Gadolinium-loaded plastic scintillators for thermal neutron detection and counting using compensation

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

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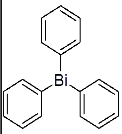
Introduction

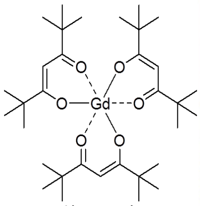
Helium 3 neutron counter

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.

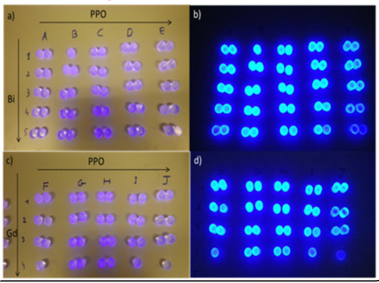
Gadolinium and bismuth loaded plastic scintillators



BiPh$_3$



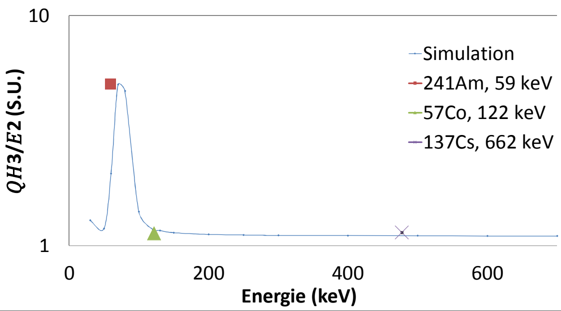
Gd(TMHD)$_3$



- Small **equal-volume** and **same-geometry** gadolinium (Gd(TMHD)$_3$ compound) and bismuth (BiPh$_3$ 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 BiPh$_3$ 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

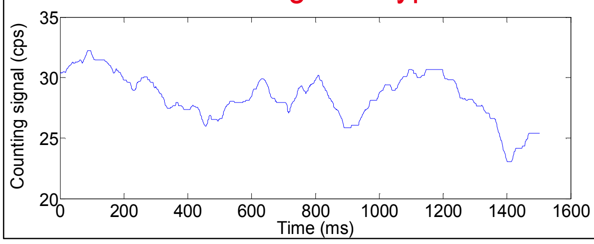


- Thermal neutron radiative capture by **157 and 155 gadolinium isotopes** :

$$^{157}_{64}\mathrm{Gd} + ^{1}_{0}\mathrm{n} \rightarrow ^{158}_{64}\mathrm{Gd}^* \rightarrow ^{158}_{64}\mathrm{Gd} + \gamma + XR + ICe^- + Ae^- \ (255000\ \mathrm{b})$$
$$^{155}_{64}\mathrm{Gd} + ^{1}_{0}\mathrm{n} \rightarrow ^{156}_{64}\mathrm{Gd}^* \rightarrow ^{156}_{64}\mathrm{Gd} + \gamma + XR + ICe^- + Ae^- \ (61000\ \mathrm{b})$$

- **Prompt gamma rays** and **IC electrons** emitted in (n,γ) radiative cascade, notably in $F_1 = [0\,;100\ \mathrm{keV}]$ and $F_2 = [100\ \mathrm{keV}\,;200\ \mathrm{keV}]$ 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** $\boldsymbol{Q} = \frac{N_{H3}}{N_{E2}}$ is a function of the incident **gamma ray energy** $\boldsymbol{E_\gamma}$
- **Agreement** between experimentally obtained values for Q and MCNPX Monte-Carlo code simulations

Nonlinear smoothing and hypothesis test

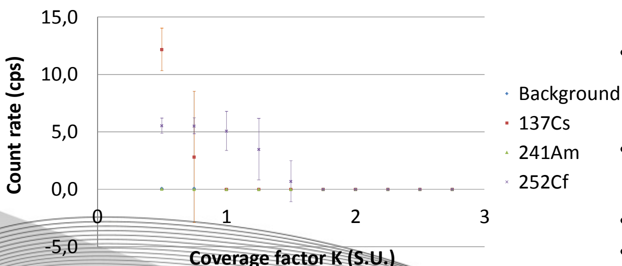


- Digitization every $\Delta t = 100$ ms over $T = 180$ s, nonlinear **Centered Skellam Test smoother** [3] for Poisson variance reduction: $\widehat{N_{H3}}$ and $\widehat{N_{E2}}$
- Hypothesis test for neutron counting parametered by a **coverage factor K**:

$$\text{If } \widehat{N_{H3}} - \bar{Q}.\widehat{N_{E2}} > \mathrm{K}.\sqrt{\sigma^2(\widehat{N_{H3}}) + \bar{Q}^2.\sigma^2(\widehat{N_{E2}}) + \sigma_{E_\gamma}{}^2\,(\bar{Q}).\widehat{N_{H3}}^2}$$
$$\text{Then } \widehat{N_n} = \widehat{N_{H3}} - \bar{Q}.\widehat{N_{E2}}$$
$$\text{Else } \widehat{N_n} = 0 \ (\text{every } \Delta t)$$

- **Moving median** over $\Delta T = 30$ s for variance reduction on $\widehat{N_n}$

Results and conclusions



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

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[1] *Understanding behavior of different metals in loaded scintillators: discrepancy between gadolinium and bismuth*, Bertrand G. H. V. et al., Journal of Chemical Materials, 2015, *submitted*.
[2] *Dispositif de détection de neutrons thermiques et dispositif de comptage de neutrons thermiques associé, Commissariat à l'Energie Atomique*, Demande de Brevet Français n° 14 60266.
[3] *An adaptative smoother for counting measurements*, V. Kondrasovs et al., Proc. of ANIMMA, 2013.