A NEW TYPE OF MODERATE-AND-CAPTURE NEUTRON SPECTROMETER

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INTRODUCTION

The Environmental Measurements Laboratory has been using the multisphere spectrometer system (1) to measure neutron spectra for many years with quite acceptable results (2,3).

Recent experience when studying the neutron environment inside pressurized water reactor containments (3) confirmed difficulties in using this type of spectrometer for field measurements. When the spheres are exposed simultaneously, as with ^{6}LiF and ^{7}LiF thermoluminescence detector pairs (TLD-600, TLD-700), the measurement has a spatial dependence. When exposed sequentially, as with ^{6}LiI scintillation detectors, the measurement has a time dependence. Therefore, variations of the neutron flux and/or spectrum with time or space, can produce errors in the measurement distribution. Though steps can be taken to minimize the effects of such variations, they remain a concern. In addition the number and weight of the detector moderator combinations comprising the multisphere spectrometer system, make its use under field conditions cumbersome.

One approach to solving the problem of time dependence is to expose passive detectors simultaneously, and spatial dependence can be overcome if a single moderator is used. An attempt at this approach placed TLDs at various depths along 14 radii of an 18 inch diameter polyethylene sphere (4). To reduce the weight (25 kg as opposed to 46 kg for the 18 inch sphere) of the moderator and provide a geometrical shape easier to manipulate, we chose to use a single polyethylene cube, 30 cm on an edge with a TLD-600, and TLD-700 detector pair at various depths along each of the major axes. The difference in signal between the TLD-600 and TLD-700 detectors, due to the $^{6}Li(n,\alpha)^{3}H$ reaction, is used as the neutron signal for that pair of detectors.

RESPONSE CALCULATIONS

Monte Carlo calculations of detector response were performed for detector depths of 1, 3, 5, 7, 9, 11, 13, and 15 cm along the major axes of the cube. These calculations were performed in the adjoint mode with the three dimensional Monte Carlo code Morse-CG (5), using both Russian roulette and splitting.

In these calculations the TLD chip used is 0.3175 x 0.3175 x 0.0889 cm on an edge, has a density of 2.678 g/cm^3, and is enriched to 95.62% ^6Li. The polyethylene cube used is 30 cm on an edge and has a density of 0.9217 g/cm^3. The cross sections used are the same as in our previous calculations for the multisphere spectrometer (6).

Large numbers of batches, each batch comprising several thousand histories, were run. Averages and standard deviations were then determined, for each energy group, among the batches. Enough batches were run to reduce the statistical uncertainty to less than 10% at the 1, 3, 5, and 7 cm depths, and to between 18% and 22% at greater depths. This statistical uncertainity was as low as could practically be achieved because of computer time restrictions. The results of these calculations are shown in Figure 1. Although the geometries are different, a comparison of these results with those found in references 4 and 6 indicates the reasonableness of these responses.

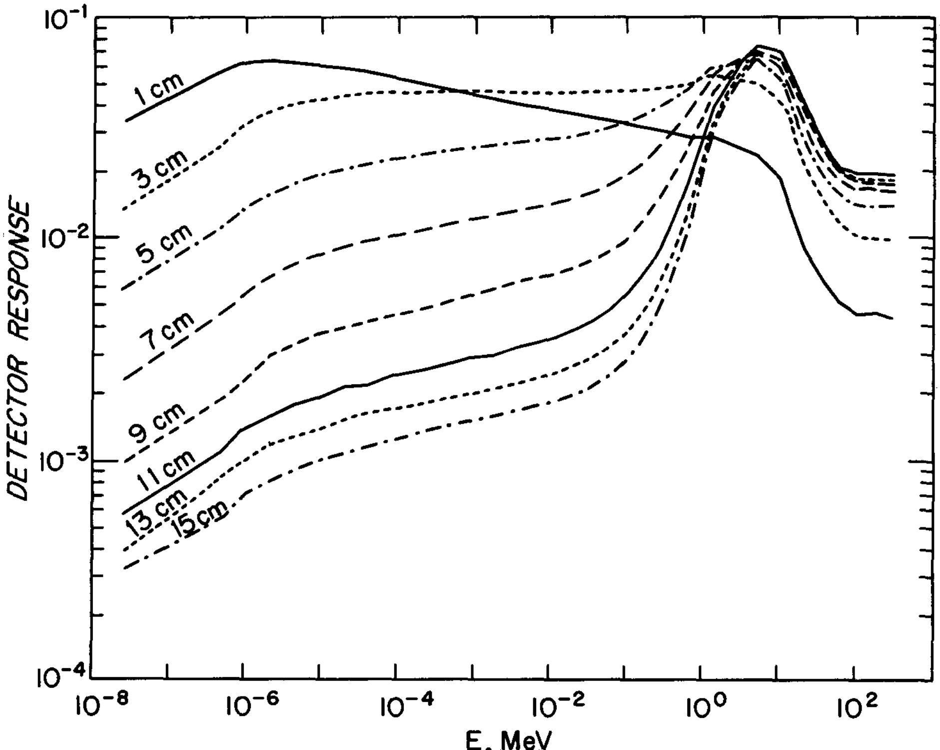

Figure 1. Response of ^{6}LiF TLD detectors at various depths along the axes of a polyethylene cube 30 cm on an edge for isotropic incidence.

TESTING THE SPECTROMETER

Mathematical testing of the ability of a spectrometer with the above responses to unfold neutron spectra from measurement distributions was performed with satisfactory results.

The response matrix was used to synthesize measurements from realistic, and idealized single and double line spectra. These pseudo-measurement distributions were analysed using the Monte Carlo spectral unfolding code SWIFT (7) to demonstrate the ability of the spectrometer to unfold neutron spectra from a variety of sources.

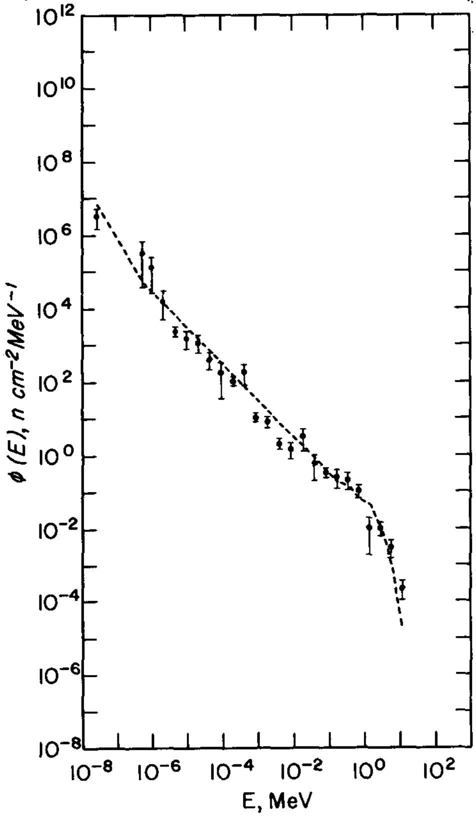

Figure 2. Comparison of original (dotted line) and unfolded spectra (points with error bars) in a beryllium reflector of a homogenous light-water reactor (8).

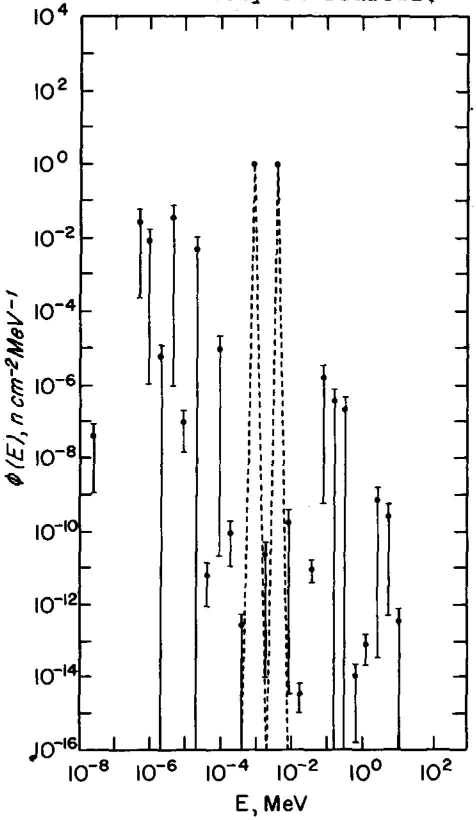

Figure 3. Comparison of original (dotted line) and unfolded spectra (points with error bars) for a double-line spectrum in energy groups 12 and 14.

Figures 2 and 3 compare the original spectrum in a beryllium reflector of a homogenous light-water reactor (8), and a double line spectrum with the unfolded spectrum from their measurement distributions. Agreement is good and is similar to that obtained for the other spectra tested. For the double line spectrum, Figure 3, the two lines contain 99.99% of the total flux and the precision is such that the standard deviations of the peaks are less than 0.5%, also the "noise" for any other energy group is less than 4% of the peaks.

In further tests, random errors were synthesized into the pseudo-measurements by sampling from cumulative Gaussian distributions. The means were the exact pseudo-measurement distributions and the standard deviations were 5%, 10%, 15%, and 20%. Four new distributions were generated for each standard deviation, unfolded, and the results compared to the original spectrum. These tests indicate that deterioration of the unfolded spectrum becomes marked when the level of error reaches 10%.

CONCLUSIONS AND ONGOING STUDIES

The cube should prove easier to use in the field and provide results of similar quality to those obtained with the multisphere spectrometer. Ongoing studies include empirical verification of the calculated responses and of the isotropy of response of the cube. Additional work will include a study of a cube, 25 cm on an edge, in an attempt to reduce even further the weight of the moderator. We also intend to study the feasibility of placing the TLDs along the diagonals of the cube to determine if better responses are obtained.

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