SPECTROMETRIC CHARACTERISTIC IMPROVEMENT OF CdTe DETECTORS*

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Abstract

A new pulse shape correction method combined with a pulse shape selection method has been proposed for a CdTe detectors energy resolution improving and the increasing the total absorption peak efficiency. The capabilities of the new technique for the spectrometric characteristic improvement are based on using specific features of the CdTe detectors output pulses. The energy resolution of about 1% FWHM at 662 keV has been achieved with planar CdTe detector under room temperature without decrease of peak efficiency. Standard measurement techniques give 3.7% FWHM. A significant spectrometric characteristic improvement of other room temperature semiconductor detectors such as HgI_2 and CdZnTe detectors was also obtained.

I. INTRODUCTION

CdTe has been known as a material for gamma radiation detectors for a long time. CdTe detectorsare distinguished by high effectiveness, good stability and capacity to operate at room temperatures. However, the areas of application of CdTe detectors are relatively limited. It is associated with a rather low energy resolution and limited sizes of the detectors sensitive volume. The most direct way to improve the spectrometric characteristics of CdTe detectors is primarily an improvement of the characteristics of the initial CdTe crystals, such as life time and mobility of electrons and holes and its homogeneity and conductivity. An improvement of detector manufacture technology defines undoubtedly the detector quality.

An energy resolution of about 1% at 662 keV line, was obtained with slightly cooled CdTe detectors with hemispheric geometry [1] and with CdTe detector with P-I-N structure [2]. However, relatively low transport characteristics of the initial material $(mt)_e$ and $(mt)_p$ restrict the possibility to increase the sensitive volume of these detectors which so far does not exceed 5-25 mm^3.

At the same time there is a possibility to fabricater planar CdTe detectors with Metal-Semiconductor-Metal structure with sensitive area of several square centimeters at the thickness of over 2 mm.

These detectors are more sensitive to gamma radiation, but they possess a poor energy resolution.

Recently there is an increased interest in different electronic methods of improvement of the spectrometric characteristics of non-cooled detectors. Among them, primarily, there are different pulse selection methods [3-4] to improve the detectors energy resolution considerably, but accompanied with a reduction of registration effectiveness in a total absorption peak. There are also pulse correction methods [5-6] which improve the spectrometric characteristics without loss or even with an increasing of the registration effeciency in the total absorption peak.

New methods of the pulse correction and pulse selection to improve considerably the spectrometric characteristics of CdTe and other wide-band semiconductor detectors are suggested in this paper.

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II. ULSE PROCESSING METHODS

A. Pulse correction method

Peculiarities of the gaussian shaping amplifier output signals are used in the suggested correction technique.

For detectors made from wide-band semiconductors, mt -product values for electrons and holes are significantly different and free lengths L_e and L_p are comparable to or more then the thickness of the detector sensitive region - *d*. The detector output pulses shapes are determined by the generation place of charge carriers in the detector sensitive region. There are pulses with various shapes having both a fast (electronic) and a slow (hole) component, Fig. 1.

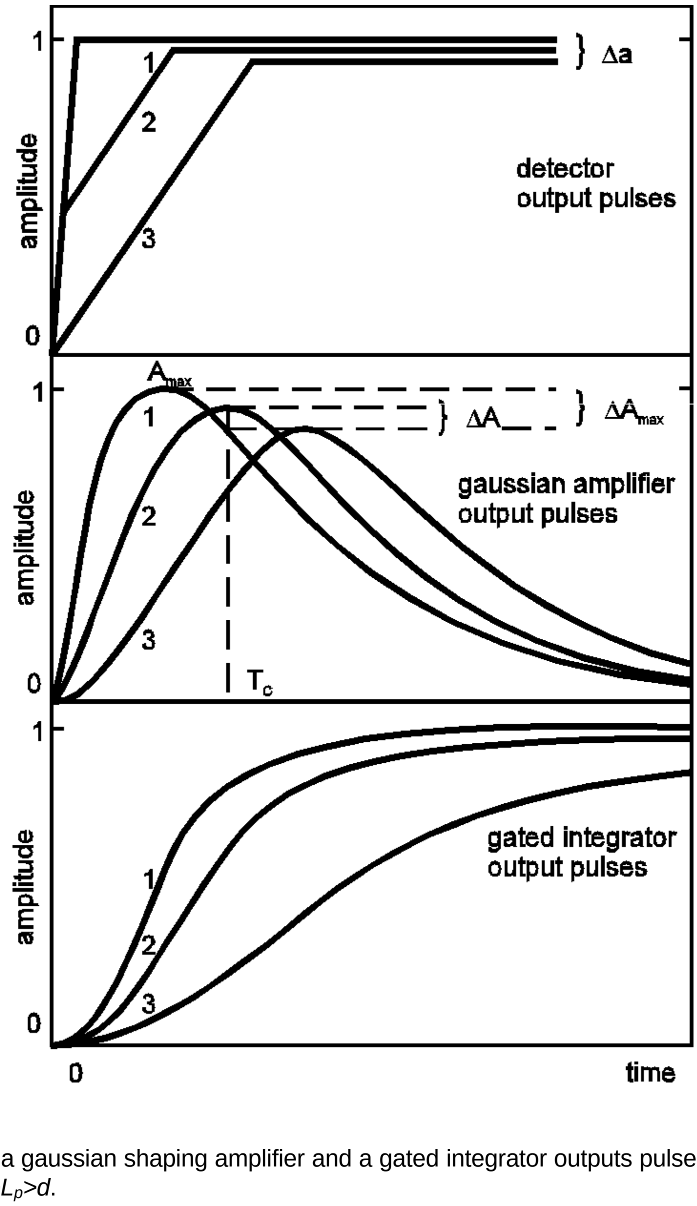

Fig. 1. A detector, a gaussian shaping amplifier and a gated integrator outputs pulses shapes. $(mt)_e/(mt)_p>10$, $L_e>L_p>d$.

As a consequence, pulses from the output of a shaping amplifier will have different shapes. The greatest contribution to the reduction of the shaped pulses amplitudes is produced by charge trapping losses. This contribution increases with the charge collection time. An additional change of the shaped signals appears due to the influence of the ballistic effect. The influence of the ballistic effect is larger as the collection time exceeds the shaping time.

The conventional technique of measurement of pulse amplitudes, maximal amplitudes A_{max} of shaped pulses are measured in the amplitude analysis. In this case, the relative spread of the maximal amplitudes DA_{max}/A_{max} determines the energy resolution of the detector. Available techniques of the pulse correction add, in one way or another, a specified magnitude to defect pulses using for this the risetime and the amplitude of the output pulses. In work [6] for this purpoce a linear relationship between charge losses and a risetime of detector output signal obtained for a specific class of "good" CdTe detectors was used.

We considered another possibility for the correction of pulse amplitudes, which represents a subtraction of a specified magnitude from the pulses amplitude. This specific magnitude must be defined by the extent of pulses shape difference from an ideal form. Our calculations showed that such an effect may be reached by measuring the shaped signal amplitude of the gaussian shaping amplifier at or after a certain point in time counted from the pulse beginning. If the shapes of shaped signals are carefully analyzed, a specific point T_c on a time axis can be found. A scatter DA of maximal values $A(T_c)$ measured within a time interval starting at the time T_c is less than a scatter DA_{max} of theshaped pulses maximal amplitudes values, Fig. 1. This point in time T_c is determined by the parameters of initial material, the magnitudes and ratio of transport characteristics of electrons and holes, a gaussian amplifier shaping time and should be individually determined for each detector. An amplitude measurement at the point in time T_c will be accompanied with an amplitude reduction and, as a result, a degradation of signal/noise ratio. In this case, the amplitude reduction for the material with very low magnitudes of $(mt)_p$ may be considerable. But the improvement of spectrometric characteristics may be extent considerable too. It is clear that the improvement of the spectrometric characteristics depends on the parameters of the initial material and the detector. A considerable improvement of the spectrometric characteristics can be predicted for the detectors in which output pulses have two linearly increasing fast and slow components.

There is a modification of the suggested correction method. It uses a gated integrator. The pulse correction is attained by assigning a specified point in time corresponding to the onset of integration of shaped signal. In this case, the resultant amplitude of integrated signals will be slightly reduced, but the amplitude reduction will be more considerable for pulses with less charge losses, which leads to a decrease of amplitude scatter. The signal integration also reduce the effects of the ballistic deficit.

B. Pulse shape selection method

Pulse shape selection or the pulse discrimination methods are more developed and more often used for the improvement of the energy resolution of the detectors. The method under discussion permits, in one way or another, to exclude from an analysis the pulses with long risetime and having the greatest amplitude deficit caused by charge losses. The pulses with shortest fronts are accepted for a subsequent analysis. The apportionment of these pulses are usually performed by using different schemes of measurement of the risetime with subsequent apportionment if the measured risetime of the pulse hits into the defined time window.

We suggested the technique for pulse selection based on a shape analysis of the signals from the output of the gated integrator. As shown in Fig. 1, for the detector output pulses with small charge losses and with the short fronts the integrated pulses flat top is reached in a time much shorter then for pulses with long fronts. Thus, carrying out a pulse shape analysis of pulses from the gated integrator output it is possible to accept for the subsequent analysis only pulses with the flat tops which have minimal charge losses.

C. Pulse processing technique

We developed, fabricated and tested several versions of the correction and selection schemes based on the methods suggested.

A simplified block schematic of the simplest version of the correction scheme is shown in Fig. 2. It represents an electronic key controlled by a logical scheme. In normal state the key is closed. The logical scheme preassigns a key unlocking time counted relative to the arrival of time control signal. The pulses from the count rate meter (CRM) output of the shaping amplifier are usually used as control signals. The key unlocking time is adjusted by the resistor *Rt* and chosen individually for each detector and each shaping time.

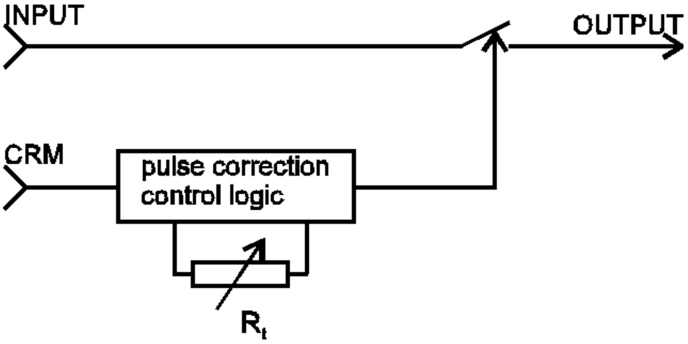

Fig. 2. Simplified block schematic of a pulse correction scheme (PCS).

For conveniant application, we developed and fabricated the correction unit made as a single chip - Pulse Correction Scheme (PCS). This scheme is easily introduced into each standard shaping amplifier.

To obtain a combined effect of the correction and selection, we developed a special correction-selection pulse processing unit. Corrected pulses may further be subjected to the selection in this unit. A pulse processing unit simplified block schematic is shown in Fig. 3.

Signals from the shaping amplifier output arrive at the inputs of two ideal integrators of the same type. One of them is a measuring device. The signal from its output arrives at ADC through the key. The signal from the second ideal integrator is used for shape-control comparator (CMP) threshold forming, which is proportional to the input signal amplitude, as well as, for analyzes of the shape deviation of the integrated signal from an ideal shape of the integrated signal with the flat top. A signal proportional to the difference of the integrated pulse shape from the ideal integrated pulse shape is transferred into the second input of comparator. The synchronization is performed by using the time control signals, i.e. the signals from the output CRM of the shaping amplifier. The control logic scheme in the pulse selection channel strobes the comparator operation. If the extent of the difference between a pulse shape from an ideal one is less than a specified threshold, the comparator generates a signal permitting pulse transmission through the key. The control logic scheme in the correction channel determines an onset of signal integration by the measuring integrator. In the case of several pulses arriving at the input simultaneously, the control logic scheme returns all keys to the starting position.

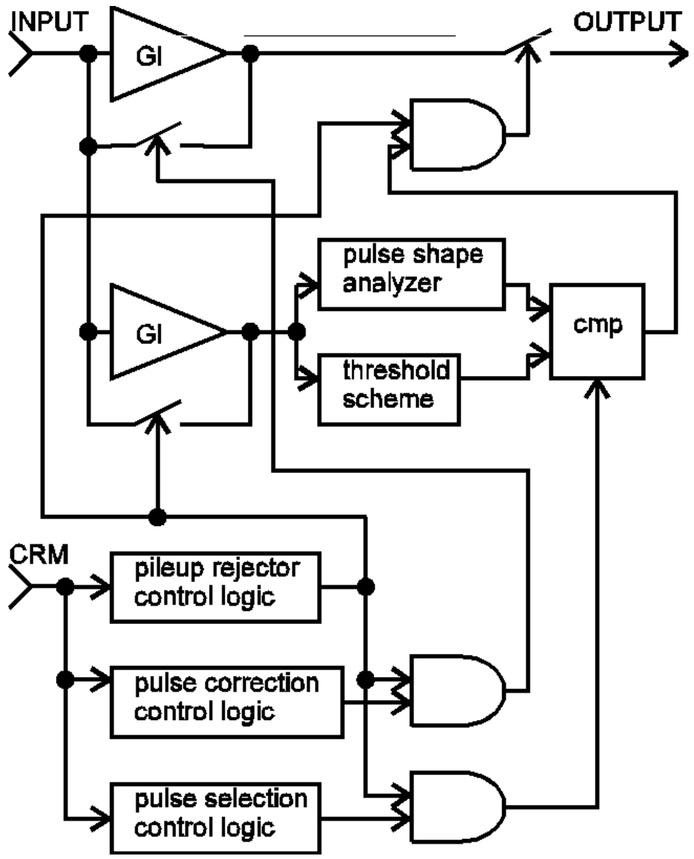

Fig. 3. Simplified block schematic of a pulse processing unite.

The correction-selection pulse processing unit may be used in combination with any shaping amplifier with CRM output. There is the possibility to use this unit only in correction or selection regime or in correction mode with additional selection.

III. EXPERIMENTAL RESULTS

A. PCS application

We suggest two methods of PCS application, first - using a single shaping amplifier. In this method PCS inputs are connected to the shaping amplifier outputs. Pulses from PCS output are sent directly to ADC input. In the second application method the PCS is placed between shaping amplifier and gated integrator. Pulses from gated integrator output are sent to ADC input.

Using the first method of PCS application, dependencies of the energy resolution, peak-to-Compton ratio, total absorption peak area with energy 662 keV on time T_c, counted from the onset of measuring of the output pulse amplitude of a spectrometric amplifier ORTEC 572 operating with CdTe detection unit were measured. This results are represented in Fig. 4. One can see a significant energy resolution and peak-to-Compton improvement together with an increasing of total absorption peak area was. For big values of T_c, when the over compensation is observed, the degradation of energy resolution and peak-to-Compton were registered.

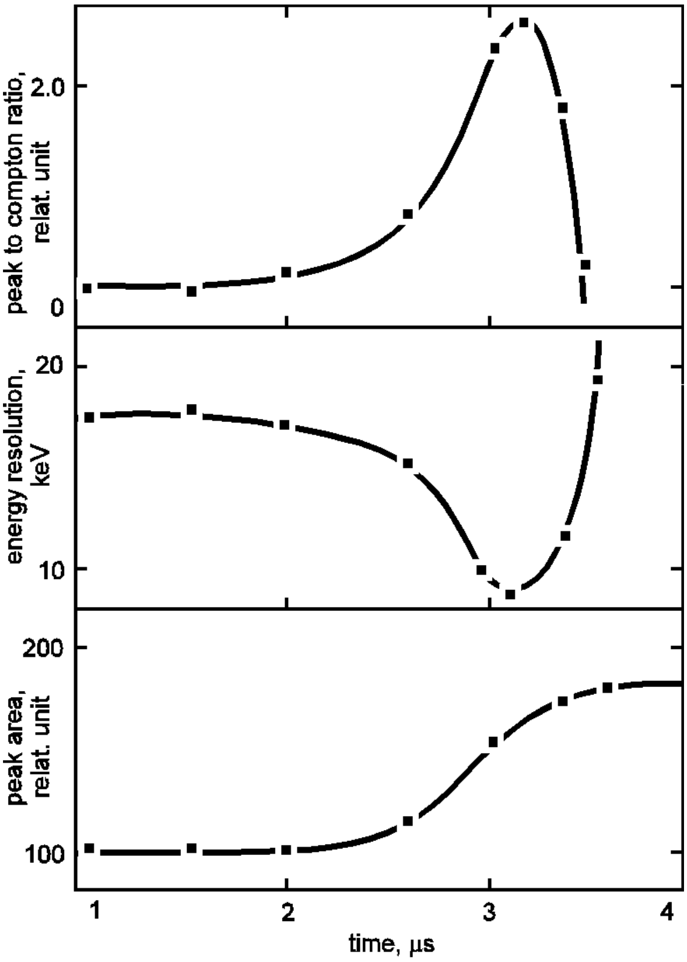

Fig. 4. Peak area, peak-to-compton ratio and energy resolution at 662 keV of a planar CdTe detector with PCS for different times *Tc*. Shaping time — 1.0 μs.

The results obtained by a spectrometric amplifier with the ideal integrator, CANBERRA 2024, having a built-in PCS (second method of PCS application) and CdTe detection unit illustrate a possibility to improve the energy resolution and increase the registration efficiency in the total absorption peak too.

B. Pulse correction-selection processing unit application

Spectra of Cs-137 obtained by means of CdTe detection unit with using a gated integrator, with correction and with correction together with selection are presented in Fig. 5. Spectra were registered by using a shaping amplifier ORTEC 572. Initial energy resolution (FWHM) of a CdTe detection unit was 25 keV at 662 keV. It is seen that the application of a single gated integrator gives only a small improvement of detector spectrometric characteristics. The correction significantly improves both the energy resolution up to 10.2 keV, peak-to-Compton ratio up to 2.4 and increases the registration efficiency in the total absorption peak approximately in three times. The selection application improves still further the energy resolution up to 9 keV, peak-to-Compton ratio up to 5.1 with reduction of the registration effectiveness in the total absorption peak by two times. The best energy resolution with CdTe detection unit and application of pulse processing unit was about 6.5 keV at 662 keV.

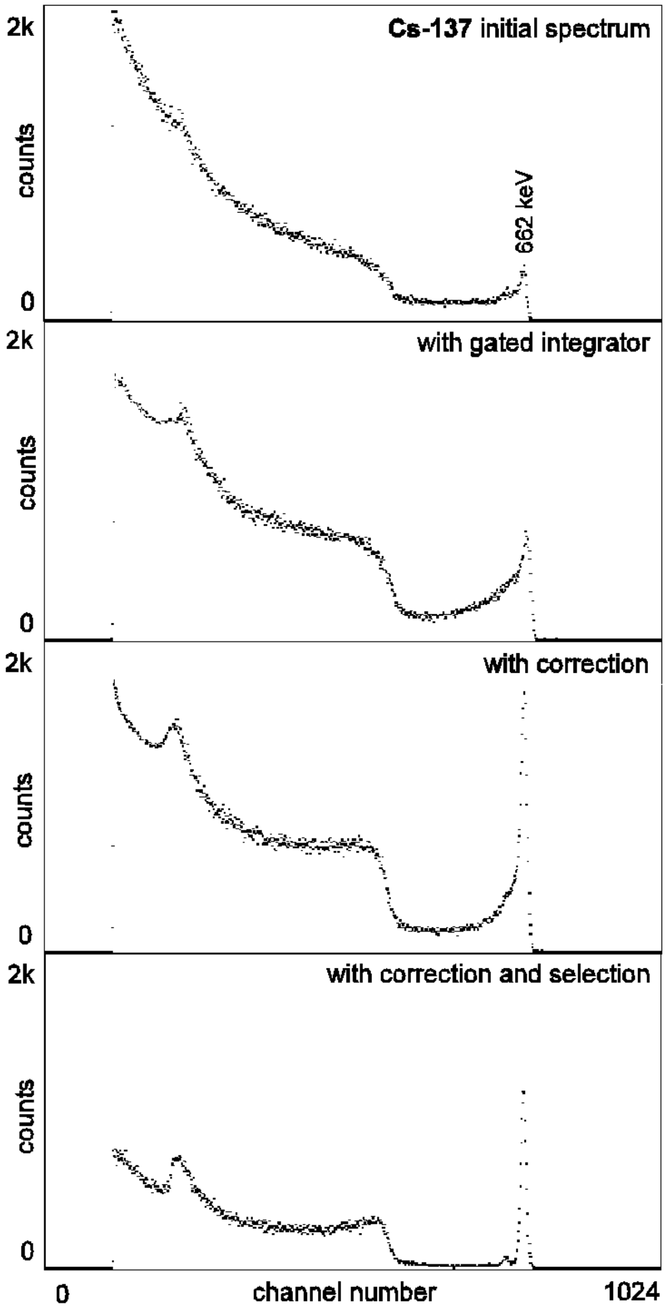

Fig. 5. Spectra of Cs-137. Planar CdTe detector 5x5x2 mm^3. Shaping time 0.5 µs.

A possibility of smooth adjustment of a selection level allows the user to choose an operation mode with the maximal registration effectiveness in the total absorption peak or an operation mode with the greatest energy resolution when the registration effectiveness is reduced.

We performed tests of the pulse processing unit with other detectors made from wide-band semiconductors, such as HgI_2 detector with sizes 20x20x1 mm^3 and CdZnTe detector with sizes

10x10x5 mm^3. We found a considerable improvement of the spectrometric characteristics too. Spectra Cs-137 registered by the HgI_2 detector and by the CdZnTe detector are represented in Fig. 6. The initial energy resolution (FWHM) of both detector type was less than 5% with peak-to-Compton ratio less than 1. The energy resolution 8.5 keV and 8.8 at 662 keV for the HgI_2 and CdZnTe detectors accordingly were obtained with single selection mode using.

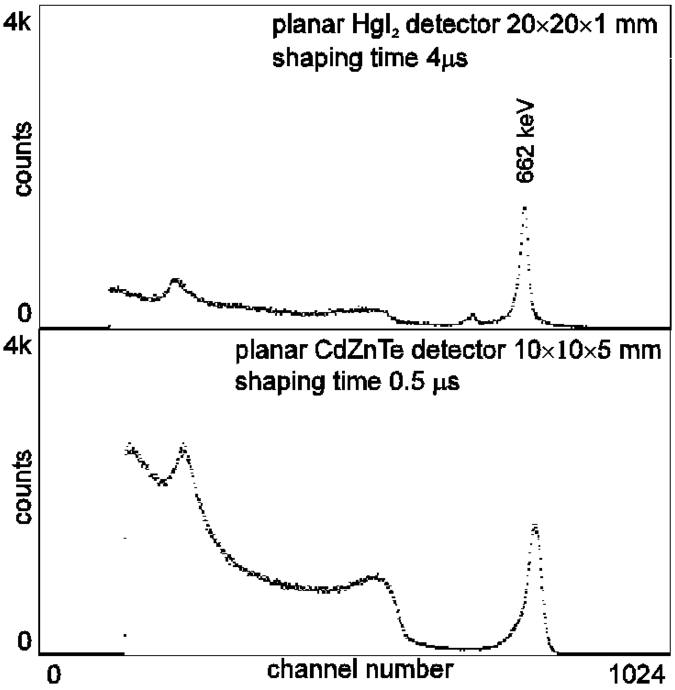

Fig. 6. Spectra of Cs-137. Planar HgI_2 and CdZnTe detectors.

The correction-selection unit improves considerably the spectrometric characteristics within a wide range of an energy registered. Spectra of Co-57, Ba-133 and Co-60 are shown in Fig. 7.

Notwithstanding the fact that cooled CdTe detectors with P-I-N structure possess the high energy resolution, the application of the correction-selection unit allows one to attain the energy resolution of 3.1 keV at 662 keV with peak-to-Compton ratio 8.1, Fig. 8.

IV. CONCLUSION

The correction and selection techniques suggested are based on a analysis of shaped signals. The basis of the correction method is the existence of a specific point on the time axis of an output signal of an gaussian shaped amplifier in which the amplitude spread is considerably less than the spread of maximal pulse amplitudes.

The selection technique is based on choosing signals having a flat top or an almost flat top from an output of an ideal integrator for subsequent analysis.

On the basis of the methods suggested, the correction device and the correction-selection pulse processing unit allowing one to improve considerably the spectrometric characteristics of detectors made from the wide-bandgap semiconductors is developed and tested.

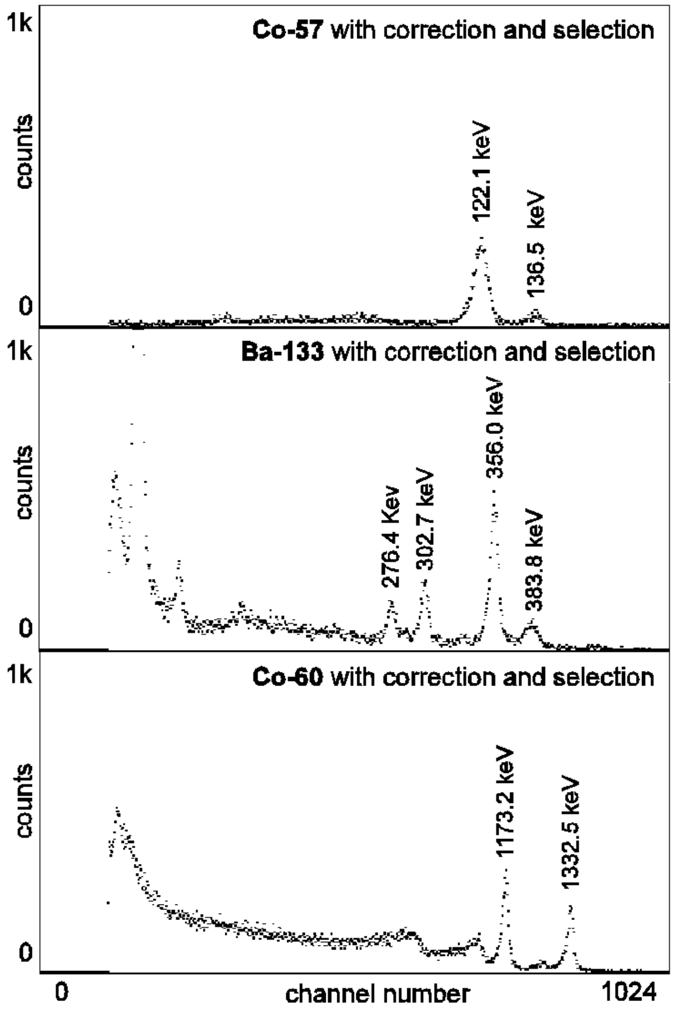

Fig. 7. Spectra of Co-57, Ba-133 and Co-60. Planar HgI_2 detector 20x20x1 mm^3. Shaping time 4 µs.

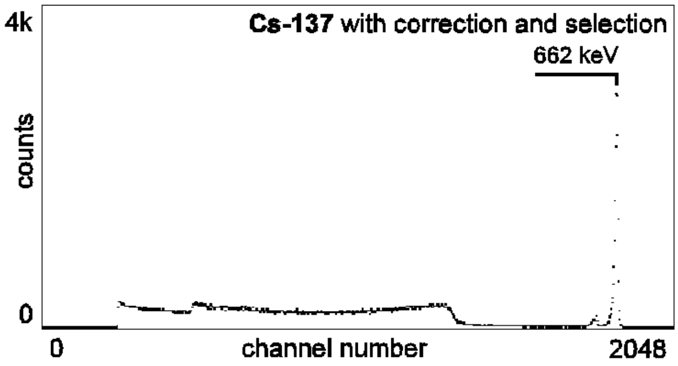

Fig. 8. Spectrum of Cs-137. CdTe detector with p-i-n structure 5x5x0.7 mm^3. Shaping time 1 µs.

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