NUCLEAR DATA AND MEASUREMENTS SERIES

ANL/NDM-28

Titanium II: An Evaluated Nuclear Data File

by

C. Philis, R. Howerton, and A.B. Smith

June 1977

ARGONNE NATIONAL LABORATORY,
ARGONNE, ILLINOIS 60439, U.S.A.

NUCLEAR DATA AND MEASUREMENTS SERIES

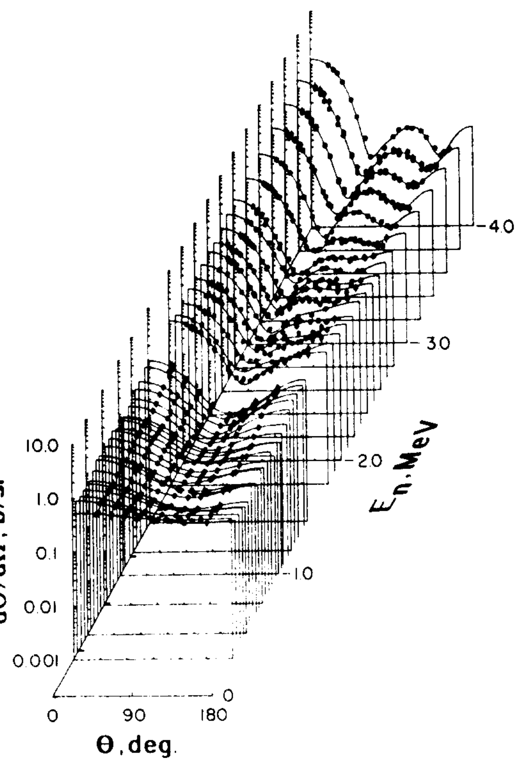
ANL/NDM-28

TITANIUM-II: AN EVALUATED NUCLEAR DATA FILE*

by

C. Philis
Centre d'Etudes de Bruyéres-le-Châtel
R. Howerton
Lawrence Livermore Laboratory
A. B. Smith
Argonne National Laboratory

June 1977



U of C AUA USERDA

ARGONNE NATIONAL LABORATORY,
ARGONNE, ILLINOIS 60439, U.S.A.

ANL/NDM-28

TITANIUM-II: AN EVALUATED NUCLEAR DATA FILE*

by

C. Philis
Centre d'Etudes de Bruyéres-le-Châtel
R. Howerton
Lawrence Livermore Laboratory
A. B. Smith
Argonne National Laboratory

June 1977

*This work is supported by the "Commissariat á l'Energie Atomique" (France) and the U. S. Department of Energy.

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 measurements, c) the analysis, correlation and interpretation of nuclear data, and d) 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.

TABLE OF CONTENTS

TITANIUM-II: AN EVALUATED NUCLEAR DATA FILE*

by

C. Philis, R. Howerton, and A. B. Smith

ABSTRACT

A comprehensive evaluated nuclear data file for elemental titanium is outlined including definition of: the data base, the evaluation procedures and judgments, and the final evaluated results. The file describes all significant neutron-induced reactions with elemental titanium and the associated photon-production processes to incident neutron energies of 20.0 MeV. In addition, isotopic-reaction files, consistent with the elemental file, are separately defined for those processes which are important to applied considerations of material-damage and neutron-dosimetry. The file is formulated in the ENDF format. This report formally documents the evaluation and, together with the numerical file, is submitted for consideration as a part of the ENDF/B-V evaluated file system.

*This work is supported by the Commissariat a l'Energie Atomique (France) and the U. S. Department of Energy.

I. INTRODUCTION

Herein, the data base, physical concepts and models and the methodology of the evaluated nuclear data file of elemental titanium are outlined. The evaluated file is presented in detailed graphical form with estimates of uncertainties. This evaluation is submitted as an elemental component of the ENDF/B-V evaluated-nuclear-data-file system (I-1). The evaluation is comprehensive in reaction type and energy scope (10^{-5} eV to 20 MeV). Particular attention is given to those aspects of most importance in the analysis of fission- and fusion-based energy systems (I-2). In addition to the primary elemental file, a secondary isotopic file is provided for selected reactions of interest in dosimetry and radiation-damage studies. This isotopic file is consistent with the primary elemental file.

The data base for this evaluation was derived from the literature as generally available to October 1976 with an extension to January 1977 in some selected areas. In the several MeV region an extensive measurement and calculational program was correlated with the evaluation providing an improved data base and nuclear models for extrapolation. This measurement and calculational program and associated models are defined in the companion document; Titanium-I (I-3). Subsequent portions of this document deal with: resonance properties, neutron total cross sections, neutron scattering, neutron emission, radiative neutron capture, various charged-particle-emitting reactions and photon production processes. The neutron-reaction Q-values of these various components are summarized in Table I-1. The entire numerical file is available from the National Nuclear Data Center (I-4) and the NEA Center for the Compilation of Nuclear Data (I-5). As available from either of these Centers, the numerical file takes alternate forms with the discrete-point or parameter representation of the resonance region. The (n;p) isotopic dosimetry files have previously been submitted as a component of the ENDF/B-V Dosimetry File and are discussed in more detail in Ref. I-6.

REFERENCES-Section I

I-1. Evaluated Nuclear Data File-B, ENDF/B, Brookhaven Natl. Lab. Report, ENDF-102, Eds. D. Garber, C. Dunford and S. Pearlstein (1975).

I-2. See, for example, WRENDA, INDC(SEC)-55/URSF, World Request List for Nuclear Data, Ed. R. Lessler, Inter. Atomic Energy Agency (1976).

I-3. P. Guenther et al., Argonne Natl. Lab. Report, ANL/NDM-31 (1977).

I-4. National Nuclear Data Center, Brookhaven Natl. Lab.

I-5. Centre de Compilation de Données Neutroniques, Saclay, France.

I-6. C. Philis et al., Argonne National Lab. Report, ANL/NDM-27 (1977).

Table I-1. Neutron Reaction Thresholds.

Reaction Type	Threshold (MeV)
Neutron Total Cross Section	0.0
Neutron Elastic Scattering Process	0.0
Neutron Inelastic Scattering Processes	
Group No.	
1	0.162
2	0.908
3	1.004
4	1.460
5	1.582
6	1.858
7	2.051
8	2.343
9	2.472
10	2.670
11	3.063
12	3.318
Continuum	3.500
Radiative Neutron Capture Process	0.0
(n;2n') Process	8.311
(n;3n') Process	1.948
(n;p) Process	0.0
(n;α) Process	0.0
(n;n',p) Process	10.570
(n;n',α) Process	8.187
(n;d) Process	8.340
(n;t) Process	10.960
(n;^{3}He) Process	9.729
(n;2p) Process	8.473
(n;p,α)	10.200

II. RESONANCE PARAMETERS AND ASSOCIATED CROSS SECTIONS (E_n < 0.2 MeV)

The evaluation provides, on the basis of contributing isotopes, a set of resonance parameters and associated cross sections for natural titanium over the energy range 10^{-5} eV to 200 keV. The evaluation in this region is taken from the work of Trochon et al. (II-1).

A. The Data Base and Underlying Evaluation Hypothesis

This evaluation is derived from a data base consisting of:

1. The total cross section of natural titanium measured by Garg et al. (II-2).

2. The total cross sections of individual isotopes measured at a number of laboratories as defined in Refs. II-3 to -8.

3. Resonance-capture areas as reported by Ernst et al. (II-9) for ^{47}Ti and by Allen et al. (II-10) for all titanium isotopes.

4. Measurements of the total cross section of the element and isotopes in the thermal region ($2{*}10^{-3}$ eV to about 40 eV) by Joki et al. (II-11), Schmunk et al. (II-12) and by Doilńitzyn (II-13).

5. Measurements of the elemental thermal capture cross section by Joki et al. (II-11).

6. The ENDF/B-IV evaluation at thermal and in the subthermal region (II-14).

7. The evaluation described in Sec. III, below, extended down to 100 keV.

In the relevant energy range of 10^{-5} eV to 200 keV only s- and p-waves contribute significantly to the cross sections. The evaluation assigns ℓ=1 (p-wave) to all resonances not clearly identified as ℓ=0 (s-wave).

In order to reproduce the strong level-level interference, the evaluation was carried out within the framework of the Reich-Moore formalism (II-15) including s- and p-wave resonances using a program written by Derrien et al. (II-21). This formulation is no longer an acceptable ENDF format; therefore, the final evaluation is made available in two alternate forms: 1) point values in good detail, and 2) Reich-Moore parameters (in Breit-Wigner format with LRF flag=3). The point-value representation is precise and an acceptable format though tedious to use in some applications. A maximum of five spin states was used, four corresponding to p-wave induced processes and one for resonances of unknown spin. The latter is a $\bar{J}$ calculated from the $\bar{g}$ as defined in Ref. II-16.

The effective radius used in the above procedures for each isotope was assumed to have a linear dependence on energy; i.e.,

$$R = AP(\frac{a}{AP} E + \frac{b}{AP})$$

where E is the energy in eV and AP is the dummy effective radius given in file 2 and a/AP and b/AP are read as new data in a modified version of the computer program RESEND.* The resonance parameters are given in Table II-1 in the ENDF format.

The evaluation was normalized to agree: 1) with the measured capture cross section of 6.09 b at the thermal energy (II-11). (This leads to consideration of a negative energy resonance.), 2) with the resonance integral of the total cross section of the natural element from 1.3 to 100.0 keV as determined from the measurements of Garg et al. (II-2) and 3) with the similar integral over the region 100 to 200 keV derived from the point values outlined in Sec. III, below.

B. Evaluation of the Resonance Parameters and Radii

The energies and widths of the s-wave resonances of ^{47}Ti, ^{48}Ti and ^{49}Ti are taken from the parameters reported by the Karlsruhe group (II-6,7). ^{46}Ti and ^{50}Ti resonance parameters are taken from the work of Refs. II-3 and -4 except when new values are available as the result of the analysis of capture

*The modified version of RESEND is aviailable from G. Simon, Centre d'Etudes Bruyères-le-Châtel, Montrouge, France.

measurements (II-10). At higher energies the ^{46}Ti neutron widths of Refs. II-3 and 4 appeared large and were reduced for this evaluation.

The energies of p-wave resonances are given by capture measurements (II-10). Their mean neutron widths, $\bar{\Gamma}_n$, have been calculated from the S_1 strength function and the average level spacing $\bar{D}_1$ by means of the expression

$$\bar{\Gamma}_n = \frac{3\, S_1 \bar{D}_1 V \sqrt{E}}{\bar{g}}$$

where V is the penetrability of the nucleus for p-wave neutrons. The corresponding S_1 and $\bar{D}_1$ values are given in Table II-2.

The capture widths have been calculated from the resonance areas of Allen et al. (II-10) using the relationship

$$\Gamma_\gamma = \frac{A_\gamma\ (\Gamma_n + \Gamma_\gamma)\ k^2}{2\pi^2 g \Gamma_n}$$

where A_γ is the capture area and k the wave number.

The effective radii for ^{46}Ti, ^{47}Ti, ^{49}Ti and ^{50}Ti were calculated using the above linear expression with AP, a and b values taken from Refs. II-3,6 and 4 adjusted as felt desirable. These parameters for ^{48}Ti were chosen to give the best agreement with the experimental total cross section of the natural element (II-2,11). The coefficients AP, a/AP and b/AP used in the evaluation are listed in Table II-3.

In order to simultaneously reproduce the total and capture cross sections in the energy range from 10^{-5} eV to the first resonance at 3.09 keV a negative resonance in ^{48}Ti was assumed at -50 eV. The capture width of this resonance was set at Γ_γ = 1.33 eV which is similar to the mean value of observed s-wave capture widths in ^{48}Ti. The neutron width was set at Γ_n = 0.011891 eV in order to obtain the experimentally observed thermal capture cross section of the natural element (i.e. 6.09 b at thermal).

C. Evaluated Resonance Cross Sections Beyond the Measured Regions

The energy range of available experimental capture data is defined in Table II-4. For each isotope, other than ^{48}Ti, the capture cross section was calculated between 25 and 200 keV using the computer code NCNR (II-17). These calculated results were then normalized to the averaged experimental data thereby providing an extrapolation beyond the measured energy range. For ^{47}Ti there is no experimental s- and p-wave data above 75 keV. Therefore, the final result was obtained by adjusting the isotpic values to give good agreement with elemental titanium results.

D. Comparisons of Measured and Evaluated Cross Sections in the Element

The evaluated resonance parameters were used to generate the respective cross sections via the computer code RESEND with a 1 percent convergence criteria. Illustrative results are given in Figs. II-1, 2, and 3.

Up to energies of 1.3 keV, the evaluated total cross section is somewhat smaller than the measured values. Corrections for these small differences have been included in the background file of the evaluation (i.e. 3-1 file). The final result is shown in Fig. II-1.

In the 1.3-75 keV energy range where almost all the resonance parameters have been determined, the calculations reproduced the experimental values quite well as far as integrals are concerned as summarized in Table II-5. The background of the file does not exceed 0.2 b up to 2.79 keV and is zero at higher energies. In the 1.3-75 keV energy range, the calculated and experimental integral values agree within $\approx$1 percent.

Above 75 keV, in spite of a deficiency in measured partial cross sections, the integrals of calculated and measured cross sections agree to within 5.8 percent. The discrepancy is probably due to deteriorating experimental resolution in the energy region. Due to these discrepancies and the uncertain knowledge of ^{47}Ti contributions; the latter were ignored above ≈75 keV. Again, the small differences are corrected for by background contributions in the 3-1 file. Generally, in the energy range 1.3-200 keV, the evaluation, as illustrated in Fig. II-2, agrees with experimental values to within ≈2 percent.

The capture cross sections needed no background corrections up to 50 keV. At higher energies the background was introduced as outlined above. The resulting evaluated capture cross sections are illustrated in Fig. II-3.

Background contributions to elastic scattering follow directly from the prior determination of total and capture cross sections. The elastic scattering cross section up to 1.3 keV is illustrated in Fig. II-1. At higher energies it closely follows the total cross section of Fig. II-3.

The only inelastic scattering contribution below 200 keV is that due to the excitation of the 159 keV state of ^{47}Ti (II-18, 19, 20). It is a small component and the elastic cross sections of the file are slightly adjusted in the region of inelastic scattering so as to assure the internal consistency of the file.

The resonance region of the present file is compared with that of ENDF/B-IV (II-14) in Figs. II-1, 2, and 3. There are considerable differences between the two evaluations in some areas. The total and elastic-scattering cross sections are very different. This is particularly true since the present file reproduces interfering resonances and p-wave resonances in much greater detail. The major capture-cross-section differences are in the 100 eV-200 keV region where p-wave resonances are the prominent contribution. Resonance integrals of the two evaluations are compared in Table II-5. Again, large differences between the two evaluations are evident.

REFERENCES — Section II

II-1. J. Trochon, G. Simon, O. Bersillon and G. Mosinski, CEA Report, CEA-R-4883 (1977).

II-2. J. Garg, J. Rainwater and W. Havens, Phys. Rev., 6 2447 (1971).

II-3. C. Bowman, E. Bilpuch and H. Newson, Ann. Phys., 17, 319 (1962).

II-4. J. Farrell, E. Bilpuch and H. Newson, Ann. Phys., 37, 367 (1966).

II-5. W. Good, D. Paya, R. Wagner and T. Tamura, Phys. Rev., 151 912 (1966).

II-6. M. Cho, F. Froehner, M. Kazerouni, K. Mueller and G. Rohr, Proc. of Conf. on Nucl. Data for Reactors, Vol. 1, IAEA Press, Vienna (1970).

II-7. K. Mueller and G. Rohr, Nucl. Phys., 164 97 (1971).

II-8. W. Good, private communication (1976).

II-9. A. Ernst, F. Froehner and D. Kompe, Proc. of Conf. on Nucl. Data for Reactors, Vol. 2, IAEA Press, Vienna (1970).

II-10. B. Allen, J. Boldeman, A. Musgrove and R. Macklin, Nucl. Phys., to be published.

II-11. E. Joki, J. Evans and R. Smith, Nucl. Sci. and Eng., 11 298 (1961).

II-12. R. Schmunk, P. Randolph and R. Brugger, Nucl. Sci. and Eng., 7 193 (1960).

II-13. Doilńitzyn, Atom. Energia, 27 144 (1969).

II-14. Evaluated Nuclear Data File-B, Version IV, (ENDF/B-IV); Available from the National Nuclear Data Center, Brookhaven National Lab.

II-15. C. Reich and M. Moore, Phys. Rev., 111 929 (1958).

II-16. Brookhaven National Lab. Report, BNL-NCS-50496 (1975).

II-17. P. Thomet, CEA Report, CEA-R-4631 (1974), also priv. communication (1976).

II-18. H. Pohl, R. Santo and G. Wagner, Zeit fur Phys., 245 216 (1971).

II-19. J. Rapaport, A. Sperduto and W. Barechner, Phys. Rev., 143 808 (1966).

II-20. M. Rao, J. Rapaport, T. Belote and W. Dorenbusch, Nucl. Phys., A151 351 (1970).

II-21. H. Derrien, et al., CEA Note, CEA-N-1564 (1972) and private communication.

TABLE II-1

ISØTØPIC RESØNANCE PARAMETERS

ENDF/BRC TAPE 100			08/20/1976		100	1 0 0	0
2,20000+04	4,74676+01	1	0	0	5	1 1451	1
~~0,00000+00~~	~~0,00000+00~~	~~0~~	~~0~~	~~90~~	~~0~~	~~1 1451~~	~~2~~
22-TI BRC	EVAL-AUG76					1 1451	3
						1 1451	4
		~~1~~	~~451~~	~~9~~		~~1 1451~~	~~5~~
		2	151	260		1 1451	6
		3	1	13		1 1451	7
		~~3~~	~~2~~	~~17~~		~~1 1451~~	~~8~~
		3	102	31		1 1451	9
						1 1 0	10
						~~1 0 0~~	~~11~~
2,20000+04	4,74676+01	0	0	5	0	1 2151	12
2,20460+04	0,07930+00	0	0	1	0	1 2151	13
~~1,00000-05~~	~~2,00000+05~~	~~1~~	~~3~~	~~0~~	~~0~~	~~1 2151~~	~~14~~
0,00000+00	0,34100+00	0	0	2	0	1 2151	15
0,45558+02	0,00000+00	0	0	42	7	1 2151	16
~~1,10600+04~~	~~5,00000-01~~	~~8,04800+01~~	~~8,00000+01~~	~~4,80000-01~~	~~0,00000+00~~	~~1 2151~~	~~17~~
3,92000+04	5,00000-01	2,50590+02	2,50000+02	5,90000-01	0,00000+00	1 2151	18
4,87000+04	5,00000-01	1,30079+03	1,30000+03	7,90000-01	0,00000+00	1 2151	19
~~6,32000+04~~	~~5,00000-01~~	~~3,00310+03~~	~~3,00000+03~~	~~3,10000-01~~	~~0,00000+00~~	~~1 2151~~	~~20~~
9,99900+04	5,00000-01	4,80150+03	4,80000+03	1,50000+00	0,00000+00	1 2151	21
1,78900+05	5,00000-01	4,00220+03	4,00000+03	2,20000+00	0,00000+00	1 2151	22
~~1,85000+05~~	~~5,00000-01~~	~~1,00150+03~~	~~1,00000+03~~	~~1,50000+00~~	~~0,00000+00~~	~~1 2151~~	~~23~~
4,55580+01	,00000+00	1	0	330	55	1 2151	24
1,23200+ 4	1,00000+ 0	1,48855+ 0	8,63620- 1	6,24929- 1	0,0 + 0	1 2151	25
~~1,37200+ 4~~	~~1,00000+ 0~~	~~1,42006+ 0~~	~~1,01332+ 0~~	~~4,06747- 1~~	~~0,0 + 0~~	~~1 2151~~	~~26~~
1,81800+ 4	1,00000+ 0	1,56822+ 0	1,53783+ 0	3,03914- 2	0,0 + 0	1 2151	27
1,93900+ 4	1,00000+ 0	2,31567+ 0	1,69157+ 0	6,24108- 1	0,0 + 0	1 2151	28
~~2,12400+ 4~~	~~1,00000+ 0~~	~~2,28630+ 0~~	~~1,93529+ 0~~	~~3,51009- 1~~	~~0,0 + 0~~	~~1 2151~~	~~29~~
2,40600+ 4	1,00000+ 0	2,36014+ 0	2,32584+ 0	3,43056- 2	0,0 + 0	1 2151	30
2,87700+ 4	1,00000+ 0	3,10068+ 0	3,02518+ 0	7,55019- 2	0,0 + 0	1 2151	31
~~3,40000+ 4~~	~~1,00000+ 0~~	~~3,97027+ 0~~	~~3,86391+ 0~~	~~1,06359- 1~~	~~0,0 + 0~~	~~1 2151~~	~~32~~
3,41000+ 4	1,00000+ 0	4,10466+ 0	3,88054+ 0	2,24126- 1	0,0 + 0	1 2151	33
3,52200+ 4	1,00000+ 0	4,49469+ 0	4,06822+ 0	4,26472- 1	0,0 + 0	1 2151	34
~~4,22900+ 4~~	~~1,00000+ 0~~	~~5,56059+ 0~~	~~5,31105+ 0~~	~~2,49548- 1~~	~~0,0 + 0~~	~~1 2151~~	~~35~~
4,28500+ 4	1,00000+ 0	6,02978+ 0	5,41355+ 0	6,16232- 1	0,0 + 0	1 2151	36
4,45200+ 4	1,00000+ 0	6,00712+ 0	5,72256+ 0	2,84553- 1	0,0 + 0	1 2151	37
~~4,74000+ 4~~	~~1,00000+ 0~~	~~6,67353+ 0~~	~~6,26690+ 0~~	~~4,06630- 1~~	~~0,0 + 0~~	~~1 2151~~	~~38~~
4,93600+ 4	1,00000+ 0	6,95588+ 0	6,64533+ 0	3,10556- 1	0,0 + 0	1 2151	39
5,56700+ 4	1,00000+ 0	8,23829+ 0	7,90496+ 0	3,33330- 1	0,0 + 0	1 2151	40
~~5,92700+ 4~~	~~1,00000+ 0~~	~~9,09277+ 0~~	~~8,65020+ 0~~	~~4,42573- 1~~	~~0,0 + 0~~	~~1 2151~~	~~41~~
6,80500+ 4	1,00000+ 0	1,09386+ 1	1,05417+ 1	3,96871- 1	0,0 + 0	1 2151	42
6,88500+ 4	1,00000+ 0	1,10755+ 1	1,07190+ 1	3,56523- 1	0,0 + 0	1 2151	43
~~7,08500+ 4~~	~~1,00000+ 0~~	~~1,15157+ 1~~	~~1,11655+ 1~~	~~3,50235- 1~~	~~0,0 + 0~~	~~1 2151~~	~~44~~
7,70200+ 4	1,00000+ 0	1,28064+ 1	1,25725+ 1	2,33944- 1	0,0 + 0	1 2151	45
7,83200+ 4	1,00000+ 0	1,33210+ 1	1,28744+ 1	4,46607- 1	0,0 + 0	1 2151	46
~~8,07700+ 4~~	~~1,00000+ 0~~	~~1,39154+ 1~~	~~1,34482+ 1~~	~~4,67122- 1~~	~~0,0 + 0~~	~~1 2151~~	~~47~~
8,15900+ 4	1,00000+ 0	1,40349+ 1	1,36417+ 1	3,93157- 1	0,0 + 0	1 2151	48
8,17200+ 4	1,00000+ 0	1,41423+ 1	1,36725+ 1	4,69807- 1	0,0 + 0	1 2151	49
~~8,45200+ 4~~	~~1,00000+ 0~~	~~1,48811+ 1~~	~~1,43388+ 1~~	~~5,42307- 1~~	~~0,0 + 0~~	~~1 2151~~	~~50~~

```
8,70500+ 4 1,00000+ 0 1,55366+ 1 1,49476+ 1 5,89060- 1 0,0       + 0    1 2151    51
8,74000+ 4 1,00000+ 0 1,55664+ 1 1,50323+ 1 5,34115- 1 0,0       + 0    1 2151    52
8,76500+ 4 1,00000+ 0 1,56138+ 1 1,50928+ 1 5,20962- 1 0,0       + 0    1 2151    53
9,06000+ 4 1,00000+ 0 1,62453+ 1 1,58122+ 1 4,33059- 1 0,0       + 0    1 2151    54
9,12000+ 4 1,00000+ 0 1,68749+ 1 1,59596+ 1 9,15350- 1 0,0       + 0    1 2151    55
9,29000+ 4 1,00000+ 0 1,69678+ 1 1,63788+ 1 5,88998- 1 0,0       + 0    1 2151    56
9,43000+ 4 1,00000+ 0 1,71579+ 1 1,67260+ 1 4,31936- 1 0,0       + 0    1 2151    57
1,05550+ 5 1,00000+ 0 2,07287+ 1 1,95771+ 1 1,15158+ 0 0,0       + 0    1 2151    58
1,06400+ 5 1,00000+ 0 2,03307+ 1 1,97967+ 1 5,33965- 1 0,0       + 0    1 2151    59
1,06750+ 5 1,00000+ 0 2,02609+ 1 1,98873+ 1 3,73543- 1 0,0       + 0    1 2151    60
1,07350+ 5 1,00000+ 0 2,04359+ 1 2,00429+ 1 3,93036- 1 0,0       + 0    1 2151    61
1,09350+ 5 1,00000+ 0 2,12277+ 1 2,05633+ 1 6,64414- 1 0,0       + 0    1 2151    62
1,13600+ 5 1,00000+ 0 2,24012+ 1 2,16792+ 1 7,22058- 1 0,0       + 0    1 2151    63
1,14800+ 5 1,00000+ 0 2,26671+ 1 2,19966+ 1 6,70434- 1 0,0       + 0    1 2151    64
1,20100+ 5 1,00000+ 0 2,42297+ 1 2,34108+ 1 8,18948- 1 0,0       + 0    1 2151    65
1,24400+ 5 1,00000+ 0 2,52732+ 1 2,45720+ 1 7,01156- 1 0,0       + 0    1 2151    66
1,28650+ 5 1,00000+ 0 2,67049+ 1 2,57314+ 1 9,73469- 1 0,0       + 0    1 2151    67
1,33400+ 5 1,00000+ 0 2,82911+ 1 2,70404+ 1 1,25076+ 0 0,0       + 0    1 2151    68
1,35750+ 5 1,00000+ 0 2,81846+ 1 2,76928+ 1 4,91799- 1 0,0       + 0    1 2151    69
1,43450+ 5 1,00000+ 0 3,15296+ 1 2,98525+ 1 1,67708+ 0 0,0       + 0    1 2151    70
1,46550+ 5 1,00000+ 0 3,13091+ 1 3,07310+ 1 5,78096- 1 0,0       + 0    1 2151    71
1,50600+ 5 1,00000+ 0 3,23367+ 1 3,18860+ 1 4,50661- 1 0,0       + 0    1 2151    72
1,53950+ 5 1,00000+ 0 3,48493+ 1 3,28475+ 1 2,00174+ 0 0,0       + 0    1 2151    73
1,57100+ 5 1,00000+ 0 3,58149+ 1 3,37565+ 1 2,05839+ 0 0,0       + 0    1 2151    74
1,60200+ 5 1,00000+ 0 3,62268+ 1 3,46555+ 1 1,57132+ 0 0,0       + 0    1 2151    75
1,67400+ 5 1,00000+ 0 3,81344+ 1 3,67598+ 1 1,37460+ 0 0,0       + 0    1 2151    76
1,70000+ 5 1,00000+ 0 3,86316+ 1 3,75250+ 1 1,10661+ 0 0,0       + 0    1 2151    77
1,72600+ 5 1,00000+ 0 3,93793+ 1 3,82930+ 1 1,08628+ 0 0,0       + 0    1 2151    78
1,74500+ 5 1,00000+ 0 3,96057+ 1 3,88559+ 1 7,49770- 1 0,0       + 0    1 2151    79
2,20470+04 0,07280+00           0          0          1          0    1 2151    80
1,00000-05 2,00000+05           1          3          0          0    1 2151    81
2,50000+00 0,34100+00           0          0          2          0    1 2151    82
0,46549+02 0,00000+00           0          0        186         31    1 2151    83
3,09000+03 3,00000+00 1,01090+02 1,00000+02 1,09000+00 0,00000+00    1 2151    84
4,19200+03 3,00000+00 2,54000+00 2,00000+00 0,54000+00 0,00000+00    1 2151    85
8,13000+03 2,00000+00 6,66100+01 6,60000+01 0,61000+00 0,00000+00    1 2151    86
8,33800+03 2,00000+00 1,48225+02 1,47000+02 1,22500+00 0,00000+00    1 2151    87
1,05400+04 3,00000+00 5,91900+01 5,80000+01 1,19000+00 0,00000+00    1 2151    88
1,21400+04 3,00000+00 1,21100+02 1,20000+02 1,10000+00 0,00000+00    1 2151    89
1,21700+04 2,00000+00 2,29000+01 2,20000+01 9,00000-01 0,00000+00    1 2151    90
1,28250+04 2,00000+00 1,76830+02 1,75000+02 1,83000+00 0,00000+00    1 2151    91
1,63300+04 3,00000+00 3,96935+02 3,96000+02 0,93500+00 0,00000+00    1 2151    92
1,74150+04 2,00000+00 5,17500+01 5,00000+01 1,75000+00 0,00000+00    1 2151    93
1,90850+04 3,00000+00 2,09700+01 2,00000+01 0,97000+00 0,00000+00    1 2151    94
2,12900+04 2,00000+00 6,34800+01 6,20000+01 1,48000+00 0,00000+00    1 2151    95
2,72000+04 3,00000+00 1,07070+03 1,06800+03 2,70000+00 0,00000+00    1 2151    96
3,02300+04 2,00000+00 7,48450+01 7,40000+01 0,84500+00 0,00000+00    1 2151    97
3,26100+04 2,00000+00 5,99920+02 5,99000+02 0,92000+00 0,00000+00    1 2151    98
3,81200+04 3,00000+00 8,05750+01 8,00000+01 0,57500+00 0,00000+00    1 2151    99
4,05500+04 3,00000+00 6,94000+02 6,92000+02 2,00000+00 0,00000+00    1 2151   100
4,10600+04 2,00000+00 5,83500+01 5,80000+01 0,35000+00 0,00000+00    1 2151   101
4,23600+04 2,00000+00 5,84400+02 5,82000+02 2,40000+00 0,00000+00    1 2151   102
4,39700+04 3,00000+00 8,82970+02 8,81000+02 1,97000+00 0,00000+00    1 2151   103
4,63000+04 3,00000+00 7,08750+02 7,06000+02 2,75000+00 0,00000+00    1 2151   104
```

4,93200+04	3,00000+00	3,16800+02	3,15000+02	1,80000+00	0,00000+00	1 2151	105
5,13400+04	3,00000+00	1,81330+02	1,80000+02	1,33000+00	0,00000+00	1 2151	106
5,53700+04	3,00000+00	2,77330+02	2,76000+02	1,33000+00	0,00000+00	1 2151	107
5,75600+04	3,00000+00	8,60330+02	8,59000+02	1,33000+00	0,00000+00	1 2151	108
6,02900+04	2,00000+00	9,03300+01	8,90000+01	1,33000+00	0,00000+00	1 2151	109
6,17800+04	2,00000+00	2,14330+02	2,13000+02	1,33000+00	0,00000+00	1 2151	110
6,33700+04	3,00000+00	9,83300+01	9,70000+01	1,33000+00	0,00000+00	1 2151	111
6,38000+04	3,00000+00	5,43300+01	5,30000+01	1,33000+00	0,00000+00	1 2151	112
7,16800+04	3,00000+00	4,91330+02	4,90000+02	1,33000+00	0,00000+00	1 2151	113
7,45500+04	2,00000+00	1,29330+02	1,28000+02	1,33000+00	0,00000+00	1 2151	114
0,46549+02	0,00000+00	1	0	246	41	1 2151	115
4,10500+ 3	2,50000+ 0	2,90392- 1	1,95164- 1	9,52280- 2	0,0 + 0	1 2151	116
4,53900+ 3	2,50000+ 0	3,28054- 1	2,26806- 1	1,01249- 1	0,0 + 0	1 2151	117
6,16700+ 3	2,50000+ 0	8,42754- 1	3,58519- 1	4,84235- 1	0,0 + 0	1 2151	118
7,55000+ 3	2,50000+ 0	6,37356- 1	4,84877- 1	1,52478- 1	0,0 + 0	1 2151	119
8,88000+ 3	2,50000+ 0	8,52120- 1	6,17546- 1	2,34574- 1	0,0 + 0	1 2151	120
9,10300+ 3	2,50000+ 0	7,94543- 1	6,40790- 1	1,53753- 1	0,0 + 0	1 2151	121
1,00800+ 4	2,50000+ 0	8,56019- 1	7,45837- 1	1,10182- 1	0,0 + 0	1 2151	122
1,23700+ 4	2,50000+ 0	1,36855+ 0	1,01128+ 0	3,57266- 1	0,0 + 0	1 2151	123
1,50700+ 4	2,50000+ 0	1,44749+ 0	1,35567+ 0	9,18252- 2	0,0 + 0	1 2151	124
1,65850+ 4	2,50000+ 0	2,17882+ 0	1,56246+ 0	6,16361- 1	0,0 + 0	1 2151	125
1,68000+ 4	2,50000+ 0	2,39593+ 0	1,59255+ 0	8,03384- 1	0,0 + 0	1 2151	126
1,82550+ 4	2,50000+ 0	2,31180+ 0	1,80088+ 0	5,10913- 1	0,0 + 0	1 2151	127
1,88200+ 4	2,50000+ 0	2,85780+ 0	1,88393+ 0	9,73874- 1	0,0 + 0	1 2151	128
2,00700+ 4	2,50000+ 0	3,35391+ 0	2,07177+ 0	1,28214+ 0	0,0 + 0	1 2151	129
2,02350+ 4	2,50000+ 0	2,54331+ 0	2,09698+ 0	4,46326- 1	0,0 + 0	1 2151	130
2,08200+ 4	2,50000+ 0	2,43421+ 0	2,18713+ 0	2,47079- 1	0,0 + 0	1 2151	131
2,19300+ 4	2,50000+ 0	2,45063+ 0	2,36138+ 0	8,92504- 2	0,0 + 0	1 2151	132
2,32250+ 4	2,50000+ 0	2,67174+ 0	2,56985+ 0	1,01885- 1	0,0 + 0	1 2151	133
2,37600+ 4	2,50000+ 0	2,69200+ 0	2,65756+ 0	3,44406- 2	0,0 + 0	1 2151	134
2,41350+ 4	2,50000+ 0	3,80540+ 0	2,71957+ 0	1,08583+ 0	0,0 + 0	1 2151	135
2,44400+ 4	2,50000+ 0	3,48800+ 0	2,77034+ 0	7,17659- 1	0,0 + 0	1 2151	136
2,44900+ 4	2,50000+ 0	3,47377+ 0	2,77869+ 0	6,95082- 1	0,0 + 0	1 2151	137
2,47550+ 4	2,50000+ 0	4,26400+ 0	2,82307+ 0	1,44094+ 0	0,0 + 0	1 2151	138
2,56500+ 4	2,50000+ 0	3,75781+ 0	2,97455+ 0	7,83259- 1	0,0 + 0	1 2151	139
2,63800+ 4	2,50000+ 0	3,50719+ 0	3,09989+ 0	4,07301- 1	0,0 + 0	1 2151	140
3,18500+ 4	2,50000+ 0	4,35362+ 0	4,08733+ 0	2,66287- 1	0,0 + 0	1 2151	141
3,22600+ 4	2,50000+ 0	4,74577+ 0	4,16460+ 0	5,81171- 1	0,0 + 0	1 2151	142
3,39400+ 4	2,50000+ 0	5,04844+ 0	4,48572+ 0	5,62724- 1	0,0 + 0	1 2151	143
3,77500+ 4	2,50000+ 0	5,94285+ 0	5,23964+ 0	7,03210- 1	0,0 + 0	1 2151	144
3,91700+ 4	2,50000+ 0	5,84656+ 0	5,52935+ 0	3,17211- 1	0,0 + 0	1 2151	145
4,01300+ 4	2,50000+ 0	6,38553+ 0	5,72778+ 0	6,57753- 1	0,0 + 0	1 2151	146
4,08100+ 4	2,50000+ 0	6,18572+ 0	5,86956+ 0	3,16159- 1	0,0 + 0	1 2151	147
4,33800+ 4	2,50000+ 0	7,17508+ 0	6,41445+ 0	7,60636- 1	0,0 + 0	1 2151	148
4,36000+ 4	2,50000+ 0	6,83178+ 0	6,46174+ 0	3,70043- 1	0,0 + 0	1 2151	149
4,38000+ 4	2,50000+ 0	6,75401+ 0	6,50482+ 0	2,49194- 1	0,0 + 0	1 2151	150
4,44300+ 4	2,50000+ 0	7,55063+ 0	6,64106+ 0	9,09569- 1	0,0 + 0	1 2151	151
4,69000+ 4	2,50000+ 0	7,67444+ 0	7,18296+ 0	4,91474- 1	0,0 + 0	1 2151	152
4,77700+ 4	2,50000+ 0	7,89012+ 0	7,37671+ 0	5,13407- 1	0,0 + 0	1 2151	153
4,79200+ 4	2,50000+ 0	8,06313+ 0	7,41027+ 0	6,52861- 1	0,0 + 0	1 2151	154
4,83500+ 4	2,50000+ 0	7,64935+ 0	7,50669+ 0	1,42661- 1	0,0 + 0	1 2151	155
4,90200+ 4	2,50000+ 0	8,04643+ 0	7,65765+ 0	3,88785- 1	0,0 + 0	1 2151	156
2,20480+04	0,73940+00	0	0	1	0	1 2151	157
1,00000-05	2,00000+05	1	3	0	0	1 2151	158
0,00000+00	0,20500+00	0	0	2	0	1 2151	159

0,47536+02	0,00000+00	0	0	72	12	1	2151	160
-5,00000+01	5,00000-01	1,34891+00	0,18915-01	1.33000+00	0,00000+00	1	2151	161
1,77600+04	0,50000+00	8,43000+03	8,42770+03	2,30000+00	0,00000+00	1	2151	162
2,21100+04	0,50000+00	7,80000+02	7,79200+02	8,00000-01	0,00000+00	1	2151	163
3,69000+04	0,50000+00	1,30000+03	1,29750+03	2,50000+00	0,00000+00	1	2151	164
5,17000+04	0,50000+00	2,40000+03	2,39860+03	1.40000+00	0,00000+00	1	2151	165
7,44000+04	0,50000+00	1,50000+02	1,49700+02	3,00000-01	0,00000+00	1	2151	166
8,36000+04	0,50000+00	1,20000+02	1,19500+02	5,00000-01	0,00000+00	1	2151	167
1,19000+05	0,50000+00	2,00000+02	1,99500+02	5,00000-01	0,00000+00	1	2151	168
1,33200+05	0,50000+00	2,00000+02	1,99500+02	5,00000-01	0,00000+00	1	2151	169
1,54900+05	0,50000+00	2,50000+02	2,47200+02	2,80000+00	0,00000+00	1	2151	170
1,85600+05	0,50000+00	6,50000+02	6,48100+02	1,90000+00	0,00000+00	1	2151	171
1,92400+05	0,50000+00	3,00000+03	2,99910+03	9,00000-01	0,00000+00	1	2151	172
0,47536+02	0,00000+00	1	0	168	28	1	2151	173
1,14600+ 4	1,00000+ 0	1,86180+ 0	1,59531+ 0	2,66490- 1	0,0 + 0	1	2151	174
1,33900+ 4	1,00000+ 0	2,25282+ 0	2,01040+ 0	2,42417- 1	0,0 + 0	1	2151	175
2,15700+ 4	1,00000+ 0	4,20086+ 0	4,07245+ 0	1,28410- 1	0,0 + 0	1	2151	176
2,39100+ 4	1,00000+ 0	5,12606+ 0	4,74027+ 0	3,85786- 1	0,0 + 0	1	2151	177
3,90900+ 4	1,00000+ 0	1,00043+ 1	9,74246+ 0	2,61792- 1	0,0 + 0	1	2151	178
4,19500+ 4	1,00000+ 0	1,08264+ 1	1,07968+ 1	2,96055- 2	0,0 + 0	1	2151	179
4,22400+ 4	1,00000+ 0	1,11679+ 1	1,09054+ 1	2,62497- 1	0,0 + 0	1	2151	180
5,64100+ 4	1,00000+ 0	1,67585+ 1	1,65711+ 1	1,87369- 1	0,0 + 0	1	2151	181
7,12100+ 4	1,00000+ 0	2,34028+ 1	2,31313+ 1	2,71560- 1	0,0 + 0	1	2151	182
7,64000+ 4	1,00000+ 0	2,58342+ 1	2,55637+ 1	2,70490- 1	0,0 + 0	1	2151	183
7,96000+ 4	1,00000+ 0	2,77145+ 1	2,70943+ 1	6,20168- 1	0,0 + 0	1	2151	184
8,02100+ 4	1,00000+ 0	2,76700+ 1	2,73886+ 1	2,81358- 1	0,0 + 0	1	2151	185
8,51700+ 4	1,00000+ 0	2,99801+ 1	2,98114+ 1	1,68790- 1	0,0 + 0	1	2151	186
8,72000+ 4	1,00000+ 0	3,15449+ 1	3,08176+ 1	7,27317- 1	0,0 + 0	1	2151	187
9,74000+ 4	1,00000+ 0	3,69173+ 1	3,59939+ 1	9,23392- 1	0,0 + 0	1	2151	188
1,06700+ 5	1,00000+ 0	4,13269+ 1	4,08748+ 1	4,52185- 1	0,0 + 0	1	2151	189
1,13400+ 5	1,00000+ 0	4,56572+ 1	4,44775+ 1	1,17977+ 0	0,0 + 0	1	2151	190
1,20500+ 5	1,00000+ 0	4,89091+ 1	4,83679+ 1	5,41224- 1	0,0 + 0	1	2151	191
1,21850+ 5	1,00000+ 0	4,93993+ 1	4,91156+ 1	2,83679- 1	0,0 + 0	1	2151	192
1,35200+ 5	1,00000+ 0	5,71538+ 1	5,66374+ 1	5.16384- 1	0,0 + 0	1	2151	193
1,40700+ 5	1,00000+ 0	6,03790+ 1	5,97991+ 1	5,79915- 1	0,0 + 0	1	2151	194
1,42100+ 5	1,00000+ 0	6,10008+ 1	6,06094+ 1	3,91441- 1	0,0 + 0	1	2151	195
1,44600+ 5	1,00000+ 0	6,22067+ 1	6,20616+ 1	1,45078- 1	0,0 + 0	1	2151	196
1,61300+ 5	1,00000+ 0	7,20883+ 1	7,19265+ 1	1,61819- 1	0,0 + 0	1	2151	197
1,66300+ 5	1,00000+ 0	7,58420+ 1	7,49311+ 1	9,10866- 1	0,0 + 0	1	2151	198
1,87700+ 5	1,00000+ 0	8,84110+ 1	8,80218+ 1	3,89218- 1	0,0 + 0	1	2151	199
1,94800+ 5	1,00000+ 0	9,29074+ 1	9,24389+ 1	4,68505- 1	0,0 + 0	1	2151	200
1,97900+ 5	1,00000+ 0	9,46572+ 1	9,43778+ 1	2,79390- 1	0,0 + 0	1	2151	201
2,20490+04	0,05510+00	0	0	1	0	1	2151	202
1,00000-05	2,00000+05	1	3	0	0	1	2151	203
3,50000+00	0,43800+00	0	0	2	0	1	2151	204
0,48527+02	0,00000+00	0	0	150	25	1	2151	205
3,83000+03	3,50000+00	1,53510+02	1,53000+02	0.51000+00	0,00000+00	1	2151	206
8,18000+03	3,50000+00	1,68620+02	1,68000+02	0,62000+00	0,00000+00	1	2151	207
1,87600+04	4,00000+00	9,03000+01	9,00000+01	0,30000+00	0,00000+00	1	2151	208
2,15400+04	3,00000+00	1,50860+02	1,50000+02	0.86000+00	0,00000+00	1	2151	209
2,27700+04	3,00000+00	7,00880+02	7,00000+02	0,88000+00	0,00000+00	1	2151	210
2,71400+04	4,00000+00	4,20730+02	4,20000+02	0,73000+00	0,00000+00	1	2151	211
3,19000+04	4,00000+00	2,00059+03	2,00000+03	0,59000+00	0,00000+00	1	2151	212
3,84000+04	4,00000+00	1,70125+03	1,70000+03	1,25000+00	0,00000+00	1	2151	213
5,61000+04	4,00000+00	4,50710+02	4,50000+02	0.71000+00	0,00000+00	1	2151	214

5,94000+04	3,00000+00	4,50710+02	4,50000+02	0.71000+00	0,00000+00	1	2151	215
6,67500+04	3,00000+00	8,00710+02	8,00000+02	0.71000+00	0,00000+00	1	2151	216
7,66000+04	4,00000+00	9,00710+02	9,00000+02	0.71000+00	0,00000+00	1	2151	217
9,66000+04	3,00000+00	3,00071+03	3,00000+03	0.71000+00	0,00000+00	1	2151	218
1,06400+05	3,00000+00	3,30071+03	3,30000+03	0.71000+00	0,00000+00	1	2151	219
1,38800+05	4,00000+00	1,60071+03	1,60000+03	0.71000+00	0,00000+00	1	2151	220
1,45700+05	3,00000+00	1,90071+03	1,90000+03	0.71000+00	0,00000+00	1	2151	221
1,51200+05	3,00000+00	3,30071+03	3,30000+03	0.71000+00	0,00000+00	1	2151	222
1,52200+05	4,00000+00	2,80071+03	2,80000+03	0.71000+00	0,00000+00	1	2151	223
1,70500+05	4,00000+00	8,00710+02	8,00000+02	0.71000+00	0,00000+00	1	2151	224
1,72300+05	4,00000+00	3,50071+03	3,50000+03	0.71000+00	0,00000+00	1	2151	225
1,76200+05	4,00000+00	1,80071+03	1,80000+03	0.71000+00	0,00000+00	1	2151	226
1,84700+05	3,00000+00	3,00071+03	3,00000+03	0.71000+00	0,00000+00	1	2151	227
1,85800+05	4,00000+00	2,50071+03	2,50000+03	0.71000+00	0,00000+00	1	2151	228
1,87700+05	3,00000+00	4,00071+03	4,00000+03	0,71000+00	0,00000+00	1	2151	229
1,97000+05	4,00000+00	3,00071+03	3,00000+03	0,71000+00	0,00000+00	1	2151	230
0,48527+02	0,00000+00	1	0	132	22	1	2151	231
4,77000+ 3	3,50000+ 0	4,28119- 1	4,09291- 1	1,88280- 2	0,0 + 0	1	2151	232
7,64000+ 3	3,50000+ 0	9,67285- 1	8,26915- 1	1.40370- 1	0,0 + 0	1	2151	233
1,31700+ 4	3,50000+ 0	1,91747+ 0	1,85973+ 0	5,77386- 2	0,0 + 0	1	2151	234
1,39700+ 4	3,50000+ 0	2,10883+ 0	2,02988+ 0	7,89562- 2	0,0 + 0	1	2151	235
1,47700+ 4	3,50000+ 0	2,55195+ 0	2,20470+ 0	3,47252- 1	0,0 + 0	1	2151	236
1,70600+ 4	3,50000+ 0	2,80577+ 0	2,72971+ 0	7,60620- 2	0,0 + 0	1	2151	237
1,85900+ 4	3,50000+ 0	3,18387+ 0	3,09965+ 0	8,42282- 2	0,0 + 0	1	2151	238
2,29000+ 4	3,50000+ 0	4,51715+ 0	4,21724+ 0	2,99912- 1	0,0 + 0	1	2151	239
2,39600+ 4	3,50000+ 0	4,67391+ 0	4,50802+ 0	1,65888- 1	0,0 + 0	1	2151	240
2,58400+ 4	3,50000+ 0	5,34591+ 0	5,03820+ 0	3,07712- 1	0,0 + 0	1	2151	241
2,83000+ 4	3,50000+ 0	6,03088+ 0	5,75859+ 0	2,72294- 1	0,0 + 0	1	2151	242
2,86500+ 4	3,50000+ 0	5,94455+ 0	5,86344+ 0	8,11066- 2	0,0 + 0	1	2151	243
3,15300+ 4	3,50000+ 0	7,60409+ 0	6,74763+ 0	8,56466- 1	0,0 + 0	1	2151	244
3,53300+ 4	3,50000+ 0	8,15382+ 0	7,96966+ 0	1,84159- 1	0,0 + 0	1	2151	245
3,61800+ 4	3,50000+ 0	8,54102+ 0	8,25119+ 0	2,89835- 1	0,0 + 0	1	2151	246
3,69700+ 4	3,50000+ 0	8,67849+ 0	8,51543+ 0	1,63064- 1	0,0 + 0	1	2151	247
4,25100+ 4	3,50000+ 0	1,07442+ 1	1,04353+ 1	3,08880- 1	0,0 + 0	1	2151	248
4,34500+ 4	3,50000+ 0	1,11446+ 1	1,07721+ 1	3,72447- 1	0,0 + 0	1	2151	249
4,40100+ 4	3,50000+ 0	1,12196+ 1	1,09743+ 1	2,45366- 1	0,0 + 0	1	2151	250
4,59500+ 4	3,50000+ 0	1,19697+ 1	1,16829+ 1	2,86875- 1	0,0 + 0	1	2151	251
4,97200+ 4	3,50000+ 0	1,33815+ 1	1,30954+ 1	2,86118- 1	0,0 + 0	1	2151	252
5,32000+ 4	3,50000+ 0	1,52413+ 1	1,44390+ 1	8,02225- 1	0,0 + 0	1	2151	253
2,20500+04	0,05340+00	0	0	1	0	1	2151	254
1,00000-05	2,00000+05	1	3	0	0	1	2151	255
0,00000+00	0,34100+00	0	0	2	0	1	2151	256
0,49516+02	0,00000+00	0	0	12	2	1	2151	257
5,65000+04	0,50000+00	2,00470+02	2,00000+02	0.47000+00	0,00000+00	1	2151	258
1,85600+05	0,50000+00	1,50047+03	1,50000+03	0.47000+00	0,00000+00	1	2151	259
0,49516+02	0,00000+00	1	0	66	11	1	2151	260
1,69900+ 4	1,00000+ 0	3,90437+ 0	3,80167+ 0	1.02701- 1	0,0 + 0	1	2151	261
5,43800+ 4	1,00000+ 0	2,10358+ 1	2,08814+ 1	1.54468- 1	0,0 + 0	1	2151	262
6,07700+ 4	1,00000+ 0	2,50146+ 1	2,44973+ 1	5.17367- 1	0,0 + 0	1	2151	263
7,35500+ 4	1,00000+ 0	3,26530+ 1	3,21726+ 1	4,80401- 1	0,0 + 0	1	2151	264
7,65000+ 4	1,00000+ 0	3,41340+ 1	3,40203+ 1	1,13712- 1	0,0 + 0	1	2151	265
7,87500+ 4	1,00000+ 0	3,70280+ 1	3,54472+ 1	1.58082+ 0	0,0 + 0	1	2151	266
8,45500+ 4	1,00000+ 0	3,92664+ 1	3,91930+ 1	7,34708- 2	0,0 + 0	1	2151	267
8,73500+ 4	1,00000+ 0	4,13774+ 1	4,10346+ 1	3.42841- 1	0,0 + 0	1	2151	268
9,76000+ 4	1,00000+ 0	4,84666+ 1	4,79477+ 1	5.18889- 1	0,0 + 0	1	2151	269

```
1,20600+ 5 1,00000+ 0 6,47001+ 1 6,43179+ 1 3,82258- 1 0,0        + 0  1 2151   270
1,35400+ 5 1,00000+ 0 7,56396+ 1 7,53787+ 1 2,60900- 1 0,0        + 0  1 2151   271
                                                                       1 2   0  272
                                                                       1 0   0  273
2,20000+04 4,74676+01          0         99          0          0  1 3   1  274
0,00000+00 0,00000+00          0          0          1         29  1 3   1  275
        29          2          0          0          0          0  1 3   1  276
1,00000-05 0,53796+00 1,00000-04 0,53796+00 1,04310-03 0,53796+00  1 3   1  277
1,96400-03 0,55787+00 6,38420-03 0,58136+00 2,25920-02 0,60034+00  1 3   1  278
1,49300-01 0,61491+00 5,02890-01 0,62524+00 2,95340+00 0,64463+00  1 3   1  279
6,71980+00 0,65006+00 8,03940+01 0,54132+00 1,44470+02 0,47192+00  1 3   1  280
2,35400+02 0,39453+00 3,23740+02 0,32777+00 4,09510+02 0,23597+00  1 3   1  281
1,32290+03 0,19427+00 1,73700+03 0,17092+00 2,05410+03 0,14743+00  1 3   1  282
2,28980+03 0,12589+00 2,54670+03 0,94420-01 2,64230+03 0,11655+00  1 3   1  283
2,69650+03 0,14892+00 2,74420+03 0,12474+00 2,78610+03 0,00000+00  1 3   1  284
1,83975+05 0,00000+00 1,84337+05-2,00000-01 1,84555+05-5,00000-01  1 3   1  285
1,84700+05-9,78000-01 2,00000+05-9,78000-01                        1 3   1  286
                                                                   1 3   0  287
2,20000+04 4,74676+01          0         99          0          0  1 3   2  288
0,00000+00 0,00000+00          0          0          1         42  1 3   2  289
        42          2          0          0          0          0  1 3   2  290
1,00000-05 0,53796+00 1,00000-04 0,53796+00 1,04310-03 0,53796+00  1 3   2  291
1,96400-03 0,55787+00 6,38420-03 0,58136+00 2,25920-02 0,60034+00  1 3   2  292
1,49300-01 0,61491+00 5,02890-01 0,62524+00 2,95340+00 0,64463+00  1 3   2  293
6,71980+00 0,65006+00 8,03940+01 0,54132+00 1,44470+02 0,47192+00  1 3   2  294
2,35400+02 0,39453+00 3,23740+02 0,32777+00 4,09510+02 0,23597+00  1 3   2  295
1,32290+03 0,19427+00 1,73700+03 0,17092+00 2,05410+03 0,14743+00  1 3   2  296
2,28980+03 0,12589+00 2,54670+03 0,94420-01 2,64230+03 0,11655+00  1 3   2  297
2,69650+03 0,14892+00 2,74420+03 0,12474+00 2,78610+03 0,00000+00  1 3   2  298
4,99900+04 0,00000+00 5,00000+04-2,18100-03 5,29900+04-2,12200-03  1 3   2  299
5,30000+04-2,65200-03 7,50000+04-2,10900-03 1,00000+05-1,77000-03  1 3   2  300
1,25000+05-1,54500-03 1,34990+05-1,48000-03 1,35000+05-1,65000-03  1 3   2  301
1,50000+05-1,54500-03 1,75000+05-1,22400-03 1,79990+05-1,19600-03  1 3   2  302
1,80000+05-1,76700-03 1,83975+05-1,73957-03 1,84337+05-2,01740-01  1 3   2  303
1,84555+05-5,01740-01 1,84700+05-9,79730-01 2,00000+05-9,79630-01  1 3   2  304
                                                                   1 3   0  305
2,20000+04 4,74676+01          0         99          0          0  1 3102   306
0,00000+00 8,51369+06          0          0          1         82  1 3102   307
        82          2                                              1 3102   308
1,00000-05 0,00000+00 1,00000-02 0,00000+00 1,00000+01 0,00000+00  1 3102   309
4,99900+04 0,00000+00 5,00000+04 2,18100-03 5,29900+04 2,12200-03  1 3102   310
5,30000+04 2,65200-03 7,50000+04 2,10900-03 1,00000+05 1,77000-03  1 3102   311
1,25000+05 1,54500-03 1,34990+05 1,48000-03 1,35000+05 1,65000-03  1 3102   312
1,50000+05 1,54500-03 1,75000+05 1,22400-03 1,79990+05 1,19600-03  1 3102   313
1,80000+05 1,76700-03 1,90000+05 1,69800-03 2,00000+05 1,62900-03  1 3102   314
2,00000+ 5 5,30274- 3 2,50000+ 5 4,81696- 3 3,00000+ 5 4,33186- 3  1 3102   315
3,50000+ 5 4,09787- 3 4,00000+ 5 3,86507- 3 4,50000+ 5 3,75667- 3  1 3102   316
5,00000+ 5 3,65075- 3 5,50000+ 5 3,61296- 3 6,00000+ 5 3,56862- 3  1 3102   317
6,50000+ 5 3,55408- 3 7,00000+ 5 3,53873- 3 8,00000+ 5 3,55341- 3  1 3102   318
9,00000+ 5 3,51625- 3 1,00000+ 6 2,72569- 3 1,10000+ 6 2,13772- 3  1 3102   319
1,20000+ 6 1,94564- 3 1,30000+ 6 1,83671- 3 1,40000+ 6 1,77716- 3  1 3102   320
1,45000+ 6 1,75710- 3 1,50000+ 6 1,73511- 3 1,55000+ 6 1,71070- 3  1 3102   321
1,60000+ 6 1,68318- 3 1,65000+ 6 1,66127- 3 1,70000+ 6 1,64532- 3  1 3102   322
1,80000+ 6 1,63090- 3 1,90000+ 6 1,62353- 3 2,00000+ 6 1,65218- 3  1 3102   323
2,20000+ 6 1,55001- 3 2,50000+ 6 1,39938- 3 3,00000+ 6 1,33412- 3  1 3102   324
```

3,50000+	6	1,08781-	3	4,00000+	6	8,59193-	4	4,50000+	6	7,59307-	4	1	3102	325
5,00000+	6	5,13456-	4	5,50000+	6	4,14348-	4	6,00000+	6	3,50784-	4	1	3102	326
6,50000+	6	3,06060-	4	7,00000+	6	2,68704-	4	7,50000+	6	2,38129-	4	1	3102	327
8,00000+	6	2,12419-	4	8,50000+	6	1,91311-	4	9,00000+	6	1,74504-	4	1	3102	328
9,50000+	6	1,62010-	4	1,00000+	7	1,54600-	4	1,05000+	7	1,52855-	4	1	3102	329
1,10000+	7	1,59511-	4	1,15000+	7	1,76854-	4	1,20000+	7	2,09580-	4	1	3102	330
1,25000+	7	2,61427-	4	1,30000+	7	3,48584-	4	1,35000+	7	4,89110-	4	1	3102	331
1,40000+	7	7,75636-	4	1,45000+	7	1,21603-	3	1,50000+	7	1,86630-	3	1	3102	332
1,55000+	7	2,77132-	3	1,60000+	7	3,95029-	3	1,65000+	7	5,37613-	3	1	3102	333
1,70000+	7	6,88478-	3	1,75000+	7	8,11303-	3	1,80000+	7	8,72306-	3	1	3102	334
1,85000+	7	8,69700-	3	1,90000+	7	8,27282-	3	1,95000+	7	7,70097-	3	1	3102	335
2,00000+	7	7,13185-	3									1	3102	336
												1	3 0	337
												1	0 0	338
												1	0 0	339
								0			0	-1	0 0	340

*EØF

TABLE II-2. Parameters Used to Calculate Mean Neutron Widths of p-Wave Resonances

Isotope	Energy Range Considered (keV)	$\overline{D}_1$ (keV)	S_1 (10^{-4})
46	13.5-120	2.675	1.017
47	4-45	1.138	0.944
48	12-170	6.452	0.882
49	4.8-53	2.164	0.830
50	17-135	9.615	0.785

The mean p - wave resonance spacing, $\overline{D}_1$, has been obtained from capture measurements (II-10). The S_1 strength functions have been calculated with NCNR code (II-17).

TABLE II-3. Parameters Used to Determine Effective Radii Via the Expression $R = AP\ [\frac{a}{AP} \cdot E(ev) + \frac{b}{AP}]$

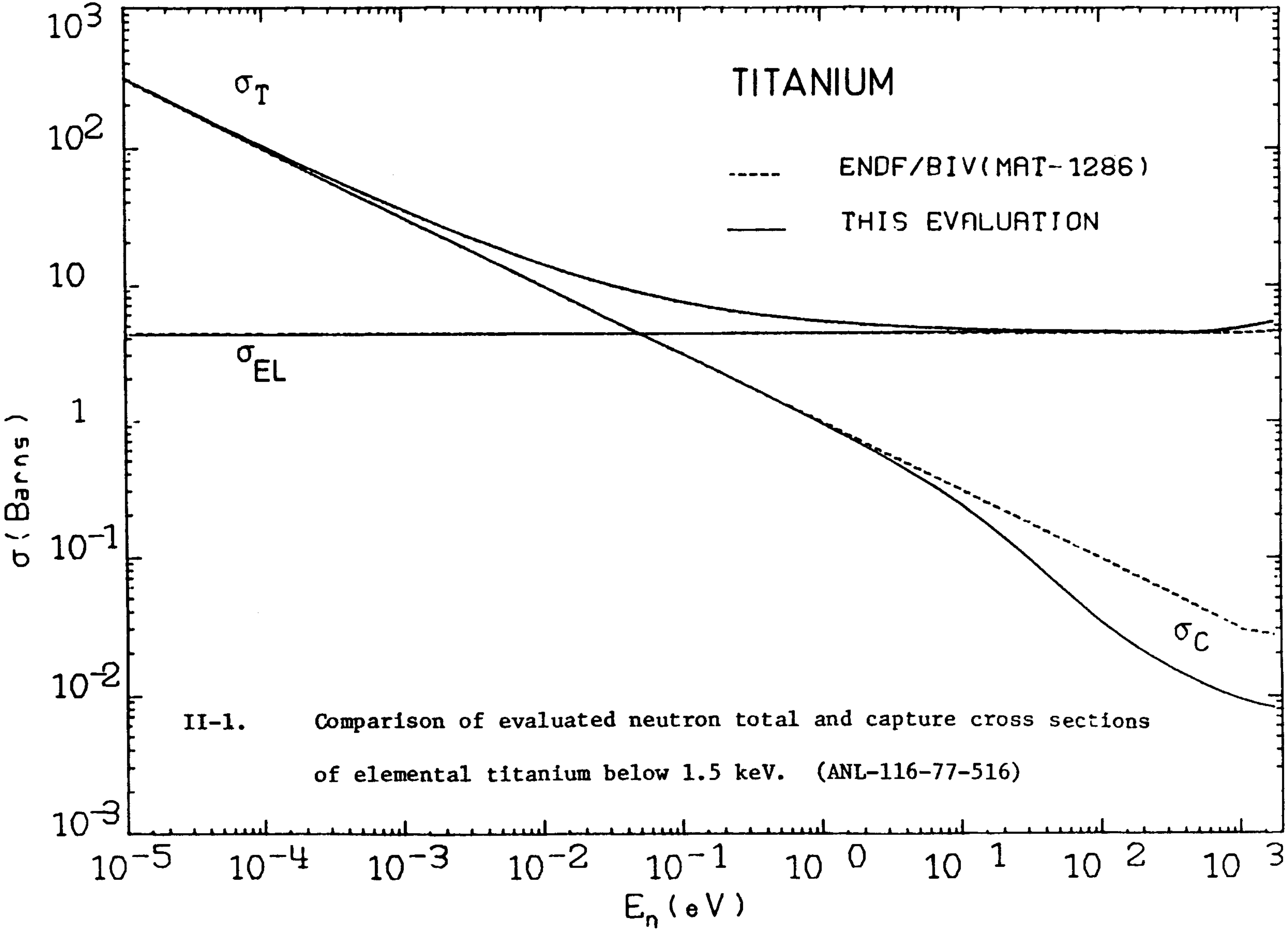
Isotope	AP (10^{-12} cm)	$\frac{a}{AP}$		$\frac{b}{AP}$	
		s-wave	p-wave	s-wave	p-wave
46	0.341	0	0	1	1
47	0.341	0	0	1	1
48	0.205	$-7.32 10^{-6}$	0	1.732	1
49	0.438	$-2.17 10^{-6}$	0	1.062	1
50	0.341	0	0	1	1

TABLE II-4. Energy Ranges of Available Experimental Capture Data

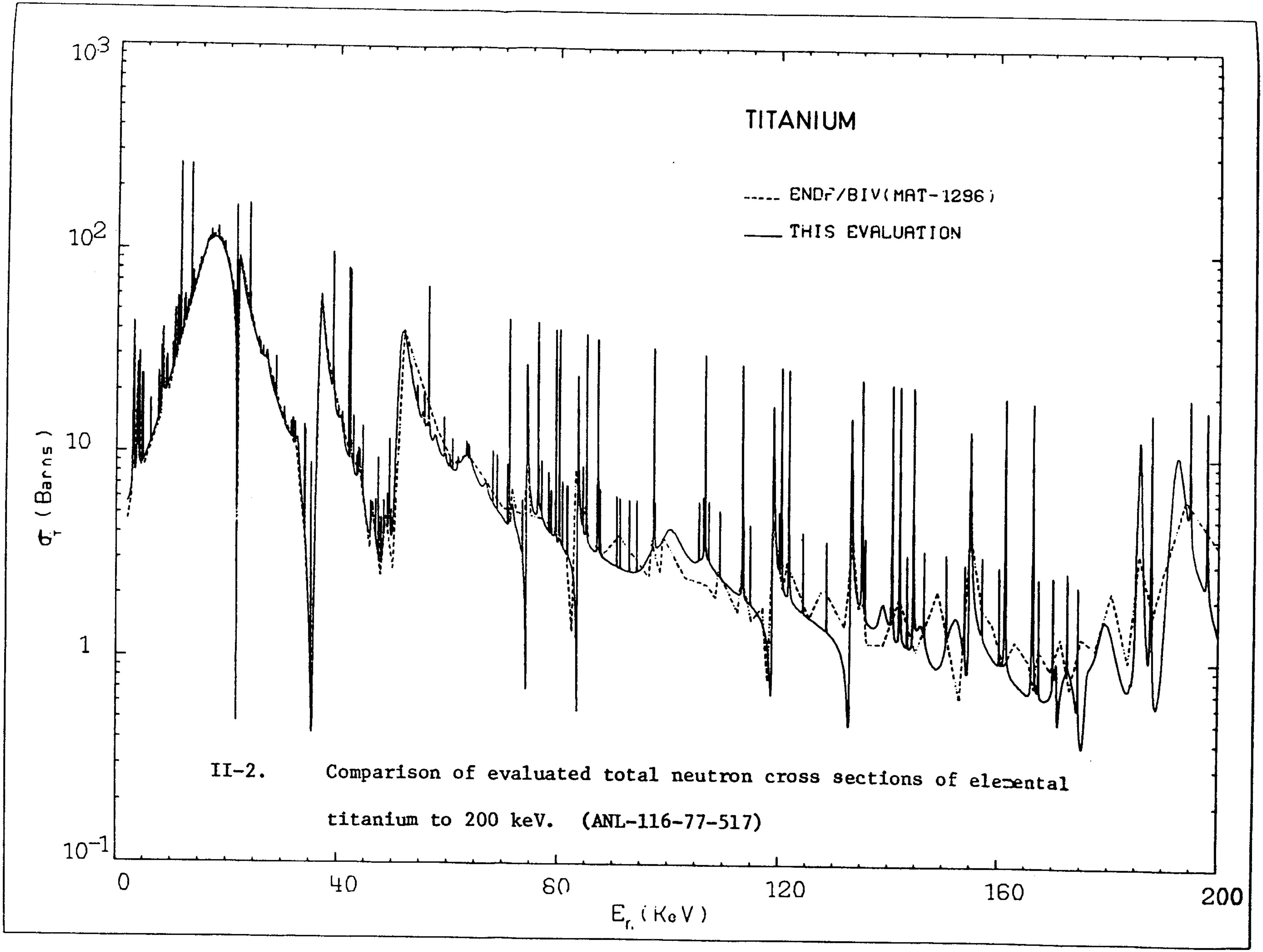
Isotope	s- or p-wave Resonance Parameters Are Given Up To:	
	s-wave	p-wave
46	200 keV	179 keV
47	75 keV	50 keV
48	200 keV	200 keV
49	200 keV	53 keV
50	200 keV	135 keV

TABLE II-5. Comparison of Total-Cross-Section Resonance Integrals as Determined from this Evaluation and from ENDF/B-IV

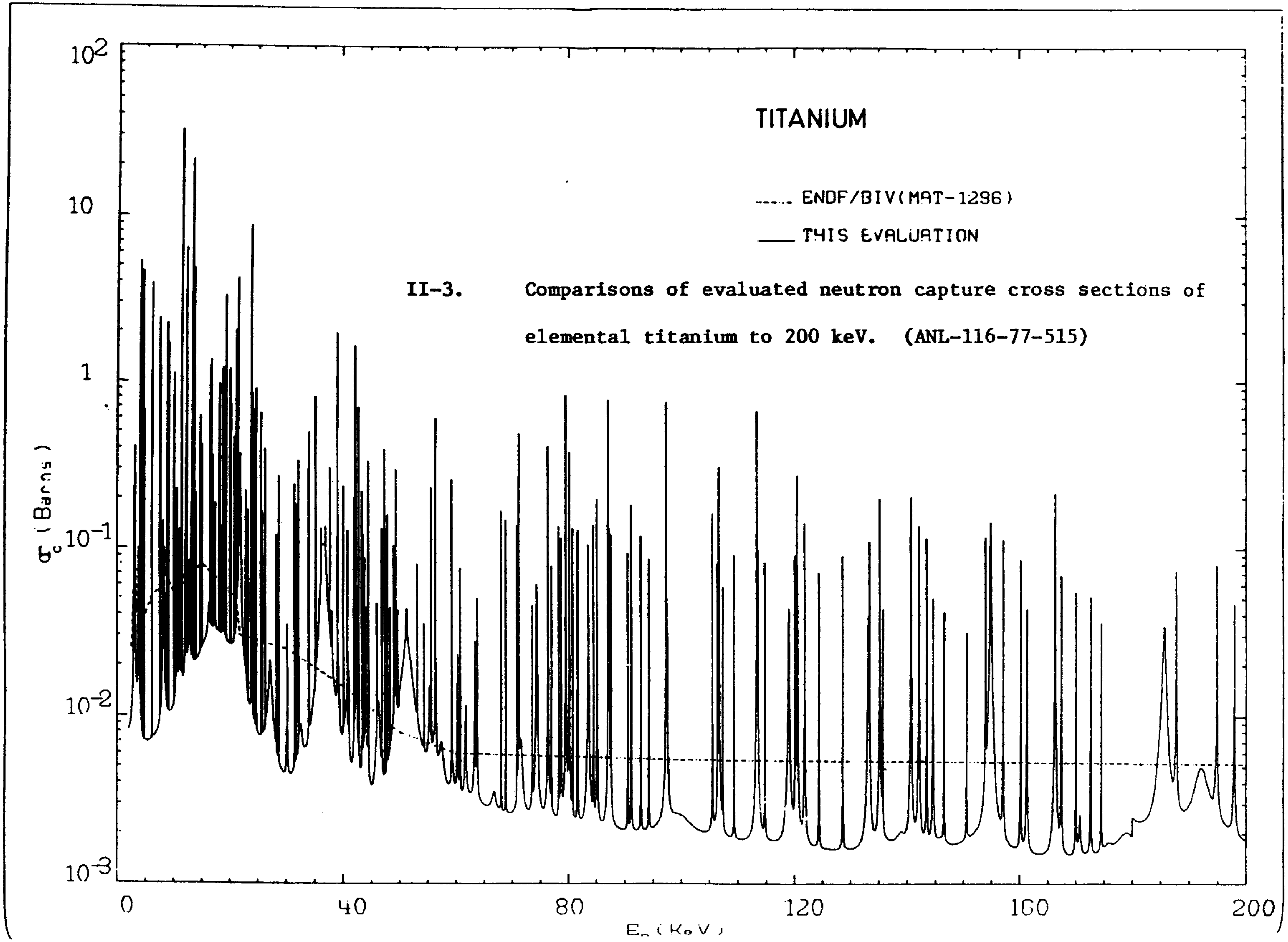
Range (eV)	Integrals in b * eV.	
	ENDF/B IV	This evaluation
$0.1*10^{-4}$ to 0.1	0.608	0.612
0.1 to $0.2*10^4$	$0.892*10^2$	$0.330*10^2$
$0.2*10^4$ to $0.2*10^5$	$0.111*10^4$	$0.788*10^3$
$0.2*10^5$ to $0.1*10^6$	$0.917*10^3$	$0.135*10^4$
$0.1*10^6$ to $0.2*10^6$	$0.535*10^3$	$0.589*10^3$



II-1. Comparison of evaluated neutron total and capture cross sections of elemental titanium below 1.5 keV. (ANL-116-77-516)



II-2. Comparison of evaluated total neutron cross sections of elemental titanium to 200 keV. (ANL-116-77-517)



II-3. **Comparisons of evaluated neutron capture cross sections of elemental titanium to 200 keV. (ANL-116-77-515)**

III. NEUTRON TOTAL CROSS SECTIONS ($E_n \geq 0.2$ MeV)

The evaluated total neutron cross sections at energies above 0.2 MeV are given as a pointwise representation. The data base was constructed from the files of the NNCSC (III-1) and the literature as referenced in CINDA-76 (III-2). The evaluation was extended down to 100 keV and this low energy region (100-200 keV) was used to verify the resonance parameter treatment given in Section II, above.

Over the energy range 200-500 keV the major data sets are those of Bilpuch et al. (III-3), Barnard et al. I(III-4) and Barnard et al. II(III-4). In addition, there are a few values from the work of Adair et al. (III-5). Considering the various experimental resolutions involved, these data sets are in reasonable agreement. The evaluated set was constructed from the data by selecting representative of the measured values in such a way as to well describe the measured results.

The results of Schwartz et al. (III-6) and Barnard et al. II(III-4) provide the primary data base in the range 500 to 1000 keV. There are a few additional values from the work of Adair et al. (III-4). The energy-average cross sections of these data sets are in good agreement. The results of Barnard et al. II clearly have the better resolution and were obtained with the thinnest samples. These were used for the evaluation. However, there is an energy discrepancy of $\approx 6 \pm 2$ keV between the results of Schwartz et al. and those of Barnard et al. II. The energy scale of the former set was believed to be more accurate due to the method employed in the measurements. Therefore, the energy scale of the evaluation was shifted by 6 keV to make it consistent with the results of Schwartz et al.

The results of Schwartz et al. (III-6), Adair et al. (III-5) and Barnard et al. II(III-4) formed the data base from 1.0 to 1.5 MeV. As above, the evaluation was based upon the results of Barnard et al. II because of the better resolution of this set. Again, an adjustment of 5 keV was made in the energy scale to bring the evaluation into energy-agreement with the results of Schwartz et al.

From 1.5 to 4.0 MeV the most detailed and best resolution data were those of Schwartz et al. (III-6). Unfortunately, this set of measurements employed very thick samples in a region of large fluctuations. Detailed broad resolution measurements by Smith and Whalen (III-7) resulted in considerably larger energy-average-cross-section magnitudes than derived from Ref. III-6. These discrepancies appear to be due to self shielding effects in the large samples of Ref. III-6 as discussed in detail in Ref. III-7. Therefore, the good-resolution results of Ref. III-6 were re-normalized to an energy-average magnitude given by the values of Ref. III-7. The resulting evaluation is relatively consistent with a few results of Conner (III-8), Kent et al. (III-9) and Nereson et al. (III-10). The values reported by Dvorach et al. (III-11) are much larger and were abandoned.

Between 4 and 5 MeV the available data are primarily from the work of Foster and Glasgow (III-12) with a few additional values from the work of Nereson et al. (III-10). The evaluation uses the results of Foster and Glasgow. From 5 to 6 MeV the primary data are from Carlson and Barschall (III-13) and Foster and Glasgow (III-12). There are a few additional values from the work of Nereson et al. (III-10) and Walt et al. (III-14). All of the data are reasonably consistent and the evaluation is constructed from an average of the results of Carlson and Barschall and of Foster and Glasgow.

Above an energy of approximately 6 MeV none of the experimental results show appreciable energy-dependent structure. Thus the evaluation was constructed from a broad energy-average of measured values to approximately 15 MeV. The primary data were those of Foster and Glasgow (III-12) and

Carlson and Barschall (III-13) with a few isolated values from Lasday (III-15), Coon et al. (III-16), Goodman (III-17), Nereson et al. (III-10), Conner (III-8), St. Pierre et al. (III-18) and Bratenahl et al. (III-19). Beyond 15 MeV there appears to be only a single value measured by Peterson et al. (III-20) at 17.5 MeV. The evaluation extrapolates smoothly through this value to 20.0 MeV.

The complete evaluated total neutron cross section is outlined and compared with that of ENDF/B-IV in Fig. III-1. From 0.2 to 6.0 MeV the present evaluation portrays much more resonance structure than does ENDF/B-IV. Above 6.0 MeV there are some differences between the two evaluations particularly in the vicinity of 14 MeV.

The estimated uncertainties in the energy-average magnitudes of the present evaluation vary from 20 percent or more near 200 keV, to a few percent from 500 keV to 14 MeV. Beyond these energy-average uncertainties are the uncertainties due to resonance fluctuations. None of the basic data were obtained with the best contemporary resolution and careful measurements may very well show that the cross section extremes are far greater than given in the evaluation. Indeed, theoretical estimates indicate far more pronounced structure (III-21). Improved measurements would be particularly desirable in the uncertain and discrepant energy region near sevearal hundred keV.

REFERENCES — Section III

III-1. National Nuclear Data Center, Brookhaven National Laboratory.

III-2. CINDA-75, IAEA Press, Vienna (1975), largely redundant with the later 76/77 issue.

III-3. E. Bilpuch et al., Ann. Phys., 14 387 (1961).

III-4. E. Barnard et al., Argonne National Laboratory Report, ANL/NDM-3 (1973); See also Nucl. Phys., A229 189 (1974).

III-5. R. K. Adair et al., Phys. Rev., 77 748 (1950).

III-6. R. Schwartz et al., National Bureau of Standards Report, NBS-138 (1974).

III-7. A. Smith and J. Whalen, Argonne National Lab. Report, ANL/NDM-33 (1977); See also Argonne National Lab. Report ANL/NDM-31 (1977).

III-8. J. P. Conner et al., Phys. Rev., 109 1268 (1958).

III-9. Kent et al., Data obtained from files of the National Nuclear Data Center (see ref. III-1).

III-10. N. Nereson et al., Phys. Rev., 94 1678 (1954).

III-11. H. R. Dvorach et al., Phys. Rev., 90 618 (1953).

III-12. D. Foster and D. Glasgow, Phys. Rev., C3 576 (1971).

III-13. A. Carlson and H. Barschall, Phys. Rev., 158 1142 (1967).

III-14. M. Walt et al., Phys. Rev., 98 677 (1955).

III-15. Lasday et al., Data obtained from the National Nuclear Data Center, (see ref. III-1).

III-16. J. H. Coon et al., Phys. Rev., 88 562 (1952).

III-17. L. Goodman, Phys. Rev., 88 686 (1952).

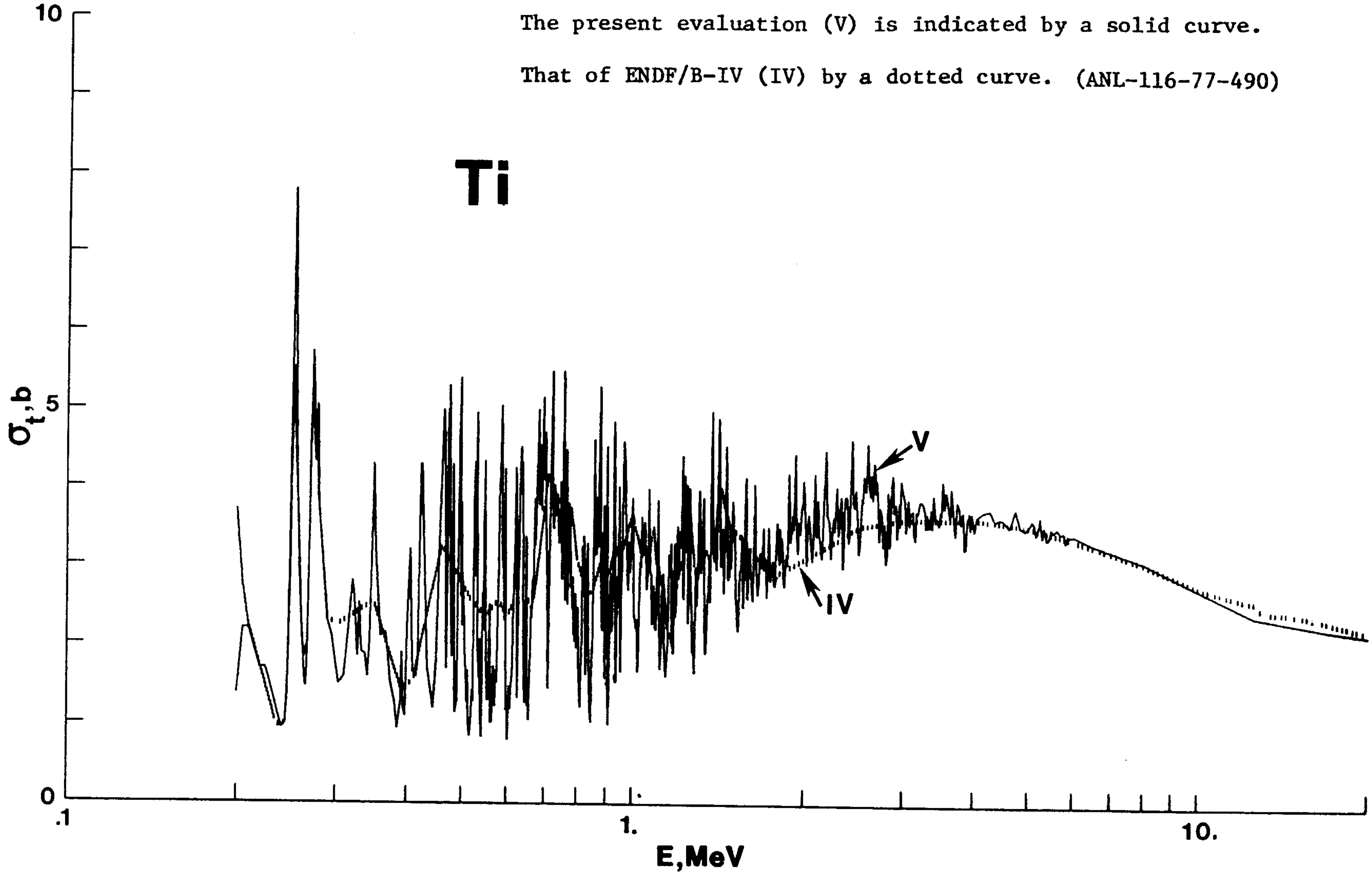
III-18. C. St. Pierre et al., Data obtained from the National Nuclear Data Center, (see ref. III-1).

III-19. A. Bratenahl et al., Inter. Atoms for Peace Conf., Geneva (1958), Vol. 32 of the proceedings.

III-20. J. Peterson et al., Phys. Rev., 120 521 (1960).

III-21. P. Moldauer, Private communication (1977).

III-1. Evaluated Neutron Total Cross Sections of Elemental Titanium. The present evaluation (V) is indicated by a solid curve. That of ENDF/B-IV (IV) by a dotted curve. (ANL-116-77-490)



IV. ELASTIC NEUTRON SCATTERING ($E_n \geq 0.2$ MeV)

These processes at energies of $\leq$ 0.2 MeV are defined by the resonance parameters of Sec. II. In this section attention is given to energies $\geq$ 0.2 MeV wherein the evaluation uses a pointwise representation of the respective cross sections. The non-elastic cross section is reasonably defined to incident energies of $\sim$ 3.25 MeV and to this energy the elastic-scattering cross sections are treated as free parameters adjusted to assure consistency between partial and total cross sections. Above 3.25 MeV the energy-averaged elastic scattering cross sections are based upon the model described in the companion report "Titanium-I, Neutron Cross Section Measurements" (Ref. IV-1, herein denoted as MODEL). The MODEL result has been shown reasonably consistent with measured total and elastic scattering cross sections (IV-1). Over the energy region 3.25 to 20.0 MeV the continuum-inelastic scattering cross sections are treated as free parameters adjusted to assure file consistency. Throughout it was assumed that fluctuations in the total cross section are very largely reflected in the elastic scattering cross section. Exceptions are some of the discrete inelastic cross sections. This is obviously an over simplification but the available experimental information leaves little alternative and statistical theory is limited in practice to a few exit channels (IV-2).

The evaluated relative elastic-scattering angular distributions at energies of less than 0.3 MeV were taken from the results of Langsdorf et al. (IV-3). The evaluation over the range 0.3 to 1.5 MeV was constructed from $\sim$ 0.1 MeV averages of the measured values of Barnard et al. (IV-2). These results are reasonable consistent with the energy-isolated values of: Korzh et al. (IV-4), Cox (IV-5), Lovchikova et al (IV-6), Walt et al. (IV-7) and Darden et al. (IV-8) in the same energy interval. The 0.1 MeV averaging increments were selected to smooth fine structure of the fluctuations yet retain their coarser intermediate-structure character. From 1.5 to 4.0 MeV the evaluation was constructed from the measured distributions given in Ref. IV-1. That reference describes the elastic scattering process in this energy range in considerable detail. The results of Ref. IV-1 are reasonably related to the few previously available experimental values (IV-9, 10). From 4.0 to 8.5 MeV the evaluated elastic angular distributions are primarily based upon the measured values of Kinney and Perey (IV-11) extended to scattering angles beyond the experimental interval using the MODEL and Wick's Limit. The evaluation is only qualitatively consistent with the $\approx$14 MeV experimental values of Ref. IV-13. However these 14 MeV experimental values appear to violate Wick's Limit and possibly show a considerable multi-event perturbation.

The uncertainty in the energy-averaged evaluated elastic scattering cross sections is estimated to be $\leq$8 percent to 14 MeV and somewhat larger at higher energies. In some energy-local regions the fluctuations are large and uncertain. Undoubtedly future and improved measurements will show far larger maxima and much larger fluctuations in the relative-elastic distributions. The present evaluation differs from that of ENDF/B-IV primarily in the detail of the fluctuating structure. There are also differences in energy-averaged magnitudes that will affect various partial cross sections. These differences between the present evaluation and that of ENDF/B-IV are illustrated in Fig. IV-1.

REFERENCES -- Section IV

IV-1. P. Guenther et al., Argonne National Lab. Report, ANL/NDM-31 (1977).

IV-2. E. Barnard et al., Argonne National Lab. Report, ANL/NDM-3 (1973), see also Nucl. Phys., A229 189 (1974).

IV-3. A. Langsdorf et al., Argonne National Lab. Report, ANL-5569 (Rev.) (1961).

IV-4. I. O. Korzh et al., Ukran. Fiz. Zh., 11 563 (1968).

IV-5. S. Cox and E. Cox, Argonne National Lab. Report., ANL-7935 (1971).

IV-6. G. N. Lovchikova et al., Atom. Energy, 12 48 (1962).

IV-7. M. Walt et al., Phys. Rev., 93 1063 (1954).

IV-8. S. E. Darden et al., Phys. Rev., 96 836 (1954).

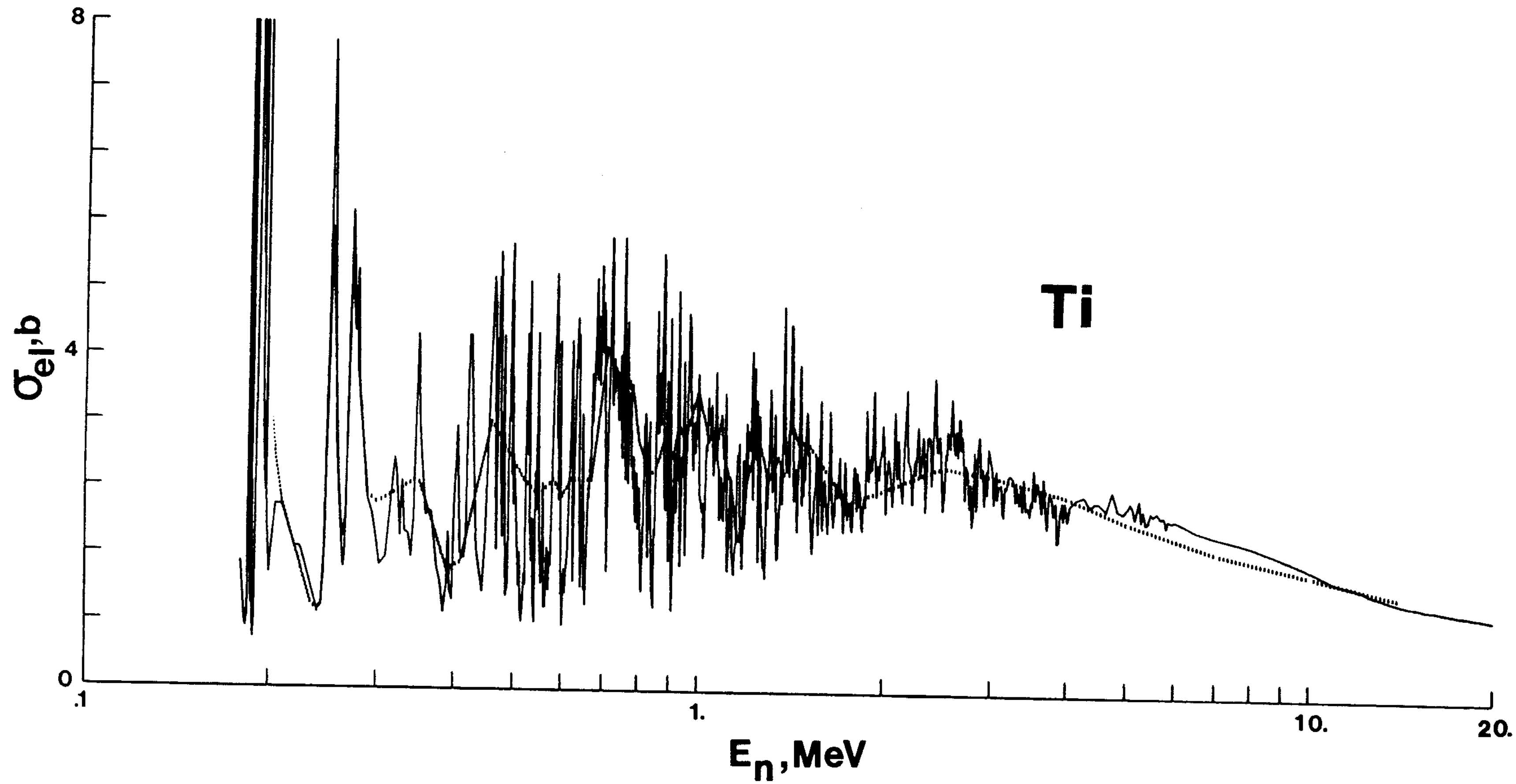
IV-9. R. Becker et al., Nucl. Phys., 89 154 (1966).

IV-10. M. Walt et al., Phys. Rev., 98 677 (1955).

IV-11. W. Kinney and F. Perey, Oak Ridge National Lab. Report, ORNL-4810 (1973).

IV-12. A. Lane and R. Thomas, Rev. of Mod. Phys., 30 257 (1958), page 293.

IV-13. C. St. Pierre et al., Phys. Rev., 115 999 (1959).



IV-1. Comparison of the present evaluated elastic scattering cross sections of elemental titanium (solid curve) with those given in ENDF/B-IV (dashed curve). (ANL-116-77-506)

V. INELASTIC NEUTRON SCATTERING

A. Discrete Inelastic Neutron Excitation Functions

This portion of the file is constructed of twelve components defined by the excitation and threshold energies of Table V-1. The Table also correlates the values with known structure as reported in Ref. V-1. The derivation of each of these components is outlined in the following sub-sections and described in detail in the companion document; Titanium-I (V-2).

1. $E_x = 0.159$ Mev

This contribution is due to inelastic processes in the minor isotope ^{47}Ti. The corresponding inelastic cross sections are qualitatively reported by Barnard et al. (V-3) and Guenther et al. (V-2). They are not well known and apparently relatively small. The file uses the MODEL of Ref. V-2 to calculate the corresponding excitation cross sections. The calculated result is consistent, within measurement error, with the fragmentary experimental evidence.

2. $E_x = 0.889$ MeV

The excitation of this state in ^{46}Ti should be similar to that of the analog (2+, 0.983 MeV) state in the prominent ^{48}Ti isotope. There are direct experimental results to incident energies of several MeV from the work of Barnard et al. (V-3), Konobeevskii et al. (V-4) and Guenther et al. (V-2). Very near threshold the evaluation relies upon the Konobeevskii et al. results. From 1.0 to 1.5 MeV it follows the Barnard et al. data. From 1.5 to 3.0 MeV a few relatively uncertain values are available from Ref. V-2 and the evaluation follows their general trend. Above 3.0 MeV there is no definitive experimental information and the evaluation assumes the general energy dependence of the similar cross section for the excitation of the 2+, 983 keV state in ^{48}Ti (see following paragraph). Fluctuating structure is included in the evaluation where it has been experimentally observed.

3. E_x = 0.983 MeV

This portion of the file was constructed from experimental values. Below 1.5 MeV the evaluation is based entirely on the results of Barnard et al. (V-3). These magnitudes are consistent with the isotopic values reported by Konobeevskii et al. (V-4) though there is a small difference between the energy scales of the two measurements. There is similar reasonable agreement with the broader resolution results of Broders et al. (V-5). The Barnard et al. results have an advantage in the better definition of flucturating structure to 1.5 MeV. From 1.5 to 4.0 MeV, the file is based upon the results of Guenther et al. (V-2), Holmquist et al. (V-6), Cranberg et al. (V-8), Broders et al. (V-5), and Pasechnik et al. (V-8). All of these results were obtained with resolutions that only partially resolved the fluctuating structure. Thus some variation in measured values can be expected and is reflected in uncertainties in the evaluation. In addition, many of the experimental values contain contributions from the above 0.889 MeV component. Small corrections were made for this perturbation as appropriate. Above 4.0 MeV the file was constructed from the measured values of Kinney and Perey (V-9) (to 8.56 MeV), Tsukada et al. (V-10) and the 14 MeV value given by Strizhak et al. (V-11). Again, corrections for contributions due to the excitation of the 0.889 MeV state were made. The appreciable excitation of this state to high energies (e.g., > 10 MeV) is consistent with calculational estimates based upon the direct excitation of this 2+ vibrational state as outlined in Ref. V-2.

4. E_x = 1.430 MeV

This component is due to contributions from several isotopes as outlined in Table V-1 and Ref. V-2. The individual components have not been experimentally resolved. The measurements of Guenther et al. (V-2) and Holmqvist and Wiedling (V-6) show a relatively small combined effect from known states at about this excitation energy. The evaluation uses the average reaction energy of the former reference. It may tend to be somewhat large but is the only quantitative excitation energy available. The corresponding cross sections were estimated from the fragmentary experimental evidence and extrapolated using theoretical estimates (V-2).

5. $\underline{E_x = 1.550 \text{ MeV}}$

The data base and the derivation of the evaluated file for this average excitation were very similar to those outlined above for the 1.43 MeV state.

6. $\underline{E_x = 1.820 \text{ MeV}}$

The data base and the evaluation is essentially the same as outlined above for the above 1.43 and 1.55 MeV states.

7. $\underline{E_x = 2.009 \text{ MeV}}$

This excitation has been reported by Holmqvist and Wiedling (V-6) and Guenther et al. (V-2). It appears to be largely due to the single state in ^{46}Ti and was assumed so in the evaluation. The evaluated cross sections were based upon the experimental results extrapolated with theory.

8. $\underline{E_x = 2.295 \text{ MeV}}$

This relatively prominent excitation was attributed to the corresponding state in ^{48}Ti. The evaluated cross sections were primarily based upon the detailed results of Guenther et al. (V-2), supported with the measured values of Kinney and Perey (V-9). The latter authors do not resolve this particular state very well but their results do define the composite excitation of the 2.295 and 2.42 states to above 8.5 MeV. The evaluation employs the results of Guenther et al. to determine the relative contributions from the two states and follows the overall magnitude reported for the composite by Kinney and Perey at energies above 4.0 MeV.

9. $E_x = 2.421$ MeV

The data base and procedure for the evaluation is essentially identical to that described above for the 2.295 MeV state. For both this state (2.421 MeV) and the above 2.295 MeV state there may be contributions due to the minor isotopes as indicated in Table V-1. These have not been explicitly observed experimentally, therefore, any such components are included within the contribution attributed to these two prominent states in ^{48}Ti.

10. $E_x = 2.615$ MeV

Experimental evidence for excitations in this region is due only to qualitative results of Guenther et al. (V-2). The evaluation uses the average excitation as determined experimentally. Very likely the measured values are inclusive of contributions from the various minor isotopes as indicated in Table V-1.

11. $E_x = 3.000$ MeV

This composite contribution was based upon the results of Guenther et al. (V-2) at lower energies and the results of Kinney and Perey (V-9) above 4.0 MeV. None of the experimental results exhibit particularly good resolution and the component is doubtless a composite of several contributions as suggested in Table V-1. Theory is not much help in this region due to structure uncertainties. The evaluation is thus an estimate based upon marginal experimental evidence.

12. $E_x = 3.250$ MeV

This last discrete component of the evaluation combines contributions from the 3.224, 3.240, 3.340, 3.360, and 3.380 states as reported by Kinney and Perey (V-9). The evaluation is empirically deduced from the measured values. Kinney and Perey also report the excitation of a group of states at energies of 3.5-4.0 MeV. However, the experimental data are somewhat limited in incident energy range thus this evaluation does not attempt to continue the discrete inelastic components into this more uncertain region.

The evaluated cross sections of the above 12 inelastic neutron scattering process are summarized in Fig. V-1. The companion report of Ref. V-2 makes detailed graphical comparisons of measured data with the present evaluation.

The angular distributions associated with the above components were generally taken to be isotropic. This assumption is reasonably consistent with available experimental evidence particularly for the majority of weakly excited levels and with the concept of statistical nuclear processes. Exceptions to this assumption of isotropy are the excitations of the first (2+) excited states of the ^{46}Ti and ^{48}Ti isotopes. At higher energies, neutrons emitted by their excitation should be anisotropic due to direct reactions associated with the vibrational behavior of these even isotopes and such anisotropy has been observed experimentally (V-11). Thus the prominent ^{48}Ti component (E_x = 0.983 MeV) is described by anisotropic distributions. These are derived from coupled-channel and compound-nucleus calculations adjusted to represent the experimental results of Kinney and Perey (V-9) and Strizhak et al. (V-11) as outlined in Ref. V-2.

Comparison of the above evaluation with that of ENDF/B-IV (MAT-1286) is not very rewarding as the latter contains only one discrete inelastic group--that associated with a 0.987 MeV "level". The estimated uncertainties in the present evaluation range from $\sim$ 5 percent in the energy-average cross sections of the prominent and experimentally well defined groups to essentially qualitative estimates in regions where there is no experimental data and calculational estimates are difficult.

B. Continuum Inelastic Neutron Cross Sections

The magnitude of this component is defined by the other non-elastic cross sections, the elastic cross sections and the total cross sections as outlined in Sec. IV.

There have been several measurements of neutron emission spectra from titanium. Those of Kinney and Perey (V-9) at incident energies of $\lesssim$ 8 MeV are most detailed and are the basis of the present evaluation at incident energies of less than 10 MeV. The Kinney and Perey results are generally characterized by isotropy and a conventional temperature dependence. In addition, relatively large spectral fluctuations were observed. In the present evaluation we describe the Kinney and Perey results with a temperature distribution having a $\sqrt{E}$ temperature dependence. In addition, the qualitative features of the observed structure are superimposed upon the temperature spectra. It is stressed that the representation of the observed structure is qualitative. Inclusion of the details of the structure would greatly increase the size of the file and structure beyond the measured energy ranges would still remain uncertain.

Recent measurements by Hermsdorf et al. (V-12) provide a detailed knowledge of the neutron emission spectra of titanium at an incident neutron energy of $\approx$ 14.5 MeV. These data are the foundation of the evaluation at incident energies about 10 MeV. The Hermsdorf et al. results are generally characterized by an angular anisotropy that becomes very strong at higher emission energies (e.g., approximately an order of magnitude at 14 MeV). The description of this type of information requires the capability to represent the observed angle-energy correlation. Within the ENDF system that appears commensurate with the use of File 6 (V-13). The latter file is not recommended (V-13). Therefore recourse must be made to File 4 and 5 formats which are less suitable. Faced with this dilemma, the evaluation compromises by averaging the Hermsdorf et al. data over all angles and assuming isotropy. This is not a very good compromise and the user is cautioned that it may have an adverse impact on some applications. Averaged over angle, the Hermsdorf et al. emission spectra consist of essentially three components: 1) a relatively soft temperature distribution which was largely attributed to (n;n',p), (n;n',α) and (n;2n') processes, 2) a harder and more prominent temperature distribution that was associated with the (n;n') process and 3) a very hard component characteristic of pre-compound processes. It is the latter component that shows the most anisotropy. The evaluation constructs the 14 MeV (n;n') neutron-emission spectrum from the second and third components. This distribution is extrapolated to the lower energy Kinney and Perey (V-9) results and to 20 MeV assuming an E dependence of the temperature of the above second component. The result is a rather hard (n;n') spectrum at incident neutron energies above 10 MeV that, within the scope of the above format approximations, should be qualitatively representative of reality.

In view of the above approximations, the continuum inelastic component is relatively uncertain. However, the non-elastic and (n;2n') cross sections are defined to within 10-15 percent and thus similar uncertainties are reflected in the continuum inelastic scattering component. The present evaluation of the continuum inelastic scattering cross sections is greatly different from that of ENDF/B-IV, partly due to the improved treatment of the discrete inelastic component in the present evaluation. This difference may have a very pronounced effect in some applications of the evaluated file.

REFERENCES -- Section V

V-1. Nuclear Data Sheets for A = 46 (R. Auble), 47 (M. Lewis), 48 (J. Rapaport), 49 (S. Raman), and 50 (R. Auble). Available from the Nucl. Data Project, Oak Ridge National Lab.

V-2. P. Guenther et al., Argonne National Lab. Report, ANL/NDM-31 (1977).

V-3. E. Barnard et al., Argonne National Lab. Report, ANL/NDM-3 (1973); See also Nucl. Phys., A229 189 (1974).

V-4. E. Konobeevskii et al., Izv. Akad. Nauk USSR Ser. Fiz. 37 1764 (1973).

V-5. D. Broders et al., Obninsk Report Series, 32 (1965).

V-6. B. Holmqvist and T. Weidling, Aktiebolaget Atomenergi Report, AE-481 (1973).

V-7. T. Cranberg and J. Levin, Phys. Rev., 103 343 (1956).

V-8. M. Pasechnik et al., Ukrain. Fiz. Zh., 14 1874 (1969).

V-9. W. Kinney and F. Perey, Oak Ridge National Lab. Report, ORNL-4810 (1973).

V-10. K. Tsukada et al., Jour. Phy. Soc. Japan, 16 166 (1961).

V-11. V. Strizhak et al., Yadernaya Fiz., 15-10 (1972).

V-12. D. Hermsdorf et al., Kernenergie, 17 176 (1974).

V-13. Brookhaven National Lab. Report, ENDF-102 (1975), Eds. D. Garber, C. Dunford and S. Pearlstein.

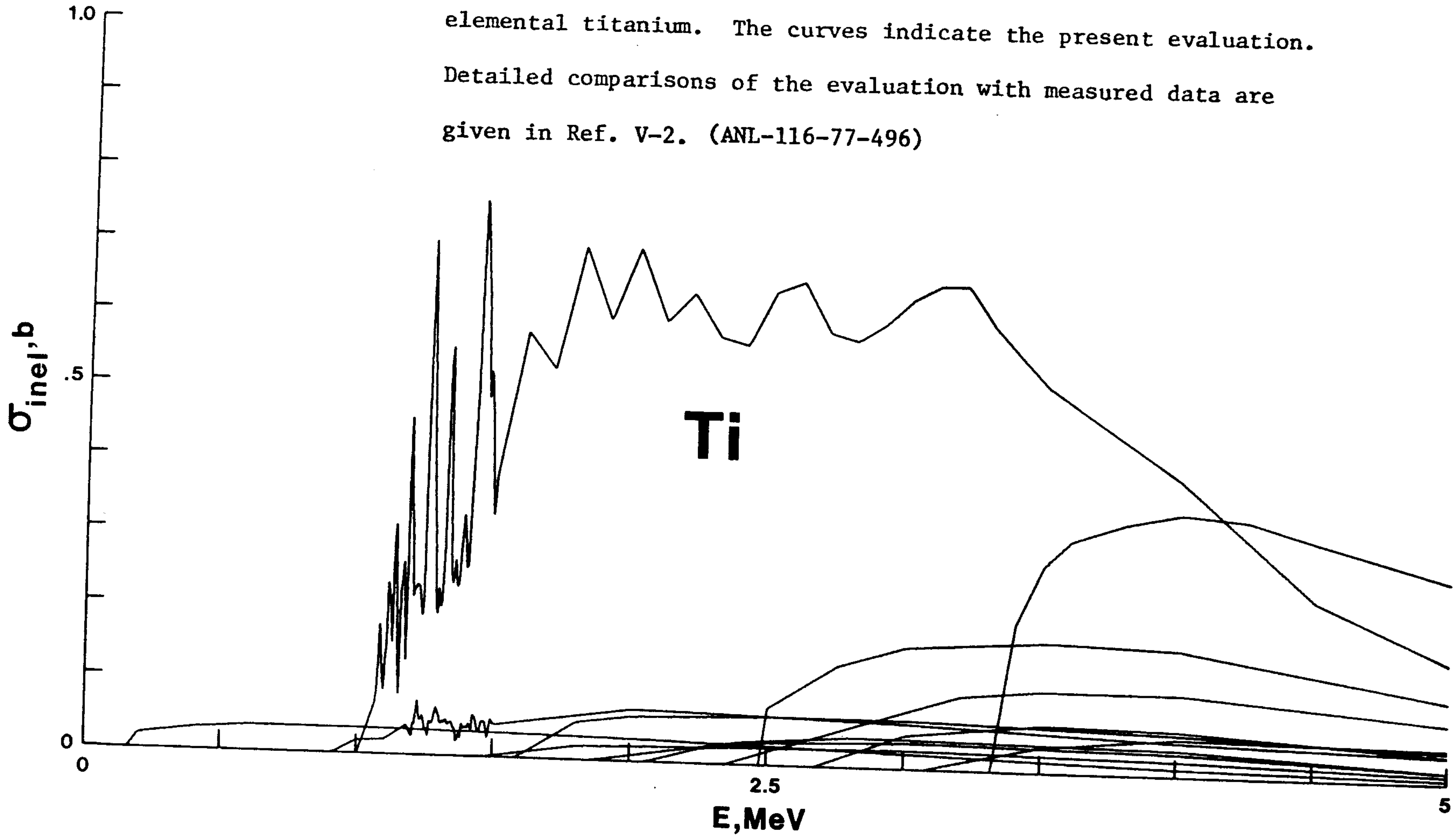
TABLE V-1. Discrete Inelastic Scattering Components

No.	E_x (MeV)	Thres. (MeV)	Isotopic Ref. (A)
1	0.159	0.1623	47
2	0.889	0.9077	46
3	0.983	1.004	48
4	1.430	1.460	47(1.247+1.442), 49(1.381)
5	1.550	1.582	47(1.549), 49(1.542+1.582+1.622), 50(1.554)
6	1.820	1.858	47(1.79+1.82), 49(1.723+1.762)
7	2.009	2.051	46(2.009)
8	2.295	2.343	47(2.161+2.256), 48(2.295), 49(2.262)
9	2.421	2.472	48(2.421), 47,49(B)
10	2.615	2.670	46(2.611), 47(B) 50(2.577)
11	3.000	3.063	46(2.962+3.059), 48(3.000), 47(B)
12	3.250	3.318	46(3.168), 48(3.239), 50(3.201), 47 and 49(B).

A = Values given in the Nuclear Data Sheets, (V-1).

B = Uncertain contributions from the indicated isotopes.

V-1. Discrete inelastic neutron scattering cross sections of elemental titanium. The curves indicate the present evaluation. Detailed comparisons of the evaluation with measured data are given in Ref. V-2. (ANL-116-77-496)



VI. RADIATIVE NEUTRON CAPTURE ($E_n \geq 0.2$ MeV)

The evaluated radiative neutron capture cross sections at energies below 0.2 MeV are outlined in the resonance parameter discussion of Sec. II, above. Further details of the evaluations in the resonance region are given in the work of Simon et al. (VI-15). At energies above 0.2 MeV the measured elemental cross sections appear limited to a single set of results reported by Diven et al. (VI-1). In addition, there have been a number of measurements of the ^{50}Ti(n;γ) activation cross sections (VI-2-8). The evaluation procedure consisted of an evaluation of the ^{50}Ti(n;γ) process using theoretical calculational models, calculation of the (n;γ) cross sections for the other isotopes using the ^{50}Ti(n;γ) model consistent with measured values and then the formation of the elemental cross section from the isotopic components and comparison with the elemental results of Ref. VI-1. It was an iterative procedure quantitatively correlating the available elemental and isotopic experimental information via theory. The individual isotopic components were calculated using the computer programs NCNR (VI-9) and FISPRØ (VI-10) and the parameters of Table VI-1.

The basic isotopic cross sections were those of the ^{50}Ti(n;γ)^{51}Ti reaction. Below $\approx$ 2.5 MeV this cross section has been measured in some detail as illustrated in Fig. VI-1 (VI-2,3,4). At higher energies the experimental results are limited to a region near 14.5 MeV. The ^{50}Ti(n;γ) evaluation up to 2.5 MeV was obtained from an eye guide interpolation through the data sets (VI-2,3 and 4). Above 2.5 MeV the evaluation relies on calculations adjusted to best describe the four available measured values at $\approx$ 14.5 MeV (VI-5,6,7 and 8). Although Ti is outside the range usually treated with FISPRØ (VI-10) we have used this code as it describes both direct and collective processes. The evaluated ^{50}Ti(n;γ) cross sections are compared with the experimental results in Fig. VI-1.

In the absence of experimental values, the (n;γ) cross sections of the other isotopes were calculated using NCNR(VI-9) and FISPRØ (VI-9). The necessary transmission coefficients were obtained from the optical model of Ref. VI-11. NCNR was used to determine the low-energy cross sections and FISPRØ at higher energies. The matching energies for the two types of calculation are given in Table VI-2. The calculated isotopic cross sections, adjusted to agree with the measured elemental values, are shown in Fig. VI-2.

The final elemental (n;γ) cross sections are compared with the measured values of Ref. VI-1 and the evaluation of ENDF/B-IV in Fig. VI-3. The present evaluation is descriptive of the experimental values. However, it is much different than that of ENDF/B-IV; being much smaller in cross section from ∿1 to 10 MeV and containing direct-capture components at higher energies that are not in ENDF/B-IV. The present evaluated (n;γ) cross section shows the compound-nucleus competition of prominent inelastic scattering channels and, as such, has a more realistic shape than the evaluation of ENDF/B-IV. The uncertainties associated with the present evaluation are subjectively estimated to be 10-20 percent below ∿ 1.5 MeV and larger at higher energies. Such uncertainties are considerably smaller than the discrepancies between the present evaluation and that of ENDF/B-IV.

REFERENCES — Section VI

VI-1. B. Diven, J. Terrell and A. Hemmendinger, Phys. Rev., 120 556 (1960).

VI-2. N. Dudey, R. Heinrich, and A. Madson, Sov. Nucl. Eng., 23 443 (1969).

VI-3. G. Zaikin, I. Korzh, N. Skliar and I. Totzkii, Atm. Energia, 23 106 (1967).

VI-4. M. Pasechnik et al., Inter. Conf. on Atoms for Peace, Geneva, (1958), Vol. 15, page 18 of conf. proc.

VI-5. F. Rigaud et al., Nucl. Sci. and Eng., 55 17 (1974).

VI-6. J. Csikai et al., Nucl. Phys., A95 229 (1967).

VI-7. J. Vuletin, P. Kulisic and N. Cindro, Lett. Nuova Comento, 10 1 (1974).

VI-8. J. Perkin et al., Proc. Phys. Soc., 75 505 (1958).

VI-9. P. Thomet, CEA Report, CEA-R-463 (1974); also private communication.

VI-10. V. Benzi and G. Reffo, CCND-NW/10, Newsletter Bulletin 10 (1969).

VI-11. O. Bersillon, private communication (1976).

VI-12. B. Allen and J. Boldeman, private communication (1976).

VI-13. A. Ernst et al., Karlsruhe Lab. Report, KFK-1231 (1970).

VI-14. Brookhaven National Lab. Report, BNL-325, Third Ed., Vol. 1, Eds. S. Mughabghab and D. Garber (1973).

VI-15. G. Simon et al., Specialists Mtg. on Neutron Data of Structural Materials for Fast Reactors, 5-8 December (1977), Geel, proceedings to be published.

TABLE VI-1. Parameters Used in Radiative Capture Calculations

	^{46}Ti	^{47}Ti	^{48}Ti	^{49}Ti	^{50}Ti
Γ_γ (eV)	1.43	1.81[c]	1.33	1.80[a]	0.226[b,c]
$\overline{D}_{obs}$ (eV	22000	1640	20900	6000	127740
Ref.	VI-12	VI-13	VI-12	VI-14	VI-14

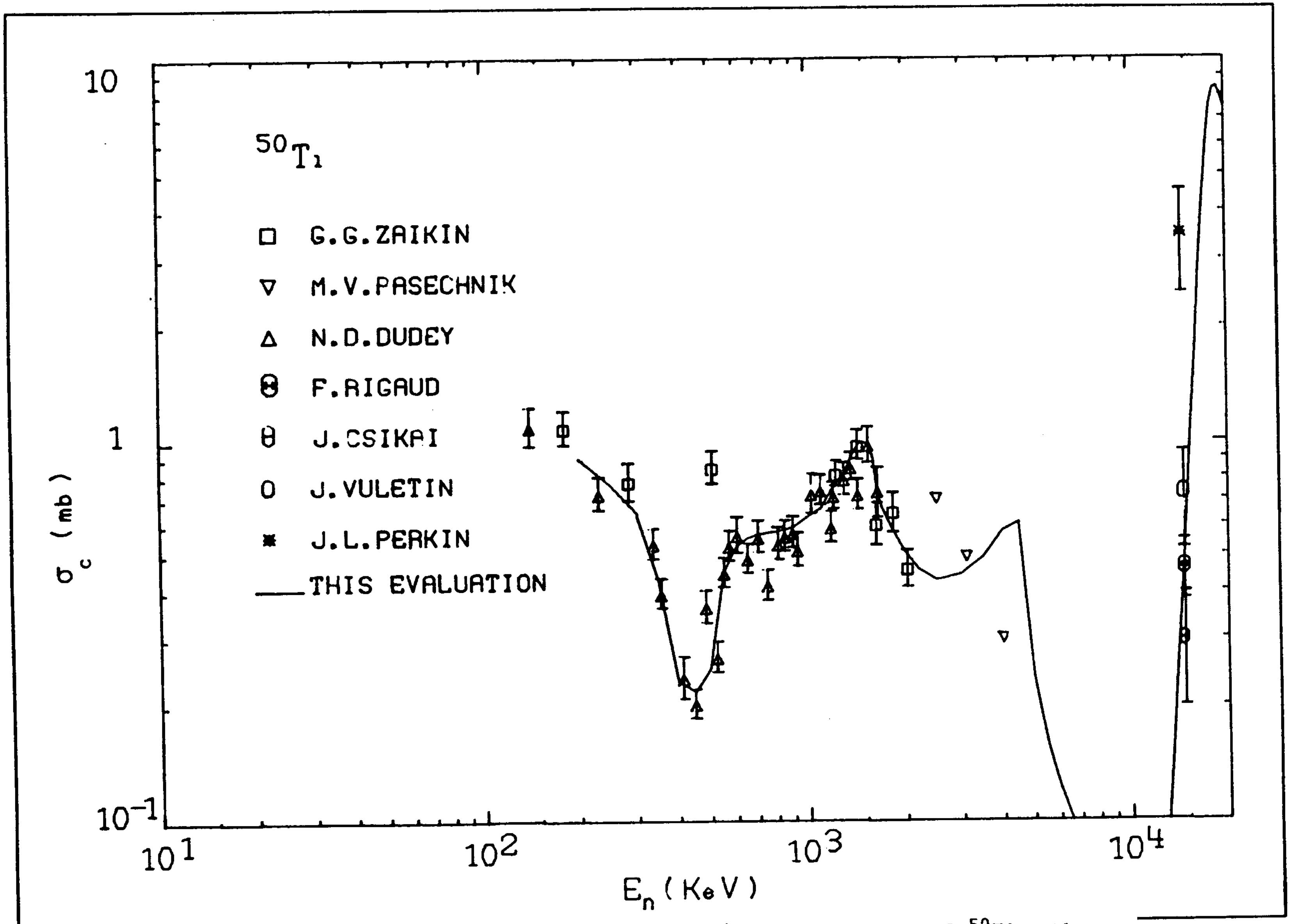
a. Assumed equal to that of ^{47}Ti, no known value.

b. Value obtained by adjustment to experimental data of Ref. VI-2,3,4.

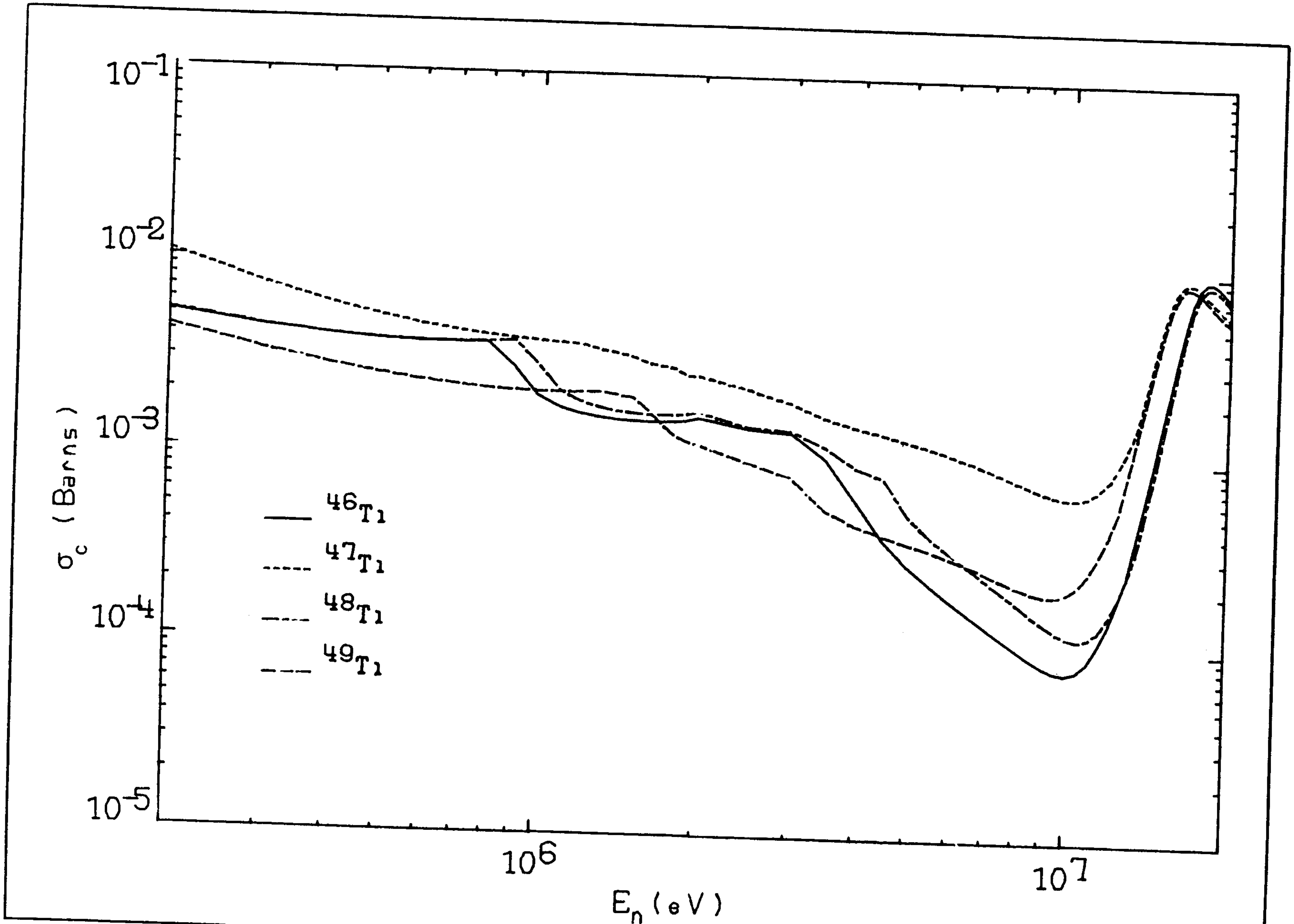
c. Recent values obtained from Allen (VI-12) are $\overline{\Gamma}_\gamma(^{50}Ti) = 0.4$ eV, $\overline{\Gamma}_\gamma(^{47}Ti) = 1.33$ eV. These values post-date the evaluation. However, changes in the evaluation due to these newer values will be small due to the low abundance of these isotopes.

TABLE VI-2. Cutoff Energies for NCNR Computations

Isotope =	46	47	48	49
E_n (MeV) =	3.5	2.5	4.0	2.5

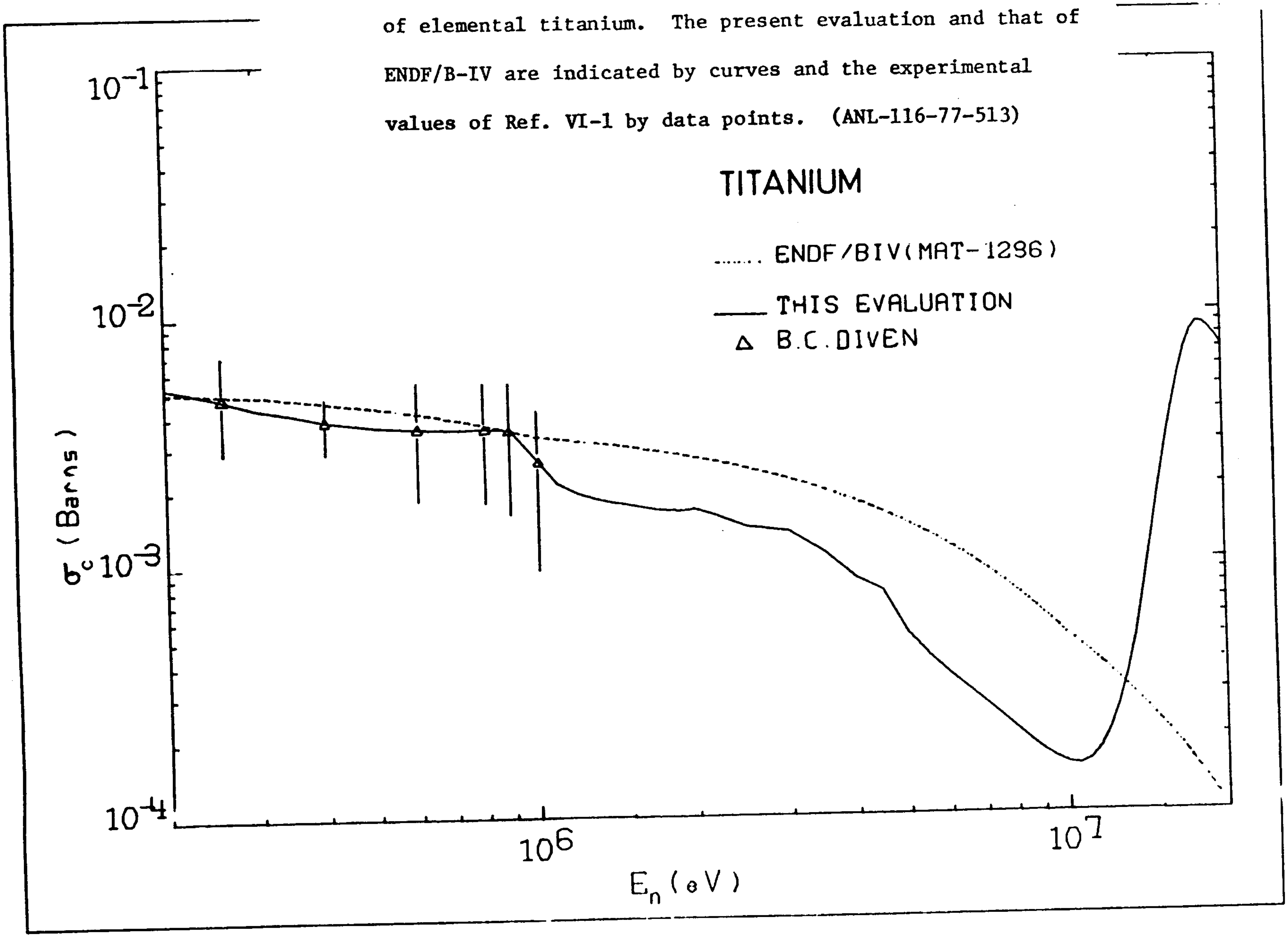


VI-1. Measured and evaluated (n;γ) cross sections of ^{50}Ti. The curve is the present evaluation. The experimental data points are referenced in the text. (ANL-116-77-508)



VI-2. Calculated (n;γ) cross sections of ^{46}Ti, ^{47}Ti, ^{48}Ti and ^{50}Ti as described in the text. (ANL-116-77-511)

VI-3. Comparisons of measured and evaluated (n;γ) cross sections of elemental titanium. The present evaluation and that of ENDF/B-IV are indicated by curves and the experimental values of Ref. VI-1 by data points. (ANL-116-77-513)



VII. (n;2n') AND (n;3n') PROCESSES

A. Elemental (n;2n') File

There are two ways of obtaining the elemental file: combining the individual isotopic components, or using the directly measured elemental cross sections. Unfortunately, the measurements of isotopic cross sections are confined to studies of the ^{46}Ti(n;2n') process. Of the titanium isotopes only ^{46}Ti gives a residual radioactive nucleus via the (n,2n') reaction. This particular reaction may be of special interest and is discussed in the subsequent isotopic section. With this limited isotopic information, construction of the file from the individual components was not very promising. Fortunately, recent experimental results by Frehaut (VII-1) provide a good definition of the elemental cross sections $\lesssim$15 MeV. The Frehaut measurements employed a large liquid scintillation method that has proven very successful in measurements over the past three years. Thus there is considerable confidence in the titanium (n;2n') values obtained in this work. The evaluation is primarily based upon the Frehaut values extrapolated through estimates of the contributions of the various isotopic components. The ^{46}Ti component was obtained from measured values, as described below, and the ^{47}Ti, ^{48}Ti, ^{49}Ti and ^{50}Ti contributions calculated using computer code THRES2 (VII-2). The components were weighted by the respective isotopic abundances and the calculated values iteratively adjusted to obtain a good agreement with the elemental cross section values reported by Frehaut. This method lends confidence to the energy dependent shape of the measured elemental values and provides a good extrapolation to a wider energy range.

The present evaluated result is compared with the measured values of Frehaut and with the corresponding ENDF/B-IV evaluation in Fig. VII-1. The experimental values well define the shape and magnitude of the cross sections from $\sim$ 10 to 15 MeV. In particular, below 12 MeV the cross section is far from negligible in contrast to that given in ENDF/B-IV. At approximately 14 MeV the two evaluations differ by $\approx$ 30 percent but then converge to similar values at 20 MeV. The uncertainty in the present evaluation over the experimentally defined range of 10 to 15 MeV is estimated to be $\lesssim$ 10 percent. Beyond this range, the uncertainty may be larger.

The energy distributions of the neutrons emitted through the (n;2n') process were initially calculated using the program GNASH (VII-3). The requisite transmission coefficients were obtained with the optical potential of Perey and Perey (VII-4). The level-density parameters were taken from Ref. VII-5 updated with more recent values where appropriate. The elemental distributions were obtained by weighting the isotopic components by their relative abundances.

These initial evaluated spectra were then tested by comparing calculated spectra with those measured in the Lawrence Livermore Laboratory 14-MeV pulsed sphere program (VII-16). These benchmark comparisons showed that the (n;2n) spectra of the evaluation had to be much harder than originally calculated. The evaluated spectra were thus adjusted to obtain reasonable agreement with the integral benchmark results. The difference between the initial and final evaluated spectra can, in part, be attributed to large level spacings in the two prominent even-even isotopes of titanium not very well defined in Ref. VII-5.

B. Isotopic (n;2n') File

The ^{46}Ti(n;2n') process is amenable to activation studies and, as a consequence, there have been a number of measurements of this cross section. These are summarized in Fig. VII-2 where the measured values have been renormalized to common reference quantities where possible. Above 15 MeV the results of Pai (VII-6), Prestwood and Bayhurst (VII-7), Paulsen et al. (VII-8) and of Borman and Dreyer (VII-9) are in good agreement. Below 15 MeV the values of Poularikas and Fink (VII-10), Prestwood and Bayhurst (VII-7), Celovani and Petralia (VII-11) and Crumpton (VII-15) are consistent but the two lower-energy values of Paulsen et al. (VII-8) (13.8 and 14.1 MeV) and the results of Rayburn (VII-12), Araminowicz and Drexler (VII-13) and Strain and Ross (VII-14) deviate from the general trend. The present evaluation is smoothly constructed through the consistent measured values as indicated in Fig. VII-2 and generally agrees with them to within 20 percent. The less consistent values may vary by 30 percent or more from the present evaluation. The calculated cross sections for the (n;2n') process in the experimentally unstudied isotopes ^{47}Ti, ^{48}Ti, ^{49}Ti and ^{50}Ti are illustrated in Fig. VII-3. These are the results of THRES2 calculations adjusted for consistency with measured elemental values of Ref. VII-1.

C. The (n;3n') Reaction

Only the single isotope ^{50}Ti can contribute to this reaction at energies of less than 20 MeV. The respective cross sections were estimated by means of THRES2 calculations. The contribution to the file is small due to the high threshold (19.4 MeV). The neutron emission spectrum is represented by relatively "hard" temperature distribution.

REFERENCES -- Section VII

VII-1. J. Frehaut, private communication (1976).

VII-2. S. Pearlstein, J. Nucl. Energy, 27 81 (1972).

VII-3. P. Young and E. Arthur, private communication (1976).

VII-4. C. Perey and F. Perey, Nucl. Data, 10 539 (1966).

VII-5. Nuclear Data Sheets, A=46 to 50. Nuclear Data Project, Oak Ridge National Lab.

VII-6. H. Pai, Can. J. Phys., 44 2337 (1966).

VI-7. R. Prestwood and B. Bayhurst, Phys. Rev., 121 1438 (1961).

VII-8. A. Paulsen et al., Atomkernenergie, 26 34 (1975).

VII-9. M. Borman and F. Dreyer, EANDC Report, EANDC(E)-57U (1965).

VII-10. A. Poularikas and R. Fink, Phys. Rev., 115 989 (1959).

VII-11. E. CeLouani and S. Petralia, Nuovo Cimento, 24 1328 (1962).

VII-12. L. Rayburn, Phys. Rev., 122 168 (1961).

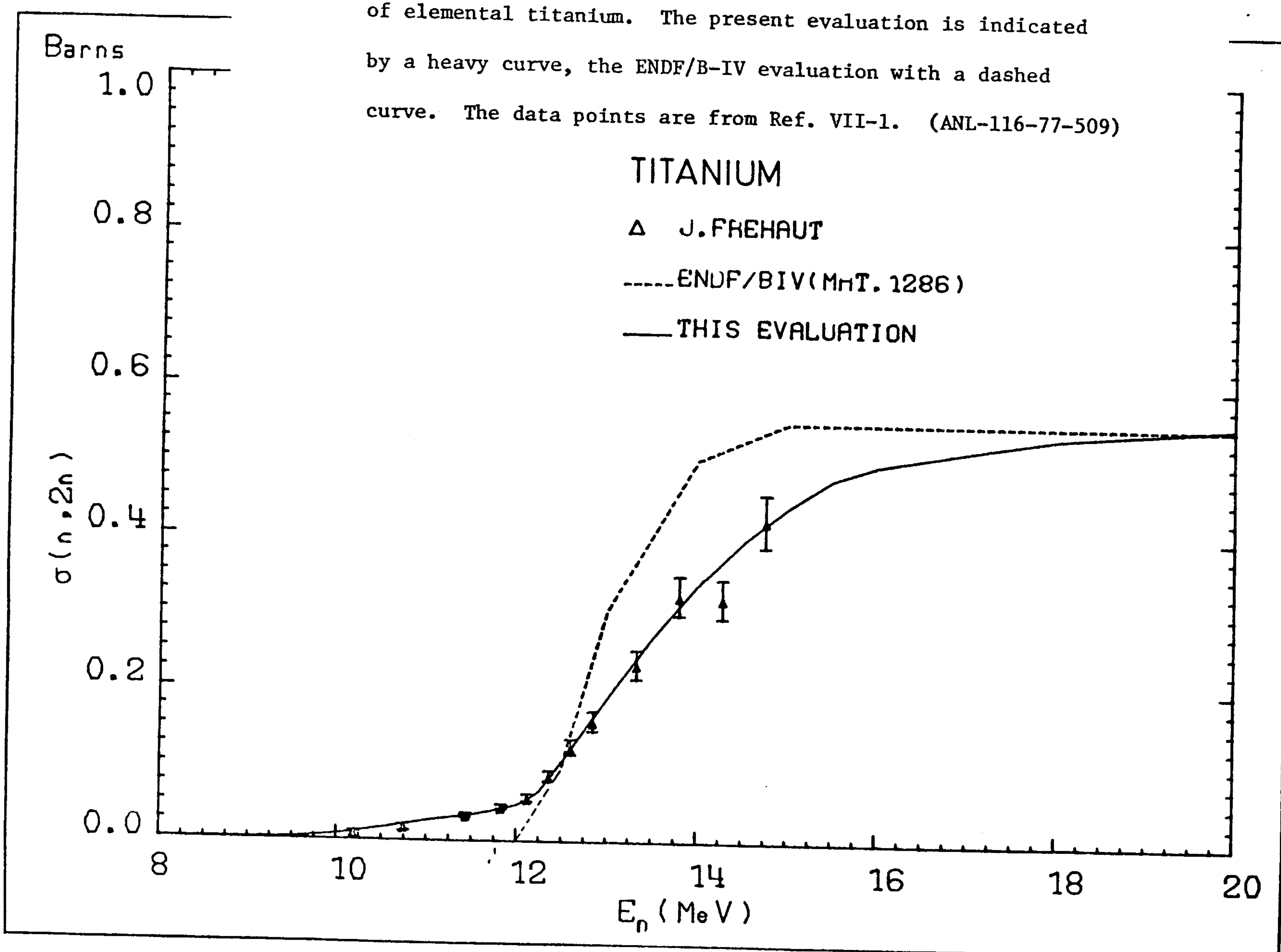
VII-13. J. Aromenowies and J. Drexler, INR Report 1464-14 (1973).

VII-14. J. Strain and W. Ross, Oak Ridge National Lab. Report, ORNL-3672 (1965).

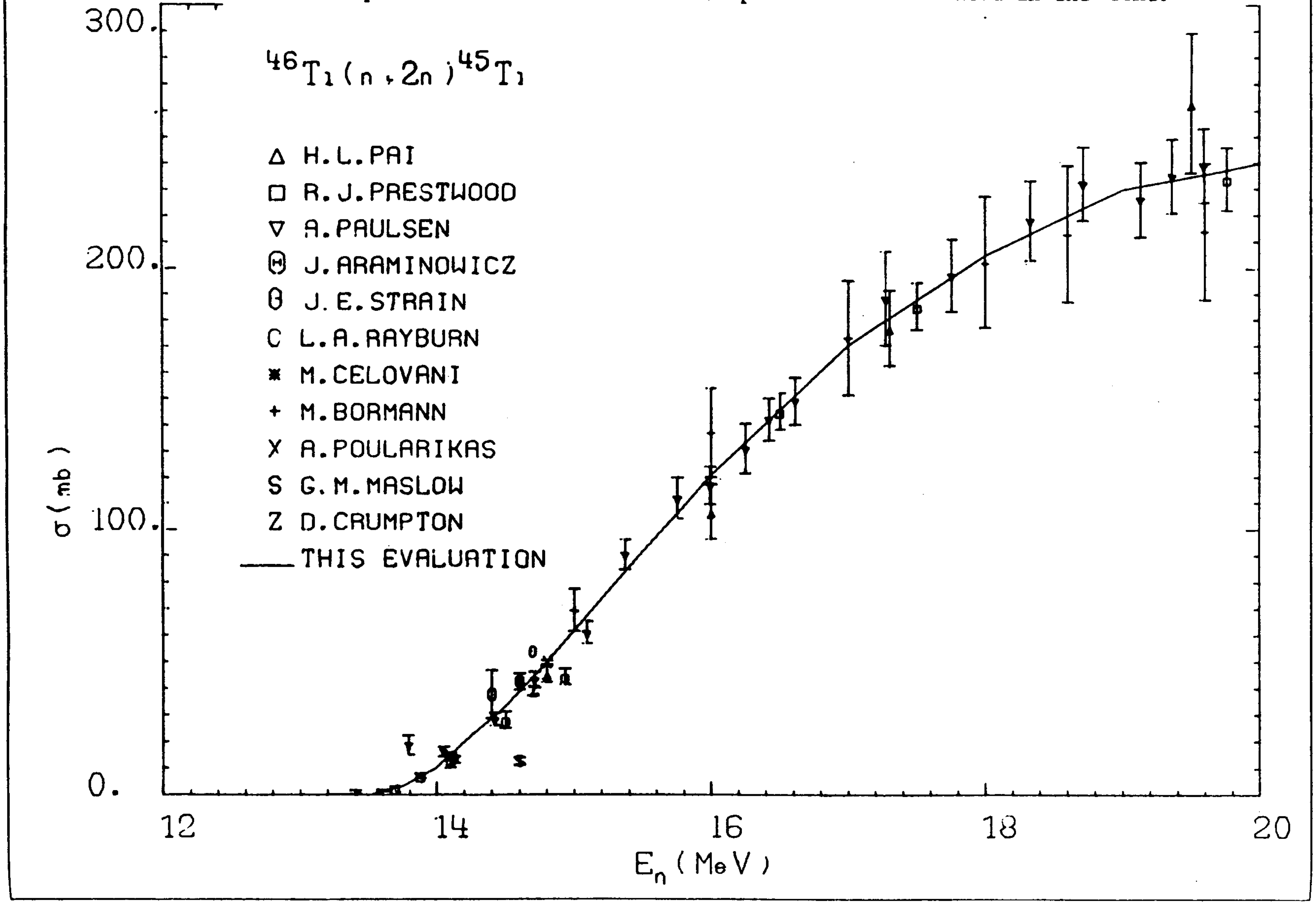
VII-15. D. Crumpton, Jour. Inorg. and Nucl. Chem., 31 3127 (1964).

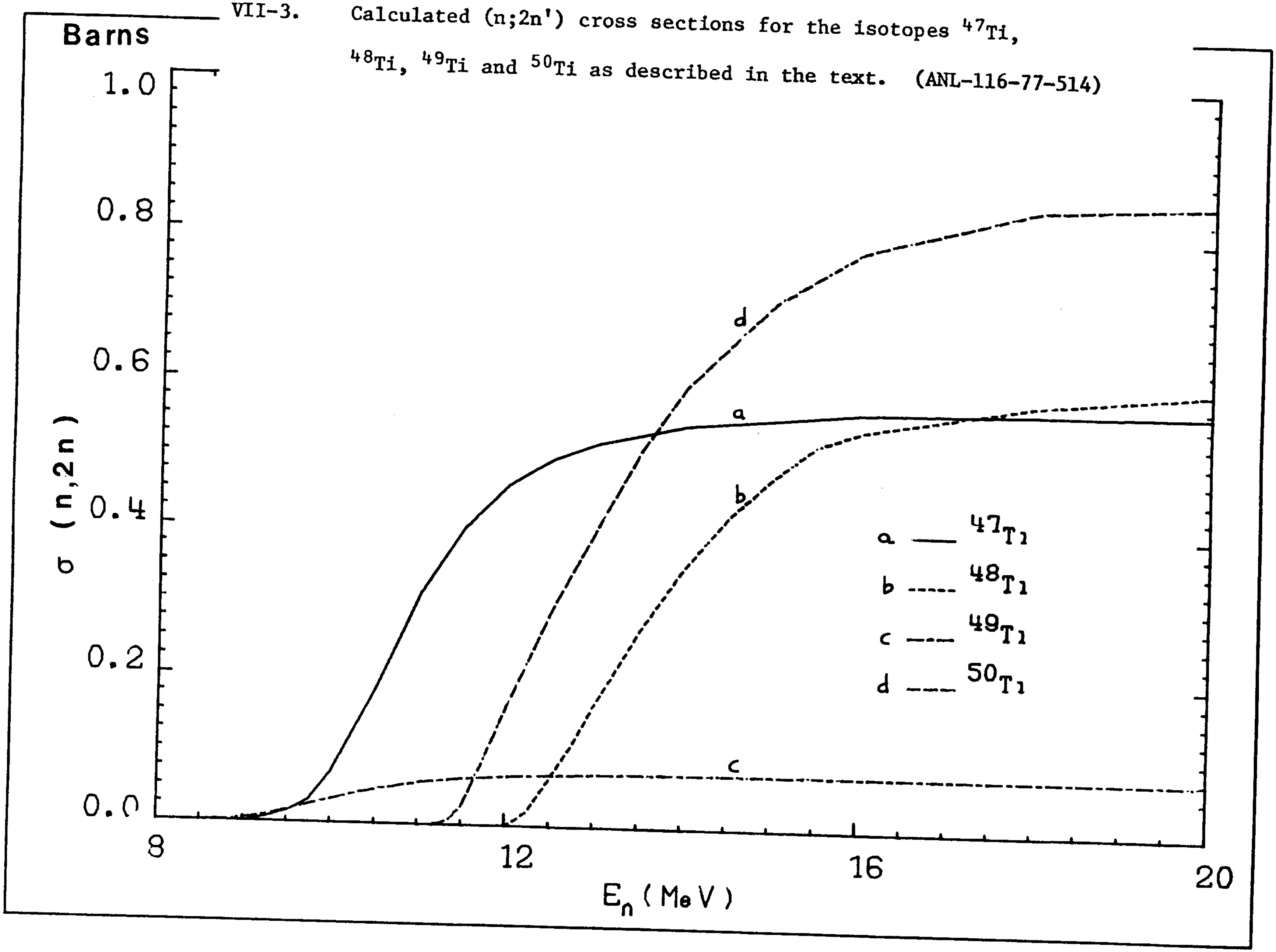
VII-16. C. Wong et al., Livermore Pulsed Sphere Program: Program Summary through July 1971, Lawrence Livermore Laboratory Report, UCRL-51144, Rev. 1 (1972).

VII-1. Comparison of measured and evaluated (n;2n') cross sections of elemental titanium. The present evaluation is indicated by a heavy curve, the ENDF/B-IV evaluation with a dashed curve. The data points are from Ref. VII-1. (ANL-116-77-509)



VII-2. Comparison of measured and evaluated cross sections for the $^{46}Ti(n;2n)^{45}Ti$ process. The curve represents the present evaluation. The data points are referenced in the text.





VII-3. Calculated (n;2n') cross sections for the isotopes ^{47}Ti, ^{48}Ti, ^{49}Ti and ^{50}Ti as described in the text. (ANL-116-77-514)

VIII. THE (n;p) PROCESS

The (n;p) elemental cross section was constructed from the weighted isotopic components. The isotopic evaluations were based upon experimental data or deduced from theoretical calculations where measurements were not available. Insofar as possible, all the experimental data were renormalized to a consistent set of standards based upon the reaction cross sections of Ref. VIII-1 and the decay schemes of Ref. VIII-2. (henceforth, these renormalized data sets are referred to) The theoretical calculations employed the statistical model including shell and pairing corrections (VIII-3). Some of these processes, notably the ^{46}Ti(n;p), ^{47}Ti(n;p) and ^{48}Ti(n;p) reactions, find wide use as dosimetry indicators. Therefore, these selected reactions have previously been reported in greater detail including comparisons with integral results (VIII-4). Subsequent paragraphs outline the isotopic components and the combined elemental file.

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 (VIII-3) 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. (VIII-5), Lukic et al. (VIII-6) and Smith and Meadows (VIII-7). The results of Refs. VIII-5 and 7 are in good agreement. Those of Ref. VIII-6 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. VIII-6 was not accepted for the evaluation. From 12.5 to 19.5 MeV the experimental values of Borman et al. (VIII-8), Pai (VIII-9), Cross and Pai (VIII-10) and Levkovskii (VIII-11) are in good agreement and were accepted for the evaluation. Results reported by Poularikas and Fink (VIII-12), Allan (VIII-13) and Koehler and Alford (VIII-14) appeared discrepant and were not accepted. The values of Liskien and Paulsen (VIII-15) appear higher than the body of the information probably due to contributions from the ^{47}Ti(n;n',p) process (VIII-16) therefore the values of Ref. VIII-15 were not accepted. The evaluation follows the experimental data base above 3.5 MeV interpolating over the unmeasured energy region of $\approx$ 10 to 12 MeV.

The present evaluation is compared with the data base and the corresponding ENDF/B-IV (MAT-6421) results in Fig. VIII-1. The two evaluations are very similar except near threshold where there is a small energy-shift difference. The response integral of the present and associated titanium evaluations over the ^{235}U fission neutron spectrum is compared with the e equivalent quantity derived from ENDF/B-IV and as reported from macroscopic measurements in Ref. VIII-4. Generally, the present evaluations are in good agreement in integral "benchmark" measured values. 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 extend to relatively low energies and the evaluation extrapolates to zero energy using theoretical calculations (VIII-3) Below 10 MeV the data base consists of the values of Smith and Meadows (VIII-7), Ghorai et al. (VIII-5), Armitage (VIII-17) and Gonzalez et al. (VIII-18). The data of Ref. VIII-7 are by far the most comprehensive and relatively precise. The results of Refs. VIII-4 and 19 are generally consistent with those of Ref. VIII-7. All four of these data sets were considered in the evaluation. The results of Ref. VIII-18 are inconsistent with the body of experimental information and were not accepted. Above 10 MeV the experimental results of Cross and Pai (VIII-10), Pai (VIII-9), Hillman (VIII-19) and Allan (VIII-13) are reasonably consistent and were accepted for the evaluation. The results of Poularikas and Fink (VIII-12) and Levkovskii (VIII-10) appear very high and the value of Tikku et al. (VIII-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 have the better precisions.

The present evaluation is compared with that of ENDF/B-IV (MAT-6422) and the experimental data base in Fig. VIII-2. There are 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 (VIII-3). From 4.7 to 10 MeV there are three sets of data: Lukic et al. (VIII-6), Ghorai et al. (VIII-5) and Smith and Meadows (VIII-7). 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. (VIII-20, Pai (VIII-9), Cross and Pai (VIII-10), Hillman (VIII-19), Poularikas and Fink (VIII-12), Gabbard and Kern (VIII-21), Borman et al. (VIII-8), Vonach et al. (VIII-22), Allan (VIII-13), Levkovskii (VIII-11), Crumpton (VIII-23) and Mannhart and Vonach (VIII-24). The data of Refs. VIII-23, 20 and 13 appear inconsistent with the body of information and/or have large experimental errors and were not accepted. In addition, the data of Ref. VIII-22 appear systematically high and their 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. VIII-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.

D. <u>The $^{49}Ti(n;p)^{49}Sc$ and $^{50}Ti(n;p)^{50}Sc$ Processes, Q = -1.223 and -6.103 MeV, Respectively</u>

The evaluation of these two processes is similar since in both cases the experimental information is limited to the approximate evergy range 14 to 20 MeV and theory must be extensively employed for extrapolation to threshold. ^{49}Ti measured values have been reported by Pai (VIII-9), Cross and Pai (VIII-10), Poularikas and Fink (VIII-12), Levkovskii et al. (VIII-11) and Khimura and Hans (VIII-25). The latter value appears anomolously large and was rejected. The others are consistent with experimental uncertainties. (n;p) cross sections of ^{50}Ti have been measured by Pai (VIII-9), Cross and Pai (VIII-10), Koehler and Alford (VIII-14), Bramlitt and Fink (VIII-26), Levkovskii et al. (VIII-11), Khimura and Hans (VIII-25) and Poularikas and Fink (VIII-12). The values of Refs. VIII-12 and 14 appear anomolous and were not accepted. In addition, the uncertainty associated with the measurement of Ref. VIII-26 is large and thus that value was not accepted. This leaves reasonably consistent values from Refs. VIII-9, 10 and 11. Below 14 MeV both evaluations rely entirely upon theoretical extrapolation with the calculated results normalized to the measured values at approximately 14 MeV (VIII-3). The normalization factors were 0.59 (^{49}Ti) and 1.5 (^{50}Ti). The resulting evaluations are compared with the limited data base in Fig. VIII-4 and 5. The uncertainties associated with these two evaluations are large (e.g. 25-30 percent) but the effect upon the elemental result is small due to the low isotopic abundance.

E. The Elemental Cross Section

The elemental evaluated (n;p) cross section derived from the isotopically-weighted sum of the above components is compared with the corresponding ENDF/B-IV (MAT-1286) in Fig. VIII-6. The elemental cross section is dominated by contributions from the prominent isotopes. These components are relatively well known and thus estimated uncertainties in the present elemental evaluation are 5 to 10 percent over much of the energy range. These uncertainties are far less than the differences between the present evaluation and that of ENDF/B-IV. By the method of formulation, the present file is consistent with the isotopic components that find wide application in dosimetry studies.

REFERENCES — Section VIII

VIII-1. ENDF/B-IV Dosimetry File, Brookhaven National Lab. Report, BNL-NCS-50446 (1975), Ed. B. Magurno.

VIII-2. Nuclear Data Sheets, A=46, 47, 48, 49 and 50.

VIII-3. J. Jary, NEANDC Report, NEANDC(E)-175L (1976).

VIII-4. C. Philis et al., Argonne National Lab. Report, ANL/NDM-27 (1977).

VIII-5. S. Ghorai et al., Jour. Nucl. Energy, 25 319 (1971).

VIII-6. Y. Lukic and E. Carroll, Nucl. Sci. and Eng., 43 233 (1971).

VIII-7. D. Smith and J. Meadows, Argonne National Lab. Report, ANL/NDM-10 (1975

VIII-8. M. Borman et al., EANDC Report, EANDC(E)-57 17 (1965).

VIII-9. H. Pai, Can. Jour. Phys., 44 2337 (1966).

VIII-10. W. Cross and H. Pai, EANDC Report, EANDC(CAN)-16 2 (1962).

VIII-11. V. Levkovskii et al., Yadernaya Fizika, 10 44 (1969).

VIII-12. A. Poularikas and R. Fink, Phys. Rev., 115 989 (1959).

VIII-13. D. Allan, Nucl. Phys., 24 274 (1961).

VIII-14. D. Koehler and W. Alford, Jour. Nucl. Energy, 18 81 (1964).

VIII-15. H. Liskien and A. Paulsen, Nucl. Phys., 63 393 (1965).

VIII-16. See for example, M. Vlasov et al., Proc. of Inter. Conf. on Study of Nucl. Structure with Neutrons, Lowell, Mass., (1976).

VIII-17. F. Armitage, Data obtained from the NNCSC, Brookhaven National Lab. (1975).

VIII-18. L. Gonzales et al., Phys. Rev., 126 271 (1962).

VIII-19. M. Hillman, Nucl. Phys., 37 78 (1962).

VIII-20. L. Tikku et al., Conf. on Nucl. Cross Sections and Tech., Washington (1968).

VIII-21. F. Gabbard and B. Kern, Phys. Rev., 128 1276 (1962).

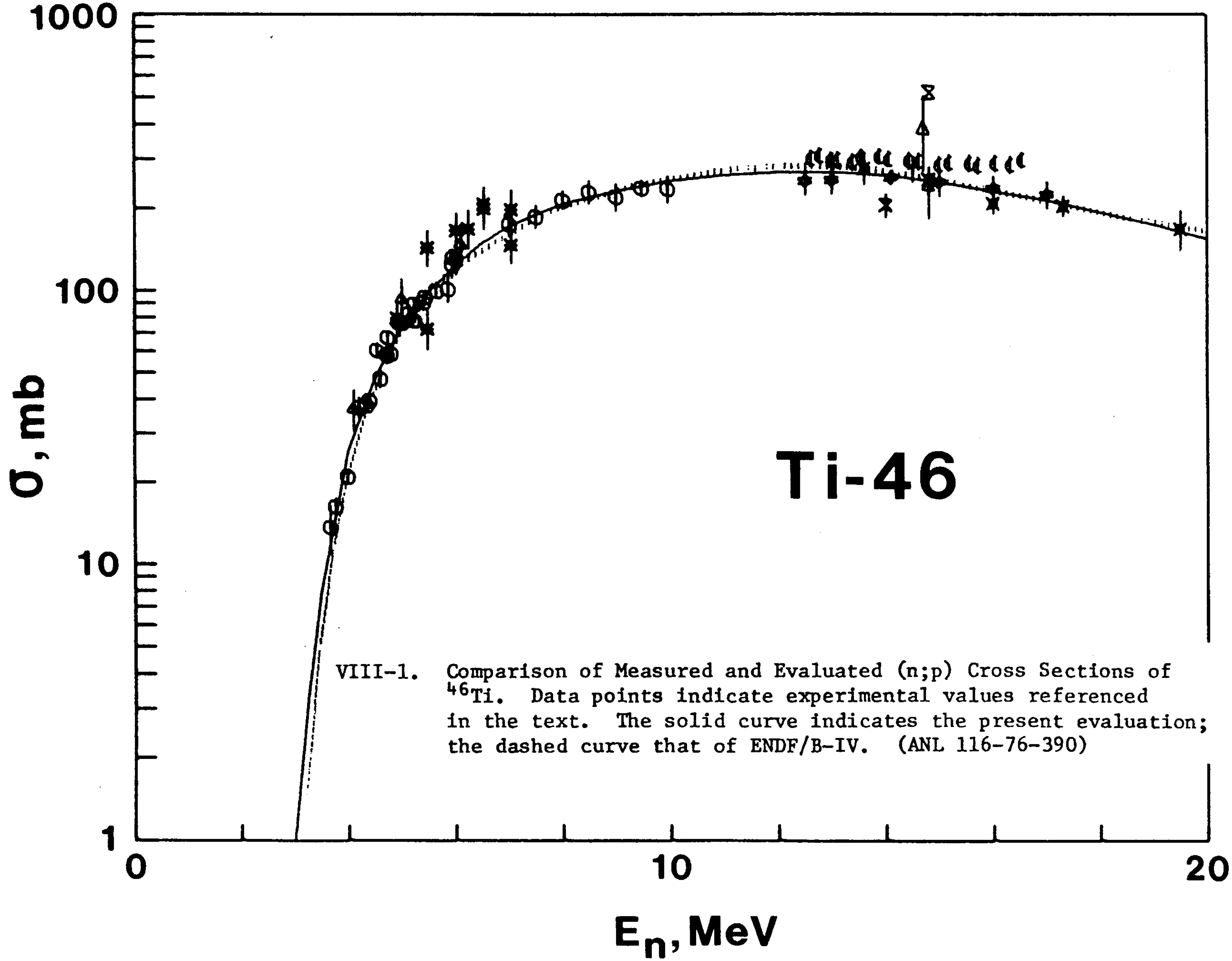
VIII-22. H. Vonach et al., Conf on Nucl. Cross Sections and Tech., Washington (1968).

VIII-23. D. Crumpton, Jour. Inorg. and Nucl. Chem., 31 3727 (1969).

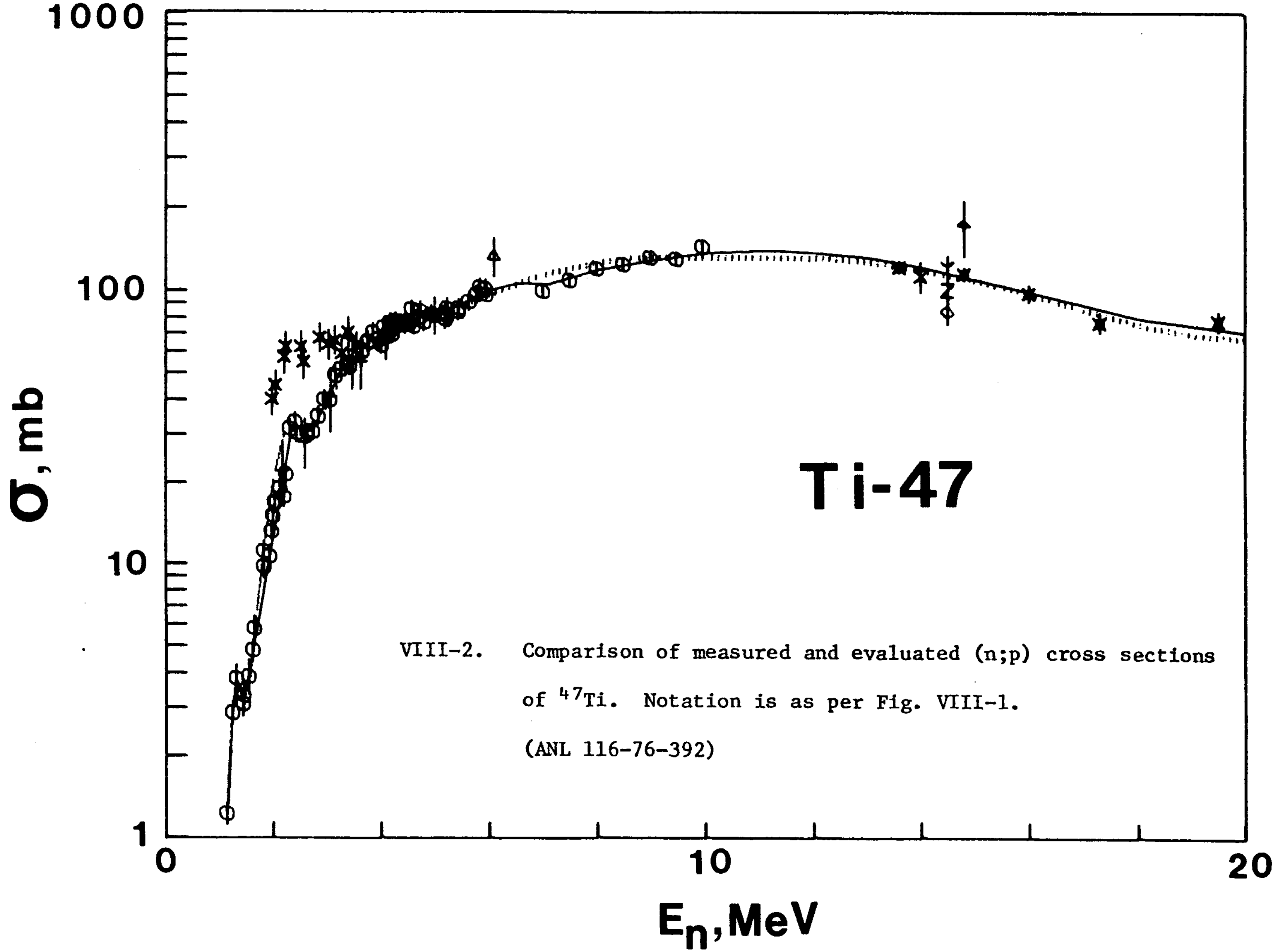
VIII-24. W. Mannhart and H. Vonach, Z. Phys., A272 279 (1975).

VIII-25. C. Khimura and H. Hans, Nucl. Phys., 13 88 (1959).

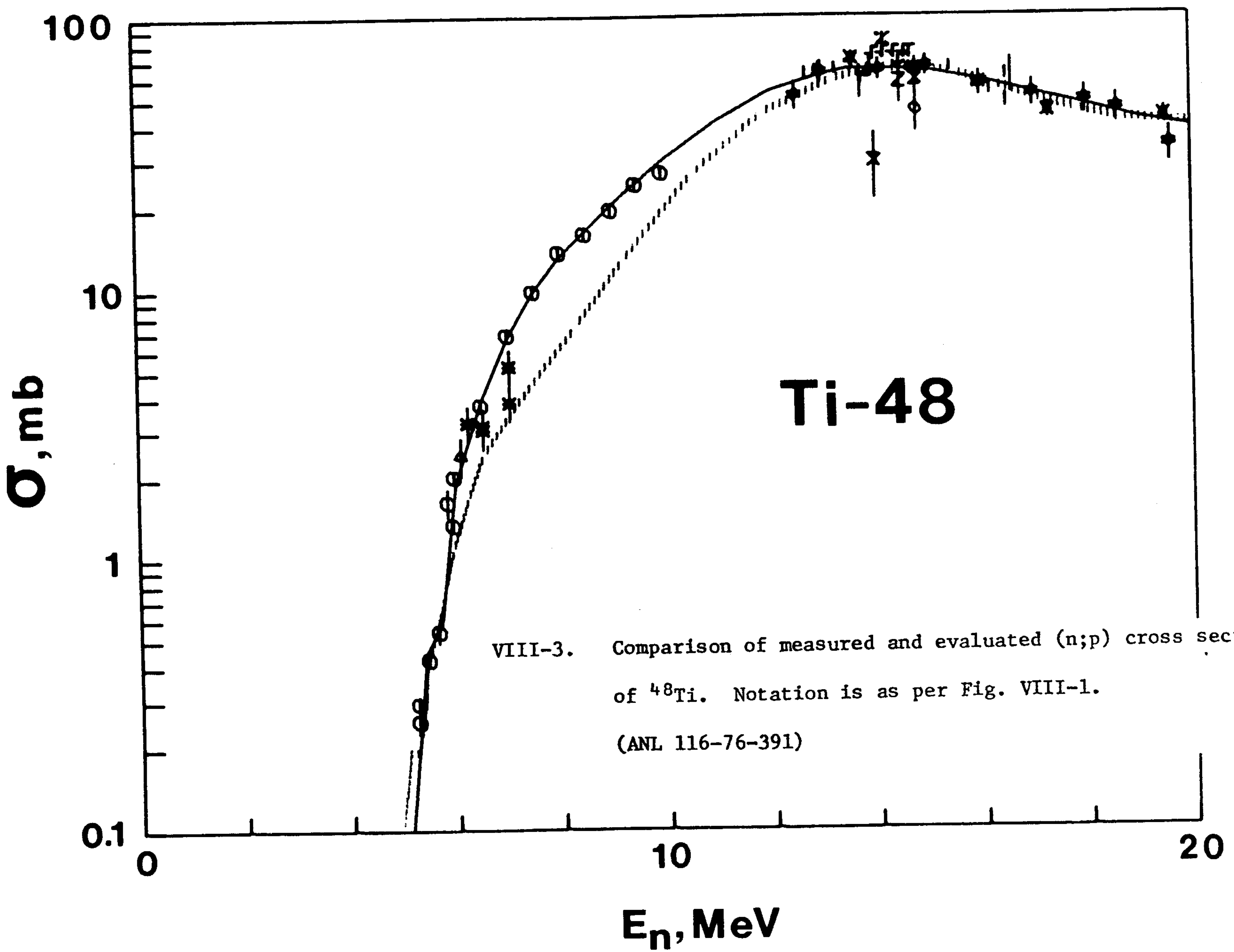
VIII-26. E. Bramlitt and R. Fink, Phys. Rev., 131 2649 (1963).



VIII-1. Comparison of Measured and Evaluated (n;p) Cross Sections of ^{46}Ti. Data points indicate experimental values referenced in the text. The solid curve indicates the present evaluation; the dashed curve that of ENDF/B-IV. (ANL 116-76-390)

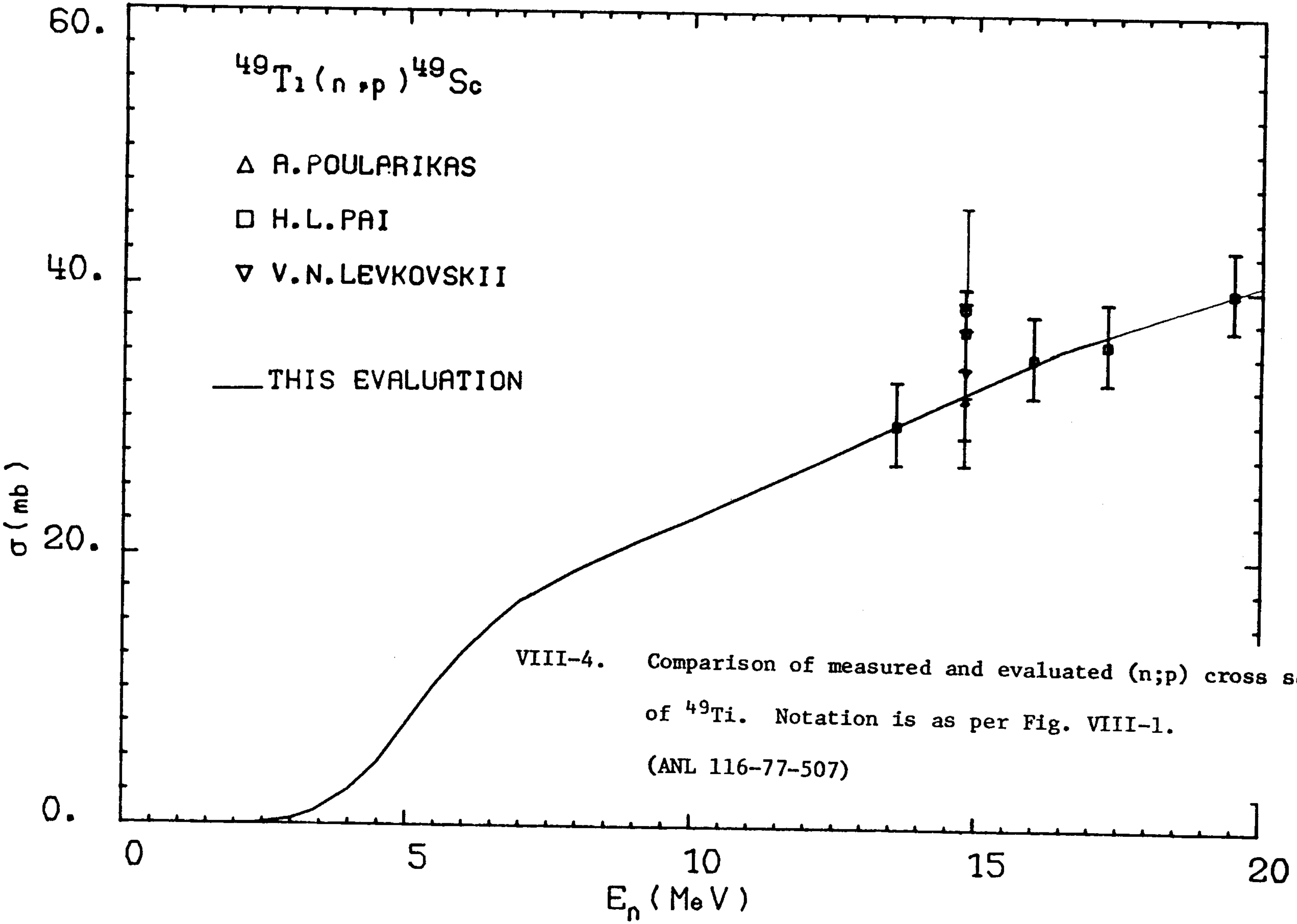


VIII-2. Comparison of measured and evaluated (n;p) cross sections of ^{47}Ti. Notation is as per Fig. VIII-1. (ANL 116-76-392)



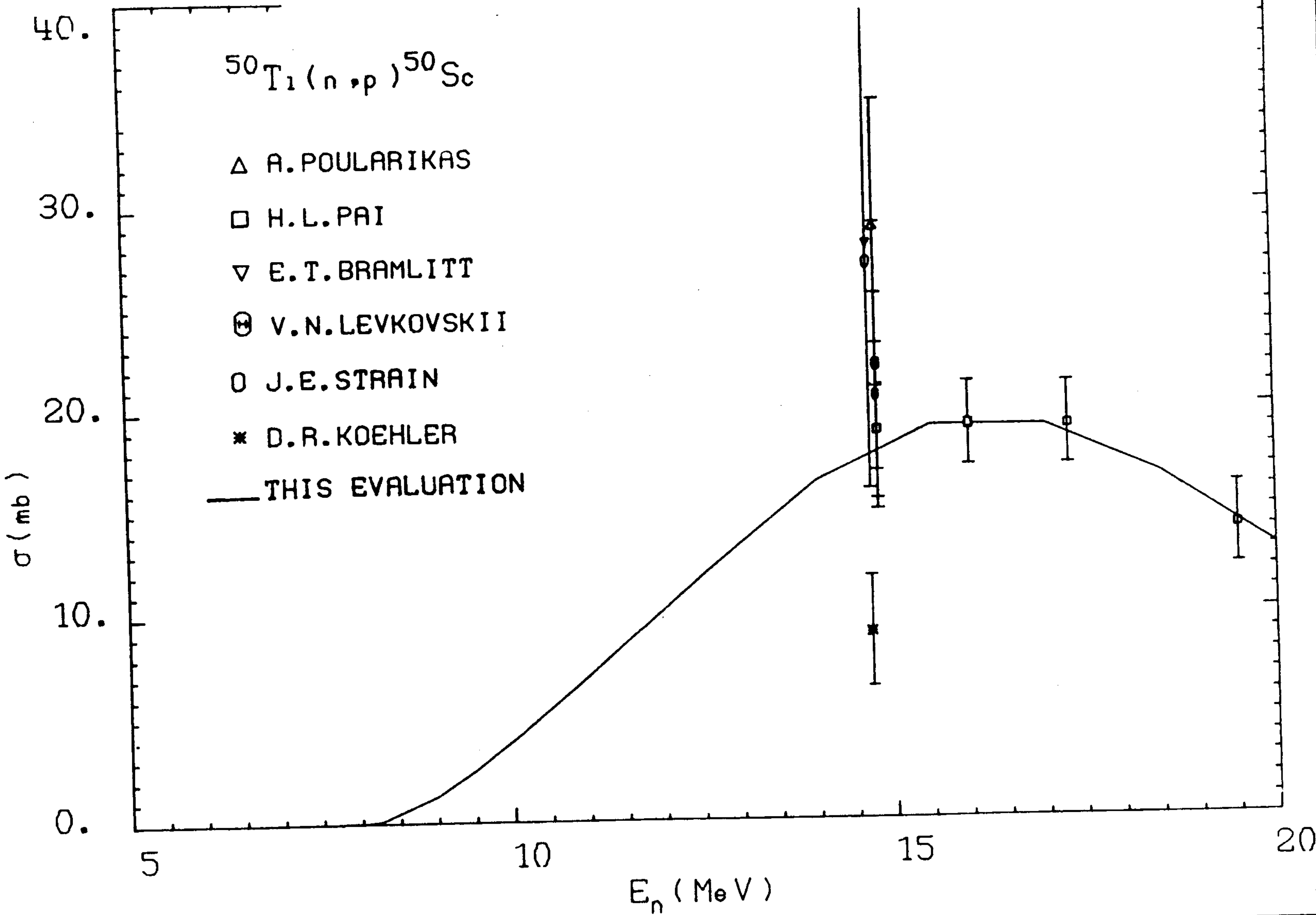
VIII-3. Comparison of measured and evaluated (n;p) cross sections of ^{48}Ti. Notation is as per Fig. VIII-1.

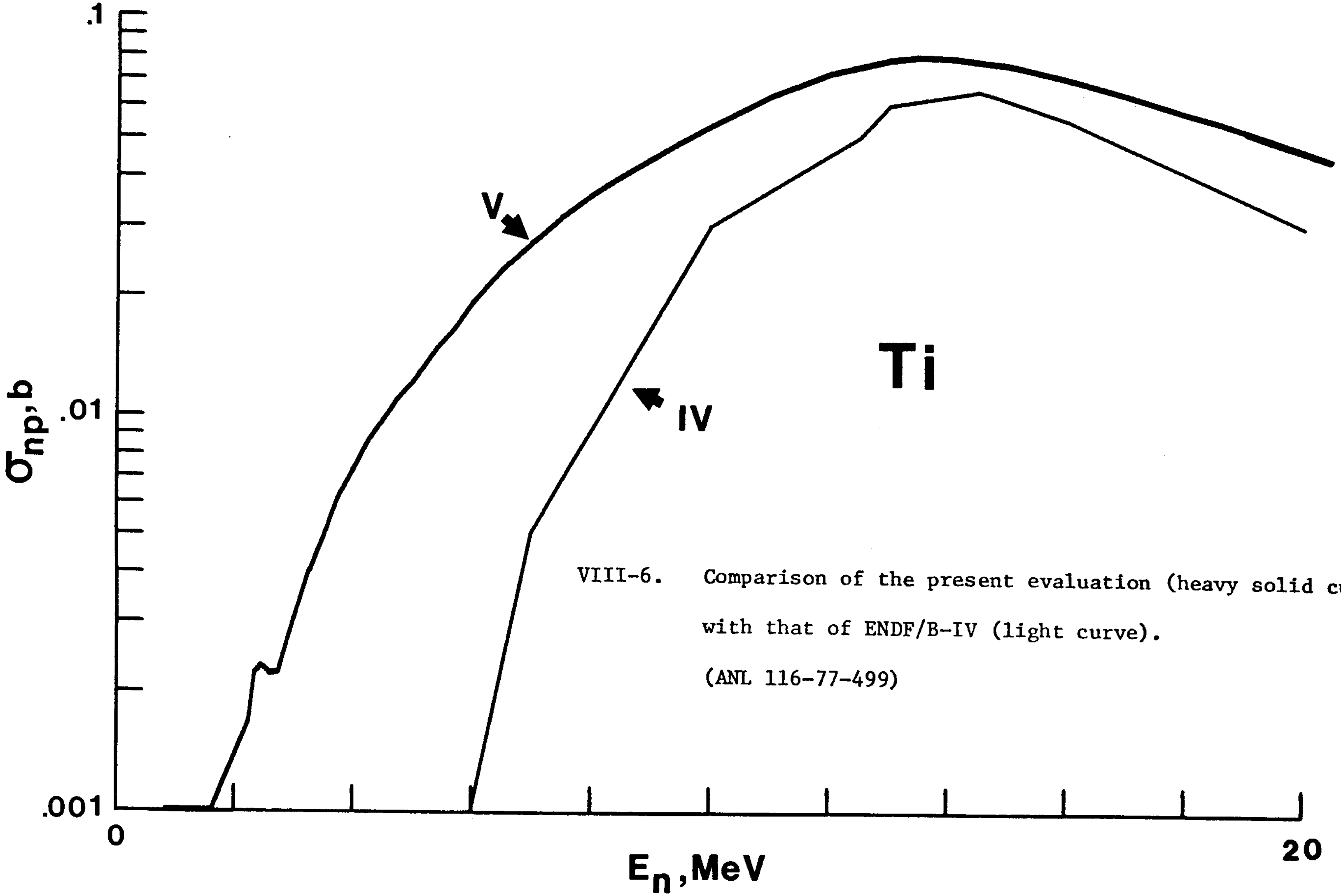
(ANL 116-76-391)



VIII-4. Comparison of measured and evaluated (n;p) cross sections of ^{49}Ti. Notation is as per Fig. VIII-1. (ANL 116-77-507)

VIII-5. Comparison of measured and evaluated (n;p) cross sections of ^{50}Ti. Notation is as per Fig. VIII-1.





VIII-6. Comparison of the present evaluation (heavy solid curve) with that of ENDF/B-IV (light curve). (ANL 116-77-499)

IX. THE (n;α) PROCESS

There is very little experimental information dealing with the (n;α) reaction in titanium isotopes. A similar lack of experimental information is characteristic of the other titanium reactions outlined in the subsequent Sections X, XI and XII. In all of these Sections a primary reliance must be placed upon theoretical estimates verified, where possible, with available experimental information. The present evaluation utilizes theoretical results obtained by E. Arthur using the computer program GNASH (IX-1). This is a cascade model including pre-compound reaction processes. De-excitation paths can be followed through a number of nuclei with conservation of parity and angular momentum. Necessary nuclear properties (e.g. level structure, masses, etc.) are available in an extensive library. Transmission coefficients are calculated from a conventional optical model (IX-2). This GNASH model has been very successful in predicting the cross sections and particle-emission spectra for (n;p), (n;d) and (n;α) reactions in ^{46}Ti and ^{48}Ti. Subsequent to the calculations, ^{46}Ti and ^{48}Ti particle-production results measured at 15 MeV by Grimes et al. (IX-3) were found in very good agreement with the theoretical predictions. In this evaluation the above model is used to provide the energy dependent cross sections of all the titanium isotopes for the reactions (n;d), (n;t), (n;^{3}He), (n;α), (n;n',p), (n;n',α), (n;p,n'), (n;2p), (n;α,n'), (n;p,α) and (n;α,p). Where experimental information was available, it was reasonably consistent with the above calculated cross sections and therefore there was no renormalization of the theoretical results. The elemental evaluation was constructed from the individual calculated isotopic components. The evaluation procedure was identical for this Section (IX) and Sections X, XI and XII.

There are a few measured (n;α) cross sections for ^{48}Ti and ^{50}Ti obtained using activation techniques at incident neutron energies of $\approx$ 14.5 MeV.

Cross and Pai give 48 mb (^{48}Ti) (IX-4), Yu-Wen Yu and Gardner 39 mb (^{48}Ti) (IX-5), Levkovskii et al. 23 mb (^{48}Ti) (IX-6) and Hillman 10 mb (^{50}Ti) (IX-7). There are also some older experimental results obtained by direct particle detection (IX-8). These consider only portions of the emission spectrum and thus provide only a lower limit to the entire (n;α) cross section. Recently Grimes et al. (IX-3) have reported proton, deuteron and alpha particle production cross sections and the particle emission spectra for ^{46}Ti and ^{48}Ti at an incident neutron energy of 15.1 MeV. These direct-particle measurements span a very large emitted-particle energy range; thus the energy-integrated cross sections can be obtained with reasonably accuracy. The calculations upon which the present (n;α) cross section is based yield alpha-particle production cross sections for ^{46}Ti and ^{48}Ti that are within a few percent of the measured values of Grimes et al. The evaluation is qualitatively consistent with the few (n;α) values for ^{48}Ti and ^{50}Ti, obtained by activation techniques as cited above.

The estimated uncertainties in the present evaluated (n;α) cross section are relatively large (20-30 percent) but are considerably less than the differences between the present evaluation and that of ENDF/B-IV as illustrated in Fig. IX-1.

REFERENCES — Section IX

IX-1. P. Young and E. Arthur, private communication (1977).

IX-2. D. Wilmore and P. Hodgson, Nucl. Phys., 55 673 (1964).

IX-3. S. Grimes et al., Lawrence Livermore Lab. Report, UCRL-78314 (1976).

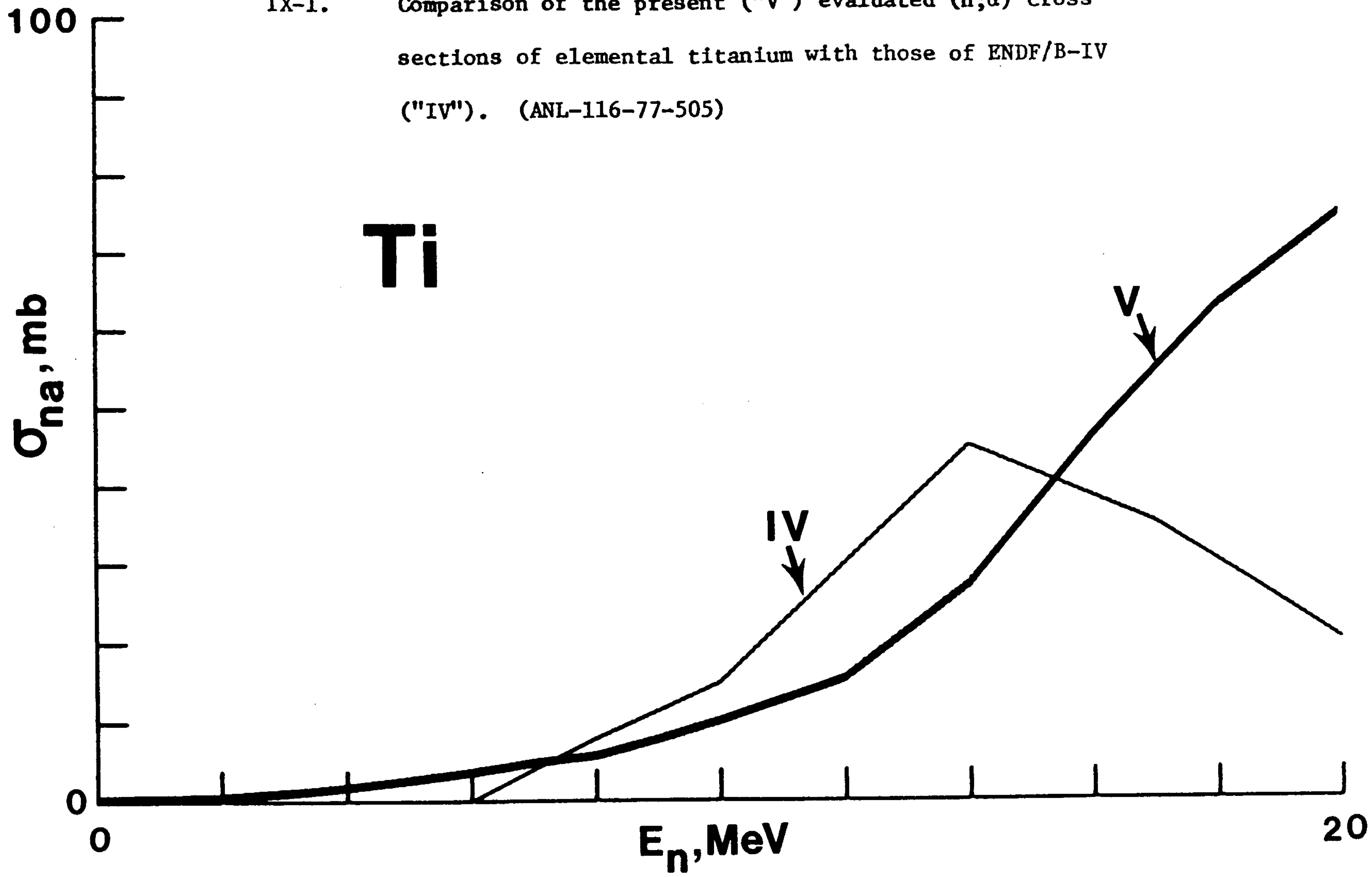
IX-4. W. Cross and H. Pai, private communication, data from NNDC.

IX-5. Yu-Wen Yu and D. Gardner, Nucl. Phys., A98 451 (1967).

IX-6. Y. Levkovskii et al., Yadernaya Fiz., 10 44 (1969).

IX-7. M. Hillman, Nucl. Phys., 37 78 (1962).

IX-8. C. Spira and J. Robson, Nucl. Phys., A127 81 (1969).



IX-1. Comparison of the present ("V") evaluated (n;α) cross sections of elemental titanium with those of ENDF/B-IV ("IV"). (ANL-116-77-505)

X. THE (n;n',p) PROCESS

There appear to be only two sets of experimental results relevant to the (n;n',p) reaction in titanium (herein the sum of (n;n',p) and (n;p,n') reactions). Pai has measured the cross sections from $\sim$ 13-20 MeV for ^{47}Ti, ^{48}Ti, ^{49}Ti and ^{50}Ti (X-1). An activation method was used. It requires the sequential order of the isotopes, corrections for the (n;d) processes and does not directly provide ^{46}Ti values. The latter contribution is probably large despite the relatively low isotopic abundance. Grimes et al. (X-2) have measured the hydrogen-production cross sections of ^{46}Ti and ^{48}Ti at 15.1 MeV using a direct-particle-detection method. The respective (n;p) processes are reasonably known (see above) thus the (n;n',p) components can be deduced.

The present evaluation relies explicity upon the calculations of Arthur outlined in Sec. IX, above (X-3). These calculated results, and thus the present evaluation, lead to cross sections 20-40 percent larger than reported by Pai (X-1). The evaluation is in very good agreement with the gas-production results of Grimes et al. (X-2). It seems that the only two available pieces of experimental information are not particularly consistent. In the present evaluation the emphasis is given to the measurements of Grimes et al. as they appear to be a more direct measurement of, at least, the gas-production cross sections and they do provide charged-particle emission spectra that support the theory upon which the present evaluation is based. The neutron-emission spectrum from the (n;n',p) process is represented by a relatively "hard" temperature distribution. The uncertainties associated with the evaluation are relatively large (25 percent or more) but the reaction threshold is high ($\sim$ 10 MeV) and the elemental cross sections relatively small (e.g. $\sim$ 50 mb at 14 MeV). There is no comparable file in the ENDF/B-IV evaluation.

REFERENCES -- Section X

X-1. H. Pai, Can. Jour. Phys., 44 2337 (1966).

X-2. S. Grimes et al., Lawrence Livermore Lab. Report, UCRL-78314 (1976).

X-3. E. Arthur, private communication (1977).

XI. THE (n;n',α) PROCESS

Apparently the only experimental information relevant to the (n;n',α) process comes from the 15.1 MeV gas-production measurements of Grimes et al. (XI-1) for the ^{46}Ti and ^{48}Ti isotopes. The present evaluation relies entirely upon the calculations of Arthur (XI-2) which are supported by the measured gas-production results of Grimes et al. Thus the evaluation of the (n;n',α) process (herein the sum of (n;n',α) and (n;α,n') processes) follows the same procedures as for the (n;n',p) process outlined above. The resulting neutron-emission spectrum is represented by a "hard" temperature spectrum. The uncertainties in the evaluation are relatively large (e.g. 20-40 percent) but the cross sections are small (e.g. $\approx$ 14 mb at 14 MeV). There is no comparable file in the ENDF/B-IV evaluation.

REFERENCES -- Section XI

XI-1. S. Grimes et al., Lawrence Livermore Lab. Report, UCRL-78314 (1976).

XI-2. E. Arthur, private communication (1977).

XII. (n;d), (n;t), (n;^{3}He), (n;2p) and (n;p,α) PROCESSES

Very little experimental information dealing with the (n;d) reaction in the titanium isotopes is available. At 14.4 MeV deuteron spectrum measurements by Valkovic et al. (XII-1) set a lower limit for the cross section at $\sim$1.6 mb. Deuteron production measurements at 15.1 MeV by Grimes et al. (XII-2) give values of 9 ± 4 (^{46}Ti) and 7 ± 3 (^{48}Ti) mb for the (n;d) cross sections of these isotopes. This evaluation uses the theory of Young and Arthur (XII-3) to calculate the (n;d) cross sections of the respective isotopes in a manner outlined in the preceding Sections and as a part of the general calculations of little measured reaction cross sections. The calculated ^{46}Ti and ^{48}Ti (n;d) cross sections agree with the values reported by Grimes et al. to within the experimental error of 25-30 percent. The uncertainties associated with the present evaluation are relatively large (e.g. 20-30 percent) but the thresholds are high and the cross sections small. The ENDF/B-IV file contains no comparable reaction.

There appears to be no experimental knowledge of the (n;t) cross sections of the titanium isotopes. Therefore the evaluation relies entirely upon the above outlined theory. Again, the uncertainties are relatively large but the cross sections are small and the reaction thresholds at relatively high energies. There is no comparable ENDF/B-IV file.

The status and evaluation of the (n;^{3}He) reaction is analogous to that of the (n;t) process outlined in the preceding paragraph.

The (n;2p) and (n;p,α) reactions are small and experimentally uncertain. Therefore, again, the evaluation relies entirely upon theoretical estimate.

The relative magnitudes of the above reaction cross sections are illustrated in Fig. XII-1.

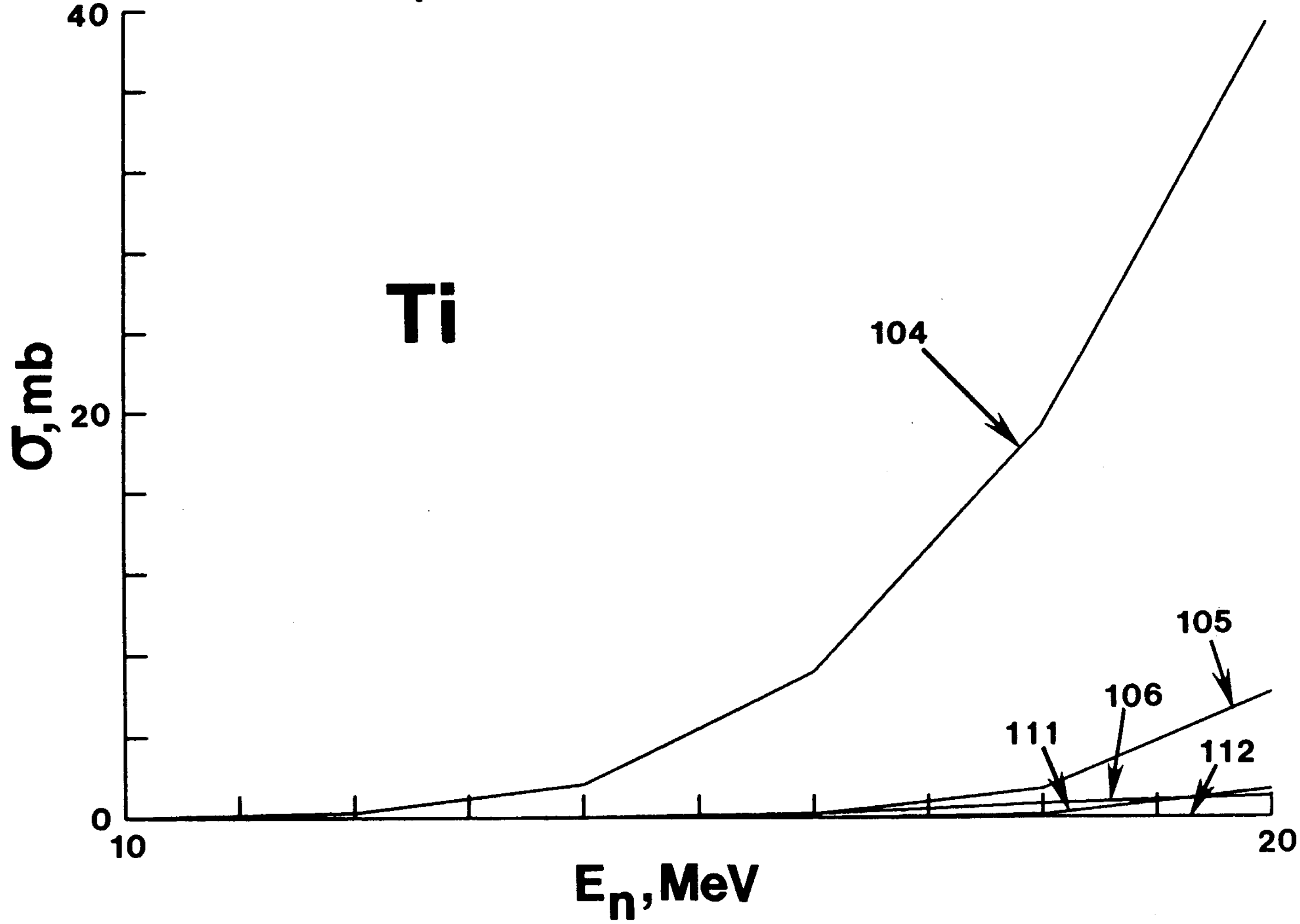
REFERENCES -- Section XII

XII-1. V. Valkovic et al., Phys. Rev., 139 331 (1965).

XII-2. S. Grimes et al., Lawrence Livermore Lab. Report, UCRL-78314 (1976).

XII-3. P. Young and E. Arthur, private communication (1977).

XII-1. Evaluated (n;d) (104), (n;t) (105), (n;^{3}He) (106), (n,2p) (111) and (n;p,α) (112) cross sections from the present evaluation. (ANL-116-77-504)



XIII. GAS PRODUCTION PROCESSES

Gas-production files are included in this evaluation for those explicitly interested in such processes. They are a simple sum of the cross sections for respective contributing reactions. These files consist of cross sections for the production of hydrogen and helium. There are direct experimental results for ^{46}Ti and ^{48}Ti isotopes and the present evaluation is consistent with the measured values as outlined in the discussions of the previous Sections.

XIV. GAMMA-RAY PRODUCTION PROCESSES

To provide photon production cross sections the incident neutron energy range was divided into two parts, with the division at 1.46 MeV where the first ambiguous level-excitation-function thresholds. (See Table V-1.) Experimental data for photon production from neutrons incident onto Ti are extremely sparse. A single measurement of the capture gamma-ray spectra is reported for thermal-energy neutrons in Ref. XIV-1. Measurements for three photon groups labeled 0.99, 1.38 and 1.56 MeV for incident neutron energies between 1.10 and 3.21 MeV were reported in Ref. XIV-2. The latter data are of little use for the present purpose since they are inconsistent with inelastic neutron scattering data. In Ref. XIV-3 photon production measurements are reported at 3 incident neutron energies between 4.9 and 5.9 MeV for 77 gamma rays together with an attempt to characterize the source state from which the photons arise. Because of the limited range of the incident neutrons, these data, while valuable for checking the evaluated data, cannot be used directly in the evaluation in the absence of a dependable extrapolation procedure. In Ref. XIV-4 data taken at 14.7 MeV are reported for a few of the low-energy discrete photons (E_γ < 2.5 MeV).

For the lower energy range ($E_n \leq 1.46$ MeV), the only sources for gamma-ray production are the capture reaction and the three inelastic scattering reactions that excite the first excited states of $Ti^{46,47,48}$. For the capture reaction, the evaluated multiplicity and spectrum at at 10^{-5} eV are based on the spectrum measurements reported in Ref. XIV-1 for thermal neutron energy. The multiplicity was obtained by dividing the mean energy of the spectrum into the available energy for photon production. For lack of other information the same spectrum was used at higher energies with an adjustment of the multiplicity to conserve energy. The three photons associated with excitation of the lowest lying state in $Ti^{46,47,48}$ are presented explicitly in this nuetron-energy range.

For the high-energy range ($1.46 \leq E_n \leq 20$ MeV) the method of Ref. XIV-5 was used even though titanium is at the lower limit of the mass range of applicability of the method. There are not sufficient experimental data on which the evaluation can be based so the method of Ref. XIV-5 was, in effect, a last resort. It conserves energy, on the average, and has been shown to reasonably agree with experimental data taken for iron.

REFERENCES -- Section XIV

XIV-1. V. J. Orphan, N. C. Rasmussen and T. L. Harper, "Line and Continuum Gamma-Ray Yields from Thermal Neutron Capture in 75 Elements," Gulf General Atomic Report, GA-10248 (1970).

XIV-2. D. L. Broder, A. G. Dovbenko, V. E. Kolesov, A. I. Lashuk, and I. P. Sadokhin, private communication from NNDC. See INDSWG-126E page 7 (1966).

XIV-3. J. K. Dickens, Nucl. Sci. and Eng., 54 191 (1974).

XIV-4. W. E. Thompson, F. G. Engesser, "Gamma-Rays Resulting from Interactions of 14.7 MeV Neutrons with Magnesium, Aluminum, Calcium, Titanium and Iron," USNRDL Report, TR-861 (1965).

XIV-5. S. T. Perkins, R. C. Haight, R. J. Howerton, Nucl. Sci. and Eng., 57 1 (1975).nties associated with the calculational model of

XV. CONCLUDING COMMENT

This report and the associated numerical file comprise the ENDF/B-V elemental nuclear data file and it's documentation. In addition, selected isotopic sub-files are provided for special applications such as dosimetry. The present file is more comprehensive than it's predecessor (ENDF/B-IV) and in some areas is very much different. The larger scope and the improved quality of the file may have a significant impact on many neutronic calculations particularly those involving high-energy processes (e.g. in fusion systems) and those sensitive to the details of low (< 200 keV) resonance structure. The full numerical file can be obtained from the National Nuclear Data Center, Brookhaven National Laboratory (U.S.) or the Centre de Compilation de Données Neutroniques, Saclay (France).

ACKNOWLEDGEMENTS

The authors are particularly indebted to Dr. E. Arthur (Los Alamos Scientific Laboratory) for a number of calculations dealing with (n;x) and (n;n',x) reactions, to Dr. E. Pennington (Argonne National Laboratory) for advice and critical comment, and to Drs. G. Simon, O. Bersillon and J. Trochon (Bruyéres-le-Châtel) for major contributions in the areas of resonance and (n;x) processes.