Energy and Time Resolution of Gamma-ray Detectors

D.N. Grozdanov[1,2], A.T. Issatov[3], Yu.N. Kopach[1],
V.R. Skoy[1], S.I. Negovelov[1], I.N. Ruskov[1,2]

[1]*Frank Laboratory of Neutron Physics (FLNP) of Joint Institute for Nuclear Research (JINR), Joliot Currie 6, 141980 Dubna, Moscow region, Russia*
[2]*Institute for Nuclear Research and Nuclear Energy (INRNE) of Bulgarian Academy of Science (BAS), Tzarigradsko chausse, Blvd., 1784 Sofia, Bulgaria*
[3]*Eurasian National University named after L.N. Gumilyov, Munaitpasov 5, 010000 Astana, Kazakhstan*

Abstract

In Frank Laboratory of Neutron Physics (FLNP) of the Joint Institute for Nuclear Research (JINR) there is a tradition of studying the characteristics of the gamma-rays emission from the neutron capture and fission reactions by multi-detector systems [1-4].

A new multi-detector gamma-ray spectrometry system of daisy-type "Romashka" was build. The basic configuration of this 24 detector system consists of hexagonal 200×78×90mm^3 Amcrys-H NaI(Tl) crystals [5], optically joint with Hamamatsu photomultipliers PMT R1306 [6].

A 32-channel computerized digital data acquisition (DAQ) system, utilizing two ADCM16-LTC 16-channel, 14-bit, 100 MHz, ADC boards (Fig.1) [7], is used for signals digitizing and determining of their amplitude and time characteristics simultaneously.

Some test measurements with different type of scintillators and PMTs were done. For determination of the energy and time resolution at different source-detector geometries and PMT's high-voltages, point-size standard ^{137}Cs and ^{60}Co gamma-ray sources were used.

Keywords: Gamma-rays, spectrometry, multichannel analyzer.

---

* Corresponding author Tel.: + 7-496-216-2131; fax: +7-496-216-5085.
E-mail: dimitar@nf.jinr.ru.

MCA ADCM, Romana and Tofana

A new multi-channel analyzer ADCM [7] was used for determination of the time and energy resolution of different detectors. Two computer programs for signal processing were used:

a) Romana – for creating the amplitude spectra as shown in Fig. 3 (used to determine the energy resolution);

b) Tofana – for creating the two detectors time-coincidence curve as shown in Fig. 4 (used to determine the time resolution);

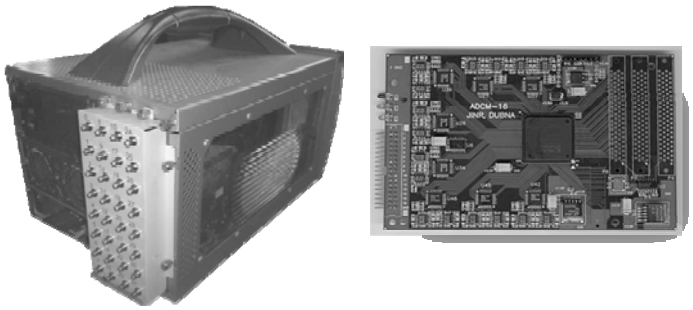

Fig. 1. DAQ system: MCA (left) and ADCM16-LTC (right).

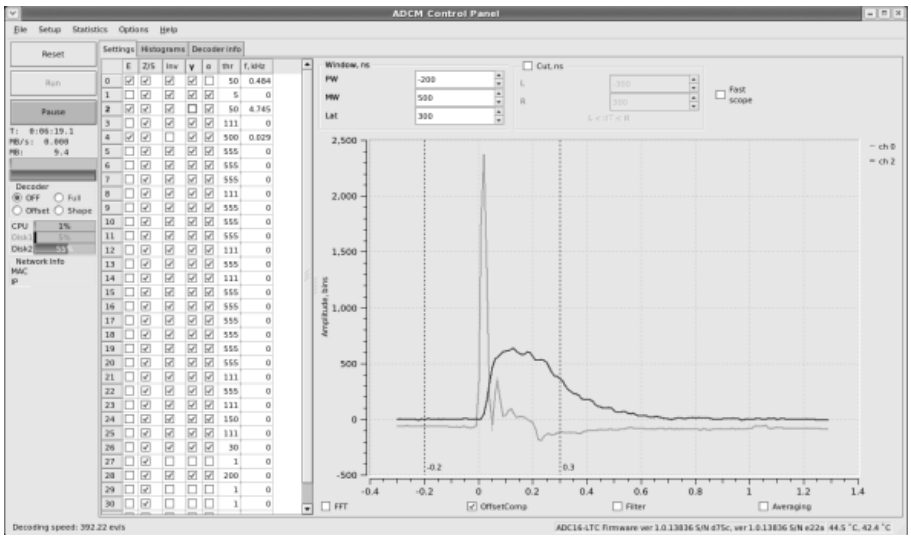

Fig. 2. ADCM software main panel.

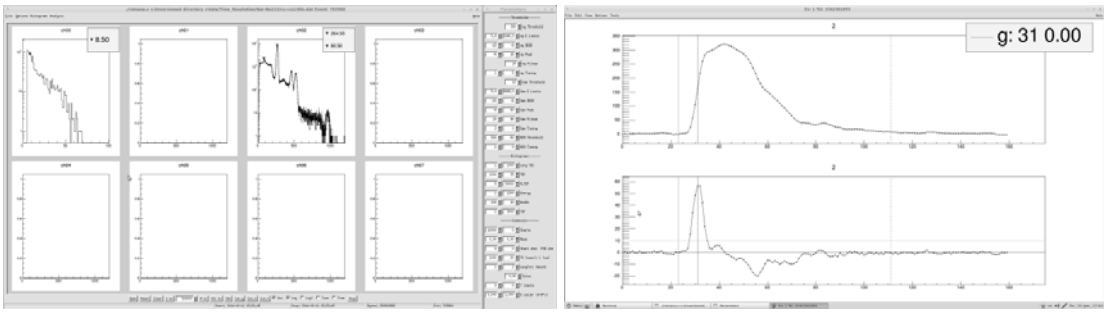

Fig. 3. Romana software display.

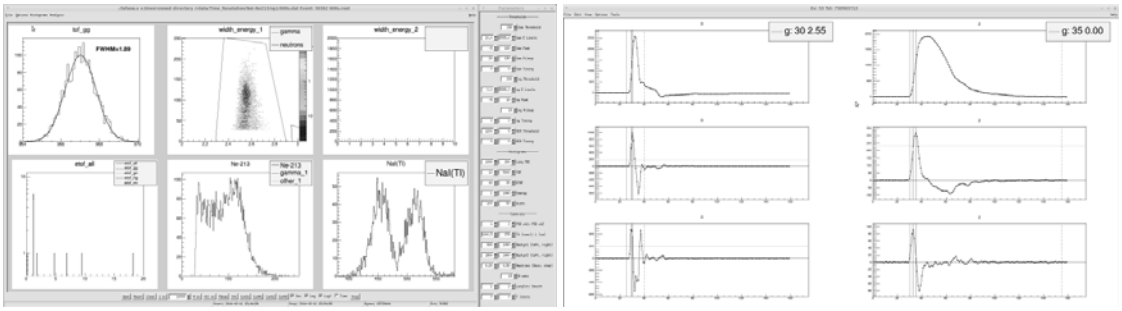

Fig. 4. Tofana software display.

Experimental setup

For determination of the energy and time resolution at different source-detector geometries and PMT's high-voltages, point-size standard ^{137}Cs and ^{60}Co gamma-ray sources were used. The block-scheme of the experimental setup is shown in Fig. 5:

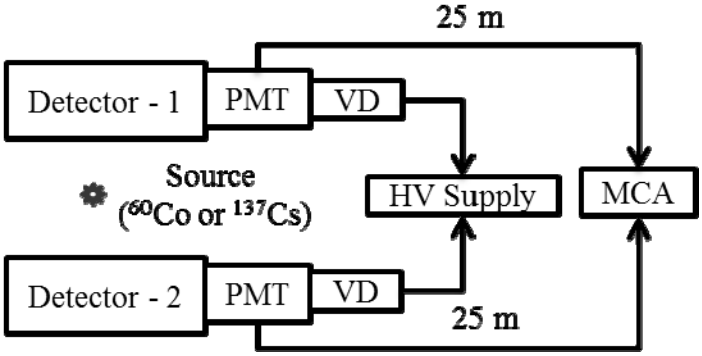

Fig. 5. Block-scheme of the experimental setup.

For the determination of the energy resolution only one detector was used without coincidence, it was set by ticking (γ-α) in the main panel of ADCM for this detector (channel). The determination of the time resolution with two detectors in coincidence was set by ticking (γ-α) of two different detectors (channels). This way one of them will be conditionally accepted as a start signal and the second as a stop signal.

Figs. 6 and 7 show the configuration of the detectors used in this experiment. In Table 1 their parameters are shown:

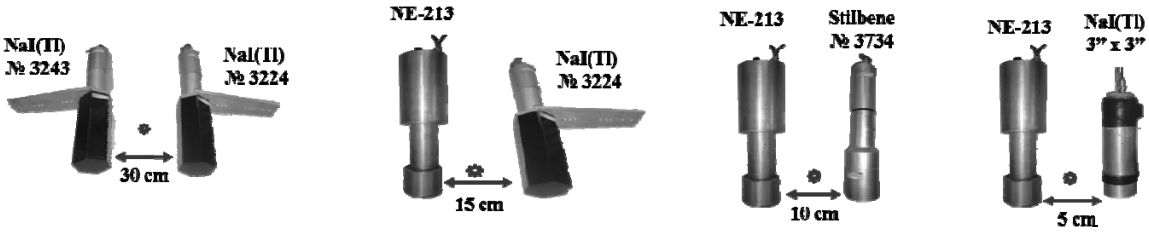

Fig. 6. Types of the detectors used in the experiments.

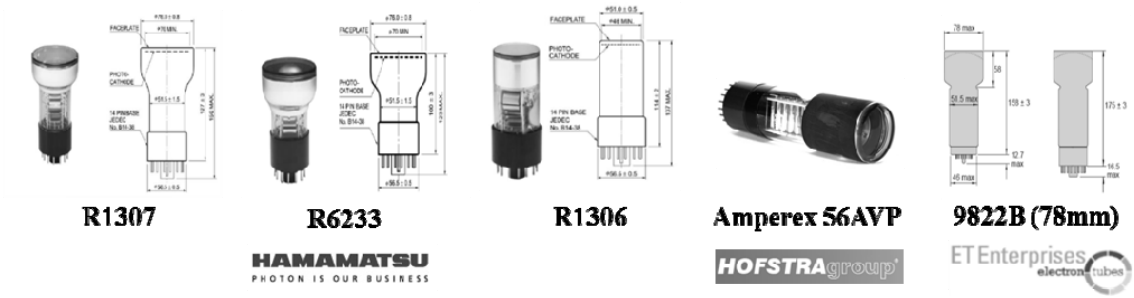

Fig. 7. Types of PMTs used in the experiments [6, 8 – 11]

Table 1. [12]

The physical characteristics of scintillations detectors			
Items	Descriptions		
	NaI(Tl)	Stilbene	NE-213
Manufacturer	Amcrys-H	Amcrys-H	Nuclear Enterprises
Part number	3243, 3224	3734	5553
Type	Crystal	Organically	Liquid
Density [g/cm^3]	0.67	0.97	0.87
Melting point [K]	924	398	414
Hygroscopic	Yes	No	Yes
Wavelength of emission maximum [nm]	415	410	425
Refractive index at emission maximum	0.85	0.46	0.15
Light output [% of NaI(Tl)] (for gamma rays)	100	30	-
Primary decay time [μs]	$2.3*10^{-1}$	$5*10^{-6}$	$3.2*10^{-3}$
Crystal dimensions	90×78×200 mm^3	ϕ76×50 mm	ϕ90 × 84 mm

Experimental results

1. Measurement of the time resolution with two NaI(Tl) (PMT R1306).

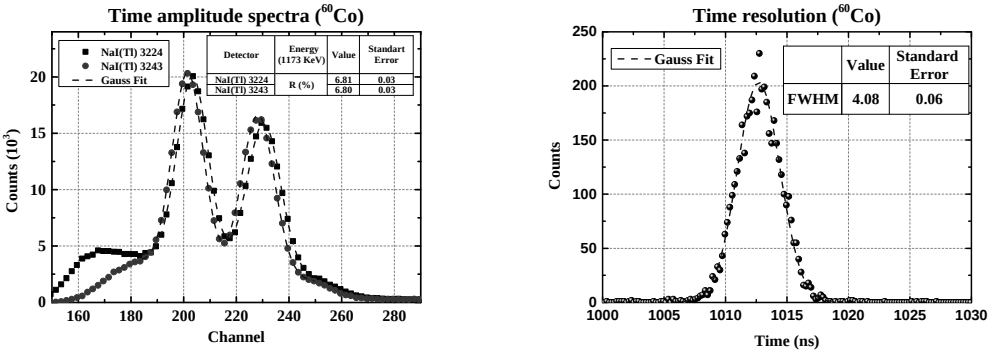

Fig. 8. The energy and time resolution curves.

2. Measurement of time resolution with NE-213 (PMT 56AVP) and NaI(Tl) (PMT R1306).

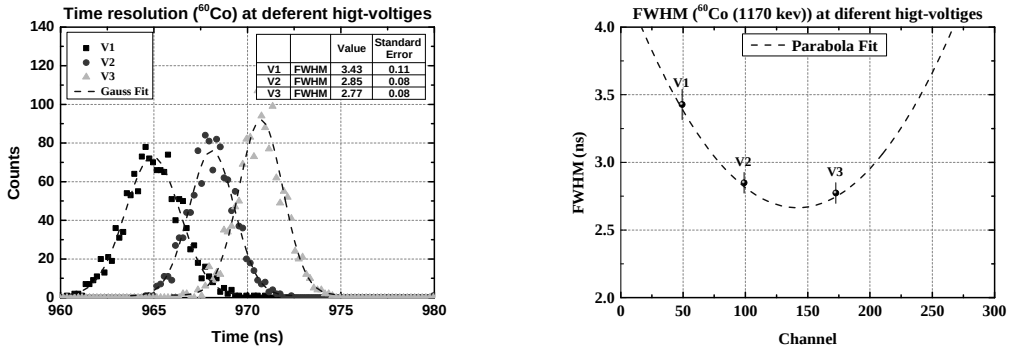

Fig. 9. The time resolution spectra at different PMT R1306 high-voltages.

3. Measurement of the time resolution with NE-213 (PMT AVP56) and Stilbene (PMT R1307).

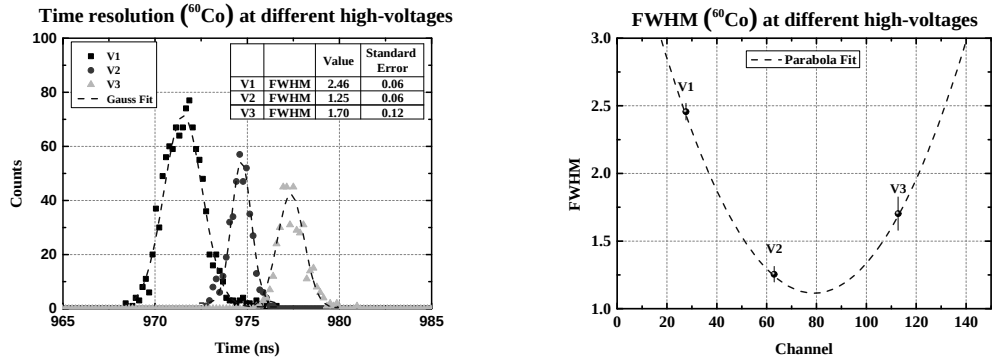

Fig. 10. The time resolution at different PMT R1307 high-voltages.

4. Measurement of the time and energy resolution with NE-213 (PMR AVP56) and 3”x3” NaI(Tl) (PMT R1307).

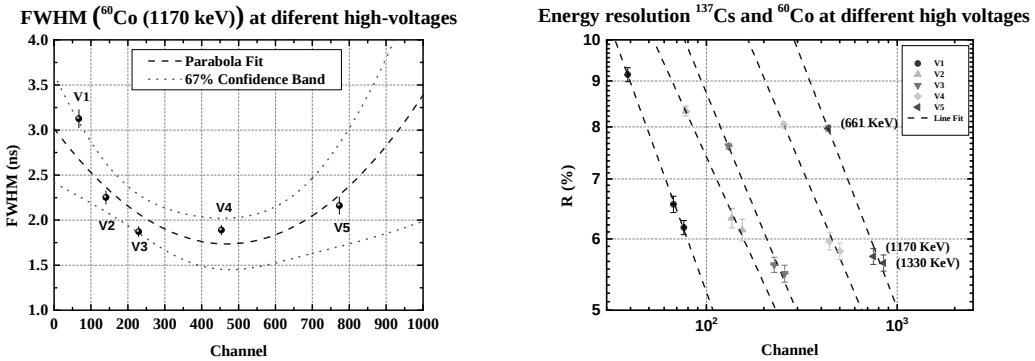

Fig. 11. The time and energy resolutions at different PMT R1307 high-voltages.

5. Measurement of the time and energy resolution with NE-213 (PMT AVP56) and 3”x3” NaI(Tl) (PMT R6233).

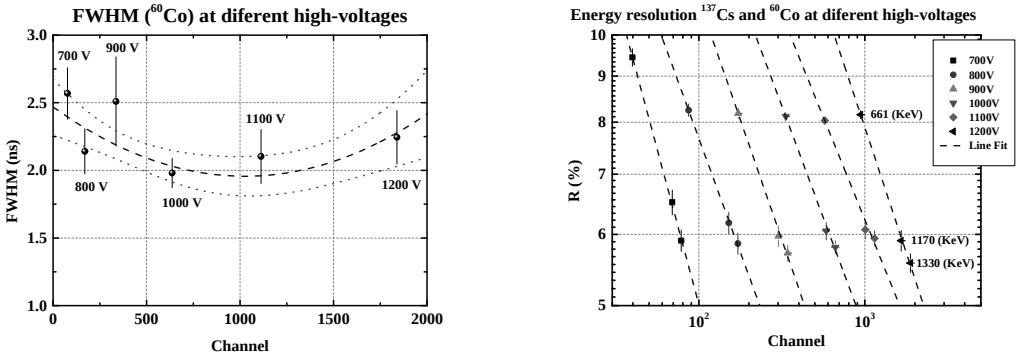

Fig. 12. The time and energy resolutions at different PMT R6233 high-voltages.

6. Measurement of time and energy resolution with NE-213 (PMT AVP56) and 3”x3” NaI(Tl) (PMT 9822B).

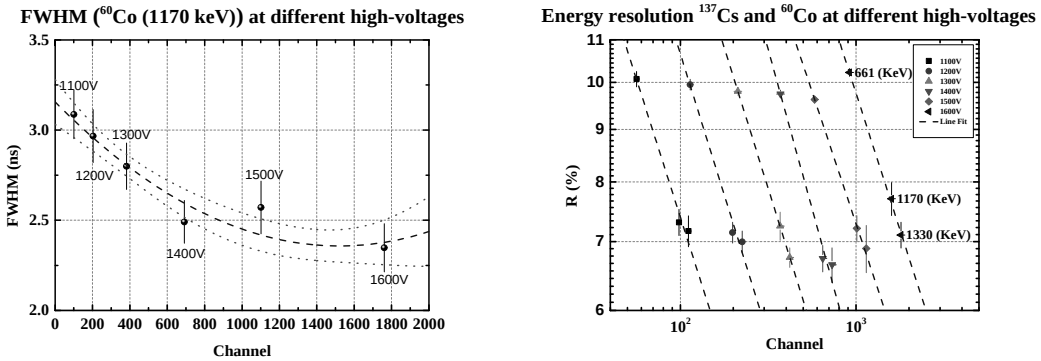

Fig. 13. The time and energy resolutions at different PMT 9822B high-voltages.

In Table 2 the results from all the measurements of the time resolution are shown.

Conclusions

The following time (τ) and energy (ξ) resolution values were obtained with:

1. Two NaI(Tl) τ = 4.37ns ±0.02;
2. NE-213 and NaI(Tl) τ = 2.57ns ±0.18;
3. NE-213 and Stilbene τ = 1.25ns ±0.05;
4. NE-213 and NaI(Tl) used PMT R6233 τ = 1.97ns ± 0.1 and ξ = 8.11% ± 0.07 for ^{137}Cs (662 keV);
5. NE-213 and NaI(Tl) used PMT R1307 τ = 1.87ns ±0.5 and ξ = 7.65% ±0.05 for ^{137}Cs (662 keV);
6. NE-213 and NaI(Tl) used PMT 9822B τ = 2.34ns ±0.13 and ξ = 9.62% ±0.05 for ^{137}Cs (662 keV);

Table 2.

№	Detector 1	Higt-voltages (V)	Detector 2	Higt-voltages (V)	Time resolution (FWHM (ns))
1.	NaI(Tl) №3224	V1	NaI(Tl) №3243	V1	4.07
2.	NaI(Tl) №3224	V1	NE213 №5553	1800	3.42
		V2			2.84
		V3			2.77
3.	Stilbene №3734	V1	NE213 №5553	1800	2.45
		V2			1.25
		V3			1.70
4.	NaI(Tl) 3"x3" PMT - Hamamatsu R1307	V1	NE213 №5553	1800	3.23
		V2			2.42
		V3			1.85
		V4			1.92
		V5			2.28
5.	NaI(Tl) 3"x3" PMT - Hamamatsu R6233	700	NE213 №5553	1800	2.56
		800			2.14
		900			2.50
		1000			1.97
		1100			2.10
		1200			2.24
6.	NaI(Tl) 3"x3" PMT - ET Enterprise 9822B	1100	NE213 №5553	1800	3.08
		1200			2.96
		1300			2.79
		1400			2.49
		1500			2.57
		1600			2.34

According to the performed study Hamamatsu PMT R1307 was found to be the best suited for our measurements.

References

[1] E . Dermendjiev, A. A. Goverdovski, V. I. Furman, L. B. Pikelner, I. N. Ruskov, P. Siegler, Yu. S. Zamyatnin, Fission Gamma-Ray Multiplicity Measurements in 233U, 235U, 237Np and 239Pu Low Energy Fission Resonances, Proceedings of an International Conference on Nuclear Data for Science and Technology, held at the Forschungszentrum Jülich, Fed. Rep. of Germany, 13–17 May 1991, pp.147-148.

[2] N. Janeva, S. Toshkov, G.V. Muradyan, Yu.V. Grigorjev, G. Georgiev, I. Sirakov, V.G. Tishin and Yu.S. Zamjatnin, A setup for precise measurement of resonance neutron capture by self-indication, Nucl. Instr. and Meth. in Phys. Res. A313 (1992) 266-272, http://www.sciencedirect.com/science/article/pii/016890029290104C.

[3] Yu.V. Adamchuk, A.L. Kovtun, G.V. Muradyan, Yu.G. Shchepkin, G. Georgiev, N. Kalinkova, E. Moravska, N. Stancheva, N. Tchikov, N. Janeva, A spectrometer for measurement of the neutron capture gamma multiplicity at a stationary research

reactor, Nucl. Instr. and Meth. in Phys. Res. 236 (1985), pp. 105-108, http://www.sciencedirect.com/science/article/pii/0168900285901330.
[4] I. Ruskov, Yu. N. Kopatch, V.R. Skoy, E. Dermendjiev, F.-J. Hambsch, V.N. Shvetsov, P.V. Sedyshev, Ts. Panteleev, L.B. Pikelner, N. Janeva, S.I. Negovelov, Yu.D. Mareev, Zh.V. Mezentseva, I. Ivanov, Experimental Setup for Investigation of the Resonance Neutron Induced Fission of 239Pu Physics Procedia, Volume 47, 2013, Pages 137-143, http://www.sciencedirect.com/science/article/pii/S1875389213004495.
[5] Amcrys-H Scintillation Materials and Detectors, www. Amcrys-h.com.
[6] Hamamatsu Scintillation Detector Photomultiplier Tubes, http://www.hamamatsu.com/jp/en/R1306.html.
[7] A digital pulse processing system for nuclear physics experiments ADCM16-LTC,M http://afi.jinr.ru/ADCM.
[8] Hamamatsu Scintillation Detector Photomultiplier Tubes, http://www.hamamatsu.com/jp/en/R1307.html.
[9] Hamamatsu Scintillation Detector Photomultiplier Tubes, https://www.hamamatsu.com/us/en/R6233.html.
[10] Amperex 56AVP High Speed Photomultiplier Tube, http://www.hofstragroup.com/product/amperex-56avp-high-speed-photomultiplier-tube/?q=Amperex%2056AVP.
[11] ET Enterprises Ltd - 78 mm (3") photomultiplier, http://my.et-enterprises.com/pdf/9822B.pdf.
[12] Knoll, G. F. (2010). “Radiation detection and measurement”, John Wiley & Sons, ISBN 0-470-13148-9.