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Time-resolved gamma spectroscopy of single events

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A B S T R A C T

In this article we present a method of characterizing scintillating materials by digitization of each individual scintillation pulse followed by digital signal processing. With this technique it is possible to measure the pulse shape and the energy of an absorbed gamma photon on an event-by-event basis. In contrast to time-correlated single photon counting technique, the digital approach provides a faster measurement, an active noise suppression, and enables characterization of scintillation pulses simultaneously in two domains: time and energy. We applied this method to study the pulse shape change of a CsI(Tl) scintillator with energy of gamma excitation. We confirmed previously published results and revealed new details of the phenomenon.

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1. Introduction

Despite many years of studies on scintillating materials many questions are still open. While luminescence processes and high energy radiation interactions with matter are well understood, the fundamental processes of energy transport and high density quenching are still puzzling [1–6]. It is well known that a scintillation pulse shape changes with change of type of excitation (γ-rays, neutrons, α particles, high energy ions) [7–13]. This phenomenon is commonly used for particle discrimination in variety of applications [14–17]. However, the origin and the exact mechanism are still not known. In last years, a dependence of a scintillation pulse shape on γ photons energy was reported for various materials [18–21]. Recent theoretical developments [2,3,5,6] provided an explanation of these observations by modeling the charge separation inside the ionization track created during a gamma energy excitation.

Despite successful results of the theoretical modeling, many aspects still require an experimental study and verification. This raises a need for new data and a new experimental approach. The aim of this study is to provide a new method of characterizing scintillators in two domains simultaneously: in terms of the excitation energy, and time evolution of scintillation.

We will demonstrate that by digitization of individual scintillation pulses and digital signal processing it is possible to study the scintillation mechanism in terms of pulse shape and light yield at the same time. For each scintillation pulse it is possible to calculate the integral light output and corresponding deposited amount of energy. The acquired pulse height spectrum can be later subdivided into energy bins. An average scintillation pulse shape can be calculated for each energy bin by taking an average of all acquired events within that bin. However, to obtain undistorted pulse shapes additional signal processing and event selections are required before taking the average.

With this method we verified previous experimental results on CsI(Tl) pulse shape dependence on gamma energy, and we compared those results with theoretical models [6]. We have found that the pulse shape change predicted by the model is in good agreement with the measured data, however we observed some differences. The proposed method was used to characterize a scintillation decay time of CsI(Tl) excited with pulsed X-rays and gamma rays. It was found that X-ray pulses produce a significantly different pulse shape compared to single gamma events of an energy equal to the aggregate energy deposition of multiple lower-energy X-ray photons in the pulse. We will conclude that the proposed method provides a new way of characterization of scintillators.

2. Materials and methods

2.1. The setup

The measuring setup is shown diagrammatically in Fig. 1. Scintillation pulses from a one inch CsI(Tl) sample are converted to electrical pulses by a Hamamatsu H5510 Photomultiplier Tube (PMT). The scintillation crystal is optically coupled with silicon oil to the PMT's entrance window. The PMT's anode signal is connected directly to the 10-bit 4 Giga Samples Per Second (GSPS) DT5761 digitizer from CAEN.

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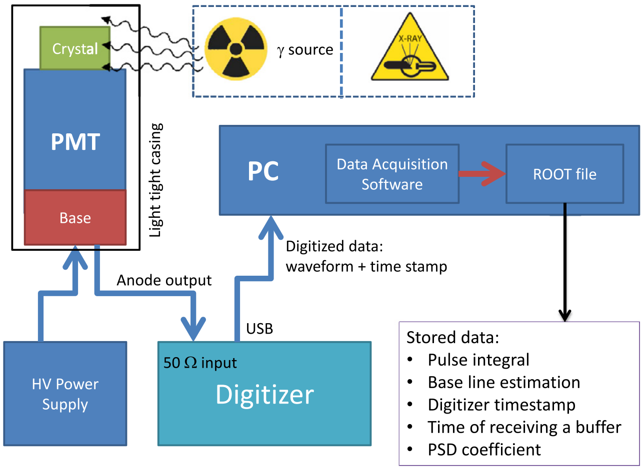

Fig. 1. Schematic of the time resolved Gamma spectroscopy setup. The gamma source or a pulsed X-ray tube excite the scintillation crystal. The resulting scintillation pulses are detected with a photomultiplier tube and digitized on event-by-event principle.

The digitizer has an input range of 1 Vpp, input impedance $Z_{in} = 50\Omega$, and a memory buffer depth of $7.2{\cdot}10^6$ samples. No preamplifier nor other ways of analog signal shaping have been used. All data acquisition and on-line processing is done with a personal computer and homemade software *veroDigitizer*.

A ^{137}Cs source has been used for excitation. The barium X-rays (32 keV) were absorbed by a lead absorber placed between the ^{137}Cs source and the detector. In this way we avoided photoelectric absorption of low energy X-rays, and only photoelectrons or Compton electrons from 662 keV gamma interaction were detected. As an alternative to γ rays, we used a light excited X-ray tube N5084 from Hamamatsu for generation of ultra short X-ray pulses ($<$ 100 ps). The X-ray tube has a tungsten target and is powered with a 40 kV power supply. Each X-ray pulse contains multiple X-ray photons, which enables low energy excitation (∼10 keV) but with a high light output.

2.2. Data acquisition

When the anode signal exceeds the digitizer's trigger voltage V_{tr} an event is triggered and stored in a local buffer. Each event contains a waveform consisting of 56 k voltage samples (14 μs time range). When the internal buffer is full, all digitized events are transferred to the PC for data processing. In order to record low energy events, the digitizer's trigger voltage V_{tr} was set as close as possible to the signal's base line. However, the low V_{tr} results in pick-up of noise spikes like in the exemplary pulse shown in Fig. 2. Fig. 3 shows the steps of the data processing which are required before the triggered events can be used for calculating average pulse shapes. Only events fulfilling multiple criteria are selected in order to remove unwanted noise events, suppress pile-up, and assure good quality of each triggered pulse. The following sections will discuss in detail each step of the data processing.

2.3. Filtering and decimation

The digitizer reduces a continuous-time signal from the PMT to a discrete-time digital signal (sampling). High sampling frequency of the used digitizer $f_s = 4$ GHz provides precise timing information, but in case of CsI(Tl) with slow decay time it results in high uncertainty of each value at a point in time of the measured signal (low signal to noise ratio). This can be seen in Fig. 2 and raw signal in Fig. 4. To increase the signal to noise ratio and decrease the uncertainty of a measured voltage each waveform was down-sampled (decimated) by first applying a low pass digital filter and then reducing the number of samples by a factor of $M = 256$.

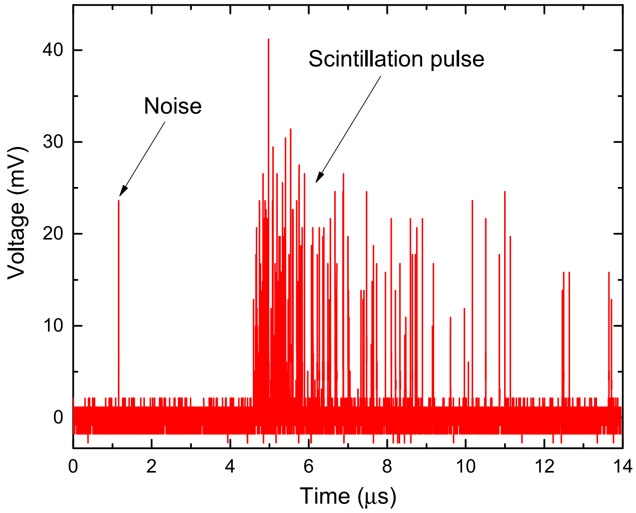

Fig. 2. Event triggered by a noise spike at around 1 μs with a coincident scintillation pulse starting at around 5 μs.

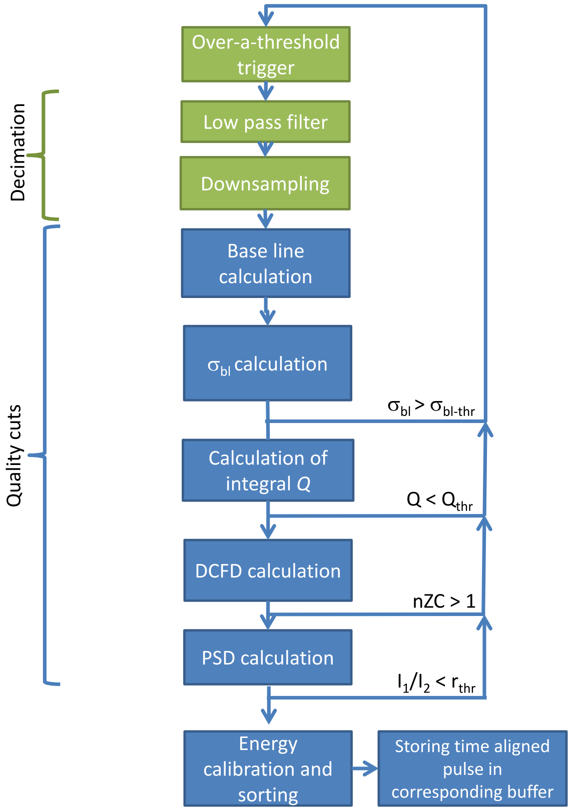

Fig. 3. Diagram of data processing workflow. σ_{bl} is the standard deviation of the base line; σ_{bl-thr} is a maximum threshold for standard deviation of the base line; Q is the pulse integral; Q_{thr} is a pulse integral minimum threshold; nZC is the number of zero crossings in the Digital Constant Fraction Discriminator (DCFD) signal; I_1/I_2 is the pulse shape factor defined as the ratio of the short and long integration gates.

To avoid aliasing it is needed to do a low pass filtering before downsampling [22]. The cutoff frequency of the filter has to be equal or lower than the Nyquist frequency of the down-sampled signal, which is $f_{co} = \frac{f_s/2}{M} = \frac{4000/2}{256} \approx 7.8$ MHz. Fig. 5 shows time and frequency domain responses of multiple standard digital filters designed for −3dB cutoff frequency at 7.8 MHz. Because in our measurements we want to preserve an undistorted time response of the signal, the filter choice

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