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NEUTRON CROSS SECTION MEASUREMENTS AT WNR+

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ABSTRACT

The Weapons Neutron Research Facility has been used to obtain moderate-resolution total neutron cross section data for H, C, ^{208}Pb, ^{232}Th, ^{238}U, and ^{242}Pu over the energy range 5 to 200 MeV. Neutrons were produced by bombarding a 2.5-cm diam by 15-cm long Ta target with an 800 MeV pulsed proton beam from LAMPF. A 10.2-cm diam by 15.2-cm thick NE110 proton recoil detector was used at a flight path of 32 meters, giving a time-of-flight resolution of 60 ps/m. The total cross section results are compared to ENDF/BV evaluations and to previous data where possible.

INTRODUCTION

The Weapons Neutron Research Facility (WNR) has recently become operational as a pulsed white-neutron source [1]. At WNR, a portion of the 800-MeV proton beam from the Los Alamos Meson Physics Facility (LAMPF) is used to produce neutrons by spallation reactions on various heavy-metal targets. Proton pulses of variable width may be provided along with suitable targets and moderators to give a time-of-flight capability covering the energy range from a few meV to several hundred MeV.

Of interest to this conference is the fact that the neutron flux at WNR is particularly suited for measurements in the 10- to 50-MeV energy range. This is because there is significantly more neutron intensity at WNR in that energy range than at any other white-source facility and because the γ-ray burst is many orders of magnitude smaller than at an electron machine, permitting data to be obtained nearly up to time t = 0.

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We give here a description of the technique used in total cross section measurements and the results for H, C, ^{208}Pb, ^{232}Th, ^{238}U, and ^{242}Pu for energies from 5 to 200 Mev.

EXPERIMENTAL PROCEDURE

Neutrons were produced by spallation reactions using an 800-MeV proton beam incident on a water-cooled aluminum-clad tantalum target (2.5-cm diam. by 15-cm high). The proton beam was pulsed at an average rate of about 1500 sec^{-1} and had a time spread less than 0.5 ns. For the fast-neutron measurements reported here, no moderator was used.

A fiducial signal (t_0) was obtained from a capacitive pick-off located upstream of the target in the proton beam line. This signal provided both a start pulse for the time-of-flight electronics, and a measure of the relative proton intensity and intensity variation using an integrating analog-to-digital converter.

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

A main collimator located approximately 16-m from the WNR target was used to define the neutron beam at the sample[a]. This collimator was composed of sections of brass, iron and lead with a length of 80 cm. A brass scraper collimator 29-cm long with a 3-cm-diam opening was placed after the samples to remove neutrons which penetrated the aluminum aligning sleeve around the main collimator.

A neutron flux monitor was placed in the neutron beam after the main collimator. Because there are a significant number of charged particles in the neutron beam, a two-detector veto-monitor system was used. This technique eliminated the charged-particle contribution which was actually greater than the neutron contribution due to the much higher efficiency for detecting 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 controlled by the data collection computer using a CAMAC interface and stepping motors. Optical encoding was used to provide positioning accuracy to about 0.03 mm.

The continuous distribution of charged particles was removed from the neutron beam using a sweep magnet after the sample changer. Tests using a thin fast-plastic detector placed at the

a) The ^{242}Pu measurement used a setup which varied somewhat from that described here due to the small (6-mm diam) sample size. Reference 2 provides more detail.

main detector location demonstrated that the charged particles were completely removed by the magnet.

Two different neutron detectors were used. For the ^{242}Pu data, a 10.2-cm diam by 3.1-cm thick cylinder of NE110, viewed by an RCA 8854 photomultiplier was used. For the other measurements, the detection efficiency for high energy neutrons was increased by replacing the scintillator by one 15.2-cm thick.

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

The electronics consisted of a complete TOF system for the main detector and a fast-scaler system for the neutron-flux monitor. Time-of-flight spectra from the main detector were collected using an EG&G TDC-100 digital clock operated in single-stop-per-start mode. The proton t_0 signal was used to start the clock. An Ortec 934 constant-fraction discriminator provided the stop signal. Data were stored at four bias settings ranging from ~ 2 MeV to ~ 10 MeV at a time-channel width of 0.5 ns. Main detector dead-time corrections were less than about 30% for all the data.

The output of the neutron-flux monitor system was time-gated to only count neutron events occuring after the γ-burst. The resulting pulses were counted by a fast scaler. Dead-time losses for this system were negligible as the rate from the gated monitor detector was only about 0.1 counts/burst.

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

A Modcomp/IV computer and CAMAC interface were used to accumulate the data. Time-of-flight spectra of 4096 channels were recorded for each bias along with various scaler readings for diagnostic purposes. The computer also controlled the sample changer, moving various samples in and out of the beam at intervals of about 15 minutes, based on a preset monitor-detector count. A typical counting time for each sample was 20 hours.

The data were reduced using the central computing facility at Los Alamos Scientific Laboratory. After correcting all spectra for dead-time losses, a normalized background spectrum was subtracted from both sample-in and sample-out data. A small residual 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 avoid any contribution from time slewing of the prompt γ-ray peak produced when the beam struck the target and to lower the time-uncorrelated background.

Data for individual time channels were combined into bins of const. energy resolution and then converted to total cross section as a function of neutron energy.

SAMPLES

All of the samples were right circular cylinders approximately 2.1-cm in diameter. Measurements of the mass and diameter of each sample were used to obtain thicknesses. Polyethylene and carbon samples matched to better than 0.1% were used to obtain the hydrogen cross section data. Where possible, the samples were analyzed for impurities. Only the thorium sample was found to contain an appreciable contaminant material (0.36 wt.% oxygen). The ^{208}Pb, ^{238}U, and ^{242}Pu samples were isotopically enriched to 99.8% or greater. Table I gives a summary of the sample thicknesses.

RESULTS AND DISCUSSION

With the exception of ^{242}Pu, total cross section data in the MeV region for each of the materials investigated here have been presented before. Below about 15 MeV there are considerable data as well as the ENDF evaluation, which extends to 20 MeV. Between 15 and 200 MeV data are sparse, but there are several results from different laboratories for comparison.

The hydrogen total cross section is used as a standard for measurements up to about 20 MeV. Above that energy, measurements by several groups show differences of nearly 3%. Our data generally agree to within 1% with the ENDF/B-V evaluation and with data of Brady et al. [3] (25 to 60 MeV), Groce and Sowerby [4], (20 to 80 MeV), and Measday and Palmieri [5] (90 to 150 MeV). The data of Bowen et al. [6] are 2-3% below our values from 30 to about 100 MeV. Fig. 1 shows our data compared to the semi-empirical fit of Gammel [7], chosen because it extends to 40 MeV and agrees with our results nearly as well as ENDF/B-V.

The carbon total cross section shown in Fig. 2 agrees with the ENDF/B-V evaluation to better than 0.6% below 8.5 MeV in the relatively smooth regions between resonances where energy resolution is unimportant. Above 8.5 MeV, our data agree better with the data of Heaton et al. [8] and Auchampaugh et al. [9] than with the ENDF/B-V evaluation. At higher energies, our results tend to agree with the data of Auman et al. [10] (24 to 60 MeV) to better than 1%, and with Meadsday et al. [11] (80 to 150 MeV) to about 2%. Data of Bubb et al. [12] (20 to 45 MeV) are systematically higher than our results; the data of Bowen et al. (15 to 120 MeV) are consistently lower than our data below about 90 MeV. Above 150 MeV, there exist no recent data; however, DeJuren and Moyer [13], and Mott et al. [14] have results which compare well with our data between 156 and 220 MeV.

Of the remaining sets of cross section data, only ^{238}U and ^{232}Th can conveniently be compared with other data since all other Pb data were obtained with a natural sample and no other fast-neutron data at all exists for ^{242}Pu.

The present results for ^{208}Pb, ^{232}Th, and ^{238}U are compared to the ENDF/B-V results in Fig. 3. Although the ENDF/B-V evaluation was for natural lead, the agreement with the present ^{208}Pb data is remarkably good, except at the ENDF/B-V dip near 16 MeV.

The ^{232}Th data were corrected for an oxygen contaminant using data measured at WNR in a separate experiment. Agreement with ENDF/B-V and with the data of Foster and Glasgow [15] is reasonable below ~ 14 MeV, the upper end of the available data. Above 10 MeV, however, the evaluated data is systematically too low, disagreeing by as much as 4% at 20 MeV.

The ^{238}U data agree with the ENDF/B-V evaluation to within about 1%, with the greatest differences being near 4 MeV and 19 MeV. The most recent ^{238}U data of Schwartz et al. [16] (0.5 to 15 MeV) and Hayes et al. [17] (0.8 to 30 MeV) agree with our data within the quoted errors, except for the data of Hayes near 30 MeV where the errors are quite large. The data of Schneider and McCormack [18] (100 to 150 MeV) provide the only high energy ^{238}U data for comparison, and again, agreement is generally better than 1.5%.

The ^{242}Pu total cross section values are shown in Fig. 4, compared to a recent evaluation by Madland and Young [19]. As was pointed out earlier, the ^{242}Pu data were obtained using the same flight path but with a different geometry due to the very limited amount of sample material available. These data were, in fact, obtained using a neutron beam collimated to 5 mm at the sample.

CONCLUSIONS

The technique used to obtain neutron total cross section data from 5 to 200 MeV at the WNR has been described and demonstrated to yield accurate results with hydrogen and carbon as test cases. In addition, high energy data for ^{208}Pb, ^{232}Th, ^{238}U, and ^{242}Pu have been provided.

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FIGURE CAPTIONS

1. Present results for the hydrogen total cross section. The solid curve was calculated from a fit to previous data by Gammel.

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

3. The total cross section for ^{208}Pb, ^{232}Th, and ^{235}U. The solid curve represents the ENDF/B-V evaluation.

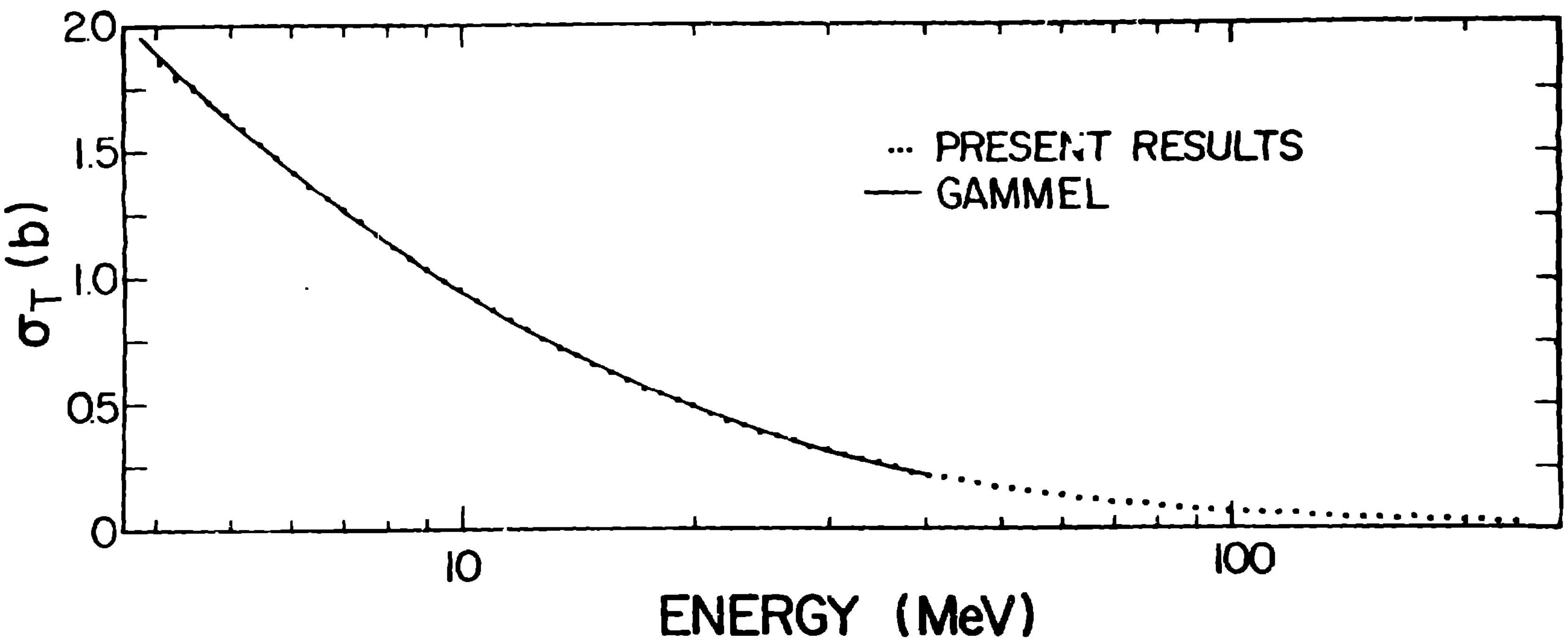
4. The total cross section for ^{242}Pu from 0.7 to 170 MeV. The solid curve represents an ENDF/B-V evaluation by Madland and Young.

TABLE I

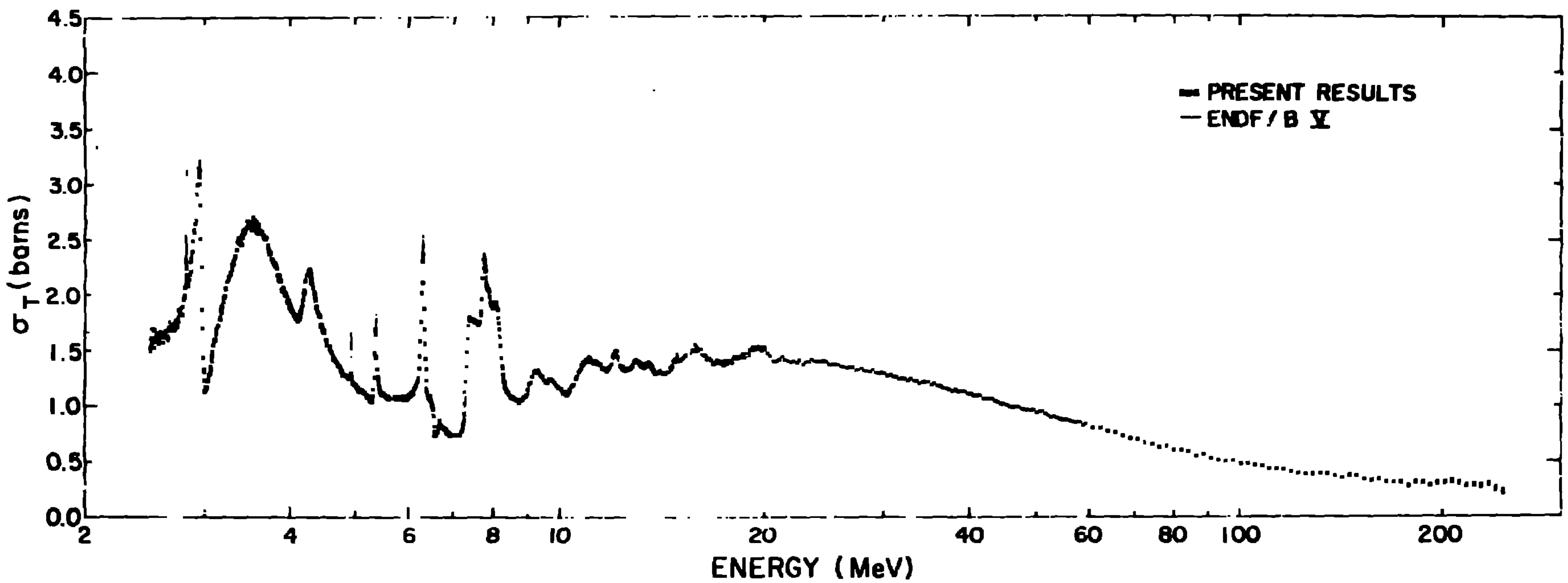
Sample Thickness

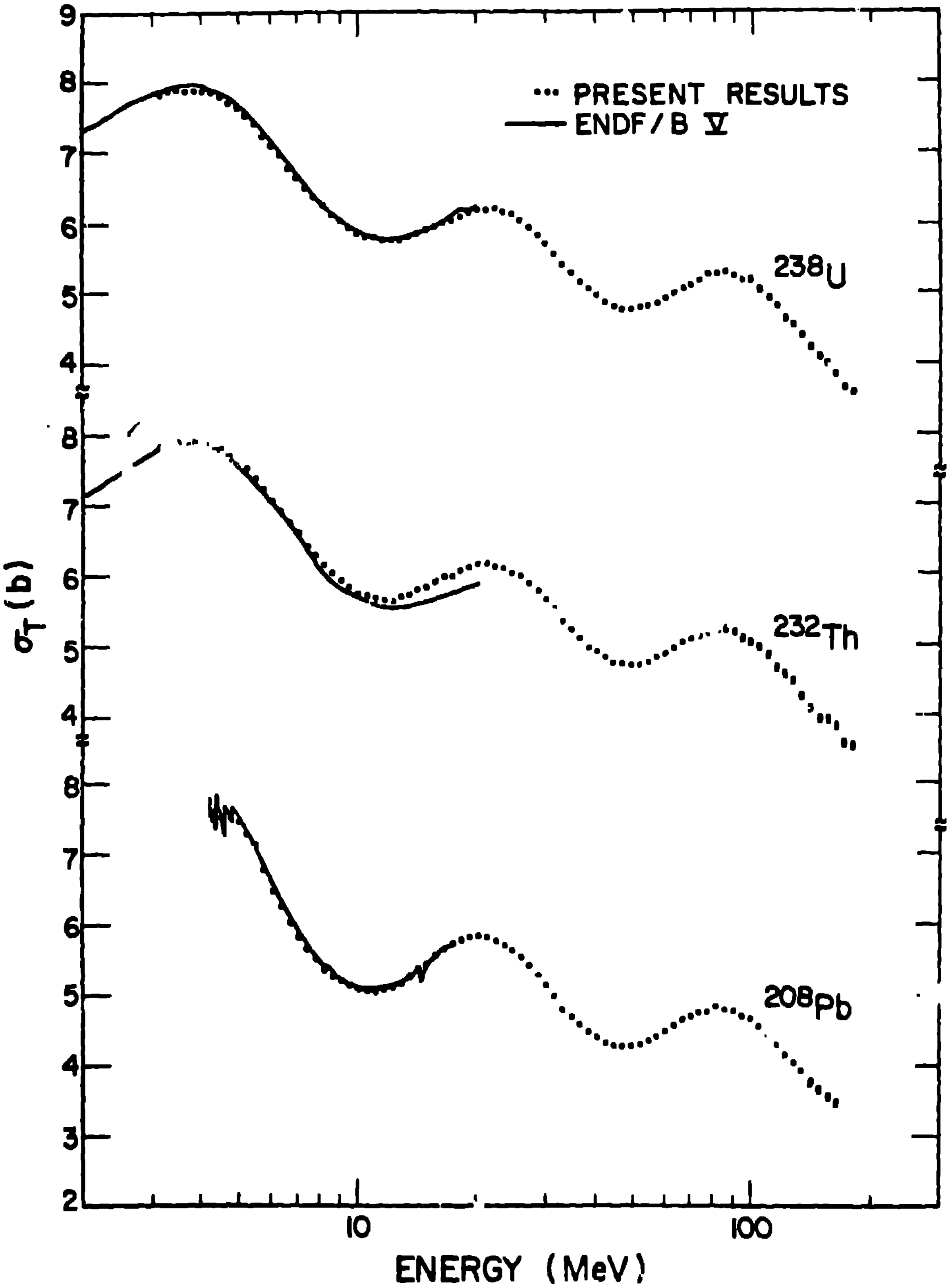
Sample	Atoms (Barn)
H	2.10280 (a)
C	1.05191 (a)
C	1.3682
^{208}Pb	0.3218
^{232}Th	0.2135
^{238}U	0.3254
^{242}Pu	0.0760

(a) matched polyethylene and carbon

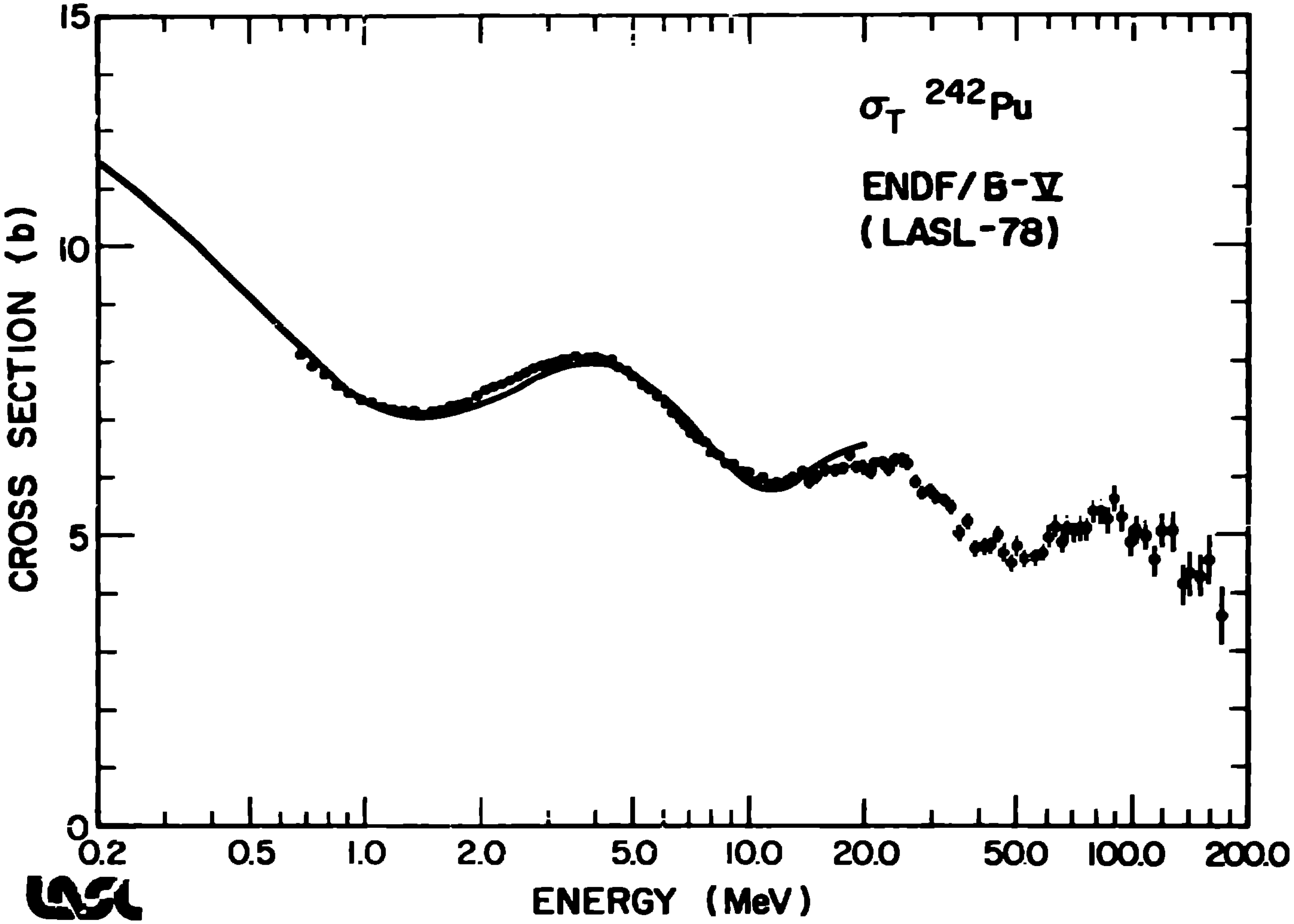


2.0
1.5
1.0
0.5
0
σ_T (b)
10
100
ENERGY (MeV)
··· PRESENT RESULTS
— GAMMEL


PRESENT RESULTS
ENDF / B V
σ_T (barns)
ENERGY (MeV)
0.0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
4.5
2
4
6
8
10
20
40
60
80
100
200



PRESENT RESULTS
ENDF/B V
238U
232Th
208Pb
σT (b)
ENERGY (MeV)
10
100
9
8
7
6
5
4
3
2


σ_T ^{242}Pu
ENDF/B-V
(LASL-78)
CROSS SECTION (b)
15
10
5
0
0.2
0.5
1.0
2.0
5.0
10.0
20.0
50.0
100.0
200.0
ENERGY (MeV)
LASL