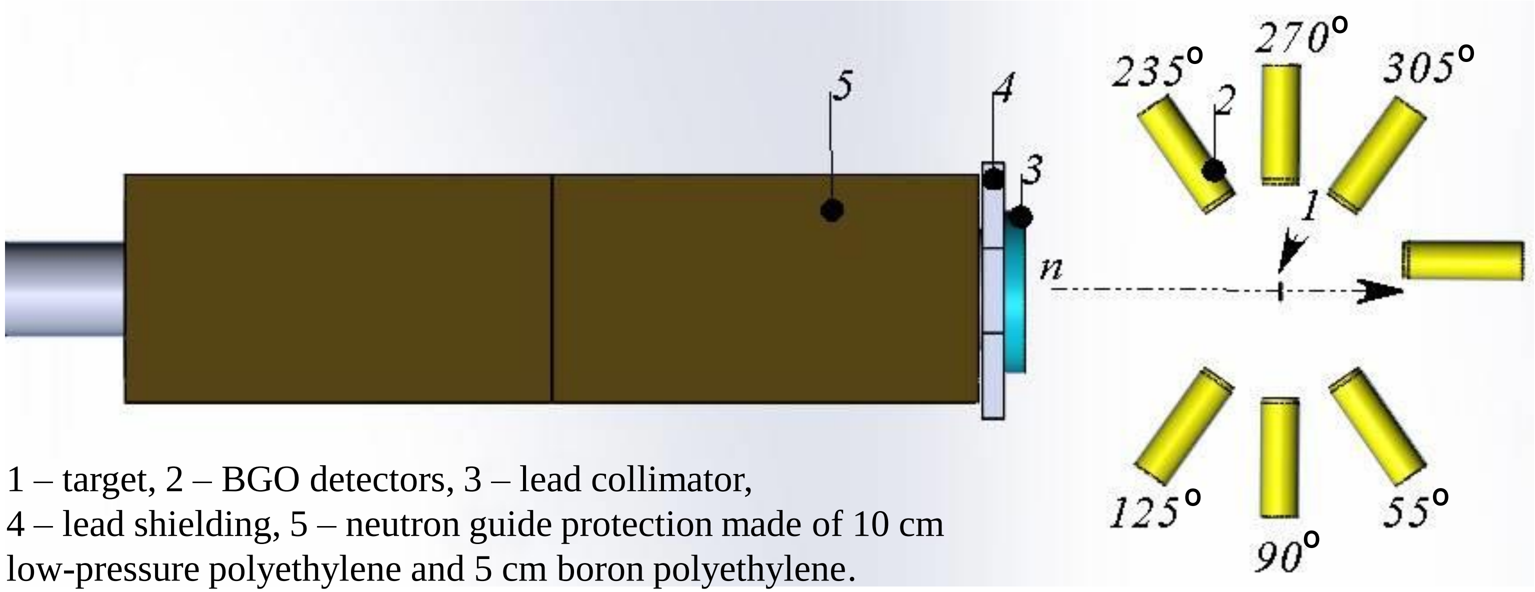
The analysis of experimental data, the assessment of the possibility of conducting, and the planning of experiments on IREN beams presuppose knowledge of the facility parameters: the absolute fluxes of resonance and thermal neutrons at the sample locations, the dependence of neutron fluxes on neutron energy, and the energy resolution function of instruments.

The method NRCA (Neutron Resonance Capture Analysis) based on 3rd channel of the IREN facility



Large liquid scintillation detector

Scheme and photos of the prototype GAMMA installation on the 11-meter base of channel 4



1 – target, 2 – BGO detectors, 3 – lead collimator,
4 – lead shielding, 5 – neutron guide protection made of 10 cm low-pressure polyethylene and 5 cm boron polyethylene.

ADC	Sampling rate	Maximum counting speed	Interface
Digital signal recorder	200 MHz	10^5 events / s	USB 3,0

2022-2025 measurements were made with silver, indium, bromine, niobium and chlorine.

Determination of resonance and thermal neutron fluxes by neutron activation analysis

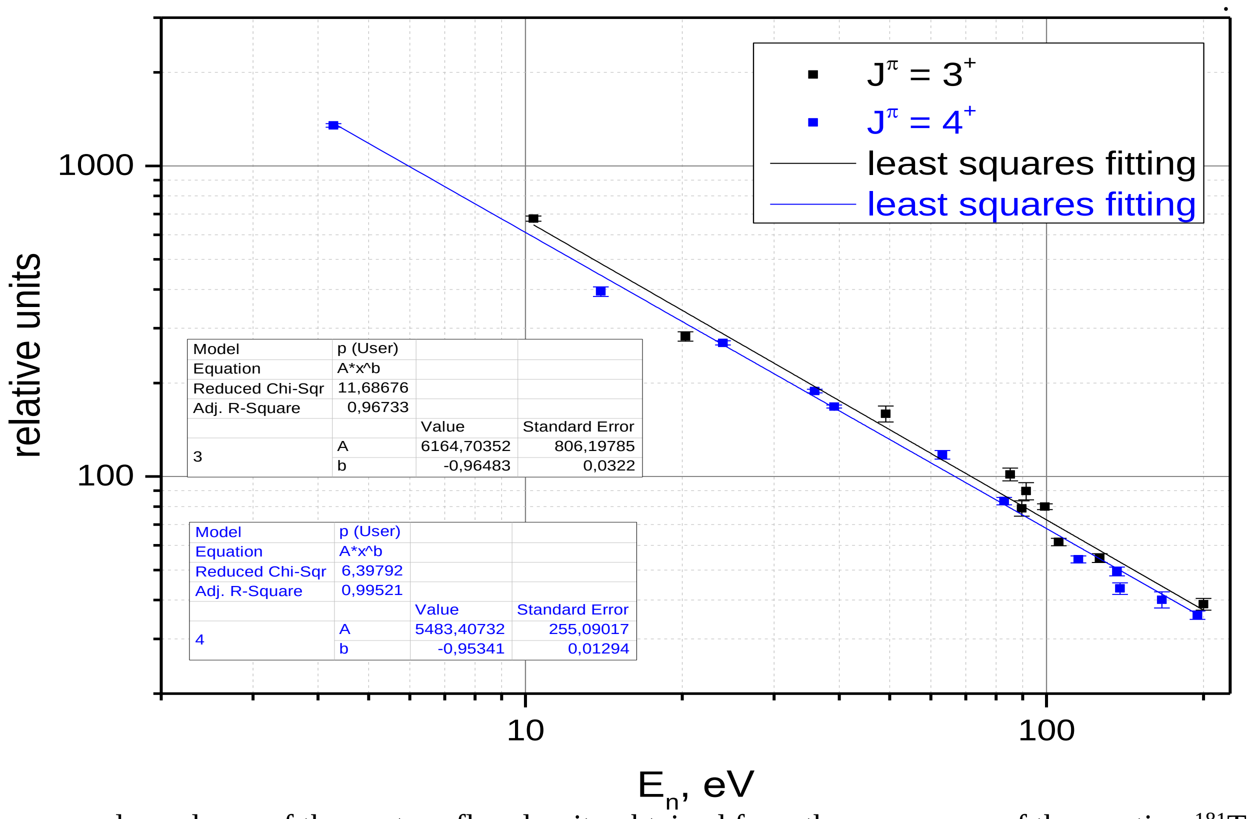
The number of neutrons at the sample location was determined using the method of neutron activation analysis. When irradiating the nucleus with thermal and resonance neutrons, the main channel is the radiation capture reaction. The result of the reaction is a neutron-excess β-active nucleus. By measuring β-activity or concomitant γ-radiation, it is possible to determine the activity that the test sample has acquired as a result of its presence in the neutron flux.

To determine the neutron flux, indicators-monitors of the same type made of gold foil with a thickness of 50 microns and an area of 1 cm^2 were installed at the sample location. Both indicators, one of which was encased in cadmium, were irradiated under the same conditions. A high-resolution HPGe detector was used to measure the activity of the monitors by recording gamma quanta from the ^{198}Au decay.

Thermal and resonance neutron fluxes measured by gold foil activation at channels No. 3, 4. The resonance neutron flux is given at 1 eV.

Channel №3		Channel №4	
$\Phi_{th}, \frac{\mathbf{n}}{\mathbf{cm^2 \cdot s}}$	$\Phi_{res}, \frac{\mathrm{n}}{\mathrm{cm^2 \cdot s \cdot eV}}$	$\Phi_{th}, \frac{\mathbf{n}}{\mathbf{cm^2 \cdot s}}$	$\Phi_{res}, \frac{\mathrm{n}}{\mathrm{cm^2 \cdot s \cdot eV}}$
217±6	133±5	(2,78±0,06) $\cdot 10^4$	(1,58±0,05) $\cdot 10^4$

Determination of the energy dependence of the neutron flux on the output of γ -quants in ¹⁸¹Ta resonances in the neutron energy range ~1 – 200 eV.



The energy dependence of the neutron flux density obtained from the resonances of the reaction $^{181}Ta(n,\gamma)$. The black squares are for resonances with $J^{\pi} = 3^{+}$, the blue squares are for resonances with $J^{\pi} = 4^{+}$; the lines are LS adjustments. The result is in the 1st row of the table for β_{α}, α is the average value for two spins.

	β_{α}	α	б
Experiment	0.9547	0.0453	0.0042
MCNP	0.9544	0.0456	0.0061
Geant4	0.9446	0.0554	0.0029

Experimental and calculated values of the parameters β_{α}, α; σ is the error of determination

The measurements were carried out on a 60–meter base of 3 channels. The sample is a tantalum foil with a thickness of 0.11 mm and a size of 12.2 x15.4 cm².

$$\sum N = \varepsilon_{\gamma} S t f(E_0) \frac{\Gamma_{\gamma}}{\Gamma} \int_{E_1}^{E_2} \left[1 - e^{-n\sigma_{tot}(E)}\right] dE$$

ε_{γ} is the registration efficiency, *S*– is the sample area, *t* is the measurement time, E_1, E_2 are the integration limits including resonance, *f(E)* is the energy density of the flow.

Neutron flux density in the Near-field of resonance with energy E_0 :

$$f(E_0) = \frac{1}{C} \frac{\Gamma}{\Gamma_{\gamma}} \frac{\sum N}{A}$$

C is a constant that depends on the registration efficiency, sample area and measurement time, A is the area above the transmission curve (dimension eV, calculated from resonance parameters).

$$f(E) \sim \frac{1}{E^{\beta_{\alpha}}} \qquad \beta_{\alpha} = 1 - \alpha$$

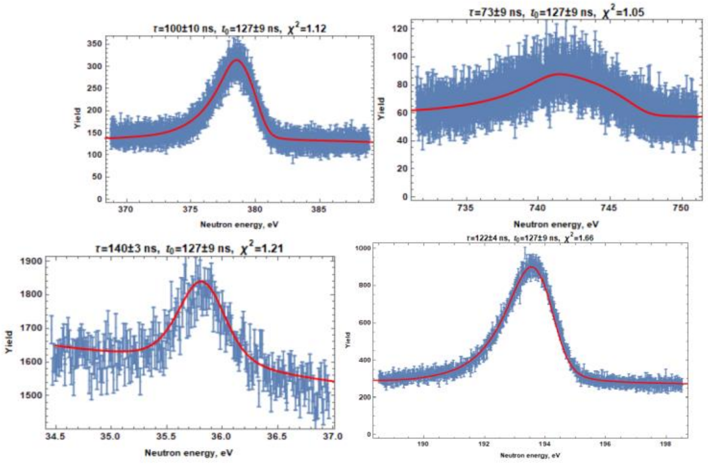
The parameters β_{α}, α were determined from the LS fitting to the experimental data.

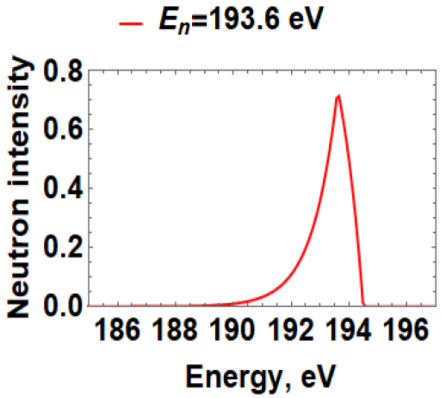
Determination of energy resolution function for 11-meter flight pass (4th channel) of the IREN facility

The resolution function of the setup according to [1] is

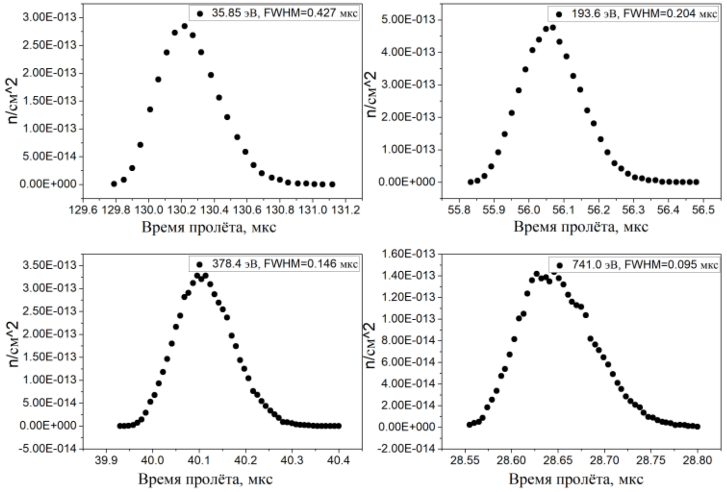
$$R(E,E') = \begin{cases} 0, \quad E' < E - \varepsilon_0; \\ \dfrac{1}{\varepsilon_0}\left(1 - e^{-t_0/\tau} \cdot e^{-\frac{E'-E}{\tau \cdot W}}\right), \quad E - \varepsilon_0 \le E' \le E; \\ \dfrac{1}{\varepsilon_0}\left(1 - e^{-t_0/\tau}\right) \cdot e^{-\frac{E'-E}{\tau \cdot W}}, E' > E, \text{где } \varepsilon_0 = \dfrac{2 \cdot t_0 \cdot E^{3/2}}{72.3 \cdot L}, W = \dfrac{2 \cdot E^{3/2}}{72.3 \cdot L}, \end{cases}$$

t_0 – the length of the electron pulse of IREN and τ is a parameter characterizing the deceleration of neutrons in a moderator surrounding a neutron–producing target.





Time-of-flight spectra of radiation neutron capture by a 200 micron thick niobium sample containing resonances of 35.85, 193.6, 378.4, and 741.0 eV.



Time distribution of neutrons of the released energies, from left to right resonances 35.85 eV, 193.6 eV, 378.4 eV, 741.0 eV.

Energy of neutrons (resonance), eV	Neutron deceleration time, τ, ns	Length of the electron pulse , t_0, ns
35,85	140±3	127±9
193,6	122±4	
378,4	100±10	
741,0	73±9	

[1] A. B. Popov, I. I. Shelontsev, N. Yu. Shirikova, Calculation of neutron resonance parameters. JINR Communication 3–9742, Dubna, 1976.

Determination of the energy dependence of the neutron flux

The energy dependence of the neutron flux was revealed from the experimental spectrum of gamma quanta by capture neutrons with 2.2 mm thick indium. The parameter α, which characterizes the deviation of the energy dependence of the flux from 1/E, was determined from the description of the experimental γ-spectra of seven detectors after background subtraction (see Fig.1) for 3 "black" resonances at energies of 1.46 eV, 3.85 eV and 9.12 eV using the least squares function $f(E) = \frac{C}{E^{1-\alpha}}$.

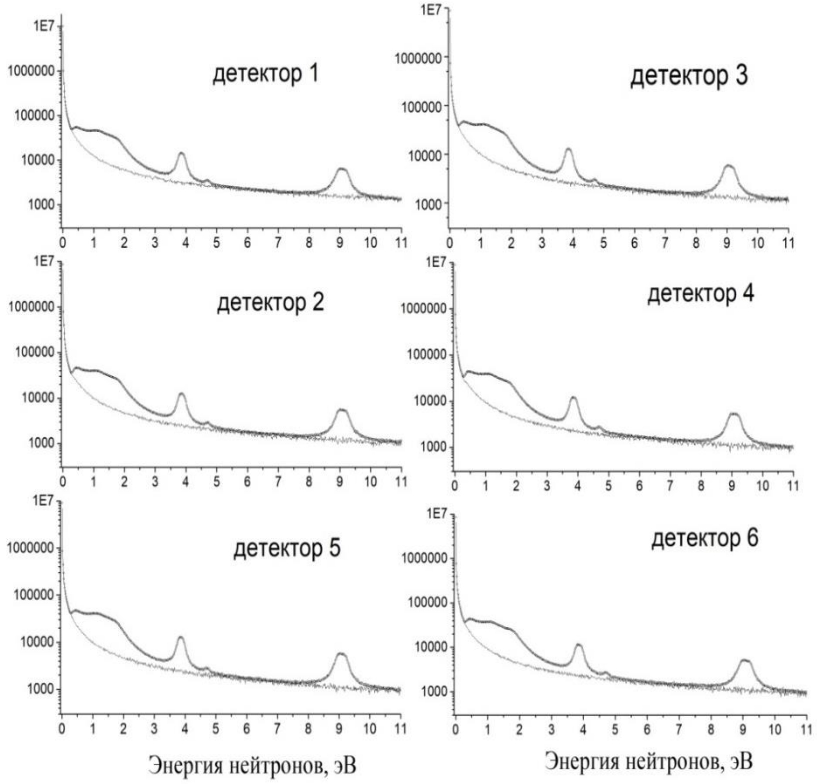


Figure 1. Gamma spectrum and corresponding background measurements.

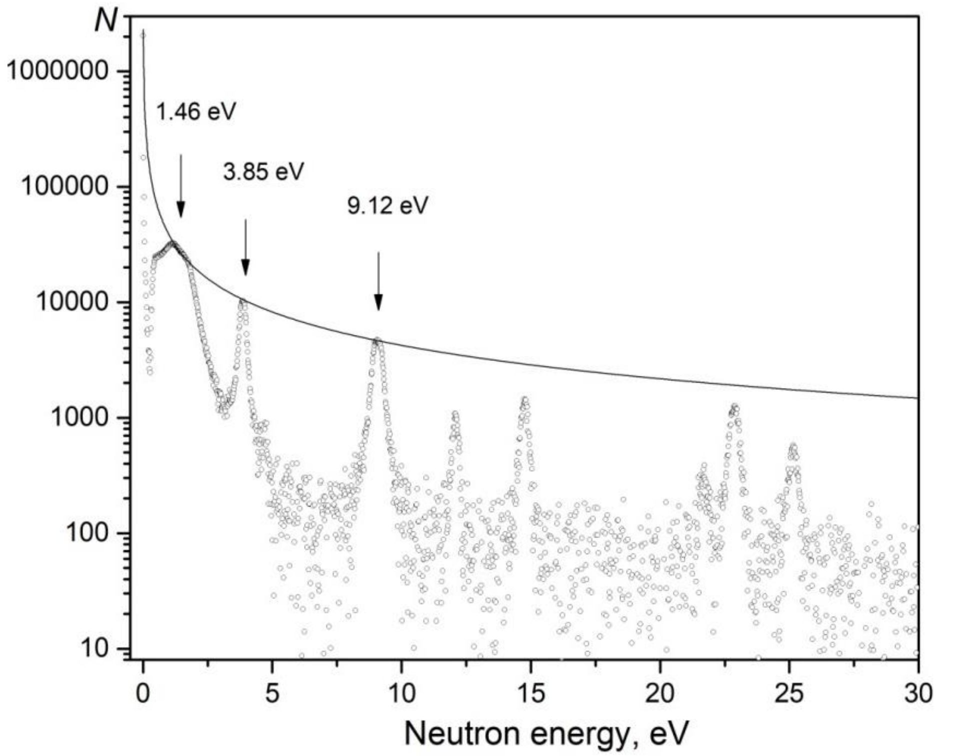


Figure 2. Fitting the function $f(E)$ to the counts in the "black" resonances of the gamma spectrum measured by detector 1.

detector	α from adjustments to the counts of 3 "black" resonances
1	0.99415E-02+/-0.4015E-02
2	0.12453E-01+/-0.4421E-02
3	0.31719E-01+/-0.4514E-02
4	0.26441E-01+/-0.4649E-02
5	0.20028E-01+/-0.4603E-02
6	0.30401E-01+/-0.4710E-02
7	0.19570E-01+/-0.5030E-02

$\alpha = 0.022 \pm 0.011.$

Conclusion

The parameters of the IREN facility necessary for evaluating the possibility of conducting and successfully planning experiments on the transmission, capture and scattering of resonance neutrons by samples have been determined experimentally and confirmed by calculations.

The values of thermal and resonance neutron fluxes, the energy dependence of the neutron flux, as well as the characteristics of the resolution function (the length of the electron pulse and the time of neutron release from the moderator) were obtained using the time-of-flight bases of two neutron beams.

Thank you for your attention!

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