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Neutron Total Cross Section Measurement at WNR

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The techniques involved in measuring fast-neutron total cross sections at the Weapons Neutron Facility (WNR) of the Los Alamos Scientific Laboratory are described. Results of total cross section measurements on natural carbon covering the range 2.5 to 250 MeV are presented.

Introduction

The Weapons Neutron Research Facility[1,2] is the first operating example of a new class of neutron sources. A part of the 800-MeV proton beam from LAMPF is used to bombard a tantalum target to produce an intense white source of pulsed neutrons. Variable width proton pulses may be supplied to permit a time-of-flight capability covering the neutron energy range from a few meV to several hundred MeV. The first nuclear physics experiments have exploited the fact that the neutron flux from the WNR is particularly suited for measurements in the MeV energy range. One such result, the total cross section of ^{242}Pu measured from 0.7 to 170 MeV, is presented in a separate contribution[3] to this conference. We give here a description of the measurement technique used in that experiment together with results for the total cross section of natural carbon, a measurement which was provided as a reference case for both ^{242}Pu and additional actinide samples.

Experimental Technique

The data were acquired using WNR as the neutron source. Neutrons were produced by spallation processes due to 800-MeV protons incident on a water-cooled aluminum-clad tantalum target (2.5-cm diam. by 15-cm high).

One out of every ten LAMPF H$^+$ beam pulses[a] was chopped at the injector to provide a 5-μs proton pulse spacing.[b] These pulses were then diverted to the WNR after acceleration by LAMPF using a kicker magnet operating at 12 Hz. The proton pulse width at the WNR target was typically 0.2-ns FWHM. A fiducial signal (t_0) was obtained from a capacitive pick-off located upstream of the target in the proton beam line. In addition to providing a start pulse for the time-of-flight (TOF) electronics, this signal was integrated in an analog-to-digital converter gated by a random signal to provide a measure of the relative proton intensity and the intensity variation.

The cross section measurements were performed using a 31.78-meter flight path. About 30 m of the flight path was evacuated in order to minimize any structure in the neutron flux caused by resonances in air.

The neutron beam at the sample was defined by a main collimator in the flight path located approximately 16-m from the WNR target. For the ^{242}Pu and for one of the reference C results, the collimating geometry and other experimental details slightly different from those of the C measurements described here may be found Ref. 3. For these measurements, larger samples and correspondingly larger collimators were used. Because there are a significant number of high-energy neutrons in the WNR beam, leakage through the collimator and through an aligning sleeve was found to be an important background contribution. The main collimator was composed of brass, iron and lead sections giving an average length of 80 cm. A brass scraper collimator 29-cm long and having a 3-cm diam opening was placed after the samples to remove any neutrons penetrating the aligning sleeve.

A neutron flux monitor was placed in the neutron beam after the main collimator. Because earlier investigations had showed that the number of charged particles[c] in the neutron beam was not a reliable indication of the neutron flux, a two-detector monitor was used. This arrangement consisted of two separate detectors separated by about 8 cm. Each detector was an 0.3-cm thick 2.9-cm square Pilot-B scintillator mounted on an RCA 8850 photomultiplier tube. The first of these detectors acted as a veto counter for the second, thus eliminating a charged particle contribution which was actually greater than the neutron contribution due to the almost 100% efficiency for charged particles.

The transmission samples were placed in a motorized changer, located about 0.5-m downstream of the main collimator. This sample changer was driven by the data collection computer via a Camac interface and stepping motors. An optical encoding system provided positioning accuracy to about 0.03 mm.

Because of the continuous distribution of high-energy charged particles produced along with the neutrons, it was necessary to use a sweep magnet located after the sample changer. This arrangement consisted of a magnet constructed from four ion-pump plate-magnets[d] with an overall length of 20 cm, a separation of 5 cm, and a central field of approximately 1 kG. Tests conducted using a thin fast-plastic detector at the location of the main detector demonstrated that the charged particles were completely removed by the magnet.

The neutron beam was stopped in a beam dump located at the end of an evacuated pipe approximately 30 meters beyond the neutron detector.

Two different neutron detectors were used in the cross section measurements. For the ^{242}Pu and corresponding C reference data, a 10.2-cm diam by 3.1-cm thick cylinder of NE 110 viewed by an RCA 8854 photomultiplier was used. This detector was replaced for

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[a] During these experiments, LAMPF was obtaining with an average current of 60 μA and a 7.44% duty cycle.

[b] For the ^{242}Pu experiment, a spacing of 7 μs was used to avoid frame overlap.

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[c] Although no absolute measurements have been made, calculations using the code NMTC indicate that about 0.3 protons/incident proton escape with an average energy of 273 MeV from the cylindrical surface of the target.

[d] Available from Permag-Pacific Corporation, 5441 West 104th St., Los Angeles, California 90045.

later measurements by a similar system having a 15.2-cm thick NE 110 cylinder to improve the detection efficiency for high-energy neutrons.

The electronics consisted of a complete TOF system for the main detector and a fast-timing system for the neutron-flux monitor. Anode signals from the two monitor detectors were fed into an Ortec 934 constant fraction discriminator with a bias set below the minimum ionizing peak using a ^{90}Sr electron source. The output of the veto monitor detector was stretched and combined in anti-coincidence with the output of a coincidence between the second monitor detector and a time gating signal. This technique gated out charged particle as well as very short and very long time events. The resulting pulses were counted in a fast (100 MHz) scaler. Deadtime losses for this system were insignificant as the rate in the detector was only about 0.1 counts per neutron burst in gated and about 0.6 counts in ungated mode. The time-of-flight spectrum from the main detector system was obtained from an Ortec TDC-100 digital clock operated in single-stop-per-start mode. Time-channel widths were set at 1 ns or 0.5 ns for the two sets of measurements. The proton t_0 signal was used to start the clock. The stop signal was derived from an Ortec 934 constant-fraction discriminator. Data were collected in four pulse-height windows, using bias settings ranging from $\sim$ 2 MeV to $\sim$ 10 MeV. The total open-beam counting rate for the ^{242}Pu experiment with a low bias of $\sim$ 300 keV and a small collimator was about 0.7/micropulse, whereas for the C data with a low bias of $\sim$ 2 MeV and a large collimator, the rate was only about 0.8/micropulse.

The background spectrum was measured by replacing the sample with a 1.9-cm diam by 46-cm long tungsten rod. These background spectra were measured several times and the shape followed roughly that expected for transmission of high-energy neutrons through the collimator. The backgrounds were less than 0.6% below 60 MeV, 0.8% at 100 MeV, and 2% at 200 MeV.

Data were accumulated using a Modcomp/IV computer system via a Camac interface. Time-of-flight spectra of 4096 channels for each bias were recorded along with various scaler signals for diagnostic purposes. The samples were cycled in and out of the beam at about 15-minute intervals, based on a preset number of monitor events. The spectra and scaler readings were recorded on tape at about 2-hour intervals as a backup against computer failure.

The carbon sample for the measurements reported here was one of three machined from a single block of high-purity, high-density, reactor-grade graphite. The measured density of each of the cylinders was found to be 1.836 g/cm^3 and density differences were less than 0.1% among all three. The sample thickness was 1.3682 atoms/barn.

The data reduction was performed using the central computing facility at Los Alamos Scientific Laboratory. The sample-in and sample-out spectra were corrected for dead-time losses and a normalized dead-time corrected background spectrum was subtracted from each. After subtraction of the measured background spectrum, a small time-uncorrelated background, typically less than 1%, was also subtracted.

For data below 60 MeV, the lowest bias data were used. Above 60 MeV, only the highest bias data were used both to lower the time-uncorrelated background and to avoid any contribution from time slewing of the prompt γ-ray peak produced when the beam struck the target.

The data for individual time channels were combined into bins of constant neutron energy resolution, as listed in Table I, and converted to total cross sections as a function of neutron energy.

Results and Comparison with Other Data

The total cross section of carbon has been the subject of many experimental investigations, particularly in the energy range below 15 MeV. Between 15 and 250 MeV, the data are sparse, but several sets of data from different laboratories are available for comparison. The present results are shown in Fig. 1 compared to the ENDF/B-V evaluation.[4] The measurements of the carbon total cross section reported here agree with the ENDF/B-V evaluation below about 8.5 MeV, to about 0.6% for the relatively smooth regions between resonances where energy resolution is unimportant. Above 8.5 MeV, these data agree better with the NBS data,[5] upon which the evaluation was largely based, than the evaluation itself. Comparison with the data of Auchampaugh et al.[6] is of similar quality. Above 15 MeV, the most recent data are those of Auman et al.[7] and Bubb et al.[8] covering the range from 24 to 60 and 20 to 45 MeV, respectively. Agreement with data of Auman et al. is generally better than 1%. The results of Bubb et al.[8] are generally higher than our results, those of Auman et al., or older results of Bowen et al.[9] From 80 to 150 MeV, there exist data from Meadsday and Palmieri[10], Bowen et al.[9], Taylor and Wood[11] and several other less comprehensive cross section measurements.[14-17] Agreement with the present data is within about 2% for Meadsday and Palmieri. The results of Bowen et al. are consistently lower than our data below about 90 MeV; at higher energies their data generally agree within errors with our systematically higher results. Above about 150 MeV, there exist no recent data; however, several sets of early results have been reported. Ragent[15], DeJuren and Moyer[16], and Mott et al.[13] all provide values which compare well with our data between 163 and 220 MeV. Table II provides a summary of selected comparison points covering the energy range of these measurements.

Conclusions

The technique for measuring fast neutron total cross sections at WNR has been described and demonstrated to yield accurate results using C as a test case. Additional data covering the complete energy range 2.5 to 250 MeV have been provided.

TABLE I

NEUTRON ENERGY BINS FOR FIGURE 1

E_n	ΔE_n
2.5 to 8.5 MeV	0.2%
8.5 to 20 MeV	0.5%
20.0 to 60 MeV	1.0%
60 to 250 MeV	2.5%

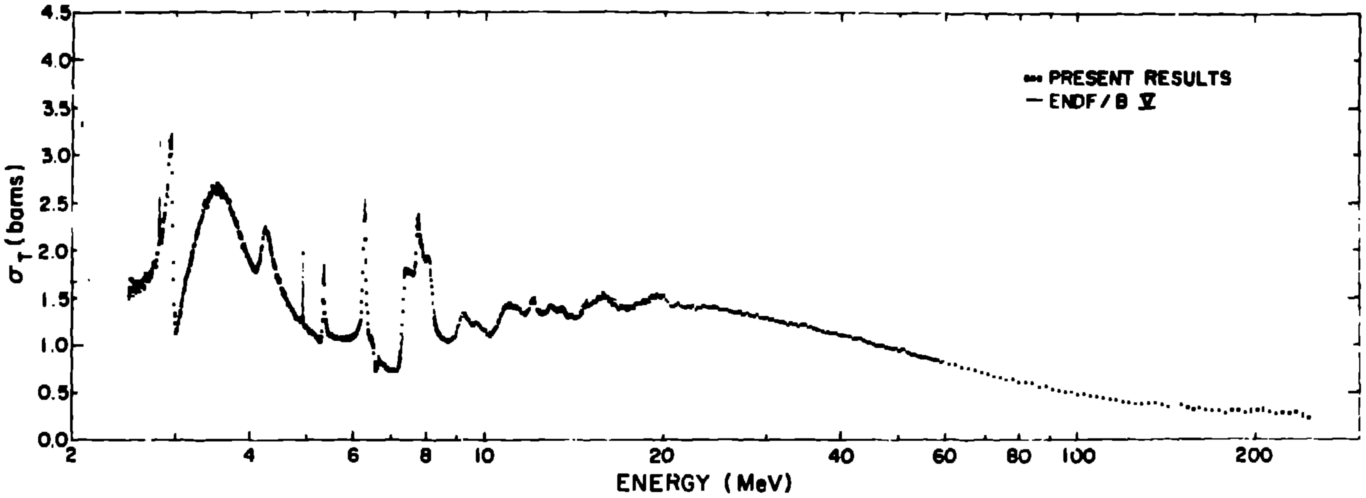

Fig. 1. Present results for the carbon total cross section. The solid curve is from ENDF/B-V evaluation.

Table II. Comparison of the present carbon total cross-section results with other work at selected energies

E_n ± ΔE_n (MeV)	Present Work σ_T ± $\Delta\sigma_T$ (b)	Previous Work σ_T ± $\Delta\sigma_T$ (b)	Difference δ ± $\Delta\delta$ (%)	Reference
3.60 ± 0.04	2.602 ± 0.012	2.607 -	- 0.2 ± 0.5	ENDF/B-V (4)
5.72 ± 0.15	1.071 ± 0.002	1.078 -	- 0.7 ± 0.2	"
8.64 ± 0.10	1.050 ± 0.004	1.066 -	- 1.5 ± 0.4	"
11.63 ± 0.30	1.346 ± 0.005	1.337 -	+ 0.7 ± 0.4	"
14.20 ± 0.50	1.308 ± 0.004	1.303 -	+ 0.4 ± 0.3	"
16.10 ± 0.26	1.497 ± 0.007	1.502 -	- 0.3 ± 0.5	"
18.13 ± 0.27	1.439 ± 0.007	1.445 -	- 0.4 ± 0.5	"
24.62 ± 2.0	1.393 ± 0.003	1.390 ± 0.002	+ 0.2 ± 0.4	Auman *et al*(7)
36.33 ± 2.0	1.175 ± 0.004	1.179 ± 0.001	- 0.3 ± 0.4	"
46.17 ± 2.0	0.995 ± 0.004	1.013 ± 0.001	- 1.8 ± 0.5	"
54..6 ± 2.0	0.882 ± 0.005	0.883 ± 0.001	- 0.0 ± 0.6	"
69.90 ± 3.0	0.714 ± 0.004	0.698 ± 0.009	+ 2.2 ± 1.8	Bowen *et al*(9)
88.2 ± 2.0	0.560 ± 0.006	0.547 ± 0.008	+ 2.3 ± 2.5	Measday (10)
98.10 ± 2.0	0.502 ± 0.006	0.490 ± 0.007	+ 2.4 ± 2.6	"
110.0 ± 2.0	0.445 ± 0.006	0.439 ± 0.006	+ 1.3 ± 2.6	"
119.6 ± 2.0	0.406 ± 0.007	0.403 ± 0.006	+ 0.7 ± 3.2	"
129.4 ± 2.0	0.384 ± 0.007	0.375 ± 0.005	+ 2.3 ± 3.1	"
140.9 ± 2.0	6.362 ± 0.006	0.346 ± 0.005	+ 4.4 ± 3.0	"
156.0 ± 5.0	0.332 ± 0.006	0.325 ± 0.010	+ 2.1 ± 4.8	Mott (13)
180.0 ± 7.0	0.290 ± 0.007	0.311 ± 0.009	- 7.2 ± 5.5	"
216.0 ± 6.0	0.292 ± 0.012	0.296 ± 0.005	- 1.4 ± 5.8	"

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