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Calibration of a TOF spectrometer in neutron measurements

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Abstract : Calibration procedure of a time-of-flight (TOF) spectrometer used in neutron measurements at Maxlab, is described This includes both pulse height and neutron flight time which is important in neutron energy determinations The pulse is recorded by ADC and time information is recorded by TDC in electronic system.

Keywords : TOF, photonuclear experiment, neutron source

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1. Introduction

Photonuclear reaction is one of the best way to investigate nuclear structure as the interaction of photons with the nuclei is relatively weak and it is described by quantum electrodynamics (QED) theory which is one of the best known theory in physics. A photonuclear reaction can be characterised by a photon incoming into a target nuclei and detection of one or more particles knocked out from target. The electronic system is a vital part of such an experiment as all information such as pulse height, time and scaler, from detectors is required to convert into digital words. A typical photonuclear experiment [1-6] at Maxlab [7] involves the collection of two types of data; event type data, from Analog-to-Digital Converters (ADC) and Time-to-Digital Converters (TDC), and scaler type data. In a (γ, n) reaction at Maxlab, the ADC, gated by neutron detector, digitizes the pulse amplitude which is necessary to calculate the neutron detection efficiency and also is useful for n/γ discrimination purposes [8]. One output of the signal from neutron detector, after suitable delay, drives the stop input of a TDC which shows which neutron detector(s) has fired. In a photonuclear experiment, it is important to know which photon causes the reaction. Tagging of the photon is the best solution. This requires simultaneous detection of neutron (in TOF) and recoil electron (in electron detector called Focal Plane Detector (FPD)). Signals from the 64 scintillators of the FPD are fed to dual-threshold discriminators and after delay they produce stop inputs for 64 FASTBUS based FPD TDC's, which are started by the neutron detector. The neutron TOF information is recorded in the FPD TDC's which shows TOF-FPD coincidences. As the neutron is uncharged, the kinetic energy is determined [9] by measuring neutron flight time (TOF method) recorded by TDC and thus, the calibration of both ADC and TDC are important. In this work, the calibration of the ADC and TDC used in photoneutron measurement at Maxlab, will be detailed and some recent (γ, n) reaction results obtained from 4mm thickness tungsten target at Maxlab will be presented.

2. The neutron TOF spectrum

The neutron carries no charge and therefore, has no Coulomb interaction with the atomic electrons of the detecting medium. A neutron may interact elastically or inelasticalty with the nuclei of the detector material. Energy transfer to the recoil nucleus is maximized when the recoil mass is minimized and therefore, the H(n,p) scattering process is the most useful for converting neutrons to detectable, energetic charged particles (protons). Thus, materials with an high hydrogen content such as organic compounds are often used for neutron detection. The TOF spectrometer [8] consists of two 60 × 60 × 10 cm tanks of NE213 liquid scintillator each segmented into a 3 × 3 array of separate detector. A plastic scintillator (NE110) surrounding the liquid scintillator is used to veto charged particles. Blocks of borated wax and lead were built around the tank to attenuate background

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neutrons and photons. A typical experimental setup for (γ, n) reaction measurement at Maxlab is shown in Figure 1.

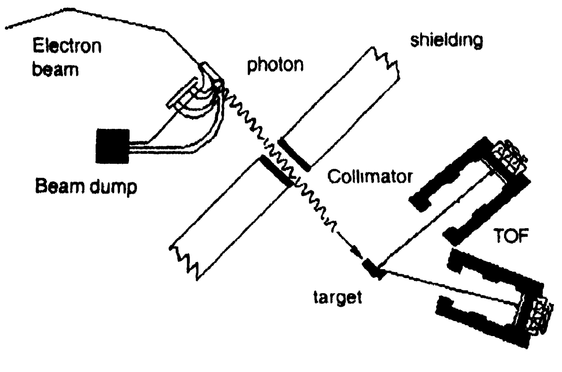

Figure 1. Experimental setup for (γ, n) reaction at Maxlab

3. Pulse-height calibration

Although neutron energy is not determined directly from pulse height collected from neutron detector to determine neutron detection efficiency, the detection threshold of the recoil charged particle has to be known. This requires calibration of the pulse-height signal in ADC. Near detection threshold, the detection efficiency is a nonlinear and it was evaluated using the Stanton [10] MC code which has been widely used for a variety of organic scintillator materials and geometry. The neutron detection threshold energy is determined in hardware and in software during offline analysis. Pu-Be n/γ [11], Pu-Be surrounded by teflon ($C_2H_2F_4$), ^{60}Co and ^{228}Th sources were used to calibrate the relationship between pulse-height in spectrum channel and recoil electron energy. The non-linear response of the NE213 liquid scintillator to protons is usually expressed in terms of the linear equivalent electron energy using the empirical expression [12]:

$$E_e = 0.83\times E_p - 2.82\times\left(1-e^{-0.25\times E_p^{0.93}}\right),$$

where the parameters were determined from fits to measured proton response. At low energy, the interaction of γ's in the liquid scintillator is mainly by Compton scattering. The Compton edge (maximum possible) electron energy is given by

$$E_e = \frac{E_\gamma}{1+\dfrac{m_0c^2}{2E_\gamma}}.$$

Figure 2A shows Compton electron energy spectra taken with various sources mentioned before. Edge determination follows the method of Knox *et al* [13]. The γ-ray lines employed for the calibration were as follows :

$$1.17, 1.33\,\text{MeV} : {}^{60}_{27}\text{Co} \rightarrow \beta^- + {}^{60}_{28}\text{Ni}^* \rightarrow {}^{60}_{28}\text{Ni}^* \rightarrow {}^{60}_{28}\text{Ni},$$

$$2.61\,\text{MeV} : {}^{228}\text{Tl} \rightarrow {}^{208}\text{Pb}^* \rightarrow {}^{208}\text{Pb},$$

$$4.44\text{-MeV} : {}^{9}\text{Be}(\alpha, n)\ {}^{12}\text{C}^* \rightarrow {}^{12}\text{C},$$

$$6.13\,\text{MeV} \quad \text{F}(n,\alpha)\ {}^{16}\text{N}^* \rightarrow {}^{16}\text{O}^* \rightarrow {}^{16}\text{O},$$

$$7.14\,\text{MeV} : {}^{19}\text{F}(n,\alpha)\ {}^{16}\text{N}^* \rightarrow {}^{16}\text{O}^* \rightarrow {}^{16}\text{O}.$$

The two highest lines are produced by neutron interactions with fluorine (F) in the teflon. A linear fit of the Compton edge *versus* observed channel number (Figure 2B) gives the calibration. In Figure 3, a typical pulse-height signal from the neutron detector is displayed.

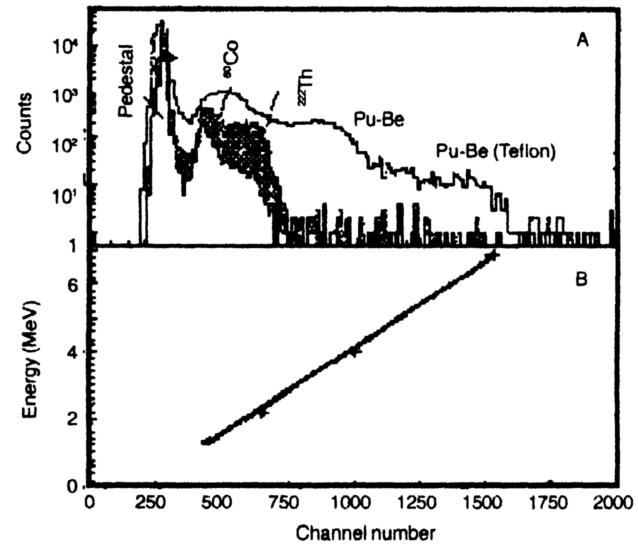

Figure 2. Neutron detector pulse-height spectrum from ^{60}Co, ^{228}Th, Pu-Be sources in A and a linear fit of energy against channel number in B

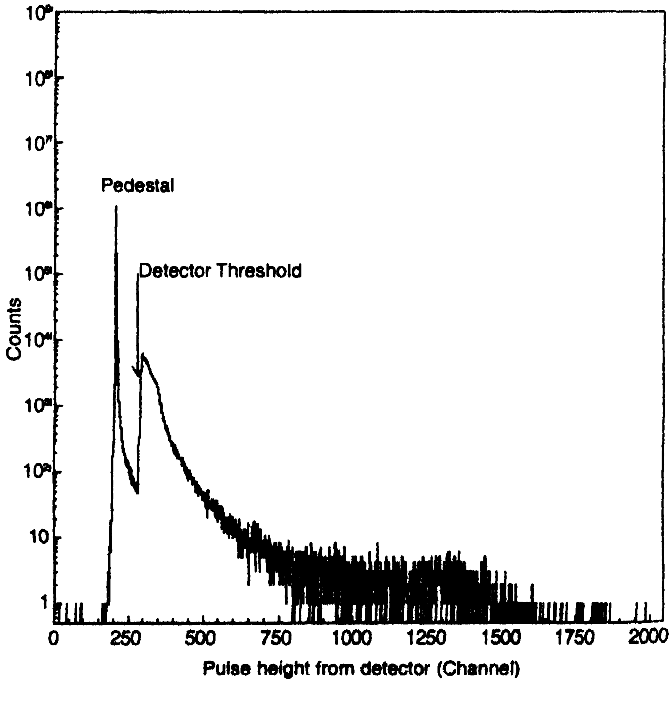

Figure 3. Pulse from neutron detector during the real experiment.

4. Neutron time-of-flight calibration

Neutron energy is determined by TOF [9] which is recorded in TDC's, started by the neutron detectors and stopped by the FPD. Time-to-channel conversion was calibrated using an ORTEC 462 time calibrator set to provide stop pulses at n x 20 ns intervals after the start where n is an integer. Figure 4A shows a typical TDC spectrum and Figure 4B shows a linear fit of time against channel. The gradient gives the TDC conversion gain and for all 64 FPD TDC's, the conversion gain is about 0.72 ns/channel.

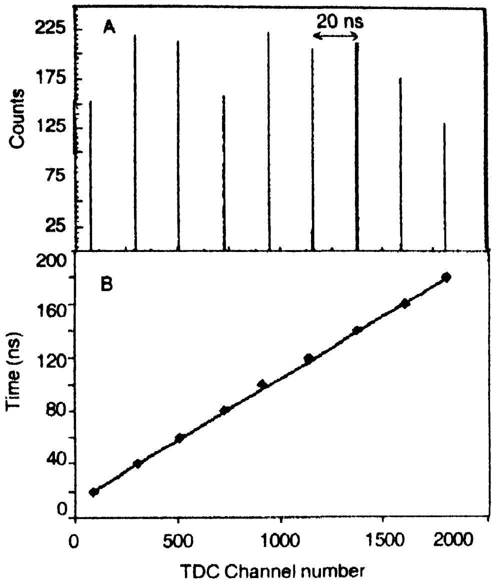

Figure 4. (A) TDC calibration spectrum from calibrator and (B) corresponding linear fit.

4.1. Time-zero calibration :

The time difference between a start signal from a neutron detector and a stop signal from the FPD is used to determine the time-of-flight of the neutrons. This time difference contains contributions from signal propagation delays in detectors and cables. In order to get the absolute flight time of the neutron, the time-zero (T_0) point was extrapolated from a measurement of relativistic electrons produced by tagged bremsstrahlung. The T_0 point is a time d/c earlier than the coincidence peak position (time runs from high to low channel). Under normal running conditions where neutrons are selected, the TDC spectrum of Figure 5 (unshaded part) results neutron distribution for ^{184}W (γ, n) reaction where tungsten thickness was 4 mm. The contents of the spectrum arise from two main sources:

(i) Neutrons from the target produced by tagged photons which gives neutron distribution [Figure 5 (unshaded histogram)].

(ii) Neutrons from the target produced by untagged photons which make random coincidences with the FPD. These give the essentially flat background on which the forementioned structure sits [Figure 5 (shaded part)].

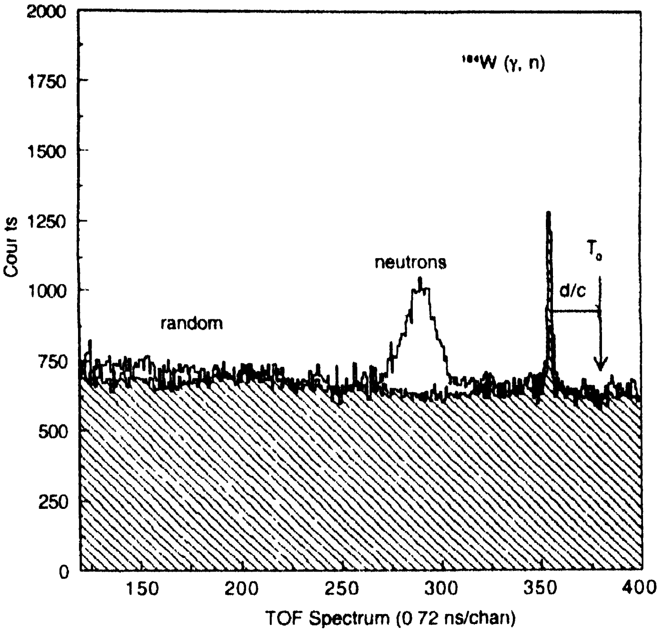

Figure 5. TOF spectrum of ^{184}W(γ, n) reaction with the contribution of random coincidences (shaded)

The neutron energy spectrum has been extracted from time information (Figure 5) and this is displayed in Figure 6 (upper)

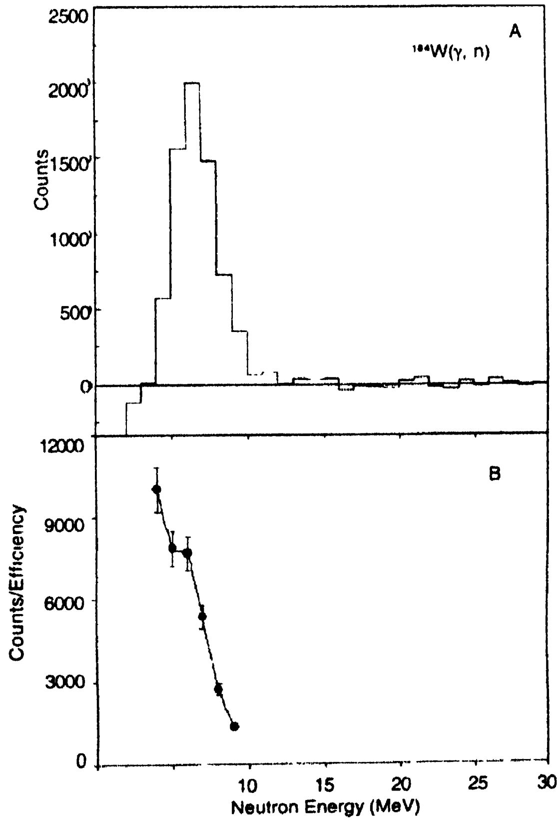

Figure 6. A: Neutron energy spectrum obtained from TOF signal for ^{184}W(γ, n) reaction. B: Neutron energy spectrum corrected for neutron detection efficiency.

for (γ, n) reaction in 4 mm thickness of tungsten target. In Figure 6(lower), the neutron energy is corrected for neutron detection efficiency. The figure shows that the detector threshold is 4 MeV and the significant counts in the 4-10 MeV corresponds the ground state of residual nucleus after ^{184}W(γ, n) reaction. It has been shown in this work that the calibration in such experiment where the energy is obtained from time information, is a vital part of the experiment.

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