Analysis of the BC501A neutron detector signals using the true pulse shape

D. Cano-Ott, M. Fernández, E. González, C. Guerrero, T. Martínez and D. Villamarín

carlos.guerrero@ciemat.es
Neutron detection activities have started at CIEMAT

Different neutron detectors have been acquired:

i) BC501A (1 unit)

ii) $^3$He counters (3 position sensitive units)

iii) BF$_3$ counters (3 units with different geometries)

iv) Plastic scintillators (6 units of BC400 with different geometries)

The BC501A is aimed to be used for:

- test for the proposed DESPEC $1\pi$ array of 30 BC501A neutron detector,
- neutron flux monitor in Integral Experiments (Yalina, Guinevere,…).

A first BC501A detector has been tested with neutron and $\gamma$-ray sources using digital electronics. For such test, an innovative Pulse Shape Analysis Routine has been developed.
Bicron BC501A neutron detector

More than one scintillation decay component allow to discriminate between different exciting particles.

\[ \tau = 3.16, 32.3 \text{ & } 270 \text{ ns} \]
Data Acquisition System

Why digital electronics?
- Maximum control of systematics in exp. conditions.
- Offline analysis with the maximum available information.
- Powerful pile-up reconstruction capabilities.
- Already in use at n_TOF: fully digital DAQ.

Am/Be source ~ 200 MBq

Lecroy LC574AM
- Sampling: 1GHz
- Resolution: 8 bits
- Coupled via GPIB to a PC
- Range up to 5-6 MeV
Pulse Shape Analysis methods

- Integration method (~analogical)
  - good $n/\gamma$ discrimination and resolution
  - poor pile-up capabilities

- Fit to parameterized shape (n_TOF) NIM A, 490 (2002) 299-307
  - good $n/\gamma$ discrimination, resolution and pile-up capabilities
  - not all pulse shapes can be parameterized easily
  - if so $\rightarrow$ long CPU times

- Fit to true shape (in use at n_TOF and this work) NIM A in preparation
  - good $n/\gamma$ discrimination, resolution and pile-up capabilities
  - it can be applied to any detector (without any parameterization)
  - fast Least Squares Fit.
Integration method: n/γ discrimination

Pulse Shape Discrimination:

\[
\frac{\text{slow}}{\text{fast}} (e^-, p, \alpha, \ldots) \Rightarrow PSD
\]

BC501A Pulse shape

![Graph showing pulse shape discrimination](image)

C. Guerrero
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Averaged true-pulse-shape used for the PSA

**BC501A Pulse shape**

![Graph showing pulse shapes with time in ns on the x-axis and normalized amplitude on the y-axis.](image)

- Gamma signal
- Neutron flashADC(25,50)
- Neutron flashADC(50,750)
- Neutron flashADC(75,100)
- Neutron flashADC(100,125)
- Neutron flashADC(125,150)
- Neutron flashADC(150,175)
- Neutron flashADC(175,200)

**Parameterization**

\[ n - \text{shape} \propto \text{Amp} \]
Pulse Shape Analysis algorithm

PSA algorithm:
1. Baseline calculation
2. Search for peak candidates
3. Estimate $t_0$
4. Least-Squares Fit to reference signal:
   1. Time
   2. Amplitude
   3. Particle type: neutron or $\gamma$ according to the lowest $X^2$
5. Baseline += fitted pulse
PSA performance I

BC501A pulse

DATA

Fitted $\gamma$ shape

Fitted n shape
PSA performance II

BC501A pulse

DATA
Fitted $\gamma$ shape
Fitted $n$ shape
PSA resolution

BC501A response to a $^{60}$Co $\gamma$-ray source

Digital integration
Fit to true shape
Canberra DSA 2000
BC501A response to an Am/Be neutron source

Am/Be neutron source spectrum

Counts

Area method

Fit to True Shape

Differ in 1.2% of all cases

Photons

Neutrons

Pulse Area

Counts

Am/Be neutron source spectrum

Differ in 1.2% of all cases

Photons

Neutrons

Pulse Area

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Photons

Neutrons

Pulse Area
Fit to True shape method: n/\gamma discrimination

Fit to True Shape: n/\gamma discrimination

\chi^2

\chi^2_{\text{neutron}}

Neutrons

Photons
Pile-up analysis

The digital restoring of the baseline after a fitted pulse, allow to identify and reconstruct pile-up events very close in time.

The PSA capabilities for the identification and reconstruction of pile-up events has been systematically studied by the analysis of Monte Carlo generated pile-up events:

1. Sort particle type \((n,\gamma)\) and amplitude \((10-250)\) of Pulse 1.
2. Sort particle type \((n,\gamma)\) and amplitude \((10-250)\) of Pulse 2.
3. Sort time distance between the pulses, up to 120 ns.
4. Build up the event with chosen characteristics introducing a realistic Gaussian noise.
5. Analyze and compare the results with the known input.
MC generated pile-up event I

Pile Up reconstruction

Amplitude

Neutron (A=80)

$\text{t}_{\text{dist}} = 150 \text{ ns}$

Neutron (A=55)

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MC generated pile-up event II

Pile Up reconstruction

Neutron (A=80)
$t_{\text{dist}} = 43 \text{ ns} \Rightarrow \text{At the limit!!!}$

Neutron (A=55)
Pile-Up analysis success rate

The pile-up successful rate has been studied as a function of the ratio of amplitudes between the two signals for in the two possible cases: $A_1 > A_2$ and $A_1 < A_2$.
True Pile-Up event with the GENEPI D-T source (CNRS-Grenoble)

BC501A with D-T neutron source
True Pile-Up event with the GENEPI D-T source (CNRS-Grenoble)

BC501A with D-T neutron source
Conclusions

Several neutron detectors have been tested at CIEMAT and other facilities. The 12.7cm x 12.7cm Bicron BC501A (NE213) neutron detector has been characterized using digital electronics. For this, an innovative Pulse Shape Analysis Routine have been designed and tested:

- The detector and the PSA have been characterized and tested with neutron and γ-sources neutron source.

- The PSA is based on the least squares fit to the true (average) γ and neutron pulse shapes. In the case neutron signals, a dependence on the magnitude of the slow component tail with the amplitude of the signal has been observed and parameterized. The γ shape does not depend on the amplitude.

- The PSA resolution and n/γ discrimination capabilities are similar to those of standard integration methods.

- The PSA allows to reconstruct successfully (both amplitude and particle type) pile-upped MC generated events as close as 60-90 ns.

- The PSA presented in this work can be applied to any detector type.

- Future work: test digitizers with higher dynamic range (≥10 bits) and other sampling rates.