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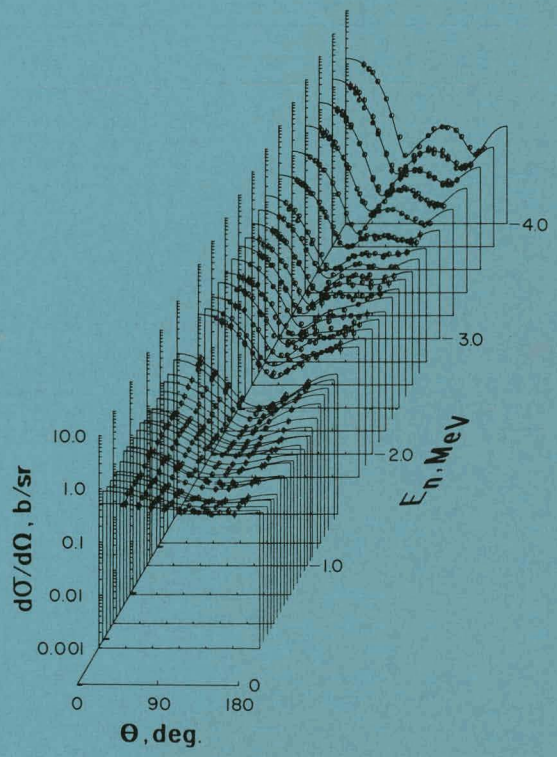

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EVALUATED(n;p)CROSS SECTIONS OF ^{46}Ti, ^{47}Ti and ^{48}Ti*

by

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NUCLEAR DATA AND MEASUREMENTS SERIES

The Nuclear Data and Measurements Series presents results of studies in the field of microscopic nuclear data. The primary objective is the dissemination of information in the comprehensive form required for nuclear technology applications. This Series is devoted to: a) Measured microscopic nuclear parameters, b) Experimental techniques and facilities employed in data measurements, c) The evaluation of nuclear data. Contributions to this Series are reviewed to assure technical competence and, unless otherwise stated, the contents can be formally referenced. This Series does not supplant formal journal publication but it does provide the more extensive information required for technological applications (e.g., tabulated numerical data) in a timely manner.

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ABSTRACT

Microscopic evaluated neutron cross sections for the reactions $^{46}Ti(n;p)^{46}Sc$, $^{47}Ti(n;p)^{47}Sc$ and $^{48}Ti(n;p)^{48}Sc$ are obtained from threshold (or zero energy) to 20 MeV. The results are presented in graphical and numerical (ENDF format) form. The microscopic evaluated cross sections are compared with measured fission-spectrum-averaged values.

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I. INTRODUCTION

These evaluations deal with the above processes on an isotopic basis and are primarily derived from the reasonably comprehensive experimental data. Insofar as possible, the experimental values are normalized to a consistent set of reference standards as defined in Ref. 1. These normalization procedures were not always certain as some of the relative measurements were not traceable to the reference standards. In these instances the measured values were accepted as reported. Fortunately, these normalization uncertainties tended to be associated with data sets of lesser quality and thus given little, if any, weight in the evaluation. Radioactive decay schemes and associated data relevant to these evaluations were explicitly taken from the spectroscopic data given in Ref. 2. Where necessary, the evaluation extrapolates the experimental values using statistical model calculations as described in Ref. 3. The literature search was closed September 1976 and included all references given in CINDA, the contents of the NNCSC-BNL compiled data files and the common physical journals. These isotopic evaluations are consistent with the titanium elemental file submitted for ENDF/B, Version V.

II. ISOTOPIC EVALUATIONS

A. The $^{46}Ti(n;p)^{46}Sc$ Process, Q=-1.585 MeV

There appears to be no experimental data available

from threshold to approximately 3.5 MeV thus the evaluation in this lower-energy region follows theoretical calculations which are consistent with measured values at higher energies. From 3.5 to 10.0 MeV the experimental data base consists of the experimental values reported by Ghorai et al. (4), Lukic and Carroll (5) and Smith and Meadows (6). The results of Refs. 4 and 6 are in only fair agreement. Those of Ref. 5 tend to be discrepant with the other two sets of values and to fluctuate, possibly due to the use of various reference-standards. Therefore, Ref. 5 was not accepted for the evaluation. From 12.5 to 19.5 MeV the experimental values of Borman et al. (7), Pai (8), Cross and Pai (9) and Levkovskii et al. (10) are in good agreement and were accepted for the evaluation. Results reported by Poularikas and Fink (11), Allan (12) and Koehler and Alford (13) appeared discrepant and were not accepted. The values of Liskien and Paulsen (14) appear higher than the body of the information probably due to contributions from the ^{47}Ti(n;n',p) process (15) therefore the values of Ref. 14 were not accepted. The evaluation follows the experimental data base above 3.5 MeV interpolating over the unmeasured energy region $\tilde{\sim}$ 10 to 12 MeV.

The present evaluation is compared with the data base and the corresponding ENDF/B-IV (MAT-6421) results in Fig. 1. The two evaluations are very similar but near threshold where there is a small energy shift. From approximately 3 to 12

MeV the uncertainties in the present evaluation are estimated to be in the range 5 to 10 percent. Above approximately 12 MeV they become progressively larger due to uncertainties associated with the (n;n',p) process.

B. The $^{47}Ti(n;p)^{47}Sc$ Process, Q=+0.181 MeV

The experimental data extends to relatively low energies and the evaluation extrapolates to zero energy using theoretical calculations. Below 10 MeV the data base consists of the values of Smith and Meadows (6), Ghorai et al. (4), Armitage (17) and Gonzalez et al. (18). The data of Ref. 6 is by far the most comprehensive and relatively precise. The results of Refs. 4 and 17 are generally consistent with those of Ref. 6. The results of Ref. 18 are inconsistent with the body of experimental information and were not accepted. Above 10 MeV the experimental results of Cross and Pai (9), Pai (8), Hillman (19) and Allan (12) are reasonably consistent and were accepted for the evaluation. The results of Poularikas and Fink (11) and Levkovskii et al. (10) appear very high and the value of Tikku et al. (20) abnormally low therefore these three values were not accepted. The evaluation is constructed through the accepted experimental data with an interpolation over the unmeasured interval 10 to 13.5 MeV. Primary emphasis was given to the measured values of Smith and Meadows and of Pai as these are the most comprehensive sets of data and generally

have the better precisions.

The present evaluation is compared with that of ENDF/B-IV (MAT-6422) and the experimental data base in Fig. 2. There are some differences between the two evaluations particularly below 10 MeV where the present evaluation portrays the structure indicated by the more recent measurements. The uncertainty in the present evaluation is generally estimated to be 5 to 10 percent below 10 MeV and somewhat larger at higher energies.

C. The $^{48}Ti(n;p)^{48}Sc$ Process, Q=-3.208 MeV

From threshold to the first measured values at about 4.7 MeV the evaluation relies upon theoretical calculations. From 4.7 to 10 MeV there are three sets of data: Lukic and Carroll (5), Ghorai et al. (4) and Smith and Meadows (6). They are in reasonable agreement but the latter is by far the more comprehensive and was used for the evaluation in this energy range. Above 12.5 MeV data has been reported by: Tikku et al. (20), Pai (8), Cross and Pai (9), Hillman (19), Poularikas and Fink (11), Gabbard and Kern (21), Borman et al. (7), Vonach et al. (22), Allan (12), Levkovskii et al. (10), Crumpton (23) and Mannhart and Vonach (24). The data of Refs. 23, 20 and 12 appear inconsistent with the body of information and/or have large experimental errors and were not accepted. In addition, the data of Ref. 22 appears systematically high and its normalization is uncertain therefore this set was not accepted. The evaluation was

constructed through the accepted experimental values, interpolating over the region 10 to 12.5 MeV.

The present evaluation is compared with that of ENDF/B-IV (MAT-6423) and with the experimental data base in Fig. 3. There is a large difference between the present evaluation and that of ENDF/B-IV at energies below approximately 13 MeV. At higher energies the two evaluations are qualitatively similar. The uncertainty of the present evaluation is estimated to be approximately 5 to 10 percent from 4.5 and 16 MeV and somewhat larger at higher energies.

III. COMPARISON OF MEASURED AND CALCULATED Ti(n;p) CROSS-SECTION-INTEGRALS OVER ^{235}U AND ^{252}Cf FISSION NEUTRON SPECTRA

The present evaluated titanium (n;p) cross sections were integrated over the ^{235}U and ^{252}Cf fission-neutron-spectra as given by Grundl and Eisenhauer (25) and compared with similar values calculated using ENDF/B-IV and reported from experimental measurements (16). The results are summarized in Table 1. The ^{46}Ti results obtained with the present evaluation and that of ENDF/B-IV are essentially identical and both are reasonably consistent with the measured ^{235}U value. The differences are well within the combined uncertainty estimates. The comparisons of ^{47}Ti results are essentially identical to those for ^{46}Ti and, again, discrepancies are within uncertainties. It has been suggested that uncertain-

ties in the β^- branch to ^{47}Ti could reduce the measured (n;p) cross sections by $\tilde{\sim}$ 6 percent (26). The present evaluation is based upon the value given in Ref. 2. 6 percent changes therefrom are well within the respective uncertainties. The ^{48}Ti result obtained with the present evaluation is considerably larger than that deduced from ENDF/B-IV and essentially identical to the measured ^{235}U value. Apparently spectrum-averaged values for the ^{252}Cf spectrum are not generally available, thus detailed comparisons are not possible.

It was concluded that the above fission-spectrum "benchmark" comparisons support the validity of the present evaluations of the (n;p) cross sections of the ^{46,47} and ^{48}Ti isotopes.

ACKNOWLEDGEMENT

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Table 1. Comparison of Spectrum-Averaged Cross Sections for Ti(n;p) Reactions[a]

Reaction	<σ>, mb U-235 Spectrum	<σ>, mb Cf-252 Spectrum
Ti-46		
ENDF	10.08	12.87
This Eval.[b]	10.88	13.81
Exp.[b]	11.8 ± 0.75	-
Ti-47		
ENDF	21.24	24.00
This Eval.[b]	21.38	24.22
Exp.[b]	19.0 ± 1.4	-
Ti-48		
ENDF	0.193	0.289
This Eval.[b]	0.303	0.446
Exp.[b]	0.300 ± 0.018	-

a. Based on fission neutron spectrum parameters of J. Grundl and C. Eisenhauer, National Bur. of Stds. Pub., 438 (1975).

b. A. Fabry et al., ASTM-EURATOM Sym. on Reactor Dosimetry (1975).

TABLE 2, NUMERICAL TABULATION OF EVALUATED CROSS SECTIONS,
[ENDF/B FORMAT]

A, TI-46[N,P]

```
                                                                                    46 0  0     0
                                                                                    46 0  0     1
,16190E 07 ,00000E 00 ,24000E 07 ,40000E-06 ,27500E 07 ,12000E-04                   46 3103     2
,30000E 07 ,10000E-02 ,32500E 07 ,33000E-02 ,35000E 07 ,80000E-02                   46 3103     3
,40000E 07 ,26000E-01 ,45000E 07 ,48000E-01 ,50000E 07 ,73000E-01                   46 3103     4
,55000E 07 ,99000E-01 ,60000E 07 ,12400E 00 ,65000E 07 ,15000E 00                   46 3103     5
,70000E 07 ,17300E 00 ,80000E 07 ,20800E 00 ,90000E 07 ,23200E 00                   46 3103     6
,10000E 08 ,25200E 00 ,11000E 08 ,26400E 00 ,12000E 08 ,27000E 00                   46 3103     7
,13000E 08 ,26800E 00 ,14000E 08 ,26000E 00 ,15000E 08 ,24500E 00                   46 3103     8
,17000E 08 ,21000E 00 ,19000E 08 ,17200E 00 ,20000E 08 ,15200E 00                   46 3103     9
                                                                                    46 3  0    10
                                                                                    46 0  0    11
                                                                                    -1 0  0    12
```

B, TI-47[N,P]

```
                                                                                    47 0  0     0
                                                                                    47 0  0     1
,10000E-04 ,00000E 00 ,83000E 06 ,85000E-09 ,90000E 06 ,36000E-08                   47 3103     2
,10000E 07 ,19000E-06 ,11500E 07 ,12500E-02 ,12250E 07 ,28000E-02                   47 3103     3
,13000E 07 ,38000E-02 ,14250E 07 ,31000E-02 ,14400E 07 ,33000E-02                   47 3103     4
,15400E 07 ,39000E-02 ,16000E 07 ,45000E-02 ,22500E 07 ,23000E-01                   47 3103     5
,23500E 07 ,30500E-01 ,24500E 07 ,31700E-01 ,26000E 07 ,30300E-01                   47 3103     6
,27500E 07 ,30600E-01 ,32500E 07 ,50000E-01 ,37500E 07 ,64000E-01                   47 3103     7
,42500E 07 ,74000E-01 ,47500E 07 ,80000E-01 ,50000E 07 ,80000E-01                   47 3103     8
,60000E 07 ,10000E 00 ,65000E 07 ,10600E 00 ,70000E 07 ,10400E 00                   47 3103     9
,80000E 07 ,11900E 00 ,90000E 07 ,12900E 00 ,10000E 08 ,13700E 00                   47 3103    10
,11000E 08 ,14000E 00 ,12000E 08 ,13600E 00 ,13000E 08 ,13000E 00                   47 3103    11
,14000E 08 ,12000E 00 ,16000E 08 ,98000E-01 ,18000E 08 ,78500E-01                   47 3103    12
,20000E 08 ,70000E-01 ,00000E 00 ,00000E 00 ,00000E 00 ,00000E 00                   47 3103    13
                                                                                    47 3  0    14
                                                                                    47 0  0    15
                                                                                    -1 0  0    16
```

C, TI-48[N,P]

```
                                                                                    48 0  0     0
                                                                                    48 0  0     1
,32750E 07 ,00000E 00 ,40000E 07 ,80000E-07 ,42000E 07 ,53000E-06                   48 3103     2
,44000E 07 ,16000E-04 ,47000E 07 ,24000E-04 ,49000E 07 ,73000E-04                   48 3103     3
,51000E 07 ,10000E-03 ,54000E 07 ,45000E-03 ,57000E 07 ,58000E-03                   48 3103     4
,60000E 07 ,19000E-02 ,65000E 07 ,39000E-02 ,70000E 07 ,66000E-02                   48 3103     5
,75000E 07 ,98000E-02 ,80000E 07 ,13100E-01 ,90000E 07 ,20400E-01                   48 3103     6
,10000E 08 ,30000E-01 ,11000E 08 ,41400E-01 ,12000E 08 ,53000E-01                   48 3103     7
,13000E 08 ,61000E-01 ,13500E 08 ,64000E-01 ,14000E 08 ,64000E-01                   48 3103     8
,15000E 08 ,62000E-01 ,16000E 08 ,57000E-01 ,18000E 08 ,46000E-01                   48 3103     9
,19000E 08 ,41000E-01 ,20000E 08 ,38000E-01 ,00000E 00 ,00000E 00                   48 3103    10
                                                                                    48 3  0    11
                                                                                    48 0  0    12
                                                                                    -1 0  0    13
```

FIGURE CAPTIONS

Fig. 1. Comparison of measured and evaluated (n;p) cross sections of ^{46}Ti. The symbolism associated with the measured values is defined in the reference list. The solid curve indicates the present evaluation, the dashed curve that of ENDF/B-IV (1). (ANL Neg. No. 116-76-390)

Fig. 2. Comparison of measured and evaluated (n;p) cross sections of ^{47}Ti. Notation is as per Fig. 1. (ANL Neg. No.116-76-392)

Fig. 3. Comparison of measured and evaluated (n;p) cross sections of ^{50}Ti. Notation is as per Fig. 1. (ANL Neg. No. 116-76-391)

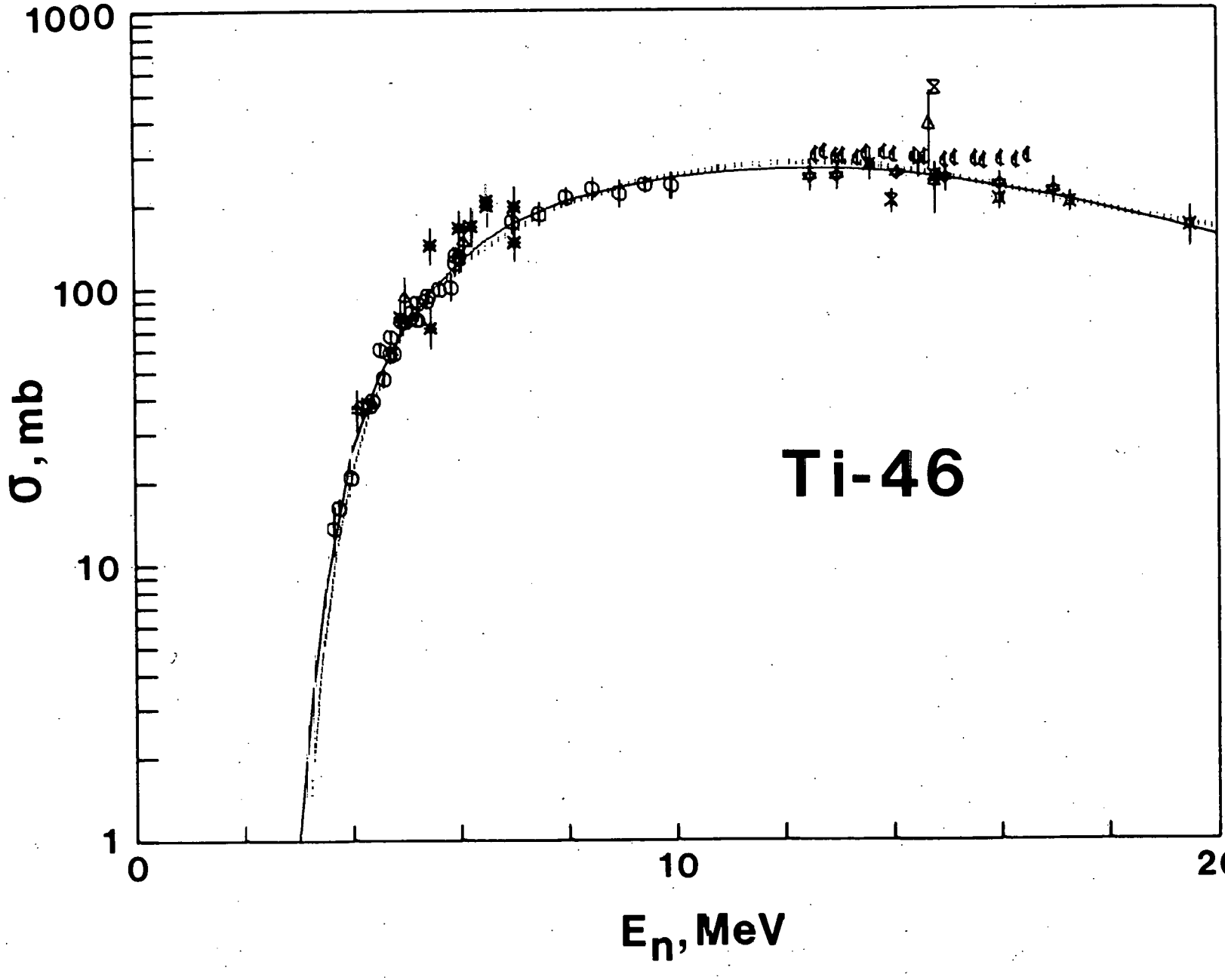

Fig.1

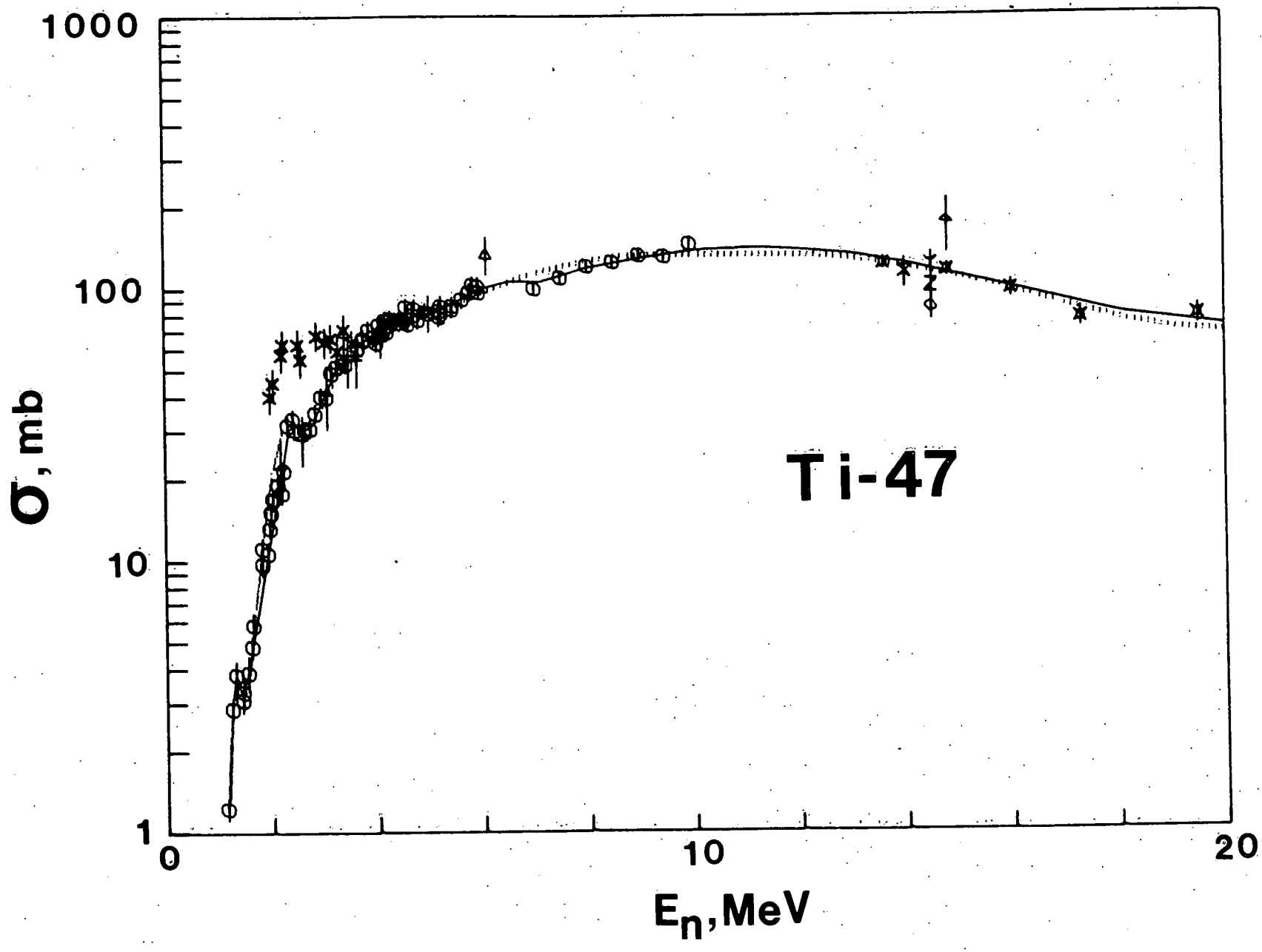

Fig.2

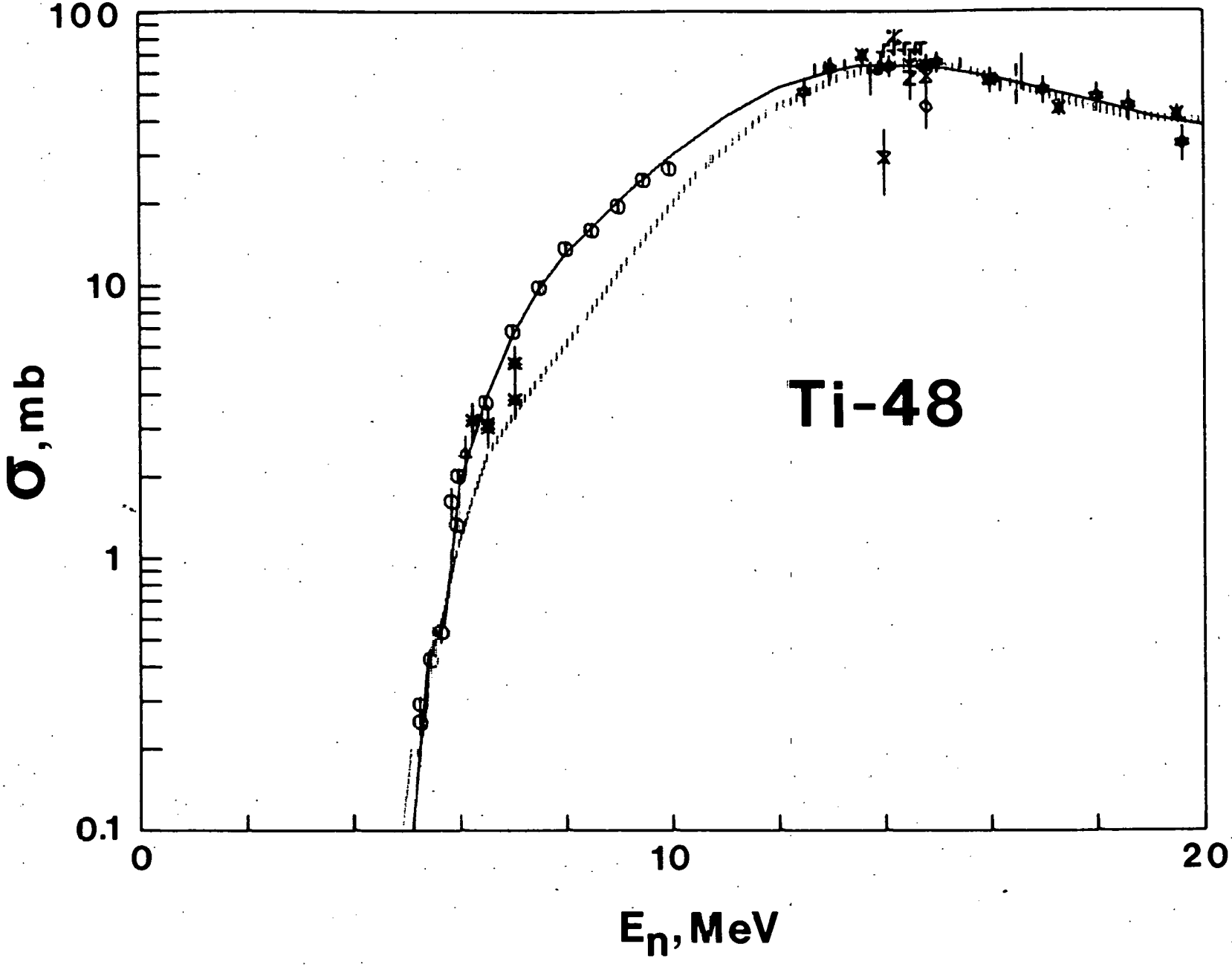

Fig.3