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Evaluation of Neutron Nuclear Data of Natural Calcium for CENDL-1

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ABSTRACT:

Neutron nuclear data of natural calcium for CENDL-1 has been evaluated in the energy region from 10^{-5} ev to 20 MeV. Evaluated quantities are the total, non-elastic scattering, elastic and inelastic scattering, radiation capture, (n,p), (n,t), (n,2n), (n,a) reaction cross sections and the angular distributions of elastic and inelastic cross sections. Some of the data were calculated with the program AUJP[1] based on optical model and the program MUP2[2] based on Hauser-Feshbach model and pre-equilibrium evaporation model.

Keywords: Evaluation, Neutron nuclear data, Natural calcium, Cross section, CENDL-1, Optical model, Hauser-Feshbach model, Pre-equilibrium evaporation model, 10^{-5}ev-20MeV.

1. Introduction

Natural Calcium is a component of reactor structure. Therefore the neutron nuclear data of natural calcium is important for improvement of the reactor design. Except the total cross section, there are not so mang experiment data of natural calcium. A few data sets on the non-elastic scattering, elastic and inelastic cross section and the capture cross sections were measured. There are no or almost no experiment data on channels of (n,t), (n,2n), (n,p), (n,a), (n,np), (n,na) reactions for

natural calcium. All the missing data (including the data of energy angular distribution of secondary neutrons) were calculated using program AUJP and MUP2, which was made basing on optical, Hauser-Feshbach and pre-equilibrium evaporation models. All the data of natural calcium were recommended in ENDF/B4 format.

2. The total cross section

There are a lot of data on the total cross section since 1968. Most of them were measured with white light neutron source and TOF method. Below 10 MeV we adopted the original data from the data measured in a certain laboratory in different energy ranges.

In the energy range of 10^{-5} ev to 1.6kev, we calculated the value using the resonance parameters and potential scattering radius given by S. F. Mughabghab et al [3]. and multiple-level B-W formula and 1/v law. The result has been compared with the value measured by A. Abdel et al.[4]

In the energy range of 1.6kev to 0.55 MeV, The recent measured data[5] were recommended. The uncertainty is about 2.0%.

In the energy range of 0.56 to 14 MeV, we adopted the data measured by R. B. Schwartz[6] in 1974. The uncertainty is about 1.5% to 2.0%.

In the energy range of 14.0-20.0 MeV, the data measured by Lorsout et al,[7] were recommended.

3. Non-elastic scattering cross section

All the collected experiment data for this reaction channel are listed in table 1. Our recommended data were given by the sum of all the reaction cross section except the elastic scattering. The experimental data shown on table 1 were used for adjusting the parameters in the calculation.

Table 1.

Year	Author	Energy (MeV)	Result(bar)
1956	V. I. Strizhak [8]	2.5	0.40±0.20
1962	D. W. Kent [9]	3.66±0.4	0.49±0.25
1960	L. D. Vincent [10]	4.0±0.1	0.70±0.30
1956	J. R. Beyster [11]	7.0	1.14±0.07
1956	N. N. Flerov [12]	14.5±0.02	1.36±0.02

4. The cross section of the elastic and inelastic scattering

All the elastic scattering cross section was given by the difference between the total and the cross section of non-elastic scattering. For the inelastic scattering cross section we only found the measured data of ^{40}Ca in the levels of 3.35 MeV, 3.75 MeV and 3.90 MeV and the results were shown on table 2. Therefore we use the calculated data as recommendation value and compared them with ^{40}Ca experiment data.

Table 2.

Year	Author	Level(MeV)	Energy(MeV)	Uncertainty
1966	R. Bass [13]	3.35	3.5-6.0	20%
		3.37	3.9-6.0	20%
		3.90	4.1-6.0	20%
1970	F. G. Perey[14]	3.35	5.0-8.25	8%
		3.73	5.0-5.50	8%
		3.90	5.18	8%
1981	C.M. Bartle[15]	3.35	3.51-5.38	<8%

5. Capture cross section

Below 1.5 MeV the excitation curve of (n,u) reaction for natural calcium has structures. We only found the experiment data at thermal and 14 MeV[16,17,18]. Therefore in the energy range of 10^{-5} eV to 1.2 MeV the cross section (0.43±0.04) was calculated using the cross section at thermal point and the resonance parameters given by S. F. Mughabghab et al. and the 1/V law. In the energy of 1.2 to 20 MeV the cross section was calculated using the program MUP2. The experiment data at 14 MeV (0.53±0.09bar) were used to determine the parameters in the program.

6. The (n,p) reaction

Only cross sections of calcium isotopes at 14 MeV could be found.[19,20] From them we took the cross section (459±21)mb as the natural calcium corresponding value at 14.1 MeV. All the calculated cross section of (n,p) reaction was recommended.

7. The (n,t) reaction

Fitted cross section of ^{40}Ca for the (n,t) reaction in the energy range of 14.9 to 19.6 MeV[21] was recommended as (n,t) cross section of natural calcium. The value was consistent with the systematic treated data given by Zhou Delin [22] and there was large difference comparing with the value calculated using program MUP2.

8. The (n,2n) reaction

Although the measured (n,2n) cross section of ^{40}Ca exists[23], but the natural calcium corresponding data can not be replaced by the ^{40}Ca data because their thresholds are quiet different. Therefore we recommended the theoretical data.

9. The (n,a), (n,na), (n,np) reactions

For these reactions only the experiment cross sections of ^{40}Ca[24,25,26] could be found at a few energy points. So all the recommended data were taken from model calculations.

10. The angular distribution of the elastic and the inelastic scattering cross section and secondary neutron energy

For angular distribution of elastic scattering cross sections 13 reference literatures have been collected and 8 of them are shown on table 3. In the energy range below 4 MeV the data measured by A. B. Smith[27] and R. O. Lame[28] were recommended. Above the energy the theoretical calculation data were used. For the angular distribution of inelastic scattering cross section and secondary neutron energy, no experiment data have been found and the theoretical calculated data were used.

Table 3.

Year	Author	E(MeV)	Uncertainty	Technical
1961	R.O. Lane [28]	0.03-1.81	10%	4 Detectors
1982	A.B. Smith [27]	1.60-8.35	5%	TOF
1969	B. Holmquvist [29]	6.09-8.05	5%	TOF
1970	F.G. Perey [14]	5.5-8.52	5%	TOF
1977	J.C. Ferrer [30]	11.0	3-5%	TOF
1966	A.J. Frasca [31]	14.0	5-10%	TOF
1977	J. Rapaport [32]	20.0	5-10%	TOF

11. Conclusion and Discussion

Our recommended data sets compared with ENDF/B4 and JANDL-2 are shown in Fig.1 to 8. From these results one sees:

1) The evaluated cross sections of the elastic scattering and the non-elastic scattering are well consist with the experimental value, especially at the 14.5 MeV point. The systematical adjusting for the data set have improved the results.

2) In the neutron energy below 4MeV, the data of the elastic scattering angular distribution were adopted from the data measured by A. B. Smith et al.[27], which improved the recommended data.

3) For the recommended data of total cross section in the higher neutron energy, the new data measured by Lorsont et al[7] were used.

The (n,t) reaction cross section of natural calcium was replaced by ^{40}Ca corresponding data, which were well consistent with the systematically calculated value done by Prof. Zhou Delin. We thought that would be more reasonable.

12. Acknowledgments

The authors would like to thank Dr. Zhou Delin for his systematic calculation program and his advice throughout this work. We also thank Dr. Liu Tingjin and Dr. Yu Baosheng for their useful help in translating the programs to us.

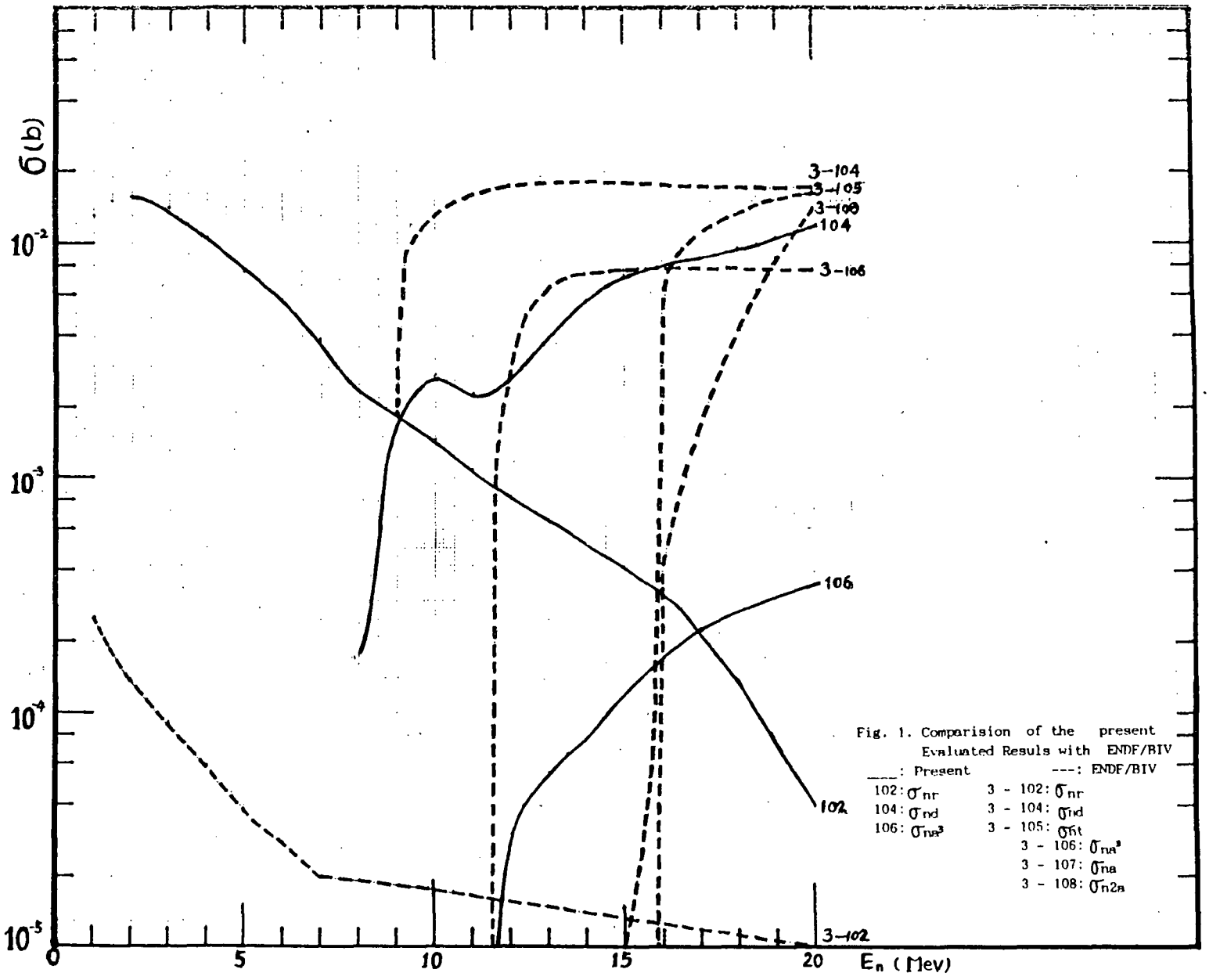


Fig. 1. Comparision of the present Evaluated Resuls with ENDF/BIV

____: Present ---: ENDF/BIV

102: σ_{nr} 3 - 102: σ_{nr}

104: σ_{nd} 3 - 104: σ_{nd}

106: σ_{na^3} 3 - 105: σ_{nt}

3 - 106: σ_{na^3}

3 - 107: σ_{na}

3 - 108: σ_{n2a}

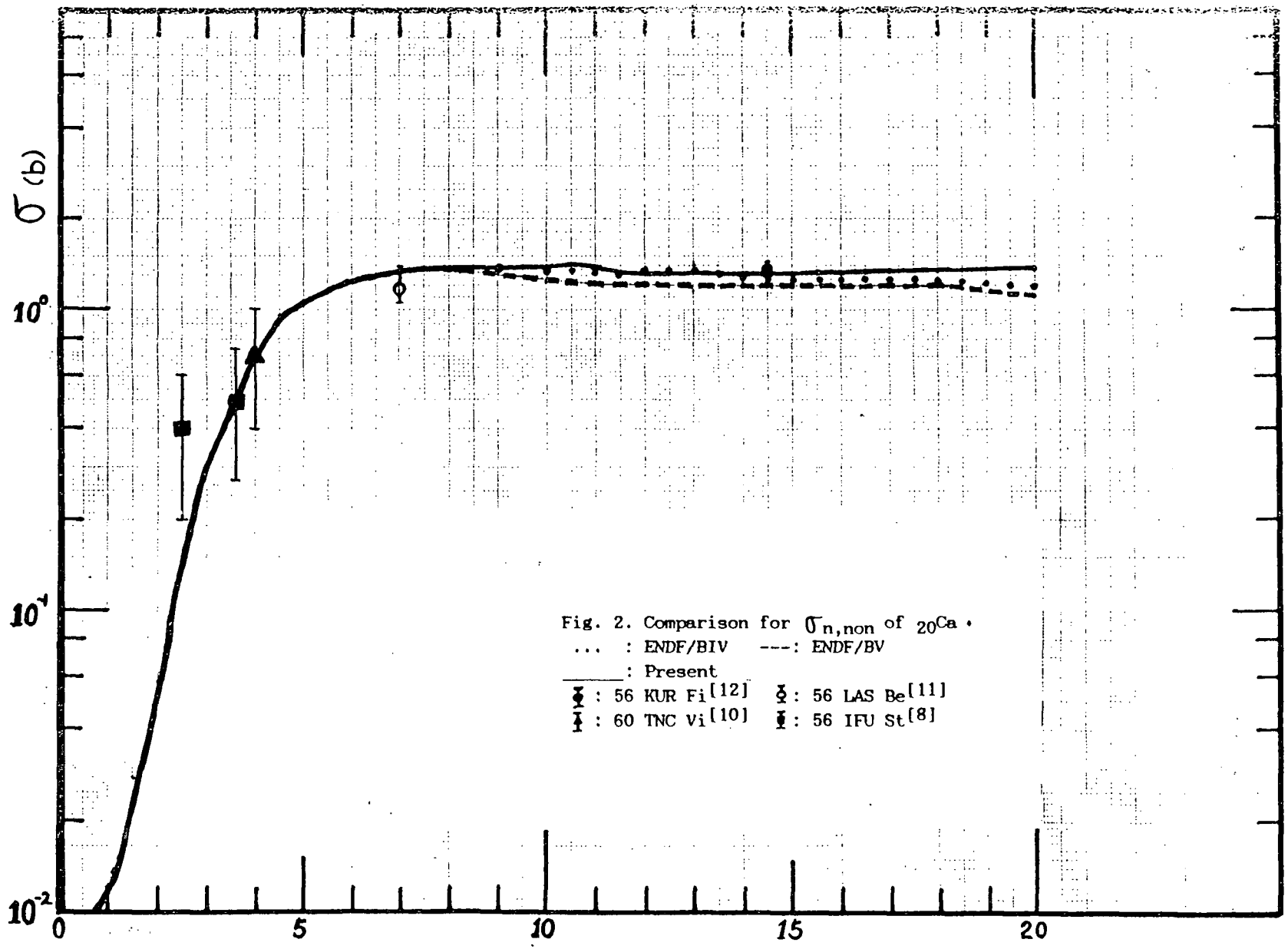


Fig. 2. Comparison for $\sigma_{n,non}$ of $_{20}Ca$.
... : ENDF/BIV ---: ENDF/BV
_____: Present
: 56 KUR Fi[12] : 56 LAS Be[11]
: 60 TNC Vi[10] : 56 IFU St[8]

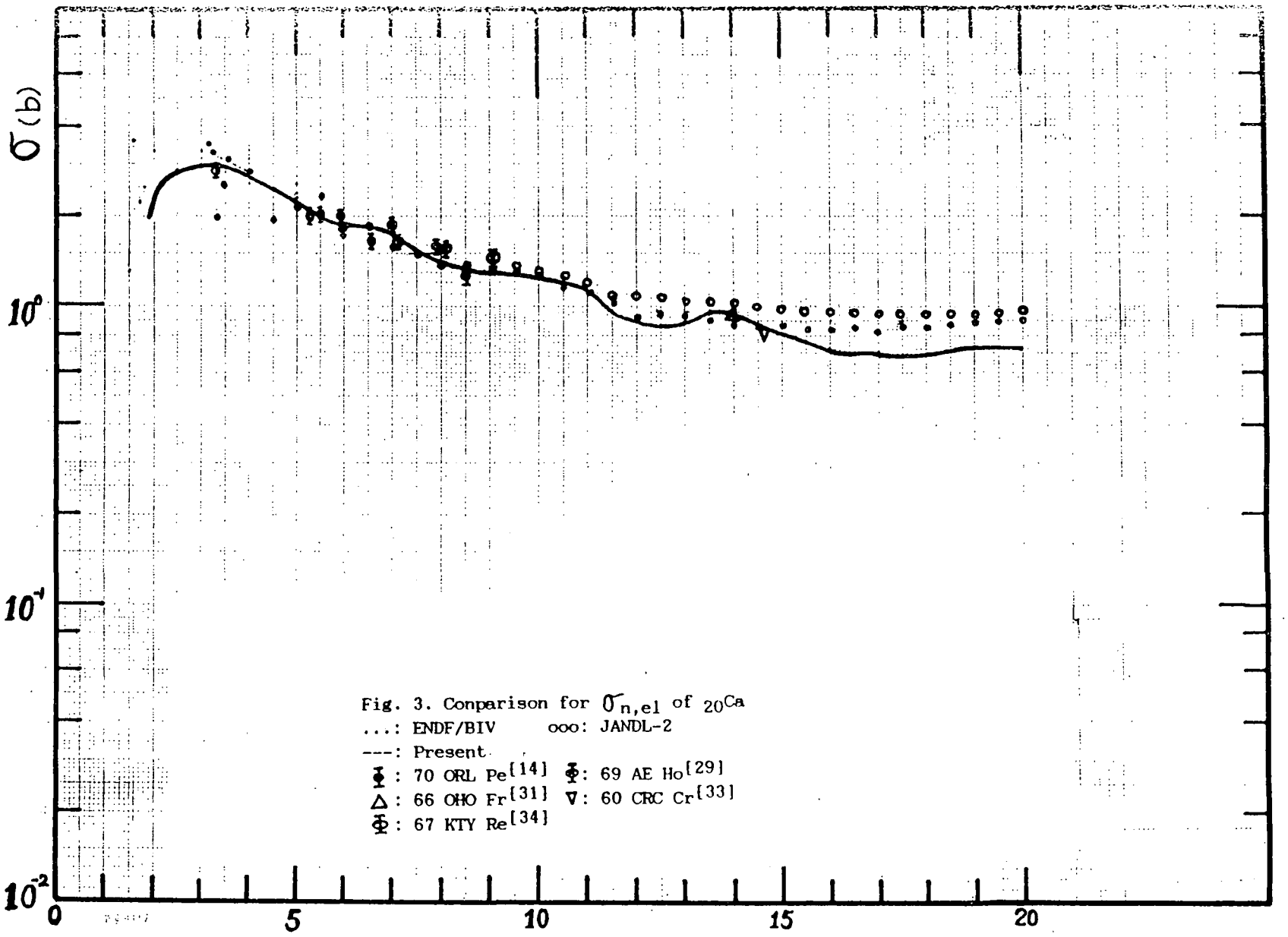


Fig. 3. Conparison for $\sigma_{n,el}$ of $_{20}Ca$

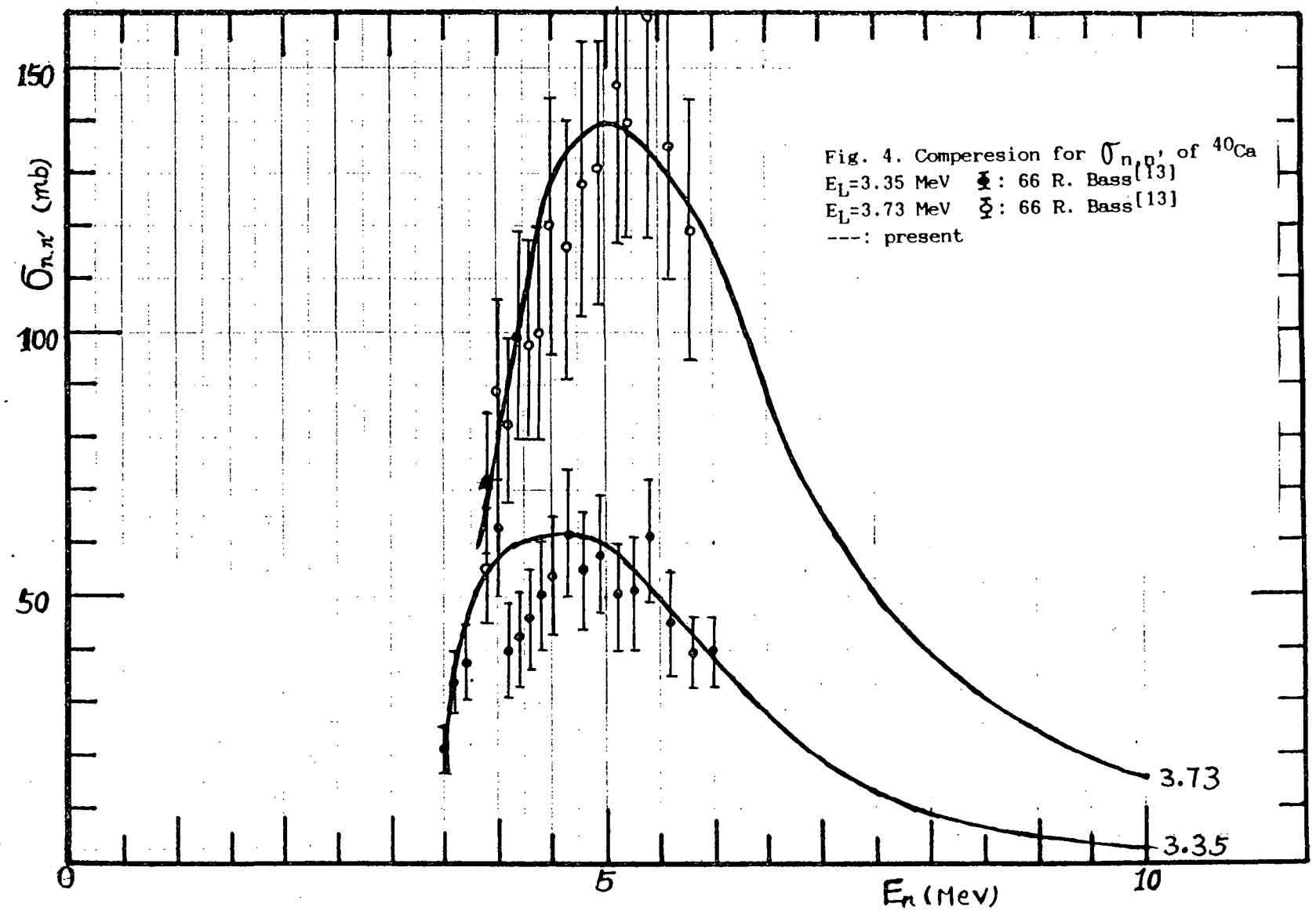
...: ENDF/BIV ooo: JANDL-2

---: Present

Ⱦ : 70 ORL Pe[14] Φ: 69 AE Ho[29]

△ : 66 OHO Fr[31] ∇: 60 CRC Cr[33]

Φ : 67 KTY Re[34]


150
100
50
0
5
10
$\sigma_{n,n'}$ (mb)
E_n (MeV)
3.73
3.35
Fig. 4. Comperesion for $\sigma_{n,n'}$ of ^{40}Ca
E_L=3.35 MeV ⊕: 66 R. Bass[13]
E_L=3.73 MeV ⊖: 66 R. Bass[13]
---: present

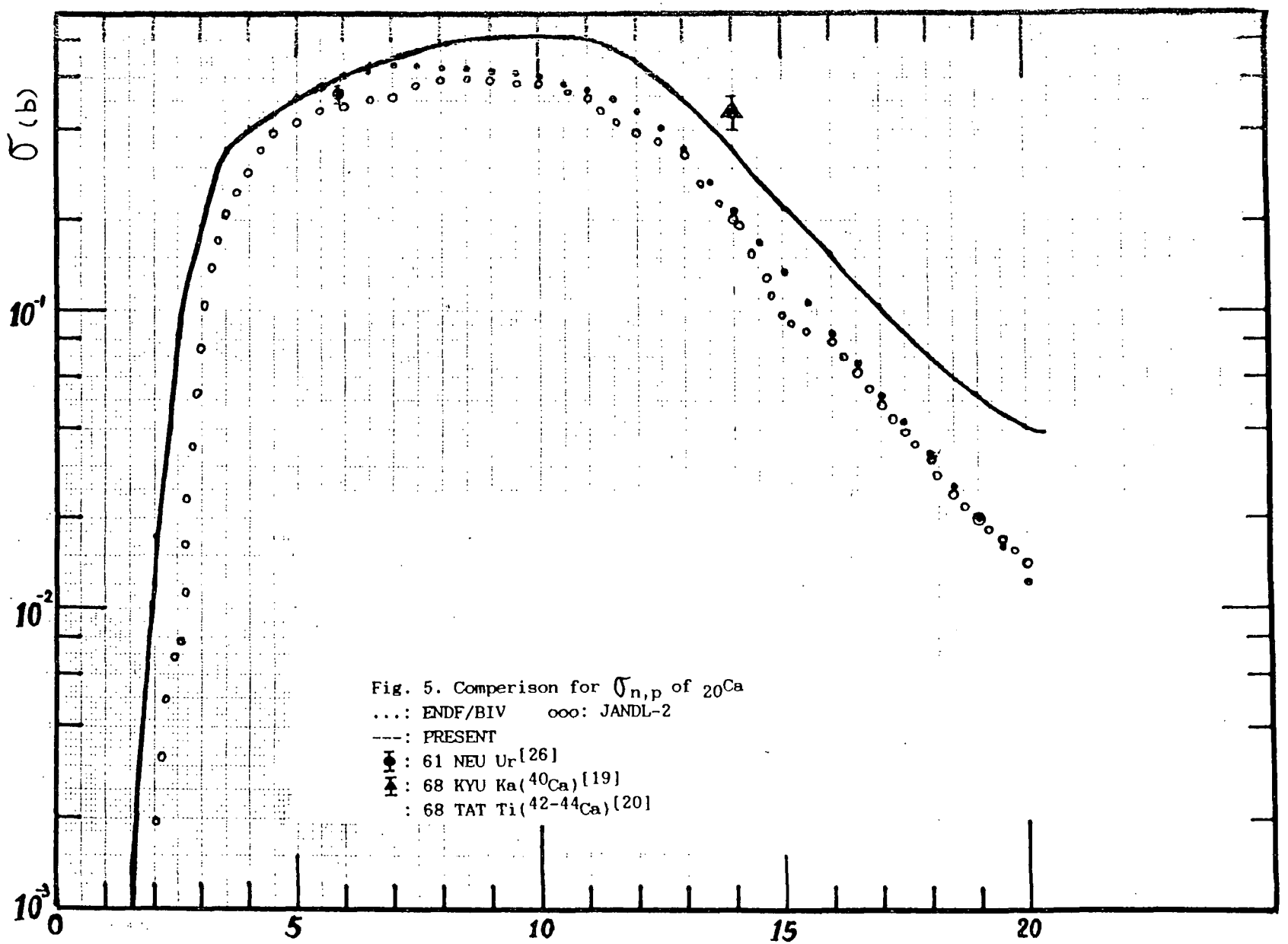


Fig. 5. Comperison for $\sigma_{n,p}$ of $_{20}Ca$

...: ENDF/BIV ooo: JANDL-2

---: PRESENT

: 61 NEU Ur[26]

: 68 KYU Ka(^{40}Ca)[19]

: 68 TAT Ti($^{42-44}Ca$)[20]

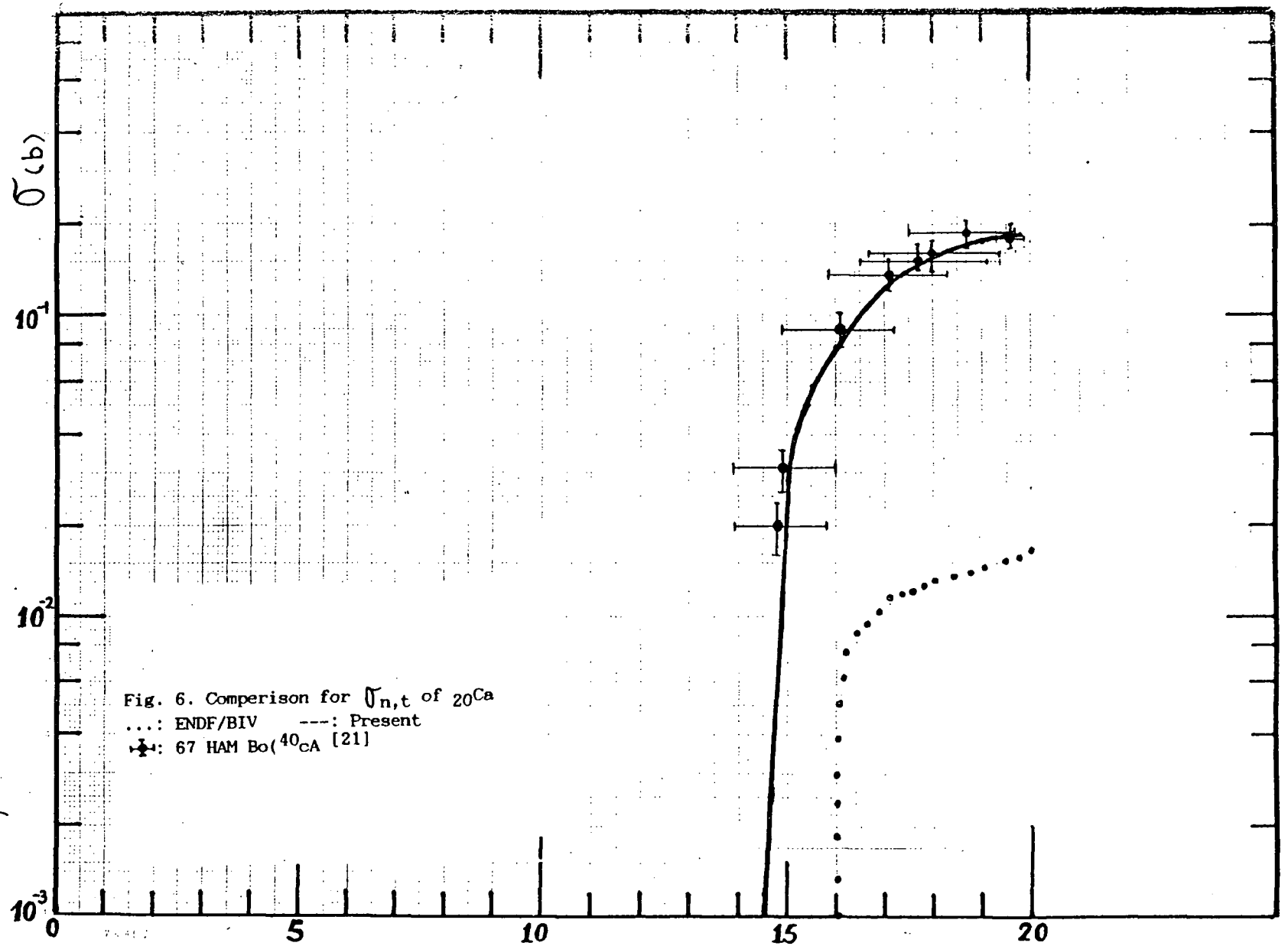


Fig. 6. Comperison for $\sigma_{n,t}$ of $_{20}Ca$
...: ENDF/BIV ---: Present
✚: 67 HAM Bo(^{40}cA [21]

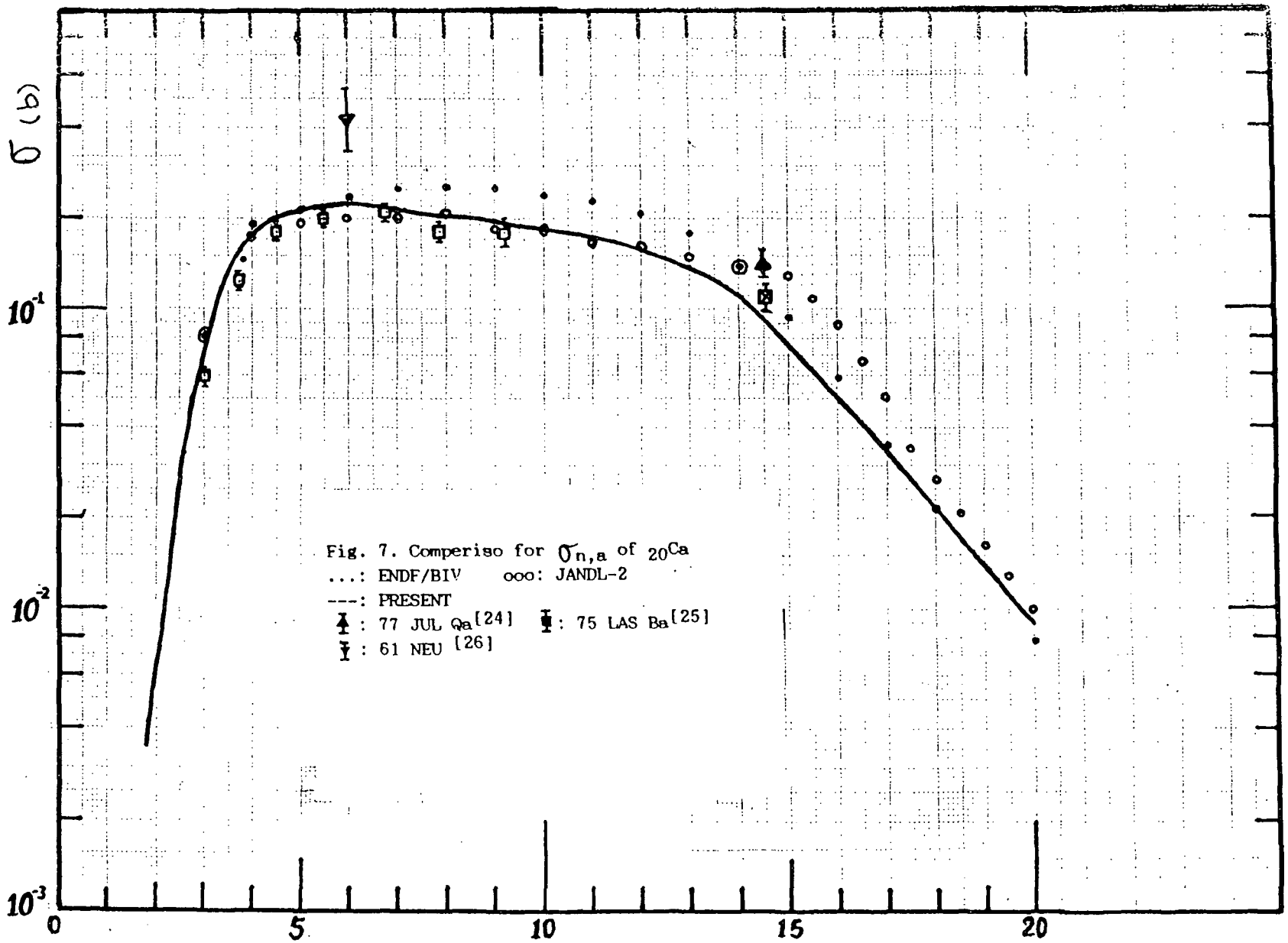
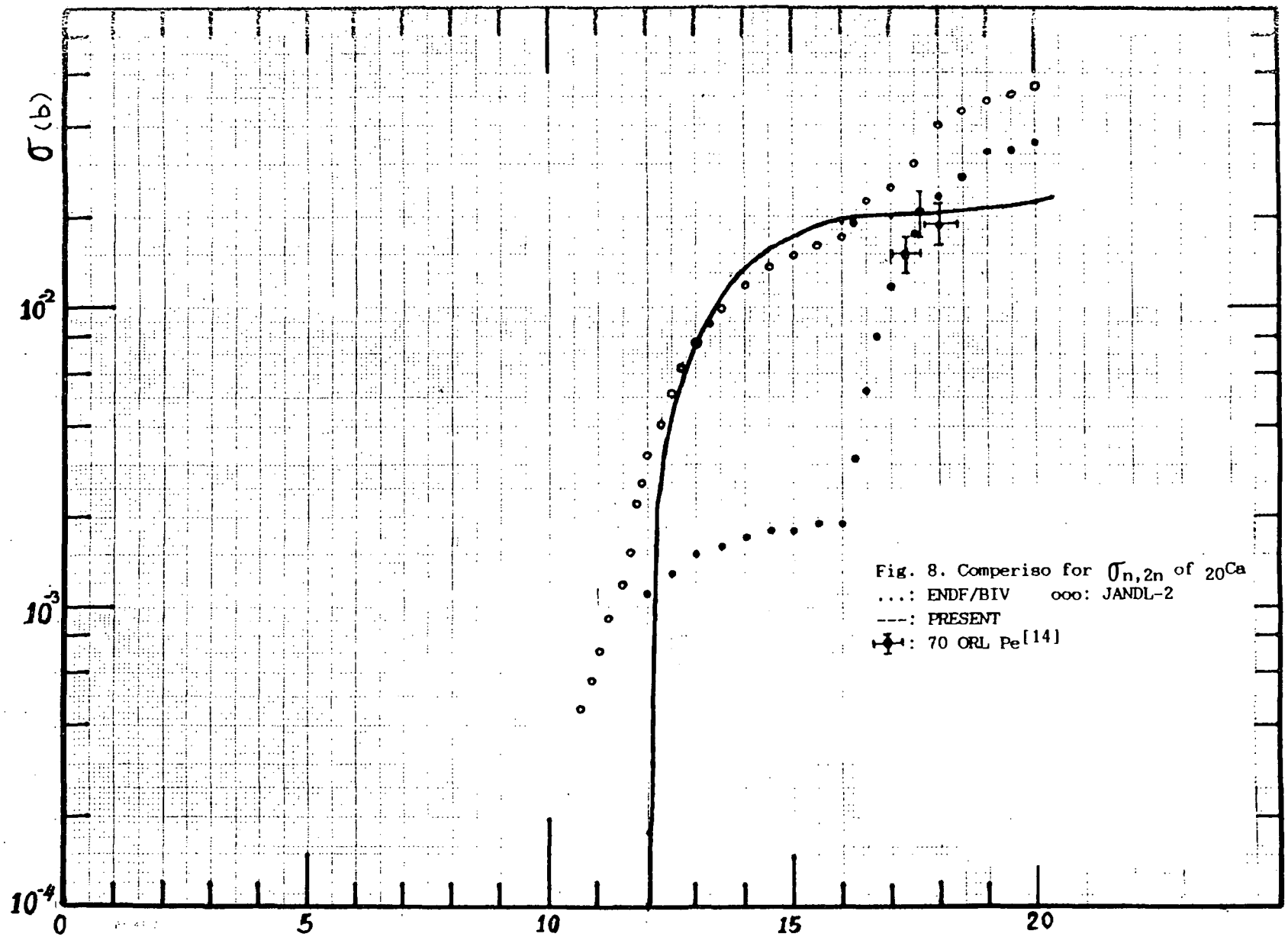


Fig. 7. Comperiso for $\sigma_{n,a}$ of $_{20}Ca$


σ (b)
10^-2
10^-3
10^-4
0
5
10
15
20
Fig. 8. Comperiso for σn,2n of 20Ca
...: ENDF/BIV ooo: JANDL-2
---: PRESENT
: 70 ORL Pe[14]

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