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Discrepancies in (n,2n) reaction excitation functions of rare earth isotopes

Recommendations for selection of the reliable data

A.I. Blokhin, V.N. Manokhin, S.M. Nasyrova

Institute of Physics and Power Engineering
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March 1998

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Abstract

Analysis of (n,2n) reaction cross sections from different evaluated nuclear data libraries is performed for rare earth isotopes (Z=58-71). The cross sections are plotted and the discrepancies are shown. The cross sections calculated on the basis of the excitation function systematics are compared against the evaluated data to determine the reliability of the latter.

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ABSTRACT.

Analysis of (n,2n) reaction cross sections from different evaluated nuclear data libraries is performed for rare earth isotopes (Z=58–71). The cross sections are plotted and the discrepancies are shown. The cross sections calculated on the basis of the excitation function systematics are compared against the evaluated data to determine the reliability of the latter.

An activity in creation of international data libraries (for example, FENDL library) leads to the problem of selection of more reliable data from different national or regional libraries. Because of large discrepancies in many cases it is not easy to decide which data is more reliable. As a rule, there are no serious arguments to reject the data even if they differ essentially from the others. To solve the problem we propose a systematics that permits to select reliable excitation functions.

The analysis of the threshold reaction cross sections from different data libraries shows considerable discrepancies in the excitation functions. These discrepancies are particularly large, when there are no or too little experimental data. As a rule, the evaluated data are calculated on the basis of theoretical models taking into account the 14-15 MeV systematics and discrepancies among these calculated data exist for most reactions and isotopes. We think that it is useful to publish the results of this comparison. We understand that it is very difficult to correct the existing libraries but hope that our recommendations will be taken into account.

In this paper the (n,2n) reaction excitation functions for rare earth isotopes from the following libraries: BROND-2 /1/, ENDF/B-VI /2/, JENDL-3 /3/, ADL-3 /4/, EAF-3 /5/ were compared. We are aware of the EAF-4 library, but unfortunately these data were not at our disposal.

As a criteria for determination which evaluated data from the libraries mentioned above seem to be more reliable, the (n,2n) reaction excitation functions, calculated on the basis of the excitation function systematics, are plotted together with those from the libraries. As the systematics' excitation functions are obtained independently from the experimental data and model calculations it seems to us reasonable to consider the systematics curves, or those excitation functions which are close to the systematics, as more reliable.

Below, a brief description of the systematics used in this work for calculation of the (n,2n) reaction excitation functions in the energy region up to 20 MeV is given. As it was mentioned above this systematics is based on experimental data and its detailed description was published in the Refs. 6-8. The essential features and relations of the systematics are the following:

1. The value of cross section in the maximum of (n,2n) reaction excitation function depends essentially on the interrelation of (n,2n) and (n,np) reaction thresholds ($Q_{n,2n}$ and $Q_{n,np}$, respectively): $Q_{n,2n} \leq Q_{n,np}$ or $Q_{n,2n} > Q_{n,np}$.

At $Q_{n,2n} \leq Q_{n,np}$ the maximum (top) cross sections of the (n, 2n)-reaction excitation functions are determined by the following equation:

$$\sigma_{top} = 65.4\ A^{2/3}\ [mb], \qquad (1)$$

where A is the atomic mass number.

This maximum (top) value is reached in the neutron energy region of 5-8 MeV (in most cases 6-7 MeV) above the reaction threshold. The analysis of experimental and theoretical excitation functions shows that this equation is reasonable for any A (within A=10-210), if the condition $Q_{n,2n} \leq Q_{n,np}$ is fulfilled. In the range of mass numbers A=50-210, where there is enough experimental data, this is quite well proved. However, for the nuclei with A<50 there are no experimental data near maximum of the (n,2n) reaction excitation functions and the reliability of the systematics was checked against theoretical model calculations which take into account recent achievements in the description of nuclear reactions.

The (n,2n)-reaction excitation functions, in the neutron energy region between the threshold and the maximum, are similar and can be described by the normalized excitation function in scales (σ/σ_{max} - $\Delta E/\Delta E_{max}$) (see Table). Here σ_{max} is cross section at the maximum, $\Delta E = E - E_{th}$, E_{th} - threshold energy, $\Delta E_{max} = E_{max} - E_{th}$, E is a neutron energy, and E_{max} - neutron energy at the maximum of (n,2n) excitation function.

If $Q_{n,2n} < Q_{n,np}$, σ_{max} is equal to σ_{top} (see eq.1).

If $Q_{n,2n} > Q_{n,np}$, σ_{max} is determined from the experimental data or from other considerations, however, the shape of the excitation function is described by the same normalized function.

Table. Normalized excitation function of the (n, 2n)-reaction.

$\Delta E/\Delta E_{max}$	σ/σ_{max}	$\Delta E/\Delta E_{max}$	σ/σ_{max}
0.05	0.03	0.50	0.81
0.10	0.09	0.55	0.85
0.15	0.18	0.60	0.88
0.20	0.30	0.65	0.91
0.25	0.42	0.70	0.93
0.30	0.53	0.75	0.95
0.35	0.60	0.80	0.97
0.40	0.68	0.85	0.98
0.45	0.75	0.90	0.99

For $Q_{n,2n} > Q_{n,np}$ the (n,2n) cross section in the maximum of the excitation function is below the values calculated from the equation (1), and the difference is determined by contribution of the (n,np) reaction cross section at the same neutron energy. The maximum of both reaction excitation functions lies near En=20 MeV and the sum of the (n,2n) and (n,np) reaction cross sections is approximately equal to σ_{top}.

$$\sigma_{top} \approx \sigma_{n,2n} + \sigma_{n,np}, \qquad (2)$$

providing the value of $Q_{n,3n}$ is above ~20 MeV.

The (n,2n) reaction cross section in the energy region above the maximum was calculated by subtraction of the (n,3n) reaction cross section from σ_{top}. The (n,3n) reaction cross sections were calculated from the relation (3), also based on the experimental data. It was shown in Refs.6-8, that the shapes of the (n,3n) reaction excitation functions are similar in the neutron energy region between the threshold and the neutron energy at the maximum of the excitation function and can be approximated by the equation:

$$\sigma = \sigma_{max} (\Delta E/\Delta E_m)^{3.3} \cdot \exp[3.3(1-\Delta E/\Delta E_m)]. \qquad (3)$$

Here ΔE and ΔE_m are counted from the (n,3n) reaction threshold, and σ_{max} is determined by the equation:

$$\sigma_{max} \approx 10 \text{ A [mb]}. \qquad (4)$$

Within experimental uncertainties these equations describe available experimental (n,3n) excitation functions. Taking into account (n,3n) reaction competition results in (n,2n) reaction excitation functions which agree very well with experimental data in a whole energy range from the threshold up to 20 MeV.

It was proposed that ΔE_m for (n,3n) reaction excitation functions is equal to 10 MeV. This value was determined from the experimental data of L.Veeser et al /9/ and B.Bayhurst et al /10/ for (n,3n) reaction cross sections in the energy region from the threshold up to 26 MeV.

The recommended data obtained using our method are presented on Fig.1-50 as solid curves.

Finally, we would like to make some general remarks. Fig.1-50 show, that in most cases the (n,2n) cross section values at the maximum of excitation functions are rather close. However, there are great discrepancies in shapes of the excitation functions. Many curves have very steep slope above the threshold that contradicts new experimental data. One can see a fast decrease of the (n,2n) cross sections in the energy region above the energy value at which the cross section maximum is observed. It was proved, on the basis of the experimental data, that the maxima of (n,3n) reaction cross sections are lower than those of (n,2n) reactions. Also the cross section increase above the threshold is weaker for (n,3n) reactions than for (n,2n) ones. The fast drop in cross sections after the maximum seems to be unreasonable. It contradicts also available experimental data.

It should be mentioned that similar discrepancies for the (n,2n) reactions are also observed for many other elements. Preliminary analysis indicates the same problems also for the (n,p) and (n,α) reactions.

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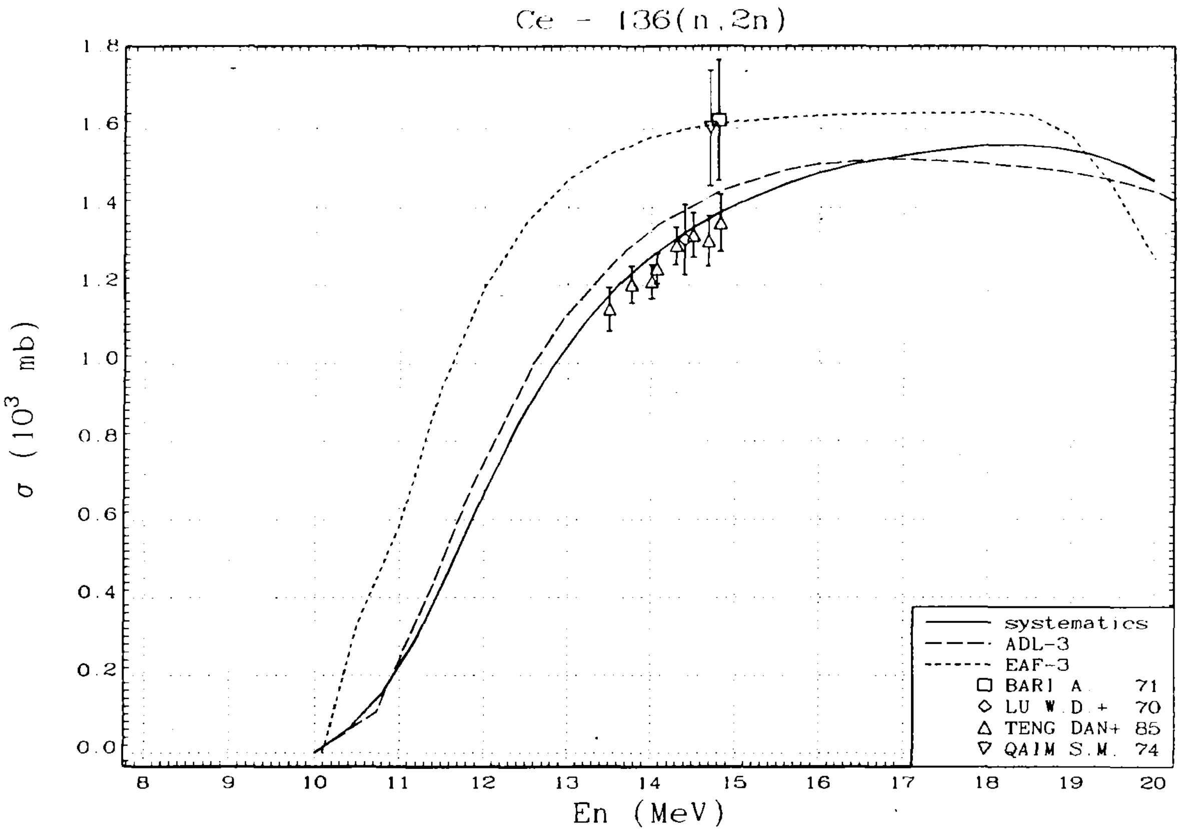

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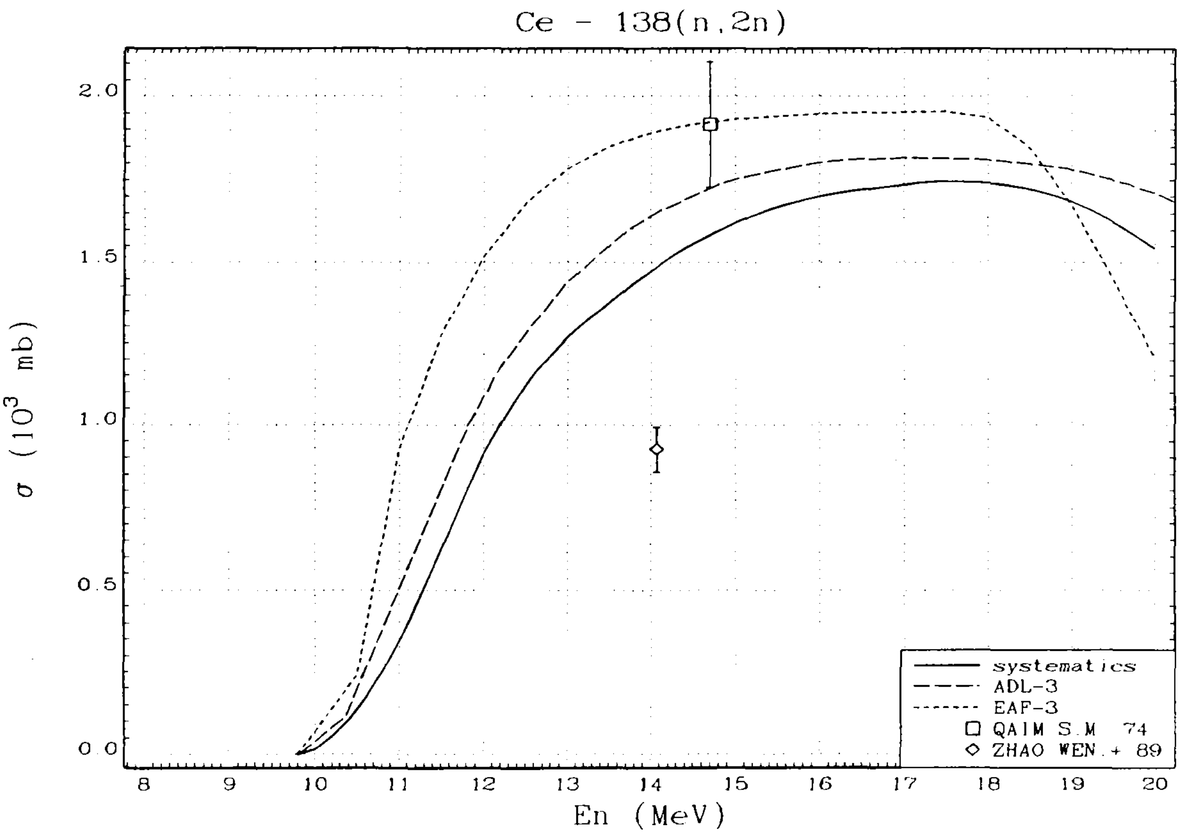

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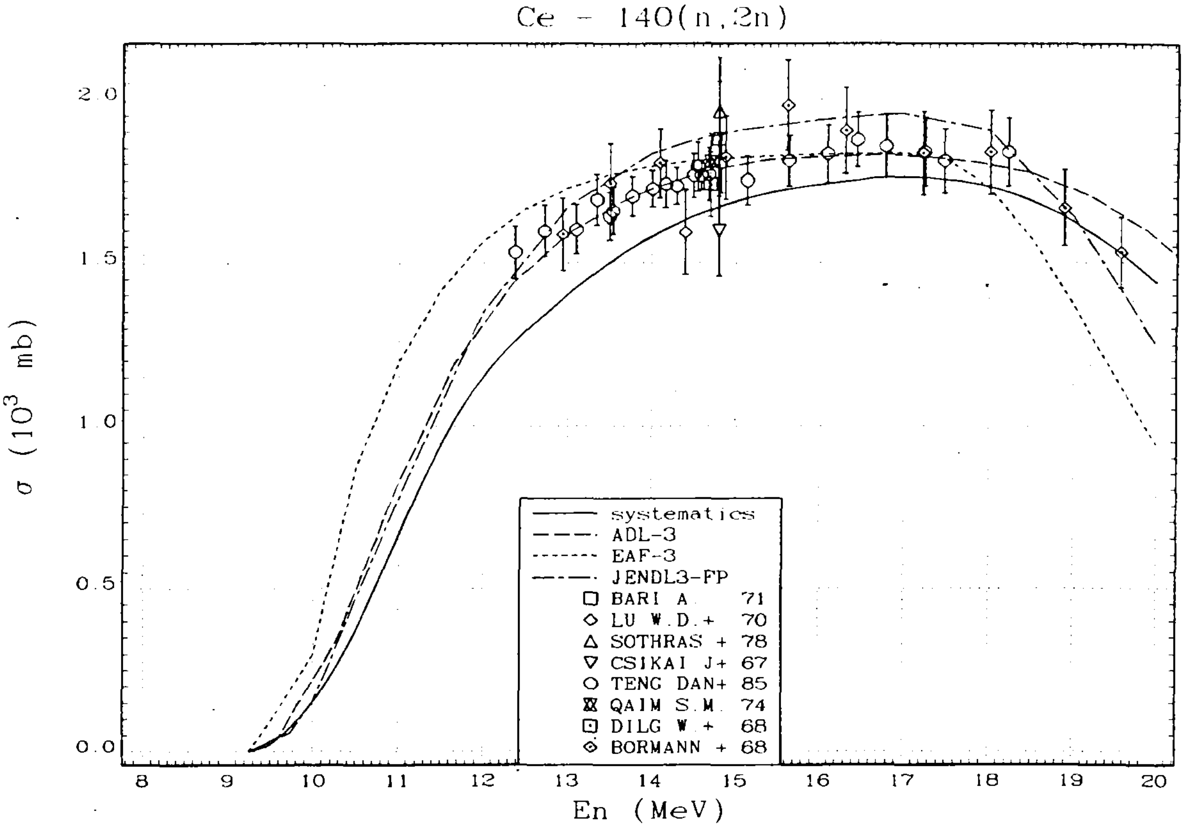

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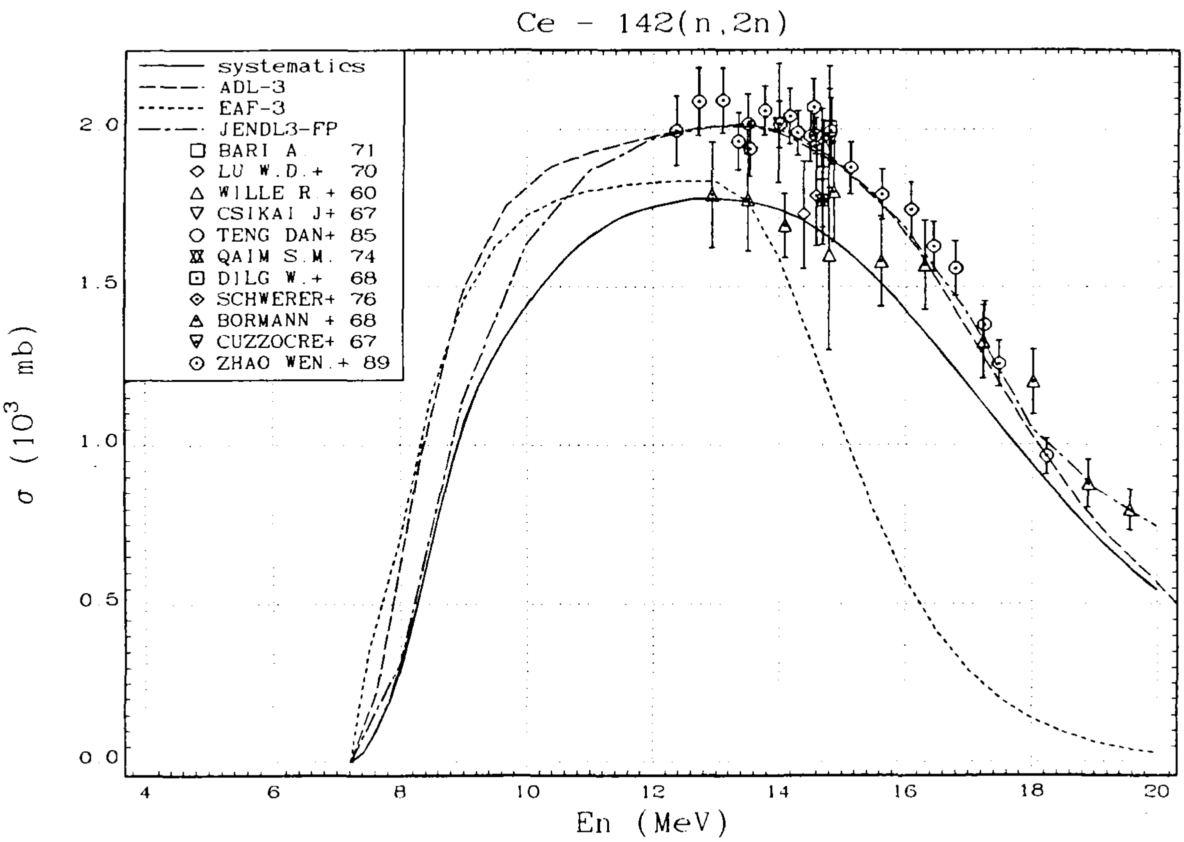

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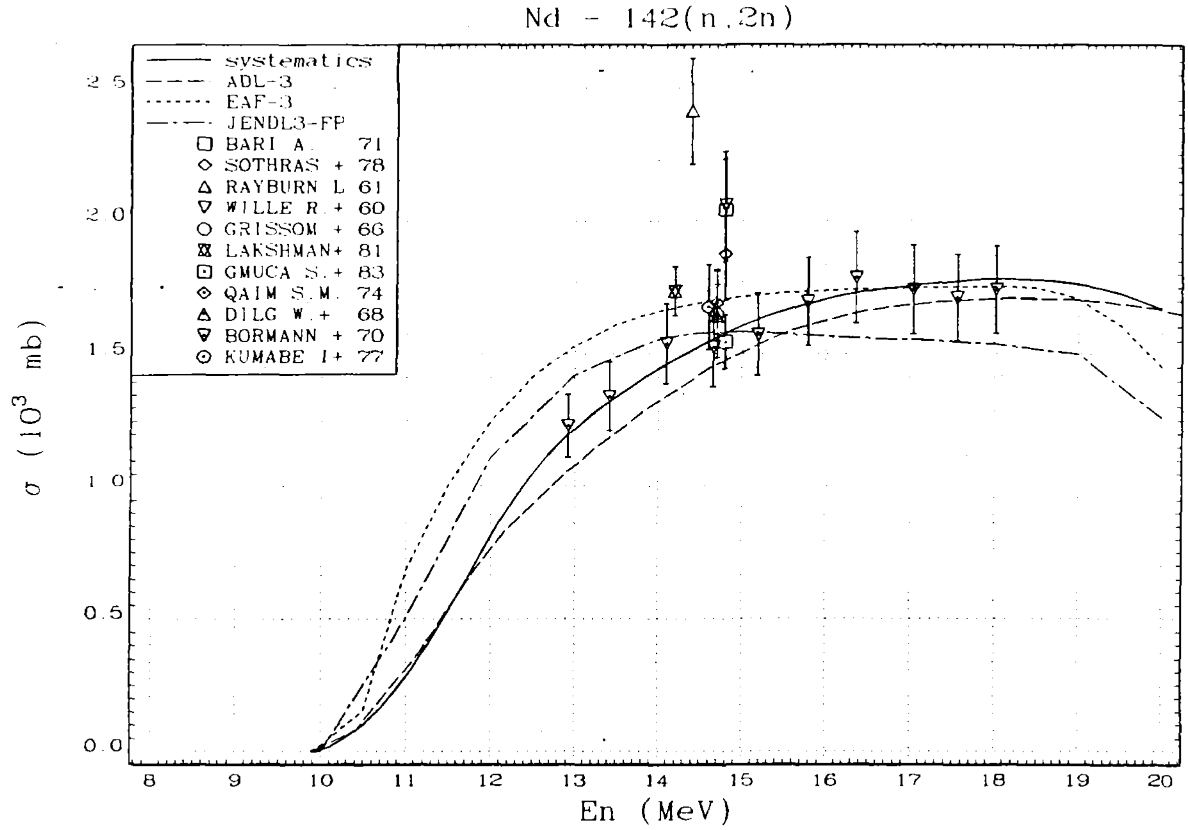

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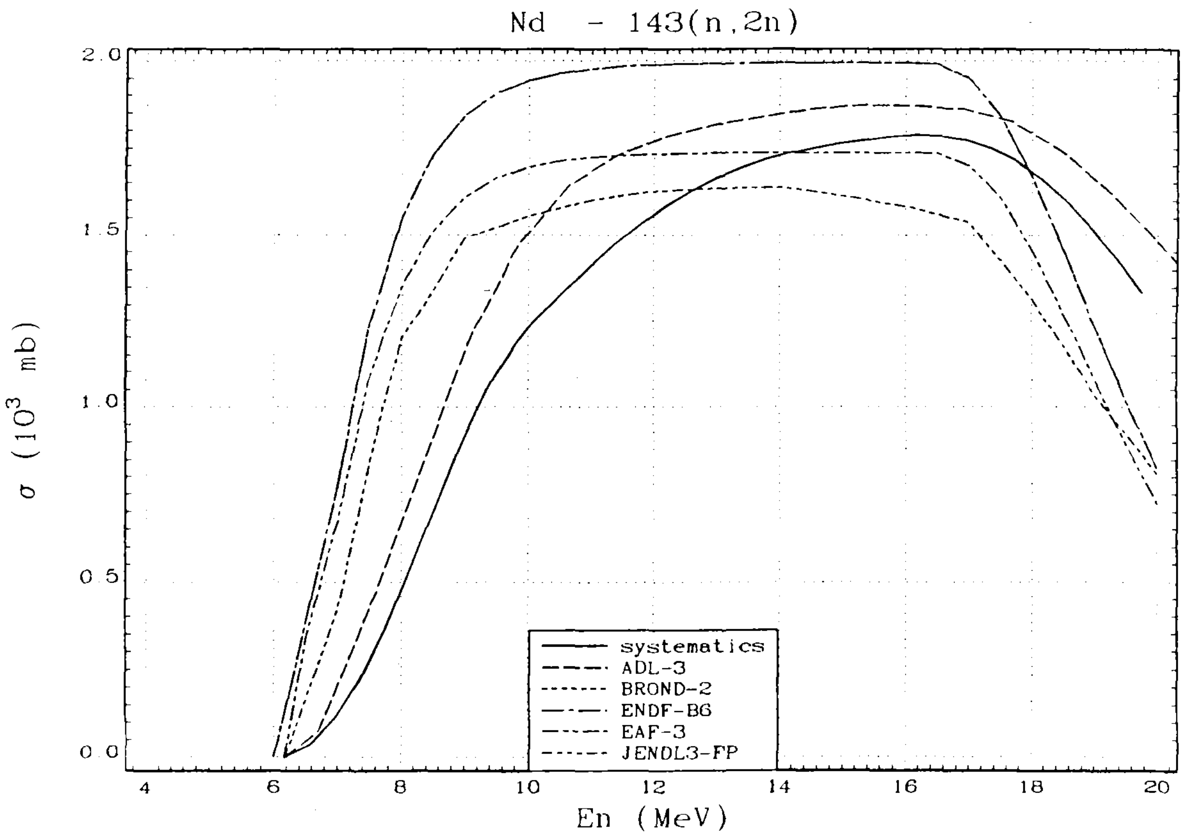

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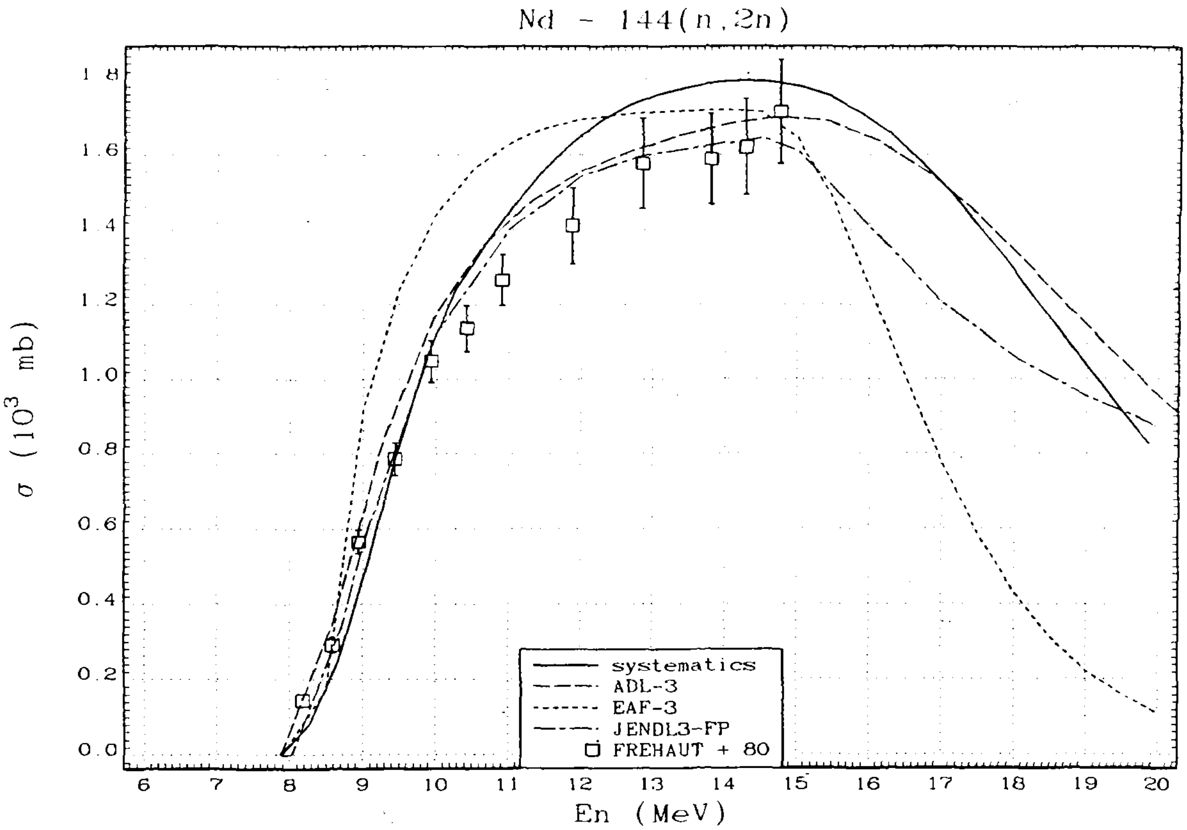

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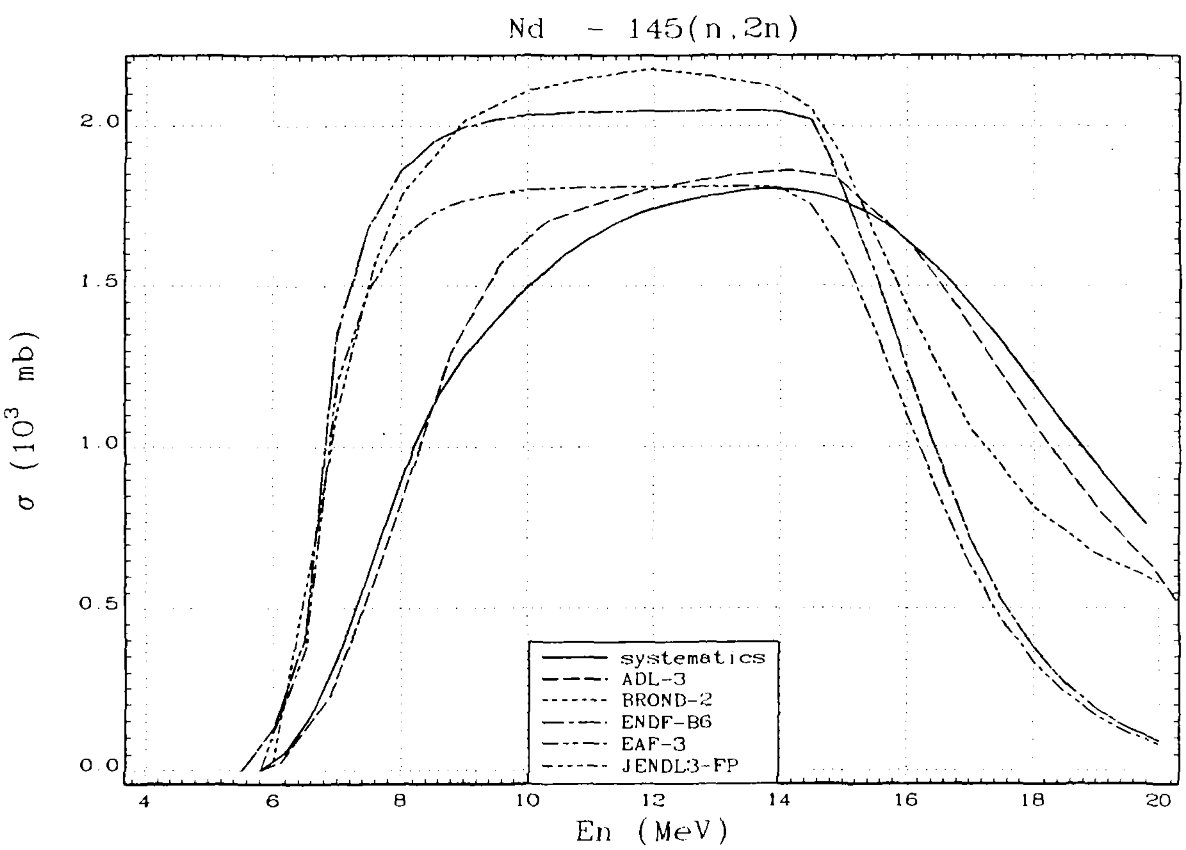

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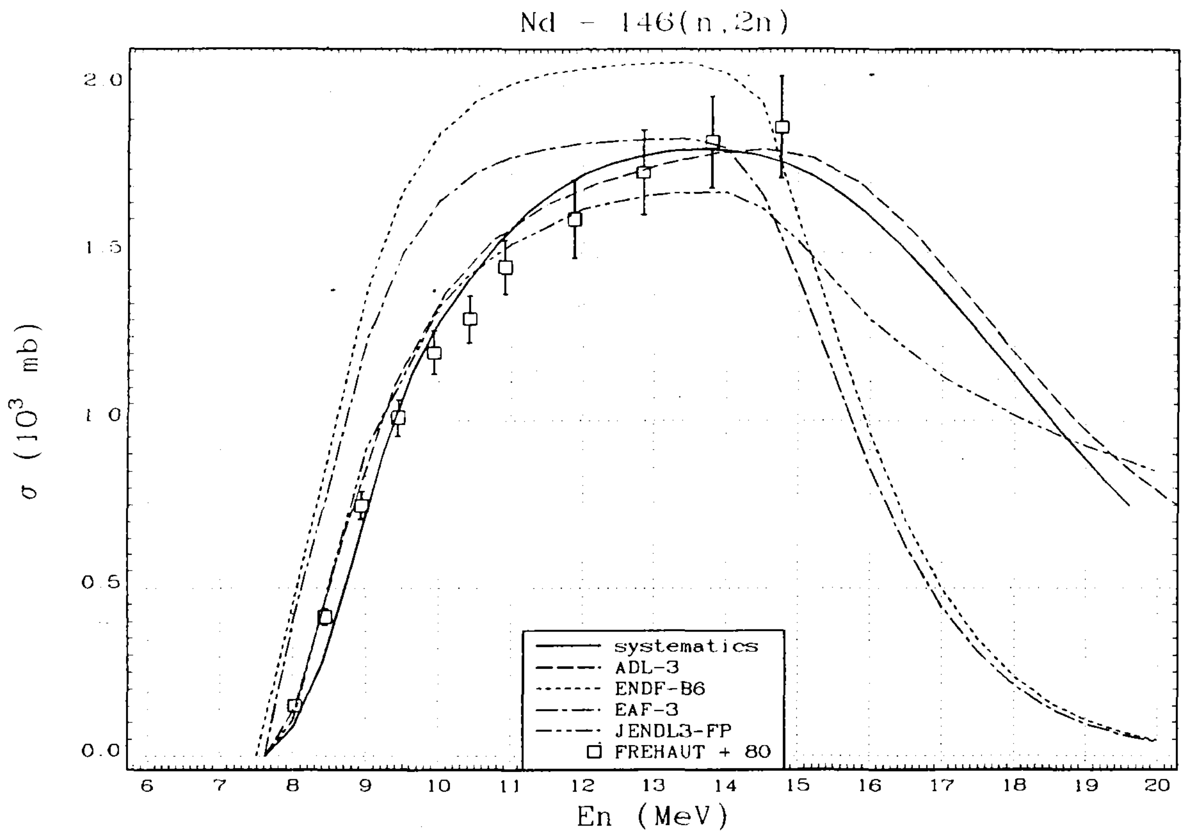

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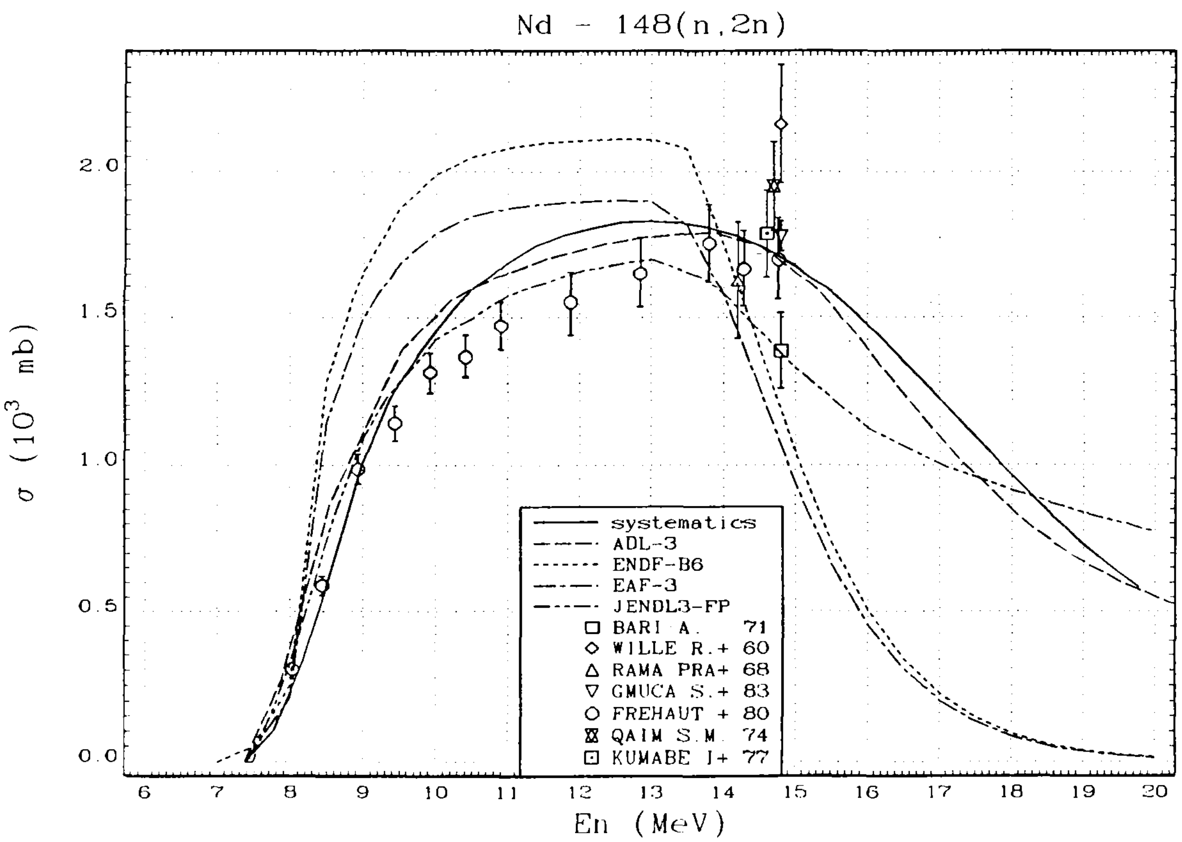

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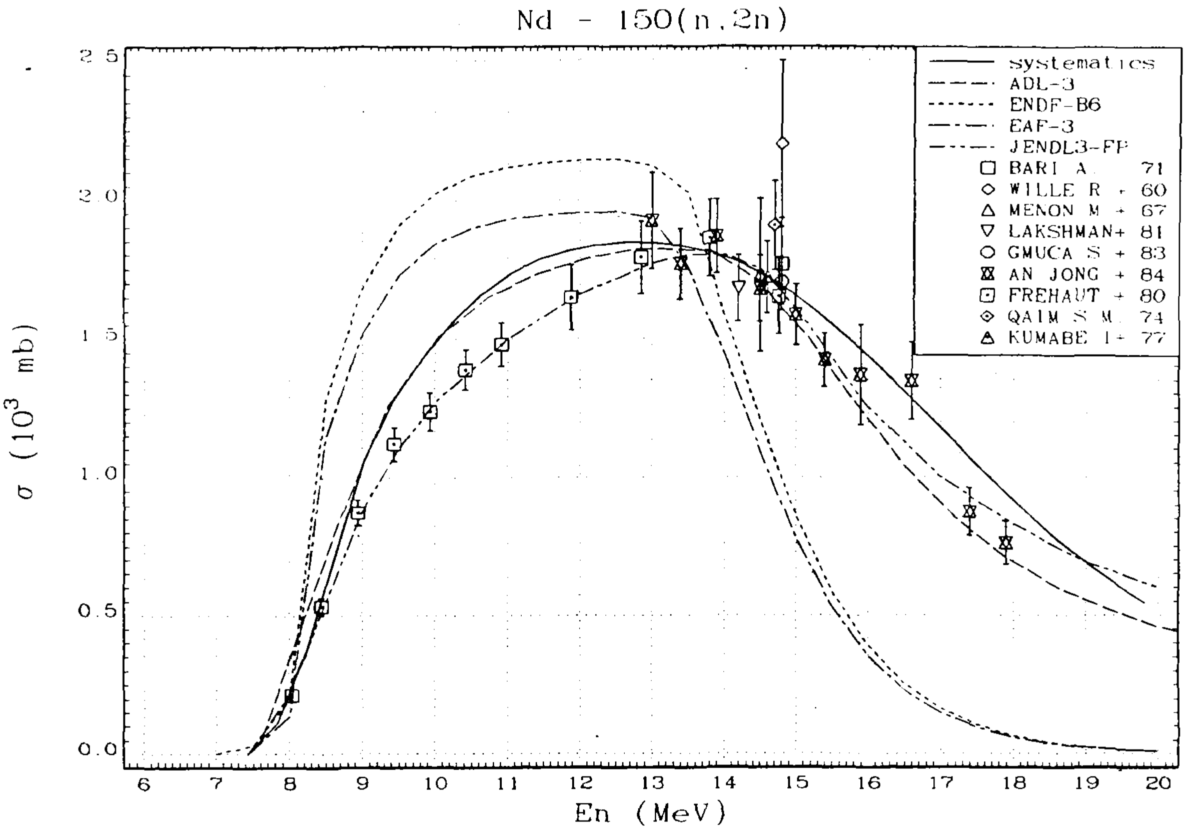

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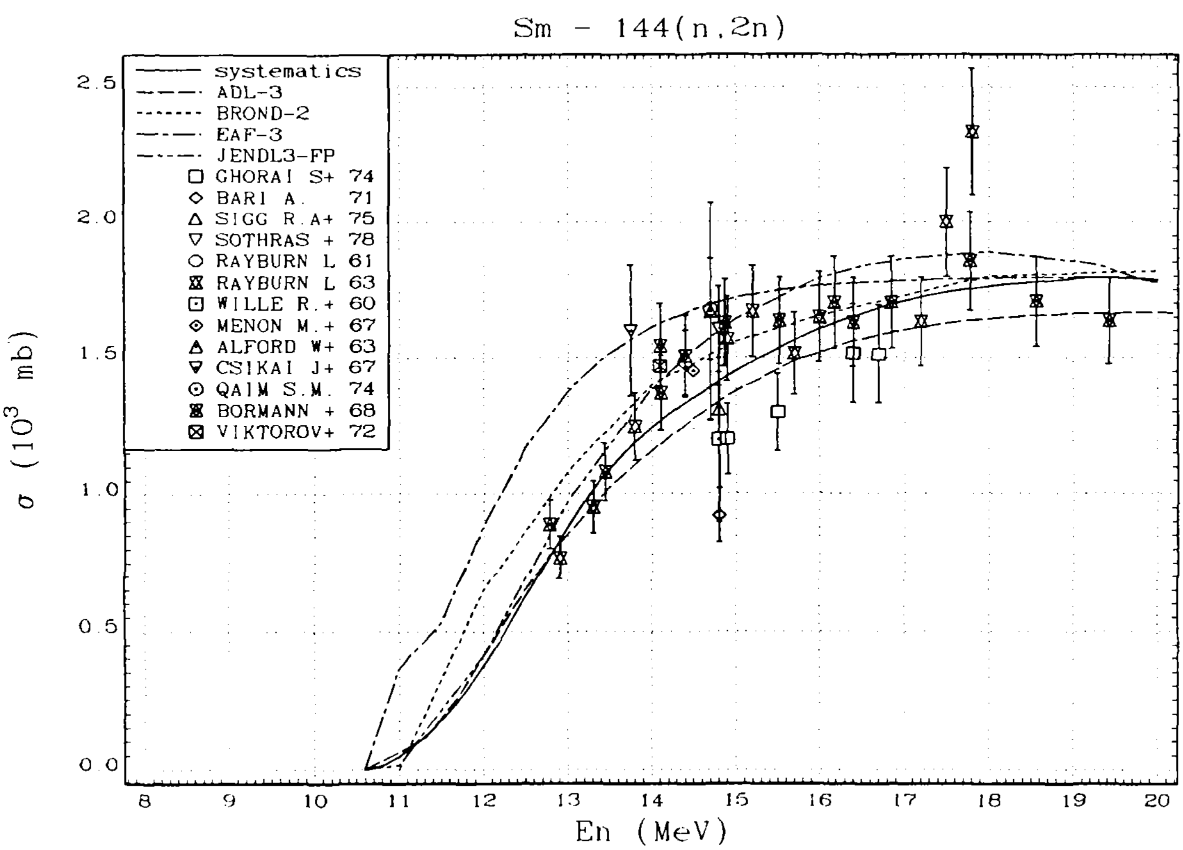

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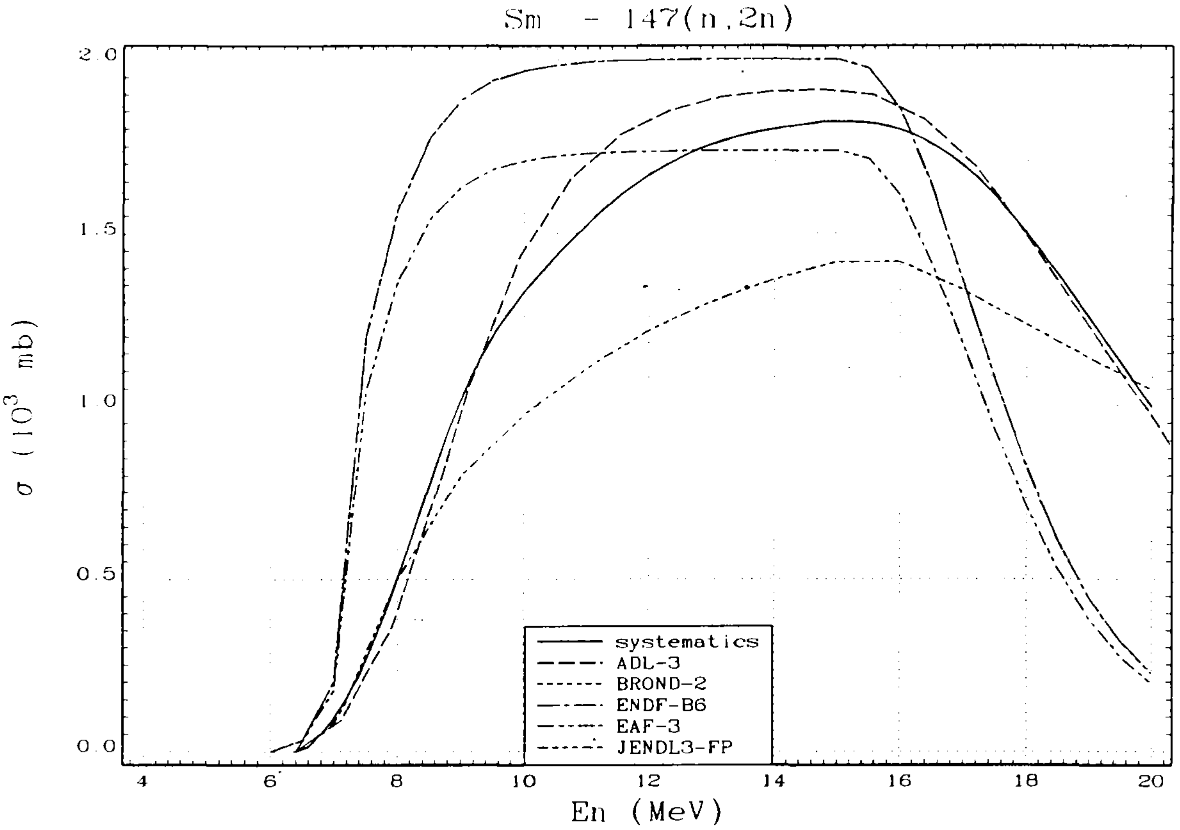

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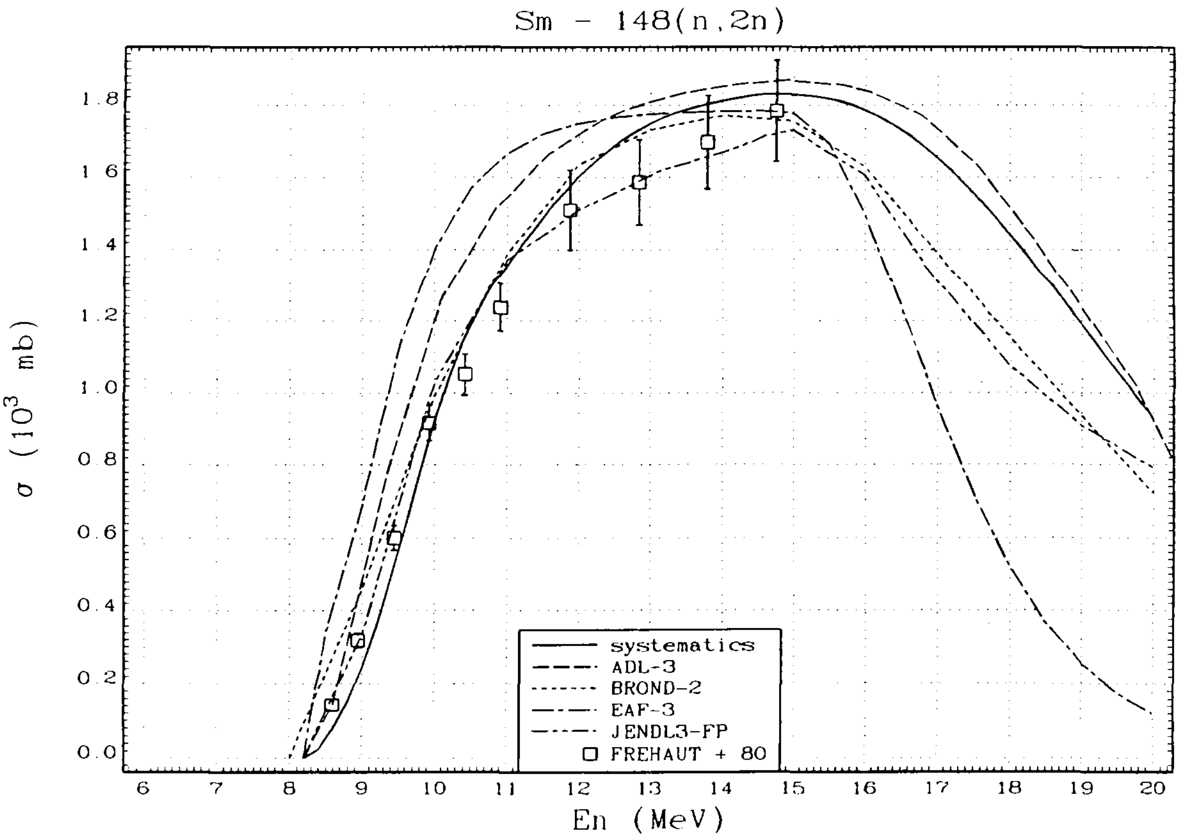

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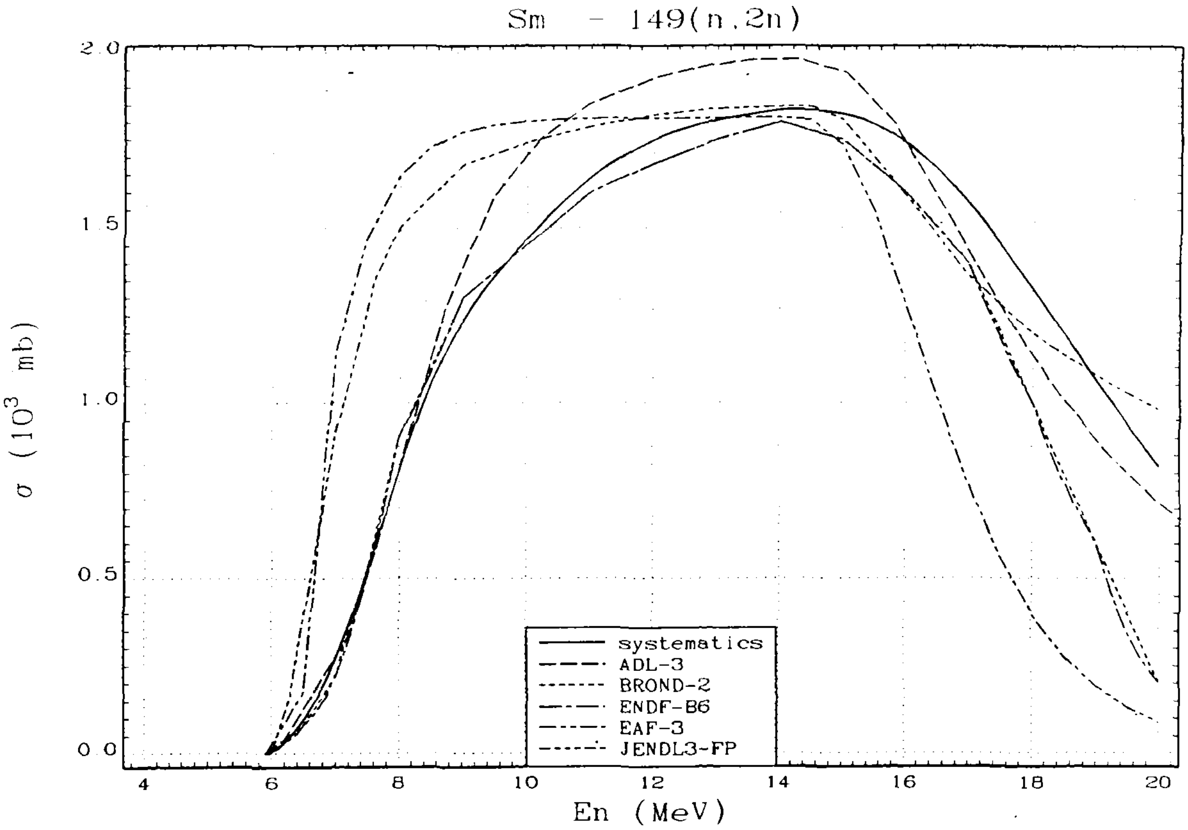

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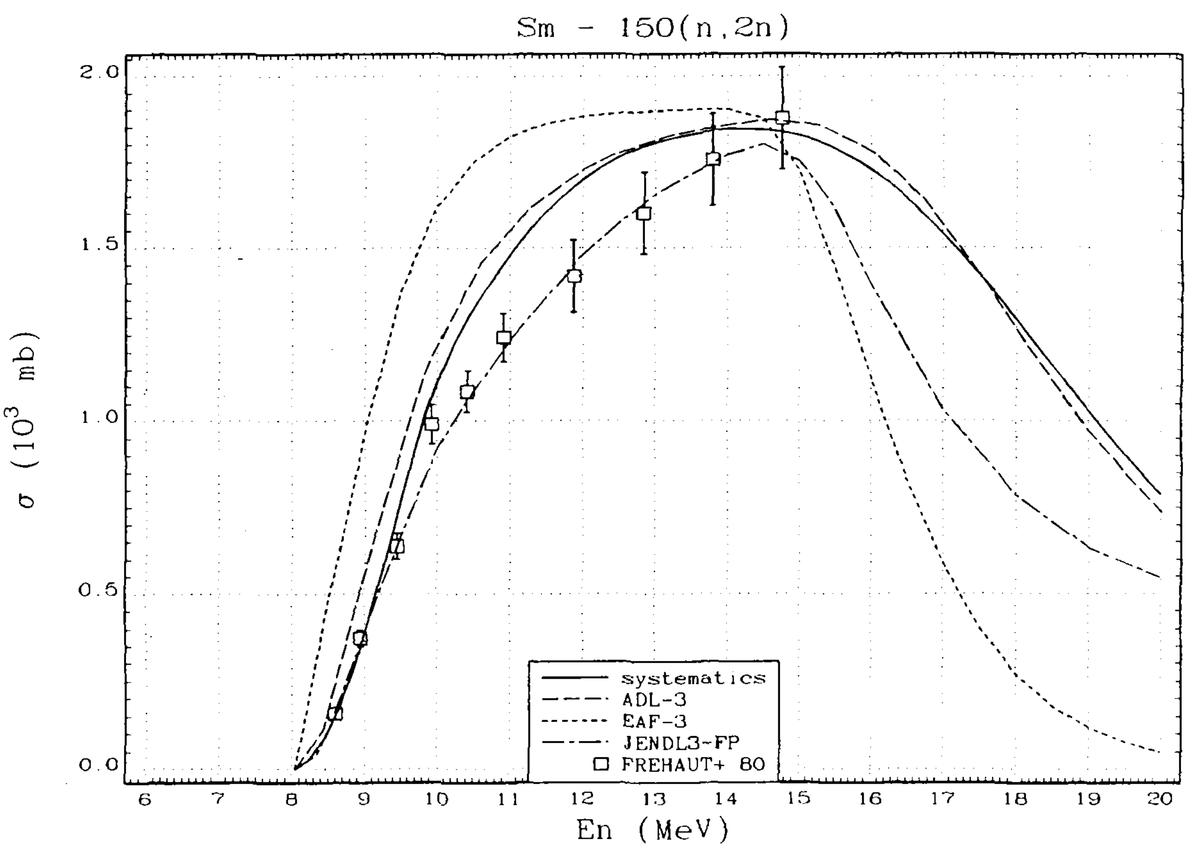

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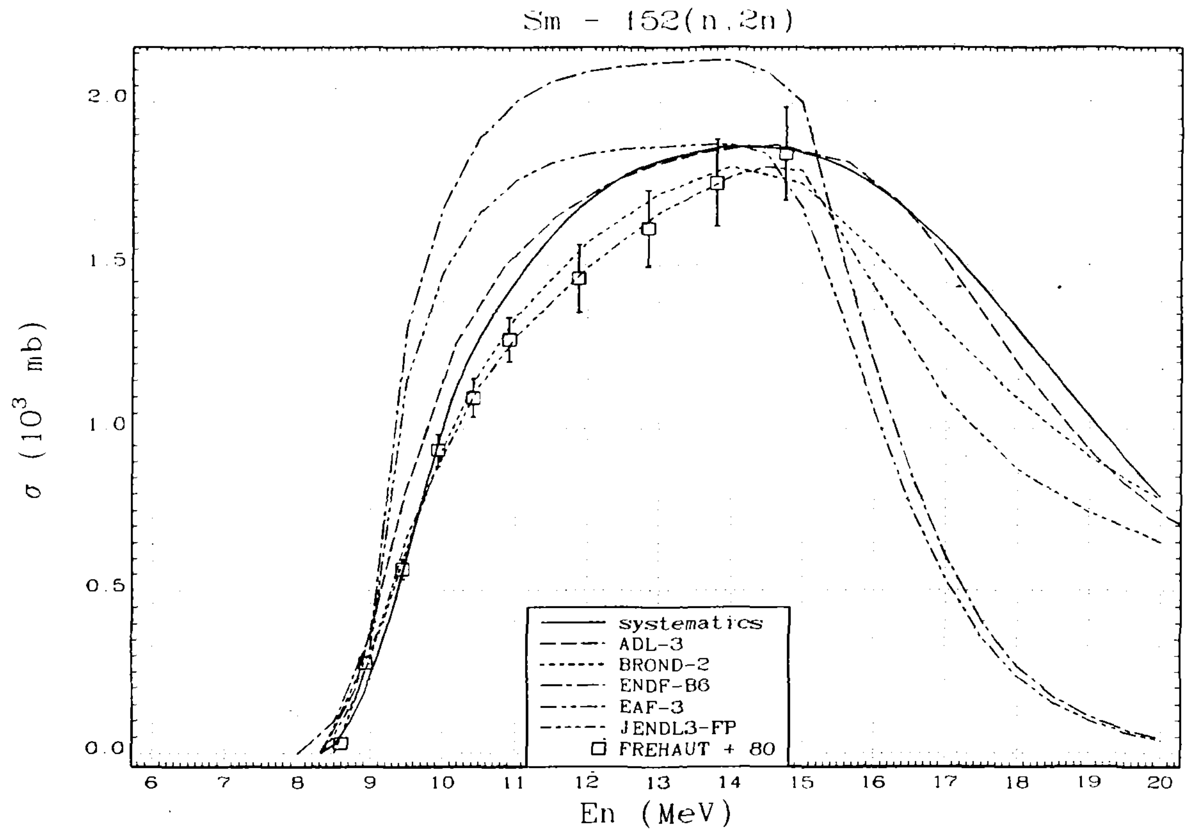

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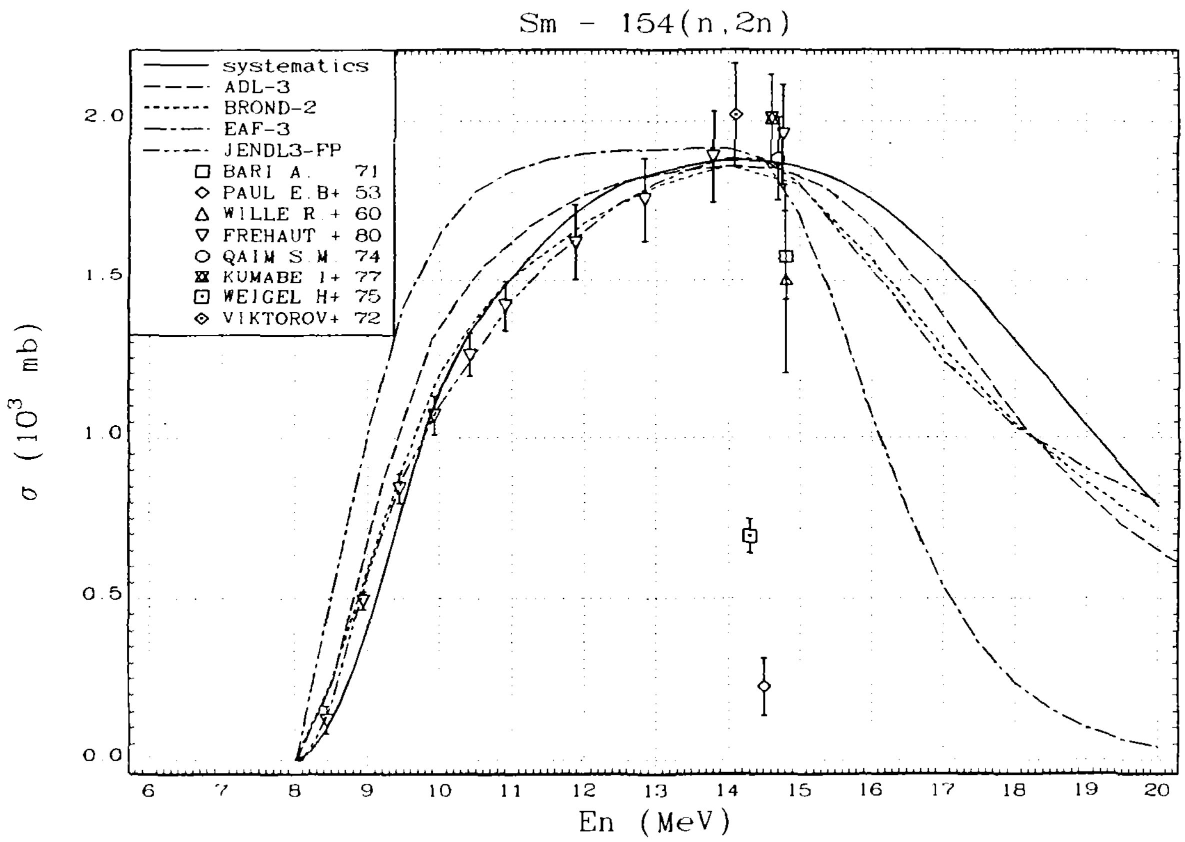

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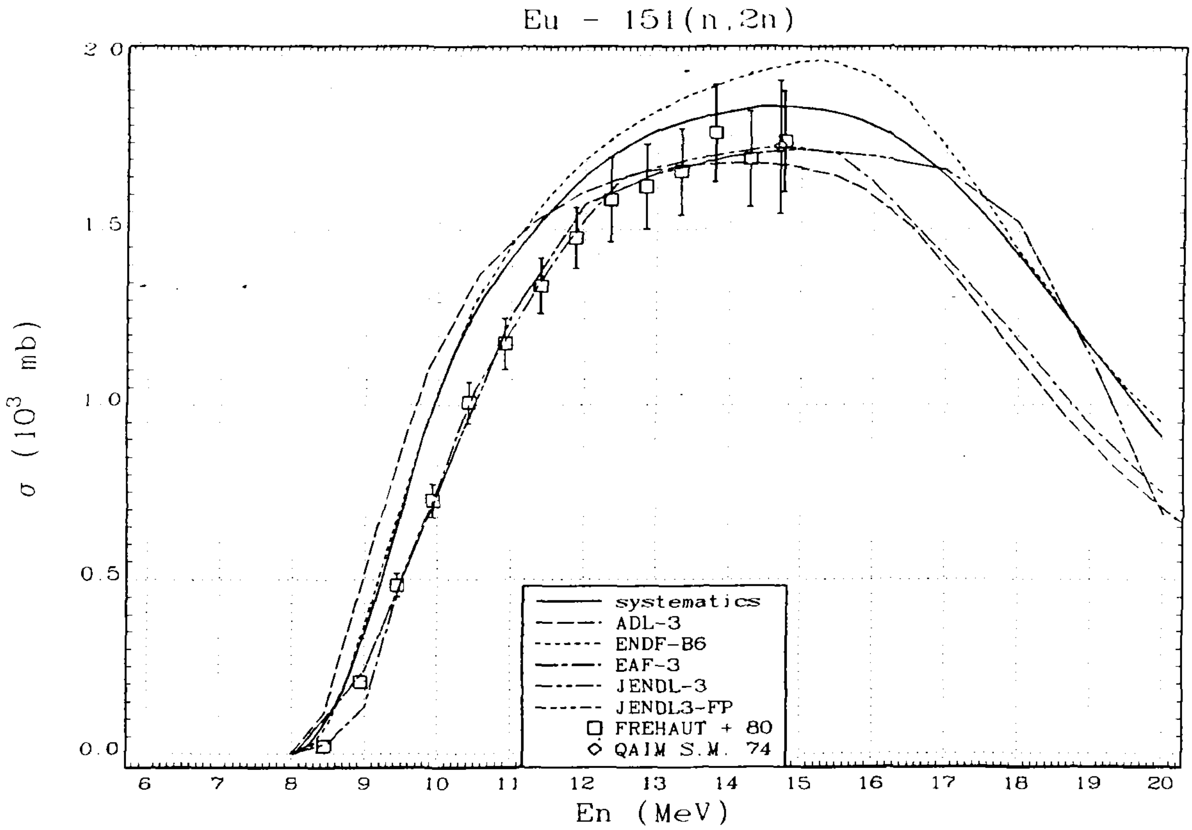

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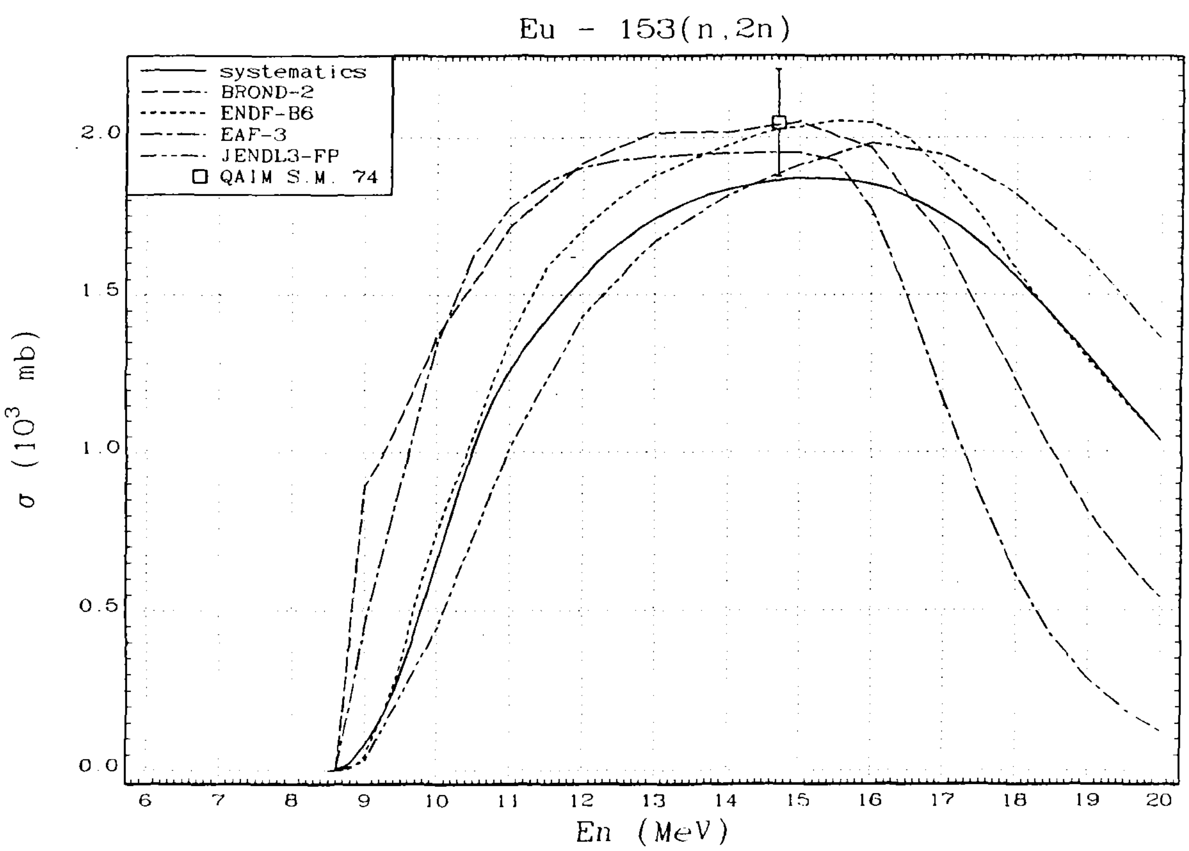

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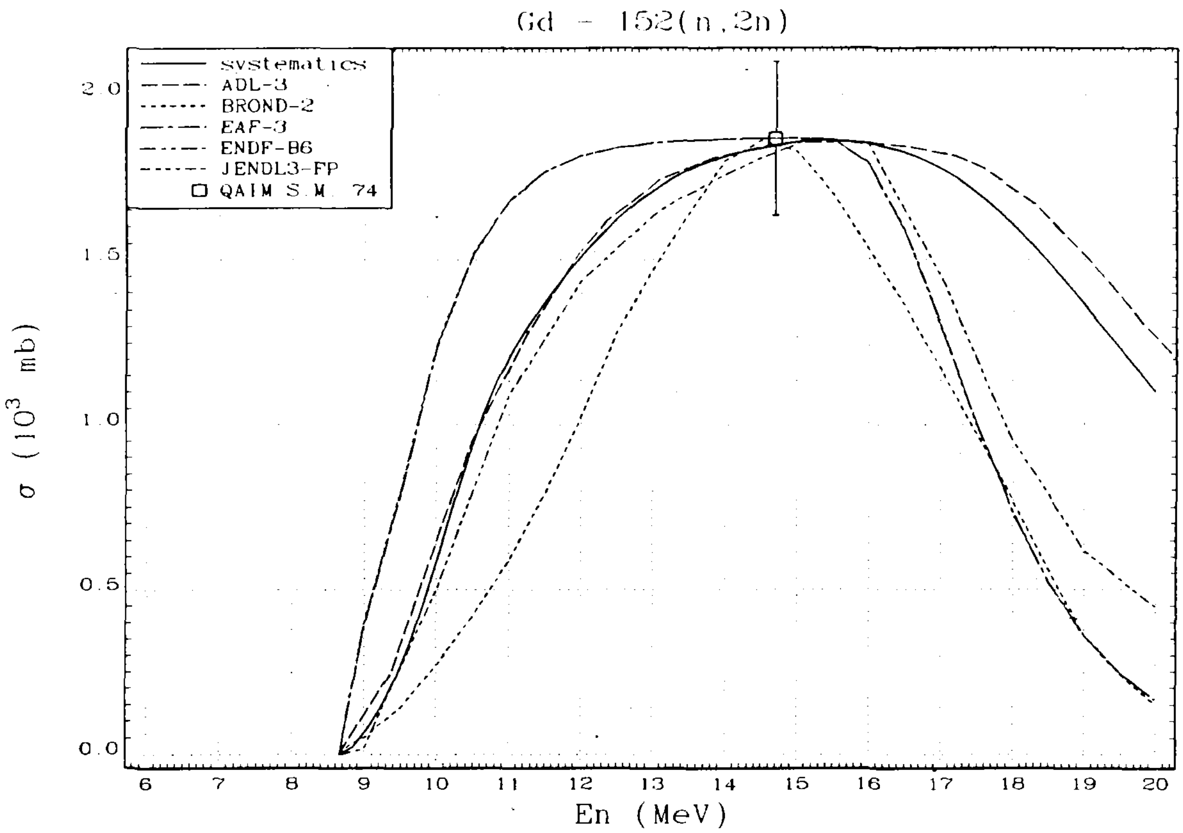

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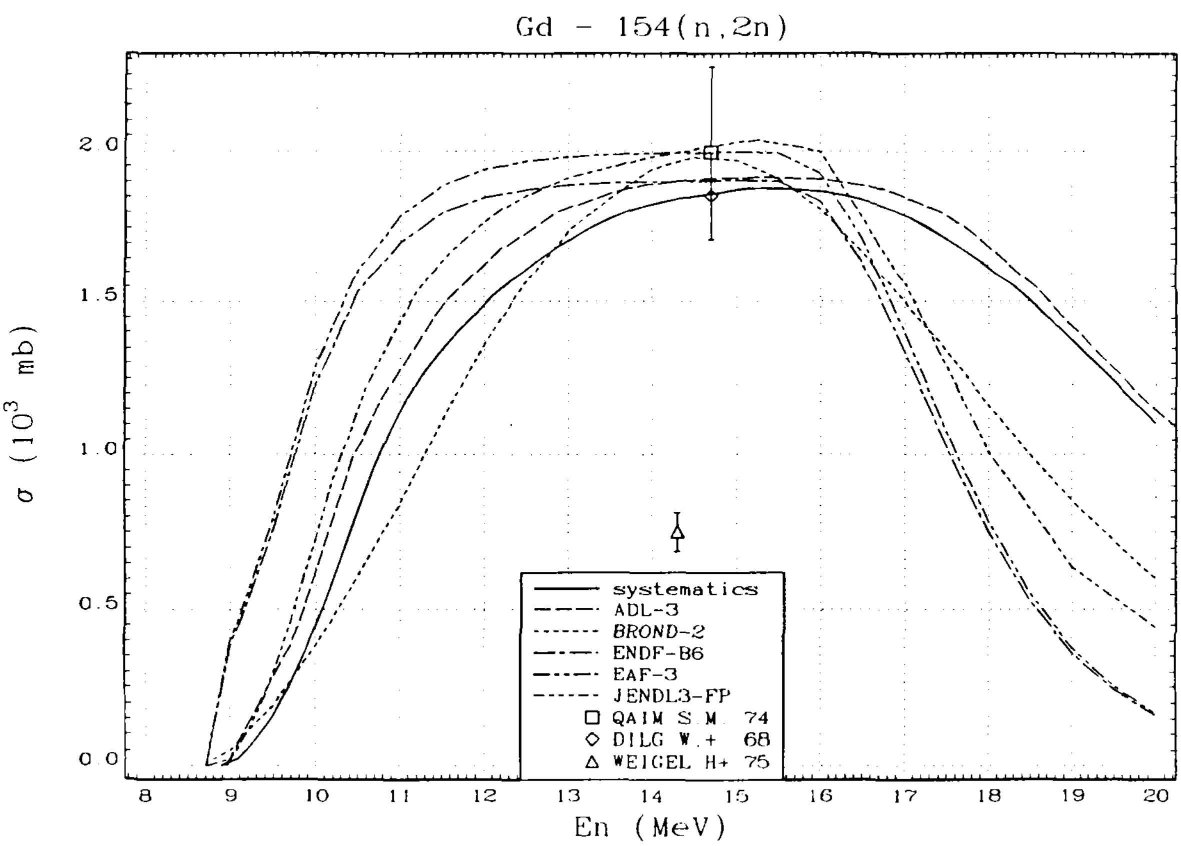

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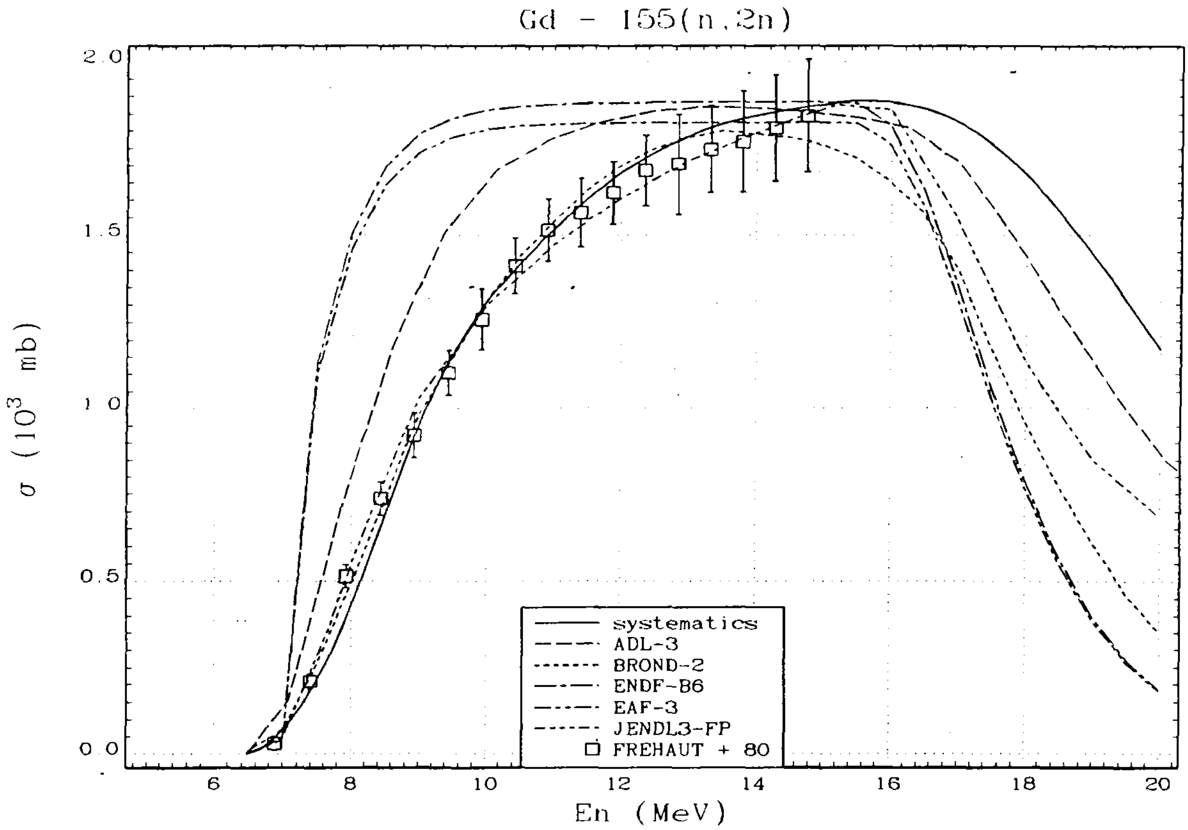

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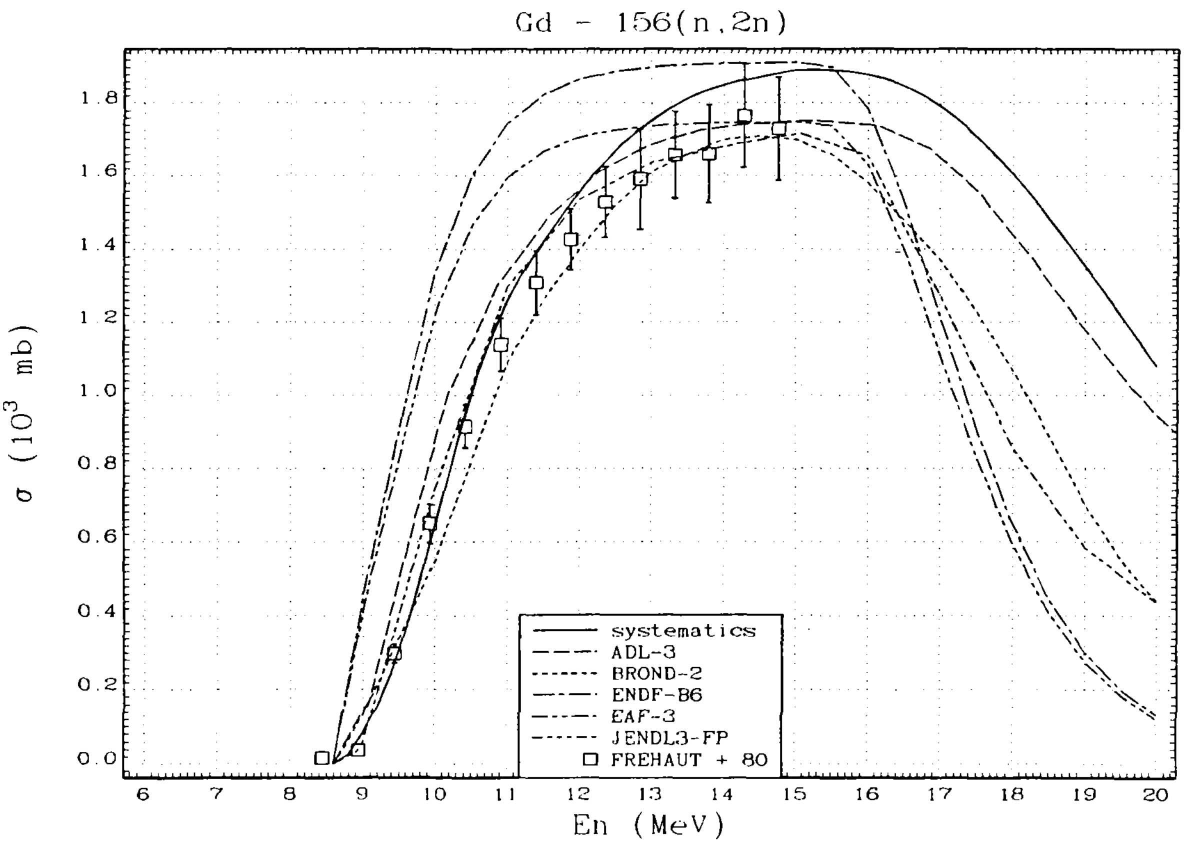

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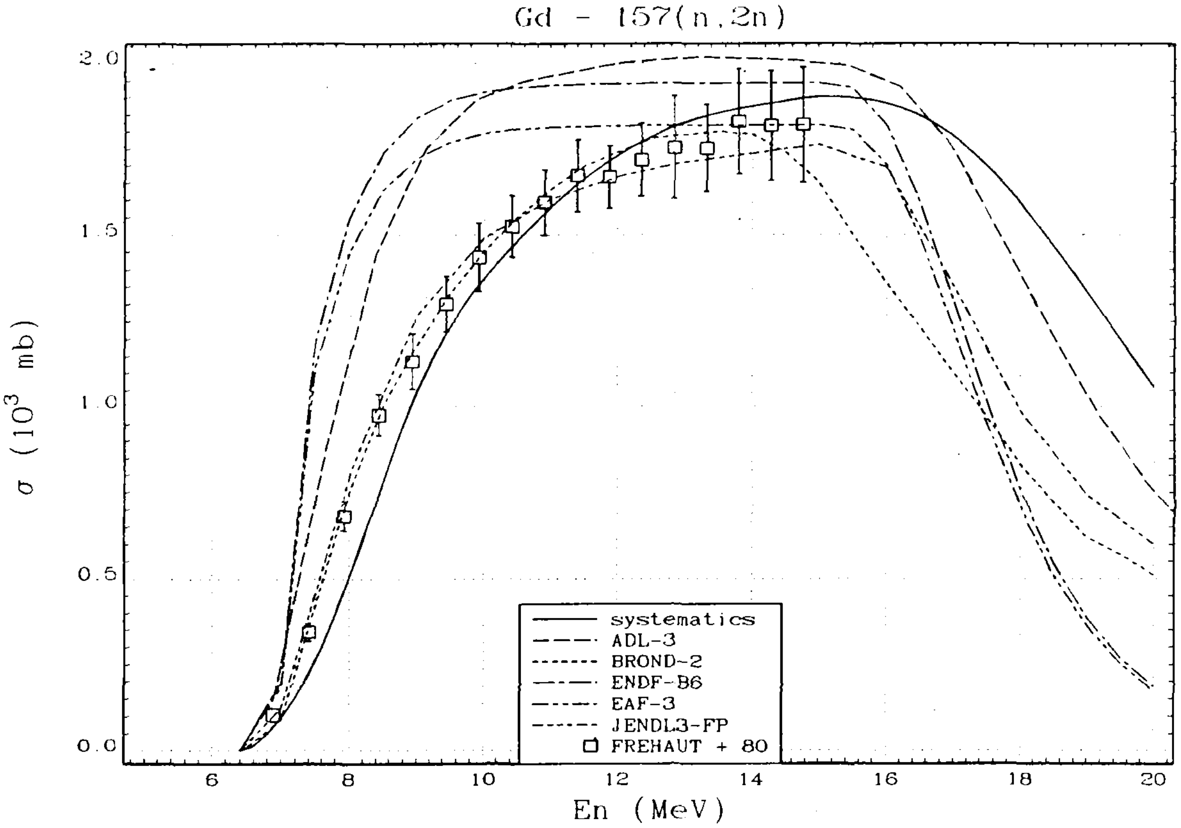

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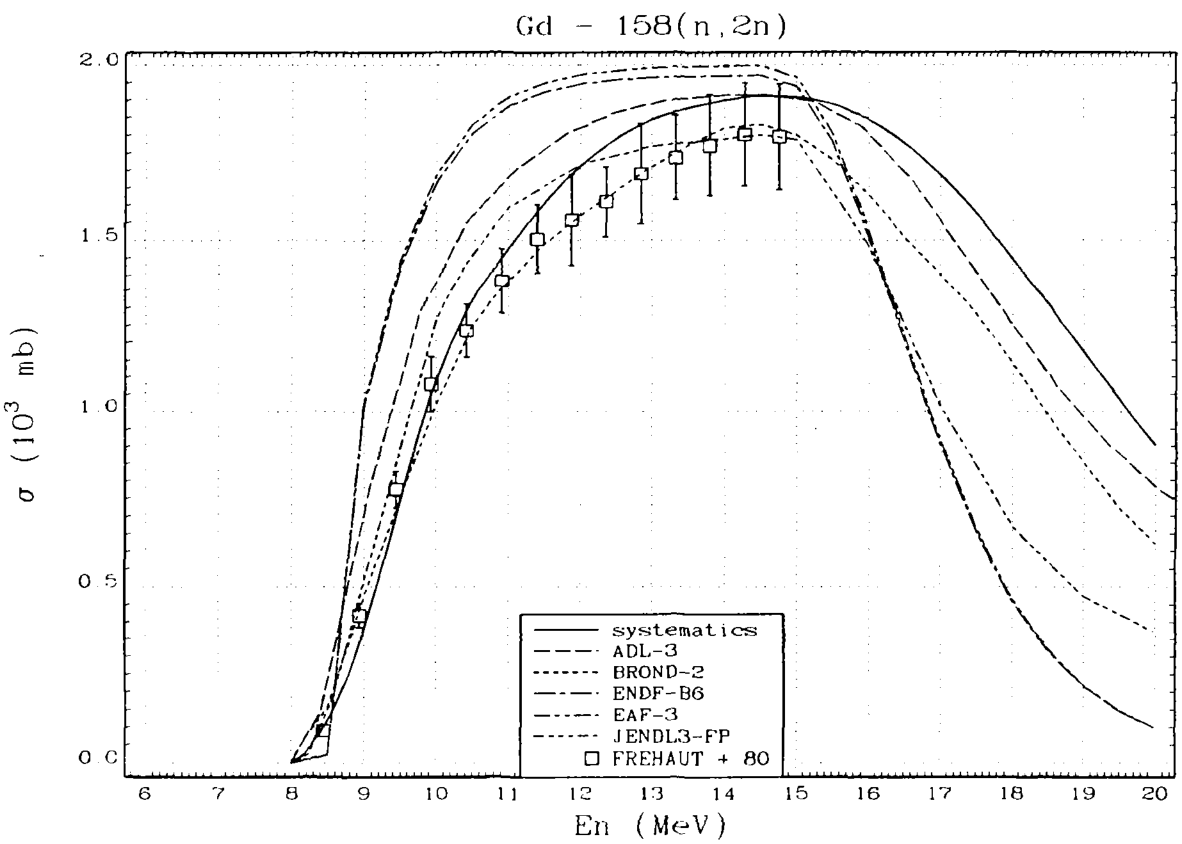

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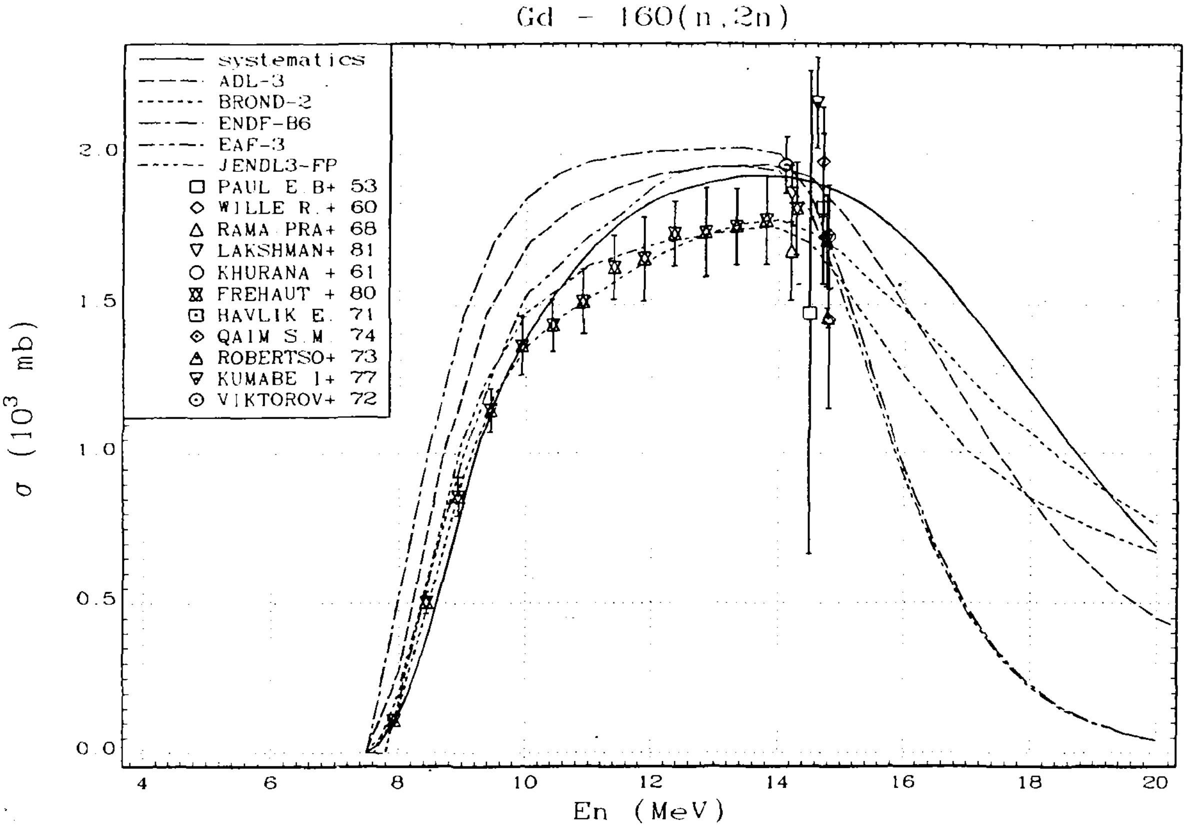

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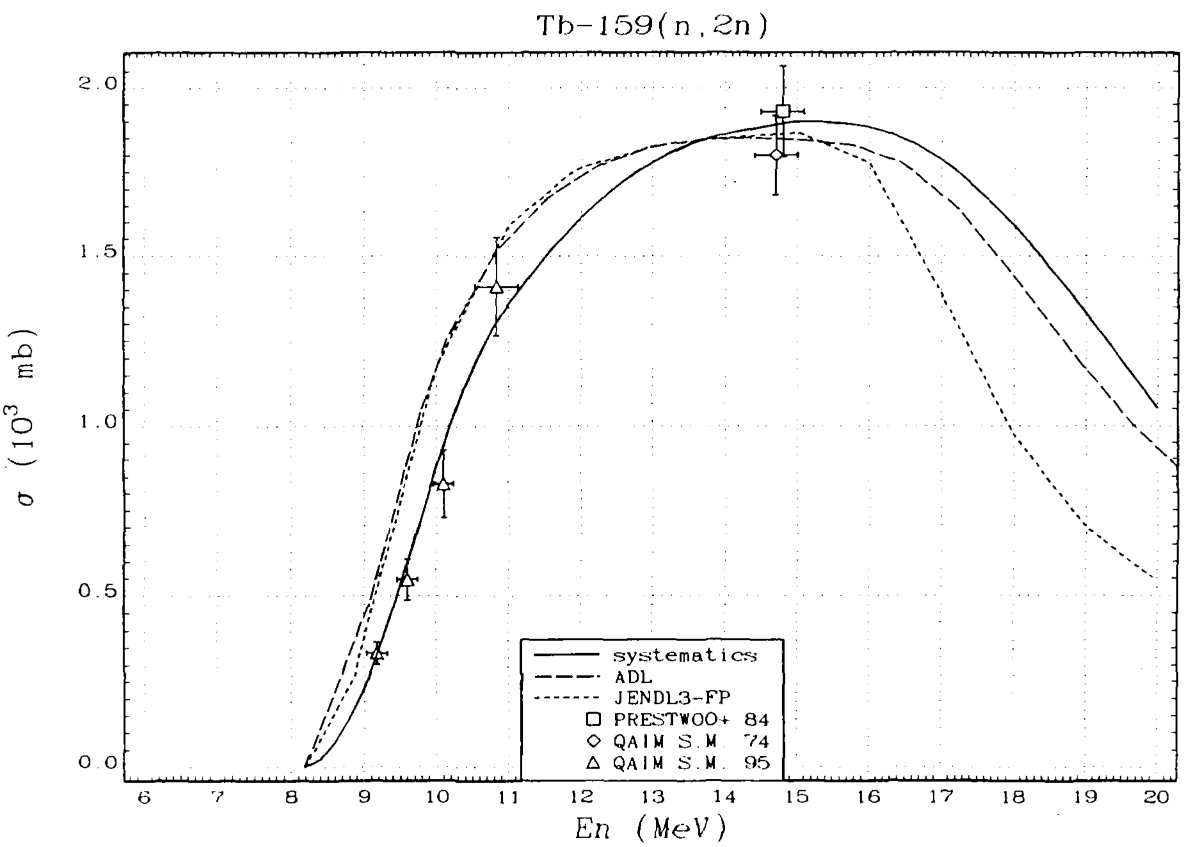

Fig.28. Cross section of $^{159}Tb(n,2n)^{158}Tb$ reaction.

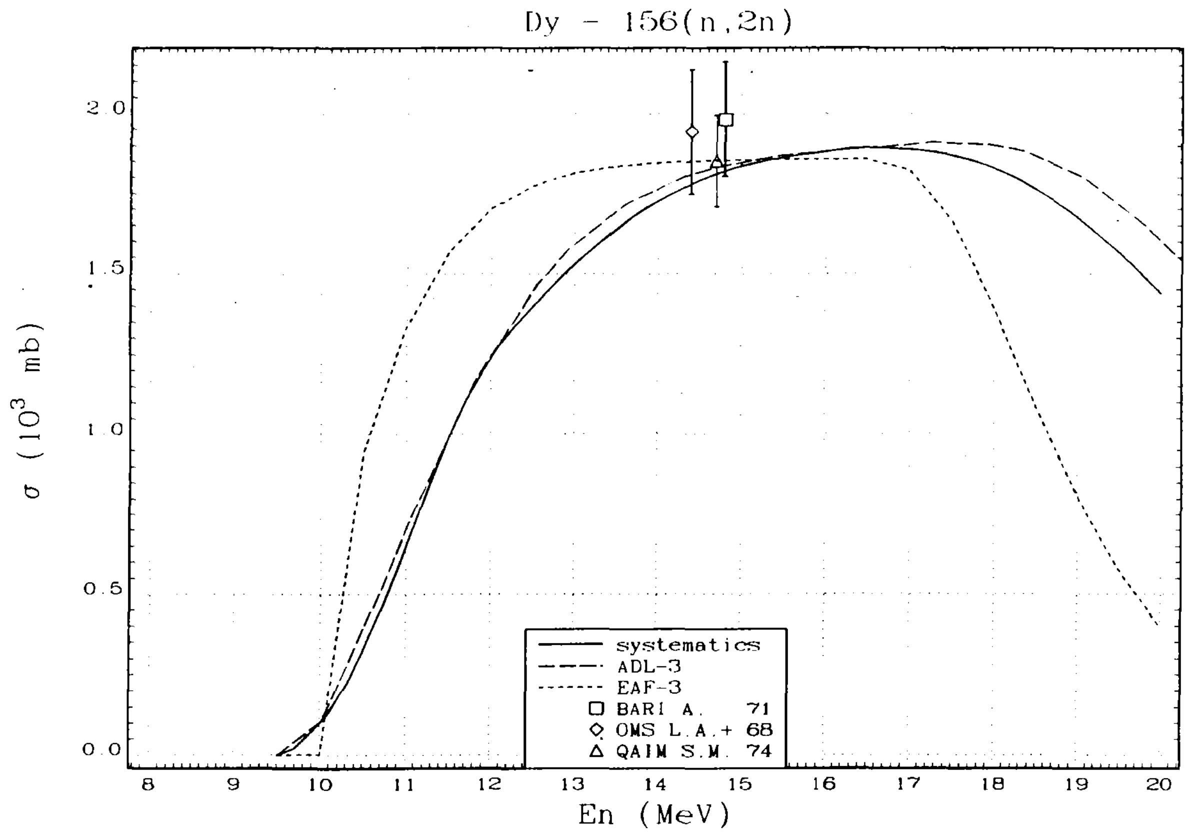

Fig.29. Cross section of $^{156}Dy(n,2n)^{155}Dy$ reaction.

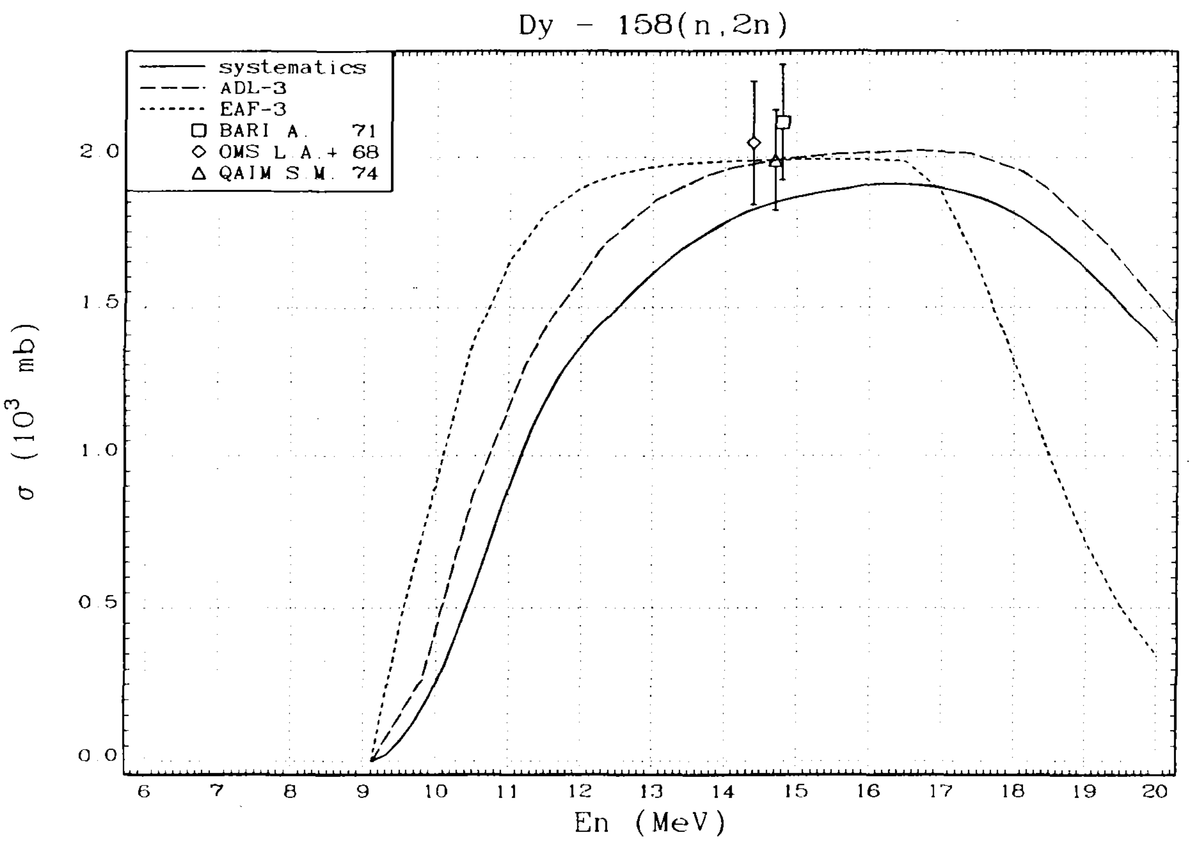

Fig.30. Cross section of $^{158}Dy(n,2n)^{157}Dy$ reaction.

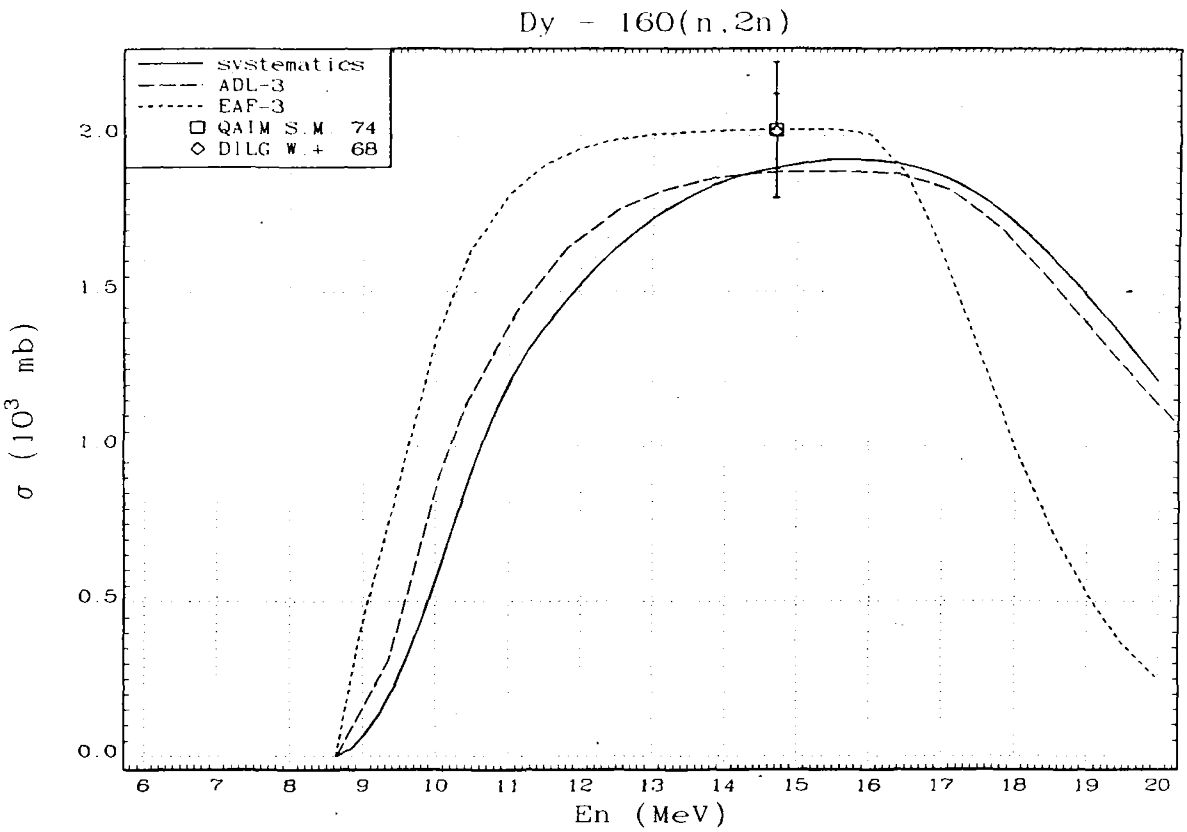

Fig.31. Cross section of ^{160}Dy(n,2n)^{159}Dy reaction.

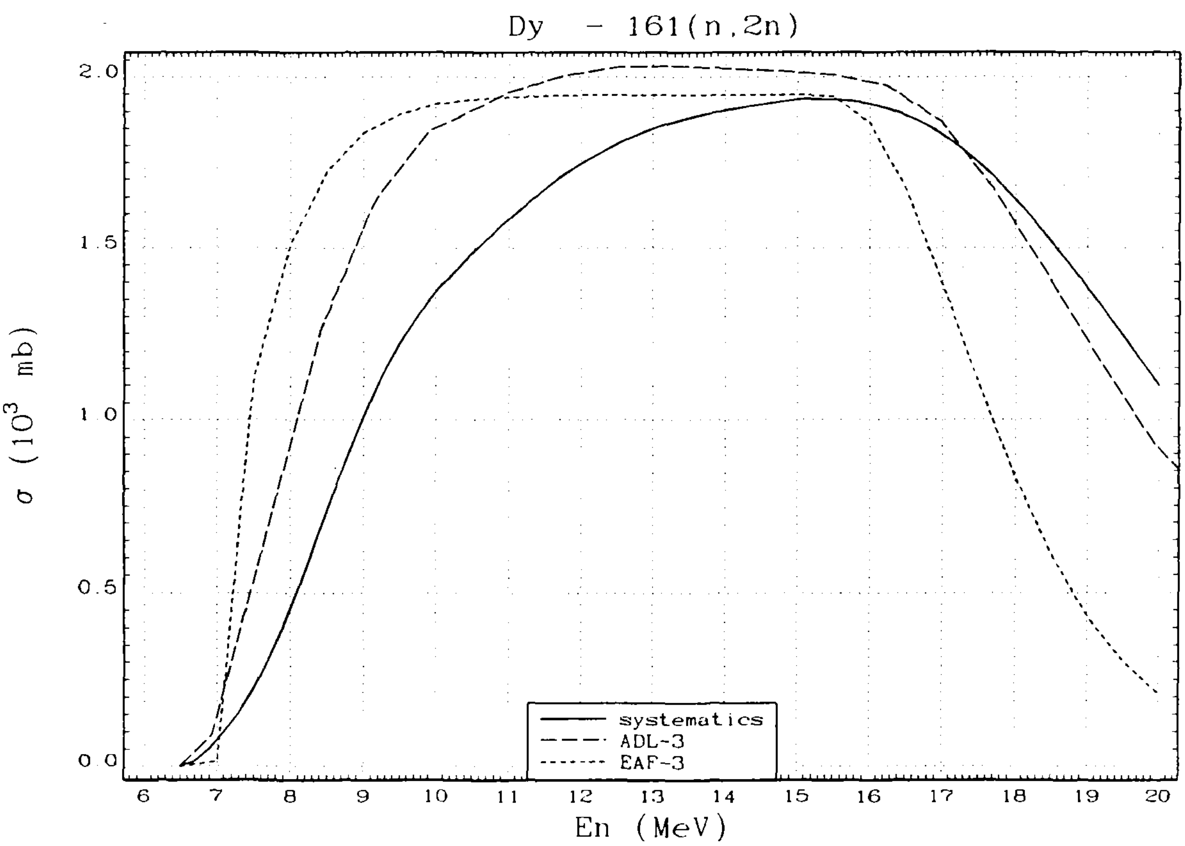

Fig.32. Cross section of ^{161}Dy(n,2n)^{160}Dy reaction.

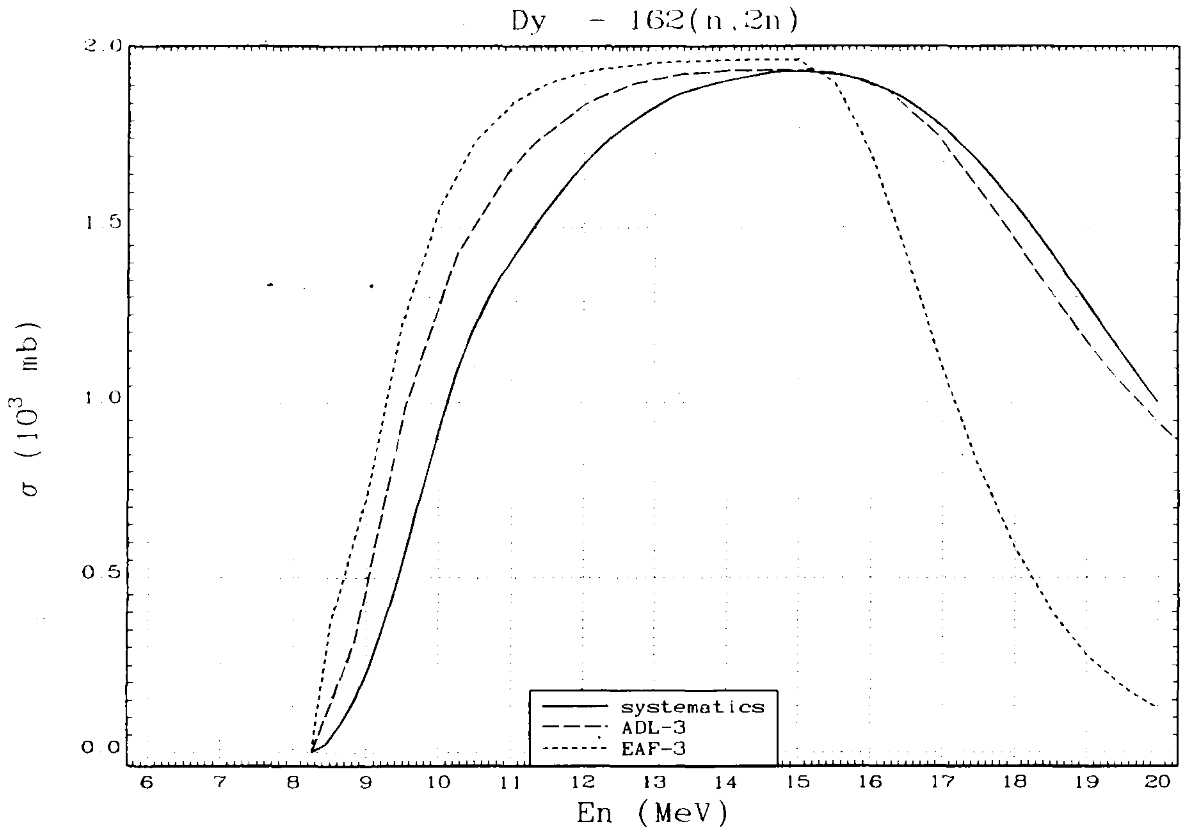

Fig.33. Cross section of ^{162}Dy(n,2n)^{161}Dy reaction.

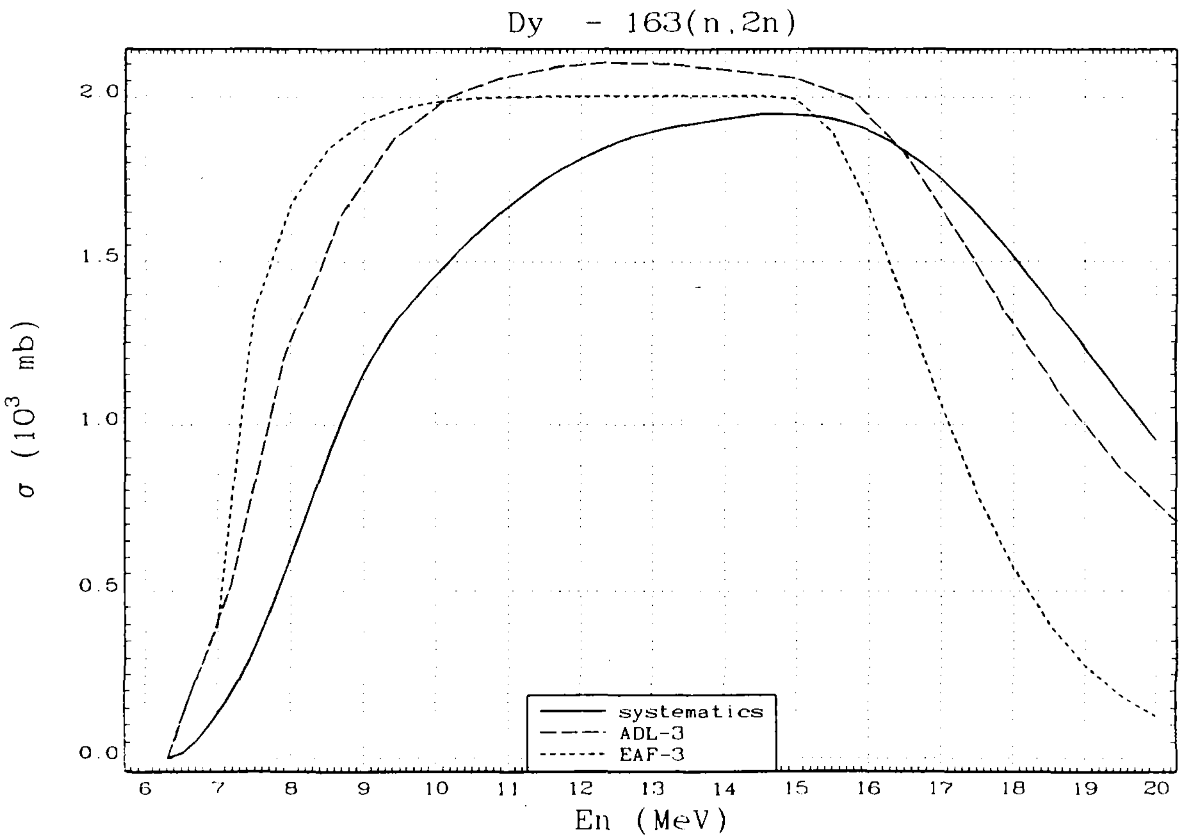

Fig.34. Cross section of ^{163}Dy(n,2n)^{162}Dy reaction.

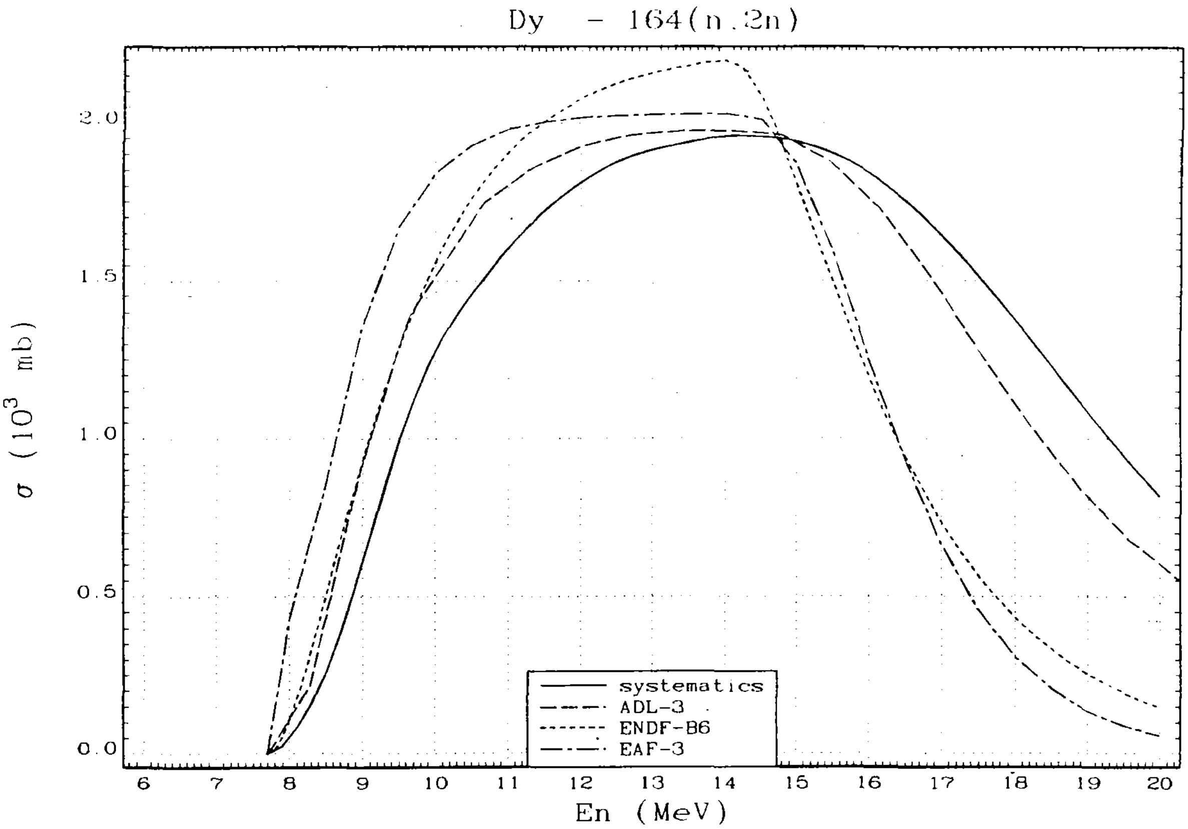

Fig.35. Cross section of ^{164}Dy(n,2n)^{163}Dy reaction.

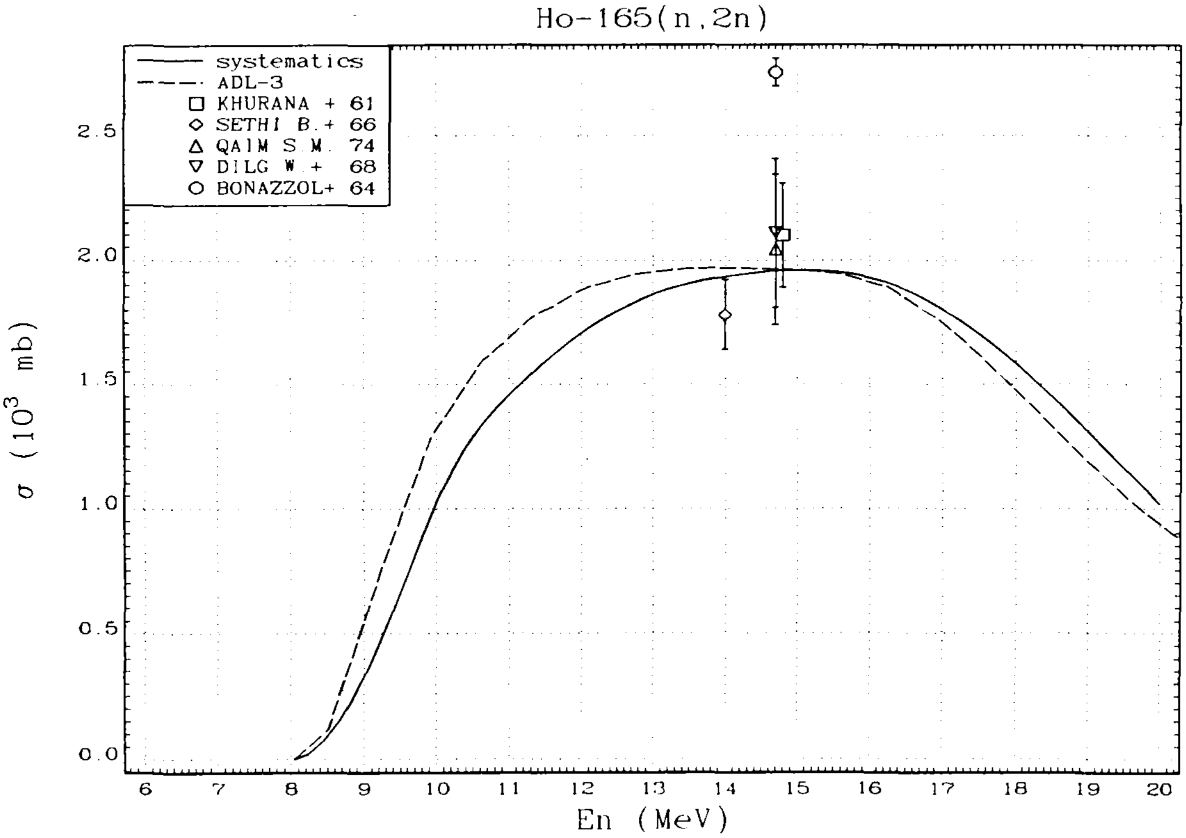

Fig.36. Cross section of ^{165}Ho(n,2n)^{164}Ho reaction.

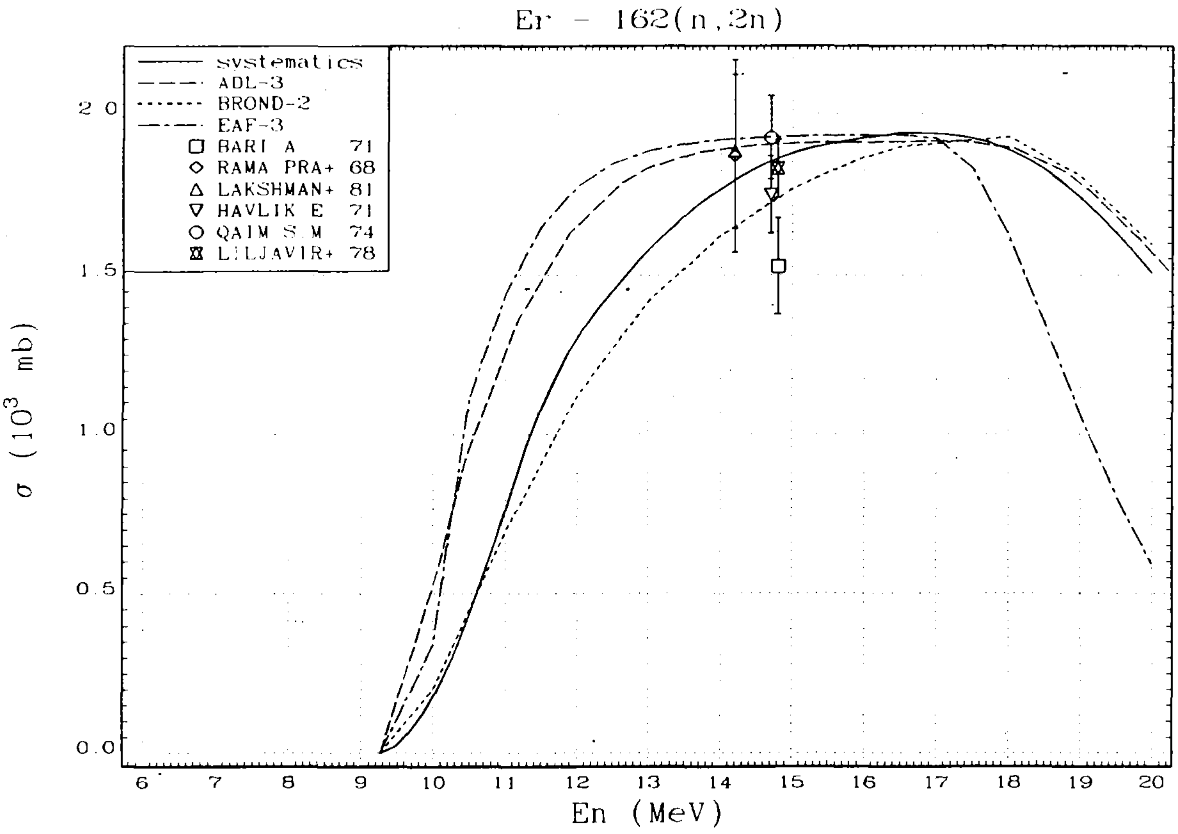

Fig.37. Cross section of $^{162}Er(n,2n)^{161}Er$ reaction.

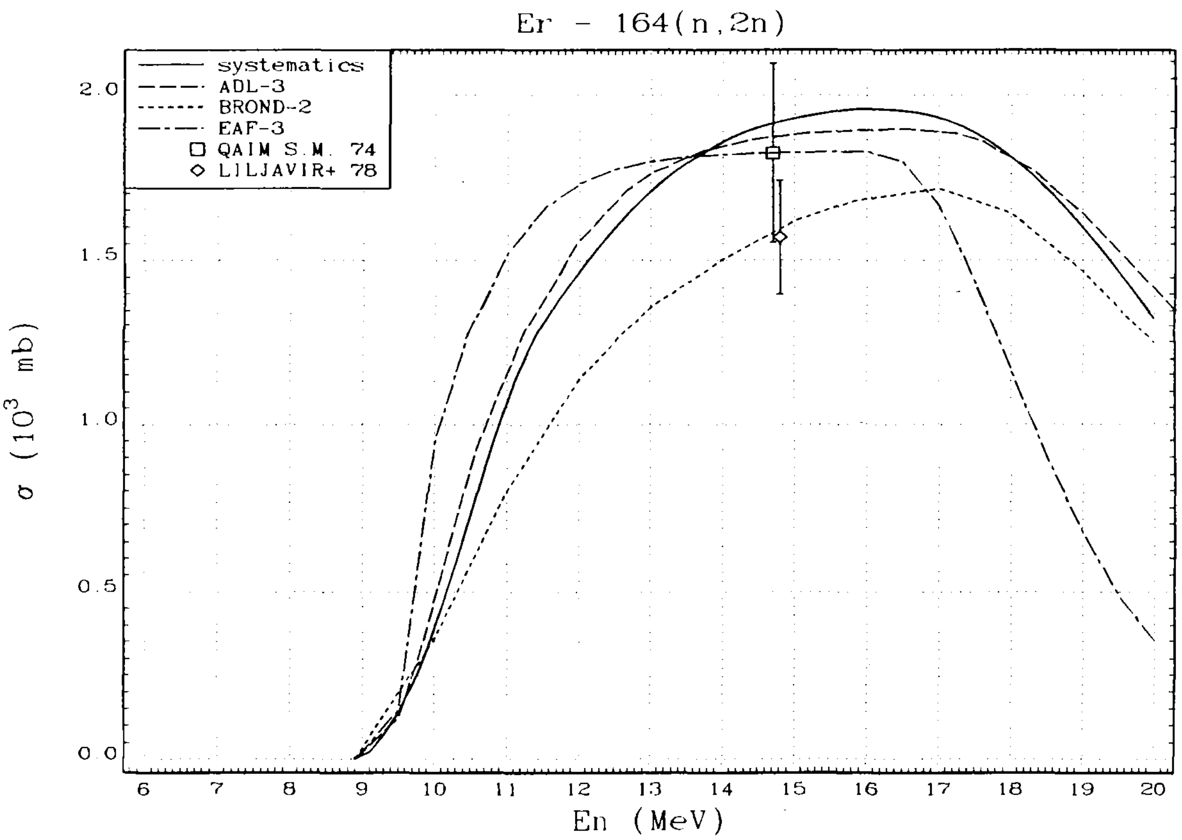

Fig.38. Cross section of $^{164}Er(n,2n)^{163}Er$ reaction.

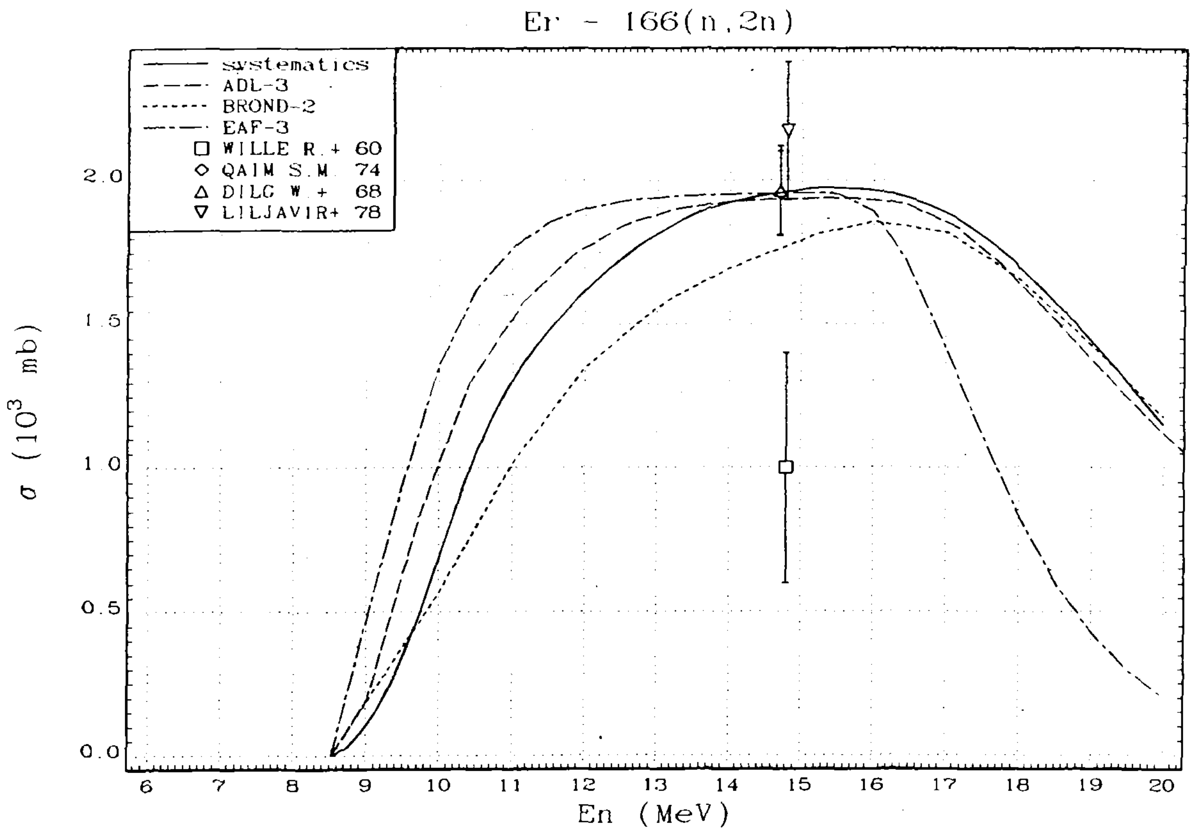

Fig.39. Cross section of ^{166}Er(n,2n)^{165}Er reaction.

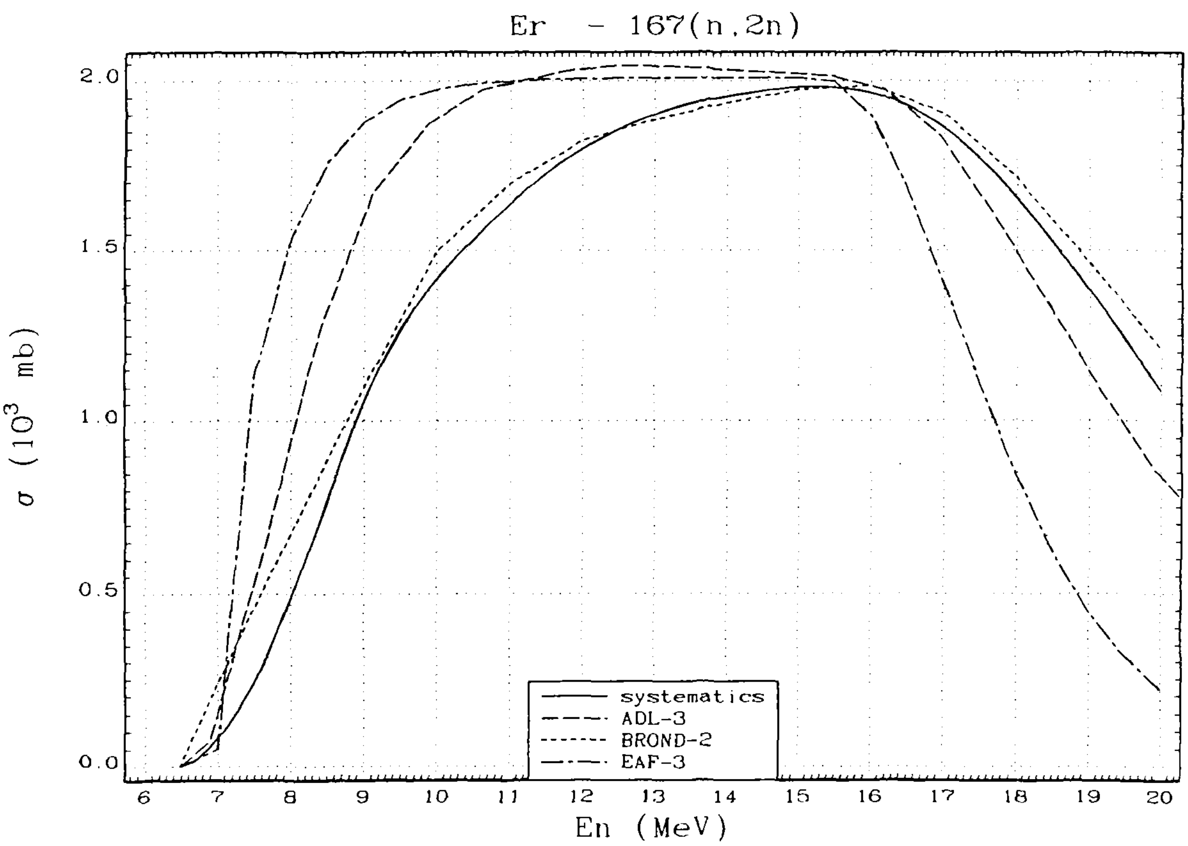

Fig.40. Cross section of ^{167}Er(n,2n)^{166}Er reaction.

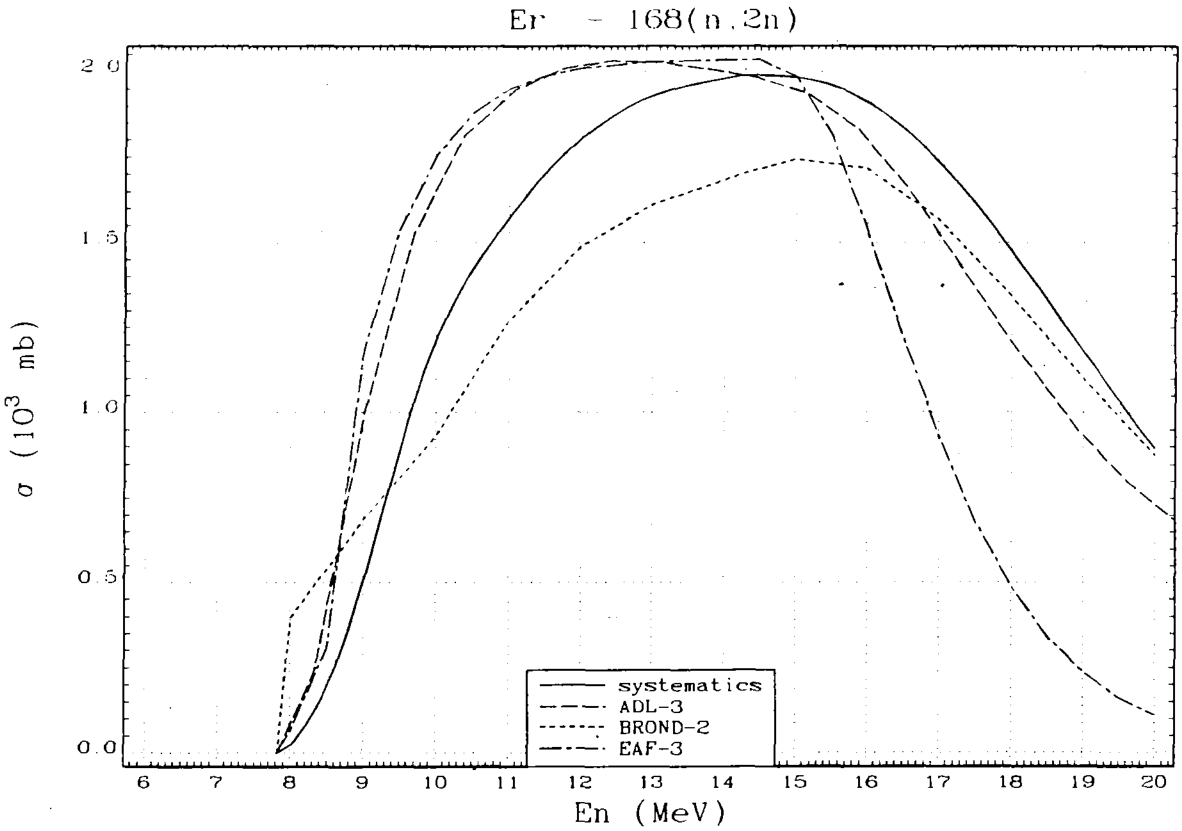

Fig.41. Cross section of ^{168}Er(n,2n)^{167}Er reaction.

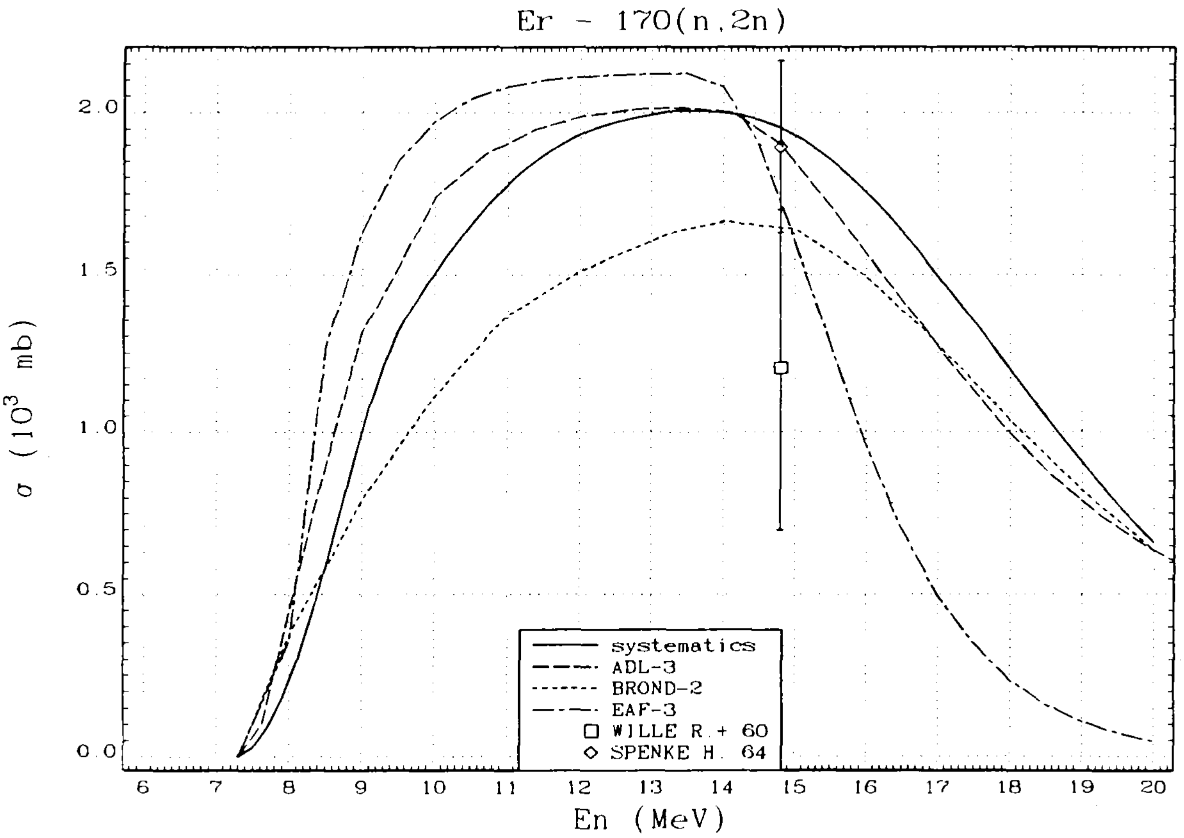

Fig.42. Cross section of ^{170}Er(n,2n)^{169}Er reaction.

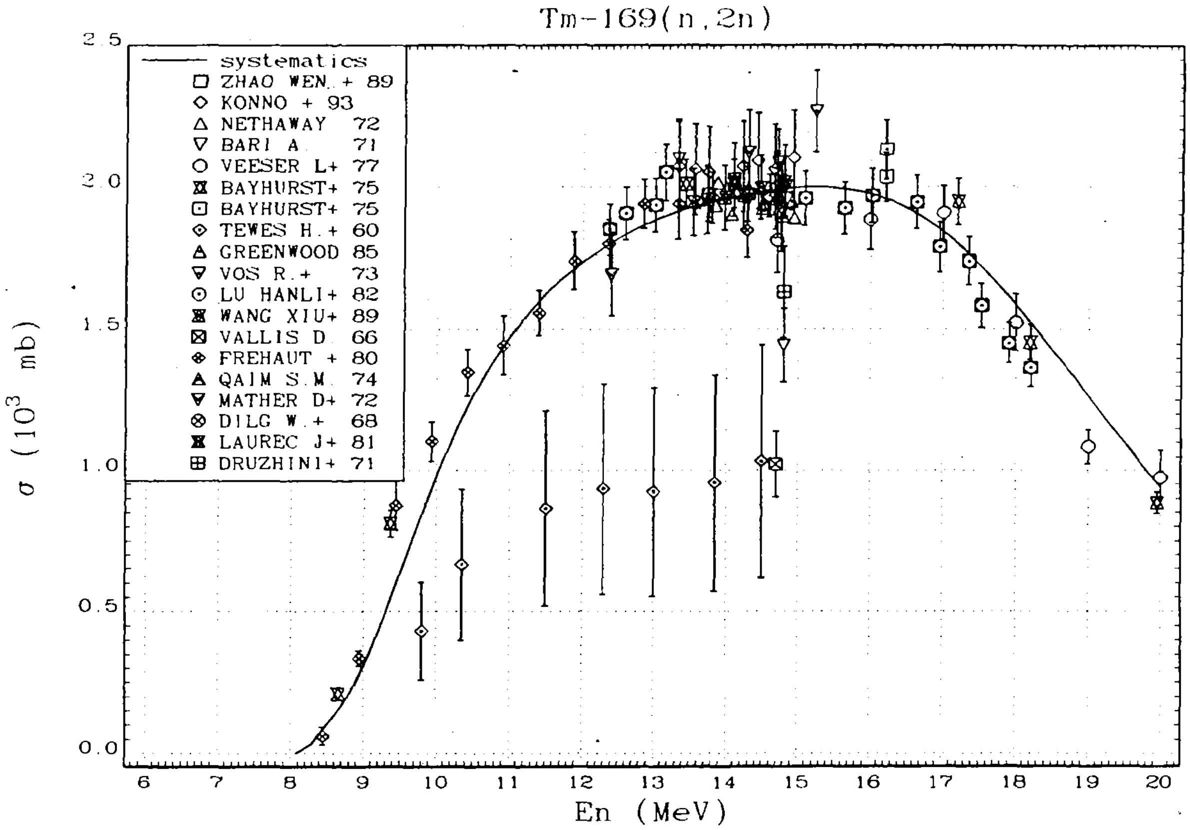

Fig.43. Cross section of $^{169}Tm(n,2n)^{168}Tm$ reaction.

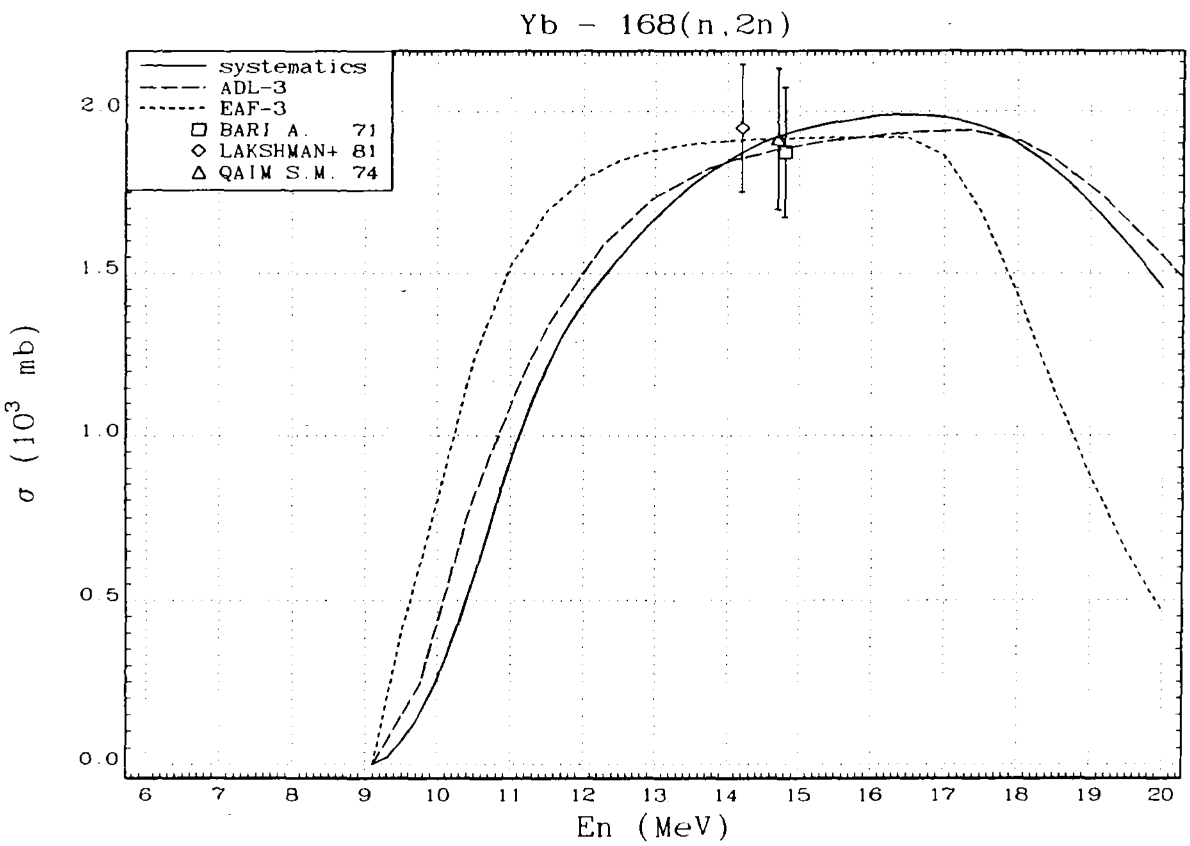

Fig.44. Cross section of $^{168}Yb(n,2n)^{167}Yb$ reaction.

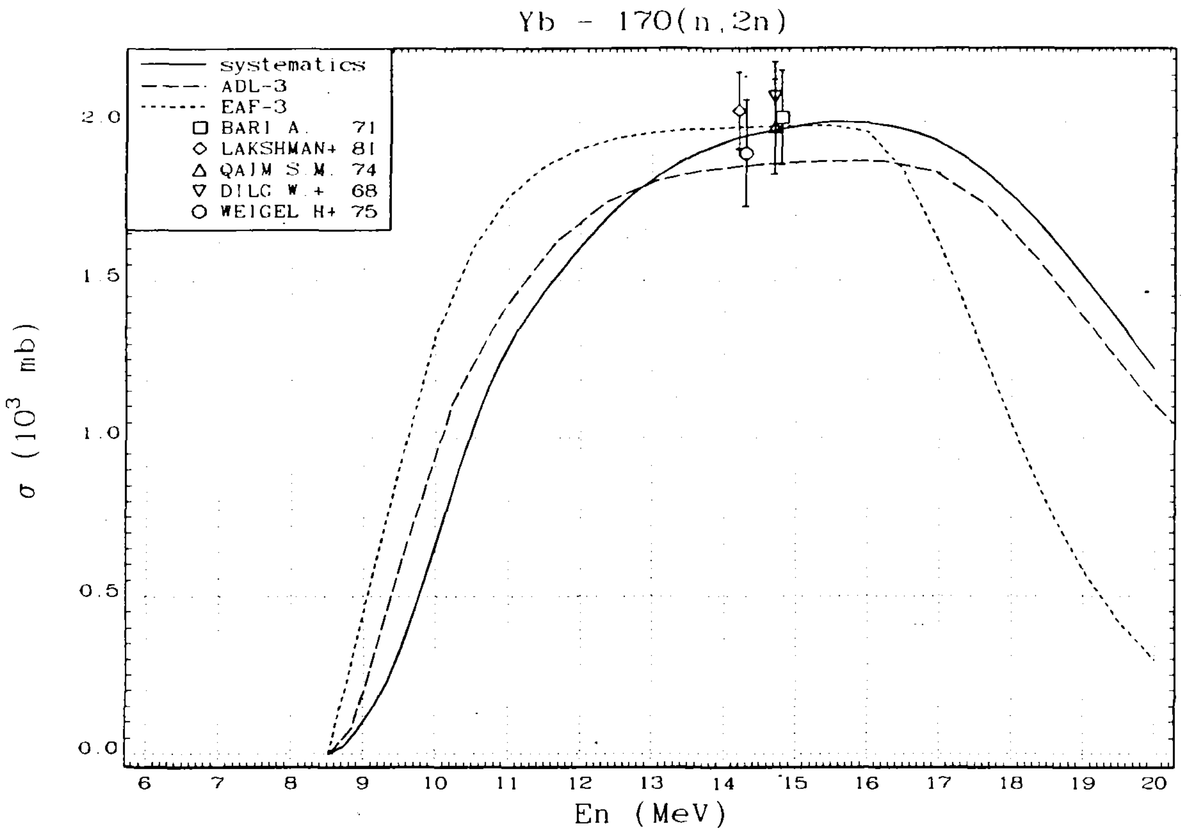

Fig.45. Cross section of ^{170}Yb(n,2n)^{169}Yb reaction.

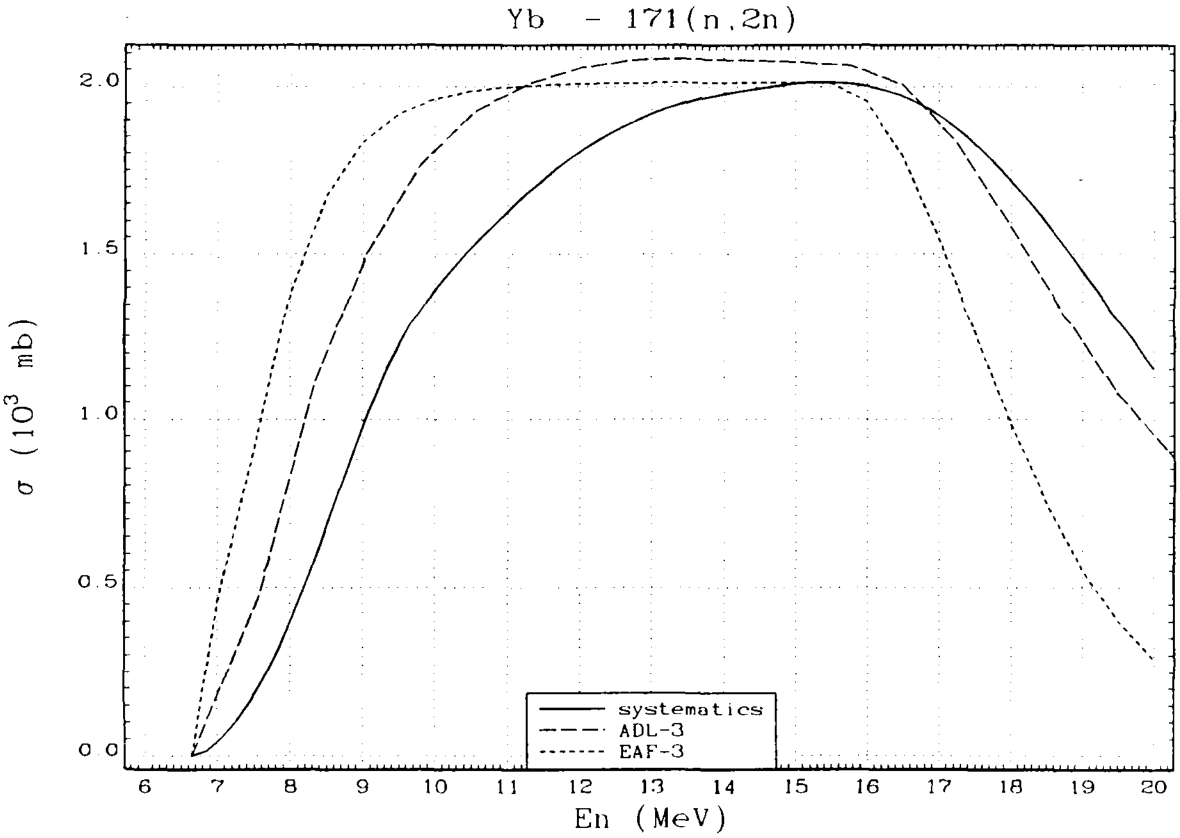

Fig.46. Cross section of ^{171}Yb(n,2n)^{170}Yb reaction.

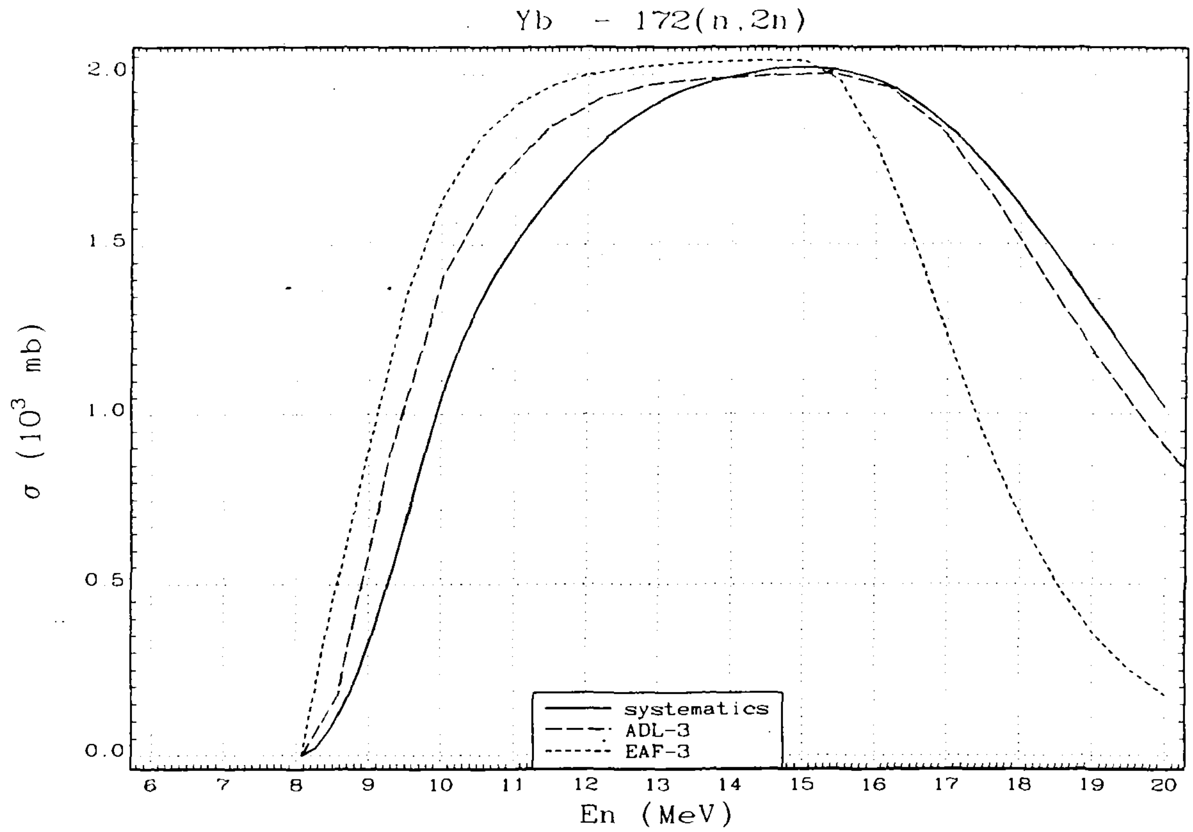

Fig.47. Cross section of $^{172}Yb(n,2n)^{171}Yb$ reaction.

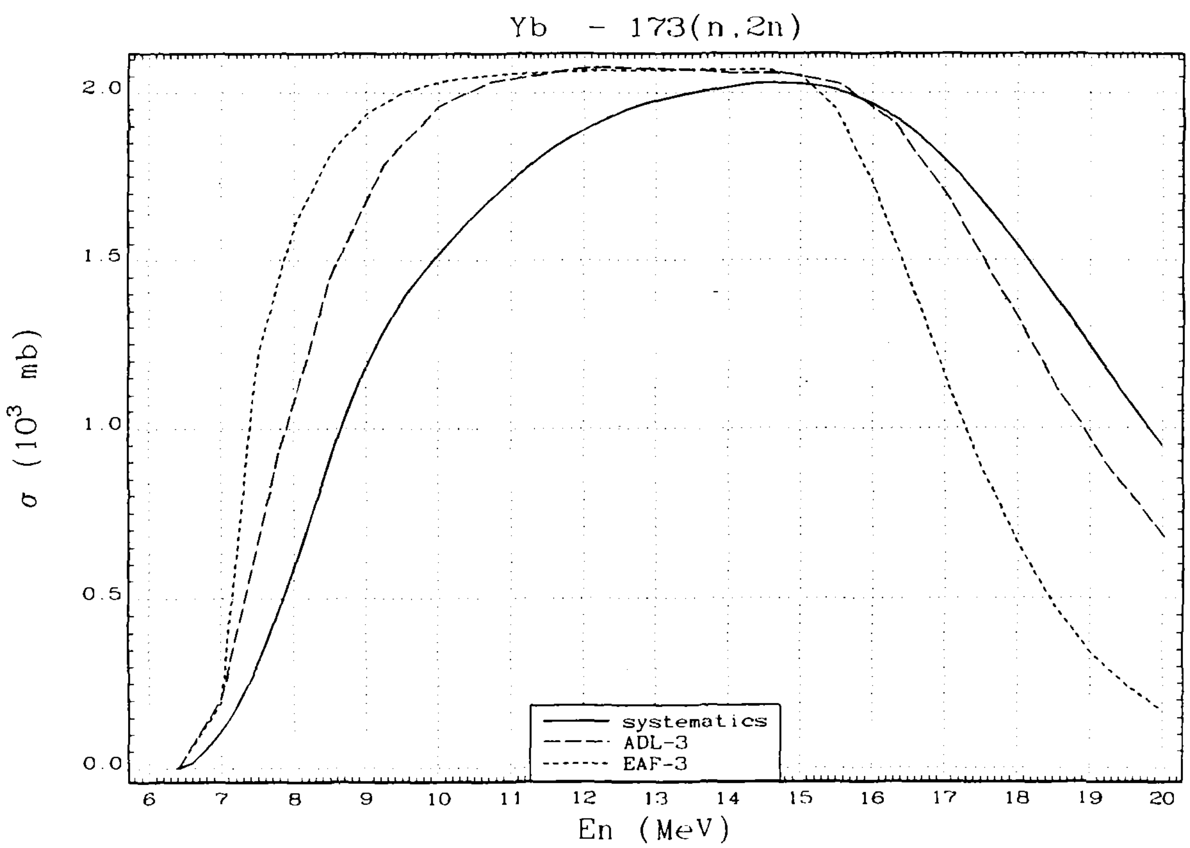

Fig.48. Cross section of $^{173}Yb(n,2n)^{172}Yb$ reaction.

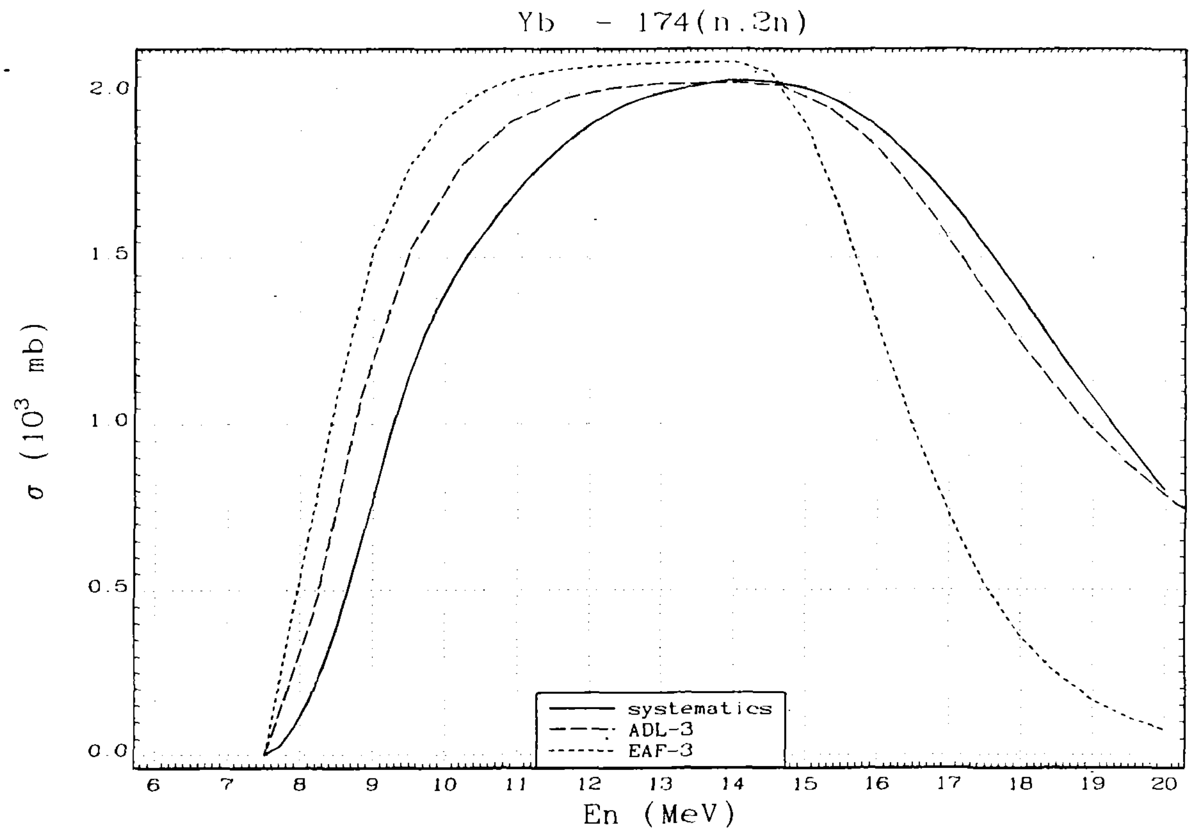

Fig.49. Cross section of ^{174}Yb(n,2n)^{173}Yb reaction.

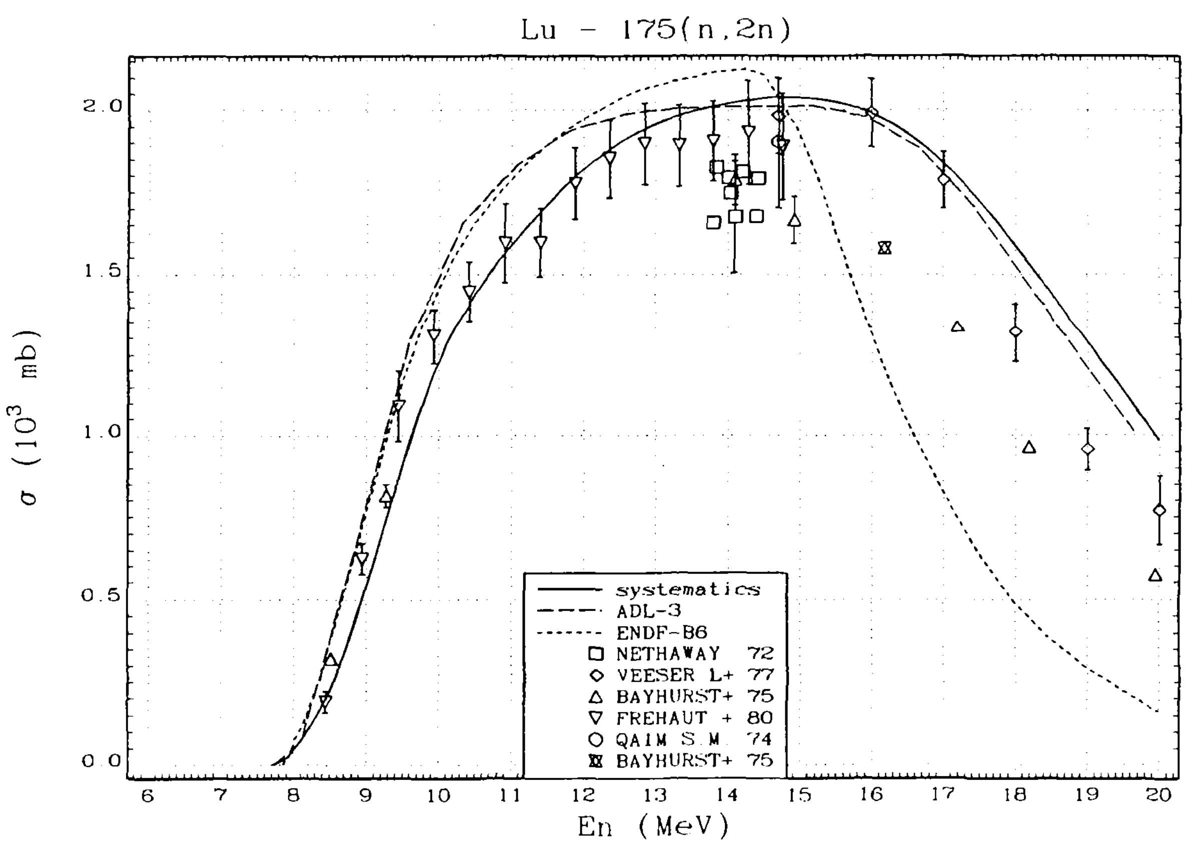

Fig.50. Cross section of ^{175}Lu(n,2n)^{174}Lu reaction.

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