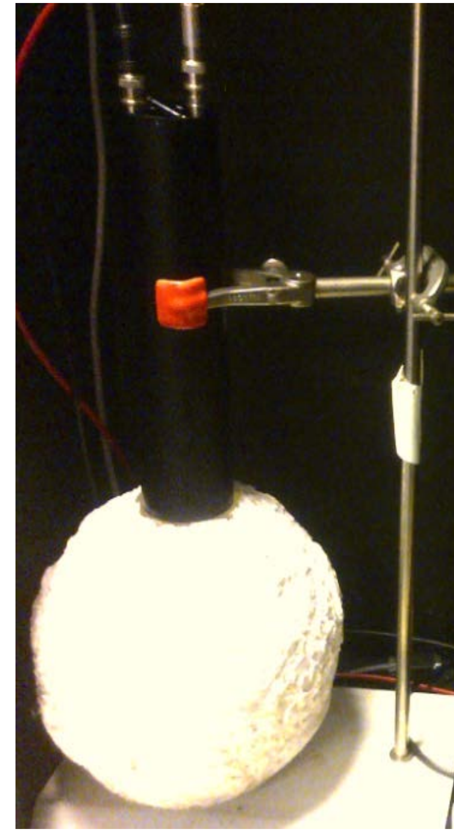

NEUTRON DETECTION USING A GADOLINIUM COVERED CDZNTE DETECTOR

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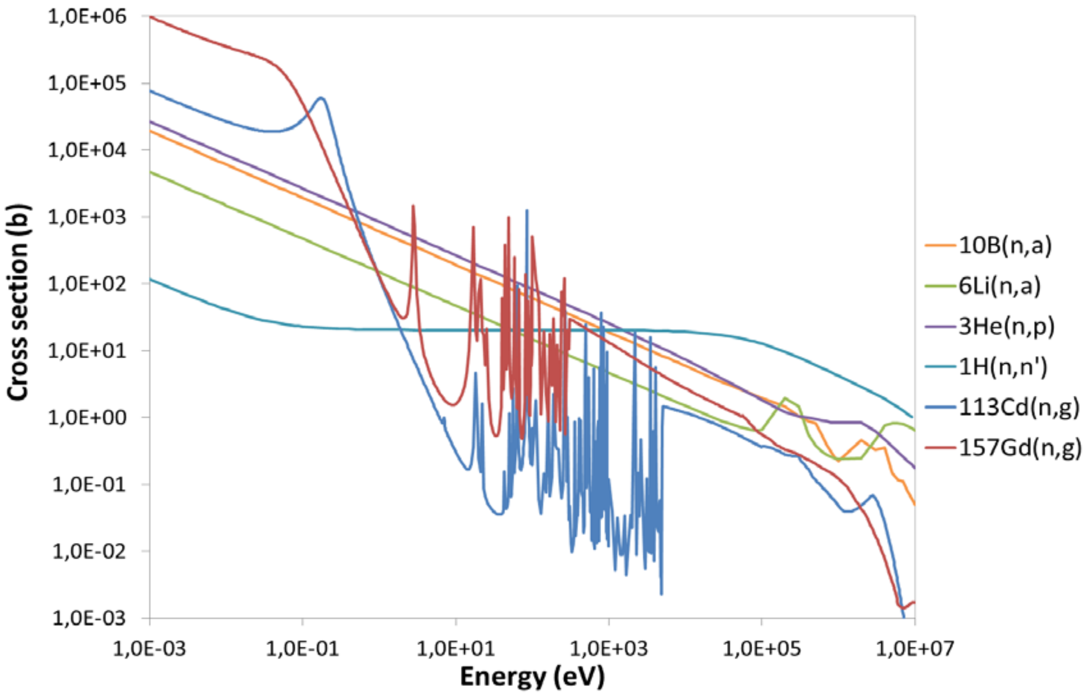
INTRODUCTION

- **CONTEXT:**
- **The need: miniaturized neutron detector.**
- **State of the art: Silicon technology implementing Boron, lithium, and PE convertors.**
- **Limitation: Low neutron efficiency / high detection limits.**

- **RESEARCH PATH:**
- **The use of Gadolinium convertor (higher cross section than ^{10}B, ^{6}Li and ^{3}He).**
- **The use of CdZnTe diode to detect the radiative signal from Gd captures.**
- **The use of a reliable compensation techniques.**

THE CHALLENGE WITH GADOLINIUM

- **ADVANTAGES**
- **The highest neutron cross-section (50000 barns)**
- **The availability and cost efficiency of the material**
- **The high energy released by the reaction (8 MeV)**



THE CHALLENGE WITH GADOLINIUM

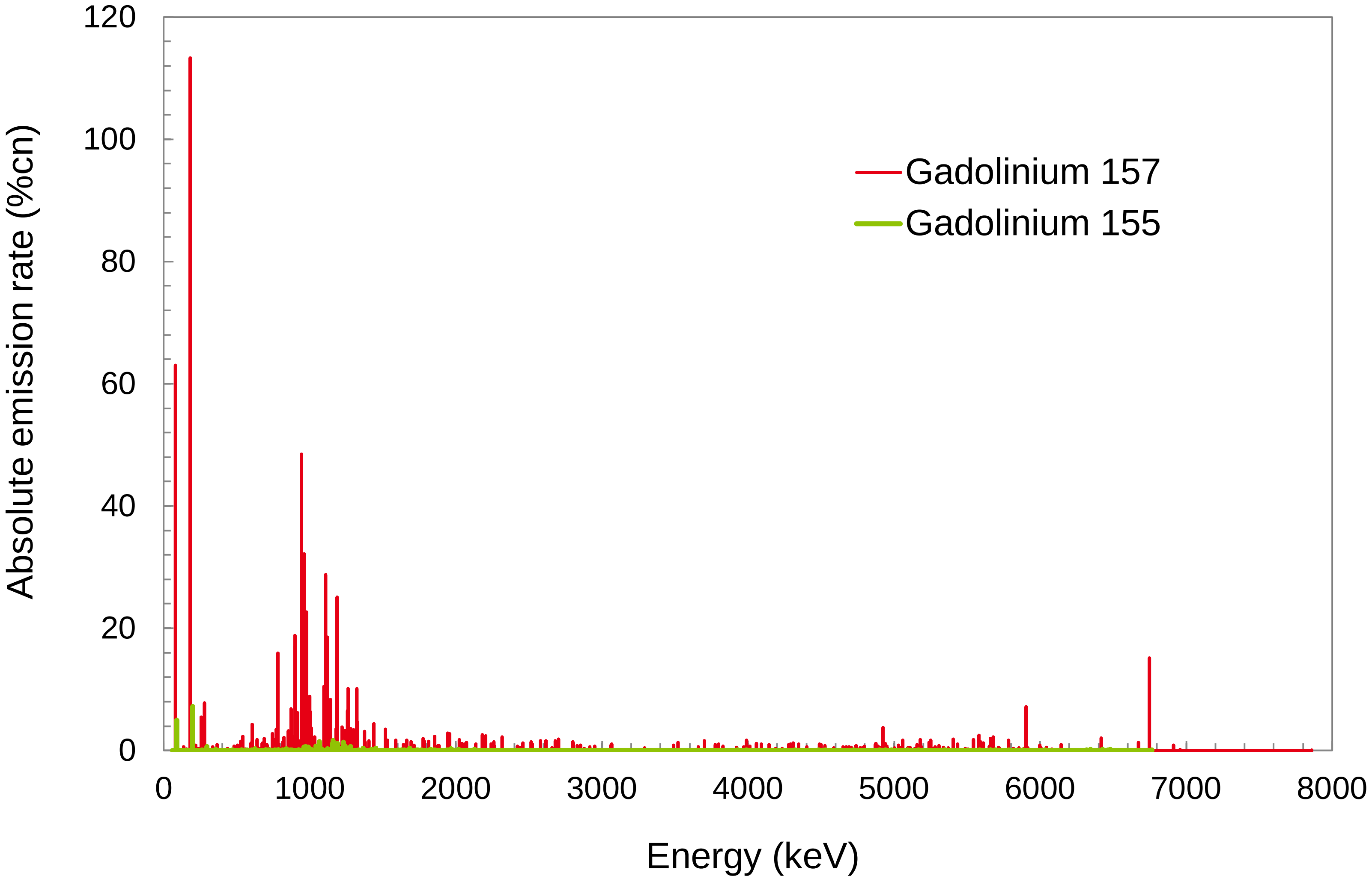
- **DRAW-BACKS**
- **The mainly radiative forms of the signature**
- **The escape of the signal of interest**
- **No discrimination with background gamma rays**

$$ {}^{113}_{48}\mathrm{Cd} + {}^{1}_{0}\mathrm{n} \rightarrow {}^{114}_{48}\mathrm{Cd}^{*} \rightarrow {}^{114}_{48}\mathrm{Cd} + \gamma + RX + CIe^{-} + Ae^{-} (1) $$

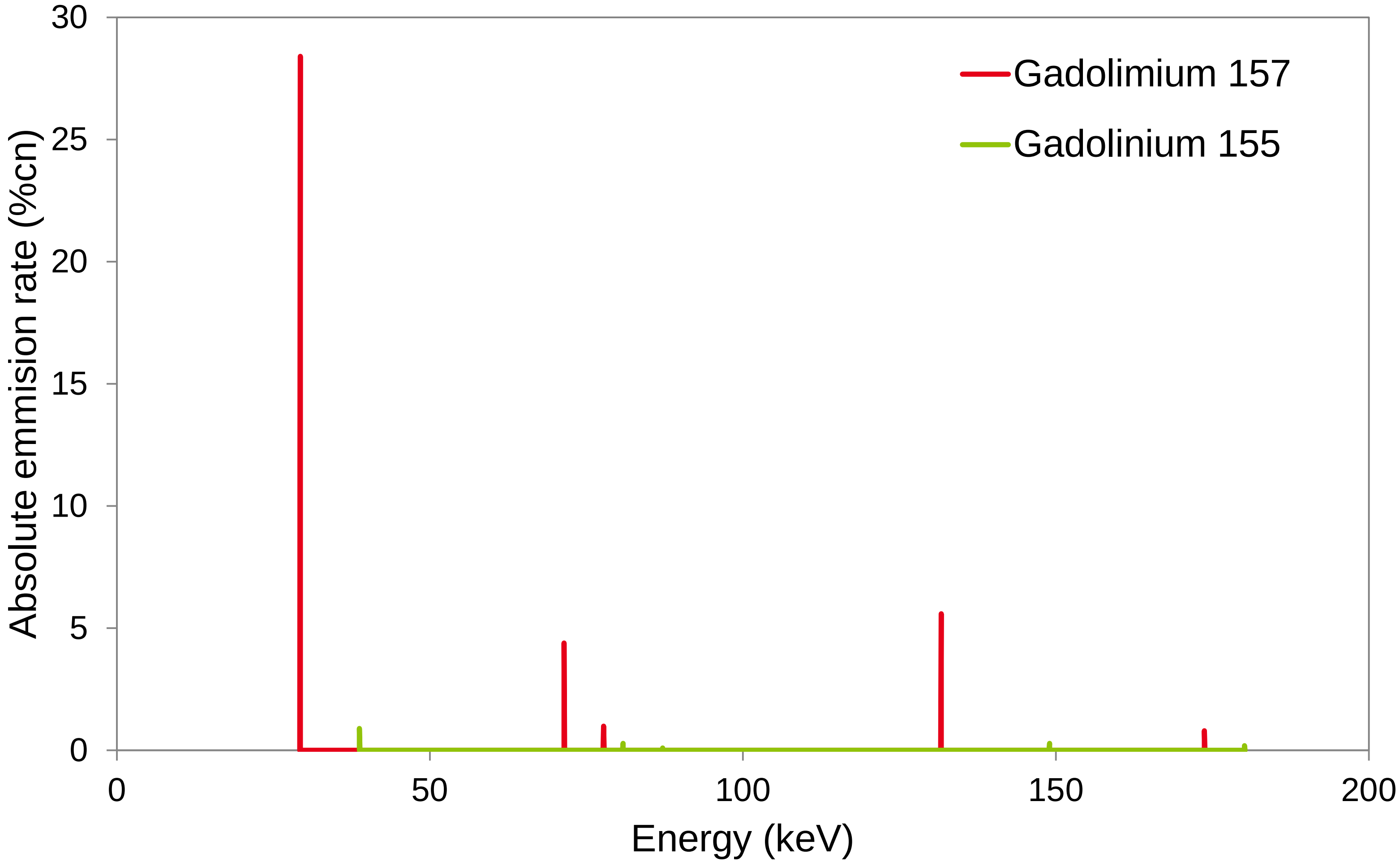
$$ {}^{155}_{64}\mathrm{Gd} + {}^{1}_{0}\mathrm{n} \rightarrow {}^{156}_{64}\mathrm{Gd}^{*} \rightarrow {}^{156}_{64}\mathrm{Gd} + \gamma + RX + CIe^{-} + Ae^{-} (2) $$

$$ {}^{157}_{64}\mathrm{Gd} + {}^{1}_{0}\mathrm{n} \rightarrow {}^{158}_{64}\mathrm{Gd}^{*} \rightarrow {}^{158}_{64}\mathrm{Gd} + \gamma + RX + CIe^{-} + Ae^{-} (3) $$

THE SIGNATURE (PROMPT GAMMA RAYS)



THE SIGNATURE (INTERNAL CONVERSION ELECTRONS)



THE SIGNATURE

- **Low energy signature [0; 200] keV (electron IC & γ rays)**
  - Measurement based on compensation techniques
  - Small size detector
  - 242 %cn

- **Medium energy signature [0.2; 3] MeV (γ rays)**
  - Measurement based on compensation techniques
  - High size detector
  - 155 %cn

- **High energy signature [3; 8] MeV (γ rays)**
  - Measurement based on pulse height discrimination techniques (PHD)
  - High size detector
  - 52 %cn

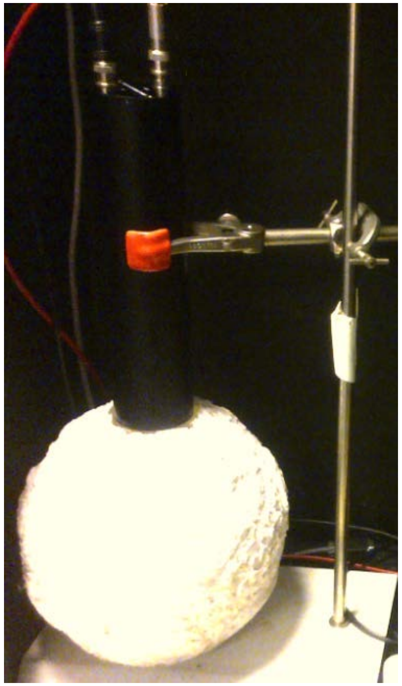
2 strategies :

- **The low energy signature [0; 200] keV : compact sensor in compensation**
- **the high energy signature [3; 8] MeV : large sensor in PHD**

THE STATE OF THE ART

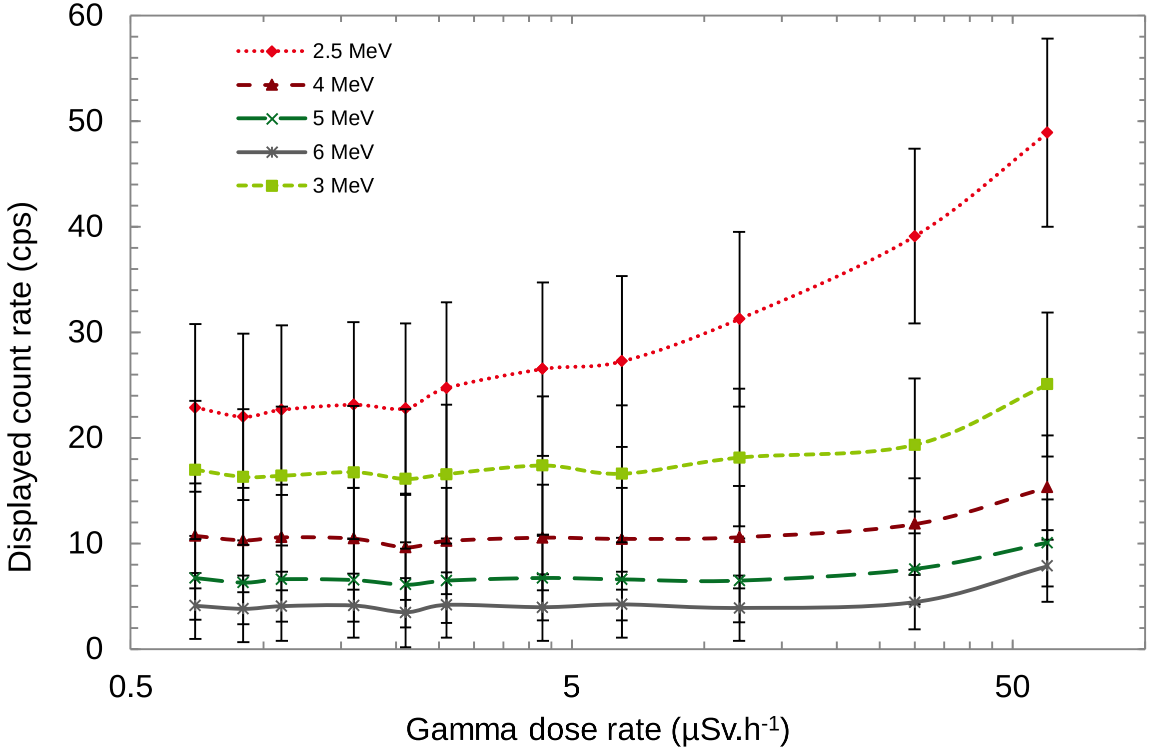
J. Dumazert et al. Nuc. Instr. Meth. A Accepted (2016)
Patent, FR 15 52110

- **The large sensor strategy (mobile or fixed systems)**



GADOPHERE®

Spherical scintillator w/ Gd core
Radius 12 cm.



Stability curves of the systems

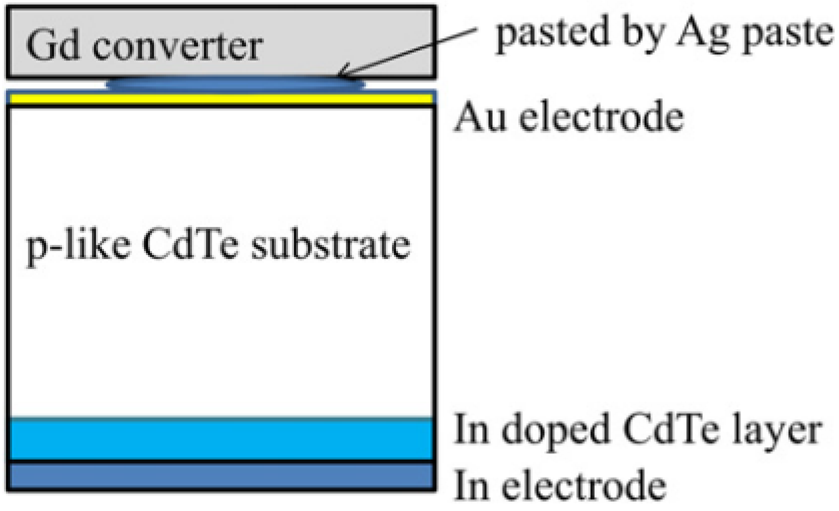
Promising system: Sensitivity close to ^{3}He Bonner sphere

THE STATE OF THE ART

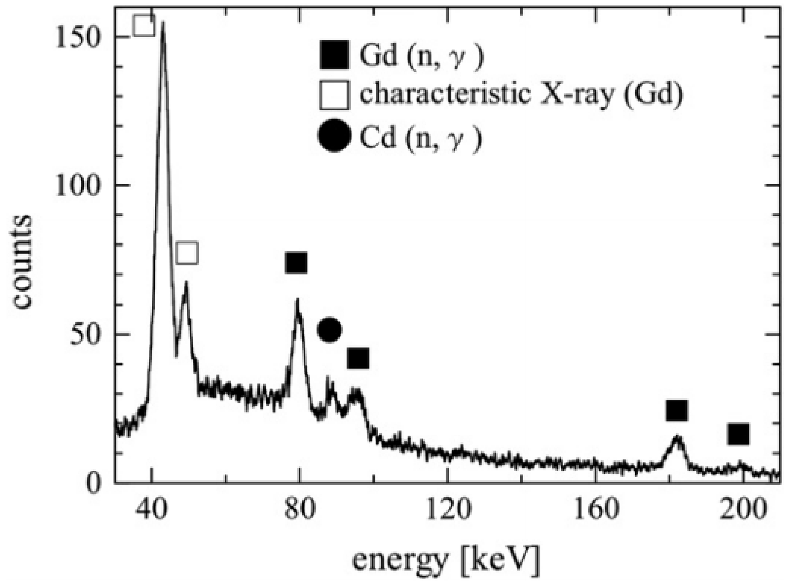
- **The compact sensor strategy (portable systems)**

N.H. Lee, et. al, IEEE Trans. Nucl. Sci. 57 (2010) 3489-3492
P. Kandlakunta and L. Cao, Rad. Prot. Dos.151 (2012) 586-590
} Silicon detectors

M. Fasasi, et. al, Rad. Rad. Prot. Dos.23 (1988) 429-431
A. Miyake, et. al, Nuc. Instr. Meth. A 654 (2011) 390–393
} CdTe detectors



Gd covered CdTe of Miyake



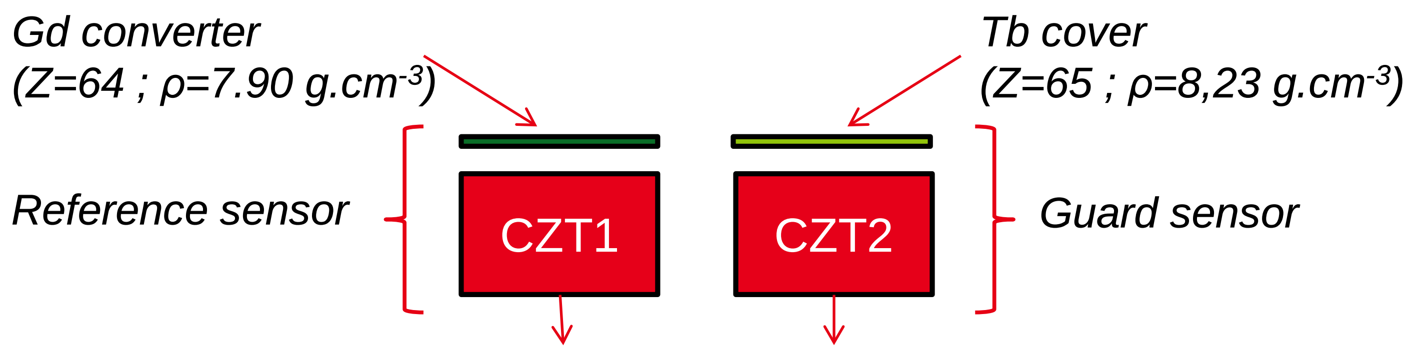
Spectrum measured under neutron flux by the Miyake detector

CdTe & CdZnTe are well suited to measure the Gd signature between [0; 200] keV
How compensate gamma rays background and provide neutron counting?

THE RUGGED COMPENSATION

- **Design of a compact neutron counter**

The optimal value for Gd converter is 25 µm. (*cf. D.A. Abdushukurov, Nova Science Publishers, Inc.* 2010)



Counting between [0; 200] keV: N_1 N_2 *every* Δt

Nonlinear smoothing: $\widehat{N}_1;\ \sigma^2(N_1)$ $\widehat{N}_2;\ \sigma^2(N_2)$ *every* Δt

Cf. R. Coulon, et. al, Rad. Meas. 87 (2016) 13–23.

Compensation algorithm (hypothesis test):

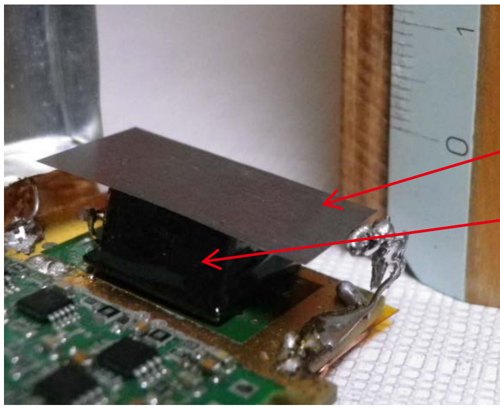
If $\widehat{N}_1 - \widehat{N}_2 > \mathrm{K}\sqrt{\sigma^2(N_1) + \sigma^2(N_2)}$

Then $\hat{S}_n = \widehat{N}_1 - \widehat{N}_2$

Else $\hat{S}_n = 0$

EXPERIMENTAL TEST

- **Experimental setup:**



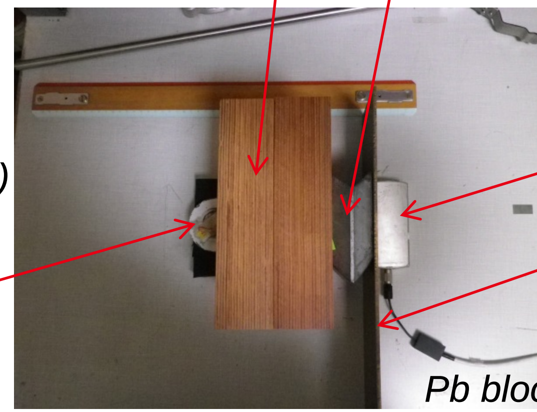
Gd or Tb Foil

CdZnTe (500 mm^3)

252Cf source

Cf. K. Boudergui, et. al, . ANIMMA 2011.

Borated wood (10 cm) Pb bloc (5 cm)

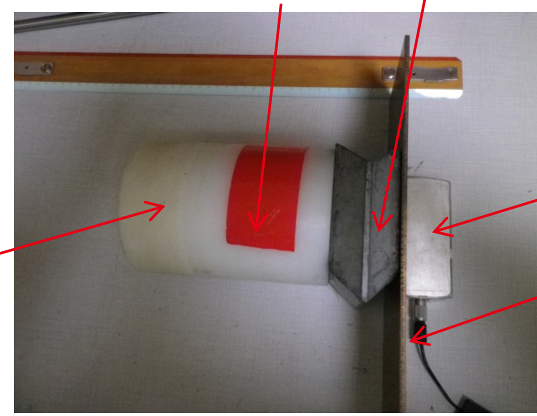


Detector

Cu foil (2 mm)

Pb bloc (5 cm)

PEHD (10 cm)



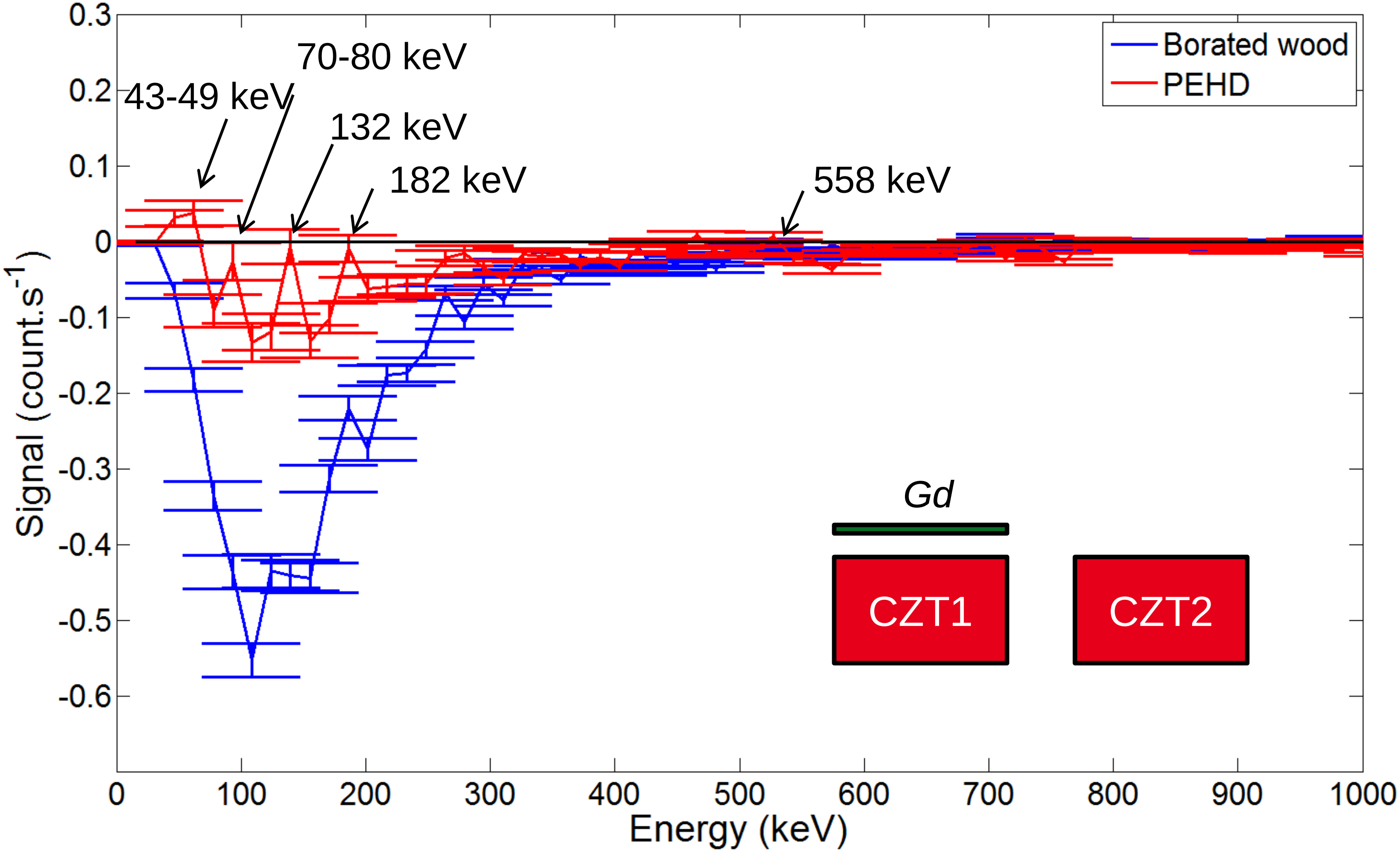
Detector

Cu foil (2 mm)

252Cf source

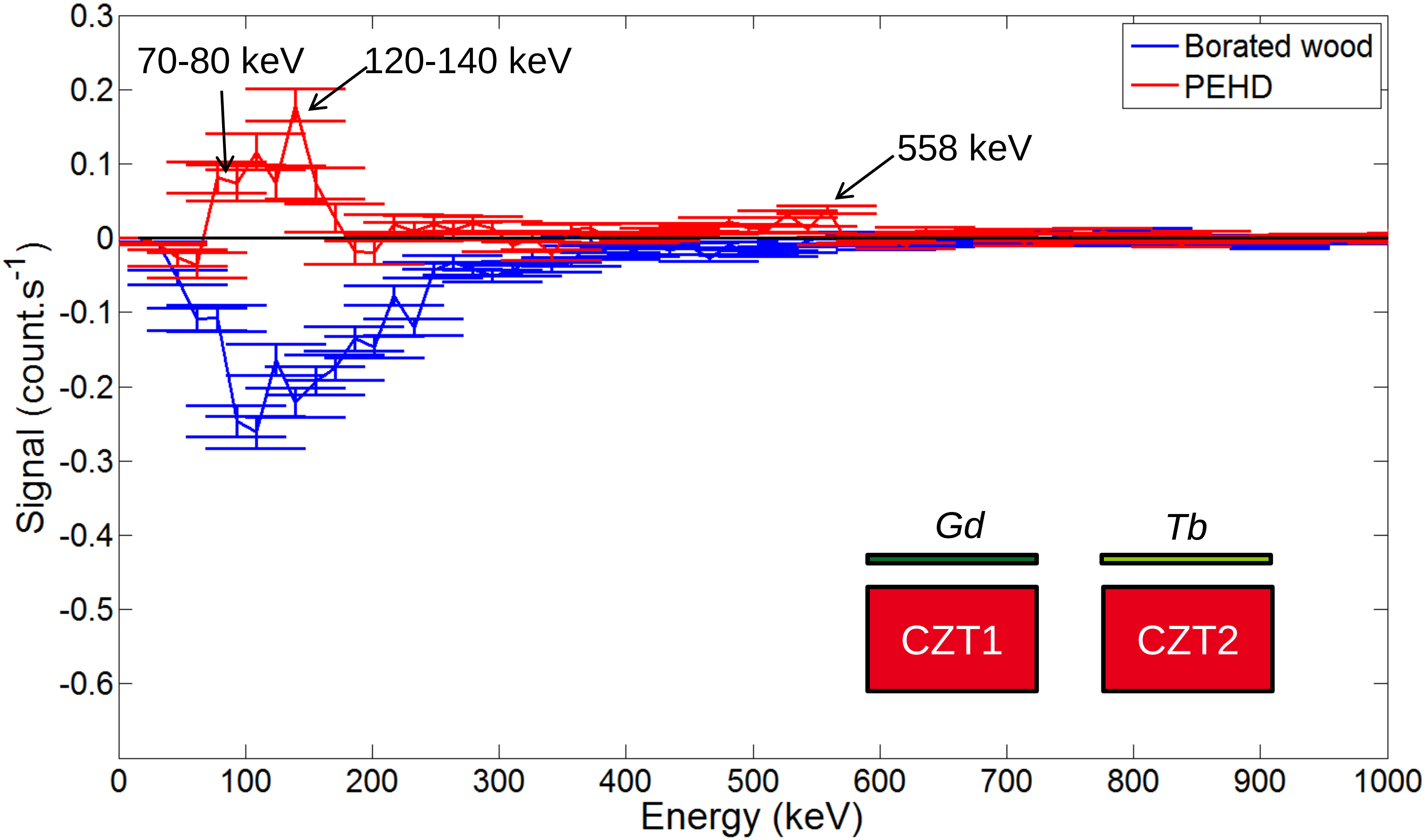
Micro-sized Gamma Spectrometer from IMS.

RESULTS



0.3
0.2
0.1
0
-0.1
-0.2
-0.3
-0.4
-0.5
-0.6
Signal (count.s^{-1})
0
100
200
300
400
500
600
700
800
900
1000
Energy (keV)
Borated wood
PEHD
70-80 keV
43-49 keV
132 keV
182 keV
558 keV
Gd
CZT1
CZT2

RESULTS


0.3
0.2
0.1
0
-0.1
-0.2
-0.3
-0.4
-0.5
-0.6
Signal (count.s^{-1})
0
100
200
300
400
500
600
700
800
900
1000
Energy (keV)
70-80 keV
120-140 keV
558 keV
Borated wood
PEHD
Gd
Tb
CZT1
CZT2

RESULTS

	PEHD	Borated wood
Gd / void [60; 200] keV	-0.65 ± 0.34	-3.64 ± 0.30
Gd / Tb [60; 200] keV	**+0.55 ± 0.33**	-1.76 ± 0.29
Gd / void [500; 600] keV	-0.13 ± 0.07	-0.098 ± 0.052
Gd / Tb [500; 600] keV	**+0.102 ± 0.066**	-0.070 ± 0.051
Gd / void [60; 600] keV	-1.23 ± 0.39	-4.88 ± 0.34
Gd / Tb [60; 600] keV	**+0.79 ± 0.38**	-2.45 ± 0.33

Sensitivity ≈ 0.5 (c/s)/nv

CONCLUSION

- **According to the state of the art, the CdZnTe is convenient to measure low energy prompt gamma rays from ^{157}Gd.**

- **A reliable compensation measurement could be implemented using a nonlinear smoothing and a hypothesis test.**

- **A significant gain in efficiency has been obtained by the implementation of a terbium covered guard CdZnTe.**

- **The concept has been proven and R&D works will be continued to design a portable neutron detector.**

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