

Development of a hybrid radiation monitor based on NaI(Li+TI) and PVT scintillators for Homeland Security

R. De Stefano, V. Buridon, G. Corre, C. Lynde, F. Carrel

Abstract— In the framework of its activities related with Homeland Security, the Sensors and Electronic Architectures Laboratory from LIST Institute of CEA Paris-Saclay is currently developing new generation radiation monitors to detect nuclear and radiological threats in strategic zones. The research line hereby proposed consists in deploying recent ${}^6\text{Li}$ doped NaILTM detectors commercialized by Saint Gobain Crystals, which present thermal neutron and gamma ray discrimination capabilities by means of Pulse Shape Discrimination (PSD); but also gamma-ray energy resolution performances close to classical NaI [1]. The resolution close to 7% for the 662 keV peak of ${}^{137}\text{Cs}$ allows the discrimination of radiological threats classically used in a dispersion explosive (also known as dirty bomb). Our patented method, which consists in the coupling of NaILTM to an array of Polyvinyl-Toluene (PVT) plastic scintillators accurately placed close to the crystal gives access to the NaILTM detector's sensitivity to thermal neutrons as they primary thermalize in the surrounding PVT. Moreover, plastic scintillators are used to detect fast neutrons, which interact by recoil proton reactions in PVT. Fast neutrons signal is mainly collected as the (γ, n) coincidence counting contribution processed with Rossi-Alpha curves, enhancing the system's sensitivity to nuclear threats. A first proof of concept experimental hybrid module based on the two inorganic/organic NaILTM/PVT scintillators and the associated signal towards radiological and nuclear simulants as well as its enhancement and data processing methods are presented in this paper.

Index terms— Radiation monitor, NaILTM, plastic PVT scintillators, Pulse Shape Discrimination (PSD), coincidence counting, Rossi-Alpha curves

I. INTRODUCTION

For more than a decade, CEA List is closely involved in Research and Development (R&D) programs to propose state-of-the-art portals and associated algorithms to fight against CBRN-E threats (*Chemical, Bacteriological, Radiological, Nuclear and Explosives*). For instance, former developments based on classical PVT plastic scintillators coupled to Cadmium layers [2] conducted to the commercialization of the new generation Radiation Portal Monitors (RPM) known as SAPHYGATE GN [3] by Bertin Technologies industrial partner. The research axis reported in this paper focuses on the use of low-cost PVT scintillators which present several

advantages such as a production for volumes and shapes adapted to the users requirements to increase detection efficiency, as well as a fast light fast response of the order of some dozens of nanoseconds. Coupled to a NaILTM inorganic scintillator, we report in this paper the potential of a first proof-of-concept module for the detection and discrimination of radiological and nuclear threats by means of its associated spectrometry, PSD spectra, and Rossi-Alpha coincidence signal post-processing.

II. PROOF-OF-CONCEPT EXPERIMENTAL SETUP

For the current developments a 3'' \times 3'' dimensions NaILTM detector coupled to two EJ-200 plastic scintillators from Eljen Technology Inc. of 10 cm width and 12 cm height forming a hollowed cylindrical shape covering a 120° angle are jointly used. The top outside corners of the two PVT scintillators are distanced from 25 cm (corresponding to a 15 cm distance for the inner corners, see Fig.1). The NaILTM detector is centered between both EJ-200 scintillators to benefit from the incident fast neutron's thermalization in PVT. Output signals and associated pre-analysis are treated with a DT5730B digitizer from CAEN[®] S.p.A. The setup is exposed to four distinct radiation sources, which are respectively a ${}^{152}\text{Eu}$ source, ${}^{60}\text{Co}$, ${}^{137}\text{Cs}$ and finally a spontaneous fission ${}^{252}\text{Cf}$ source. The three firstly mentioned gamma-ray sources were used for the setup's energy calibration and represent common radiation threat simulants, whereas the ${}^{252}\text{Cf}$ source simulates a nuclear threat. An additional passive background measurement is presented for further detection limits estimation. Each measurement was timed to 10-minutes acquisition. The four sources were placed at a 30-cm distance from the NaILTM; and at equidistance from the two EJ-200 plastic scintillators. The experimental hybrid NaILTM/PVT setup is presented in Fig.1.

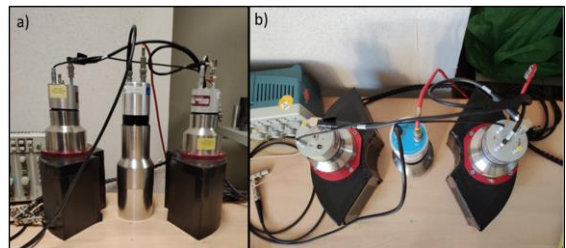


Fig. 1. a) Front and b) Top view of the proof-of-concept Radiation Monitor under development in the CisLAB platform of CEA Paris-Saclay

III. THREAT'S MAIN SIGNATURES

The NaILTM signal connected to the first channel of the digitizer is collected with a record length fixed to 2 μs . The charge value Q_{Long} under the global pulse allowed the building of the energy spectra reported after energy calibration

Paper submitted the 5th of May, 2022. This work has received funding from the French ministerial research and development program to fight CBRN-E (Chemical, Biological, Radiological, Nuclear and Explosives) threats. R. De Stefano, V. Buridon, G. Corre, C. Lynde and F. Carrel are with the University of Paris-Saclay, CEA, LIST, F-91129, Palaiseau, France (e-mail: roberto.destefano@cea.fr).

presented in Fig. 2. PSD two dimensional histograms reported in Fig. 3 were processed with Short Gate and Long Gate values ranging respectively at 140 and 1400 ns.

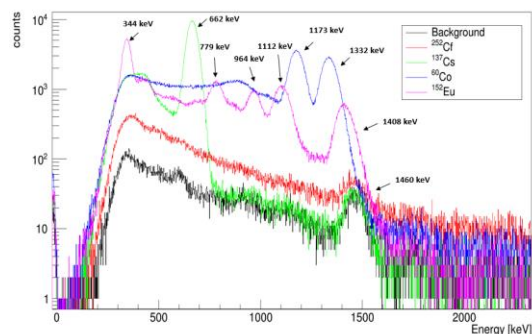


Fig. 2. Gamma-ray energy spectra processed for the NaIL™ detector for the respective ^{252}Cf , ^{137}Cs , ^{60}Co , ^{152}Eu and passive background measurements.

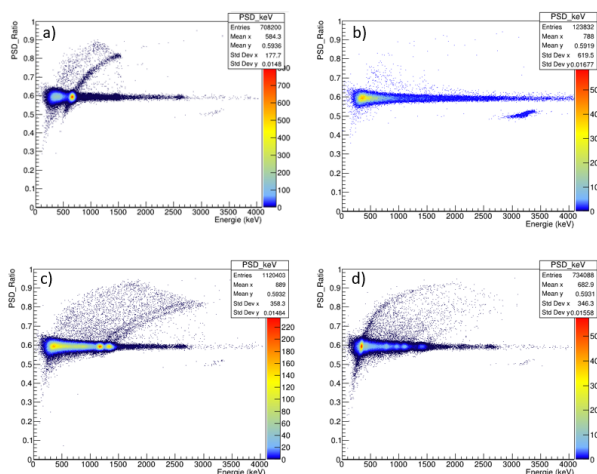


Fig. 3. PSD spectra processed for the NaIL™ detector for the respective a) ^{137}Cs ; b) ^{252}Cf ; c) ^{60}Co and d) ^{152}Eu measurements.

At first, gamma-ray spectrometry performances presented in Fig. 2 show the potential of the setup's capability to discriminate the main energy peaks of the classically used radiation simulants thanks to energy resolution close to 7%. Second, the net signal increase in the neutron Region of Interest (RoI) from 3000 to 3500 keVee and 0.4 to 0.5 PSD ratio values for the PSD graphic reported in Fig. 3 b) with respect to a); c) and d); shows a particular monitor's sensibility as a response to a nuclear threat. For these developments, EJ-200 plastic scintillators are used with two main objectives:

- Their presence as a fast neutrons moderator allows enhancing the signal presented in the neutron RoI detected by the NaIL™.
- They are used as gamma-ray and neutron detectors.

Indeed, coupled respectively to digitizer's channel 2 and 4, for which shorter record length values were fixed to a hundred of nanoseconds, an online Constant Fraction Discrimination (CFD) processing is applied in order to collect the pulses *TimeStamp* (in fine the particles interaction time in both PVT). By means of a post-processing software based on ROOT® C++ Data Libraries, Rossi-Alpha graphics are computed with

the *TimeStamp* values which are tagged with a picosecond accuracy [4]. Rossi-Alpha graphics built for the two EJ-200 scintillators for this study are reported in Fig. 4.

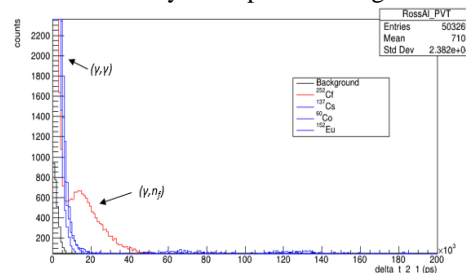


Fig. 4. Rossi-Alpha coincidence counting processed for the two EJ-200 plastic scintillators enrobing the NaIL™ for the respective ^{252}Cf , ^{137}Cs , ^{60}Co , ^{152}Eu and passive background measurements.

The signal detected for the red Rossi-Alpha histogram, peaked at 18 nanoseconds for the ^{252}Cf source, corresponds to the main detection of spontaneous fission prompt fast neutrons detected in coincidence with prompt gamma rays [5, 6]. This signal corresponds to an additional signature pointing the presence of a nuclear threat, thus enhancing the global hybrid system's sensitivity but also the measurement's confidence by means of two separate independent signal analysis.

IV. CONCLUSION

The current developments under patent reported in this paper show the potential of the coupling of a hybrid system based on organic/inorganic scintillators to fight against radiological and nuclear threats. At NSS 2022, the proof-of-concept setup characterization (energy and time calibration) as well as the acquisition parameters optimization for both detector families will be presented. An additional analysis of the PSD spectra in the CisLAB platform to understand pile-up contribution in the gamma-ray signal as well as the influence of several PVT configurations surrounding the NaIL™ in the neutron RoI, but also a signal optimization of the Rossi-Alpha graphics for the (γ, n_γ) coincidence counting will be reported.

REFERENCES

- [1] Kan Yang et al., "Li Co-Doped NaF:Tl (NaIL)—A Large Volume Neutron-Gamma Scintillator With Exceptional Pulse Shape Discrimination", *IEEE Transactions on Nuclear Science*, Vol. 64, no. 8, pp. 2406-2413, 2017.
- [2] J. Dumazert et al., "Advancements in Gd-based neutron detection: γ - γ coincidence approach", *Nuclear Inst. And Methods in Physics Research. Sect. A*, Vol. 954, 161199, 2020.
- [3] SAPHYGATE GN, Specification data sheet, available online, <https://www.berlin-instruments.fr/produits/portiques-detection-radioactive/saphygate-gn>
- [4] UM5960 CoMPASS User Manual, CAEN SyS., Feb. 2022.
- [5] R. De Stefano, B. Pérot, C. Carasco et al., "Pulsed neutron interrogation with PVT plastic scintillators to detect nuclear materials", *Nuclear Inst. And Methods in Physics Research. Sect. A*, Vol. 976, 164276, 2020.
- [6] V. Bottau et al., "Detection of Fission Coincidences With Plastic Scintillators for the Characterization of Radioactive Waste Drums", *IEEE Transactions on Nuclear Science*, Vol. 69, no. 4, pp. 818-824, 2022.