UNFOLDING OF NEUTRON SPECTRA FROM PROTON-RECOIL DATA USING THE ITERATIVE DIFFERENTIATION METHOD

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ABSTRACT

An "Iterative Differentiation method", has been developed to the differentiation unfolding of neutron spectra from proton recoil pulse height distributions. It allows the differentiation method to correct for any distortions that can be measured or calculated and used to construct neutron response functions for a given detector. Iterative Differentiation unfolding utilizes a response matrix to calculate corrections for the proton energy distribution based on an estimated neutron spectrum. The neutron spectrum is then calculated using a simple differentiation method. The newly calculated neutron spectrum is used to calculate a more accurate correction and this process continues untill a converged spectrum is obtained. This method has the advantage of improved resolution associated with differentiation method. The " Iterative Differentiation Method" proved to get results comparable to those obtained by the matrix inversion methods using half as much computer time.

Keywords: Neutrons, Fusion, Iteration, Plasma.

1- INTRODUCTION

An ideal proton recoil spectrometer would record the energy distribution of recoil protons without distortion and would be thin enough so that none of the incident neutrons would scatter more than once in the detector. In this case the measured proton energy distribution can be used to obtain the incident neutron fluence, / 1 /.

$$\Phi(E) = \frac{-E}{\sum_{h}(E)} \frac{d}{dE} N(E) \qquad (1)$$

where Φ (E) is the incident neutron fluence (neutrons/cm^2. Mev), Σ_h(E) is the hydrogen macroscopic scattering cross section (cm^{-1}) and N(E) is the density of recoiling protons (protons/Mev. cm^3).

When an organic scintillator is used as a proton recoil spectrometer, the resulting pulse height distribution is distorted in a variety of ways compared to what would be measured by hypothetical ideal spectrometer. The individual effects on the measured distribution of the most important factors contributing to distortion are described else where, /2/.

2- ITERATIVE DIFFERENTIATION METHOD

Defining R (E$'$ → E) as the distribution of counts per unit proton energy, E, in an actual spectrometer due to 1 incident neutron of energy E$'$, and M(E) as the observed counts per unit energy distribution for an arbitrary incident neutron, fluence spectrum gives ;

$$M(E) = A \int_{E''-E}^{\infty} \Phi (E') R(E' \rightarrow E)\, dE' \qquad (2)$$

Where A is the area of the detector upon which neutrons are incident. By defining the average thickness of the ideal detector to be the same as the neutron mean free path, then Σ_h (E) = A/V, and the ideal response in protons per unit energy is :

$$I(E) = A \int_{E'=E}^{\infty} \frac{\Phi(E')}{E'} \, dE' \qquad (3)$$

where V is the detector volume.
If an approximation to the incident neutron is available, then by forming the ratio of ideal to actual response a correction factor for the measured counts per unit energy distribution may be obtained. Defining qapproximate fluence as $\Phi^*(E)$ and the correction factor as C (E) gives:

$$C(E) = \frac{\int_{E'=E}^{\infty} \frac{\Phi^*(E')}{E'} dE'}{\int_{E'=0}^{\infty} \Phi^*(E') R(E' \rightarrow E) dE'} \qquad (4)$$

Now equation (1) can be applied

$$\Phi(E) = \frac{-E}{A} \frac{d[M(E)C(E)]}{dE} \qquad (5)$$

This formulation provides a way for combining the resolution capability of differentiation methods with the correction accuracy of matrix methods. Because an approximate neutron spectrum is used to obtain the correction factor, the method will be iterative.

Qualitatively, there are two steps in practical implementation of the method. First, a crude approximation to the neutron spectrum is calculated in order to obtain a rough correction factor that is used to calculate a better estimate of the spectrum. Then, the better estimate is used to calculate a better correction and so on until the neutron spectrum does not change with further iterations. Because experimental continuous data are not available, so equation (5) must be written in a matrix form. Therefore, some new variables are defined: Φ_{i*n} is the approximate neutron fluence in the ith energy bin for the nth iteration. The energy index for the measured proton recoil energy distribution and the calculated fluence is i. The energy giving rise to a particular response function is given an index j. $\Phi_{j*\,n-1}$ is the approximate neutron fluence from the (n-1) iteration rebinned in j energy bins each with a width E_j so that the correction factor may be calculated.

Now equation (5) can be written as :

$$\Phi_i^{*n} = E_i \frac{d}{dE} \left[\frac{M_i \sum_{j=k}^{j} \Phi_j^{*n-1} \delta E_j / E_j}{A \sum_{j=1}^{j} \Phi_j^{*n-1} R_{ij} \delta E_j} \right] \qquad (6)$$

where k is defined so that E_k is the first j energy value larger than E_i . When M_i and the denominator agree within the limits of experimental error, the process has converged and the last set of values for the neutron spectrum is the one desired.

3- NEUTRON SPECTRUM UNFOLDING CODE

The first step in converting the formalism developed in the previous section into a viable method for analysing experimental data is to choose an appropriate binning structure. The highest energy of interest to the author was that of DT neutrons generated in Deuterium-Tritium fusion plasma, i.e., a miximum source energy of about 15 Mev. The detector resolution was expected to be the better than 10 % fwhm at this energy. Adding 2 fwhn to the maximum source energy gives about 18 Mev, which was chosen as the high energy cutoff. The bining structure chosen consisted of 113 energy bins, / 3 /.

The present state of the art in unfolding NE-213 proton recoil data is well represented by the code MFERDOR, / 4 /. MFERDOR is based on the matrix inversion method and comes with a 113 x 70 neutron response matrix. Before this response matrix could be used to unfold the available experimental data, / 4 /, it had to be rebinned. The rebining was accomplished using code that deleted response function outside the energy range to be considered. This code generated two sets of response functions. One was the response versus pulse height, which is used by MFERDOR and the other was the response versus energy, which is used by MIDM (Modified Iterative Differentiation Method), /5 /, which was the code used to implement the iterative differentiation unfolding formula developed in this paper. A data preparation code was used to smooth the pulse height distribution using Fourier transform techniques, / 6 /.

4- TEST OF RESULTS

As a test of the new unfolding method, MIDM, Am-Be, ^{252} Cf , D-D and D-T spectra, / 4 / were unfolded. Plots of the MFERDOR and MIDM results were presented in Figures (1-4). The Am- Be and ^{252}Cf spectra are shown in Figure (1) and (2) respectively it is apperent that the agreement between MFERDOR and MIDM results for 2.5 Mev neutrons (D-D) and 14 Mev neutrons (D-T) are shown in Figures (3) and (4) respectively. The MIDM unfold peak is higher and has a narrower full width at half maximum than the MFERDOR unfolded peak. Therefor, MIDM demonstrated better resolution than MFERDOR. A typical spectrum unfolded by MIDM required half of the computer time required by MFERDOR because the iterative method proposed here uses the response matrix as a correction term instead of using it directly for unfolding, it is likely that the iterative method will be able to accurately unfold spectra for a wider range of variations in experimental systems than can the matrix inversion methods.

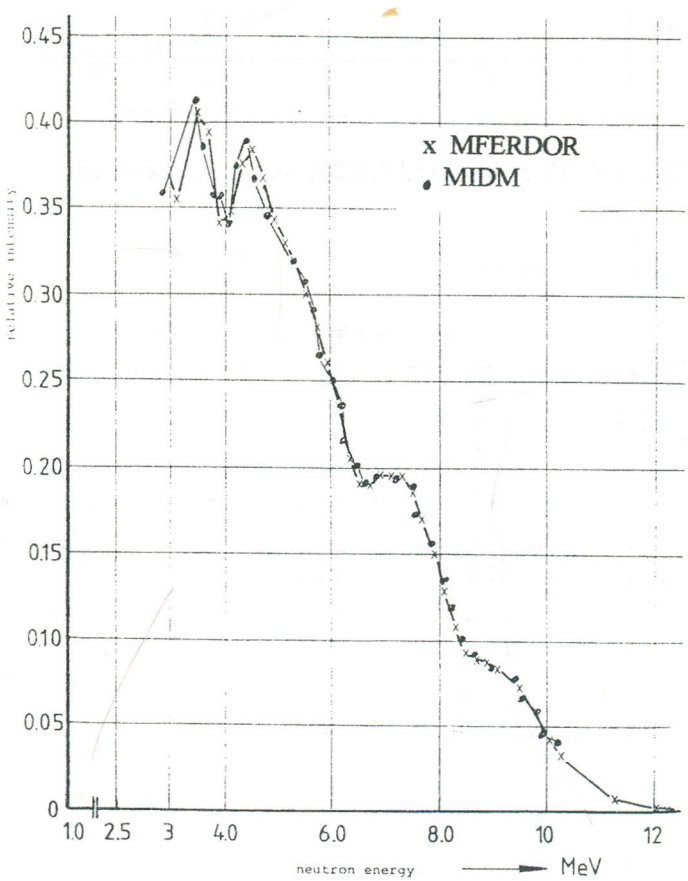

Figure 1. Am-Be neutron spectrum unfolded using MFERDOR and MIDM.

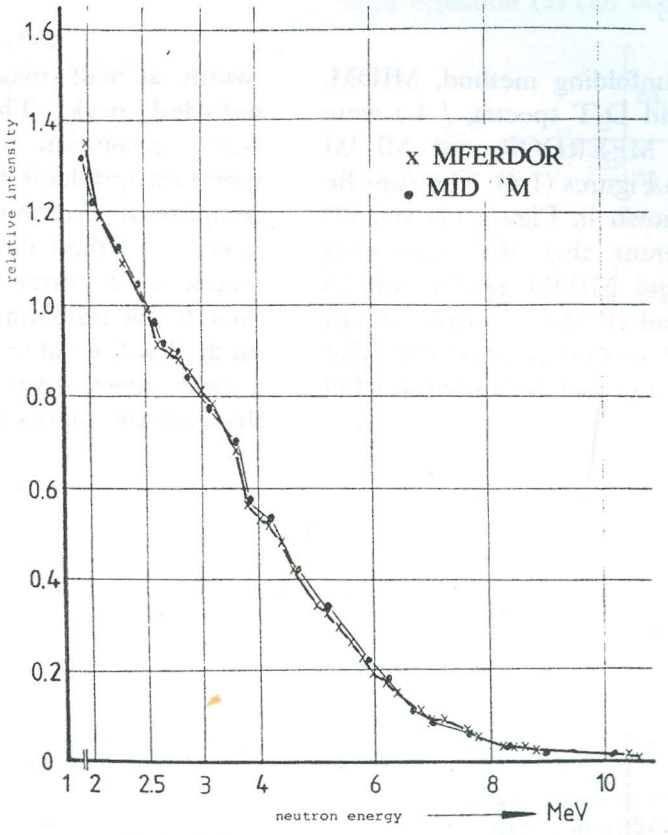

Figure 2. The unfolded Cf-252 neutron spectrum.

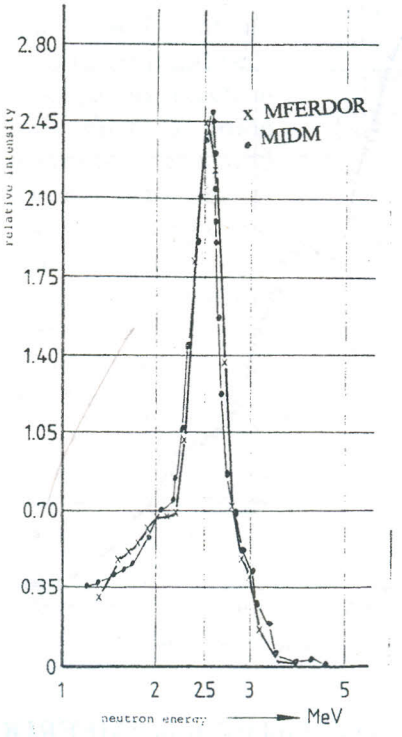

Figure 3. Neutron spectrum of D-T (14 Mev) neutrons unfloded by FERDOR and MIDM.

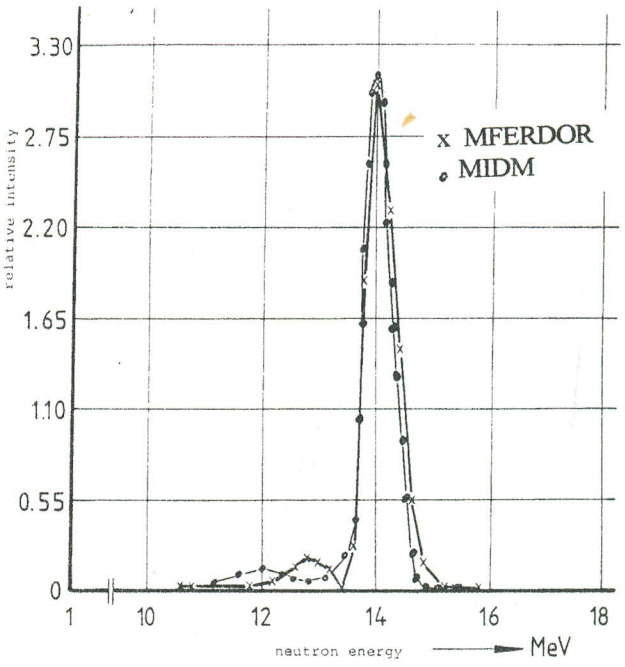

Figure 4. Neutron spectrum of D-D (2.5 Mev) neutrons unfloded by FFERDOR and MIDM.

5- CONCLUSIONS

The method of Iterative Differentiation Unfolding provides a combination of some of the features attributed to either differentiation method or response matrix unfolding, but not to both. The MIDM provides results with the accuracy associated with the state of the art MFERDOR while avoiding the large matrix inversions and the extraneous oscillations they introduce. Differentiation method proved also to obtain the improved resolution associated with differentiation methods. Finally the iterative differentiation unfolding method uses about one-half the computer time required to the matix inversion methods.

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