Nuclear Data for Science and Technology (1988 MITO), 1029-1032, Copyright © 1988 JAERI.

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

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Abstract: The ^{235}U(n,f) cross section is often considered the most favorable of the neutron cross section standards. Above a few MeV, however, the uncertainties are still unacceptably high, except for the 14 MeV region. In an effort to improve the accuracy of this cross section, measurements have been initiated at the new target 4 facility at the Los Alamos National Laboratory (LANL) 800 MeV proton accelerator. This target provides an intense source of high energy neutrons at the 20 meter flight path used in the present study. The fission reaction rate is determined with a fast parallel plate ionization chamber designed at LANL while the neutron fluence is being measured with an annular proton recoil telescope whose properties were carefully studied earlier at the National Bureau of Standards (NBS). This detector provides satisfactory performance for neutron energies up to about 30 MeV. Possible use of this detector at higher neutron energies where the recoil proton range exceeds the solid state detector thickness is being investigated. The measurements provide the shape of the ^{235}U(n,f) cross section relative to the hydrogen scattering cross section. The data will be normalized to the very accurately known values at 14 MeV. Experimental tests, diagnostic studies and preliminary cross section determinations have been completed and will be reported.

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

Introduction

The ^{235}U neutron fission cross section is probably the most important of the neutron cross section standards above ~ 100 keV. In certain energy regions almost all fission cross section measurements have been made relative to this standard. With the large body of data relative to this standard it should be noted that any improvement in the ^{235}U(n,f) cross section improves all cross section measurements made relative to this standard. In spite of the fact that many measurements of this cross section have been made, significant differences in the measurements exist, particularly at high neutron energies. Also very few measurements have been made above 14 MeV neutron energy and only one rather old measurement extends above 20 MeV neutron energy. 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 radiotherapy, fusion, accelerator shielding, radiation damage, etc.

The measurements to be reported in this paper are preliminary shape measurements which are to be normalized to the very accurately known cross section at 14 MeV neutron energy.

Experimental Details

This experiment was performed at the 20 m station of the new Weapons Neutron Research (WNR) target 4 neutron time-of-flight facility at LANL. The data were obtained during two separate running periods involving different data acquisition systems. Most of the discussion that follows relates to the first of the running periods. The second group of data is presently under analysis. A white spectrum of neutrons is produced by 800 MeV protons from the proton linear accelerator of the Los Alamos Meson Physics facility bombarding a tungsten target. The spallation reactions produce neutrons with maximum energies of greater than 400 MeV. The 20 m flight path is at an angle of 60° with respect to the incident proton beam. The spacing between microstructure pulses for this experiment was ~ 4 μs. The neutron fluence and fission reaction rates were determined with an annular proton telescope (APT) and a multiplate fission chamber, respectively. These detectors and a vertical view of the collimation are shown in Fig. 1. The flight path tube between the target and the fission chamber is evacuated to reduce the scattering of neutrons by air.

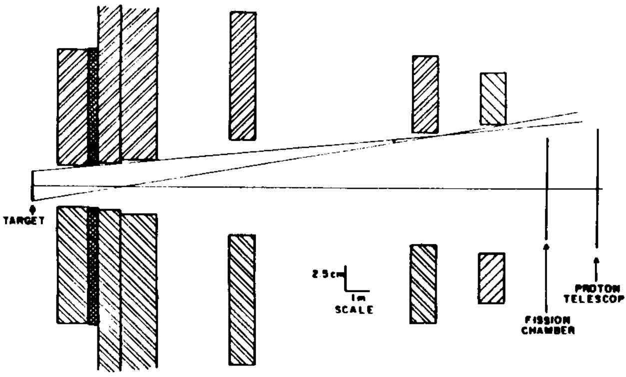

Fig. 1. Experimental geometry of the 60°-20 m flight path showing the target, collimators and detectors.

Neutron Fluence Detector

An APT similar to that described by Sidhu and Czirr[1] was used to measure the energy dependence of the neutron fluence. Recoil protons, emitted from a thin polyethylene film placed in the neutron beam, are counted in a Si(Li) detector which is shielded from the neutron beam by a shadow shield suspended in the center of the beam. The present detector employs a slightly different geometry compared with that used in ref. 1 with a larger evacuated containing vessel and a tapered copper shadow shield in order to reduce the background. This detector has been used in measurements[2] of the ^{235}(n,f) cross section on the NBS linac which have been finalized from 1-6 MeV neutron energy. A significant improvement in the timing of this detector system has been made compared to that shown in ref. (2). This has been possible as a result of conditioning of the detector so that it will operate at very high voltages (as high as 1200 V) and improvements in the timing electronics. The timing walk was measured using a variable amplitude pulser adjusted to provide pulses having approximately the same shape as that produced by ^{241}Am alpha particles. Subtle walk related effects which may not be present with pulser pulses but may be present with proton recoil pulses were investigated my measuring the walk with a novel technique. The measurements were made at the LANL tandem Van de Graaff facility using the pulsed beam time-of-flight technique with monoenergetic 11 MeV neutrons obtained using the H(t,n) reaction. The APT was placed in this beam with a polyethylene film having a thickness greater than the range of 11 MeV protons. Thus a spectrum of proton recoils was produced in the polyethylene film and detected in the Si(Li) detector with energies from 0 - ~ 10 MeV. The walk could then be measured for a wide range of proton recoil energies simultaneously. The only correction required is an accurately determined one for proton time-of-flight. The walk measured in this manner generally agreed with that obtained in the pulser work. Maximum timing walk effects are now in the ns range.

The layout of the detector is shown in Fig. 2. For the measurements a polyethylene film thickness of 2.08 mg/cm^2 was used. Monte Carlo calculations were made of the background associated with neutrons which scatter from the shadow shield and then either strike the polyethylene film or scatter from the containing vessel and strike the polyethylene film. This background was found to be negligible.

The background was determined from a series of measurements made with and without the polyethylene 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. The ambient background was determined from a time window located just before the WNR micropulse. Information relating to the subtraction of the remaining background is contained in Table 1. This table shows sources of signals in the Si(Li) detector and therefore includes the true recoil proton events from the polyethylene (CH_2) film, shown by a circle, and the background contributions, shown by crosses, which must be subtracted to leave only the desired recoil events. In the table, the term tank refers to containing vessel and all other material in the detector system except the polyethylene film. An examination of Table 1 reveals that the quantity A-B+C yields the proper background present in the foreground run. Normalization of the various background runs was obtained by using the ^{235}U fission chamber as a monitor. The background in the telescope was small, typically a few percent.

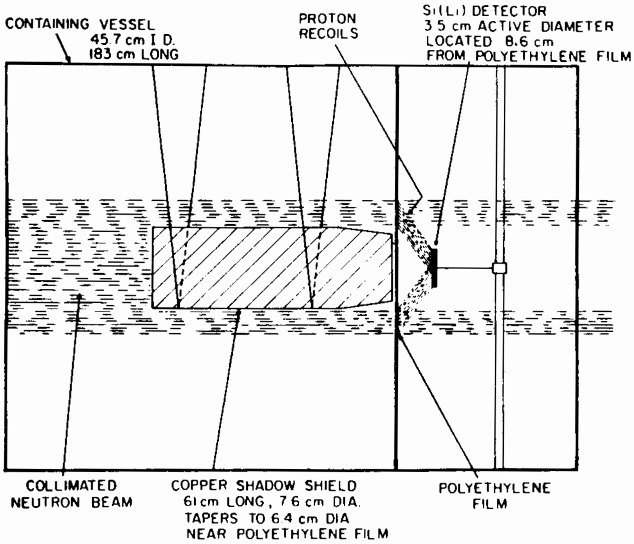

Fig. 2. Experimental set-up for the APT.

Table 1. Processes producing events in the Si(Li) detector. 0 indicates true proton recoil events, X indicates background events.

Run	Measurement Conditions		Processes Leading to Events Recorded in Si(Li) Detector						
			Recoil Protons from CH_2	Neutrons Scattered in CH_2	Neutrons Scattered by Tank	Charged Particles from Tank	γ-Rays from Tank	Charged Particles from Ta	γ-Rays from Ta
Foreground	CH_2	No Ta	0	X	X	X	X		
Background A	CH_2	Ta		X	X		X	X	X
Background B	No CH_2	Ta			X		X	X	X
Background C	No CH_2	No Ta			X	X	X		

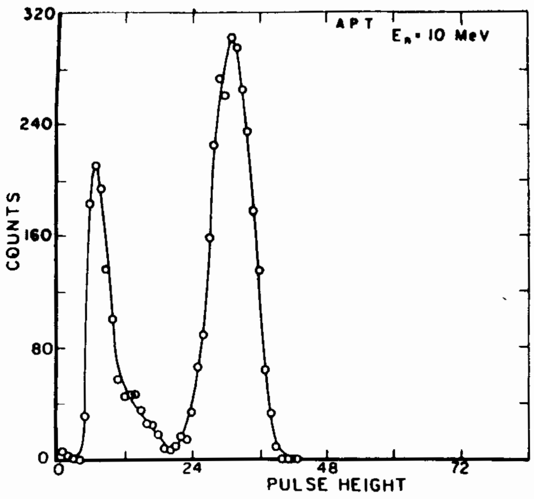

Fig. 3. Pulse height distribution observed with the APT for a neutron energy of 10 MeV.

The pulse height distribution obtained with this detector for 10 MeV neutrons is shown in Fig. 3. The bias channel for the proton telescope pulse height distribution is energy dependent and was set to include the proton recoil events and eliminate events from ^{12}C + n reactions in the polyethylene film. Some corrections for ^{12}C + n reactions are required at the higher neutron energies. The intrinsic resolution of the 2-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 polyethylene film.

The efficiency of this detector was calculated taking into account the angular distribution of the proton recoils and the geometry of the detector. The Hopkins-Breit evaluation[3] of the hydrogen scattering cross section (ENDF/B-V) was used in these calculations. The efficiency is shown in Fig. 4.

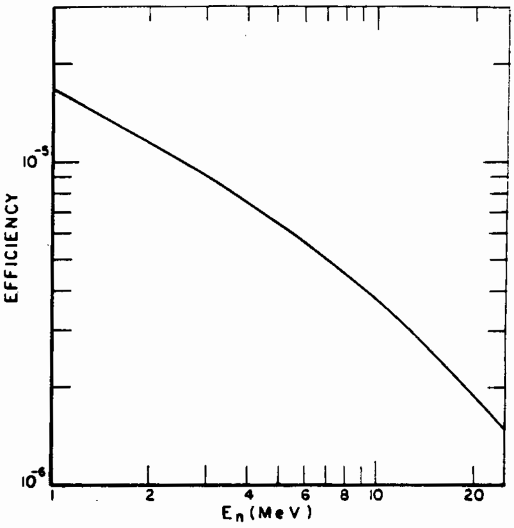

Fig. 4. Efficiency of the APT with a polyethylene film thickness of 2.08 mg/cm^2.

Fission Ionization Chamber

A multiplate fission ionization chamber with 3 mm plate spacings was used to measure the ^{235}U fission reaction rate. This chamber is similar in design to that used by ref. 4. It is used at room temperature. The chamber contained ~ 200 μg/cm^2 ^{235}U deposits of 10.2-cm diameter on stainless steel backings of 0.00127-cm thickness. Also a backing with no deposit for background estimation and a ^{252}Cf deposit for diagnostic work were 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 to the $^{235}U(n,f)$ cross section were also contained in the chamber which will be the subject of another paper[5] at this conference. The neutron beam at the chamber is ~ 12.7-cm diameter. The chamber was filled with a 1.5 atmosphere mixture of 70% argon and 30% methane counting gas.

The ambient background for the fission chamber was measured in the standard way using a time gate just preceding the WNR micropulse. A run with the fission chamber out of the beam agreed with ambient. A determination of the background from neutron interactions in the backing material indicates 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.

A typical pulse height distribution obtained with this detector is shown in Fig. 5. A single pulse height bias was used for the entire neutron energy range for each of the ^{235}U deposits.

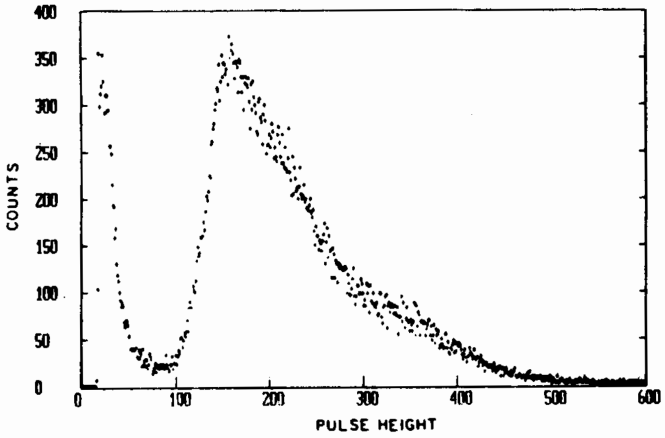

Fig. 5. Pulse height distribution for one of the ^{235}U fission chamber deposits.

Corrections for angular distribution and momentum effects were not made but are judged to be very small. The deposits are all facing away from the neutron producing target.

Overlap neutrons from previous micropulses does cause a background in the fission chamber. It is estimated that the maximum correction is ~ 1%. This correction has not yet been made to the data. Some of the overlap neutron background is removed in the ambient background subtraction.

Data Acquisition, Analysis and Results

The proton telescope and each fission foil employ essentially the same electronics which permits 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 analogue to digital converter (ADC). 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.

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.

The APT data were sorted with an energy dependent bias, divided by the efficiency, corrected for backgrounds and grouped into appropriate energy groups. The resulting data are shape measurements of the neutron fluence. Figure 6 shows a comparison of that fluence measurement with a Monte Carlo calculation of the neutron spectrum at an angle of 60° with respect to an 800 MeV proton beam on a tungsten target. The target is a 3-cm diameter by 7.6-cm long tungsten cylinder aligned with its axis coincident with the beam. The deviation between measurements and calculation at the higher energies has been noted with similar targets previously.[6]

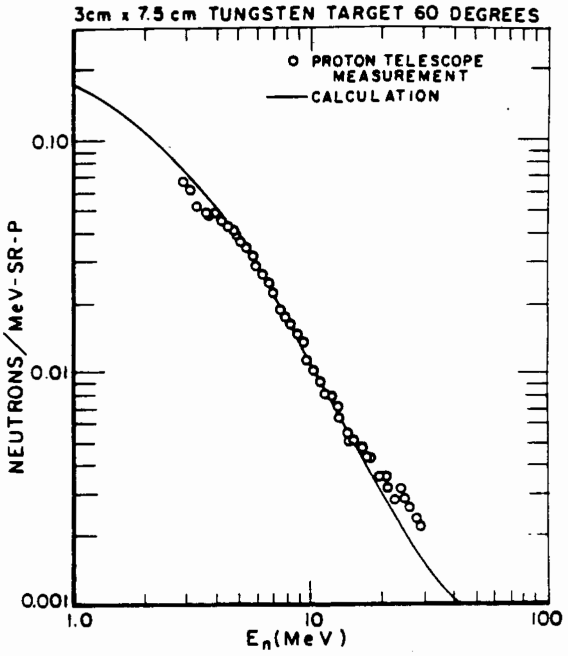

Fig. 6. Comparison of the present measurements of the fluence shape with Monte Carlo calculations.

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 preliminary results of the present investigation are shown in Fig. 7. The uncertainties shown are statistical only. The present results agree well with the ENDF/B-V evaluation[7] and reveal additional structure above 20 MeV where measurements have not been made in the past.

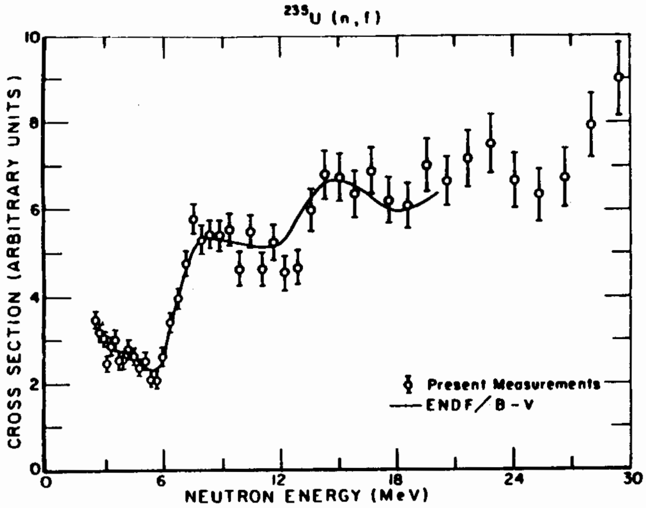

Fig. 7. Preliminary results of the present measurement of the ^{235}U(n,f) cross section shape compared with ENDF/B-V.

Further work is planned which should result in significantly smaller uncertainties in the cross section for this important standard. Also for future study is the possibility of using the APT detector at very high neutron energies where the proton range is greater than the thickness of the Si(Li) detector. For a large range of neutron energies, a peak is observed in the pulse-height distribution. However, proper determination of the background requires further investigation.

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