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Analysis of S/N with pin Photodiode and Charge Sensitive Preamplifier for Low Energy Gamma

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Abstract

With analytical approach, it is possible to detect low energy gamma such as Tc-m99 with combination of scintillator, pin-type photodiode, and charge sensitive preamplifier (hereinafter “CSA”). In practical, however, no analysis and experiments of its possibility was performed. We tested the characteristics of signal and noise with pin-type photodiode and CSA to detect low energy gamma. From each noise measurement for both several photodiodes and CSAs, the lowest photodiode and CSA was selected and tested for low energy gamma source. Contrary to general expectations, we found that it is difficult to detect any below energy with present commercialized pin-type photodiode and CSA

I. Introduction

In medical application, it is becoming increasingly important to develop small gamma detection system, based on pin photodiode, that is capable of measuring low energy gamma of 140KeV from Tc-m99[1, 2]. For the system, CsI(Tl) crystal, which converts radiation into light, is coupled to pin photodiode and the photodiode generates electron-hole pairs as a signal. Even though this photodiode based detection systems have several advantages such as compactness and high efficiency of cost to performance, there are some difficulties to choose pin photodiode and the related electronic systems to be a low energy gamma detection system since the performance characteristics of the detection system is not always expectable. Because of low signal from photodiode, system noise is critical factor whether it is possible or not to detect low energy gamma. However, any criteria about photodiode and electronic system are not well known and their performance characteristic was not clearly investigated for low energy gamma. Therefore, it is necessary to estimate noise of detection system so as to compare with expected signal charge. In order to compare the expected signal with the noise, we should select the lowest photodiode and CSA at any operation condition through tests. After selecting the best photodiode and CSA with operating conditions, we measure several gamma sources and analyzed the results.

II. Signal Charge

Through analytical approach, the signal charge at the end of the photodiode is driven directly with simple assumption. If we assume the arriving amounts of photon in the i-layer of pin photodiode create electron-hole pairs without any loss, with light yield L_y in the CsI(Tl) crystal, light transmission efficiency ε at the geometry of the CsI(Tl) crystal and quantum efficiency of the photodiode $\eta(\lambda)$, it is possible to define briefly the number of electron charges Q_S generated in the photodiode as follows:

$$Q_S = L_y \cdot \varepsilon \cdot \eta(\lambda) \tag{2}$$

where the L_y of CsI(Tl) for 140KeV was 9100 [3], the value of ε was 0.69 by using DETECT97 simulation code, and the $\eta(\lambda)$ of the photodiode at wavelength of λ was 0.92 as given as Eq. (3). For the DETECT97 simulation, we used the CsI(Tl) crystal of 2.4mm×2.4mm×6mm having refractive index 1.79, the optical coupling thickness of 1μm having refractive index 1.56, and the thickness of optical window of the photodiode 1μm having refractive index 1.46.

$$\eta(\lambda) = \frac{S \times 1240}{\lambda} \times 100[\%] \tag{3}$$

For the selected photodiode with the high photosensitivity S of 0.4 and the crystal emitting light having the wavelength of 540nm[3], the total generated electron charges of 5767 were expected as a signal at the end of the photodiode. And it is of utmost importance to effectively collect at the photodiode the light produced by excitation due to the incident energy in the scintillator. In order to get a high degree of light transmission efficiency, ε from the crystal to the surface of the photodiode, the index of refraction matching between the crystal and the photodiode is important because other factors such as the light yield of crystal and quantum efficiency of photodiode are dependent on the their manufacturer.

III. Noise Characteristics

A. The noise of photodiode

The lower limits of light detection for the photodiodes are determined by the noise characteristics of the device. The photodiode noise i_{PD} is the sum of the thermal noise i_T caused by the shunt resistance R_{SH} and the shot noise i_S, resulting from the dark current

I_d and the photocurrent I_L.

$$i_{PD} = \sqrt{i_T^2 + i_S^2} \tag{4}$$

Since $i_S \rangle\rangle i_T$ for the bias with the application of incident light, I_L exists and if $I_L \rangle\rangle I_d$, the photodiode noise i_{PD} is briefly as follows:

$$i_{PD} = i_S = \sqrt{2qI_L B} \tag{5}$$

where q is electron charge and B is noise bandwidth.

B. The noise from detector-amplifier system

The noise of the detector and the CSA generally comes from the following three major sources assuming pulse shaping amplifier type is CR-(RC)^4 [4]:

a) Shot noise from detector, $0.9\frac{I_R}{q}\tau$, b) Thermal noise of amplifier, $A\frac{1}{\tau}$, and c) 1/f noise of amplifier. And its total noise is, therefore,

$$E_{TOT} = 0.9\frac{I_R}{q}\tau + A\frac{1}{\tau} + B \tag{6}$$

where I_R is the reverse current of detector, q is the electron charge, τ is shaping time of amplifier, A and B are constant related to measurement.

IV. Test and Results

A. Noise Measurement of CSA (Charge Sensitive Preamplifier)

Noise measurements were performed with considerable several CSAs to choose the CSA of the lowest $E_{TOT.}$ Model no of eV 5091 and eV 5093 from eV Product Company and A250 and A250F from Amp-Tek Company were considered as test CSAs in our experiments. The CSA noise was characterized using the pulser method with charge calibration. The variation of the electronic noise (Noise Equivalent Charge: NEC) as a function of shaping time and detector capacitance were measured for the CSAs. The observed results are shown in Fig. 1, Fig. 2, Fig. 3, and Fig. 4 for each CSAs.

From the test results, model no. of eV 5093, A250, and A250F agreed with theoretical noise model [5] although there were some fluctuations according to the shaping time, except eV 5091. The amount of noise charge at eV 5093 was the lowest among others and the lowest value was shown at low detector capacitance as general expectation.

B. Consideration of Photodiode

After the tests of CSAs, so as to consider electric characteristics of photodiode depending on its capacitance and dark current, we measured dark current of photodiodes for two models of PDC 24s-MU and PDC 100s-CR from Detection Technology Company, respectively having the capacitance of 5pF and 54pF. In this test we also considered the effect of coupling CsI(Tl) and photodiode to find operating bias voltage since the small active area of photodiode makes it uneasy to stable dark current.

Test results are shown in Fig. 5 and Fig. 6. In Fig. 5 a1, b1, and c1 are not coupled photodiode with crystal and a2, b2, and c2 are coupled photodiode of a1, b1, and c2 respectively. These a, b and c photodiodes are PDC 24s-MU, having active area of 2.4mm×2.4mm and the capacitance of 5pF. From Fig. 5, there are some difference between the uncoupled and the coupled which causes break down voltage around 15 voltage. In Fig. 6 g and h are PDC 100s-CR, actives area of 10mm×10mm and the capacitance of 54pF. From both Fig. 5 and Fig. 6, there are no big differences of dark current between PDC 24s-MU and PDC 100s-CR. These results were used in testing of photodiode concerning the effect of capacitance of photodiode with the same dark current.

With the CSA of eV 5093 and the measurements of the dark current of photodiode, it is possible to select the lowest noise photodiode. We measured NEC value as a function of shaping time for a1, a2, b2, and c2 photodiode. Fig. 7 and 8 show that there are difference NEC of about 200 for the uncoupled and the coupled, a1 and a2 which means two times of different dark current effects on the difference of 400 NEC value. In order to investigate the effect of different capacitance of photodiode but with the same dark, Fig. 9 compare g, uncoupled photodiode with 54pF, with a2, the coupled photodiode, and show that although there are two times of different dark current between g and a2, there are difference of 700 NEC between them. These results tell us the capacitance of photodiode more influences than dark current of photodiode on noise value. From Fig. 7 and 8 we additionally are able to select c2, coupled photodiode as a stable one at 15V regardless of shaping time. Therefore we chose c2, coupled photodiode because it is comparative stable and low capacitance among others for gamma energy detection.

C. Noise Measurement of Detection System

Before low energy gamma detection, we measured system noise with the selected photodiode, c2, PDC 24s-MU and CSA, eV 5093 as a function of reverse bias voltage and shaping time which are shown in Fig. 10. In this Fig. at the shaping time of 0.5 micro seconds and the reverse bias voltage of 15V the minimum NEC value of around 700 for the prepared gamma detection system. In case that we simply consider the noise of detection system, it is expectable to measure low energy gamma since signal to noise ration is about 6.4 for Tc-m99 and 5.6 for Co-57. Considering operating time with other noise source, however, is more realistic in low energy gamma detection.

D. Low Energy Gamma Detection

From Fig. 10 we decided operating condition, the shaping time of 0.5 micro sec. and the reverse bias of 15V for the system. With the selected photodiode, CSA, and operating conditions, we finally measured low energy gamma using Multi Channel Analyzer (MCA). Since Ba-133 was detected with our detection system as shown in Fig. 11, Ba-133 having the energy of 356KeV was used for system calibration. The known two test pulses are applied to the detection system and the measured of the number of charge per channel is calculated to convert virtual channel into real channel for the photopeak according to the incident gamma energy.

After the calibration procedures, the detection system operated for 2 hours without any source showed in Fig. 12, revealing background noise. To imitate of Tc-m99 source, Co-57, the energy of 122KeV was measured also for 2 hours shown in Fig. 13.
Unfortunately, only the partial influence of Co-57 was appeared but the photopeak of Co-57 was concealed in the noise level as shown in Fig. 14.

V. Conclusion and Further Study

As mentioned in "C. Noise Measurement of Detection System", if we compare the expected signal with the system noise, no problem is found to detect low energy gamma. The expected signal, however, for Co-57 was in the noise area in the MCA. Based on the calculation of the photopeak of Ba-133, the photopeak of Co-57 would appear near 200 channels at the MCA and near 240 channels for Tc-m99 which is all in the noise area in the MCA.

In this study, the lowest capacitance and dark current of photodiode reduced NEC value of detection system according to the reverse bias voltage. But, we should remind the electrical structure of the selected photodiode. Since the lowest one among several products was not optional for our purpose, we used already made product having some defects of electrical structure as wiring problem in the photodiode causing the photodiode not to operate below 15V reverse bias when the photodiode is coupled with CsI(Tl) crystal. We expect that there must be possibility of reducing NEC value if reverse bias is less than 15V with proper structure. Therefore, it is recommendable to use of self-designed photodiode having low capacitance, dark current, and perfect wiring for the low energy gamma detection.

Other possibilities of reducing system NEC are the degradation of atmosphere temperature since the temperature is dominant factor of CSA for thermal noise. In the near future thermal effect on the detection system will be investigated.

VI. Acknowledgement

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VII. References

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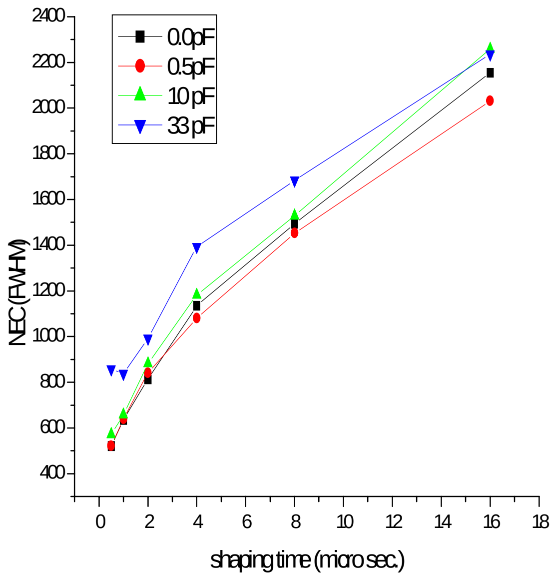

Fig. 1 NEC Measurements of eV 5091 CSA

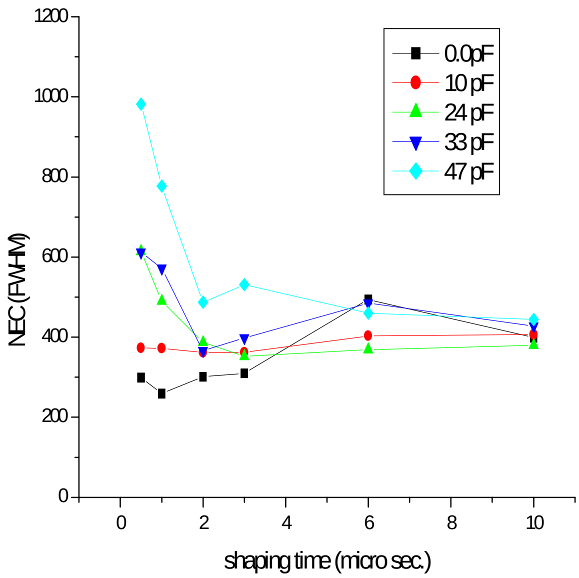

Fig. 2 NEC Measurements of eV 5093 CSA

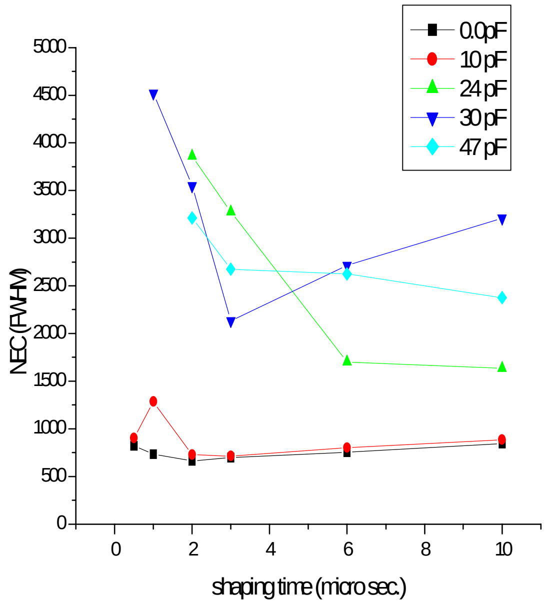

Fig. 3 NEC Measurements of A250 CSA

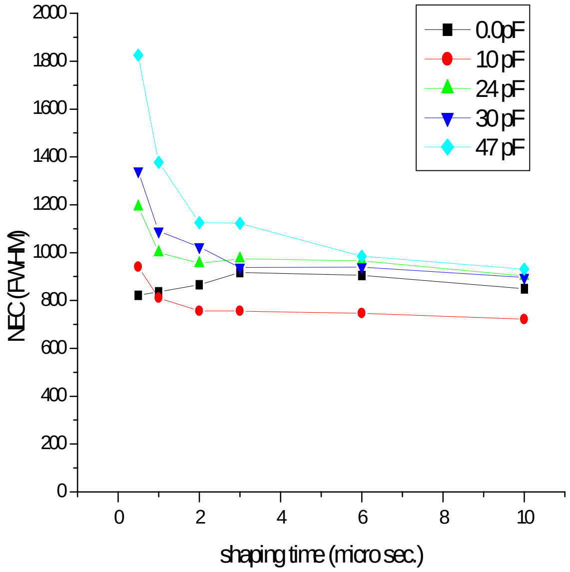

Fig. 4 NEC Measurements of A250F CSA

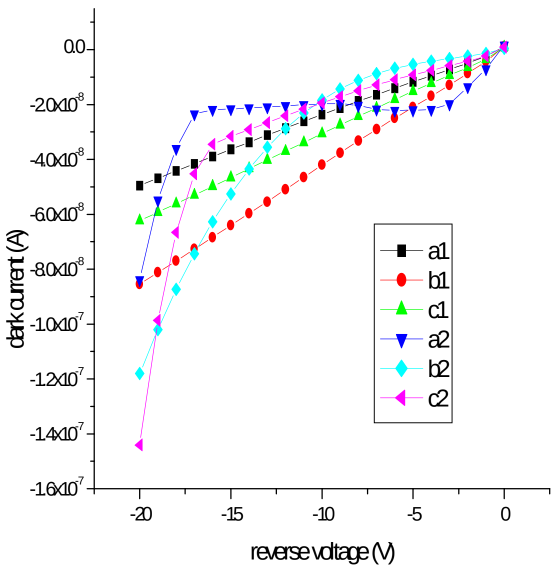

Fig. 5 Dark Current Measurements of PDC 24s-MU

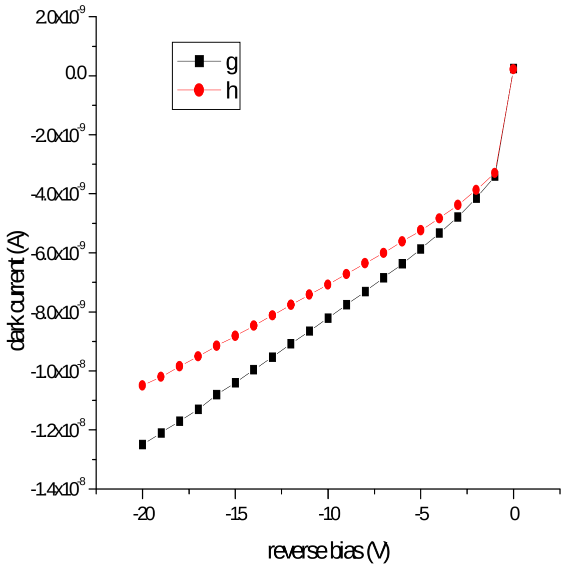

Fig. 6 Dark Current Measurements of PDC 100s-CR

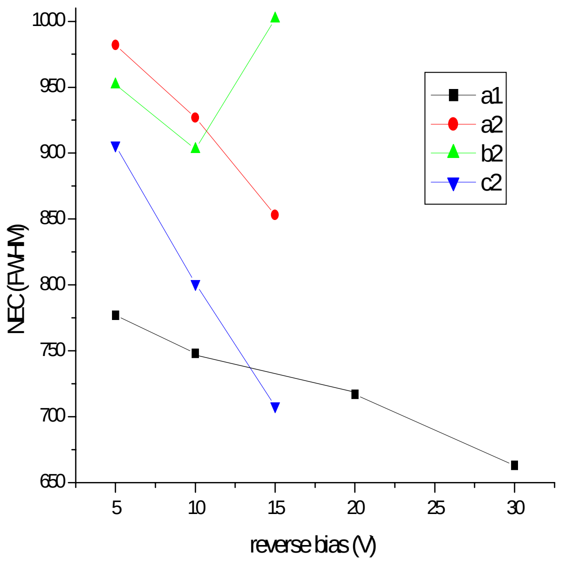

Fig. 7 NEC Measurements of
PDC 24s-MU for Reverse Bias
@ shaping time of 0.5 micro sec.

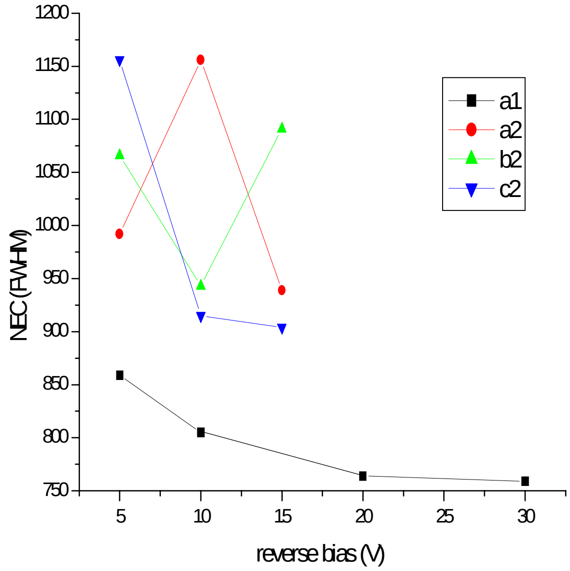

Fig. 8 NEC Measurements of
PDC 24s-MU for Reverse Bias
@ shaping time of 1.0 micro sec.

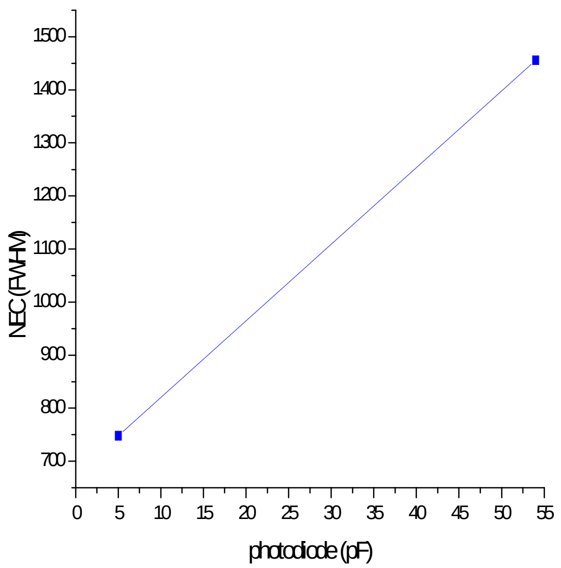

Fig. 9 NEC Measurements of
PDC 24s-MU & PDC 100s-CR

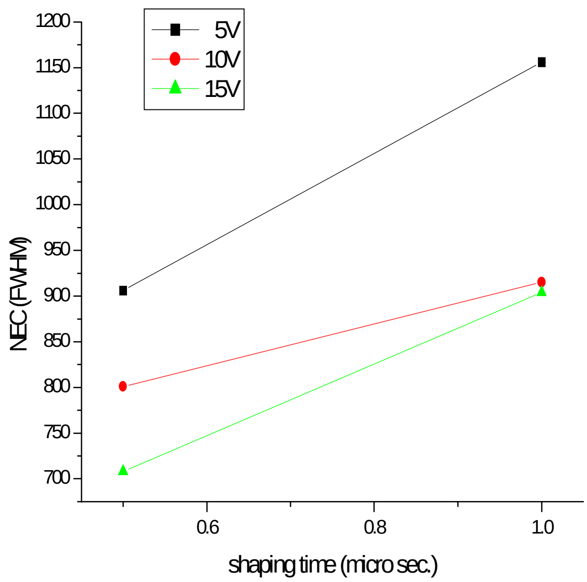

Fig. 10 NEC Measurements of
PDC 24s-MU & eV 5093 CSA

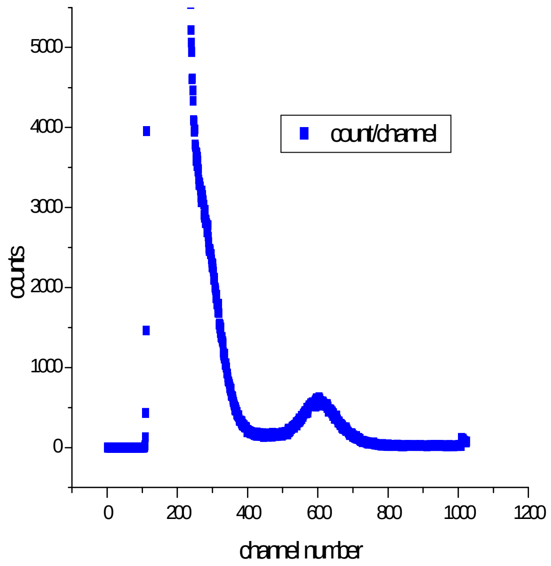

Fig. 11 Counts per Channel in MCA With Ba-133 Source

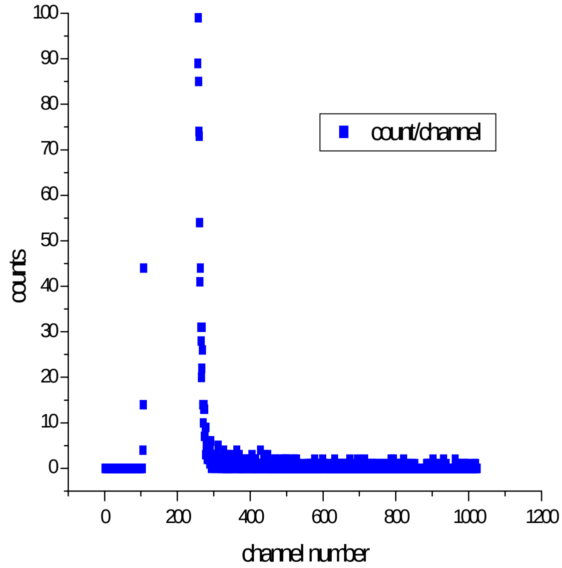

Fig. 12 Counts per Channel in MCA Without Any Source

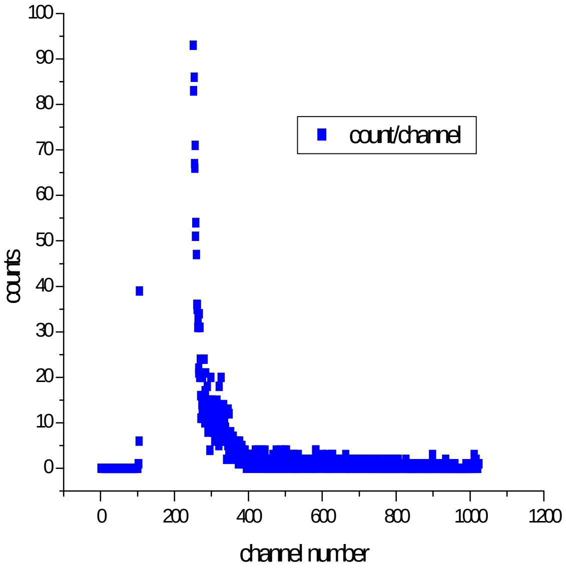

Fig. 13 Counts per Channel in MCA With Co-57 Source

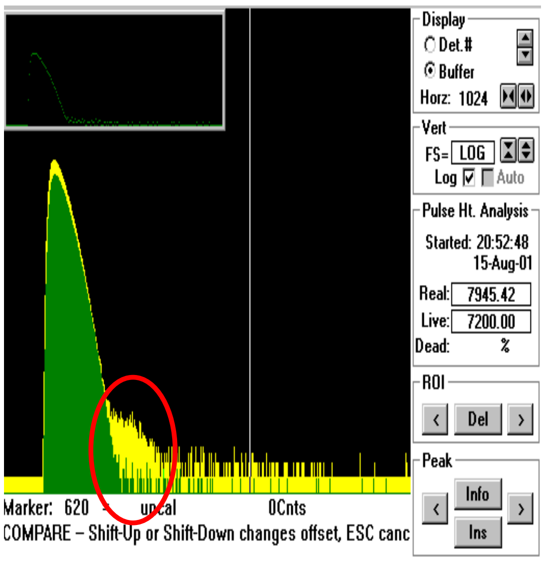

Fig. 14 Comparison in MCA With and Without Co-57 Source