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MEASUREMENTS OF THE ^{235}U(n,f) CROSS SECTION IN THE 3 TO 30 MeV NEUTRON ENERGY REGION*

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A. D. Carlson and O. A. Wasson

National Institute of Standards and Technology
Gaithersburg, MD 20899, U.S.A.

P. W. Lisowski and J. L. Ullmann

Los Alamos National Laboratory
Los Alamos, NM 87545, U.S.A.

N. W. Hill

Oak Ridge National Laboratory
Oak Ridge, TN 37831, U.S.A.

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Abstract: To improve the accuracy of the ^{235}U(n,f) cross section, measurements have been made of this standard cross section at the target 4 facility at Los Alamos National Laboratory (LANL). The data were obtained at the 20-meter flight path of that facility. The fission reaction rate was determined with a fast parallel plate ionization chamber and the neutron fluence was measured with an annular proton recoil telescope. The measurements provide the shape of the ^{235}U(n,f) cross section relative to the hydrogen scattering cross section for neutron energies from about 3 to 30 MeV neutron energy. The data have been normalized to the very accurately known value near 14 MeV. The results are in good agreement with the ENDF/B-VI evaluation up to about 15 MeV neutron energy. Above this energy differences as large as 5% are observed.

(^{235}U(n,f) standard cross section; H(n,n) standard cross section; annular proton recoil telescope; fission; fission chamber; fluence; neutron; standard)

Introduction

The ^{235}U neutron fission cross section is one of the most commonly used neutron cross section standards. In certain energy regions almost all fission cross section measurements have been made relative to this standard. It should be noted that any improvement in the ^{235}U(n,f) cross section, in the region where it is used as a standard, improves all cross section measurements which have been made relative to this standard. Though many measurements of this cross section have been made, significant differences in the data exist, particularly at high neutron energies. There is recent interest in neutron fluence standards in the upper MeV energy region and notably above 20 MeV as a result of applications in radio-therapy, fusion, accelerator shielding, radiation damage, etc. In response to this need the present shape measurements were made which are normalized to the very accurately known ^{235}U(n,f) cross section near 14 MeV neutron energy.

Experimental Details

The measurements were made at the 20 m station of the Weapons Neutron Research (WNR) target 4 neutron time-of-flight facility at LANL. The experiments were performed during several different running periods with different data acquisition systems and experimental conditions. The neutron fluence and fission reaction rates were determined with an annular proton telescope (APT) and a multiplate fission chamber, respectively. A white spectrum of neutrons was produced by 800 MeV protons from the proton linear accelerator of the Los Alamos Meson Physics Facility bombarding a tungsten target 7.5 cm long and 3 cm in diameter. The 20 m flight path is at an angle of 60 degrees with respect to the incident proton beam. For this work, the spacing between the sub-nanosecond width microstructure pulses was about 4 μs. The experiment employed a collimated beam which passed through an evacuated flight path tube with a 2.54-cm thick polyethylene (CH_2) filter to reduce overlap effects due to previous micropulses and permanent magnets to deflect charged particles from the beam. The beam then entered the fission chamber, passed through 0.46 m of air, entered the APT, and was finally dumped in a concrete slab 5 m from the APT.

Neutron Fluence Detector

A proton telescope with an annular geometry was used to measure the energy dependence of the neutron fluence. Recoil protons, emitted from a thin CH_2 film placed in the neutron beam, were counted in a lithium drifted silicon (Si(Li)) detector which was shielded from the neutron beam by a carefully aligned copper shadow shield suspended in the center of the beam. The present detector is a design improved over that used in Ref. 1 since it has a larger evacuated containing vessel and a tapered copper shadow shield to reduce the background. This APT detector was used in measurements [2] of the ^{235}U(n,f) cross section on the National Institute of Standards and Technology linac. Significant improvements [3] in the performance of this detector system have been made compared to that given in Ref. 2. For the measurements a CH_2 film having a thickness of 2.08 mg/cm^2 and a diameter of 12.7 cm was used. The background was determined from a series of measurements made with and without the CH_2 film in place and with and without a tantalum cap over the Si(Li) detector. The tantalum cap is sufficiently thick to eliminate proton recoil events but was assumed to be transparent to neutron and gamma ray backgrounds.

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For each measurement, the ambient background was determined from a time window located just before the WNR micropulse. The time dependent background was determined from the quantity A–B+C. Where A is the measurement obtained with the CH_2 film and the Ta cap, B is the measurement obtained with no CH_2 film and the Ta cap, and C is the measurement obtained with no CH_2 film and no Ta cap. Normalization of the various background runs was obtained by using the fission chamber as a monitor. The background in the telescope was small, a maximum of a few percent. Measurements with CH_2 and CH films indicated there were no statistically significant contributions from neutron reactions with carbon.

Monte Carlo calculations were made of an additional background associated with neutrons which scatter from the shadow shield and then either strike the CH_2 film or scatter from the containing vessel and strike the CH_2 film. This background was found to be negligible.

Further information about the APT, and typical pulse height distributions for this detector and the fission chamber employed in this experiment are shown in Ref. 3. The bias channel used for the APT was neutron energy dependent and was set to include the proton recoil events and discriminate against background events. The intrinsic resolution of the 3-mm thick Si(Li) detector was better than 2% for ^{241}Am alpha particles. The pulse height resolution observed in this experiment was dominated by the angular spread of the proton recoils and their energy loss in the CH_2 film. The efficiency of the APT detector was calculated taking into account the angular distribution of the proton recoils and the finite size of the CH_2 film. Relativistic transformations from the center of mass to laboratory system were used in these calculations. The hydrogen scattering cross section from the ENDF/B-VI evaluation [4] was used in these calculations.

Fission Ionization Chamber

A fast multiplate fission ionization chamber [5] with 3 mm plate spacings was used to measure the ^{235}U fission reaction rate. It was used at room temperature and contains a 1.5 atmosphere gas mixture of 70% methane and 30% argon. A single pulse height bias was used for the entire neutron energy range for each of the ^{235}U deposits. The chamber contained 200 $\mu g/cm^2$ ^{235}U deposits of 10.2-cm diameter on stainless steel backings of 0.00127-cm thickness. A backing with no fission deposit for background estimation and one with a ^{252}Cf deposit for diagnostic measurements were included in the chamber. The ^{252}Cf deposit was also used to match the gains of the sets of electronics associated with each of the fission chamber plates so the background from neutron interactions in the backing material could be determined. Other deposits used for fission cross section ratio measurements [6] to the ^{235}U(n,f) cross section were also contained in the chamber. The neutron beam at the chamber is 12.7-cm diameter. The diameter of the supporting structure for the fission backings was 15.2 cm thus the detector could easily be aligned to ensure that the neutron beam would not strike this structure.

Corrections for fission events which do not escape from the deposit were made using the expression given by Carlson [7]. This expression takes into account both angular distribution and momentum effects. The deposits were all facing away from the neutron producing target. The maximum correction relative to the 14 MeV value where the data are normalized is 0.5%. The background contribution in the fission chamber due to overlap neutrons from previous micropulses was calculated using the neutron spectra of Russell [8]. This contribution was less than 0.1%.

The ambient background for the fission chamber was measured by using a time gate located just before the WNR micropulse. The results of a run with the fission chamber out of the beam agreed with that of an ambient run. A determination of the background from neutron interactions in the backing material indicated a negligible effect for the energy range of these cross section measurements. A check was made to determine if neutrons scattering from the shadow shield in the annular proton telescope caused a background in the fission chamber. The test was performed by moving the telescope entirely out of the beam. No change in fission chamber count rate was observed. Further tests for background which related to both the fission chamber and the APT were performed. These tests included a run to check for high energy charged particles in the beam, a run to check for "cross talk" backgrounds related to the other flight paths, and a run with the target out of position. These runs indicated no significant background. Monte Carlo calculations were made of the background from neutrons which scatter from the beam defining collimators into the detectors. This contribution was negligible.

Data Acquisition

The APT and each fission foil employed essentially the same electronics. The electronic system permitted fast timing which is needed for the use of the time-of-flight technique and some integration of the pulse to provide reasonable pulse height resolution. A tagging method was used which allowed the timing information from all the detectors to be digitized in one analog to digital converter (ADC). The energy scale was established from transmission measurements of carbon resonances. Similarly all the pulse height signals were digitized in a single separate ADC. The data were taken and stored in an event by event mode. Each event is composed of three words: the tag which defines the detector in which the event occurred, the digitized time-of-flight and the digitized pulse height. Storing the data in this manner allows the experiment to be "replayed" so that shifts, etc. can be noted and handled appropriately. It does, however, require the storage of a significant amount of data.

Analysis and Results

The APT data were sorted with an energy dependent bias, divided by the efficiency, corrected for backgrounds and the transmission through the materials between the fission chamber deposits and the APT, and grouped into energy groups. The resulting data are shape measurements of the neutron fluence. The fission chamber data, which uses an energy independent bias, were sorted, corrected for backgrounds, grouped and divided by the fluence to produce a cross section shape. The statistical uncertainty, one standard deviation, yfor the measurements varies from about 1% at the lowest energy to about 2% at the highest energy. The dead time correction for the APT as a function of neutron energy is almost identical to that for each of the fission chamber deposits. Since the ratio of these quantities is used in the analysis, no correction was made for dead time effects.

A separate measurement [9] of the $^{235}U(n,f)$ cross section was made using the same fission chamber and at the 20 m station used for the present investigation, however, the neutron fluence was determined with two new proton telescopes. The low energy telescope (LET) uses a thin CH_2 film and a Si(Li) detector in a vacuum enclosure at -15 degrees from the beam line. The geometry allows very good proton recoil pulse height resolution. This detector is located downstream from the fission chamber. The other telescope is the medium energy telescope (MET) which is also at an angle of 15 degrees from the beam but is operated in air downstream from the LET. The MET is composed of a CH_2 disk and three collinear proton detectors. The detectors are a 0.16-cm thick plastic scintillator, a 0.6-cm thick plastic scintillator and a 15.2-cm thick CsI scintillator. The MET is used in a coincidence mode in order to reduce the background. By combining the results from these two detectors, the fluence can be determined from 3 to greater than 250 MeV.

The results of the present investigation are shown in Fig. 1. They agree well with the ENDF/B-VI evaluation below 15 MeV. At higher energies differences as large as 5% exist. Also shown in this figure are the results obtained by Alkhazov [10] and those of the separate measurement [9] at this facility. These measurements are in generally good agreement with the present work and suggest that the ENDF/B-VI evaluation is low above 15 MeV.

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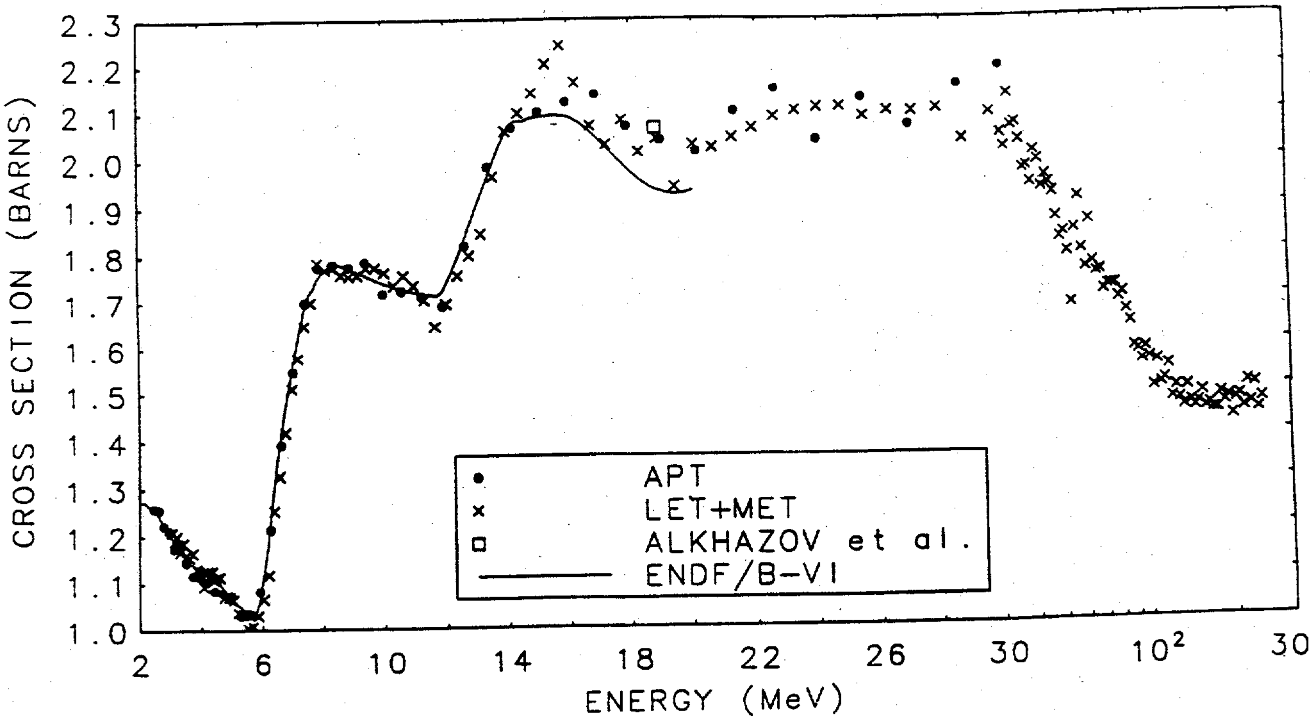

Fig. 1. Comparisons of the most recent measurements of the $^{235}U(n,f)$ cross section with the ENDF/B-VI evaluation. The data shown are the present measurements (labelled APT), those of Ref. 9 (labelled LET + MET) and Ref. 10. The statistical uncertainties, one standard deviation, on all these data are ~ 1-2%. The energy scale in the figure changes from linear to logarithmic at 30 MeV.

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