# Modeling of BC501A scintillation pulses for pulse shape discrimination using Pulse Gradient Analysis method

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## Introduction

Radioactive decay often results in the production of a mixed radiation field consisting of gamma rays and neutrons. Neutrons interact with organic material to produce recoil protons, whereas gamma rays interact to produce electrons. Protons are heavier particles and hence experience a greater energy loss rate than gamma rays while interacting with matter. Thus, neutron-induced scintillation pulses decay more slowly than gamma-ray-induced scintillation pulses [1]. It is essential to distinguish neutrons and gamma rays in a mixed radiation environment. This can be done by Pulse Shape Discrimination (PSD), which exploits the information stored in the individual pulses due to gamma rays and neutrons. It is, therefore, important to understand the mathematical modeling of pulses to exploit the information contained within them fully. Modeling and generation of pulses are important where there are experimental constraints such as the unavailability of a suitable source, detector, enough number of pulses, etc.

The present work reports the modeling of gamma and neutron pulses using the six-parameter model [2]. The modeled pulses were subsequently analyzed for discrimination using the Pulse Gradient Analysis (PGA) method. PGA is based on a comparison between the peak amplitude and the amplitude of a sample occurring at a defined time interval after the peak amplitude [1]. The optimized time interval used in the present work was 18 nsec after the peak amplitude. The ratio of these two amplitudes is known as the “discrimination index”, whose probability distribution reflects the ability to discriminate gammas and neutrons. The FoM so obtained is compared with the FoM obtained from the Charge Integration (CI) method to check the potential of the PGA method for modeled pulses.

## Experiments and Methods

Experiments were performed at the Radiation Detectors and Spectroscopy (RDS) Laboratory, IIT Roorkee, to acquire pulses from a $^{252}$Cf source using a 3"×3" BC501A detector supplied by Saint-Gobain. A total of 10,000 pulses were acquired. $^{252}$Cf source emits 3.8 neutrons and 8 gamma rays on average in each fission, equivalent to 6700 gamma and 3300 neutron pulses out of 10000 acquired pulses. Raw pulses and curve-fitted pulses are shown in Fig.1. Out of these pulses, 395 gamma and 500 neutron pulses were picked randomly to make several sets of 30 pulses, and used them to determine fitting parameters in the six-parameter equation of a scintillation pulse [2], given by

$$V(t) = A\left(e^{-\theta(t-t_0)} - e^{-\lambda_f(t-t_0)}\right) + B\left(e^{-\theta(t-t_0)} - e^{-\lambda_s(t-t_0)}\right) \quad (1)$$

where $A$ and $B$ are the amplitudes of fast and slow components, $\theta$ is the scintillation decay time, $\lambda_f$ and $\lambda_s$ are the decay constants for the fast and slow components and $t_0$ is the time reference for the start of the signal.

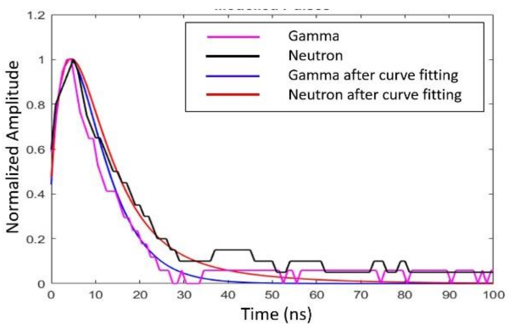


**Fig. 1.** Gamma and neutron pulses before and after curve fitting.

In order to obtain the generalized equations for pulses due to gamma rays and neutrons acquired from the BC501A detector, a standard fitting procedure described in Ref. [2] was followed, and the following generalized equations were obtained:

$$V_G = A\left(e^{-\left(\frac{t-40.6}{4.49}\right)} - e^{-\left(\frac{t-40.6}{5.66}\right)} + 0.099*\left(e^{-\left(\frac{t-40.6}{5.64}\right)} - e^{-\left(\frac{t-40.6}{5.66}\right)}\right)\right) \quad (2)$$

$$V_N = A\left(e^{-\left(\frac{t-37.6}{5.78}\right)} - e^{-\left(\frac{t-37.6}{6.76}\right)} + 0.0853*\left(e^{-\left(\frac{t-37.6}{9.83}\right)} - e^{-\left(\frac{t-37.6}{6.76}\right)}\right)\right) \quad (3)$$

Eq. (2) and (3) are the generalized equations for the gamma and neutron pulses, respectively. Parameter A was given a value ranging between the maximum and minimum amplitude of both neutron and gamma pulses.

The generalized equations can be used to obtain the modeled gamma and neutron pulses over a wide range of energies from the BC501A detector.

## Results and Discussion

A CAEN-make fast desktop digitizer DT5751 was used to obtain PSD from the experimentally acquired pulses (6700 gammas and 3300 neutrons). The Charge Integration (CI) method was used and obtained FoM value was 1.21.

The modeled pulses obtained using the generalized equations consist of no noise. As any practical scintillation detector generates some noise, the modeled pulses were provided with random noise [3]. A total of 6700 gamma pulses and 3300 neutron pulses were generated using eq. (2) by varying the normalization constant 'A'. Thus, a total of 10,000 pulses were generated, and the PGA algorithm was applied to them. The scattered plot obtained from the PGA method is shown in fig.2. The probability distribution of the discrimination index, i.e., peak amplitude divided by sample amplitude obtained from PGA, is presented in fig.3. The separation between gamma and neutron plumes was calculated as:

$$FoM = \frac{S}{FWHM_\gamma + FWHM_n} \quad (4)$$

where S is the separation of peaks and $FWHM_{\gamma/n}$ is the Full Width at Half Maximum of gamma/neutron events. The FoM obtained was 1.29. Thus, the FoM obtained using PGA with 6700 gamma and 3300 neutron pulses matches well with that obtained using the CI method applied on the same number of pulses, showing the satisfactory performance of the PGA method to estimate the FoM using modeled pulses.

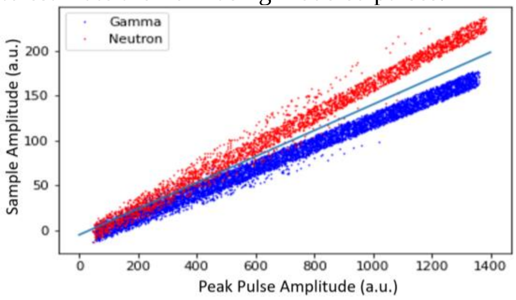


**Fig. 2.** Scattered plot for PGA for pulse shape discrimination.

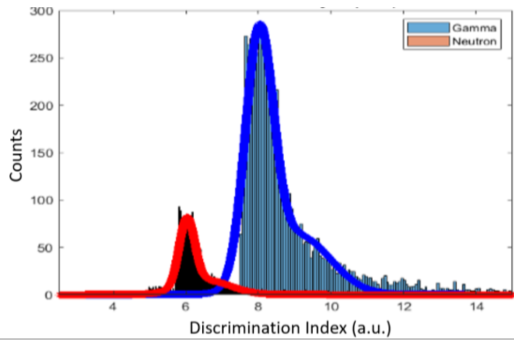


**Fig. 3.** The probability distribution of the discrimination index returned by PGA method.

## Summary

The six-parameter model was used to model scintillation pulses of gamma rays and neutrons for a BC501A detector. Experimental pulses were used to determine the fitting parameters, and 10,000 pulses were generated using the obtained general equations. The modeled pulses were fed into a PGA algorithm developed by us, and the obtained FoM was in good agreement with the measured FoM using Charge Integration (CI) method.

## References

[1] Gamage et al., Nucl Instrum Methods Phys Res A. 642 (2011): 78-83.

[2] Marrone et al., Nucl Instrum Methods Phys Res A. 490 (2002): 299-307.

[3] Saleh, Hassan I. and A. A. Arafa. "Modeling and Simulation of Scintillation Pulses for Crystal Identification Applications." (2016).