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P22 Miniature detection probes with CZT detectors

V. Ivanov, P. Dorogov, A. Loutchansky, L. Aleksejeva, E. Mochaev
Ritec Ltd., 23 Aizkraukles St., LV-1006 Riga, Latvia
Proofs should be sent to Mr. V. Ivanov
Address: Ritec Ltd., 23 Aizkraukles St., office 407, LV-1006, Riga, Latvia
Tel./fax: 371-7543304
E-mail: ritec@wireless.lv

Abstract

The existing level of perfection of CdZnTe (CZT) crystals allows to make gamma-radiation hemispherical detectors with different sizes from a very small 0.5-2 mm^3 to a few cubic centimeters are available. Improvement in the technology of hemispherical detector fabrication improves spectroscopy performance. Small size hemispherical detectors, volume 5-15 mm^3, have energy resolution (FWHM) at a 662 keV about 1%. Large volume detectors, volume 500 mm^3, have energy resolution about 2% at the same line. Various detection probes for different applications based on hemispherical detectors produced by Ritec Ltd. are described.

Keywords: detector, gamma radiation detector, hemispherical detector, CdZnTe, CZT, room temperature detector

1. Introduction

Hemispherical detectors are well known as detectors where conditions of a single charge collection are realized [1, 2]. Progress in improvement of the CZT crystal characteristics allows fabrication of high quality hemispherical detectors. The main progress in improvement of the CZT crystals consists in the achievement of high values of the electron transport properties when a high specific resistance is preserved. The holes transport properties have remained at a rather low level. As was shown [3], there is an optimal relation for big and small radiuses of hemispherical detector electrodes for certain sets of parameters $(mt)_e$, $(mt)_p$ and operating voltage. For optimization of single charge collection conditions the ratio $(mt)_e/(mt)_p$ must be as mush as possible, at least more then 20.

For simplification of manufacturing of hemispherical detectors, in practice are made quasi-hemispherical detectors with the sizes of rectangular sensitive volume *a´a´d*, where *a* - the cross size of detector, *d* - detector thickness, *d=a/2*, Fig 1.

The high level of electrons transport characteristic $(\mu\tau)_e$ of CZT crystals allows to make hemispherical detectors with a volume up to a few cubic centimeters. For detector fabrication we used CZT crystals with $(mt)_e$ =(1÷7)x10^{-3} cm^2V^{-1} produced by eV PRODUCTS.

2. Hemispherical detectors. Main characteristics.

Efficiency of hemispherical detectors. The detector registration efficiency is defined by a gamma-radiation absorption efficiency and by charge collection efficiency in the detector. For a small volume of detectors the total absorption peak efficiency is mainly defined by the photoelectric absorption. For larger volumes of detectors the Compton effect gives its own contribution too.

Fig 2 shows calculated photoelectric absorption efficiency and measured total absorption peak efficiency versus detector thickness. The efficiency calculation was done assuming that the whole detector volume is sensitive to the radiation. Essential disagreement of calculated and experimental results is visible. For small thickness it can be connected with decreasing of the quasi-hemispherical detector real sensitive volume. The distribution of an electrical field in the quasi-hemispherical detector having the rectangular shape, strongly differs from an ideal distribution in an ideal hemispherical detector. There are areas with a low electric field in a detector's corners, Fig 1. These areas reduce the detector sensitive volume. With using of experimental dates about the total absorption peak efficiency the effective sensitive volume of quasi-hemispherical detectors was calculated. For small sizes detectors it is about 80 % from the total detector volume.

The exceeding of measured efficiencies for larger detectors over-calculated is connected with an unaccounted contribution of multievent Compton absorption.

The increasing of registration efficiency is directly connected to an opportunity of increasing of the detector volume. For achievement of good spectrometer characteristics detectors must operate at optimal operation voltage. It may be up to several kilovolts for large volume detectors. In this case the intensity of an electric field near a small dot electrode can reach several tens of kilovolts per centimeter. At such high electric fields different strong field effects can take place. These effects may worsen conditions of the charge collection. Therefore it is necessary to operate at too low not optimal operation voltage and/or to use too large size of a central electrode. It results in the unsatisfactory spectrometric characteristics.

At the moment quasi-hemispherical detectors with volume of 0.5 cm^3 are commercially available. By the special selection of crystals with high values of $(mt)_e$ and low values of $(mt)_p$ it is possible to make detectors with volumes up to 1.5÷2 cm^3. Attempts to make detectors with larger volumes were unsatisfactory. It is easier to increase the detector volume or area by assembly of several detectors of the small size in one detector [4].

Energy resolution. Except the requirements of the values of parameters $(mt)_e$ and $(mt)_p$ the high uniformity of CZT crystals is very important. The presence of nonuniformites in the CZT crystals does not give an opportunity to increase hemispherical detectors volume with preservation of the high energy resolution. In the works [5-7] various nonuniformities of CZT crystals are described. It was found that presence of some nonuniformities do not significant influence to parameters of planar detectors. In case of the hemispherical detectors the influence of these uninformities can be significant. One example, the presence of crystalline defects in the strong electric field near the small dot positive electrode can result in significant reduction of operation voltage. Therefore the CZT crystals which can be used for good planar detectors manufacturing may be unsuitable for manufacturing of the hemispherical detectors.

The other important factor determining the detector energy resolution is perfection of manufacturing technology. As was already mentioned, for simplification of the hemispherical detectors manufacturing process, instead of an ideal hemispherical detectors, quasi-hemispherical rectangular detectors are fabricated with a flat dot central electrode. Such replacement may worsen the characteristics of the detector.

Errors and discrepancies in technological process of hemispherical detectors manufacturing can not only essentially worsen the spectrometer characteristics, but also even result in occurrence of false peaks.

As already was marked the hemispherical detectors with volumes from 0.4 mm^3 up to several cubic centimeters were fabricated. In the Tables 1 the best values of the energy resolution and peak-to-Compton ratio at a line 662 keV for different volumes of quasi-hemispherical detectors are submitted. The best energy resolutions were received for detectors with volumes 10-60 mm^3. The opportunity of the energy resolution improvement is limited by deviation of the quasi-hemispherical detector shape from the ideal hemispherical detector shape.

On Fig 3 spectrum of Cs-137 registered by quasi-hemispherical detector with volume 0.5 cm^3 is shown.

Peak-to-Compton ratio. The value of the peak-to-Compton ratio is an important parameter for practical application of detectors. As a rule detectors with the high energy resolutions have also high value of the peak-to-Compton ratio. On Fig 4 dependence of the peak-to-Compton ratio versus energy resolution at 662 keV line for a large number of quasi-hemispherical detectors with volume 0.5 cm^3 is shown. The direct connection between these parameters is possible to see.

Range of operation temperatures. As is known, one of the main advantages of radiation detectors made of CdTe or CZT is the opportunity of operation at room temperature. It is connected with the low level of leakage current from these detectors. Leakage currents of quasi-hemispherical detectors do not exceed a few nA at room temperature and at operation voltage.

It was found that there are different behaviors of detector made of various ingots at change of operation temperature. Some detectors can work up to temperature + 60°Ñ. Degradation of spectrometric performance was observed at low operation temperatures, less then -15°Ñ.

Stability in time. The largest percentage of hemispherical detectors work stable at room temperature, but some detectors show instability in time. Degradation of the spectrometer characteristics, shift peak position and variation of registration efficiency were observed. These changes, as a rule, are appeared during the first hours of operation, sometimes during the first days. Apparently, it may be connected to polarization of the detector sensitive volume. For exclusion of such unstable detectors all commercial detectors should pass through the long-term stability test during not less then 200 hours.

At temperatures -20°C and lower some detectors becomes unstable in time.

3. Encapsilated quasi-hemispherical detector, spectrometric detection probes.

Miniature Spectrometric Detection Probe, Model 310. There are a few commercially available modifications of Spectrometric Detection Probes, Model 310. The detection probes consist of the quasi-hemispherical detector, charge sensitive preamplifier, watertight case, and connecting cable. Small dimensions, diameter of the removable of probe 8 mm, and length 60 mm allow application of these detection probes in difficult of access places. Typical energy resolutions at a 662 keV line for Super Grade probes with the detector's of volumes 5÷20 mm^3 - no more than 10 keV, for probes with detector's volume 60 mm^3 - no more than 15 keV. These probes are applying for the nuclear material verification [8]. On Fig 5 a spectrum of reactor grade plutonium sample registered by super grade detection probe Model 310 is shown.

Slim Spectrometric Detection Unit, Model 311. Distinctive peculiarity of the given detection unit is a very small thickness only 4 mm. The other dimensions of the detection unit are 20õ45 mm.

Large Volume Encapsulated Detectors. A few models of encapsulated large volume detectors are distinguished by the size of the quasi-hemispherical detector and by the level of the spectrometer characteristics. All detectors have an identical design and differ only by external dimensions. The quasi-hemispherical detectors are mounted in the case with BNC connector. Such detectors are applied for registration and search of rather low intensity radiation sources, on an example, fresh nuclear fuel.

There are commercially available large volume detectors, Model CZT/500 with the quasi-hemispherical detector of volume 0.5 cm^3. Such detectors have high energy resolution in a wide range of energy registered. These detectors can work with standard charge sensitive preamplifier. On Fig 6 a spectrum of U-235 obtained with the super grade detector CZT/500 is shown.

The detector CZT/1500 with the quasi-hemispherical detector with the size 15x15x7.5 mm is available. The energy resolution of these detectors was about of 25 keV at a 662 keV line. However the serial manufacture of such detectors while is not present. It is connected with difficulty of selection of CZT crystals.

Assembled Detector. Assembled four element detector was made. Detector consists of four single quasi-hemispherical detectors with volume 500 mm^3. Total volume of assembled detector is 2 cm^3, total area 4 cm^2. The characteristics of the assembled detector and its design are described in work [4]. On Fig 7 a spectrum of a weak source Ra-133 of old wristwatch is shown.

Thermostabilized Detection Unit, Model 410. The thermostabilized detection unit consists of removable probe with external diameter of 10 mm and length 100 mm, connecting cable and thermostabilzation board with size mm. There are the quasi-hemispherical detector, preamplifier and miniature Peltier element Inside of the removable probe. Removable probe can operate at increased temperature up to + 75°Ñ. Thermostabilization broad supports the detector's operation temperature. It also serves for indication of a current detector's operation temperature and value input low voltage and for signaling by sound and visual about operating troubles. Temperature instability of energy resolution is not more then 0.1%/°C

Peltier element is supplied from an external power supply through thermostabilization board. As an external power supply can be used storage batteries.

Some other detection units were developed and tested. It are detection units with the very small quasi-hemispherical detector for application in intensive radiation fields [4], surgical probes for nuclear medicine with spectroscopy quasi-hemispherical detector, and the detection unit with the large volume detector and preamplifier in a one case.

4. Conclusions

Progress in improvement of the CZT crystal characteristics and in technology of hemispherical detector fabrication allows fabrication of high quality hemispherical detectors with different volumes, from a very small to a few cubic centimeters. These detectors have a high energy resolution in a wide range of an energy registered. Different detection units with hemispherical detector for various applications were fabricated. They are widely using for nuclear material verification.

Further improvement of hemispherical detectors spectroscopic performance and sensitive volume increasing are connected with development of technology of detector fabrication and with the rising of uniformity of CZT crystals.

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References

[1] H.L. Malm, C. Canali, J.W. Mayer, M-A. Nicolet, K.R. Zanio, W. Akutagawa, Appl. Phys. Lett. 26 (1975) 344.

[2] K. Zanio, W. Akutagava, H. Montano, IEEE Trans. Nucl. Sci. NS-19 (1972) 257.

[3] L.A. Alekseeva, P.G. Dorogov, V.I. Ivanov, A.K. Khusainov, Pribory I Teknika Eksperimenta 1 (1985) 54.

[4] V. Ivanov, P. Popov, A. Loutchasky, L. Aleksejeva, E. Mozchaev, Proc. 21th Annual Symp. on Safeguards and Nuclear Matetial Management, Sevilla, Spain, 1999, will be published

[5] J.E. Toney, B.A. Brunett, T.E. Sclesinger, R.B. James, E.E. Eissler, IEEE Trans. Nucl. Sci. 44 (1997) 499.

[6] H. Yoon, J.M. Van Scyoc, T.S. Gilbert, M.S. Goorsky, B.A. Brunett, J.C. Lund, H. Hermon, M. Schieber, R.B. James, Mat. Res. Symp. Proc. 487 (1998) 115.

[7] B.A. Brunett, J.M. Van Scyoc, N.R. Hilton, J.C. Lund, R.B. James, T.E. Schlesinger, IEEE Trans. Nucl. Sci. 46 (1999) 237.

[8] V. Ivanov, P. Dorogov, R. Arl, , Proc. 19th Annual Symp. on Safeguards and Nuclear Matetial Management, Montpellier, France (1997) p. 447.

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Figure legends

Fig. 1. Ideal hemispherical and quasi-hemispherical detectors

Fig. 2. Calculated photoelectric absorption efficiency and measured total absorption peak efficiency at 662 keV line versus detector thickness

Fig. 3. Spectrum of Cs-137 registered by quasi-hemispherical detector, volume 0.5 cm^3

Fig. 4. Ratio peak-to-Compton versus energy resolution at 662 keV line for quasi-hemispherical detectors volume 0.5 cm^3

Fig. 5. Spectrum of reactor grade plutonium registered by super grade detection probe SDP310/Z/60S

Fig. 6. Spectrum of U-235 registered by super grade large volume detector CZT/500S

Fig. 7. Spectrum of old wristwatch (source Ra-226) registered by four element assembled detector

Tables

Table 1

Best energy resolutions obtained with quasi-hemispherical detectors of different volumes at 662 keV line.

Detector sizes, mm	Volume, mm^3	Energy resolution, keV (%)	Peak-to-Compton ratio
1.0x1.0x0.5	0.5	7.1 (1.1)	2.0
1.5x1.5x0.75	1.7	5.1(0.8)	3.6
2.0x2.0x1.0	4.0	5.5(0.8)	4.4
2.5x2.5x1.25	7.8	7.6(1.2)	4.0
5.0x5.0x2.5	62.5	7.1(1.1)	7.2
10.0x10.0x5.0	500	9.9(1.5)	5.9
15.0x15.0x7.5	1687.5	22.9(3.5)	4.0
20.0x20.0x10.0	4000	38.3(5.8)	1.3

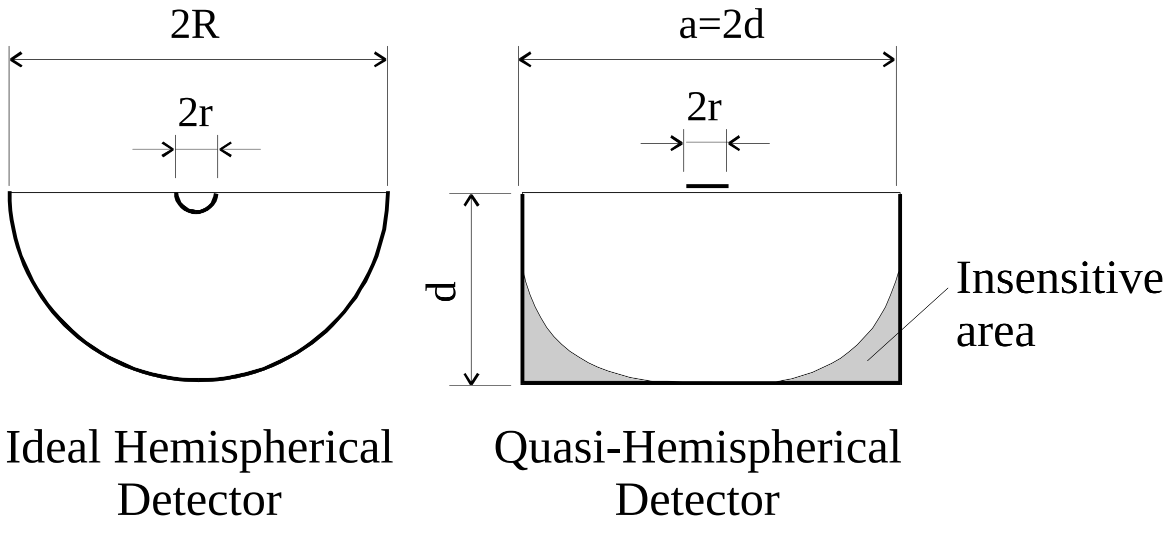

2R
2r
a=2d
2r
d
Insensitive area
Ideal Hemispherical Detector
Quasi-Hemispherical Detector

Fig. 1

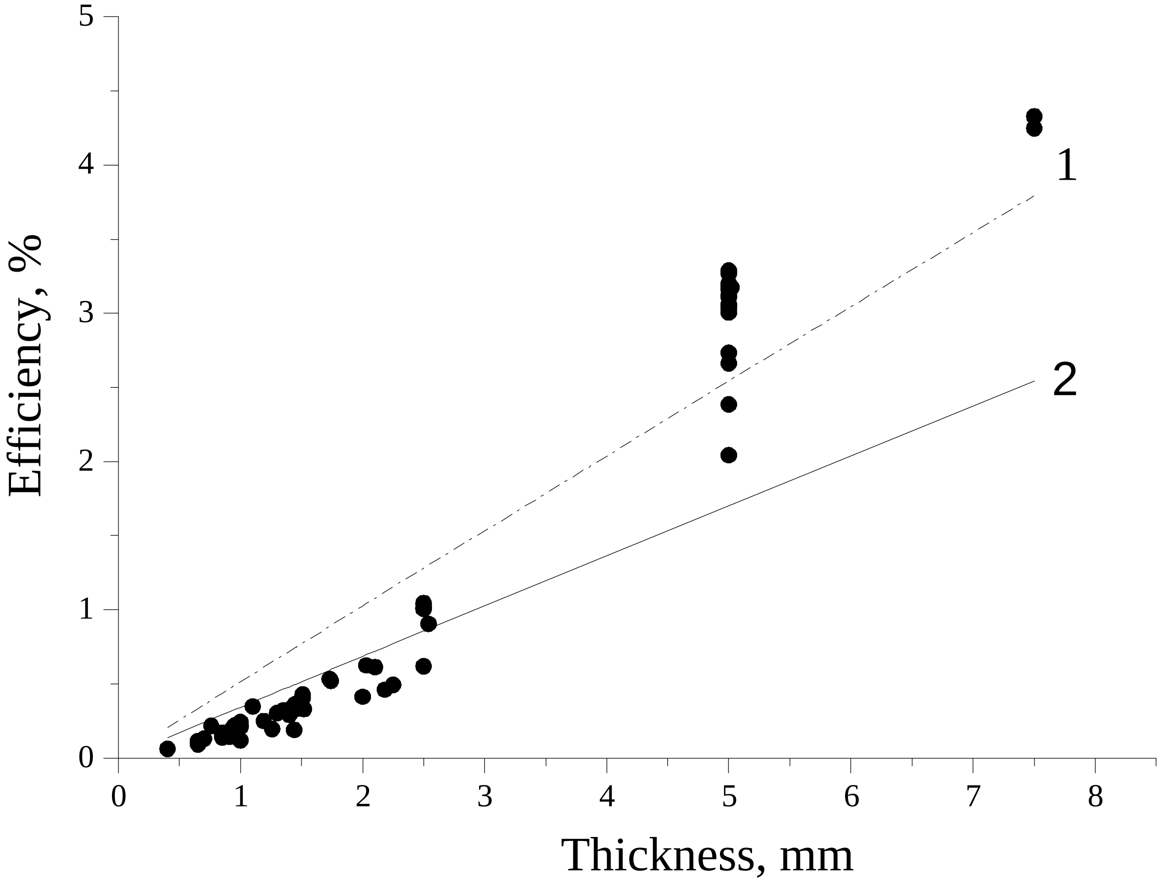


Fig. 2

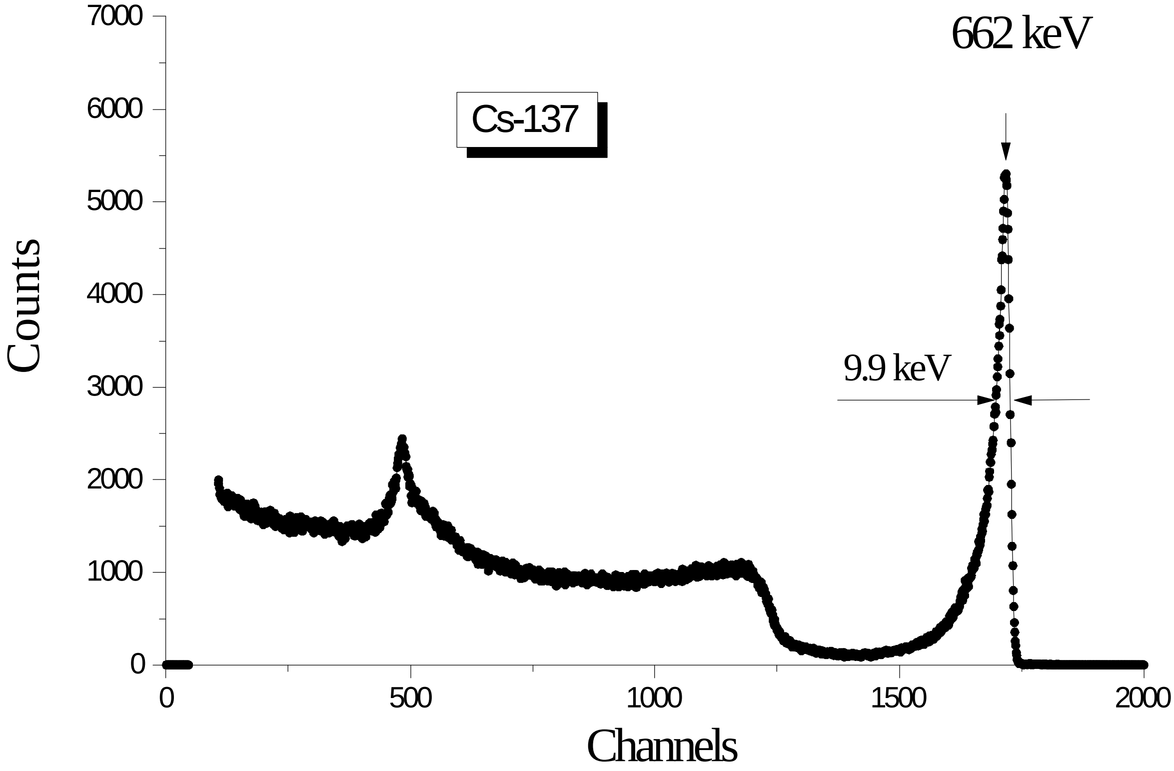

662 keV
Cs-137
9.9 keV
Counts
Channels
7000
6000
5000
4000
3000
2000
1000
0
0
500
1000
1500
2000

Fig. 3

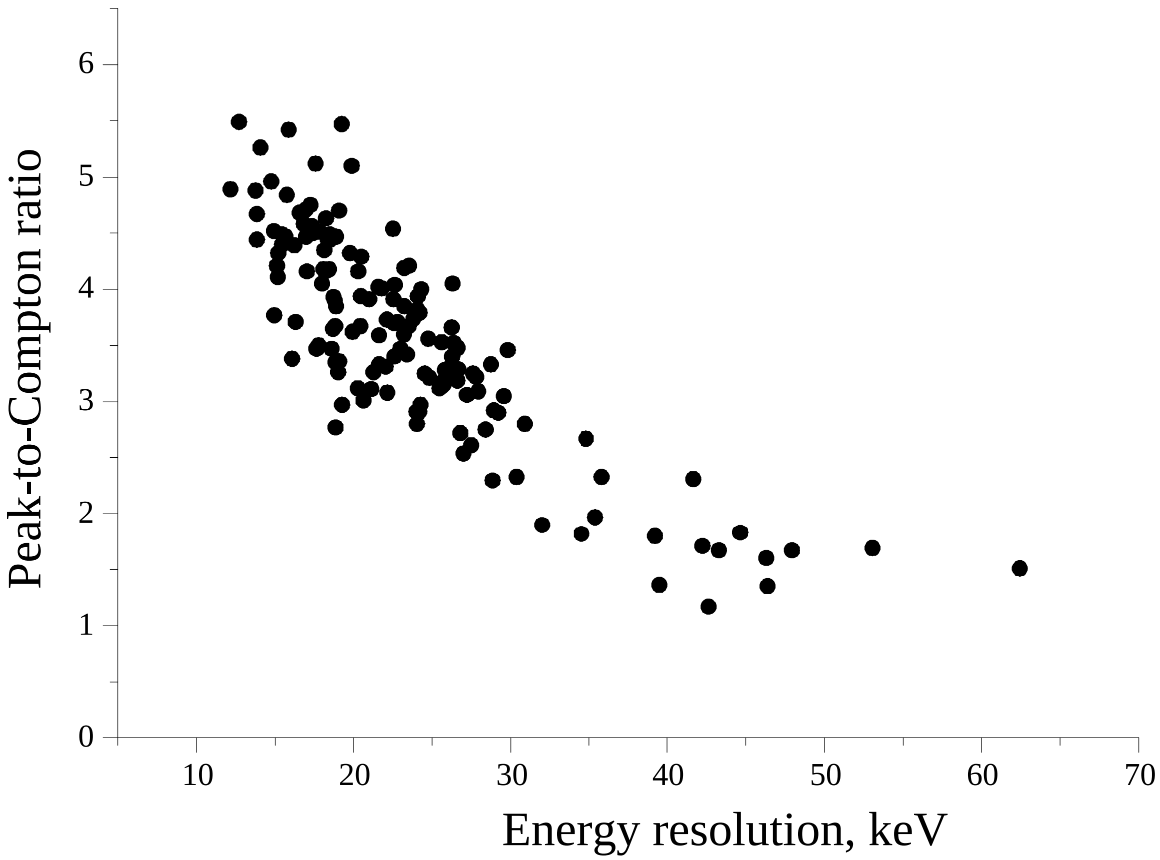

Peak-to-Compton ratio
0
1
2
3
4
5
6
10
20
30
40
50
60
70
Energy resolution, keV

Fig. 4

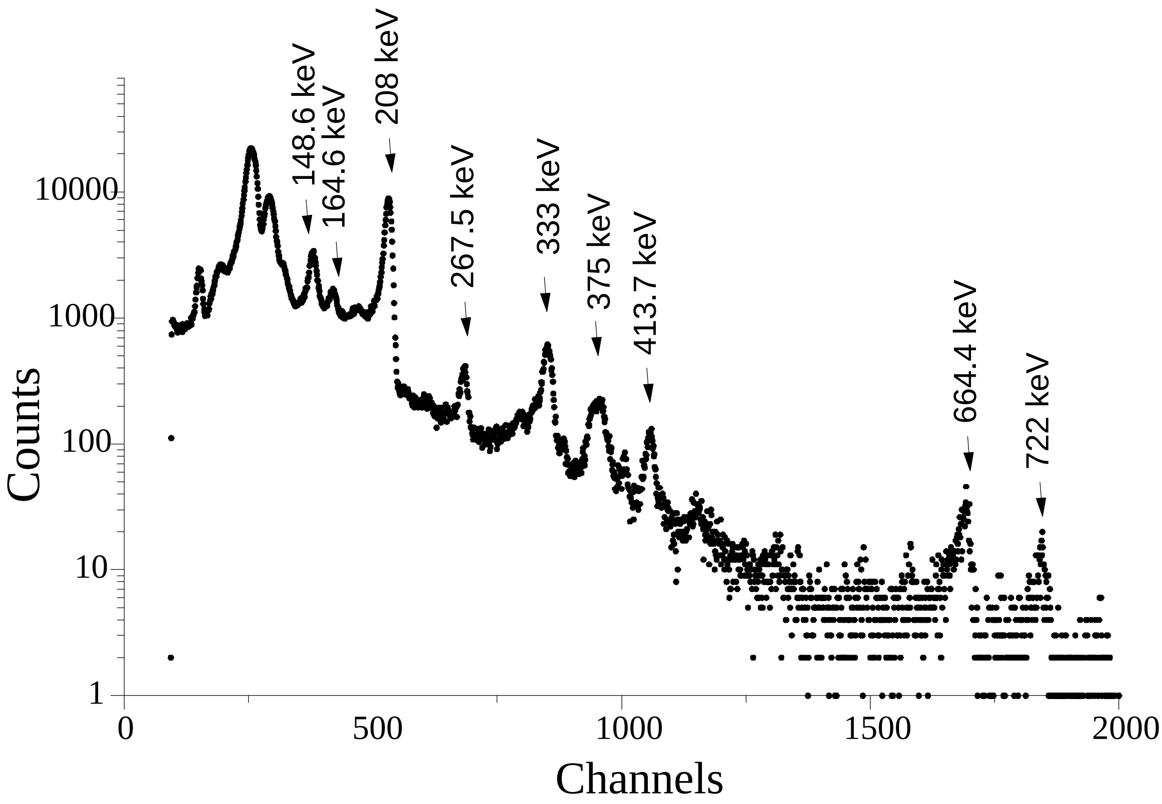
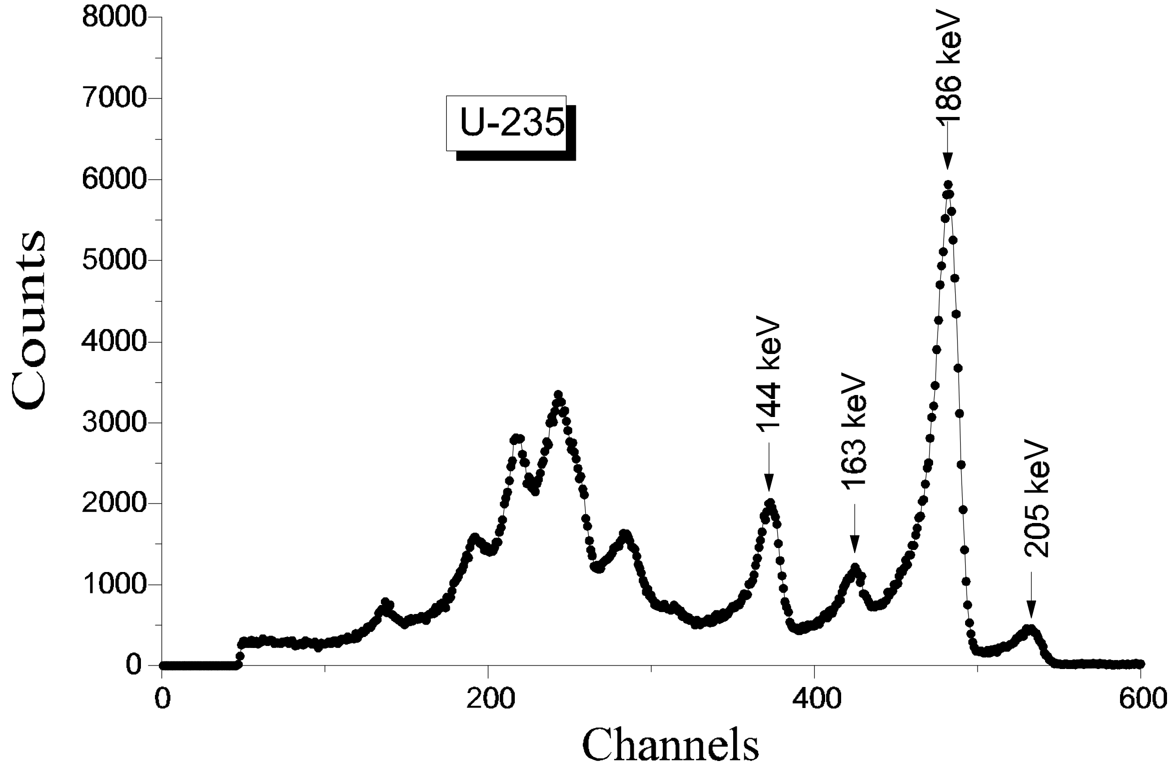

148.6 keV
164.6 keV
208 keV
267.5 keV
333 keV
375 keV
413.7 keV
664.4 keV
722 keV
Counts
10000
1000
100
10
1
0
500
1000
1500
2000
Channels

Fig. 5



8000
7000
6000
5000
4000
3000
2000
1000
0
Counts
U-235
186 keV
144 keV
163 keV
205 keV
0
200
400
600
Channels

Fig. 6

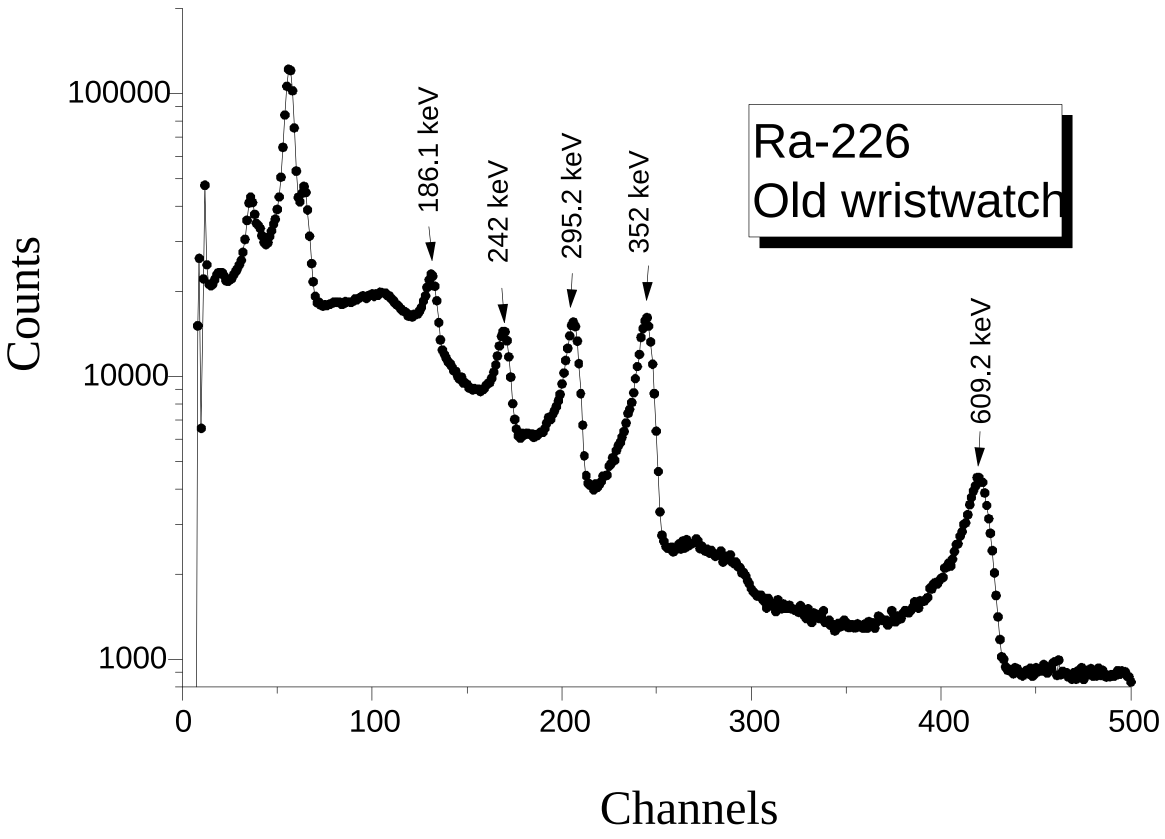

Ra-226
Old wristwatch
186.1 keV
242 keV
295.2 keV
352 keV
609.2 keV
Counts
100000
10000
1000
0
100
200
300
400
500
Channels

Fig. 7