

Energy Linearity Change of the NaI(Tl) Detector with the Time of use as Evidence of Changing the Structure of Dynodes

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Abstract
In this paper, we studied the energy linearity of two identical NaI(Tl) detectors, one new (unused) and the other old (long-term), to determine if there was a change in the structure of the NaI(Tl) detectors. For any supply voltage, we found from the dependence on channel number to the source energy that the slope for the old detector is greater than the new detector, indicating an increase in the secondary emission factor δ with the time of use. That is meaning a change in the behavior of the Cs-Sb mixture from semiconductor to conductor. The average deviation $\overline{\sigma}$ of the channel number for the old detector is greater than the new one, indicating the detector linearity is becoming worse with the time of use. That is meaning the conductor may be partially and random constructed in the mixture.
Keywords: energy linearity, dynodes, Cs-Sb mixture.

1. Introduction

Linearity is one of the most important characteristic of the NaI(Tl) detector. When the linear range of a detector is small and we need measurements in the nonlinear range of the detector, for an accuracy determining of the identity and intensity of the gamma rays, non-linear calibration must be performed [1]. In order to perform non-linear calibration, detector pulse height (or channel number) versus supply voltage must be done. The NaI(Tl) detector consists of photomultiplier tube (PMT), voltage divider and scintillator. The detector linearity depends on the PMT and scintillation materials [2]. The photomultiplier tube is a light-sensitive and versatile device that ensures high sensitivity and ultra-fast response [3]. More importantly, as a high gain device, the PMT is extensively used as photon detector in fields such as high energy physics experiments, chemical analysis and medical diagnosis. Although PMTs performance is so superior, its linear range is someway limited which restricts its application [4]. The study of energy linearity for the gamma NaI(Tl) scintillation detector is a studying dependence on amplitude pulse generated by the detector (or channel number) of gamma photon energy (source energies) [5,6]. It is said that the dependence is linear if it is on a straight form. Otherwise it is nonlinear. When nonlinear, part of the curve can be considered linear. The gamma sources are mono-energetic and they have distinct energies. We will study the energy linearity at specific supply voltages$(600,700,750)$V. The dynodes of photomultiplier tube are a thin film from Cs-Sb mixture evaporated on metal plate [7-10]. The PMT gain changes with the supply voltage [11], with the temperature change [12], and with the form and the material of the dynode [13]. However, we will study the change of gain as function of the time of use through studying linearity.

2. Results and discussion

Tables 1, 2, and 3: The dependence on the channel number of photo-peak (N_{ch}) to gamma energies (E) from different sources for the old and new detectors, at voltage of $(600, 700, 750)$ V respectively.

At supply voltage $(600, 700, 750)$ V, the dependence for old and new detectors, which in tables 1, 2, and 3, shown in Figures 1, 2, and 3 respectively.

By fitting with the graphical points, we obtained the solid straights in Figures 1, 2 and 3, which show that the relationship between the source energy and the channel number of photo-peak is almost linear,

$$y = ax - b$$

or

$$N_{ch} = aE - b$$

where N_{ch} - channel number, and E - source energy.

We arrange the slopes of the fitting straights for figures 1,2 and 3 for both detectors in table 4.

From table 4, at the same supply voltage for both detectors, we note that the slope of dependence on the channel number to the source energy for the old detector is greater than the new detector. By evaluation the standard deviation $\boldsymbol{\sigma}$ for the values corresponding to the fitting straight, we obtained the values shown in table 5.

From table 5, at the same supply voltage for both detectors, we note that the average standard deviation $\overline{\boldsymbol{\sigma}}$ for the old detector is greater than the new detector, which means that the detector linearity worsens with the time of use.

3. Conclusions and Recommendations

1. At any supply voltage, for the dependence on channel number to the source energy, the slope for the old detector is greater than the new detector, indicating the secondary emission factor δ is increased with the time of use, which indicates a change in the behavior of the Cs-Sb mixture, may be, from semiconductor to conductor.

2- The average standard deviation $\bar{\sigma}$ for the old detector is greater than the new detector, meaning that the detector linearity is worse with the time of use, indicating the random change in the secondary emission factor, (Which is expected to be Cs_3Sb) has been partially formed in the mixture.

We recommend a structural spectral analysis by X-rays for the material dynodes of photomultiplier tube and studying the electrical properties of the Cs-Sb mixture to determine the resulting compound and to change the mixture ratios so that the linearity advantage becomes more stable with the time of use.

4. References

[1] Nicholas Tsoulfanidis: "Measurement and Detection of Radiation", Hemispherev Publication Corporation (1983).
[2] Glenn. F. Knoll: "RADIATION DETECTION and MEASUREMENT (Third Edition)" John Wiley & Sons, Inc. (1999).
[3] Photomultiplier Tubes: Construction and Operating Characteristics, Hamamatsu Photonics K.K., 2010.
[4] H. K. Lv, X.D. Sheng, J. Liu, for the lhaaso collaboration international, cosmic ray conference, RIO DE JANEIRO 2013.
[5] Photomultiplier Tubes: Basics and Applications (Second Edition), Hamamatsu Photonics, Hamamatsu City, Japan, (1999).
[6] Lavagno A, Gervino G, Scarfone A. Study of linearity and internal background for LaBr 3 (Ce) γ-ray scintillation detector. Nuclear Instruments and Methods in Physics Research Section A: Accelerators, Spectrometers, Detectors and Associated Equipment. 2013 Aug 1;718:504-5.
[7] Cromer, D. T.: Acta Crystallogr. 12 (1959) 41.
[8] Busmaun, B., Lohmeyer, S.: Z. Anorg. Allg. Chem. 312 (1961) 53.
[9] Wyckoff, R. W. G.: Crystal Structures, Vol. 1 and 2, 2nd. Ed., Interscience Publishers, New York 1965.
[10] Schnering von, H. G., Hönle, W., Krogull, G.: Z: Naturforsch. 34b (1979) 1678.
[11] Wang C, Li H, An S, Zhang Y, Baghaei H, Ramirez RA, Liu S, Wong WH. A study of transit time variation in the PMT with a gain programmable voltage divider for a TOF PET. InNuclear Science Symposium Conference Record (NSS/MIC), 2010 IEEE 2010 Oct 30 (pp. 2155-2157). IEEE.
[12] Young AT. Temperature effects in photomultipliers and astronomical photometry. Applied Optics. 1963 Jan 1;2(1):51-60.
[13] Tao, S., Hong Wah Chan, and Harry Van Der Graaf. "Secondary electron emission materials for transmission dynodes in novel photomultipliers." (2016).

Table 1. At supply voltage 600 V.

The source			^{57}Co	^{133}Ba	^{22}Na	^{137}Cs	^{60}Co	
E (keV)		0	137	384	511	662	1173	1333
N_{ch}	for old detector	0	2	6	12	14	25	28
	for new detector	0	2	3	4	7	10	13

Table 2. At supply voltage 700 V.

The source			^{22}Na	^{137}Cs	^{60}Co	
E (keV)		0	511	662	1173	1333
N_{ch}	for old detector	0	68	86	148	165
	for new detector	0	15	19	25	33

Table 3. At supply voltage 750 V.

The source			^{57}Co	^{133}Ba	^{22}Na	^{137}Cs	^{60}Co	
E (keV)		0	137	384	511	662	1173	1333
N_{ch}	for old detector	0	31	81	-	146	237	247
	for new detector	0	8	17	24	33	56	64

Table 4: The slopes of straights as a function of supply voltage for both detectors.

supply voltage (V)		600	700	750
slope	for old detector	0.0216	0.1237	0.1901
	for new detector	0.0092	0.0226	0.0477

Table 5: The standard deviation σ and average standard deviation $\bar{\sigma}$.

supply voltage (V)		600	700	750	$\bar{\sigma}$
σ	for old detector	0.7041	1.8559	21.5113	**8.0237**
	for new detector	0.6752	2.0184	0.7445	**1.1460**

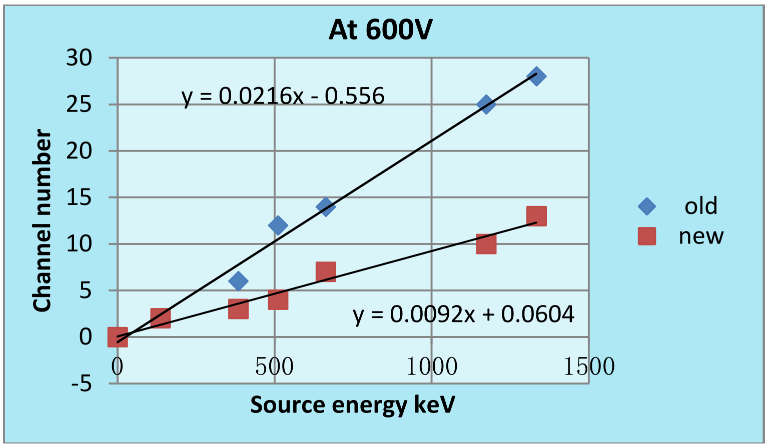

Figure1. At supply voltage 600V.

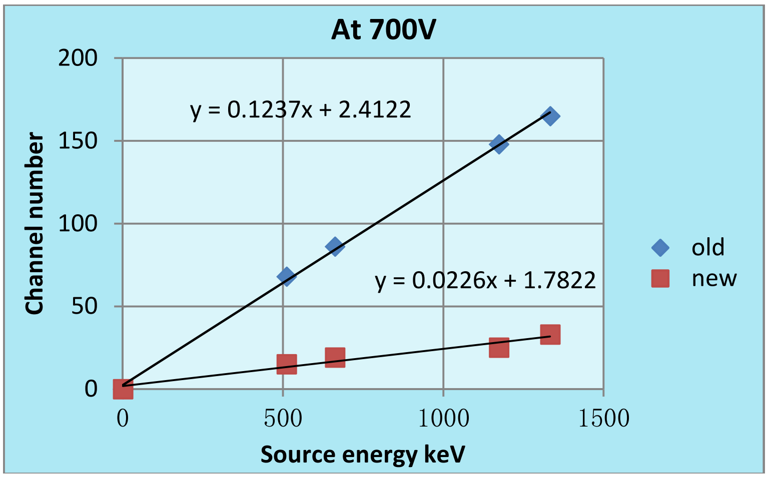

Figure 2. At supply voltage 700V.

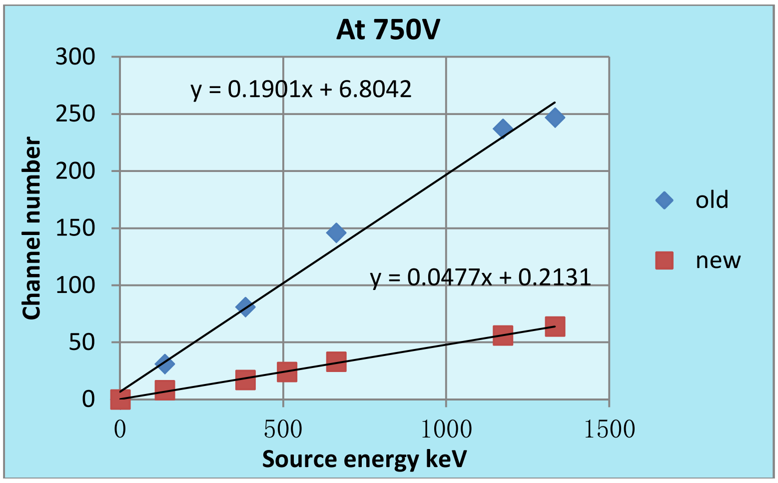

Figure 3. At supply voltage 750V.