Universal Monitor of Low Intensity Mixed Neutron-Gamma Radiation Fields Utilizing the Computer Sound Card as Multichannel Pulse Analyzer

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Abstract

At Frank Laboratory of Neutron Physics (FLNP) an exploratory research on the development of a low-cost universal detector-monitor of mixed neutron-gamma fields of low intensities is ongoing. As a detector-monitor any protected by a suitable (n,γ)-convertor γ-sensor can be used. As a multichannel analog-to-digital converter (ADC) of the pulses from the detector a PC computer sound card is used.

Keywords: Neutron-Gamma Detector; Neutron-Gamma Convertor; Prompt Gamma-Ray Emission; Prompt Gamma-Ray Neutron Activation Analysis; PGNAA.

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1. Introduction

At Frank Laboratory for Neutron Physics (FLNP) of the Joint Institute for Nuclear Research (JINR) there are 3 different types of complementary sources of neutrons of different energies, namely IBR-2 [1], IREN [2] and Van de Graaf electrostatic accelerator EG-5 [3]. A portable VNIIA ING-27 neutron generator [4] is used in TANGRA-setup [5], which is designed for the investigation of 14.1 MeV neutron induced inelastic scattering, capture and fission reactions on a number of important for nuclear science and engineering nuclei. For calibration of neutron detectors ^{252}Cf, ^{241}Am-Be, ^{239}Pu-Be are very often used. All these sources develop different intensity mixed (n+γ)-radiation fields at the places where the experimental setups are located. It is quite useful to have a single detector in a simple setup to control the level of the mixed radiation in the absence of (or in addition to) the neutron beam monitors and/or radiation dosimeters.

During the last decades there is a permanent interest in creating of such a portable and universal (n+γ) detector-monitor. The idea behind it is to register the fast neutrons [6] or to moderate them and to capture the thermalized neutrons by material having a big capture reaction cross-section (neutron-gamma converter), and to register the characteristic gamma-rays by HPGe [7-12], BGO [13-15], NaI(Tl) [13;15-17] or PVT [19-20] detectors, using the computer sound card as a multichannel amplitude analyzer (MCA) [21; 22].

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Table 1. Neutron moderating and capture media, and prompt gamma-rays producing reactions data [32; 33].

Neutron moderator and (n-γ)-converting material and reaction	%	(Most intensive) Gamma-rays energy, keV	Intensity, %	Cross sections for thermal neutrons, barns
BPE (Borated Polyethylene) $^{10}_{5}B + ^{1}_{0}n \rightarrow \begin{cases} ^{4}_{2}He + ^{7}_{3}Li \\ ^{4}_{2}He + ^{7}_{3}Li^{*} \rightarrow ^{7}_{3}Li + \gamma \end{cases}$	6 94	 477.595(3)	 92.5	759 3840
^{nat}Cd **iso** – **NA** ^{106}Cd – 1.25% ^{108}Cd – 0.89% ^{110}Cd – 12.49% ^{111}Cd – 12.8% ^{112}Cd – 24.13% ^{113}Cd – 12.22% ^{114}Cd – 28.73% ^{116}Cd – 7.49%		558.6 651.3 806.0 1209.4 1364.2 1399.0	72.73 13.9 4.95 3.61 4.95 3.17	2522(50)
PVC (Poly Vinyl Chloride) – (C_2H_3Cl)n $^{35}_{17}Cl + ^{1}_{0}n \rightarrow ^{36}_{17}Cl^{*} \rightarrow ^{36}_{17}Cl + \gamma$ $^{37}_{17}Cl + ^{1}_{0}n \rightarrow ^{38}_{17}Cl^{*} \rightarrow ^{38}_{17}Cl + \gamma$	75.5 24.5	786-788 1164.7 1950-1960	24.60 19.93 36.32	33.1(3)
NaCl $^{23}_{11}Na + ^{1}_{0}n \rightarrow ^{24}_{11}Na^{*} \rightarrow ^{24}_{11}Na + \gamma$	100	472.202(9)	90.39(57)	0.530(5)
$^{1}_{1}H + ^{1}_{0}n \rightarrow ^{2}_{1}H^{*} \rightarrow ^{2}_{1}H + \gamma$	100	2223.24835(9)		0.3326(7)
$^{127}_{53}I + ^{1}_{0}n \rightarrow ^{128}_{53}I^{*} \rightarrow ^{128}_{53}I + \gamma$	100	442.901(10) 526.557(14) 2119	16.9 1.58(7) 80	6.20(20)
^{nat}Gd **iso** – **NA** ^{152}Gd – 0.20% ^{154}Gd – 2.18% ^{155}Gd – 14.80% ^{156}Gd – 20.47% ^{157}Gd – 15.65% ^{158}Gd – 24.84% ^{160}Gd – 21.86%		780.174(10) 897.502(10) < 897.3 > 897.611(10) 944.174(10) 962.104(10) 977.121(10) 1107.612(9) 1185.988(9) < 1186.5 > 1187.122(9)	10.83 6.51 10.56 7.42 4.13 4.47 10.83 	48770(150)

The most used materials and reactions for capturing of neutrons are listed in Table.1. The main characteristics of the most used detectors of gamma-rays are shown in Table 2.

Table 2. Gamma-rays detector properties and performance [23].

Detector	BGO ($Bi_4Ge_3O_{12}$)	NaI(Tl) (compact)	$LaBr_3$(Ce) (La:Ce::200:1)	HPGe (thick planar)
Type	scintillator	scintillator	scintillator	Solid-state
Dim: Area(cm^2) x Thick.(cm)	5x2.5 or larger	5x5 or much larger	5x4 – 20x5	5x1.5 or much larger
Volume, (cm3)	13 or larger	26 or much larger	20	8
<Z>	28	32	41	32
Density, (g/cm3)	7.1	3.67	5.3	5.3
Energy resolution: % FWHM@ 122keV (Intrinsic Photoel. Eff., %)	~ 28, Fair (2.8)	~13, Fair (1.00)	~7, Good (1.00)	~0.4, Excellent (0.81)
Energy resolution: % FWHM@ 662keV (Intrinsic Photoel. Eff., %)	~12, Fair (1.00)	~7, Fair (1.00)	~2.8, Good (0.40)	~0.2, Excellent (0.10)
Photon peak λ, (μm)	480	415	360	n/a
Photon Decay τ, (μs)	300	230	35 (90%)	n/a
Cooling	No, t^o-shifts	No	No	Electro or LN_2, t^o

2. Experimental setup

Two experimental setups (Setup-1, Setup-2) have been arranged (Table 3) and their resolutions for 661.7 keV gamma-rays from a ^{137}Cs point calibration source were measured and compared.

Table 3. NaI(Tl) gamma-ray spectrometry experimental setups.

Setup	Gamma-ray detector	PMT and electronic base	Pulse (pre) amplifier	Multichannel analyser
1	Amcrys™ NaI(Tl) 78x90x200 mm^3 (Table 4)	Hamamatsu R1306 PMT with EM/2.VD.HVG	POLON Active-filter Amplifier 1101	Parsek 4k (Table 5) Parsek 8k
2		Hamamatsu R1306 PMT with EM/3.VD.HVG.PA.001	Incorporated in EM/3	Realtek ALC889 @ Intel Cougar Point PCH - High Definition Audio Controller.

The characteristics of Amcrys NaI(Tl)-crystal detector assembly are given in Table 4. Those of Parsek 4k Analog-to-Digital Convertor (ADC) are shown in Table 5.

The working voltage for Hamamatsu R1306 PMT (~1000V) is delivered by the incorporated into the PMT EM/2 (and EM/3) electronic base high-voltage generator (HVG). This voltage is “shared” between the PMT-dynodes via a resistive voltage divider (VD).

In Setup-1 the output from the NaI(Tl) PMT EM/2-base after amplification was split and fed to the inputs of 4k and 8k Parsek ADCs for a simultaneous measurement (Fig. 1).

In Setup-2 the output from the NaI(Tl) PMT EM/3-base was fed to the PC sound card Line-in. The desktop computer audio controller (sound card) was a Realtek ALC889@Intel Cougar Point PCH-High Definition one. All ADC input/outputs support independent 44.1k/48k/96k/192kHz sample rate (Figs. 4 and 5).

Table 4. Amcrys NaI(Tl) scintillation probe characteristics [24].

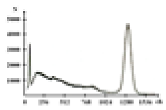
Certificate		
Production	Scintillation assembly on the base of NaI(Tl) mono-crystal in the form of regular hexagonal prism with circumradius *r* = 45 mm, side length *l* =45mm, inradius (apothem) *a* = 39 mm, and height *h* = 200mm with Hamamatsu R1306 PMT	
Date of certificate	13.01.2011	
Serial number	3243.01.01	
Type of the scintillation assembly	12x14S32/2	
Scintillator dimensions	78x90x200 mm^3	
Case material	aluminum	
PMT [25]	Hamamatsu R1306 #SV1934	
Type of electronic PMT base: VD: voltage divider HVG: high-voltage generator	EM/2.VD.HVG EM/3.VD.HVG.PA.001	
Measuring	Experimental value	
Gamma-ray source	^{137}Cs (661.7MeV)	
Energy resolution (FWHM)	6.9 %	

Table 5. Parsek 4K-SADC-USB: 4K spectrometric ADC with USB interface and USB bus supply [26].

4K-SADC-USB	http://www.parsek.ru/en/products/4KSACPUSB.html
Conversion type	Wilkinson
Number of analog inputs	1
Amplitude of input pulses	40 mV – 4.0 V
Rise time	0.5μs ≤ 20μs
Charger channel capacity	2^{32} (4096)
Number of output bits (channels)	12 (4096)
Conversion frequency	100 MHz
Integral non-linearity	0.04%
Differential non-linearity	+1.0 % at the level $5x10^4$ in the channel
Value of drift of generating peak, not worse then	0.1% within 8 hours of continuous work
Time of test	5.0 μs (or by order)
Power requirements +5 V	470 mA (2.35 W)
Structure / construction	Plastic box / 150x80x30 mm^3
Bus type	USB

3. Data acquisition and analysis

The measuring conditions, data acquisition and the results from it are shown in Figs. 2-5.

In Fig. 2 the pulse-height spectrum of gamma-rays from the ^{137}Cs calibration point source (after background subtraction), collected with Setup-1 using 4k MCA [26] is shown.

In Fig. 3 the pulse-height spectrum of gamma-rays from the ^{137}Cs calibration point source (without background subtraction), collected with Setup-1 using 8k MCA is shown. The fitting of the photo-peaks was done by Origin™ scientific graphing and data analysis software [27].

For the scintillation assembly used, the obtained by the both experimental setups gamma-energy resolution values for 661.7 MeV gamma-line of ^{137}Cs agreed with the certified value.

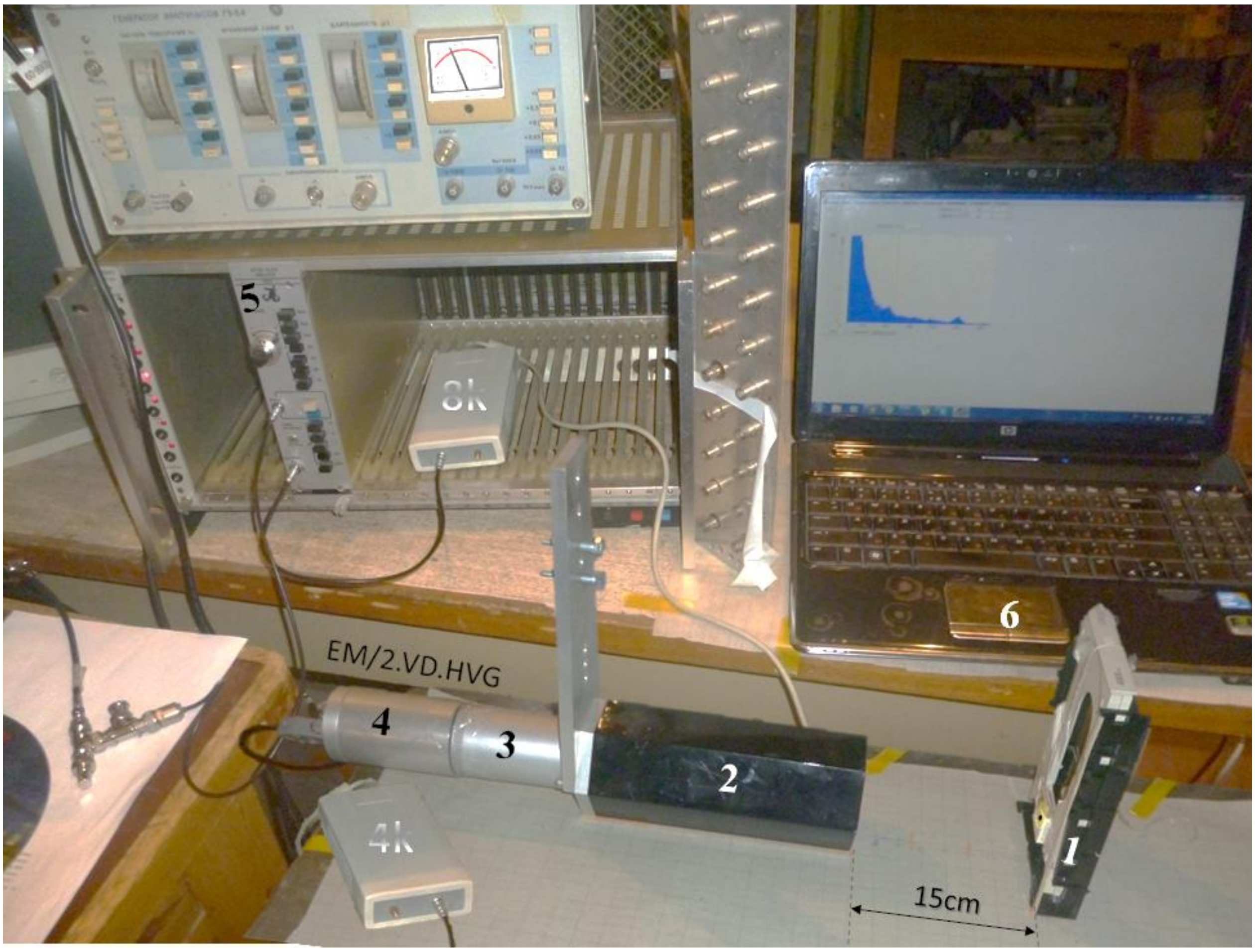


Fig. 1. Setup-1: 1-^{137}Cs calibration point source; 2- hexagonal NaI(Tl); 3- Hamamatsu R1306 PMT; 4-EM/2.VD.HVG electronic PMT-base; 5-Polon Active-filter amplifier; 6-Laptop with data acquisition (DAQ) software.

In Setup-2 (Figs. 4 and 5) the detector pulses were collected and analyzed by FitzPeaks demo software (Fig. 4) and by pulse recording and analyzing free software PRA (Fig. 5).

The FitzPeaks [28], PRA [29], Theremino [30] and BecqMoni [31] are smart software programs that transform any PC sound card into a powerful multi-channel analyzer for gamma- spectrometry. The sound card can digitize the analog "audio" signal from the scintillation detector with a sampling rate depends on its characteristics. A sampling rate of 48 kHz or in some cases of 96 kHz is sufficient for correct recording of ~1-2 kHz pulse rate from the detector.

The FitzPeaks [28] is a combined research and general purpose gamma spectroscopy analysis and calibration program capable of operating on spectral data from a variety of different manufacturer's systems. It is designed to run under all 32-bit versions of Microsoft® Windows™.

In Fig. 4 the pulse-height spectrum of the gamma-rays from ^{137}Cs calibration point source (without background subtraction), collected with Setup-2 using FitzPeaks, is shown.

The pulse recording & analyzing software PRA [29] is free software with a number of preset functions for representing of the recorded events (pulses) distributions in the form of histograms:

a) Pulse-height histogram: The most used function, which creates the gamma-spectrum. The program calculates the pulse-height and automatically bins it in up to 32,000 bins. The bin size can be changed in the settings panel. Individual peaks can be selected and highlighted, to reveal more information about the peak, such as net counts, standard deviation, etc.;

b) Count-rate vs. Time histogram: it can be used to monitor (control) the stability of the gamma-radiation intensity, as well as to measure the decay-rate of the activated object;
c) Pulse-width histogram: it is useful when testing different types of scintillators and/or (pre) amplifiers;
d) Pulse-interval histogram: creates a histogram of the intervals between gamma pulses;
e) Radiation collection sound On/Off function: for an easy sound recognition of ^{54}Mn, ^{57}Co, ^{60}Co, ^{133}Ba, ^{109}Cd, and ^{137}Cs isotopes used for calibration of a NaI(Tl) detector.

The data from PRA-histograms can be exported as text files and imported into other programs such as Excel for a better presentation of into Origin for further analyzing. Because PRA-software processes the signal by calculating its RMS-value and filtering out any badly formed pulses it improves the quality of the pulse-height spectra (Fig. 5).

There are two more free MCA software to be tested with Setup-2: Theremino (Italian MCA) [30] and BecqMoni (Japanese MCA) [31].

Like PRA, Theremino also uses a standard PC audio port to collect and digitize the signals. It is the easiest to understand and calibrate. The histograms and other data can be exported as .csv files.

BecqMoni free software was developed in Japan in response to the urgent need for environmental monitoring after the Fukushima disaster. Its pulse-shape recognition algorithm is based also on the PRA-principle. The program has many functions, such as the ability to subtract background, auto-detection of peaks, as well as to display the activity (Bq) of a sample of a given size. Its pulse-shape discriminator helps to discard any accidental (noise) pulses.

All the above presented MCA software can run also on computers with Mac (via Crossover) or Linux and Unix (via Wine) operating systems.

4. Conclusion

In order to create a low-budget detector-monitor of mixed neutron-gamma radiation a feasibility study is in progress. The review of the literature, the detectors and electronics on hand and the preliminary experiments shown that one can use a single gamma-ray spectrometer for detecting (and monitoring) low intensity mixed (neutron + gamma) fields.

The neutron-gamma converter can consist of cadmium (Cd), gadolinium (Gd) layers, borated polyethylene (BPE) and polyvinyl chloride (PVC) (or filled with NaCl) panels (or end-caps). Its dimensions can be determined by Monte Carlo simulations (MCNP, GEANT, FLUKA) and proved experimentally.

The gamma-rays can be registered by 1 (or 2; second one is if a simultaneous background radiation measurement needed) large-volume Amcrys NaI(Tl) gamma-ray spectrometer(s) using a desktop (or laptop) PC sound card as a multi-channel pulse analyzer and free MCA software for pulse data analysis. Further research includes also comparing of all known at the moment free MCA software: FitzPeaks, PRA, Theremino and BecqMoni.

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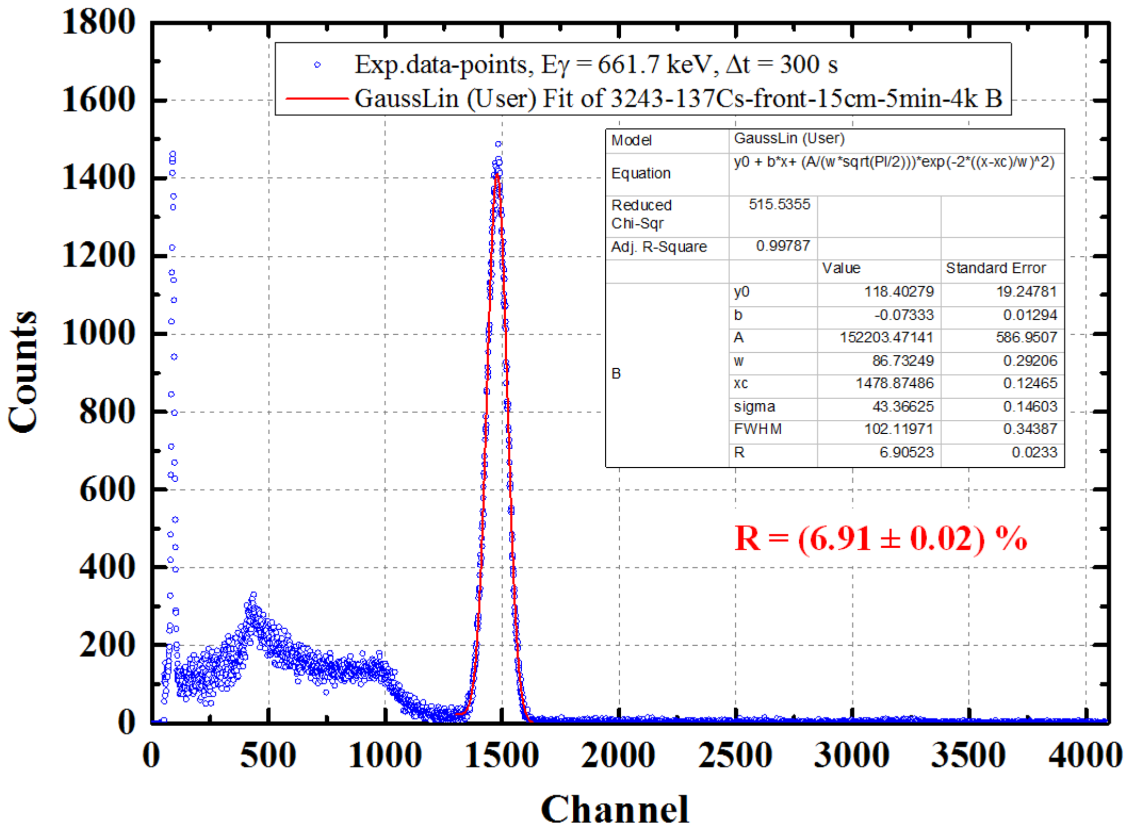

Fig. 2. ^{137}Cs gamma-rays pulse-height spectrum by Setup-1 with Parsek 4k MCA [26].

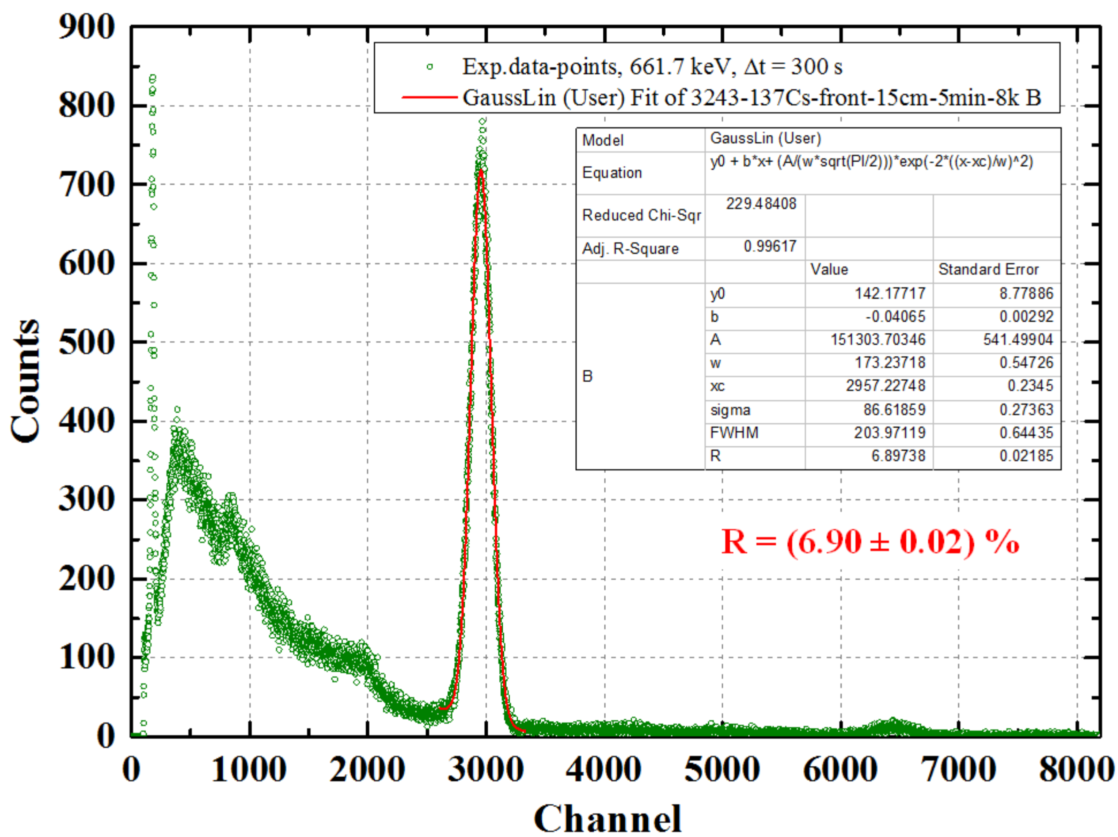

Fig. 3. ^{137}Cs gamma-rays pulse-height spectrum by Setup-1 with Parsek 8k MCA [26].

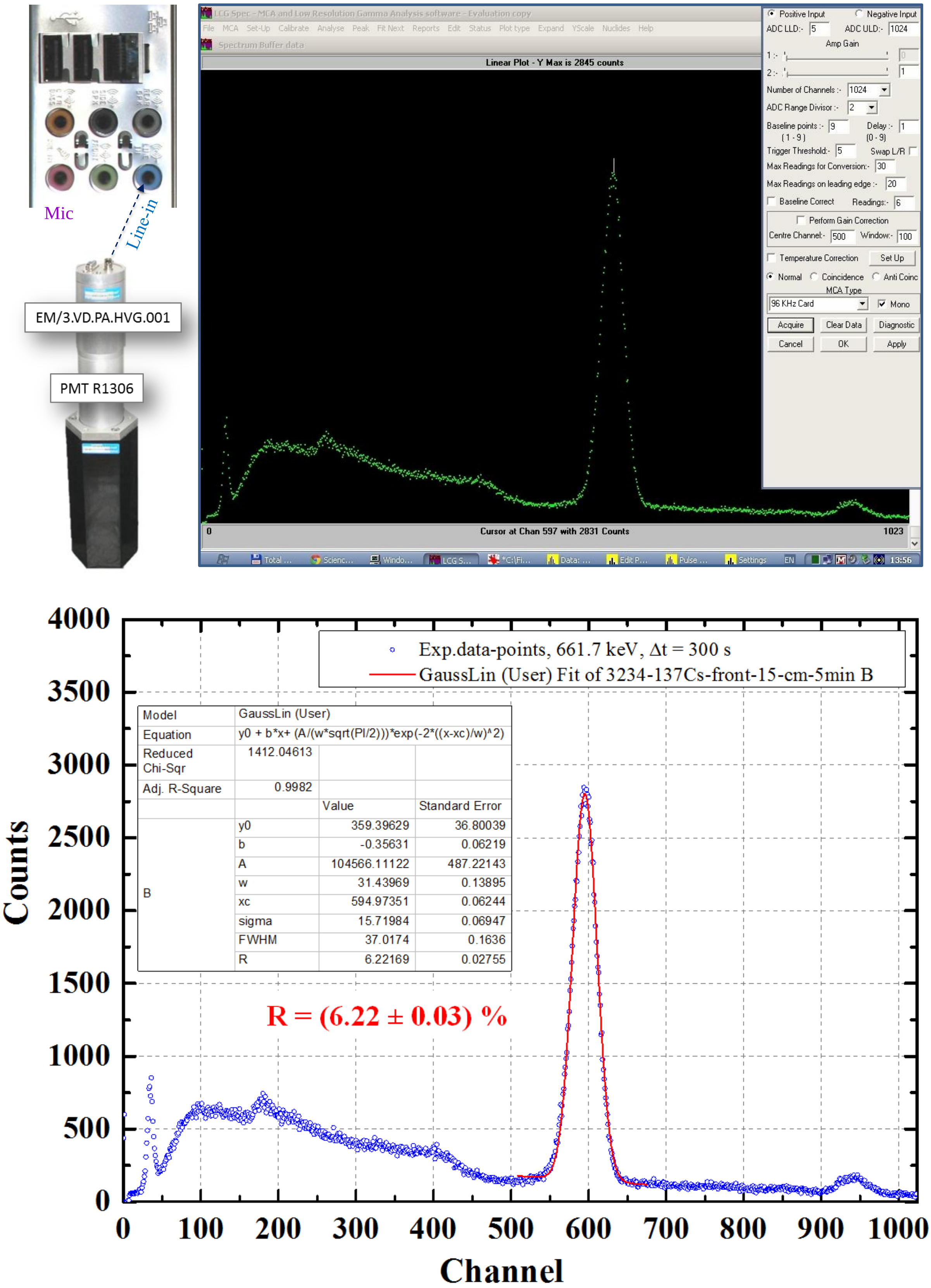

Fig. 4. ^{137}Cs gamma-rays pulse-height spectrum by Setup-2 with FitzPeaks Gamma Analysis and Calibration Software [28].

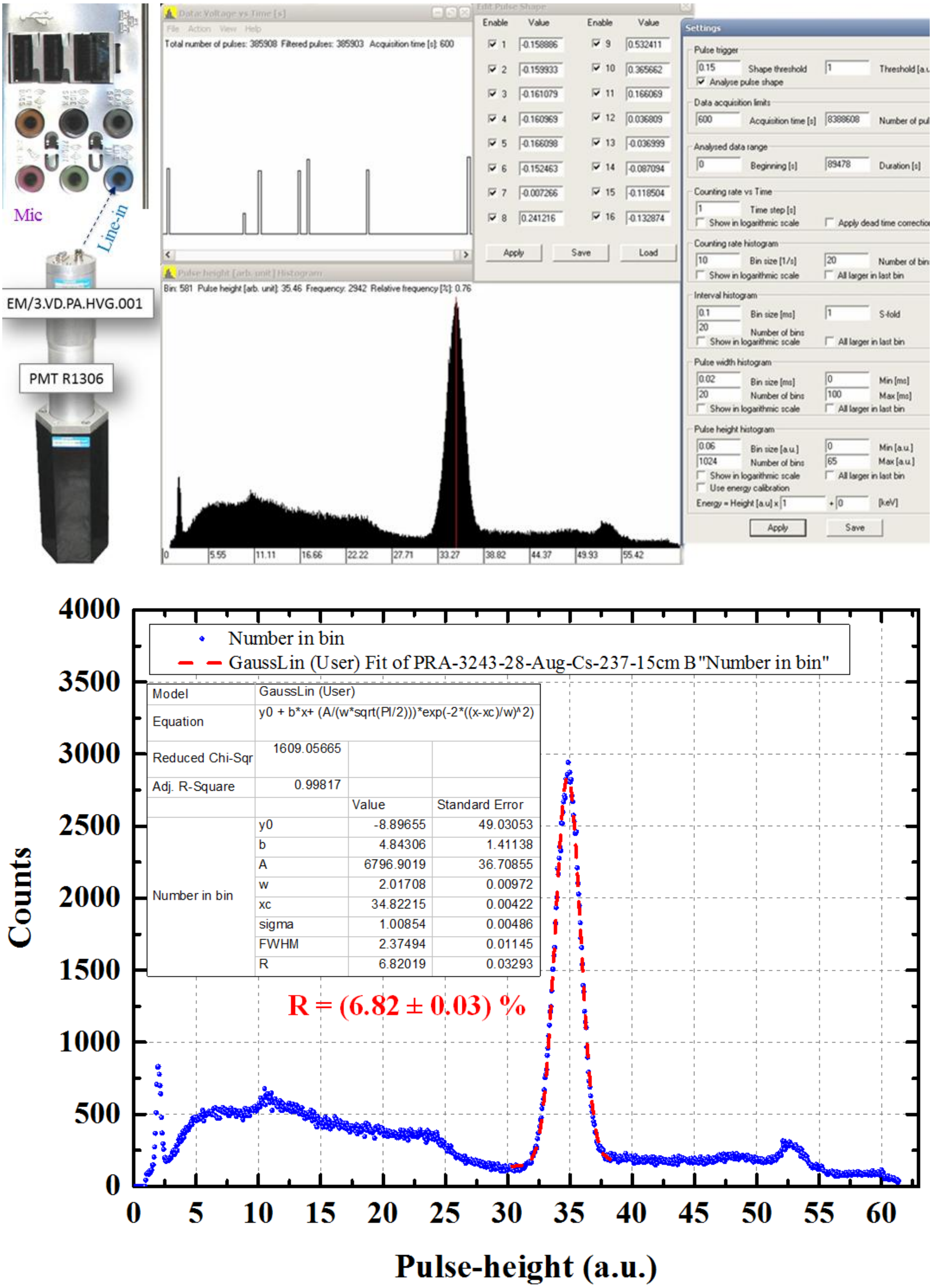

Fig. 5. ^{137}Cs gamma-rays pulse-height spectrum by Setup-2 with PRA Pulse Recording and Analysing Software [29].

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