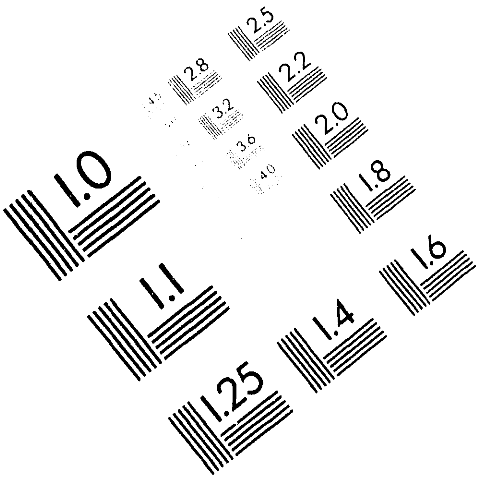

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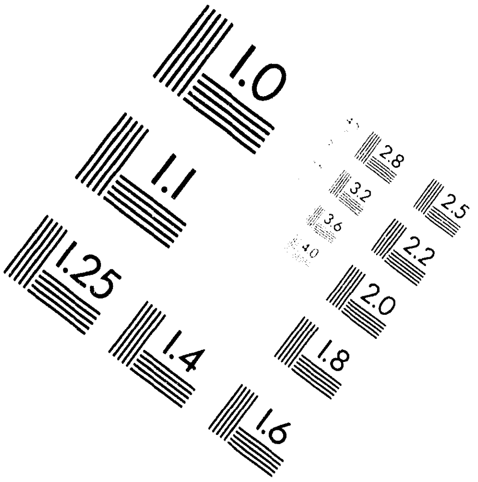

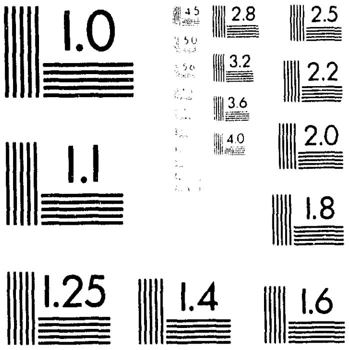

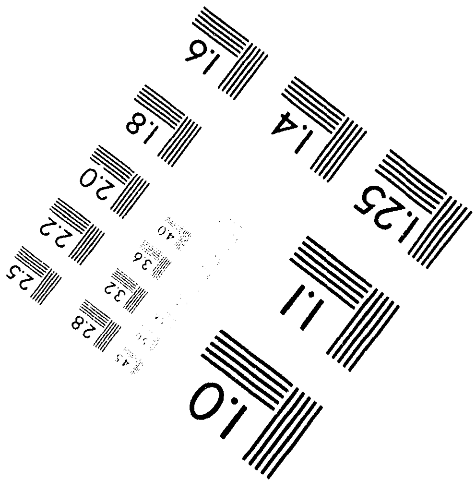

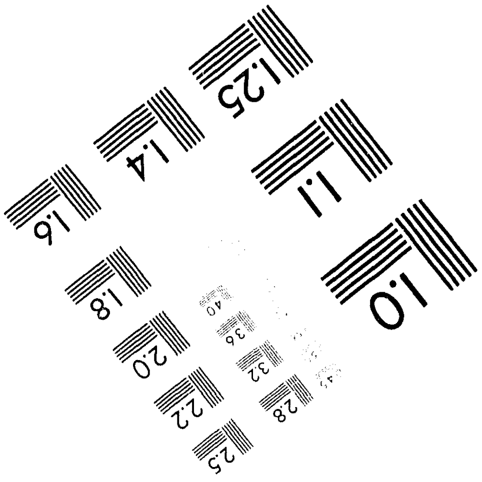

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Title:

THE ^{56}Fe(n,x alpha) REACTION FROM THRESHOLD TO 30 MeV

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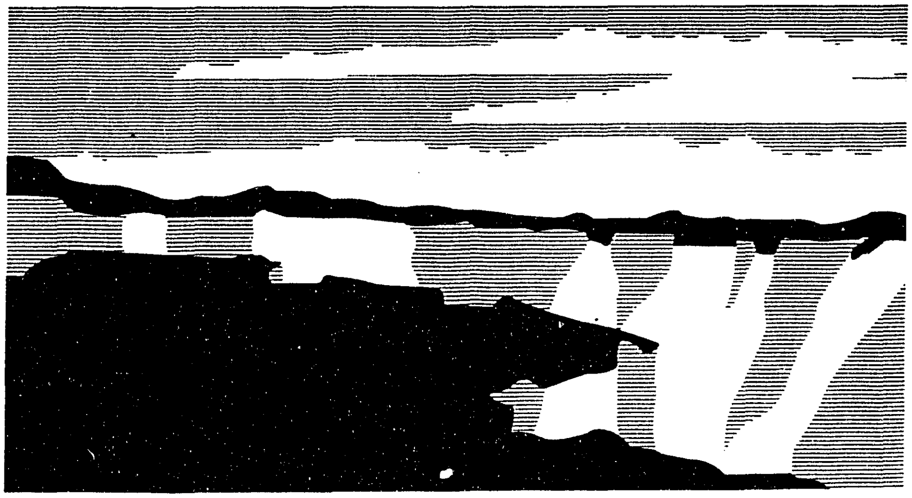

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The 56Fe(n,xα) Reaction From Threshold to 30 MeV

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ABSTRACT

Alpha-particle emission in neutron reactions with ^{56}Fe has been studied from threshold to over 30 MeV using the spallation neutron source at WNR/LAMPF. Alpha-particle production cross sections, spectra, and angular distributions were measured at scattering angles of 30, 60, 90, and 135 degrees using detector telescopes consisting of a low-pressure gas proportional counter and a large area silicon detector. Time-of-flight techniques with a 10-meter flight path were used to deduce the incident neutron energies. Our results are compared with literature values and with several theoretical calculations.

I. INTRODUCTION

Fast neutron-induced alpha-particle production by ^{56}Fe is a process which is of interest in basic as well as applied nuclear research. Theoretical understanding of the process is limited by significant uncertainties in such quantities as level density parameters , pre-equilibrium process modeling, and alpha-cluster preformation probabilities. The process is of fundamental importance in nuclear energy technology, since iron (of which 91.7% is isotope 56) is used extensively in structural materials in fission and prospective fusion reactors. The ^{56}Fe(n,xα) reaction is responsible for changes in the structural strength of these materials through mechanisms including nuclear transmutation, damage to crystal structure, and helium gas buildup. Thus, more extensive data are highly desirable both as constraints for theoretical models and for practical applications .

Alpha production data generally can be obtained from activation cross sections (if all residual nuclides can be counted), from helium production measurements, or by direct alpha-particle detection. For ^{56}Fe, however, the activation approach is not possible, since the residual nuclides ^{52,53}Cr are stable. Helium production measurements have been carried out at 10 and 14 MeV[1,2], but they are difficult and require intense, monoenergetic neutron sources. Direct alpha-particle detection experiments have given data at 14 MeV (total cross sections[3,4,5,6,7] alpha spectra[3,4,5] and angular distribution data[4,5,6]) and from 5 to 11 MeV[7,8,9] However, there are no measurements between 11 and 14 MeV and above 15 MeV. Furthermore, there are several discrepancies in the data between 5 and 11 MeV. Thus, a measurement that spans the range of the existing data, fills in the region between 11 and 14 MeV, and extends the range to well above 15 MeV is very much needed.

II EXPERIMENT

Investigation of this process using the Neutron Weapons Research (WNR) spallation neutron source at the Los Alamos Meson Physics Facility (LAMPF) offers the significant advantage of covering a wide range of bombarding energies at the expense of relatively low count rate per unit incident energy. Our runs at WNR were therefore long (on the order of 2.5 weeks for the present work), but not labor-intensive.

We have obtained data on the ^{56}Fe(n,xα) reaction at bombarding energies ranging continuously from 1 to 30 MeV and, correspondingly, since the Q-value for the (n,α) binary reaction is only .318 MeV, for alpha energies up to 30 MeV. Our apparatus consists of a set of four two-element detector telescopes positioned at 30°, 60°, 90°, and 135° relative to the beam. Angular acceptance of the detectors ranges between ±9° and 13°. The front element of each telescope was a gas proportional counter filled with 25 torr of Xenon and having entrance and exit windows of 210 μg/cm^2 aluminized mylar. The stopping detectors were 450 mm^2 silicon detectors (500μm depth), capable of stopping alpha-particles up to 33 MeV).

Determination of neutron energies was performed via time-of-flight measurements between microbursts (≈250 ps wide with a 1.8 μs interval) of the LAMPF 800 MeV primary proton beam on the spallation target and hits in our detectors. The beam monitor was a multi-element ionization chamber containing steel foils coated with films of ^{235}U and ^{238}U. Measurement of fission events in this detector and the correlated time-of-flight information was used to determine the incident neutron flux spectrum.

The target was isotopically enriched ^{56}Fe with an areal density of 3.23 mg/cm^2. It was large enough to cover the entire 5 cm × 5 cm beam spot of the 10 meter, 90° left flight path at WNR. Background subtraction was performed using data from empty target runs in precisely the same configuration as the ^{56}Fe-target runs. The background yield was generally quite small compared with that of the foreground except in the region of the Coulomb barrier threshold in the 30° and 60° detectors

III. RESULTS AND DISCUSSION

The remarkable coverage provided by the WNR spallation neutron source is best demonstrated in Fig.1, where we present a cross section surface for the $^{56}Fe(n,x\alpha)$ reaction measured by our 60° detector for neutron and alpha-particle energies up to 30 MeV. This surface, which has been smoothed and interpolated, shows the Coulomb barrier threshold, the high energy endpoint corresponding to the binary reaction transition to the ^{52}Cr ground state, and a small upward shift of the peak of the alpha spectrum with increasing bombarding energy. The tremendous amount of information contained in this and in the surfaces for the other three angles clearly represents a significant challenge for theoretical modeling. We have, in addition, similar cross-section surfaces for neutron energy against other observables; namely: binary reaction Q-value, channel energy, and these same quantities in the binary reaction center-of-mass frame.

In Fig.2, we compare our excitation function data with literature values, with the ENDF/B-VI evaluation, and with calculations of Pronyaev[10], Ignatyuk[11], and the statistical Hauser-Feschbach code-system GNASH[12]. Our data shown here have been binned in neutron energy slices .5 MeV wide up to 15 MeV, 1 MeV wide from 15 to 20 MeV, and 2 MeV wide above 20 MeV. They were then integrated over solid angle-weighted scattering angle. A secondorder Legendre fit to our angular distribution gives a very similar total cross section at 14 MeV. Error bars shown for our data in all figures here are statistical only.

The large excess of the ENDF/B-VI evaluation relative to our data below 14 MeV is particularly noteworthy. ENDF/B-VI appears to follow data of Paulsen[8] and Chiba[9] more closely here. The GNASH calculation, which has not been guided by the present measurements, was carried out using realistic optical model coefficients and default level density parameters. This calculation follows our data rather well up to 20 MeV, but significantly overpredicts the cross section at higher energies. The calculations of Pronyaev[10] follow our data even more closely than GNASH, but extend only to 20 MeV. Finally, the calculations of Ignatyuk[11] underpredict our data below 15 MeV, following the two low-energy points of Saraf[7] but not the higher ones.

Total cross sections near 14 MeV tend to cluster in the 40 to 45 mb range. Our total cross-section, integrated from 13.5 to 14.5 MeV, is 41.2±3.5 mb with all sources of error included. The only measurement that is inconsistent with this value is the one of Dolya[6], at 51.8±4.5 mb.

We present a comparison among 14 MeV angle-integrated spectra and energy-spectrum-integrated angular distributions in Figs. 3 and 4. In Fig. 3, we see that there is relatively good agreement between our data and those of Grimes[3] and fair agreement with those of Fischer[4], the peak values in the latter dataset being somewhat higher than in the other two. The calculated spectrum of Ignatyuk follows the higher values of Fischer, but appears to be somewhat too narrow. The default GNASH calculation is in good agreement with our data and the Grimes data. The angular distribution comparison in Fig.4 shows notable departures among the various datasets only at backward angles. Our data do not support the strong backward rise reported by Dolya[6].

Clearly, our relatively large dataset permits extensive further exploration and comparison with data and calculations in the literature. In addition, it will help us to refine theoretical models of the pre-equilibrium emission process and make inferences on statistical level density parameters. Recently, we have also collected data on inclusive proton emission from fast neutrons on ^{56}Fe. Our ultimate aim is to use the two sets of data together to achieve even more global modelling constraints in this mass region.

REFERENCES

1) R. C. Haight, D. W. Kneff, B. M. Oliver, L. R. Greenwood, and H. Vonach, "Helium Production by 10 MeV Neutrons in Iron, Nickel, and Copper", this conference.

2) D. W. Kneff, B. M. Oliver, H. Farrar IV, and L.R. Greenwood, "Helium Production in Pure Elements, Isotopes, and Alloy Steels by 14.8-MeV Neutrons", *Nucl. Sci. Eng.* **92**, 491 (1986).

3) S. M. Grimes, R. C. Haight, K. R. Alvar, H. H. Barschall, and R. R. Borchers, *Phys. Rev. C* **19**, 2127 (1979).

4) R. Fischer, G. Traxler, M. Uhl, and H. Vonach, *Phys. Rev. C* **30**, 72 (1984).

5) E. Wattecamps, H. Liskien and F. Arnotte, *Proc. Int. Conf. on Nucl. Data for Sci. and Eng., Antwerp, Belgium, 6-7 Sept., 1982*, D. Reidel publ. 1983, p156.

6) G. P. Dolya, A. P. Klyucharev, V. P. Bozhko, V. Ya. Golovnya, A. S. Kachan, and A. I. Tutubalin, *Neitronnaya Fizika*, Part 4, p. 173. *Proc. 3rd All-Union Conference on Neutron Physics, Kiev, 9th-13th, June, 1975.* (NNDC ref#40514)

7) S. K. Saraf, C. E. Brient, P. M. Egun, S. M. Grimes, V. Mishra, and R. S. Pedroni, *Nucl. Sci. and Eng.* **107**, 365 (1991).

8) A. Paulsen, H. Liskien, F. Arnotte, and R. Widera, *Nucl. Sci. and Eng.* **78**, 377 (1981).

9) Satoshi Chiba, Nobuo. Ito, and Mamoru. Baba, Private communication, 1993.

10) V. Pronyaev, Private communication, May 2, 1994.

11) A. Ignatyuk, Private communication, Sept. 16, 1991.

12) P. G. Young, E. D. Arthur, and M. B. Chadwick, *Comprehensive Nuclear Model Calculations: Introduction to the Theory and Use of the GNASH code.*, Los Alamos National Laboratory Publication LA-12343-MS, July,1992.

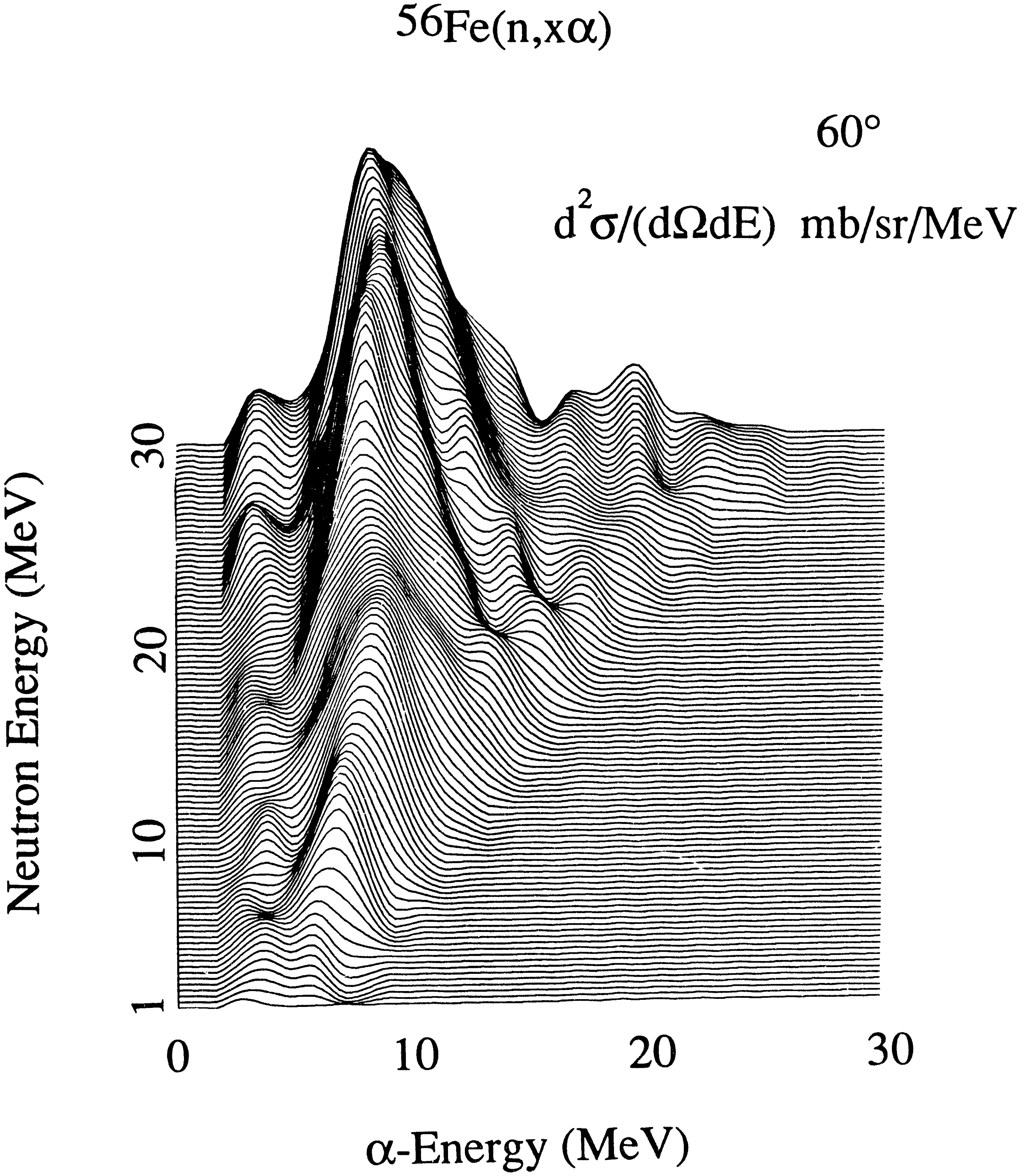
56Fe(n,xα)
60°
d²σ/(dΩdE) mb/sr/MeV
Neutron Energy (MeV)
1
10
20
30
0
10
20
30
α-Energy (MeV)

Fig. 1

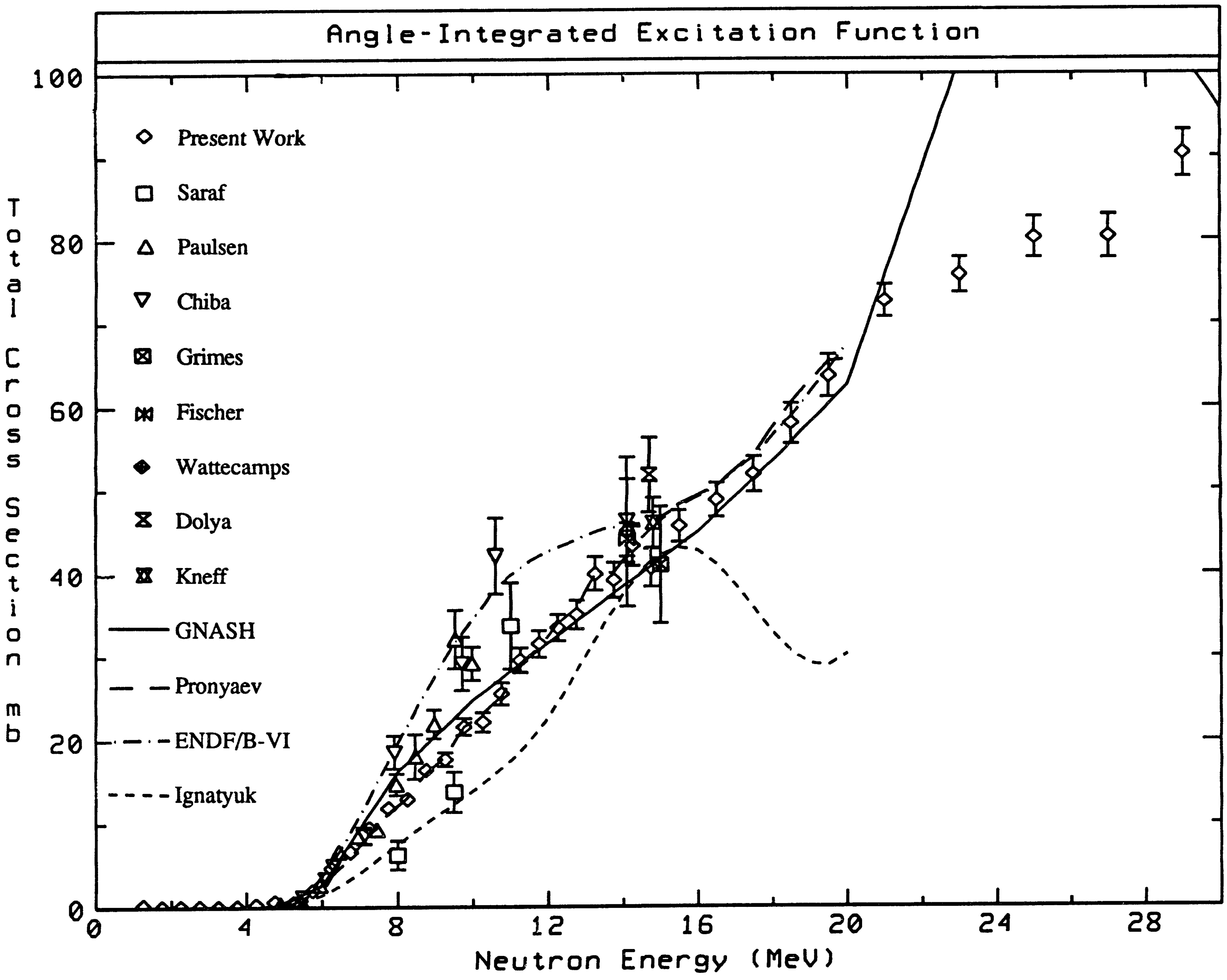
Angle-Integrated Excitation Function
Total Cross Section mb
Neutron Energy (MeV)
0
20
40
60
80
100
0
4
8
12
16
20
24
28
◇ Present Work
□ Saraf
△ Paulsen
▽ Chiba
⊠ Grimes
⋈ Fischer
◆ Wattecamps
⧖ Dolya
⧗ Kneff
GNASH
Pronyaev
ENDF/B-VI
Ignatyuk

Fig. 2

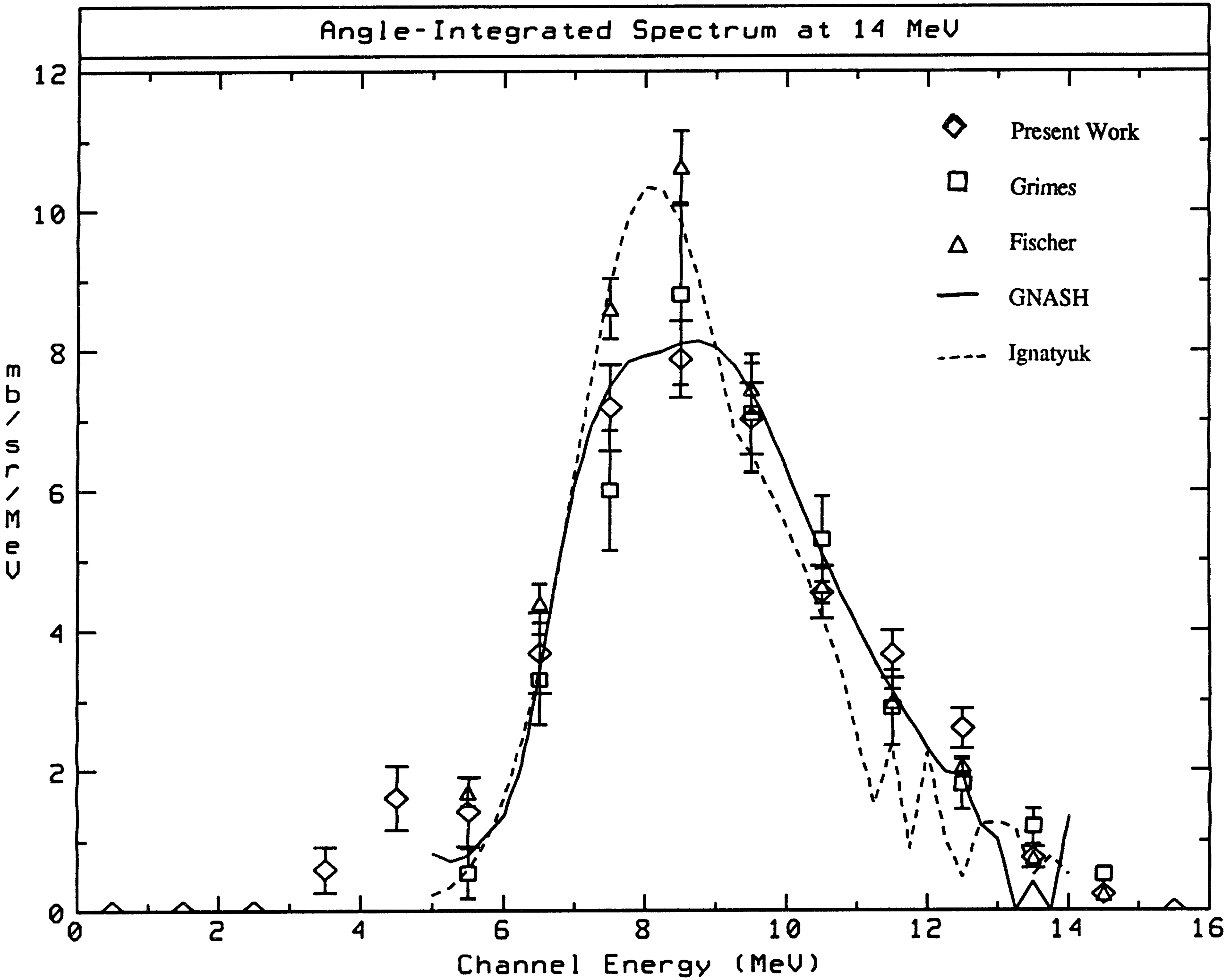
Angle-Integrated Spectrum at 14 MeV
mb/sr/MeV
Channel Energy (MeV)
0
2
4
6
8
10
12
14
16
Present Work
Grimes
Fischer
GNASH
Ignatyuk

Fig. 3

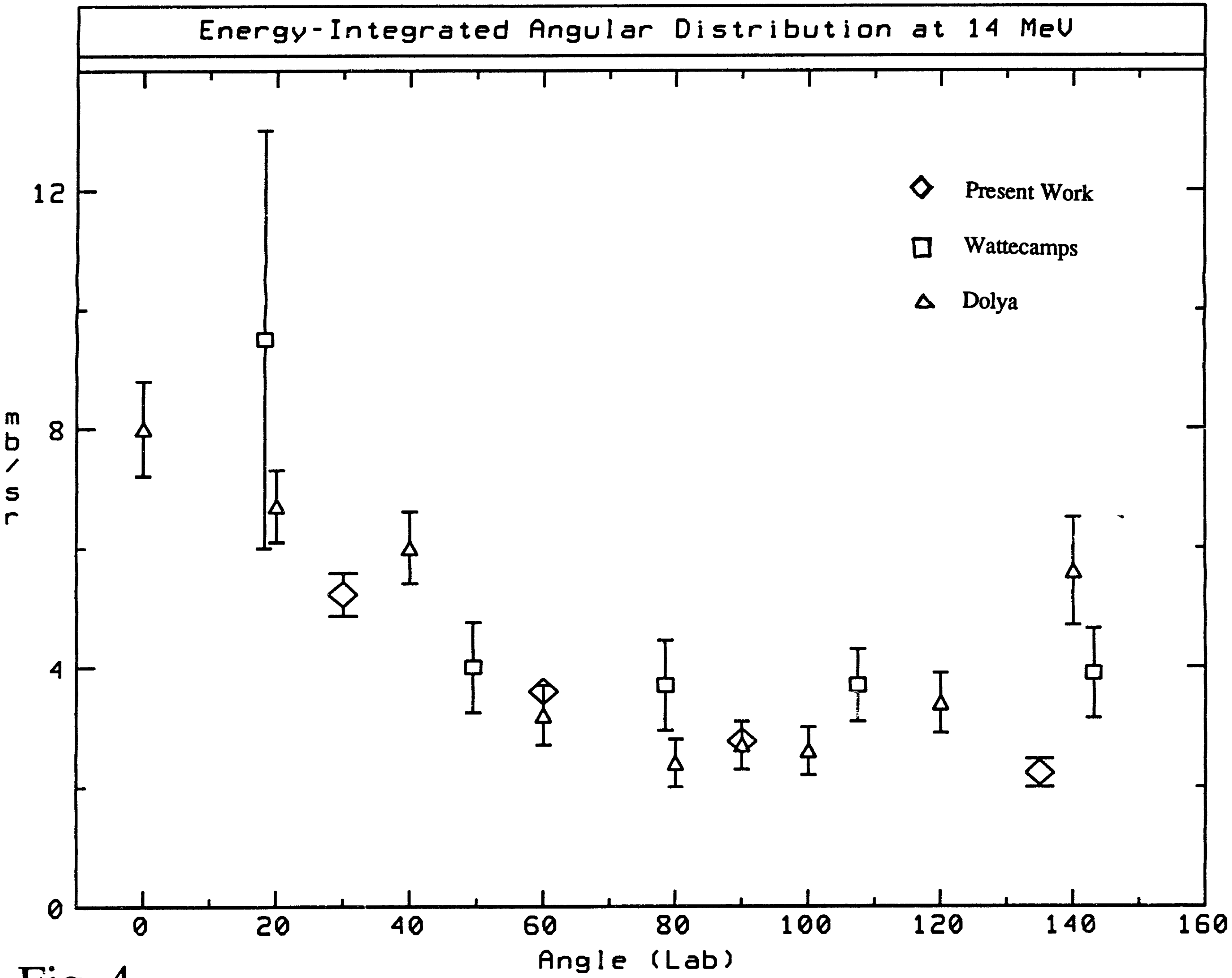
Energy-Integrated Angular Distribution at 14 MeV
◇ Present Work
□ Wattecamps
△ Dolya
m b / s r
0
4
8
12
0
20
40
60
80
100
120
140
160
Angle (Lab)

Fig. 4

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