Determination of neutron energy spectra using pulse height unfolding technique and its comparison with time of flight method

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Two methods are often used to determine the energy in neutron spectroscopy using recoil proton technique. These are pulse height (PH) unfolding and time of flight (TOF). TOF is more popular than PH unfolding due to its more straight forward approach and higher level of accuracy. In this method, the time of flight distribution of neutrons for a known flight path is recorded. Start signal is generally taken from an ancillary detector or using the RF signal from the accelerator. This time distribution is converted to neutron energy using the known flight path and the proper Jacobian transformation. The accuracy of the measurement depends on the flight path length and time resolution of the instruments used. Although, longer flight path provides greater accuracy but the flux detected are reduced due to poor solid angle. Also this needs large experimental area to keep the detectors at a large distance. Besides this, there are other situations like; (i) non availability of the pulsed beam or suitable ancillary detector, (ii) broad source distribution, (iii) unkown source position etc. In those cases, the PH unfolding technique is the only method to determine the neutron energy distribution. In unfolding method PH spectra of the detector is unfolded to get the neutron energy using a known response matrix.

In PH unfolding technique neutron energy spectra $\Phi(E)$ can be determined from the measured PH spectra C(E′) using the following Fredholm integral equation

$$C(E') = \int_{E_{min}}^{E_{max}} R(E', E)\Phi(E)dE \qquad (1)$$

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Here, R(E′, E) is the detector response function which is defined as the probability that a neutron of energy E would deposits an energy in between E′ and E′+dE′. The limits of the integration should be same as the range of the neutron energy spectrum. Different computer codes like FERDOR[1], MAXED[2], GAVEL[3] are developed to solve the Fredholm equation to determine the neutron energy spectrum $\Phi(E)$ from PH spectrum. FERDOR code used in this work, transforms the counts of a particular PH bin (C_i) to an estimated counts in the neutron energy bin (p_k). This is done using a linear combination of C_i with a suitable coefficients u_i

$$p_k = \sum_{i=1}^{m} u_i C_i \qquad (2)$$

where m and k are the number of PH and energy bins respectively. Substituting the values of C_i from Eqn. 2 into Eqn. 1, the estimated counts in the k^{th} neutron energy bin p_k can be written as

$$p_k = \int_{E_{min}}^{E_{max}} (\sum_{i=1}^{m} u_i R_i(E))\Phi(E)dE \qquad (3)$$

In the above expression E′ is dropped because, for a given PH bin E′ response function will be a function of E only. Replacing $\sum_{i=1}^{m} u_i R_i(E)$ with W_k(E), the Eqn. 3 becomes

$$p_k = \int_{E_{min}}^{E_{max}} W_k(E)\Phi(E)dE \qquad (4)$$

The estimated counts are the weighted average of neutron energy spectrum. A plot of p_k versus k would give an useful approximation of the neutron energy spectrum. But for continuous functions like $\Phi(E)$ and p_k it is not possible to choose u_i which can match them for all values of E with a finite number of PH

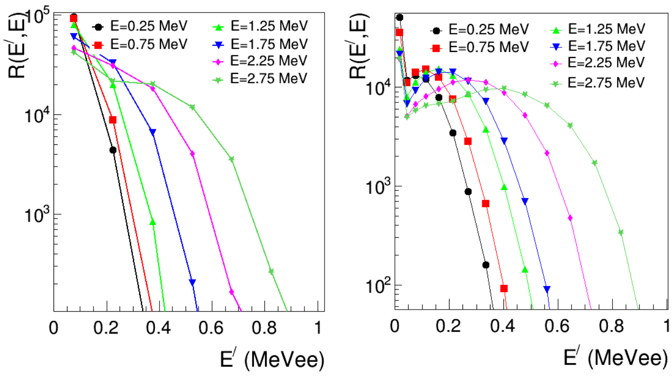

FIG. 1: Pulse height spectra for different neutron energies using usual binning (left) and conformal binning (right).

bins. So, u_is are chosen within a finite confidence interval only, in which the solution lies between lower and upper bound of the confidence interval. Within that confidence interval the coefficients u_is are determined using the least square method [4].

The accuracy of the measured neutron energy spectra depends on the accuracy of the response function $R(E', E)$ used. In this work, response functions have been calculated carefully using the Geant4 simulation at a regular energy interval of 0.25MeV up to the neutron energy 20MeV. The calculated response matrix needs to be compared with the measured data at several neutron energies prior to its use. This was done in our earlier work using the mono-energetic neutrons [5]. The deposited energy in the scintillator E' is a nonlinear function of neutron energy E. As the low PH region contains more information, so conformal binning procedure has been adopted to prepare the response function [6]. In conformal binning, the width of PH bin is varied as a function of energy binning rather than the equal interval as used in the usual binning. Fig. 1 shows PH spectrum has peak like structure at low pulse height in the conformal binned spectrum which is not visible in the normal binned spectrum.

Neutron energy spectrum was determined from the measured PH spectrum using the above mentioned unfolding technique for ^{252}Cf source. Energy spectrum thus obtained is compared with the same using TOF method and are shown in Fig. 2. Area under the

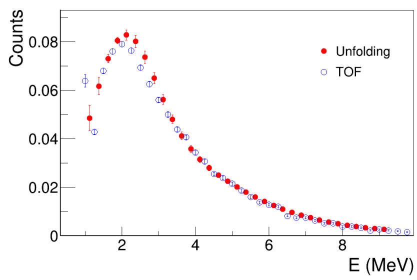

FIG. 2: Neutron energy spectrum obtained using PH unfolding and TOF method.

curves are normalized to 1. Energy spectrum thus obtained using PH unfolding technique shows a good agreement with that obtained from the TOF method. However, more stringent tests using mono-energetic neutrons are required to validate the unfolding procedure.

References

[1] Rust et. al., ORNL, 1983.
[2] M.Reginatto et. al., NIM A 476, 242 (2002).
[3] Y. Chen et al., Sci. China Phys. Mech. Astron. 57, 1885 (2014).
[4] W. R. Burrus et. al., Nucl. Instr. Meth. 67, 181 (1969).
[5] A.S. Roy et. al., JINST 16 P07045 (2021).
[6] Christopher C. Lawrence, PhD Thesis, University of Michigan (2014).