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NSS-06-N-21-01 | Scintillators, Photodetectors and Applications V

Developpement of a hybrid radiation monitor based on NaI(Tl+Li) and Plastic Scintillators for Homeland Security



R. De Stefano¹, V. Buridon¹, G. Corre¹, C. Lynde¹, S. Foucambert¹, F. Carrel¹



¹University of Paris-Saclay, CEA, LIST, F-91129, Palaiseau, France

November 09, 2022

Contact : roberto.destefano@cea.fr





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Outline :

- I. Introduction
- II. Approach
- III. Proof-of-concept setup
- III. Main performances
- IV. Conclusion and prospects



➤ General context :

- Research & Development program to fight against **CBRN-E threats** (Chemical, Biological, Radiological, Nuclear and Explosives)
- Focus on the development of technologies for **civil zones monitoring** (stadium, airports, train stations...)

Tense Geopolitical context : Press paper October 27, 2022

The Washington Post
Democracy Dies in Darkness

U.N. looks to ‘cool’ fears of dirty bomb with visit to Ukraine

Example of classical NaI based radiation monitor



➤ Objectives :

- Development of a new generation of Radiation Portal Monitors (RPM) able to **detect, identify and discriminate** radioactive and nuclear threats



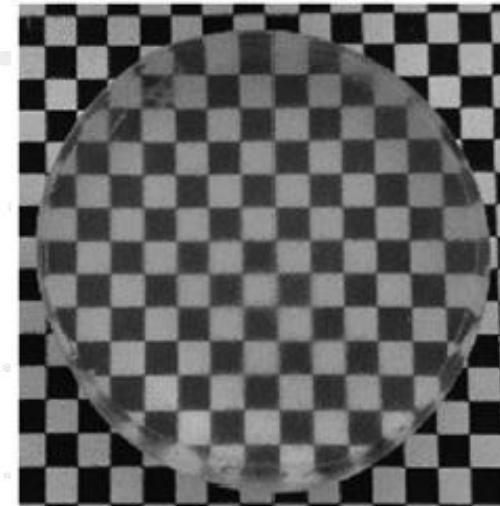
➤ Background developments :

- CEA List know-how in the development of **plastic scintillators based** Radiation Portal Monitors (RPM)
- Know-how and experience in the synthesis of **organic scintillators for neutron/gamma discrimination**

Example of plastic scintillator based RPM



Example of a 1.70 wt% ^6Li loaded lab. synthesized Plastic Scintillator : 15 mm height, 30 mm diam.



III. Proof-of-concept setup

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G. Sannie et al., "Scintilla European project, the successful research results," 2015 4th International Conference on Advancements in Nuclear Instrumentation Measurement Methods and their Applications (ANIMMA), 2015, pp. 1-4

C. Frangville, M. Hamel, et. al, "Large solubility of lithium carboxylates reaching high rates of ^6Li incorporation in polystyrene based plastic scintillators for fast/thermal neutron and gamma ray detection", Mater. Chem. Front., 2019, 3, 1626





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➤ Lithium-doped NaI™:



- **high Z** molecules (Na,I,Tl) and density close to $\sim 3,7 \text{ g.cm}^{-3}$
- ➔ **Gamma spectrometry** possible
- ^6Li concentration up to 8-9 %
- Sensibility to **thermal neutrons** : $^6\text{Li}(n_{\text{th}},\alpha)t$

➤ Plastic Scintillators :



- **Low Z** molecules (C,H) and density close to $\sim 1 \text{ g.cm}^{-3}$
- ➔ **Neutron thermalization** properties
- Fast light response $\sim 100 \text{ ns}$
- Neutron and gamma rays sensibility

Approach : Plastic scintillators signal **confirms** the presence of a **NR threat** (Go/No go), **identification** by means of a **gamma ray spectrometry**, **enhance** the **neutron sensitivity** in the NaI™ if N threat presence



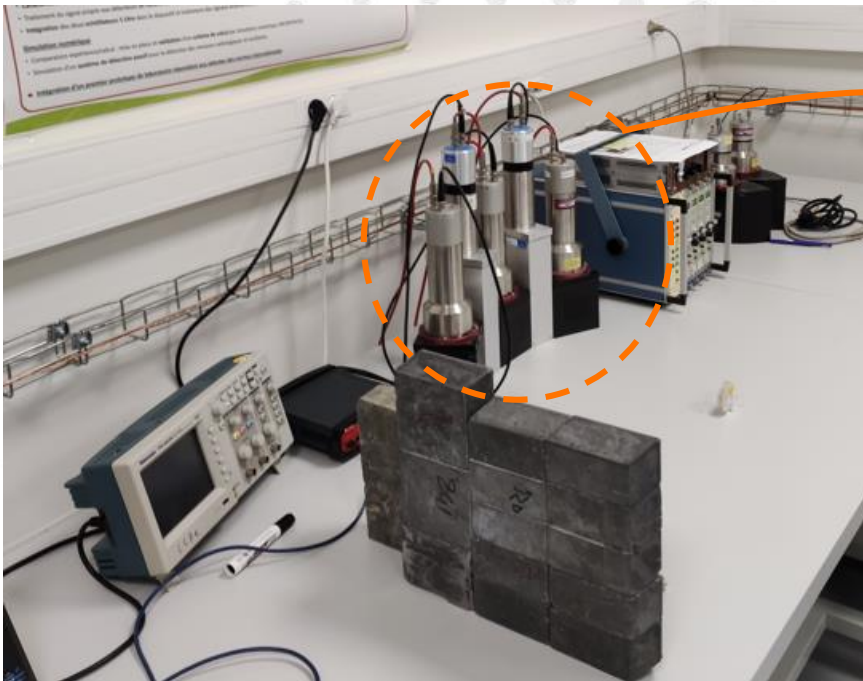
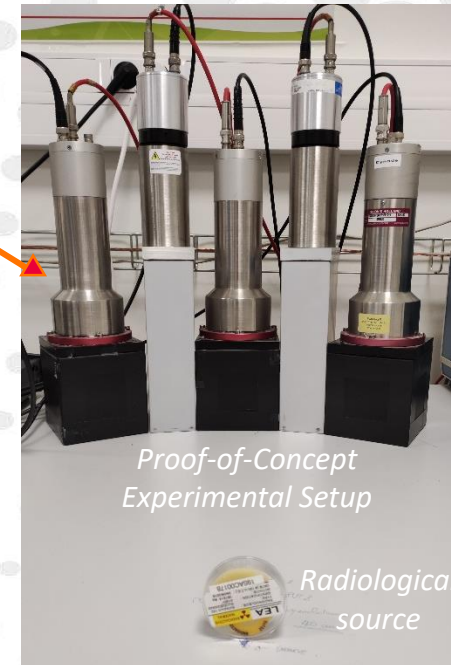
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Zoomed-in
Front View

- Two NaI™ inorganic scintillators of $5 \times 10 \times 20 \text{ cm}^3$ dimensions and three EJ-200® plastic scintillators of 10 cm^3
- Irradiations sources for the simulation of a radiological environment : ^{152}Eu , ^{60}Co , ^{137}Cs , ^{68}Ge , ^{252}Cf
- CAEN DT5730SB 8 channels digitizer with a **sampling @500Mhz** | Canberra and ORTEC High Voltage modules





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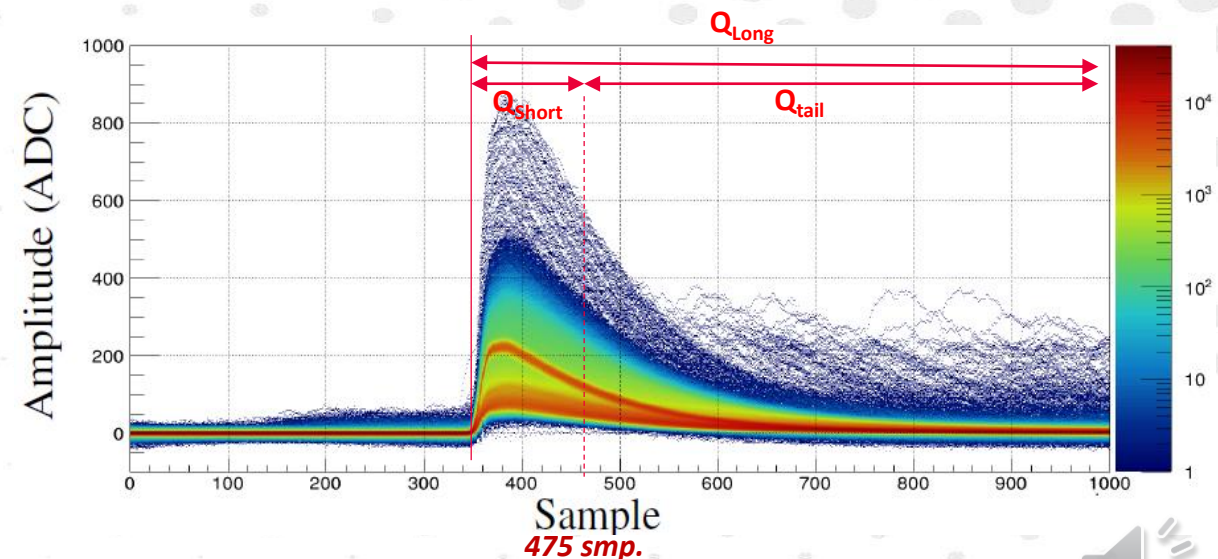
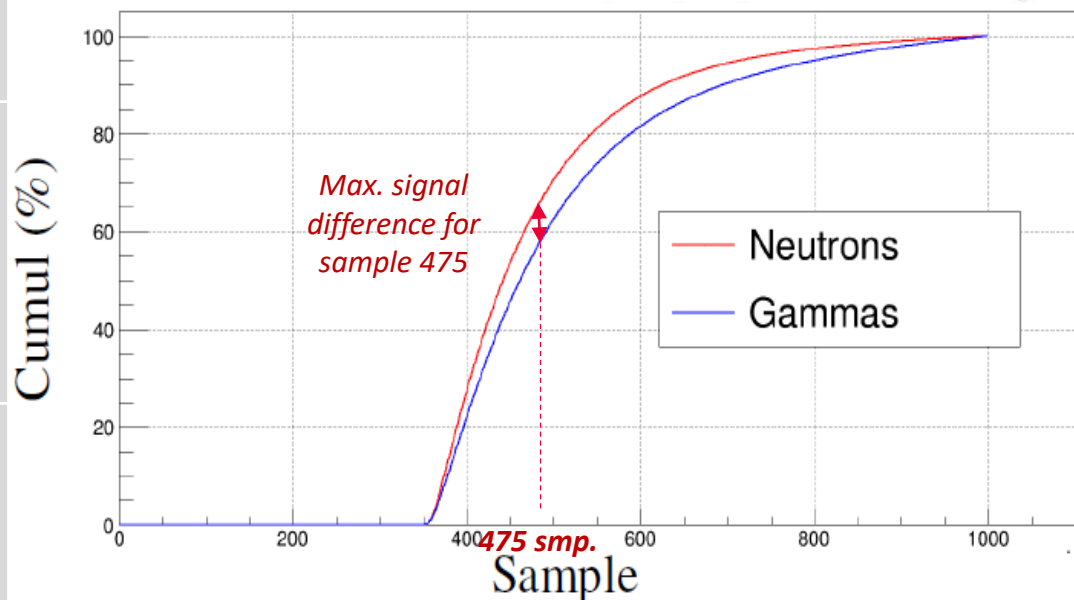
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➤ Main parameters :

- HV for the NaITM at **+1kV** | HV rounding **-1.8 kV** for the EJ-200[®] scintillators
- Signal acquisition : **Channels 0 & 6** for both NaITM | **Channels 2,3,4** for the EJ-200[®] scintillators
- **Optimisation** of $Q_{\text{Long}}/Q_{\text{Short}}$ integration parameters for **n/ γ discrimination** for Ch. 0 & 6



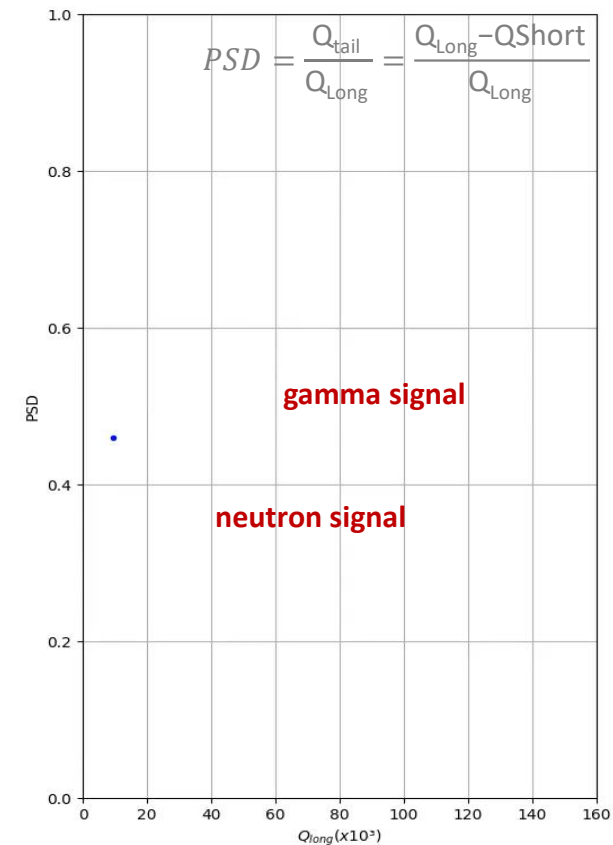
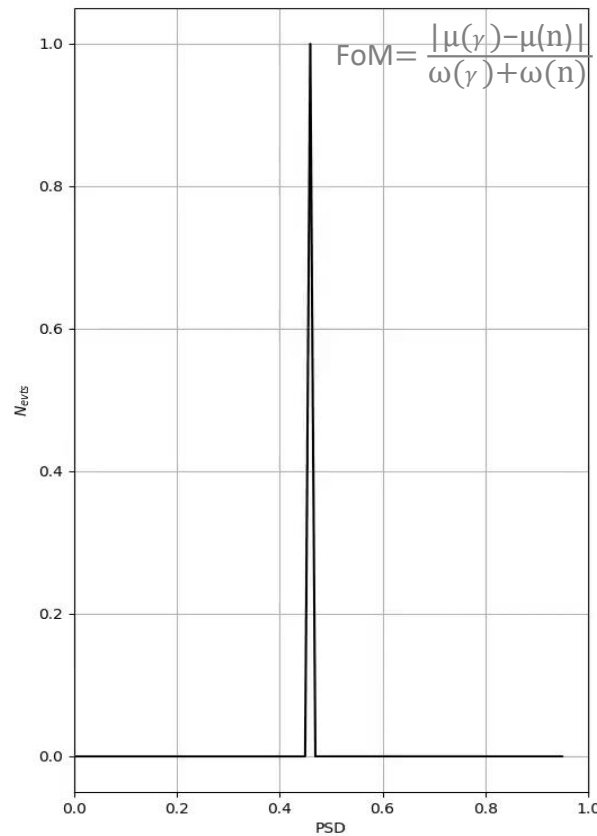
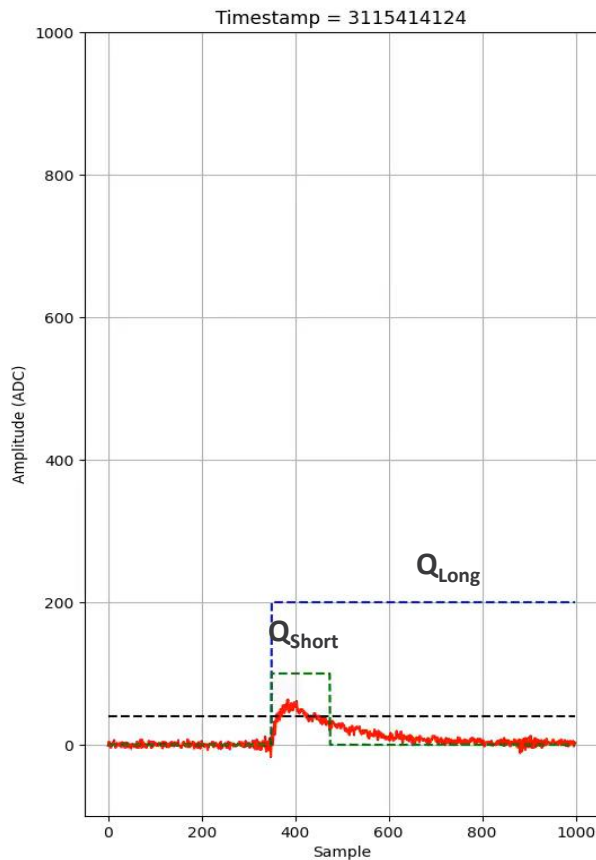
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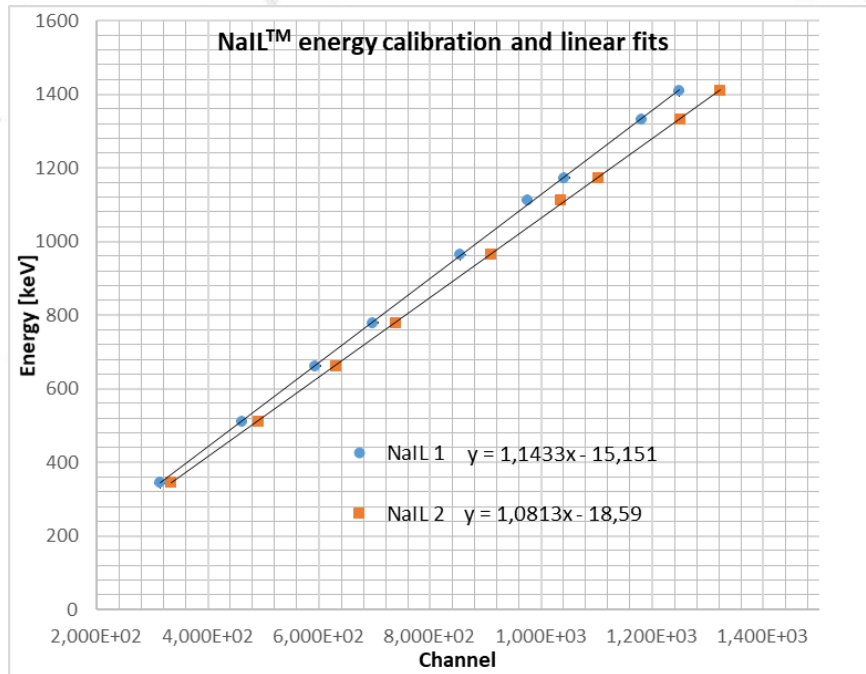
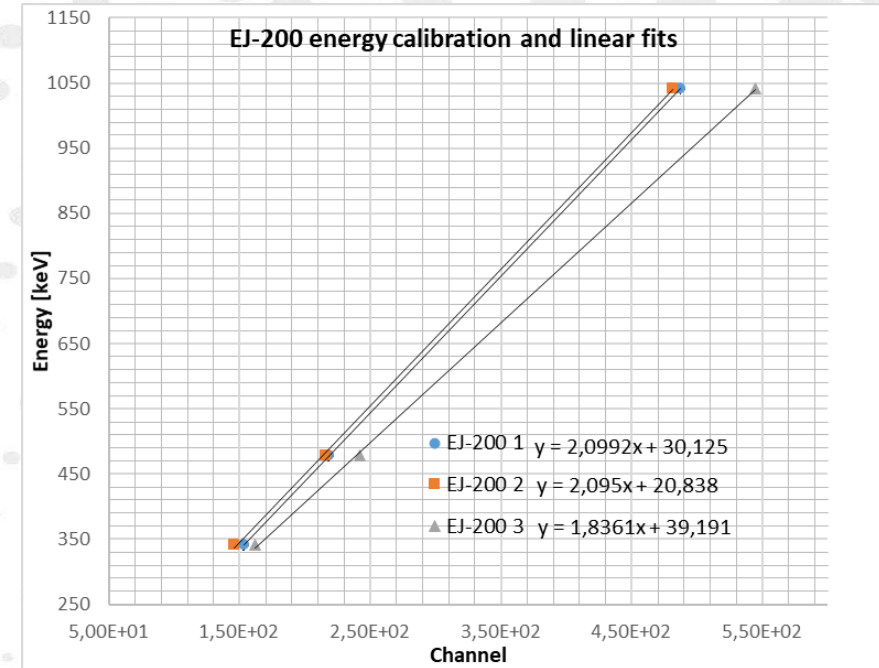
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- **Figure of Merit of 4.37** (> 3.89 from *Lai Caifeng, et.al (2020)*) and accurate neutron/gamma discrimination capabilities by means of Pulse Shape Discrimination



➤ NaITM :➤ EJ-200[®] :

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- Classical approach by means of Gaussian fits in the RoI
- Energy resolution at 661.7 keV :

NaITM n°1: 9.26 %NaITM n°2: 9.14 %

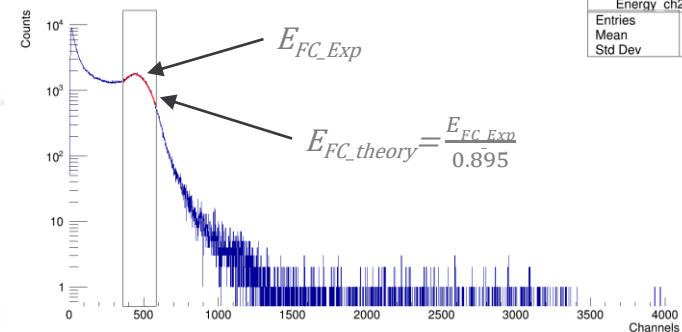
Slightly higher than Classical NaI:Tl

γ identification possible

- Siciliano et. al (2008) approach :

$$E_{FC_Theory} = \frac{E_{\gamma}}{\left(1 + \frac{2 \cdot E_{\gamma}}{m_e \cdot c^2}\right)}$$

Energy ch2 can	
Entries	1157008
Mean	232.8
Std Dev	193.7



V. Conclusion & Prospects

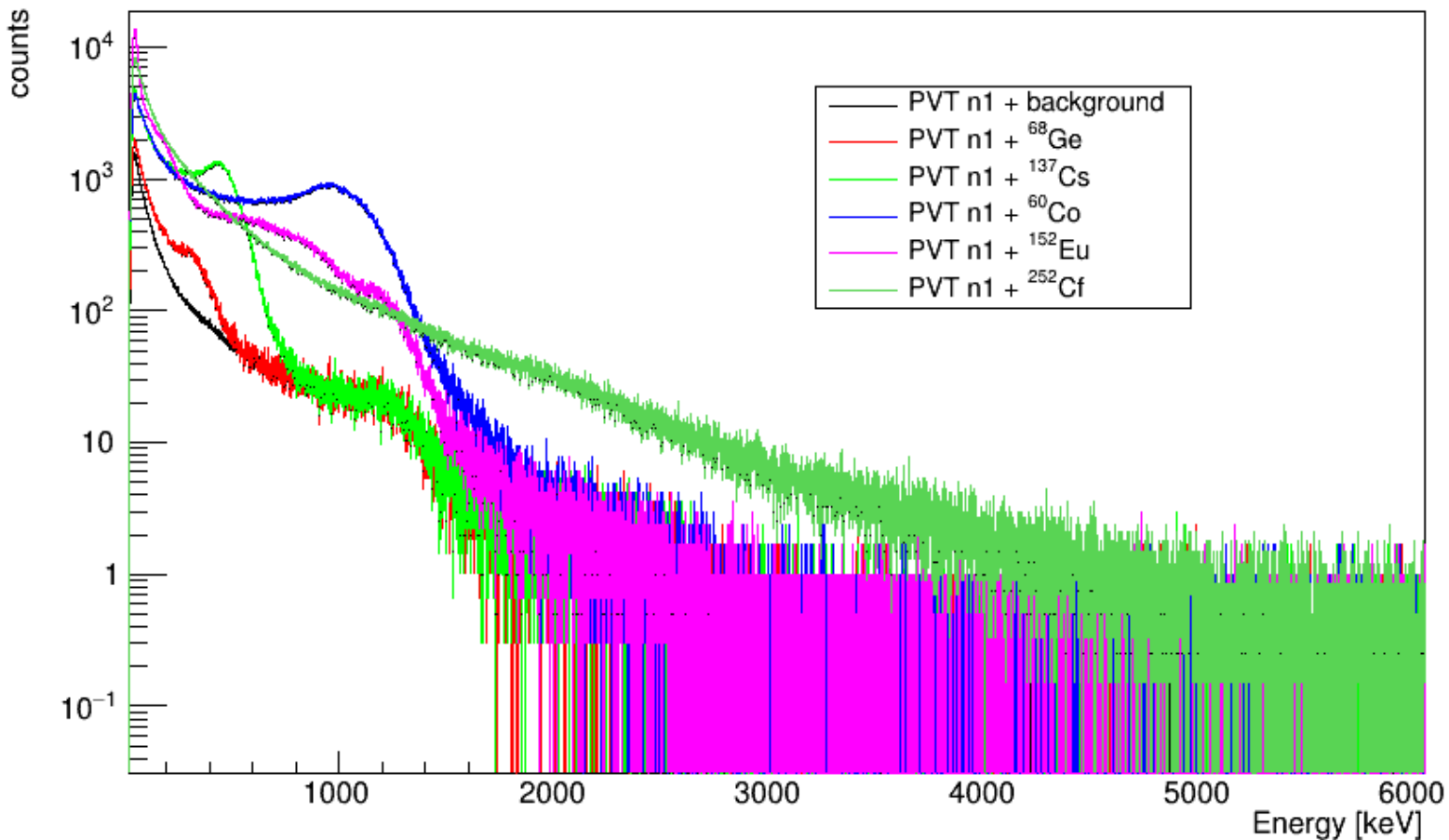


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- Sources activities on the day of measurements :

$$A_{\text{Eu-152}} : 325.03 \text{ kBq}$$

$$A_{\text{Co-60}} : 289.83 \text{ kBq}$$

$$A_{\text{Cs-137}} : 396.39 \text{ kBq}$$

$$A_{\text{Cf-252}} : 168.52 \text{ kBq}$$

- Acquisition time fixed to 5 min
- Simulant placed at a 40 cm distance from the setup

- *Go/no go information thanks to the over-signal from the energy deposit on the PVT with respect to the passive background measurement*



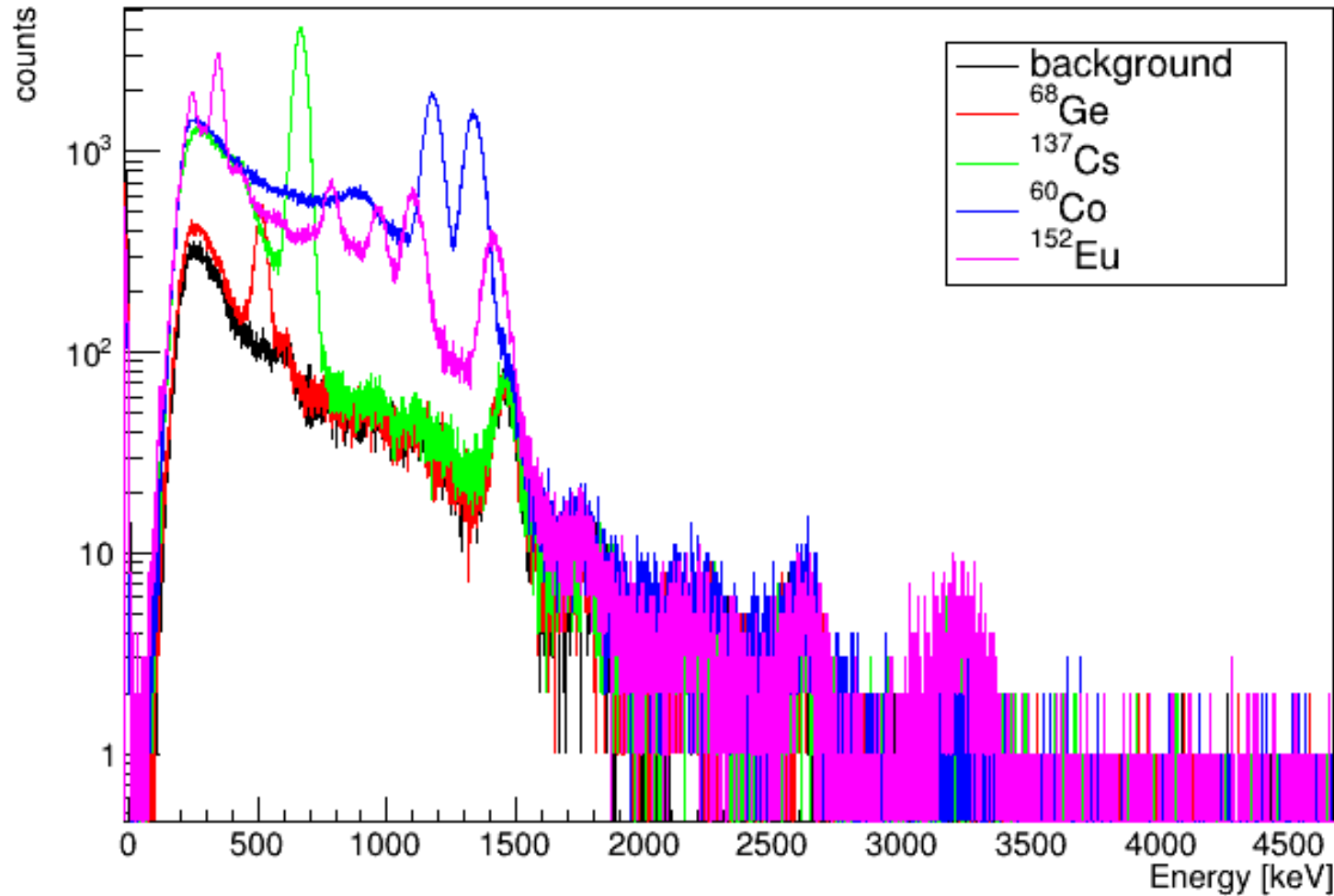
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- *Discrimination of the main radiological threats possible and identification by means of gamma-ray spectrometry*



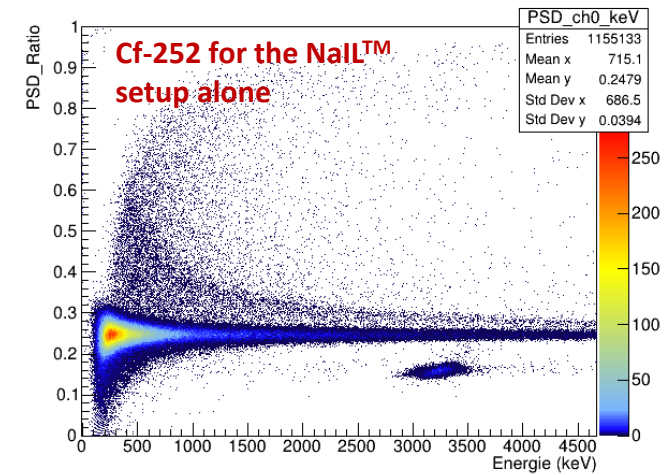
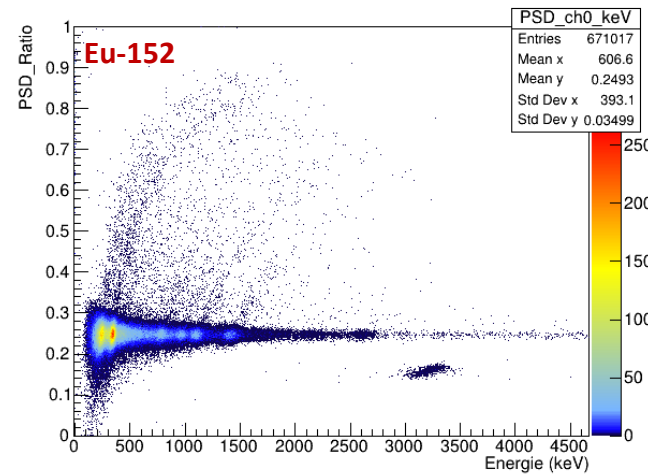
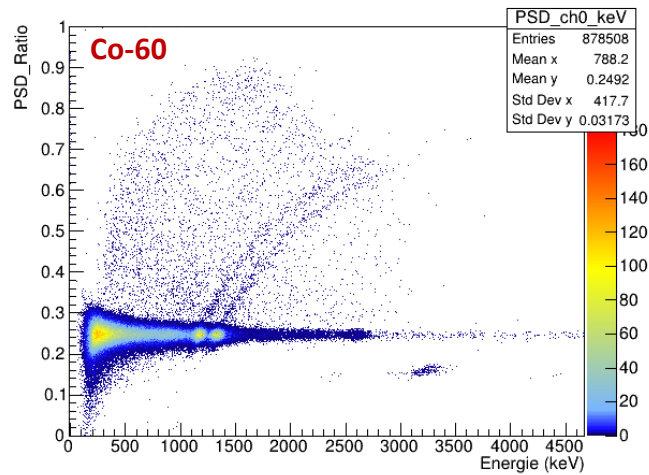
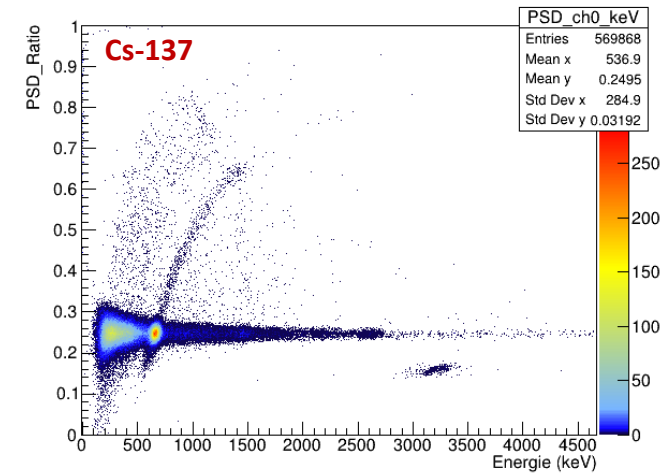
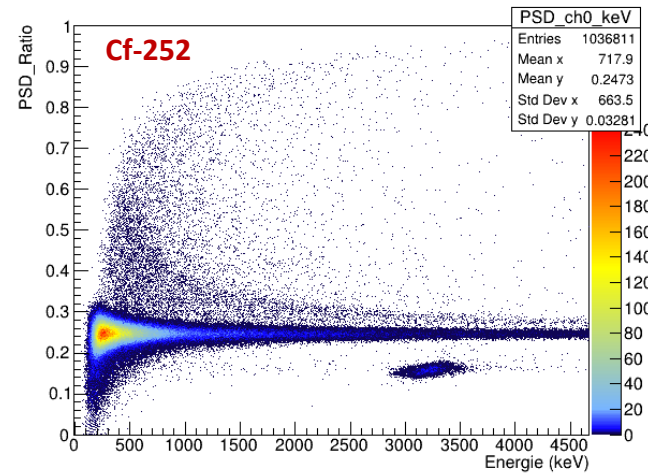
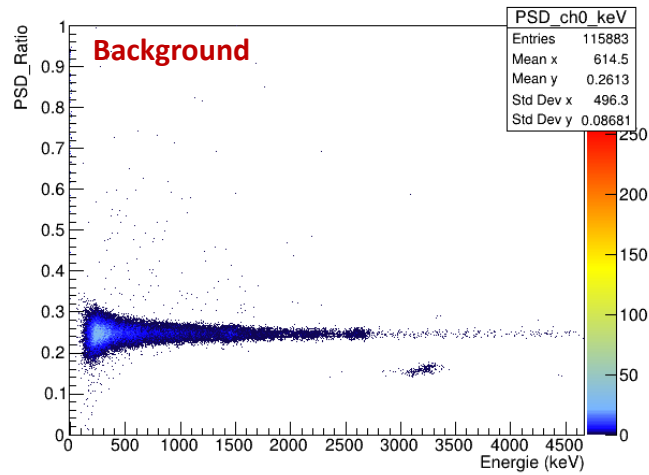
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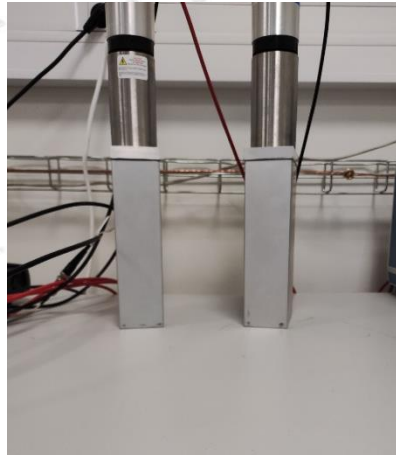
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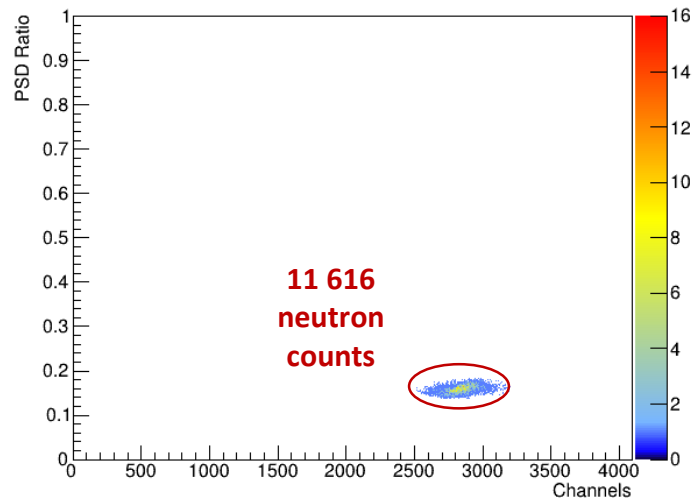
- *Discrimination between radiological and nuclear threats thanks to the FoM of 4.37*



➤ **NaIL™ :**➤ **NaIL™ /EJ-200:**

Cf-252 source of $18\,705\text{ n.s}^{-1}$
neutron emission

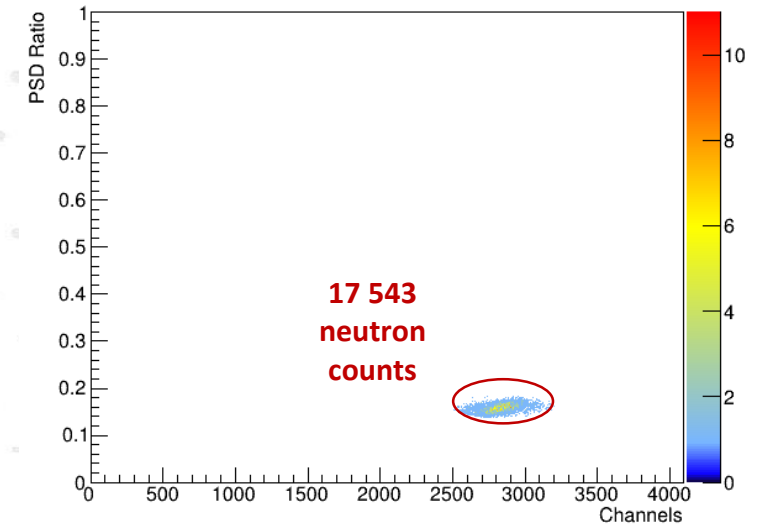
Acquisition time fixed to 5 min



Extraction of the useful neutron
signal in the Ellipsoid *RoI*

$$\frac{(x-x_0)^2}{(x_{\max}-x_0)^2} + \frac{(y-y_0)^2}{(y_{\max}-y_0)^2} = 1$$

$$\left. \begin{aligned} x_0 &= 2850 \\ x_{\max} &= 3200 \\ y_0 &= 0.16 \\ y_{\max} &= 0.185 \end{aligned} \right\}$$



- Signal increase of **51.02 %** in the **neutron RoI** validating the use of combined NaIL™ with Plastic Scintillators



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➤ **Conclusion:**

- **Optimization** of the **signal acquisition parameters** to reach a **FoM of 4.37**

- Proof-of-concept experimental **setup characterization** and **radiological/nuclear simulants detection and discrimination** by means of gamma ray-spectrometry and *Pulse Shape Discrimination (PSD)*

- **Validation** of the use of **combined NaITM** with **plastic scintillators** to increase the **neutron signal** from **51.02 %**

➤ **Prospects:**

- Study of **additional signal information** by the use of coupled detectors

- **Performance assessment** in terms of **signal sensitivity** with respect to international regulations

- **Optimization** and **sizing** of a combined NaITM/Plastic Scintillator based **RPM** by means of **Monte Carlo modeling**



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Thank you for your attention

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