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Slow Neutron Total and Fission Cross Sections of U^{233}†

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The slow neutron total and fission cross sections of U^{233} have been measured from 0.02 ev to 200 ev on the MTR (Materials Testing Reactor) fast chopper. The strong resonances are resolved below a neutron energy of 15 ev, and show marked interference effects in the fission cross section. No resonances are observed in the total cross section which are not also present in the fission cross section, except for those attributed to the known contaminants in the samples. An estimate of the neutron strength function $\langle\Gamma_n^0/D\rangle$, made by an area analysis, gives the value $(1.0\pm0.2)\times10^{-4}$ for this energy region in U^{233}.

I. INTRODUCTION

Slow neutron cross-section measurements on U^{233} are of both theoretical and practical interest. This isotope holds promise as a fuel for thermal breeder reactors, since the number of neutrons produced per thermal neutron absorbed is higher than for either U^{235} or Pu^{239}. In the resonance region both the average fission cross section and the fission to capture ratio for U^{233} are higher than for these other common fissionable isotopes. In addition, the study of the cross sections of fissile nuclei is expected to provide information for the understanding of the fission process. The resonances in U^{233} are found to be relatively wide and closely spaced, and to exhibit pronounced interference effects. An analysis of these cross section data is presented in an accompanying paper.[1]

II. EXPERIMENTAL PROCEDURE

The procedure which was used for measuring total cross sections with the MTR fast chopper has been previously described,[2] and consists of measuring the transmission of a sample of known thickness in good geometry. The samples used were metal plates, 0.030 ±0.0005 and 0.170±0.001 inch thick, of 97.6% purity in U^{233}. The thinner of these samples has been discussed in detail.[2] Both samples were supplied by the Los Alamos Scientific Laboratory, and were fabricated at the same time under the same conditions. The cross-section data obtained with the thicker sample agreed to within 1% with those obtained with the thinner sample in energy regions where resolution effects were not important.

The experimental arrangement used in measuring the fission cross section of U^{233} is shown in Fig. 1. Each of the two fission fragment ionization chambers contained six circular foils, five inches in diameter, on each of which was deposited a thin layer of U_3O_8 whose purity was greater than 99% in U^{233}. Fission fragment counting requires that the fission foils be extremely thin, preferably less than 200 μg/cm^2. Neutron beam intensities are so low, however, that such thin foils require a prohibitively long irradiation time to obtain acceptable counting statistics. As a compromise, the average thickness of the foils used was 570 μg/cm^2, so that the twelve foils could give adequate statistical accuracy. The foils were not uniform; they were estimated to be 30% thicker in the center than at the edges. The measurement of the fission cross section of U^{233} was complicated by the high level of alpha activity in the fission foils, which is due both to the relatively short half-life of U^{233} and to the presence of trace amounts of the contaminant U^{232}. It was found that the pileup of alpha pulses in the ionization chambers posed a serious background problem. The foils were sufficiently thick that the complete fragment pulse distribution could not be resolved from the alpha background. As a result, no attempt was made to do absolute fission counting. The data were normalized to the value of 524 barns at 0.0253 ev.[3] The number of neutrons per unit time which passed through the fission foils was measured by banks of $B^{10}F_3$ proportional counters. The variation of the efficiency of the BF_3 detector system was calculated, and was found to agree with the experimentally measured efficiency to energies as low as 0.001 ev. The data were taken at a flight path of 15.66 m, with a resolution of 0.12 μsec/m for neutron energies above 12 ev, and 0.18 μsec/m for neutron energies between 1.7 ev and 12 ev. Although the resolution was as low as 2.0 μsec/m at 0.02 ev, resolution effects were negligible below 1.7 ev.

Simultaneous measurements of the total and fission

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[1] M. S. Moore and C. W. Reich, following paper [Phys. Rev. **118**, 701 (1960)].

[2] O. D. Simpson, M. S. Moore, and F. B. Simpson, Nuclear Sci. and Eng. **7**, 187 (1960).

[3] J. E. Evans and R. G. Fluharty, Nuclear Sci. and Eng. (to be published).

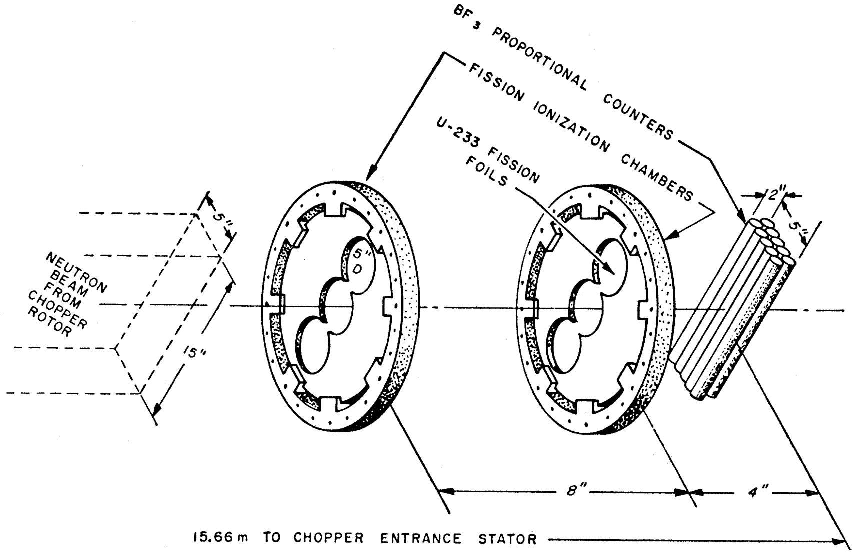

FIG. 1. Experimental arrangement. The two fission chambers each contained six U^{233} fission foils, arranged in two back-to-back columns of three foils each. The neutron beam, after passing through the fission chambers, was monitored by an array of B^{10} enriched BF_3 proportional counters.

cross sections were made in order to obtain the radiative capture cross section of U^{233}. These measurements were made possible by two features of the instrumentation. The 1024 channel analyzer was programmed to operate as four 256 channel analyzers.[4] The simultaneous measurements involved the storage of fission counts in one pair of analyzers and counts from the BF_3 proportional counters in another pair while cycling the total cross-section sample as has been previously described.[2] The second feature was an automatic time delay circuit[5] between the individual fission chambers, and between the fission chamber system and the BF_3

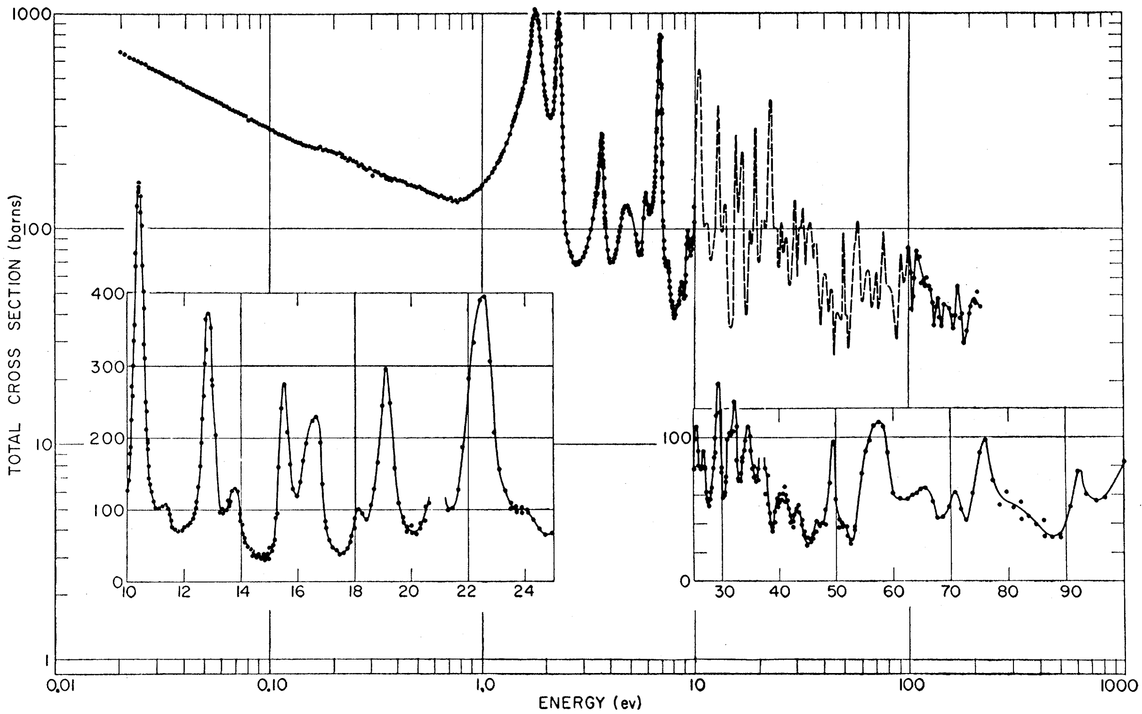

FIG. 2. The total cross section of U^{233} from 0.02 to 200 ev. The insets show data points between 10 and 100 ev. The data have been suppressed in the region of 5.2 ev because of a resonance in the 1.12% U^{234} contaminant, and in the regions of 21 and 37 ev because of resonances in the 1.02% U^{238} contaminant.

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[4] F. L. Petree, Atomic Energy Commission Report IDO-16470, 1959 (unpublished).

[5] B. G. Nelson, Atomic Energy Commission Report IDO-16510, 1959 (unpublished).

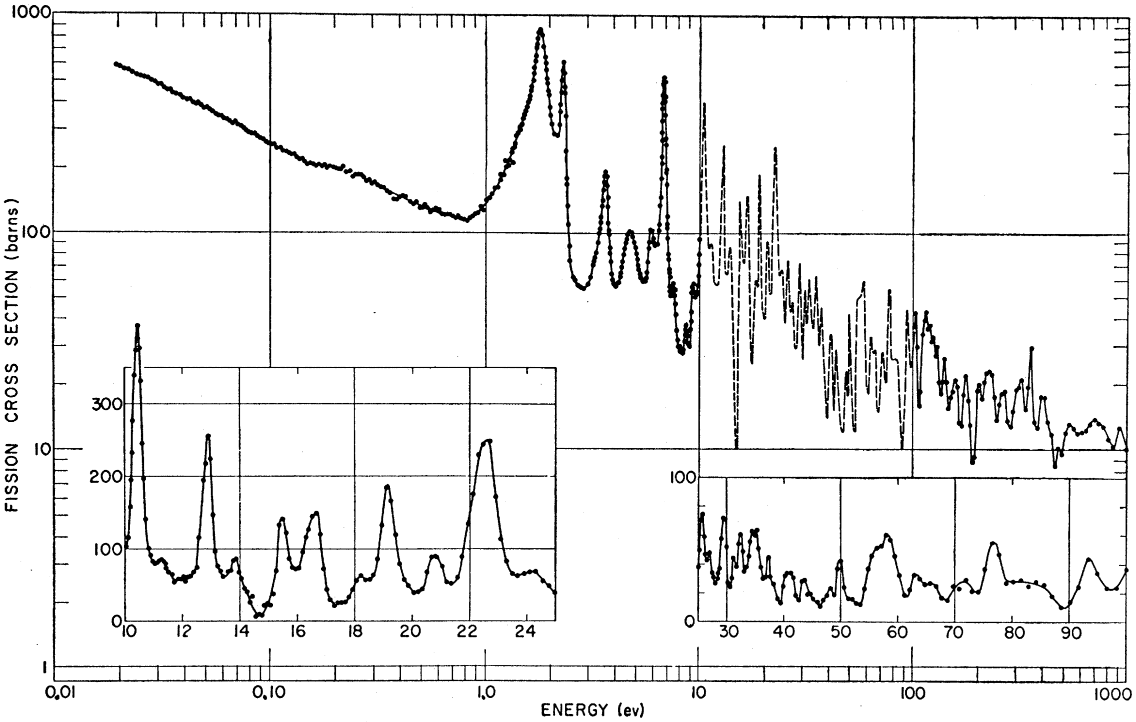

FIG. 3. The fission cross section of U^{233} from 0.02 to 1000 ev. The insets show data points between 10 and 100 ev.

detector system, to correct for the differences which existed in flight path.

The usual corrections applied to total cross-section data obtained with the MTR fast chopper have been discussed in detail.[2] For the fission data, the area of the beam was larger than the area of the fission foils. However, since the foils were thin to the neutron beam (with a transmission of greater than 99.5%), and since the efficiency of the fission detectors was measured relative to the value at 2200 m/sec, no correction was necessary.

III. DISCUSSION

Figures 2 and 3 show the measured total and fission cross sections of U^{233}, respectively. These total data represent an average of 24 individual runs, and the fission data an average of 29 runs. As a consequence, the errors to be associated with any given data point or region of data points are difficult to determine. The errors have in general an energy dependence, which is summarized in Table I.

In the total cross-section measurements, statistical uncertainties are important at energies above 12 ev, where only one or two runs are represented. Background effects are also small below 12 ev, but become much larger at higher energies, as a result of structure in the background which is due to fast neutrons transmitted through the rotor.[6] The errors which arise from sample thickness uncertainties are less than 1.5% at all neutron energies. Below 0.5 ev, particular care was taken in the sample alignment to reduce the effects of sample nonuniformity.[2]

In the fission cross-section measurements, the statistical uncertainties depend on the number and quality of the runs represented in a given energy region. The fission data are a relative measurement, and were normalized to absolute measurements at 0.0253 ev. A recent evaluation of Evans and Fluharty gives the absolute fission cross section at 0.0253 ev as 524 barns ±0.6%.[3] The present data were normalized to this value by a linear least squares fit from 0.02 to 0.03 ev, and the normalization error is a combination of the standard deviation of the residuals and the error of 0.6% in the normalization point. Runs which did not extend to 0.02 ev were normalized to those which did by matching the areas on a time-of-flight plot, to remove the effects of resolution broadening. The standard deviations of the normalizations were estimated from the agreement of such runs over the entire region of overlap, combined with the error associated with those runs which had already been normalized.

Both the total and fission cross sections contain an uncertainty in the energy scale, which is introduced by an uncertainty in the initial delay. The chopper alignment requires either a coincidence or a known delay between the neutron burst and a light pulse used for timing. The uncertainty in this initial delay was found to be of the order of 1.5 μsec at the highest rotor speeds

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[6] R. G. Fluharty, F. B. Simpson, and O. D. Simpson, Phys. Rev. **103**, 1778 (1956).

TABLE I. Estimated standard deviations to be associated with the total and fission cross-section data as a function of neutron energy. The sources of error are discussed in the text. The combined error was obtained under the assumption that the separate errors are independent.

Energy (ev)	0.02 to 0.1	0.1 to 0.5	0.5 to 5	5 to 12	12 to 25	25 to 200	200 to 1000
Error in σ_T from counting statistics	0.5%	0.5%	1.0%	1.0%	9%	15%	
Error in σ_T from background uncertainties	<0.3%	1.0%	1.0%	1.0%	4%	10%	
Error in σ_T from sample uncertainties	0.6%	0.6%	1.5%	1.5%	1.5%	1.5%	
Combined error in σ_T	0.8%	1.3%	2.0%	2.0%	10%	18%	
Error in σ_F from counting statistics	0.8%	4%	6%	8%	12%	12%	12%
Error in σ_F from background uncertainties	<0.3%	1%	1%	1%	4%	5%	10%
Error in σ_F from normalization uncertainties	1.5%	1.5%	4%	6%	7%	7%	7%
Combined error in σ_F	1.7%	4.5%	7.5%	10%	15%	15%	17%
Error in energy scale from initial delay uncertainties	0.7%	0.8%	1.0%	1.0%	1.5%	4%	8%

used (6000 rpm). The energy dependence of this effect is also shown in Table I.

The simultaneous measurements of the total and fission cross sections served as a basis for the determination of the radiative capture cross section. The results of this determination, which involved a calculation of the scattering cross section from multilevel parameters, are given in the accompanying paper.[1] The errors in the radiative capture cross section are for the most part the cumulative errors of the total and fission measurements. Resolution broadening precluded the extraction of radiative capture cross sections above 5 ev.

An estimate of the neutron strength function $\langle\Gamma_n^0/D\rangle$ was made by an area analysis of the data below 20 ev, the method used being similar to that of Simpson et al.[7] A value for this quantity of $(1.0\pm0.2)\times10^{-4}$ was obtained, and is in agreement with that determined from measurements of the U^{233} total cross section in the kilovolt region, where the resonances are not resolved.[7]

ACKNOWLEDGMENTS

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[7] O. D. Simpson, R. G. Fluharty, and R. S. Shankland, Bull. Am. Phys. Soc. 3, 176 (1958).