NEUTRON RESPONSE MATRIX FOR UNFOLDING NE-213 MEASUREMENTS TO 21 MeV

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ABSTRACT

We have generated a neutron response matrix from measured neutron responses of NE-213 in the energy range of 0.2 to 22 MeV. An interpolation scheme was used to construct an 81-column matrix from the data of Verbinski, Burrus, Love, Zobel, and Hill. As a test of the new response matrix, the Cf-252 neutron spectrum was measured and unfolded using the new response matrix and the FORIST unfolding code. The spectrum agrees well with previous measurements at lower energies, while providing new information above 8 MeV.

INTRODUCTION

The organic scintillator NE-213 has found widespread use as a fast-neutron spectrometer. Compactness and pulse-shape discrimination capability make NE-213 scintillators convenient for many fast-neutron applications. However, measured NE-213 proton-recoil pulse-height spectra require unfolding to yield neutron energy spectra. A widely used unfolding technique for NE-213 detectors is the FERDOR/COOLC code.[1] The FORIST code,[2] developed at the University of Illinois, is a recent improvement in the FERDOR series. These codes are available from the Radiation Shielding Information Center and are supplied with a standard neutron response matrix calculated using Monte Carlo techniques.[3] We have constructed from existing data a neutron response matrix for NE-213 which will replace the previous matrix supplied with FORIST. The new response matrix is based on accurate experimental results and extends to higher energies, permitting a correspondingly wider energy range for unfolding.

MEASURED DATA

The neutron response functions used to construct the response matrix were measured at Oak Ridge National Laboratory by Verbinski, Burrus, Love, Zobel, and Hill.[4] A 5-MeV Van de Graaff generator was used to produce neutrons from the $T(p,n)^3He$, $D(d,n)^3He$, and $T(d,n)^4He$ reactions. Using time-of-flight techniques and pulse-shape discrimination, they measured 20 neutron responses in the energy range of 0.2 to 22 MeV. The neutrons were incident on the curved surface of a 4.60- by 4.65-cm diam NE-213 detector. An additional response at 10 MeV was constructed from Monte Carlo calculations and from interpolation of the 8 and 12 MeV responses. Monte Carlo calculations of the detector response in the region of the proton-recoil plateau were used to normalize the measured responses on an absolute basis.

INTERPOLATION PROCESS

The 21 neutron responses reported in Ref. 3 constitute an insufficient number of responses to be used directly as a response matrix for unfolding NE-213 proton-recoil spectra. As an example, the FERDOR/COOLC response matrix contains 77 columns corresponding to 77 calculated responses. Therefore, it was necessary to develop an interpolation scheme which could be used to construct additional responses from the measured data.

Since several interpolations were required, it was important that the interpolation scheme introduce a minimum amount of smoothing to the original data. The formula which was developed fitted a parabola to four adjacent data points by requiring that the curve exactly fit the inner two points and least-squares fit the outer two points. In this way, a smooth interpolation could be made within the range of the two inner points while preserving the original data.

The 60 new response columns were constructed in a multistep process. First, the original spectra were stretched so that the endpoint pulse heights were aligned. The endpoint of each response was taken at the point where the differential efficiency fell below 0.00001 counts per incident neutron-light unit. Each spectrum was then interpolated at 156 new pulse heights yielding a 21 by 156 matrix of stretched responses. Next, the 156 rows were interpolated creating 3 new responses equally spaced between each of the existing spectra. Finally, all 81 spectra were compressed in the appropriate manner and each new response was interpolated at the original pulse-height values. For all of the intermediate interpolations, the 4-point second-order least-squares formula was used.

RESPONSE MATRIX

The final step in the construction of the neutron response matrix for use with the FORIST code, was the rebinning of each of the 81 response columns into the pulse-height structure required by the code. Using the same 4-point interpolation formula as before, the spectra were rebinned into 113 pulse-height bins with one overlap region. This requires that the proton-recoil spectra be input as two distinct runs with the appropriate gains.

Figure 1 shows an isometric comparison of the new FORIST response matrix with the FERDOR/COOLC matrix. The largest discrepancies occur at low pulse height where carbon- and alpha-recoils are important. This discrepancy is not surprising since Monte Carlo calculations may not accurately describe the more complicated response in this region. Despite the differences in the two matrices, proton-recoil spectra that were unfolded with both matrices gave results that were nearly identical at intermediate energies. However, the FORIST matrix did give improved results at lower energies, and results at high energies that could not be obtained with the FERDOR/COOLC matrix.

Cf-252 FAST-NEUTRON SPECTRUM

The extension to higher neutron energies is important for fission spectrum measurements, since the fission spectrum extends to high neutron energies. Using an NE-213 neutron spectrometer,[5] a measurement of the ^{252}Cf spontaneous fission neutron spectrum was made and unfolded

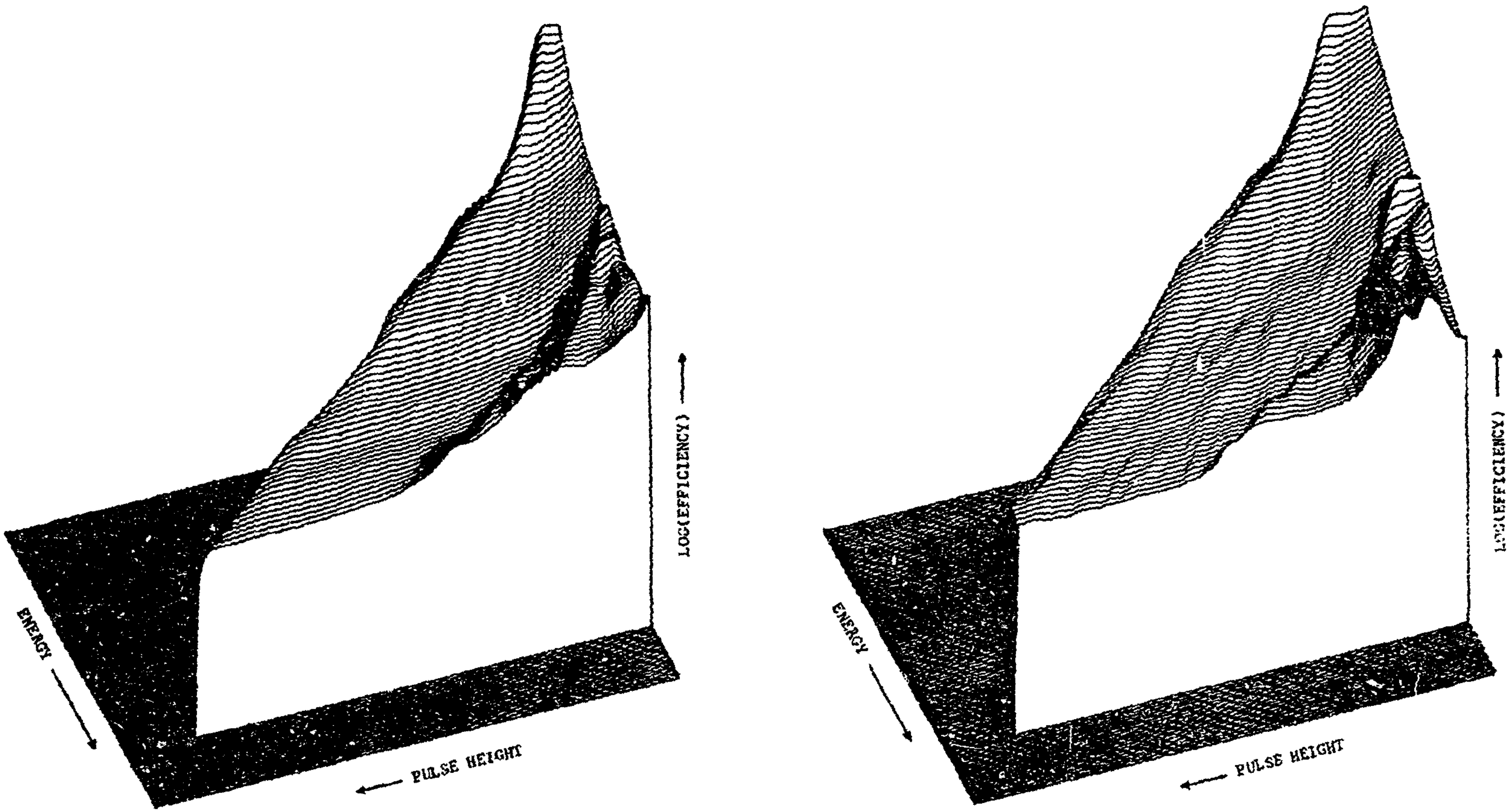

Fig. 1. Isometric representations of the FORIST (left) and FERDOR/COOLC (right) neutron response matrices. The pulse-height and energy scales are somewhat distorted for plotting purposes.

with FORIST and the new response matrix. Since the counting rate at 20 MeV was quite low, the low gain (high energy) measurement was taken for approximately 120 hrs. To minimize the effect of gain drift in the multichannel analyzer, the low gain run was recalibrated every 8 hrs. Background was measured using a paraffin shadow cone placed between the detector and the ^{252}Cf source.

The unfolded ^{252}Cf fast-neutron spectrum is shown in Fig. 2 as the vertical error bars. The line represents a Maxwellian distribution fitted to the spectrum. A pure Maxwellian distribution would appear as a straight line when plotted in the manner of Fig. 2. However, the unfolded solution vector was smoothed with a Gaussian window function in the unfolding process, so that it was appropriate to fit the unfolded spectrum with a Maxwellian distribution which was also smoothed with the same window function. The full-width-at-half-maximum of the Gaussian smoothing function is shown in the upper part of Fig. 2. The temperature of the fitted Maxwellian was found to be 1.45 ± .02 MeV when fitted between 2.0 and 20 MeV. The assigned error is a systematic error in the measurement attributed to a maximum 2% gain drift in the electronics. The fitted temperature agrees with previous measurements summarized in Ref. 6 and with the recommended value of 1.42 MeV given by Grundl and Eisenhauer.[7] Their evaluation was based mainly on lower energy spectrum measurements.

CONCLUSIONS

We feel that the neutron response matrix generated from the measured ORNL data more accurately describes the neutron response of NE-213 than the previously available FERDOR/COOLC matrix. The new matrix will be distributed with the FORIST code, but should also replace the older matrix supplied with the FERDOR/COOLC code. The ^{252}Cf fast-neutron spectrum unfolded with this response matrix provides new and significant information above 8 MeV and unique results above 15 MeV. The ^{252}Cf neutron spectrum from 2 to 20 MeV is adequately described by a single Maxwellian distribution with a temperature of 1.45 ± .02 MeV.

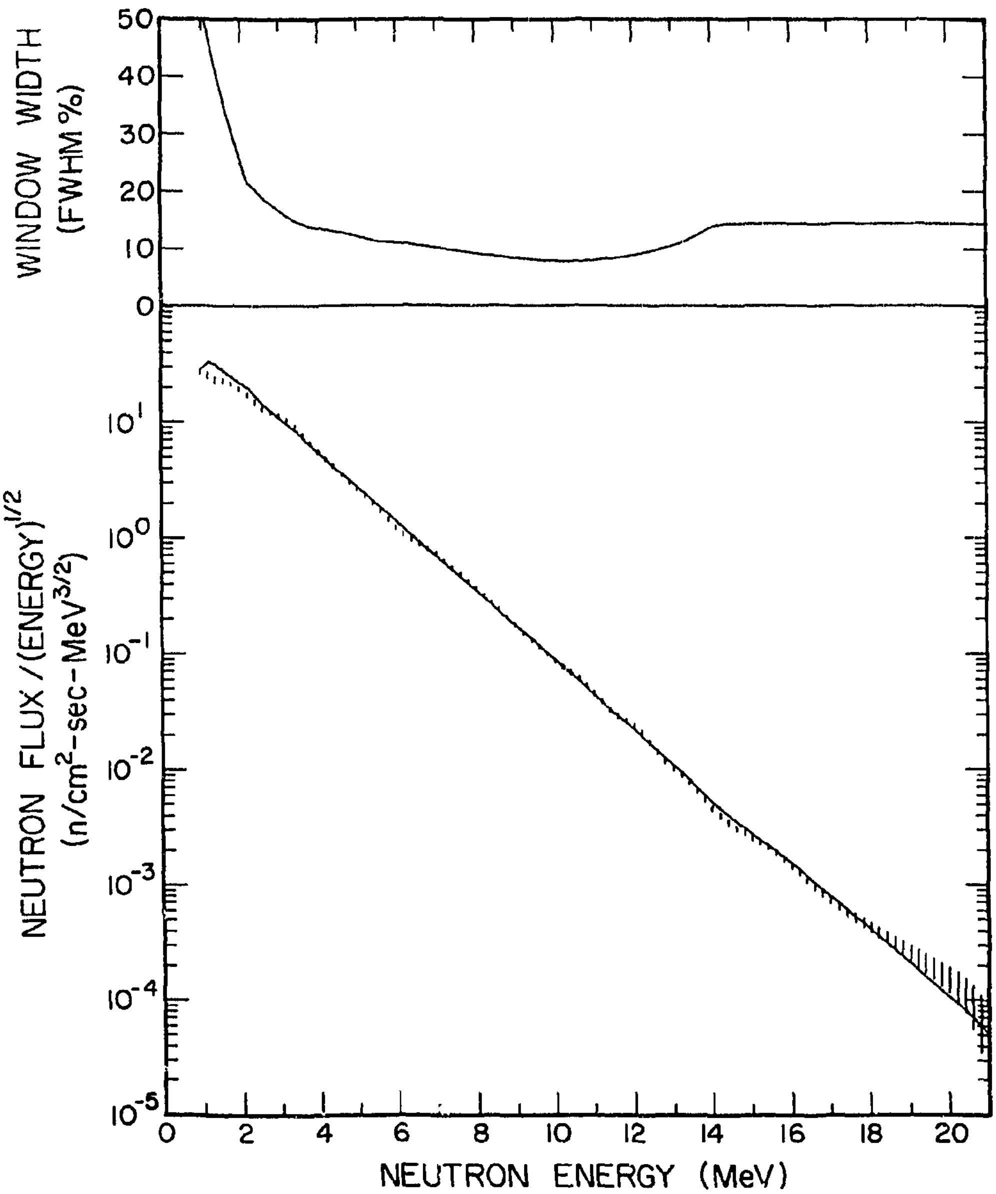

Fig. 2. Fast-neutron spectrum for Cf-252. The experimental results are shown as vertical error bars (± 1 standard deviation due to counting statistics). The line is a weighted least-squares fit between 2 and 20 MeV of a smoothed Maxwellian distribution (temperature, 1.45 MeV).

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