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 $^{10}\text{B}$, $^{6}\text{Li}$ and $^{3}\text{He}$).
  • 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

\[ ^{113}_{48} \text{Cd} + {}^0_1 \text{n} \rightarrow ^{114}_{48} \text{Cd}^* \rightarrow ^{114}_{48} \text{Cd} + \gamma + RX + C{l}e^- + Ae^- (1) \]

\[ ^{155}_{64} \text{Gd} + {}^0_1 \text{n} \rightarrow ^{156}_{64} \text{Gd}^* \rightarrow ^{156}_{64} \text{Gd} + \gamma + RX + C{l}e^- + Ae^- (2) \]

\[ ^{157}_{64} \text{Gd} + {}^0_1 \text{n} \rightarrow ^{158}_{64} \text{Gd}^* \rightarrow ^{158}_{64} \text{Gd} + \gamma + RX + C{l}e^- + Ae^- (3) \]
THE SIGNATURE (PROMPT GAMMA RAYS)

Absolute emission rate (%cn)

Energy (keV)

- Gadolinium 157
- Gadolinium 155
THE SIGNATURE (INTERNAL CONVERSION ELECTRONS)

![Graph showing the absolute emission rate vs energy for Gadolium 157 and Gadolinium 155.](graph.png)
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

- The large sensor strategy (mobile or fixed systems)

**GADOPHERE®**

*Spherical scintillator w/ Gd core Radius 12 cm.*

Promising system: Sensitivity close to $^3$He Bonner sphere

*Stability curves of the systems*
**THE STATE OF THE ART**

- The compact sensor strategy (portable systems)


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

**Gd covered CdTe of Miyake**  
**Spectrum measured under neutron flux by the Miyake detector**
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)

Gd converter (Z=64 ; ρ=7.90 g.cm⁻³)

Reference sensor

CZT1

Tb cover (Z=65 ; ρ=8.23 g.cm⁻³)

Guard sensor

CZT2

Counting between [0; 200] keV: \( N_1 \) \( N_2 \)

Nonlinear smoothing:

\( \hat{N}_1; \sigma^2(N_1) \) \( \hat{N}_2; \sigma^2(N_2) \)

every \( \Delta t \)


Compensation algorithm (hypothesis test):

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

Then \( \hat{S}_n = \hat{N}_1 - \hat{N}_2 \)

Else \( \hat{S}_n = 0 \)
Experimental setup:

Gd or Tb Foil

CdZnTe (500 mm³)

252Cf source

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

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![Graphical representation showing energy levels and signal counts for different keV values: 43-49 keV, 70-80 keV, 132 keV, 182 keV, and 558 keV. The graph compares Borated wood and PEHD signals.]

- 43-49 keV
- 70-80 keV
- 132 keV
- 182 keV
- 558 keV

Gd

CZT1

CZT2
RESULTS

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- 70-80 keV
- 120-140 keV
- 558 keV
## RESULTS

<table>
<thead>
<tr>
<th></th>
<th>PEHD</th>
<th>Borated wood</th>
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</thead>
<tbody>
<tr>
<td>Gd / void [60; 200] keV</td>
<td>-0.65 ± 0.34</td>
<td>-3.64 ± 0.30</td>
</tr>
<tr>
<td>Gd / Tb [60; 200] keV</td>
<td>+0.55 ± 0.33</td>
<td>-1.76 ± 0.29</td>
</tr>
<tr>
<td>Gd / void [500; 600] keV</td>
<td>-0.13 ± 0.07</td>
<td>-0.098 ± 0.052</td>
</tr>
<tr>
<td>Gd / Tb [500; 600] keV</td>
<td>+0.102 ± 0.066</td>
<td>-0.070 ± 0.051</td>
</tr>
<tr>
<td>Gd / void [60; 600] keV</td>
<td>-1.23 ± 0.39</td>
<td>-4.88 ± 0.34</td>
</tr>
<tr>
<td>Gd / Tb [60; 600] keV</td>
<td>+0.79 ± 0.38</td>
<td>-2.45 ± 0.33</td>
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**Sensitivity ≈ 0.5 (c/s)/nv**
• 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.