Signal counting properties according to pulse duration for the high-dose radiation environment

Seonkwang Yoon, Chaehun Lee, Seok Jun Seo, Byung Hee Won, and Seong-Kyu Ahn
Korea Atomic Energy Research Institute, 111 Daedeok-daero 989 beon-gil, Yuseong-gu, Daejeon, Republic of Korea
sy@kaeri.re.kr

***Keywords : radiation measurement, counting capacity, gamma-spectroscopy, high-dose radiation**

1. Introduction

To count radiation signals has been widely used in diverse fields, such as accounting for nuclear material samples, nuclear facility monitoring, and disposal of nuclear wastes [1]. Because the counting results could fundamentally present the quantitative characteristics of nuclear materials. It is important to establish an accurate counting system in terms of the safety of workers in radiation environments, prognostic purposes for nuclear facilities, and assurance of detector performance.

Gamma-ray spectroscopy accompanying a charge-sensitive preamplifier is a common technique for those applications through dose rate estimation, and radioisotope and its radioactivity analysis. Due to the long pulse duration (~ 100 μs) when using a preamplifier, however, the use of the conventional approach is limited to high-dose radiation environments [2]. Accordingly, direct processing of a PMT anode signal whose pulse duration is even shorter (~ 5 μs) could be considered a rather appropriate option.

Even though the pulse scale of PMT anode signals with scintillation detectors is already very short enough to theoretically accommodate more than 1,000,000 signals per second, a shorter pulse duration could indicate significant improvement in the counting capacity of a measurement system for high-level inducing radiation. In this study, that tendency was experimentally confirmed using two scintillation detectors ($LaBr_3$ and LBC). Also, the output count rate as the counting capacity (denoted as 'CC') was examined according to the pulse scale (1000, 500, 100, and 50 ns) using the signal emulator (DT-5810, CAEN). Both were performed based on the same digitizer (DT - 5730B, CAEN) and showed that the pulse duration of a measurement system should be considered as a dominant parameter to achieve fine counting capacities for high-dose radiation environments.

2. Methods

In the experiment, two scintillation detectors for gamma-ray spectroscopy were used and their specifications are described in Table 1. LBC has a bit higher light output compared to $LaBr_3$ and its pulse scale (35 ns) which is also very short is, notably, almost 2 times longer than $LaBr_3$ (16 ns). Both detectors were attached with PB-2 PMT (OKEN) and analog signals from the anode were directly provided to the DT-5730B digitizer (CAEN, 14-bit resolution, 500 MS/s sampling rate). Digitized pulse signals were investigated by using CoMPASS software (CAEN, DPP-PSD firmware integrated). Measurements were performed using Co-60 gamma-ray point sources whose activities are each 1.42 MBq (calibration source) and 2.18 GBq (KARA gamma-ray irradiator III). Detectors were located at 40 cm from the former source to evaluate the basic performance of detectors. However, the source-detector distance was varied for the latter source to see the counting capacities of the given detectors.

Table 1. The specifications of $LaBr_3$ and LBC scintillation detectors

	$LaBr_3$	LBC
Materials	$LaBr_3(Ce)$	$LaBr_{2.85}Cl_{0.15}(Ce)$
Density (g/cc)	5.1	4.9
Size	2.0" Dia.	1.0" Dia.
Light output (#/MeV)	63,000	70,000
Pulse scale (Decay time, τ)	16 ns	35 ns

On the other hand, the DT-5810 emulator was used to quantitatively examine the impact of pulse duration on the resultant counting capacity. Such spectra of Co-60 (1.17 and 1.33 MeV gamma-rays emitter) were emulated with varying decay constant (1000, 500, 100, 50 ns) and pulse generation frequency (1000/s – 5,000,000/s). Additionally, the counting capacities were also confirmed when wave mode, which is for the acquisition of pulse waveform data, is switched on and compared to when it was turned off.

3. Results and Discussion

3.1. Comparison between $LaBr_3$ and LBC

For the calibration source (Co-60, 1.42 MBq), both detectors showed good energy resolution (2.07% and 1.43% for each $LaBr_3$ and LBC, respectively, at 1.33 MeV peak) without dead time. A rather favorable performance was found for LBC compared to the $LaBr_3$, and this might be due to the higher light output. As long as the dose rate is at a moderate level, scintillator light output could be a more significant property than pulse duration for gamma-ray spectroscopy. However, in the case of the experiments using gamma-ray irradiation (Co-60, 2.18 Gbq) as presented in Table 2, the counting capacity of LBC was limited by a lower dose rate (≈ 0.685 mGy/h at 900 mm source-detector distance) compared to the $LaBr_3$ (≈ 1.510 mGy/h at 600 mm source-detector distance), even though the geometry of LBC is smaller. From the result, the pulse duration of utilized scintillators would be a dominant parameter to deter the counting capacity to measure high-dose radiation environments.

Table 2. Measured peak count rates (1.33 MeV peak) of diverse scintillation detectors according to the source-detector distance

woCollim			
Dist (mm)	LaBr3	LBC	CLLB
1000	37,092	20,767	FALSE
900	39,962	22,480	FALSE
800	42,256	11,264	FALSE
700	44,283	FALSE	FALSE
600	46,146	FALSE	FALSE
500	18,200	FALSE	FALSE
443.615	5,521	FALSE	FALSE

3.2. Tests for emulated signals

In the case of using the pulse emulating system, the ideal peak count rate (iPCR) was calculated based on the linear trend between input count rate (ICR) and real peak count rate (rPCR) where no significant dead time is presented. Assuming the counting capacity of a measurement system is ideally sufficient, the linearity would be sustained. However, in reality, increasing dead time at higher ICR would distort the linearity because of diverse factors including pulse pile-up (underestimated count, saturation in dynamic range), and the data transmission capacity by cabling the digitizer specifications. In this study, it was assumed to be 'non-linear' if the ratio between iPCR and rPCR is smaller than 0.85.

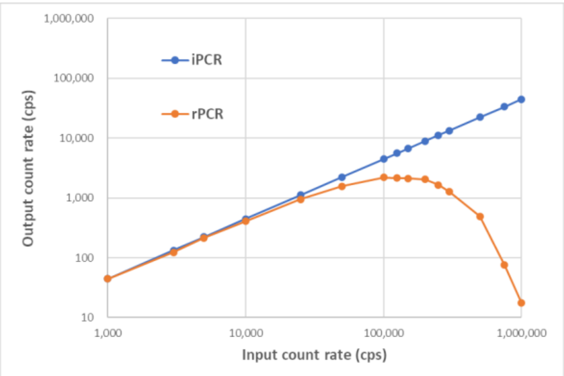

Figure 2. Peak count rates (1.33 MeV peak) according to emulated input count rate

The evaluated counting capacities according to the pulse scale and data acquisition mode were summarized in Table 3. When the decay constant of generated pulses is 1000 ns, the counting capacity was found at only 10,000 cps and this was increased by 25,000 cps (2.5 times) once the time constant became half of the initial value. Similar results were found when the time constant changed from 100 ns to 50 ns as 100,000 to 250,000 cps which are larger at 1-order compared to each 1000 and 500 ns. Also, dramatic decreases occurred once the wave mode was turned on for 1000 and 100 ns of decay constants.

Table 3. The counting capacities (CC, cps) according to the decay constant and data acquisition mode

	w/o Wave mode				w/ Wave mode	
τ (ns)	1000	500	100	50	1000	100
CC (cps)	10 k	25 k	100 k	250 k	5 k	35 k

4. Conclusion

The importance of the pulse duration was investigated in terms of the counting capacity to develop applications for high-dose radiation environments. To that end, two scintillation detectors, $LaBr_3$ and LBC, were utilized for different intensities of gamma-ray sources. Also, the emulated signals of different pulse scales and generation frequencies were tested. Consequently, it was verified that pulse duration could significantly influence the counting capacity of measurement systems. In addition, it would be encouraged to advance the signal processing devices, correction techniques, and the designs of external shielding for desirable practical applications in high-dose radiation environments.

REFERENCES

[1] G.F. Knoll, Radiation Detection and Measurement, third ed., John Wiley & Sons, New York, 2002

[2] 신선이 외, "신호성형유무에 따른 고방사선장선량 환경에서의 CLLB 검출기 계수율 비교", 2023 대한방사선방어학회 추계학술대회(제주), 2023.11.24

Acknowledgments

This work was supported by the National Research Foundation of Korea (NRF) grant funded by the Ministry of Science and ICT of the Republic of Korea (RS-2022-00154985) and the KAERI Institutional Program (Project No. 524441-24).