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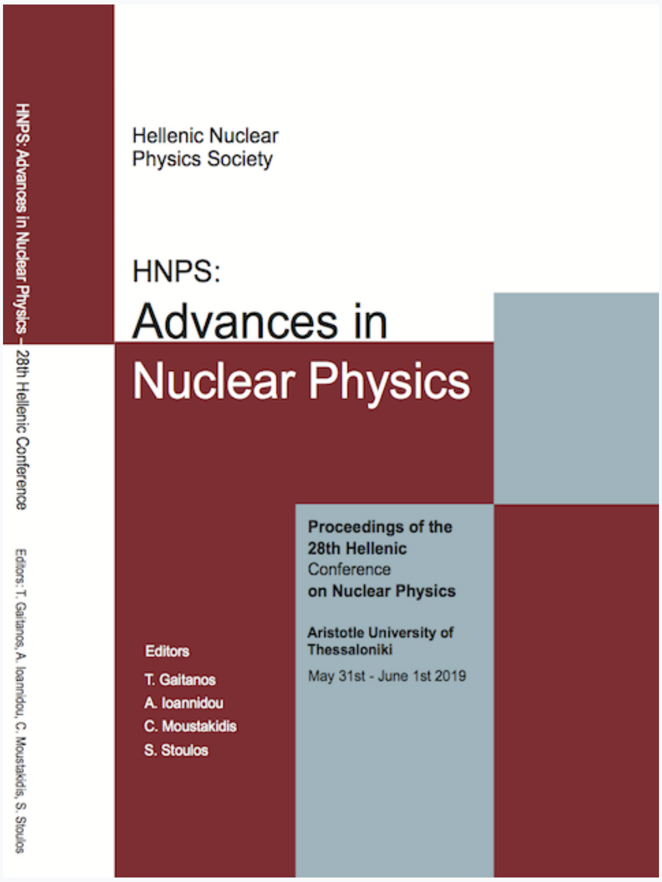

A detailed study of the high energy neutron flux (15-20 MeV) at NCSR “Demokritos” using a BC501A liquid scintillator

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A detailed study of the high energy neutron flux (15–20 MeV) at NCSR "Demokritos" using a BC501A liquid scintillator

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Abstract *The current study was carried out for neutron beam energies ranging between 14.8 and 19.2 MeV using the $^{3}H(d,n)^{4}He$ reaction and included neutron/gamma discrimination and neutron monitoring utilizing a BC501A liquid scintillator, followed by a pulse shape discrimination-capable circuit. Tests were conducted in order to determine the characteristics and limitations of the employed experimental setup. The deconvolution of the acquired spectra was performed using the DIFBAS computer code. The algorithm is based on the Bayesian conditional probability, while the covariance filter method was employed to calculate the a posteriori neutron flux spectrum along with its covariance matrix. The produced neutron beam proved to be practically monoenergetic for low energy deuterons, while at higher deuteron beam energies, the strong presence of parasitic and scattered neutrons was revealed.*

Keywords *fast neutrons, liquid scintillator, pulse shape discrimination, deconvolution*

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INTRODUCTION

Neutron induced reactions, especially the (n,p), (n,xn) and (n,f) ones, are of considerable importance for the fundamental nuclear physics research as well as for nuclear technology, medical and industrial applications. These reactions, for the highest possible neutron beam energies, have been studied by our group in a variety of medium and high–Z targets at the 5.5 MeV Tandem Accelerator of NCSR "Demokritos", where such neutrons are produced via the $^{3}H(d,n)^{4}He$ reaction. The primary deuteron beam, as well as the secondary neutron one, may further induce parasitic neutrons having lower energies and the accurate characterization of the total neutron beam flux impinging on the targets under study is mandatory in order to extract reliable cross section values. Neutron fields are generally contaminated with photons, which either stem from the neutron source itself or are produced by interaction of the neutrons with matter in the environment of the source, target, experimental area and the detector itself [1]. Hence, neutron spectrometers used to characterize the neutron fields should either be insensitive to photons, or capable of discriminating photon-induced events [2–5]. Furthermore, acquired neutron spectra require appropriate software in order to derive the neutron flux.

NEUTRON/GAMMA DISCRIMINATION

Neutron and γ-ray (n/γ) discrimination techniques working with liquid scintillation detectors are widely used in applications involving fast neutrons. The n/γ discrimination property of liquid scintillators is based on a difference in the intensity of the delayed fluorescence components of the scintillation light pulse in the organic scintillators, generated by the recoil protons and electrons. The

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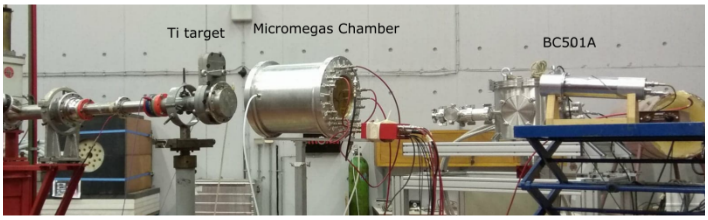
common method of exploiting this property in scintillation detectors is a pulse shape discrimination (PSD) circuit.[6–8].

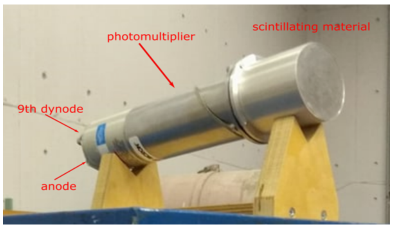
In the present work the liquid scintillator BC501A was implemented followed by a PSD circuit based on the analog Zero-Crossing (ZC) method [4–5] in which a zero-crossing time bears the pulse-shape information. Since neutron and γ-rays are distinguished, the latter can be rejected and only the neutron energy spectra can be recorded.

The aforementioned experimental setup was placed at the neutron facility in the 5.5 MV tandem T11/25 Accelerator Laboratory of NCSR "Demokritos", where high-energy neutron beams, at energies ~15–20 MeV, were produced by means of the $^{3}H(d,n)^{4}He$ reaction [5]. The corresponding deuteron beam energies obtained from the accelerator, were 1.75–4.5 MeV and bombarded a Ti–Tritiated target of 373 GBq activity. The scintillator was placed at a distance of ~3 m away from the target and behind an experimental chamber filled with MicroMegas detectors used for fission cross-section measurements on actinides.

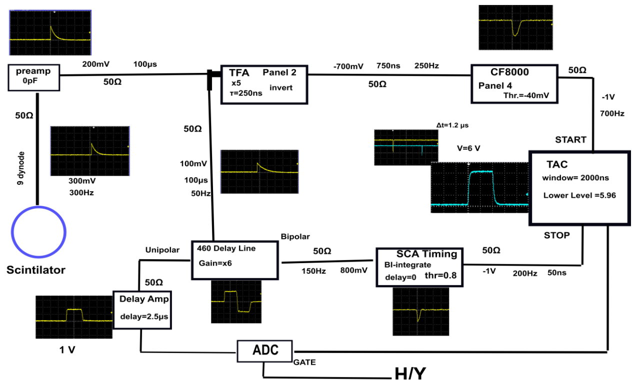
The experimental setup along with the scintillator and a diagram of the employed circuit are depicted ın the following images.



(a)



(b)



(c)

Figure 1. *(a) The experimental setup, (b) Image of BC501A liqid scintillator, (c) A schematic diagram of the PSD circuit*

THE DIFBAS CODE

Acquired experimental pulse high spectra can be described in terms of a matrix as:

$$z=R\Phi$$

where z stands for the recorded counts, R is the response matrix of the scintillator, which is derived from a Monte Carlo simulation and Φ is the requested neutron flux. The aim of the unfolding task is to adjust Φ on the base of the measurements, on the condition of a precisely known response matrix and give as a result the a posteriori probability distribution and the covariance matrix of the spectrum.

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The DIFBAS code [9] was used to unfold the pulse height spectra measured by the BC501A scintillator into neutron spectra. The algorithm is based on the Bayesian conditional probability assuming normal distributions of the pulse height spectra:

$$P(\Phi|\mathrm{R,z}) \propto P(z|\Phi,\mathrm{r}) \times P(\Phi,\mathrm{R})$$

The DIFBAS code employs the covariance filter method to calculate the a posteriori spectrum and covariance matrix of the neutron spectrum, which minimizes the demands on computer time, is a numerically stable method and is advantageous in cases where the widely used matrix inversion method has failed.

A short demonstration of the code's flowchart is depicted below:

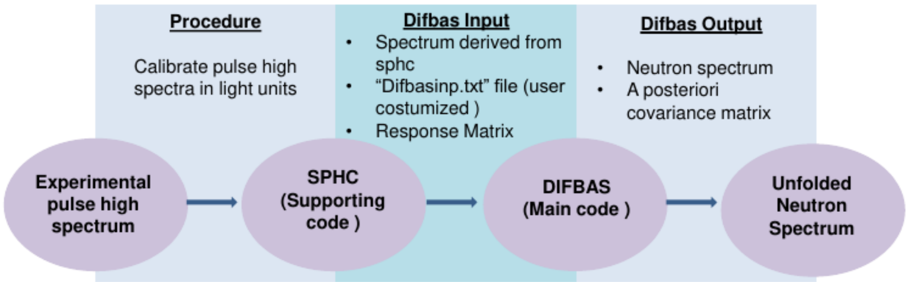

Figure 2. *Flowchart of unfolding procedure and DIFBAS code*

EXPERIMENTAL AND UNFOLDED NEUTRON SPECTRA

In terms of experimental spectra, the aforementioned experimental procedure along with the unfolded spectra is shown in the following images:

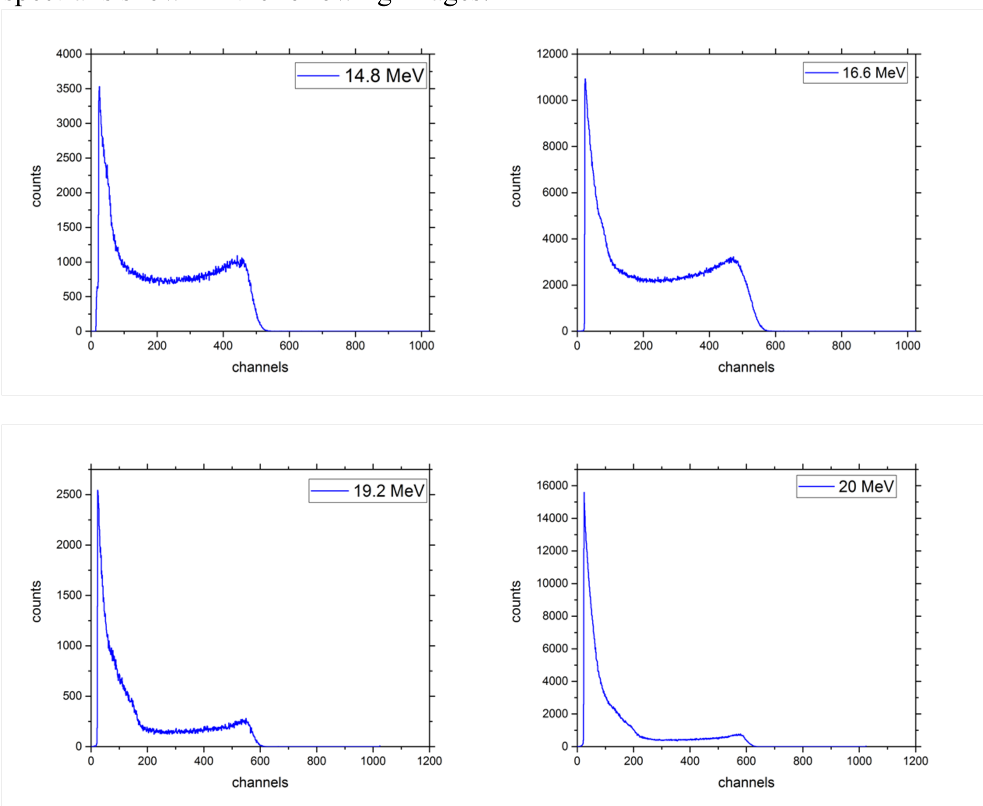

Figure 3. *Neutron spectra derived from BC501A for different beam energies*

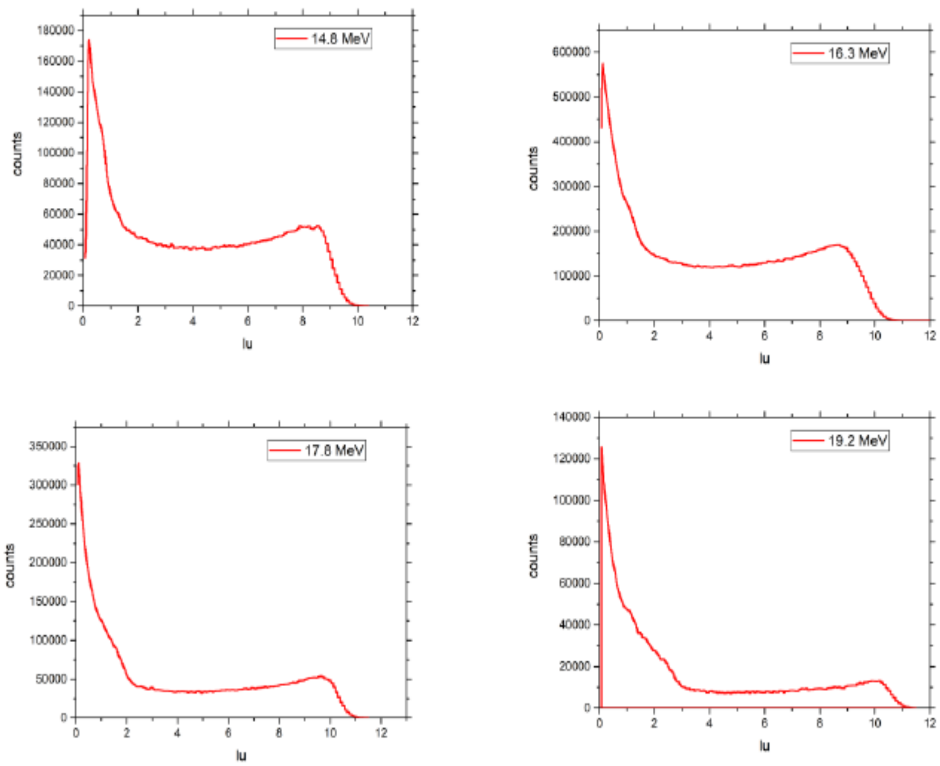

Figure 4: *Neutron spectra calibrated in light units for different beam energies using the SPHC supporting code*

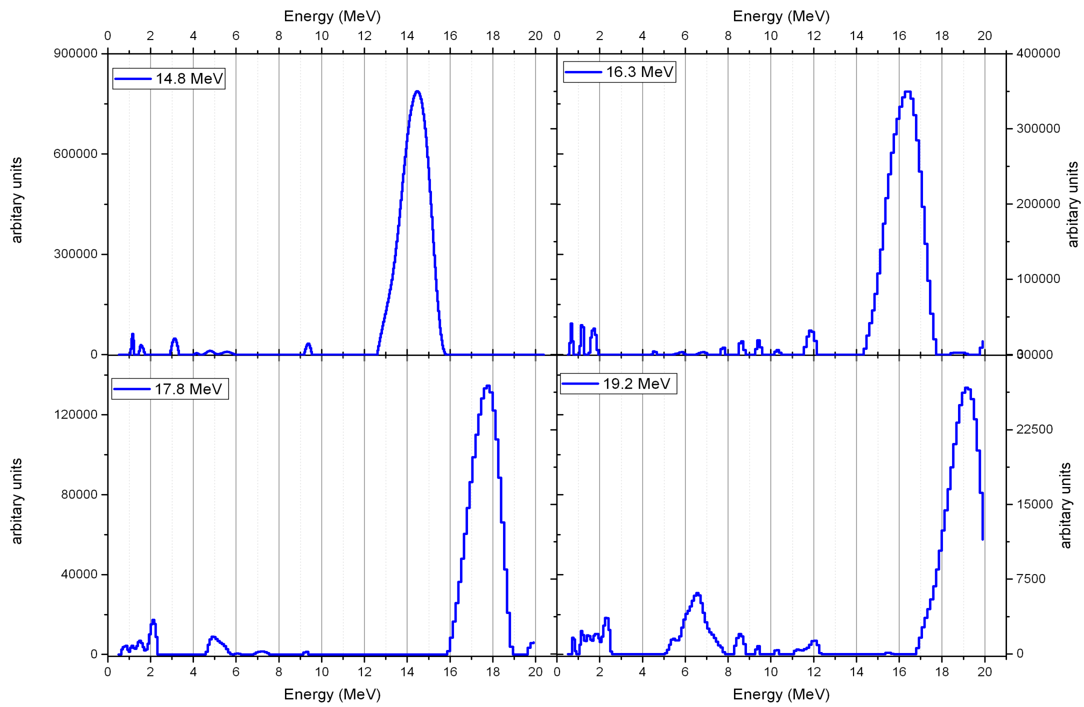

Figure 5. *Deconvoluted neutron spectra using DIFBAS code*

CONCLUSIONS

During the conducted experiment BC501A proved its excellent n/γ discrimination capability and is suggested to be used as an online neutron monitor in several neutron experiments.

Regarding the neutron beam produced by the $^{3}H(d,n)^{4}He$ reaction, it was fairly monoenergetic for the lower deuteron beam energies but had a considerable production of lower energy neutrons for the high energy deuteron beams, originating from deuteron induced reactions and multiple scattering of neutrons with the structural materials of the target, beam line or the experimental room.

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