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ESTIMATION OF COVARIANCES OF CR AND NI NEUTRON NUCLEAR DATA IN JENDL-3.2

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Estimation of Covariances of Cr and Ni Neutron Nuclear Data in JENDL-3.2

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Covariances of nuclear data have been estimated for 2 nuclides contained in JENDL-3.2. The nuclides considered are Cr and Ni, which are regarded as important for the nuclear design study of fast reactors. The physical quantities for which covariances are deduced are cross sections and the first order Legendre-polynomial coefficient for the angular distribution of elastically scattered neutrons. The covariances were estimated by using the same methodology that had been used in the JENDL-3.2 evaluation in order to keep a consistency between mean values and their covariances. The least-squares fitting code GMA was used in estimating covariances for reactions of which JENDL-3.2 cross sections had been evaluated by taking account of measurements. Covariances of nuclear model calculations were deduced by using the KALMAN system. The covariance data obtained were compiled in the ENDF-6 format, and will be put into the JENDL-3.2 Covariance File which is one of JENDL special purpose files.

Keywords: Covariance, Nuclear Data, JENDL-3.2, Cr, Ni, Cross Section, Angular Distribution

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JENDL-3.2 に収納されている中性子核データ
Cr 及び Ni の共分散の推定

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JENDL-3.2 に収納されている 2 核種の核データの共分散を推定した。対象となった核種は高速炉の核設計研究で重要な、Cr 及び Ni である。共分散が求められた物理量は、断面積及び弾性散乱における 1 次のルジャンドル展開係数である。共分散推定においては、JENDL-3.2 の評価に用いられたのと同じ方法が用いられた。JENDL-3.2 で与えられている反応断面積が実験値を基に求められた場合は、最小自乗フィッティングコード GMA を用い共分散を推定した。一方、理論計算値の共分散は KALMAN システムにより計算した。ここで得られた共分散データは ENDF-6 フォーマットでファイル化され、JENDL 特殊目的ファイルの 1 つである JENDL-3.2 共分散ファイルに収納される。

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Contents

目 次

1. Introduction

Uncertainties in nuclear data are needed not only to estimate margins in design and safety of nuclear facilities, but also to adjust group constants by considering critical experiments. The Nuclear Data Center of the Japan Atomic Energy Research Institute (JAERI) has been involved in providing the covariances of the JENDL-3.2 data[1] to the Japan Nuclear Cycle Development Institute (JNC), where the unified cross-section library is being produced by considering various integral measurements and covariances of evaluated data.

In the present work, we estimated the covariances of nuclear data for Cr and Ni contained in JENDL-3.2. The physical quantities for which covariances were estimated are cross sections and the 1st order Legendre-polynomial coefficient for the elastic angular distributions of neutrons.

Covariances were estimated on the basis of the same methods that had been taken in the JENDL-3.2 evaluation. The least-squares fitting code GMA[2], which was developed at the Argonne National Laboratory, was applied to estimate covariances when the JENDL-3.2 data had been obtained by fitting to available experimental data. In cases where the JENDL-3.2 data are based on nuclear model calculations, the code system KALMAN[3], which was developed at Kyushu University, was used to deduce uncertainties in model parameters. Then, the covariances of the model calculations were obtained by using the law of error propagation. On the KALMAN system, one can get covariances of cross sections and angular distributions of emitted neutrons calculated from nuclear model codes.

In this report, we describe the methods of covariance estimation taken for each nuclide together with the results obtained.

2. Covariances of Cr Data

Covariances were estimated for the total, inelastic scattering, (n,2n), (n,nα), (n,np), (n,p), (n,α), and (n,γ) reaction cross sections and for the 1st order Legendre coefficient for the elastic angular distributions of neutrons. The covariances of the elastic scattering cross section, which was evaluated by subtracting the non-elastic cross section from the total cross section in JENDL-3.2, were constructed from those of other cross sections. A covariance file for natural chromium was produced in the present work. The JENDL-3.2 data for natural chromium were made from the isotopic data except the total cross section which was obtained from experimental data on the natural element. The contribution of minor isotopes (^{50}Cr, ^{53}Cr, and ^{54}Cr) to the covariance for the natural element is quite small since the weight for each isotope is the square of the isotopic abundance. Therefore, the covariances for the most abundant ^{52}Cr (abundance: 83.8%) were estimated except for the total cross section.

2.1 Total Cross Section

In the energy region above 300 keV, the GMA code was applied to the four experimental data sets used in the JENDL-3.2 evaluation. Error information for each experiment is given as follows:

Cierjacks et al.[4] E_n = 500 keV – 32 MeV
Total errors are given in the data. A systematic error of 2.8% was deduced.
Foster, Jr. and Glasgow[5] E_n = 2.3 – 15 MeV
Total errors are given in the data. A systematic error of 0.5% was deduced.
Perey et al.[6] E_n = 180 keV – 30 MeV
Statistical errors are given in the data. A systematic error of 4% was deduced.
Larson[7] E_n = 2 – 81 MeV
Statistical errors are given in the data. A systematic error of 4% was assumed.

The experimental data were averaged in the intervals of 200 keV to 1 MeV in order to smooth the resonance structure seen below several MeV, and fed into the input to the GMA code. Figure 1 shows the evaluated total cross section and its standard deviations. The square root of χ^2 per degrees of freedom, which is referred to as χ hereafter, was found to be 29.0 below 4.5 MeV and 6.2 above 4.5 MeV.

In the energy region below 300 keV, the relative standard deviation was set to be 2% by considering the thermal cross section and its uncertainty recommended by Mughabghab et al.[8]

2.2 (n,2n) Reaction Cross Section

The covariances were obtained by applying the GMA code to the following experimental data sets:

Wenusch and Vonach[9], Bormann et al.[10], Sailer et al.[11], Molla et al.[12], Ribansky et al.[13], Ghorai et al.[14], Ikeda et al.[15], Liskien et al.[16], Wagner et al.[17]

The χ value obtained is 1.0. The cross sections and standard deviations of ^{52}Cr and natural Cr are shown in Figs. 2 and 3, respectively. It is found from the figures that the JENDL-3.2 evaluation of ^{52}Cr is based on the measurement of Bormann et al.[10] in the high energy region, and therefore the evaluation of the natural element is inconsistent with the data of Auchampaugh et al.[18]

2.3 Inelastic Scattering and (n,γ) Reaction Cross Sections

The covariances of the parameters required as input to the statistical model code CASTHY[19] were estimated on the KALMAN system[3]. Then, the uncertainties in the calculated cross sections were obtained by the law of error propagation. The measurements considered are given as follows:

Inelastic scattering

Voss et al.[20], Van Patter et al.[21], Degtjarev and Protopopov[22], Pasechnik et al.[23], Degtjarev and Protopopov[24], Korzh et al.[25], Kramarovsky[26]

(n,γ) reaction

Frenes et al.[27], Kenny et al.[28]

The calculated χ values are 12.1 for the inelastic scattering and 0.8 for the (n,γ) reaction.

The (n,γ) reaction cross section in JENDL-3.2 was obtained by normalizing nuclear model calculations to 10 mb at 50 keV. The relative uncertainty in this value is expected to be 20%. Therefore, the standard deviations calculated by the KALMAN system were scaled up so as to yield a relative uncertainty of 20% at 50 keV. Figures 4-6 show the cross sections and standard deviations for the 1.43-, 2.37-, and 2.96-MeV levels of ^{52}Cr, respectively. The (n,γ) reaction cross sections and standard deviations for ^{52}Cr and the natural element are shown in Figs. 7 and 8, respectively.

Above 10 MeV, the (n,γ) reaction cross sections were underestimated in JENDL-3.2, because the direct and semi-direct processes were not taken into account. Thus, the differences between the JENDL-3.2 cross sections and those calculated from a systematics[29)], which reasonably reproduces measured data, were given as the uncertainties in the energy region above 10 MeV.

Below 300 keV, the uncertainties in the (n,γ) cross section was set to be 10% by considering the recommendation of Mughabghab et al.[8)] and the measurements of Le Rigoleur et al.[30)]

2.4 (n,p), (n,α), (n,np), and (n,nα) Reaction Cross Sections

The statistical model code EGNASH[31)] was applied to estimate the covariances by using the KALMAN system. The covariances of model parameters were obtained by considering experimental data on the (n,2n) and (n,p) reactions. The experimental data on the (n,2n) reaction were mentioned in Sect. 2.2, while those on the (n,p) reaction are given as follows:

Paul and Clarke[32)], Kern et al.[33)], Chittenden and Gardner[34)], Mitra and Ghose[35)], Clator[36)], Prasad and Sarkar[37)], Dresler et al.[38)], Valkonen[39)], Qaim and Molla[40)], Gupta et al.[41)], Ribansky et al.[13)], Hong Dac Luc et al.[42)], Ghorai et al.[14)], Ikeda et al.[15)], Kawade et al.[43)], Viennot et al.[44)]

The χ value obtained is 1.84. Figures 9 and 10 show the (n,p) and (n,α) cross sections of ^{52}Cr and their uncertainties, respectively. The cross sections and standard deviations for the natural element are illustrated in Figs. 11-14.

2.5 Angular Distributions of Elastically Scattered Neutrons

The optical model code ELIESE-3[45)] was used to estimate the covariance of the 1st order Legendre coefficient for the elastic angular distribution. The uncertainties in the optical model parameters were obtained by considering the experimental data on the total cross section mentioned in Sect. 2.1., and the χ value was found to be 1.4. Figure 15 shows the relative standard deviation.

3. Covariances of Ni Data

Covariances were estimated for the total, inelastic scattering, (n,2n), (n,nα), (n,np), (n,p), (n,d), (n,t), (n,α), and (n,γ) reaction cross sections and for the 1st order Legendre coefficient for the elastic angular distributions of neutrons. The covariances of the elastic scattering cross section, which was evaluated by subtracting the non-elastic cross section from the total cross section in JENDL-3.2, were constructed from those of other cross sections. A covariance file for natural nickel was produced in the present work. The JENDL-3.2 data for natural nickel were made from the isotopic data except the total cross section which was obtained from experimental data on the natural element. The contribution of minor isotopes (^{61}Ni, ^{62}Ni, and ^{64}Ni) to the covariance for the natural element is quite small since the weight for each isotope is the square of the isotopic abundance. Therefore, the covariances for the two abundant isotopes ^{58}Ni (68.1%) and ^{60}Ni (26.2%) were estimated except for the total cross section.

3.1 Total Cross Section

In the energy region above 557 keV, the GMA code was applied to estimate the covariances from two experimental data sets. Error information for each experiment is given as follows:

Larson et al.[46)] E_n = 2.2 keV – 20 MeV

Total errors are given in the data. A systematic error of 0.61% was deduced.

Larson[7] $E_n = 2 - 80$ MeV

Statistical errors are given in the data. A systematic error of 5% was deduced.

The experimental data were averaged in the intervals of 200 keV to 1 MeV in order to smooth the resonance structure seen below several MeV, and fed into the input to the GMA code. Figure 16 shows the total cross section and its standard deviations. The χ value obtained from the GMA analysis was found to be 2.99.

In the energy region below 557 keV, a relative standard deviation of 2% was obtained by considering the thermal cross section and its uncertainty recommended by Mughabghab et al.[8] and the average cross sections measured by James et al.[47]

3.2 ^{58}Ni(n,2n), ^{58}Ni(n,p), and ^{60}Ni(n,p) Reaction Cross Sections

The following experimental data sets was taken into account in the GMA analyses:

^{58}Ni(n,2n)

Prestwood and Bayhurst[48], Glover and Weigold[49], Pavlik et al.[50], Ikeda et al.[15], Yuan Jungqian et al.[51]

^{58}Ni(n,p)

Konijin and Lauber[52], Bormann et al.[53], Temperley[54], Paulsen and Widera[55], Smith and Meadows[56], Wu and Chou[57], Husain and Hunt[58], Pavlik et al.[50], Vonach et al.[59], Ikeda et al.[60], Smith et al.[61], Viennot et al.[44], Li et al.[62]

^{60}Ni(n,p)

Paulsen[63], Vonach et al.[59], Wang et al.[64], Wagner et al.[65], Viennot et al.[44]

The χ values were found to be 0.8 for the ^{58}Ni(n,2n) reaction, 8.5 for the ^{58}Ni(n,p) reaction and 3.2 for the ^{60}Ni(n,p) reaction. Figure 17 shows the cross section for the ^{58}Ni(n,2n) reaction and its standard deviations. The cross section and standard deviations for the (n,2n) reaction on the natural element are illustrated in Fig. 18, where the contributions from ^{60}Ni, which will be described later, are included. The (n,p) reaction cross sections and their uncertainties are shown in Figs. 19-21.

3.3 Inelastic Scattering and (n,γ) Reaction Cross Sections

The covariances of the parameters required as input to the statistical model code CASTHY[19] were estimated on the KALMAN system. Then, the uncertainties in the calculated cross sections were obtained by the law of error propagation in the energy region above 557 keV. The measurements considered are given as follows:

Inelastic scattering for ^{58}Ni
Voss et al.[20], Rogers et al.[66], Bazakvov et al.[67], Sokolov et al.[68], Korzh et al.[25]
Inelastic scattering for ^{60}Ni
Nishimura et al.[69], Broder et al.[70], Rogers et al.[66], Korzh et al.[25]
(n,γ) reaction on ^{60}Ni
Perey et al.[71]

There are no experimental data available for the (n,γ) reaction on ^{58}Ni. Thus, the JENDL-3.2 data with 30% relative uncertainties were regarded as experimental values in the analyses. The χ values were found to be 10.9 for ^{58}Ni inelastic scattering, 3.1 for ^{60}Ni inelastic scattering, 0.2 for the (n,γ) reaction on ^{58}Ni, and 0.8 for the (n,γ) reaction on ^{60}Ni.

The cross section for the (n,γ) reaction on ^{58}Ni was measured by Wisshak et al.[72] at 30 keV, and its uncertainty was deduced to be 7%. As for the (n,γ) reaction on ^{60}Ni, the JENDL-3.2 data were normalized to the data measured by Perey et al.[71] at 700 keV, and the relative uncertainty in the measurement is 1%. The standard deviations of the (n,γ) cross sections obtained from the KALMAN system were modified so as to be consistent with these experimental uncertainties. In the energy region below 557 keV, the relative uncertainties in the (n,γ) cross section were determined by considering the thermal cross sections and uncertainties recommended by Mughabghab et al.[8] and average cross sections and errors measured by Perey et al.[71]: 2% in the region from 10^{-5} eV to 1 keV, and 5% in the region form 1 keV to 557 keV. Above 10 MeV, the difference between JENDL-3.2 and the systematics[29] were regarded as the uncertainty in the (n,γ) cross section, as in the case of Cr.

The inelastic scattering cross sections and standard deviations are shown in Figs. 22-25, and the (n,γ) reaction cross sections and standard deviations are shown in Figs. 26-28.

3.4 ^{60}Ni(n,2n), ^{58,60}Ni(n,d), ^{58,60}Ni(n,t), ^{58,60}Ni(n,α), ^{58,60}Ni(n,np), and ^{58,60}Ni(n,nα) Reaction Cross Sections

The EGNASH code was used on the KALMAN system to estimate the covariances of the model parameters. We took account of the experimental data on the ^{58}Ni(n,2n), ^{58,60}Ni(n,p), ^{58,60}Ni(n,d), ^{58}Ni(n,t), and ^{58}Ni(n,α) reactions. Concerning the ^{58}Ni(n,2n) and ^{58,60}Ni(n,p) reactions, the data sets mentioned in Sect. 3.2 were employed. As for the other reactions, the measurements considered are given as follows:

^{58}Ni(n,d) reaction
Cross et al.[73)], Hemingway et al.[74)], Pavlik et al.[50)]
^{58}Ni(n,t) reaction
Qaim and Stoecklin[75)], Woo and Salaita[76)]
^{58}Ni(n,α) reaction
Seebeck and Bormann[77)], Dolja et al.[78)], Qaim and Molla[40)], Qaim et al.[79)]
^{60}Ni(n,d) reaction
Allan[80)], March and Morton[81)]

The χ values were found to be 2.67 for ^{58}Ni and 3.96 for ^{60}Ni. The cross sections and standard deviations are shown in Figs.29-44.

3.5 Angular Distributions of Elastically Scattered Neutrons

The optical model code ELIESE-3 was used to estimate the covariance of the 1st order Legendre coefficient for the elastic angular distribution. The uncertainties in the optical model parameters were obtained by considering the experimental data on the total cross section mentioned in Sect. 3.1., and the χ value was found to be 0.84. Figure 45 shows the relative standard deviation.

4. Concluding Remarks

Covariances of nuclear data were estimated for Cr and Ni contained in JENDL-3.2. The quantities of which covariances were obtained are cross sections and the 1^{st} order Legendre coefficient for the elastic scattering. The uncertainty in the Legendre coefficient was estimated in order to calculate an uncertainty in an average cosine of elastic-scattering angles.

In covariance estimation, we used the same methodology that had been taken in the JENDL-3.2 evaluation in order to keep a consistency between mean values and their covariances.

The results obtained were compiled in the ENDF-6 format, and will be put into the JENDL-3.2 Covariance File which is one of the JENDL special purpose files managed by the JAERI Nuclear Data Center. The data are also used in making the unified cross-section library at JNC.

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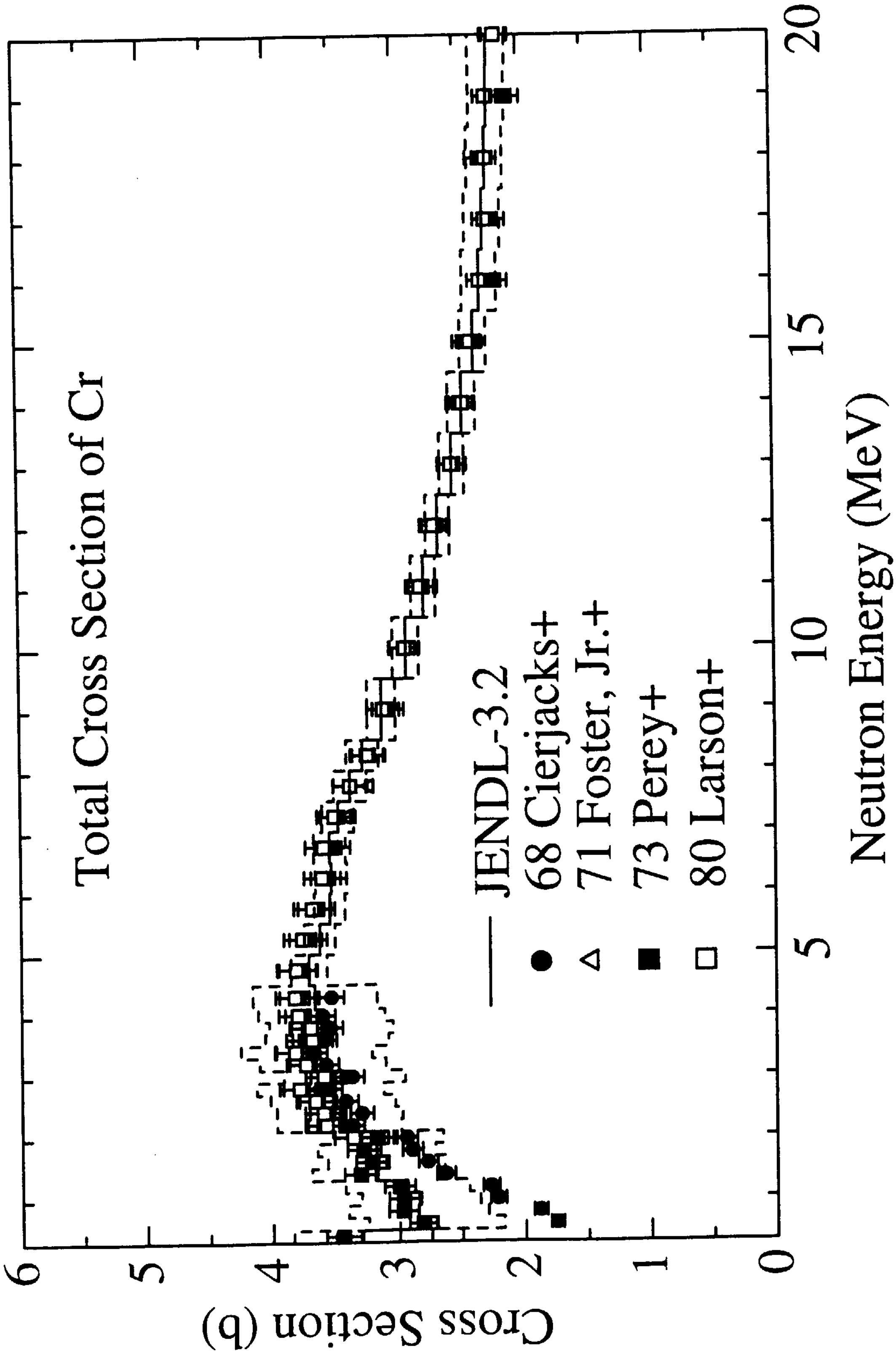

Fig. 1 Total cross section of elemental Cr.

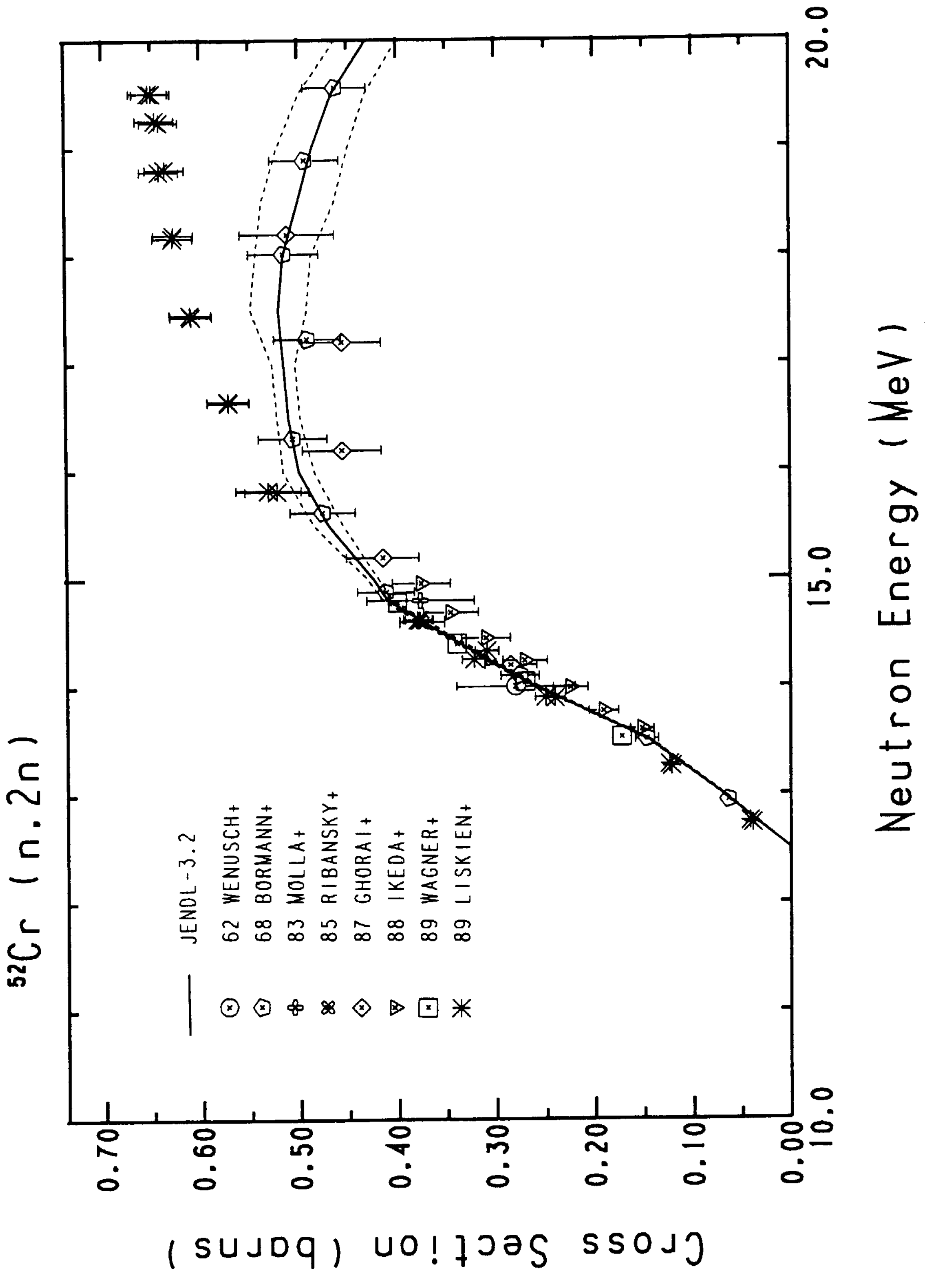

Fig. 2 (n,2n) reaction cross section of ^{52}Cr.

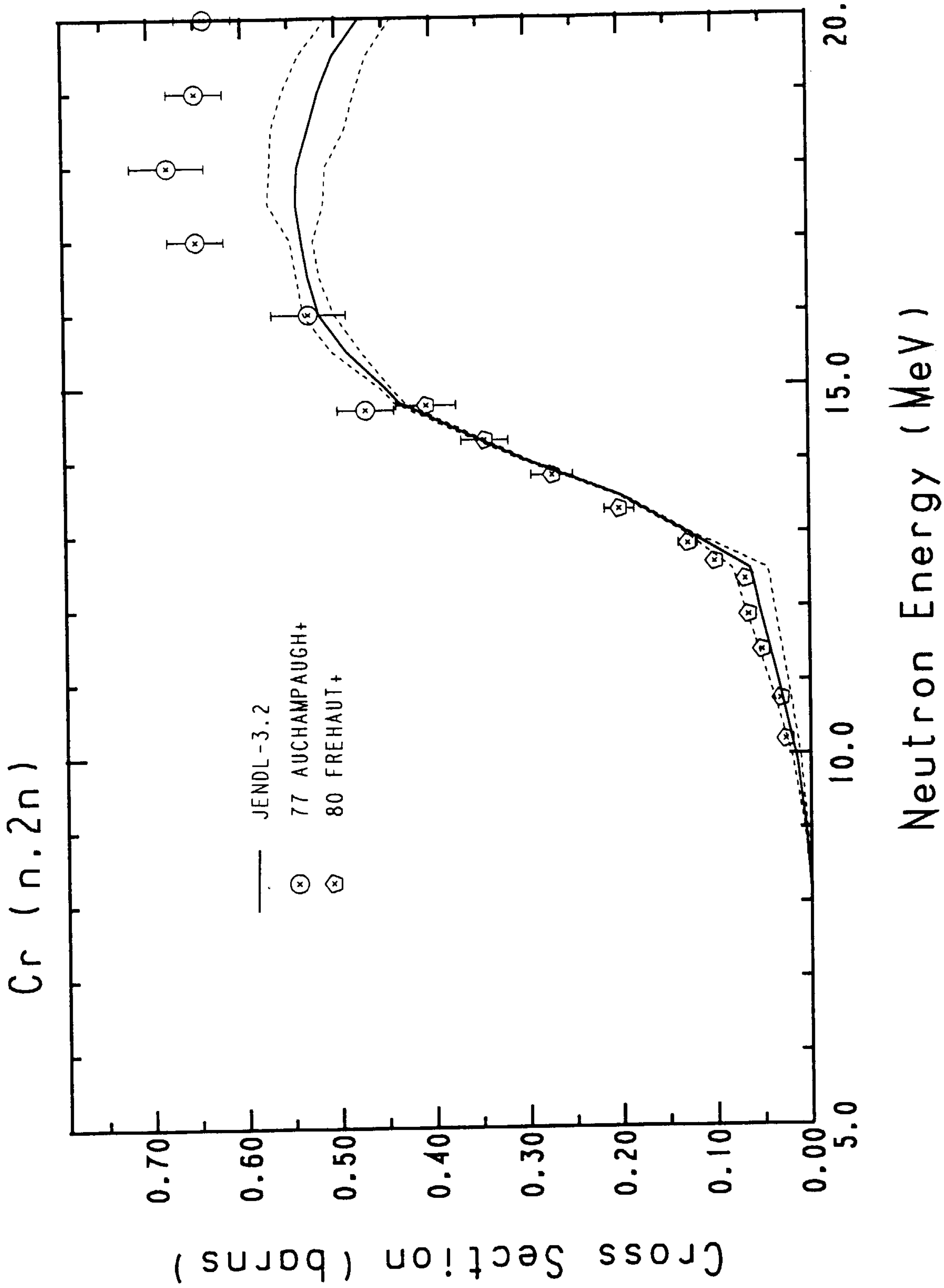

Fig. 3 (n,2n) reaction cross section of elemental Cr.

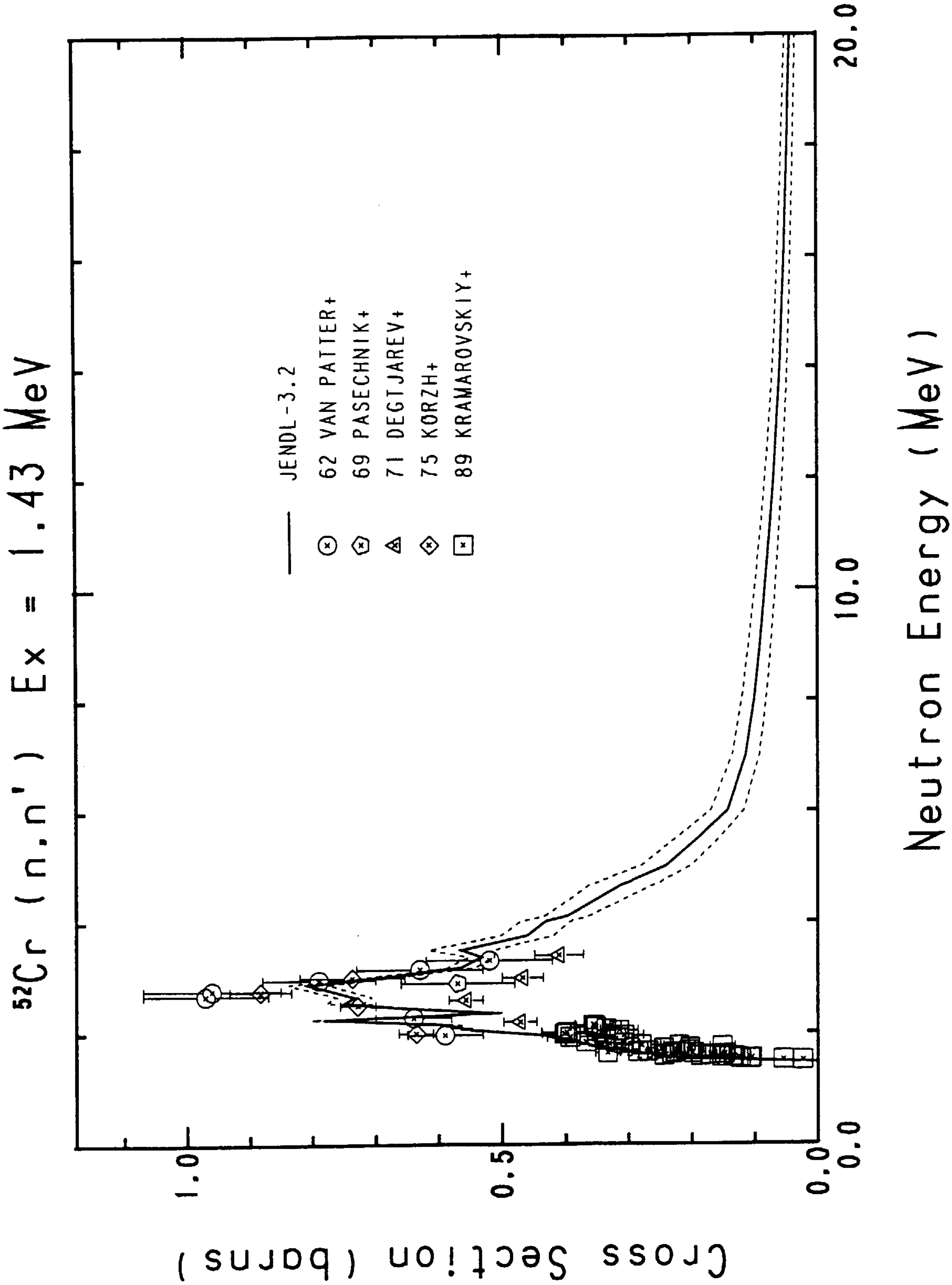

Fig. 4 Inelastic scattering cross section for the 1.43-MeV level of ^{52}Cr.

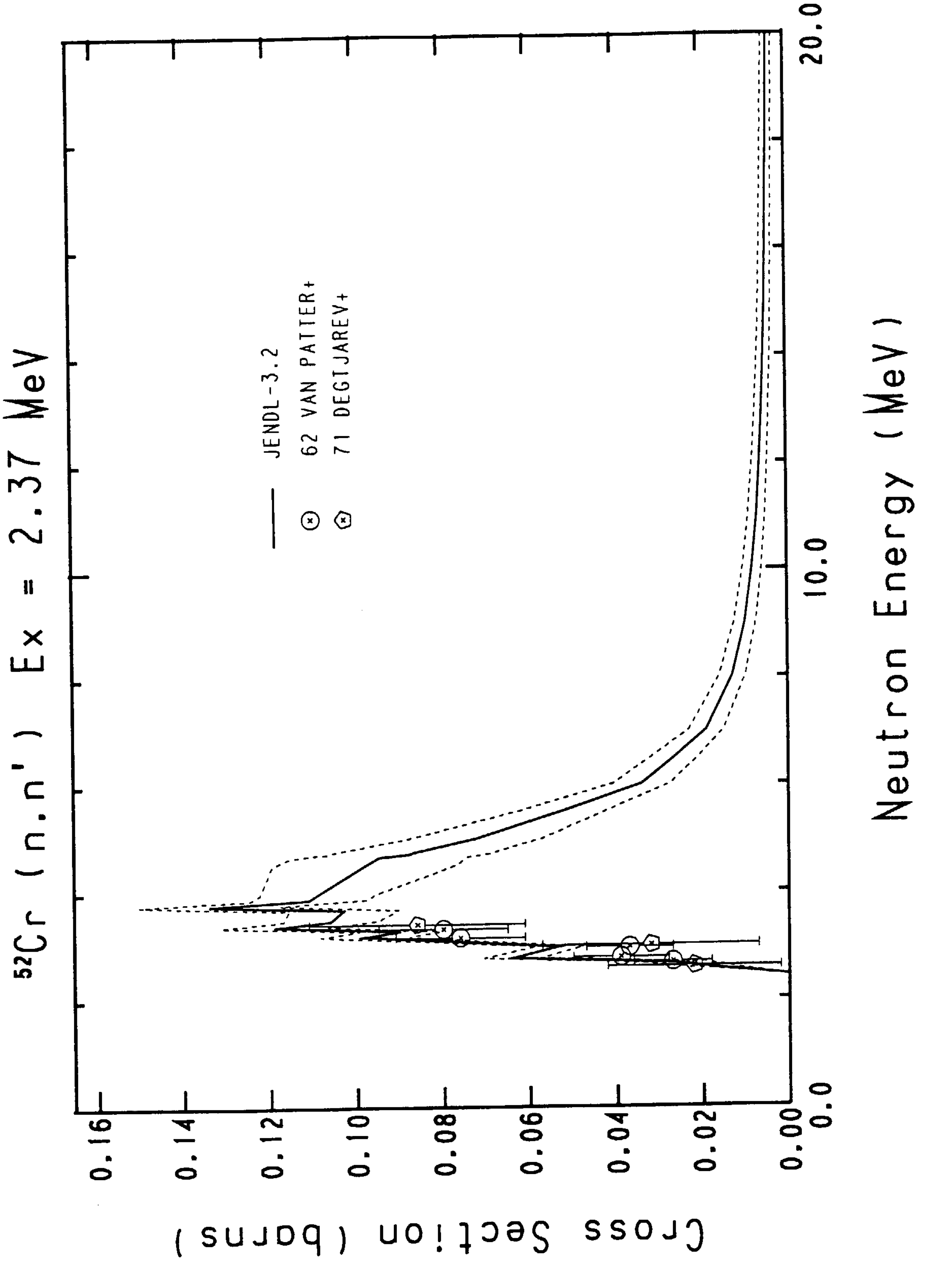

Fig. 5 Inelastic scattering cross section for the 2.37-MeV level of ^{52}Cr.

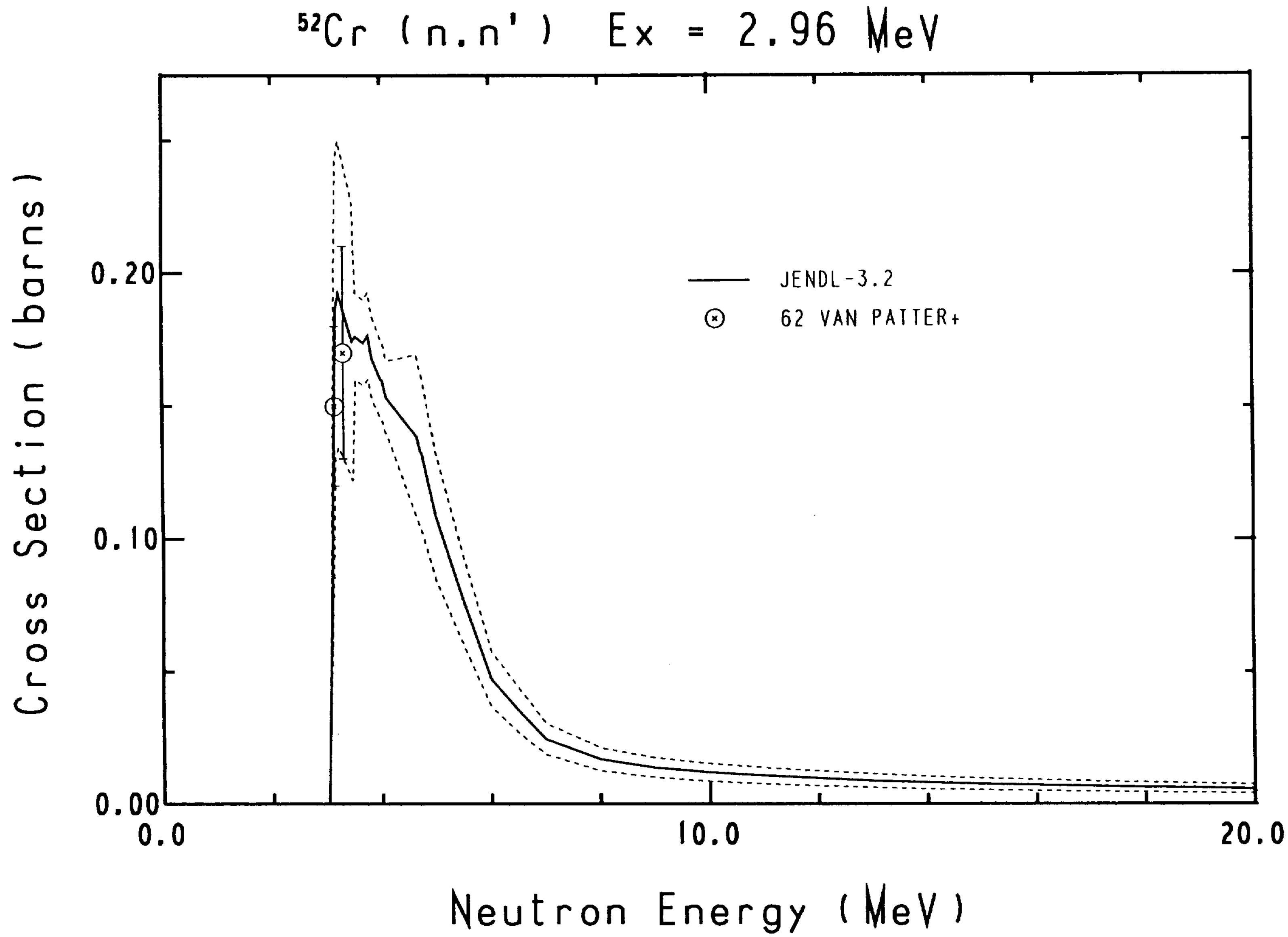

Fig. 6 Inelastic scattering cross section for the 2.96-MeV level of ^{52}Cr.

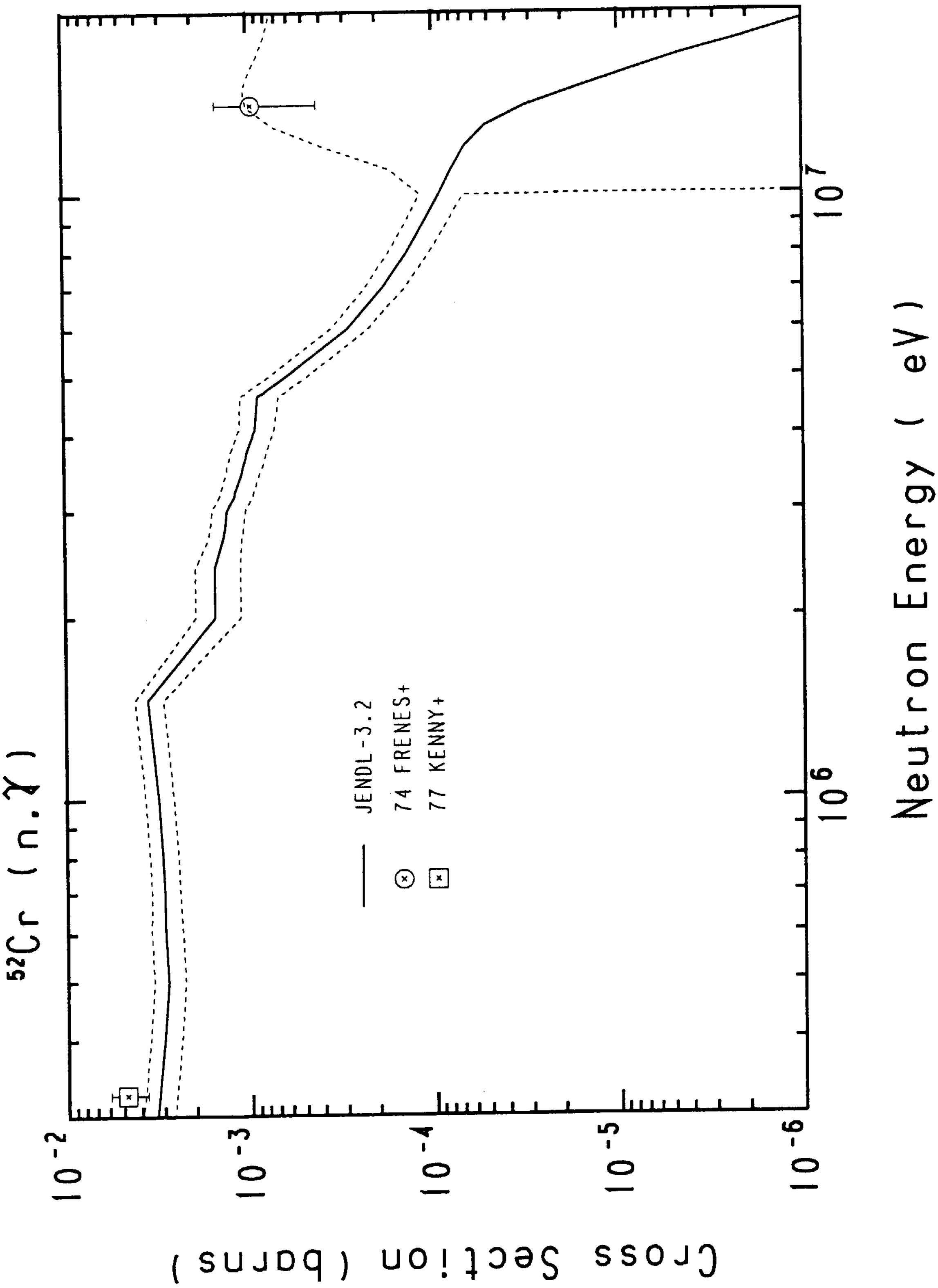

Fig. 7 Capture cross section of ^{52}Cr.

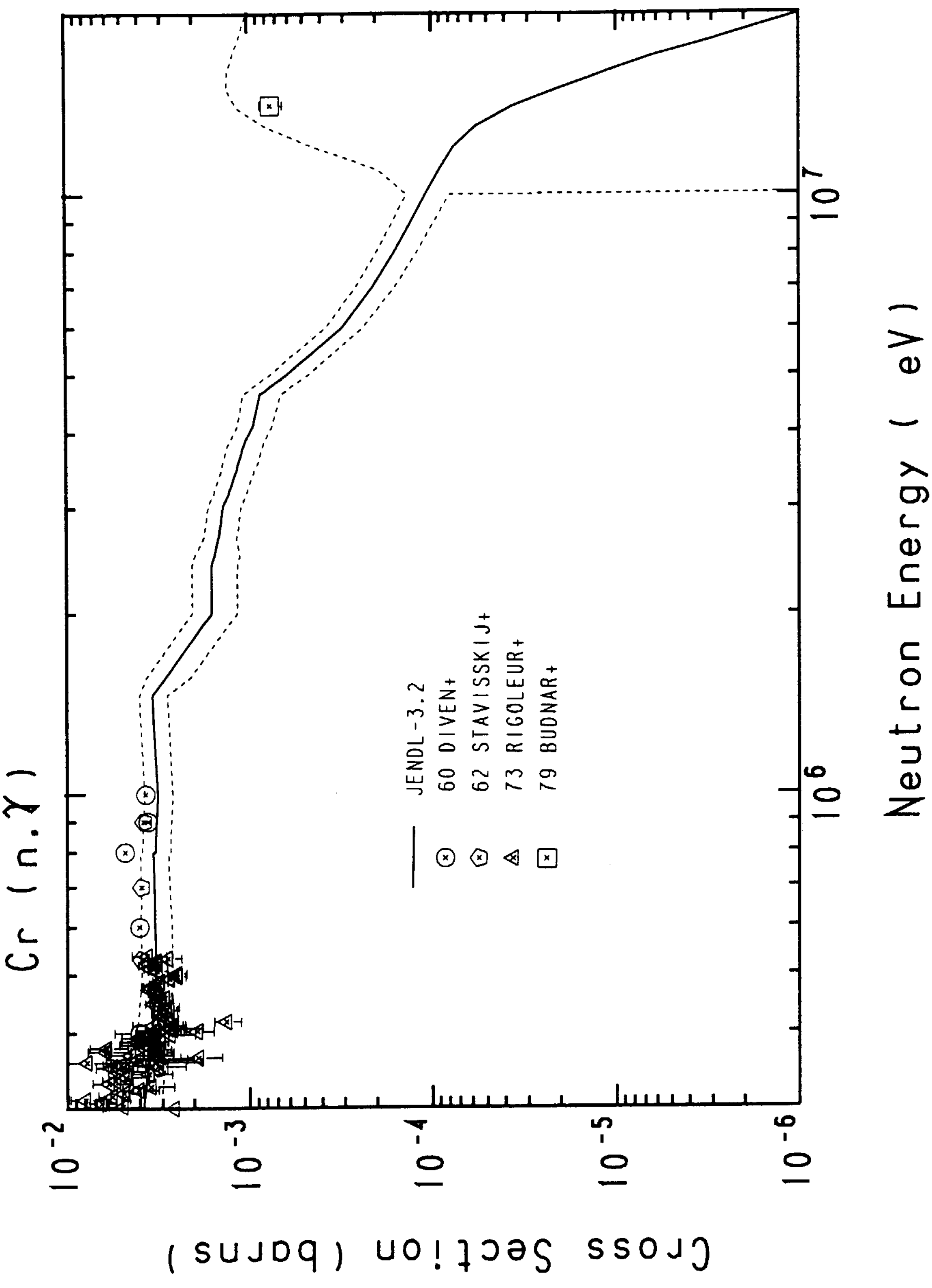

Fig. 8 Capture cross section of elemental Cr.

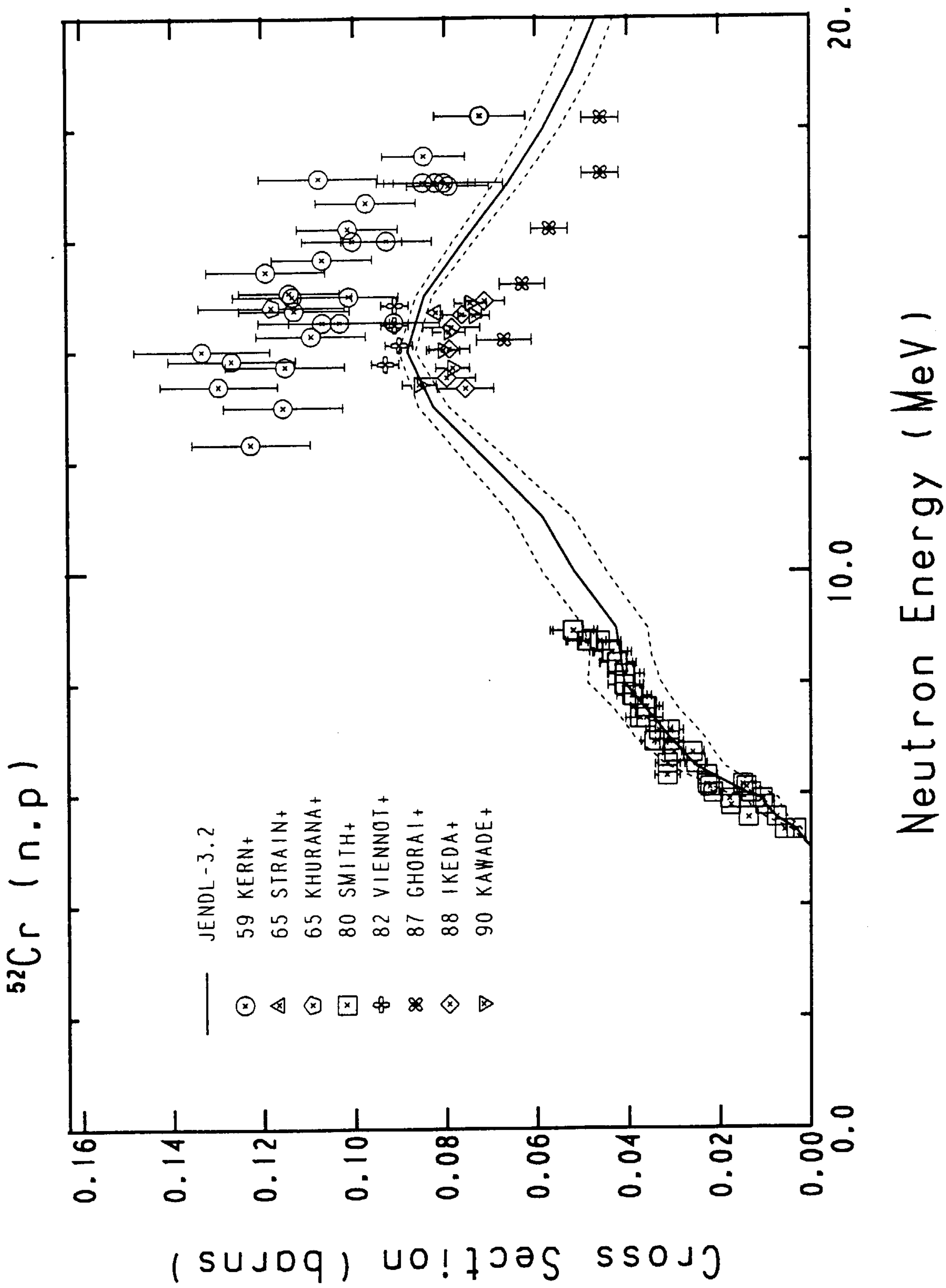

Fig. 9 (n,p) reaction cross section of ^{52}Cr.

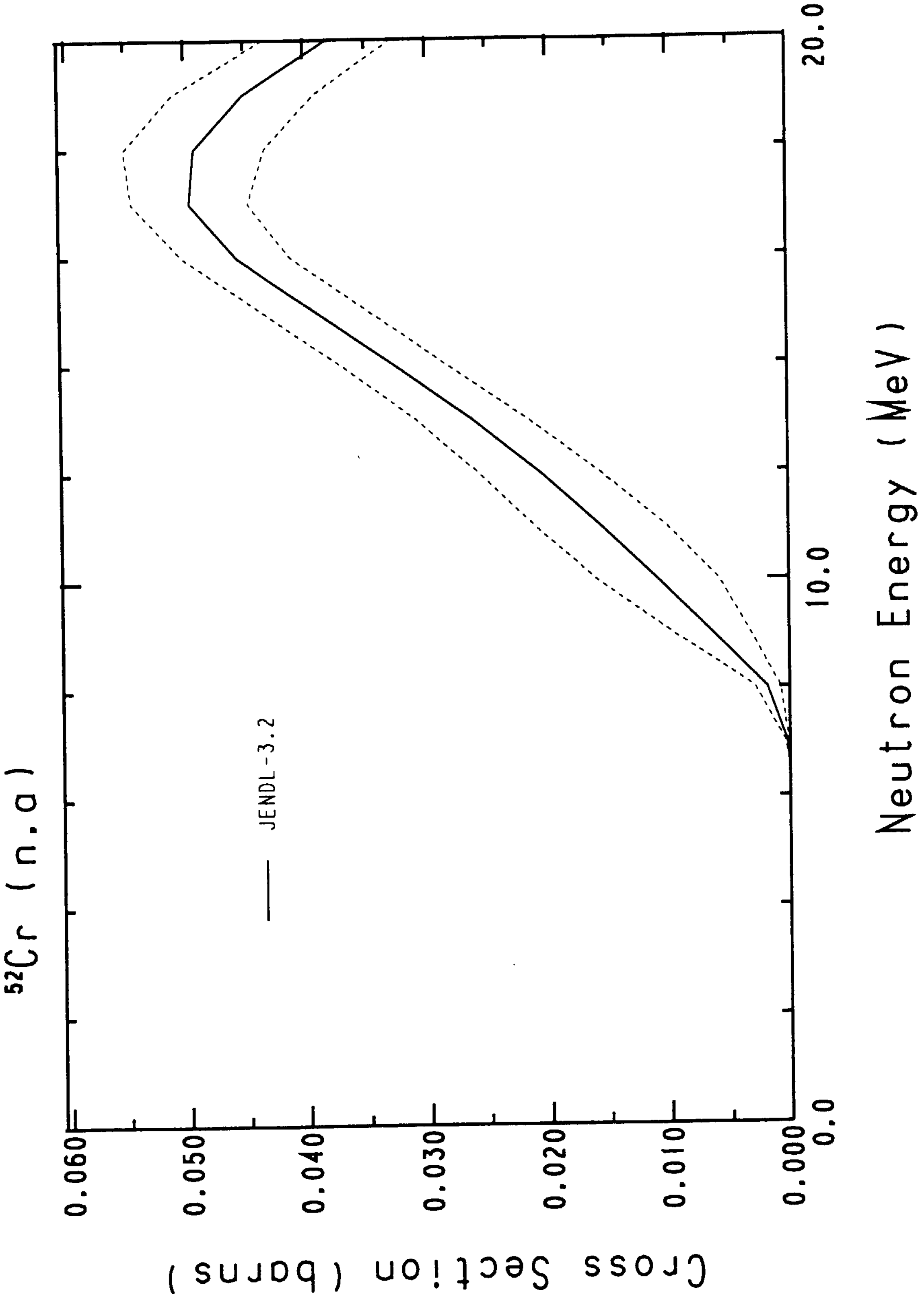

Fig. 10 (n,α) reaction cross section of ^{52}Cr.

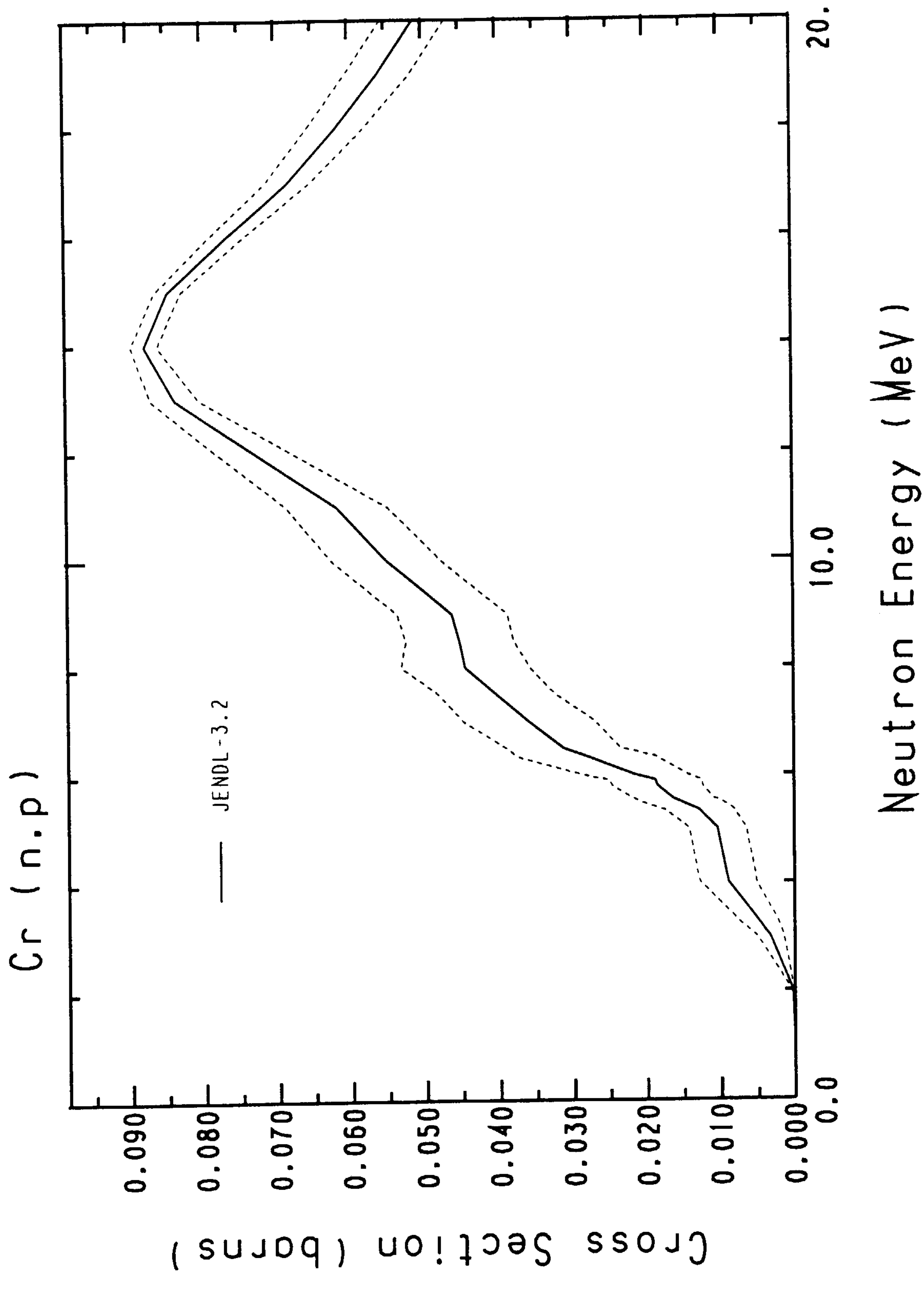

Fig. 11 (n,p) reaction cross section of elemental Cr.

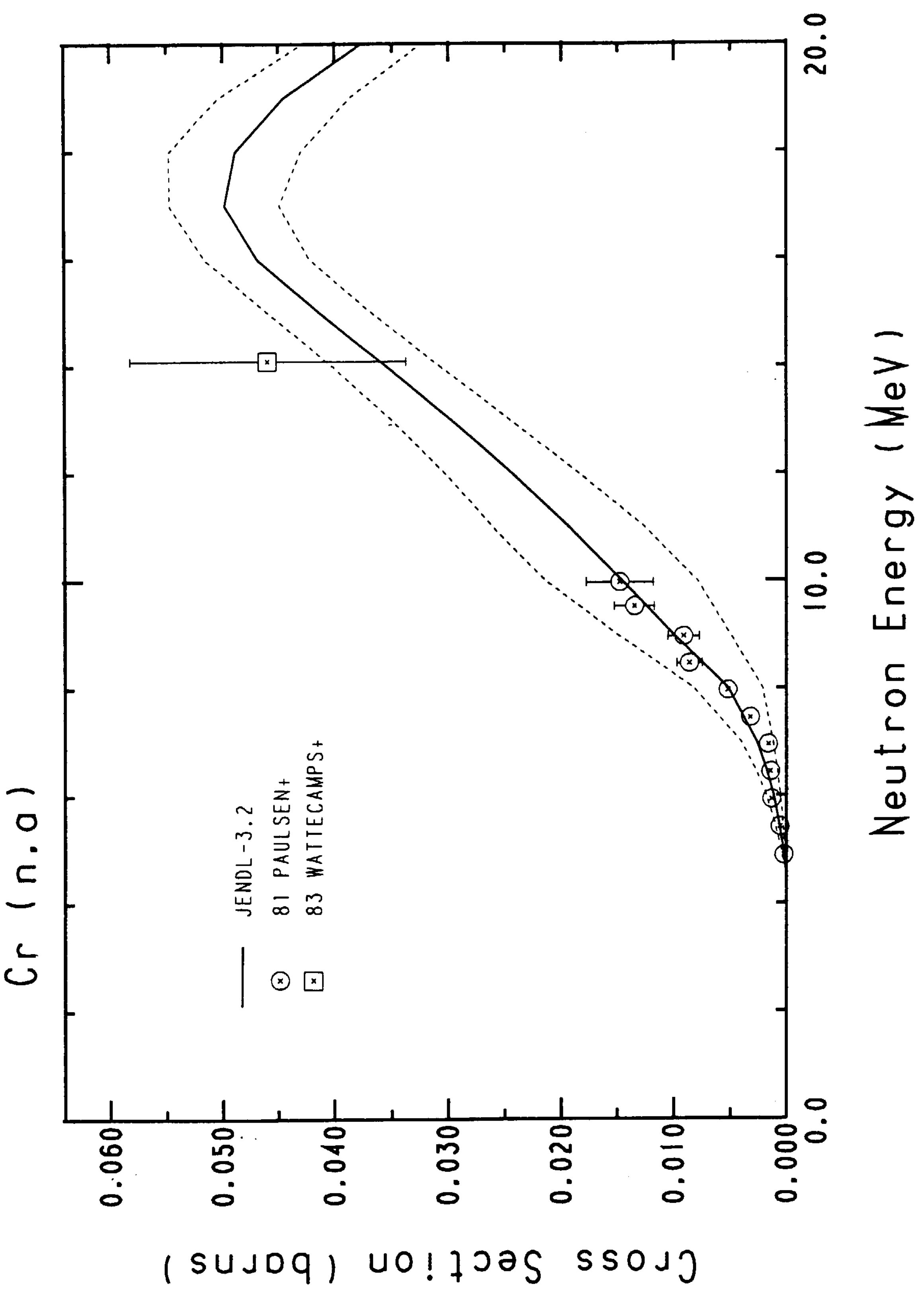

Fig. 12　(n,α) reaction cross section of elemental Cr.

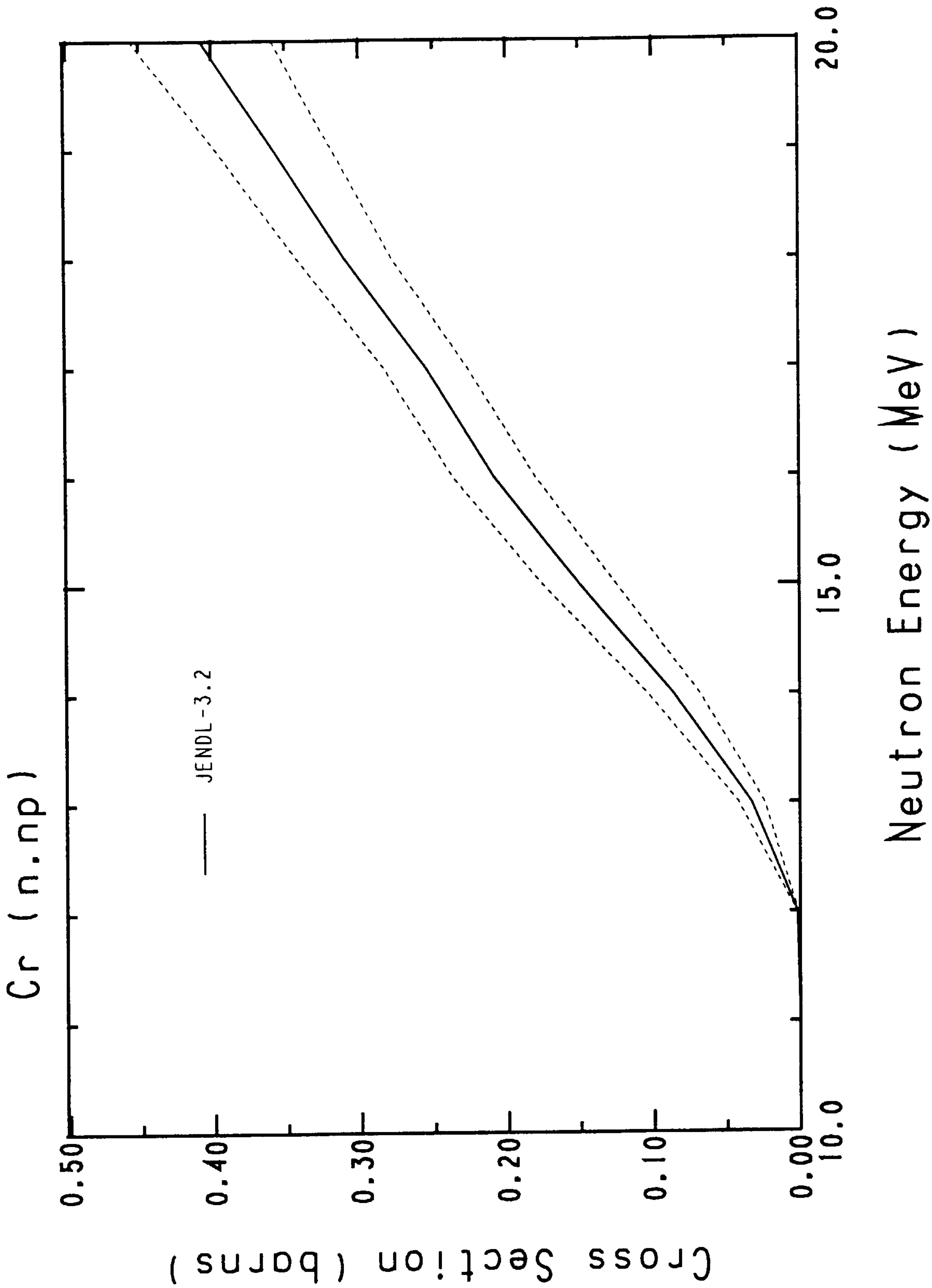

Fig. 13 (n,np) reaction cross section of elemental Cr.

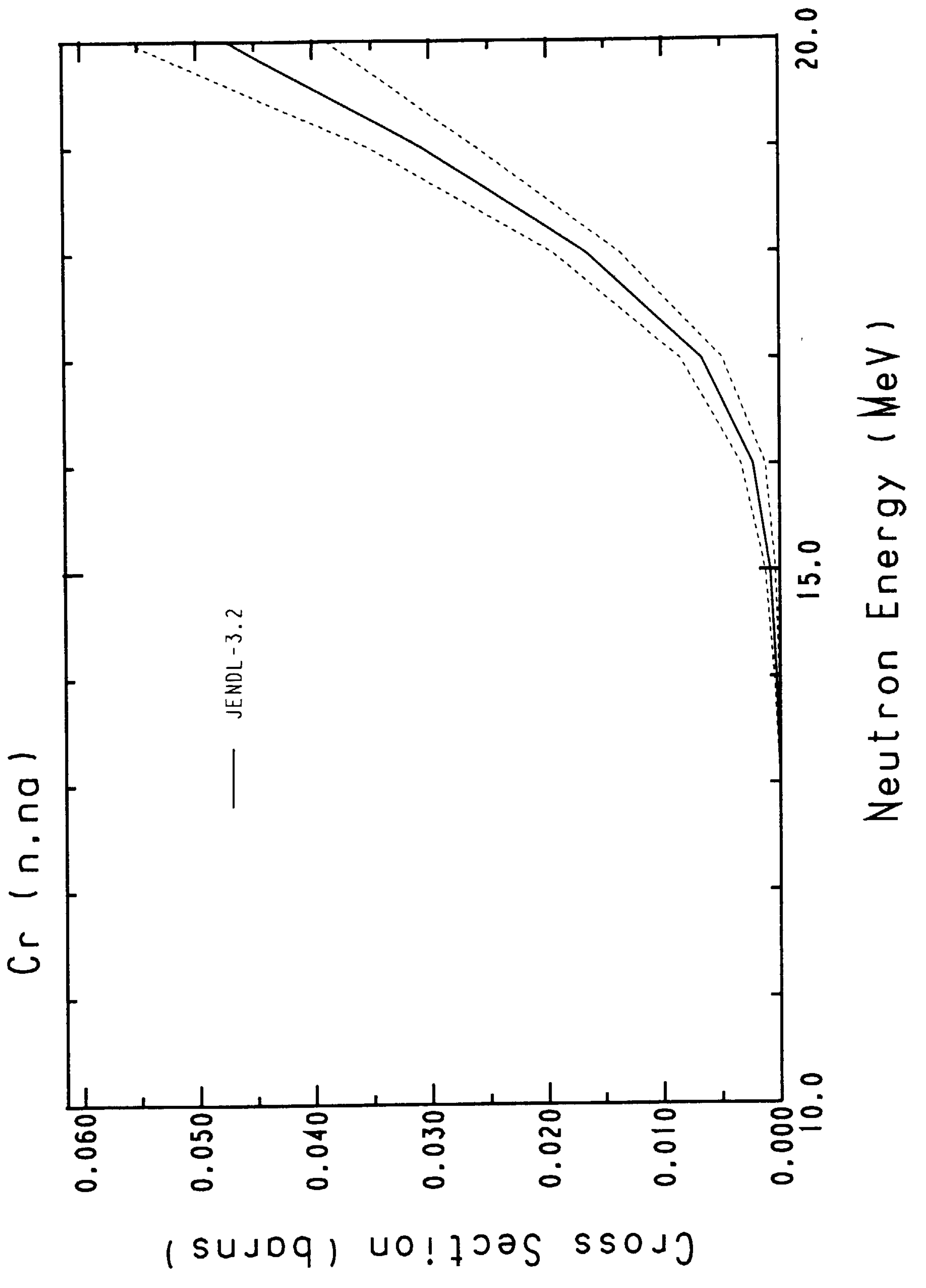

Fig. 14　(n,nα) reaction cross section of elemental Cr.

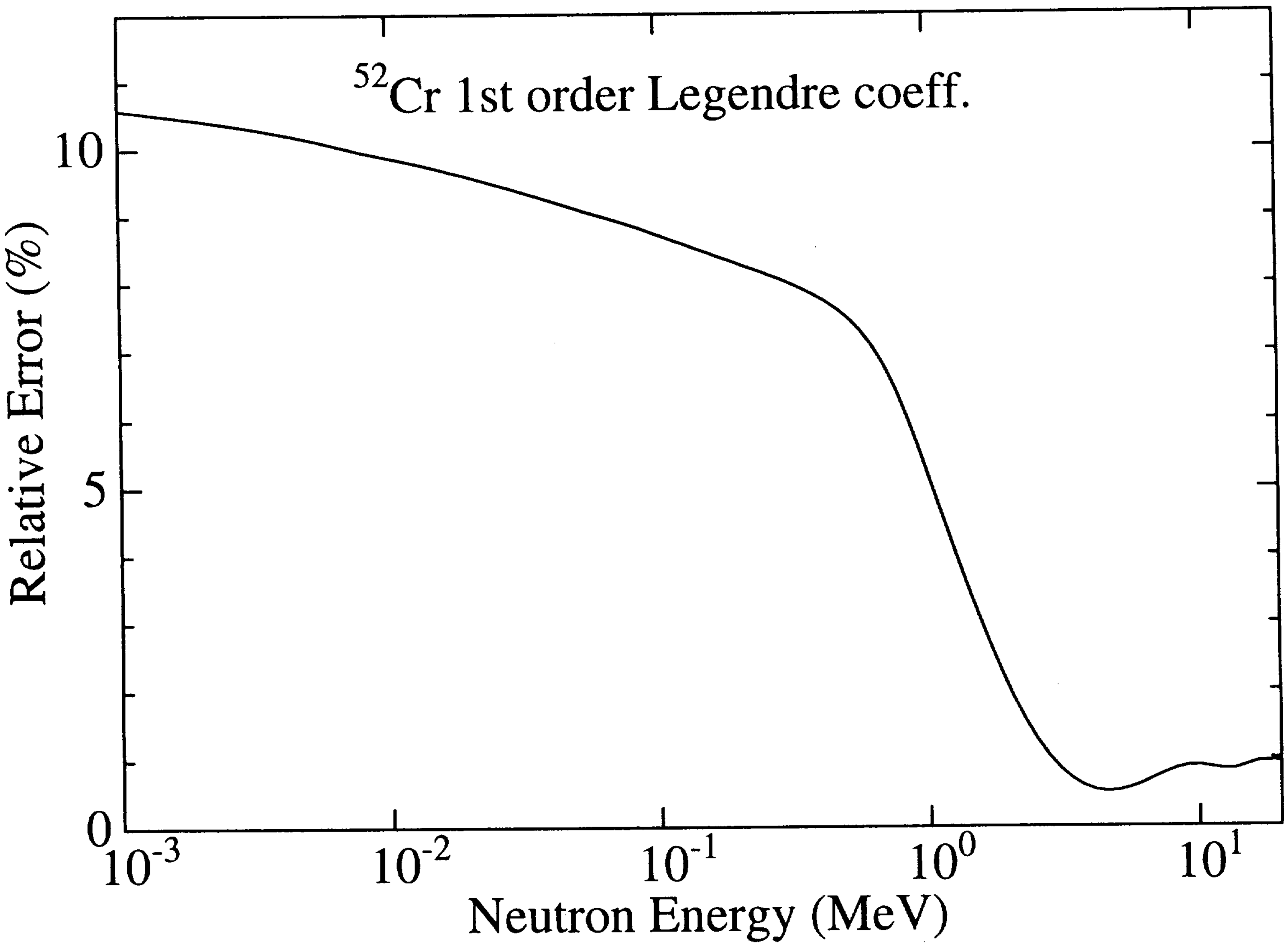

Fig. 15 Error of the 1st order Legendre-polynomial coefficient for ^{52}Cr.

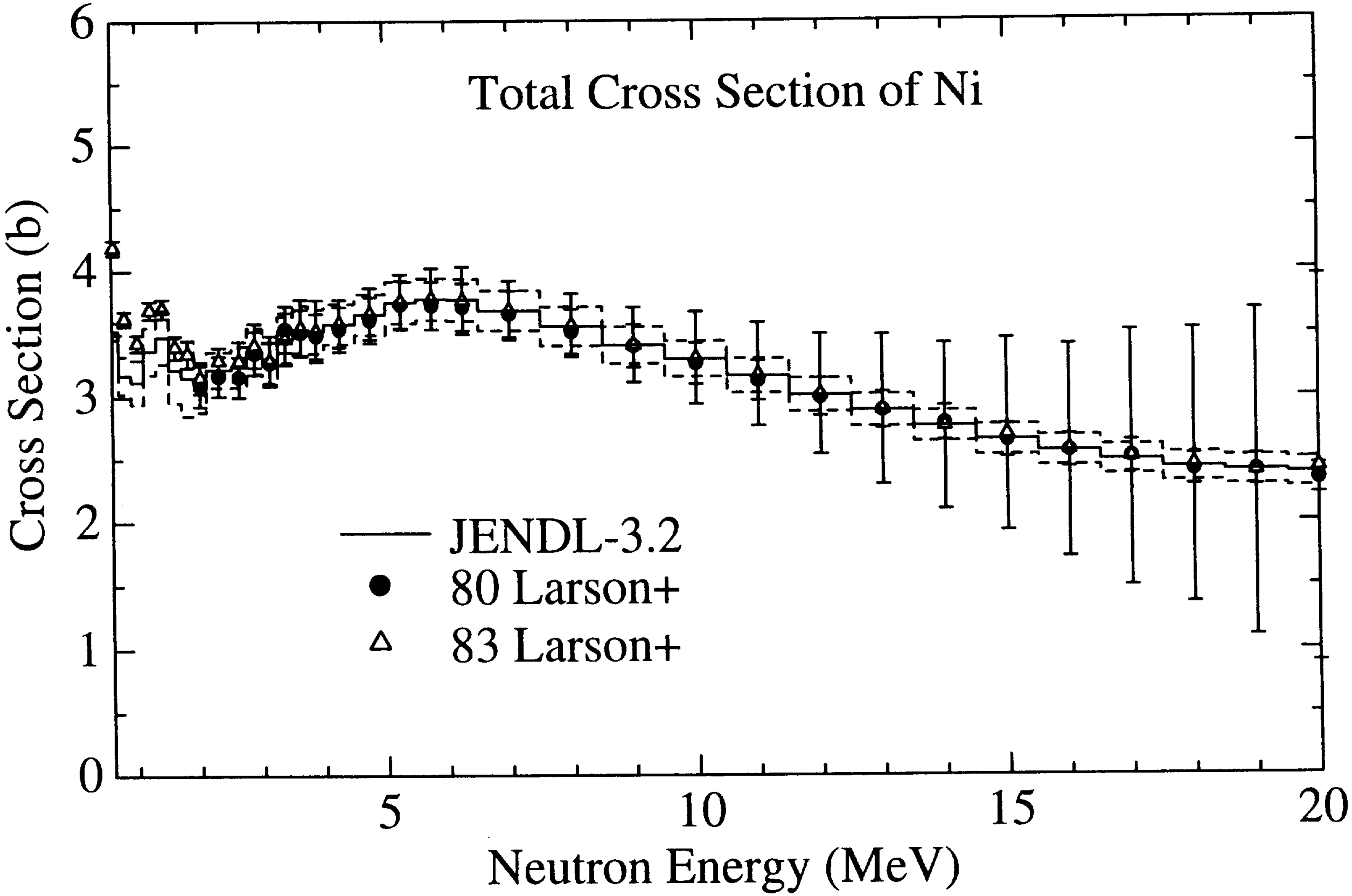

Fig. 16 Total cross section of elemental Ni.

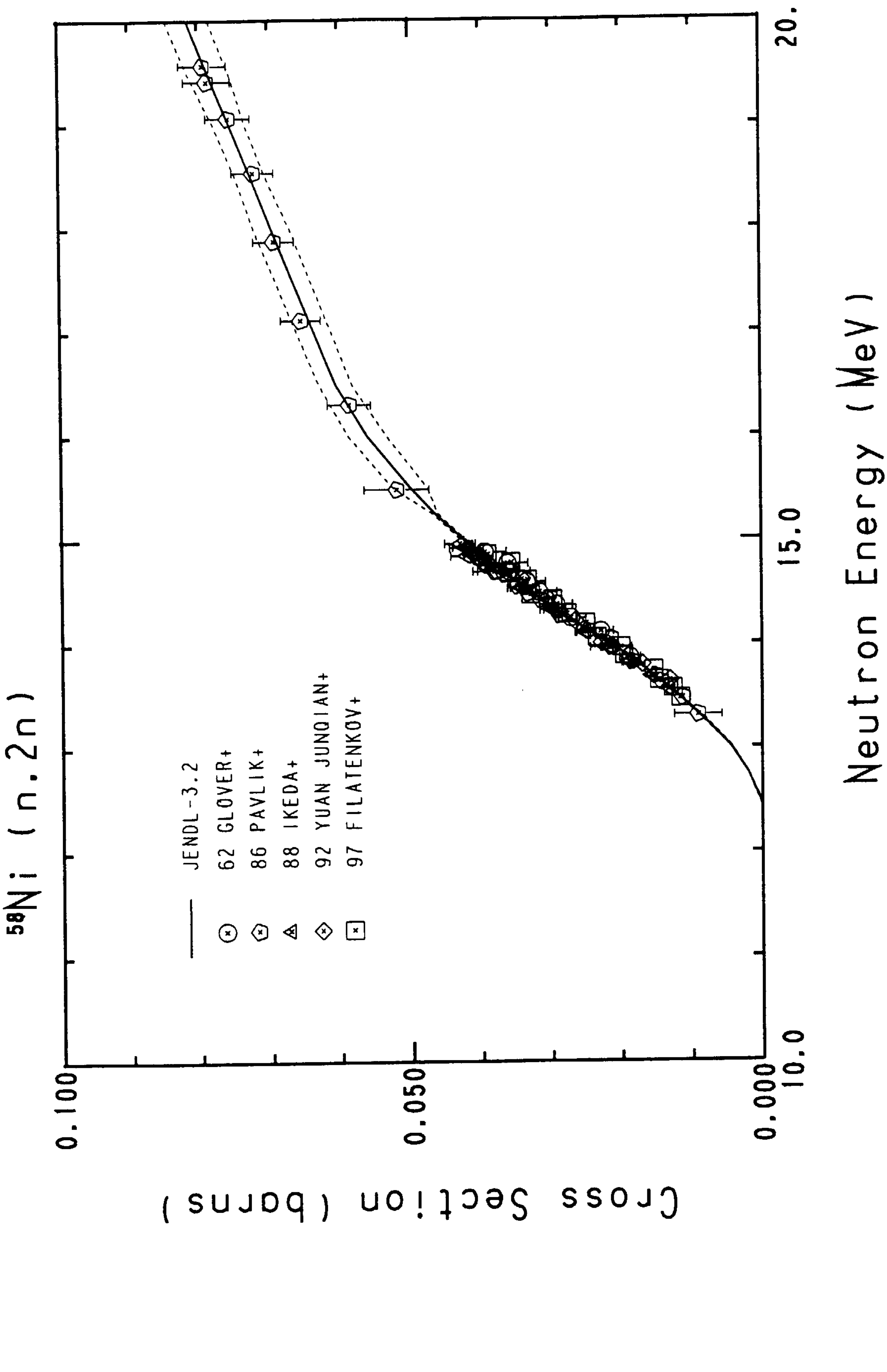

Fig. 17 (n,2n) reaction cross section of ^{58}Ni.

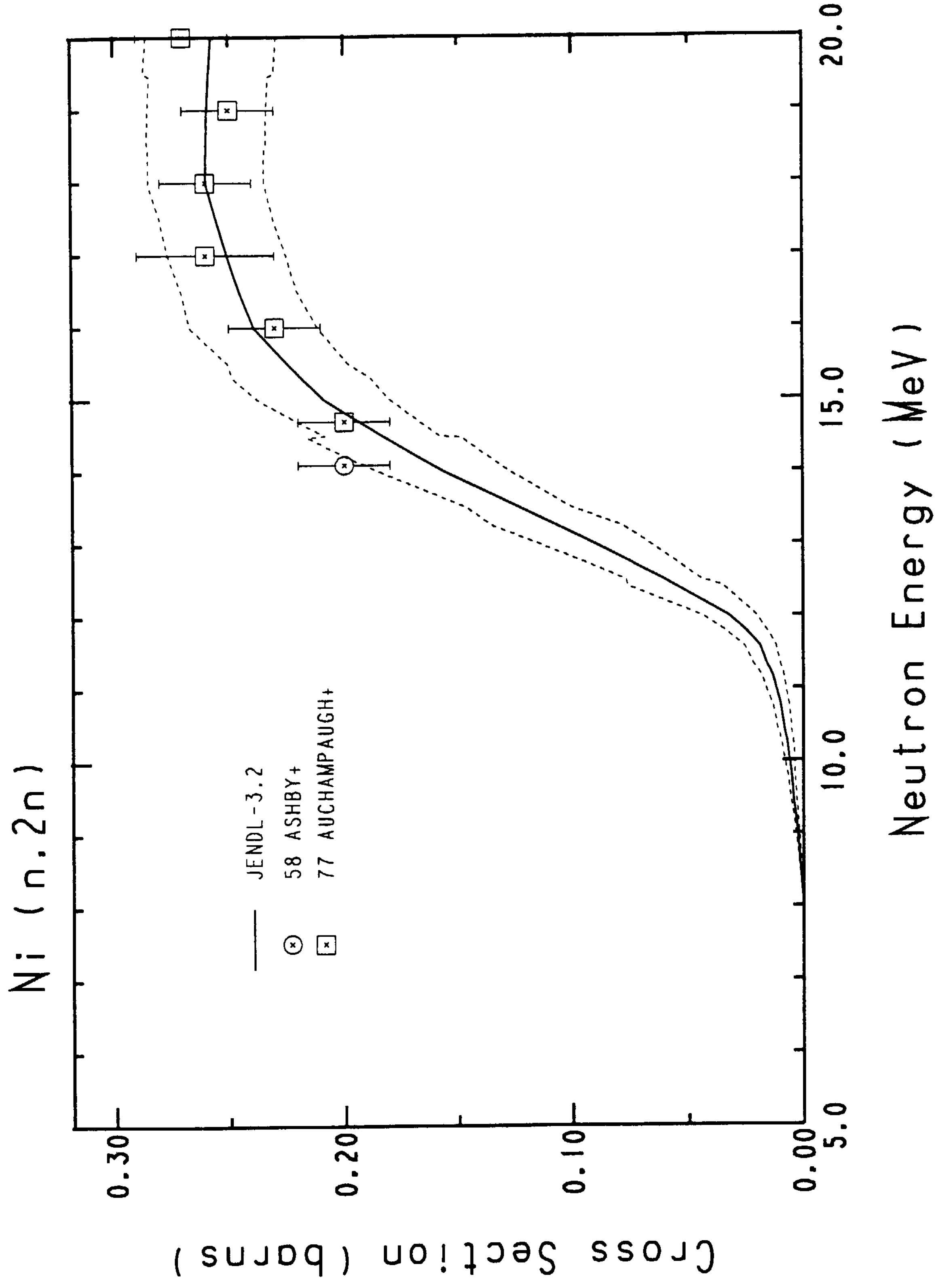

Fig. 18 (n,2n) reaction cross section of elemental Ni.

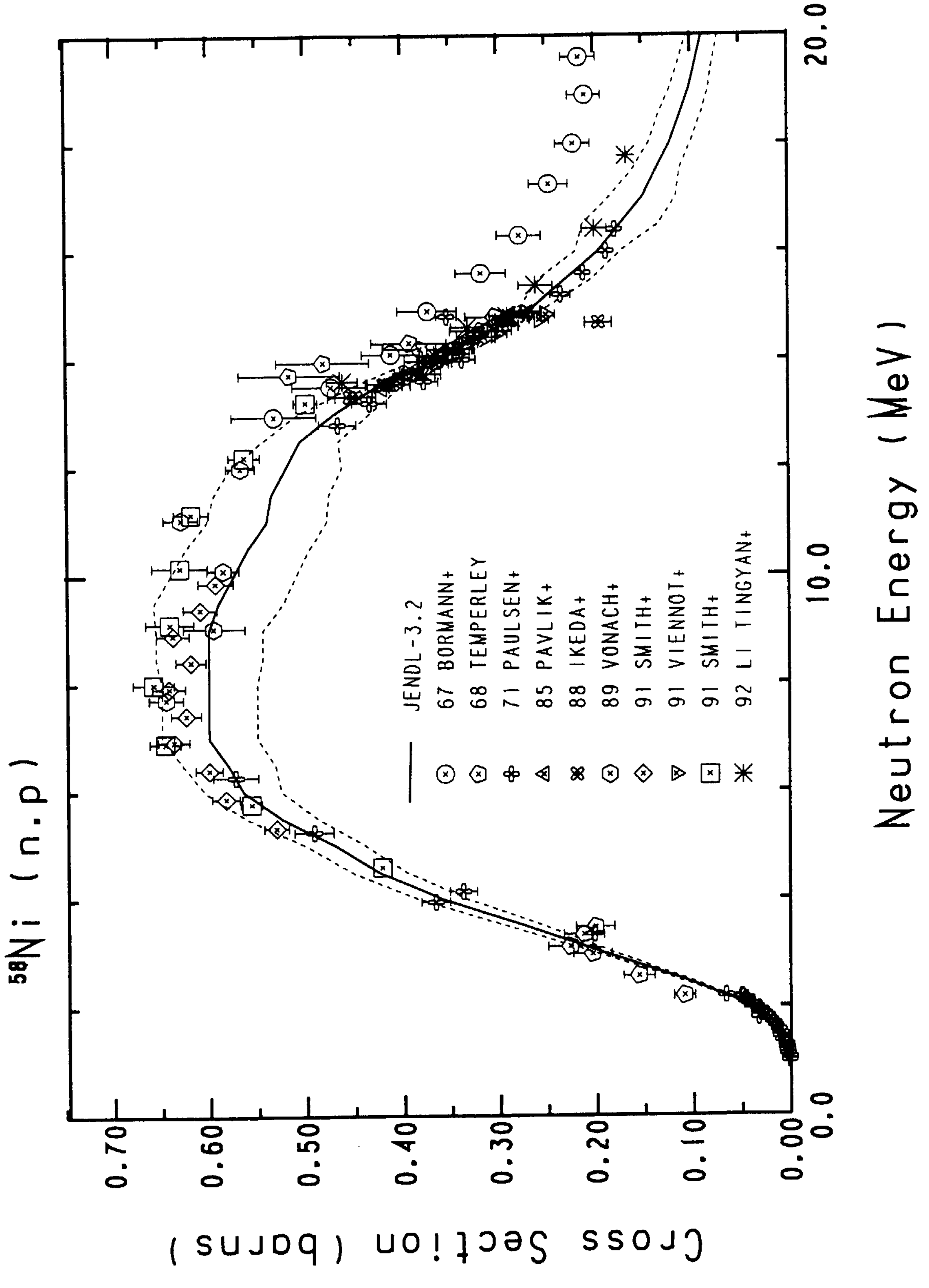

Fig. 19 (n,p) reaction cross section of ^{58}Ni.

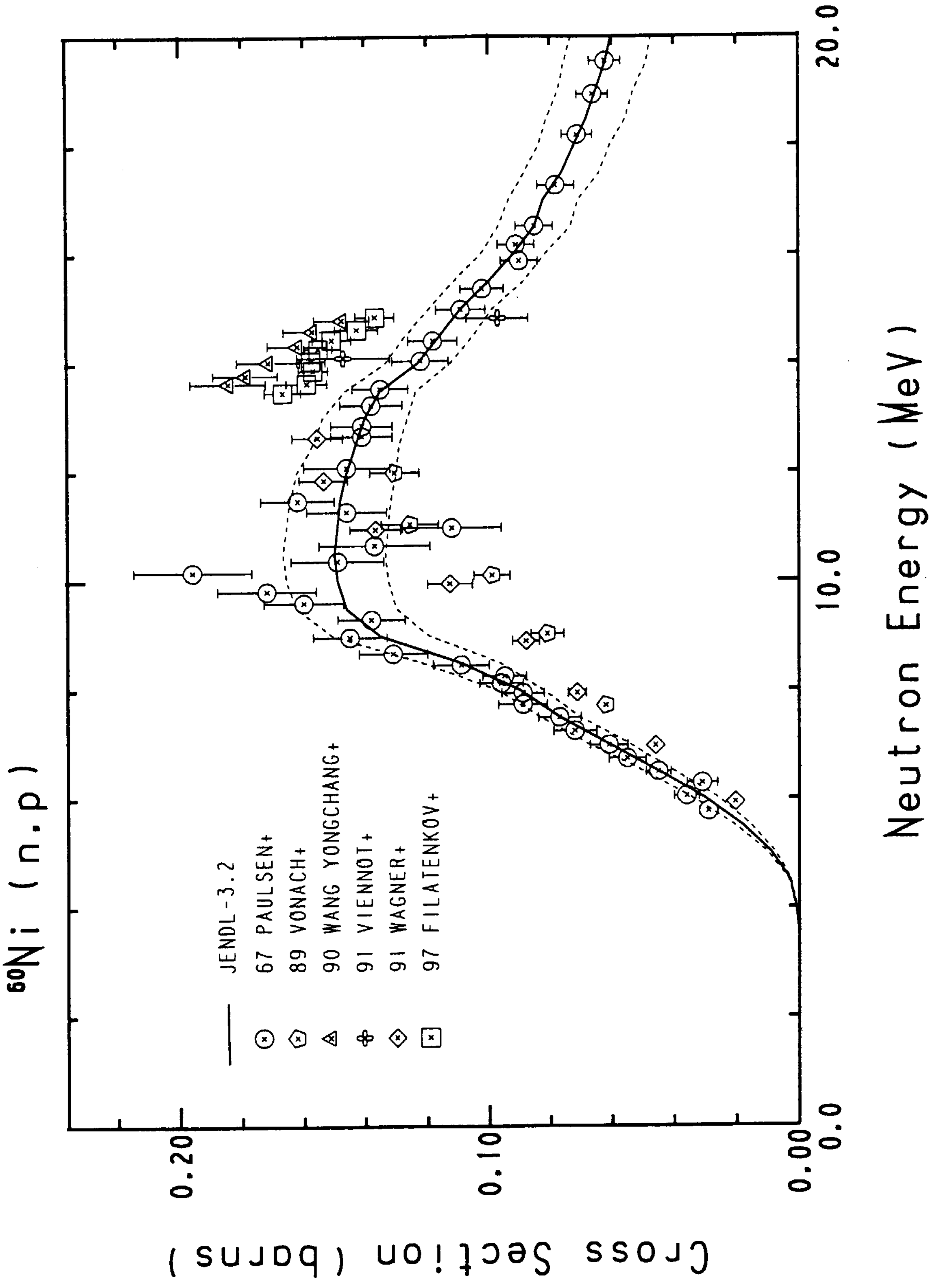

Fig. 20 (n,p) reaction cross section of ^{60}Ni.

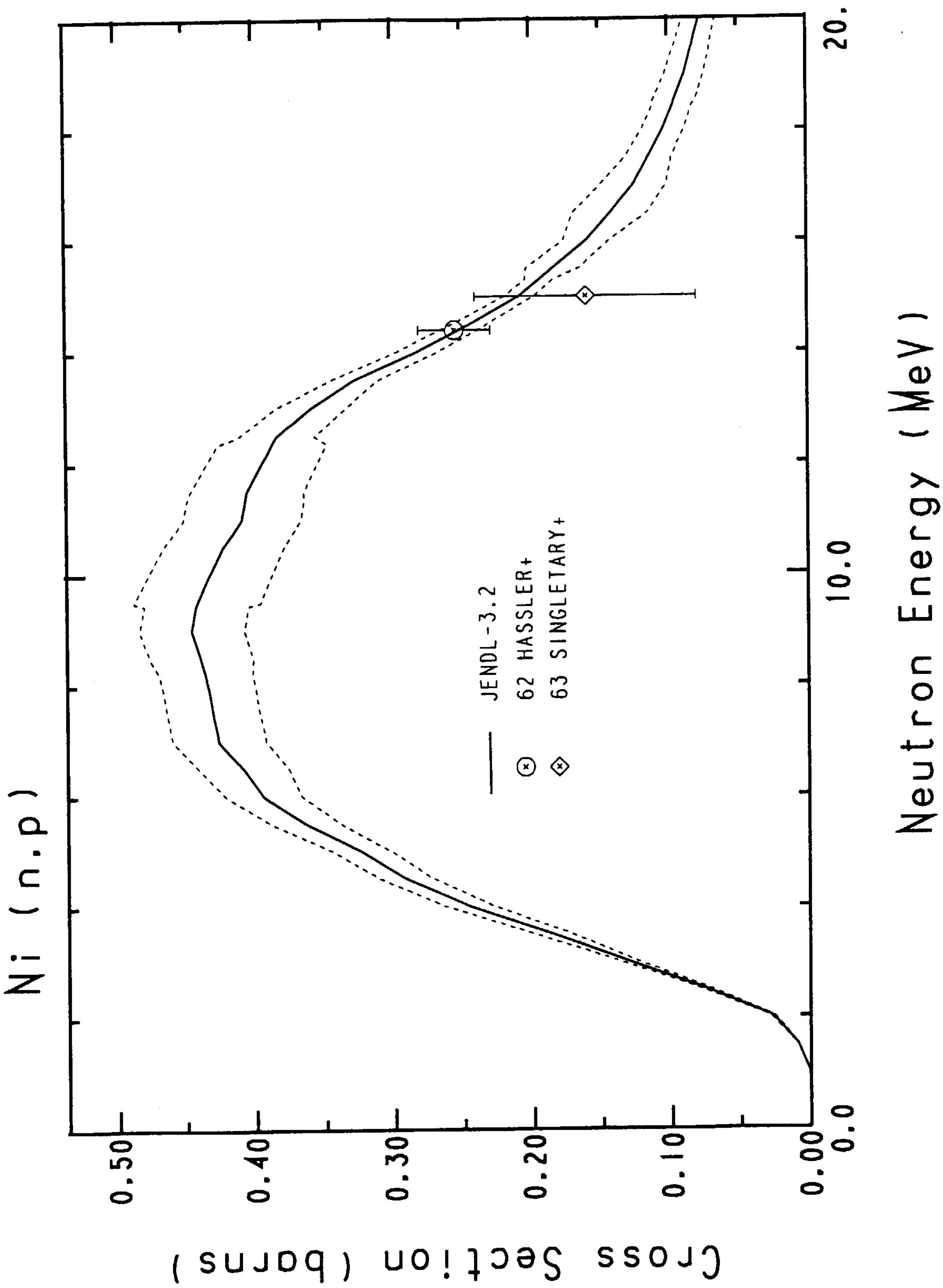

Fig. 21　(n,p) reaction cross section of elemental Ni.

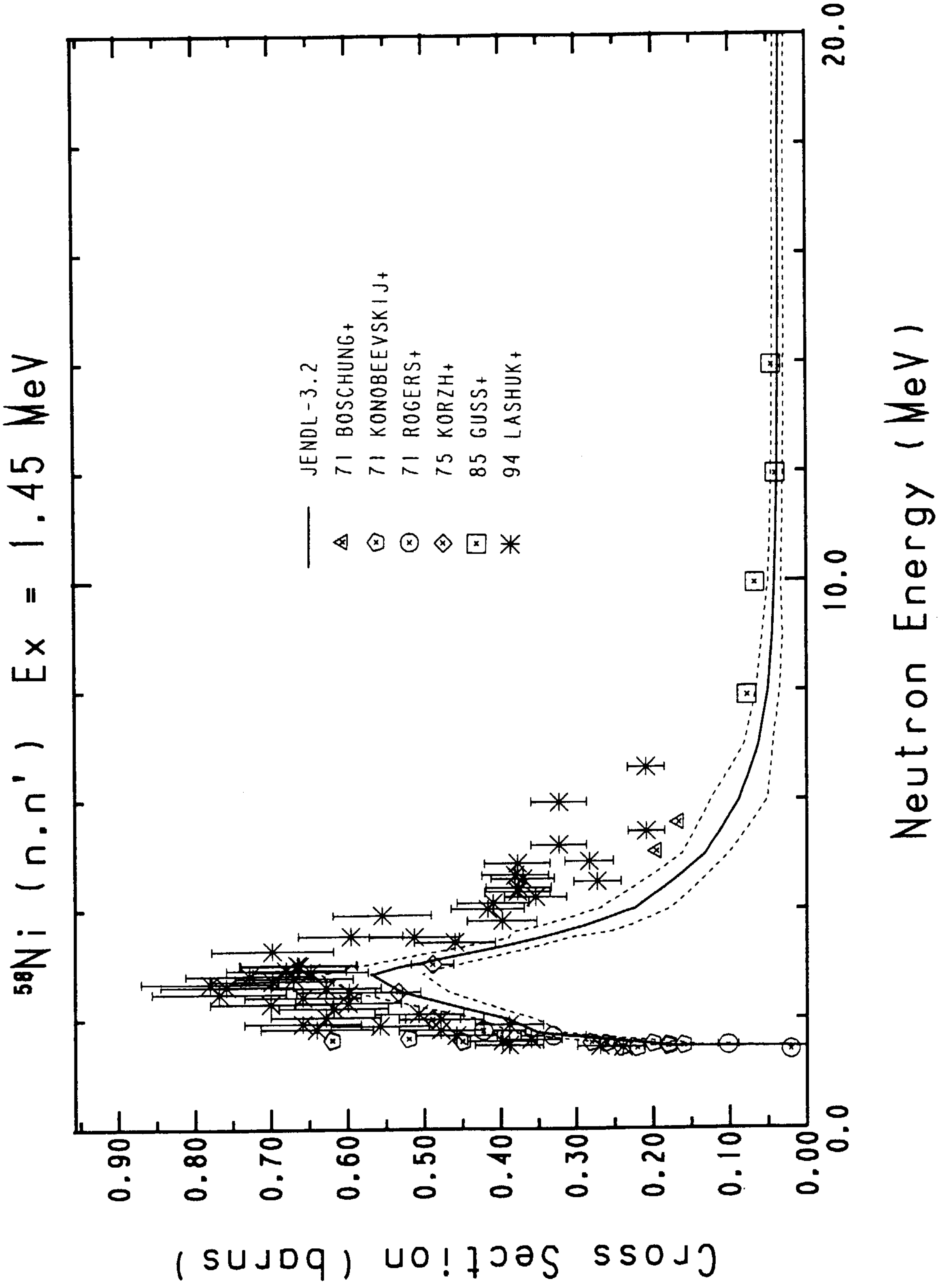

Fig. 22 Inelastic scattering cross section of the 1.45-MeV level of ^{58}Ni.

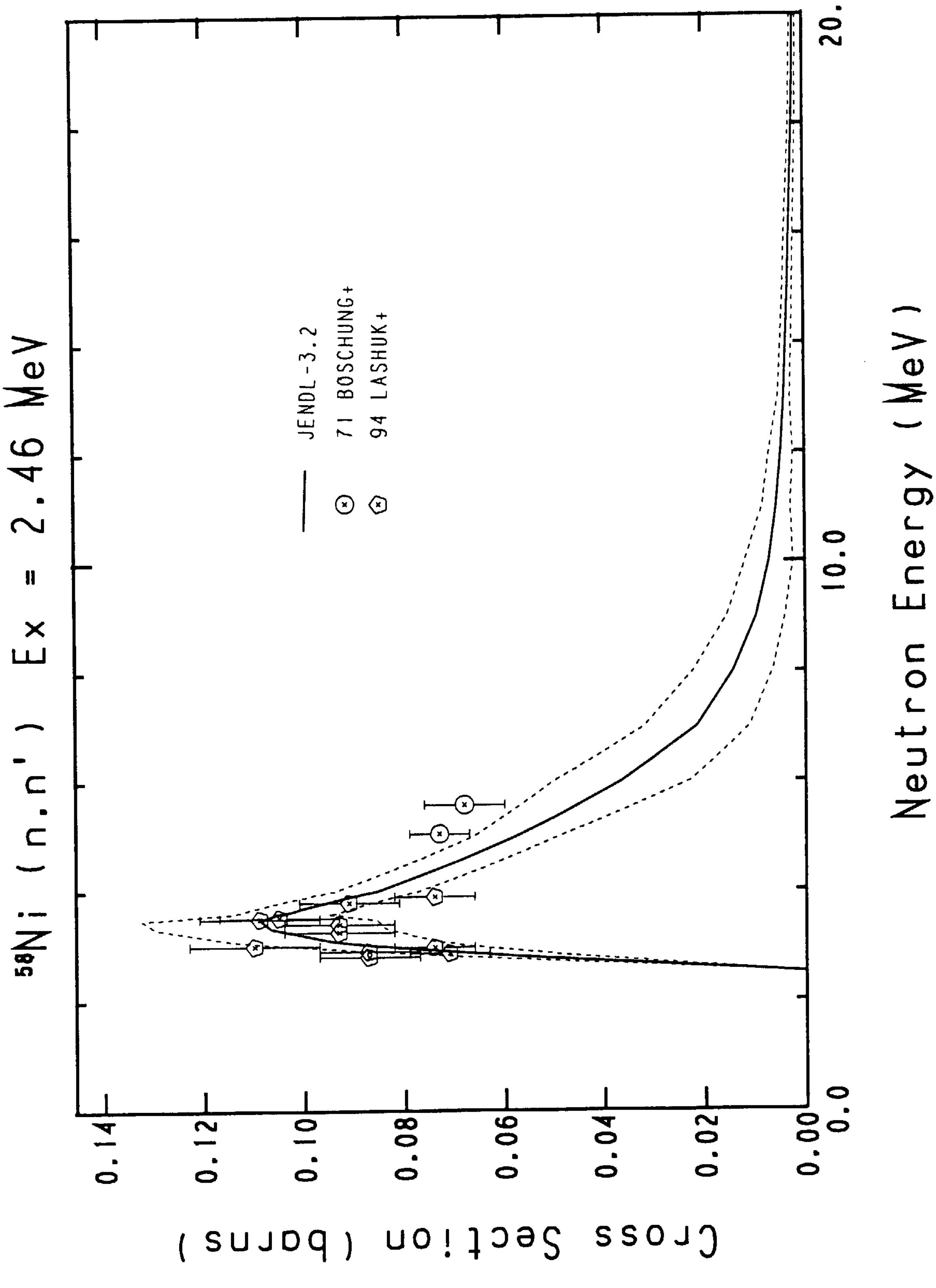

Fig. 23 Inelastic scattering cross section of the 2.46-MeV level of ^{58}Ni.

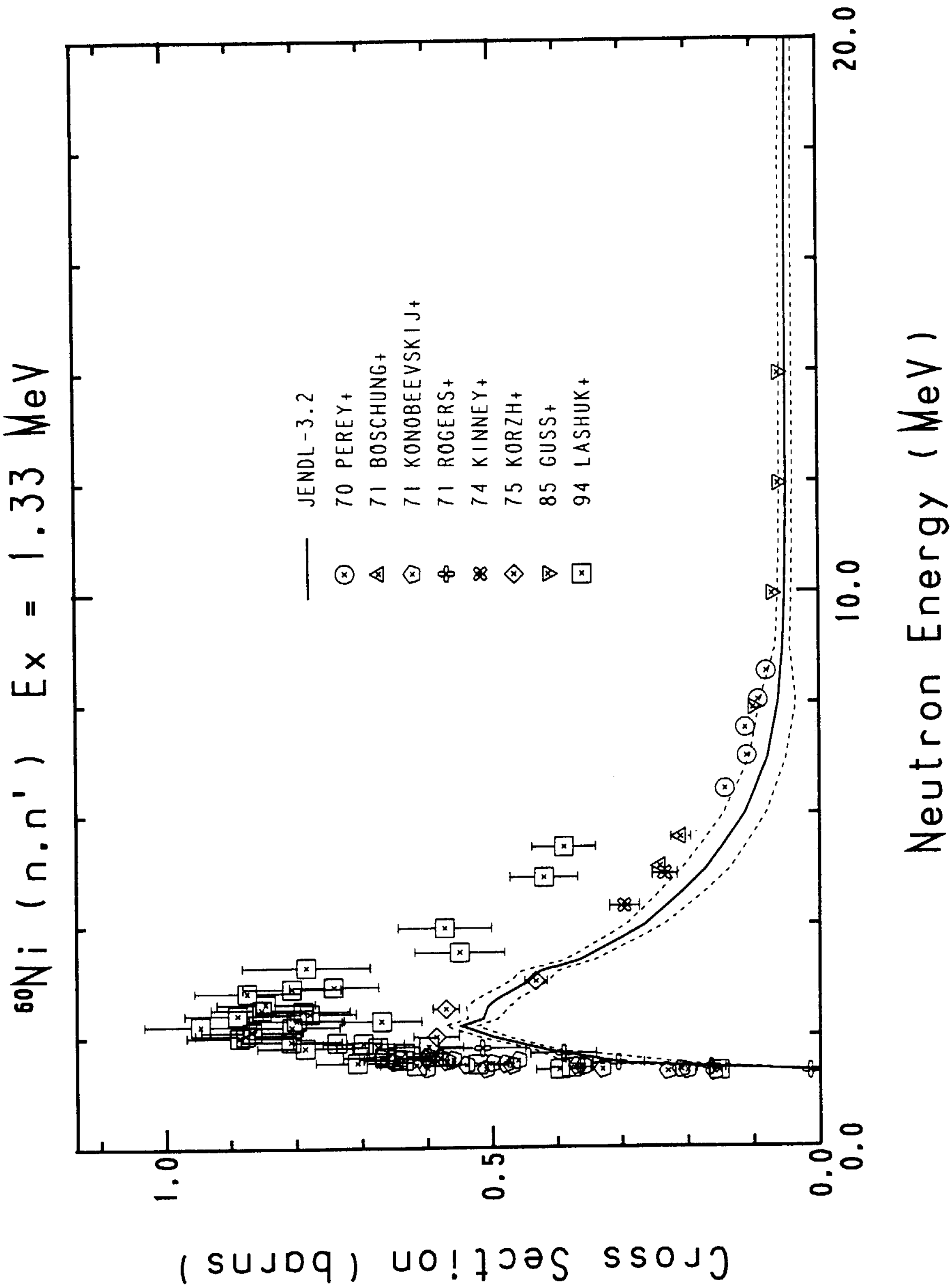

Fig. 24 Inelastic scattering cross section of the 1.33-MeV level of ^{60}Ni.

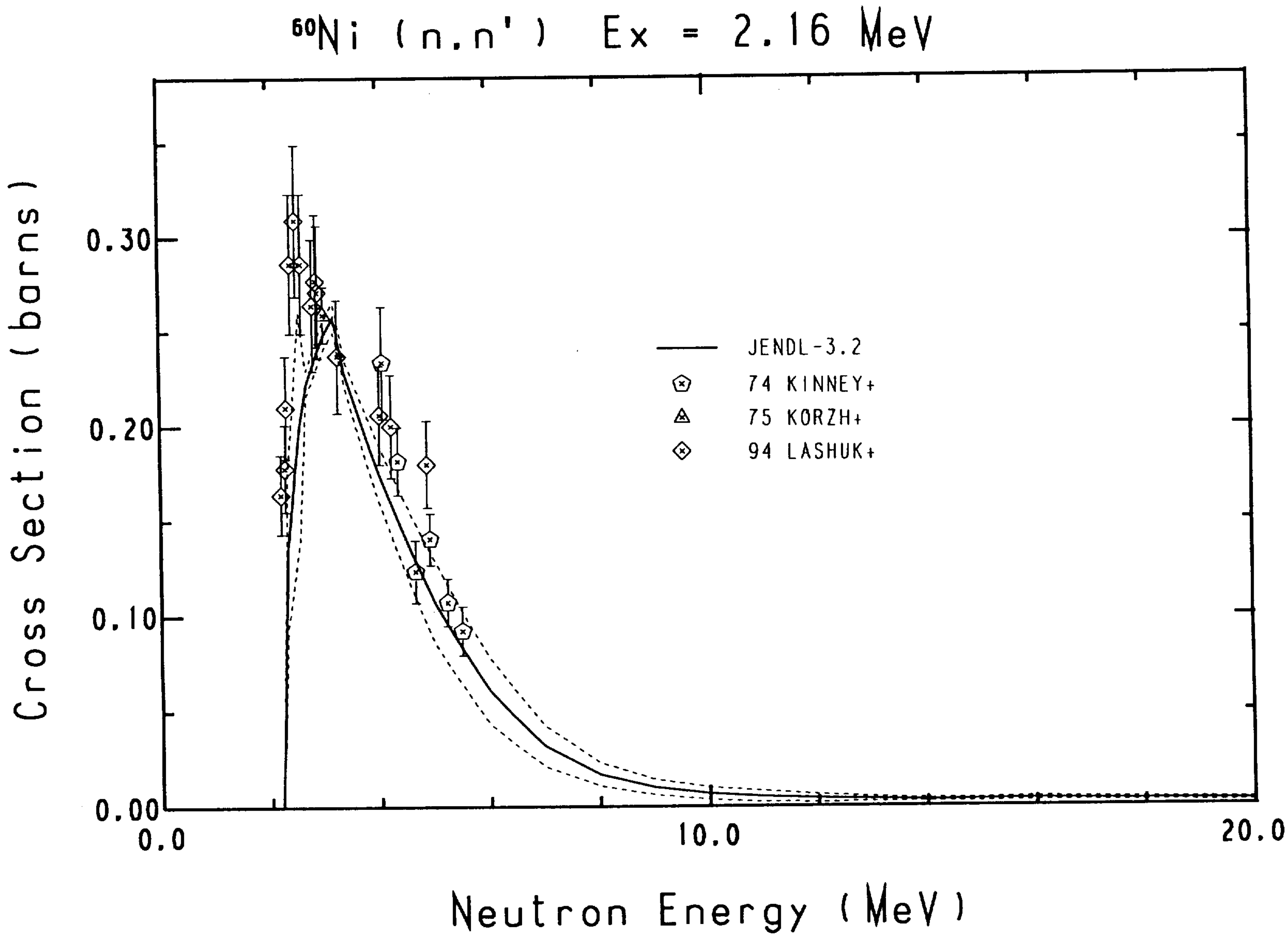

Fig. 25 Inelastic scattering cross section of the 2.16-MeV level of ^{60}Ni.

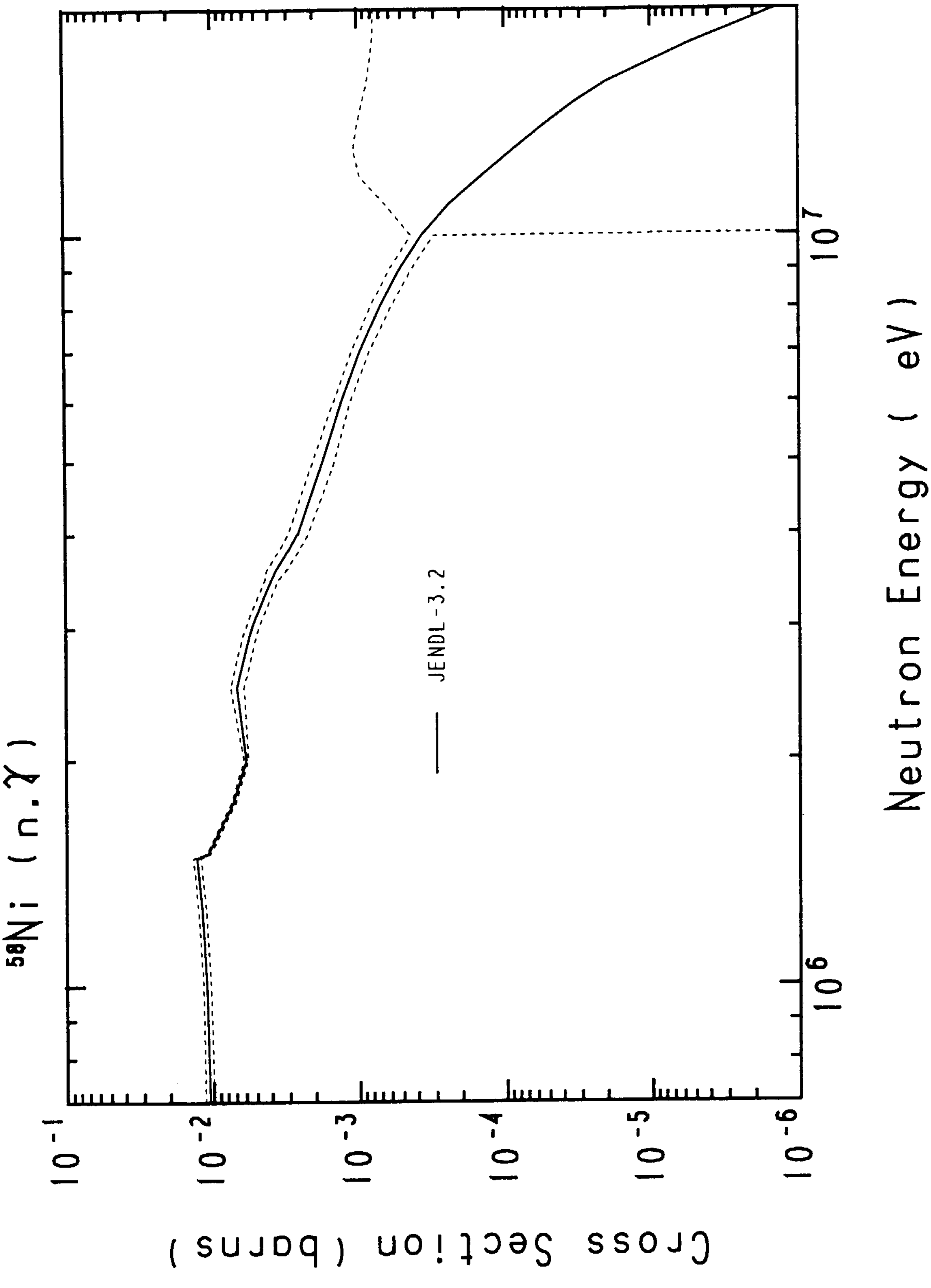

Fig. 26　Capture cross section of ^{58}Ni.

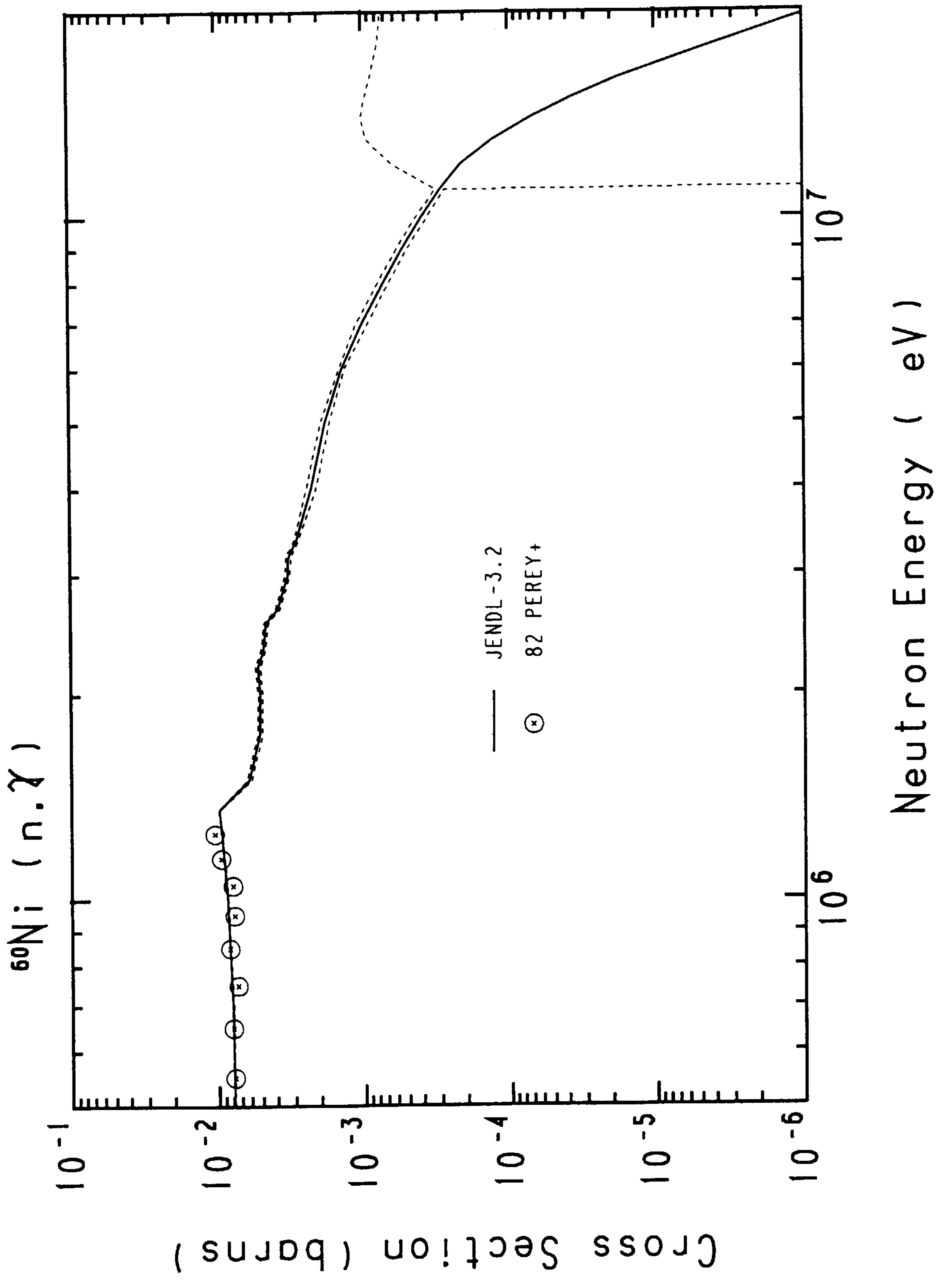

Fig. 27 Capture cross section of ^{60}Ni.

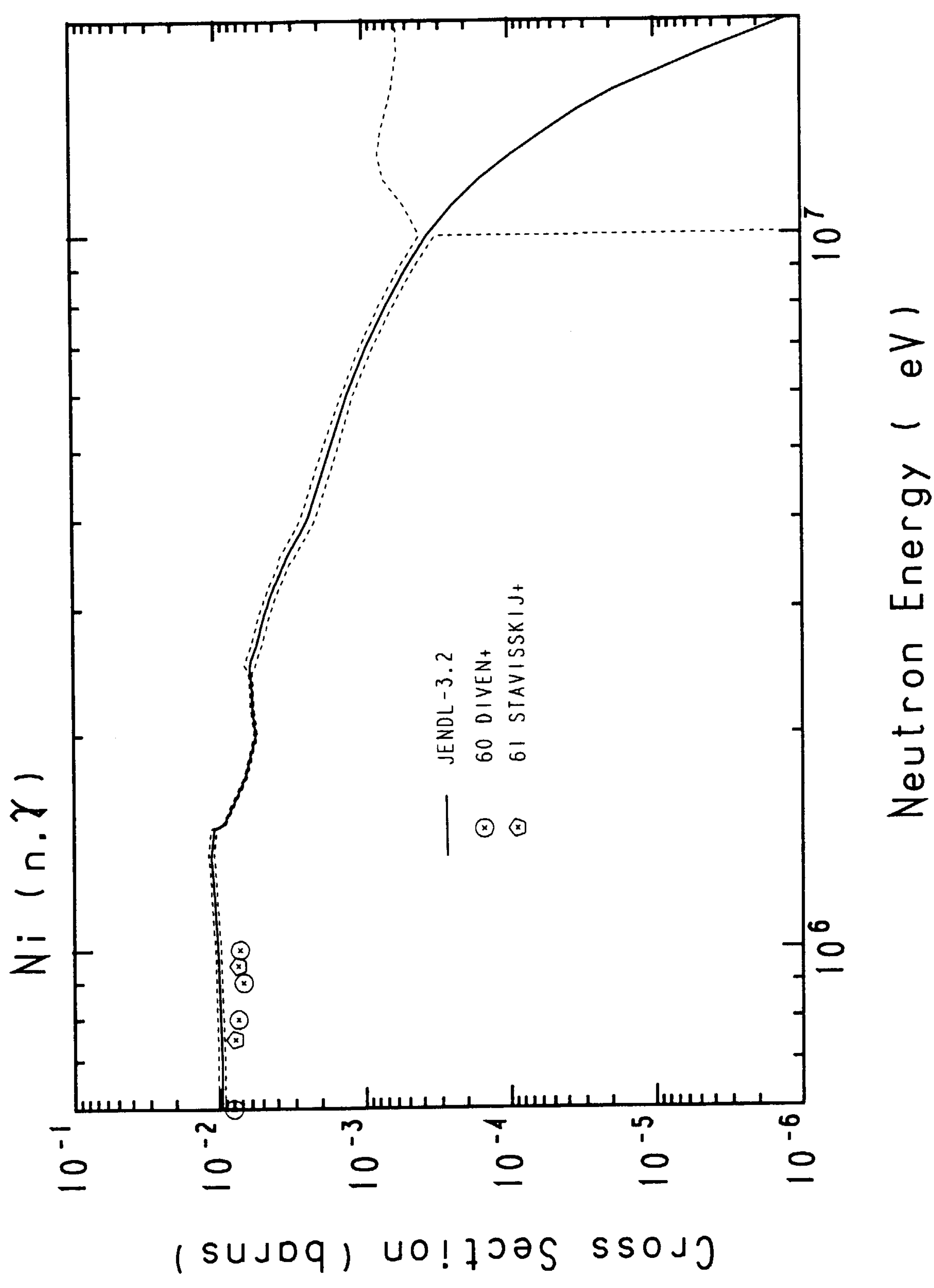

Fig. 28 Capture cross section of elemental Ni.

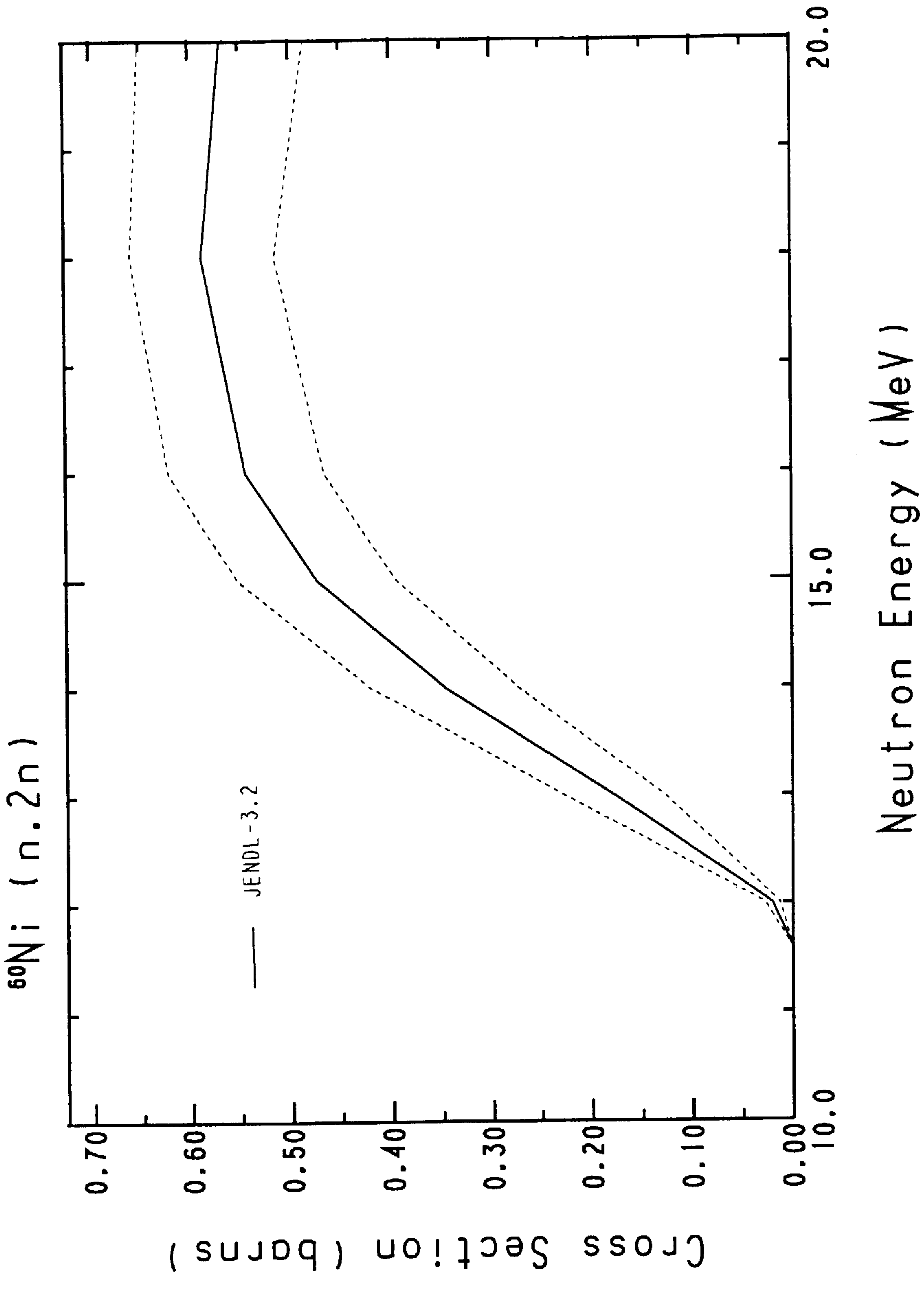

Fig. 29 (n,2n) reaction cross section of ^{60}Ni.

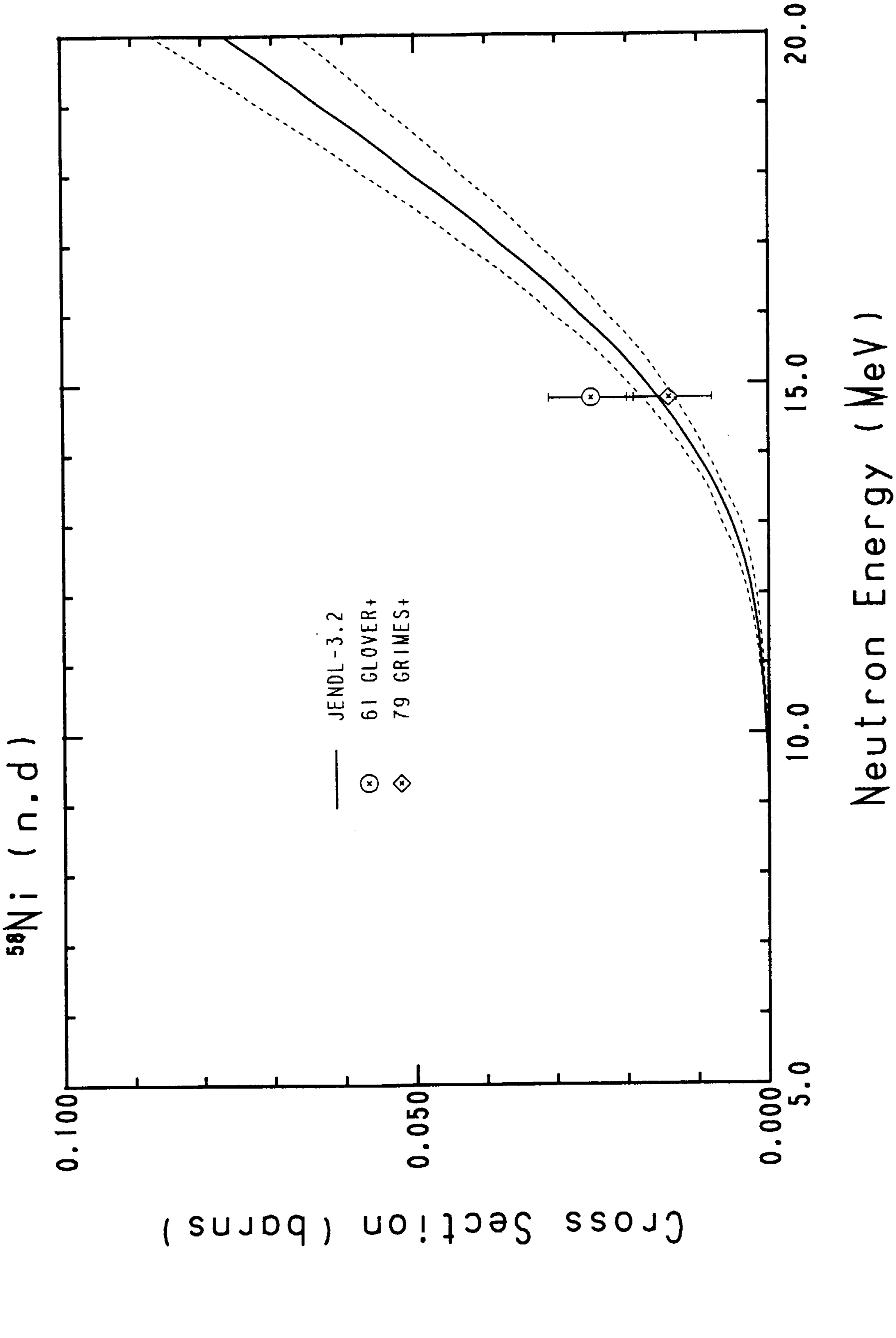

Fig. 30 (n,d) reaction cross section of ^{58}Ni.

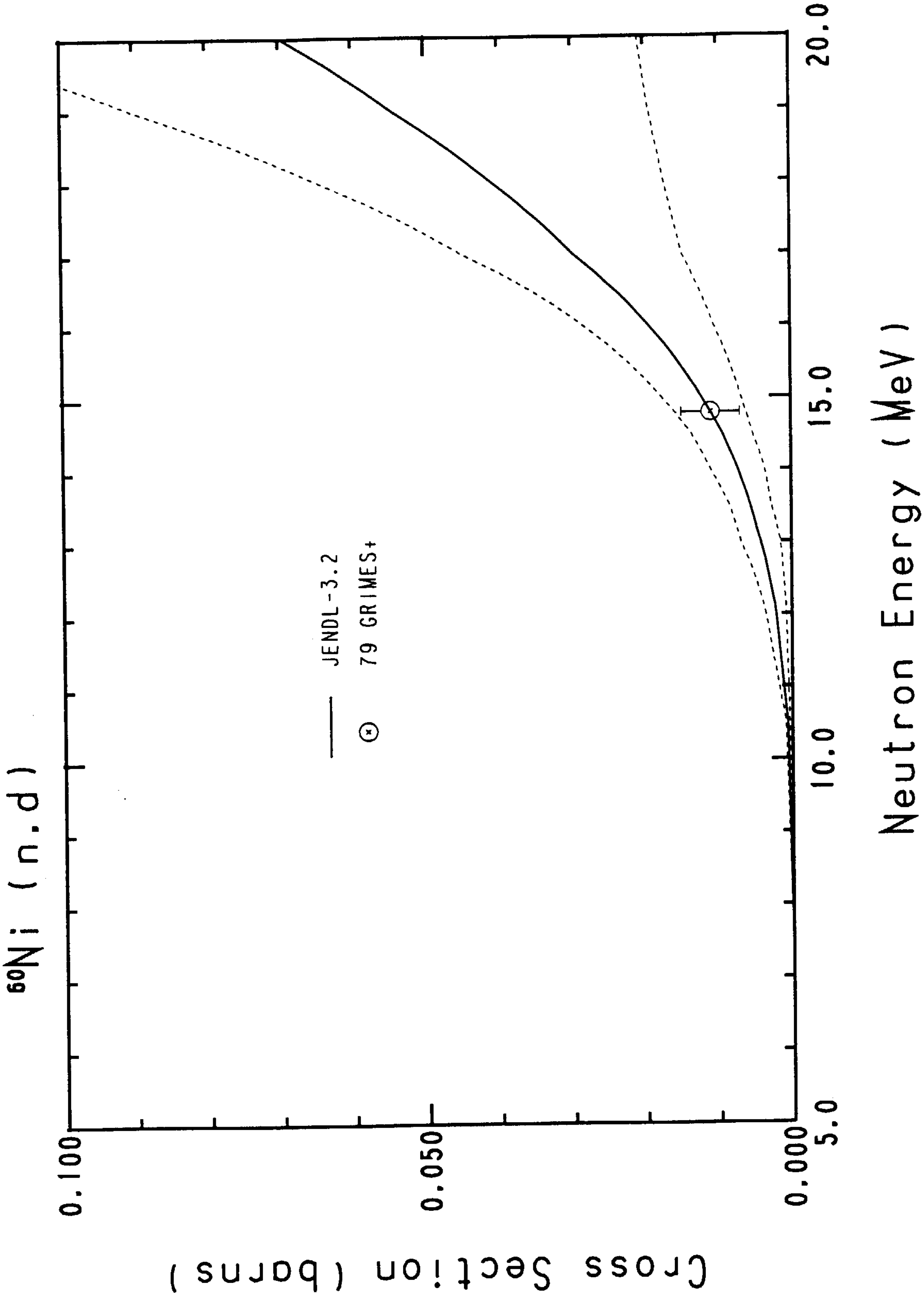

Fig. 31 (n,d) reaction cross section of ^{60}Ni.

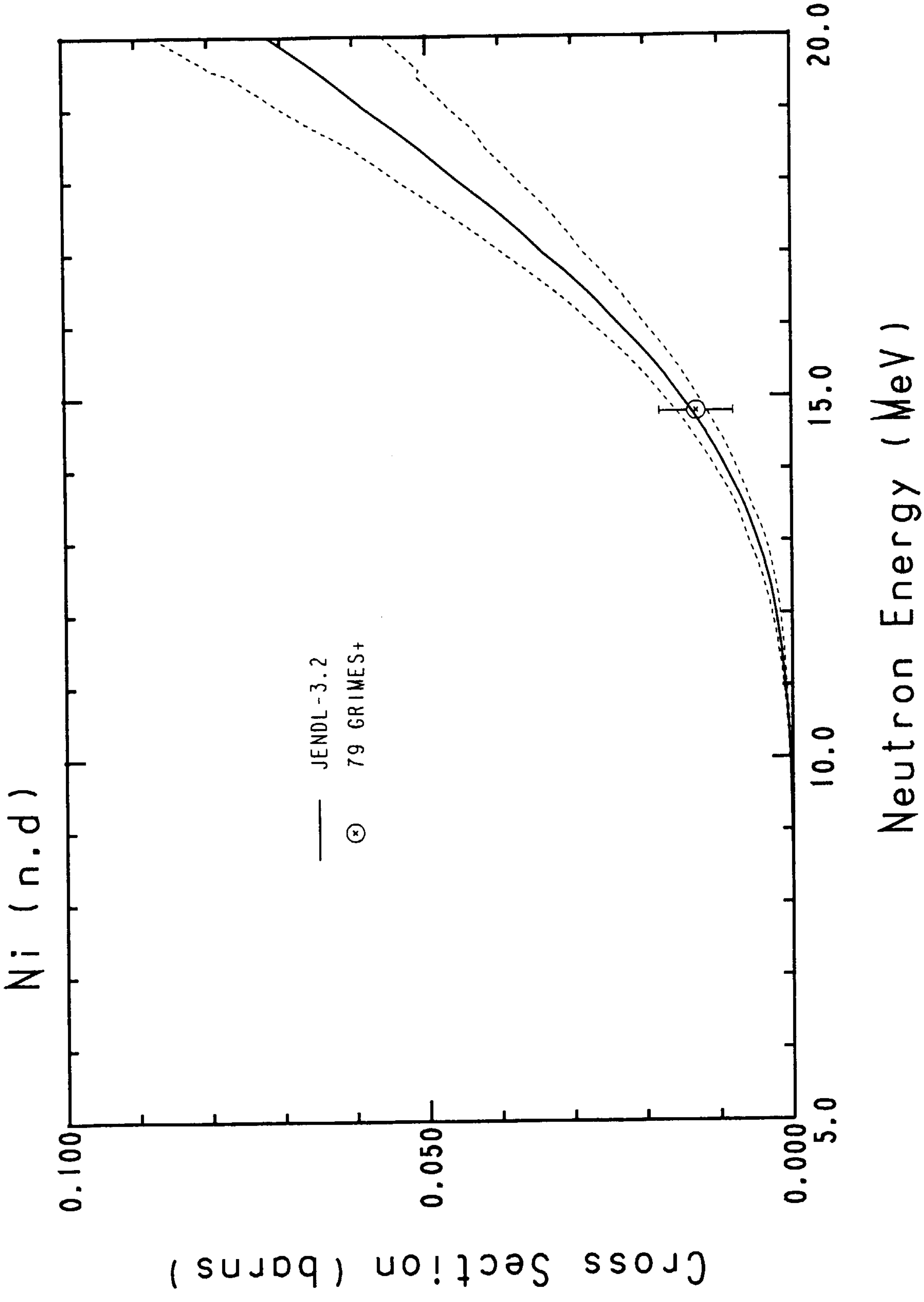

Fig. 32 (n,d) reaction cross section of elemental Ni.

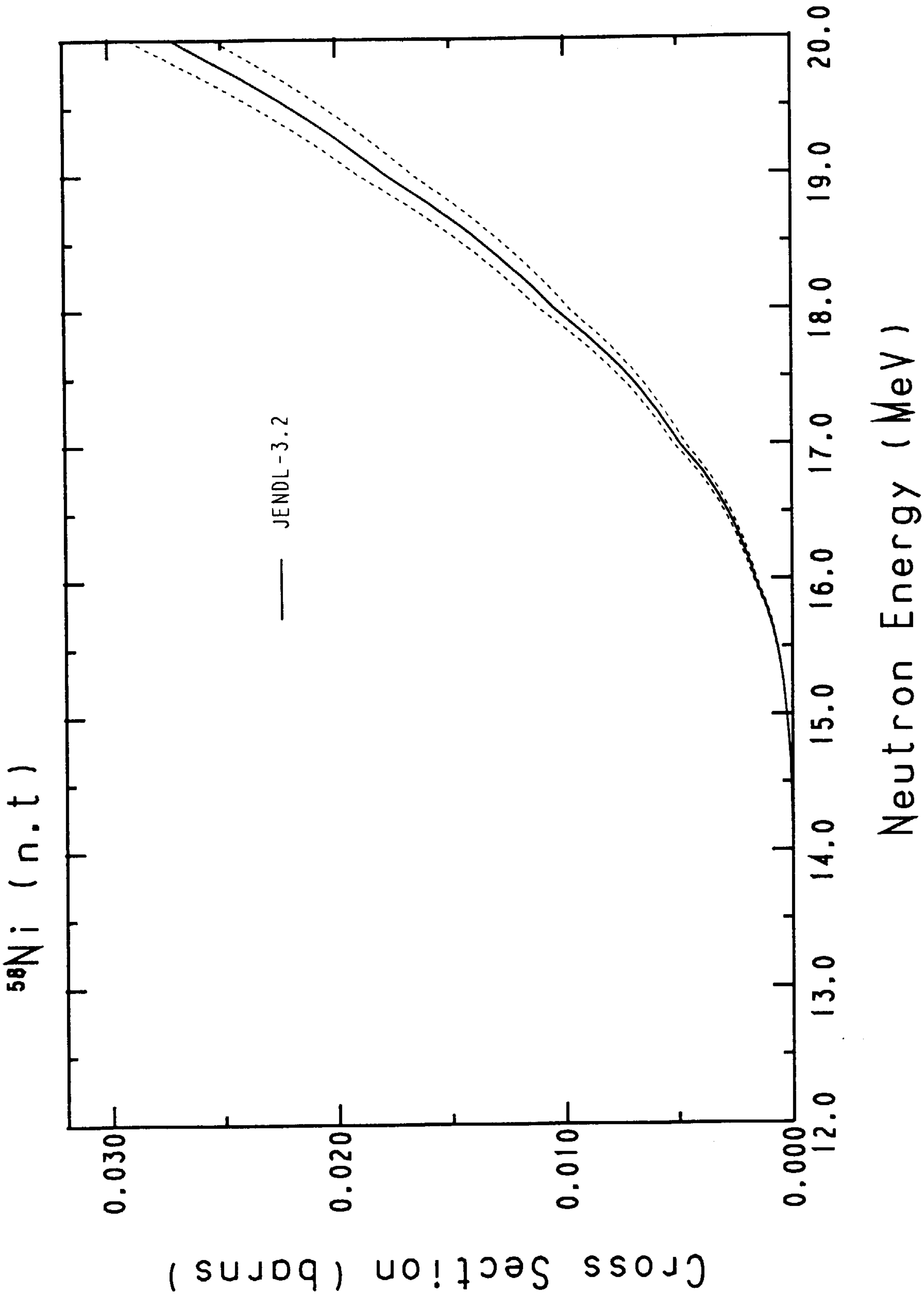

Fig. 33 (n,t) reaction cross section of ^{58}Ni.

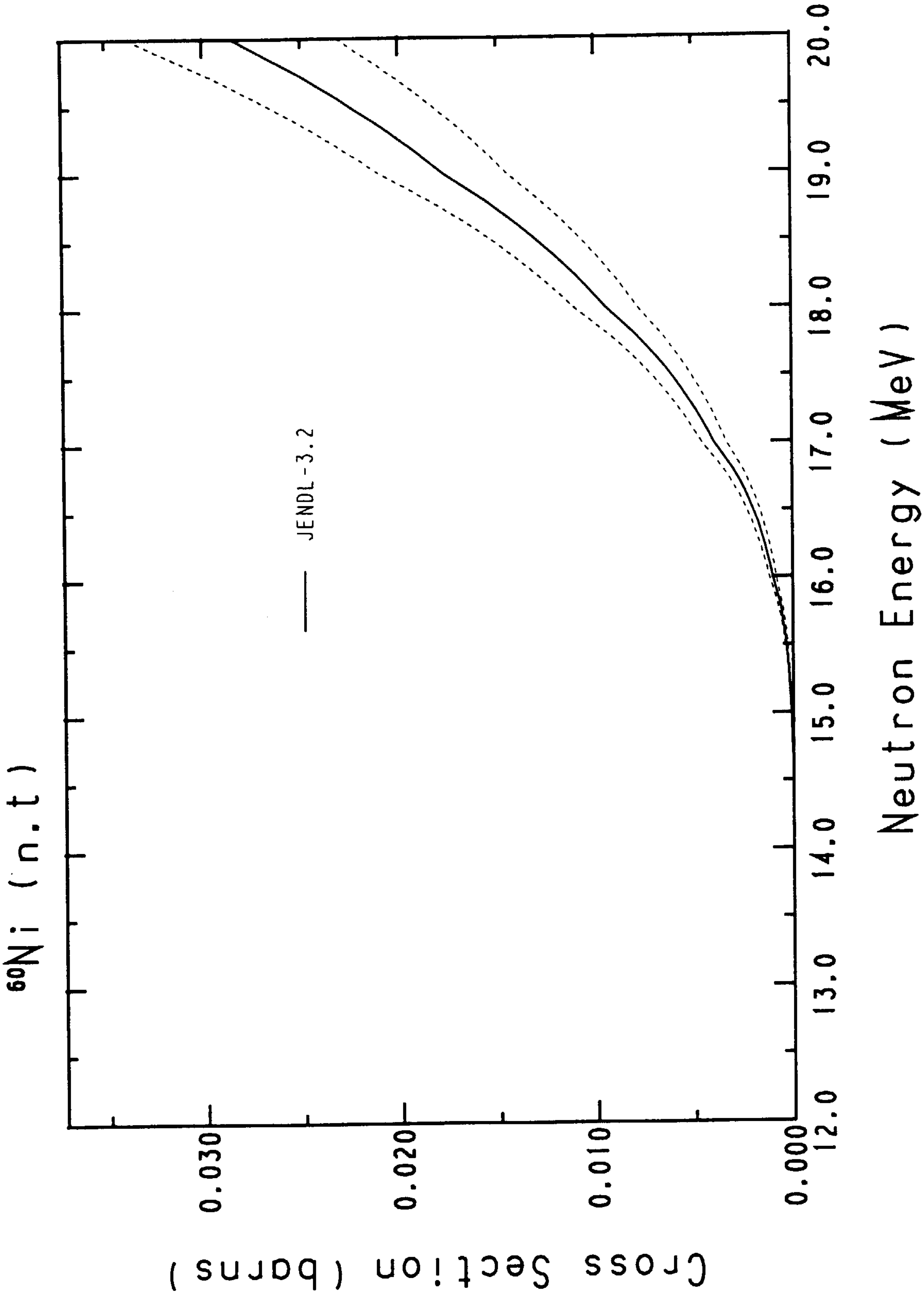

Fig. 34 (n,t) reaction cross section of ^{60}Ni.

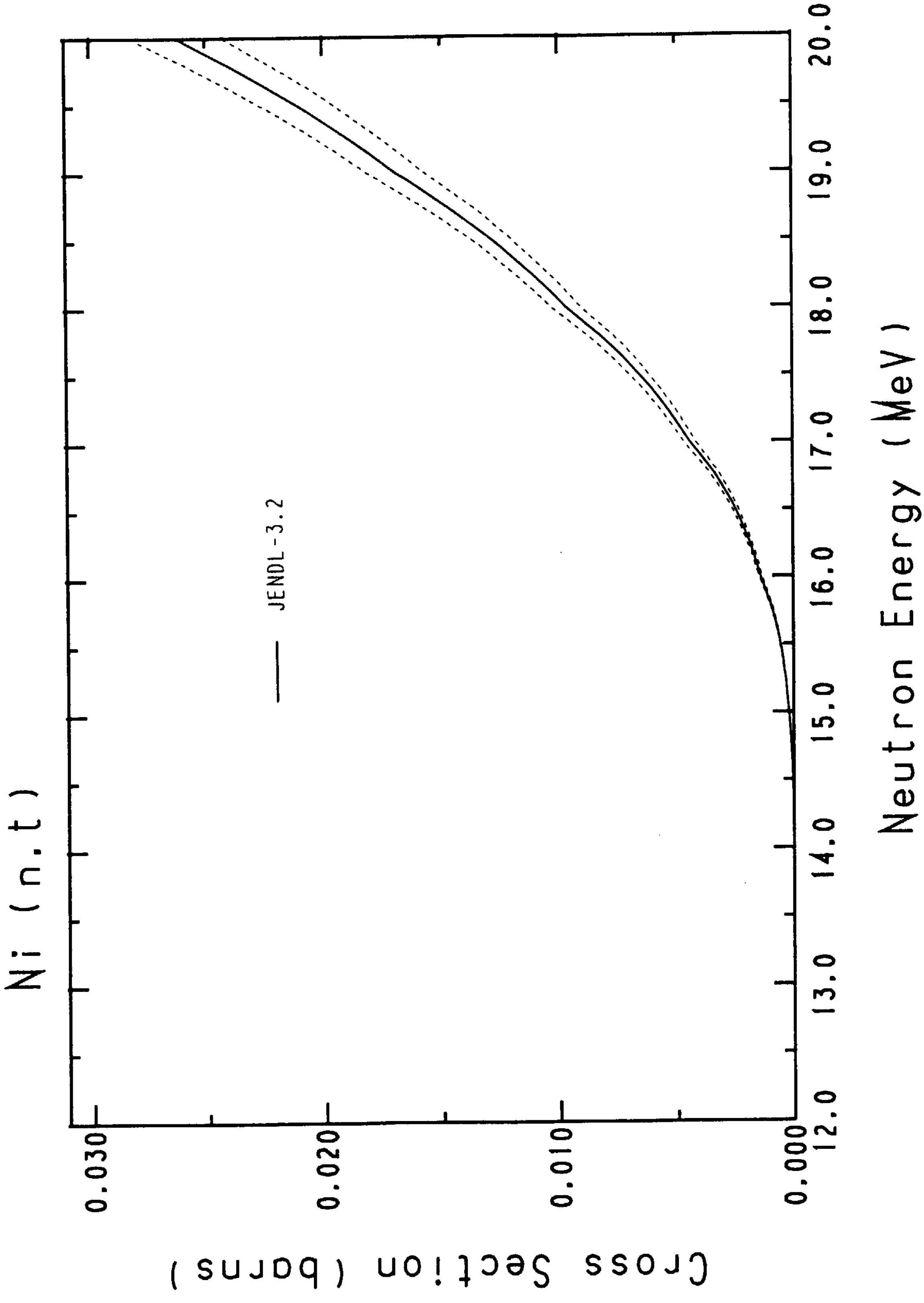

Fig. 35 (n,t) reaction cross section of elemental Ni.

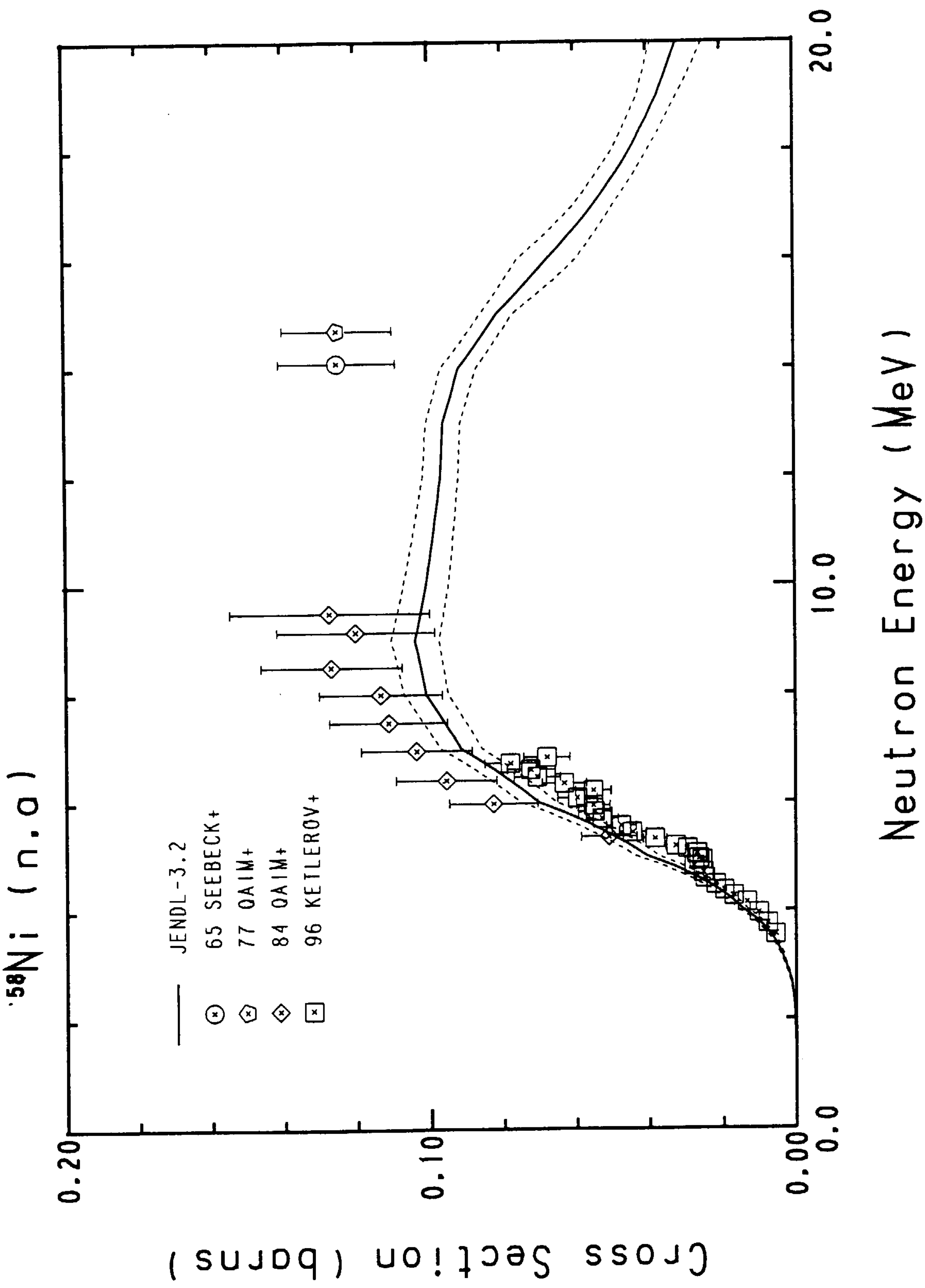

Fig. 36 (n,α) reaction cross section of ^{58}Ni.

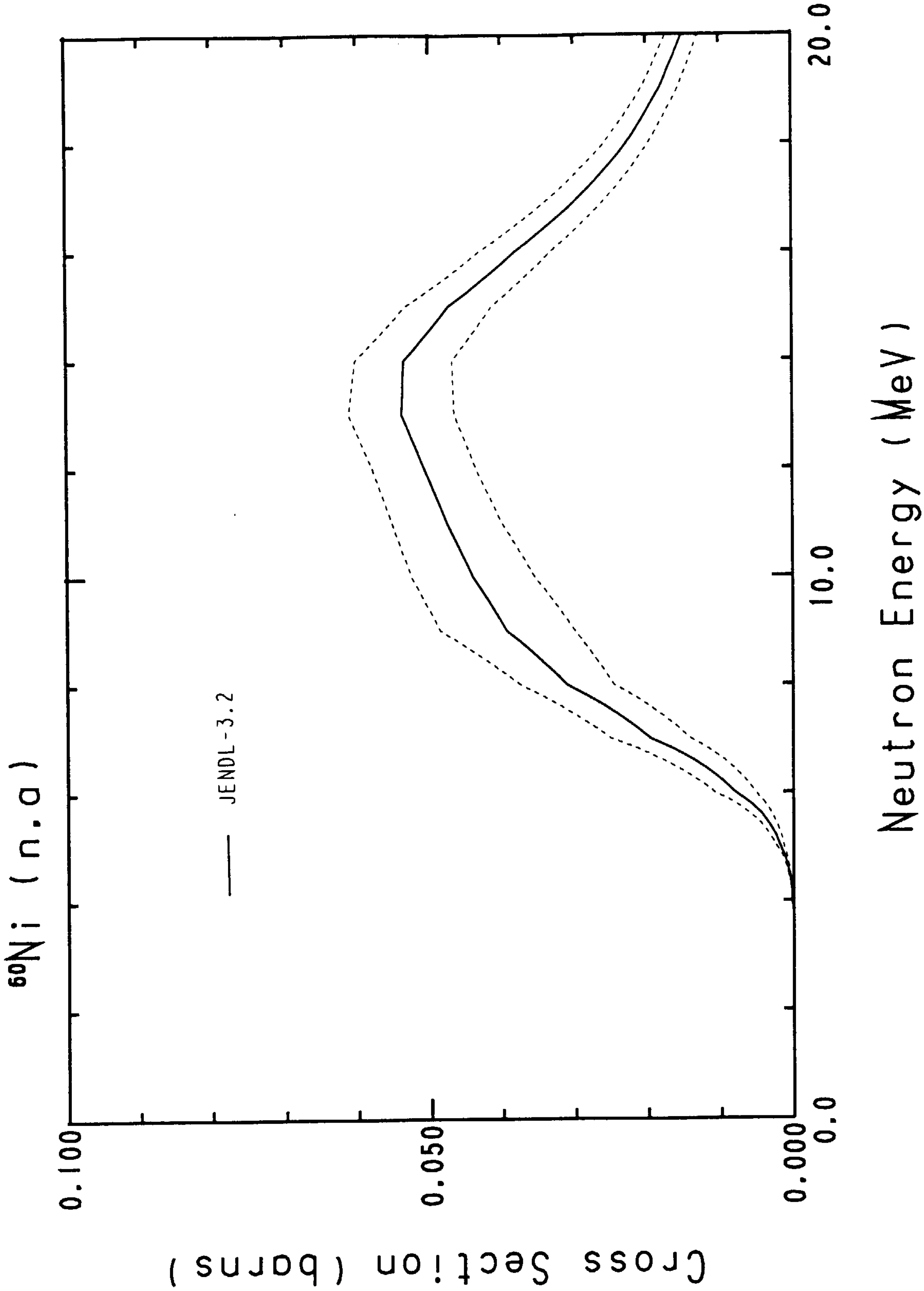

Fig. 37　(n,α) reaction cross section of ^{60}Ni.

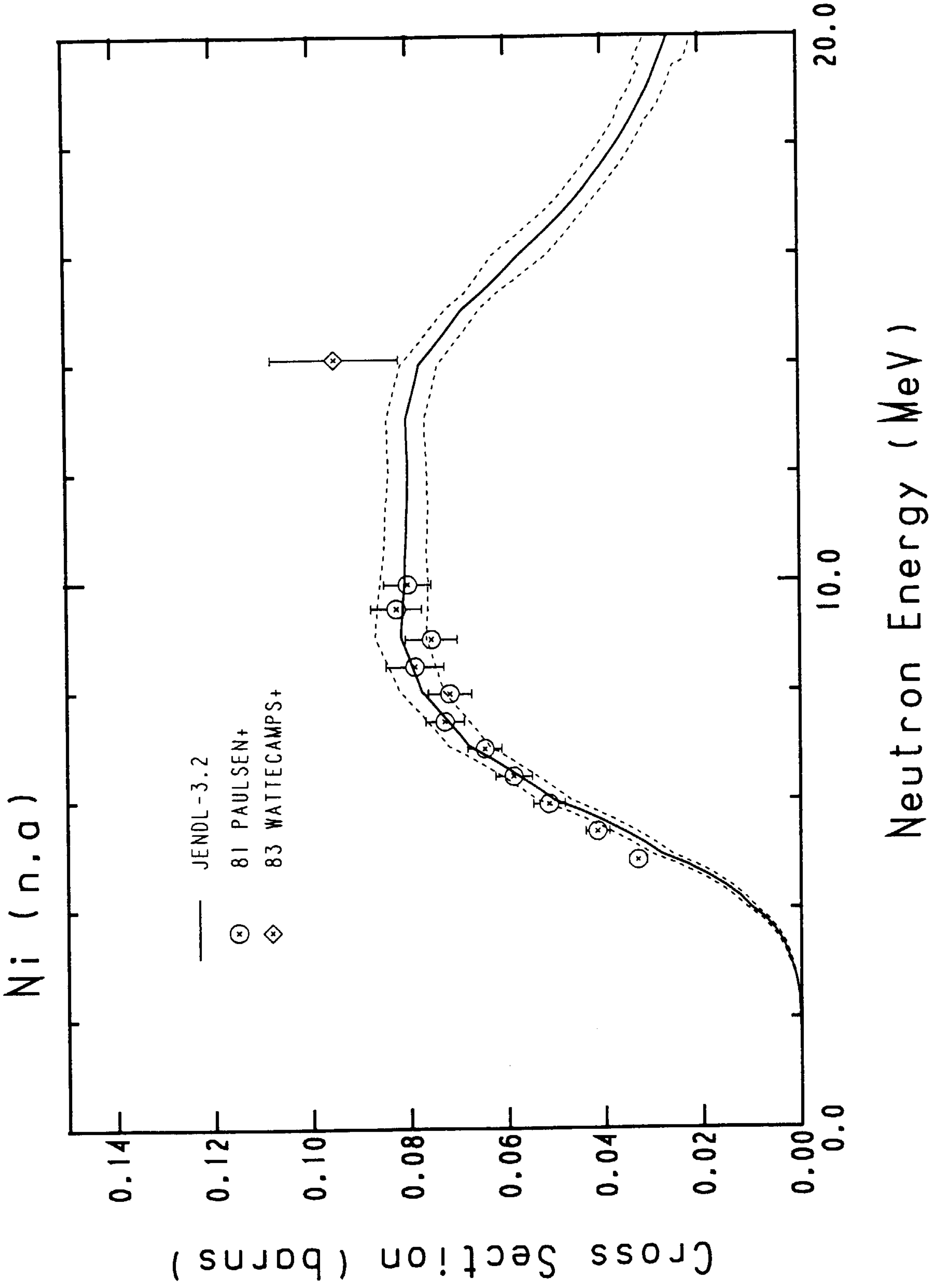

Fig. 38 (n,α) reaction cross section of elemental Ni.

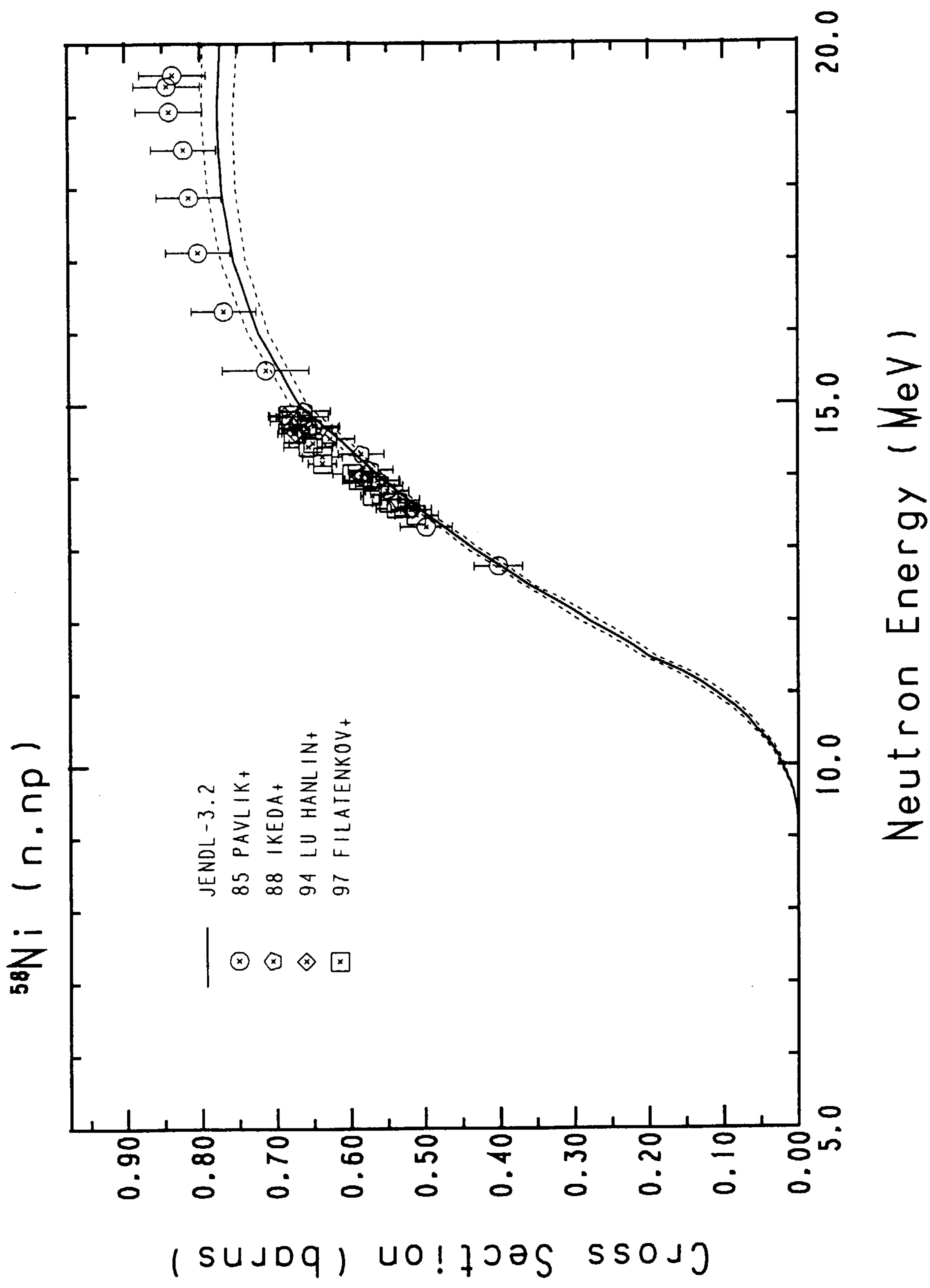

Fig. 39 (n,np) reaction cross section of ^{58}Ni.

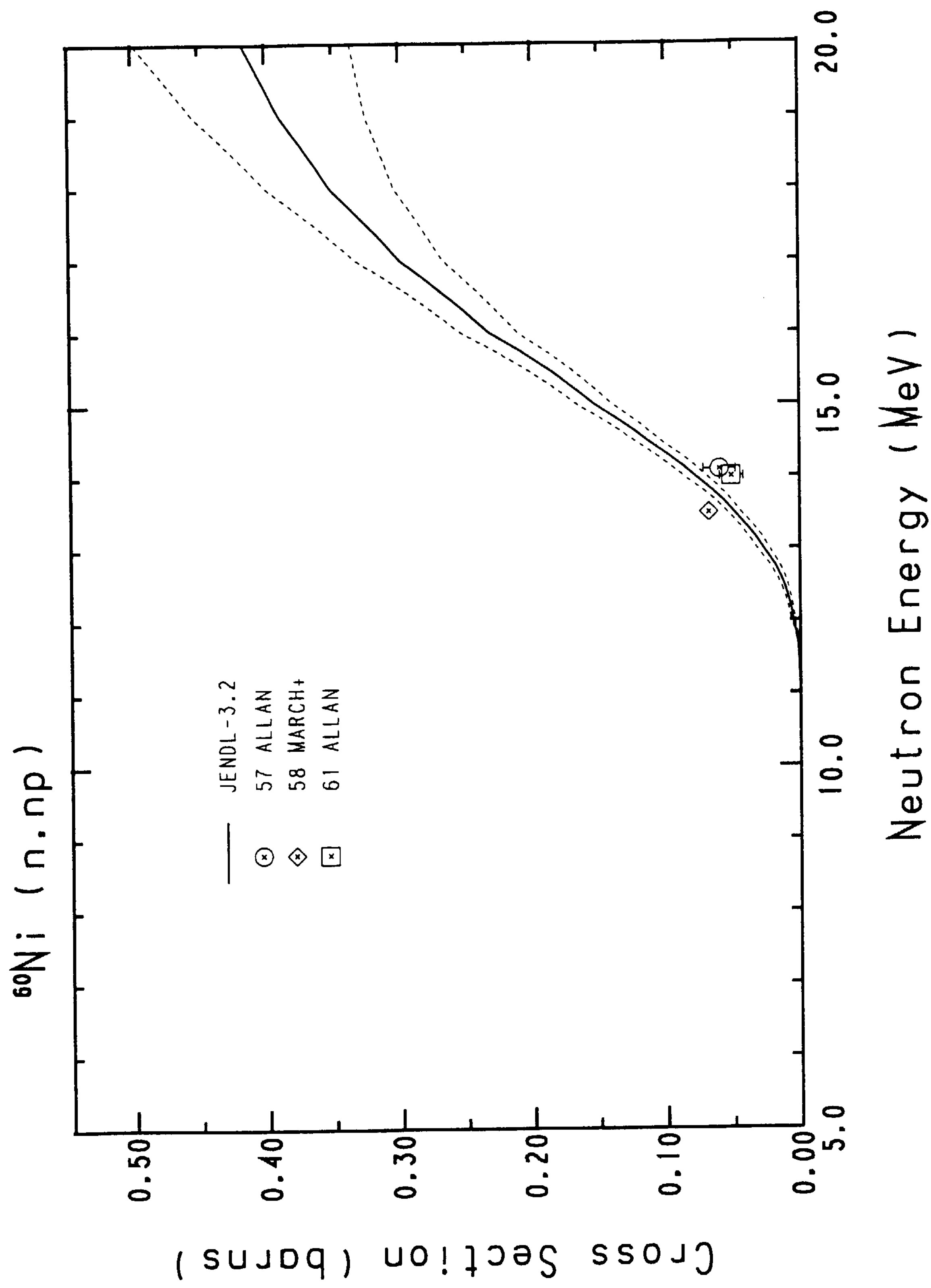

Fig. 40 (n,np) reaction cross section of ^{60}Ni.

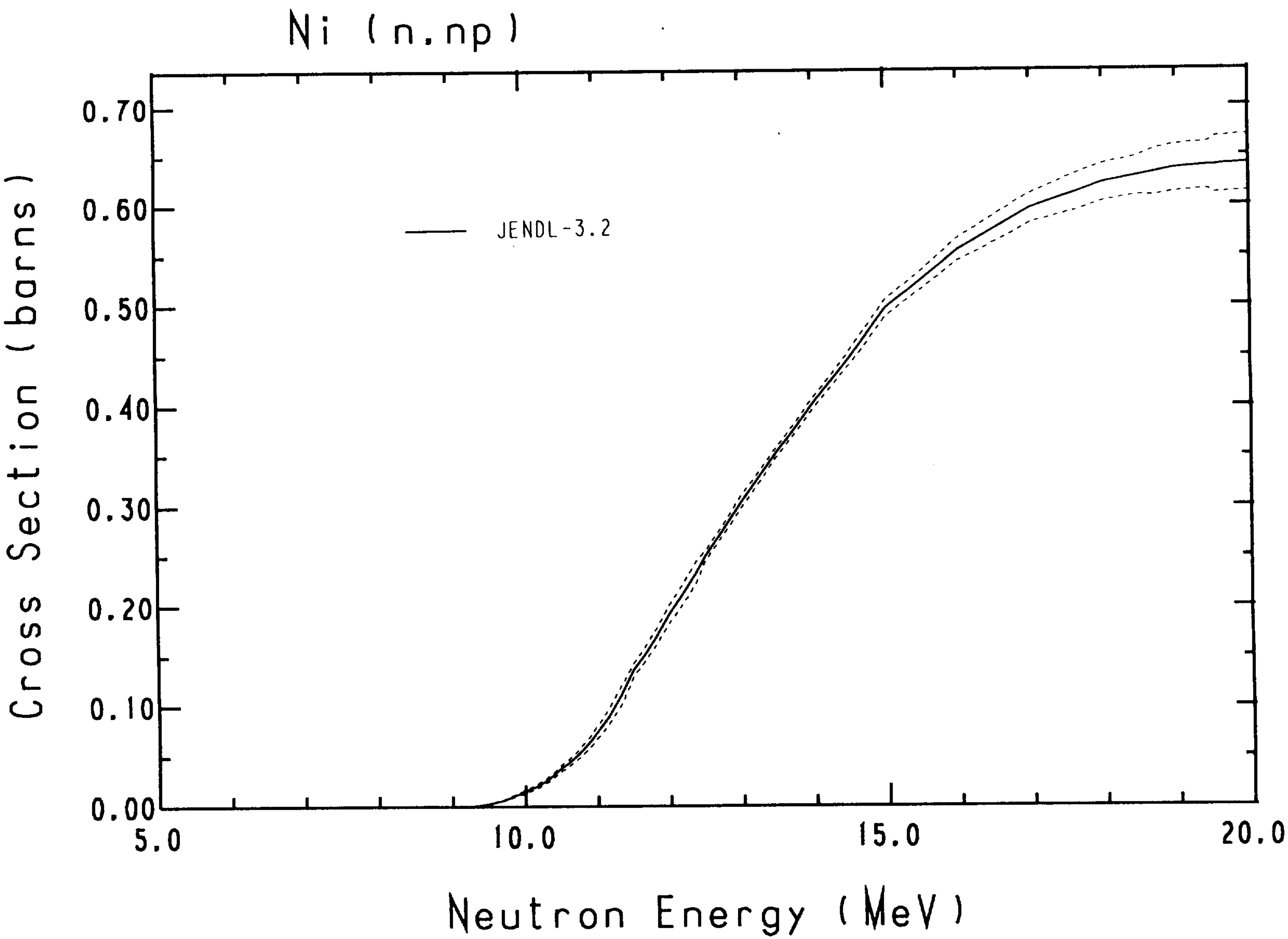

Fig. 41 (n,np) reaction cross section of elemental Ni.

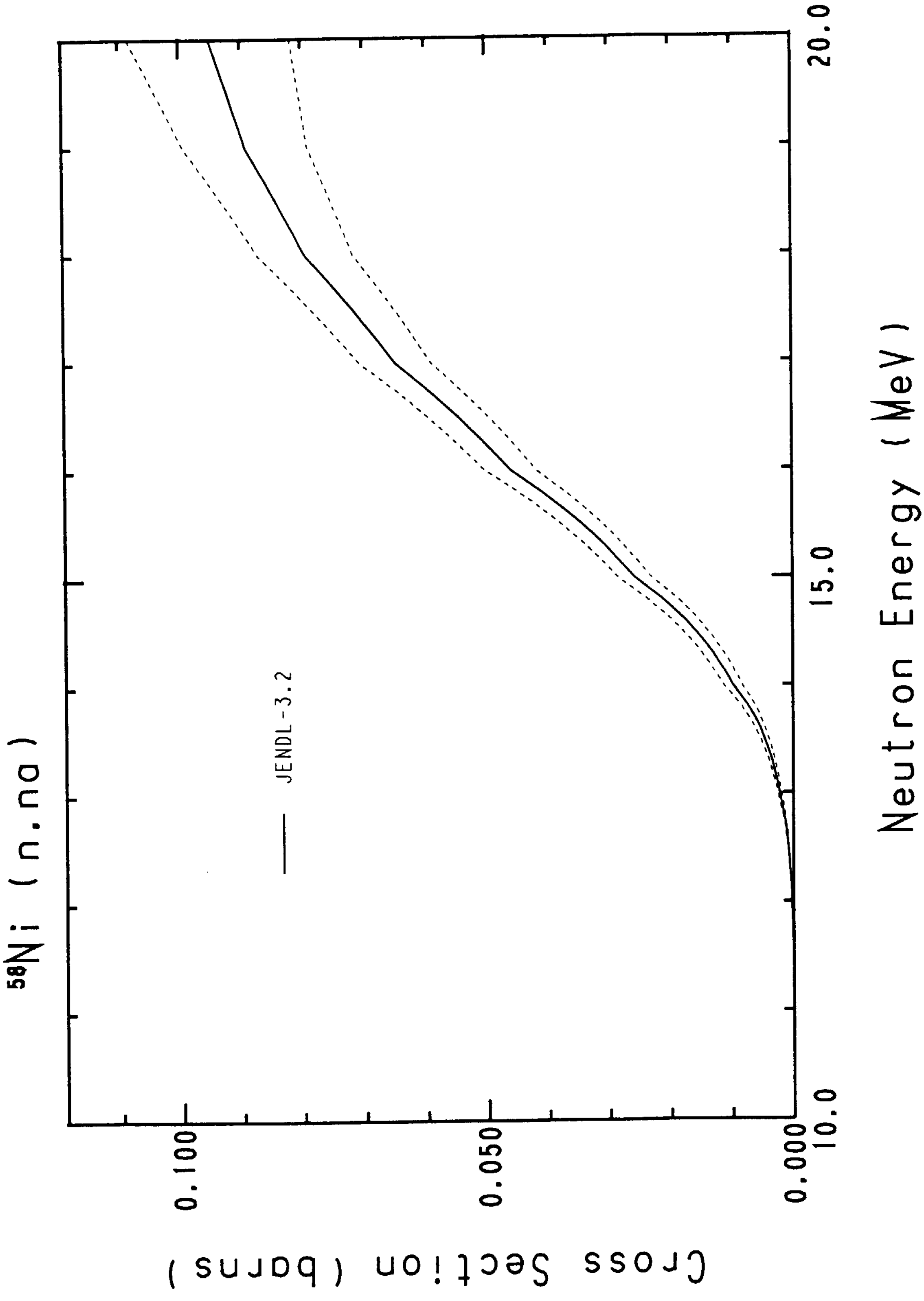

Fig. 42 (n,nα) reaction cross section of ^{58}Ni.

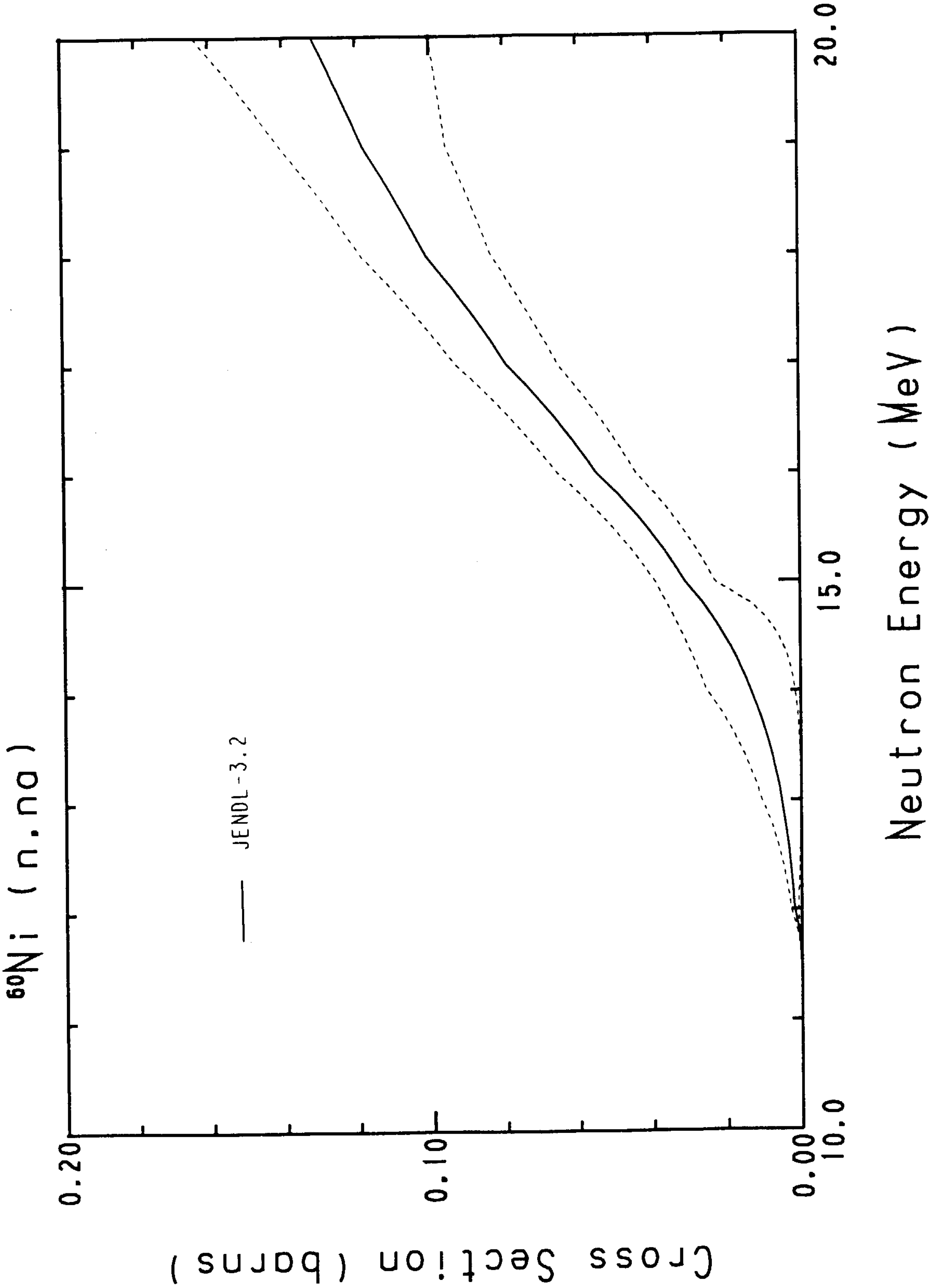

Fig. 43 (n,nα) reaction cross section of ^{60}Ni.

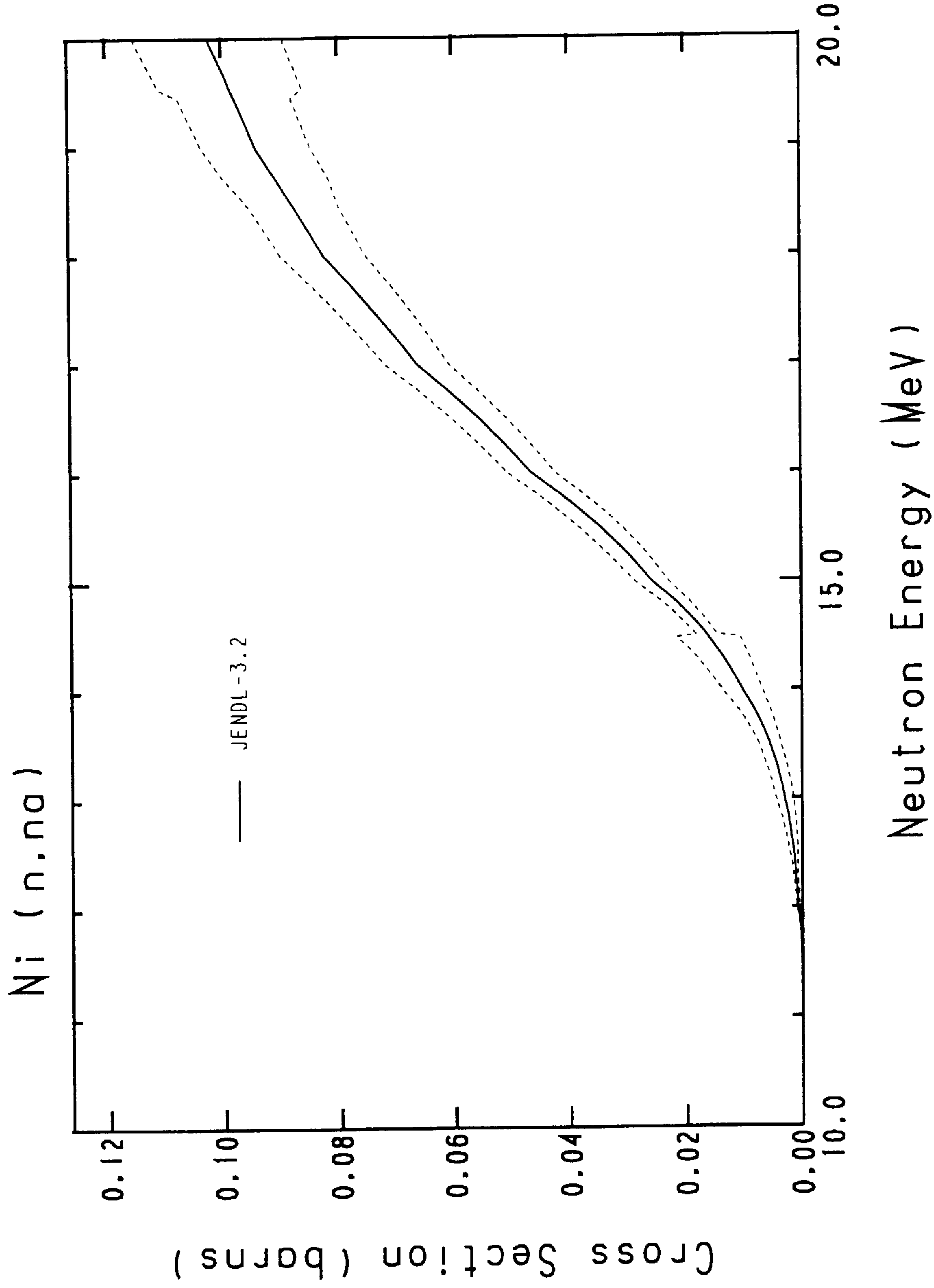

Fig. 44 (n,nα) reaction cross section of elemental Ni.

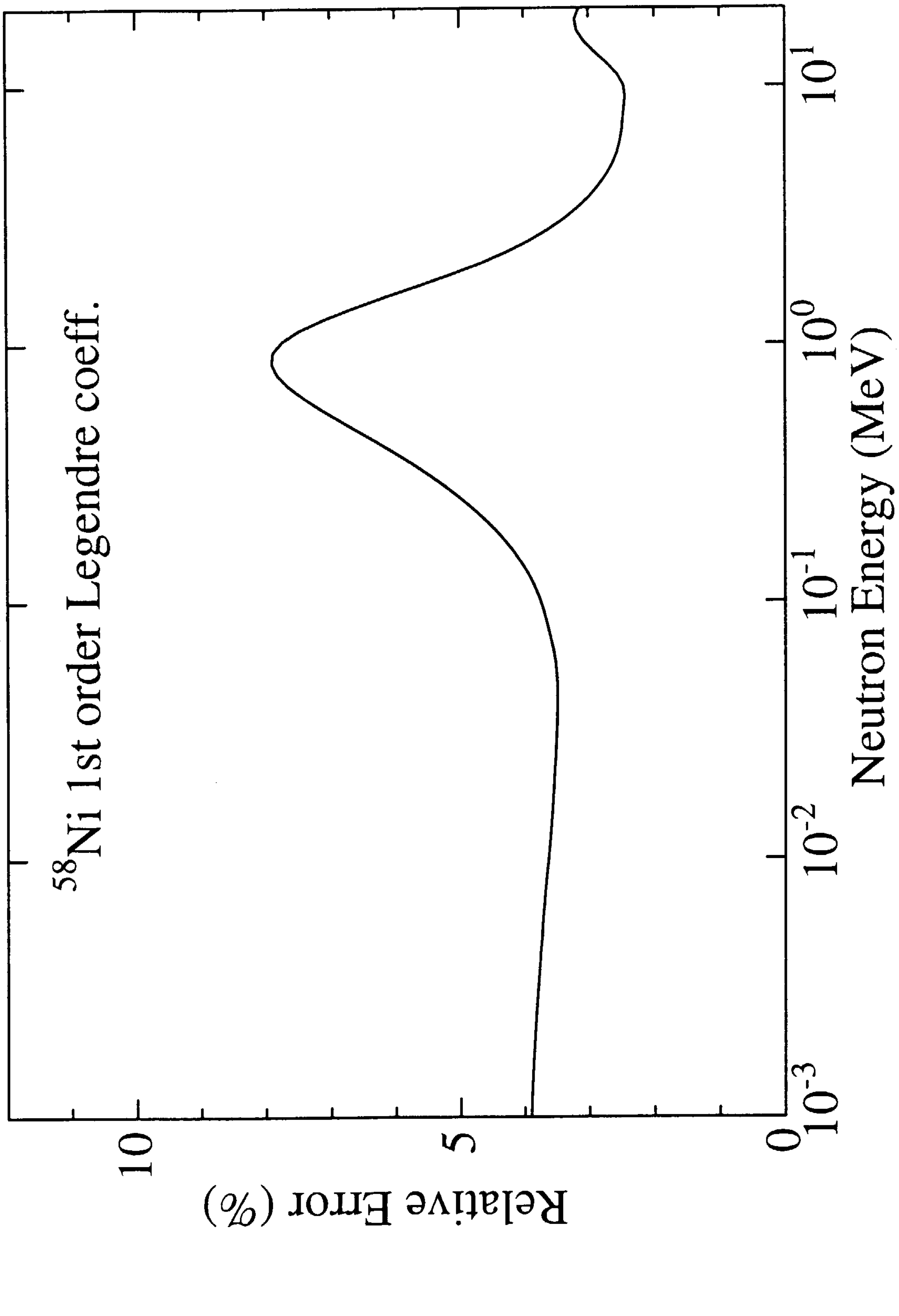

Fig. 45 Error of the 1st order Legendre-polynomial coefficient for ^{58}Ni.

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国際単位系(SI)と換算表

表1　SI基本単位および補助単位

量	名　称	記　号
長　さ	メートル	m
質　量	キログラム	kg
時　間	秒	s
電　流	アンペア	A
熱力学温度	ケルビン	K
物質量	モル	mol
光　度	カンデラ	cd
平面角	ラジアン	rad
立体角	ステラジアン	sr

表3　固有の名称をもつSI組立単位

量	名　称	記号	他のSI単位による表現
周波数	ヘルツ	Hz	s^{-1}
力	ニュートン	N	$m \cdot kg/s^2$
圧力，応力	パスカル	Pa	N/m^2
エネルギー，仕事，熱量	ジュール	J	$N \cdot m$
工率，放射束	ワット	W	J/s
電気量，電荷	クーロン	C	$A \cdot s$
電位，電圧，起電力	ボルト	V	W/A
静電容量	ファラド	F	C/V
電気抵抗	オーム	Ω	V/A
コンダクタンス	ジーメンス	S	A/V
磁束	ウェーバ	Wb	$V \cdot s$
磁束密度	テスラ	T	Wb/m^2
インダクタンス	ヘンリー	H	Wb/A
セルシウス温度	セルシウス度	℃	
光束	ルーメン	lm	$cd \cdot sr$
照度	ルクス	lx	lm/m^2
放射能	ベクレル	Bq	s^{-1}
吸収線量	グレイ	Gy	J/kg
線量当量	シーベルト	Sv	J/kg

表2　SIと併用される単位

名　称	記　号
分，時，日	min，h，d
度，分，秒	°，′，″
リットル	l，L
トン	t
電子ボルト	eV
原子質量単位	u

$1\ eV = 1.60218 \times 10^{-19}\ J$

$1\ u = 1.66054 \times 10^{-27}\ kg$

表4　SIと共に暫定的に維持される単位

名　称	記　号
オングストローム	Å
バーン	b
バール	bar
ガル	Gal
キュリー	Ci
レントゲン	R
ラド	rad
レム	rem

$1\ Å = 0.1\ nm = 10^{-10}\ m$

$1\ b = 100\ fm^2 = 10^{-28}\ m^2$

$1\ bar = 0.1\ MPa = 10^5\ Pa$

$1\ Gal = 1\ cm/s^2 = 10^{-2}\ m/s^2$

$1\ Ci = 3.7 \times 10^{10}\ Bq$

$1\ R = 2.58 \times 10^{-4}\ C/kg$

$1\ rad = 1\ cGy = 10^{-2}\ Gy$

$1\ rem = 1\ cSv = 10^{-2}\ Sv$

表5　SI接頭語

倍数	接頭語	記　号
10^{18}	エクサ	E
10^{15}	ペタ	P
10^{12}	テラ	T
10^{9}	ギガ	G
10^{6}	メガ	M
10^{3}	キロ	k
10^{2}	ヘクト	h
10^{1}	デカ	da
10^{-1}	デシ	d
10^{-2}	センチ	c
10^{-3}	ミリ	m
10^{-6}	マイクロ	μ
10^{-9}	ナノ	n
10^{-12}	ピコ	p
10^{-15}	フェムト	f
10^{-18}	アト	a

(注)

1. 表1－5は「国際単位系」第5版，国際度量衡局 1985年刊行による。ただし，1 eVおよび1 uの値はCODATAの1986年推奨値によった。
2. 表4には海里，ノット，アール，ヘクタールも含まれているが日常の単位なのでここでは省略した。
3. barは，JISでは流体の圧力を表わす場合に限り表2のカテゴリーに分類されている。
4. EC閣僚理事会指令ではbar，barnおよび「血圧の単位」mmHgを表2のカテゴリーに入れている。

換　算　表

力	N(=10^5dyn)	kgf	lbf
	1	0.101972	0.224809
	9.80665	1	2.20462
	4.44822	0.453592	1

粘　度　$1\ Pa \cdot s(N \cdot s/m^2) = 10\ P$(ポアズ)$(g/(cm \cdot s))$

動粘度　$1\ m^2/s = 10^4 St$(ストークス)(cm^2/s)

圧力	MPa(=10 bar)	kgf/cm^2	atm	mmHg(Torr)	lbf/in^2(psi)
	1	10.1972	9.86923	7.50062×10^3	145.038
	0.0980665	1	0.967841	735.559	14.2233
	0.101325	1.03323	1	760	14.6959
	1.33322×10^{-4}	1.35951×10^{-3}	1.31579×10^{-3}	1	1.93368×10^{-2}
	6.89476×10^{-3}	7.03070×10^{-2}	6.80460×10^{-2}	51.7149	1

エネルギー・仕事・熱量	J(=10^7 erg)	kgf・m	kW・h	cal(計量法)	Btu	ft・lbf	eV
	1	0.101972	2.77778×10^{-7}	0.238889	9.47813×10^{-4}	0.737562	6.24150×10^{18}
	9.80665	1	2.72407×10^{-6}	2.34270	9.29487×10^{-3}	7.23301	6.12082×10^{19}
	3.6×10^6	3.67098×10^5	1	8.59999×10^5	3412.13	2.65522×10^6	2.24694×10^{25}
	4.18605	0.426858	1.16279×10^{-6}	1	3.96759×10^{-3}	3.08747	2.61272×10^{19}
	1055.06	107.586	2.93072×10^{-4}	252.042	1	778.172	6.58515×10^{21}
	1.35582	0.138255	3.76616×10^{-7}	0.323890	1.28506×10^{-3}	1	8.46233×10^{18}
	1.60218×10^{-19}	1.63377×10^{-20}	4.45050×10^{-26}	3.82743×10^{-20}	1.51857×10^{-22}	1.18171×10^{-19}	1

1 cal = 4.18605 J(計量法)
= 4.184 J　(熱化学)
= 4.1855 J　(15 °C)
= 4.1868 J(国際蒸気表)

仕事率　1 PS(仏馬力)
= 75 kgf・m/s
= 735.499 W

放射能	Bq	Ci
	1	2.70270×10^{-11}
	3.7×10^{10}	1

吸収線量	Gy	rad
	1	100
	0.01	1

照射線量	C/kg	R
	1	3876
	2.58×10^{-4}	1

線量当量	Sv	rem
	1	100
	0.01	1

(86年12月26日現在)

ESTIMATION OF COVARIANCES OF CR AND NI NEUTRON NUCLEAR DATA IN JENDL-3.2