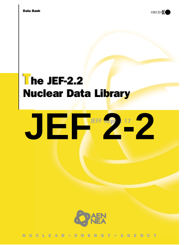

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Titel

STATUS OF THE NI-EVALUATION FOR JEF-2

(Contribution to the JEF-2 meeting, April 17-19, 1989)

Auteur(s)

H. Gruppelaar

Petten, April 12, 1989

NETHERLANDS
ENERGY RESEARCH FOUNDATION ECN
PETTEN, THE NETHERLANDS

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D R A F T

STATUS OF THE NI-EVALUATION FOR JEF-2

(Contribution to the JEF-2 meeting, April 17-19, 1989)

compiled by

H. Gruppelaar

Petten, April 12, 1989

Status of the JEF-2/EFF-2 evaluation for the Ni-isotopes

contributions: CEA-Cadarache (H. Derrien)
IRK-Vienna (M. Uhl)
NEA-Data Bank (I. Forest, C. Nordborg)
ECN-Petten (H. Gruppelaar, H.A.J. van der Kamp,
J. Kopecky, D. Nierop)

Updated manuscript: April 12, 1989

1. Introduction

For the re-evaluation of the cross-sections for Ni the following decisions were made at previous meetings:

a. The evaluations are made only for the natural Ni-isotopes; not for elemental Ni (some evaluation should also be made for Ni-59). The data will be stored in ENDF-VI format. From the large number of options those applied in the EFF-1 lead evaluation will be adopted for Ni-58 and Ni-60 as well.

b. For the major isotopes (Ni-58, Ni-60) the resolved-resonance parameters of H. Derrien (CEA, Cadarache) will be adopted. At energies above 1 MeV the evaluation of M. Uhl (IRK, Vienna) will be used. In the intermediate energy range from about 500 to 600 keV upto 1 MeV ECN supplies the evaluation, using the optical model parameters of Uhl and the average statistical parameters of Derrien. The evaluation of Uhl will be reformatted at ECN.

c. For the remaining isotopes of Ni the JENDL-2 evaluations will be used, after replacing the resolved-resonance parameters with those of Derrien.

d. Only for Ni-58 and Ni-60 energy-angle distributions will be given in file 6.

e. The natural element cross-sections will be constructed only for checking with the experimental data and only for file 3.

f. The photon-production files for Ni-58 and Ni-60 will be constructed at ECN; for the remainig Ni-isotopes the photon-production spectra for natural Ni will be used.

g. The covariance files will be constructed after completion of the evaluation; in fact only the covariance data for the natural element are relevant.

The present status is that points a) through e) have been completed. A preliminary JEF-2PR file has been sent to the NEA Data Bank.

Work performed during the first quarter of 1989:

A preliminary file with Ni-58 and Ni-60 and (partial) natural Ni was sent to the NEA Data Bank early this year. The Ni-58 and Ni-60 files contained complete data files MF1,2,3,4 and 6. For those parts that were not yet in ENDF-VI format (MF1 to 4) a translation into ENDF-VI format was made at the NEA Data Bank. Some checks on format and physics were applied at the Data Bank by C. Nordborg. During a two-days visit of H. Gruppelaar to the Data Bank on February 6 and 7, 1989 some format corrections were applied to the evaluations. Also, a list of further actions was defined, including the addition of (n,p) and (n,α) cross-sections below 1 MeV, test of file 6 with the GROUPXS code, comparitive plots, corrections to the less-important Ni-isotopes, suggestions for Ni-59, etc.

With respect to the resolved-resonance range the Data Bank agreed to prepare plots to compare the resolved-resonance ranges by means of point-wise graphs and histogram plots (group constants) for all stable Ni-isotopes, after applying the ECN-corrections. Most of these graphs have already been made and have been included in Apps. A2 and A3.

By the end of February plots of the MF3 data for Ni-58, Ni-60 and natural Ni were obtained from the Data Bank; see Appendix A1. A comparison was made with EXFOR data and the new ENDF-VI results. These figures were also sent to H. Vonach for comments.

At ECN-Petten further testing of the files was made. Some format corrections were applied and the (n,p) and (n,α) data below 1 MeV were added. Furthermore, the data were adjusted such that they are accepted by the GROUPXS processing code. This means that at present there is an exact correspondence between the incident energies in MF3 and MF6 for MT10. A linear-linear interpolation scheme has been adopted. The corrected files can be read by GROUPXS and it is expected that a conversion to the laboratory system is possible. Also plots of emission spectra for neutrons, protons and alphas can be made by GROUPXS. The results are forthcoming (action ECN). A final check is the comparison between results of NJOY-87.1 and GROUPXS. The version NJOY-87.1 has been installed at the ETA-10 supercomputer at ECN-Petten.

At the NEA Data Bank I. Forest has made plots emphasizing the resolved resonance ranges for Ni-58, Ni-60, Ni-62 and Ni-64 (App. A3). Still to be made are some plots for Ni-61 and Ni-59 (action NDB). With respect to Ni-61 and Ni62 the maximum values of the resolved resonance range still have to be changed.

For Ni-59 a combination of KEDAK-3 and REAC-ECN-4 was recommended. Moreover, the resonance parameters should be replaced by data given in the most recent BNL compilation. For this purpose the REAC-ECN-4 file was sent to the NEA Data Bank. The work for Ni-59 will be performed at the NEA Data Bank and the results will be checked at ECN-Petten.

In summary: the preliminary JEF-2 file for Ni is ready and has been tested. Some minor modifications may still be necessary. The next phase is the introduction of photon-production and covariance data. In fact the work for the photon-production file is in good progress. GNASH calculations have been made for a number of incident energies. The final run waits for the development of an interfacing code to produce the data in ENDF-VI format. This work could be ready before this summer. The work on covariance data will start during the sevcond half of this year with the help of H. Vonach.

In the following a detailed status report is given for each MF subfile.

1. MF1 (general information)

The descriptive text will be added at the end of the evaluation process, taking into account existing information from the files of H. Derrien, M. Uhl, the JENDL-2 information and new information from ECN (action ECN).

It has to be noted in MF1 that the continuum particle emission cross-sections are not given separately, but that they have been lumped into MT10. Only for MT10 the energy-angle distributions are giben in MF6. The processing code should take this into account. The processing will be tested at ECN (action ECN).

From the experience of I. Forest the present version of NJOY makes an error in calculating the total cross-section, because MT10 is added, whereas all partial cross-sections are also given in MF3. A correction is easily made.

2. MF2 (resolved-resonance parameters)

The resolved-resonance parameters of H. Derrien have been inserted into the JENDL-2 file by the NEA Data Bank. These parameters are based upon the multi-level Breit-Wigner formula for all Ni-isotopes. The NEA Data Bank has also calculated point-wise cross-sections, thermal values, resonance integrals and has provided plots of averaged cross-sections (histograms) calculated from the resonance parameters (App. A2).

At ECN the work has concentrated on Ni-58 and Ni-60. The Japanese parts of these libraries have been removed and replaced by data from ECN and M. Uhl. The thermal values and capture resonance integrals were found to be in fair agreement with the recommended data given in the latest Brookhaven compilation (table 1). Some small adjustments of the negative resonance parameters were necessary. The following modifications were made at the NEA Data Bank, upon request of ECN-Petten:

Ni-58: The radius R' has been changed from 0.7405 into 0.77921 ($\sqrt{b}$) and the negative resonance radiative capture width has been changed from 2.094 into 2.11222 eV. These changes fit the thermal data and resonance integral given in the latest BNL evaluation very well, see table 1.

Ni-60: The radiative capture width of the negative resonance at -3.84 keV has been modified from Γ_γ = 4.99 eV into Γ_γ = 1.80483 eV; the neutron width has been changed from Γ_n = 52.5 eV into Γ_n = 142.09 eV. The result is excellent agreement with the BNL-values , see table 1.

Ni-61: The energy range of the resolved resonance range should be limited at E_H = 69.4 keV (the last resonance is at 68.77 keV).
This change has still to be performed (action NDB).

Ni-62: The energy range of the resolved resonance range has been limited to E_H = 609.0 keV (the last resonance is at 600.7 keV).

Ni-64: The radiative capture width of the first resonance at 14.3 keV should be increased from 1.01 to 2.5816 eV. This modification strongly increases the thermal capture cross-section and resonance integral; see table 1 (agreement with BNL compilation).

Natural Ni: The thermal values for natural Ni are in excellent agreement with the values as given in the most recent BNL-evaluation.

We recall that for all Ni-isotopes the resolved-resonance parameters of Derrien were used. In the case of Ni-58 and Ni-60 we have adopted E_H = 550 keV as prescribed by H. Derrien. A correction was made to compensate for the loss of (n,γ) cross-section at the high-energy end of the resolved-resonance region. This correction is based upon a statistical method, discussed in STEK-memo-144 and 148 (also JEF/Doc-...). The method was mainly used to determine the shape of the correction function, that is given in file MF-3. The absolute magnitude of the correction was slightly decreased in order to obtain corrected cross-sections, in agreement with the few experimental data (averaged capture cross-sections) for Ni-58, Ni-60 and natural Ni. A second reason for this adjustment was the argument that there should be a no large differences in the broad group constants above and below the dividing energy E_H.

The adopted smooth correction functions for Ni-58 and Ni-60 are shown in Figs. 1 and 2, respectively. For Ni-58 a quite large correction was necessary in the range above 250 keV; a much smaller correction was required for Ni-60. We believe that the above correction method is adequate, altough there is the possibillity that already some implicit corrections are present in the resolved resonance parameters, e.g. when the radiative widths have been overestimated. This is the main justification for the above-mentioned decrease of the correction function. The large difference in the corrections for Ni-58 and Ni-60 are difficult to explain. Apperently (according to the statistical analysis) the detection limit for the Ni-60 measurement was somewhat lower at high energies than that for Ni-58.

The corrected cross-sections for (n,γ) are somewhat higher than in most evaluations, leading to a higher cross-section for natural Ni at about 850 keV, still in agreement with the experimental low-resolution data, see Fig. 3.

No corrections were made to the elastic scattering cross-section. The missing strength is relatively small, due to the contribution of the potential scattering and strong s-wave resonances.

3. MF3 (smooth cross-sections)

For Ni-58 and Ni-60 the following cross-sections were explicitly calculated by M. Uhl: σ_{el}, $\sigma^{discr}(n,n')$, $\sigma^{discr}(n,p)$, $\sigma^{discr}(n,\alpha)$. All continuum emission cross-sections were combined in MT=5 with yields for each individual reaction product in file MF6. At ECN a code was written to reconstruct the various reaction cross-sections, e.g. $\sigma(n,2n)$, $\sigma(n,p)$, $\sigma(n,np)$, $\sigma(n,\alpha)$, etc. Note that it was not possible to distinguish between $\sigma(n,d)$ and $\sigma(n,nd)$, thus the sum of these cross-sections is given in file MF3.

The (n,γ) reaction cross-sections for Ni-58 and Ni-60 were completely re-evaluated at ECN, taking into account the optical-model used by Uhl (at least upto 5 MeV) and average resonance parameters taken from Derrien, with, however, some adjustments. At high energies a direct-collective term was added. The cross-sections initially calculated with the average parameters taken from Derrien were too high. A decrease was necessary in order to obtain agreement with existing capture data and the cross-sections calculated from the resonance parameters, see Figs. 1 and 2. This decrease was obtained by adjusting the values of D_{obs} and Γ_{γ}. The finally adopted parameters are still within the error margins and agree quite well with the earlier evaluation of Fröhner, used in JEF-1; see table 2. There are very few experimental data in the range near 1 MeV. The adopted cross-sections for Ni-58, Ni-60, but also for natural Ni are in reasonably good agreement with these data. Note that a smooth background cross-section was added at energies below E_H, see Sect. 3.

From the same evaluation procedure the elastic scattering cross-section was obtained upto 1 MeV. At higher energies these cross-sections were already available from the work of Uhl. There is a smooth connection between the two parts, mainly because the same optical model parameters were adopted.

Almost no other reactions than elastic scattering and radiative capture are possible below 1 MeV in the cases of Ni-58 and Ni-60. There are, however, a very small contributions from (n,p) and (n,α) to discrete levels which have to be added. This has been performed at ECN in an approximate way.

For the purpose of the calculation of the transfer matrices also the lumped quantity MT=10 (total continuum particle emission cross-section) has been introduced (equal to the difference between MT5 and MT102). Only for MT=10 data are given in file MF6, cf. Sect. 7. Recently, the MT10 file has been checked. The interpolation law has been changed into linear-linear for the purpose of easy processing by means of the ECN code GROUPXS. The incident energies in MF6 and MF3 are entirely consistent.

For the other stable isotopes the JENDL-2 cross-sections have been adopted. The region around E_H still needs to be inspected (action ECN/NDB).

4. MF4 (angular distributions)

For the low-abundant Ni-isotopes the JENDL-2 data are used without modifications.

In the evaluation of Uhl for Ni-58 and -60 the file MF4 contained only angular distribution data for elastic scattering above 1 MeV. The angular distributions for the discrete inelastic scattering and discrete (n,p) and (n,α) reactions have been reconstructed from MF6 and placed in MF2, by means of a utility code written at ECN. The results have been extended by

ECN to the energy range below 1 MeV (isotropy in the center-of-mass assumed). Note that no angular distributions are given for continuum cross-sections, since these have been included in MF6 (MT10).

For the elastic scattering angular distribution below 1 MeV the ECN evaluation was used. These data are given pointwise in KEDAK format. Since these angular distributions should be expressed in Legendre polynomials (in order to be consistent with the data file of Uhl), a conversion routine was written. The data have been inserted at ECN.

5. MF5 (energy distributions)

Except for the minor stable isotopes taken from JENDL-2 there is no file MF5 given. Instead, for Ni-58 and -60 file MF6 is used (see below).

6. MF6 (energy-angle distributions)

MF6 is only used for Ni-58 and Ni-60 and only for data type MT10 (total continuum energy-angle distributions). This data type contains yields for continuum neutron, proton and alpha particle production and the corresponding energy-angle coupled distributions. The data type has been taken from the original data type MT5, introduced by M. Uhl, by multiplication of all yields with the ratio $\sigma(MT5)/\sigma(MT10)$. A code for this transformation has been written and has been applied. Some extensions have been made in order to obtain an exact correspondence between the incident energies in files MF3 and MF6. Also, the interpolation law have been adjusted to linear interpolation.

The ENDF-VI checker codes have been used to test the MF6 file. In addition the code GROUPXS has been used to test the evaluation. This code accepts the format. The next step is the transformation to the laboratory system and the calculation of multi-group constants. Furthermore, plots have to be made of the energy-distributions stored in MF6, in particular for E = 14.5 MeV. Finally, a comparison between NJOY-87.1 and GROUPXS is necessary (action ECN).

It is noted that no explicit energy-angle distributions are available for all individual reactions, like (n,2n), (n,p), etc. Strictly speaking this is not in agreement with the ENDF-VI format rules. In practice, it is probably very convenient for the user, as has been demonstrated in the case of the EFF-1 lead evaluation. The existing ECN processing code GROUPXS can be used to process the quantity MT10.

Finally, it may be of interest that the original file of Uhl also contained recoil spectra for all reaction products. If this information is useful these data can be stored on the JEF-2 file as well (not decided as yet).

7. Photon-production cross sections

The JENDL-2 datafile does not contain photon production spectra. These data are given on the data file of Uhl for Ni-58 and Ni-60, given in file MF6. However, no data are given for (n,γ) reaction below 1 MeV and no data are given for the direct-collective contribution. These data will be supplemented by ECN. The code GNASH is used for this purpose. At high incident energies the GRAPE code system will be used to calculated the direct/semi-direct and pre-equilibrium components of the (n,γ) emission spectrum. The photon emission spectra will be stored in MF12 (multiplicities for photon production), MF14 (angular distributions) and MF15 (energy distributions for photon production) as a lumped quantity, i.e. for the non-elastic cross-section (MT3).

The present status is that the data file of Uhl (E>1 MeV) still has to be converted to MF12, 14 and 15. Meanwhile, GNASH calculations have aleady been made for a number of selected energies in the energy range from 10-5 eV to 2 MeV. The absolute value of the photon strength function has been adjusted to fit the radiative capture cross-section at 1 MeV. The final calculation will be made as soon as a code to read the GNASH data and store these in ENDF-VI format has been written. This work is underway (action ECN).

No photon production data have been found for the other stable Ni-isotopes. A solution to supplement these data has still to be worked out (action ECN).

The total photon production spectrum for natural Ni has to be compared to the experimental data.

8. Covariance data

No covariance data are available for the evaluation of Uhl. A practical solution has to be found to provide these data. A difficulty is the fact that wheras the user is only interested in the uncertainties of cross-sections for the natural element, the evaluations are given only for the isotopes.

A procedure for the creation of covariance data has to be found before the actual work can be initiated.

In the framework of the EFF-2 project an agreement has been made with Prof. Vonach (IRK, Vienna) to assist ECN in constructing the covariance data (at high energies). At low energies the uncertainties in the resolved resonance parameters should be added (action ECN).

9. Cross-sections for the long-lived isotope Ni-59

A partial evaluation for Ni-59 is given in the KEDAK library. Furthermore, activation cross-sections are available on the REAC-ECN-4 library.

At the NEA Data Bank the KEDAK data have been translated into ENDF-format. However, this file only extends to 9 keV does not contain resolved-resonance parameters and is limited to MF=1 and 3.

ECN has suggested to add the new resolved resonance parameters from the latest BNL compilation to MF2 and to clear the MT=1,2, 102 sections in MF3. Instead, a background cross-section consisting of MT=103+107 should be added to MT1 in MF3. The MT=103 and 107 data should be kept and extended to lower energies by means of a 1/v extrapolation. At high energies the REAC-ECN-4 evaluation could be used for an extension upto 20 MeV (not for MT2, not for MF>3), (action NDB) The REAC-ECN-4 file has been sent to the NEA Data Bank for use in JEF-2.

10. Natural Ni

The code CRECTJ5 has been used to construct a preliminary natural Ni file for MF3 at energies above 550 keV (smooth energy range). The results are shown in App. A1.

11. Comparison with ENDF-VI data

The results of some preliminary comparisons are given in the figures enclosed in this report.

Some observations from the graphs at energies above 550 keV (App. A1) are:

1. The ENDF/B-VI evaluations uses point-wise data (based upon experimental data) for the elastic scattering cross-section upto very high energies. This makes a graphical comparison difficult without averaging.

2. For most reactions the differences are rather small, except for (n,γ) and (n,α), see below.

3. The total inelastic scattering cross-sections are rather close to each other (Figs. 2, 11).

4. The Ni-58(n,p) cross-section in ENDF/B-VI (dosimetry) is based upon experimental data (those given in Fig.4) rather than upon calculations. Vonach has recently analysed new experimental data for Ni-58(n,p), Ni-58 (n,np) and Ni-60(n,p). He has announced that the Ni-60(n,p) cross-section has to be changed considerably (Fig.16). Action: IRK.

5. For (n,γ) it seems that the ENDF/B-VI evaluation is not based upon calculations; see Figs. 7,15. The ENDF/B-VI evaluation near 1 MeV seems high compared to the data for natural Ni (based upon ORL average capture data). From Fig. 22 for natural Ni it is seen that the JEF2PR evaluation is already high with respect to the data; the ENDF/B-VI is still higher. Above the first inelastic threshold the ENDF/B-VI evaluation seems to be too low. The higher ECN values are caused by the fact that the width fluctuation correction changes sign at the first inelastic threshold.

6. The shapes of the (n,α) cross-sections (figs. 9 and 17) of JEF-2PR are different from those of ENDF/B-VI. This problem deserves further study.

Some observations from the histogram plots (App.A2) are:

7. The elastic scattering cross-section for Ni-58 are different at thermal energies, mainly due to the use of a different radius. The ECN-value is in agreement with experimental data evaluated in the latest BNL-compilation.

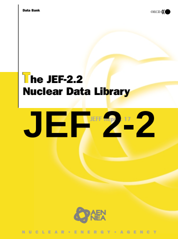
8. The ENDF/B-VI data for elastic scattering are much higher in the resolved energy range and the energy range just above it. This is due to a different source of experimental data used. In JEF-2PR the resolved range extends to 550 keV, whereas in ENDF/B-VI this range extends to 812 keV and 450 keV for Ni-58 and Ni-60, respectively. However, in ENDF/B-VI also fluctuating point-wise given data (exp. total - calc. nonelastic) have been used above E_H. The reason for this large discrepancy is not clear.

9. The ENDF/B-VI data for (n,γ) show an additional resonance at about 1 keV for Ni-60. Furthermore, there are various other discrepancies in the resolved range that extends only up to 450 keV in ENDF/B-VI (average resonance parameters upto 812 keV). A close investigation is required. The ENDF/B-VI curve is certainly above the experimental data given in Fig.1 of the main text.

Finally we make some observations from the graphs of App. A3:

10. From Figs. 4 (Ni-60), 8,9 (Ni-62) and 18 (Ni-64) it follows that the range near E_H needs further inspection.

11. For Ni-62 and Ni-64 a comparison has been made between JEF-1 and JEF-2PR. In general we see improvements, except that JEF-2PR does not contain a direct-collective part in σ(n,γ). This part could be copied from JEF-1 (=RCN-2). The different shape of the cross-section near the first resonance in Ni-64 is due to the fact that other negative resonance parameters have been used in the two evaluations.



13. Conclusion

The JEF-2PR evaluation for the Ni-isotopes has been completed, although photon-production data and covariance data still have to be added. The JEF-2PR file has been checked with the ENDF/B-VI checker codes and is accepted by NJOY and GROUPXS. Some preliminary group constant calculations have already been performed (1-dimensional cross-sections).

The comparison with the other evaluations and with experimental data is in good progress. From the available graphs we find good overall agreement, but still there is a need for data adjustment in the energy range above 1 MeV. We rely upon the cooperation of IRK-Vienna to obtain the required modifications. In the resolved-resonance range the ENDF/B-VI evaluation is based upon new experimental data and therefore a critical intercomparison between JEF-2PR and ENDF/B-VI is necessary. A discussion between experts in the resolved range is required.

No testing has been made as yet of the neutron emission spectra and angular distributions. Here the graphical intercomparison is not so straightforward and software to make the graphs is lacking. At ECN work is in progress to provide such graphs for the JEF-2PR evaluation.

The addition of photon-production data is in good progress. The main obstacle is the development of ad-hoc codes to prepare the data files. It is expected that MF 12,14 and 15 will be available by this summer.

The creation of covariance data is the final problem. Here we have the cooperation of H. Vonach for the high-energy region. In the resolved-resonance range ECN will try to supplement the information.

It is far too early to comment on the quality of the JEF-2PR and ENDF/B-VI evaluations for the Ni-isotopes. Both are primarily based upon experimental data in the low-energy range and sophisticated calculations at high energies. It is noted that at high energies adjustments have been applied in ENDF/B-VI, whereas this has not been performed as yet for JEF-2PR (except for n,γ). Interesting features of ENDF/B-VI are the use of new resolved-resonance data and the extended use of MF6 for all partial cross-sections; covariance data are lacking. Interesting features of JEF-2PR are the fact that it is an independent evaluation and that the all particle continuum cross-sections have been lumped into MT10, which is given in MF3 and MF6. The radiative capture cross-section in JEF-2PR is perhaps better than that of ENDF/B-VI in the smooth energy range. Furthermore, the covariance data will be added to JEF-2PR. An extended study of the two evaluations (perhaps after adjustments) should be recommended. The work should be divided between experts in the resolved resonance range and high-energy range.

Table 1. Thermal values and resonance integrals

Table 1a: σ_γ (2200 m/s)

Isotope	Derrien JENDL -2[a] (barn)	JEF-2[b] (barn)	BNL-325 (barn)	ENDF/B-VI (barn)
Ni-58	4.5701	4.60	4.6±0.3	4.55
Ni-60	2.929	2.87	2.9±0.2	2.59
Ni-61	2.464	2.46	2.5±0.2	
Ni-62	14.417	14.4	14.5±0.3	
Ni-64	0.7351	1.52	1.52±0.03	
Ni	4.44	4.46	4.49±0.16	

a) Calculated by the NEA Data Bank
b) Preliminary JEF-2 evaluation, except for Ni-62 and Ni-64 (JEF-1)

Table 1b: σ_{el} (2200 m/s)

Isotope	Derrien JENDL-2[a] (barn)	JEF-2[b] (barn)	BNL-325 (barn)	ENDF/B-VI (barn)
Ni-58	23.938	25.3	25.3±0.4	21.55
Ni-60	0.4638	0.980	0.98±0.07	0.979
Ni-61	8.830	8.83	9.0±1.0	
Ni-62	9.922	9.92	9.1±0.4	
Ni-64	0.0151	0.0151	0.0014±0.003	
Ni	16.9	17.89	17.8±0.4 (calculated)	

a) Calculated by the NEA Data Bank
b) Preliminary JEF-2 evaluation

Table 1c: I_γ

Isotope	Derrien JENDL-2[a] (barn)	JEF-2[b] (barn)	BNL (barn)	ENDF/B-IV (barn)
Ni-58	2.133	2.19	2.2±0.2 (calculated)	2.16
Ni-60	1.480	1.50	1.5±0.2 (calculated)	1.40
Ni-61	1.814	1.81	1.5±0.4 (calculated)	
Ni-62	5.882	5.88	6.6±0.2 (calculated)	
Ni-64	0.4468	0.85	0.98±0.15	
Ni	2.078	2.12	-	

a) Calculated by the NEA Data Bank.
b) Preliminary EFF-2 evaluation, except for Ni-62 and Ni-64 (EFF-1).

Table 2. Avarage parameters for Ni-58 and Ni-60

A	Reference	S_0 10^4	D_0 (keV)	$\langle\Gamma_\gamma\rangle$ (eV) l=0	$\langle\Gamma_\gamma\rangle$ (eV) l=1	
58	Derrien	2.92±0.64	0.51±0.11	13.19±1.91	1.92±0.5	0.58
	Fröhner	3.2±1.0		16.7±1.6	2.3	0.5
	BNL	2.8±0.6	0.5±0.1	13.7±2.0	2.6	-
	Adopted EFF-2	2.92±0.64	0.51±0.11	15.1	$\langle\Gamma_{\gamma v}^{s}\rangle$=1.015; $\langle\Gamma_{\gamma}^{v}\rangle$=0.905	0.58
60	Derrien	2.40±0.57	0.24±0.12	12.81±3.06	0.7-1.3[a]	0.51
	Fröhner	2.6±0.8		15.1±1.7	1.7	0.4
	BNL	2.7±0.6	0.3±0.1	16.0±2.5	1.7	0.9
	Adopted EFF-2	2.40±0.57	0.24±0.12	15.87	$\langle\Gamma_{\gamma v}^{s}\rangle$=0.65; $\langle\Gamma_{\gamma}^{v}\rangle$=0.35	0.51

$\langle\Gamma_\gamma\rangle$ = 1.3 eV Perey et al.
= 1.0 eV when 8 very strong resonances are excluded.
= 0.7 eV from 16 values considered as normal below 300 keV.

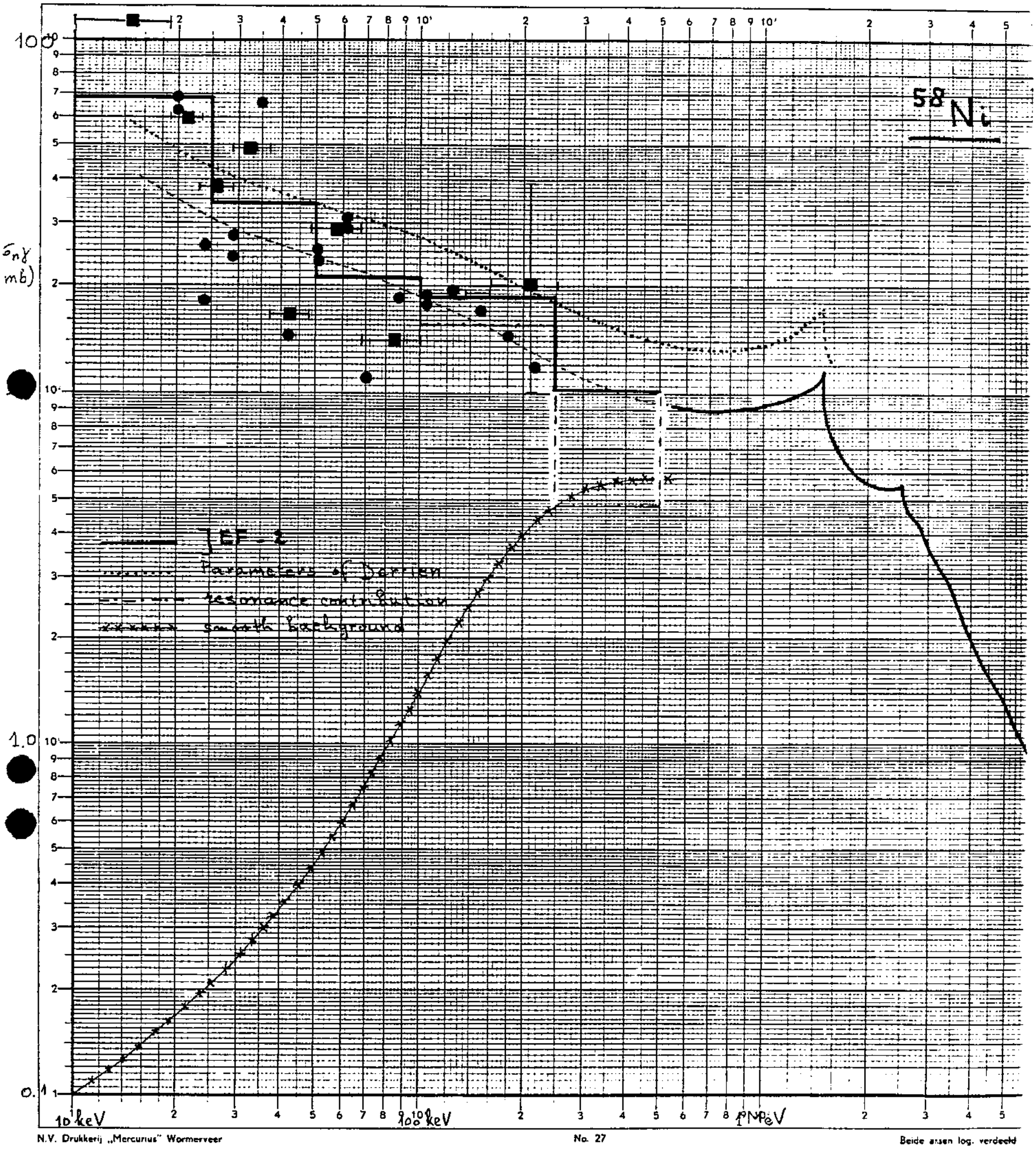

58 Ni
JEF - 2
Parameters of Derrien
resonance contribution
smooth background
10 keV
100 keV
1 MeV
100
1.0
0.1
N.V. Drukkerij „Mercurius" Wormerveer
No. 27
Beide assen log. verdeeld

FIG. 1

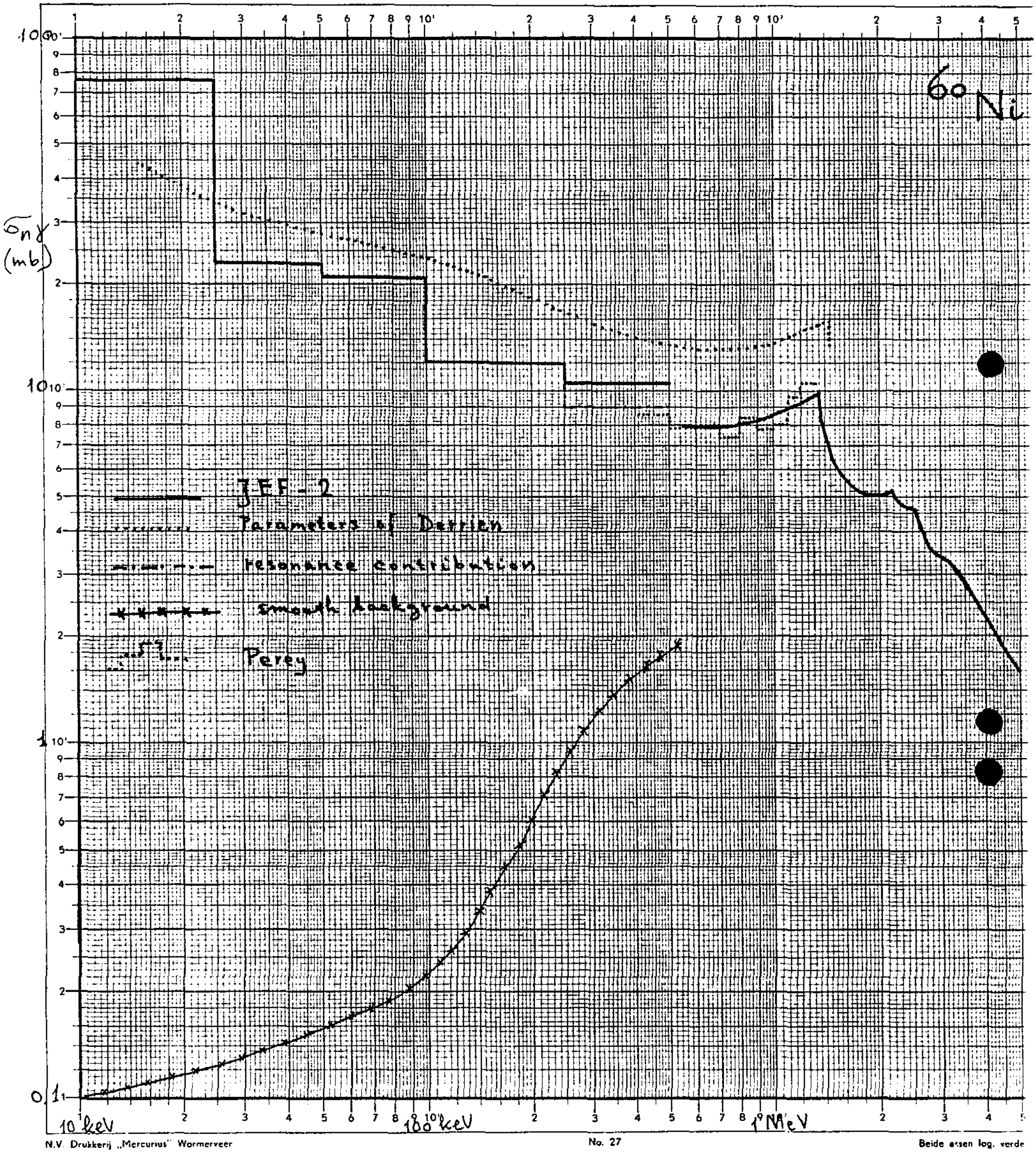

60 Ni
σnγ (mb)
JEF-2
Parameters of Derrien
resonance contribution
smooth background
Perey
10 keV
100 keV
1 MeV
N.V. Drukkerij „Mercurius" Wormerveer
No. 27
Beide assen log. verde

FIG. 2

141203

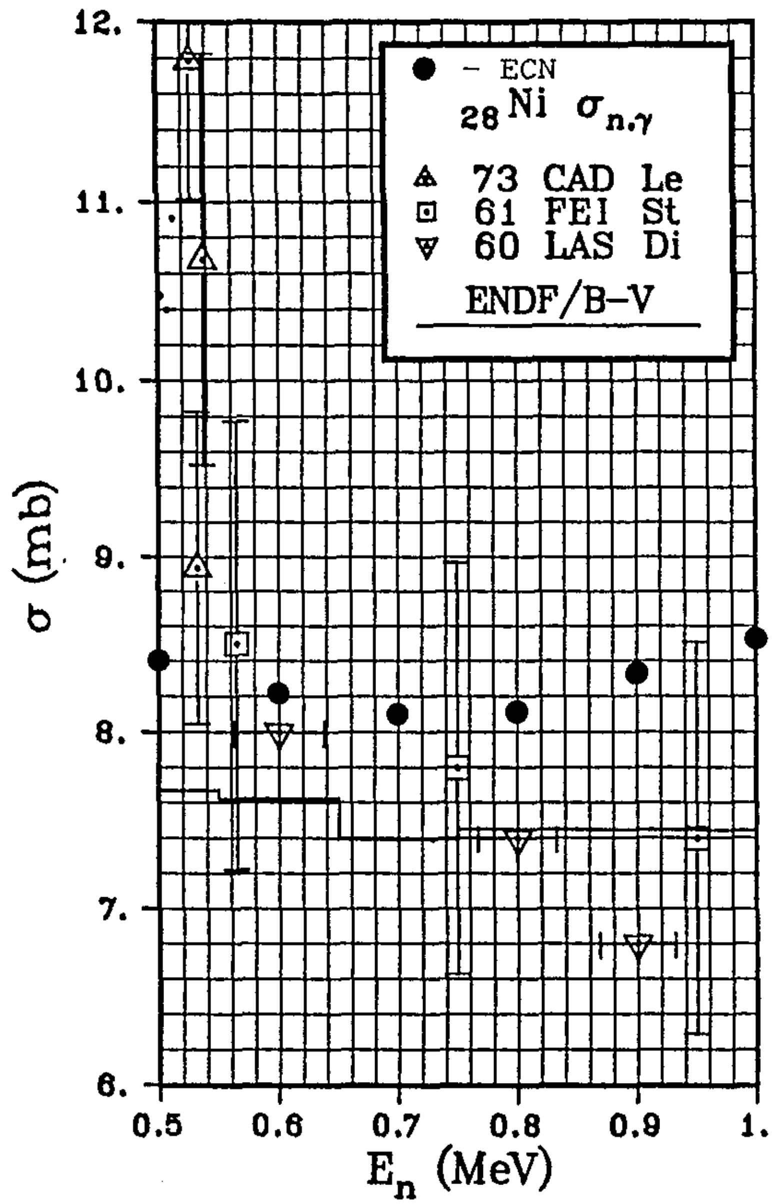
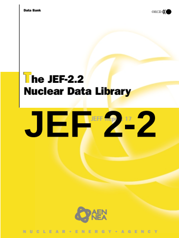

ECN
28 Ni σ n,γ
73 CAD Le
61 FEI St
60 LAS Di
ENDF/B-V
σ (mb)
E n (MeV)
12.
11.
10.
9.
8.
7.
6.
0.5
0.6
0.7
0.8
0.9
1.

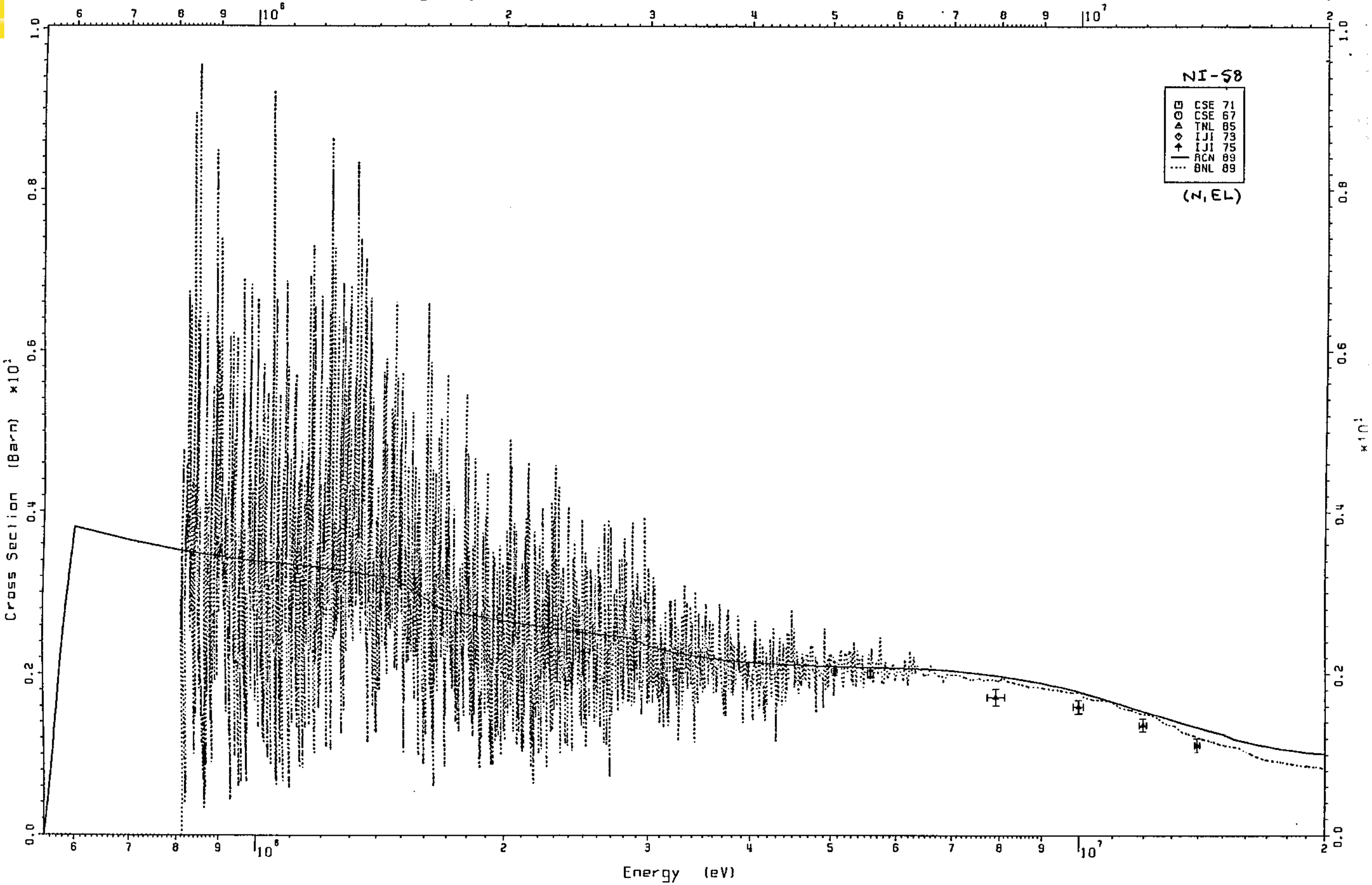
FIG. 3

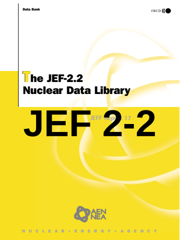


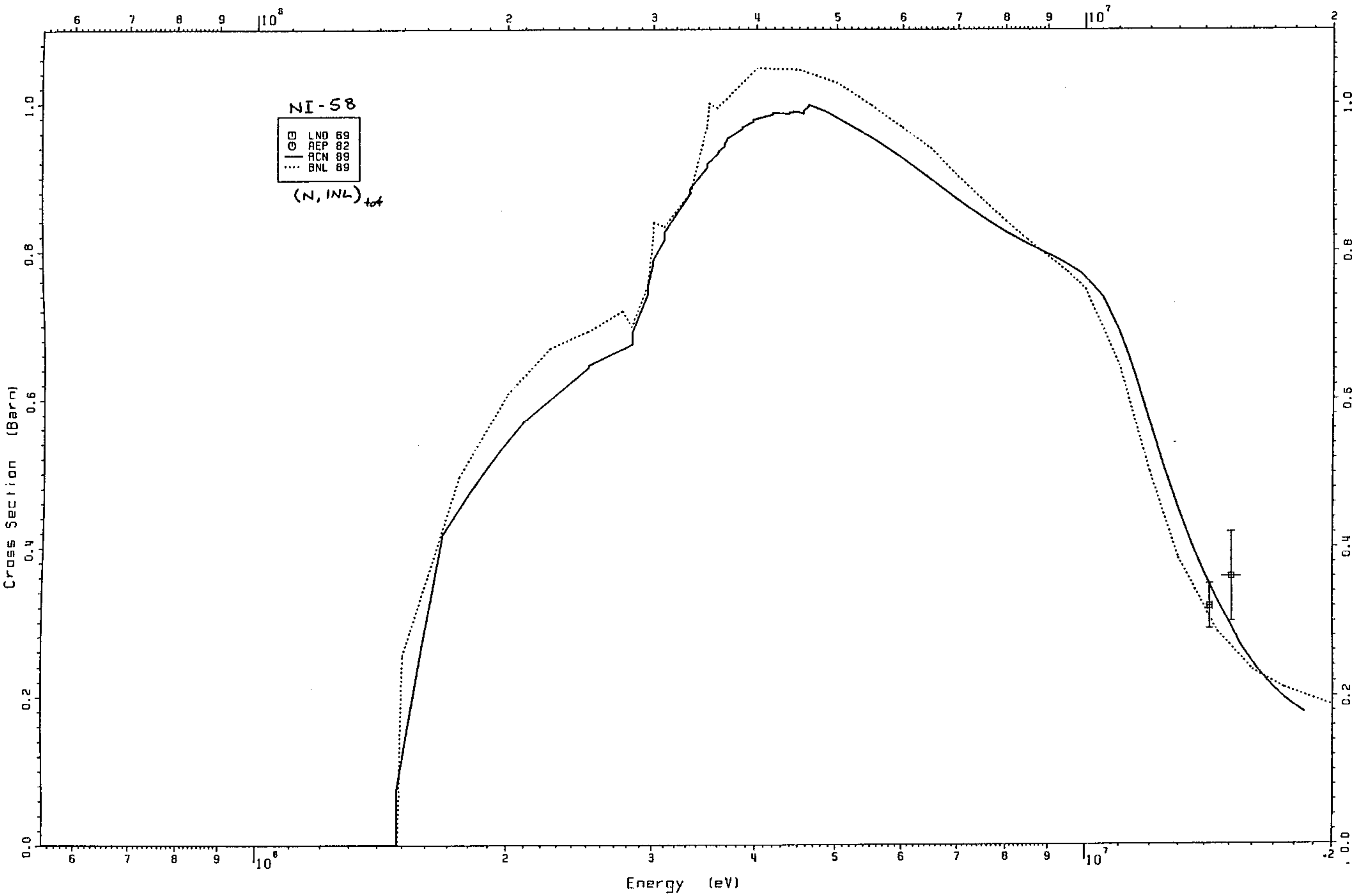
APPENDIX A1. GRAPHS OF MF3 CROSS SECTIONS FOR NI-58 , NI-60 AND NATURAL NI

(Comparison between JEF-2PR, ENDF/B-IV and EXFOR data)

Fig. 1


NI-58
CSE 71
CSE 67
TNL 85
IJI 73
IJI 75
RCN 89
BNL 89
(N,EL)
Cross Section (Barn) ×10¹
Energy (eV)


The JEF-2.2
Nuclear Data Library
JEF 2-2
AEN NEA

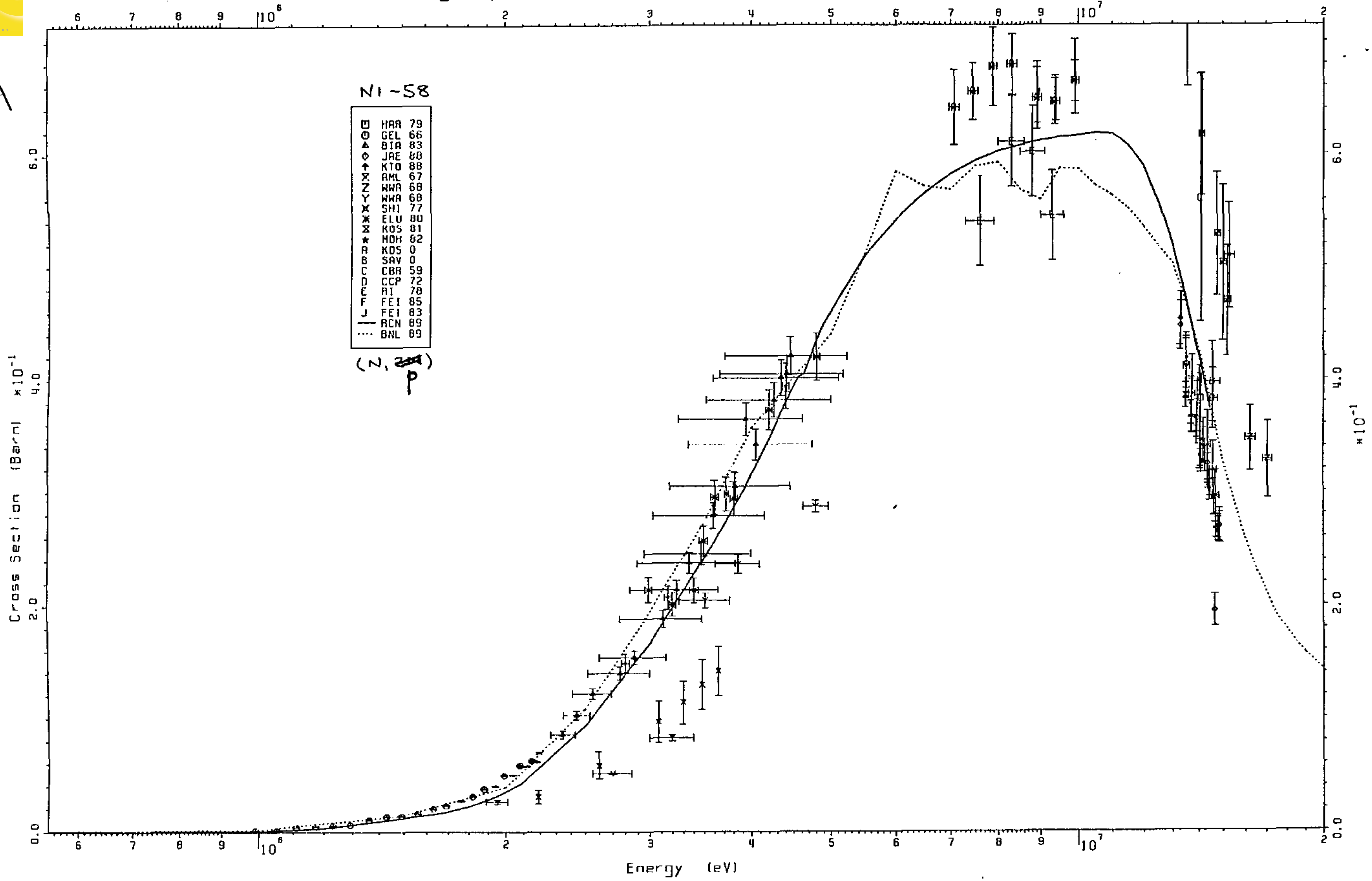

NI-58
LND 69
AEP 82
ACN 89
BNL 89
(N, INL)tot
Cross Section (Barn)
Energy (eV)
0.0
0.2
0.4
0.6
0.8
1.0
6
7
8
9
10^6
2
3
4
5
10^7
2

14120371

The JEF-2.2 Nuclear Data Library

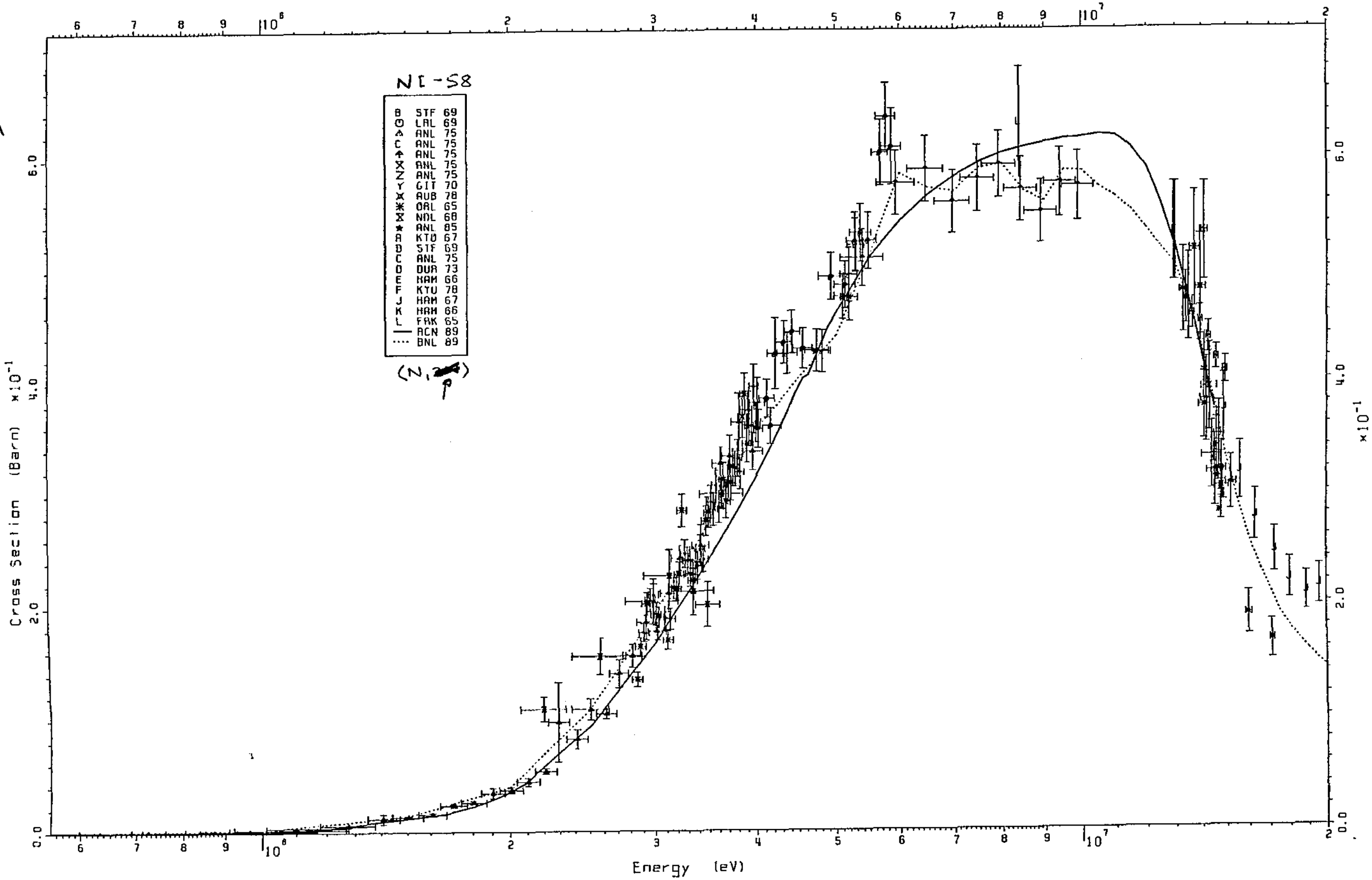
JEF 2-2

Fig. 3



14120372

Fig. 4



1A120373

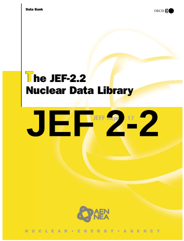

The JEF-2.2 Nuclear Data Library
JEF 2-2

Fig-5

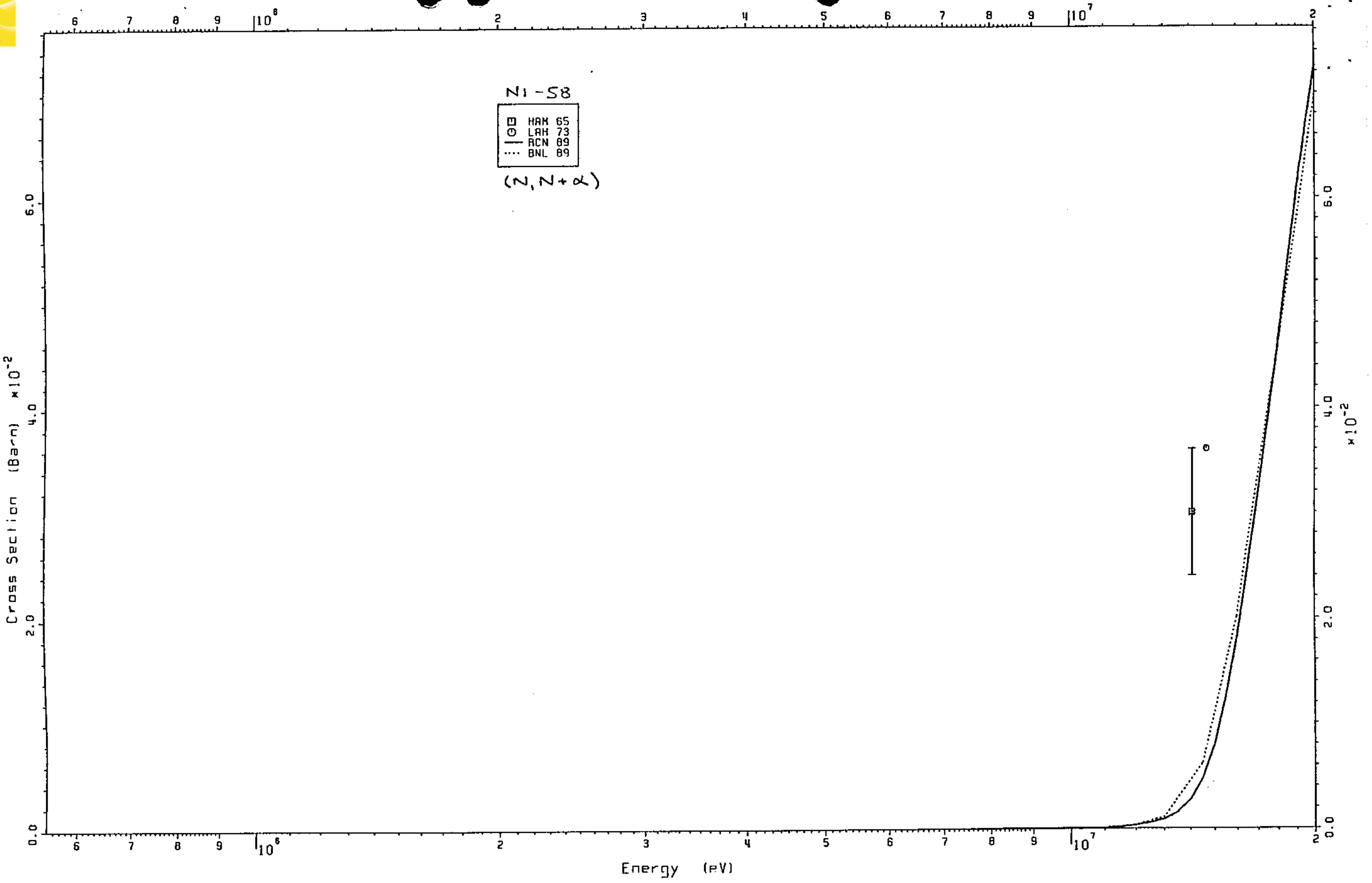
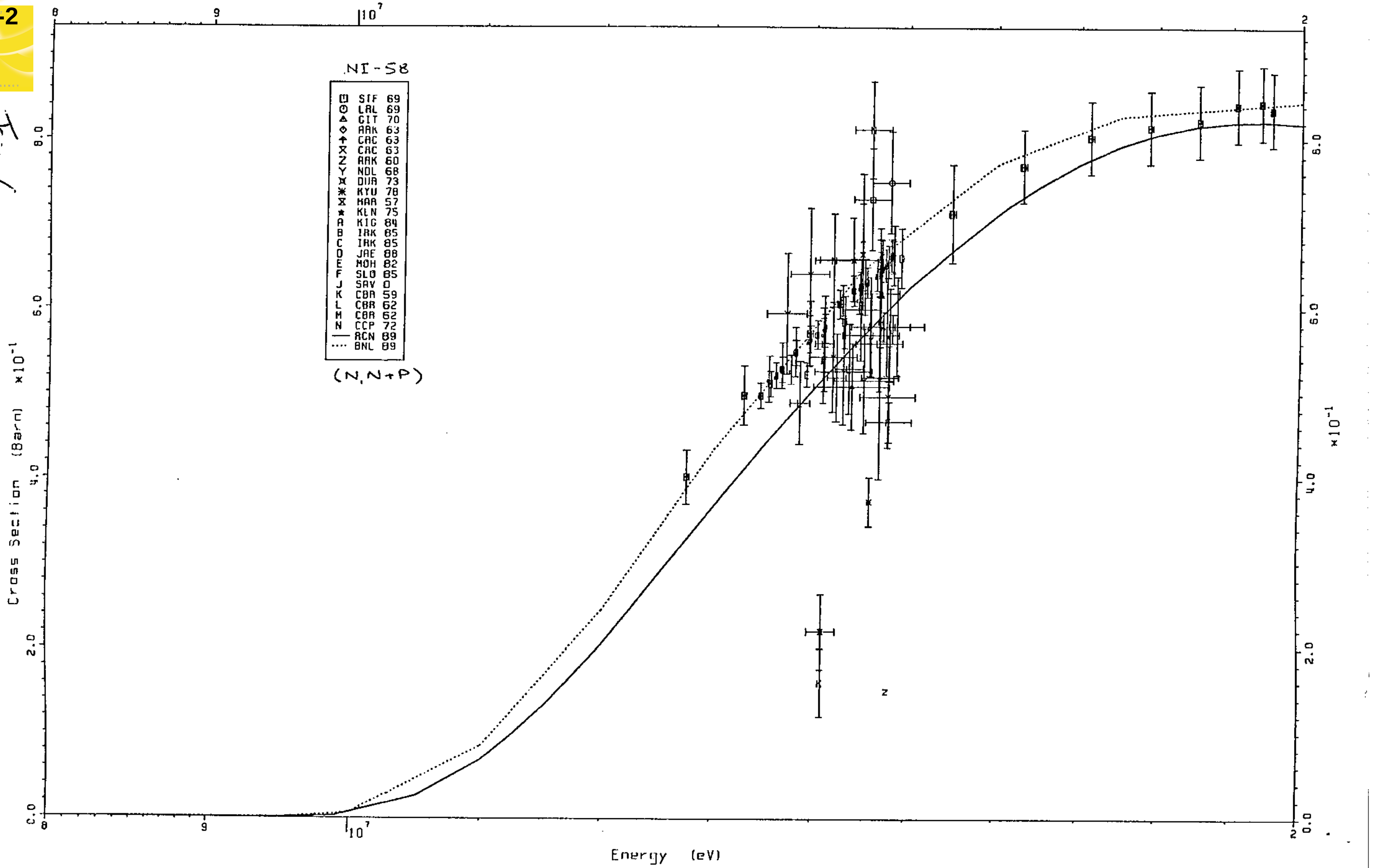

Ni-58
HAN 65
LAN 73
RCN 89
BNL 89
(N, N+α)
Cross Section (Barn) ×10⁻²
Energy (eV)
6
7
8
9
10⁶
2
3
4
5
10⁷
0.0
2.0
4.0
6.0

Fig. 6



14120375

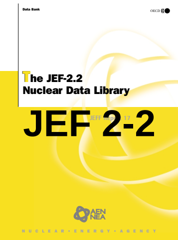
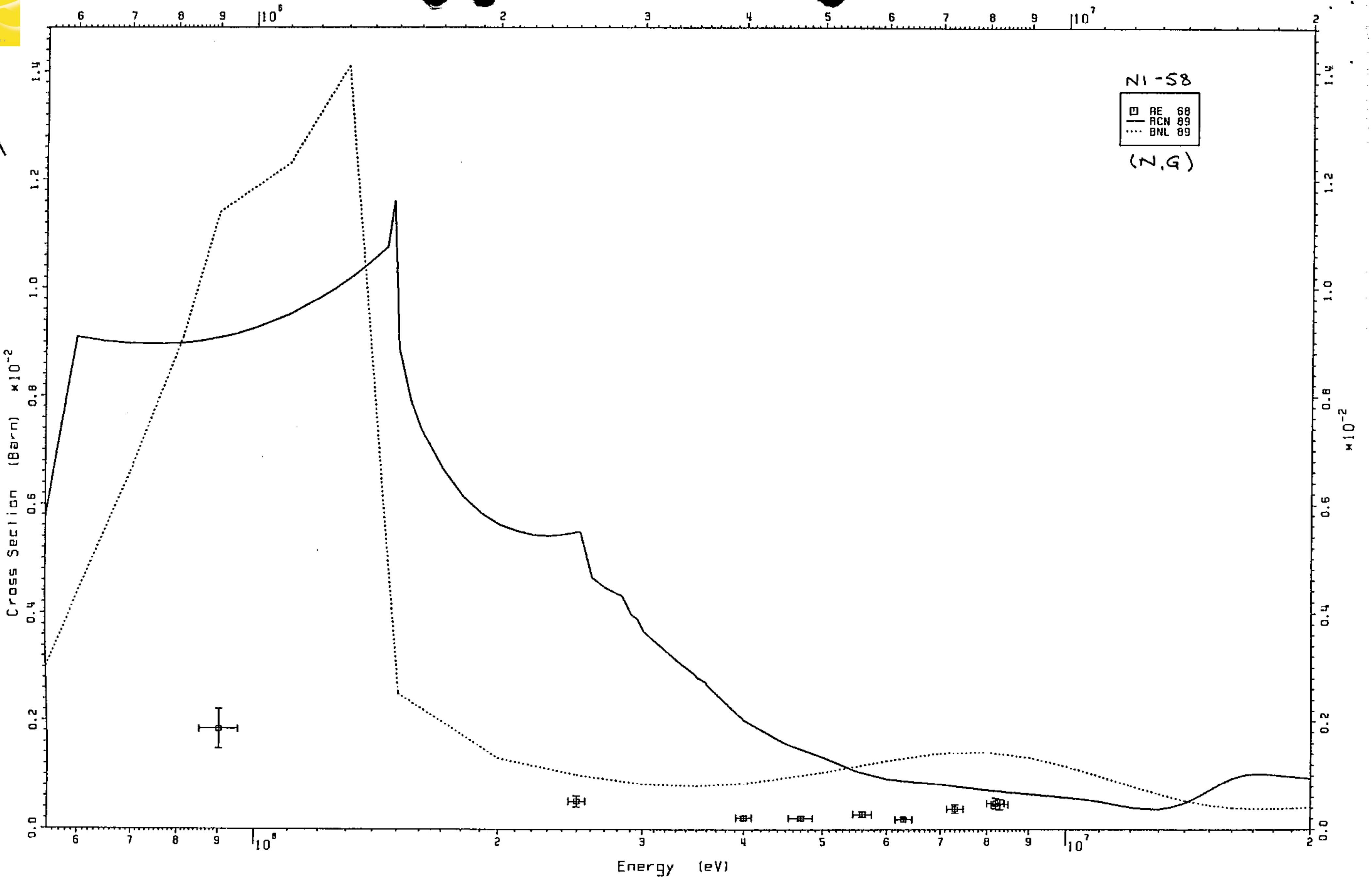
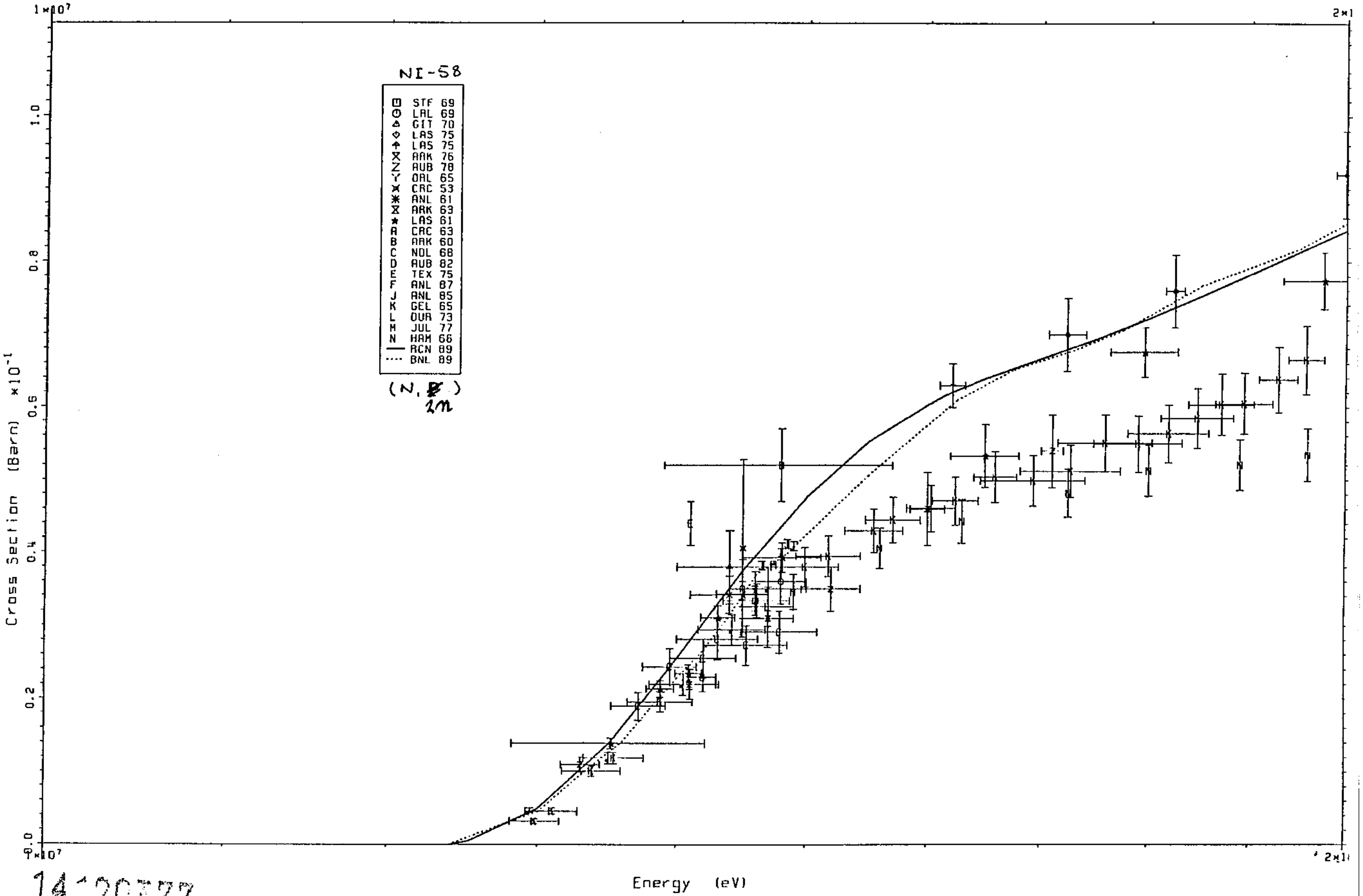


Fig. 4



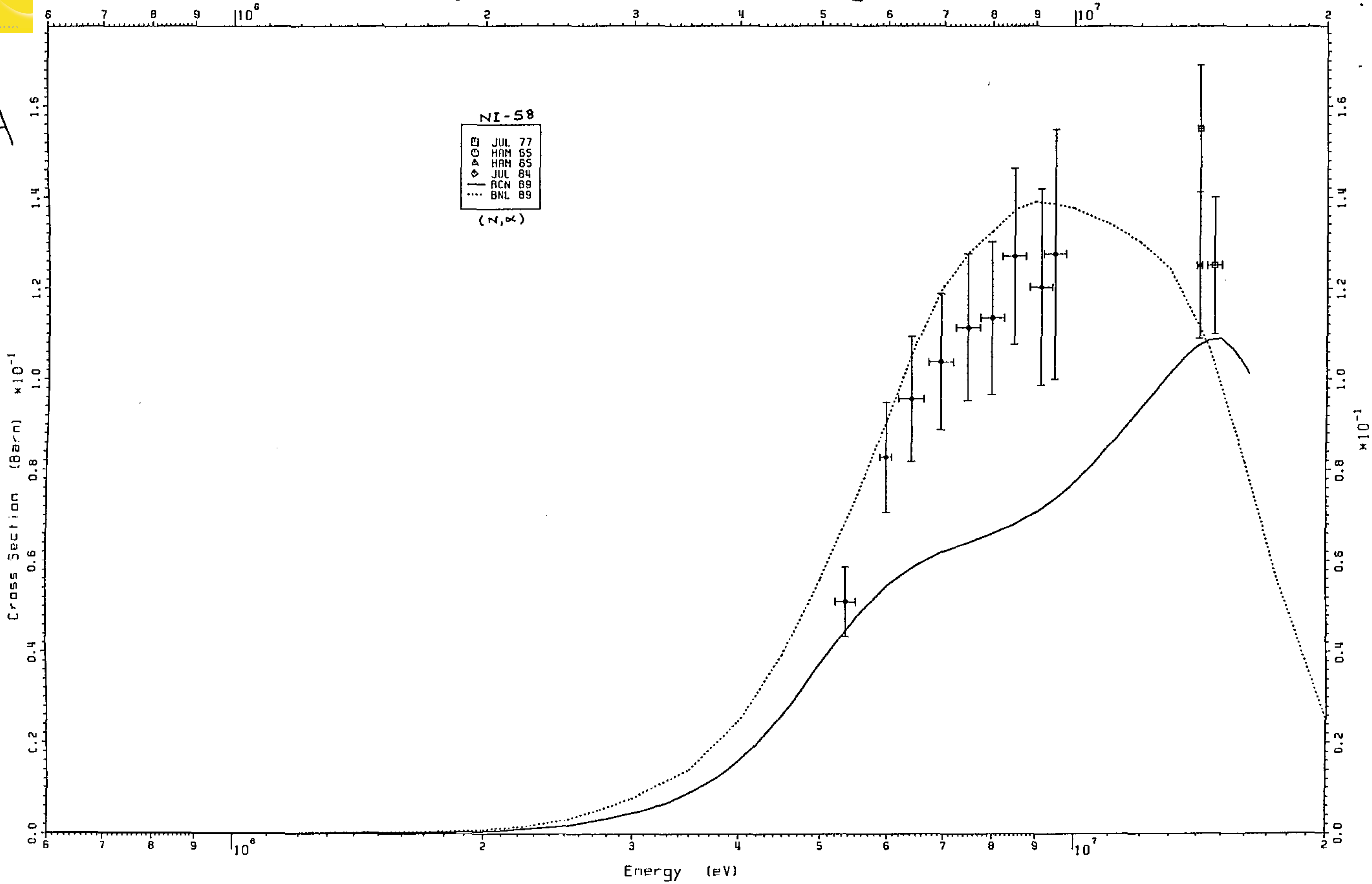
14120376

Fig-5



14120377

Fig-9



14120378

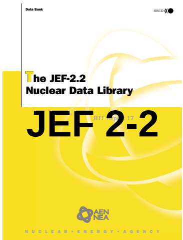
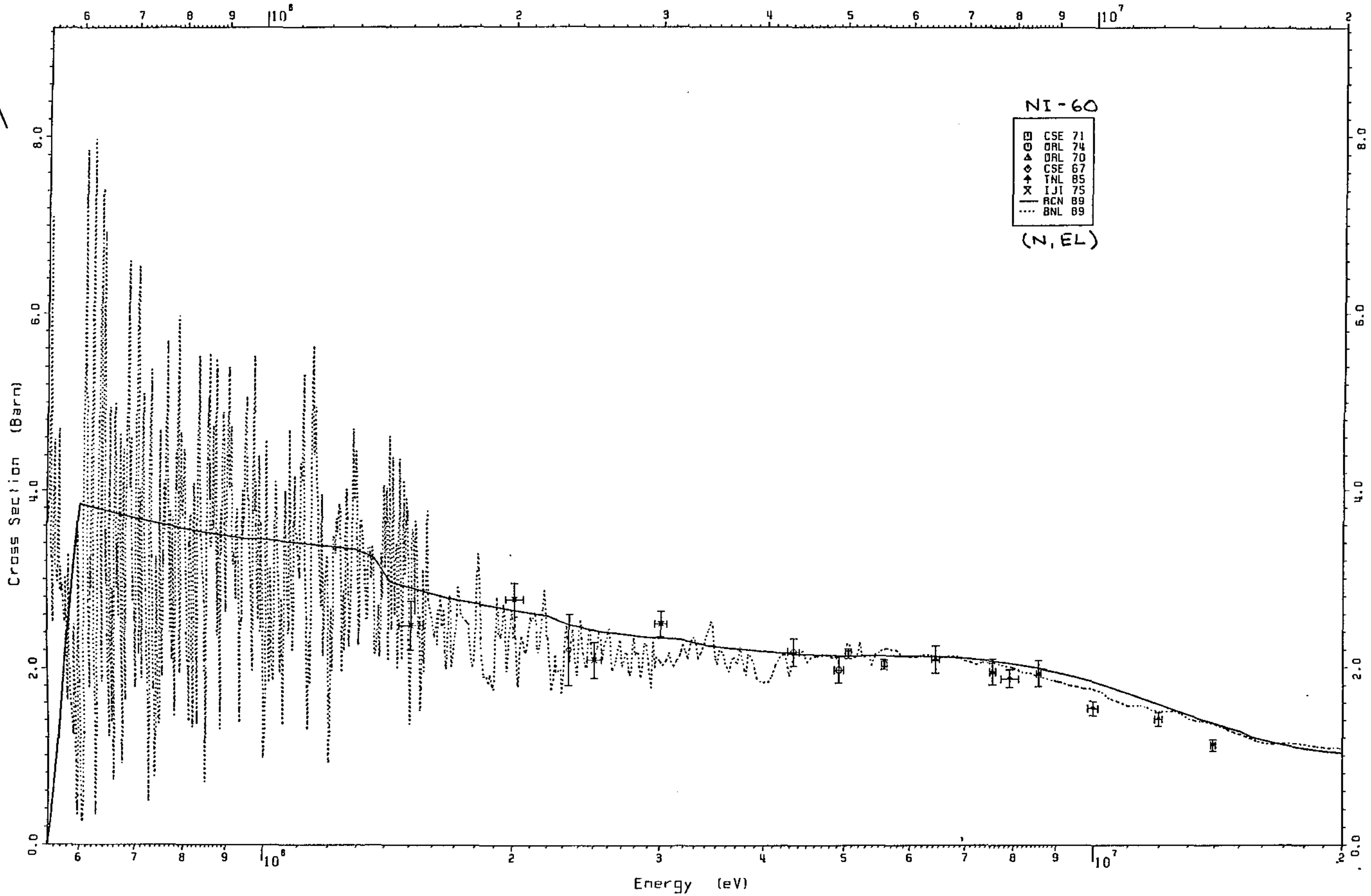
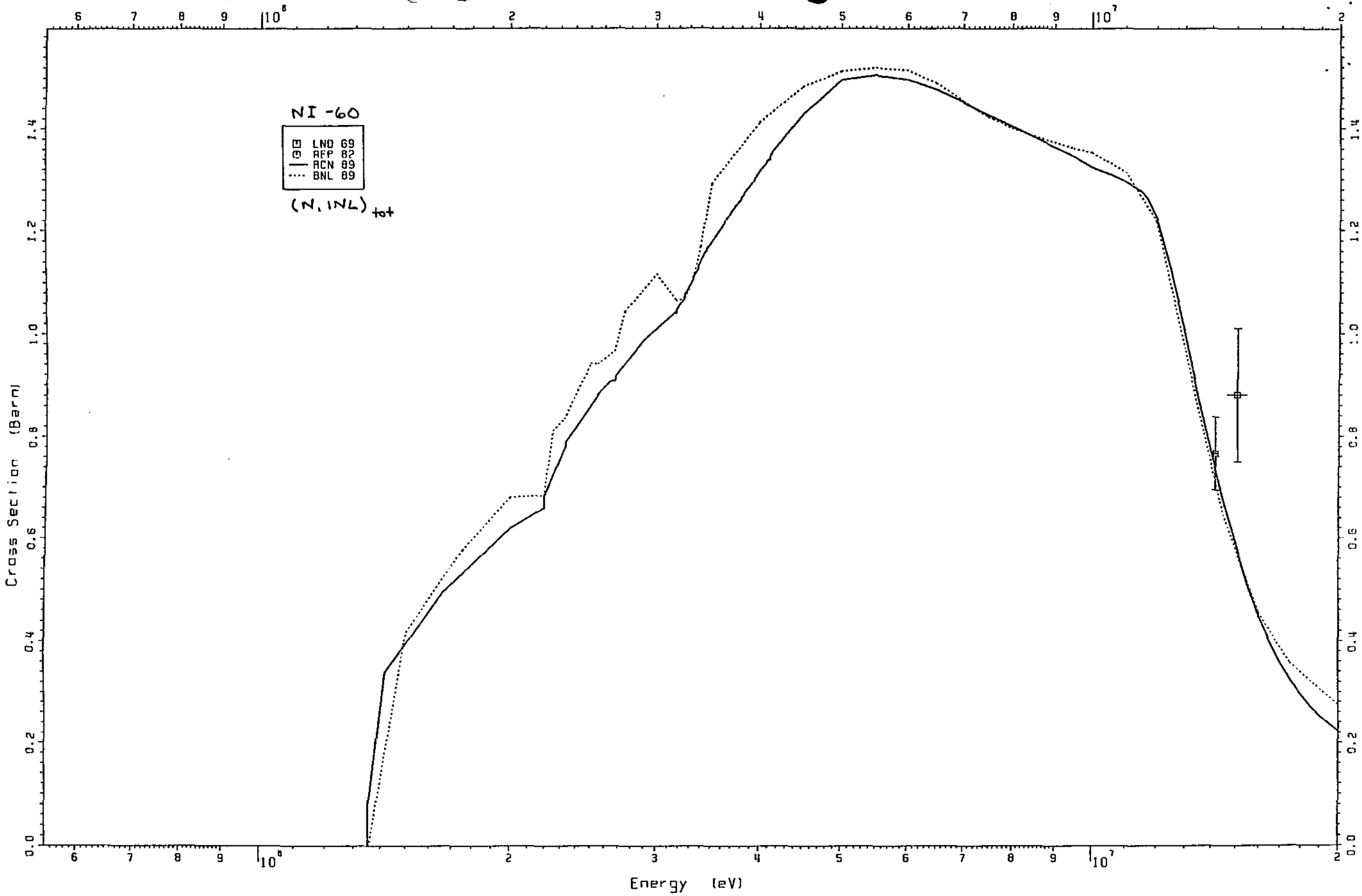


Fig. 10



14120379

Fig. 11


NI -60
LND 69
AEP 82
ACN 89
BNL 89
(N, INL) tot
Cross Section (Barn)
Energy (eV)

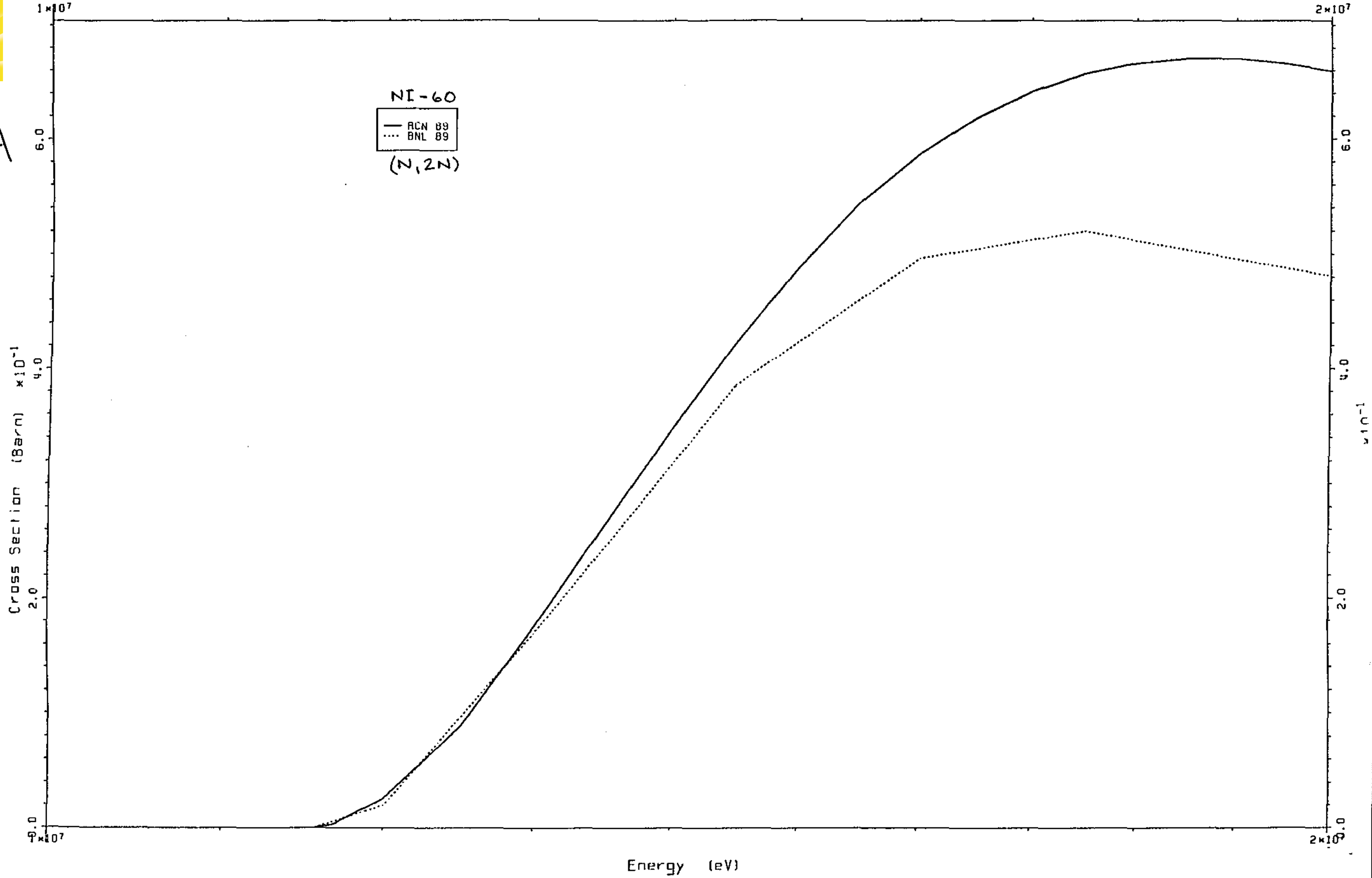
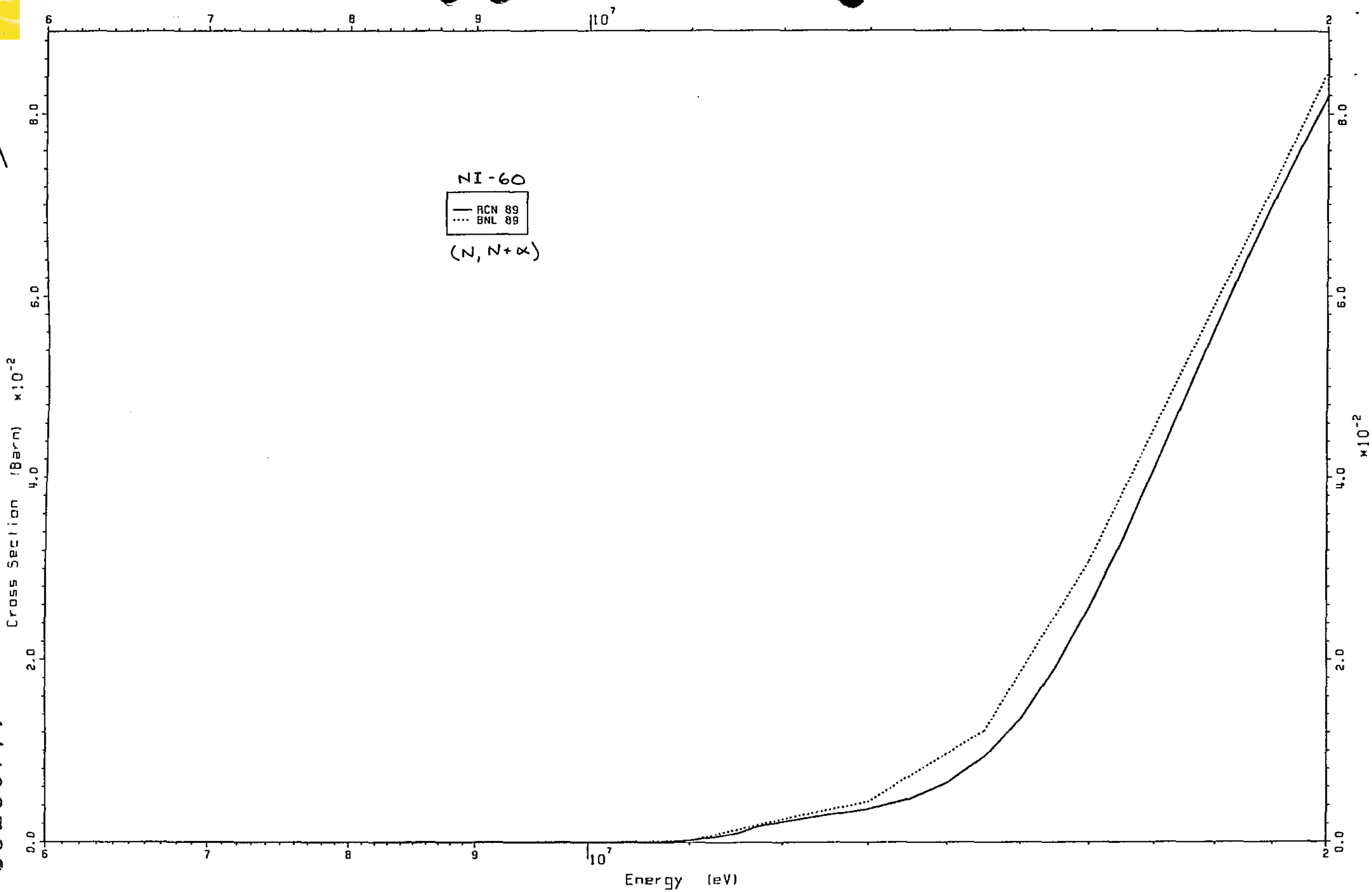


Fig. 12

14120381

Fig. 13



14120382

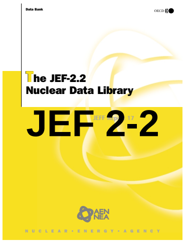
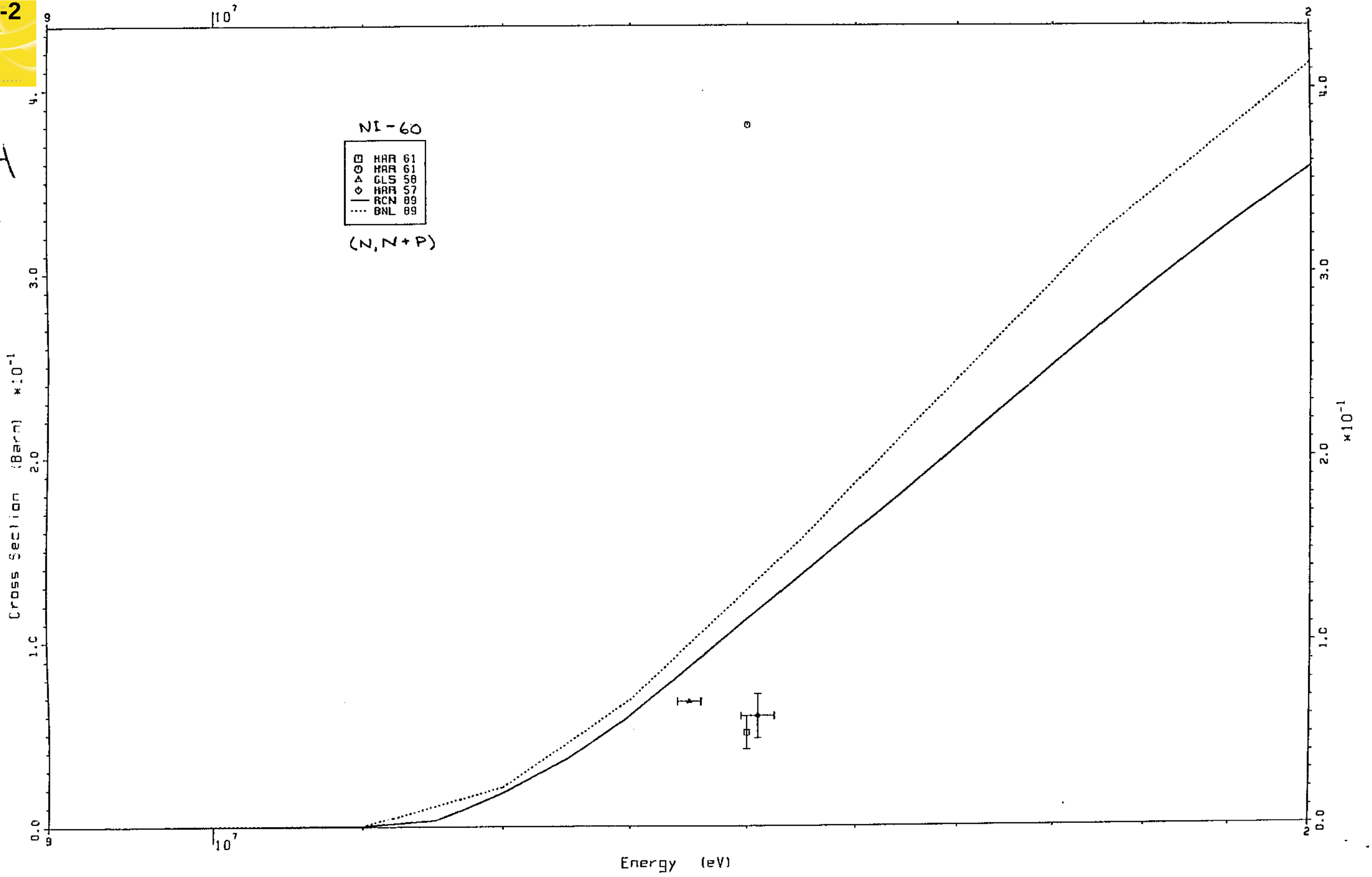
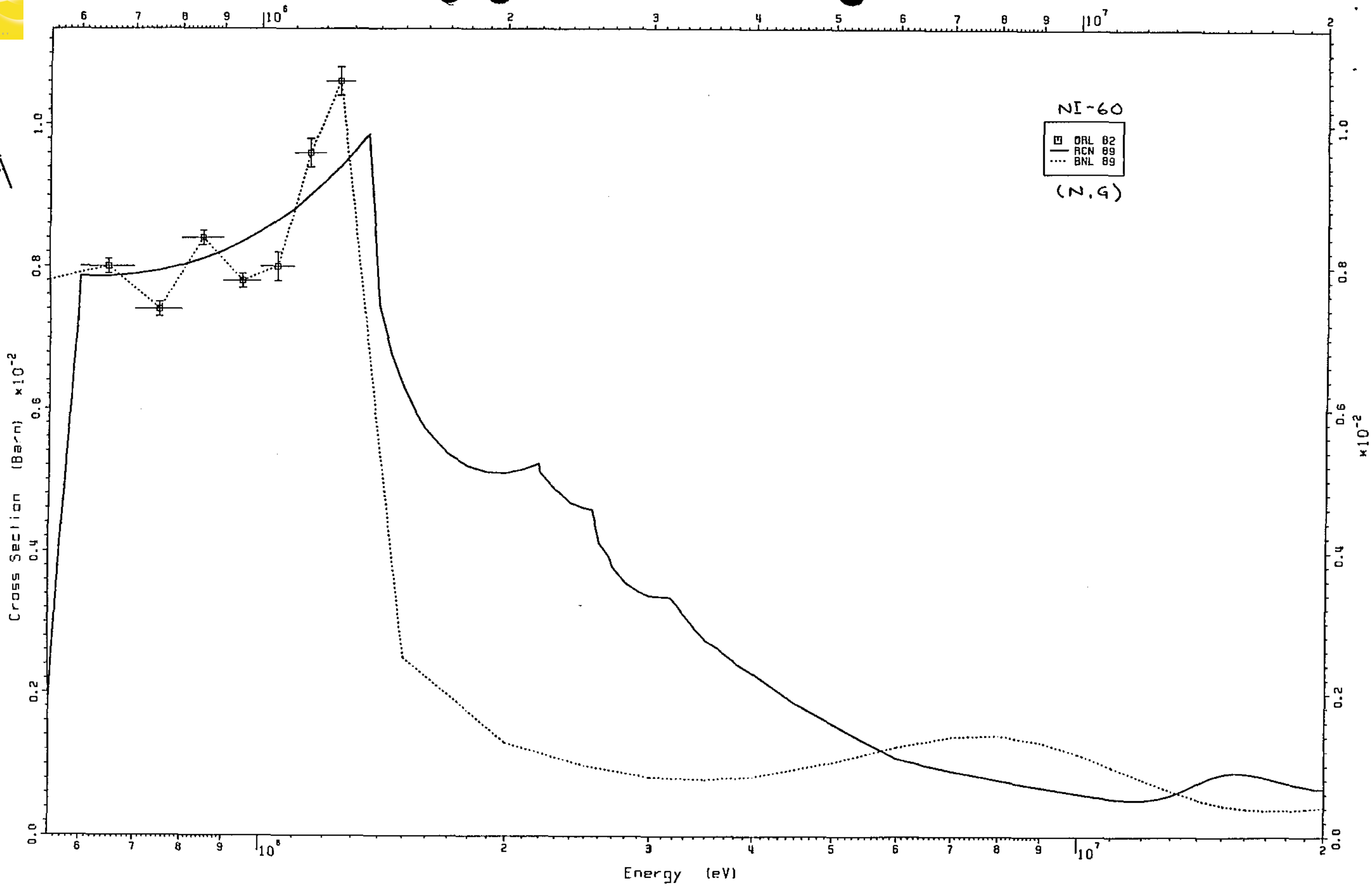


Fig. 14



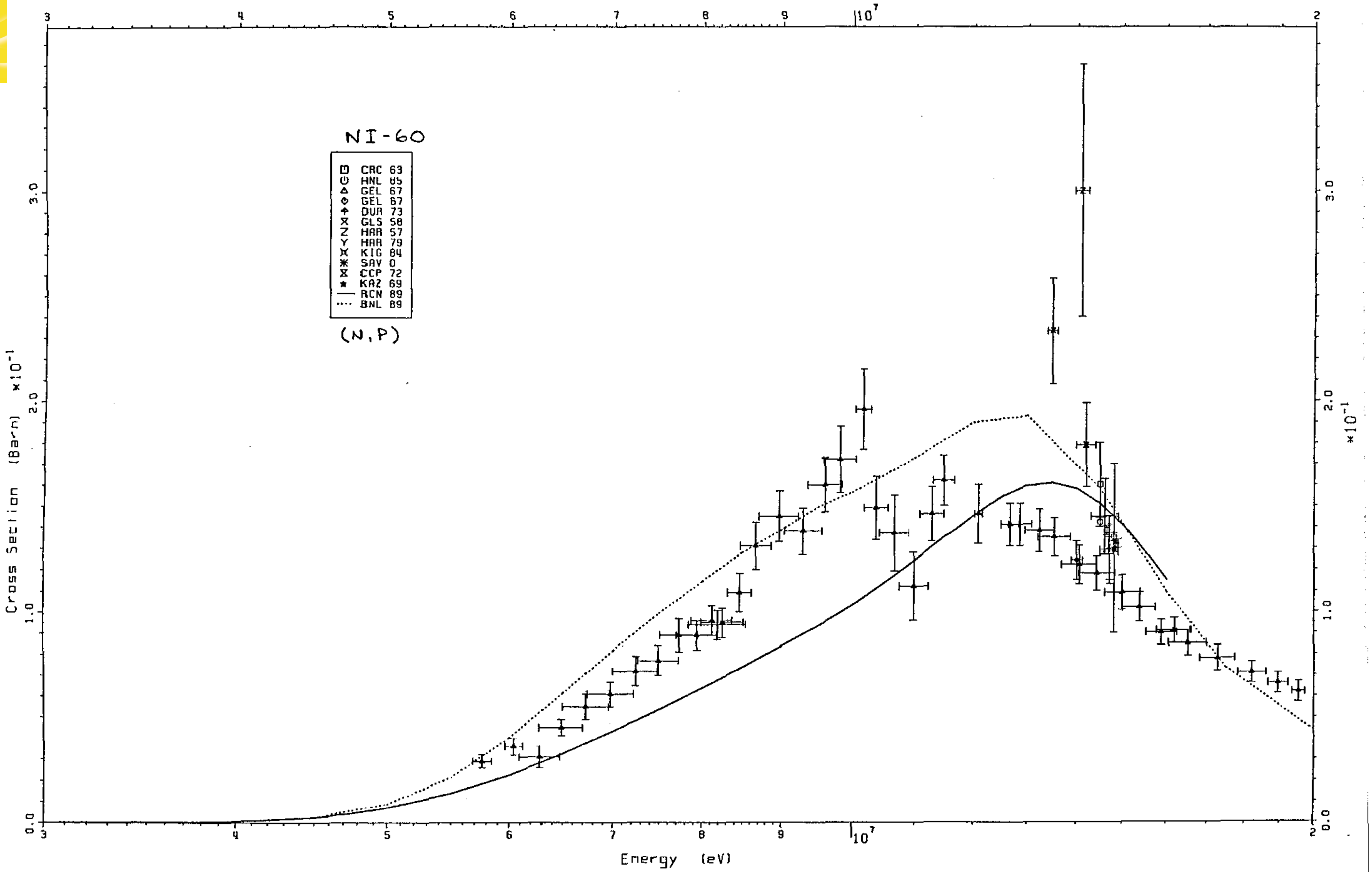
14120383

Fig. 15

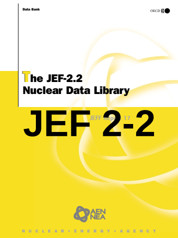


14120384

Fig. 16



14120385


The JEF-2.2
Nuclear Data Library
JEF 2-2

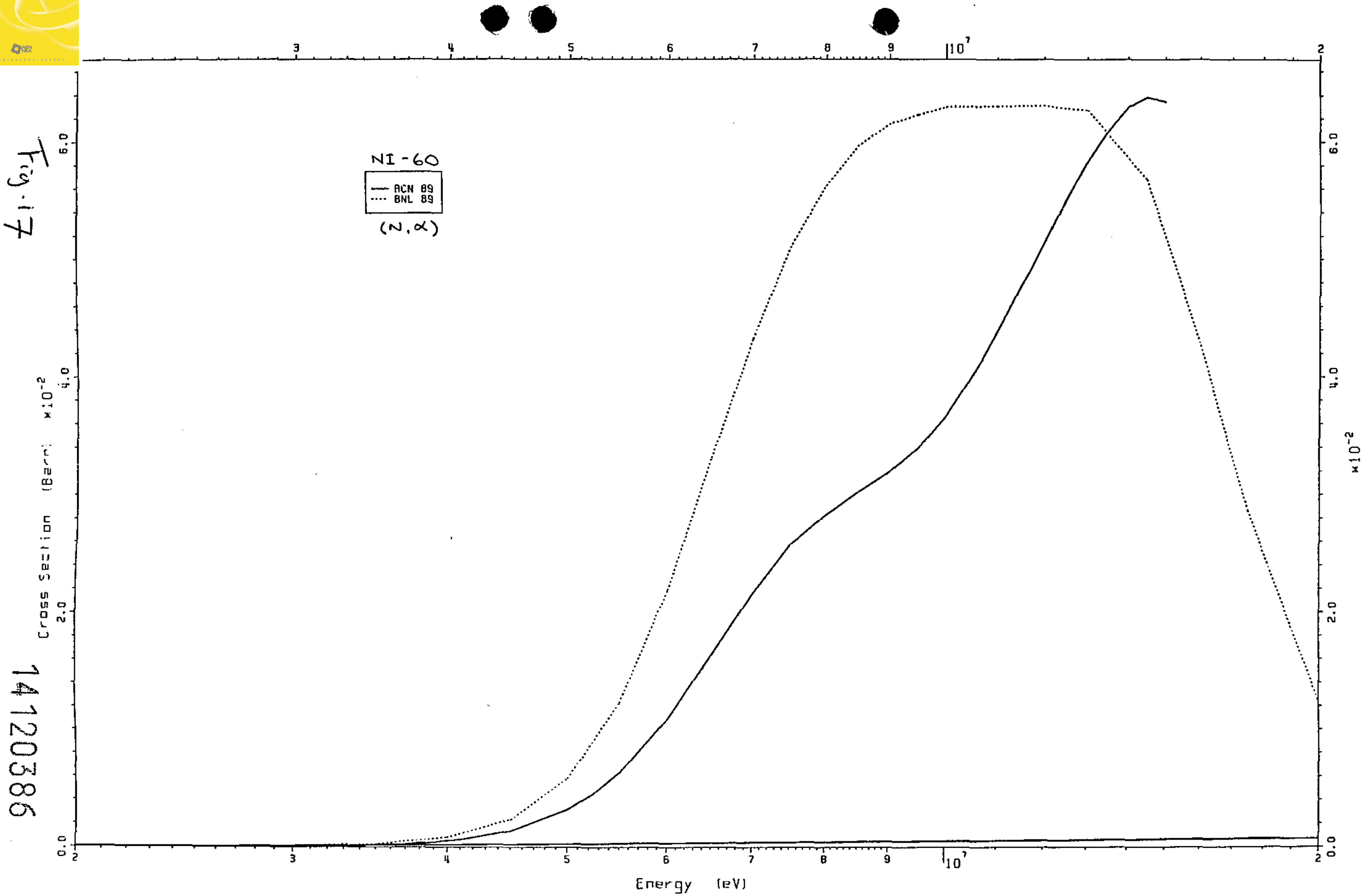

NI-60
ACN 89
BNL 89
(n,α)
Cross Section (Barn) x10^{-2}
Energy (eV)
0.0
2.0
4.0
6.0
2
3
4
5
6
7
8
9
10^{7}
x10^{-2}
1412038 6

Fig. 17

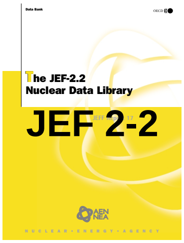
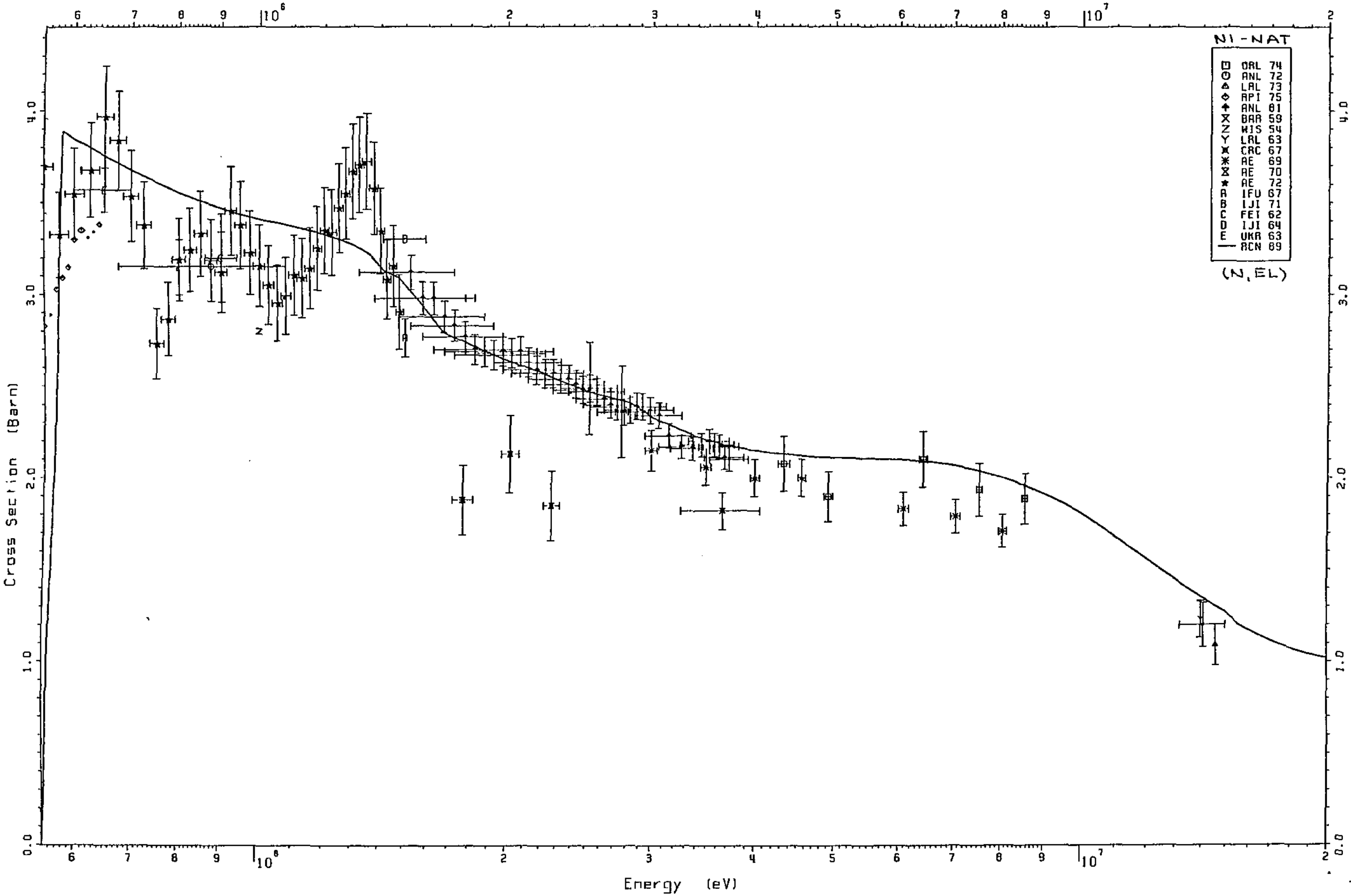


Fig-18



14120387

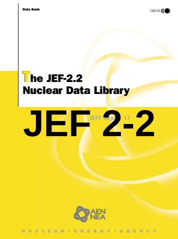
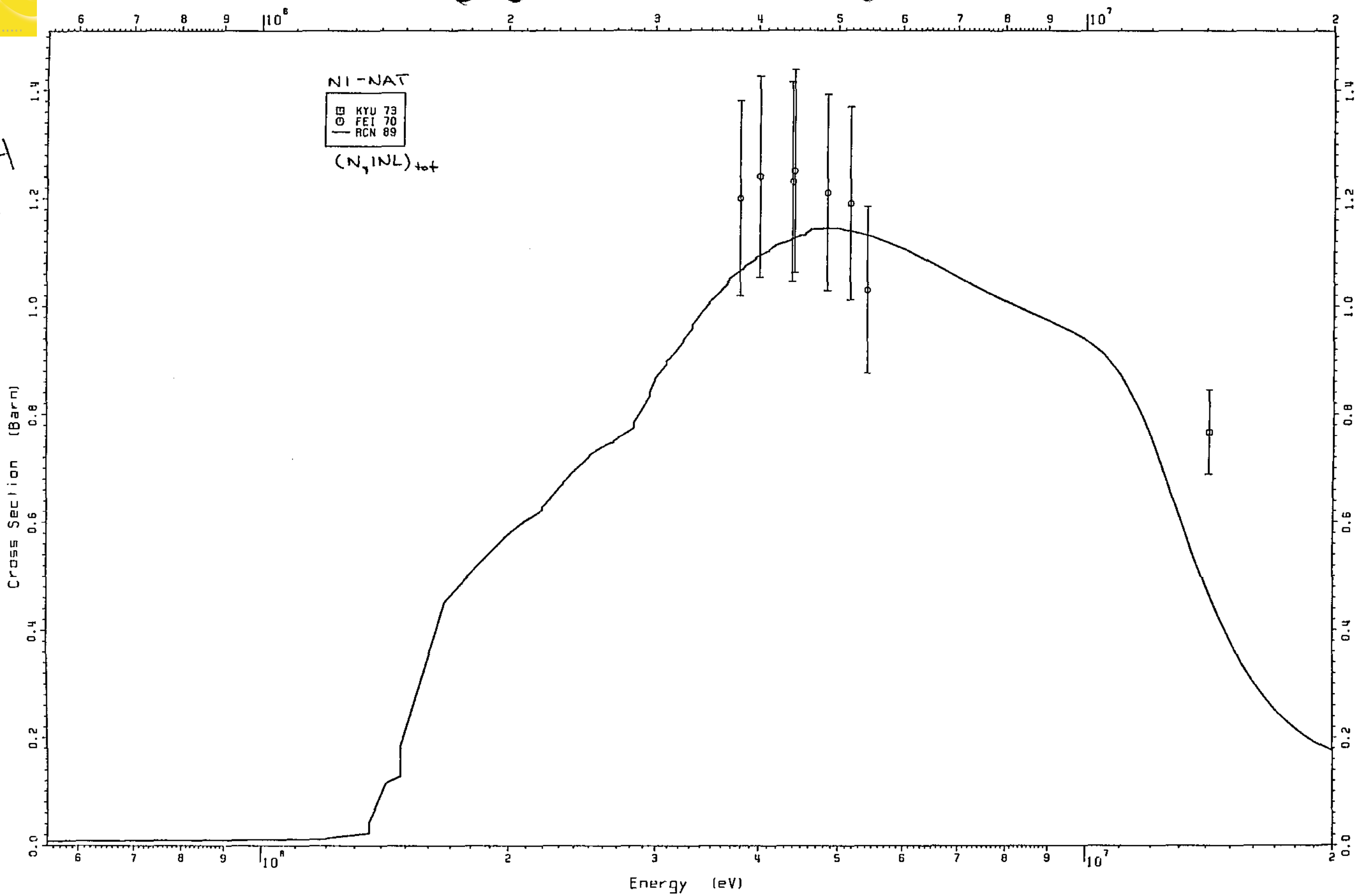
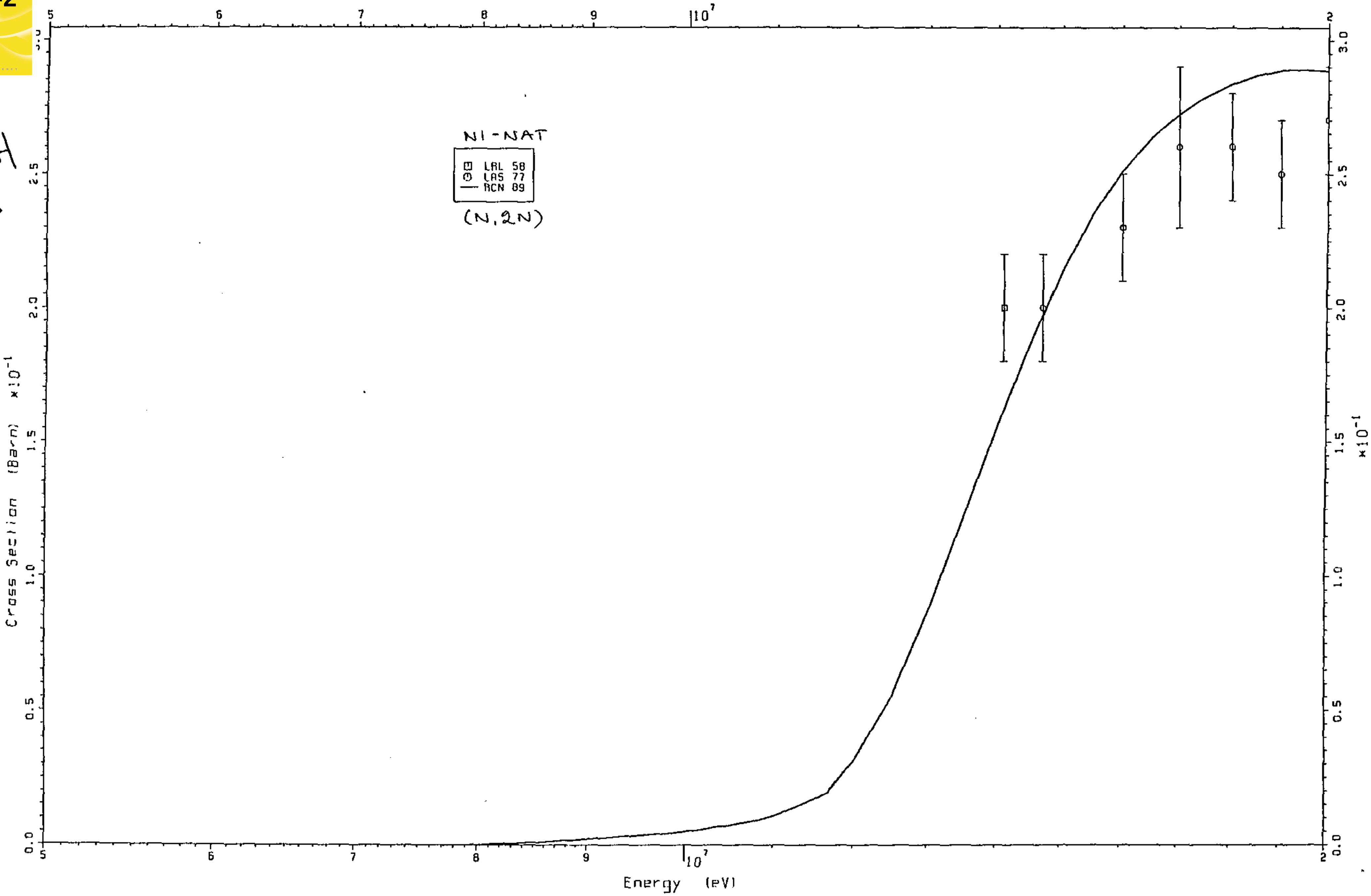


Fig. 19



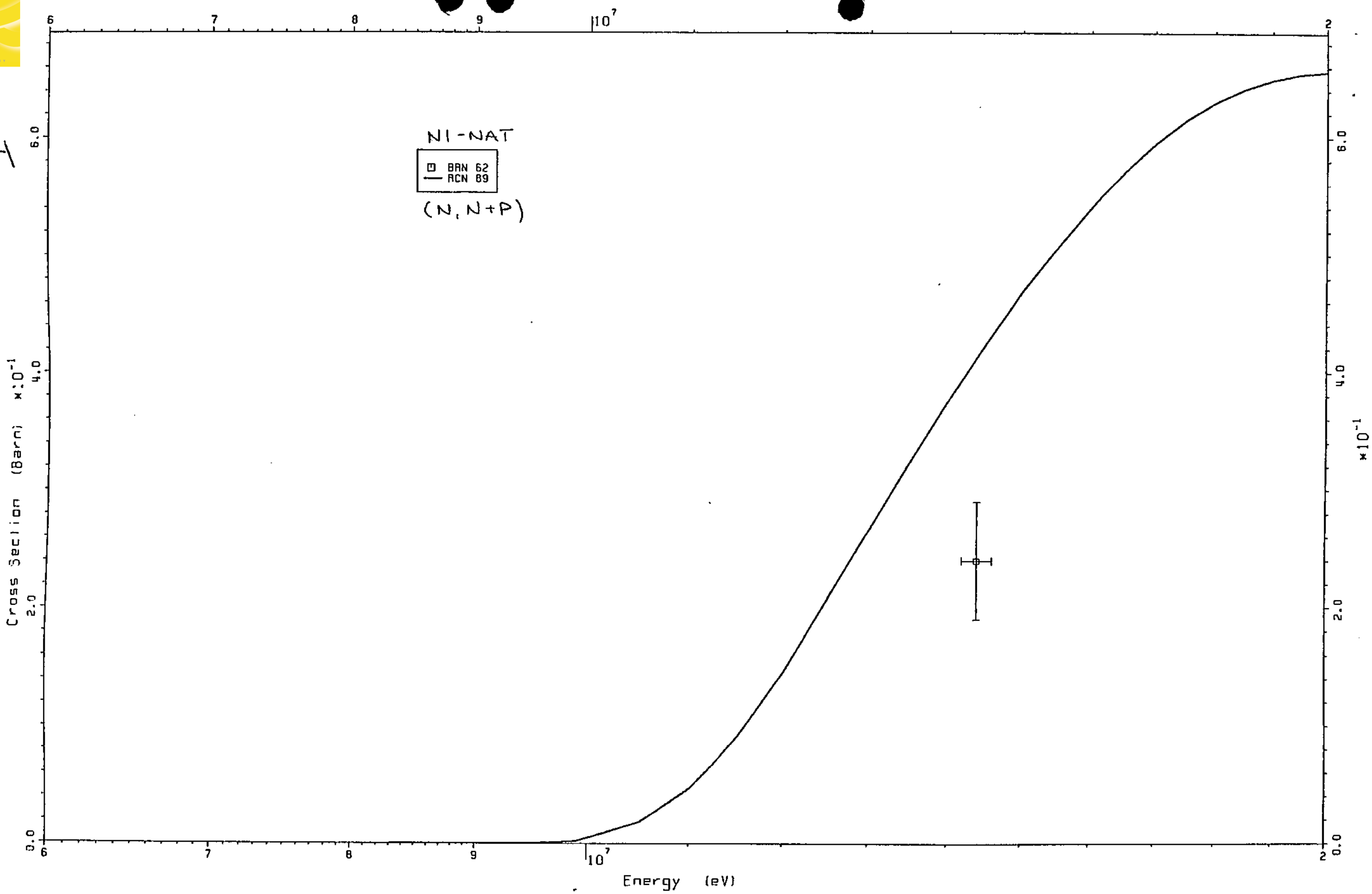
14120388

Fig. 20



14120389

Fig. 21



1412 0390

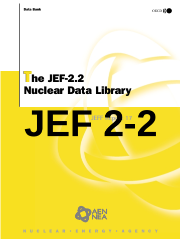
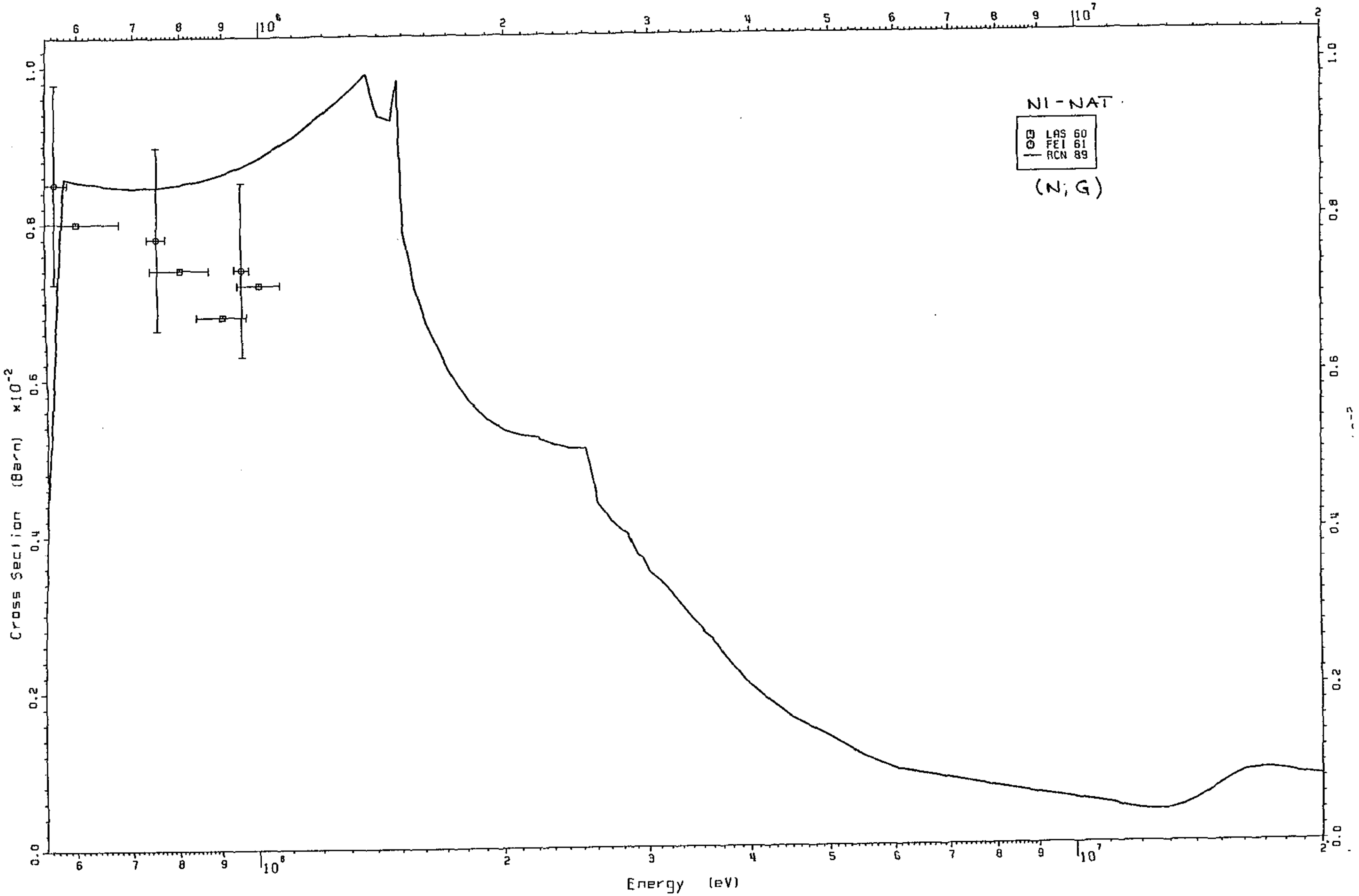
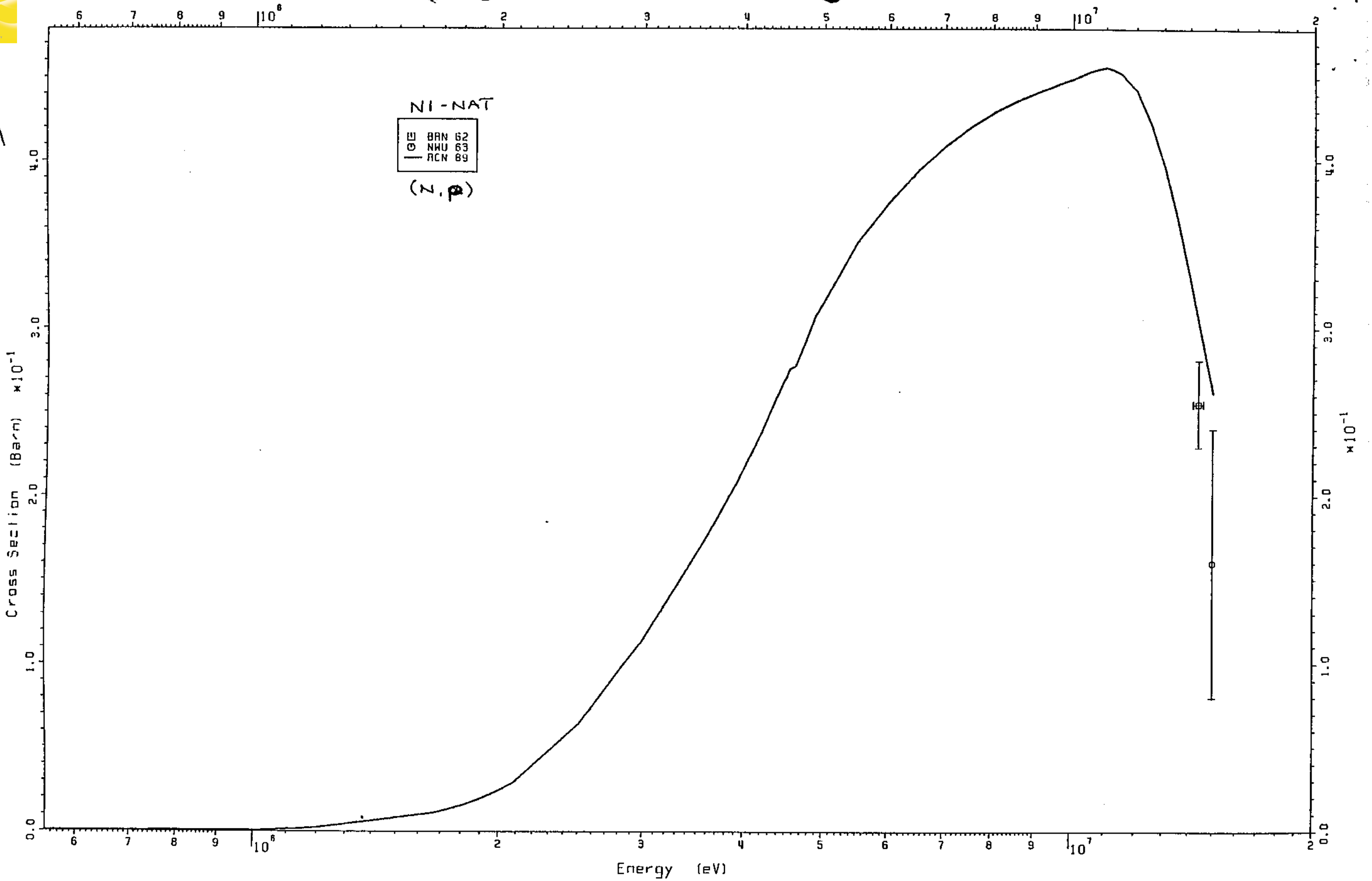


Fig. 22

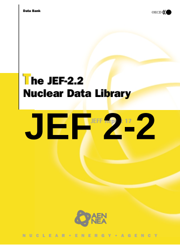


14120391

Fig. 23



14120392



APPENDIX A2. GRAPHS OF GROUP-AVERAGED CROSS-SECTIONS FOR NI-58 AND NI-60

(Comparison between JEF-2PR and ENDF/B-VI)

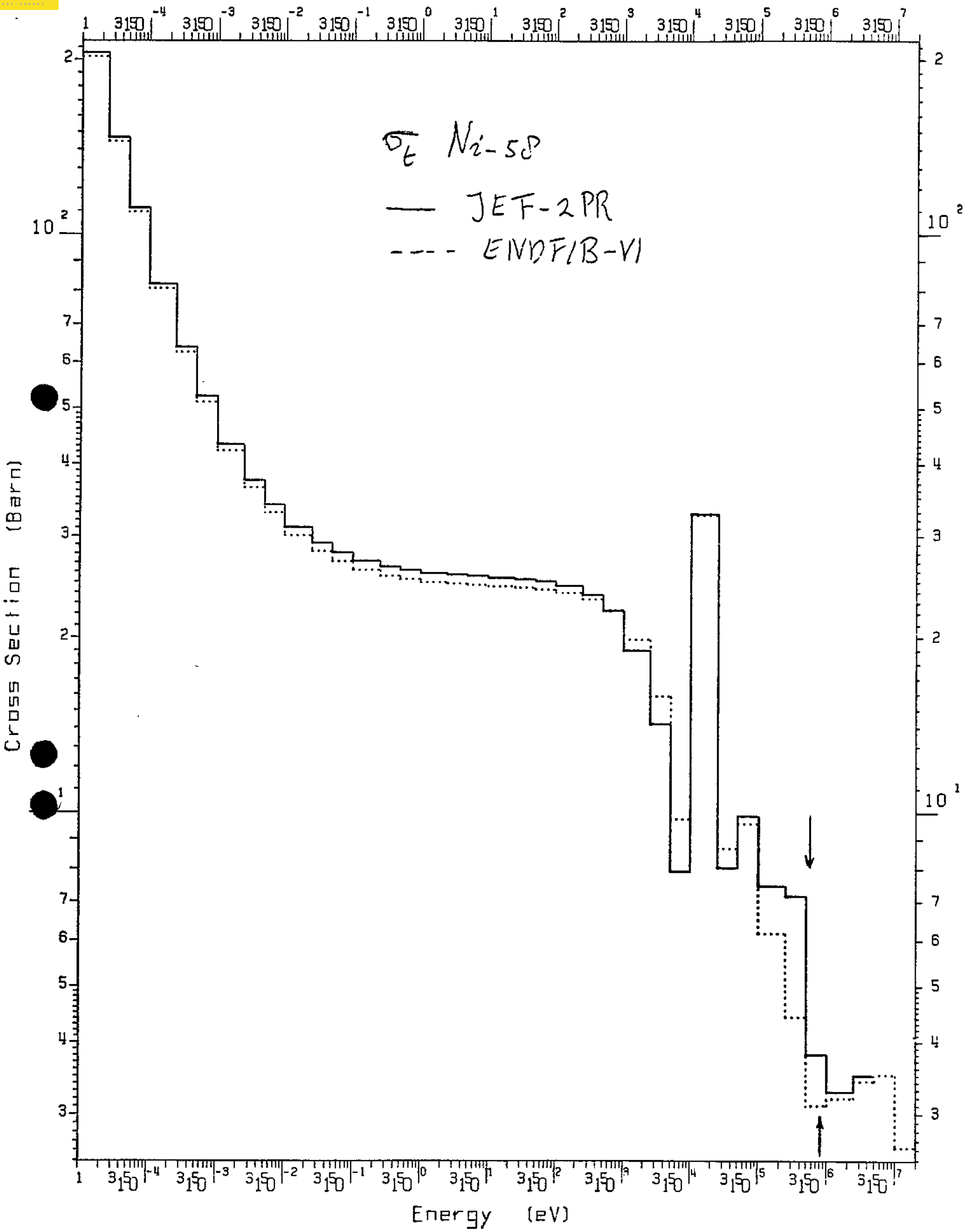
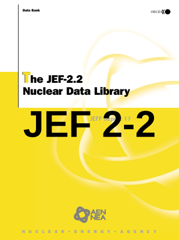


Fig. 1

14120394


The JEF-2.2
Nuclear Data Library
JEF 2-2

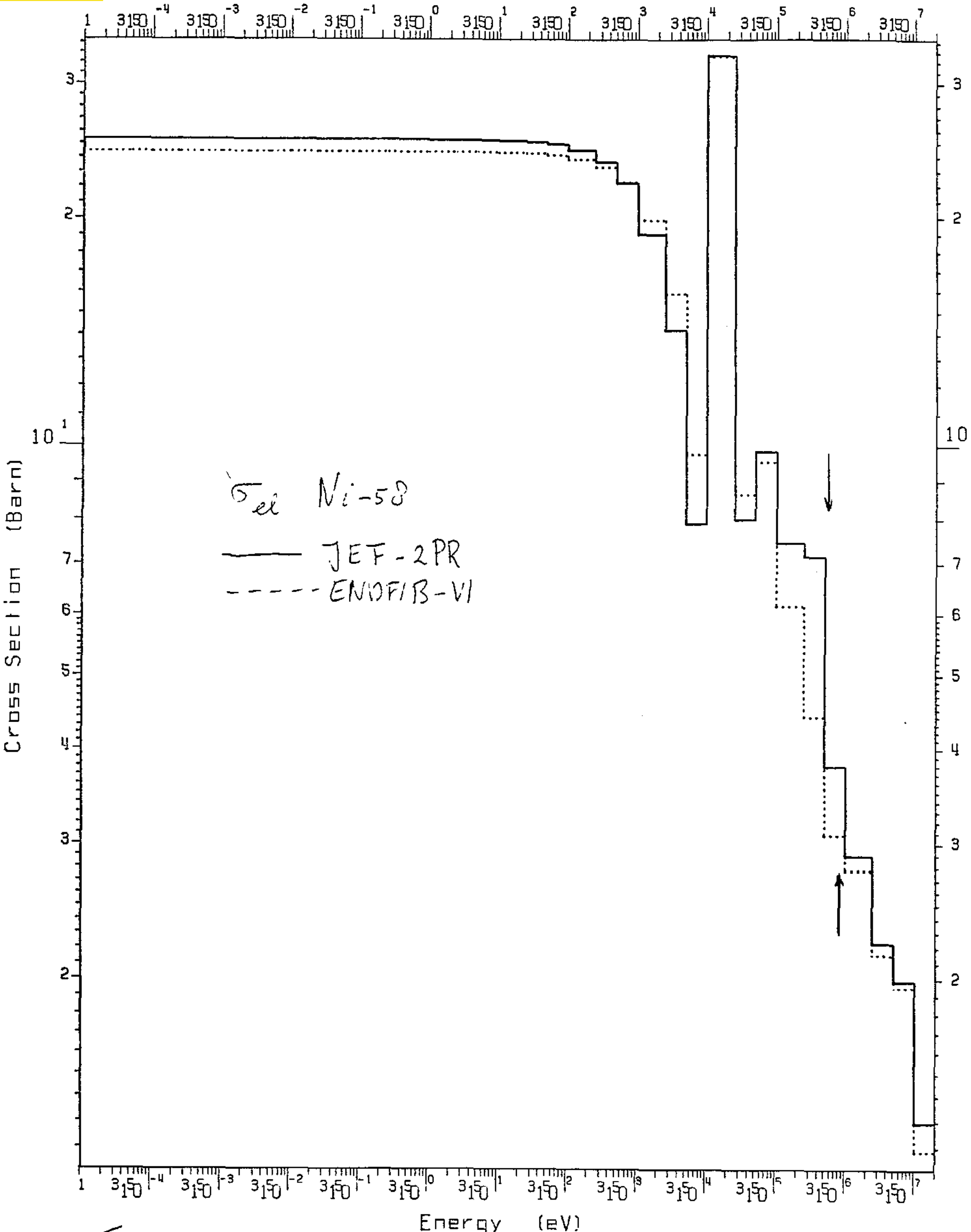
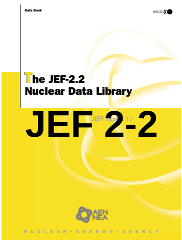

σel Ni-58
JEF-2PR
ENDF/B-VI
Cross Section (Barn)
Energy (eV)

Fig. 2



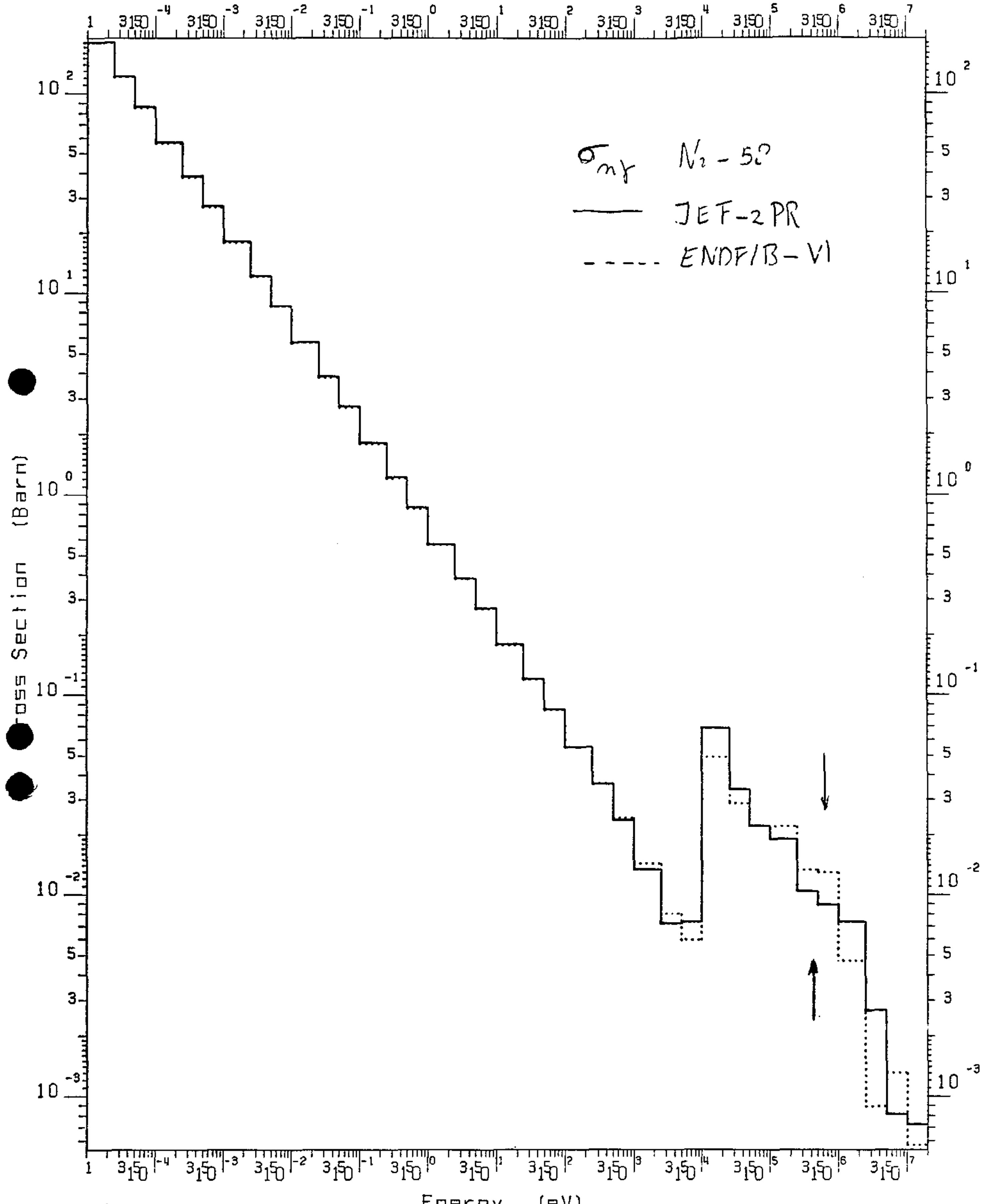
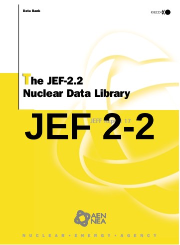


Fig. 3

14120396


The JEF-2.2
Nuclear Data Library
JEF 2-2

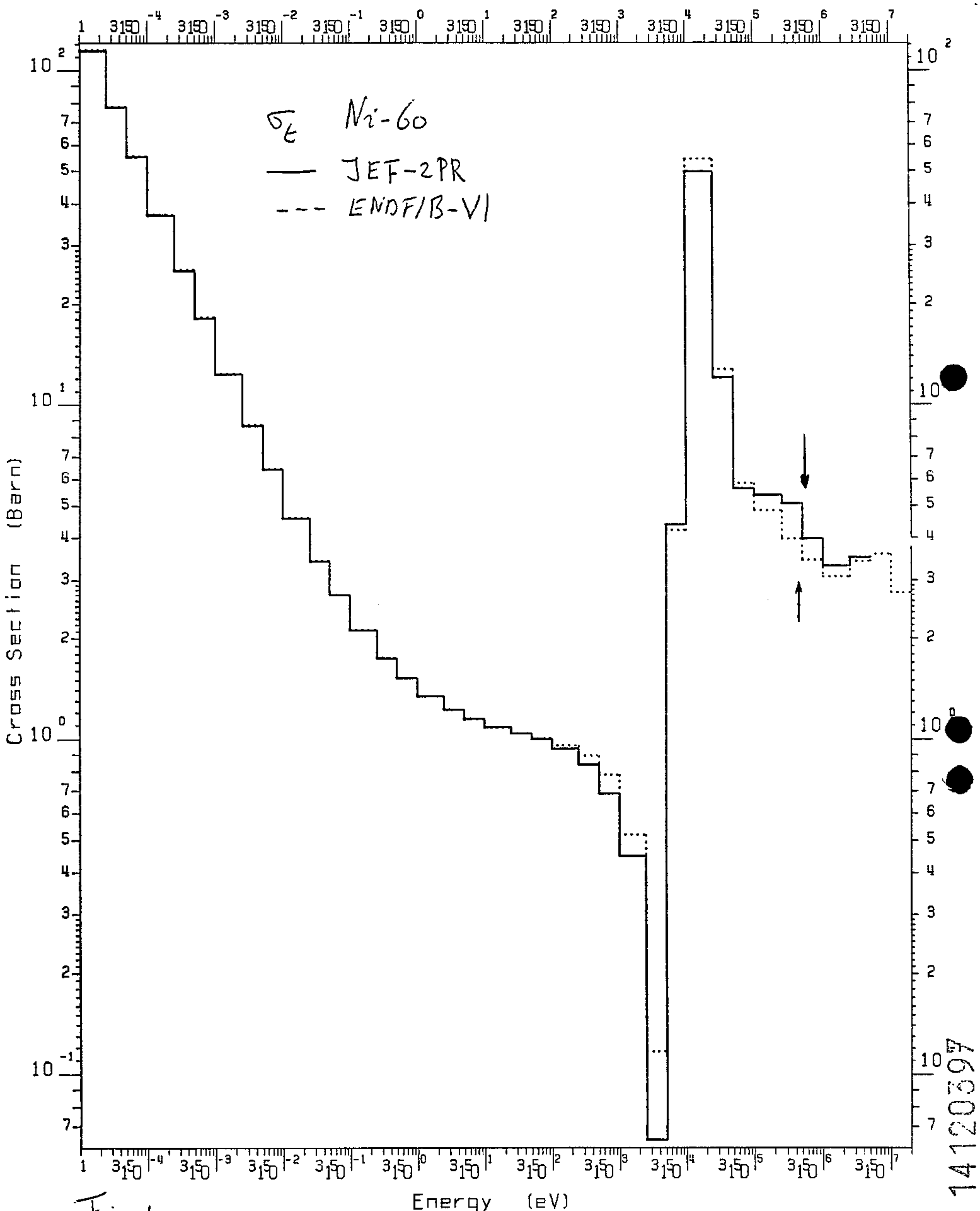
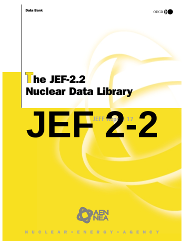

σt Ni-60
JEF-2PR
ENDF/B-VI
Cross Section (Barn)
Energy (eV)

Fig. 4



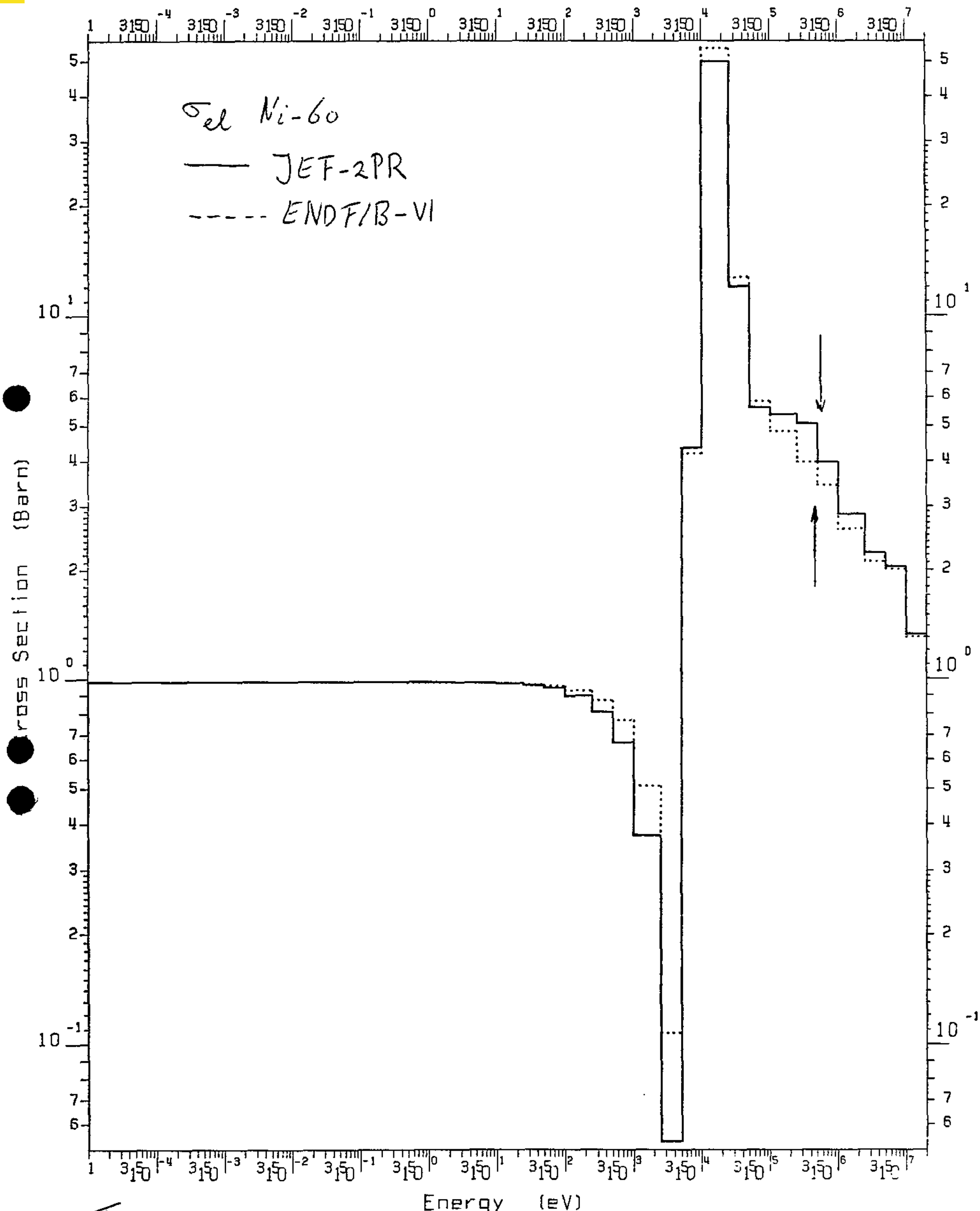
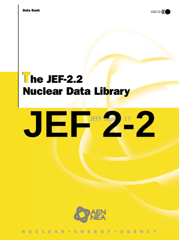


Fig. 5

14120398



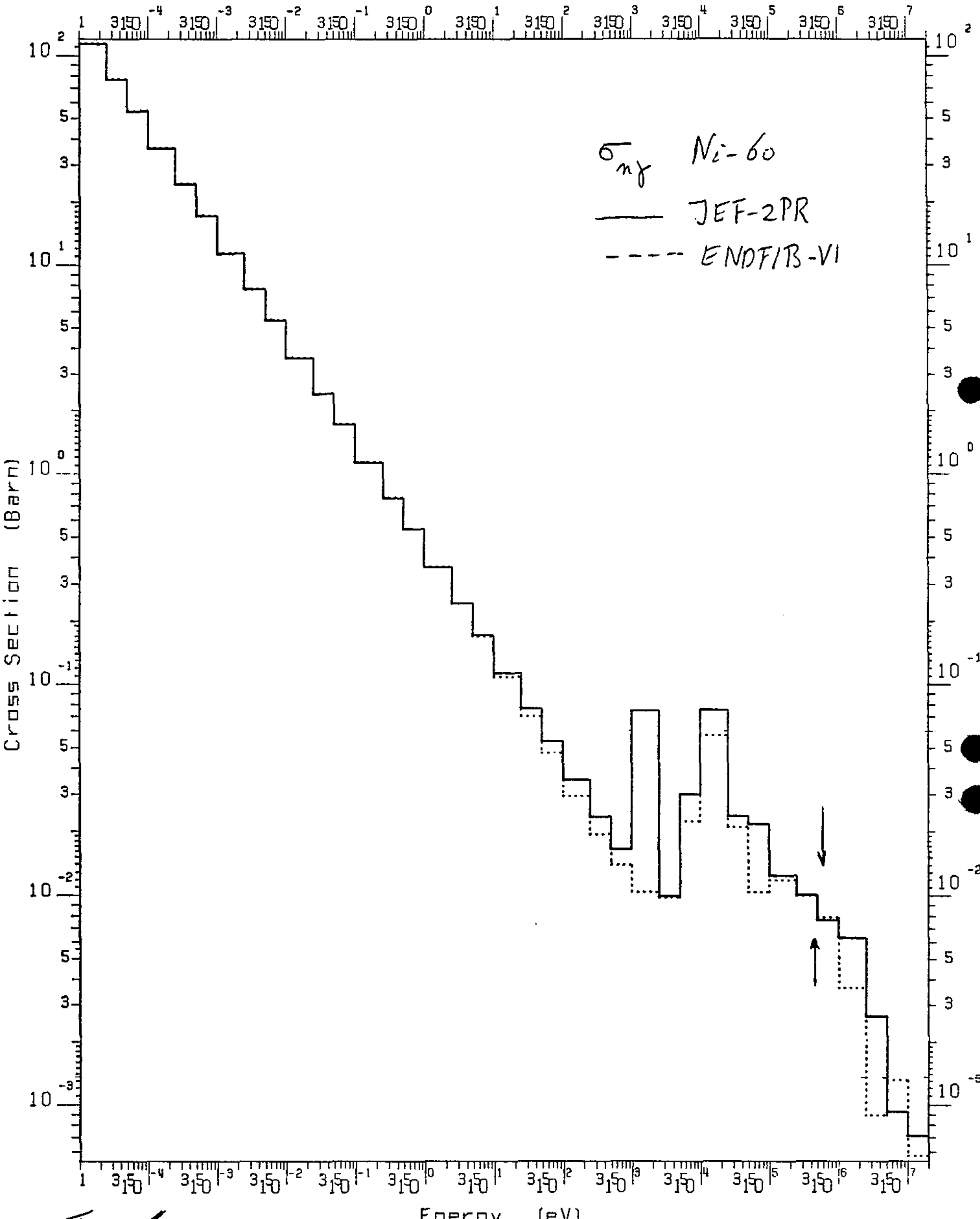
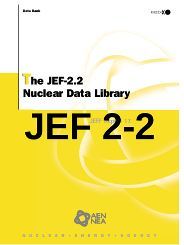


Fig. 6

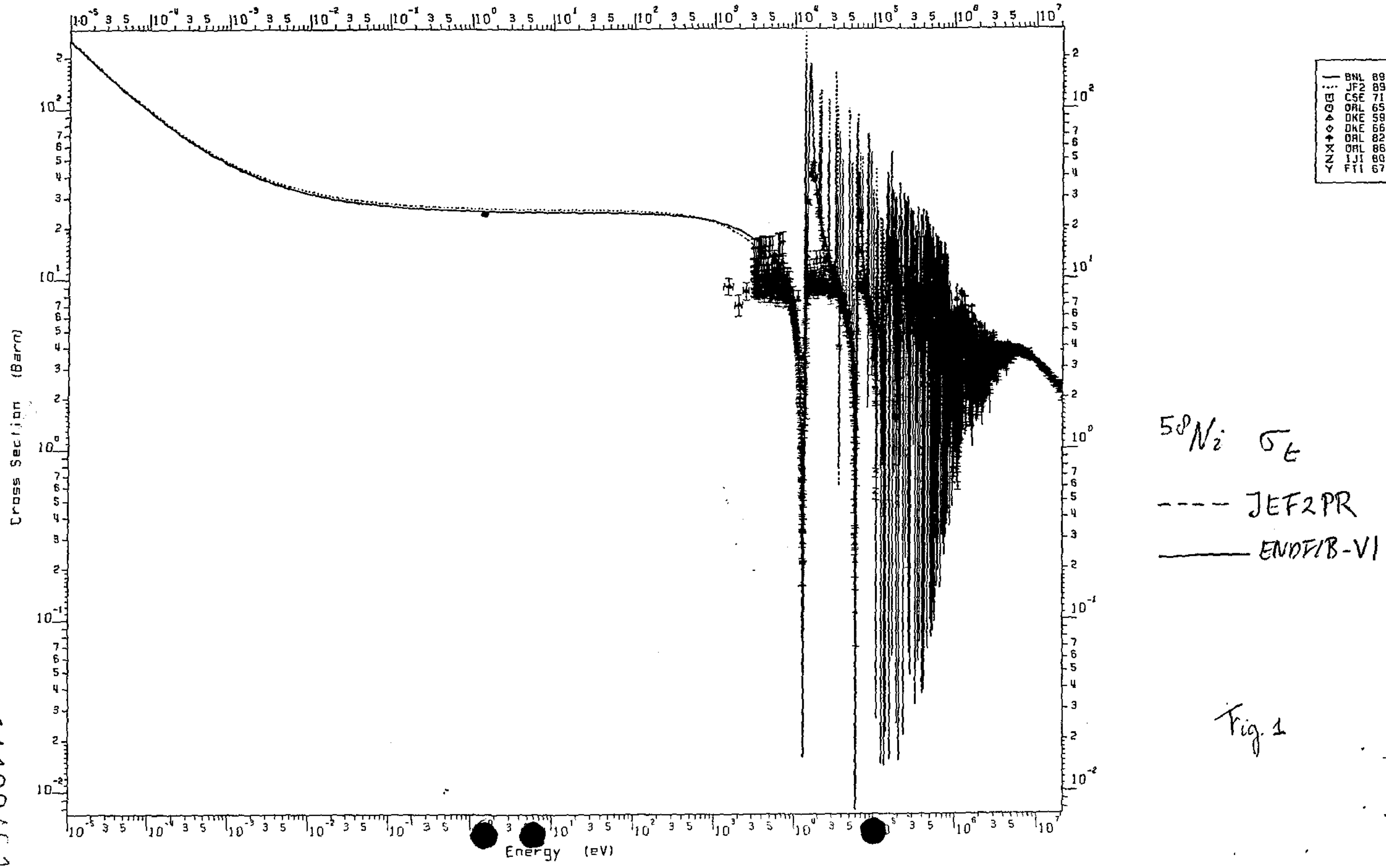
14120399



APPENDIX A3. GRAPHS OF MF3 CROSS-SECTIONS IN THE RESONANCE RANGE

(Comparison between JEF-2PR, JEF-1, ENDF/B-VI and EXFOR)

Ni58(n,TOT)



^{58}Ni σ_t

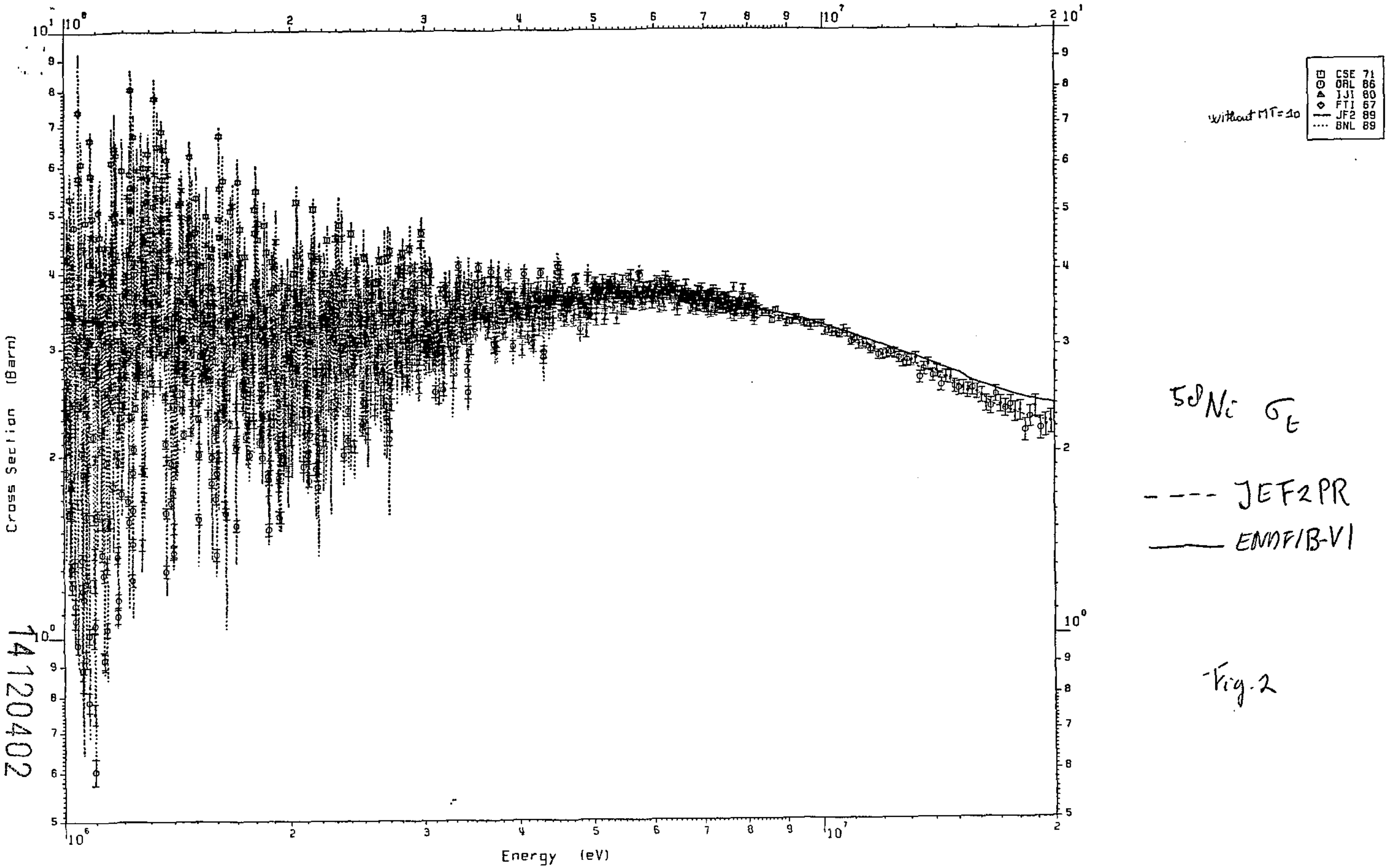
---- JEF2PR

—— ENDF/B-VI

Fig. 1

1412046.1

Ni 58 (n,TOT)



without MT=10

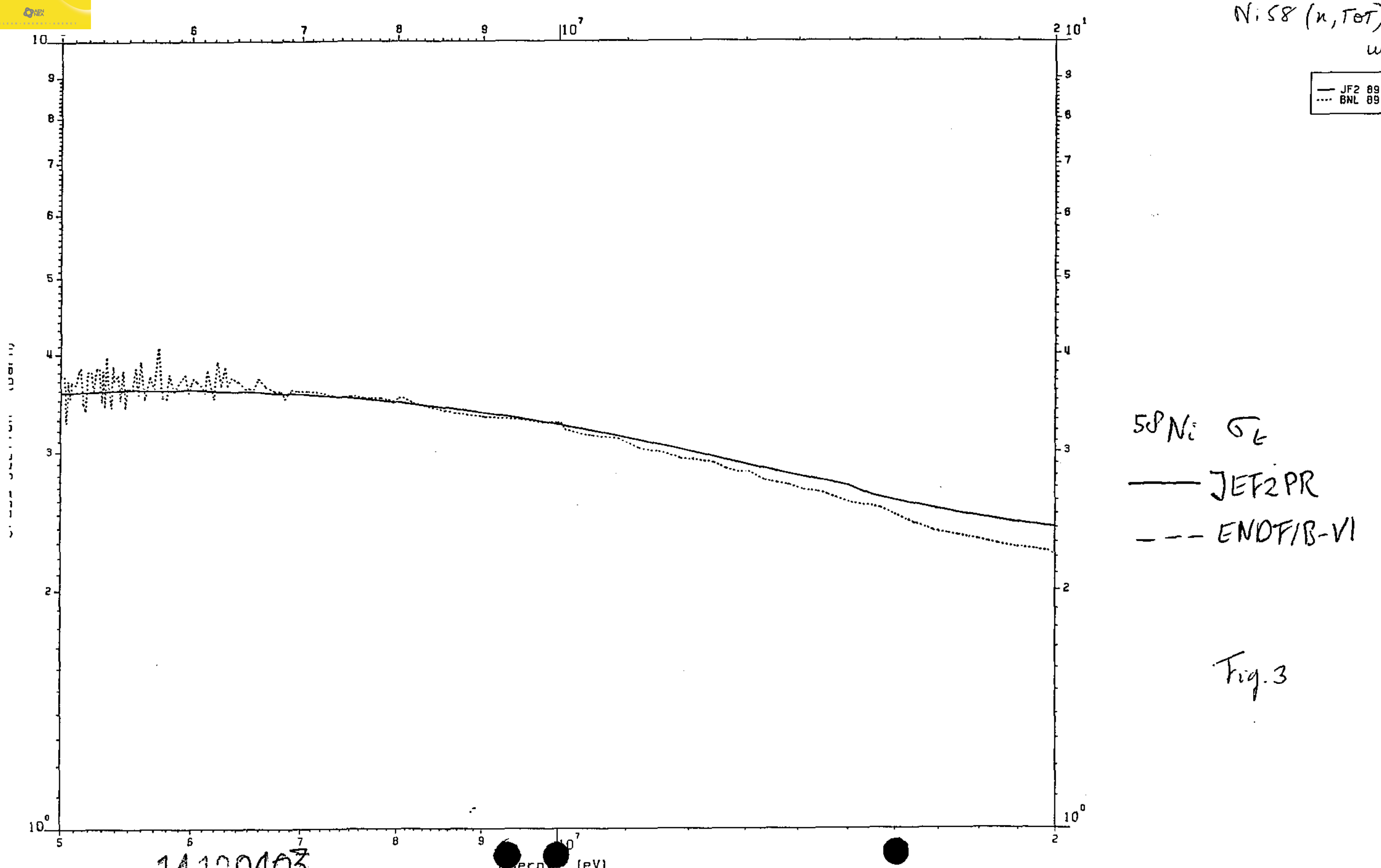
^{58}Ni σ_t

---- JEF2PR

—— ENDF/B-VI

Fig. 2

Comparaison. Pointu…
Ni 58 (n, TOT).



mi-Hiou… HT… ENDF

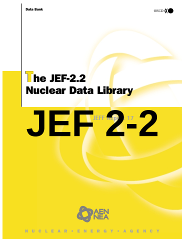
^{58}Ni σ_t

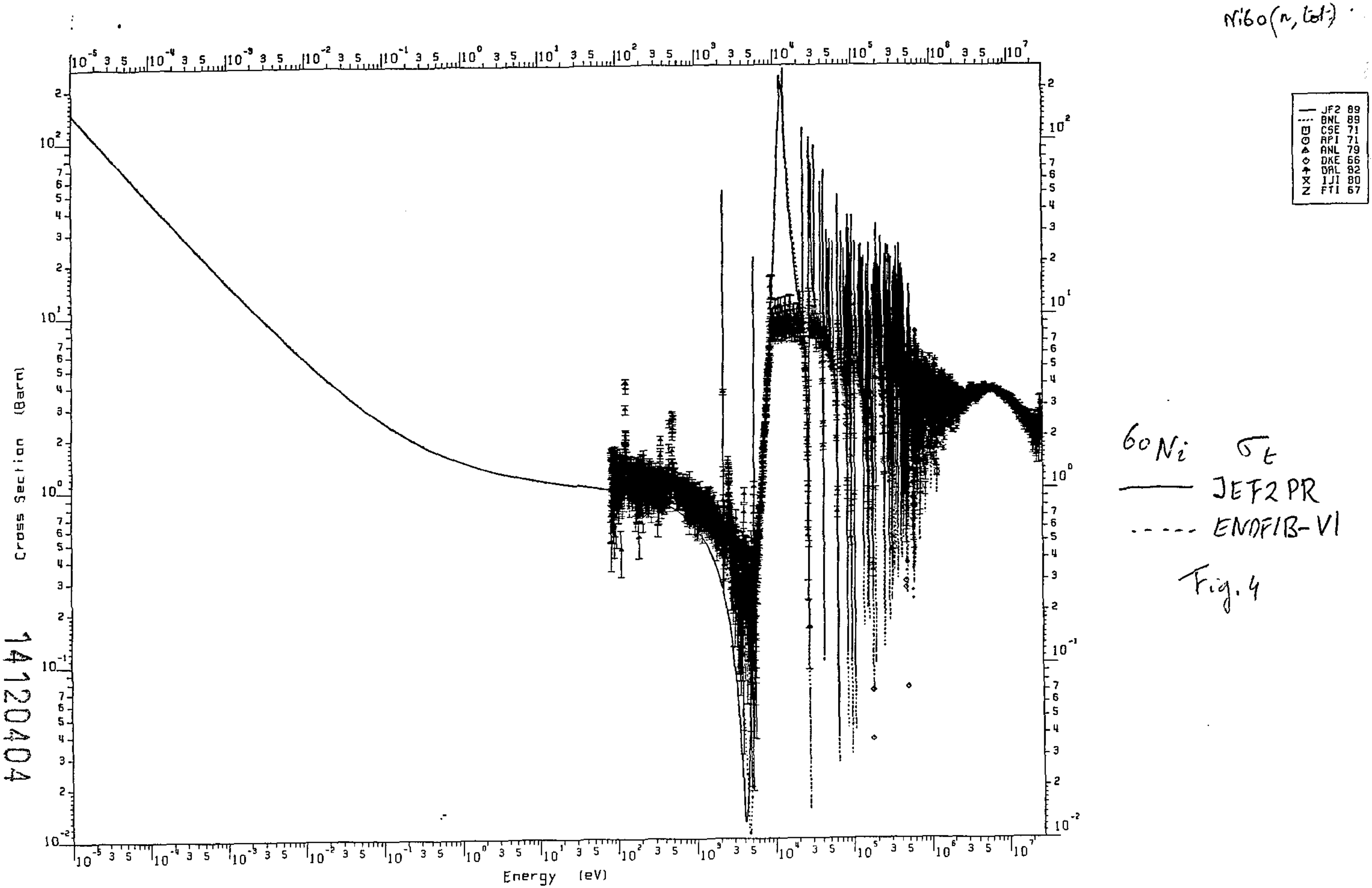
——— JEF2PR

- - - ENDF/B-VI

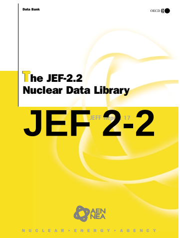
Fig. 3

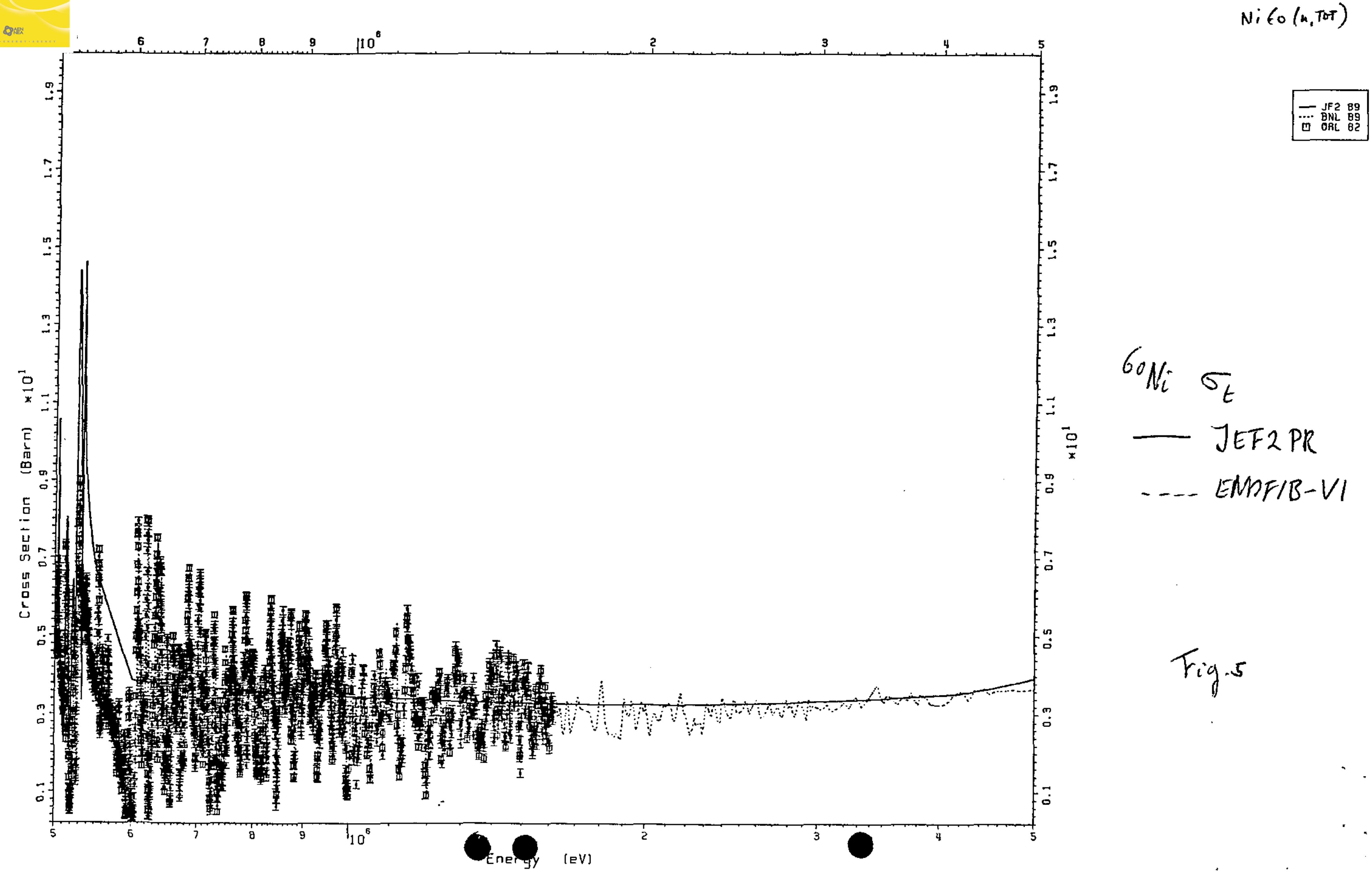
14120403

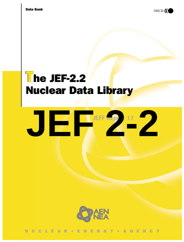

The JEF-2.2
Nuclear Data Library
JEF 2-2


Ni60(n,tot)
Cross Section (Barn)
Energy (eV)
JF2 89
BNL 89
CSE 71
RPI 71
ANL 79
DKE 66
DAL 92
IJI 80
FTI 67
60Ni σt
JEF2 PR
ENDF/B-VI
Fig. 4

14120404


The JEF-2.2
Nuclear Data Library
JEF 2-2


Ni 60 (n,TOT)
JF2 89
BNL 89
ORL 82
Cross Section (Barn) ×10[1]
Energy (eV)
10[6]
^{60}Ni σ_t
JEF2 PR
ENDF/B-VI
Fig.5



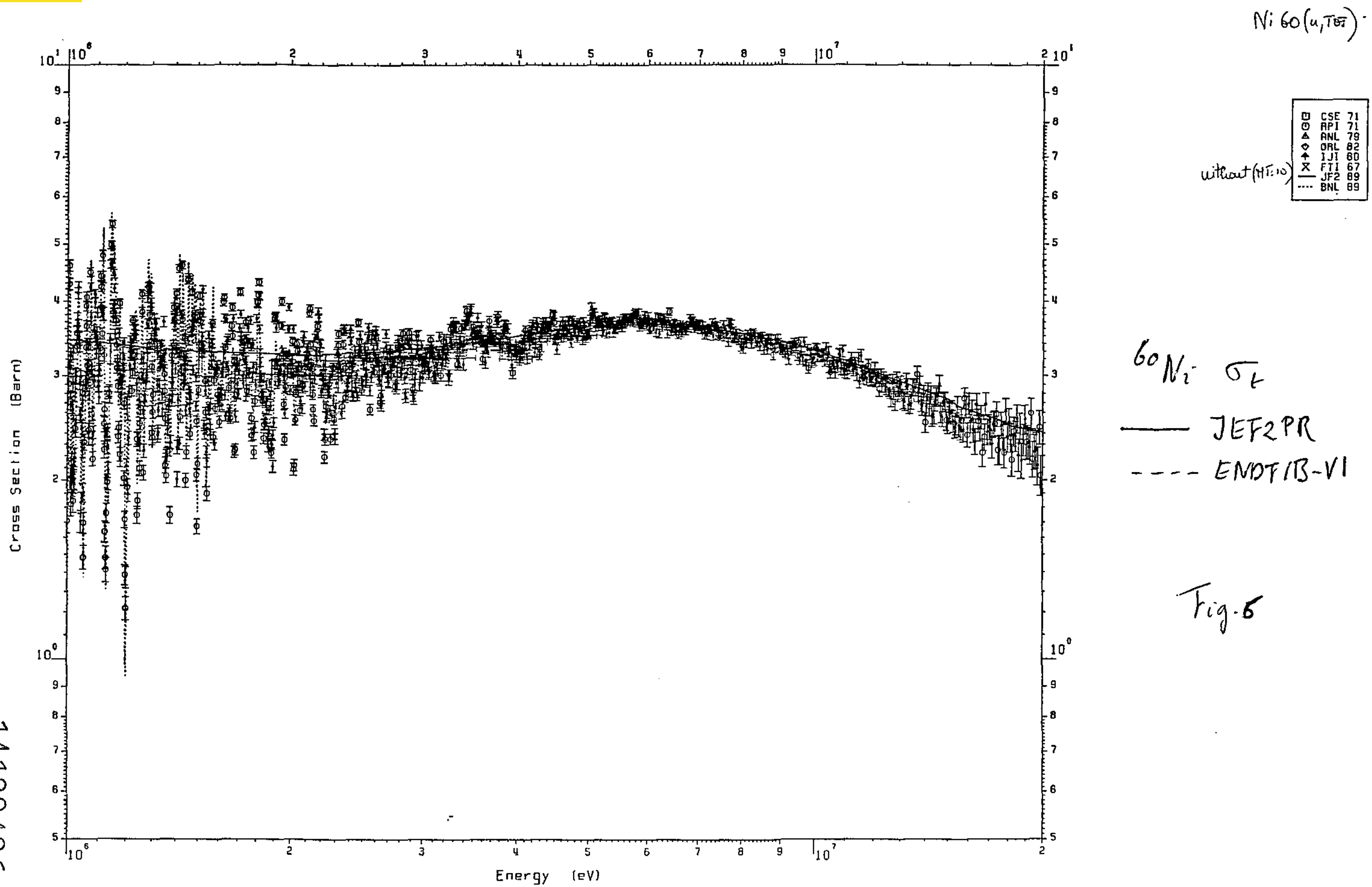
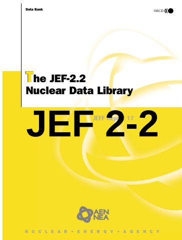


Fig. 6

14120406



Ni 62. (n,

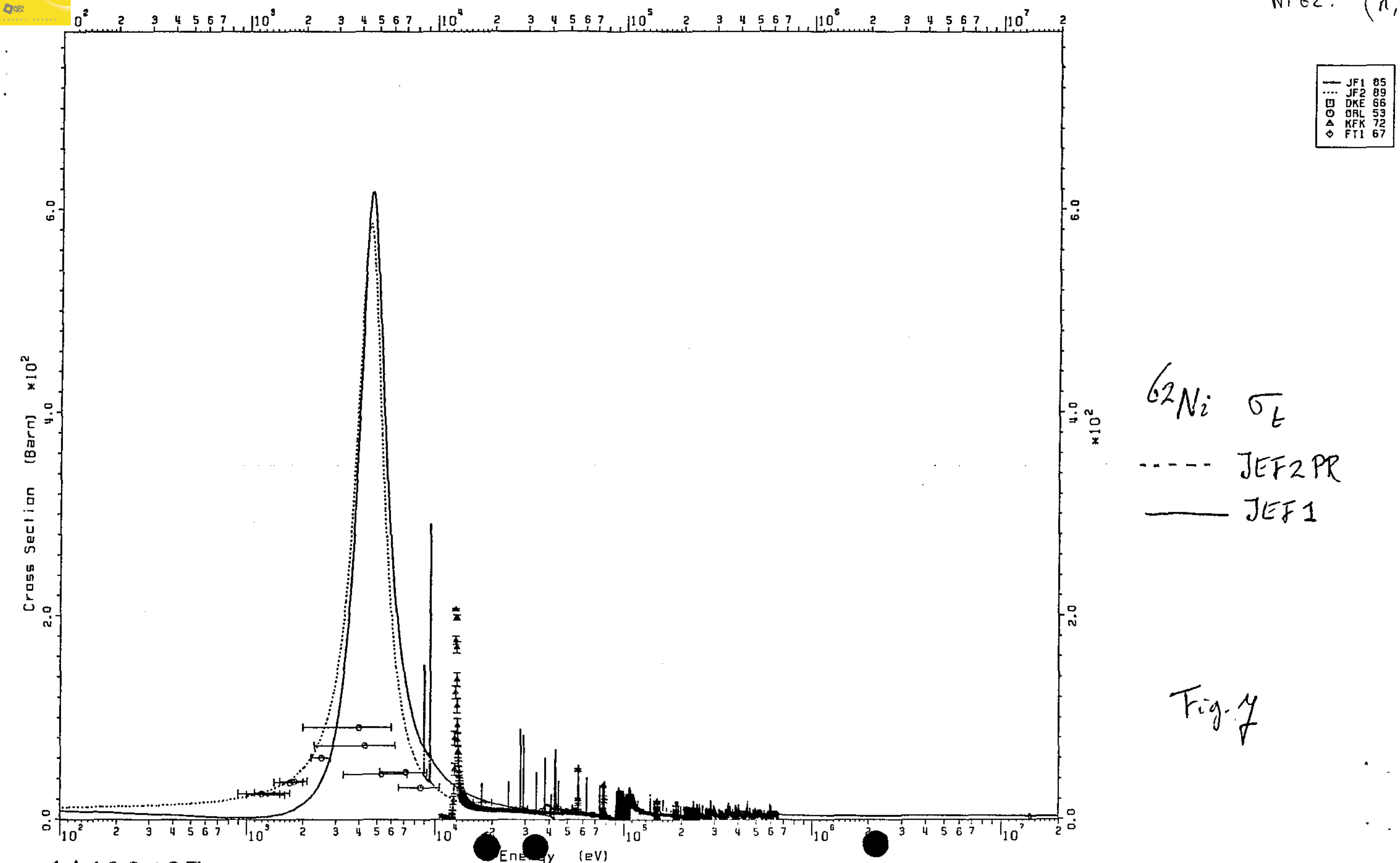
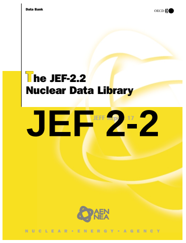


Fig. 7

14120407



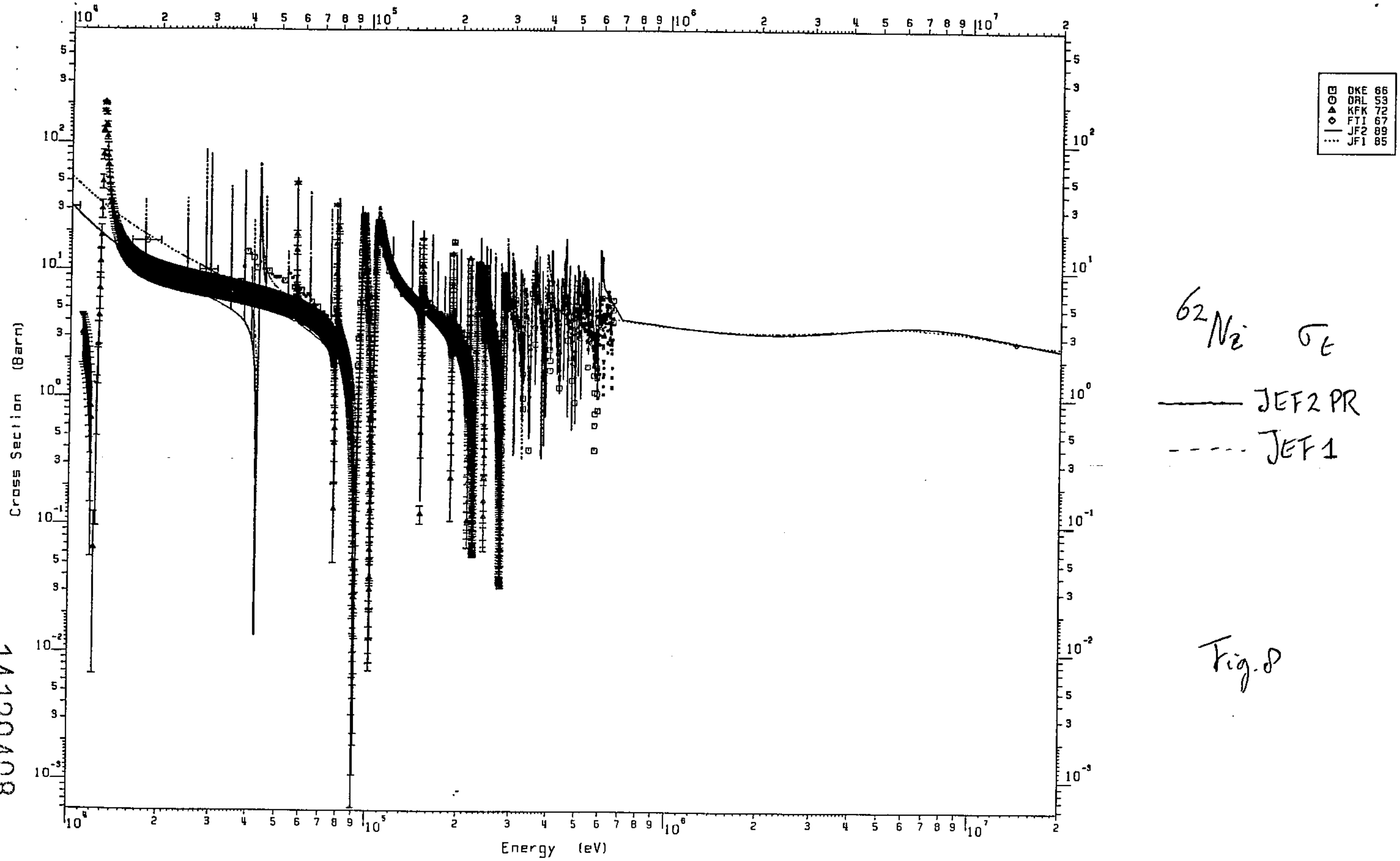
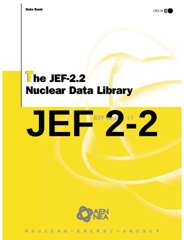


Fig. 8

141204O8



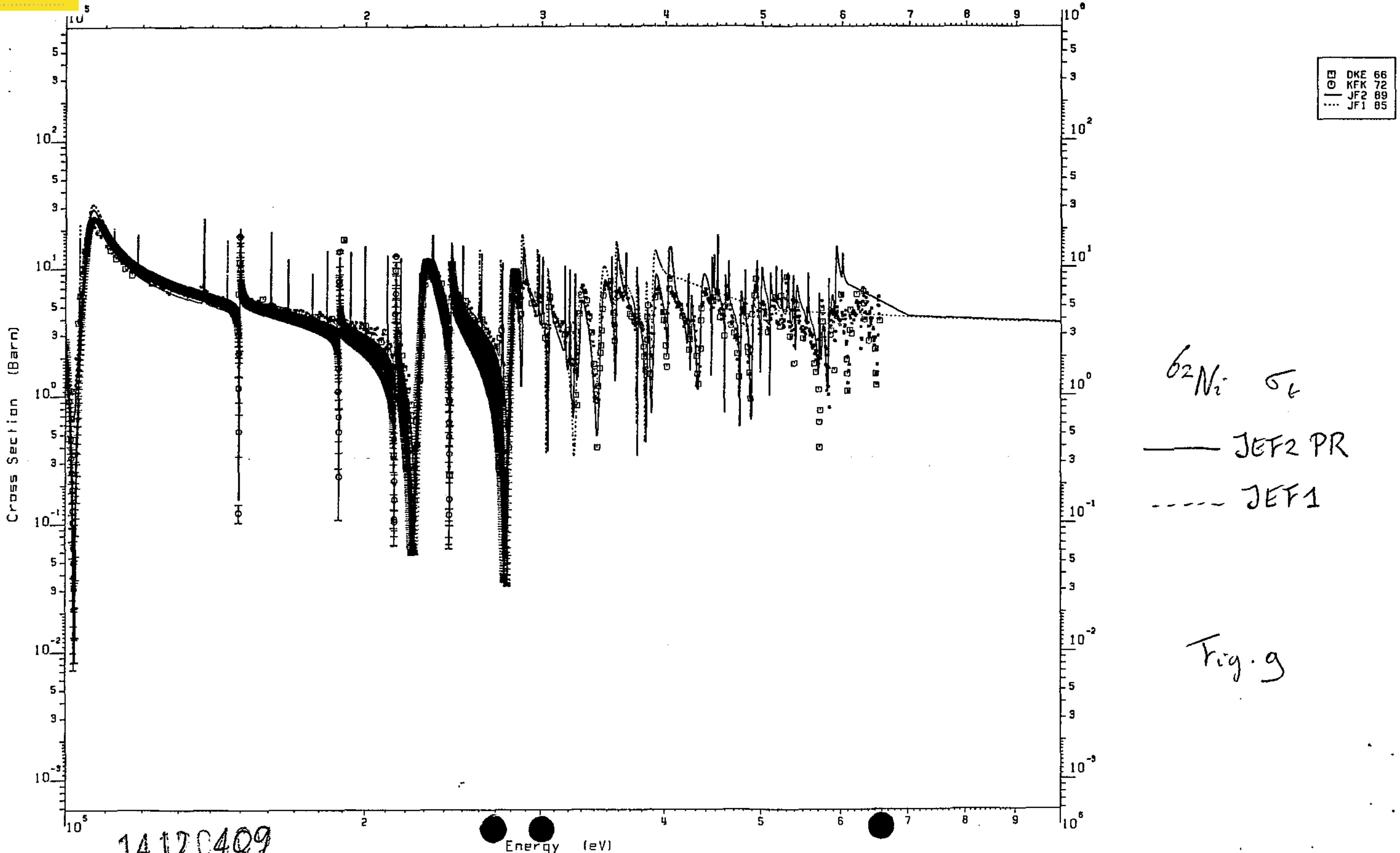
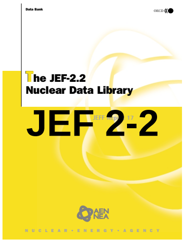
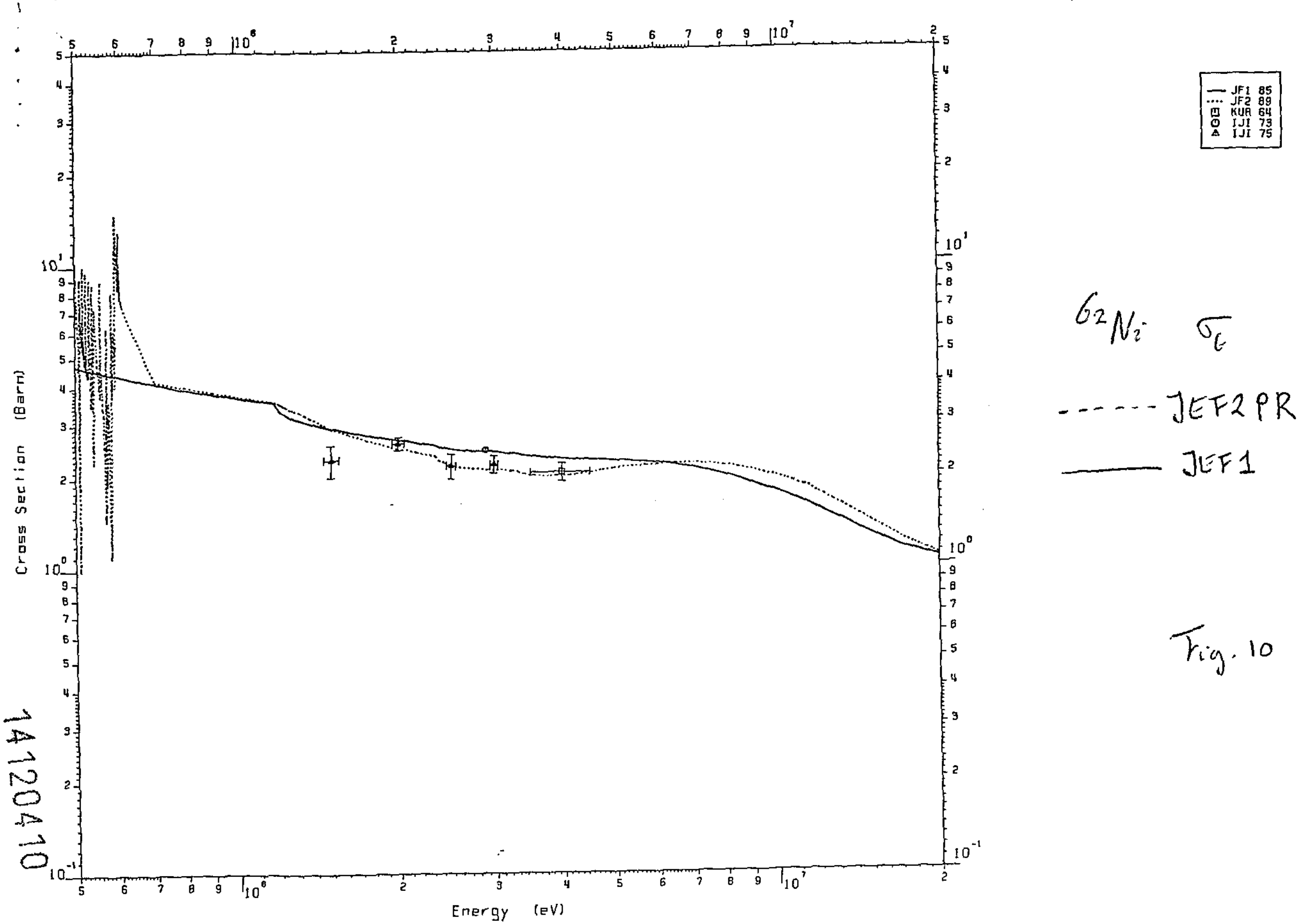
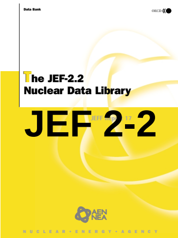


Fig. 9

14120409


The JEF-2.2
Nuclear Data Library
JEF 2-2


JF1 85
JF2 89
KUR 64
IJI 73
IJI 75
Cross Section (Barn)
Energy (eV)
σ_t
JEF2PR
JEF1
Fig. 10
1412 0410



Ni 62
(n,el)

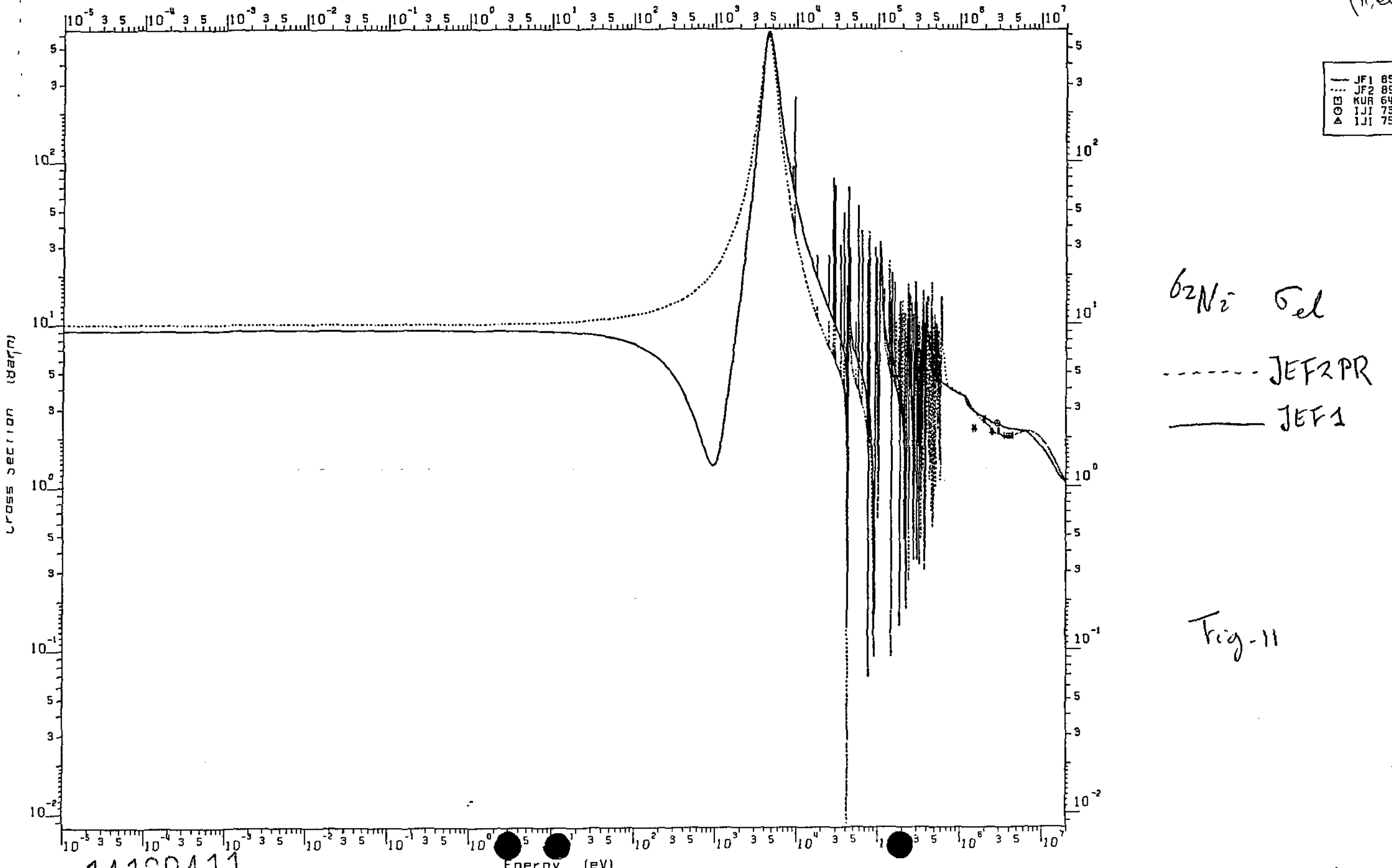
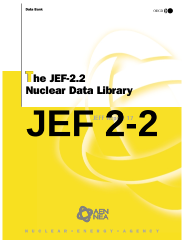
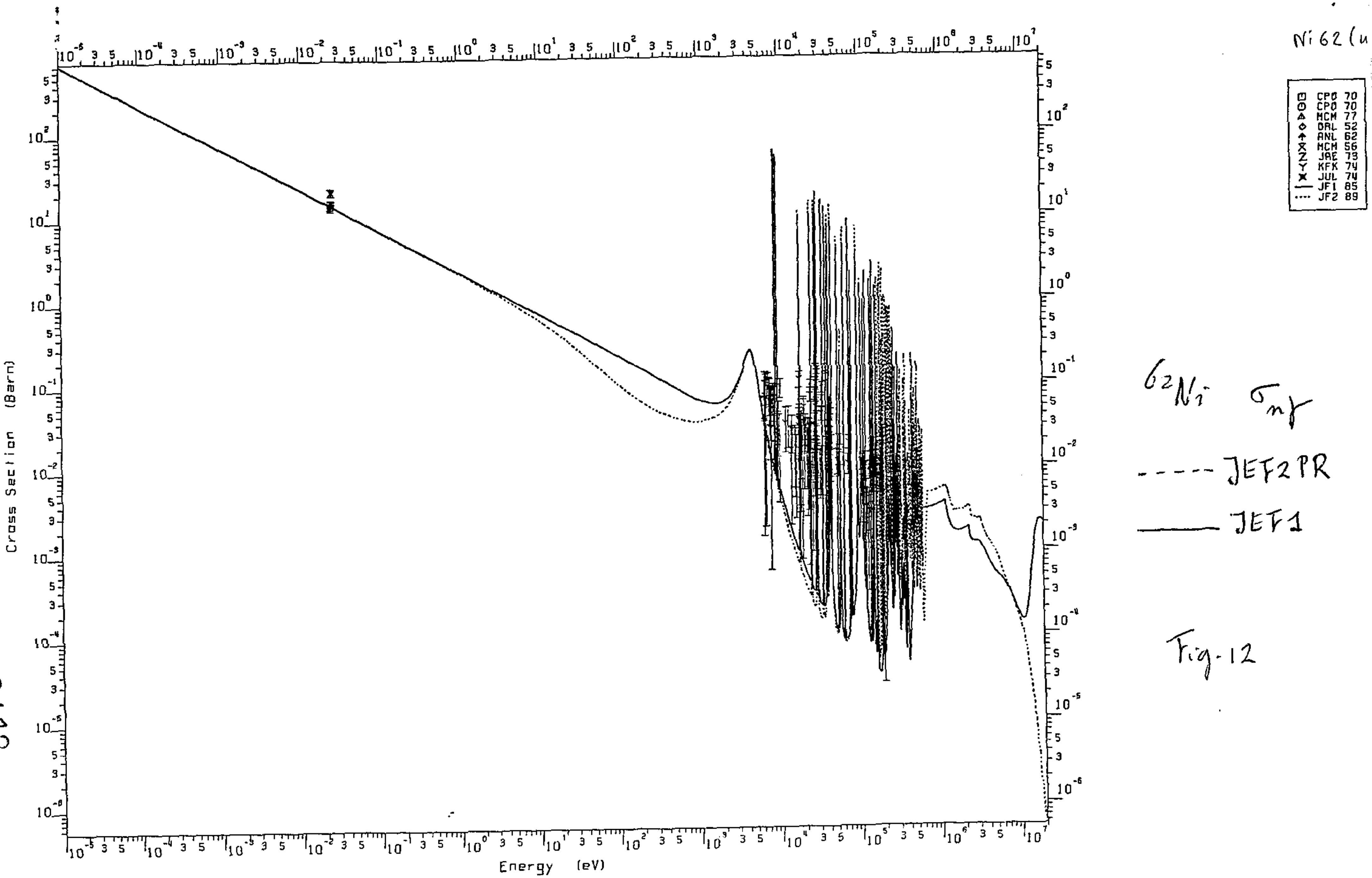


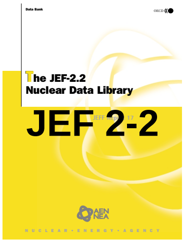
Fig-11

14120411


The JEF-2.2
Nuclear Data Library
JEF 2-2


Ni 62 (n
CP0 70
CP0 70
MCM 77
ORL 52
ANL 62
MCM 56
JAE 73
KFK 74
JUL 74
JF1 85
JF2 89
Cross Section (Barn)
Energy (eV)
62Ni σnγ
JEF2PR
JEF1
Fig. 12

14120412



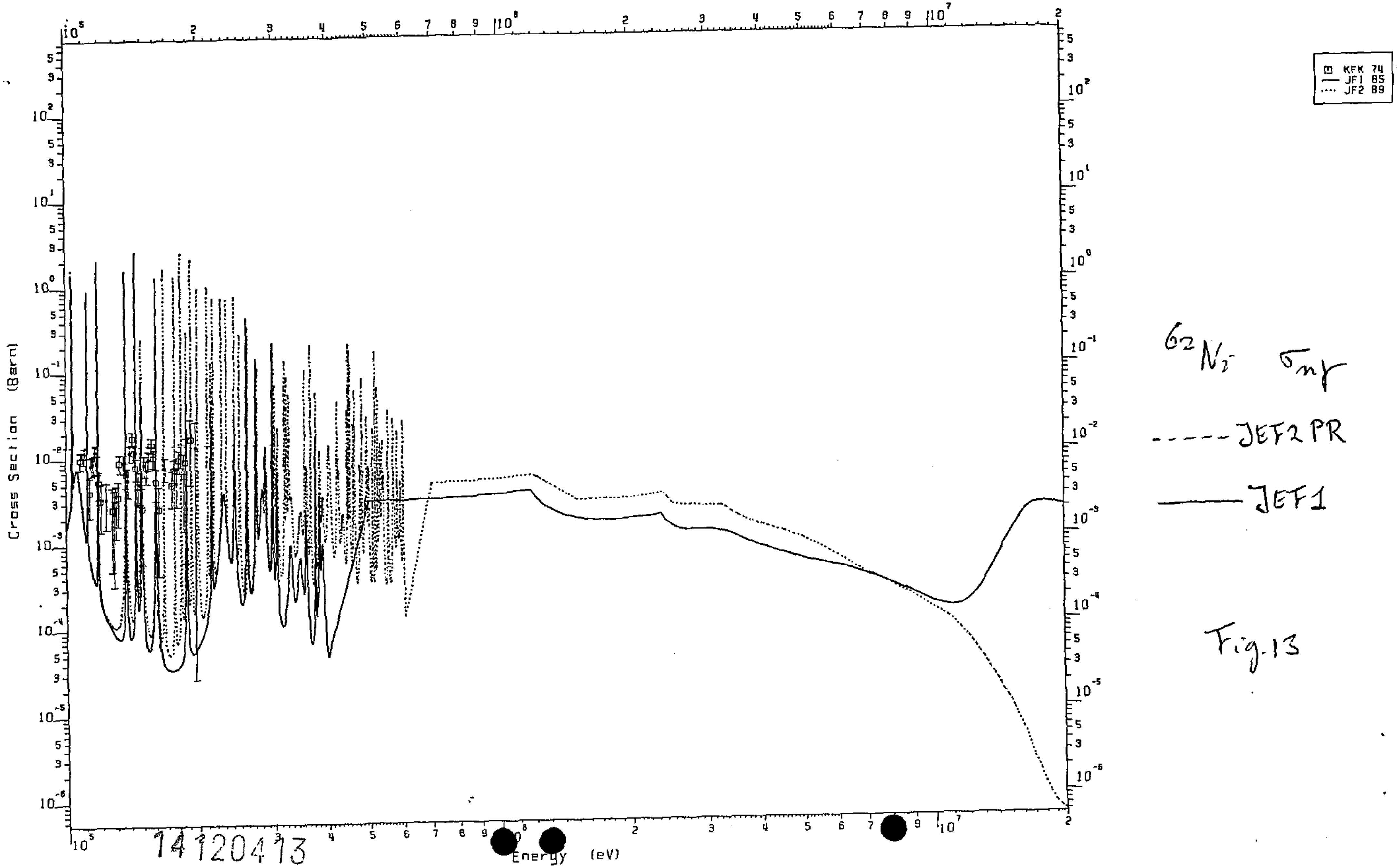
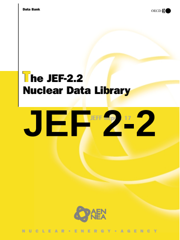


Fig. 13

14120413



Ni 64 (n,TOT)

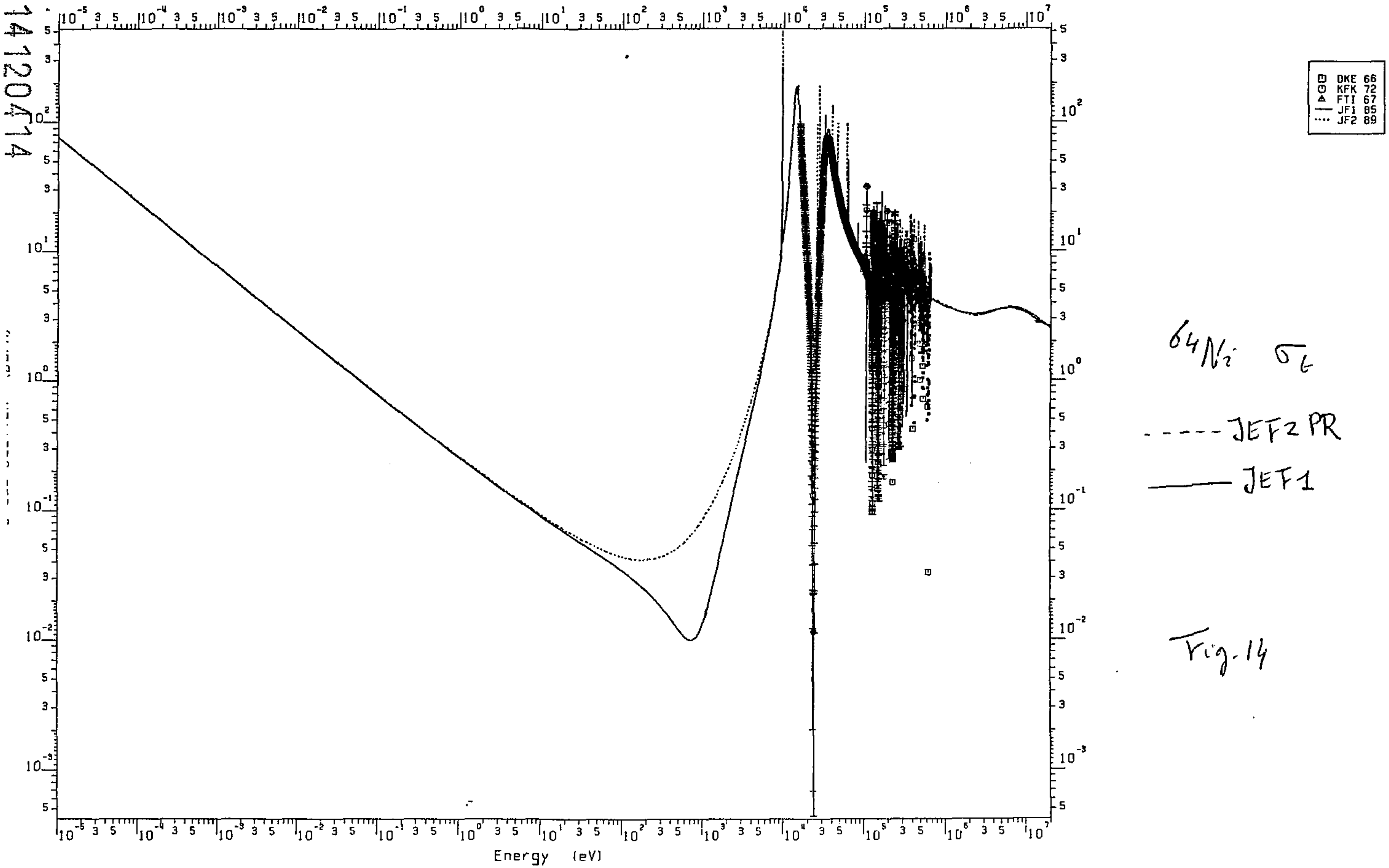
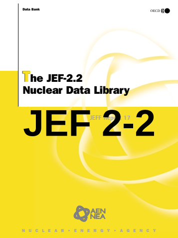
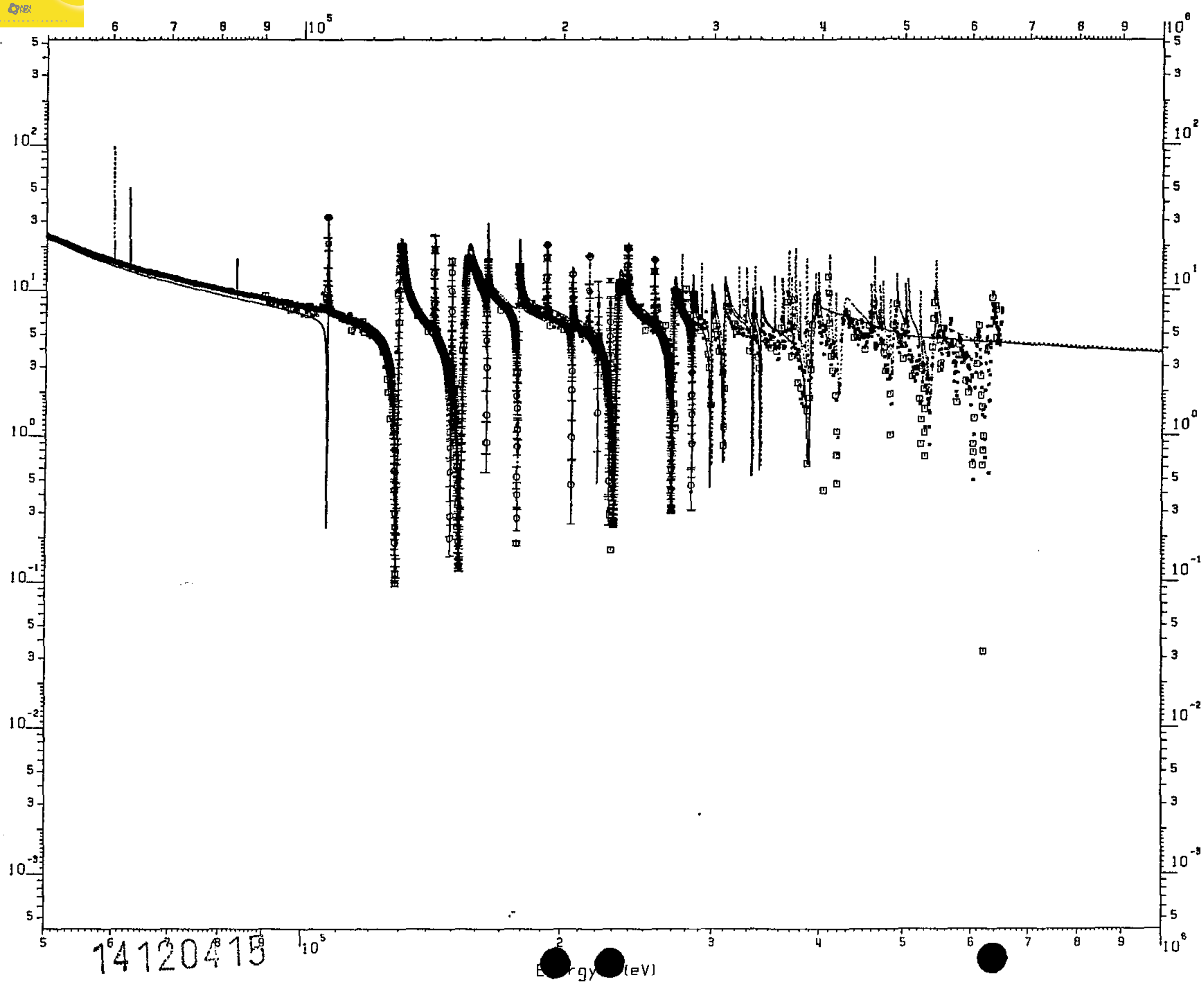


Fig. 14



Ni 64 (n, TOT)



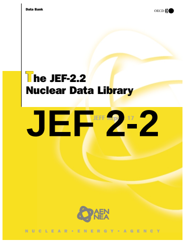
^{64}Ni σ_t

---- JEF2PR

—— JEF1

Fig. 15

14120415



Ni 64(n,TOT)

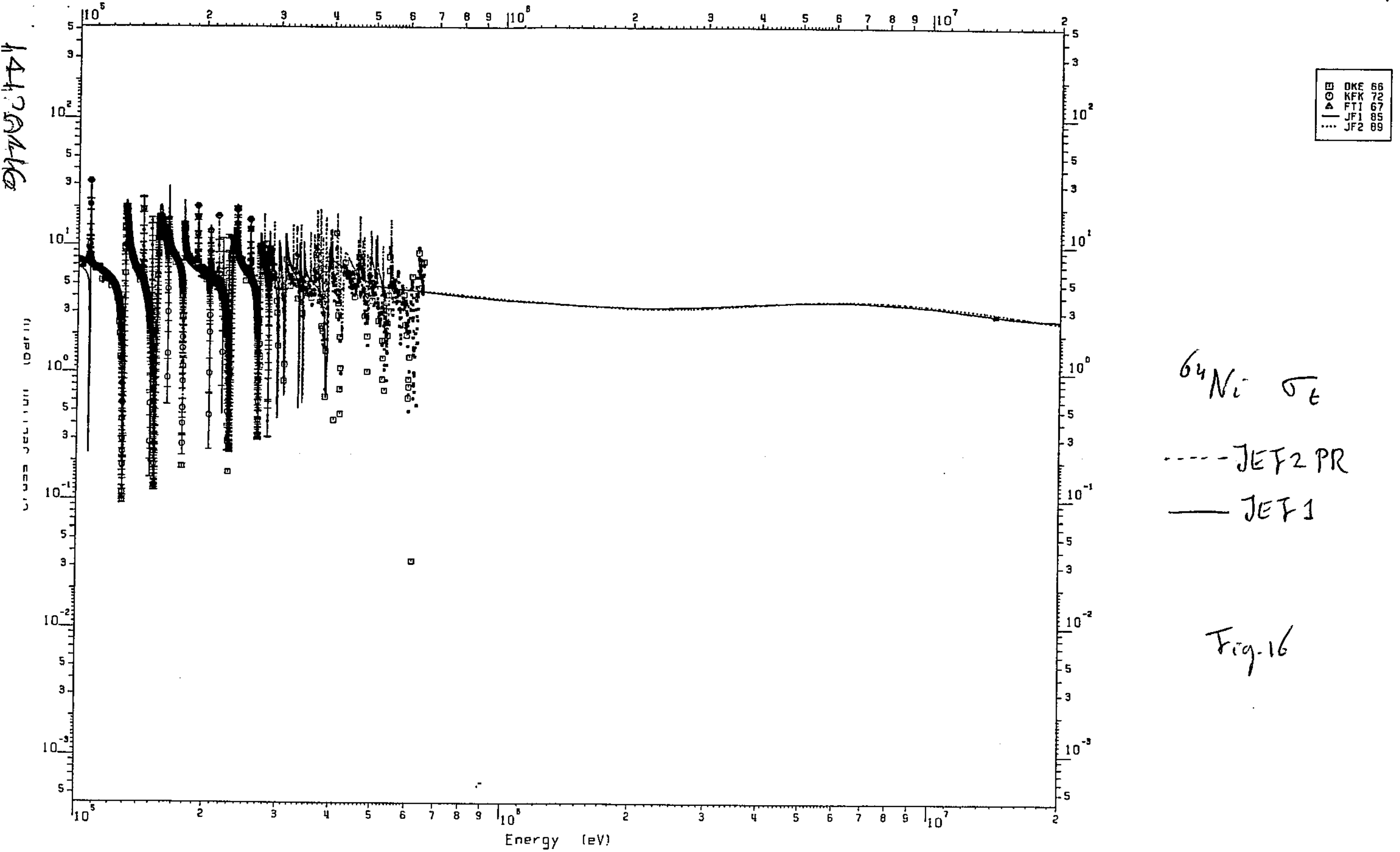
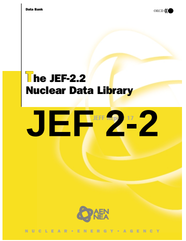
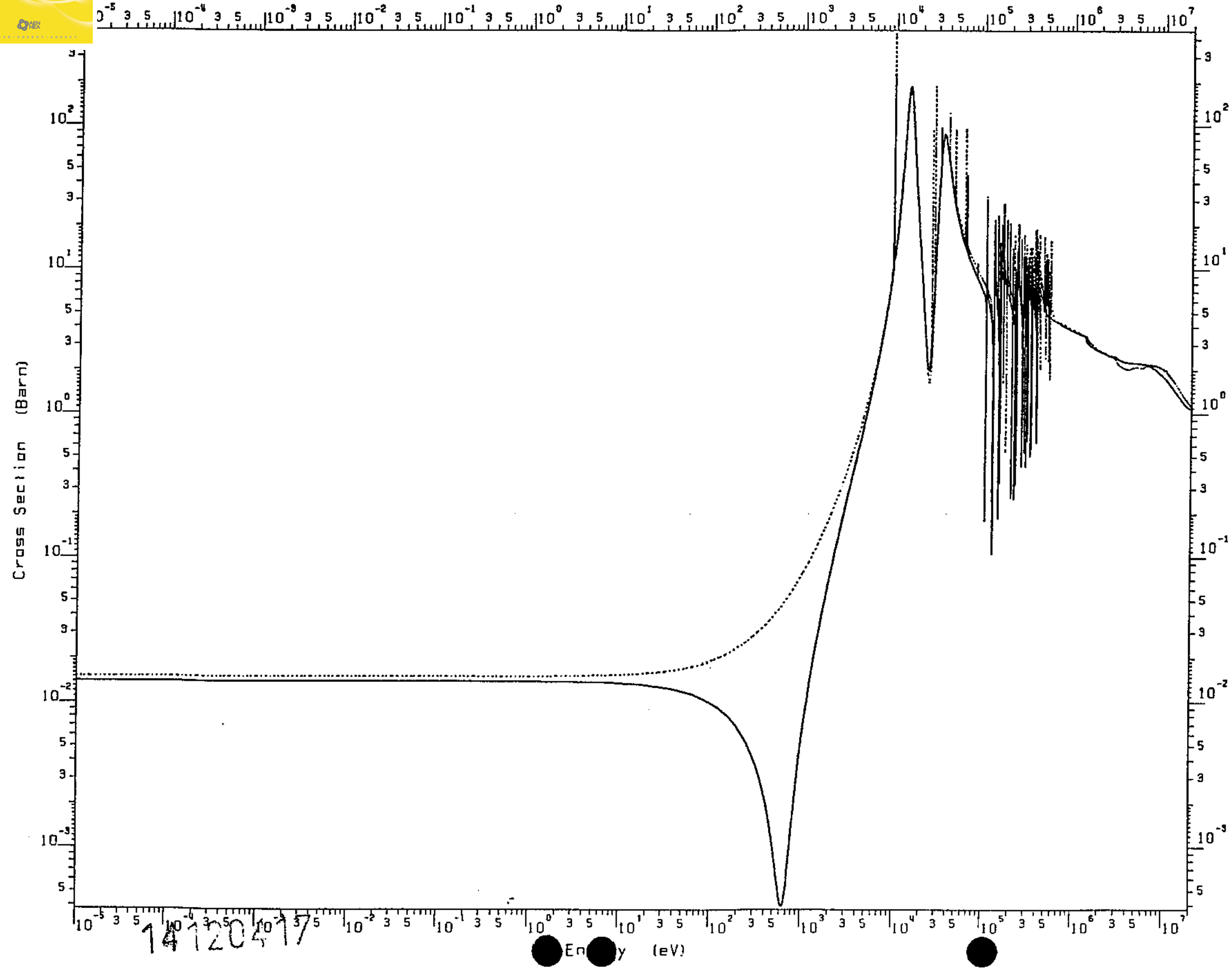


Fig. 16



Ni 64 (n,
(n,el)



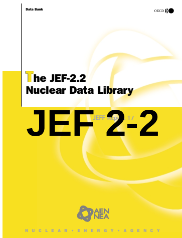
64Ni σel

JEF2 PR

JEF1

Fig. 1y

14120417



Ni 64/n,e

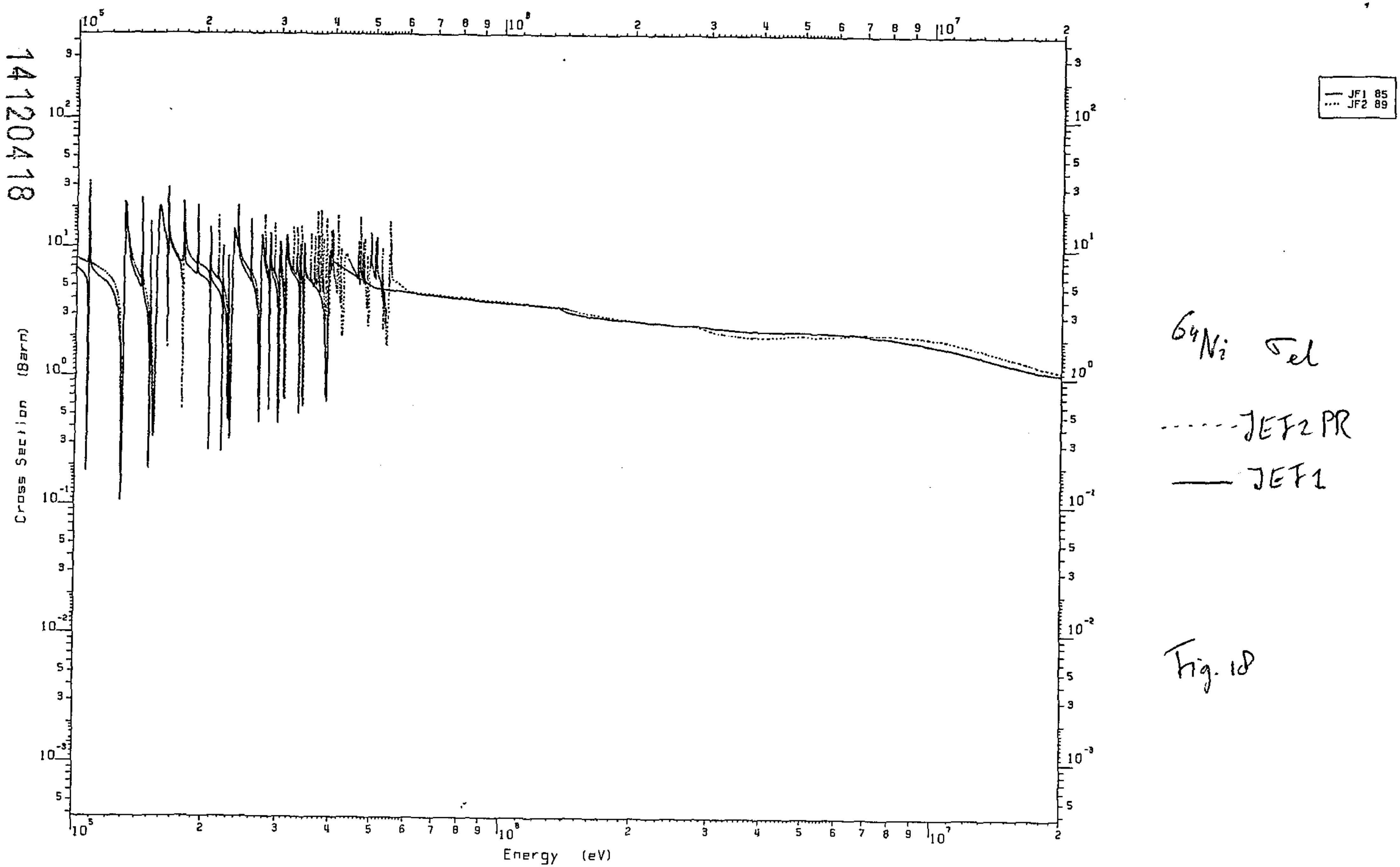
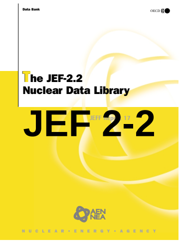


Fig. 18



Ni64 (n,γ)

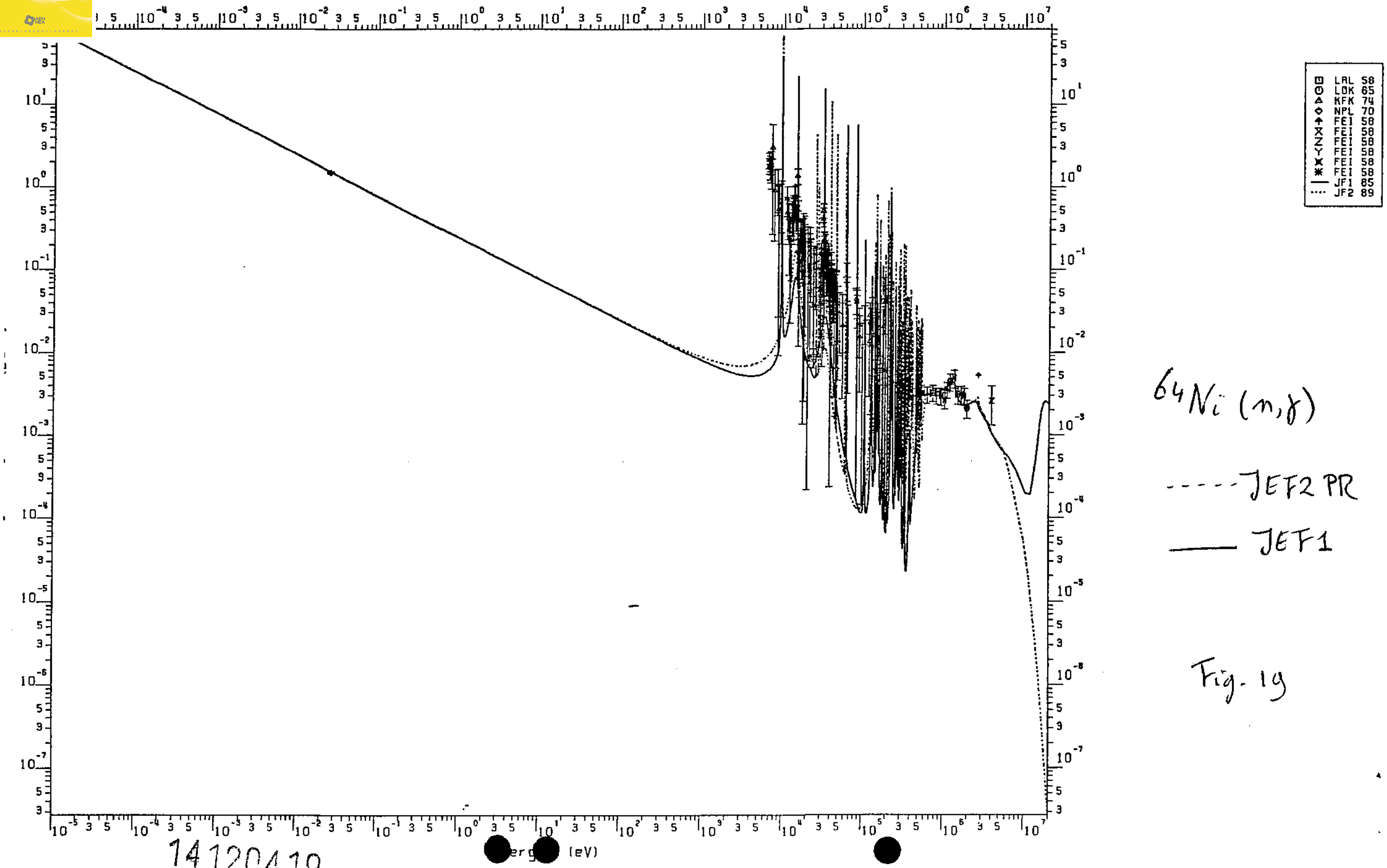
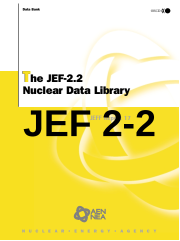


Fig. 1g

14120419



14120420

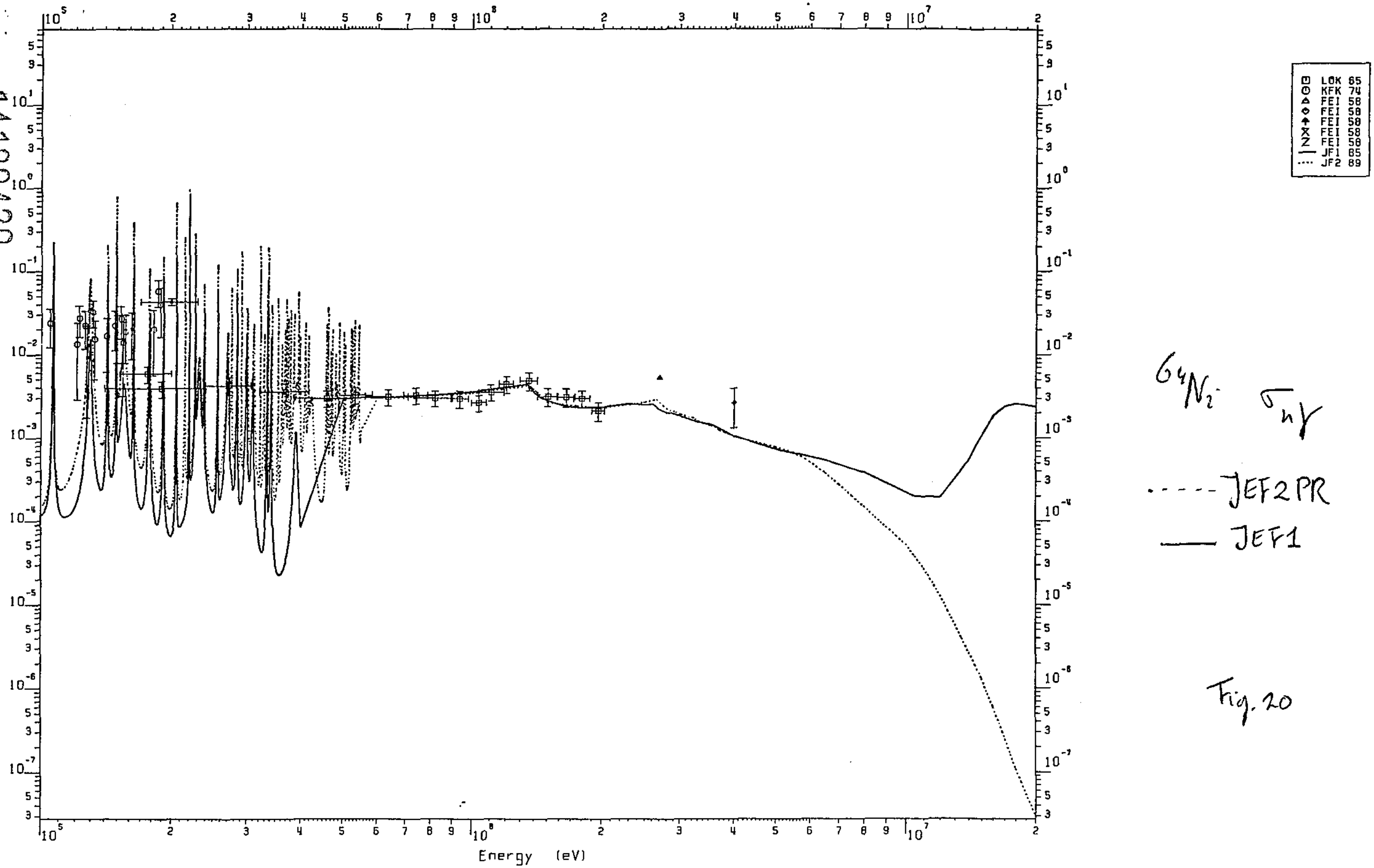


Fig. 20