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

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Introduction

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 ρ = 1.1 g.cm⁻³; 2% wt gadolinium
  - E2 sample: Density ρ = 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 :
  \[ \frac{157}{68}^{68}\text{Gd} + \alpha \rightarrow \frac{158}{68}^{68}\text{Gd}^{*} \rightarrow \frac{158}{68}^{68}\text{Gd} + \gamma + X + ICe^{-} + Ae^{-} \ (255000 \text{ b}) \]
  \[ \frac{155}{68}^{68}\text{Gd} + \alpha \rightarrow \frac{156}{68}^{68}\text{Gd}^{*} \rightarrow \frac{156}{68}^{68}\text{Gd} + \gamma + X + ICe^{-} + Ae^{-} \ (61000 \text{ b}) \]
- Prompt gamma rays and IC electrons emitted in (n,y) radiative cascade, notably in F₁ = [0 ; 100 keV] and F₂ = [110 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 \( E_{Y} \)
- Agreement between experimentally obtained values for \( Q \) and MCNPX Monte-Carlo code simulations

Nonlinear smoothing and hypothesis test

- Digitization every Δt = 100 ms over \( T = 180 \text{ s} \), nonlinear Centered Skellam Test smoother [3] for Poisson variance reduction: \( \tilde{N}_{H3} \) and \( \tilde{N}_{E2} \)
- Hypothesis test for neutron counting parametered by a coverage factor \( K \):
  \[ \text{If } N_{H3} - \tilde{Q} \cdot \tilde{N}_{E2} > K \cdot \sqrt{\sigma^{2}(N_{H3}) + \tilde{Q}^{2} \cdot \sigma_{E2}^{2} + \sigma_{E2}^{2} (\tilde{Q}) \cdot N_{E2}^{2}} \]
  Then \( \tilde{N}_{H3} = N_{H3} - \tilde{Q} \cdot \tilde{N}_{E2} \)
  Else \( \tilde{N}_{H3} = 0 \) (every Δt)
- Moving median over \( \Delta T = 30 \text{ s} \) for variance reduction on \( \tilde{N}_{H3} \)

Results and conclusions

- Essentially high energy gamma background of \(^{252}\text{Cf} \) source compensated over \( F_{1} \) and \( F_{2} \) for \( K = 1 \)
- Count rate \( \tilde{X}_{H3} = 13.6 \text{ cps over } F_{1} \) for \( K = 1.25 \), guarantees null count rate for the room and \(^{137}\text{Cs} \) backgrounds, but falsely counts for \(^{241}\text{Am} \) background
- Count rate \( \tilde{X}_{E2} = 5.1 \text{ cps over } F_{2} \) for \( K = 1 \), guarantees null count rate for the room, \(^{137}\text{Cs} \) and \(^{241}\text{Am} \) background
- Compares to \( \tilde{X}_{E2} = 42.3 \text{ cps } \)
- Scale-up for higher precision and alternative to bismuth compensation