UNIVERSITÀ DEGLI STUDI DI PADOVA

Neutron detectors for homeland security*

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Helium Replacement in Italy

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NEUTRON DETECTORS FOR H. S. GENERAL REQUIREMENTS

IAEA document: **Technical and Functional Specifications for Border Monitoring Equipment.**

4.3.3. Radiation interference

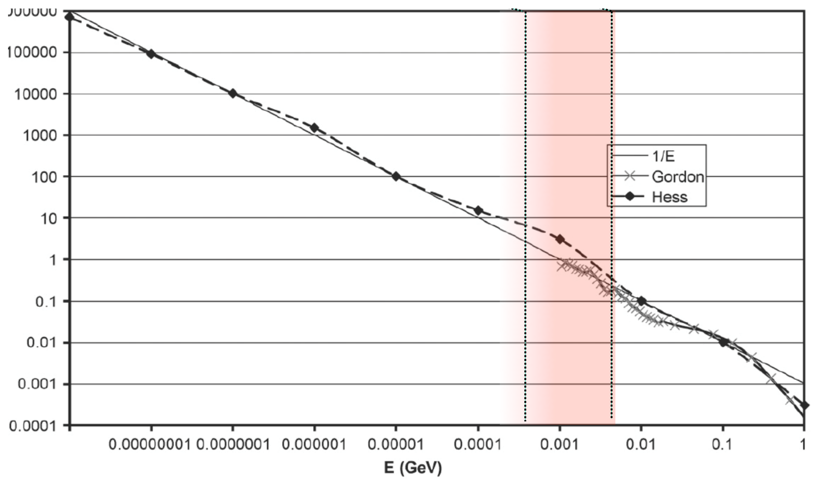
- Neutron detection instruments shall not misinterpret gamma radiation as neutrons.
- Neutron detectors must be insensitive to gamma radiation, as illicit trafficking incidents involving detection of neutrons require a higher level of response.
- Instruments featuring neutron detection shall not trigger a neutron alarm when exposed to a ^{60}Co gamma ray source producing a dose equivalent rate averaged over the face of the neutron detector of 100 μSv/h^{-1}.
- The instrument shall continue to respond to neutrons as specified in the presence of gamma radiation.

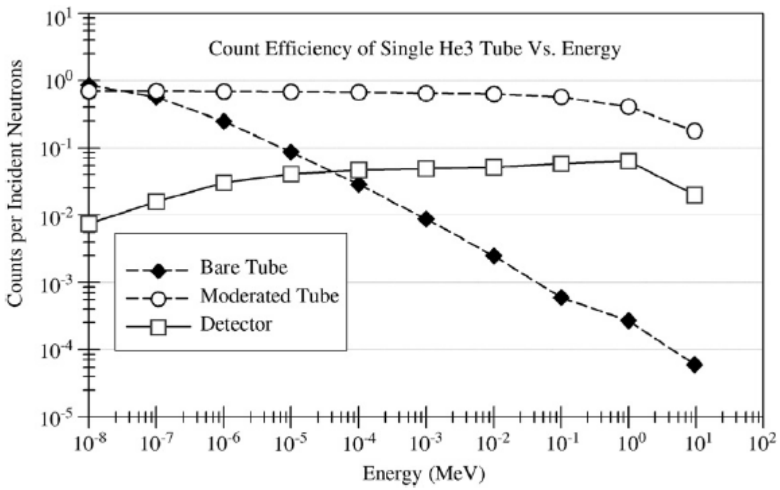
The detection of neutrons is an essential task in Homeland Security applications since it is a specific signature for the presence of SNM.

STANDARD NEUTRON DETECTORS: ^{3}He proportional counters featuring a very large gamma rejection factor (about 10^{-6}).

FAST NEUTRON DETECTION IN HOMELAND SECURITY SYSTEMS

Origin of the terrestrial neutron background: spallation reaction induced by the cosmic ray particles (typically 20 counts/s per m² of detector,1/E dependence).





1. ^{3}He-poly assembly: good efficiency from thermal to 10 MeV
2. Fast neutron detector (0.1-10 MeV) has efficiency centered in the SNM fast neutron spectrum.
3. Terrestrial background is minimized thus enhancing the detection capability of weak fast neutron signal.

LIQUID SCINTILLATOR

Liquid scintillators were not considered as a valid alternative for ^{3}He detector not only for their chemical hazard (toxicity and flammability) but also for their intrinsically good gamma efficiency.

With the development of new materials intrinsically more secure in the field of liquid scintillators, **it is interesting to reconsider the possibility offered by these detectors**

Detector investigated

EJ-301: is a Eljen Technology product equivalent to the well known NE213

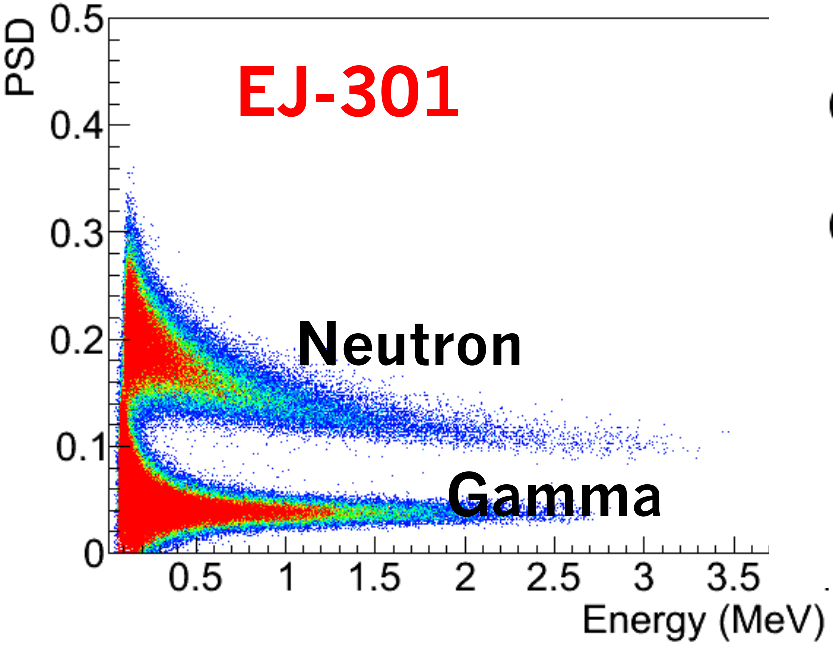
EJ-309: is a novel detector with interesting characteristics:

- High flash point (144 °C)
- Low vapor pressure
- Low chemical toxicity

PULSE SHAPE DISCRIMINATION 2-D PLOT

On-Line Pulse Shape Discrimination by using the Digital Pulse Processing with the CAEN VT1720 250 MHz digitizer.

PSD = (Long Gate Integration – Short Gate Integration) / Long Gate Integration



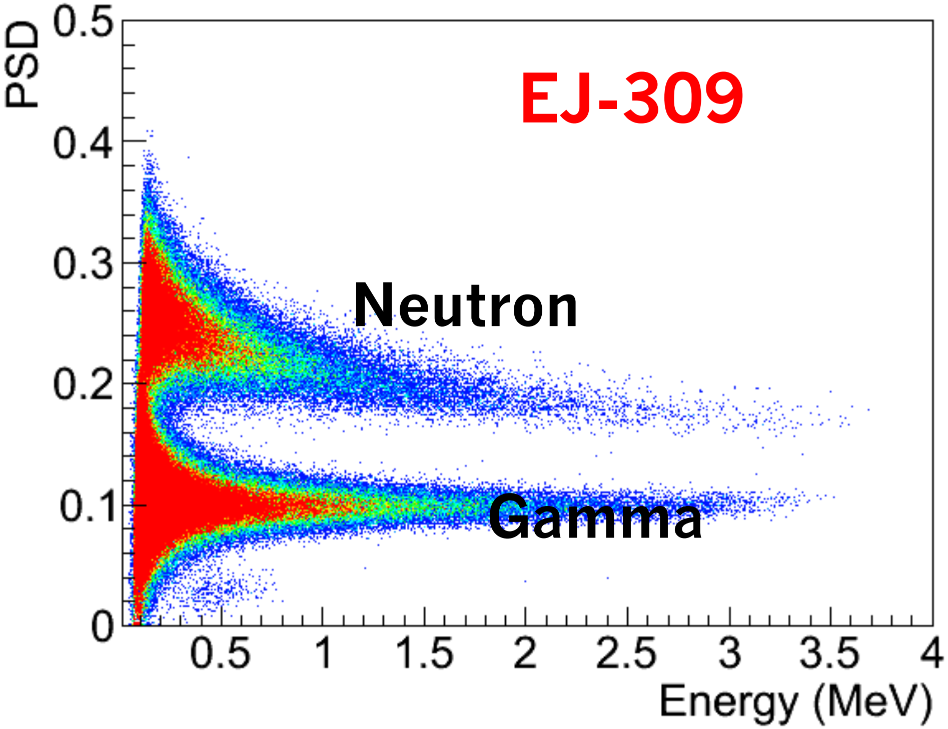
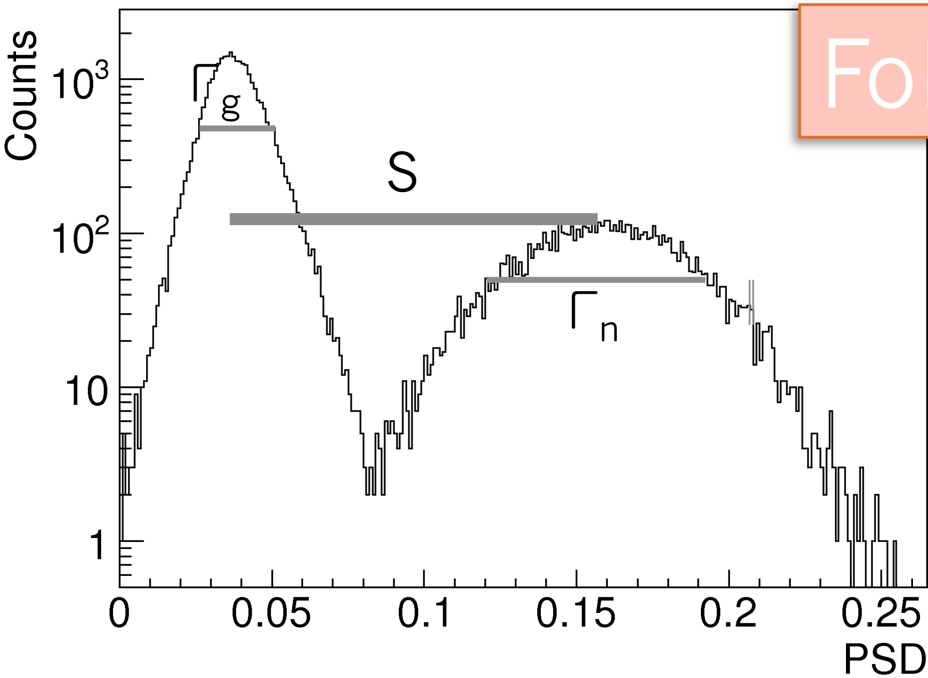


FIGURE OF MERIT (FoM)

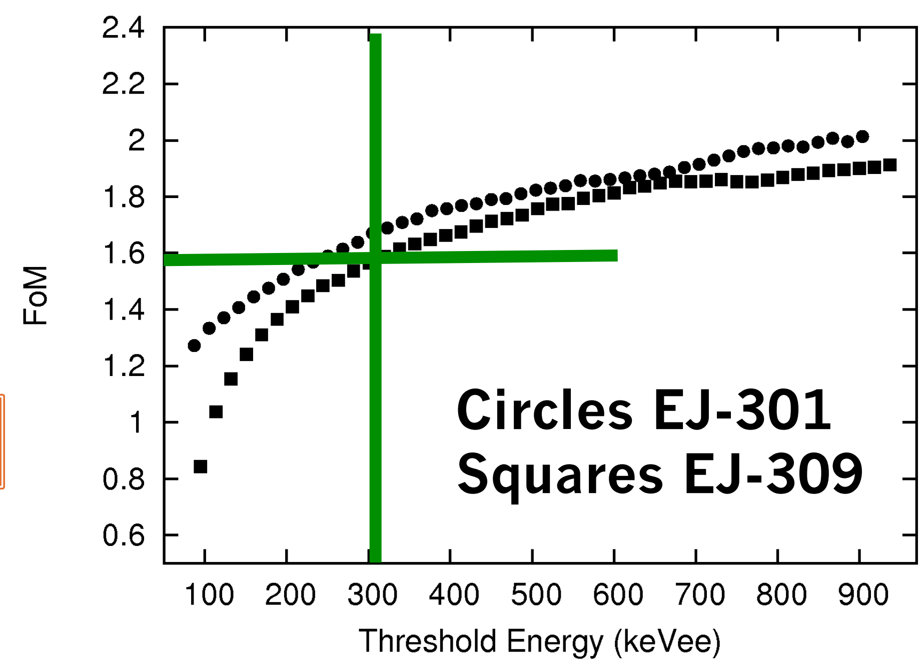


$$FoM = S / (\Gamma_n + \Gamma_g)$$

EJ 309 @ 300 keVee – FOM 1.6

NE-213 @ 300 keVee [1]

FOM 1.6 - 1.8



[1] N.V. Kornilov, I. Fabry, S. Oberstedt,F.-J. Hambsch, Nucl. Instrum. And Methods A599 (2009) 226–233.

REJECTION CAPABILITY

Homeland Security applications

Requirement: detect the presence of neutrons inside a high gamma-ray background up to 100 μSv/h

What it means?

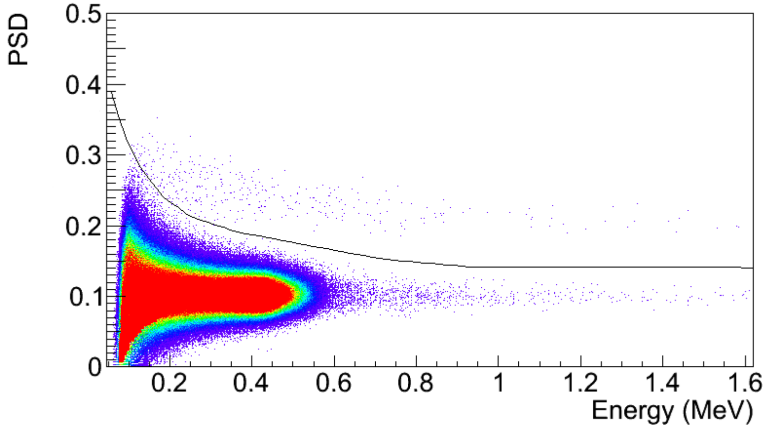
IEC62244 standard [2] provides the definition of "detect":
Hand-held systems must generate a neutron alarm within 10 second sampling time when a unmoderated ^{252}Cf source (equivalent to $2x10^4$ neutron/s) is placed at 25 cm from the detector

Requirements		In Laboratory
100 μSv/h at face detector	→	**590 MBq ^{137}Cs @ 67 cm**
$2x10^4$ neutron/s @ 25 cm	→	**$7x10^3$ neutron/s @ 15 cm**

[2] M. Voytchev, P. Chiaro, R. Radev, Radiation Measurements 44 (2009) pp. 1–5

HIGH RATE TESTS

^{137}Cs@100 µSv/h + ^{252}Cf@15 cm



EJ-309 neutron counts in different configuration. The neutron selection was made with a polynomial function reported on the left panel [3].

Irradiation (T = 10s)	With Filter
Background	0.1
^{252}Cf @15 cm	57
^{137}Cs@100 µSv/h	1
^{137}Cs@100 µSv/h + ^{252}Cf@15 cm	53

[3] Stevanato et al, Nucl. Instrum. And Methods A690 (2012) 96-101.

HIGH RATE TESTS

Following the prescription of [4] it was defined the probability of detection at PD = 95% (threshold alarms N>1) and verify it with a confidence level of CL = 95%.

For this values, the minimum number of consecutive success are a = 59

Irradiation on EJ-309	Trials	Alarms
Background	188	2.1%
^{252}Cf @15 cm	59	100%
^{137}Cs@100 μSv/h	62	4.8%
^{137}Cs@100 μSv/h + ^{252}Cf@15 cm	63	100%

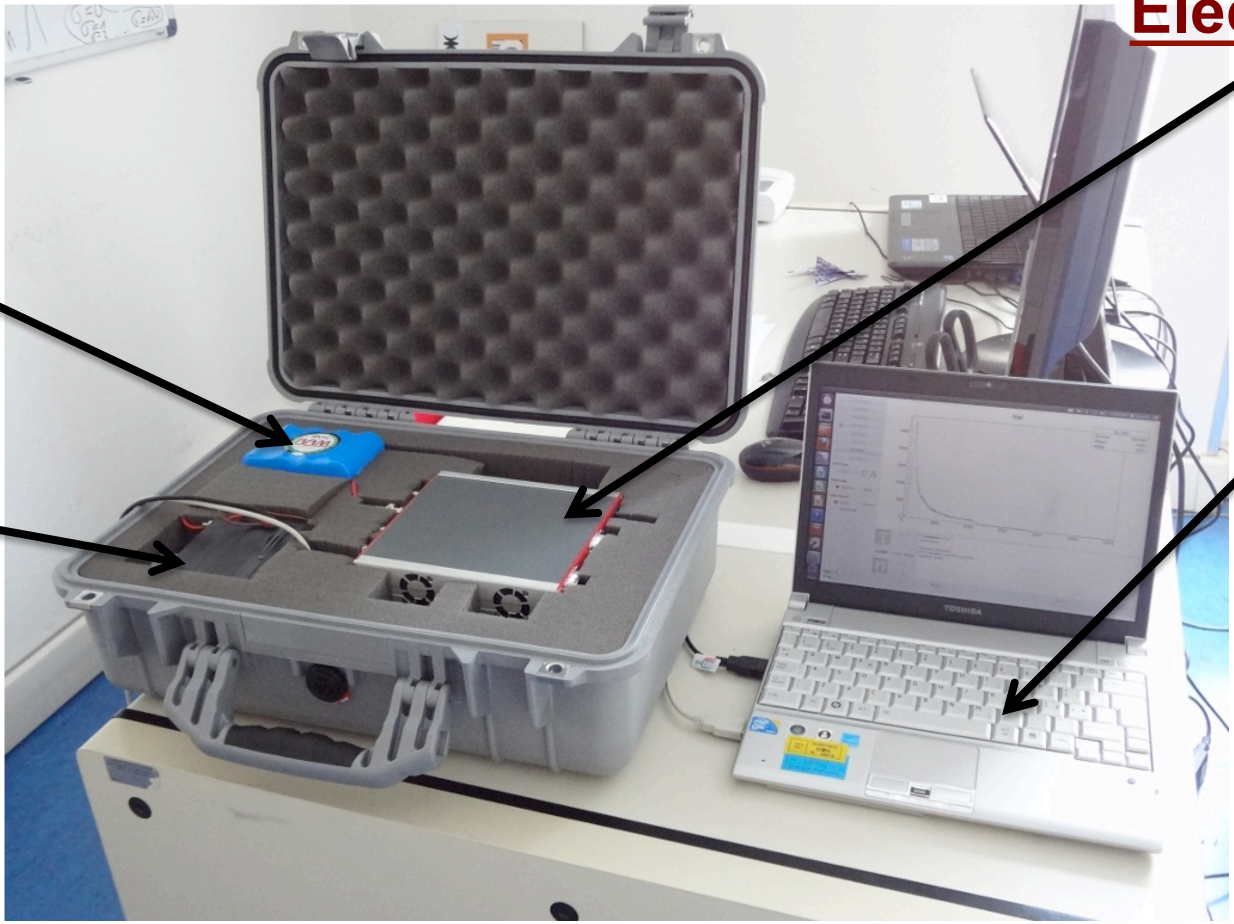
PD=95%
CL=95%
@ 100 μSv/h

The low threshold on neutron alarms (N>1) would allow us to detect extremely low intensity neutron sources in standard natural gamma-ray background. On the other hand a slight increase of the threshold value would result in a substantial reduction of the false alarm rate in a strong gamma-ray background.

[3] D. Gilliam et al, J. Res. Natl. Inst. Stand. Technol. 114 (2009) 195-199

APPLICATIONS
THE PLUTONIUM HUNTER 2.0

- The Plutonium Hunter 2.0 is under development within a collaboration between the CAEN SpA and the University of Padova.
- The current system is the prototype of a man portable device capable of detecting the presence of gamma rays and neutrons exceeding the natural background level and performing the identification of the gamma ray or neutron source.
- The source classification is performed by a specific methodology patented by the University of Padova and classified by the Italian Government that has been transferred to CAEN.

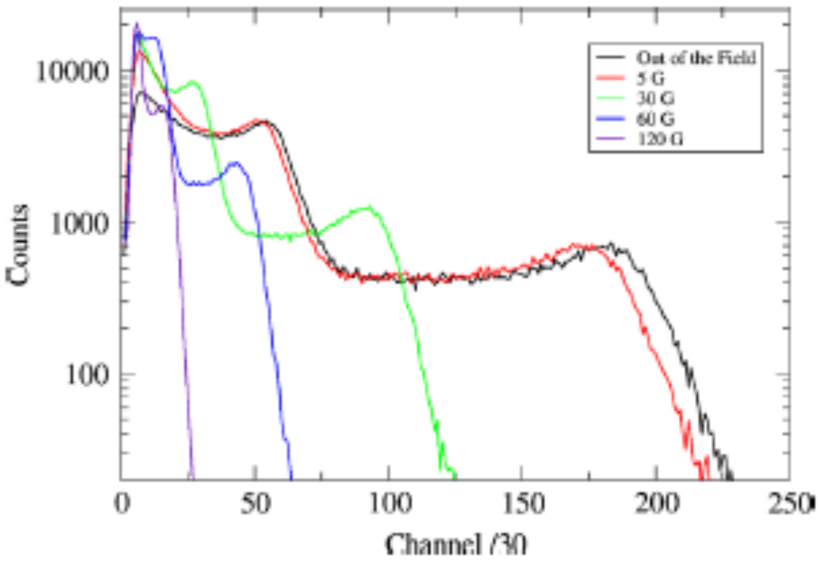

Electronics
Battery
Detector
PC
TOSHIBA

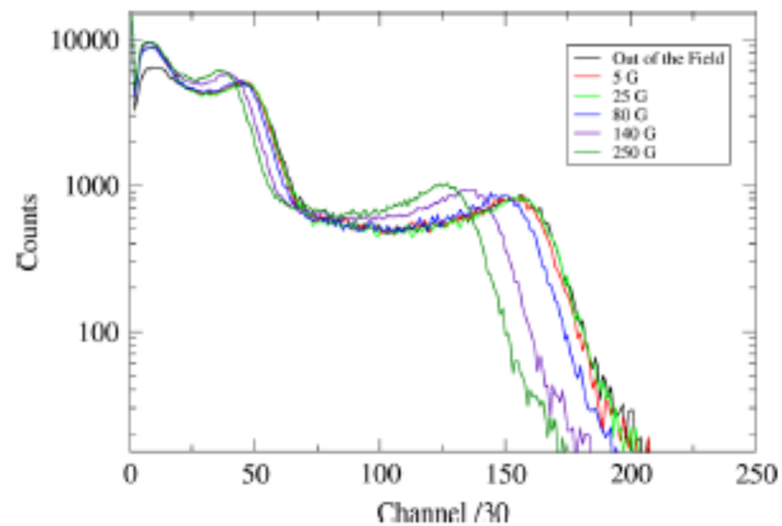
COMPONENTS: DETECTOR

A 2″ x 2″ cell of the liquid scintillator EJ-309 is used. Such detector provide sufficient efficiency for gamma ray and neutron detection to be compliant with the requirements of the IEC62327. The scintillation light is read by flat panel PMT. This solution provides two key advantages:

a) lower power consumption relative to normal PMT

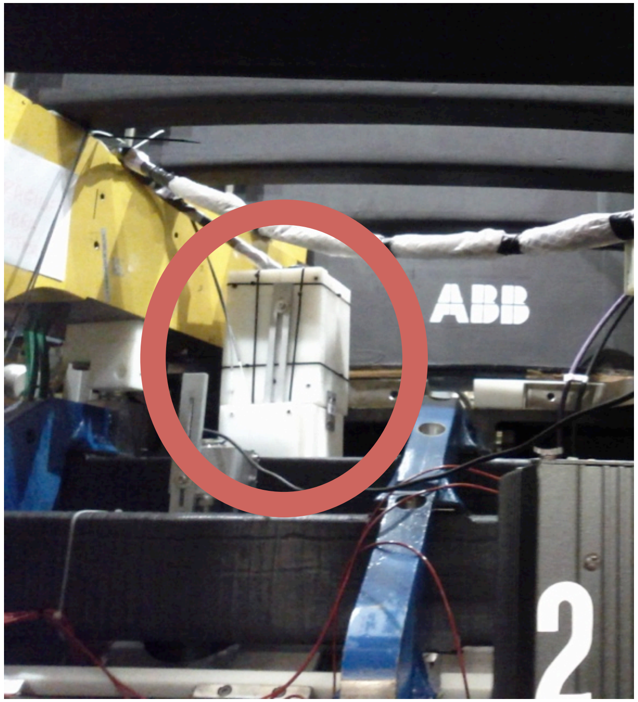
b) possibility of operating the instrument under magnetic fields. See D. Cester et al., NIM A719 (2013) 81

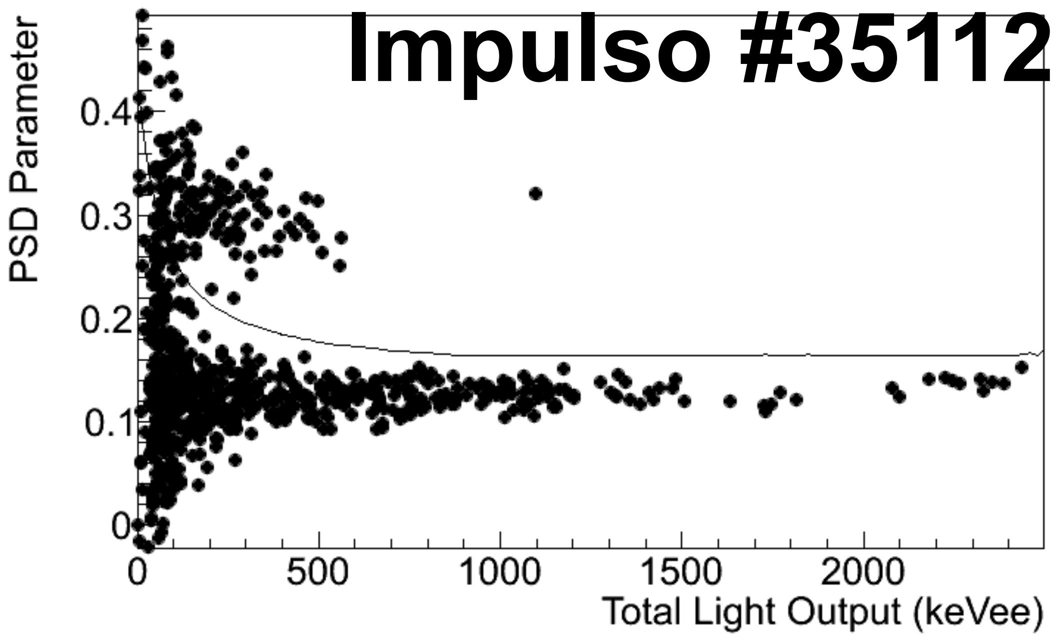




APPLICATIONS
MEASUREMENT IN HIGH MAGNETIC FIELD

Due the possibility of measurement in magnetic field, the detector is used to evaluate the neutron flux near the plasma camera in Deuterium plasma inside the fusion reactor RFX (Padova).





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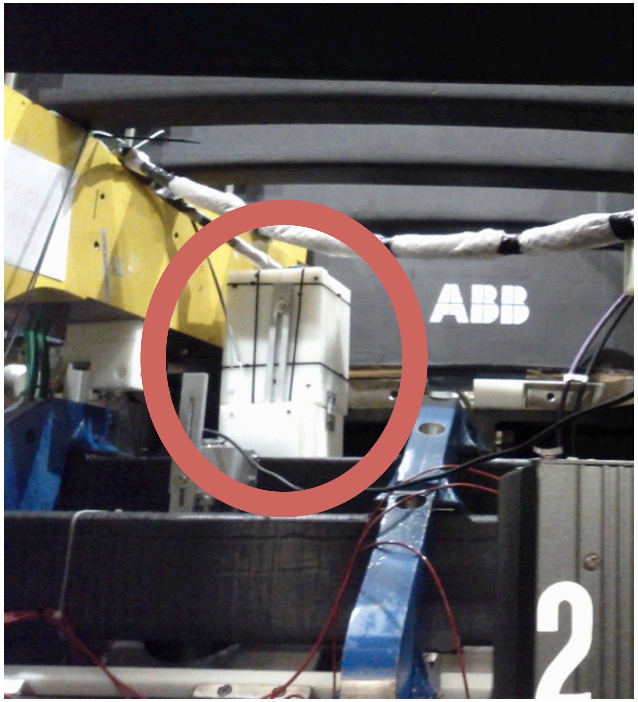
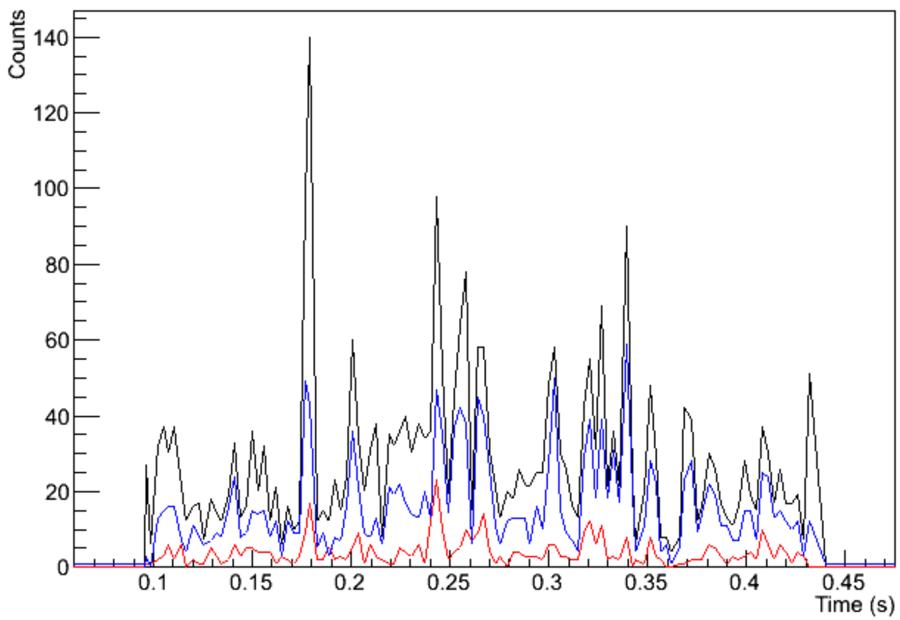
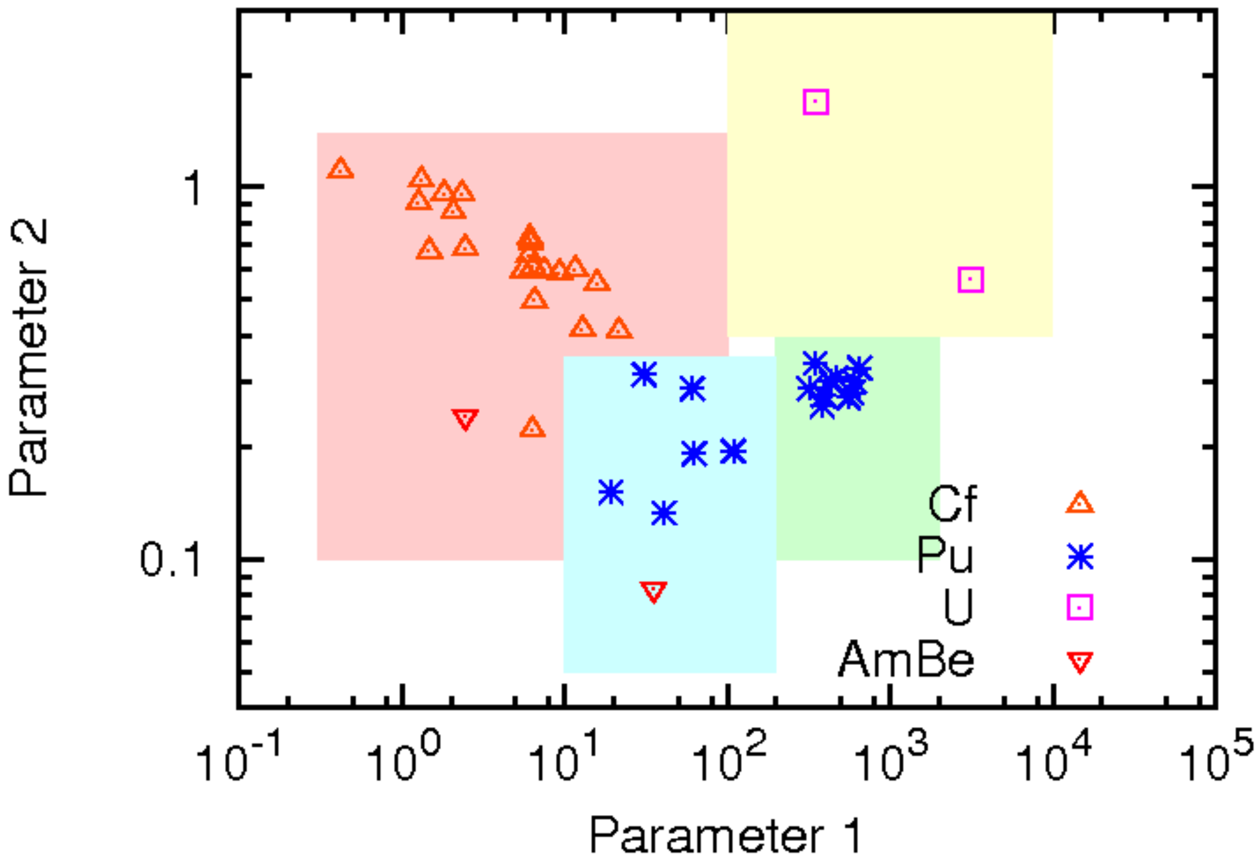




MODE OPERATION IDENTIFICATION PROCESS

1. Continuous acquisition to generate alarms (every 3s for gamma-ray and 10s for neutron)
2. After an alarm the identification task takes 1 minute followed by the analysis of the results yielding indication of:
   a. Californium source
   b. Am-Be source
   c. Plutonium source
   d. Uranium source
   e. Gamma ray source
3. The capability of the classification methodology is then expanded to identify the type of gamma ray emitting isotope by analyzing the gamma-ray spectrum.

Example Of Neutron Sources Classification Methodology



Experimental points for Cf and Pu samples correspond to:
Naked Sources
Poly shielded Sources
Lead Shielded Sources

AmBe is identified by an additional parameter

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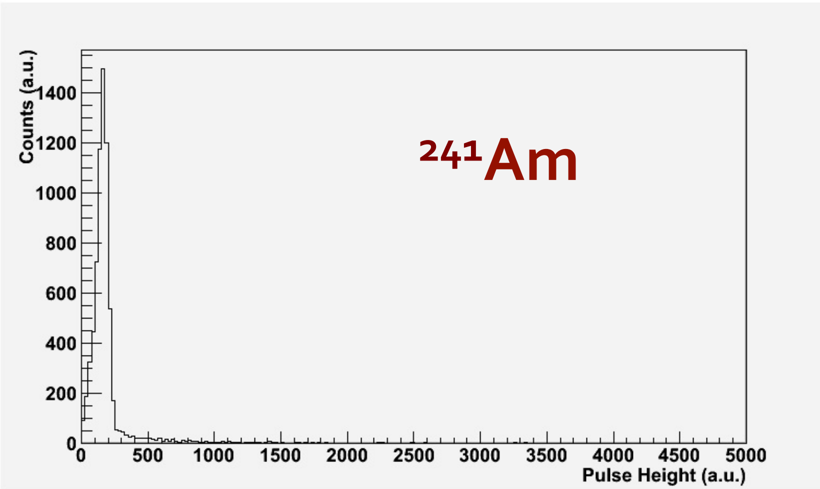
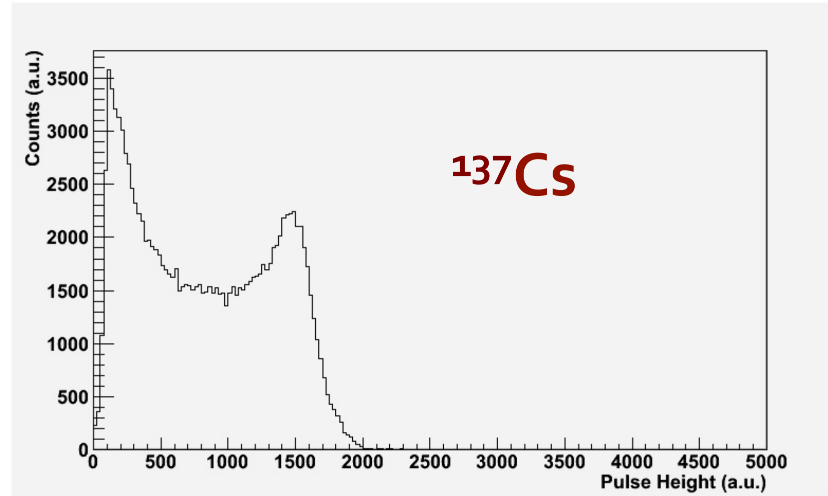
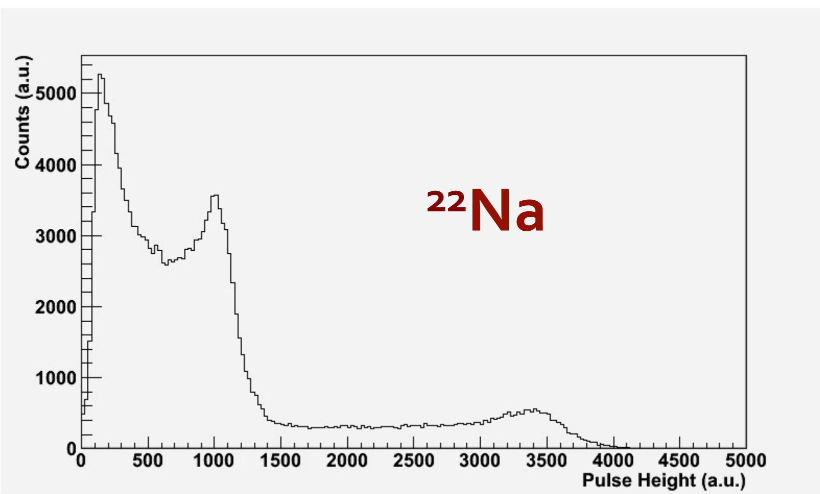
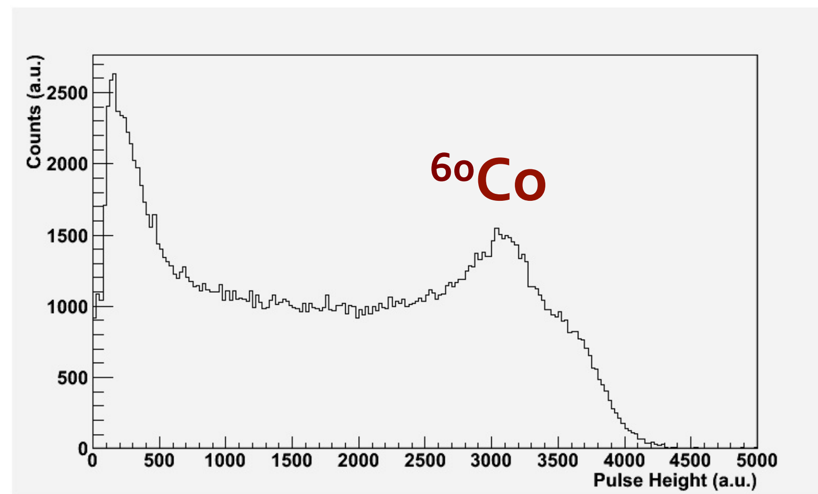
ANALYSIS OF THE GAMMA-RAY SPECTRA: RESPONSE FUNCTION LIBRARY









The library includes currently only ^{241}Am, ^{137}Cs, ^{22}Na and ^{60}Co high statistics spectra

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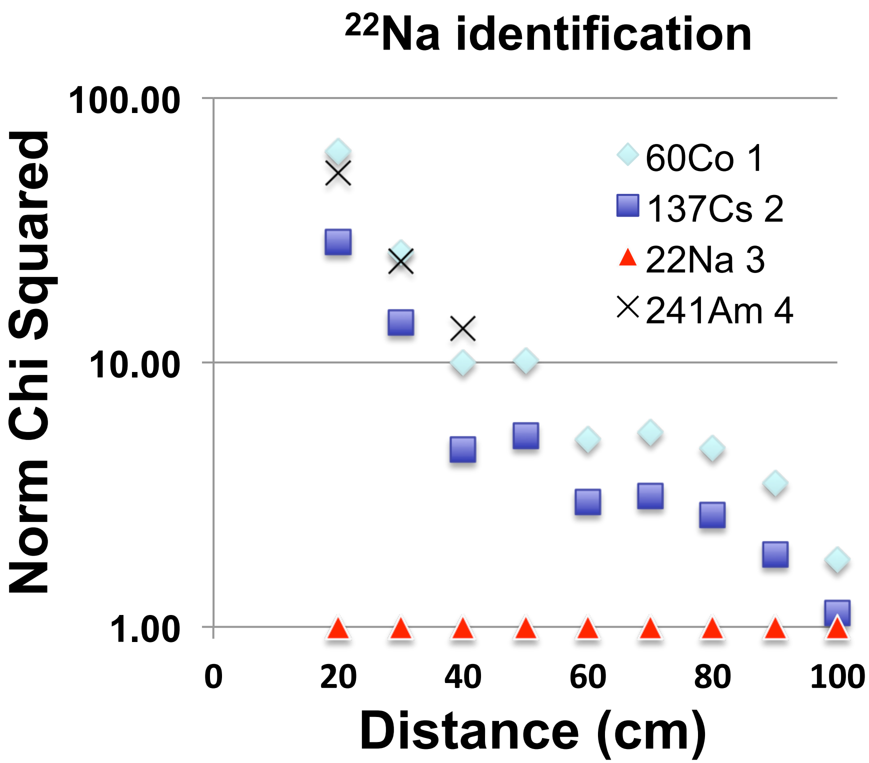
ANALYSIS OF THE GAMMA-RAY SPECTRA SOURCE IDENTIFICATION



The gamma ray spectra acquired during the "IDENTIFICATION TASK" (1 min) are compared with the response function library and the normalized χ^2 is evaluated. This allows identifying the source. Note that the HS response function depends weakly on the source-detector position.

However in case of shielded sources the backscattering peak might significantly affect the spectral shape.

Results: the ^{137}Cs and ^{60}Co sources are correctly identified up to a distance of 100 cm from the detector (corresponding to a dose rate of 29 and 85 nSv/h). For the ^{22}Na source (see figure) the maximum distance for identification is 90 cm (55 nSv/h).

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CONCLUSIONS

1. The Homeland Security applications of the novel type of liquid scintillators EJ-309 with fast-digitizer read out is presented.
2. A 2" x 2" cell coupled to a flat panel PMT provides sufficient gamma-ray and neutron efficiency. It can be operated in magnetic field allowing the possibility of detecting neutrons in strong gamma-ray background (up to 300 µS/h).
3. The PLUTONIM HUNTER 2.0 is a portable spectrometric system featuring the possibility of detecting the presence of radioactive source raising neutron and/or gamma alarms.
4. The IDENTIFICATION task provides the possibility of classifying the neutron source using a novel approach the discriminates U, Pu, Cf and AmBe sources. This classification works also in case of shielded (poly of lead) Cf or Pu sources.
5. The analysis of the gamma ray spectra provides the identification of the gamma emitting Isotope by using a library of response functions (currently under development).
6. The developed technologies are also used in plasma diagnostics.
7. Future developments are foreseen within the University of Padova-CAEN collaboration agreement.