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Advanced approach to estimation scintillator energy resolution

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Digitalization of scintillation pulse data allows to get significantly more information comparing with analogue approach dominated in scintillation technique. Previous investigations with ^{137}Cs source demonstrated the ability to refine the structure of photopeak and significantly improve energy resolution. The present work is devoted to application of new method to multipeak isotope analysis. It is shown that this approach allows to separate data from close located peaks and demonstrate efficiency of this method in wide range of ionizing particle energies from 100 to 1500 keV.

Keywords: scintillator, energy resolution, photopeak, pulse digitalization.

Оцифровка данных сцинтилляционного импульса позволяет получить значительно больше информации по сравнению с аналоговым подходом, доминирующим в сцинтилляционной технике. Ранее с использованием источника ^{137}Cs продемонстрирована возможность получить тонкую структуру фотопика и значительно улучшить значение энергетического разрешения детектора. Работа посвящена применению нового метода для анализа многопиковых изотопов. Показано, что этот подход позволяет разделить данные от близко расположенных пиков, продемонстрирована эффективность этого метода в широком диапазоне энергии гамма-квантов от 100 до 1500 кэВ.

Вдосконалений підхід до визначення енергетичної роздільної здатності сцинтилятора. *О.Гектін, А.Васильєв, В.Суздаль, О.Соболєв, І.Тавровський.*

Оцифровка даних сцинтиляційного імпульсу дозволяє отримати значно більше інформації у порівнянні з аналоговим підходом, домінуючим у сцинтиляційній техніці. У 2019, з використанням джерела ^{137}Cs вперше показано можливість отримати тонку структуру фотопіку і значно поліпшити значення енергетичного дозволу детектора. Робота присвячена застосуванню нового методу для аналізу многопікових ізотопів. Показано, що цей підхід дозволяє розділити дані від близько розташованих піків, продемонструвати ефективність цього методу у широкому діапазоні (від 100 до 1500 кеВ) енергії радіації.

1. Introduction

Energy resolution (ER) of scintillation detectors is a crucial parameter for many spectrometry devises and application. This parameter often play role of the main criteria for scintillator selection. Well known study [1] determine the theoretical limit for ER for different scintillators and demonstrate the gap between this limit and experimental values. In major cases physical background of this difference is not known and experimental studies during years did not give significant improvement of scintillators.

For example, recent experiments with NaI:Tl, CsI:Tl, CsI:Na co-doping [2, 3] or melt purification by scavenger technique [4] gave some ER improvement (for about 1 % only) but anyway leave spectroscopy performance very far from theoretical limit (which is about 2.6 % for ^{137}Cs source).

Fig. 1 demonstrates the gap between theoretical limit and experimental values for more than 100 NaI:Tl grown ingots. This trend lead to assumption that only part of ER (R_{ext}) could be improved by extrinsic manipulation (growth technology, co-doping, purity etc.). The second part (R_{int}) has intrinsic nature, i.e. it is connected with crystal lattice, excitation volume and thermalization length. It means that this part of ER could not be improved technologically and is the subject for estimation only [6, 7]. Recently theoretical investigations of particle track structure demonstrate large deviation from track to track that has to be reflected at the integral statistics of events [8–11]. Such track structure analysis should be taken into account during estimation of ER.

We have to note that standard spectrum analysis is always based on analogue technique [12], whereas new digital methods give more possibilities to obtain information for each individual pulse, separate events using different decay patterns [13]. In other words, we have additional chances to use more factors in the analysis. Data Mining approach is one of the best statistical methods to resolve multi-parameter problem [14–17]. Unfortunately, this approach was not used in scintillator physic yet. The first application of such methods to scintillator analysis gave very promising results [13]. There are many different approaches to treat waveform data and at the moment we could not recommend the optimal approach. But it was shown that Data Mining together with clustering method [6, 7, 13] allows to reveal thin structure of photopeak and obtain ER NaI:Tl at ^{137}Cs photopeak to be about 3 %. This value is very close to the theoretical limit for halide scintillators. The tasks of revealing hidden dependences, structuring data, separating existing factors without their analytical description was successfully solved by clustering and further analysis.

This work describes the next step of development, namely the analysis of ability scintillation spectra for multiple peak isotope verification with high accuracy. It is important to separate closely located peak and reach maximal resolution for each of them.

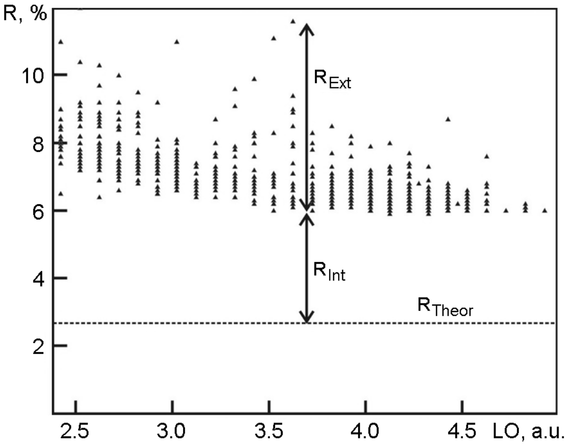

Fig. 1. Statistics of energy resolution dependence from light yield (units correspond the range from 25000 to 45000 ph/MeV) for NaI:Tl crystals grown by continuous growth technique [5].

2. Experiment technique and method for the pulse amplitude spectra analysis

In the frame of the study both conventional scintillation spectra method and new one, based on discretization of the pulse shape of individual events, were used. NaI:Tl crystals were chosen for tests. Initial samples with cylindrical shape ∅1"×1" demonstrated 6.2 % at room temperature. Spectra measurements were performed using standard analogue approach at MCA, model Multiport II (Canberra) with standard Hammamatsu PMT HM R1308 2" (HV:1075 V) or with fast PMT ET 9821B 3" (HV:2085 V). Digital oscilloscope LeCroy waveSurfer 422, 200 MHz, 2 gigasample/s type was used for digitizing of individual events. 99000 events were used to obtain enough statistics.

The digital approach to the data accumulation and separation is based on the following. When constructing the spectrum of amplitudes of scintillation pulses, the signal from each scintillation flash at the output of the photodetector is integrated in a given time interval. Using the obtained array of scalar values, amplitude distribution histogram is constructed to represent the spectrum. The kinetics of each scintillation pulse can be digitized using contemporary digital oscilloscopes. Therefore, each event can be characterized by the vector of the digitized values. These vectors can be then treated using modern algorithm of data processing [18–20]. Such algorithms are effectively used in cases when the models of

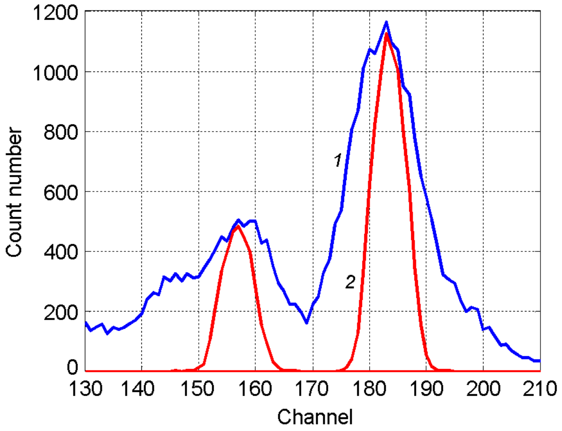

Fig. 2. Part of the amplitude spectrum (blue curve *1*) of the ^{133}Ba isotope measured by a NaI:Tl detector with initial resolution of 6.0 % for ^{137}Cs source. The amplitude spectrum obtained with the same crystal after processing the decay data proposed method and highlighting the peaks corresponding to one cluster of events (red curve *2*).

formation of the response on each event are so complex that one-to-one correlation between pulse shape and its amplitude is impossible. The statistical noise is the additional factor. These algorithms allow to perform the clustering of the events without any a priori knowledge of the models.

Clustering procedure is widely used in the systems of artificial intelligence and data mining problems [20]. The clustering of data and the following analysis of them are successfully used in the problems of visualization of hidden dependences, structuration of data, distinguishing of acting factors without their analytical description, etc. Clustering procedure implies decomposition (dissection) of the data array in the parameter area. Section planes are set by the selected norms, by which the distances between primitives (data array elements) are calculated. Implementations of the clustering procedure can be very diverse, have significantly different computational complexity, different convergence and accuracy of solutions.

3. Results and discussion

The purpose of this work is to develop the described above method with respect to the analysis of spectra from multicomponent isotopes or spectra from several simultaneously acting radiation sources. In fact, each of the scintillation spectrum peak is decomposed into groups according to the shape of each pulse. Events similar in a certain parameter are gathered into the group. In particular, we select events close in pulse decay shape. A mathematical measure of proximity is the norm, the choice of which allows us to control the criterion for the formation of groups. The described procedure is essentially clustering applied separately for each peak. Specific to this work is the modeling of situations where peaks in the energy range are so close to each other that they begin to overlap. Naturally, in this case, the resolution at each peak is deteriorated. In this case, the resolution of the fine structure of the photopeak [13] should contribute to the separation of various isotopes in the spectrum.

Table. Energy resolution data for main peaks of ^{152}Eu source measured by conventional analogue technique and advanced one

Energy of the peak, keV	Energy resolution (analogu approach)	Energy resolution (new method)
122	16.4 %	14.2 %
245	16.4 %	9.7 %
344	12.1 %	6.5 %
779	27.4 %	3.5 %
964	10.1 %	3.2 %
1408	5.4 %	2.1 %

As a simple example, Fig. 2 shows the spectrum of ^{133}Ba isotope with two peaks whose centers are located fairly close to each other. ^{133}Ba emits quanta with energies 303 keV and 356 keV, i.e. the distance between the peaks is about 53 keV. Nevertheless, the amplitude peaks are slightly overlapping without treatment. The same set of experimental data is used for treatment with the proposed approach (red curve). Thin structure verification and the optimal peak selection allows us to improve the spectrum and to reach better ER in each peak (both 303 keV and 356 keV peaks). In this case the peaks well resolved.

The second set of tests is based on the data obtained with the same detector and ^{152}Eu source. This isotope has several peaks (see Table) and is appropriate to check new method in wide range of particle energies(from 122 to 1408 keV). Typical spectrum measured by NaI:Tl for this case is shown in Fig. 3. The base spectrum demonstrates main peaks. Insets show decomposition of each peak in accordance with method and procedures presented in [13]. Table demonstrates data for conventional test pro-

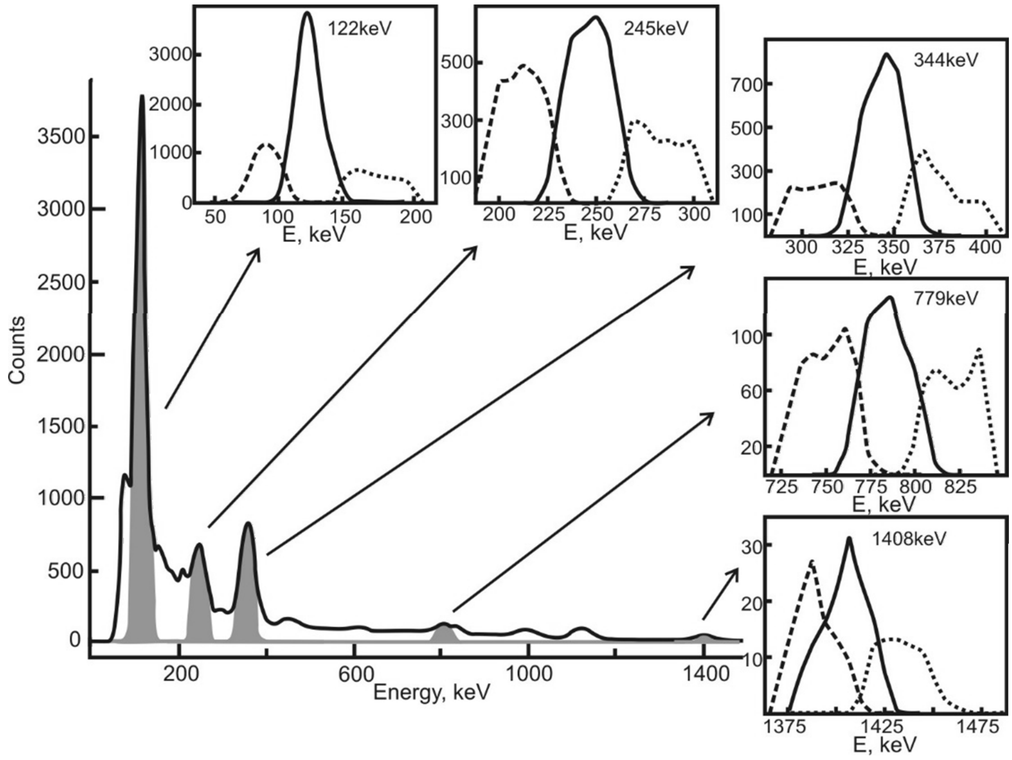

Fig. 3. ^{152}Eu source spectrum measured with NaI:Tl detector. The insets show the main peaks and their fine structure obtained by clustering according to method [13].

cedure and optimal value obtained after clustering into three peaks.

We have to note that new method allows to receive better ER for all energy range. Moreover, the improvement of ER is manifested better for high energy peaks, reaching values close to the theoretical limit of energy resolution. The reasons why the dependence of the ER improvement depend on the peak energy is the subject of a separate study.

4. Conclusions

In conclusion, it should be noted that the field of effective use of the new approach to determining scintillator energy resolution is large and covers almost the entire range of detectors operating. It is shown that the digitization of decay pulses together with data processing allows one obtain substantially more accurate information from the photopeak structure. This approach is extremely important for the analysis of the spectra of multicomponent isotopes and the separation of overlapping isotopes. As experimentally confirmed, the proposed technique is effective for alkaline halide scintillators. However, it is likely that it will be effective for other types of scintillation materials, which nevertheless needs to be checked separately.

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