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Title: MEASUREMENT OF THE NEUTRON SPECTRUM OF THE BIG TEN CRITICAL ASSEMBLY BY LITHIUM-6 SPECTROMETRY

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MEASUREMENT OF THE NEUTRON SPECTRUM OF THE BIG TEN CRITICAL ASSEMBLY BY LITHIUM-6 SPECTROMETRY

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ABSTRACT

The central neutron-flux spectrum of the Los Alamos Scientific Laboratory's critical assembly, Big Ten, was measured with a ^{6}Li spectrometer and techniques developed at the Centre d'Étude de L'Énergie Nucléaire, Mol, as part of an experimental program to establish the characteristics of Big Ten.

BIG TEN

Big Ten is a cylindrical assembly of uranium metal.[1] The 53.3-cm-diam core consists of U(10) metal surrounded by interleaved plates of U(93) and normal uranium such that the average enrichment is 10 weight percent ^{235}U. For the measurements described here, the effective core length was 54.4 cm. The reflector is of depleted uranium, 15.2-cm thick radially and 21.1-cm thick on each end. The spectrometer was accommodated by a 3.81-cm-diam by 4.36-cm-long central cavity with a 0.48-cm-diam axial channel for two coaxial leads that carried both high-voltage biases and signals.

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LITHIUM-6 SPECTROMETER

The detector assembly (the CEN/SCK Assembly of Ref. 2, Fig. 1) contained two parallel solid-state detector disks with variable separation. A ^{6}LiF film was deposited on one of these detectors. The silicon detectors responded to alpha particles and tritons from the reaction ^{6}Li(n,t)^{4}He.

The electronics system (Ref. 2, Fig. 2) had one channel that carried the signal (alpha or triton) from a single detector and another channel that carried the combined signal (alpha plus triton) from both detectors whenever coincidence occurred within 15 ns. Pulse height distributions were converted to energy distributions by calibration and correction techniques to be described later. The combined energy distribution leads to a neutron flux spectrum by the simple relation

$$E_\alpha + E_t = Q + E_n \tag{1}$$

where E_n is the neutron energy and Q = 4.787 MeV. The neutron spectrum may also be derived from the triton energy distribution through the more complex relation

$$E_t = \left[\frac{\sqrt{M_n M_t E_n}}{M_\alpha + M_t} \cos\theta + \sqrt{\frac{M_n M_t E_n \cos^2\theta}{\left(M_\alpha + M_t\right)^2} + \frac{M_\alpha Q + E_n\left(M_\alpha - M_t\right)}{M_\alpha + M_t}} \right]^2 \tag{2}$$

where M_n, M_α, and M_t represent the mass of the neutron, alpha, and triton, and θ is the angle between neutron and triton velocities in Laboratory coordinates.

EXPERIMENTAL PROCEDURE

The measurement was performed in two steps: preliminary runs with a 0.07-μm-thick ^{6}LiF deposit, followed by primary data collection with a 0.77-μm-thick deposit. The thin ^{6}LiF was intended principally for background measurement, although it was adequate for thermal-neutron calibration and for confirming proper functioning of the spectrometer in Big Ten.

Thermal neutrons for energy calibration were provided by a ^{252}Cf source in a polyethylene moderator. After coincidence circuitry had been adjusted for a 15-ns time window, and X-Y display of the alpha or triton and sum peaks was checked: amplifier gains and biased offsets were adjusted to place E_α and

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E_t distribution peaks in specific counting channels for the X parameter, and E_t and $E_\alpha + E_t$ peaks in other specified channels for the Y parameter. The E_t peak on the Y-axis was obtained by removing the coincidence restriction. The energies $E_t = 2.730$ MeV and $E_\alpha = 2.057$ MeV for $E_n = 0$ then established the energy equivalent of each counting channel.

For primary data collection with the 0.77 μm deposit, a new energy calibration with thermal neutrons was followed by runs in Big Ten. Experimental refinements, as described in Ref. 2, guarded against channel shifts, effects of detector fatigue, and background effects.

DATA REDUCTION

The experiment is designed to measure the multigroup reaction spectrum, $R_g = \phi_g(\text{Big Ten})\sigma_g[{}^6\text{Li}(n,t){}^4\text{He}]$. The alpha plus triton sum distribution requires one unfolding operation because of the finite resolution function of the detectors. The thermal calibration represents an experimental determination of the function which, for the thick ^{6}LiF deposit, had a full width at half-maximum of about 200 keV. In going to lower energies, the uncertainty in R_g values, determined by the sum distribution, becomes progressively larger due to uncertainty in neutron energy assignment and uncertainty in the detector resolution function and associated unfolding operation. By limiting the reduction of the sum-distribution data to the portion of the reaction spectrum above $E_n = 500$ keV, the uncertainty in absolute R_g values is kept at or below 10%. One notes that the fraction of events produced by neutrons with energy less than 500 keV is thus determined but that this fraction is not further subdivided.

The triton pulse height distribution requires two unfolding operations in order to yield R_g values. The first is for the finite resolution function of the detector, which, for the thick ^{6}LiF deposit and as determined by the thermal calibration, had a full width of about 60 keV. The second is for the E_n-dependent energy distribution of tritons produced by monoenergetic neutrons with energy E_n; the upper and lower bounds of this spectrum are determined by kinematics but the spectrum within these bounds is determined by the angular correlation function between neutron and triton velocities. Although the general features of this triton spectrum are revealed in the two parameter data display by the triton pulse height distribution at constant $E_\alpha + E_t$, we use, for the second unfolding operation, the angular correlation data of Overly et al.[3] and Schroder et al.[4] Because of increasing overlap of alpha and triton distributions at higher neutron energies, analysis of the triton pulse-height distributions is restricted to $E_\alpha + E_t$ slices of the two parameter data display corresponding to $E_n \leq 700$ keV.

All unfolding operations were performed with the UCLIS code.[5] The principal uncertainty in the reaction spectrum is below $E_n = 500$ keV and arises from uncertainty in the neutron-triton angular correlation data which may be as large as 15% for $E_n \sim 100$ keV.[2]

The multigroup flux spectrum of Big Ten was obtained from the measured reaction spectrum by dividing with the ^{6}Li(n,t)^{4}He cross sections evaluated by Poenitz[6] and is listed in Table I. This spectrum corresponds to that of the neutrons incident on the detector assembly and should be slightly softer than the central flux spectrum of Big Ten without cavities. Also listed in Table I are central flux spectra calculated with Big Ten material cross sections obtained from the U.S. evaluated nuclear data files ENDF/B-III and ENDF/B-IV. The respective transport calculations used Maxwellian fission neutron spectra with T = 1.300 and 1.336 MeV.

Qualitatively, the three spectra listed in Table I are very similar. They imply essentially the same values for integral cross sections of such reactions as ^{197}Au(n,γ), ^{10}B(n,He), ^{6}Li(n,He), and ^{235}U(n,f). For the sensitive spectral index $\bar{\sigma}_f(^{238}U)/\bar{\sigma}_f(^{235}U)$, the value implied by the measured spectrum is intermediate between those implied by the ENDF/B-III and ENDF/B-IV spectra and is 3% less than the experimental value.

Relative to the calculated spectra, the measured spectrum appears low in the energy interval 40-85 KeV and high below 20 KeV. The spectrum shape observed by Dowdy, et al., with a proton-recoil spectrometer is more supportive of the calculated spectra in the 40-85 KeV range although their observations did not extend below 30 KeV.[7]

TABLE I. MEASURED (Li-6) AND CALCULATED (ENDF) CENTRAL FLUX SPECTRUM OF BIG TEN

E_n Lower Limit	Lethargy Interval	Group Flux (%) Measured	ENDF/B-III	ENDF/B-IV
6.065 MeV	∞	-	0.36	0.42
4.724 MeV	0.250	0.60	0.56	0.60
3.679 MeV	0.250	1.12	0.94	1.02
2.865 MeV	0.250	1.56	1.33	1.46
2.231 MeV	0.250	1.75	1.65	1.86
1.738 MeV	0.250	1.89	1.86	2.19
1.353 MeV	0.250	2.13	2.09	2.53
1.054 MeV	0.250	3.05	2.95	3.33
820.8 keV	0.250	5.03	4.55	4.70
639.3 keV	0.250	6.80	6.85	6.44
497.9 keV	0.250	8.93	8.83	8.33
387.7 keV	0.250	9.66	9.73	9.30
302.0 keV	0.250	9.48	9.33	9.49
235.2 keV	0.250	8.24	9.19	8.90
183.2 keV	0.250	8.03	8.10	7.84
142.6 keV	0.250	7.76	6.80	6.64
111.1 keV	0.250	6.02	5.83	5.67
86.52 keV	0.250	4.58	5.08	5.03
67.38 keV	0.250	3.44	4.23	4.25
52.48 keV	0.250	2.28	3.26	3.26
40.87 keV	0.250	1.82	2.32	2.52
31.83 keV	0.250	1.64	1.52	1.74
19.30 keV	0.500	1.78	1.45	1.67
15.03 keV	0.250	0.60	0.30	0.36
9.12 keV	0.500	0.86	0.26	0.31
7.10 keV	0.250	0.40	0.057	0.063
5.53 keV	0.250	0.09	0.031	0.034
0 keV	∞	-	0.041	0.044

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