Nuclear Data for Helium Production in Fusion

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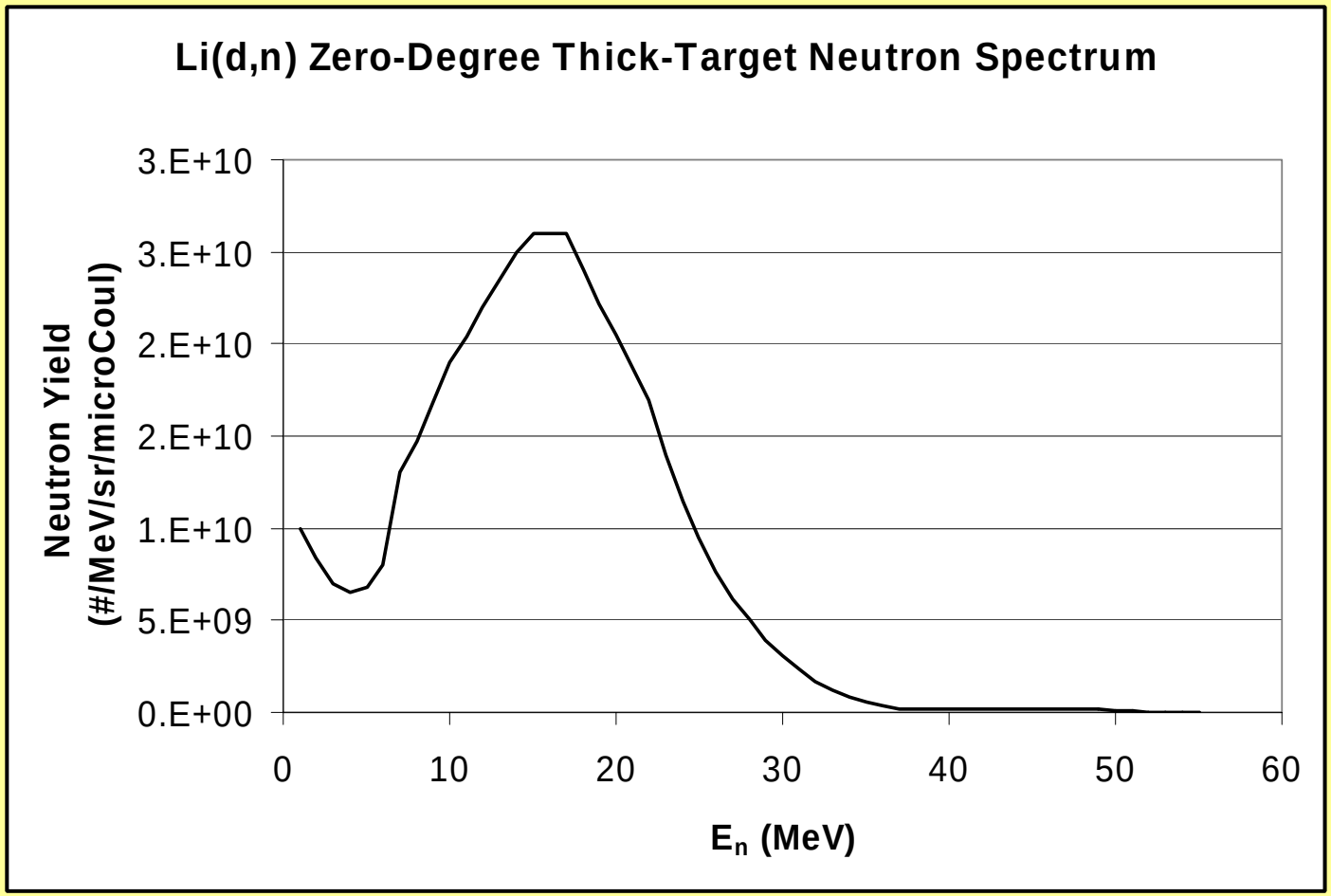
The Issue

- The production of helium in structural materials and associated material damage – mainly as a consequence of fast neutron irradiation – is a major concern for fusion reactor technology
- Actual d-T fusion reactor neutron spectra consist of a strong peak in the vicinity of 13-15 MeV plus a tail of lower energy neutrons
- It is planned to test fusion reactor materials by using a neutron spectrum produced by several tens of MeV deuterons on lithium targets, resulting in neutrons with energies up to 60 MeV
- Thus, the status of data for neutron reactions that produce helium needs to be investigated

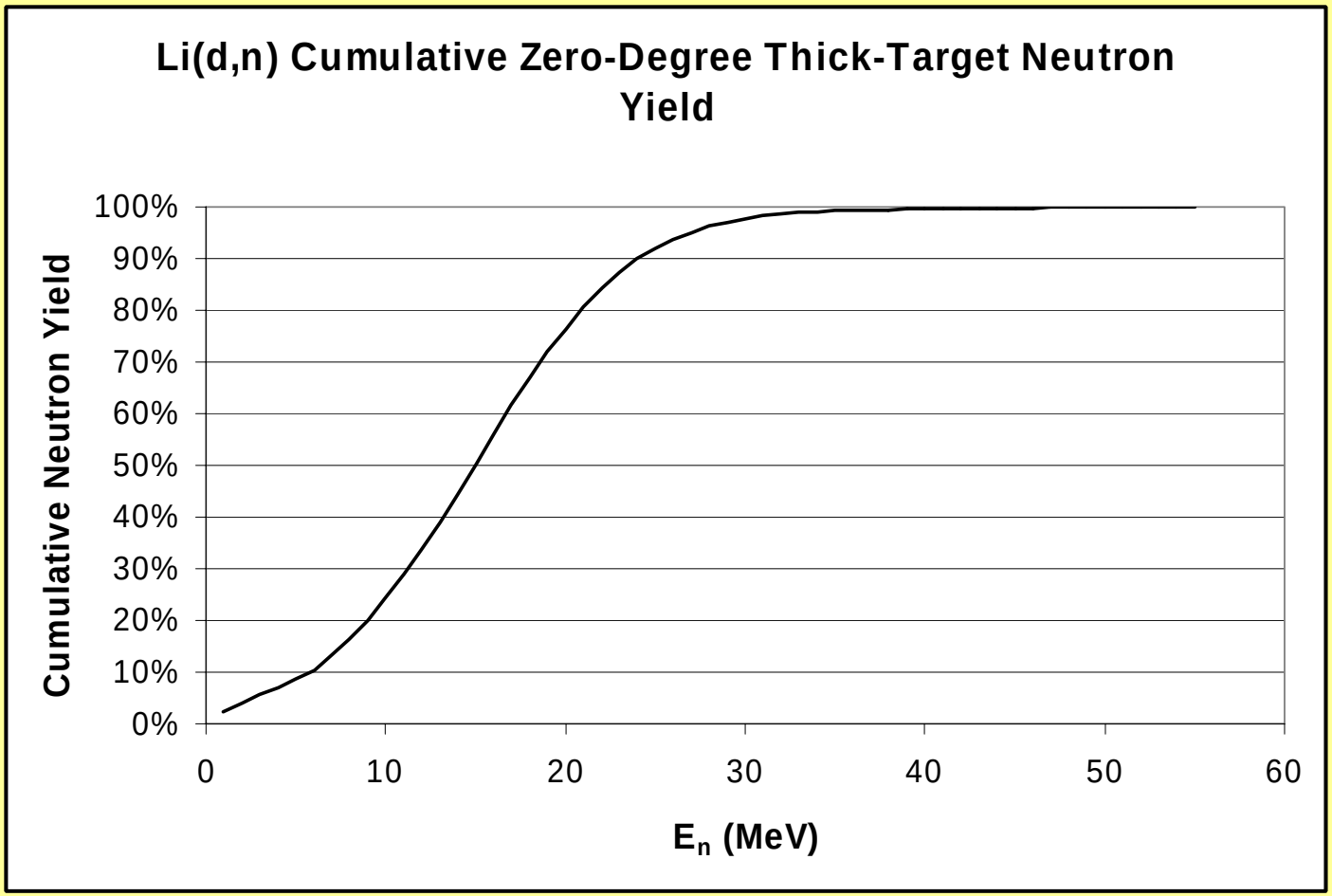
IFMIF Neutron Source

- The proposed International Fusion Materials Irradiation Facility (IFMIF) will generate an intense neutron source with a spectrum that peaks around 14 MeV, but otherwise it is very broad and differs significantly from true d-T fusion reactor spectra
- For the IFMIF spectrum, approximately 50% of the neutrons will have energies above 14 MeV and 25% above 20 MeV
- Most of the contemporary general purpose evaluated data files address the energy region below 20 MeV, although higher energy files for some materials have been developed as a consequence of APT and ATW programs

IFMIF Spectrum - 1



IFMIF Spectrum - 2



Review of Data Status

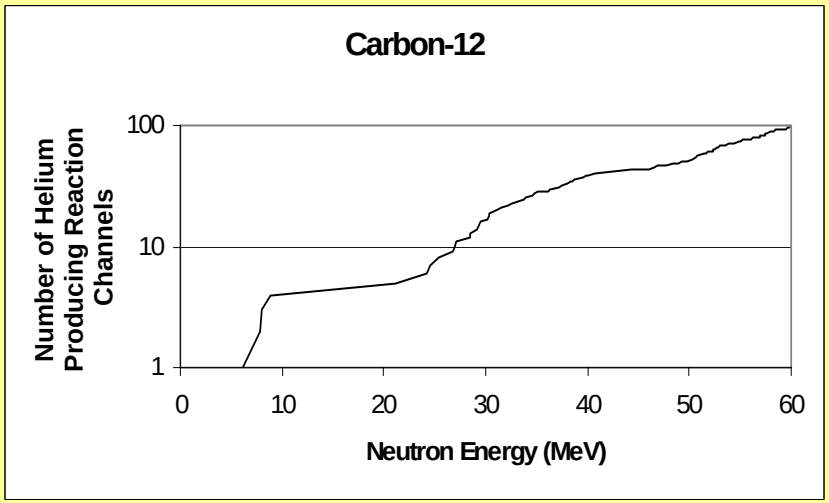
- The current investigation is limited to helium producing neutron reaction data for Carbon, Silicon, Titanium, Vanadium, Chromium, Iron, Nickel, and Tungsten
- This review is based on compiled data available from the NNDC and IAEA Nuclear Data Section
- Various physics constraints have been imposed to limit the scope of this study to reactions that are likely to contribute meaningfully to the production of helium in materials irradiated by neutrons with energies below 60 MeV

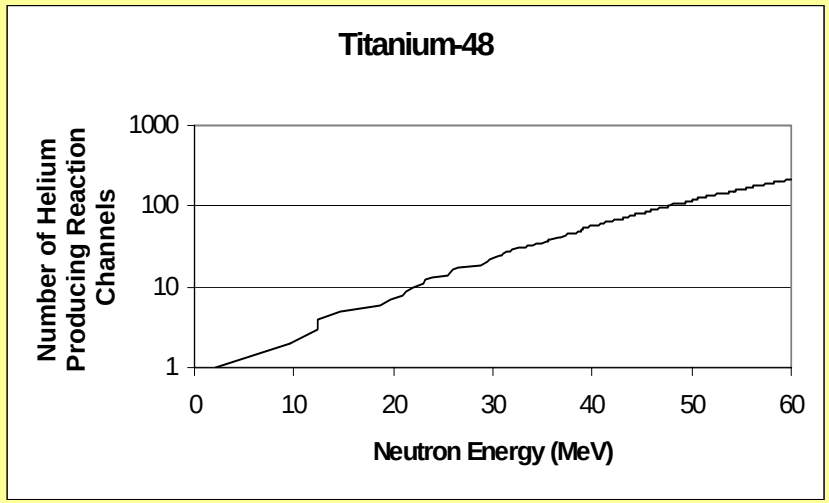
Scope of Review

- Identify the accessible helium producing reaction channels and determine Q-values and threshold energies
- CINDA citations to the literature
- Experimental data from EXFOR system
- General purpose evaluations
- FENDL-2 evaluations
- Conclusions and recommendations

Helium Reaction Channels

- It is observed that the number of reaction channels that are energetically accessible and produce helium increases roughly exponentially with neutron energy
- A limited number of these are significant

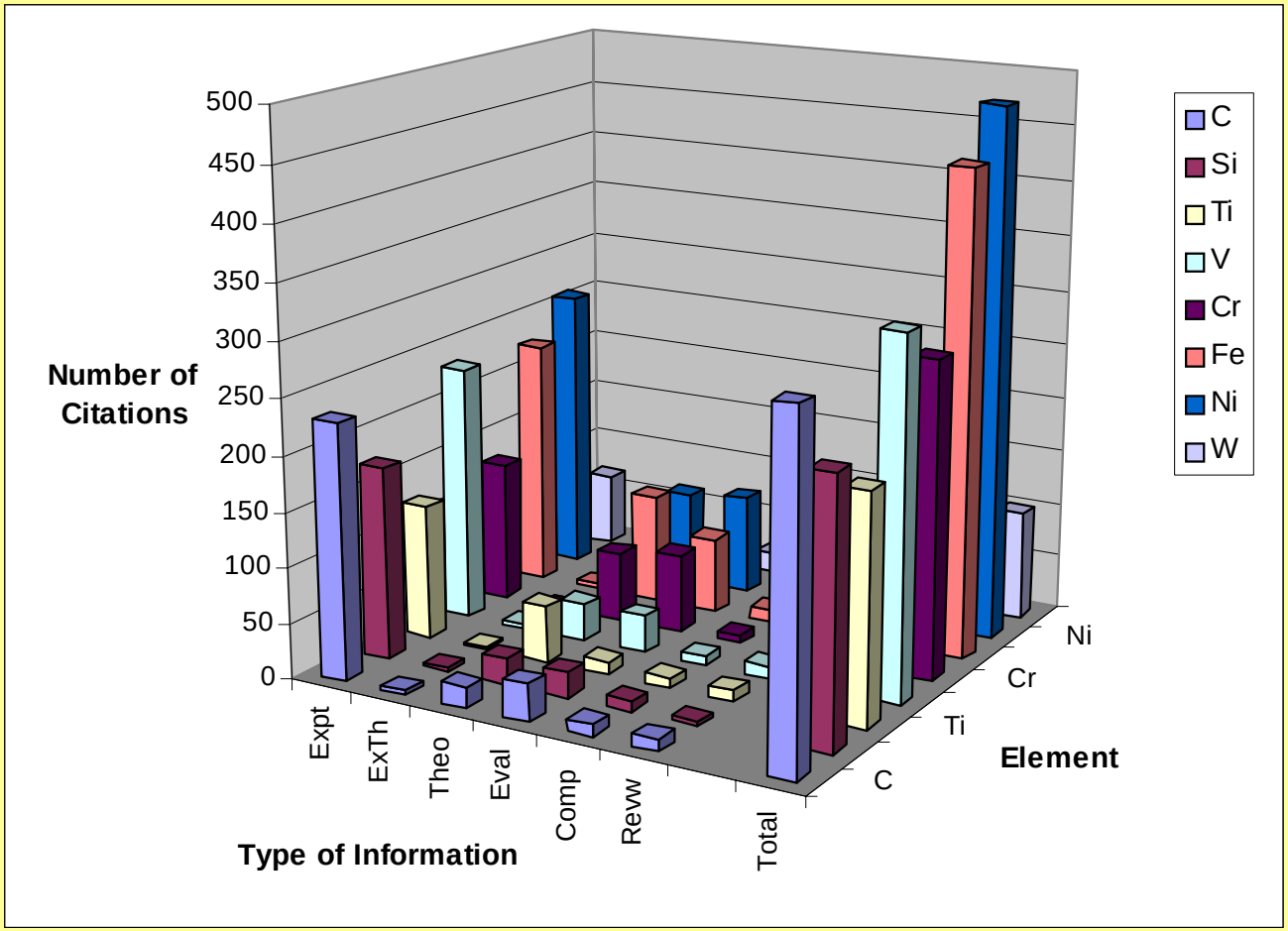




Reaction Pruning Criteria

- Reaction pruning criteria based on physics
- Limit to isotopes with abundance > 1%
- Limit total number of particles in the exit channel and specify how many must be neutrons and how many can be charged particles (see Argonne report for details)
- Categorize reactions according to those with thresholds below 14 MeV and those with thresholds above 14 MeV

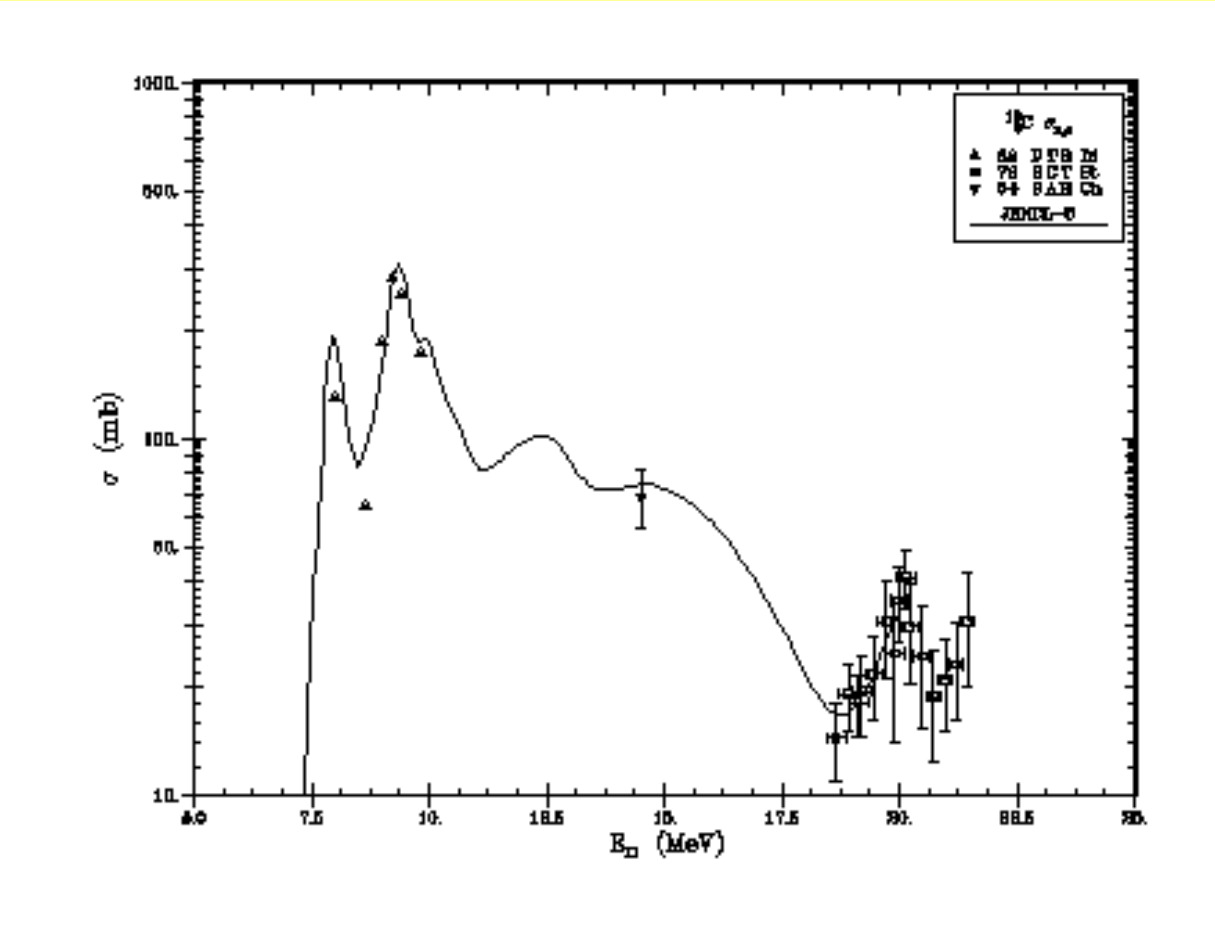
CINDA Citations



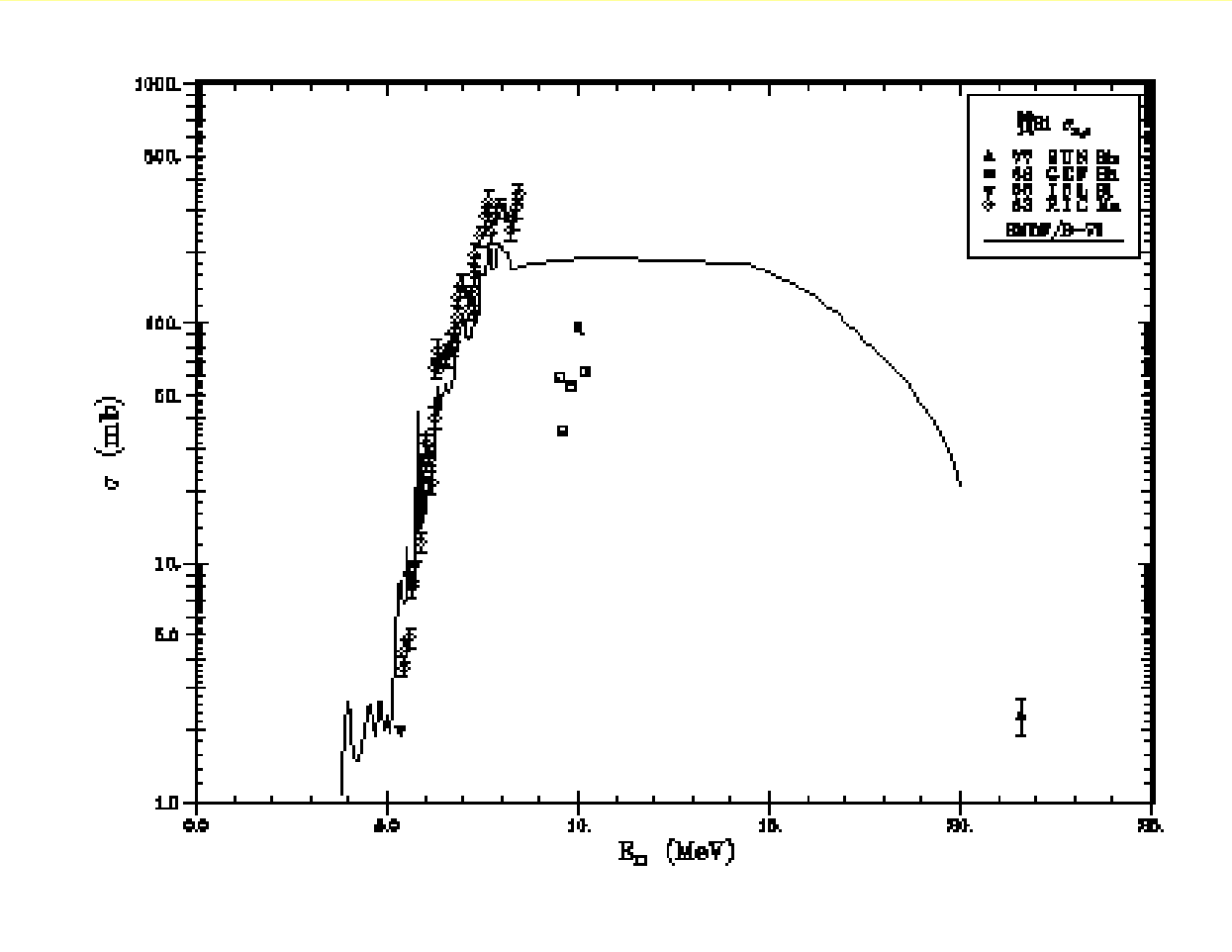
Experimental Data from EXFOR

- Employed an on-line NNDC plotting utility program to generate BNL-325 format data plots
- It was found that the availability of experimental data is very limited when compared to the total number of open helium reaction channels
- Most of the available data correspond to the (n,α) and (n,n+α) reactions … only a few data sets are available for (n,^{3}He) or (n,p+α)
- Most data are limited to energies below 20 MeV
- Clearly, nuclear models must be used to provide estimates of reaction cross sections > 20 MeV

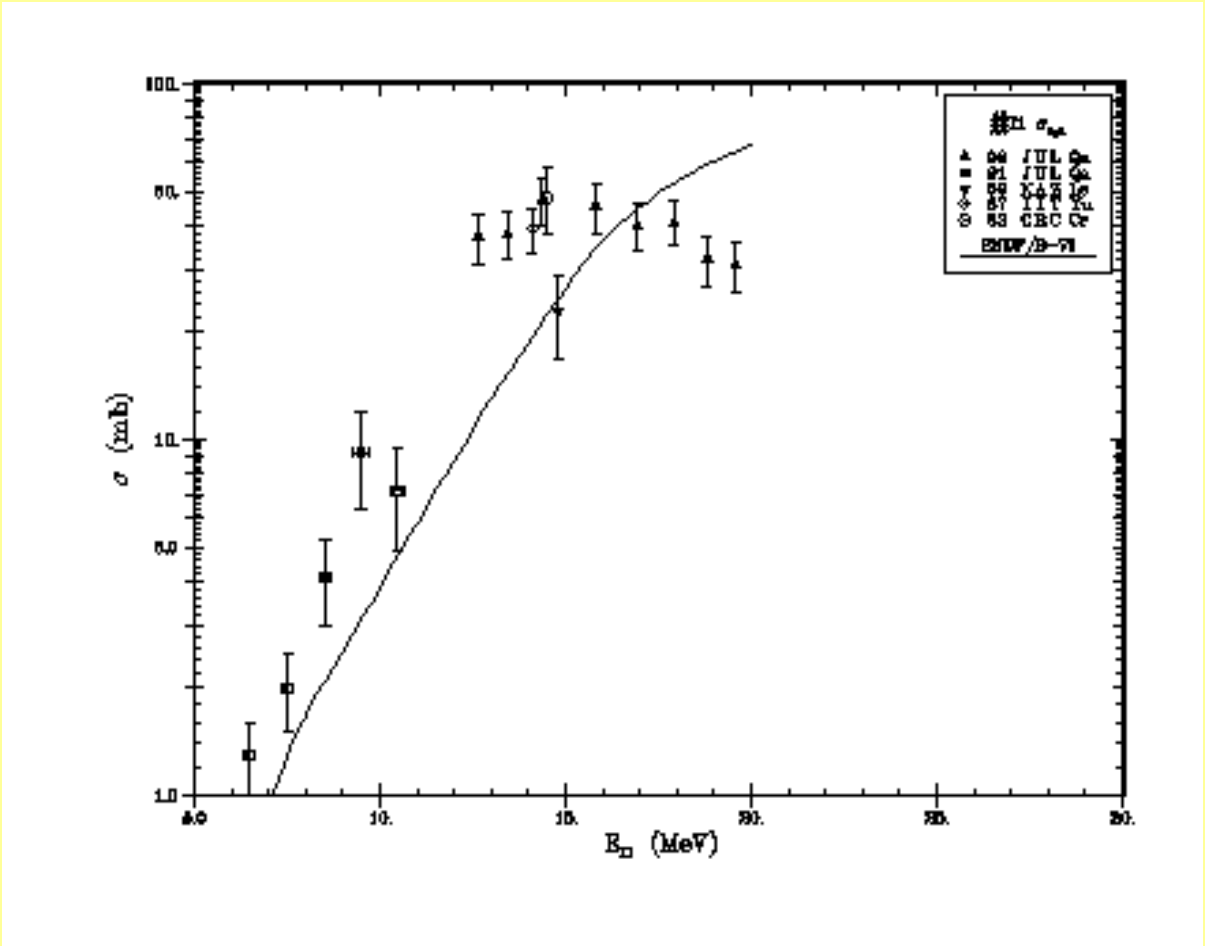
$^{12}C(n,\alpha)$ Reaction



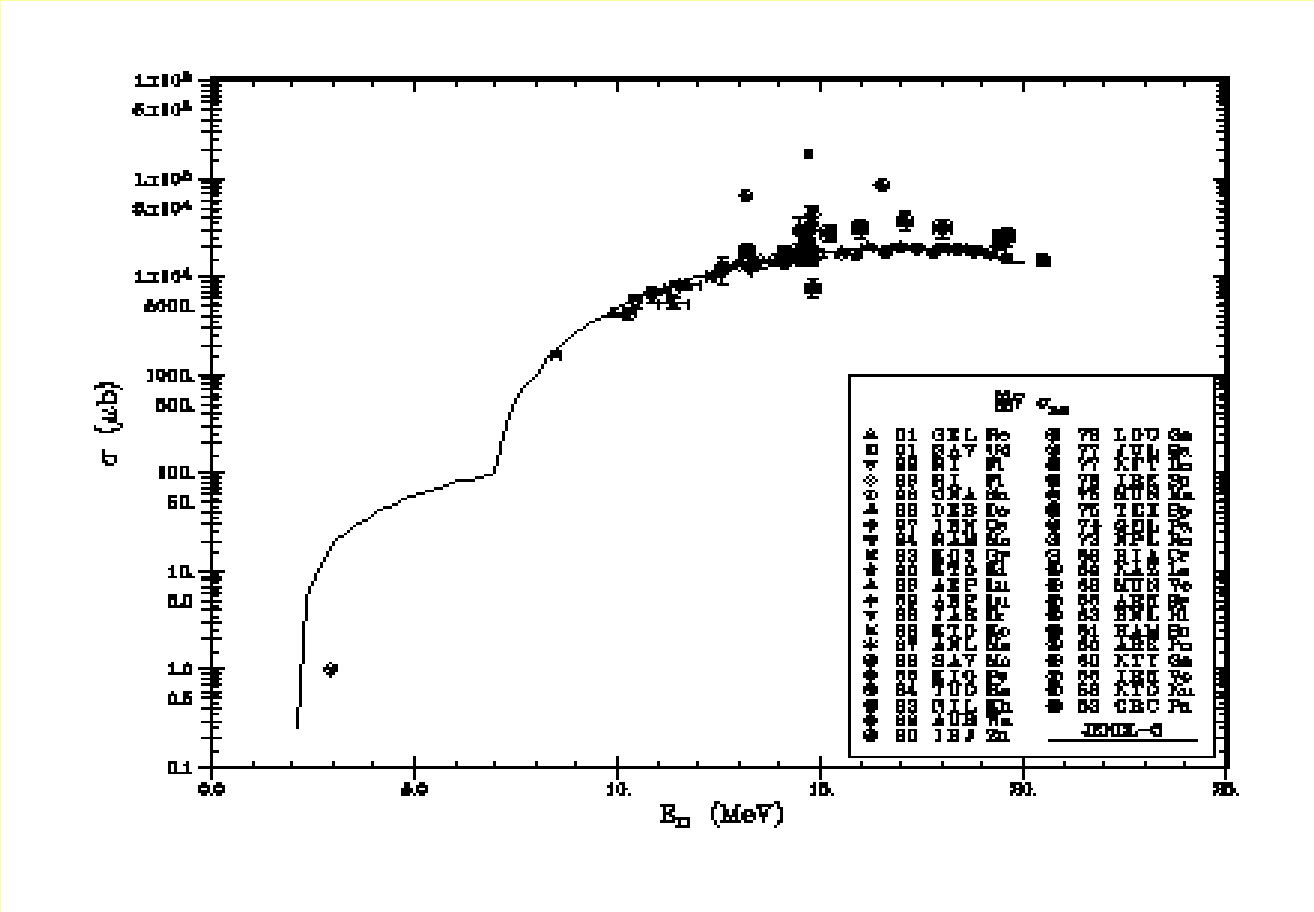
$^{28}Si(n,\alpha)$ Reaction



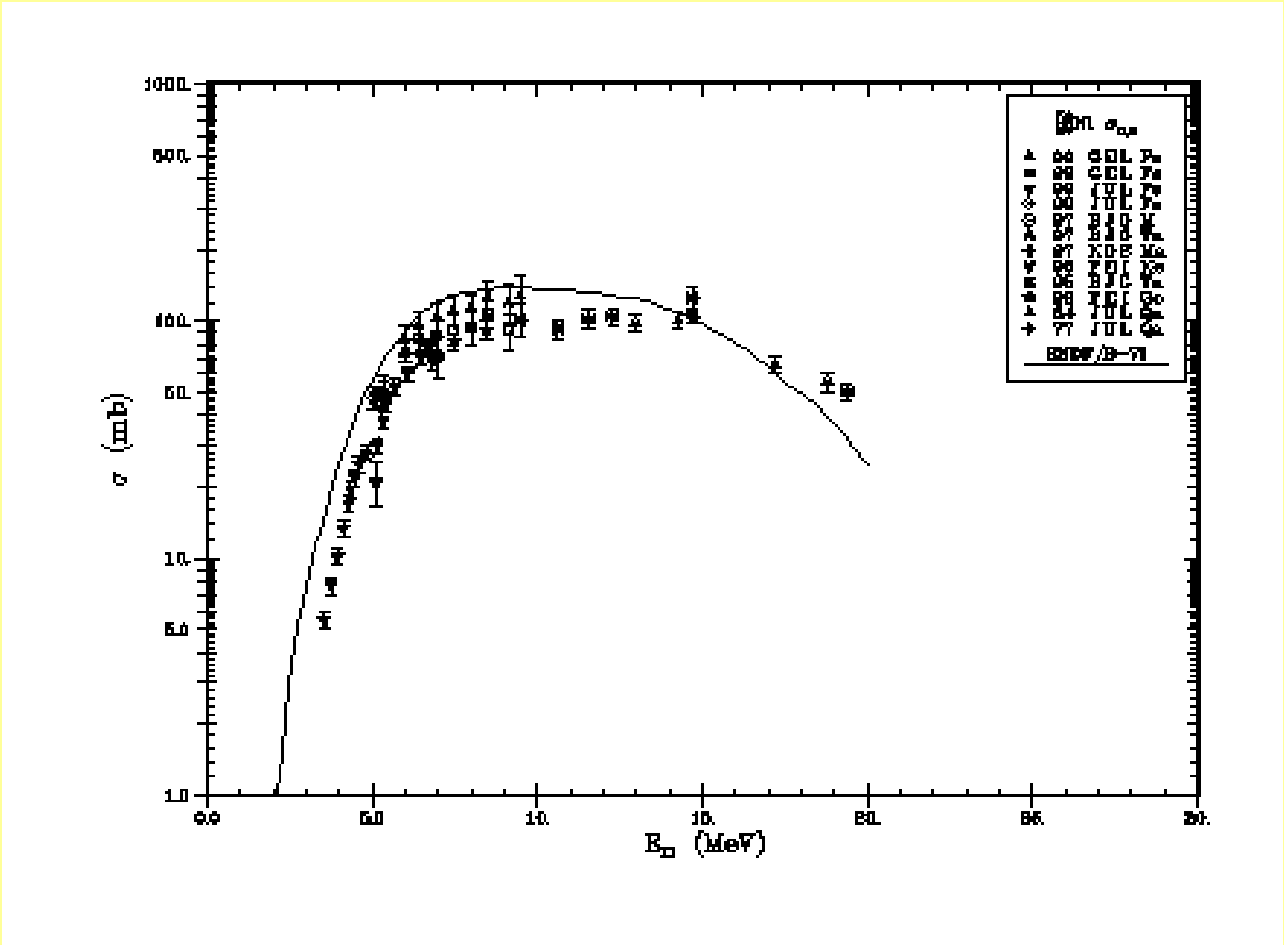
$^{48}Ti(n,\alpha)$ Reaction



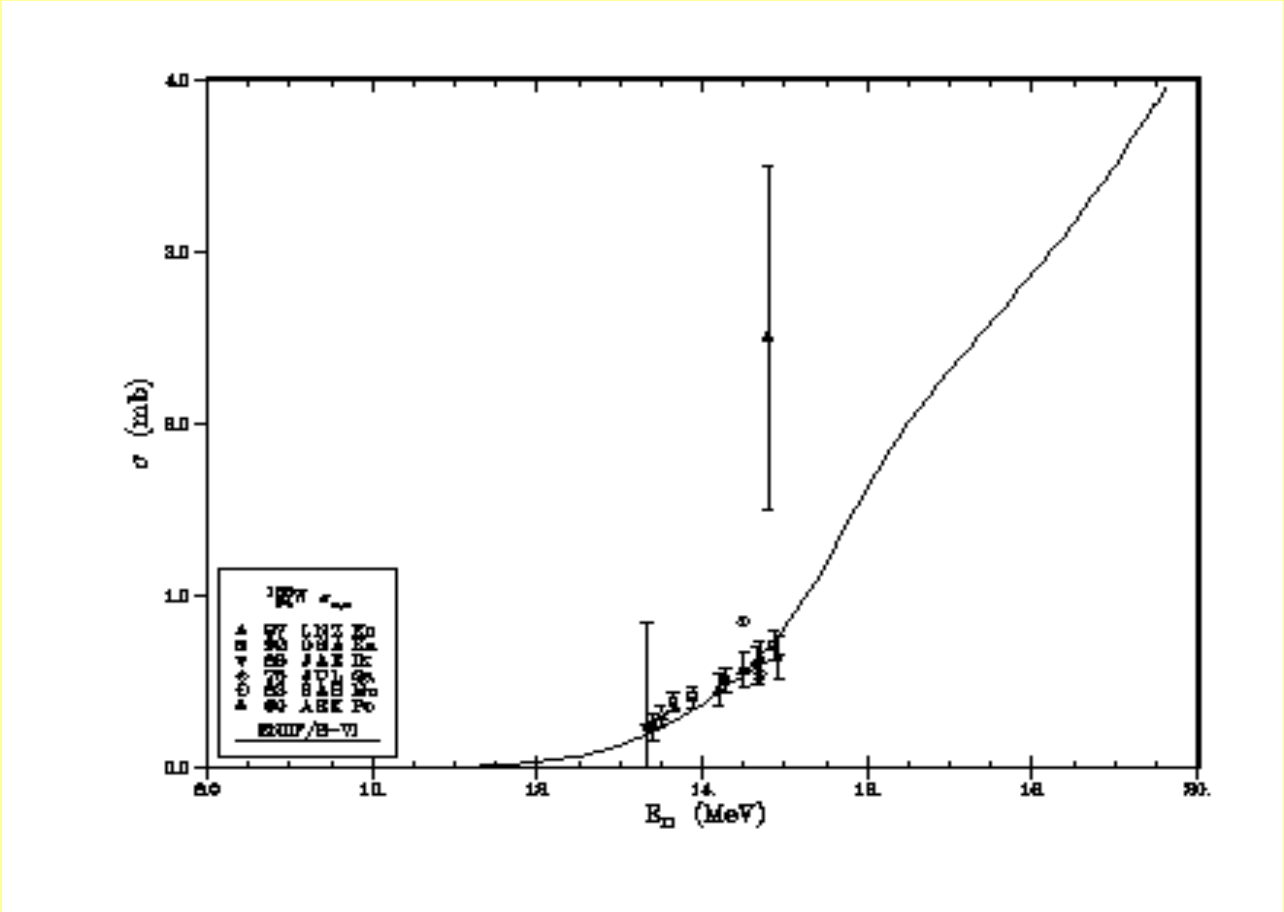
$^{51}V(n,\alpha)$ Reaction



$^{58}Ni(n,\alpha)$ Reaction



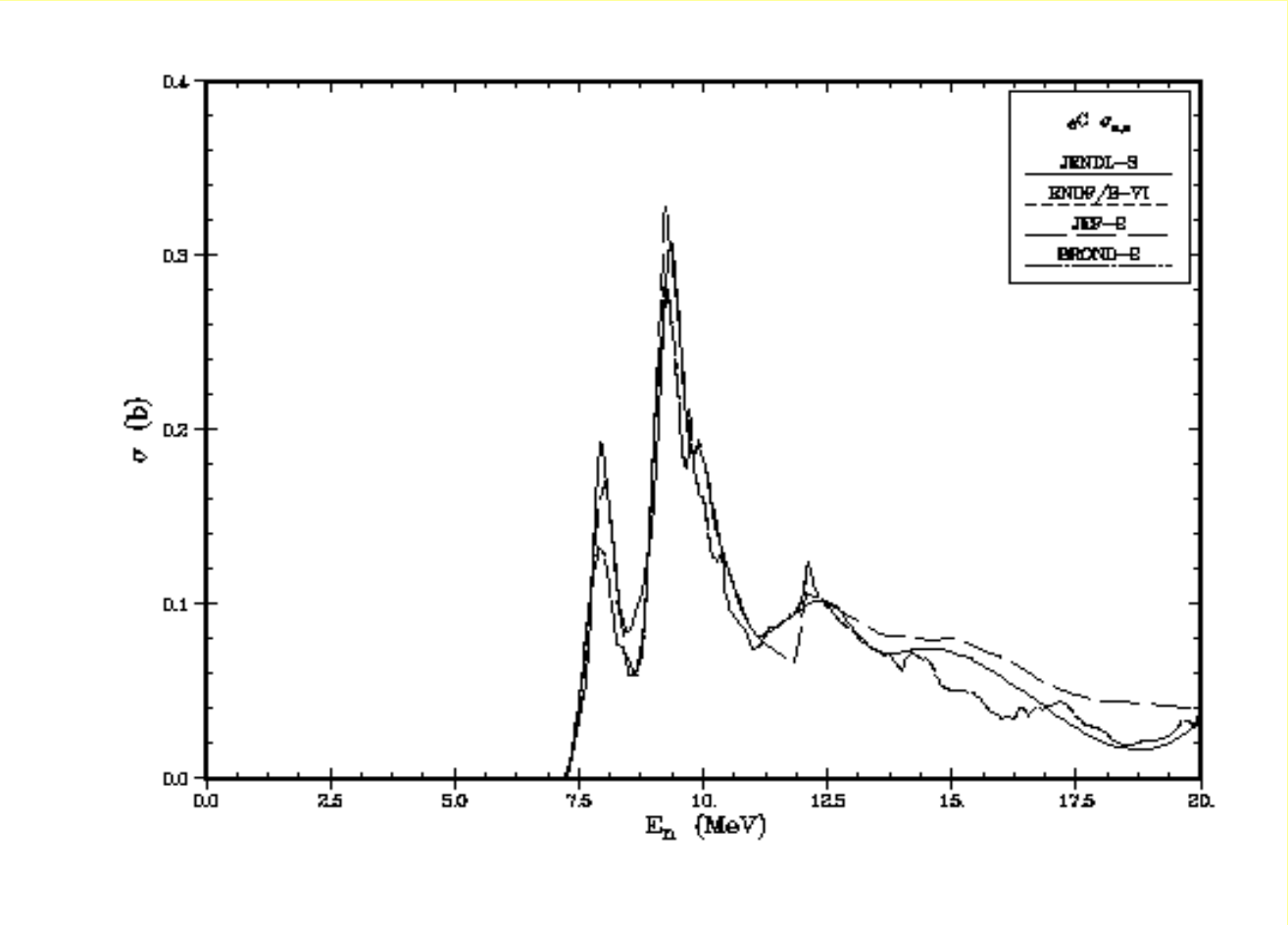
$^{186}W(n,\alpha)$ Reaction



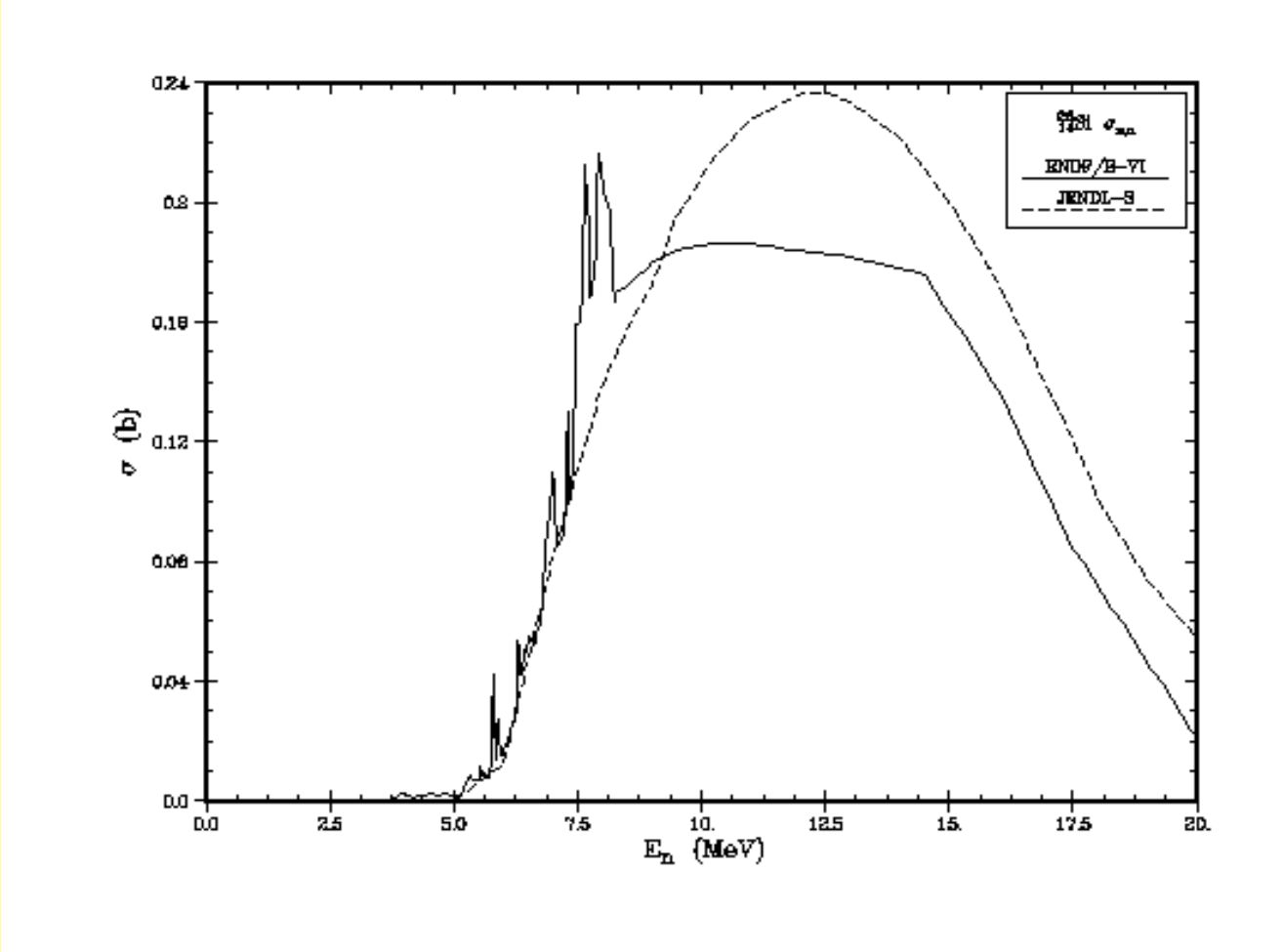
Evaluated Data from GP Files

- Evaluated data from contemporary versions of the ENDF, JENDL, JEF, BROND, and CENDL general purpose libraries were surveyed
- Composite plots were prepared using an on-line plotting utility program available from the NNDC to generate the BNL-325 type data plots
- Most of these GP files were limited to the (n,α), (n,n+α), and (n,^{3}He) reactions … also, these cross section files were not found in all of the considered libraries

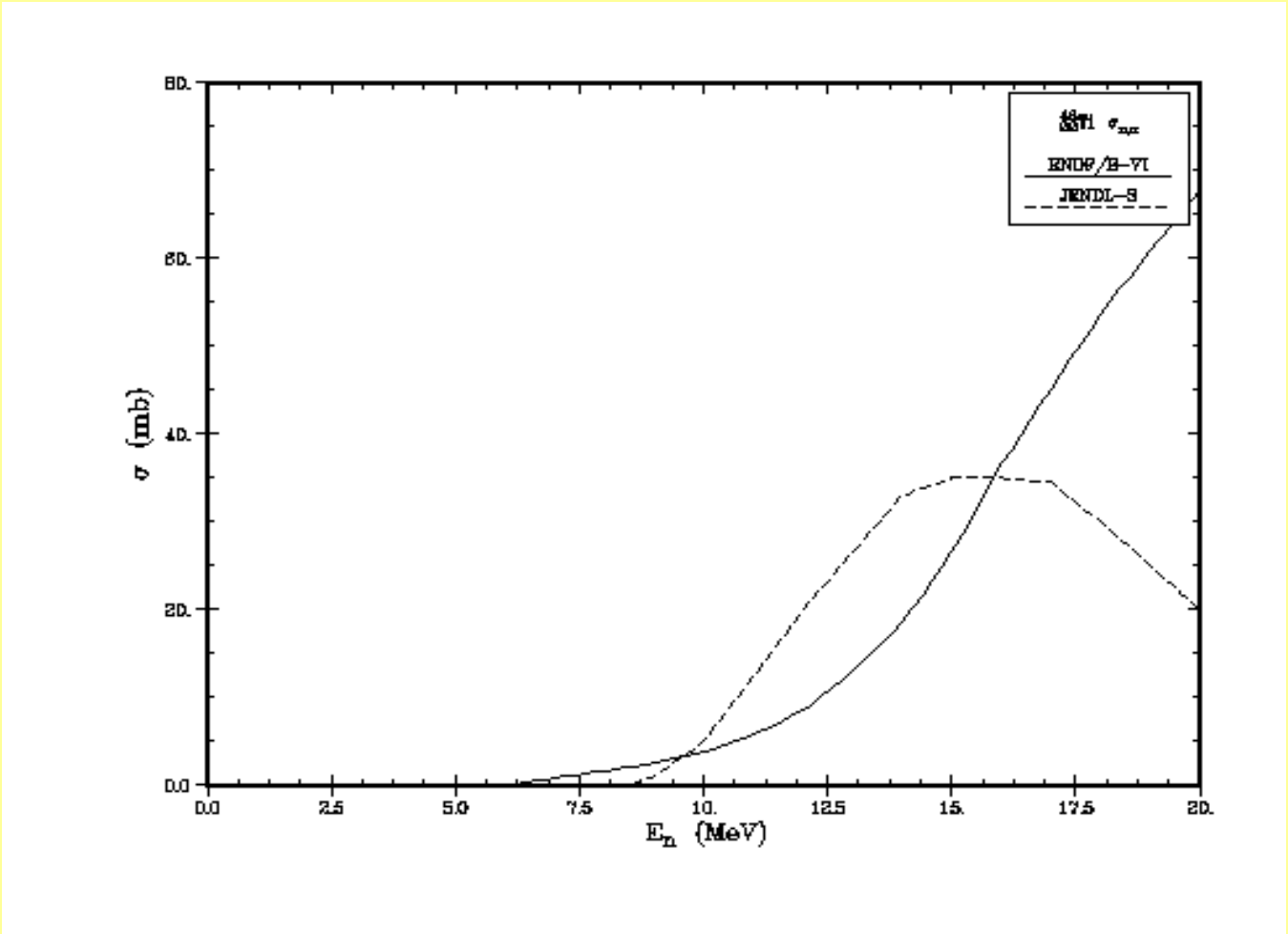
$^{nat}C(n,\alpha)$ Reactions



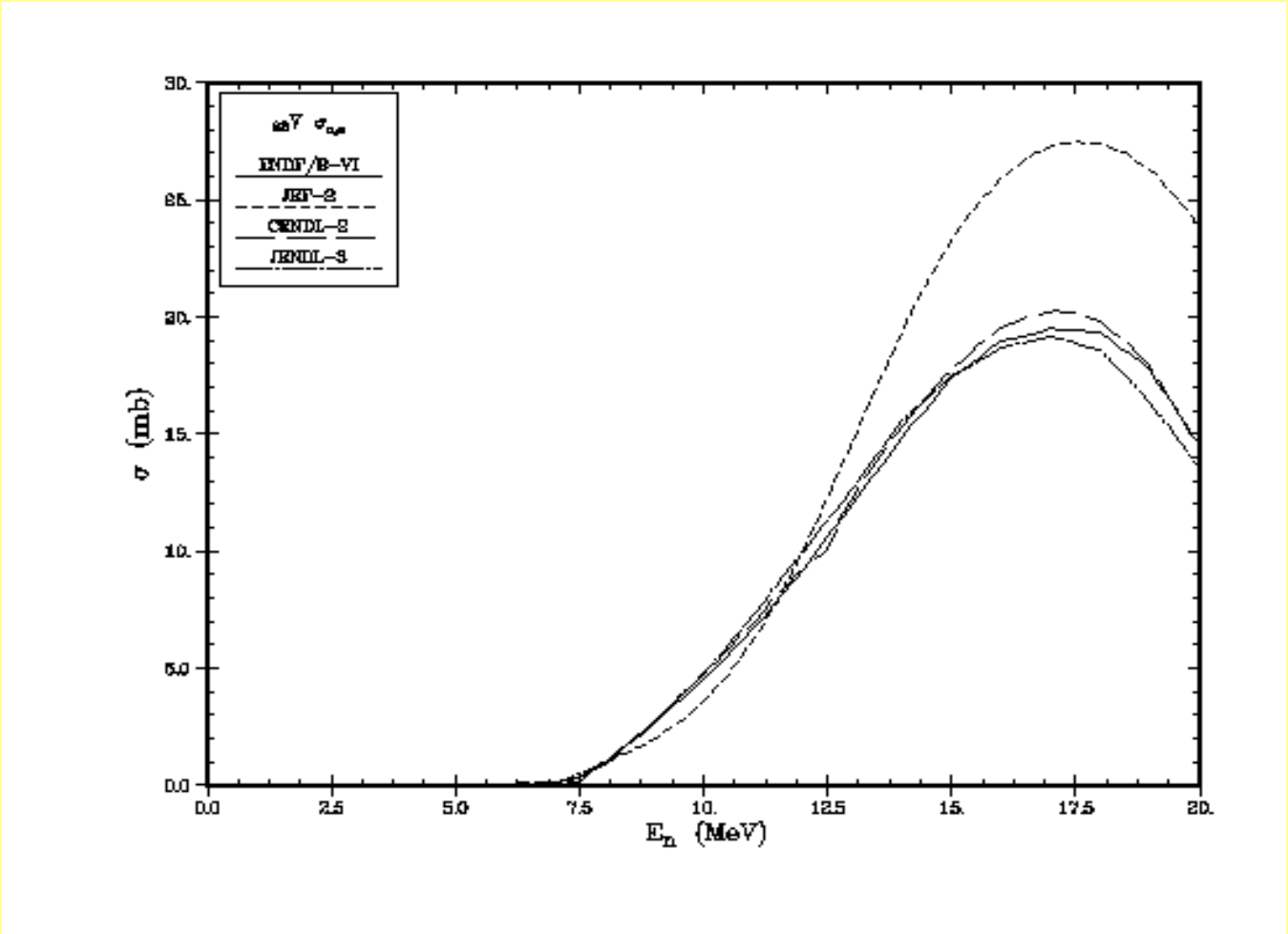
$^{28}Si(n,\alpha)$ Reaction



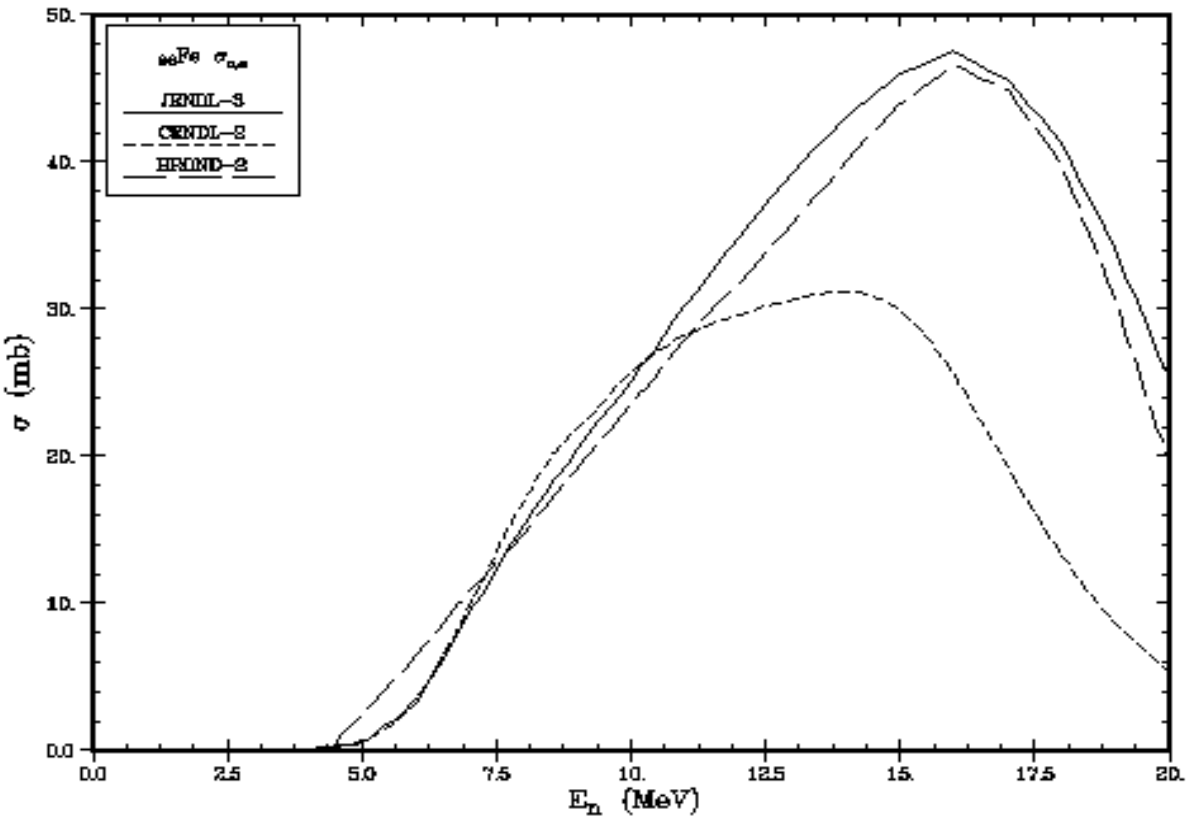
$^{48}Ti(n,\alpha)$ Reaction



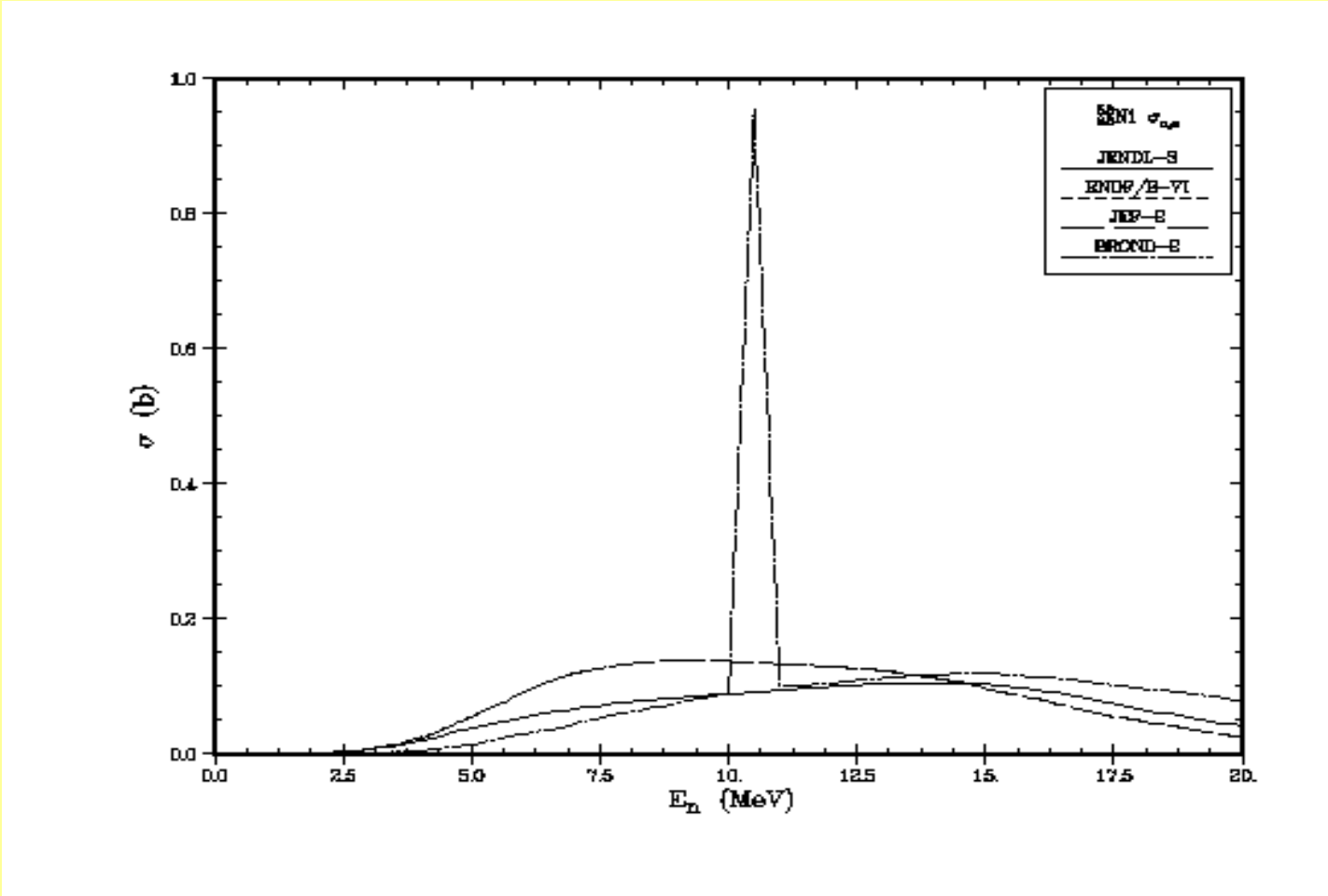
$^{nat}V(n,\alpha)$ Reactions



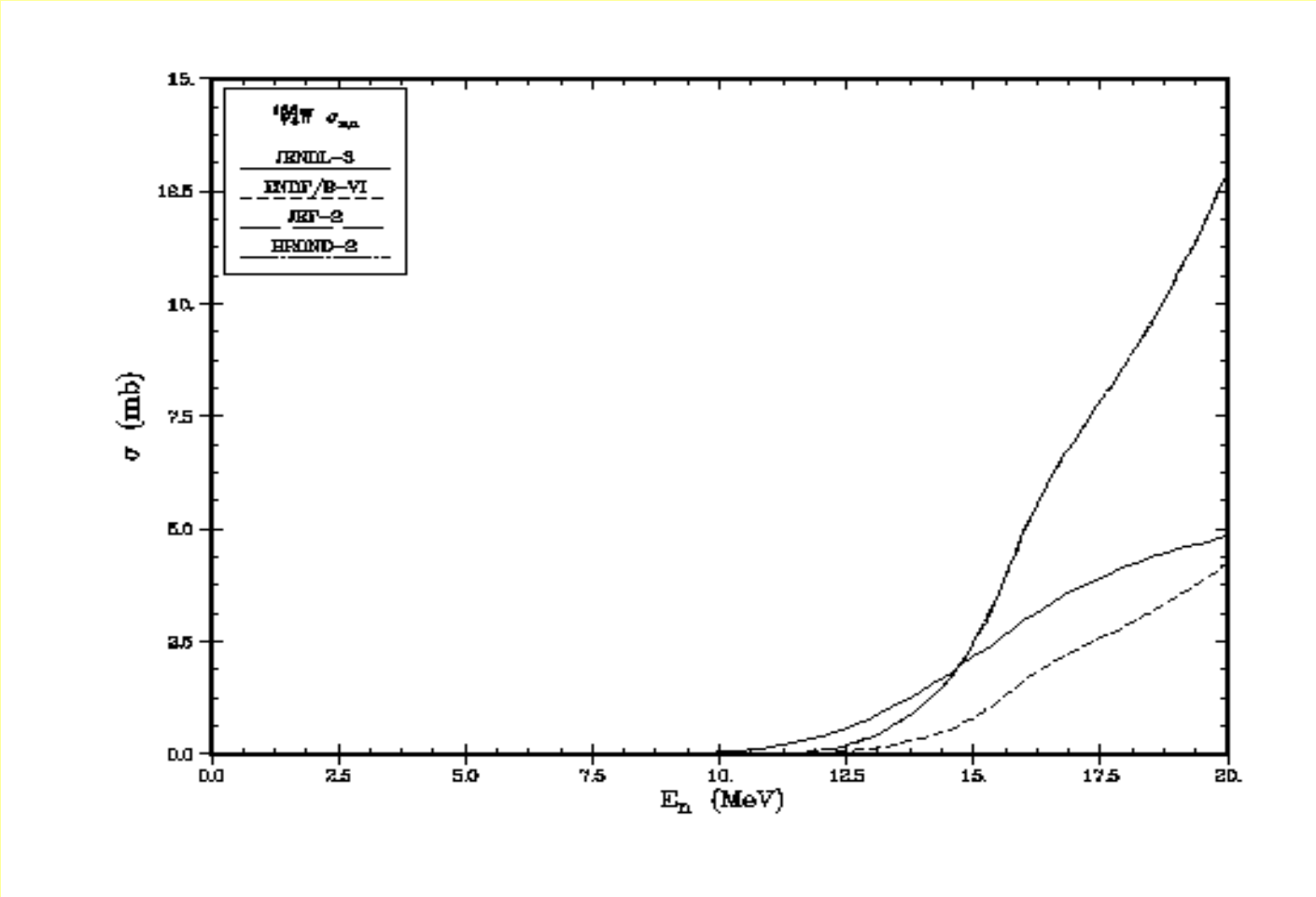
$^{nat}Fe(n,\alpha)$ Reactions



^{58}Ni(n,α) Reaction



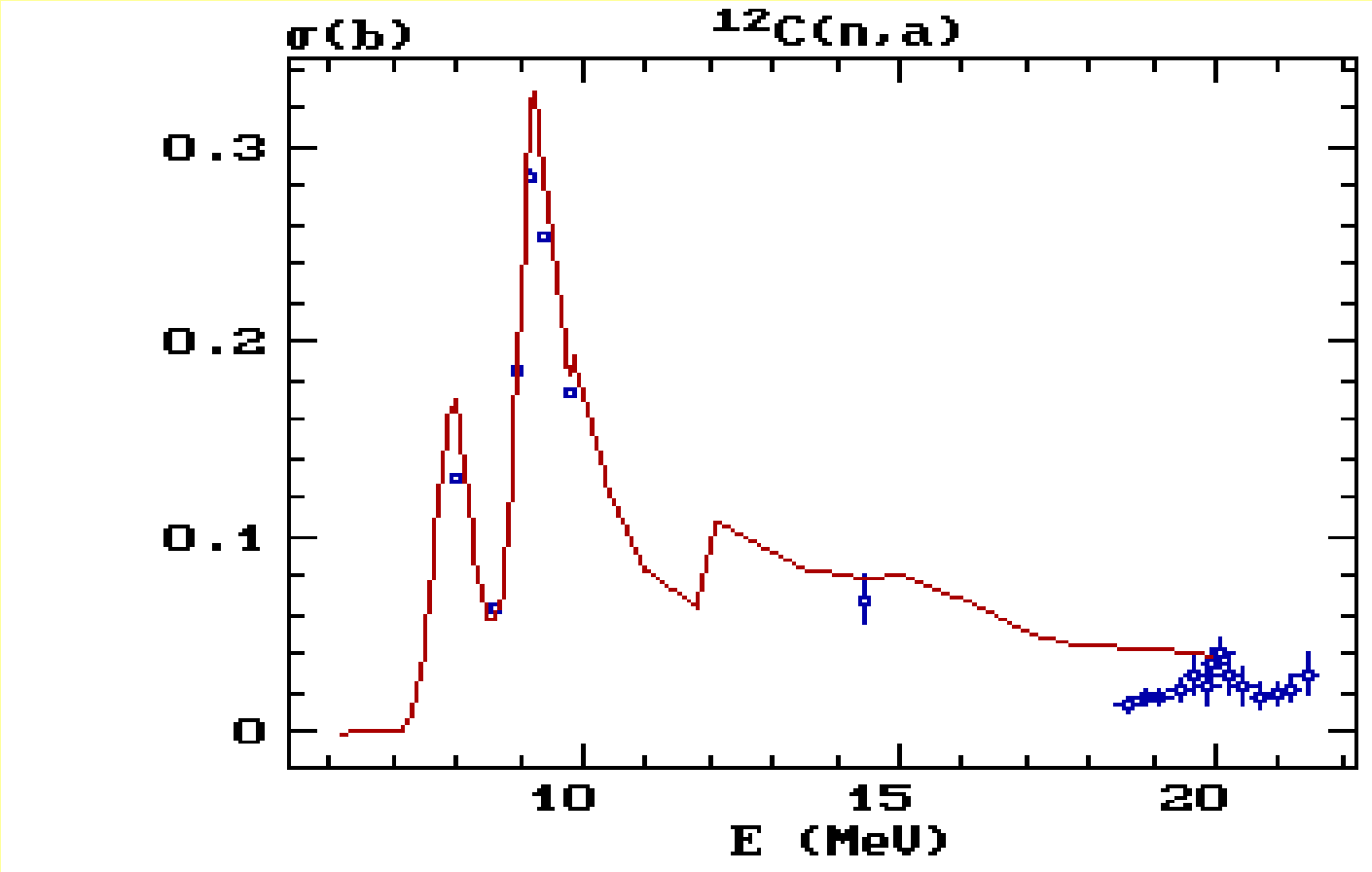
$^{186}W(n,\alpha)$ Reaction



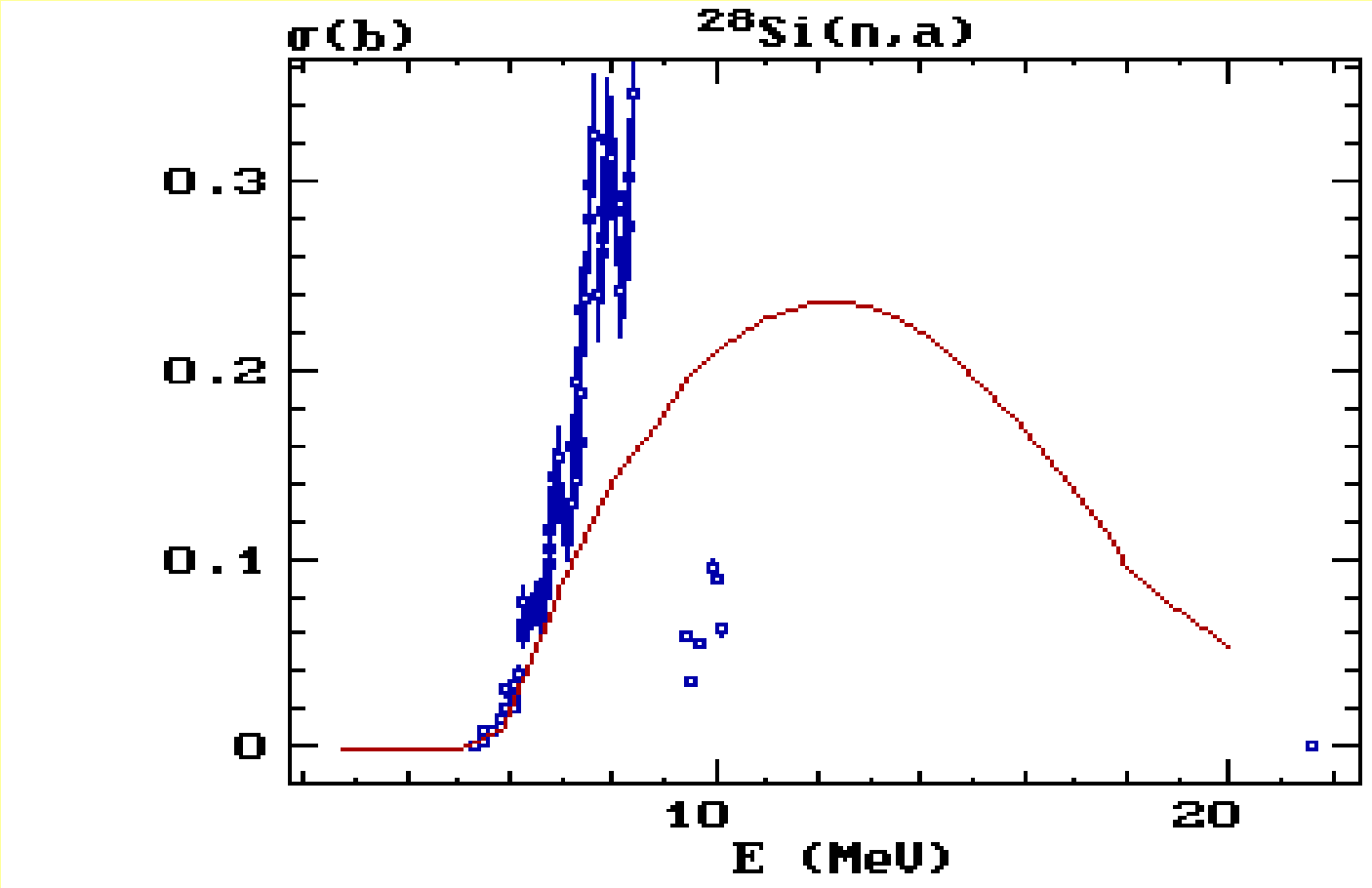
Evaluated Data from FENDL-2

- FENDL-2 is a library of neutron cross sections for use in fusion … it is the basis for ITER design studies and related fusion applications
- FENDL-2 evaluations are drawn from other libraries, with the selection based on what has been deemed “best” in each instance by a panel of experts organized by the IAEA
- Strong reliance on evaluations based on nuclear models is evident in FENDL-2 because of the need to include all the significant channels open to at least 15 MeV and possibly up to 20 MeV

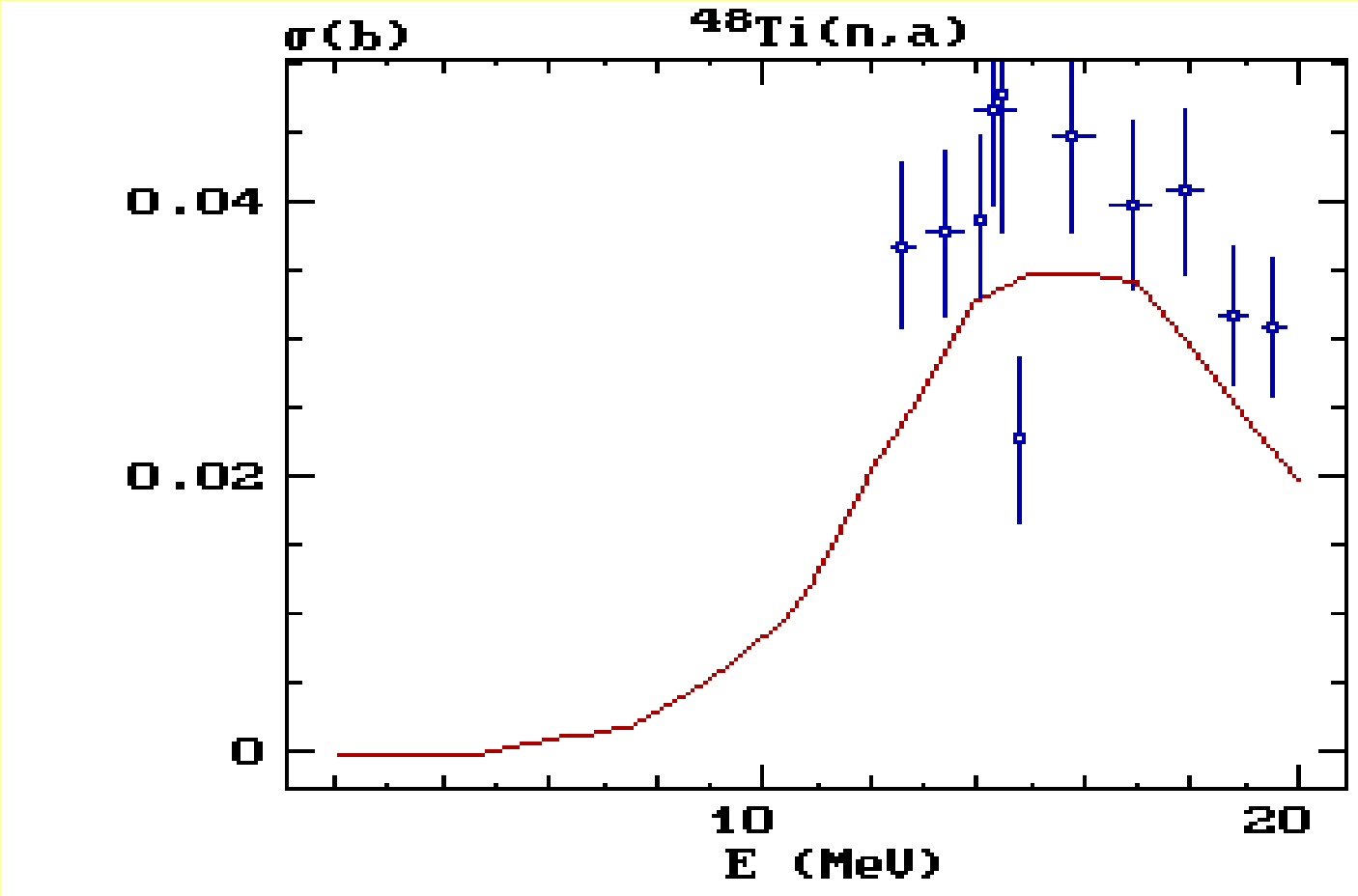
$^{12}C(n,\alpha)$ Reaction



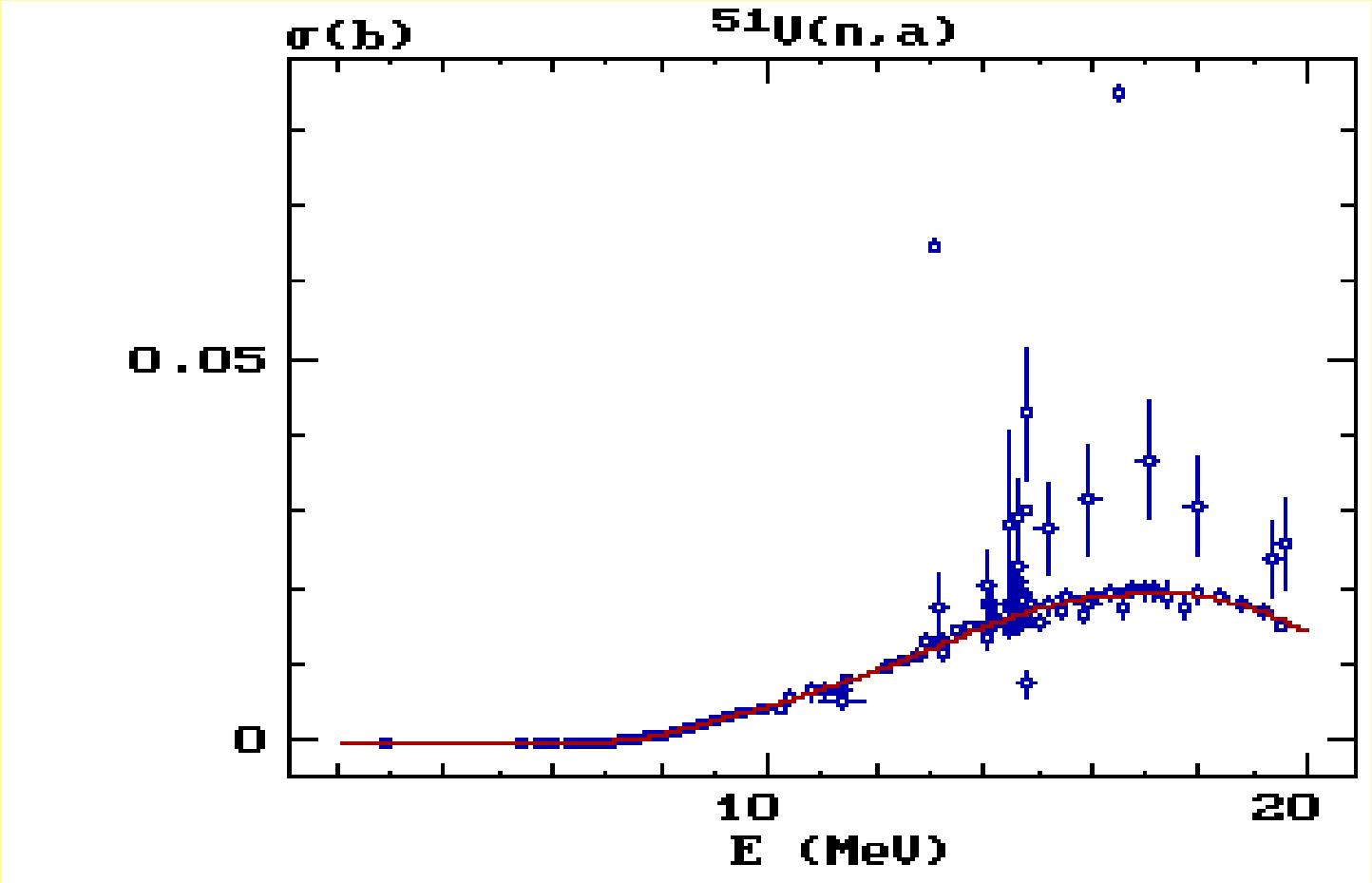
$^{28}Si(n,\alpha)$ Reaction



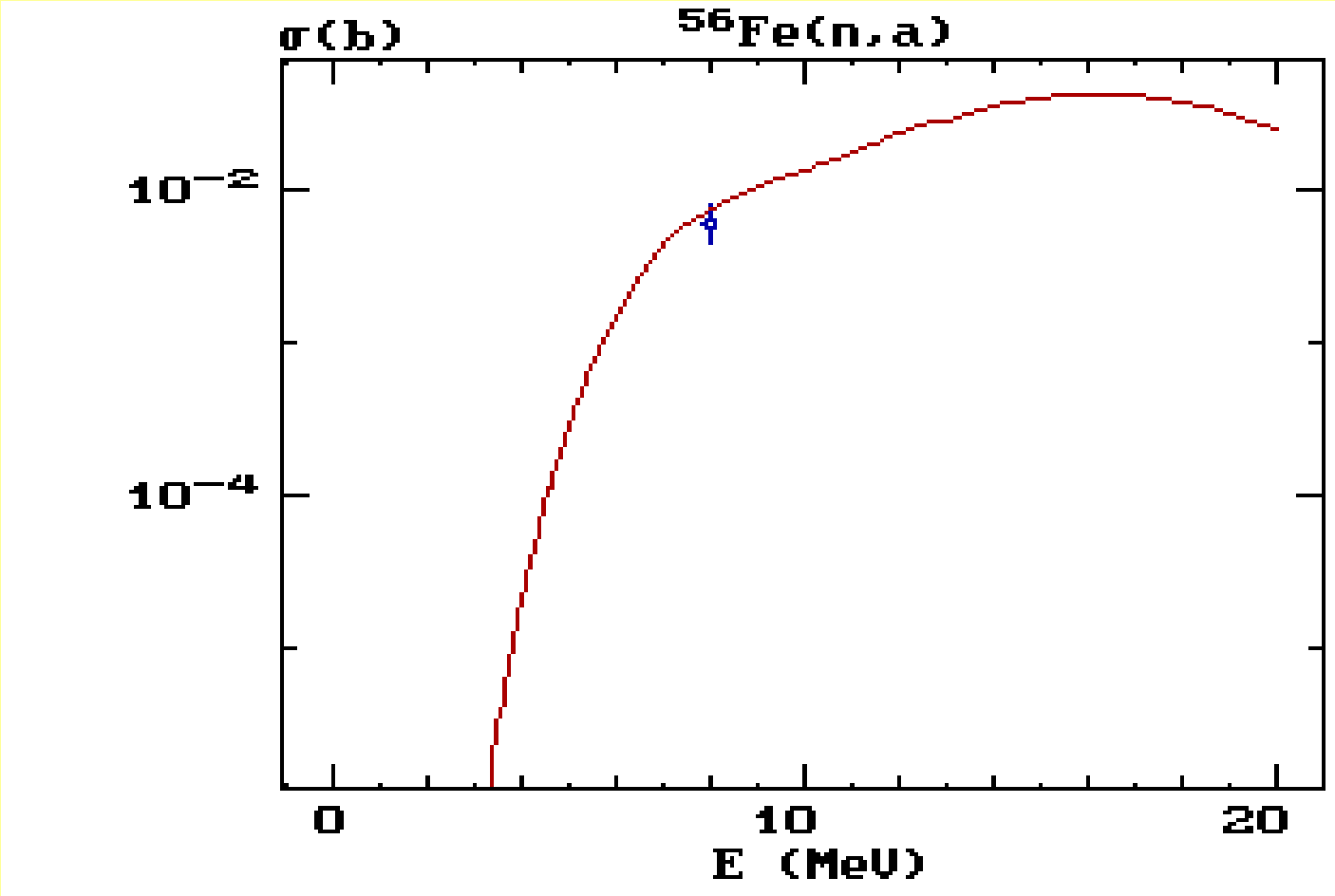
^{48}Ti(n,α) Reaction



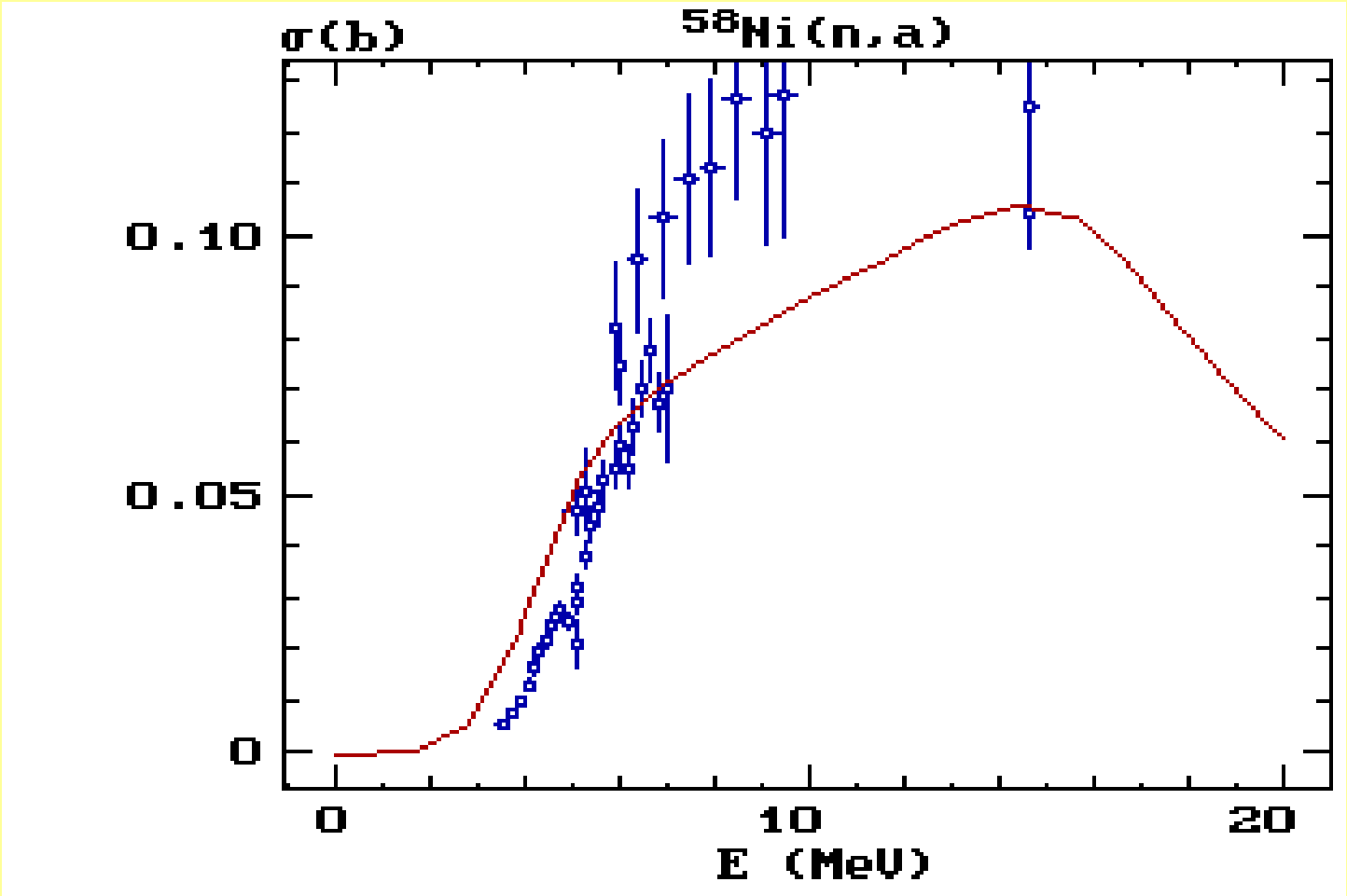
$^{51}V(n,\alpha)$ Reaction



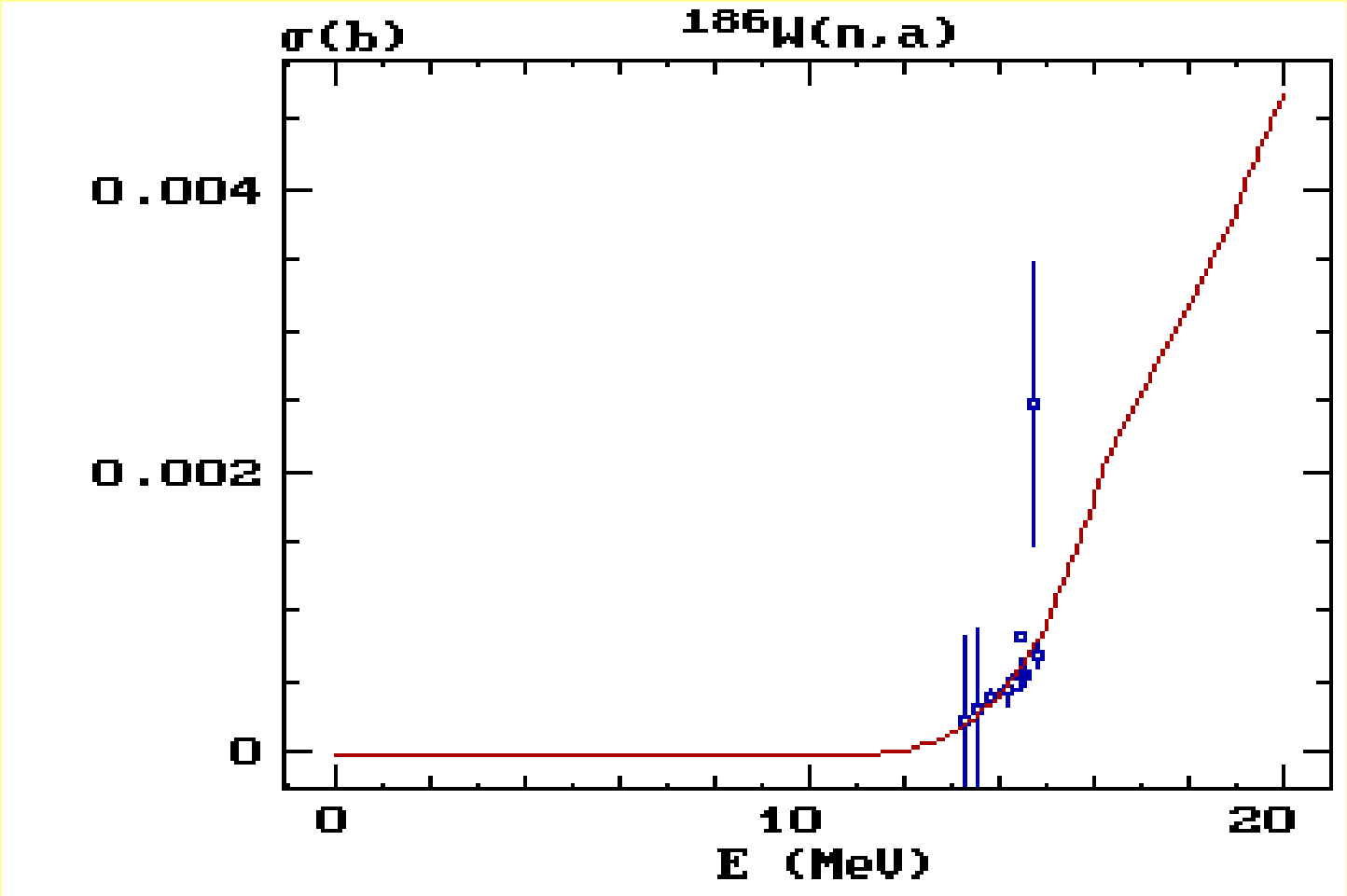
$^{56}Fe(n,\alpha)$ Reaction



^{58}Ni(n,α) Reactions



$^{186}W(n,\alpha)$ Reaction



Conclusions

- The experimental data are generally limited to a few prominent reaction channels and to energies below 20 MeV
- There are wide differences in the evaluated cross sections, especially for those based on models with limited experimental guidance
- The prognosis for measuring cross sections for all the individual reaction channels is poor so strong reliance on nuclear models – guided by experiments where possible - will be required if detailed cross section estimates for all the individual processes is desired

Recommendations

- Systematic model calculations for all the open reaction channels would be worth pursuing to identify qualitatively which reactions are the most significant … but, reliance on these results for design purposes is inadvisable
- Direct measurements by the HAFM method of integrated helium production (including all reaction channels and energies) is suggested for both the d-T and IFMIF spectra … note that some data for 14 MeV already exist from similar studies that have been reported earlier

Documentation

- The results of this study have been published as an Argonne National Laboratory Report:

  ANL/NDM-158

- This report can be downloaded from the Internet as a PDF file from the following URL:

  http://www.td.anl.gov/reports/index.html