Cd^{114}, and the general behavior of the strength function, are in good qualitative agreement with the predictions of such a model. Detailed calculations of the (d,p) spectroscopic factors have produced very good quantitative agreement with experimental values for the zero- and one-phonon states, but poor agreement for the two-phonon states. It must be emphasized that there are uncertainties in the DW treatment of the reaction mechanism which affect the experimental spectroscopic factors as well as uncertainties in the selection of model parameters for the odd isotopes so that the observed agreement for the lowest two states in Cd^{112} and Cd^{114} need not be conclusive evidence for the model. Nevertheless, modification of the model in order to account for the static quadrupole moment of the one-phonon states must be constrained to preserve agreement with the measurements reported here.

ACKNOWLEDGMENTS

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^{252}Cf Fission Neutron Spectrum from 0.003 to 15.0 MeV*

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The spontaneous-fission neutron spectrum of ^{252}Cf has been measured from 0.003 to 15.0 MeV by time-of-flight techniques. A hydrogenous liquid scintillator was used as a detector at the higher energies, while a ^{6}Li-loaded glass scintillator was used at the lower energies. The measured spectrum has an average energy of 2.348 MeV. A Maxwellian distribution, $N(E)\sim E^{1/2}\exp(-E/1.565)$, fits the data well for $0.5<E<10.0$ MeV. Below 0.1 MeV, $N(E)$ has a $\sqrt{E}$ dependence but with values ~25% larger than those predicted by the extended Maxwellian spectrum. The results are interpreted in terms of a simplified evaporation model.

I. INTRODUCTION

RECENT measurements[1–3] of the energy and angular distributions of ^{235}U and ^{252}Cf fission neutrons have established that, for energies greater than 0.3–0.5 MeV, the majority are emitted isotropically from the fully accelerated fragments while 10 to 15% may be emitted by a source stationary in the laboratory system. The neutron energy distribution for isotropic emission from a moving fragment is given by[4]

$$N(E)=\int_{(\sqrt{E}-\sqrt{E_F})^2}^{(\sqrt{E}+\sqrt{E_F})^2}\frac{\phi(E_{\mathrm{c.m.}})dE_{\mathrm{c.m.}}}{4(E_{\mathrm{c.m.}}E_F)^{1/2}}, \qquad (1)$$

where E is the energy in the laboratory system, $E_{\mathrm{c.m.}}$ is the center-of-mass energy, E_F is the energy per nucleon of the fragment, and $\phi(E_{\mathrm{c.m.}})$ is the center-of-mass energy distribution. Those neutrons with small E are the ones emitted backwards and nearly parallel to the fragment direction. As E approaches zero, $E_{\mathrm{c.m.}}$ becomes restricted to a small range of values around E_F and

$$\lim_{E\to 0}N(E)=E^{1/2}\phi(E_F)/E_F^{1/2}. \qquad (2)$$

Thus, regardless of the form of $\phi(E_{\mathrm{c.m.}})$, this part of the fission neutron spectrum should have an $E^{1/2}$ dependence at low energies. If $\phi(E_{\mathrm{c.m.}})$ is slowly varying near $E_{\mathrm{c.m.}}=E_F$, then $N(E)$ will retain the dependence $E^{1/2}$ to quite large values of E.

The inclusion of the neutrons not emitted from the moving fragments does not greatly affect this conclusion. They appear to have an evaporation type of spectrum,[1,2]

$$P(E)\propto\sigma_c(E)E\exp(-E/\Theta), \qquad (3)$$

where σ_c is the cross section for compound-nucleus formulation and Θ, the nuclear temperature, is approximately 1 MeV. The high average energy, coupled with their low abundance, implies a small effect at low energies. Secondly, at very low energies $\sigma_c(E)$

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* Work supported by the U. S. Atomic Energy Commission.

[1] H. R. Bowman, S. B. Thompson, J. C. D. Milton, and W. J. Swiatecki, Phys. Rev. **126**, 2120 (1962).

[2] K. Skarsvag and K. Bergheim, Nucl. Phys. **45**, 72 (1963).

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approaches an $E^{-1/2}$ dependence,[5] giving $P(E)$ and $N(E)$ the same energy dependence for small values of E.

At higher energies, the spectrum is dependent on the exact form of $\phi(E_{\mathrm{c.m.}})$. It has been shown that nuclear evaporation theory, with an allowance for the distribution of the nuclear temperatures of the fission fragments, predicts a Maxwellian form for the laboratory spectrum,[4]

$$N(E) \propto E^{1/2} \exp(-E/T). \tag{4}$$

A large amount of experimental information[6–8] is now available which is in good agreement with Eq. (4). However, there are few data available below 0.1 MeV and none below 0.05 MeV. The present state of fission theory is not such that an *a priori* statement concerning the completeness of the above description can be made. Thus it is desirable to have a good experimental description of fission neutron spectra over as wide an energy range as possible.

Most of the previous measurements have depended on range or energy determinations of recoil protons or on time-of-flight techniques with hydrogenous detectors. Both involve *n,p* scattering for neutron detection which places a severe practical limitation on the minimum energy. The development of the ^{6}Li-loaded glass scintillator has greatly extended the range of the time-of-flight technique. A primary purpose of this experiment was to study the low-energy part of a fission neutron spectrum using this method.

There were three reasons for choosing ^{252}Cf as the fission source for this experiment. First, there were significant disagreements in the previous experimental data.[1,8–10] Second, a spontaneous fission source avoided the high neutron and γ backgrounds often associated with particle-induced fission. This was a serious problem with a detector sensitive to both γ rays and low-energy neutrons. Finally, the increasing availability of ^{252}Cf had made it a convenient standard neutron source, and it was very desirable to have an accurate knowledge of the neutron energy distribution.

II. EXPERIMENTAL METHODS

A. Apparatus and Procedures

A schematic drawing of the apparatus is given in Fig. 1. The energy of the fission neutrons was determined by measuring the flight time over a known distance. The times involved, ranging from 20 to 350 nsec, were measured with a conventional time-to-pulse-height converter in which the time was measured by the amount of charge collected on a condenser in the interval between two timing pulses. Here the pulses came from the detection of a neutron and its associated fission.

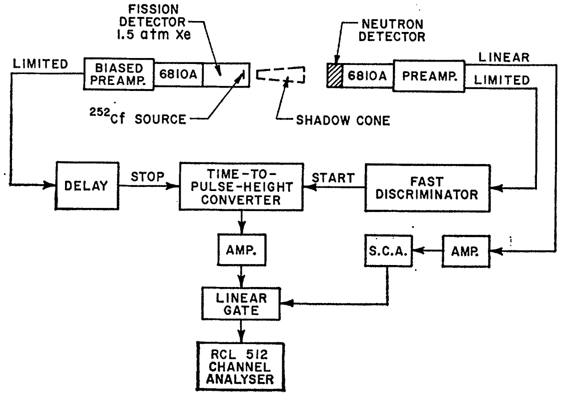

FIG. 1. Schematic diagram of the apparatus. S.C.A.: single-channel analyzer. 6810A: photomultiplier tube.

Because of the high count rate of the fission detector, the neutron detector was used to start the time converter. In order to keep the start rate as low as possible, the bias level of the fast discriminator was set slightly below the amplitude of the limited pulse. Then the phototube voltage was adjusted so pulses a little below the minimum amplitude just limited. However, this cutoff was not very sharp, so the linear pulse was sent through a discriminator biased at a level corresponding to a slightly higher energy. This was used to control the linear gate.

The stop signal was provided by the fission detector. The ^{252}Cf fission source, amounting to 8.6×10^5 fissions per minute, was volatilized onto a thin platinum foil and mounted at the end of a gas scintillator cell filled with 1.5 atm of xenon. The cell was 6 cm in diameter and 12 cm long. To reduce scattering, it was entirely constructed of 0.03-cm stainless steel except for the window and flange at one end. The resolution was good enough to separate clearly the two fission peaks and to give good separation of the α pulses. The phototube output went to the base of a transistor which was biased at a level high enough to block the α pulses. The limited signal from the preamplifier was then sent through a delay of 200–400 nsec to the stop input of the time converter.

The zero time of the system was determined from the position of the prompt γ-ray peak plus a correction for the γ-ray flight time. The time scale was calibrated by recording the position of this peak for different values of the delay using calibrated delay lines. For measurements with the glass scintillator the time per channel was 1.5 nsec while with the liquid scintillator it was 0.85 nsec. The time resolution, based on the width of the prompt γ-ray peak, was ±1.5 nsec.

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[5] J. M. Blatt and V. F. Weisskopf, *Theoretical Nuclear Physics* (John Wiley & Sons, Inc., New York, 1952), p. 349.

[6] A comprehensive review of the experimental data prior to 1963 is given by Earl K. Hyde, *The Nuclear Properties of the Heavy Elements* (Prentice-Hall, Inc., Englewood Cliffs, New Jersey, 1964), Vol. III, pp. 237–260.

[7] E. Barnard, A. T. G. Ferguson, W. R. McMurray, and I. J. Van Heerdan, Nucl. Phys. **71**, 228 (1965).

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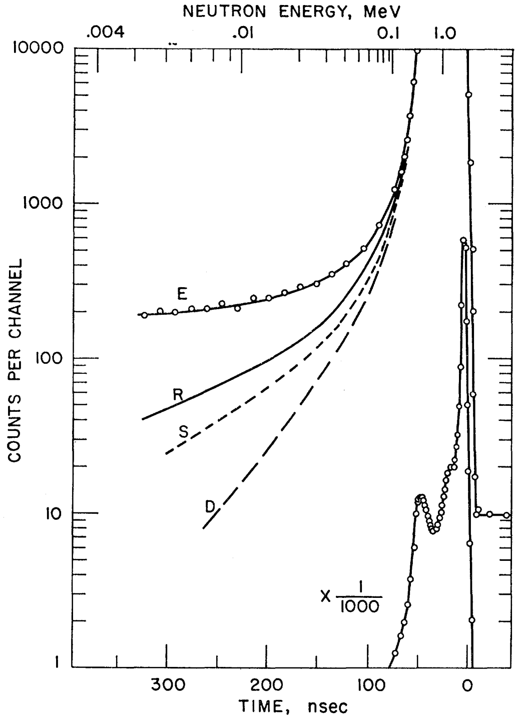

FIG. 2. Time-of-flight spectrum of neutrons and γ rays for the 32.7-cm flight path with the ^{6}Li glass scintillator. Curve E is the original spectrum. Curves R, S, and D illustrate the result of the successive subtraction of the random, scattered, and delayed γ-ray background components.

Each series of measurements covered a period of one to three weeks. The time calibration, detector pulse heights, and bias levels were checked daily and adjusted if necessary. The system as a whole proved to be very stable. The position of the γ-ray peak shifted by no more than 1% during any one series. This variation resulted from a long-term drift in the base line of the 512-channel analyzer.

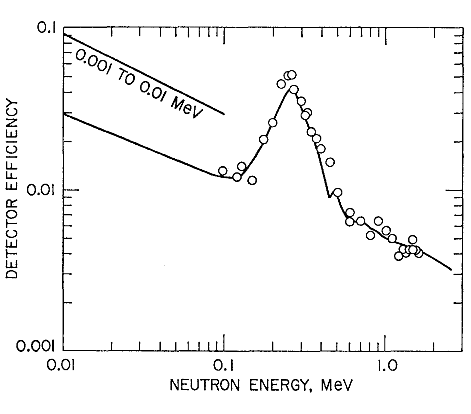

FIG. 3. Efficiency of the glass scintillator. The solid curve is the calculated efficiency. The open circles show the result of a comparison with a ^{235}U fission detector. The data are normalized to the calculated curve in the region above 1.0 MeV.

Several different flight paths, ranging from 18.6 to 136.8 cm, were used in order to emphasize different parts of the spectrum. Figure 2 shows the results with a 32.7-cm flight path. At this distance the time separation between the neutrons and prompt γ rays was very poor. With flight paths over 100 cm the separation was very good, and for all such measurements there was a region between the prompt γ and neutron peaks where the counts per channel went to zero after making the background corrections.

B. Neutron Detectors

The lower-energy neutrons were detected with a 5.08-cm-diam by 0.95-cm-thick glass scintillator[11] containing 7.3% lithium enriched in ^{6}Li to 96%. The efficiency, shown in Fig. 3, was calculated from experimental cross sections[12–17] with multiple-scattering corrections made according to the method of Schmitt.[18] The most important factor in calculating the efficiency was the $^6\mathrm{Li}(n,{}^3\mathrm{H})^4\mathrm{He}$ cross section. Above 0.01 MeV, experimental data on this reaction were directly available.[12–15] Below 0.01 MeV, the measurements of Schwarz[16] were used but were renormalized to agree with the other data in the energy interval 0.01 to 0.1 MeV.

An additional check on the energy dependence of this detector was made by comparing it with a ^{235}U fission detector over the energy range 0.1 to 1.6 MeV. The results are shown in Fig. 3. Although there is considerable scatter about the calculated curve, there is no evidence of any systematic difference.

At sufficiently high energies, neutron detection by other charged-particle-producing reactions in the glass was possible. The glass scintillator was not used in this energy region. In determining the cutoff energy, it was conservatively assumed that all charged particles gave the same light output as an electron of equal energy. Since the first interfering reaction likely to be detected was the $^6\mathrm{Li}(n,n'd)^4\mathrm{He}$ reaction with a threshold at 1.7 MeV, and since the discriminator bias setting corresponded to a γ-ray energy of 0.8 MeV, the glass scintillator was not used above 2.6 MeV.

Above 1.0 MeV, neutrons were detected by *n,p* scattering in a hydrogenous liquid scintillator 4.75 cm in diameter and 2.35 cm thick. There was a possible error of ~3% in the dimensions due to an uncertainty

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[11] Nuclear Enterprises, Ltd., NE 905.

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[13] F. Gabbard, R. H. David, and T. W. Bonner, Phys. Rev. **114**, 201 (1959).

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[17] Brookhaven National Laboratory Report No. BNL-325 (U. S. Government Printing and Publishing Office, Washington, D. C., 1958), 2nd ed.

[18] H. W. Schmitt, Oak Ridge National Laboratory Report No. ORNL-2883, 1960 (unpublished).

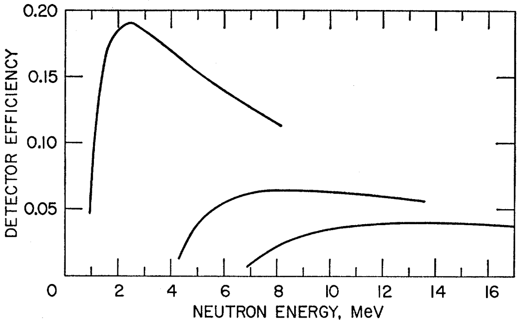

FIG. 4. Efficiency of the liquid scintillator. The three curves are for bias levels corresponding to 0.85-, 4.0-, and 6.5-MeV neutrons.

of the wall thickness of the scintillator cell. The detector efficiency is shown in Fig. 4. It was calculated from the n,p cross section,[17] the discriminator levels, and a knowledge of the dependence of the pulse height on proton energy. The latter was obtained by measuring the position of the cutoff of the fission neutron time spectrum as a function of the discriminator bias. The calculated efficiency also included the effect of double scattering and a correction for edge effects.

Measurements with this detector were made with three discriminator settings: 0.85 MeV for measurements to 7.5 MeV, 4.0 MeV for measurements to 13.0 MeV, and 6.5 MeV for measurements to 18.0 MeV. The purpose of this was to avoid complications from the ^{12}C$(n,\alpha)^9$Be reaction at energies above 7.3 MeV and to reduce any γ-ray backgrounds at very short times.

The agreement between the detectors was good. At 1.5 MeV, measurements with the two detectors differed by 7%. The 3% uncertainty in the dimensions of the liquid scintillator was enough to account for this difference.

C. Background Corrections

The background came from three sources which were identified as (1) random, (2) scattered, and (3) the delayed component of the prompt fission γ rays.

(*1*) *Random background.* The correction to the ith channel was given by

$$\Delta N_i = \Delta t\, R_F \sum_{m=i+1}^{\infty} N_m\,, \tag{5}$$

where the sum over N_m was the total number of starts that gave time-converter pulses larger than those associated with the mth channel, R_F was the fission rate, and Δt was the channel width.

(*2*) *Scattered background.* In order to reduce the scattered background as much as possible, the detectors were lightly constructed and suspended by an open framework 1.7 m above the floor in a location well removed from the room walls. It was measured by placing a brass shadow cone between the neutron detector and the fission source and then measuring the time distribution of the events detected. For the longer flight paths this was a straightforward correction, but at 18.6 cm the cone almost completely filled the intervening space and shielded the neutron detector from a sizable fraction of the scattered neutrons. It was assumed that the correction for this effect was equal to the geometric shielding factor (0.35) and was independent of time.

(*3*) *Delayed γ rays.* Experiments by Johansson[19] have shown that, although most of the prompt γ's (those emitted prior to β emission) from ^{252}Cf fission are emitted in times shorter than 1 nsec, about 6% have half-lives in the range 15–100 nsec. If the neutron detector is γ sensitive these can cause a distortion in the measured neutron spectrum. As is shown in Fig. 2, the problem was very serious with the ^{6}Li glass detector at low neutron energies. Although γ rays with $E<0.8$ MeV were rejected by the discriminator level there were still enough delayed γ rays of higher energy to make a correction necessary.

The following estimate of this correction is intended only to indicate the order of magnitude of the effect and to justify the procedures used in its experimental determination. Some of the assumptions to be made concerning the fission γ rays and the lithium glass detector are not strictly accurate, but they are based on experimental data or on reasonable simplifications of such data.

There are $\sim$10 prompt γ rays per fission.[20] About 6% of these are delayed[19] and for simplicity it was assumed these all had $t_{1/2}\approx 100$ nsec. About 10% have energies greater than the 0.8 MeV, which corresponded to the discriminator level of the neutron detector. The detection efficiency for these γ rays is taken to be $\sim$1%, the measured efficiency for ^{60}Co γ rays. It is assumed that the neutron-detection efficiency is proportional to $E^{-1/2}$. While this is true only at very low neutron energies it does represent the general trend of the ^{6}Li$(n,{}^3$H$)^4$He cross section except for the resonance at 0.25 MeV. Then if the fission neutron spectrum is represented by Eq. (3), the number of γ rays detected per neutron detected for the conditions of this experiment is given by

$$\frac{R_\gamma(t)}{R_n(t)} \approx (0.4\times 10^{-3})\frac{t^3}{L^2}\exp\left[\frac{0.52L^2}{Tt^2}-\frac{0.693t}{100}\right], \tag{6}$$

where t is the time after fission in nsec, L is the flight path in cm, and T is the "temperature" of the Maxwellian spectrum in MeV.

At large values of t and small values of L, which correspond to the required conditions for the measurement of the low-energy part of the spectrum, Eq. (6) shows $R_\gamma/R_n>1$. However, at 3.0 cm (the practical minimum) Eq. (6) shows $R_\gamma/R_n>1$ for $t>30$ nsec and >10 for $t>70$ nsec. Measurements at this distance were

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[19] S. A. E. Johansson, Nucl. Phys. **64**, 147 (1965).

[20] A. B. Smith, P. R. Fields, and A. M. Friedman, Phys. Rev. **104**, 699 (1956).

used to determine the time dependence and magnitude of the delayed γ component from 70 to 350 nsec. The results of these measurements were used to correct the measurements made at longer flight paths. The combined measurements yielded a corrected neutron spectrum extending up to 1.0 MeV. However, the correction was less than 10% above 0.2 MeV in all measurements.

The time dependence of the delayed γ rays could be represented, for $t>30$ nsec, by the sum of two exponentials,

$$R_\gamma(t)=[2.57\exp(-t/216)+11.29\exp(-t/27)]\times10^{-5}, \quad (7)$$

where $R_\gamma(t)$ was the number of delayed γ rays detected per nsec normalized to the total number of fission related events (neutron plus γ) detected. Since $R_\gamma(t)$ defined in this way was not dependent on L, this correction was used for all measurements with the ^{6}Li glass scintillator.

Figure 2 illustrates the contributions of the three background sources for a measurement with the glass scintillator over a 32.7-cm flight path. Although this example is typical in a qualitative sense, the total background and the relative magnitudes of the three components at a given time were dependent on the length of the flight path. For example, with longer flight paths the relative importance of the scattered background increased while the delayed γ-ray background decreased.

For measurements with the liquid scintillator, the background was not a serious correction except for energies above 10 MeV. There, it was almost entirely due to the random component. The delayed γ-ray component was negligible in this energy range because of the high discriminator bias settings. The scattered neutrons only became an important part of the total background at times corresponding to lower energies where the total neutron detection rate was high.

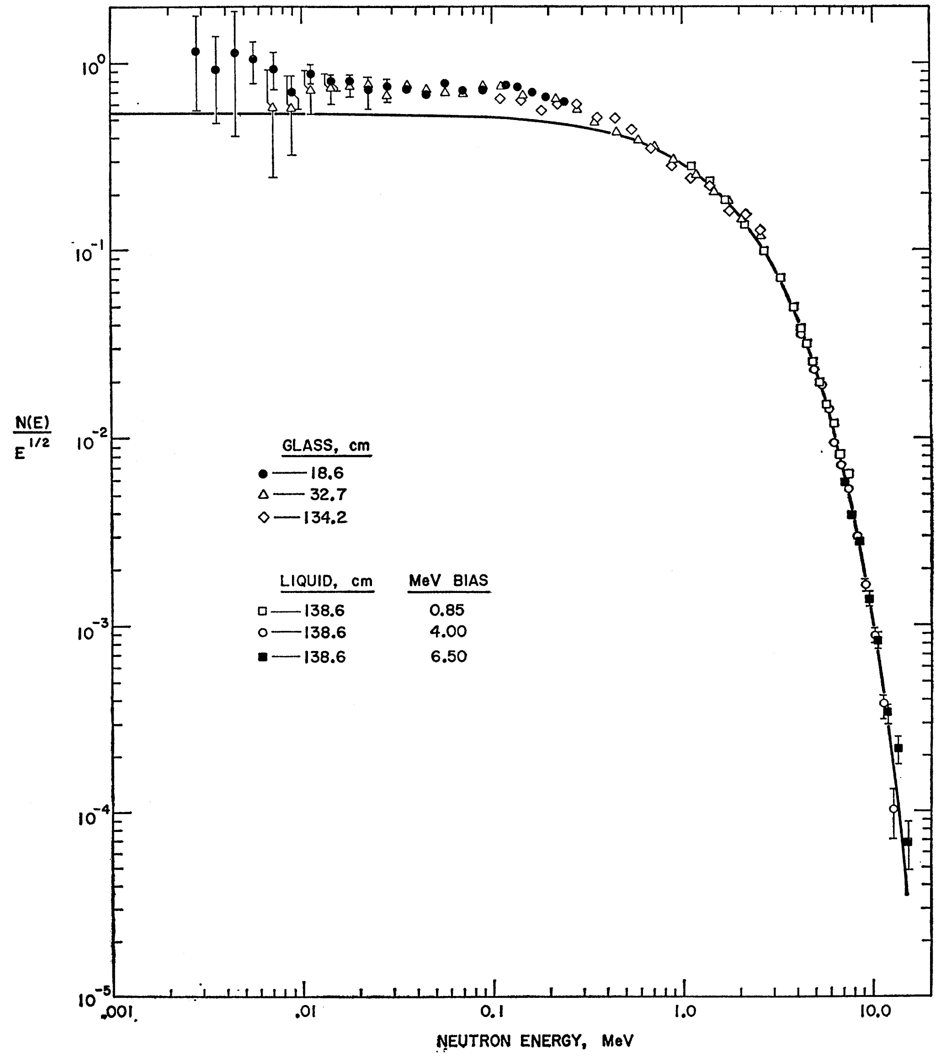

FIG. 5. The experimental ^{252}Cf fission neutron energy spectrum. The spectrum has been normalized so the integral of $N(E)$ is equal to 1. The solid curve is the result of a fit of Eq. (4) to the data with $0.5<E<10.0$ MeV. The error bars indicate the statistical error.

TABLE I. Values obtained for various parameters in least-squares fits to the data. The first column refers to the corresponding curves in Fig. 4. H is a number indicating the relative goodness of the fit. See the text for explanation of cases.

	Description	T (MeV)	ω_i	Θ_i (MeV)		H	$\bar{E}$ (MeV)
	Experimental						2.348
(1)	Eq. (4); all data	1.565				15.3	2.350
(2)	Eq. (4); $0.5<E<10.0$	1.592				0.44	2.388
(a)	Eq. (1); $n=2$		0.717	0.481		13.4	2.22
			0.283	1.342			
	Eq. (1); $n=3$		0.840	0.359		9.8	2.27
			0.376	1.274			
			−0.216	0.128			
(b)	Eqs. (1), (10); $n=2$		0.470	0.386	$b=0.43$	2.6	2.33
			0.530	1.114			
(c)	Eqs. (1), (3); $n=2$		0.467	0.424	$a=0.03$	1.2	2.35
			0.533	1.115	$\theta_L=0.18$		

III. RESULTS AND DISCUSSION

The measurements with the two detectors were matched in the region of overlap and normalized. The composite results are shown in Fig. 5. In order to make the graph more legible and to improve statistics, a number of data channels were averaged to give each point shown. The average energy, as calculated from the experimental data, was 2.348 MeV. It was in good agreement with the results of Smith, Fields, and Friedman[9] (2.35 MeV) and Bowman *et al.*[1] (2.34 MeV), but was significantly larger than the value of Conde and During[8] (2.12 MeV) or Bonner[10] (2.05 MeV).

A possible explanation of the differences in these experimental values of the average energy may lie in the different methods of detector calibration. The results of this experiment, Bowman *et al.*,[1] and Smith *et al.*[9] were based primarily on detector efficiencies calculated from the n,p cross section. In the other measurements,[8,10] the detector efficiencies were based on the energy dependence of neutron-producing reactions such as $^7\mathrm{Li}(p,n)^7\mathrm{Be}$, $^3\mathrm{H}(p,n)^3\mathrm{He}$, and $^2\mathrm{H}(d,n)^3\mathrm{He}$.[21,22]

A Maxwellian distribution was fitted to all the data of this experiment with the results shown by curve 1 in Fig. 6 and row 1 of Table I. Although the average energy is in good agreement with the value obtained directly from the data, this distribution did not give a good representation of all the data. However, when only the data with $0.5<E<10.0$ MeV were used, the Maxwellian distribution gave a very good representation of the data. This is illustrated in Fig. 5 and by curve 2 of Fig. 6. Extension of this curve to lower energies shows that it predicts values of $N(E)$ that are ~25% less than the experimental values. This phenomenon has not been observed in other measurements of the ^{252}Cf or other fission spectra, although several have extended to 0.1 MeV or lower.[6–8] In this experiment it was observed in all measurements under conditions where both the total background and the relative magnitudes of the different parts varied greatly. Furthermore, since the departure from the Maxwellian distribution begins to be obvious at 0.2 to 0.3 MeV where the background is a relatively small correction, it is unlikely that the effect can be attributed to errors in the background correction. The possibility of an error in the efficiency of the ^{6}Li glass detector was also considered. However, a comparison of this detector with a ^{235}U fission detector gave good agreement over the energy range 0.1 to 1.6 MeV.

Although the difference between the experimental data and the second Maxwellian distribution is ~25% at the lower energies, the number of neutrons involved is small, being only ~2% of the total. In the experimental spectrum, 13.3% of the neutrons had $E<0.5$ MeV while the Maxwellian distribution predicted 11.2%.

Inspection of Fig. 5 shows that the low-energy part of the spectrum is very nearly proportional to $E^{1/2}$. A least-squares fit to the weighted data below 0.1 MeV to determine the power of E gave

$$k=0.46\pm0.02.$$

A second fit was made assuming the spectrum to be approximately represented by Eq. (4). For $E\ll t$, k is

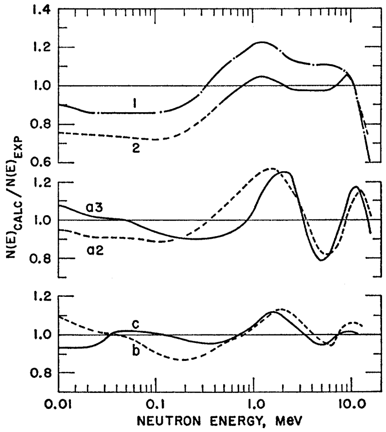

FIG. 6. A comparison of the calculated and experimental spectra. Curves 1 and 2 refer to comparisons with Maxwellian distributions fitted to all the data and data with $0.5<E<10.0$ MeV. Curves a, b, and c refer to the corresponding cases described in Table I and in the text.

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[22] R. L. Bramblett, R. I. Ewing, and T. W. Bonner, Nucl. Instr. Methods **9**, 1 (1960).

not sensitive to the exact value of T. For $T=1.565$ MeV,

$$k=0.49\pm0.02.$$

It has been shown that a very approximate form of evaporation theory can account for the principal features of the fission neutron spectrum, including the Maxwellian distribution.[4] An attempt was made to interpret these results in terms of a simplified evaporation model similar to that used by Bowman *et al.*[1] The center-of-mass spectra were assumed to be the same for both fragments and the distribution of nuclear temperatures was approximated by a superposition of discrete evaporation spectra,

$$\phi(E_{\text{c.m.}})=\sum_{i=1}^{n}\frac{\omega_i E_{\text{c.m.}}}{\Theta_i}\exp(-E_{\text{c.m.}}/\Theta_i)\,, \tag{8}$$

where ω_i was a weighting factor and Θ_i was a nuclear temperature. It was further assumed that 54% of the neutrons came from the light fragment and that E_F was 0.98 MeV for the light fragment and 0.56 MeV for the heavy one. The 10% of the neutrons not emitted from the moving fragments were ignored. If these neutrons have an evaporation spectrum with an average energy in the vicinity of 2 MeV they will have no gross effect on the energy spectrum. The following attempts were made to fit the experimental data using these assumptions:

(a) The first trials assumed only isotropic evaporation from the fragments. Equations (1) and (8) were fitted to the experimental data by varying ω_i and Θ_i for $n=1$, 2, and 3. The results of the two attempts with $n=2$ and 3 are shown in Table I and Fig. 6. The agreement was very poor for $n=1$. It was much improved for $n=2$, although still poor. There was no significant improvement for $n=3$.

(b) It has been shown than an anisotropic angular distribution with preferential emission along the line of fragment motion has the effect of increasing the yield of high- and low-energy neutrons at the expense of the average energies.[4] Several trials were made using Eqs. (1) and (8) and including an angular distribution function of the form

$$\Phi(\vartheta)\propto 1+b\cos^{2j}\vartheta\,, \tag{9}$$

where ϑ was the angle of neutron emission relative to the direction of the fragment motion, and j was an integer. Fits to the experimental data were made by setting $n=2$ and varying b, ω_i, and Θ_i. Equally good agreement was obtained for all values of j that were tried. However, the results of Bowman *et al.*[1] show very little, if any, anisotropy of this type with $2j=2$. Their results do show the possibility of a distribution that is very sharply peaked along the line of fragment motion. This was approximated by making $2j$ large. The results of a fit with $2j=16$ are shown in Table I and by curve b in Fig. 6.

(c) With $n=2$, it was possible to obtain good agreement with the data in the energy interval $0.5<E<0.10$ MeV under the conditions of case (a). On extension to lower energies, the difference between the calculated and observed spectra was very suggestive of an evaporation spectrum with a most probable energy of ~0.1 MeV and amounting to ~4% of the total neutrons. Table I and curve c of Fig. 6 show the results of a trial assuming isotropic evaporation from the fragments plus a low-energy component described by Eq. (3) with a fractional contribution a and a temperature Θ_L.

Some caution must be used in attempting to derive any physical content from the results of these calculations, particularly in view of the simplifying approximations that have been made. Although (a) gives very poor agreement with the experimental results, it cannot be completely discarded. Equation (8) is supposed to approximate a continuous distribution in Θ. This is best done if n is large. Undoubtedly a sufficiently large value of n would result in good agreement between the calculated and experimental spectra. Then, if all the ω_i were positive there would be no reason to discard (a). The assumptions made in (b) and (c) do result in calculated spectra that are in fair agreement with the experimental one. Their significance lies in the fact that agreement can be obtained using these particular assumptions, but they only indicate possibilities. Because of the uncertainties in evaporation theory and particularly because of the many simplifying approximations made here, one is not able to decide between the various possibilities on the basis of the neutron spectrum alone. A more definite decision could be made if angular distributions of the very low-energy neutrons were available.