A TEST OF AN APPLICATION OF THE GENETIC ALGORITHM TO OBTAIN NEUTRON SPECTRA FROM BONNER-SPHERE MEASUREMENTS

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The Bonner-sphere technique [1] has been used for many years to determine neutron spectra. Using a set of moderating spheres having a range of diameters and known energy-dependent response functions, $R_i(E)$, the differential neutron flux density, w(E)-the "neutron spectrum", can be obtained from the measured responses, C_i, by "unfolding" the following integral:

$$C_i = \int_0^\infty \varphi(E) R_i(E) dE .$$

The unfolding problem is underdetermined, and therefore the solution is difficult. Several codes have been developed and are widely used to treat this problem. These include BUNKI [2], which uses an iterative recursion method, LOUHI [3], which uses a least-squares fitting technique, SWIFT [4], a Monte Carlo program, and PREF [5], which uses techniques based on Tikhonov's regularization method. In practice, it is desirable to use more than one code to obtain a given spectrum, so that one may compare results and guard against unphysical results.

We have tested a procedure developed by one of us [6], using the "Genetic Algorithm" [7] to obtain neutron fields from Bonner sphere measurements. Genetic algorithms are techniques that perform optimization by emulating Darwinian "Survival of the Fittest" concepts. Potential solutions to a problem are analogous to members of a species. Each individual member is characterized by a set of values, or "genes". When optimizing a solution to a problem, a member's "fitness" is measured by how well the problem is solved. "Fit" individuals are allowed to "survive" and "mate" to form new solution-sets.

The neutron spectrum of “n” energy groups (bins) can be represented as:

$$C_i = \sum_{j-1}^{n} \Phi_j R_{ij}, \quad j = 1,\ 2,\ 3,\ \ldots,$$

where

C_i = count rate for i^{th} sphere [s^{-1}],
F_j = neutron fluence of j^{th} group [neutron-cm^{-2}],
R_{ij} = response of i^{th} sphere for neutrons belong to j^{th} group [s^{-1}/neutron-cm^{-2}], and
i = 0, 2, 3, 5, 8, 10 (sphere diameter in inches).

We write, for each individual sphere:

$$A_i = C_i / \sum_{j-1}^{n} \Phi_j R_{ij} .$$

The starting values of fluence for each group, which we take as the "genes" in our example, define the initial set of "members of the species".

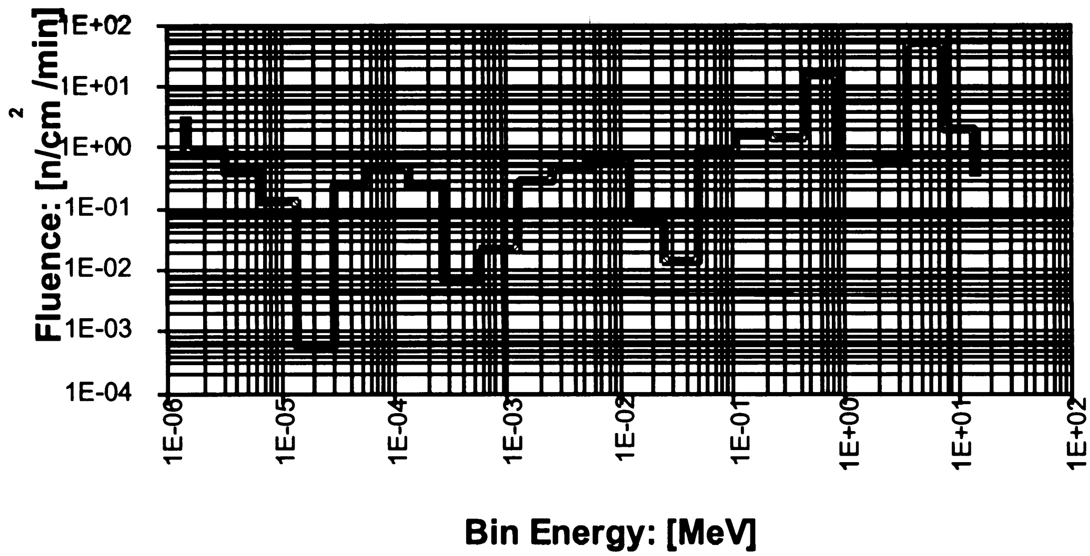

Figure 1: Un-Moderated Spectrum: E_{av} = 3.93 MeV, F = 971 n/cm^2/min

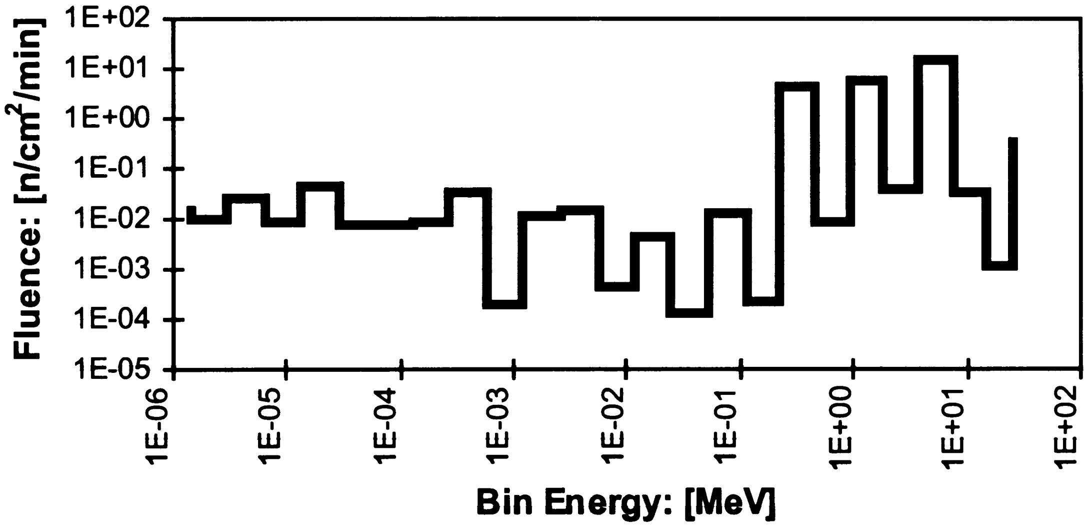

Figure 2: Paraffin-Moderated Spectrum: E_{av} = 2.80 MeV, F = 962 n/cm^2/min

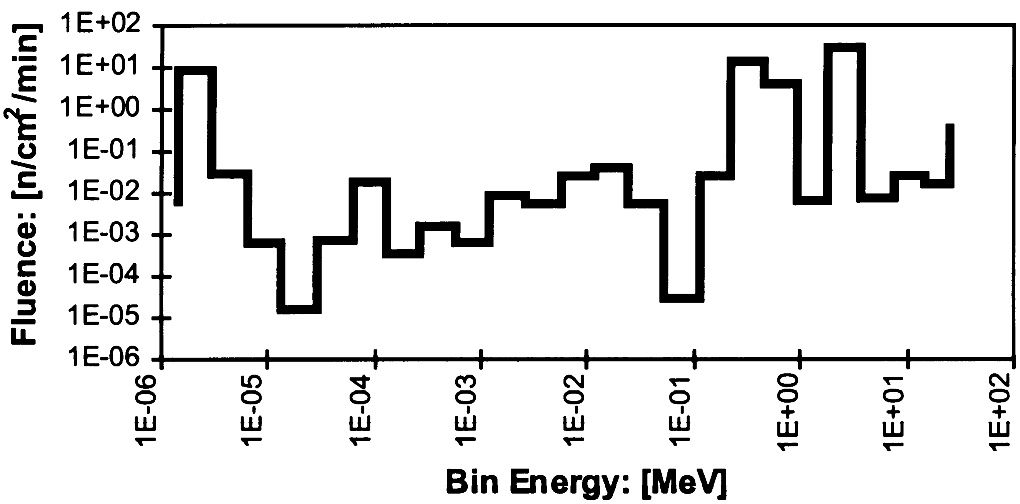

Figure 3: Steel-Moderated Spectrum: E_{av} = 1.59 MeV, F = 834 n/cm^2/min

The Genetic Algorithm program “EVOLVER” [7] optimizes ("mates" and determines the most "fit" members) the fluence vector $\sum_{j=1}^{n} \Phi j$ to fulfill the following conditions:

$$\text{AVERAGE}\ (A_0, A_2, A_3, A_5, A_8, A_{10}) \sim 1 \text{ (close to 1)} \qquad (1)$$

$$\text{STDEV}\ (A_0, A_2, A_3, A_5, A_8, A_{10}) \sim \text{small} \qquad (2)$$

When these conditions are met, the fluence vector component "genes" ensure the "fittest species", or solution. "EVOLVER" runs on an Excel Version 5 spreadsheet in the Windows 95 environment. In Reference 6, a standard deviation (STDEV) of ±10% (*i.e.*, goodness of unfolding of the neutron spectra) was achieved in about 10 minutes (10000 trials) using a Pentium 200 MHz PC.

To test this approach, the NSCL's Bonner-sphere set and a ^{239}Pu-Be neutron source (its activity was 5 Ci) were used to make measurements, using a well-reproducible geometry. The spheres had diameters of 2, 3, 5, 8, 10, and 12 inches. Measurements were also made without a moderating sphere, and with the detector covered with a layer of cadmium. The source-detector distance was 2 meters. The source was placed on a wooden platform, 1.87 meters above a concrete floor.

Measurements were made using the source without a moderator, with a paraffin moderator, and with an iron moderator. The paraffin was in an annular form (thickness = 30 mm). The iron was also in annular form (thickness = 76.2 mm). In each case, we deduced the neutron spectrum using the measured detector responses, and the unfolding code BUNKI. The "Sanna" response matrix set [8] was used. Then, the Genetic Algorithm technique was used to obtain each neutron spectrum, and the results were compared to that from BUNKI. Figures 1, 2 and 3 show the neutron spectra, deduced using the Genetic Algorithm, for the unmoderated source, the paraffin-moderated source, and the steel-moderated source, respectively. In each case, the spectrum, its average energy, and the measured flux were found to agree very well with those deduced using BUNKI.

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References

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