Unfolding and Reconstruction of Neutron Spectra using Hybrid Neutron Detector

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Introduction

A custom-built hybrid neutron detector (HND) is used in this study, which consists of Bicron BC501A and BC702 that are sensitive for fast and thermal neutrons, respectively [1]. The characteristics and performance of the HND adopted in this measurement was described in detail in Ref.[1].

Response Function and Unfolding

The response function $R_{ij}(L_i, E_j)$ was generated by using Monte Carlo simulation, by means of generating 1 million neutron particles at energy E_j to obtain the light output spectrum L of recoil particles.

For the calculation of the neutron flux $\Phi(E_j)$, the response functions was calculated for 1000 neutron energies of E_j between 0 and 20 MeV. For a specific incidence neutron energy E_j and i^{th} component of light output L_i

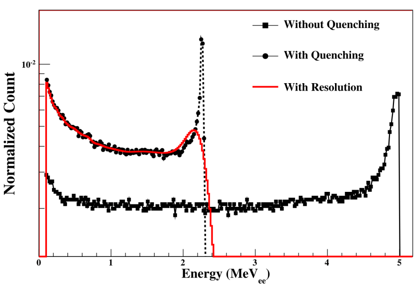

FIG. 1: Simulation of the detector response to 5 MeV monochromatic neutron beam with and without quenching effect [1].

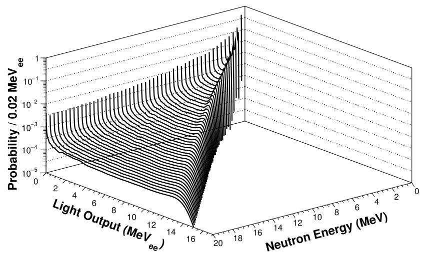

FIG. 2: Response functions R(L,E) for $E_n = 0$ - 20 MeV monochromatic neutrons [1].

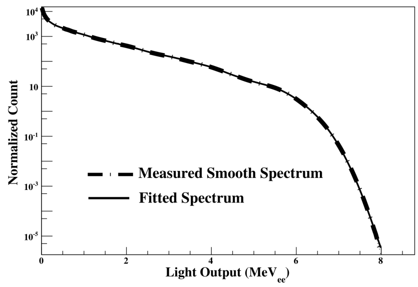

FIG. 3: Measured recoil spectrum of $^{241}AmBe(\alpha, n)$ source [1].

the response function given as [1],

$$R_{ij}(L_i, E_j) = \sum_k \int_{L_i-\Delta L}^{L_i+\Delta L} \frac{C_k}{\sqrt{2\pi}\sigma} e^{\frac{-(L'-L_k)^2}{2\sigma^2}} dL' , \quad (1)$$

where L_i is the i^{th} bin of light output value of the response function. C_k is the content of the k^{th} bin of the spectrum. $\sigma(L_k)$ is the RMS error for L_k.

Figure 1 shows the response function for incident neutrons with 5 MeV obtained from the corresponding simulated light output of recoil spectrum and the resolution functions.

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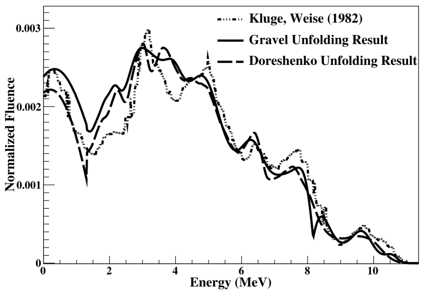

FIG. 4: Convoluted neutron influence of $^{241}AmBe(\alpha, n)$ source with two unfolding methods in comparison with the measurement of Kluge and Weise (1982) [1, 3].

The response functions of R(L,E) are constructed for 1000 neutrons energies up to 20 MeV with 20 keV energy steps. The response functions for all neutron energies is illustrated in Figure 2 [1].

Unfolding is a widely used computational method in spectroscopy. There are several computational algorithms for unfolding in literature [1–3]. In this work two of them are used, one is developed by Doroshenko [2] and the other one is Gravel unfolding method [1, 2], both of them calculate the neutron flux by an iterative method. The iteration algorithm of Doroshenko can be written as,

$$\Phi_j^{n+1} = \frac{\Phi_j^n}{\sum_i R_{ij}} \sum_i R_{ij} \frac{N_i}{\sum_k \Phi_k^n R_{ik}}. \quad (2)$$

This algorithm calculates the j^{th} bin of the neutron flux $\Phi_j(E_j)$. The index n over the Φ indicates the iteration number. The algorithm works with the inputs $N_i(L_i)$, detector measurement, response function $R_{ij}(L_i, E_j)$ and an initial neutron flux $\Phi_j^0(E_j)$.

The Gravel unfolding method can be written as,

$$\Phi_j^{n+1} = \Phi_j^n exp \left(\frac{\sum_i W_{ij}^n ln \left(\frac{N_i}{\sum_k \Phi_k^n R_{ik}} \right)}{\sum_i W_{ij}^n} \right), \quad (3)$$

where R_{ij} represents the response function obtained from Eq. 1. N_i is the measured counts in i^{th} bin light output. W_{ij} is a weight factor defined as,

$$W_{ij}^n = \frac{R_{ij}\Phi_j^n}{\sum_k \Phi_k^n R_{ik}} \frac{N_i^2}{\sigma^2}, \quad (4)$$

where σ represents the RMS error of the light output. The convergence of the iterative procedure is controlled by χ^2/degree of freedom (dof) given in Eq. 5. When it is close to unity the iteration will be terminated.

$$\chi^2/dof = \frac{1}{dof} \sum_i \frac{\left(\sum_j R_{ij}\Phi_j - N_i \right)^2}{\sigma_i^2}. \quad (5)$$

The detector has been exposed to a well known fast neutron source of ^{241}AmBe(α,n) to test the unfolding methods. The fast neutron band shown in Figure 12 of Ref. [1], which is equivalent to the recoil spectrum as shown in figure 3 taken as an input for both of the iterative methods. The resulting unfolded ^{241}AmBe(α,n) fluxes for both methods are shown in figure 4 along with the measurement of Kluge and Weise in 1982 [3]. Figure 4 show the perfect match of the peak positions and the shape in general are obtained successfully. Therefore, the simulation package developed in this study is able to reproduce the actual neutron energy spectra from the recoiled spectra.

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