# UNCERTAINTIES RELATED TO NUMERICAL METHODS FOR NEUTRON SPECTRA UNFOLDING

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## ABSTRACT

*One of the often used techniques for neutron detection in radiation protection utilizes the Bonner multisphere spectrometer. Besides its advantages and universal applicability for evaluatting integral parameters of neutron fields in health physics practice, the outstanding problems of the method are data analysis and the accuracy of the results.*

*This paper briefly discusses some numerical problems related to neutron spectra unfolding, such as uncertainty of the response matrix as a source of error, and the possibility of real time data reduction using microcomputers.*

## INTRODUCTION

Most important quantity in radiation protection is the dose equivalent. It depends on QF (quality factor) of radiation. This factor describes biological effectivness of radiation , it is a function of the type of radiation, and in the case of neutrons, of neutron energy spectra. But this is the field that still has no unique solution. Often, shape of neutron spectrum can be predicted, but there are some situations in radiation protection practice, when the knowledge of neutron energy spectrum is required. For example,some of them are when neutron monitors with no flat response are used , when the leakage from the shielding is suspected or whenever atipical situation occur.

One of the common techniques utilizes Bonner multisphere spectrometer. Its main advantages are that it covers an energy range from thermal to tens of MeV, and a possibility of evaluating integral parameters (such as neutron fluence, dose, dose equivalent, dose to fluence conversion factors) of leakage and stray neutron fields. But, outstanding problems of the method are data analysis and the accuracy of the final results.

The aim of this work is to establish a portable system capable of measuring and recording neutron spectra at a site,to transfer data to a microcomputer and to unfold spectra with

sufficient speed and accuracy. In order to achieve this aim, one of world's referenced numerical codes is installed on IBM PC AT, teated and adjusted.

## THE MULTISPHERE TECHNIQUE

This design as a spectrometer was proposed in 1960.(1), and since,many of papers on its applicability have been reported. It consists of a thermal neutron detector (originaly 4mm diameter and 4 mm thick LiI(Eu) scintilator) and several polyethylene spheres of different sizes. The detector is placed in the center of the moderator and it is conected with photomultiplier and the rest of electronics with the light pipe.

Modereted neutrons are detected from scintilations arised from 4.787 MeV alphas released in $^{6}Li\ (n,\alpha)^{3}H$ reaction.

## THE UNFOLDING PROBLEM - THE FORMULATION

The unknown neutron spectrum is not given directly as the result of measurement./4/ Its relation to the measured quantities can be expressed by the equation:

$$A_i = \int_E R_i(E)\,\phi(E)\,dE + \varepsilon_i \qquad i=1,\ldots,m \qquad (1)$$

where

$A_i$ is the i-th mesured response ,i.e. the count rate of a multisphere detector

$R_i$ is the response function of the detector

$\phi(E)$ is the energy dependent neutron flux

$\varepsilon_i$ is the unknown error reflecting the uncertainties of measured responses

Mathematically the problem is a degenerate case of the Fredholm's integral equation of the first kind. It does not have a unique solution since a finite number of discrete measurement cannot define a continuous function. The solution of this problem is called spectrum unfolding or deconvolution.

Response functions of different detector systems are measured and calculated and may be foun in matrix form as a "response matrix" for 31 discrete energy groups. Thus,for numerical solving, equation (1) can be rewritten as:

$$A_i = \sum_g R_{i,g}\phi_g \Delta E_g + \varepsilon_i \qquad i=1,\ldots,m \qquad (2)$$

or in the matrix form:

$$\underline{A} = \underline{R}\,\underline{\phi} + \underline{\varepsilon} \qquad (3)$$

## THE UNFOLDING PROBLEM - SOLUTION

The solution of this problem is called deconvolution or unfolding. The true spectral flux density function $\phi(E)$ is unobtainable because of uncertainties in the matrix elements R the finite number m of detectors and the experimental errors of the count rates. The goal of spectrometry can then only be to establish a set of quantities which include as much of the overall information about $\phi(E)$ as possible.

Assuming in the first step $\varepsilon=0$ ,equation (3) becomes a set of linear homogeneous equations. Usually the system is underdetermined,which means that the number of detectors is much smaller than the number of elements desired in the solution vector for the spectrum.

Deconvolution methods can be grouped into four categories: derivative,parametric,quadrature and Monte Carlo./3/

The primary application of the derivative method is with recoil particle detectors.

The parametric procedure may be used if a functional representation of the spectrum exists (evaporation spectra or fission spectra).

The quadrature method involves the solution of equation (3) by linear estimation,least squares, iterative or mathematical programming techniques or a combination. Three most common deconvolution codes (BON,LOUHI and SAND) used with Bonner multisphere spectrometer belong to this category.

The Monte Carlo category uses Monte Carlo technique to choose a neutron spectrum randomly. The only code known in this category is SWIFT. This method is very time consuming, with running times of 1000 - 10 000 s on CDC 6600.

## BON - THE ITERATIVE UNFOLDING CODE

Sanna /6/ has implemented an iterative method in the programme BON for unfolding multisphere spectrometer data.

The matrix equation (3) assuming $\varepsilon=0$, can be multiplied with $\underline{R}^T$ and tronsformed to:

$$\underline{R}^T\underline{A} = \underline{R}^T \underline{R}\ \underline{\phi}$$

or

$$\underline{B} = \underline{S}\ \underline{\phi}$$

where

$\underline{B} = \underline{R}^T \underline{A}$ and $\underline{S} = \underline{R}^T \underline{R}$.

Iterative procedure can be desribed with

$$\phi_i^{(k+1)} = \frac{B_i \, \phi_i^{(k)}}{\sum_i S_i \phi_i^{(k)}} \qquad i=1,\ldots,m$$

where k is the iteration step number.

The solution is not very sensitive to the selection of the initial guess. The iteration is terminated after 1000 steps.

The Bonner sphere method and the unfolding programme BON gives good results for smoothly varying continuous spectra, such as cosmic ray spectra or leakage spectra outside thick shields.

The programme is adjusted to be run at IBM PC AT. It is rewritten on IBM Proffessional Fortran Language.

Matrix solution is very unstable, so the test of stability and convergence should be implemented into the program.

## CONCLUSION

The very important thing in application of numerical codes is that they should never be used as "black boxes". Proper test runs should be taken, taking into acount all sources of error that can appear./6/ But, with the development of microcomputer techniques real time data aquisition and analysis becomes reality.

## REFERENCES


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