A Composite Method for Improving the Pulse Shape Discrimination Efficiency of a Scintillation Detector Using EJ-301 Liquid

Phan Van Chuan, Nguyen Xuan Hai, Nguyen Ngoc Anh, Pham Dinh Khang, Nguyen Quang Hung, Truong Van Minh, and Nguyen Duy Ly

***Abstract*— This article presents a composite (COM) method to obtain the high-resolution pulse shape discrimination (PSD) for the neutron and gamma-ray pulses generated from scintillation detectors. The method, which is based on a selective combination of the digital charge integration (DCI) with the reference pulse method, aims to reduce the mixed radiation events in the low-energy range. An EJ-301 liquid scintillation detector together with a fast sampling analog-to-digital converter (ADC) is used to measure and digitize the pulses induced from the radioactive decays of ^{60}Co and ^{252}Cf, which are then analyzed by our COM method. The proposed method is evaluated using the figure of merit (FoM) and separation quality function $F(u)$, and the results are compared with three known methods, namely the DCI, standard event fit (SEF), and artificial neural network (ANN) methods. We show that the average values of FoM and $F(u)$ obtained within the COM method are about ten times higher than those obtained within the DCI and SEF in the whole energy range from 50 to 1000 keV electron equivalent (keVee). In particular, by using the COM method, the percentage of gamma events being confused as neutrons ranges from 0.32% to 8.80% when the energy is reduced from 400 to 50 keVee. This finding, which is significantly lower than those obtained by using the DCI and SEF, indicates that the proposed COM method should be considered as a leading method for producing a neutron/gamma PSD counter system with high resolution.**

***Index Terms*— Discrimination parameter, neutron/gamma high resolution, neutron/gamma pulse shape discrimination.**

I. INTRODUCTION

THE scintillation detectors have been popularly used for the neutron measurement systems due to their high efficiency, but it is too sensitive to gamma rays. The neutron/gamma pulse shape discrimination (PSD) is one of the most effective solutions to reduce the effect of gamma on the neutron detection results. The deposited neutron energies in the scintillation liquid, which have a distribution from zero to a maximum kinetic energy of the recoil particles, are converted to the pulse amplitudes, which also have a distribution from zero to a maximum conversion value. The typical shapes of the converted pulses are, thus, dependent on the interaction types induced by neutron or gamma particles in the scintillator [1], [2]. However, these typical pulse shapes are often affected by the electronic noise and statistical fluctuations, leading to the deformation of the pulse shapes. Such unexpected deformations restrict the capacity of the PSD methods as well as the applications of scintillation detectors. Especially, in the low-energy range below 100 keVee, the pulse tails generated from the scintillation detectors are strongly affected by the electronic noise. Consequently, the efficiency of neutron/gamma PSD becomes very low and the corresponding figure of merit (FoM) values of most PSD methods are less than 1. Therefore, the improvement of the neutron/gamma PSD efficiency has become an interesting topic, which has attracted many research and studies.

Among the neutron detectors, the fast neutron detector using the EJ-301 scintillation liquid is sensitive to both neutron and gamma rays [1], [2]. By coupling the scintillator with a photomultiplier tube (PMT), one is able to collect the scintillating lights produced via the interactions between the radiations with the scintillation liquid and convert them into the voltage pulses, whose shapes can be used to distinguish between the neutron and gamma events. The emission light from each deexcited decay of EJ-301 scintillator has fast and slow decay components, which are associated with different proportions of neutron and gamma rays [3]–[5]. Many neutron/gamma PSD techniques have been recently developed, including the analog, digital, and artificial intelligent implementations such as the charge comparison (CC) [6], zero crossing (ZC) [6]–[8], digital charge integration (DCI) [2], [7], [9], frequency gradient analysis (FGA) [10], pulse gradient analysis (PGA) [4], correlation pattern recognition (CPR) [11], [12], digital zero crossing (DZC) [13], threshold crossing time (TCT) [14], curve fitting (CF) [11], standard event fit (SEF) [15], discrete wavelet transform (DWT) [16], histogram-difference method (HDM) [17], artificial neural network (ANN) [18]–[20], Gaussian mixtures

Manuscript received November 4, 2020; revised January 25, 2021; accepted February 8, 2021. Date of publication March 11, 2021; date of current version March 18, 2021. This research was funded by Vietnam National Foundation for Science and Technology Development (NAFOSTED) under grant number 103.04-2019.388. The Associate Editor coordinating the review process was Dr. John Lataire. *(Corresponding author: Nguyen Xuan Hai.)*

Phan Van Chuan is with the Faculty of Physics and Nuclear Engineering, Dalat University, Dalat 66000, Vietnam (e-mail: chuanpvdlu@gmail.com).

Nguyen Xuan Hai and Nguyen Ngoc Anh are with the Dalat Nuclear Research Institute, Dalat 660000, Vietnam (e-mail: nxhai@nri.gov.vn; ngocanh8999@gmail.com).

Pham Dinh Khang is with the Department of Nuclear Engineering and Environmental Physics, Hanoi University of Science and Technology, Hanoi 100000, Vietnam.

Nguyen Quang Hung is with the Institute of Fundamental and Applied Sciences, Duy Tan University, Ho Chi Minh City 700000, Vietnam, and also with the Faculty of Natural Sciences, Duy Tan University, Da Nang 550000, Vietnam (e-mail: nguyenquanghung5@duytan.edu.vn).

Truong Van Minh is with the Department of Natural Science, Dong Nai University, Dong Nai 760000, Vietnam.

Nguyen Duy Ly is with the Faculty of Fundamental Science, Van Lang University, Ho Chi Minh City 700000, Vietnam.

Digital Object Identifier 10.1109/TIM.2021.3060600