A TECHNIQUE TO OPTIMIZE THE TIME RESOLUTION OF NE213 SCINTILLATION DETECTORS

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: الخلاصة

يصف هذا البحث طريقة للحصول على أفضل دقة زمنية للكاشف الومضي NE213 . وذلك
بتقليل كلٍ من توزيع زمن الانتقال وتأثير الشحنة المحيطية داخل المضاعف الضوئي . وقد أجريت
هذه الدراسات على الكاشف بقياس الدقة الزمنية لإشعة جاما مترابطة من المصدرين Na²² و Co⁶⁰
لفروق جهد مختلفة بين القطب السالب الضوئي وأول مصدر ثانوي للألكترونات . وتم الحصول على
تحسين إضافي في الدقة الزمنية باستخدام إشارة المصدر الثانوي السادس لتوقيت الإشارات بدلاً من
إشارة القطب الموجب التقليدية .

لقد تحسنت دقة الكاشف الزمنية بنسبة (١٤٪) للمصدر Na²² و(٢١٪) للمصدر Co⁶⁰ عند
استخدام أفضل قيمة لفرق الجهد بين القطب السالب الضوئي وأول مصدر ثانوي للألكترونات . كما
تحسنت الدقة الزمنية بنسبة (٤٪) للمصدر Na²² و(٦٪) للمصدر Co⁶⁰ عندما استخدمت إشارة
المصدر الثانوي السادس .

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ABSTRACT

A technique has been described to optimize time resolution of NE213 scintilla-
tion detectors. The technique involves minimization of transit time spread and
space charge effects in the photomultiplier. The photomultiplier space charge
effect was minimized by optimizing the voltage between the photocathode and the
first dynode while the transit time spread was minimized by using a 6th dynode
signal as timing signal instead of a conventional anode signal. During these studies
the time resolution of the detector for correlated gamma rays from ^{22}Na and ^{60}Co as
well as their ratio was used as a check for optimization of detector time resolution.

The detector time resolution is improved by 14 and 21% for ^{22}Na and ^{60}Co
sources when voltage between the photocathode and the first dynode is optimized.
By using the 6th dynode signal for timing analysis, a further improvement of 4
and 6% is achieved in the detector time resolution for ^{22}Na and ^{60}Co sources
respectively.

A TECHNIQUE TO OPTIMIZE THE TIME RESOLUTION OF NE213 SCINTILLATION DETECTORS

1. INTRODUCTION

Organic scintillation detectors are widely used in nuclear experiments requiring excellent time resolution [1–5]. Various authors have carried out theoretical and experimental investigations on time resolution of organic scintillators [6–9]. The scintillation detector time resolution results from a combination of the transit time spread of the incident radiation on the scintillator and the photomultiplier resolving time. The transit time spread of a scintillator is mainly determined by its geometry, which is fixed by experimental requirements. However, it is always possible to optimize the photomultiplier time resolution. The photomultiplier time resolution is mainly determined by the spreads in the transit time and electron emission time [10]. From a practical point of view, the transit time of photomultiplier, which represents the time for the current pulse to pass from cathode to anode, merely introduces a delay within the experimental system, whereas the transit time spread (representing statistical fluctuations in transit time), imposes limitations on the time resolution of the photomultipliers. There are four basic causes of transit time spread: spread in emission time of secondary electrons; spread in emission velocities of secondary electrons; spread in electron path length; and space charge effects [11]. For all practical purposes, the contribution of the spread in emission time of the secondary electrons towards the transit time spread is negligibly small and may be ignored. The spread in electron path length can be reduced by choosing focussed systems, but at the cost of electron multiplication efficiency. The spread in electron emission velocities is strongly dependent upon the interdynode voltage and number of dynode stages in the photomultiplier. For a photomultiplier consisting of N similar stages, the transit time spread is proportional to $N^{1/2}$. Therefore the spread in electron emission velocities can be reduced by choosing a smaller number of dynode stages and increasing the interdynode voltage.

In addition to spread in electron emission velocities if space charge effect is also present, the time resolution is further deteriorated and the transit time spread per stage further increases. The space charge effect in cathode-first dynode region is very significant for cathodes exposed to energetic radiation which results in the emission of large number of photoelectrons. Due to space charge effect all of the photoelectrons cannot be collected simultaneously, hence increasing the spread in transit time. This effect can be reduced by increasing the voltage V_{k-d1} between cathode and first dynode. The time resolution of the photomultiplier is very sensitive to overall voltage V of the detector and varies as $V^{-1/2}$ [12]. Considering the above mentioned two major causes of spread in transit time, one can optimize the time resolution of the photomultiplier by increasing the voltage V_{k-d1} and selecting the timing output across smaller number of dynode stages of photomultiplier.

For organic scintillators, the time resolution is inversely proportional to square root of the energy loss of the particle in the scintillator [13]. With the known energy loss of a particle at two different energies, the ratio of time resolution of the detector at those energies should be given by square root of inverse ratio of the particle energies. We have measured the time resolution ratio of the scintillation detector for strongly correlated Gamma rays from ^{60}Co and ^{22}Na sources. The time resolution ratio was optimized by varying the V_{k-d1} voltage and selecting 6th dynode output as fast signal. In the following we describe the experiment.

2. EXPERIMENTAL

2.1. Scintillator–Photomultiplier Assembly

The cylindrical NE213 liquid scintillation detector, of BA1 cell type, was acquired from Nuclear Enterprise Limited U.K. The scintillator has a thickness of 50 mm and a diameter of 50 mm. The scintillator was directly coupled to a 60 mm diameter fast photomultiplier Thorn–EMI model 9815B. The photomultiplier tube had 10 dynodes with linearly focussed structure of the dynodes.

The photomultiplier tube was powered by a commercially available EMI-GenCom transistorized base model No. GS-8575. Transistorized bases are active photomultiplier divider circuits which utilize transistors in the last 3 dynode stages to maintain the interdynode voltages [14]. The dynamic performance of this type of divider permits the utilization of a higher percentage of divider chain current to be delivered by the photomultiplier tube into the output circuit before encountering the gainshift. Because of the high current utilization, the transistorized divider

overall current gain can be kept low, resulting in low power dissipation and high reliability.

2.2. Electronics

The experimental arrangement used for time resolution measurements in our studies was similar to that in reference [4] and is shown in Figure 1. The timing peak of NE213 detector was measured with reference to a 25 mm thick and 50 mm in diameter NE102A plastic scintillator which was directly coupled to a Thorn-EMI fast photomultiplier tube model No. 9815B. The electronics used in this experiment was basically a fast-slow coincidence circuit. The timing resolution information was derived from gamma–gamma coincidence timing peaks (FWHM) using a constant fraction discriminator (CFD). Timing Single Channel Analyzer (TSCA) were used to select the energy window for each detector. The TAC-ADC system was calibrated using a precise time calibrator ORTEC model 462. The average time spread per

channel was 51.1 ± 3.0 ps/ch. The time spread (FWHM) due to the electronics was measured with a fast pulser and found to be 33.5 ± 3.0 ps (FWHM). The data was acquired on a VAX 11/785 computer using XSYS data acquisition system [15].

3. OPTIMIZATION OF TIME RESOLUTION

For the sake of optimization the detector time resolution was measured with reference to another detector over a small dynamical energy window. In the first part of experiment we have experimentally determined the optimum width of the window. The window width ΔE can be chosen as a function of the energy E of the particle undergoing energy loss in the scintillator, such that $\Delta E \propto E$ or $\Delta E \propto E^{1/2}$ [13]. In order to choose the appropriate energy window we have measured the time resolution of the detector as a function of Compton electrons energy for ^{60}Co gamma ray source using two different energy window namely $\Delta E = 0.1 E_c$ and $\Delta E = 2 E_c^{1/2}$ where E_c is
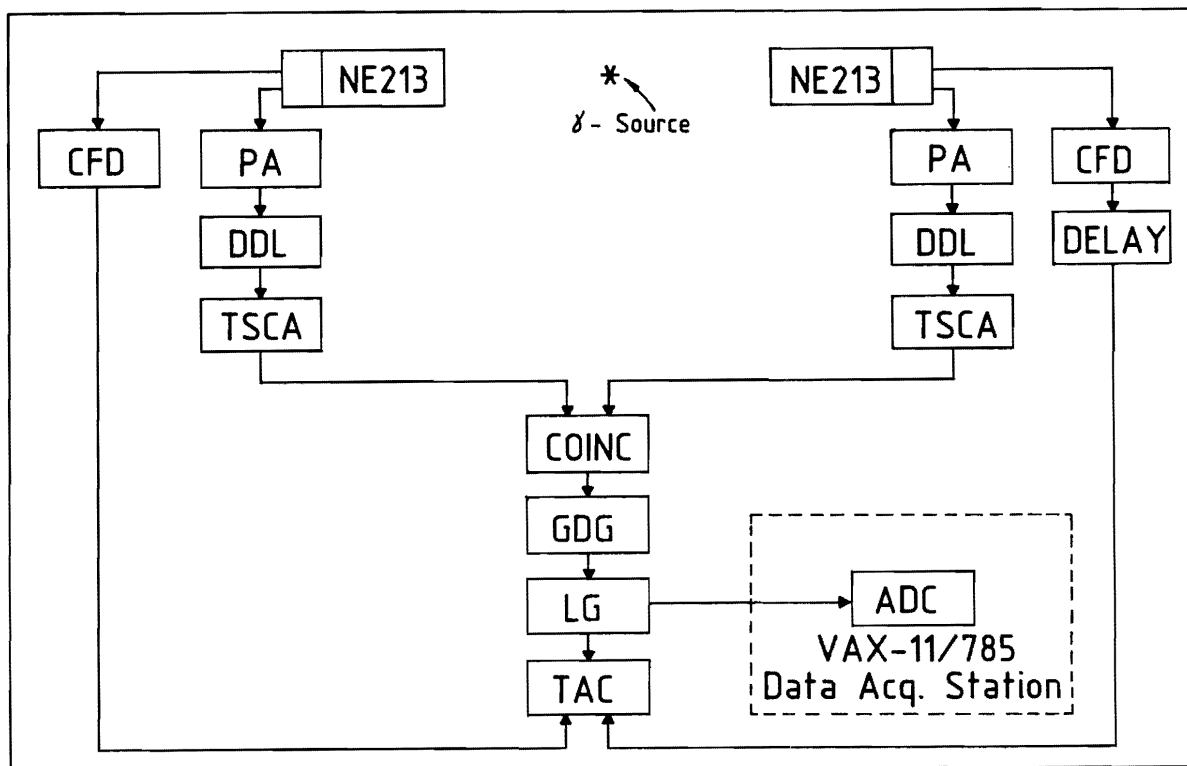

Figure 1. Block Diagram of the Experimental Setup Used in Time Resolution Tests.
Symbols are: PA = Preamplifier; DDL = Double Delay Line Amplifier; CFD = Constant Fraction Discriminator; TSCA = Timing Single Channel Analyzer; COIN = Universal Coincidence Unit; GDC = Gate and Delay Generator; LG = Linear Gate and Stretcher; TAC = Time to Amplitude Converter; ADC = Analog to Digital Converter.

maximum energy of Compton electrons measured from pulse height spectra of ^{60}Co. For both windows data was taken at $E_c = 0.11, 0.41, 0.67$, and 0.93 MeV. Figure 2 shows the measured time resolution (FWHM) as function of $E_c^{-1/2}$ for both types of the windows. The figure demonstrates proportionality of FWHM to $E_c^{-1/2}$. This is consistent with the data of Bengston and Mozynski for NE111 scintillators [13]. Both types of windows result in almost the same time resolution. Due to the higher count rate, 10% energy window (*i.e.* $\Delta E = 0.1 E_c$) was chosen for the remaining part of the experiment.

In order to minimize the space charge effects between the photocathode and first dynode one needs to measure the time resolution of the detector as function of voltage V_{k-d1}. We have varied the voltage by using zener diodes of different voltages between cathode and first dynode. The measured time resolution as function of V_{k-d1} for ^{60}Co and ^{22}Na

sources is shown in Figure 3. Varying V_{k-d1} from 150 volts to 400 volts resulted in an improvement in time resolution from 0.519 ± 0.005 to 0.411 ± 0.005 ns in case of ^{60}Co and in case of ^{22}Na from 0.853 ± 0.005 to 0.729 ± 0.005 ns. Thus it resulted in an improvement of 21% in detector time resolution for ^{60}Co while for ^{22}Na the improvement in the time resolution was 8%. The experimentally measured larger improvement in time resolution of the detector for higher energy gamma rays is understandable because for higher energy gamma rays result in larger space charge effects. When space charge effect is compensated, one expects larger improvement in time resolution. For the remaining part of the experiments the V_{k-d1} was chosen to be 350 volts.

As the photomultiplier transit time spread is proportional to the square root of the number of dynode stages, one can minimize transit time spread significantly by choosing timing output signal across a
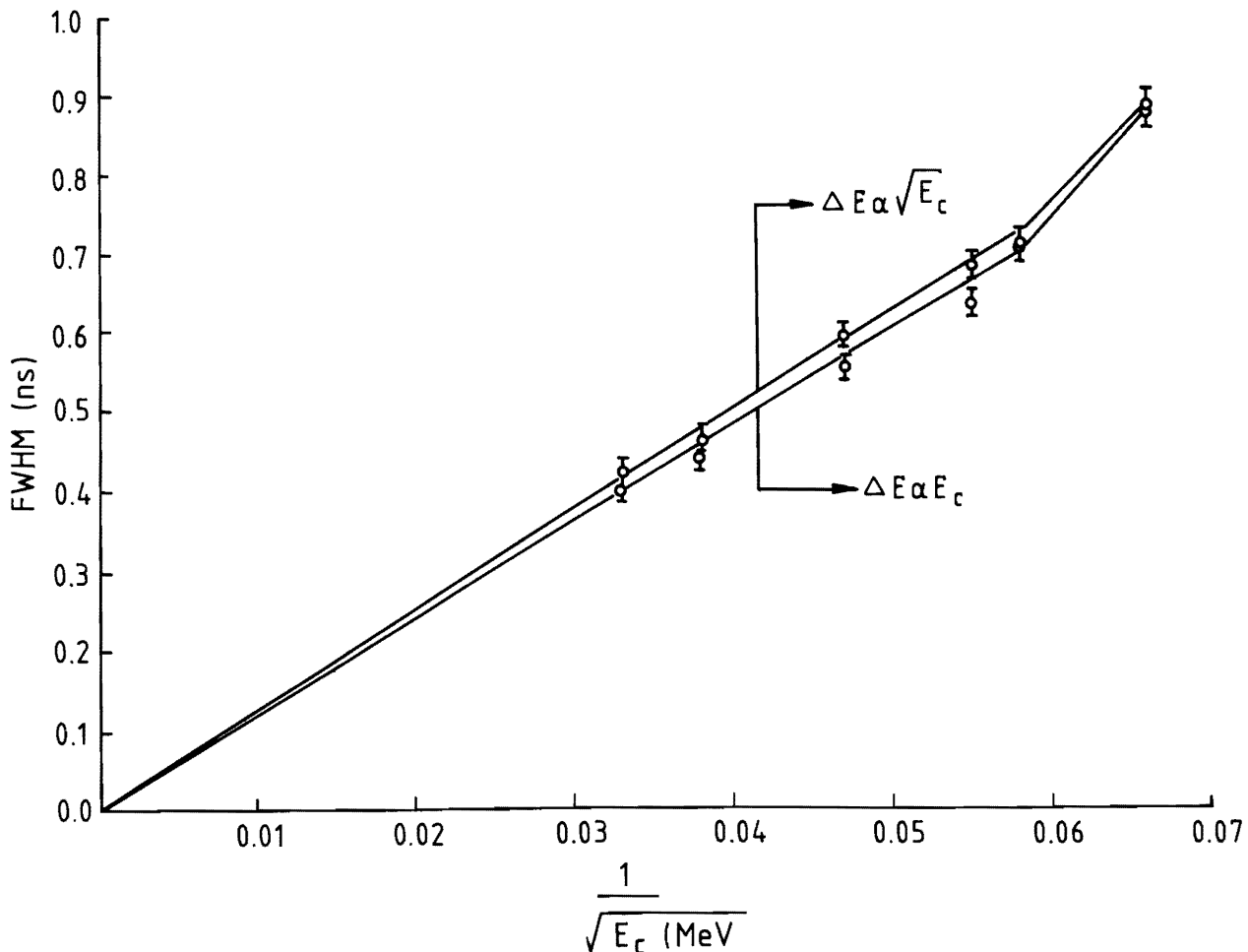

Figure 2. Measured Time Resolution FWHM of the Detector as a Function of $E^{-1/2}$ for Two Different Energy Windows.
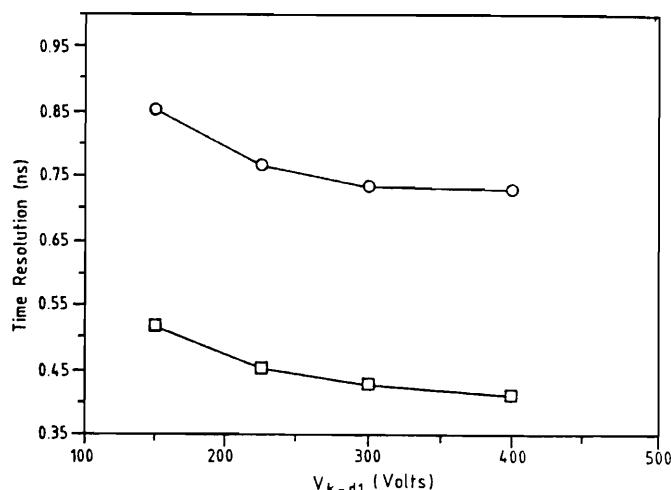
Figure 3. Detector Time Resolution as Function of Photomultiplier Photocathode-First Dynode Voltage V_{k-1d}. Data Symbols are □.... ^{60}Co and ○.... ^{22}Na Sources.

smaller number of dynodes stages. In order to select the appropriate dynode signal as the timing signal, a comparison was made of the timing characteristics of the anode signal with those from other dynodes. This comparison was done by observing the signal on the fast 500 MHz TEKTRONIX oscilloscope and relating its parameters such as amplitude, rise time, and FWHM to those from other dynodes. It was observed that as the number of dynodes increases, the amplitude of the signal increases but its timing characteristics deteriorate. For signals derived from dynodes earlier than 6th dynode, their rise time and FWHM was comparable with the 6th dynode signal but their amplitude was significantly lower than the 6th dynode signal, which may cause problems in triggering fast discriminators. On the other hand, signals from dynodes after 6th dynode had larger amplitude but poorer FWHM as compared to the 6th dynode signal. Therefore a compromise between the signal amplitude and its timing characteristics resulted in a choice of the 6th dynode signal as the fast timing signal. For the sake of comparison, the characteristics of the anode and 6th dynode are listed in Table 1. Although the amplitude of the dynode signal is half of the anode signal, its FWHM is 43% less than that of the

Table 1. Characteristics of the Anode and Dynode Signals of NE213 Detector.

	Amplitude (mV)	Rise time (ns)	FWHM (ns)
Anode Signal:	500 ± 20	3.0 ± 0.1	7.0 ± 0.1
6th Dynode Signal:	250 ± 20	3.0 ± 0.1	4.0 ± 0.1

anode signal. In order to be processed by fast timing electronics, positive dynode signals, need to be converted into negative signals without loss of amplitude and timing characteristics. This can be achieved either by using a fast transformer or fast timing amplifier with inverter output. In our case, we used the second option and the dynode signal was inverted by using a Timing Filter Amplifier. Then the time resolution of the detector was measured using ^{22}Na and ^{60}Co gamma ray sources with 10% energy windows, utilizing the anode and dynode signals of the photomultiplier tube. The time resolution data for the detector is tabulated in Table 2. The time resolution ratio R is given by the equation:

$$R = (FWHM)_{^{22}Na}/(FWHM)_{^{60}Co}$$

$$= [(E_c)_{^{60}Co}/(E_c)_{^{22}Na}]^{1/2}$$

The theoretical value of the ratio R is 1.63. Due to photomultiplier noise, the experimentally measured ratio for a non-optimized photomultiplier tube is less than the theoretical one. However, the value of the experimental ratio can be larger than the theoretical ratio if the detector shows poorer time resolution for ^{22}Na. Therefore one cannot use this ratio alone as the sole criterion to optimize the detector timing characteristics. Apart from the ratio R, one also needs to compare the detector time resolution measured using anode and dynode signals for ^{22}Na and ^{60}Co sources. One can define an improvement factor F, which is simply the ratio of detector time resolution measured using dynode and anode signals for a given gamma ray source. We have measured F for ^{22}Na and ^{60}Co sources respectively. The measured time resolution ratio needs to be corrected for the

Table 2. Results of Time Resolution Tests Using the Anode and the Dynode Signals of the Detector.

Source	Anode Signal Timing			6th Dynode Signal Timing			Improvement factor F (%)
	FWHM (ns)	$R_{measured}$	$R_{corrected}$	FWHM (ns)	$R_{measured}$	$R_{corrected}$	
^{60}Co	0.458 ± 0.01	1.56 ± 0.05	1.62 ± 0.05	0.399 ± 0.01	1.65 ± 0.07	1.77 ± 0.08	18.0 ± 0.8
^{22}Na	0.756 ± 0.01	1.56 ± 0.05	1.62 ± 0.05	0.659 ± 0.01	1.65 ± 0.07	1.77 ± 0.08	13.0 ± 0.4

transit time spread of gamma rays in both the scintillation detectors [13]. In Table 2 we have included the time resolution after correction for the transit time spread. Also shown in Table 2 are improvement factors. It is obvious from Table 2 that the detector has a corrected ratio for both types of outputs very close to the theoretical value 1.63, but the improvement factor shows an improvement of 18% for ^{60}Co source while for ^{22}Na it is only 13%. Due to the larger number of photoelectrons produced by high energy gamma rays, the improvement in time resolution for ^{60}Co source is larger than ^{22}Na source. This demonstrate that by minimizing space charge effects and the transit time spread of the photomultiplier, one can improve the timing characteristics of scintillation detector significantly.

We have also measured time resolution of 50 mm detectors for ^{60}Co source at 0.5 MeV electron energy bias. In order to calculate the true time resolution of the detector, the time resolution of reference detector was subtracted in quadrature from the measured FWHM. The time resolution of reference NE102A detector was measured in a separate experiment. The measured and calculated time resolution are reported in Table 3. As no experimental data is available for 50 mm diameter scintillator we have included the data of Anand *et al.* [16] on larger size of NE213 detectors for comparison. The time resolution of the 125 mm detector is 45% larger than for our detector because these authors used a 125 mm diameter photomultiplier tube. This technique has provided an efficient means to optimize the time resolution of NE213 scintillation detectors.

Table 3. Optimum Time Resolution of NE213 Detector for ^{60}Co Source Using Dynode Signal at 0.5 MeV Electron Energy Bias.

Detector size (cm)	Present Work		Anand *et al.* [16]
	FWHM (ns)	Δt_{calc} (ns)	FWHM (ns)
5.0	0.53 ± 0.01	0.33 ± 0.01	–
12.5	–	–	0.48
25.0	–	–	0.82

4. SUMMARY

A technique has been described to optimize the time resolution of NE213 scintillation detectors. This involves minimization of transit time spread and space charge effects in the photomultiplier. These studies were carried out by measuring the time resolution of the detector for correlated gamma rays from ^{22}Na and ^{60}Co at various values of the voltages between the photocathode and first dynode. Further improvement in time resolution was achieved by using 6th dynode signal for timing signal instead of conventional anode signal.

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