A Neutron Spectrum Unfolding Code Based on Iterative Procedures

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Abstract: In this work, the version 3.0 of the neutron spectrum unfolding code called Neutron Spectrometry and Dosimetry from Universidad Autónoma de Zacatecas (NSDUAZ), is presented. This code was designed in a graphical interface under the LabVIEW programming environment and it is based on the iterative SPUNIT iterative algorithm, using as entrance data, only the rate counts obtained with 7 Bonner Spheres based on a 6LiI(Eu) neutron detector. The main features of the code are: it is intuitive and friendly to the user; it has a programming routine which automatically selects the “initial guess” spectrum by using a set of neutron spectra compiled by the International Atomic Energy Agency. Besides the neutron spectrum, this code calculates the total flux, the mean energy, \( H^*(10), h^*(10), \) 15 dosimetric quantities for radiation protection porpoises and 7 survey meter responses, in four energy grids, based on the International Atomic Energy Agency compilation. This code generates a full report in html format with all relevant information. In this work, the neutron spectrum of a 241AmBe neutron source on air, located at 150 cm from detector, is unfolded.

Keywords: Neutron; Spectrometry; Dosimetry; SPUNIT algorithm; Iterative procedures; Unfolding codes.

1. Introduction

The process of unfolding the neutron energy spectrum has been the subject of research for many years [1, 2 3]. The spectrum unfolding is expressed by the homogeneous Fredholm equation, whose discrete version is showed in equation (1).

\[
C_j = \sum_{i=1}^{M} R_{ij} \Phi(k) - \Phi(k) \rightarrow j = 1, 2, ..., N
\]

(1)

where \( R_{jk} \) is the response of the \( j^{th} \) detector to neutrons in the \( k^{th} \) energy interval multiplied by the width of the \( k^{th} \) energy interval. \( M \) is the number of energy intervals.

Unfolding consists of determining \( \Phi(k) \) for all energy groups, given a limited number of detector measurements and an appropriate detector response matrix \( R_{jk} \) [2]. The physical constraints that all matrix elements be non-negative are imposed upon the problem.

Normally, the resolution of the unfolded \( \Phi \) vector in terms of the number of energy groups is far greater than the number of sphere measurements practically obtained; this is an undetermined matrix problem, leading to an infinite number of solutions to equation (1).

The goal of the unfolding process is to determine a single solution that closely approximates the actual neutron fluence energy spectrum and that produces an associated personnel dose that closely estimates the actual dose [3].

The Bonner spheres System (BSS), has gained wide spread acceptance as a dose assessment tool since it was introduced in 1961 [4, 5]. Unfolding the neutron spectrum from BSS measured data becomes somewhat complicated as well as tricky and thus requires specialized unfolding techniques [6]. This is because, the number of detectors used is much less compared to the number of energy intervals in which the flux distribution is sought at. Therefore, the system of equations to be solved becomes undetermined and the numerical algorithm to be used for unfolding the data needs validation for specific use.

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In general, the desired neutron spectrum is obtained by numerically inverting equation (1) using an unfolding algorithm that implicitly defines a solution of this equation [7].

During the past decades have been carried out intents to develop new neutron spectra unfolding codes like BUNKIU [8], BUMS [9], FRUIT [6], UMG, etc., to attain improved energy resolution through spectrum unfolding.

However, these methods still present serious drawbacks such as the complexity in their use, the necessity of a very expert user and an initial guess spectrum, where their appropriate selection affects in great measure the quality of the obtained solution, however, in the practice the proper selection is a difficult task. Each of the mentioned difficulties has motivated the development of alternative techniques. In this work, a new version, 3.0, of the neutron spectra unfolding code known as Neutron Spectrometry and Dosimetry from Universidad Autónoma de Zacatecas (NSDUAZ), developed under LabVIEW environment, is presented.

By using the NSDUAZ code, Ver. 3.0, the neutron spectrum of three Lineal Accelerators (LINACs), were unfolded.

### 2. Materials and Methods

In prior works, an earlier version of the NSDUAZ unfolding code was designed for a $^6$Li(Eu) neutron detector [10, 11, 12, 13]. Main drawbacks associated with this version of the code, 1.0, were that unfolding is carried out using few energy groups using the UTA4 response matrix, expressed in 31 energy bins.

In this work, the version, 3.0 of the NSDUAZ code, showed in figure1, is presented.

In this version, the energy was taken from IAEA compilation which is expressed in 60 energy bins. A response matrix for a $^6$Li(Eu) neutron detector was selected from this spectrum compendium. 15 dosimetric quantities and 7 survey meter responses are calculated in four energy grids, with the IAEA dose conversion coefficients.

The method for solving the unfolding problem is based on the SUPNIT iterative algorithm, which was implemented in a programming routine under the LabVIEW programming environment.

By using the IAEA neutron spectrum compilation, a programming routine was designed in order to automate the selection of the initial guess spectrum. The trend of the count rates plotted against the sphere diameter allows using this information to select the initial guess spectrum.

Once the neutron spectrum is unfolded, the total flux $\Phi$, the mean energy $E_{AV}$, $H^{+}(10)$, $h^{+}(10)$, 15 dosimetric quantities for radiation protection porpoises, and 7 survey meter responses, in four energy grids, are calculated. The numerical values of the fluence-to-dose conversion factors for the doses and instruments, $h^{+}\Phi(E)$ and $i^{+}\Phi(E)$, respectively, were taken from the IAEA neutron spectrum compilation.

In NSDUAZ, the BSS count rates are saved in a TXT file writing the count rates of Balls 0, 2, 3, 5, 8, 10 and 12 in a single column. Once the user calls the TXT file, by clicking the folder icon, the convergence error and the maximum amount of iterations must be input by the user; by default the code has 10% and 1000, respectively. By pressing the “Unfold Spectra” button, the unfolding process begins.

### 3. Results

In this work, the NSDUAZ unfolding code, Ver. 3.0, was used for unfolding the neutron spectrum of three Lineal Accelerators (LINACs): A 10 MV MEVATRON, a 10 MV PRIMUS and 18 MV Varian respectively.

The BSS rate counts were used as the only entrance data to the code. Figure 2 through 4, shown the spectra unfolded with the NSDUAZ code. These figures show the graphical shape of the neutron spectrum unfolded with the SPUNIT algorithm, faced with the initial guess spectrum selected by the automated programming routine.

The numerical values of the maximum number of iterations, the $\chi^2$ - value, the total flux $\Phi$ are calculated. Also, the mean energy $E_{AV}$, the Ambient dose equivalent, $H^{+}(10)$ and the Fluence-to-Ambient dose factor $h^{+}(10)$, calculated for four energy bin criteria: Lower, Intermediate, Upper and Median, these are shown also shown in the main interface of the code.
In order to generate a report of the neutron spectrum unfolding carried out, the user should clicking in the “Generate Report” button.

4. Conclusions

At present there are several unfolding codes which use iterative routines. The main disadvantage of these procedures is that require an initial solution to start the unfolding process. The quality of the final solution is affected by the initial guess spectrum.

NSDUAZ is a user friendly neutron spectra unfolding package for a BSS with a $^{6}$Li(Eu) neutron detector and based on the iterative SPUNIT algorithm. It works with a response matrix taken from IAEA compilation, expressed in 60 energy groups ranging from thermal to 630 MeV.

The main features of the code are: was designed in a graphical user interface under the LabVIEW programming environment; it is friendly, intuitive and easy to use for the end user; for the deconvolution of the spectrum it uses a programming routine which automate the initial guess spectrum selection from a library of neutron spectrum compiled by IAEA and its corresponding calculated rates counts.

A programming routine was designed in order to generate a report, in html format, which contains the most important information of the unfolding process. Contrary to the existent iterative codes, the main feature of this tool is the automated selection of the initial guess spectrum by means of a catalogue of neutrons spectra.

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References


