Novel Neutron Detector Technologies

Nerys Davies[1], Andrew Boston[1], John Browning[2], Matthew Castle[2], David Joss[1]

[1] University of Liverpool, UK. [2] Sizewell C, UK., Contact Information: Nerys.Davies@Liverpool.ac.uk

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Research Background and Motivation

This research involves investigations into the pulse shape discrimination (PSD) capacity of a fast neutron and gamma-ray plastic scintillator, EJ-276, and the characterisation of both pulse shapes. Different methods of pulse shape discrimination will be tested such as charge integration, rise time discrimination, zero-cross over, constant time discrimination and time over threshold, charge integration PSD is presented here. Alongside this the results of a fully validated Monte-Carlo simulation of an experimental facility are displayed; validated using measurements of thermal neutron flux as a function of polythene moderator thickness, borated polythene shield thickness and neutron dose rate.

Simulations

A Monte-Carlo N Particle (MCNP) simulation of the thermal neutron spectrum in an experimental facility was constructed. This model was then validated using a variety of experimental set-ups. This entailed using ^{3}He gas-filled detectors to evaluate the thermal neutron count rate detected from a water moderated Am/Be source as a function of polythene moderator and borated polythene shield thickness in different experimental layouts. Scattering and shielding sources were added or removed from the model to investigate their effects on the detected thermal neutron count rate. The MCNP model of the thermal neutron spectrum in the experimental facility was validated at the 95% confidence level, Fig. 1.

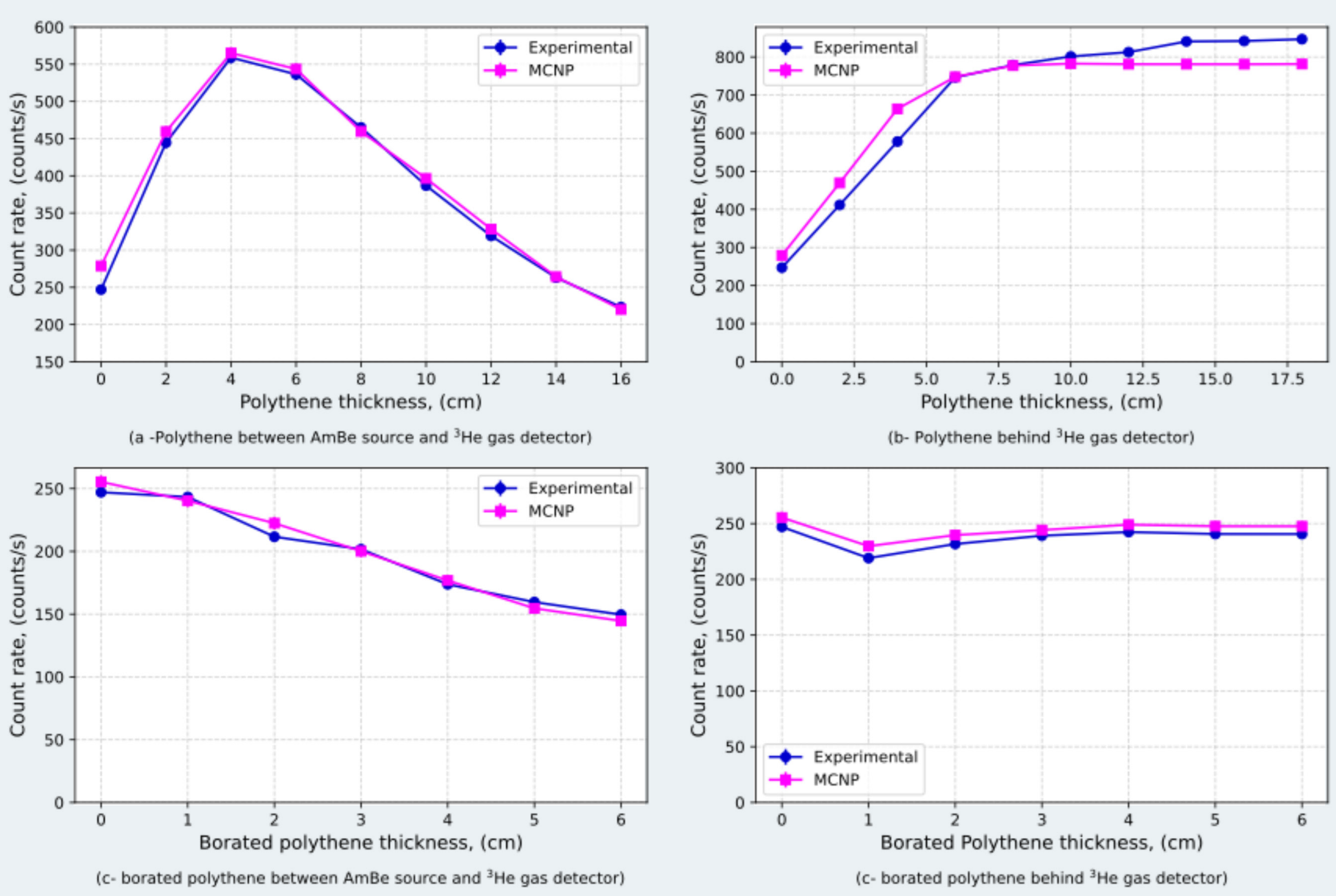

Figure 1: Experimental and simulated thermal neutron count rate. Error bars have been plotted but are smaller than data points.

To enhance the level of confidence in the MCNP model's accuracy in describing the experimental facility, neutron dose maps were generated using the FMESH function in MCNP 6, with fluence-to-dose conversions taken from ICRP 74. The simulated neutron dose maps, Fig. 2, were then compared to experimental data recorded with a Bonner sphere, yielding validated results. The γ dose rates were simulated and also yielded results validated at the 95% confidence level.

Neutron dose rate at position $X_{simulated}$ = 9.08±0.45 μSv/h

Neutron dose rate at position $X_{experimental}$ = 9.0±0.2 μSv/h

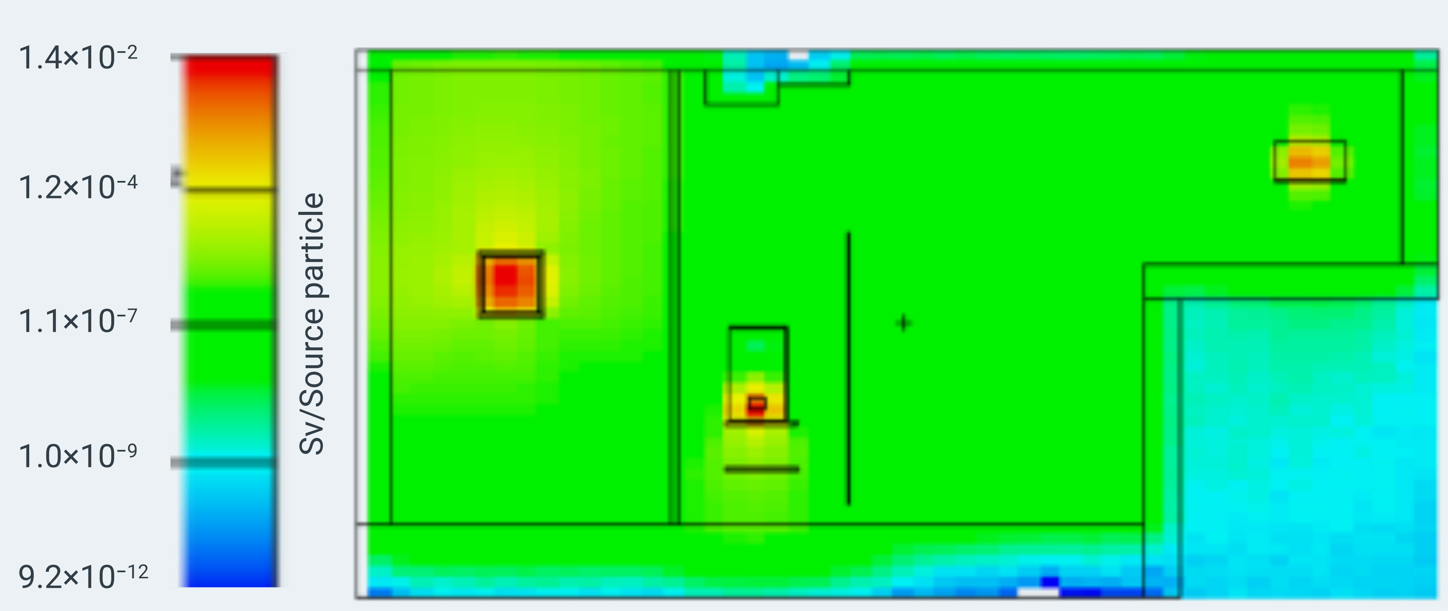

Figure 2: Neutron dose heat map of experimental facility.

Future Work

- Test alternative PSD methods such as zero-cross over, time over threshold and constant time discrimination to quantify the best method for PSD with EJ-276.
- Down-sample data and assess if PSD techniques uphold their ability to separate out fast neutrons and γ at much reduced sampling rates.
- Combine PSD algorithms, selected DAQ and EJ-276 detector in an environment with large fast neutron and γ fluxes to investigate the use of the detector in environments of both fast neutrons and γ.
- Apply the same principles of DAQ choice and PSA to other novel neutron detector technologies for applications in reactor cores, or peripheral monitoring of reactors

EJ-276 Plastic Scintillator

- EJ-276 plastic scintillator (Eljen Technologies), is a relatively low-cost, robust scintillator used for fast neutron and γ pulse shape discrimination (PSD), by utilising the difference in pulse shape formed from the two types of radiation.
- Electrical signals formed from recoil protons (fast neutron) have longer decay components than those formed from recoil electrons (γ).
- Characteristic pulse shapes can be separated out and sorted into fast neutron or γ.

γ pulse shape

- Pulse shape and size analysed at different bias voltages from anode and dynode pins of EJ-276, Fig. 3.
- Largest pulse amplitude possible desirable for large scale PSD when using Digital acquisition system (DAQ)

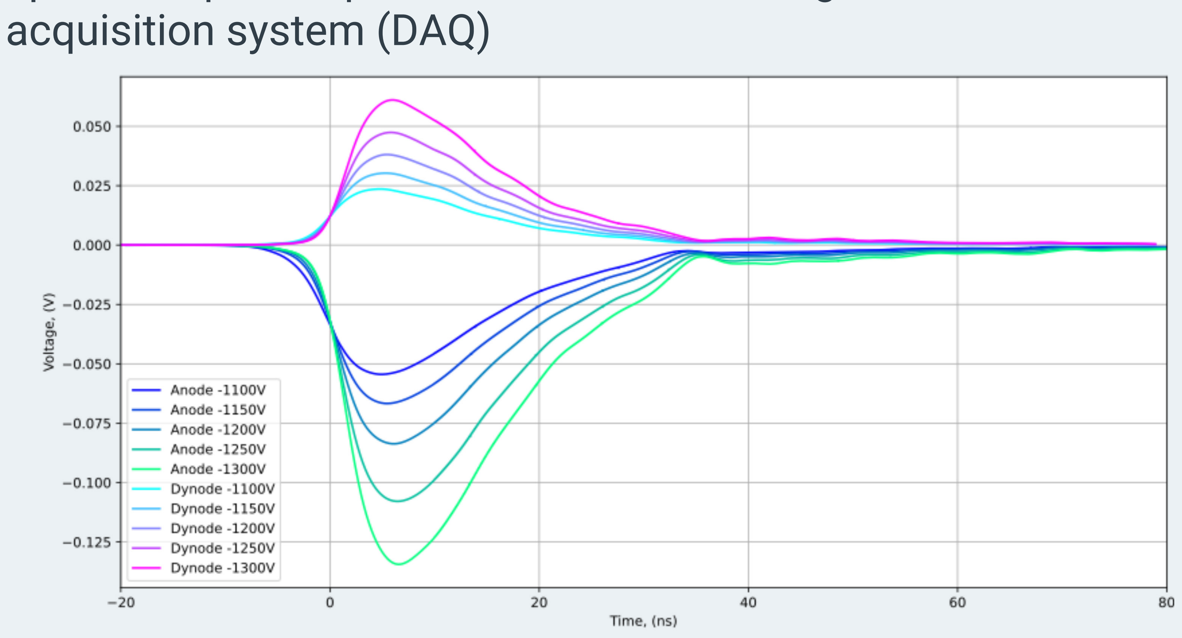

Figure 3: Average (500 pulses) pulse shape from EJ-276 at different bias voltages from anode and dynode, Eγ=662 keV.

- Effect of external pulse amplification tested using Gain and Offset (GO) box and Timing Filter Amplifier (TFA) (integration and differentiation set to out)

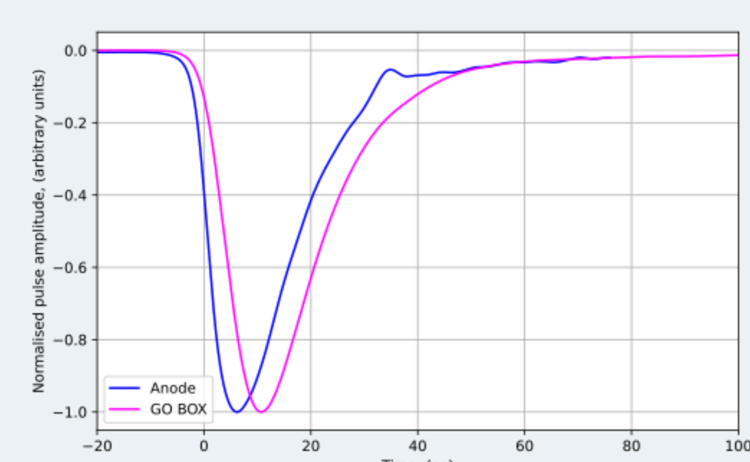

Figure 4: Plot of average normalised anode pulse shape with and without GO box.

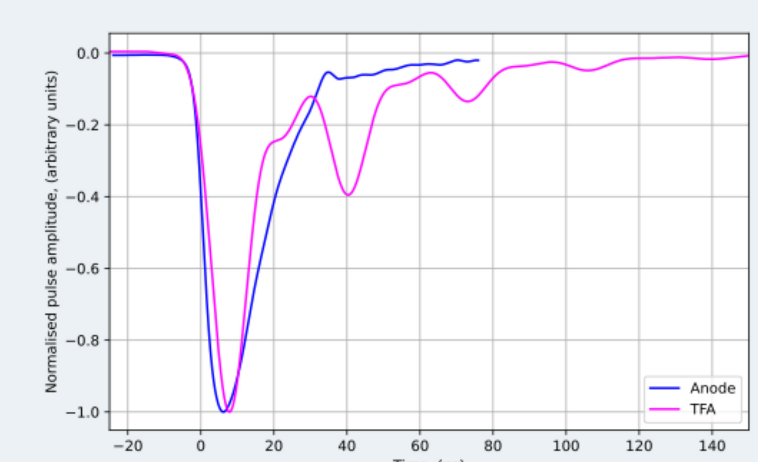

Figure 5: Plot of average normalised anode pulse with and without TFA.

PSD

- Charge integration PSD compares the area under short and long gates placed upon individual pulses to separate signals generated from neutron and γ's [1].

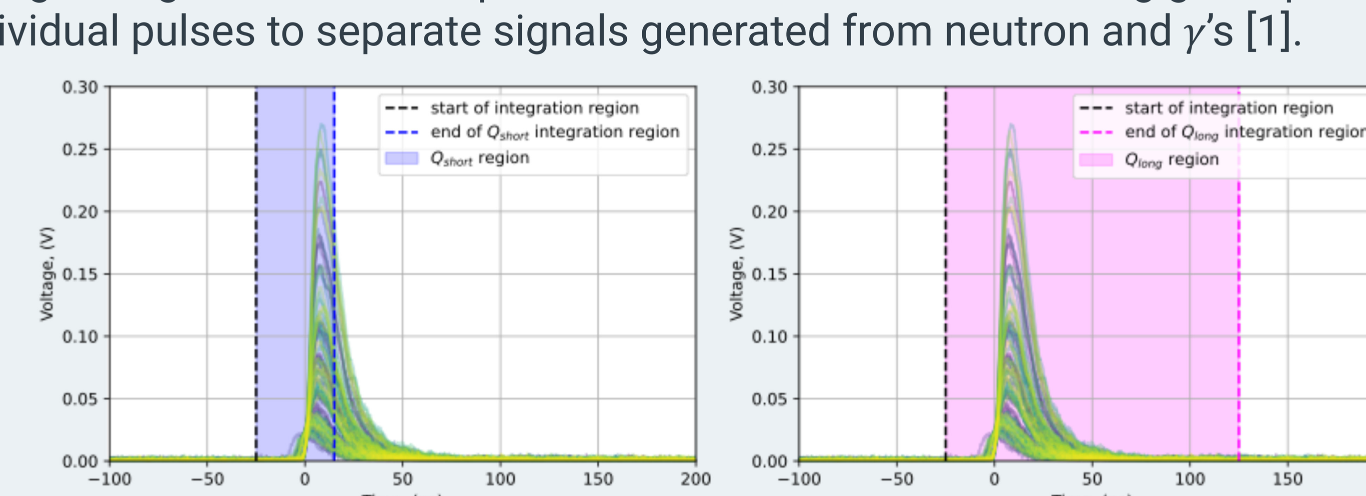

Figure 6: Plots displaying integration regions used for calculating PSD factor.

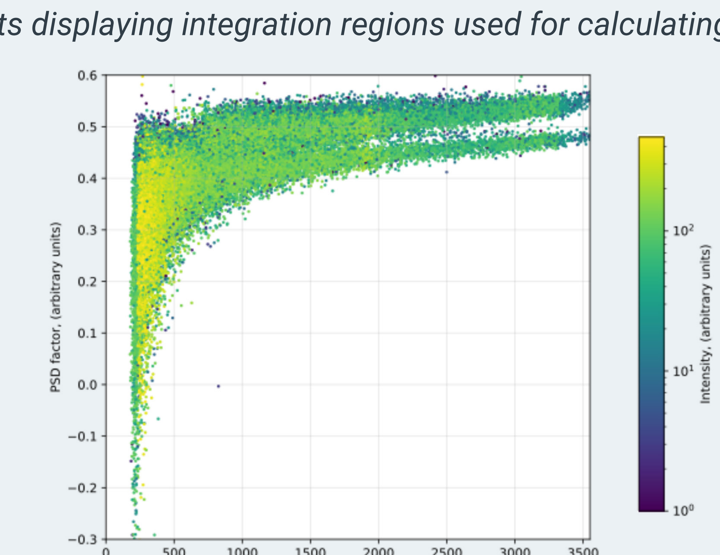

Figure 7: Plot of charge integration PSD factor as a function of energy.

References

[1] E. V. Ryabeva et al., "Calibration of EJ-276 plastic scintillator for neutron–gamma pulse shape discrimination experiments," Nuclear Instruments and Methods in Physics Research Section A: Accelerators, Spectrometers, Detectors and Associated Equipment, vol. 1010, pp. 165495–165495, Sep. 2021, doi: https://doi.org/10.1016/j.nima.2021.165495.

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