Neutron efficiency and gamma rejection of pulse shape discriminating multi mode radiation detectors

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Outline

- Dual mode neutron gamma detectors
- Scatter corrected neutron detection efficiency and GARRn
- Experimental setup
  - Dual mode neutron gamma detectors
  - Pulse shape discrimination
- Data Analysis
- Neutron efficiency and *GARRn*
- Comparison to Identifinder 2
- Summary and Future work

Dual mode neutron gamma detectors

- Detection science has a remit to assess dual neutron-gamma detectors for a wide range of applications.

- A current piece of work is the development of a TRL 5 demonstrator which could be used in search and response applications.

- To select the most suitable scintillator, studies into performance metrics such as neutron efficiency were undertaken.

Neutron detection metrics

- To choose the most suitable detector material for any application certain performance metrics need to be known:
  - Fast neutron detection efficiency:
    - Number neutrons detected in presence of neutron source
  - Gamma rejection value:
    - Number of neutrons “detected” in presence of gamma source
  - Gamma Absolute Rejection Ratio for Neutrons (*GARRn*):
    - Change in number of detected neutrons in dual neutron gamma field

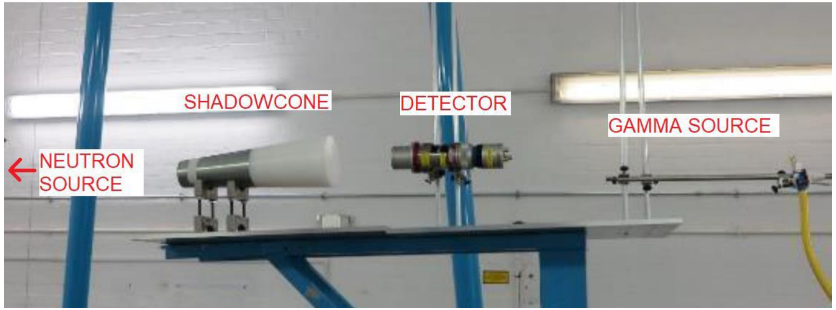
$$\varepsilon_{int\ n} = \frac{N_n}{\frac{\Omega_n}{4\pi}\varphi_n t}$$

$$\varepsilon_{int\ \gamma} = \frac{N_\gamma - N_{BG}}{\frac{\Omega_\gamma}{4\pi}\varphi_\gamma t}$$

$$GARRn = \frac{\varepsilon_{int\ n\gamma}}{\varepsilon_{int\ n}}$$

Scatter corrected neutron detection efficiency and *GARRn*

- The metrics were measured at the AWE Neutron calibration facility and a scatter correction technique was utlized.
- In such a facility the total number of detected neutrons $\left(N_n^{total}\right)$ will be ones directly emitted from the source $\left(N_n^{direct}\right)$ and neutrons that have undergone elastic scattering $\left(N_n^{scattered}\right)$ in the surrounding environment.
- Measurements of equal duration recorded with and without a shadow cone consisting of concentric 20 cm thick truncated steel and high-density polyethylene cones(termed the shadow cone).
- As a result the total (without the cone) and scattered neutron (with the cone) contributions can be measured and number of neutron detected directly from the source calculated.



$$\varepsilon_{int\ n} = \frac{N_n^{direct}}{\frac{\Omega_n}{4\pi}\varphi_n t}$$

$$N_n^{direct} = N_n^{total} - N_n^{scattered}$$

Experimental Equipment

- Six different detectors investigated.
- 2” diameter 2” long right cylindrical detectors in 1.5 mm Al housings.
- All detectors identical as possible to rule out differences in size and shape.
- Light collection provided by ETL 9214 KFLB 12-stage dynode PMT .
- Data acquisition provided by Caen DT5730B digitizer (14 bit, 500 MSa/s, 0.5 Vp-p).

Detector	Construction	Thermal Neutron	Fast Neutron
EJ-299	Plastic	✗	✓
EJ-309	Liquid	✗	✓
Stilbene	Crystalline	✗	✓
CLYC	Crystalline	✓	✓
P-terphenyl	Crystalline	✗	✓
EJ-270	Plastic	✓	✓

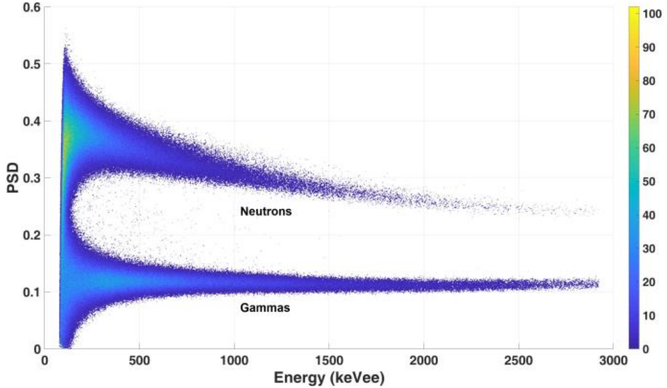
Pulse shape discrimination

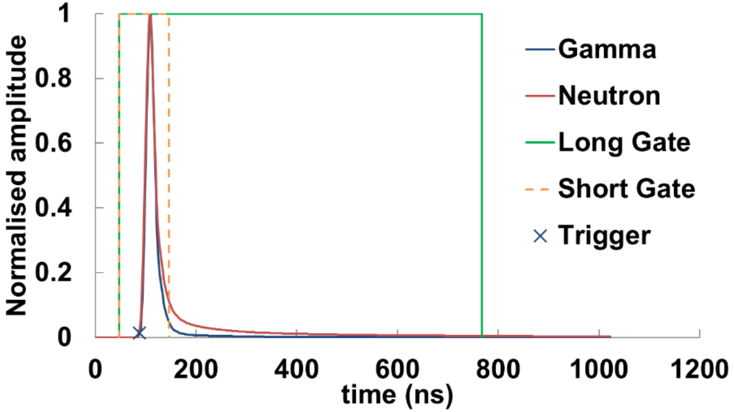
- Different scintillation modes result in different scintillation pulse shapes.

- Once the charge pulse from a light collector is digitised by a fast data acquisition system it is possible to define a PSD metric, one such metric is the charge integration algorithm used in digitizers produced by Caen.

- $PSD = 1 - \frac{Q_s}{Q_l}$

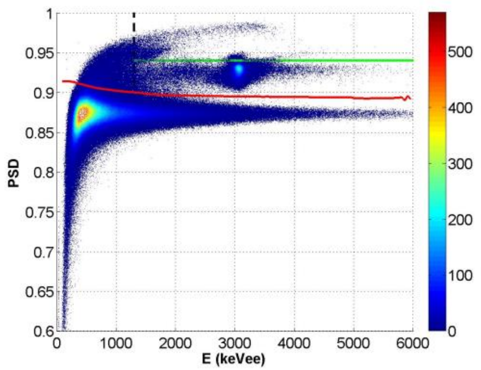
- Charge in two windows calculated and the ratio is a measure of the interaction type.

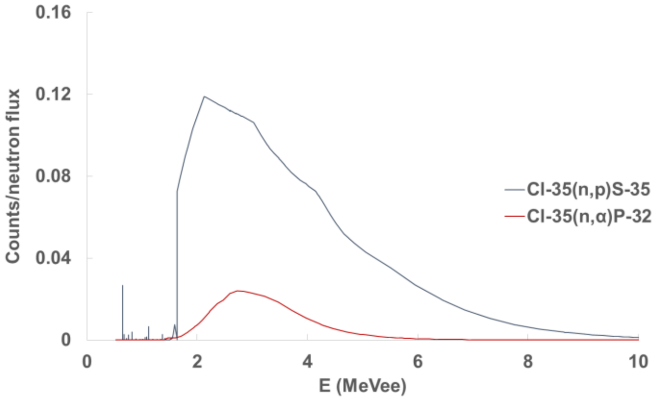




Data Analysis

- To assess the number of detected neutrons a series of energy and PSD cuts were used.
- PSD cuts involving a straight line or cuts 4 sigma from the centre of the gamma and neutron lobes (assuming a gaussian profile).
- An energy cut of 1.3 MeVee was used for CLYC as neutron interaction energies not observed below this.





Neutron Efficiency

- The detectors were irradiated by a ^{252}Cf source which had a neutron emission rate of 1.62×10^7 neutrons/sec and was positioned at a distance of 100 ± 0.5 cm from the source.

- Measurements were taken with and without the cone for 1800 s for CLYC and 900 s for all other detectors.

- Efficiency values similar for both PSD cut definitions.

Detector	Intrinsic neutron efficiency with simple PSD cut (%)	Intrinsic neutron efficiency with complex PSD cut (%)
EJ-299	24.1 ± 0.1	23.2 ± 0.1
EJ-309	35.1 ± 0.2	40.6 ± 0.2
Stilbene	23.8 ± 0.1	27.9 ± 0.1
CLYC	1.17 ± 0.02	0.75 ± 0.02
P-terphenyl	42.6 ± 0.2	41.0 ± 0.2
EJ-270	27.1 ± 0.1	16.01 ± 0.09

Gamma Rejection and *GARRn*

- To assess the gamma rejection and *GARRn* performance a 84.9 MBq ^{137}Cs source was placed 85 ± 0.5 cm from the back of the scintillator cell resulting in an exposure rate of 1.048 ± 0.006 mR/hr.
- *GARRn* values were in the 0.9-1.1 acceptable window for all detectors except CLYC.
- The degradation observed for CLYC was due to increased gamma sensitivity of CLYC and longer temporal pulse shape resulting in higher levels of pile up.

Detector	Gamma Rejection	*GARRn*
EJ-299	$(3.07 \pm 0.01) \times 10^{-3}$	0.960 ± 0.002
EJ-309	$(2.005 \pm 0.004) \times 10^{-2}$	1.009 ± 0.002
Stilbene	$(5.47 \pm 0.02) \times 10^{-3}$	1.000 ± 0.002
CLYC	$(6.3 \pm 0.1) \times 10^{-5}$	1.35 ± 0.04
P-terphenyl	$(9.14 \pm 0.02) \times 10^{-3}$	0.960 ± 0.002
EJ-270	$(2.32 \pm 0.01) \times 10^{-3}$	0.976 ± 0.003

Comparison to Identifinder 2

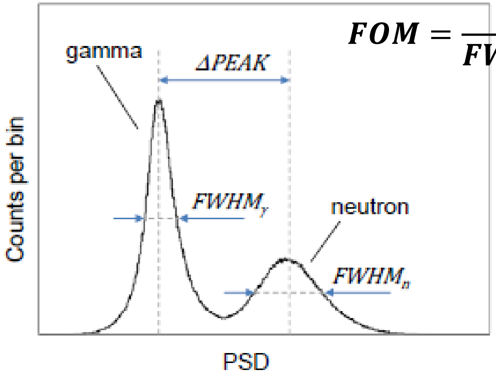
- FLIR Identifinder 2 NGH is a handheld radionuclide identifying device which is used widely in search applications.
- Measurements were taken with the Identifinder 2 to get a bassline comparative performance.
- As the Identifinder is only sensitive to thermal neutrons the absolute neutron detection efficiency ($\varepsilon_{abs\ n}$) was measured for each detector.
- Higher efficiency found for the 2” x 2” detector crystals due to large sensitive area and increased sensitivity to fast neutrons.
- Should be noted that the Identifinder isn't directly comparable in all aspects and each solution will have different positive and negative traits.

$$\varepsilon_{abs\ n} = \frac{N_n^{total}}{\frac{\Omega_n}{4\pi}\varphi_n t}$$

Detector	**Absolute neutron detection efficiency**
EJ-299	(4.622 ± 0.003) x 10^{-5}
EJ-309	(6.763 ± 0.007) x 10^{-5}
Stilbene	(4.562 ± 0.006) x 10^{-5}
CLYC	(1.591 ± 0.001) x 10^{-5}
P-terphenyl	(8.950 ± 0.008) x 10^{-5}
EJ-270	(6.304 ± 0.007) x 10^{-5}
Identifinder 2	(6.647 ± 0.003) x 10^{-7}

Detector technologies comparison

- EJ-309 and P-terphenyl have higher neutron efficiency however have certain disadvantages:
  - EJ-309 is liquid so not suitable for operational applications.
  - P-terphenyl: high cost
- CLYC:
  - Lower neutron efficiency and gamma rejection performance.
  - However have added benefits like spectroscopic performance.
- PSD performance comparable for majority of detectors.



$$FOM = \frac{\Delta Peak}{FWHM_\gamma + FWHM_n}$$

Detector	$\varepsilon_{int\,n}$	$\varepsilon_{int\,\gamma}$	*GARRn*	PSD FoM @ 1 MeVee
EJ-299	23.2 ± 0.1	(3.07 ± 0.01) x 10^{-3}	0.960 ± 0.002	1.03 ± 0.03
EJ-309	40.6 ± 0.2	(2.005 ± 0.004) x 10^{-2}	1.009 ± 0.002	1.36 ± 0.01
Stilbene	27.9 ± 0.1	(5.47 ± 0.02) x 10^{-3}	1.000 ± 0.002	2.17 ± 0.01
CLYC	0.75 ± 0.02	(6.3 ± 0.1) x 10^{-5}	1.35 ± 0.04	1.66 ± 0.01
P-terphenyl	41.0 ± 0.2	(9.14 ± 0.02) x 10^{-3}	0.960 ± 0.002	1.79 ± 0.02
EJ-270	16.01 ± 0.09	(2.32 ± 0.01) x 10^{-3}	0.976 ± 0.003	1.13 ± 0.01

Summary and Future work

- The neutron efficiency was not found to change significantly in the presence of large gamma field.

- No significant change between simple and complex PSD cuts highlighting the ability to use a simple straight-line algorithm in any future demonstrator.

- A two orders of magnitude increase in absolute efficiency was observed for the 6 candidate materials compared to the Identifinder 2 thus highlighting the benefit of using larger dual mode detectors in any system going forward.

- Future work includes:
  - Assessment of other detectors including: NaIL, CLLB, CLLBc, EJ-276.
  - Perform the same measurements with Silicon photomultiplier light collection, how does change in PSD effect measured efficiency?
  - Assessment of relative neutron efficiency to a moderated neutron source.