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Vladislav Todorov, Philippe Cassette, Chavdar Dutsov, Benoit Sabot, Strahil Georgiev, Krasimir Mitev

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SUPPORTING DOCUMENT

Study of the Non-uniformity of the PMT Photocathode Response and its Influence on the Results Obtained in Different Scintillation Counting Experiments.

V. Todorov, P. Cassette, Ch. Dutsov, B. Sabot, S. Georgiev, K. Mitev

Introduction The non-uniformity of the response of photomultiplier tubes (PMT) has been studied in the past [1,2] and has been identified as one of the factors that can deteriorate the energy resolution in scintillation spectrometry [3]. In a recent study [4] we have shown that, when analyzing alpha spectra obtained after pulse-shape discrimination (PSD) in measurements with plastic scintillators, the shape of the alpha peaks is affected if there is a significant non-uniformity of the PMT response. This situation is illustrated in Fig. 1, showing PSD measurements of a plastic scintillator loaded with ^{222}Rn .

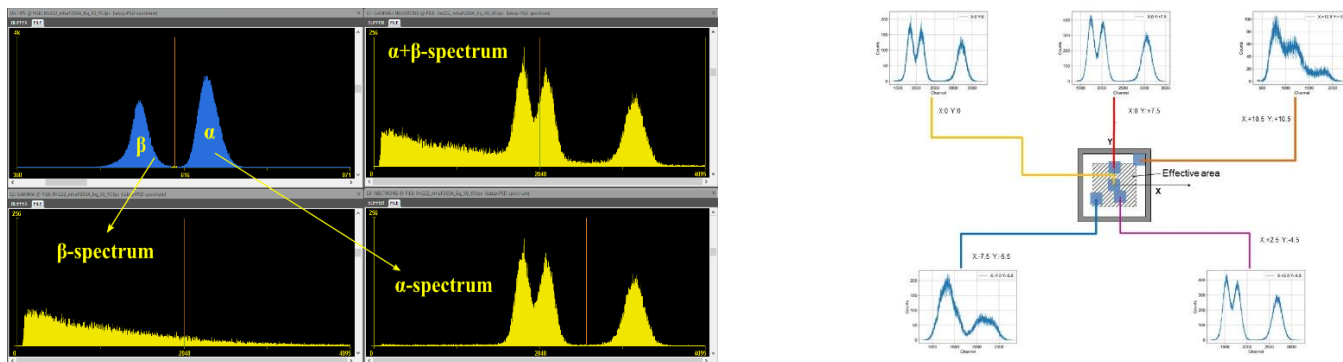


Fig.1 Left: PSD measurements of ^{222}Rn loaded in a small piece of a pulse-shape discriminating plastic scintillator. Right: Changes of the alpha spectra shape with the position of the scintillator at the surface of a Hamamatsu R7600U-200 PMT.

The objective of this work was to develop an experimental system allowing the quantification of the non-uniformity of the photocathode response of the PMTs and to study the influence of this non-uniformity in various scintillation measurements like: the analysis of alpha spectra obtained after pulse-shape discrimination and the absolute activity measurements using the free parameter model in Liquid Scintillation Counting [5].

Methods and materials We have developed the experimental system shown in Fig. 2. It consists of an in-house developed low-frequency oscillator which is driving a fast light emitting diode (LED) pulser based on an avalanche transistor. The system also provides a logical output signal, which is used as a gating signal of the acquisition electronics. The LED emits light pulses at 405 nm and the light intensity can be reduced by using calibrated grey filters. The light is then focused at the entrance of an optical fiber. The optical fiber delivers the light directly on the photocathode of the studied PMT on a 200 μm diameter spot. In order to study the spatial non-uniformity of the PMT, a mask with holes drilled in a 5x5 mm² grid is placed in front of the PMT and the optical fiber can be moved to each hole. The output of the PMT is connected to the input of the nanoPSD analyzer [6] and the logical output from the low frequency generator is used as a coincidence signal after proper delay adjustment. Thus, using the nanoPSD functionality [7], only the PMT pulses which are in coincidence with the reference signal from the generator are analyzed. This fully eliminates noise pulses and allows to analyze only the PMT pulses which are generated by the LED. The studied PMT is Hamamatsu R7600U-200, operating at + 850 V, but the system can easily be used with other PMTs.

Results and discussion An example of a spectrum from the LED source is shown in Fig. 3. No spurious or noise pulses are detected and all the pulses are in the LED peak. Fig 3 contains also the interpolated maps of the measured counting rates and centroid positions. The measurements were performed on a 5x5 mm grid. The figure shows that the PMT clearly exhibits non-uniform response, with both the counting rates and the centroid position, shifting to lower values at the edges of the photocathode. The estimated energy resolution ($R=FWHM/H$, where $FWHM$ and H are the full width at half maximum and the position of the LED peak, respectively), also decreases near the edges of the PMT, confirming that in these regions the non-uniformity of the response affects the energy resolution of the spectra.

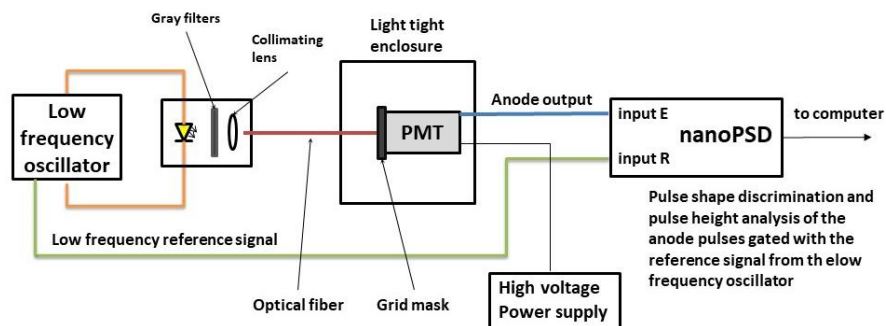


Fig.2 The experimental set-up used to test the non-uniformity of the PMTs photocathode response

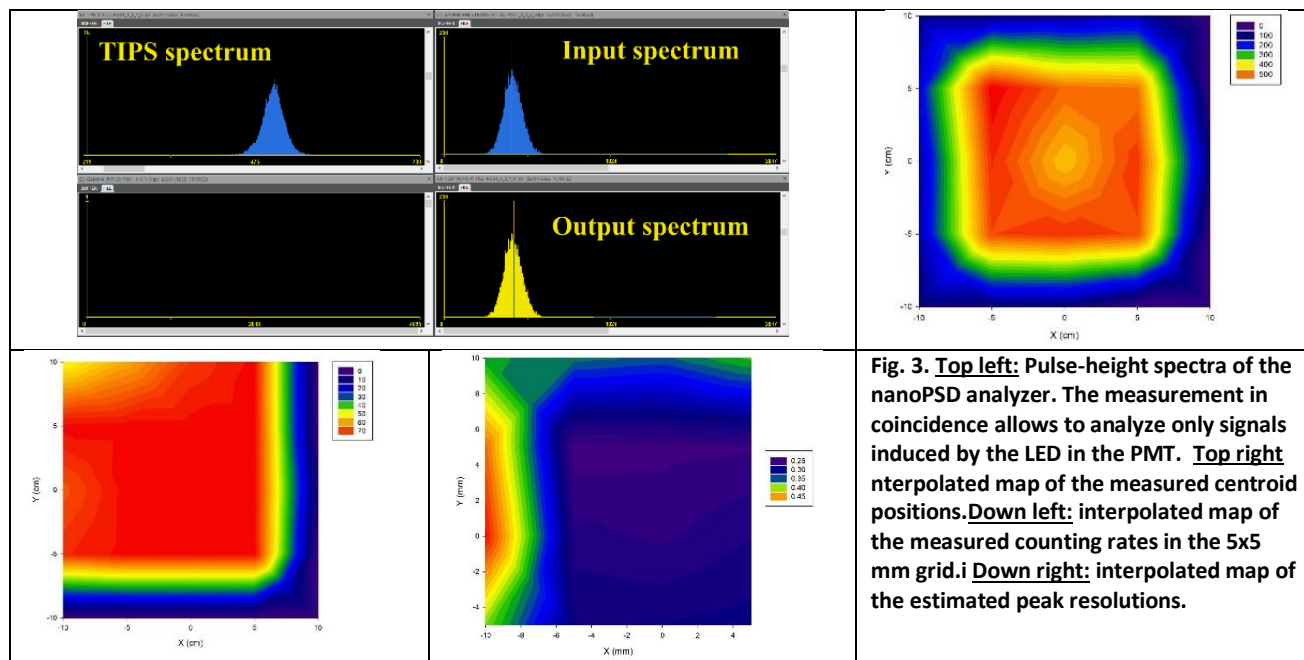


Fig. 3. **Top left:** Pulse-height spectra of the nanoPSD analyzer. The measurement in coincidence allows to analyze only signals induced by the LED in the PMT. **Top right** interpolated map of the measured centroid positions. **Down left:** interpolated map of the measured counting rates in the 5x5 mm grid. **Down right:** interpolated map of the estimated peak resolutions.

The free parameter model is used in radionuclide metrology for the direct calibration of the activity of radionuclides [5]. In this model, the Poisson distribution of the number of photons emitted by the scintillation light pulse, is traditionally used to calculate the detection efficiency from the non-detection efficiency, i.e., the probability that no photoelectron is detected. In case of a spatial non-homogeneity of the PMT response, the mean value of the Poisson distribution, describing the intrinsic light yield of the detection process, is no more a constant value but becomes a random variable with a distribution taking into account the fluctuations of the detection process. This leads to a compound Poisson distribution. The non-detection efficiency calculation is similar to the one using a Poisson distribution, but its uncertainty is larger, due to the variability of the random variable describing the mean value of the compound Poisson distribution. This effect leads to an increase of the uncertainty of the detection efficiency, which becomes especially important in the measurement of low-energy radionuclides.

Conclusions In this work we have developed an experimental system to study the effects that the non-uniformity of the PMT response may have on the scintillation counting measurements. We identified a degradation of the counting efficiency and the energy resolution at the end of the PMTs, which will affect the performance of the scintillation spectrometry and the radionuclide activity measurements using the free parameter model. These effects are described and quantified for scintillation detectors using Hamamatsu R7600U-200 PMTs.

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