Nuclear Data for Science and Technology (1988 MITO), 101- 104, Copyright © 1988 JAERI.

MEASUREMENT OF THE $^{235}U(n,f)$ REACTION FROM THERMAL TO 1 keV†

Roald A. Schrack

National Bureau of Standards
Gaithersburg, MD 20899, USA

Abstract: The neutron induced fission cross section for ^{235}U has been measured from .02 to 1000 electron volts at the NBS electron LINAC facility. This cross section, especially the integrals from 7.8 to 11 eV and from 100 to 1000 eV, is widely used as a standard to normalize shape experiments. A special ion chamber incorporating both the ^{235}U foils and the ^{10}B foils used to monitor the neutron beam was built. The geometry of the chamber and the data taking system are designed to give the effect of a common environment and flight path so as to reduce or eliminate background and energy assignment problems. The shape measurements were normalized at thermal. Results are compared to other recent measurements and ENDF/B-V.

(fission, ^{235}U, cross section, integrals, ^{10}B, time-of-flight, neutron)

A measurement of the shape of the neutron-induced fission cross section for ^{235}U as been undertaken at the 140-MeV electron linear accelerator (linac) located at the National Bureau of Standards (NBS). The integral cross sections from 7.8 to 11 eV and 100 to 1000 eV are widely used as standards[1]. Discrepancies between different measurements on the order of 7% have been reported for these integrals. In addition, a set of thirteen integrals from .02 to 1000 eV is widely used in the comparison of data sets to the values given using the Evaluated Nuclear Data Files (ENDF/B)[1-4]. The shape measurements made at NBS have been normalized at the thermal cross section to produce absolute cross sections. Values of the integrals over the ranges of interest have been computed and compared to version five of the Evaluated Nuclear Data Files (ENDF/B-V).

The shape of the $^{235}U(n,f)$ reaction cross section is obtained by measuring the yield of a uranium fission chamber, Y_u, in the same neutron beam that the yield of a ^{10}B ionization chamber, Y_b, is being measured. The average cross section in a data collection bin is then:

$$\bar{\sigma}_u = N \frac{Y_u}{Y_b} \times \bar{\sigma}_b$$

where $\bar{\sigma}_b$ is calculated from the ENDF/B-V values and N is determined by the normalization process. The data collection bins were made narrow enough in energy so that errors induced by the approximations assumed in this equation would not be appreciable. The data were collected in 8192 bins covering the energy range from .015 eV to 1.4 keV. The width of the bins was adjusted as a function of energy so that in all cases the bin width was less than the doppler width at room temperature.

Two ^{235}U fission chambers placed on either side of a ^{10}B ionization chamber were combined in a single housing to obtain geometrical symmetry and proximity. This arrangement allows the data to be treated as if the boron and uranium chambers were at the same location in data reduction and background evaluation. In addition, the actual separation of the chambers (3.4 cm) was taken into account as the events from the chambers were recorded, so that there was no loss of resolution. Figure 1 shows the construction of the chamber.

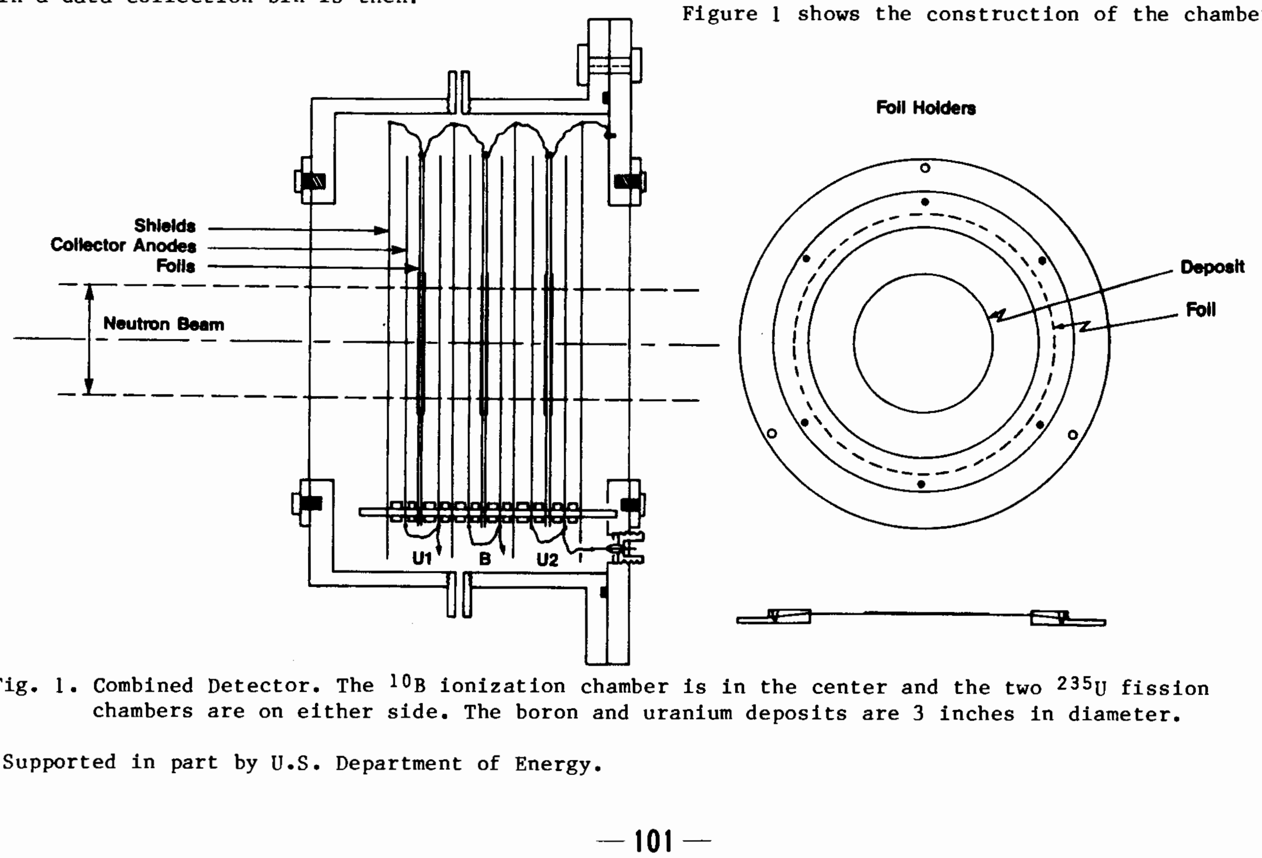

Fig. 1. Combined Detector. The ^{10}B ionization chamber is in the center and the two ^{235}U fission chambers are on either side. The boron and uranium deposits are 3 inches in diameter.

†Supported in part by U.S. Department of Energy.

Note that the neutron beam is smaller in diameter than the deposits of uranium and boron and that it passes through only thin aluminum foils. The deposits of uranium and boron are uniform to within about 10% in the regions seen by the neutron beam. The approximate areal densities of materials in the neutron beam are given in Table I. The exact values are not needed as the final data are normalized at thermal energies to obtain the absolute cross sections.

Table I. Areal Densities

Material	atoms/barn
aluminum	3.8×10^{-2}
^{10}B	2.8×10^{-6}
^{235}U	3.5×10^{-6}

The chamber is operated at atmospheric pressure with a continuous flow of 90% argon and 10% methane with 500 volts collector potential.

The physical layout and collimation of the beam are shown in figure 2. The neutrons are generated by a 50-nanosecond pulse of 100-MeV electrons impinging on a tungsten target. The neutrons are moderated in a block of polyethylene approximately 3-cm thick to enhance the low-energy neutron production. The gamma-flash is reduced by 2 cm of lead. A 3-mm-thick piece of pyrex glass having 1.35% by weight ^{10}B content is used as an overlap filter.

With the linac operating at 60 pulses per second the measured overlap contribution was about 0.2% of foreground.

The detector system was placed in a small shielded room with 1-meter-thick concrete walls and cadmium shielding around the detector. The linac off ambient background was 0.2% of foreground for the boron detector and less than 0.02% for the uranium detector.

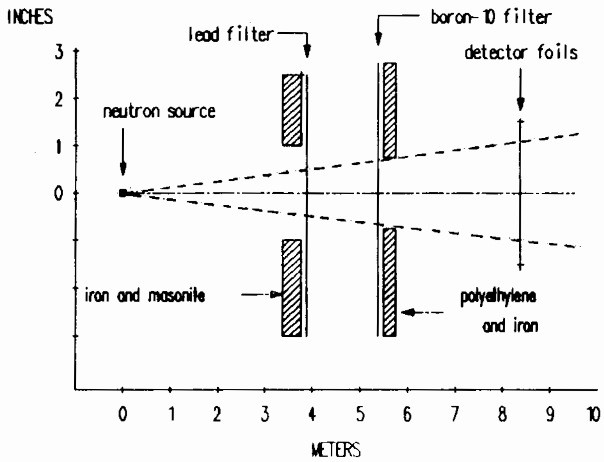

Fig. 2. Beam Line. The lead filter is at the exit of a 2.4 meter thick concrete wall. There is an additional 1 meter of concrete surrounding the detector after the boron filter.

Linac-dependent backgrounds were measured at .2, 4.9, 11.9, 132, and 1200 eV with black filters. The average backgrounds were found to be 1.1±.02%. The thermal background was determined with a cadmium filter to be 0.5%.

The data were collected using a camac-interfaced computer that recorded pulse height and time-of-flight for each event. A diagram of the electronics is shown in figure 3. Only one count per linac pulse was accepted. Dead-time corrections were negligible and not made in the reduction of the data. The average rate was .25 recorded events per linac pulse. The pulse height distributions for three different time regions were recorded. There were no observable differences in the pulse height distributions for the different neutron energy ranges.

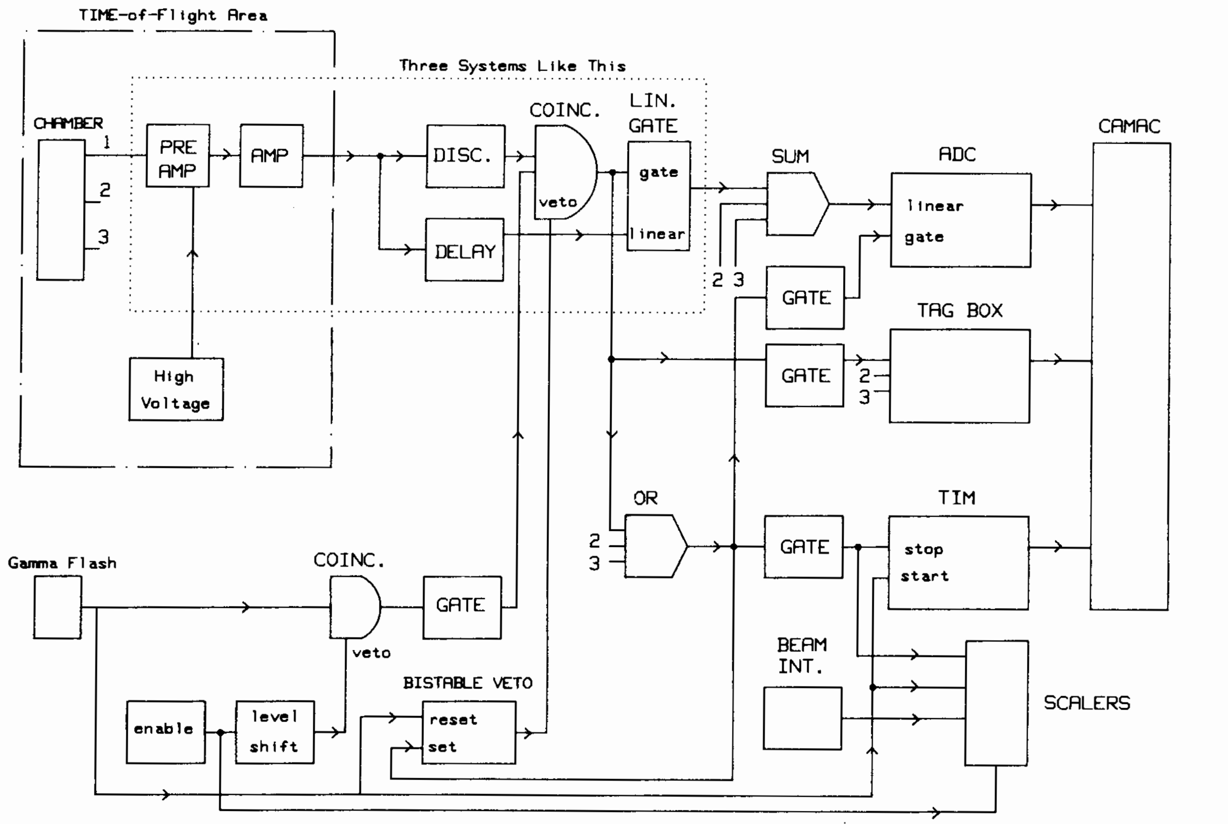

Fig. 3. Electronic Circuitry. The CAMAC interface is coupled to a Harris 6024/5 computer programmed to store the pulse height and time- of-flight information for each event.

Linac runs typically lasted about 100 hours, during which time approximately 4×10^6 events would be recorded. The weighted mean of four such runs are represented in the results reported here. The data of the four runs were reduced separately and compared. The errors reported on the final results are based on the scatter of the results of the individual runs. These scatter errors are about twice as large as one would obtain from statistical considerations alone.

The only background explicitly subtracted in the data reduction was the linac-independent ambient background. The other backgrounds were assumed to be yield-dependent and occurring in both detectors. It can be shown that these background contributions should cancel out in the measurement process.

The relative cross sections obtained in the experiment were normalized using the value of the ^{235}U fission cross section at thermal energies given by Deruytter. The value of this integral cross section from .0206 to .06239 eV is 19.26 eV barns/atom for a thermal cross section of 587.6 ± 2.6 barns/atom[5]. This normalization technique has been used by others[1,2]. It has the virtue that the integral provides a technique having good statistical precision and little sensitivity to systematic errors. Figure 4 shows the experimental results from .02 eV to 2 eV with the region of the normalization integral indicated.

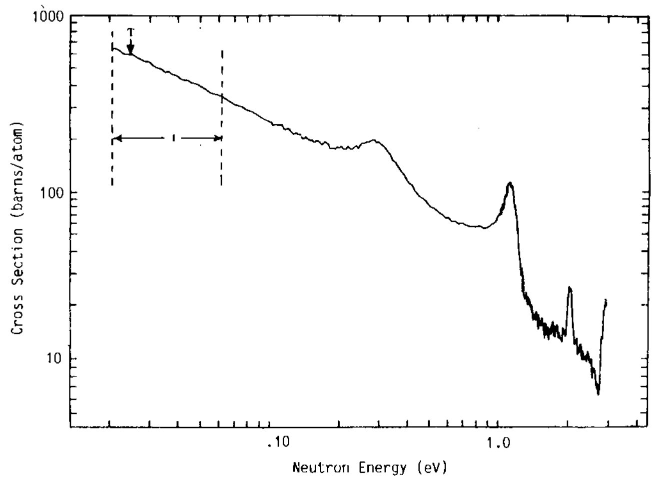

Fig. 4. ^{235}U Fission Cross Section from .02 to 3 eV. The region of normalization is shown.

The conversion of time-of-flight to energy is based on the formula:

$$T = Tz + (72.3 \times L/\sqrt{E})$$

where L is the path length that the neutron travels from moderator source to detector and Tz is a time offset determined by cable lengths, electronic delays, etc. These two parameters were determined from the data itself by matching the structure of the data to the ^{235}U cross sections as given in the ENDF/B-V files. The values obtained were:

$$L = 8.367 \pm .004 \text{ meters}$$

$$Tz = 90 \pm 20 \text{ nanoseconds}$$

The uncertainty induced in the resulting cross sections induced by the uncertainty in L and Tz is about 10% of the observed scatter uncertainty.

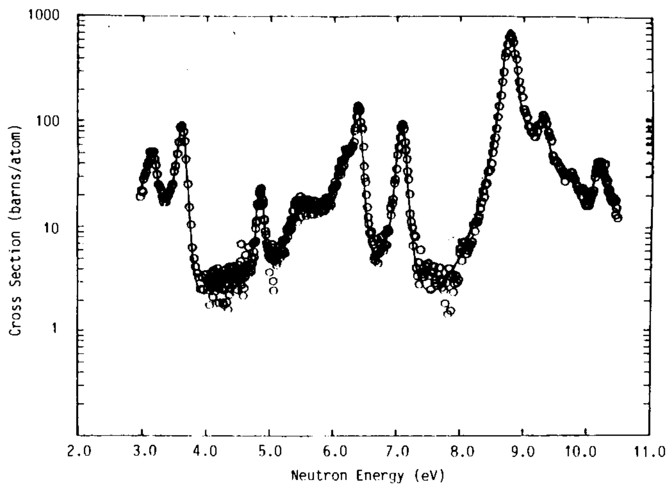

Fig. 5. ^{235}U Fission Cross Section from 3 to 10 eV.

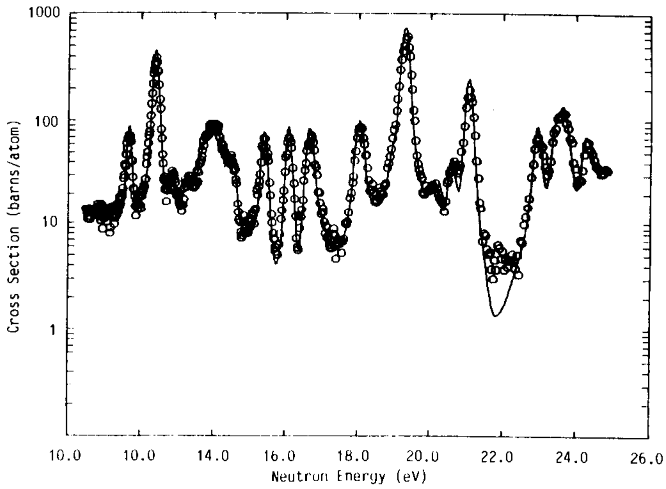

Fig. 6. ^{235}U Fission Cross Section from 10 to 25 eV.

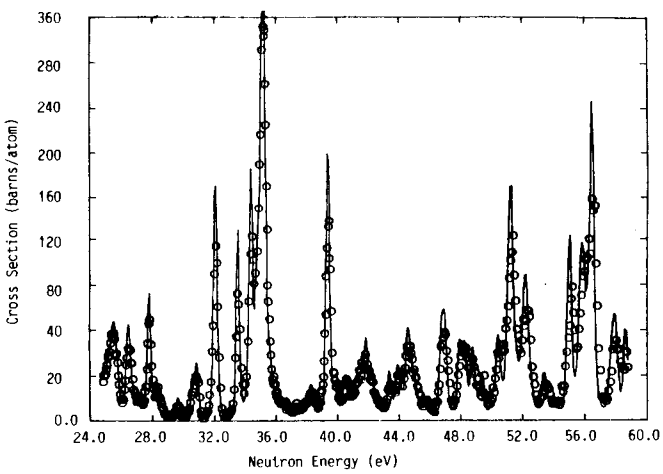

Fig. 7. ^{235}U Fission Cross Section from 25 to 60 eV.

Comparisons of the normalized results and ENDF/B-V are shown in figures 5, 6, and 7. The values of the integrals obtained from this experiment are tabulated in Table II as ratios to the ENDF/B-V integral and compared to ratios obtained in other experiments. These tabulated ratios are shown graphically in figure 8. It can be seen that the results reported on here are in general agreement with other recent experiments. It can also be seen that ENDF/B-V in the energy region

Table II. Integral values obtained by Recent Experiments. Ratio of recent measured values to ENDF/B-V. The ratios for all measurements are based on a thermal value of 587.6 b. The Weston values have been modified to reflect the common normalization.

E_1	E_2	ENDF/B-V (eV-barns)	Gwin[2] Ratio	Wagemans[1] Ratio	Weston[3] Ratio	NBS Ratio	error on NBS Ratio
.02	.1	30.46	1.011	1.011		1.010	± 0.001
.1	.5	63.79	1.009	1.021		1.006	0.002
.5	1	31.04	0.995	1.022		0.996	0.005
1	10	377.2	0.995	0.992		0.977	0.006
10	20	545.4	0.992	0.983		0.986	0.006
20	30	380.5	0.983	0.992	0.981	0.978	0.013
30	40	587.4	0.990	0.991	0.995	0.975	0.002
40	50	343.5	0.995	0.979	0.987	0.983	0.006
50	60	630.3	1.018	1.011	1.004	0.996	0.011
60	100	992.9	0.998	1.017	0.986	1.008	0.015
100	200	2071	1.024	1.035	1.017	1.043	0.011
200	300	2021	1.043	1.053	1.021	1.022	0.013
300	1000	7883	1.041	1.049	1.010	1.029	0.012
7.8	11	249.3	0.995	0.987		0.967	0.011

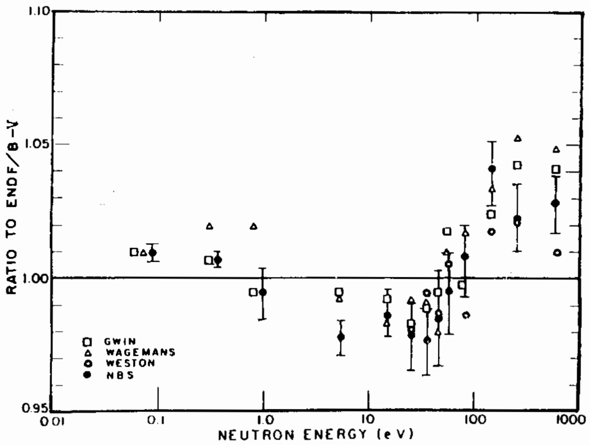

Fig. 8. Ratio of Experimental Value of Cross Section Integrals to Value Obtained Using ENDF/B. Ratios are shown for this work and other recent experiments based on a thermal normalization of 587.6 b.

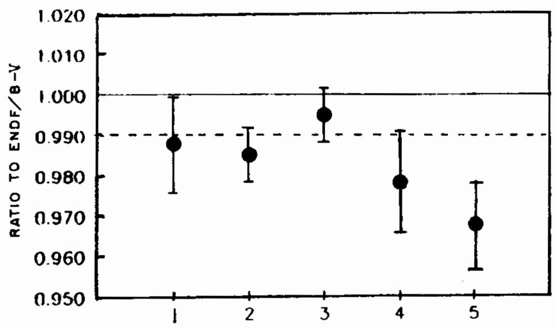

Fig. 9. Ratio of Experimental Value of 7.8 to 11 eV Integral to Value obtained using ENDF/B. Ratios are shown for several recent experiments and this work. The values shown are based on a thermal normalization of 587.6 b. 1) Wagemans (1979), 2) Czirr (1977), 3) Gwin (1984), 4) Weston (1984), and 5) NBS (1988).

covered by this experiment may be discrepant from the current best estimate of the ^{235}U cross section by as much as 3% for the higher energy integrals. Figure 9 shows the results of recent measurements for the 7.8-11 eV integral. The values are shown in Table III. The dashed line shows the value 246.5 given by ENDF/B-VI.

Table III. Values of 7.8-11 eV integral based on a thermal normalization of 587.6 b.

Source	Date	Value (eV-barns)
Wagemans[1]	1979	246.2 ± 2.0
Czirr[6]	1977	245.6 ± 1.7
Gwin[2]	1984	248.0 ± 1.7
Weston[7]	1984	243.7 ± 2.9
NBS	1988	241.1 ± 2.7

I would like to thank many people for their assistance in this work. The many hundreds of hours of experimental effort were made possible by the effective and dependable operation of the NBS linac. The kind assistance of the members of the Neutron Measurements and Research Group at NBS made the technical and analytic work possible by their continuous support and assistance.

References:

1. C. Wagemans and A.J. Deruytter, data given as "revised C" of Table 4, Proc. Conf. on Fast Neutron Cross Section and the ^{252}Cf Fission Neutron Spectrum, INDC (NDS)-146, Intl. Atomic Energy Agency, Smolenice 1983.

2. R. Gwin et al., Nucl. Sci. 88, 37 (1984).

3. L. W. Weston and J.H. Todd, Nucl. Sci. Eng. 88, 567 (1984).

4. ENDF/B Evaluated Data Files for ^{235}U available from Brookhaven National Laboratory (July 1979).

5. A.J. Deruytter and C. Wagemans, J. Nucl. Energy 26, E, 293 (1972).

6. As cited in O.A. Wasson, XV Int. Symposium on Nuclear Physics-Nuclear Fission 1985, Gaussig, DDR.

7. Personal communication (1984). Weston reports a value of the 7.8-11 eV ingegral of 242.0 ± 2.9 eV b based on a thermal normalization of 583.5 b.