24th IEEE Real Time Conference

Quy Nhon, Vietnam

Dependence of detection efficiency and neutron/gamma discrimination ability on the volumetric parameters of EJ-301 liquid scintillation detector

Phan Bao Quoc Hieu, Phan Van Chuan, Nguyen Nang Hai, Le Van Tung, Nguyen Quang Hung, Nguyen Ngoc Anh, Dinh Tien Hung, Vu Thi Thanh Quy, Nguyen Duy Quang, Nguyen Xuan Hai

Email: hieupbq@dnri.vn

Abstract

We investigated the relationship between the volumetric parameters of the cylindrical EJ-301 liquid scintillation detector and its detection efficiency and neutron/gamma discrimination capability. Eight detector configurations corresponding to cylindrical EJ-301 detectors of different length and diameter values connected to a photomultiplier tube have been modeled. Signals corresponding to these models, which were obtained using the Geant4 simulation program, have been analyzed using a neutron/gamma pulse shape discrimination method, i.e., the digital charge integration one. The results indicate that the detector's diameter has an important impact on its neutron detection efficiency, whereas its neutron/gamma discrimination ability strongly depends on its length-to-diameter ratio.

Methodology

Detector modeling

We constructed detector models in the Geant4 environment to investigate the relationship between scintillator size versus detector efficiency and neutron/gamma discrimination capability. The eight detectors corresponding to eight configurations of the scintillator of EJ-301 liquid scintillation (Table 1) are studied.

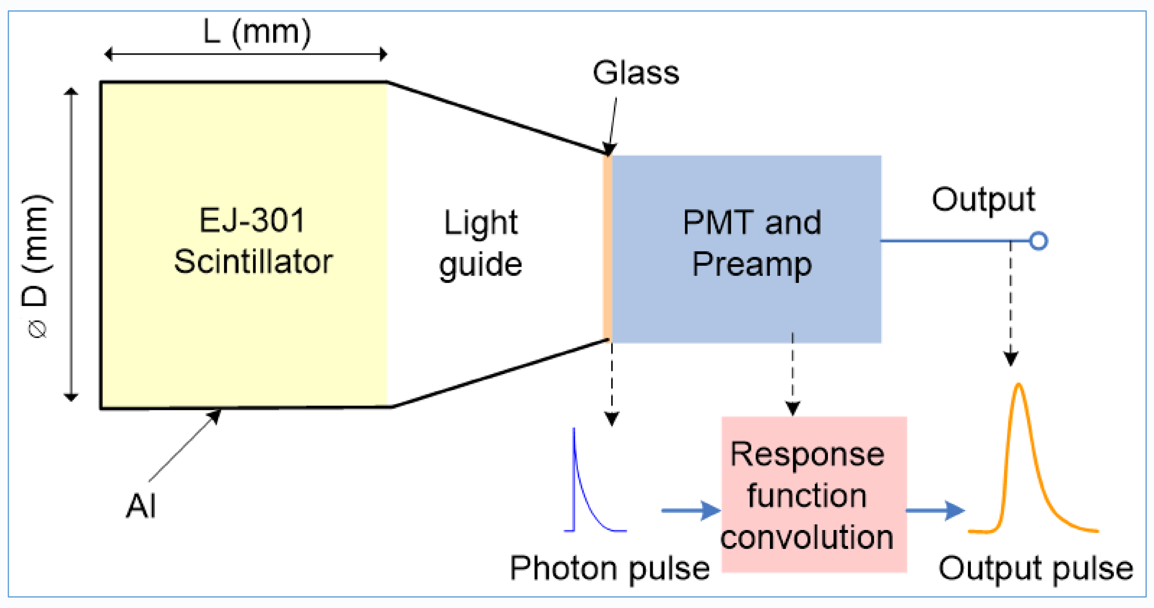

Fig.1. Modeling the EJ-301 detector.

$$y(t) = B.exp\left(\frac{t}{\tau_L}\right) - A.\exp\left(\frac{t}{\tau_s}\right) \quad (1)$$

$$G_{PMTP}(t) = G_{PMT}(t) \otimes V_{Preamp}(t) \quad (2)$$

$$V_{Out}(t) = y(t) \otimes G_{PMTP}(t) \quad (3)$$

Table 1. Size of the cylindrical EJ-301 liquid scintillation cells.

Configuration	N⁰1	N⁰2	N⁰3	N⁰4	N⁰5	N⁰6	N⁰7	N⁰8
Size (D × L) (mm)	34×25	34×50	50×50	50×100	75×50	75×100	100×50	100×100

Decay time constant modeling

The shape of the simulated photon pulses represents the temporal distribution of the scintillation photon counts reaching the anode of photomultiplier tube.

In this work, the time decay constants of EJ-301, along with their relative weightings for both neutrons and gamma rays, have been included into the Geant4 program, used experimental values of Marrone S. et al (Table 2) [1].

Response of photomultiplier tube and preamplifier

The simulated pulses are calculated including the influence of the photomultiplier tube (G_{PMT}(t)) and the preamplifier circuit (G_{Preamp}(t)) on the shape of the output pulse (V_{Out}(t)). These are expressed by the convolution operation G_{PMTP}(t) as shown in Equation (2).

The response function of the PMT to single photon was referenced from the research of De Haas J.T.M. et al [2]. Additionally, the response function of the Preamp was derived from the research results of Chuan P.V. et al [3].

Table 2. Decay time constants and relative weightings for EJ-301 scintillator

Particle	B/A	τ_s	τ_L
Gamma	0.01658	4.887	34.286
Neutron	0.04151	4.887	34.276

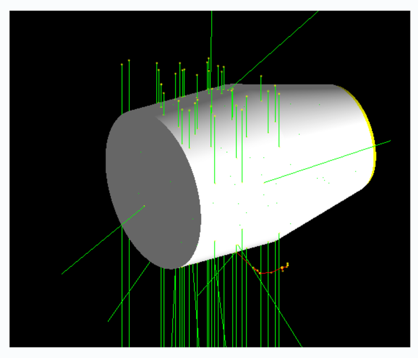

Fig. 2. Geometry configuration of the Det 5 was simulated using Geant4

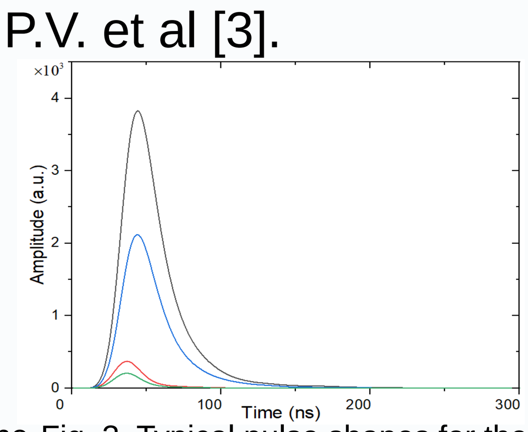

Fig. 3. Typical pulse shapes for the EJ-301 scintillator were simulated

Results and discussions

The relative efficiency to neutron energies thresholds of eight detector configurations were calculated and are shown in Fig 4. This efficiency is strongly dependence on the diameter of the detectors

The gamma/neutron discrimination of the detector is evaluated by using the zero crossing method (ZC) and the figure of merit (FoM). Fig. 6 shows statistical pulse shape discrimination (PSD) parameters for each detector, and the FoM results are shown in Table 3. Fig. 7 shows the neutron/gamma discrimination capability of detectors versus the energy threshold.

Table 3. FoM values of detectors measured on ^{252}Cf neutron source.

Detector	Gaussian peak-to-peak distance	Width of the 1st Gaussian peak	Width of the 2nd Gaussian peak	FoM
Det 1	0.058	0.010	0.015	1.03 ± 0.07
Det 2	0.056	0.012	0.013	1.03 ±0.09
Det 3	0.056	0.011	0.014	0.95 ±0.05
Det 4	0.049	0.012	0.012	0.86 ±0.04
Det 5	0.057	0.012	0.014	0.92 ±0.08
Det 6	0.054	0.013	0.012	0.92 ±0.09
Det 7	0.058	0.013	0.015	0.88 ±0,.5
Det 8	0.057	0.016	0.015	0.78 ±0.04

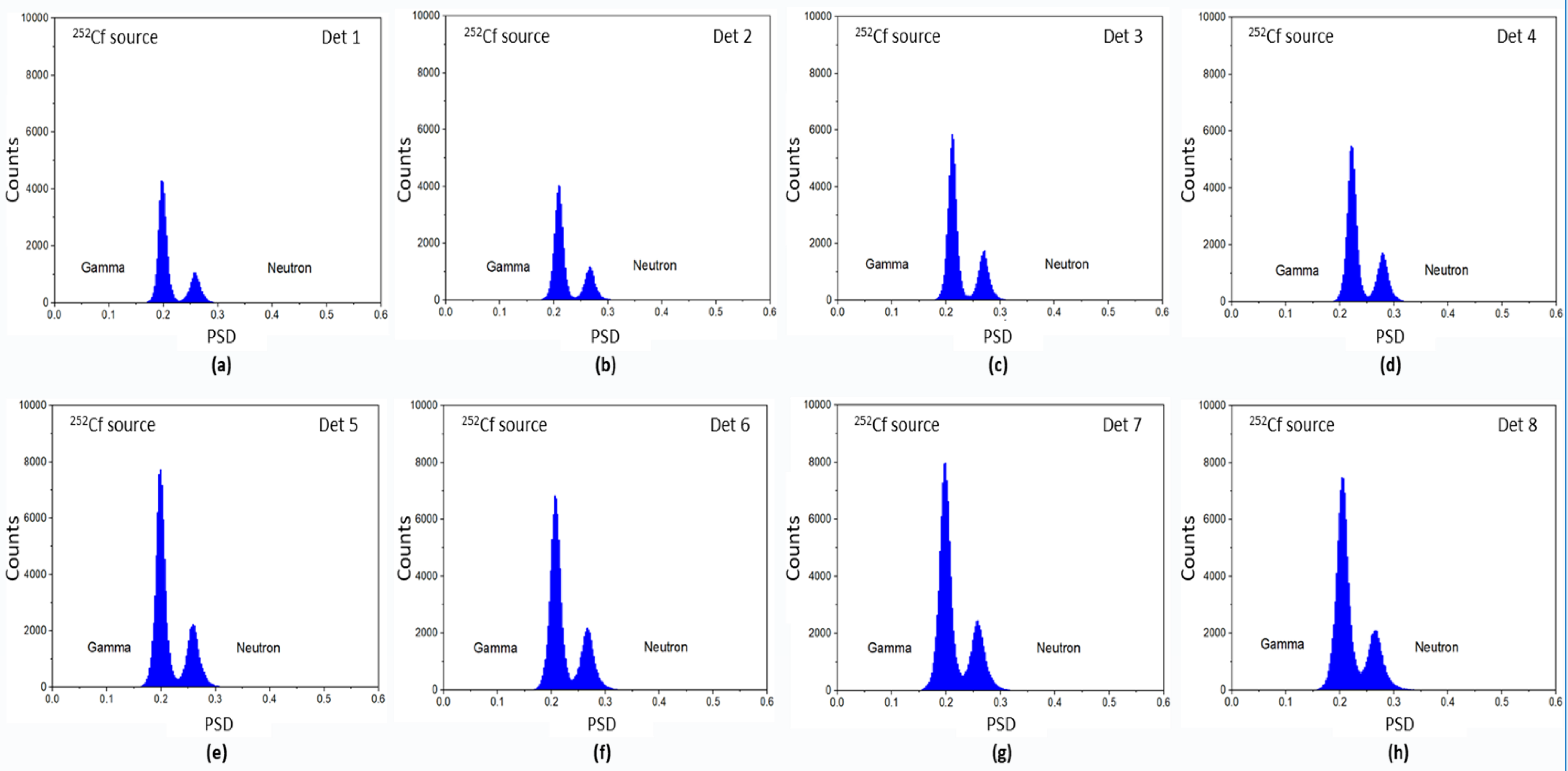

Fig. 6. The PSD parameters of the detectors simulated used a ^{252}Cf neutron source

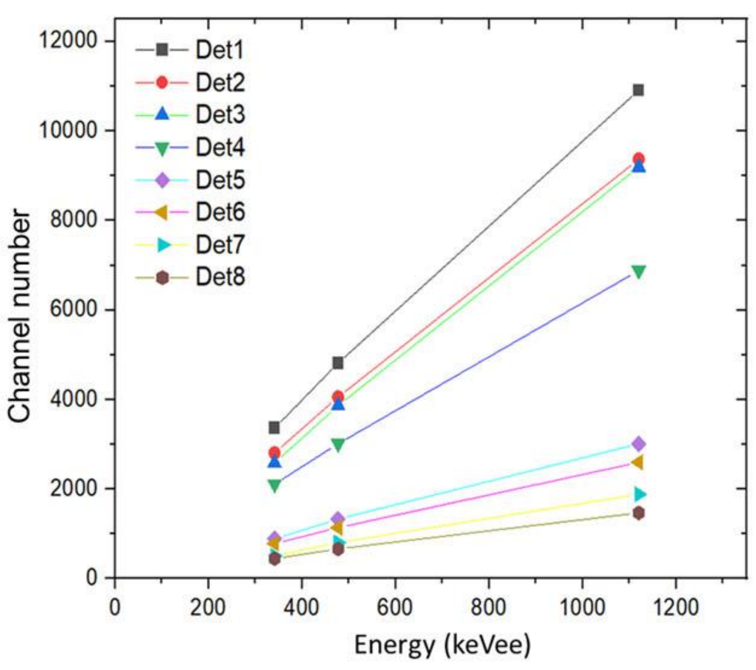

Fig. 4. Energy calibration curves for EJ-301 detectors simulated by Geant4.

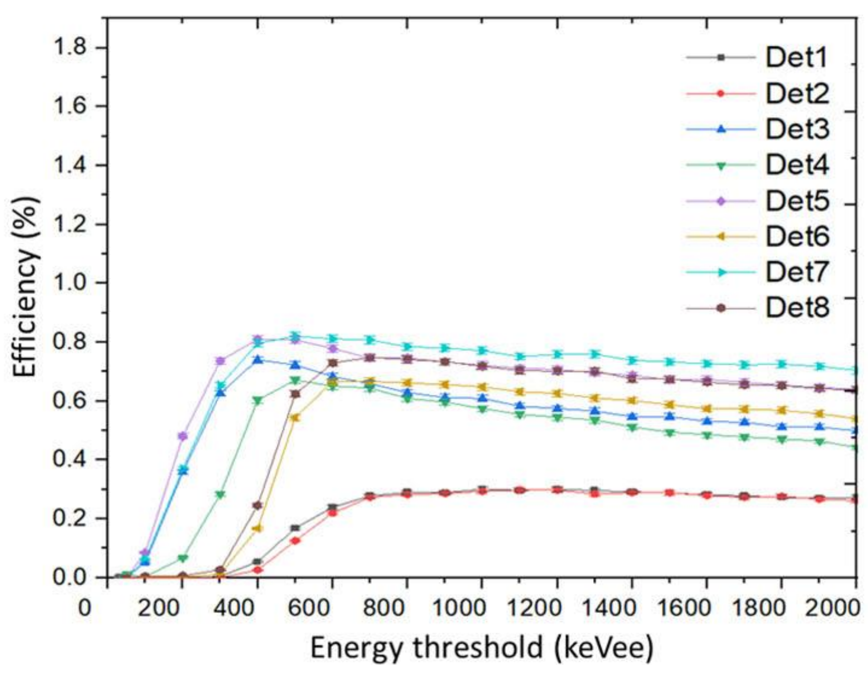

Fig 5. Efficiency curves of detectors simulated by Geant4

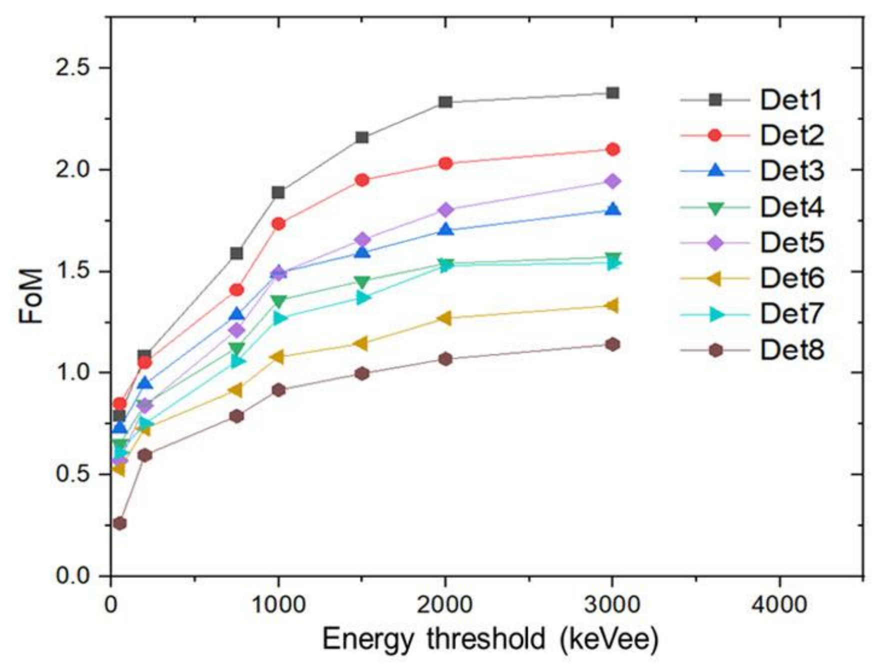

Fig. 7. The neutron/gamma discrimination capability of the detectors.

References

[1] Marrone, S., Cano-Ott, D., Colonna, N., Domingo, C., Gramegna, F., Gonzalez, E. M., et al. (2002). Pulse shape analysis of liquid scintillators for neutron studies. Nuclear Instruments and Meth ods in Physics, 490, 299–307.

[2] De Haas J.T.M., Dorenbos P., 2011, Methods for accurate measurement of the response of photomultiplier tubes and intensity of light pulses, IEEE Transactions on Nuclear Science, (58), pp. 1290-1296.

[3] Chuan, P. V., et al. "A study on the impact of pulse shaping parameters on zero-crossing method performance for neutron/gamma discrimination." *IEEE Transactions on Nuclear Science* (2023).

Acknowledgement: This research is funded by Vietnam National Foundation for Science and Technology Development (NAFOSTED) under grant number NCUD.02-2022.38