Pulse Shape Discrimination in Stilbene-H Detectors Using DRIFT Software

Junsik Kim, Beomkyu Kwon, Gyuhaeng Jo, Kyoung-Jae Chung[a*]

[a]Department of Nuclear Engineering, Seoul National University, 1, Kwanak-ro, Kwanak-gu, Seoul, Republic of Korea

**Corresponding author: jkjlsh1@snu.ac.kr*

Introduction

❖ **Purpose of the study**
- Pulse shape discrimination (PSD)
  - Neutrons are inevitably accompanied by gamma-rays produced by neutron sources.
  - It is essential to distinguish neutrons from gamma-rays in neutron detection.
  - PSD allows the detector to discriminate between neutrons and gamma-rays.
- Problem Statement
  - Neutron detection requires shielding due to the hazards posed by neutron sources.
  - Neutron detection in extreme environmental conditions is challenging.
  - More efficient and reliable approach for neutron detection is necessary.

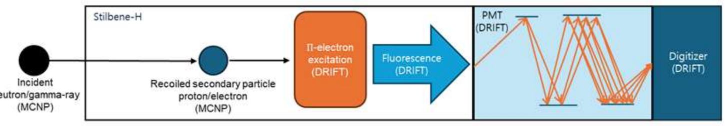
❖ **Introduction of DRIFT software**
- Detector Response Function Toolkit (DRIFT)
  - DRIFT is a post-processing software that simulates pulses induced by scintillation light.
  - This software simulates decay time differences between neutron and gamma-ray signals
  - It utilizes PTRAC data from the Monte Carlo N-Particle (MCNP).
- Benefits of the Approach
  - DRIFT software provides reliable PSD results with customizable settings.
  - PMT effect, digitizer setting, pulse shape can be customed.
  - It provides reliable data for neutron measurements of sources that do not physically exist.

❖ **Stilbene-H**
- Stilbene-H is an organic detector with the chemical formula $C_{14}H_{12}$, commonly used in PSD experiments.
- It provides a high light output and features a significant decay time difference between neutron and gamma.
- The pilot study shows a figure of merit of 1.79 by using the Stilbene-H detector in the PSD experiment.[1]

❖ **This paper attempts to validate the performance of DRIFT by comparing it with experimental**

Method

❖ **Customizable Drift settings.**
- Light collection efficiency and PMT Voltage, corresponding gain can be specified.
- Resolution, sampling rate, voltage range, offset of digitizer can be specified



❖ **Charge comparison method (CCM)**
- CCM is a one of the signal processing method used to perform PSD
- CCM can distinguish generated pulses by computing the ratio of pulse integrals
  1. Q_{total} : Integral from pulse rise to signal tail (~ 80 ns)
  2. Q_{slow} : Integral from signal head to signal tail (~ 32 ns)
  3. Q_{fast} : Integral from signal rise to signal head (~ 48ns)
- Ratio between the slow component and the total PSD parameter can be defined as

$$\text{PSD parameter} : \frac{Q_{slow}}{Q_{total}}$$

- Figure of merit (FOM) can be described as

$$\text{FOM} : \frac{\text{(Distance between two peaks)}}{\text{(Sum of full width half maximum of two peaks)}}$$

❖ **Custom pulse shape**
- DRIFT computes a pulse shape based on the equation provided by F.Q.L Friesen [2].
- Each parameter has been computed by fitting the pulse shape from the real experiment.

$$y(t) = Af(t)[Rg(t) + (1 - R)h(t)]$$

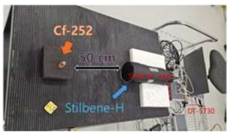
$$f(t) = \left(\exp\left(\frac{t-t_0}{T_r}\right)+1\right)^{-1}, g(t) = \left(\exp\left(\frac{t-t_0}{T_f}\right)+1\right)^{-1}, h(t) = \left(\exp\left(\frac{t-t_0}{T_s}\right)+1\right)^{-1}$$

- T_r = Rise time
- T_f = Fast decay time representing fluorescence
- T_s = Slow decay time representing return from phosphorescence
- R = Relative weighting of decay times
- A = Pulse amplitude
- t_0 = Pulse arrival time

Parameter	Neutrons	γ-rays
$T_r(ns)$	0.80	1.80
$T_f(ns)$	5.20	5.40
$T_s(ns)$	46.0	40.0
R	0.99	0.91
$t_0(ns)$	102	98

Table.1. Values of the parameter by fitting

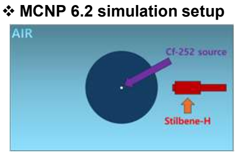
❖ **Experimental setup**



- Stilbene scintillator detector is coupled to a H6525 PMT (3in. diameter, HAMAMATSU)
- PMT signal was sent directly to a high-speed digitizer: DT5730 (500MS/s, 14-bit resolution, CAEN)
- One detector is positioned 50 cm away from capsule type ^{252}Cf source at room temperature.

Fig.1. Measurement experiment using a stilbene scintillator detector

❖ **MCNP 6.2 simulation setup**



- 3-inch diameter Stilbene-H detector is encased in aluminum with a thickness of 0.153 cm.
- one detector is positioned 50 cm away from ^{252}Cf point source.

Fig.2. Geometry of MCNP 6.2 simulation

Acknowledgments

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Results

Pulse shape

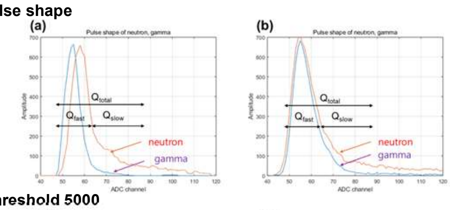

Fig.3. Pulse shape of neutron & gamma in (a) DRIFT (b) experiment

Threshold 5000

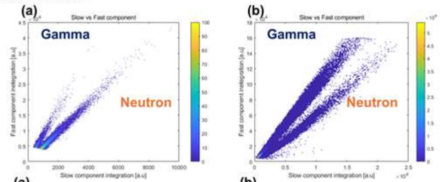

Fig.4. Scatter plot for slow component vs fast component with threshold 5,000 (a) DRIFT (b) experiment

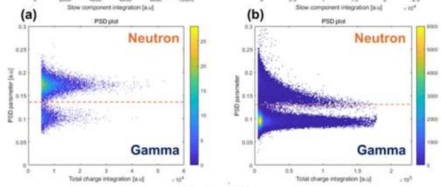

Fig.5. PSD scatter-density plot of Cf-252 threshold 5,000 (a) DRIFT (b) experiment

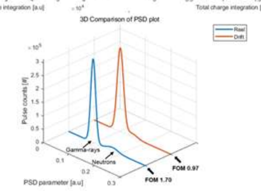

Fig.6. Distribution of PSD parameter at threshold 5,000

Threshold 10000

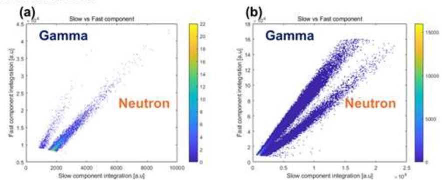

Fig.7. Scatter plot for slow component vs fast component with threshold 10,000 (a) DRIFT (b) experiment

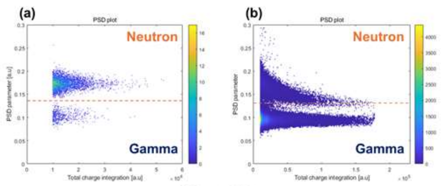

Fig.8. PSD scatter-density plot of Cf-252 threshold 10,000 (a) DRIFT (b) experiment

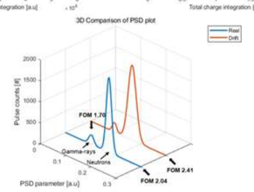

Fig.9. Distribution of PSD parameter at threshold 10,000

Threshold (a.u)	FOM from DRIFT	FOM from experimental
5,000	0.97	1.70
10,000	2.41	2.04

Table.2. Values of FOM

❖ **At threshold 10,000, the DRIFT simulation showed a higher FOM of 2.41 compared to the experimental value of 2.04.**

❖ **However, at threshold 5,000 the experimental value showed a higher FOM of 1.70, while the DRIFT simulation showed a lower value of 0.97.**

❖ **The difference in FOM values suggests that the background noise overestimate the gamma-ray pulses.**

❖ **The total charge integration between the experiment and DRIFT shows differences because the PMT and digitizer settings of DRIFT were not matched to those used in the experimental.**

Conclusion

❖ **In this study, we compared the PSD results of experimental with simulation using DRIFT.**

❖ **DRIFT closely matched the pulse shape from experiment by equation provided by F.Q.L Friesen**

❖ **DRIFT software has succeeded PSD plot obtainment through the artificially generated pulse.**

❖ **This study presents the potential to provide reliable data on conceptual design devices, such as the K-DEMO demonstration reactor.**

Reference

[1] Kim, C., J.-Y. Yeom, and G. Kim, Digital n-γ Pulse Shape Discrimination in Organic Scintillators with a High-Speed Digitizer. J. Radiat. Prot. Res, 2019. 44(2): p. 53-63.

[2] F.Q.L. Friesen and C.R. Howell. A functional form for liquid scintillator pulse shapes. NIM A, 2019.

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