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GADOLINIUM-LOADED PLASTIC SCINTILLATORS FOR THERMAL NEUTRON DETECTION AND COUNTING USING COMPENSATION

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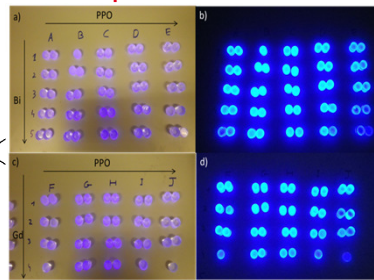
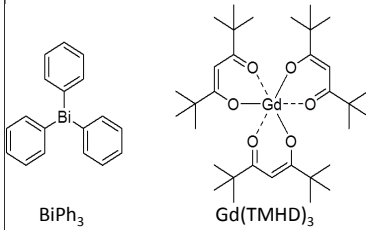
Introduction



Helium 3 neutron counter

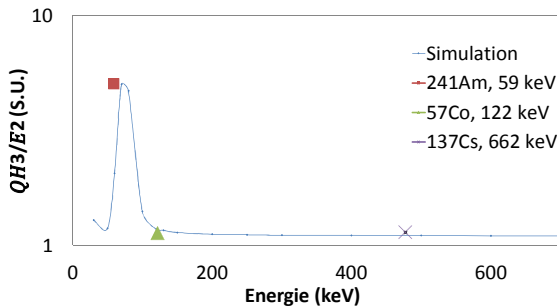
Neutron counting forms a critical branch of nuclear-related issues, whether dose rate monitoring for radioprotection or radiological material detection addressing CBRN threats are concerned. More specifically, the last decade has been driven by the quest for competitive **alternative technologies to neutron counters based on the helium 3 isotope**, whose worldwide shortage has generated massive market value fluctuations. **The loading of plastic scintillators** with thermal neutron absorbing elements, such as **gadolinium**, represents a **cost-effective** and **scalable** strategy.

Gadolinium and bismuth loaded plastic scintillators



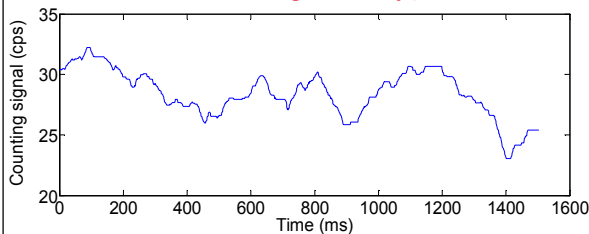
- Small **equal-volume** and **same-geometry** gadolinium (Gd(TMHD)₃ compound) and bismuth (BiPh₃ compound) loaded scintillators (Left figure) [1]
 - Diameter $d = 17.5$ mm and height $h = 8.1$ mm
 - H3 sample: Density $\rho = 1.1$ g.cm⁻³; **2 %wt gadolinium**
 - E2 sample: Density $\rho = 1.0$ g.cm⁻³; **1 %wt bismuth**
- Right figure : a) and b) Bismuth-loaded plastic scintillators with various loadings in BiPh₃ and PPO under UV ; c) and d) Gadolinium-loaded plastic scintillators with various loadings in Gd(TMHD)₃ and PPO under UV illumination.

Counting method using gamma compensation



- Thermal neutron radiative capture by **157 and 155 gadolinium isotopes** :
 $^{157}_{64}\text{Gd} + {}^1_0\text{n} \rightarrow ^{158}_{64}\text{Gd}^* \rightarrow ^{158}_{64}\text{Gd} + \gamma + XR + ICe^- + Ae^-$ (255000 b)
 $^{155}_{64}\text{Gd} + {}^1_0\text{n} \rightarrow ^{156}_{64}\text{Gd}^* \rightarrow ^{156}_{64}\text{Gd} + \gamma + XR + ICe^- + Ae^-$ (61000 b)
- **Prompt gamma rays** and **IC electrons** emitted in (n, γ) radiative cascade, notably in $F_1 = [0 ; 100$ keV] and $F_2 = [100$ keV ; 200 keV] energy ranges
- H3 **gamma and neutron sensitive**, E2 **solely gamma sensitive** : **compensation** of the gamma response of H3 by the response of E2 [2]
- The gamma compensation **coefficient** $Q = \frac{N_{H3}}{N_{E2}}$ is a function of the incident **gamma ray energy** E_γ
- **Agreement** between experimentally obtained values for Q and MCNPX Monte-Carlo code simulations

Nonlinear smoothing and hypothesis test



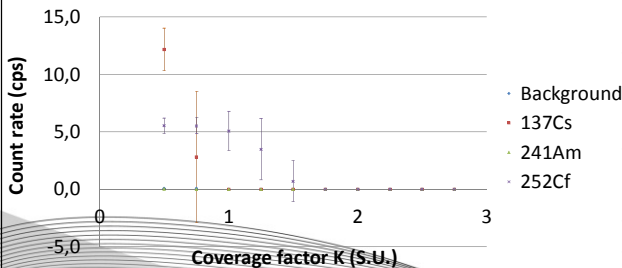
- Digitization every $\Delta t = 100$ ms over $T = 180$ s, nonlinear **Centered Skellam Test smoother** [3] for Poisson variance reduction: \widehat{N}_{H3} and \widehat{N}_{E2}
- Hypothesis test for neutron counting parametered by a **coverage factor K**:

$$\text{If } \widehat{N}_{H3} - \bar{Q} \cdot \widehat{N}_{E2} > K \cdot \sqrt{\sigma^2(\widehat{N}_{H3}) + \bar{Q}^2 \cdot \sigma^2(\widehat{N}_{E2}) + \sigma_{E_\gamma}^2(\bar{Q}) \cdot \widehat{N}_{H3}^2}$$

$$\text{Then } \widehat{N}_n = \widehat{N}_{H3} - \bar{Q} \cdot \widehat{N}_{E2}$$

$$\text{Else } \widehat{N}_n = 0 \text{ (every } \Delta t)$$
- **Moving median** over $\Delta T = 30$ s for variance reduction on \widehat{N}_n

Results and conclusions



- Essentially **high energy gamma background** of ²⁵²Cf source **compensated** over F_1 and F_2 for $K = 1$
- Count rate $\widehat{\lambda}_n = 13.6$ cps over F_1 for $K = 1.25$, guarantees null count rate for the room and ¹³⁷Cs backgrounds, but falsely counts for ²⁴¹Am background
- Count rate $\widehat{\lambda}_n = 5.1$ cps over F_2 for $K = 1$, guarantees null count rate for the room, ¹³⁷Cs and ²⁴¹Am background
- Compares to $\widehat{\lambda}_n = 42.3$ cps helium 3 count rate (65NH45 model)
- **Scale-up** for higher precision and **alternative to bismuth compensation**