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ENERGY CALCULATIONS OF NEUTRONS AND GAMMAS FROM FISSION INDUCED BY THERMAL TO 14-MEV NEUTRONS

by
R. B. Leachman

AEC RESEARCH AND DEVELOPMENT REPORT

PHYSICS AND MATHEMATICS
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ABSTRACT

The excitation energy distributions of fragments from U^{235} fission as derived in Report LA-1863 are used in Monte Carlo calculations to obtain the energies of the prompt neutron and gamma rays from fission. These calculations are an extension to 14-Mev fission of the Monte Carlo analysis previously described. The method has the disadvantages of requiring assumptions of both the neutron-fragment angle relation and the dispersion effect on the tail of the excitation energy distribution. Though the fit of the calculated spectrum to measurements of the thermal neutron fission spectrum is not good, the results do indicate a negligible change in the spectrum of the fission neutrons as a function of the energy of the neutron inducing fission. The calculations indicate the prompt gamma ray energy from fission increases from 3.8 Mev to 4.5 Mev with an increase of 0 to 14 Mev in the incident neutron energy.

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INTRODUCTION

The success of the method of calculating the emission probabilities of prompt neutrons from fission as described in Report LA-1863 (December 1954) has led to an extension of this method to the determination of the energies of these prompt neutrons from U^{235} fission. These neutron energy calculations were undertaken by a Monte Carlo type analysis employing the same excitation energy distributions calculated in LA-1863 and, in addition, an assumed isotropic distribution of neutrons from the moving fragments. These Monte Carlo calculations for thermal to 3-Mev fission are described in another paper.* In this report the results of these Monte Carlo calculations for incident neutron energies up to 14 Mev are considered.

The method employed in LA-1863 and the referenced paper is reviewed briefly in the following sentences: The excitation energy distributions of the fragments from fission are determined from the measured kinetic energy distributions of the fragment pairs by means of an analysis based primarily on the mass equation of fission. These excitation energies are combined with neutron boil-off considerations. The maximum neutron energy ϵ in the frame of reference of the moving fragment is, for the first neutron, determined from the excitation energy being considered and, for the subsequent neutrons, from the

* R. B. Leachman, "On the Emission of Prompt Neutrons from Fission," submitted to Physical Review for publication in the fall of 1955.

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residual excitation. For a conversion to the energy E in the laboratory system the usual isotropic emission of neutrons from the moving fragments is assumed. The energy of the prompt gamma rays from each fragment is obtained from the excitation energy remaining after all the energetically possible neutrons have been emitted. In the calculations attention is given to even-odd considerations, the various mass ratios of fission, and the dependence of the fragment velocity on these quantities as well as on the excitation energy of each of the fragments.

RESULTS

As discussed in the referenced journal paper, the results of these calculations are, for the low energies of emitted neutrons, strongly dependent upon the neutron-fragment angle relation and, for the higher neutron energies, are strongly dependent upon the tail of the excitation energy distribution. This tail depends upon the amount of the dispersion assumed to exist in the kinetic energy distribution of the fission fragments, from which the excitation energy distribution is derived. Because of these difficulties, it was not considered important to adjust the "temperature" T and the dispersion u to obtain the optimum fit of the calculated neutron spectrum to the measured neutron spectrum for thermal-neutron fission.

The results of some trial calculations with various values of T and u are shown in Fig. 1 along with the measured spectrum of thermal-

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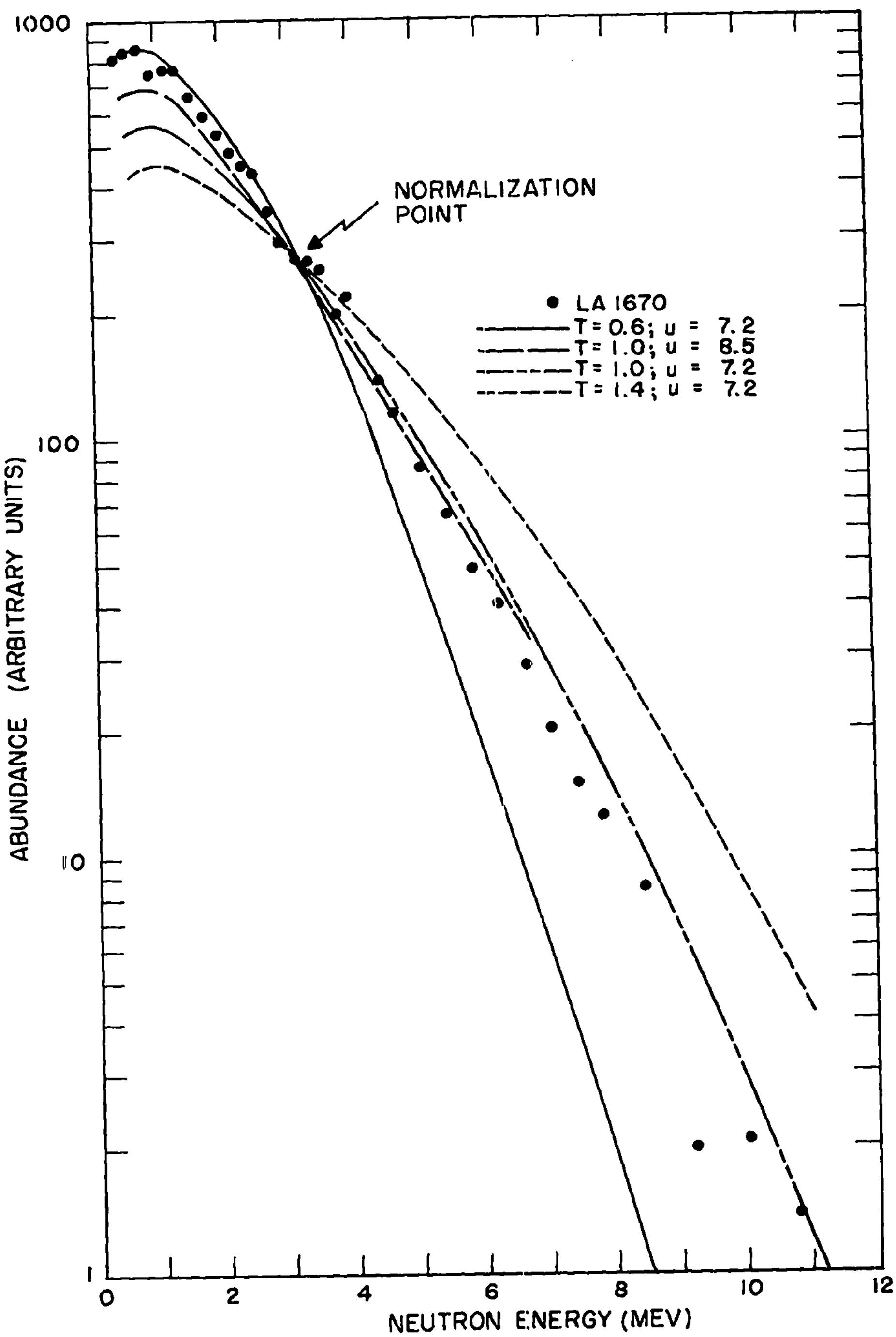

Fig. 1 Neutron spectra for various T and u conditions. These calculations are for only two conditions of the mass ratio parameter and the even-odd parameter. The T and u quantities used are in Mev. Experimental data are from LA-1670.

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neutron fission from Report LA-1670 (May 1954). For simplicity, the calculations given in Fig. 1 are based on only two of the 24 conditions of the even-odd parameter and mass ratio parameter used in the final calculations. The use of all 24 conditions of these parameters was found to change the calculated spectrum slightly from those in Fig. 1. It is to be noted in Fig. 1 that a "temperature" T of 0.6 Mev results in the best fit for low neutron energies. However, determinations of T by other methods all indicate larger values than 0.6 Mev. It is also to be noted from Fig. 1 that a better fit of the calculated data to the experimental data is obtained when a large dispersion u is removed from the initial kinetic energy data.

In Fig. 2 are the calculated neutron spectra for u = 7.2 Mev and T = 1.0 Mev. An additional calculation for 7-Mev fission gave the same shape of spectrum as those plotted in this figure. The 14-Mev calculations are only of the (n,f) process and do not include the effects of the (n, n'f) process. On the basis of the unchanged spectra in Fig. 2, the neutron spectrum for the post-fission neutrons from (n,n'f) is expected to be the same. The pre-fission neutrons n' are expected to have the usual boil-off spectrum with negligible change due to the recoil of the compound nucleus undergoing fission.

Because of the difficulties mentioned above, the agreement between the calculated and measured spectra in Fig. 2 is not good. However, it is believed that the calculations give a reasonably correct indication of the change of the fission spectrum with the

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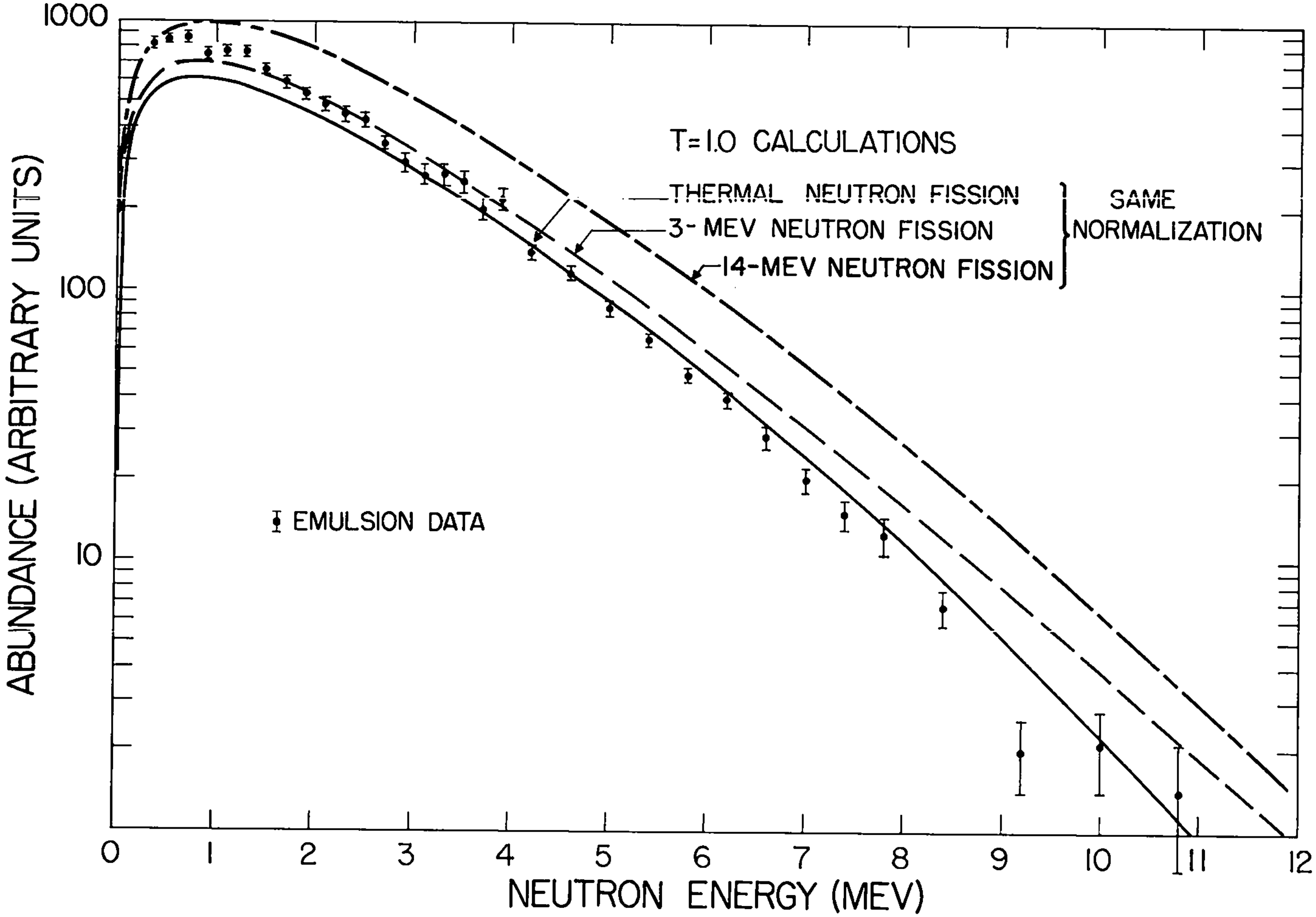

Fig. 2 Complete calculations of the fission spectrum. The spectrum labeled thermal-neutron fission is actually for -0.5-Mev fission, but is the same shape as the thermal-neutron spectrum shown in the published paper. Additional calculations which are not shown indicate that the differences in the spectra at the highest neutron energies can be explained by the statistics of the Monte Carlo calculations. Experimental data are from LA-1670.

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energy of the neutron inducing fission. It should be mentioned that any change of the neutron-fragment angular relation with the energy of the neutron inducing fission will have an effect on the neutron spectra that is not included in these calculations.

The results of Fig. 2 indicate that any hardening of the neutron spectrum with the increase of excitation energy accompanying an increase of the incident neutron energy E_n is compensated by the softening of the spectrum due to the lower excitation energy available to neutrons emitted after the previous emission of one or more neutrons.

In Table I are given the results of the calculations of the average prompt gamma energy E_γ from fission. As discussed in the referenced journal paper, these determinations are not dependent upon the neutron-fragment angular assumption and so are believed to be significant. The variation of the average number $\bar{\nu}$ of neutrons in Table I results in a slope $d\bar{\nu}/dE_n = 0.130$, as compared to 0.137 from the integral calculations of LA-1863. The small difference between these slopes is probably explained by the omission of negative probabilities of excitation energies in the present Monte Carlo calculations. Also, in the Monte Carlo calculations, negative gamma ray energies resulted occasionally from the use of the negative excitation energies in the probability distributions. In the determination of the average gamma ray energy these negative gamma ray energies were taken as zero.

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TABLE I RESULTS OF MONTE CARLO CALCULATIONS BASED ON T = 1.0 MEV AND u = 7.2 MEV

E_n (Mev)	$\bar{E}_\gamma$ (Mev)	$\bar{\nu}$
0	3.82	2.45
3	4.05	2.84
7	4.28	3.35
14	4.50	4.20

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