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MEASUREMENTS OF THE $^{235}U(n,f)$ STANDARD CROSS SECTION AT THE NATIONAL BUREAU OF STANDARDS

R.G. Johnson, A.D. Carlson, O.A. Wasson, K.C. Duvall,
J.W. Behrens, M.M. Meier,* B.D. Patrick,** and M.S. Dias***

National Bureau of Standards, Gaithersburg, MD 20899, U.S.A.

Abstract: The primary mission of the Neutron Interactions and Dosimetry Group at the National Bureau of Standards (NBS) is the measurement of the standard neutron cross sections. The group has had a long-term program for the measurement of one of the most important of these cross sections - the neutron-induced fission cross section of ^{235}U. Since the ENDF/B-VI evaluation has been recently released, it is appropriate to review the measurements of the $^{235}U(n,f)$ cross section which have been made at the NBS using accelerator-based neutron sources.

In the 0.1 to 20 MeV region where this cross section is a standard, six separate measurements of the differential cross section, using a variety of techniques have been made. Both the NBS 150-MeV Electron Linac and the 3-MV Positive Ion Accelerator have been used as neutron sources. Two of the measurements are relative to the H(n,p) cross section while the remainder are absolute. These measurements will be reviewed and compared to ENDF/B-VI. The current status of this program and possible future improvements will be discussed.

(cross section; fission; neutron; review; standard; ^{235}U)

Introduction

The neutron-induced fission cross section of ^{235}U is one of the most important standard cross sections. Neutron detectors using foils with deposits of ^{235}U are relatively easy to build and calibrate. Thus, part of this standard's importance is in its widespread use for neutron fluence monitoring. In addition, ^{235}U forms the basis for an entire industry, the power reactor industry. Consequently, an accurate knowledge of the fission cross section for this material is vital.

The Neutron Interactions and Dosimetry Group at the National Bureau of Standards (NBS) has had a long-term program for the measurement of the neutron-induced fission cross section of ^{235}U. In this program six separate measurements of this cross section using a variety of techniques have been made.[1-6] Each measurement covers a portion of the 0.1 to 20 MeV range where the cross section is a standard, but with considerable overlap among the measurements. Both the NBS Neutron Time-of-Flight Facility (NTOFF) which uses the 150-MeV electron linac as a white neutron source and the NBS 3-MV Positive Ion Accelerator Facility have been employed for the measurements.

Recently, the ENDF/B-VI evaluation of the standard neutron cross sections was released. In view of this re-evaluation it is appropriate to review the NBS program for the measurement of the $^{235}U(n,f)$ cross section. These measurements will be compared to both ENDF/B versions V[7] and VI[8] below.

Measurements

Since it is proposed to review six separate measurements, detailed discussion of each is obviously impossible in this limited space. Four of these measurements were performed using NTOFF and therefore have many common characteristics (and consequently some correlated errors). The electron linac produces a pulsed white source of neutrons and energy is determined by neutron time-of-flight. Data are recorded in two-parameter arrays (pulse height and time-of-flight) for both the fission detector and the fluence monitor.

All but one of the six measurements use the same well characterized parallel-plate ionization chamber which contains a total ^{235}U mass of 170.9 ± 2.0 mg. The characterization of this chamber was reported in Ref. 9.

The major difference in the NTOFF measurements is in the choice of fluence monitors. Two of the measurements are relative and obtain shape information from the hydrogen cross section. In one case a hydrogen gas proportional counter was used and in the other case a proton recoil telescope system with an annular geometry was employed. The remaining two measurements were done with absolute fluence monitors, the NBS Black Detector[10] and the NBS Dual Thin Scintillator (DTS)[11], respectively.

At the 3-MV Positive Ion Accelerator Facility two measurements have been performed. In the first a pulsed beam time-of-flight technique was used with monoenergetic neutrons from the $^7Li(p,n)^7Be$ reaction. The fission detector was the one discussed above while the neutron fluence monitor was the Black Detector. The second measurement was an absolute measurement at 14.1 MeV in which the time-correlated associated-particle technique was used. In this case the fission detector was a smaller parallel-plate ionization chamber with a total ^{235}U mass of 1546.1 ± 1.6 µg.

All six measurements are summarized in Table 1. Further details on each can be obtained from the references.

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*Present address: Los Alamos National Laboratory, Los Alamos, NM, USA.

**Permanent address: Atomic Energy Research Establishment, Harwell, United Kingdom.

***Permanent address: Instituto de Pesquisas Energéticas e Nucleares, São Paulo, Brasil.

Table 1. Summary of $^{235}U(n,f)$ cross section measurements at the NBS

Ref.	Energy Range (MeV)	Neutron Source	Fission Chamber	Fission Chamber Flight Path (m)	Fluence Monitor	Fluence Monitor Flight Path (m)
1	0.005 - 0.8	white	A	69	H_2 Gas Proportional	200
2	1 - 6	white	A	63	Annular Proton Recoil	61.7
3	0.3 - 3	white	A	69.4	Black Detector	200.8
4	1 - 6	white	A	69.4	DTS	200.8
5	0.2 - 1.2	$^7Li(p,n)^7Be$	A	1.3	Black Detector	5.9
6	14.1	$^3H(d,^4He)n$	B	---	Time-Correlated Associated-Particle	--

A Large parallel-plate ionization chamber.
B Small parallel-plate ionization chamber.

Results

The cross sections obtained in each of the six measurements are shown in Figures 1, 2, and 3. The regions of energy covered by the three figures are from 0.1 to 1.0 MeV, from 1.0 to 1.9 MeV, and 1.9 to 6.2 MeV, respectively. Also shown as an inset in Figure 3 is the result at 14.1 MeV. The error bars represent the total error (1 standard deviation) including the estimated systematic errors. The dashed and solid lines in these figures are ENDF/B versions V and VI respectively.

For the two relative measurements the normalization is the same as that stated in the most recent publications of the data. The data of Ref. 1 are normalized to the 7.8 to 11.0 eV integral of 243.7 eV-b and the data of Ref. 2 are normalized to 1.20 b at 1.2 MeV.

The two sets of data from Ref. 5 differ by the size of the collimation between the fission chamber and the fluence monitor.

Discussion

For the region up to approximately 2.6 MeV all of the NBS data sets are in excellent agreement. Above that energy there are two data sets which extend to 6.0 MeV. There appears to be a difference of about 2% between these measurements. However that difference is still within their estimated uncertainties.

For the comparison with the ENDF/B evaluation the NBS data sets are generally in better agreement with version VI than they are with version V. For the region up to approximately 1.2 MeV this conclusion is readily apparent. Above that energy, the uncertainties in the data are too large and the difference between V and VI too small to form a conclusion.

At 14.1 MeV the NBS measurement is in excellent agreement with either version V or version VI. Combined with other associated-particle measurements near this energy, the 14-MeV point is known to better than 1.0%.

In general for the region between 250 keV and 2.6 MeV the goal of obtaining the cross section to an accuracy of 1.0% has nearly been achieved with these NBS data. Most of the data points in this region have uncertainties of about 2%. Weighted combination of these data over appropriate energy bins can achieve the 1.0% goal. However below 200 keV there are only two points and between 2.6 and 6.0 MeV the two data sets may disagree somewhat. Above 6.0 MeV there are no measurements at the NBS except for the point at 14.1 MeV.

Currently the group is involved in a collaboration which will cover the region from 3 to 20 MeV. With this measurement the problems pointed out above are being addressed. Preliminary results are being reported at this conference.

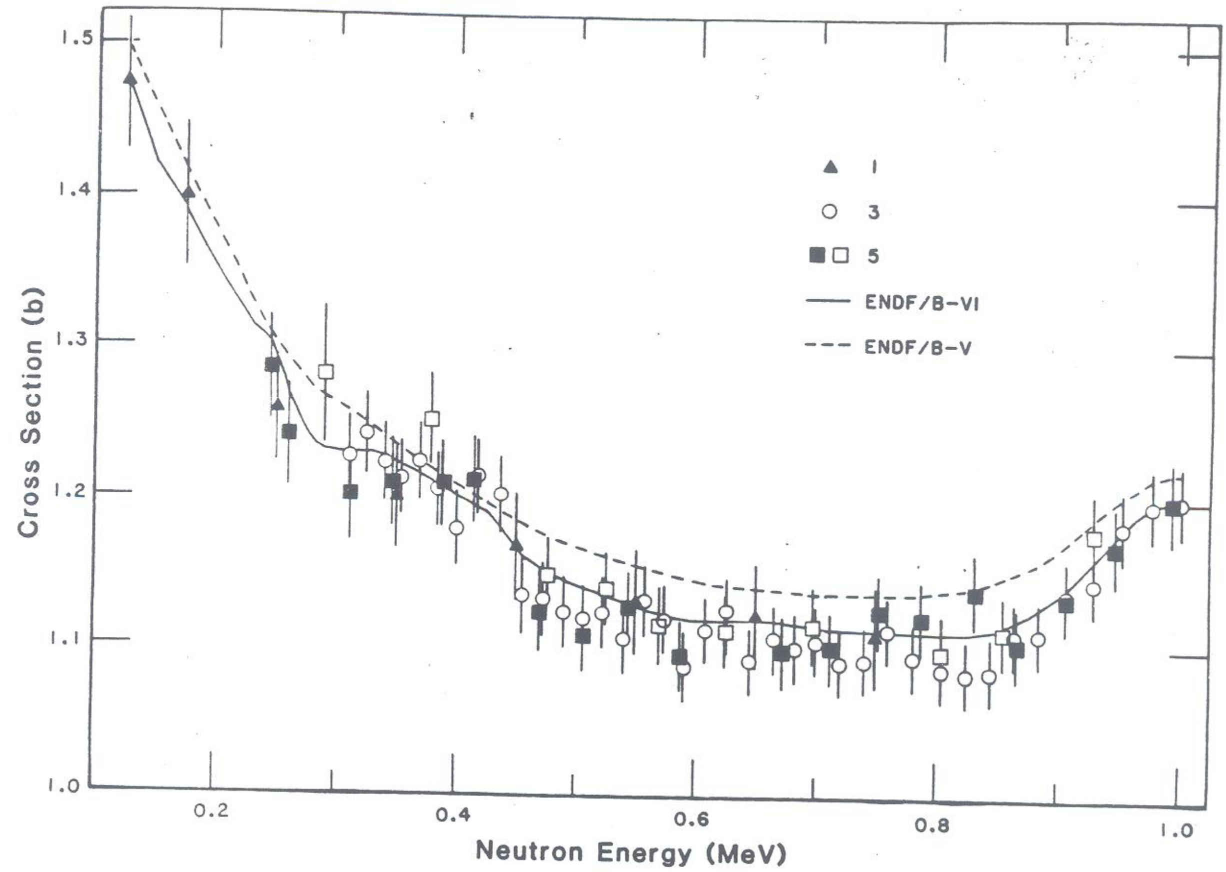

Figure 1. $^{235}U(n,f)$ Cross Section. Symbols are labeled by reference number.

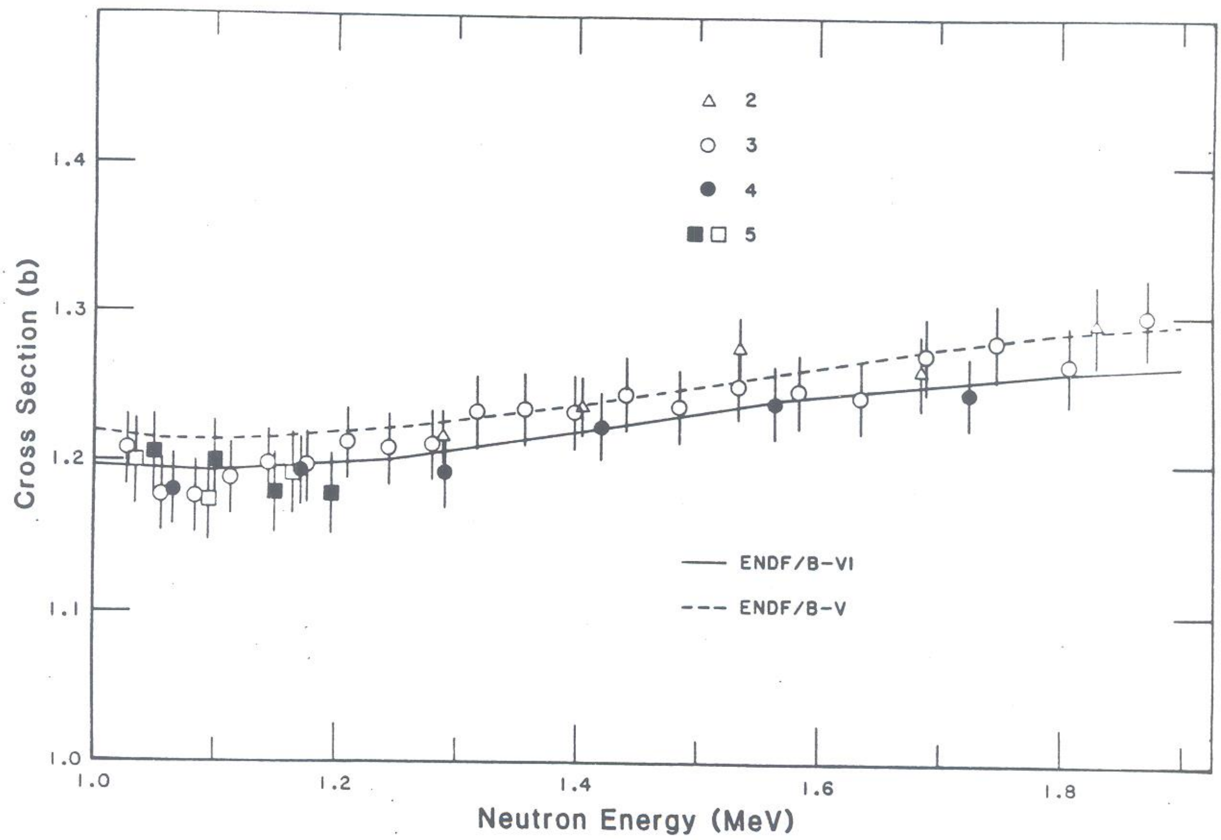

Figure 2. $^{235}U(n,f)$ Cross Section. Symbols are labeled by reference number.

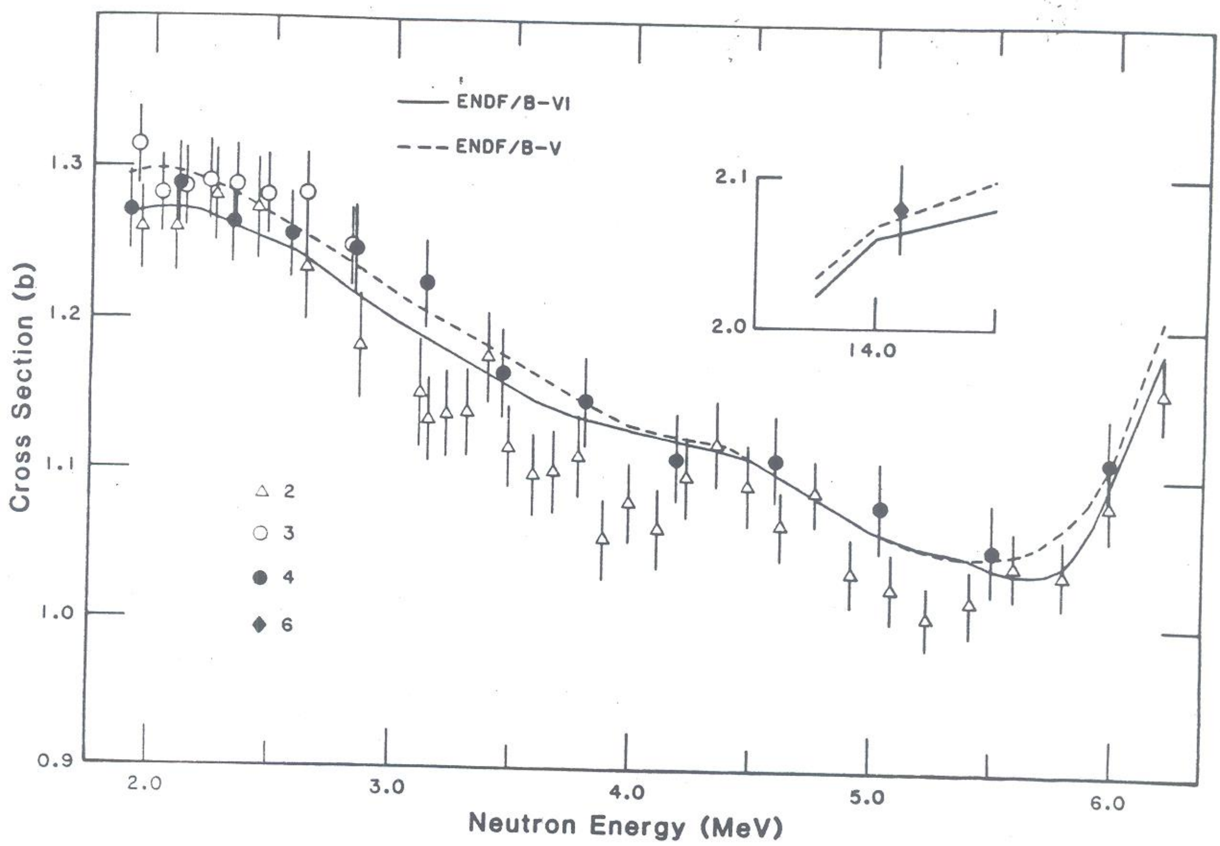

Figure 3. $^{235}U(n,f)$ Cross Section. Symbols are labeled by reference number.

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