Neutron spectra from $^{57}Fe(p, n)^{57}Co$, $^{56}Fe(d, n)^{57}Co$ reactions and level density of ^{57}Co

B.V. Zhuravlev, ***A.A. Lychagin, N.N.Titarenko***

State Scientific Center of Russian Federation - Institute for Physics and Power Engineering, 249033 Obninsk, Kaluga Region, Russia

The basic statistical function of excited nuclei is the nuclear level density being very important for the creation of consistent theoretical description of excited nucleus statistical properties and in making nuclear reaction cross-section calculations in the framework of statistical model. One of the information sources on nuclear level density in a range between the discrete states and the neutron binding energy with accuracy comparable with neutron resonance data are the spectra of particles emitted in nuclear reactions. In the present work neutron spectra have been measured from $^{57}Fe(p,n)^{57}Co$ reaction at proton energies between 8 and 11 MeV and from $^{56}Fe(d,n)^{57}Co$ reaction at deuteron energies of 2.7 and 3.8 MeV.. Analyses of the measured data have been carried out in the framework of statistical equilibrium and pre-equilibrium models of nuclear reactions. The nuclear level density of ^{57}Co, its energy dependence and model parameters have been determined. Such studies have been undertaken to compare the results from these reactions for one excited nucleus in a wide range of excitation energy.

Experiment

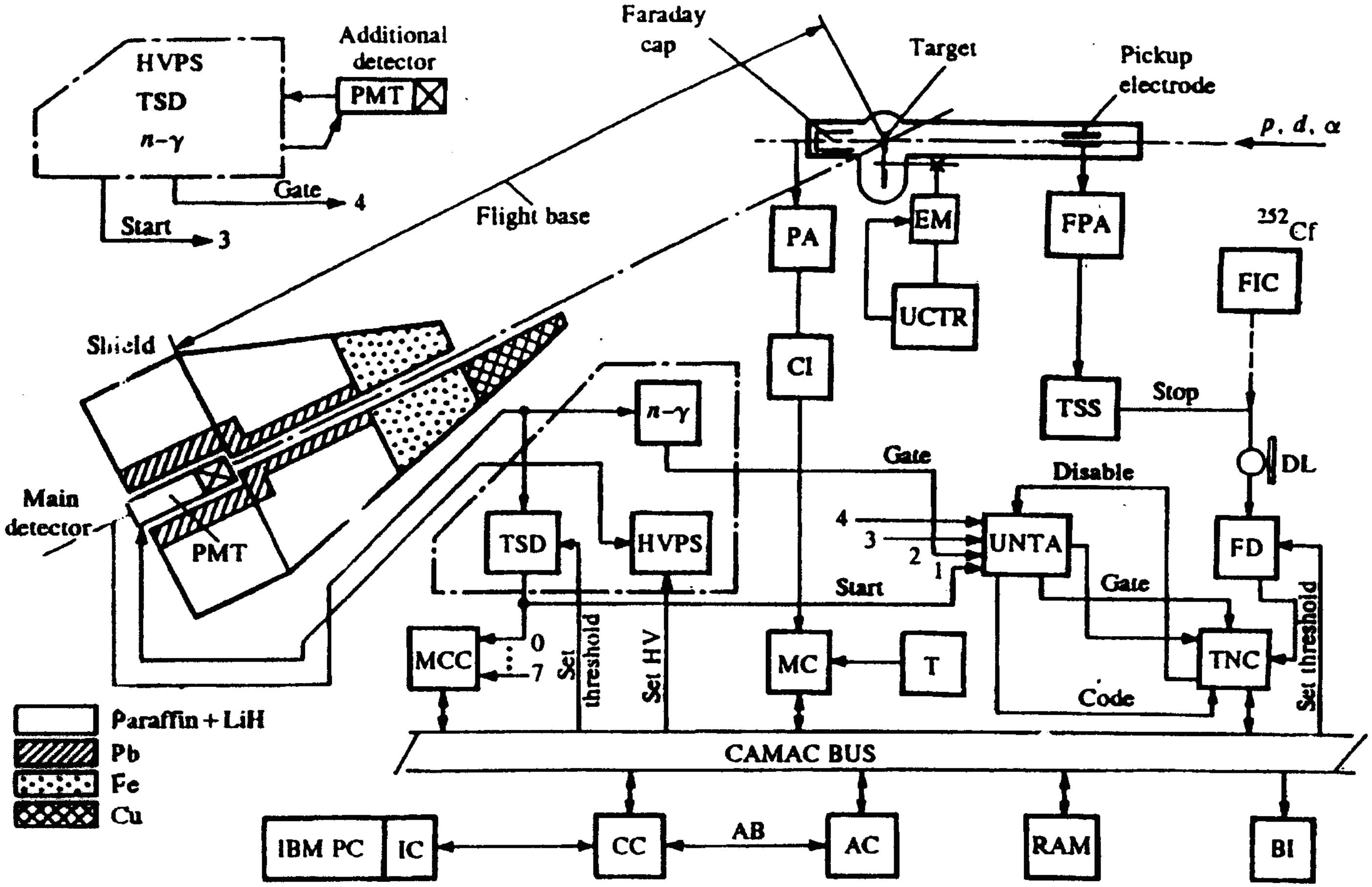
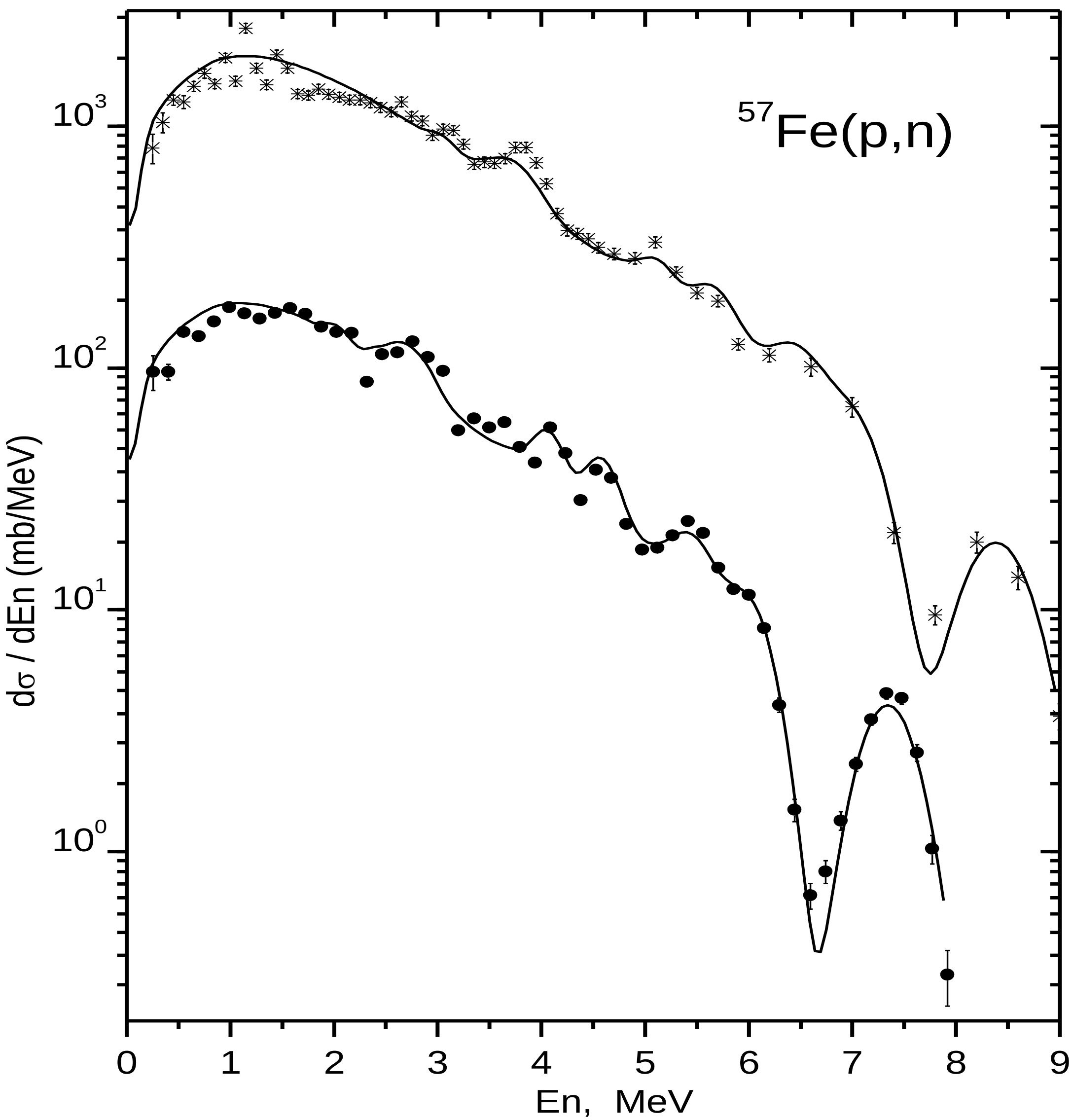
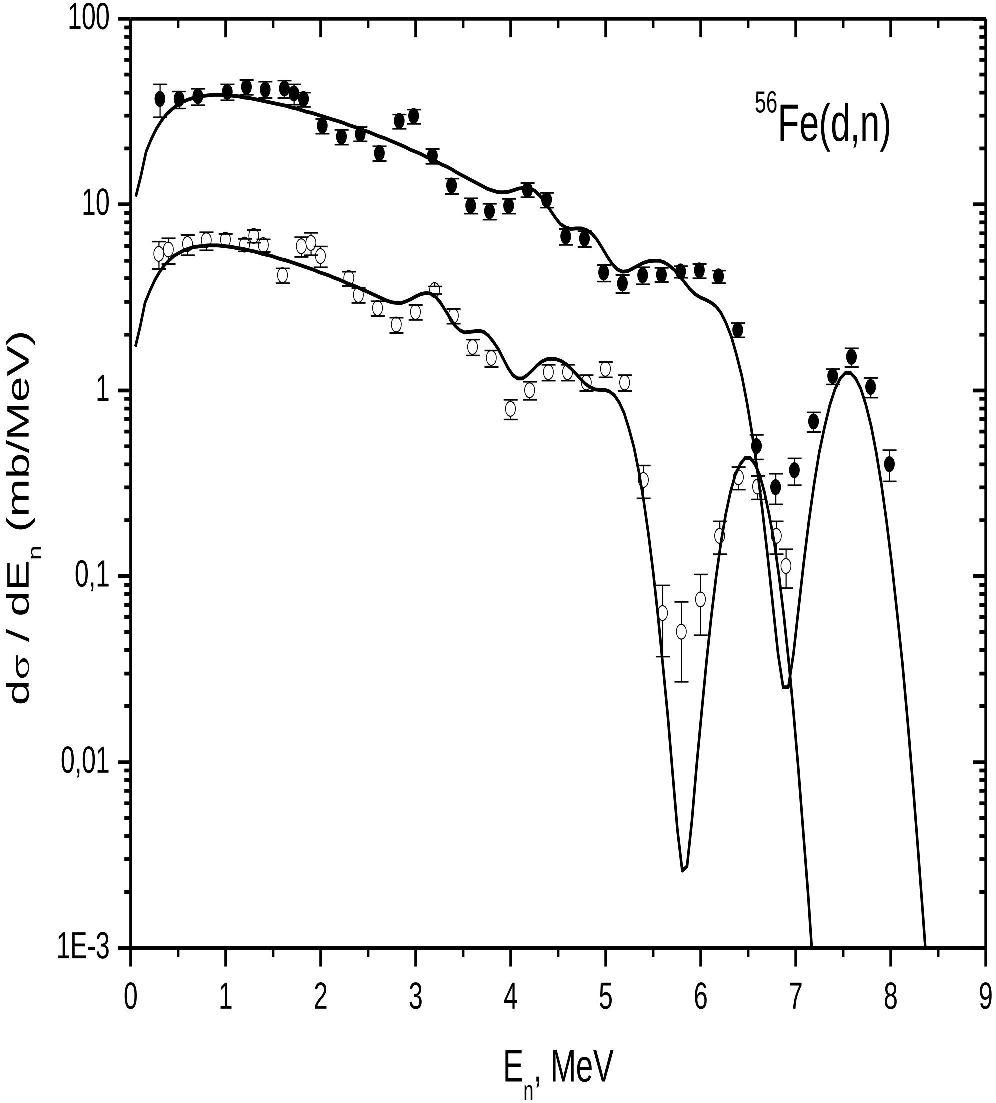


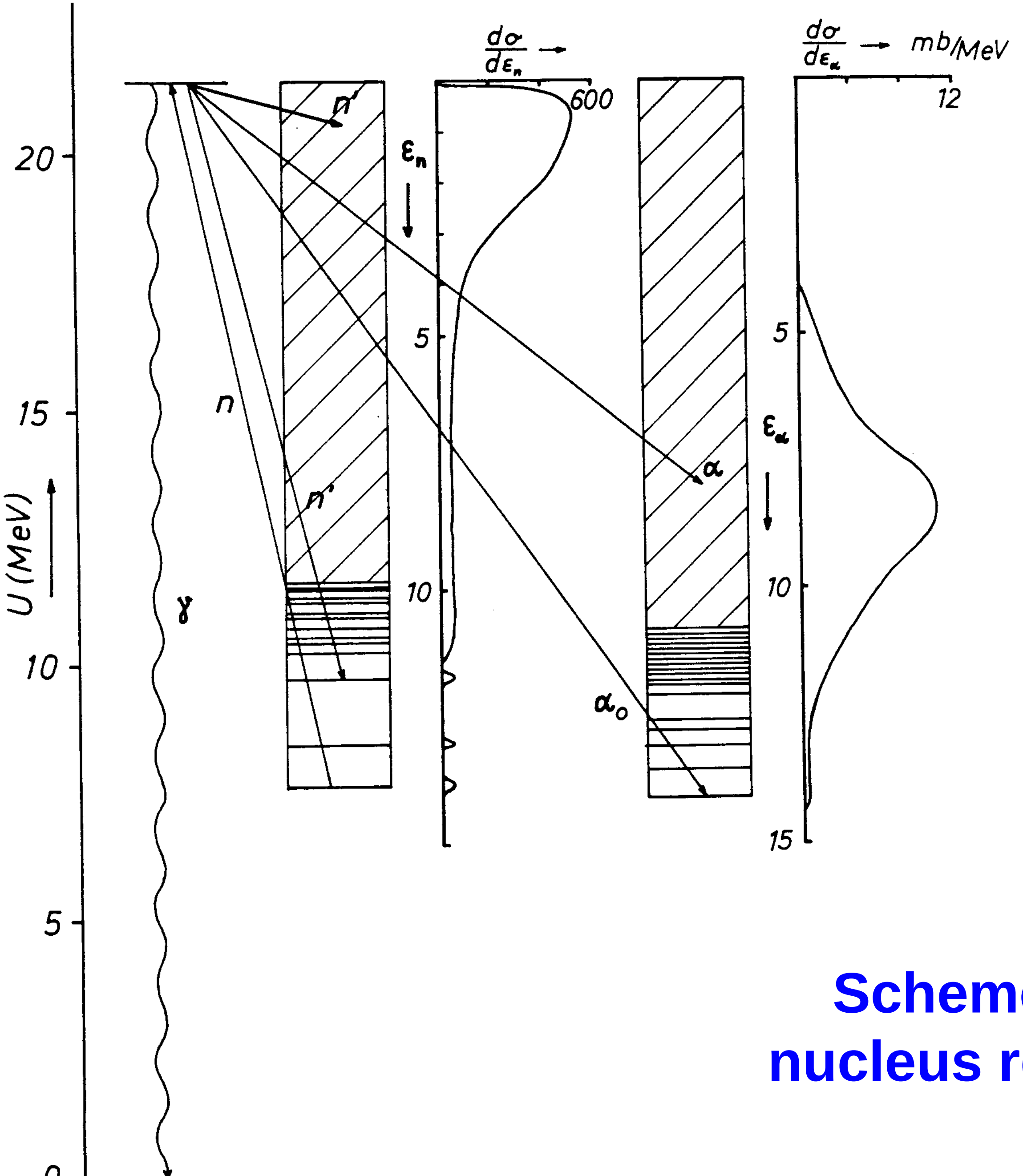
Fig. Block diagram of the spectrometer, its detecting, storing, and data processing circuits: HVPS) high-voltage power supply; TSD) tunable threshold discriminator; $n-\gamma$) separation circuit; PA) preamplifier; CI) current integrator; EM) electric motor; UCTP) unit controlling the target position; FPA) fast preamplifier; TSS) time signal shaper; FIC) fission ionization chamber; DL) delay line; FD) fast discriminator; UMTA) unit of multidetector time analysis; MCC) multichannel counter; MC) monitoring counter; T) timer; TNC) time-to-number converter; BI) bus indicator; RAM) random-access memory; AC) additional controller; CC) 106A crate controller; IC) interface circuit; AB) additional bus.



Angle-integrated neutron emission spectra from ^{57}Fe(p,n) ^{57}Co reaction. Symbols – experimental data: ● – Ep = 9.2 MeV, * - E_p = 10.2 MeV, curves – results of the calculations The values at E_p = 10.2 MeV are displaced on 1 order of magnitude.



Neutron emission spectra from $^{56}Fe(d,n)^{57}Co$ reaction. Symbols – experimental data: o– E_d= 2.7 MeV, ● - E_d = 3.8 MeV, curves – results of the calculations



Scheme of a compound nucleus reaction for specific example.

Data analysis

The method of nuclear level density determination from emission spectra is based on the fact that the nuclear level density is one of the most critical component of statistical model calculations. The procedure of nuclear level density determination consisted in following:

The model parameters of the level density are adjusted such that the cross-section calculated by means of Hauser-Feshbach formula fits the measured value in the energy range of well-known low-lying levels. It means that the total decay width of compound nucleus is determined.

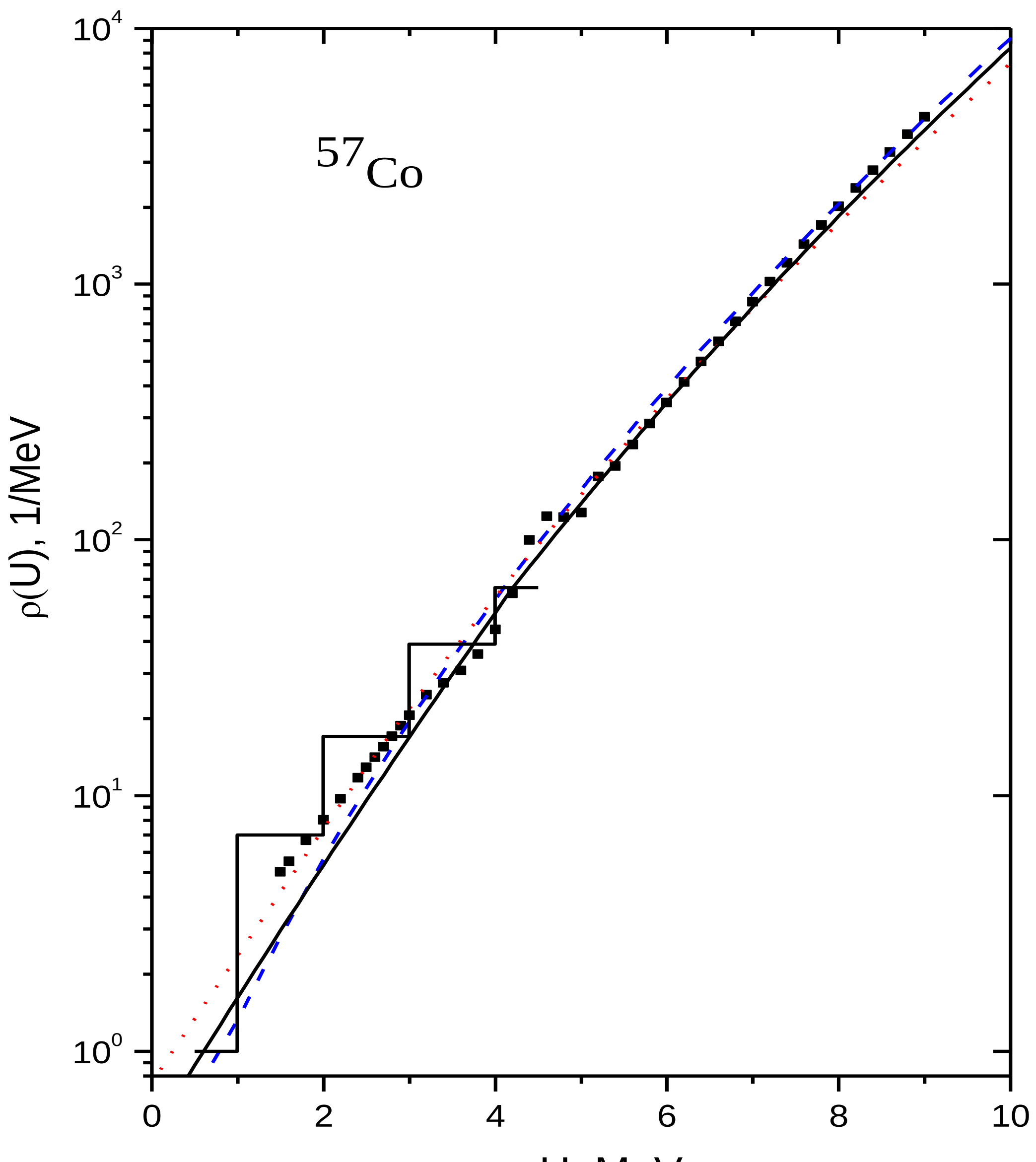
Using, at first, the chosen model of the level density and, in next iterations, the absolute values of the level density, the differential cross-section for continuum part of spectrum is calculated and the absolute level density is determined in a wide range of excitation energy from the best fit with the spectra measured.

$$\frac{d^2\sigma(E_0,E_2,\theta)}{dE_2 d\Omega} = \frac{1}{4K_0^2}\cdot\sum_{kJ_1}\sum_{l_0 j_0 l_2 j_2}\frac{2J_1+1}{(2S_0+1)\cdot(2J_0+1)}\cdot B_k(l_0,S_0,j_0,J_0,J_1)\cdot\sum B_k(l_2,j_2,S_2,J_2,J_1)\cdot\tau\cdot\rho(E_0+Q_{\alpha,n}-E_2,J_2)\cdot P_k(\cos\theta),$$

$$\tau = \frac{T_{l_0 j_0}(E_0)\cdot T_{l_2 j_2}(E_2)}{\sum_c (\sum_{l,j} T_{l,j} + \sum_{l,j,J}\int_{U_c} T_{l,j}\cdot\rho(E_0+Q_{\alpha,n}-E_2,J_2)\cdot dU},$$

$$B_k(l,S,j,J_f,J_i) = (-1)^{J_f-J_i-S}\cdot(2J_i+1)\cdot(2j+1)\cdot\langle l_0 l_0 | K_0\rangle W(J_i J_i jj;KJ_f)\cdot W(jjll;KS)$$

ρ (U) = ρ (U)assumed · [(dσ /dEn)meas. / dσ /dEn)calc.]



Results: **The extracted level density of ^{57}Co excited in reactions studied is presented in the next fig. The total uncertainties of the level density are about 15 %.**

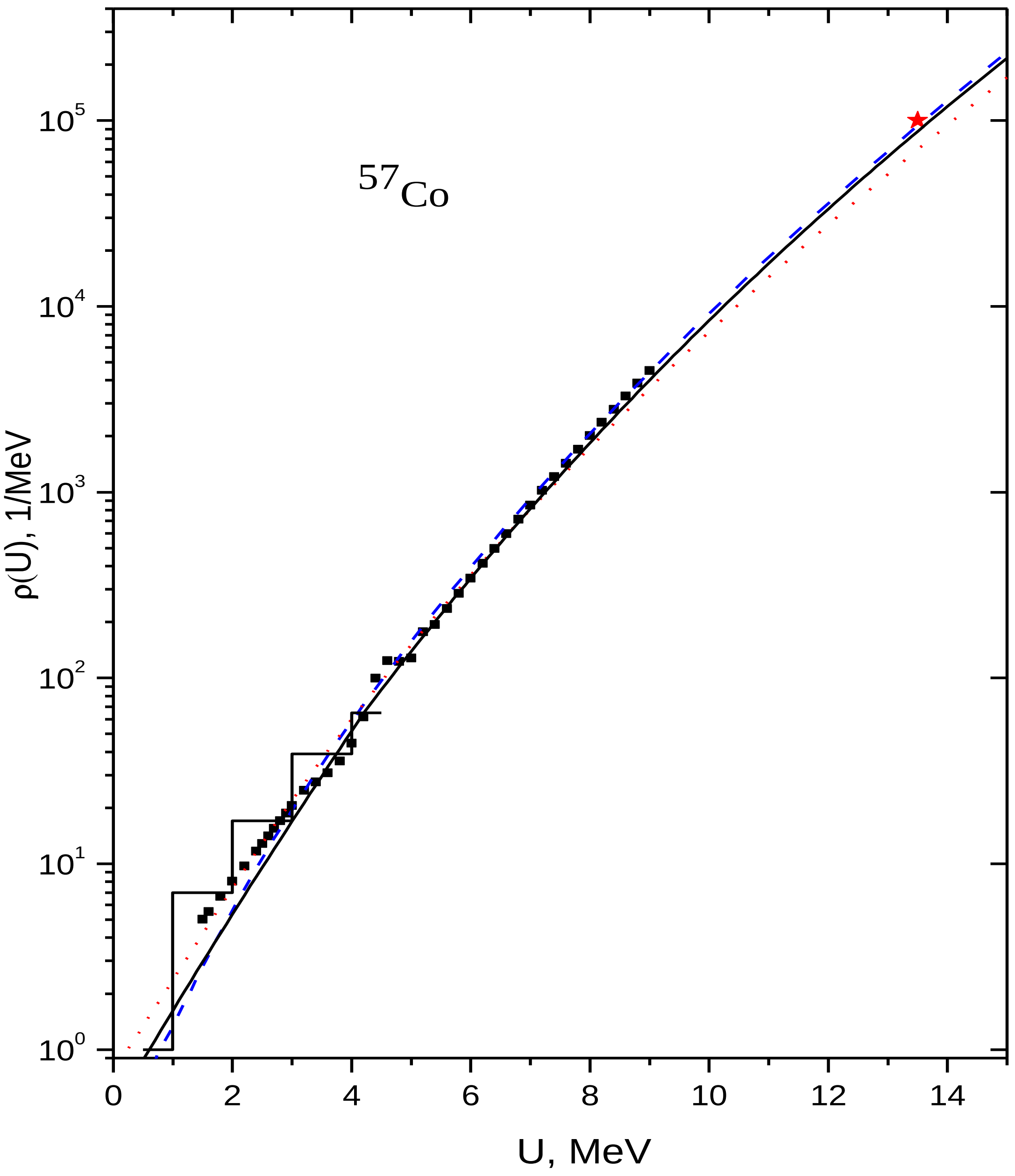
Nuclear level density of ^{57}Co.

Experimental data: ■ - present work, histogram - low-lying level data. The curves are calculated results: solid - GSN, dashed - BSFG, dotted - G-C systematics.

Table. Level density model parameters.

Model	GSN						G - C					BSFG		
Parameter / Nucleus	ã	Δ_o	δW	γ	C_v	Δ	a	Δ	E_x	T	E_o	a	Δ	I
^{57}Co a)	7.28	1.59	-3.35	0.104	0.029	0.47	6.86	0.34	1.52	0.88	0.69	6.92	0.68	I_{rig}
^{57}Co b)	5.86	1.59	-3.35	0.104	0.029	0.00	5.95	0.00	6.3	1.27	0.05	6.12	-0.02	I_{rig}

a) Parameters corresponded the best fit,
b) Parameters recommended in systematics GSN [8], BSFG [9], G-C [10]



Nuclear level density of ^{57}Co.

Experimental data: ■ – present work, histogram - low-lying level data, * - fluctuation measurements.
The curves are calculated results: solid - GSN, dashed - BSFG, dotted - G-C systematics.

Conclusions:

1) Neutron emission spectra from $^{57}Fe(p,n)^{57}Co$ reaction at proton energies of 8.1, 8.7, 9.2, 10.2, 11.2 MeV and from $^{56}Fe(d,n)^{57}Co$ reaction at deuteron energies of 2.7 and 3.8 MeV have been measured and analyzed within the framework of statistical equilibrium and pre-equilibrium models of nuclear reactions.

2) The absolute nuclear level density of ^{57}Co, its energy dependence and model parameters are determined.

3) In transition field from well-identified discrete states to continuum part of excitation spectrum the weak-marked structure is observed connected with nonuniformity of a single-particle state spectrum.

4) It is shown also that the obtained data differ essentially from the predictions of the nuclear level density model systematics.