National Institute of Standards and Technology

Nuclear Data Verification and Standardization Program

PROGRESS REPORT

USNDP Meeting
Brookhaven National Laboratory
November 9, 2006

Nuclear Structure Activities:

- None are supported by DOE funding.
- A modest effort (1 FTE) in structure and decay studies is supported by NIST funds.

Nuclear Reaction Activities: **Neutron cross section standards evaluation**

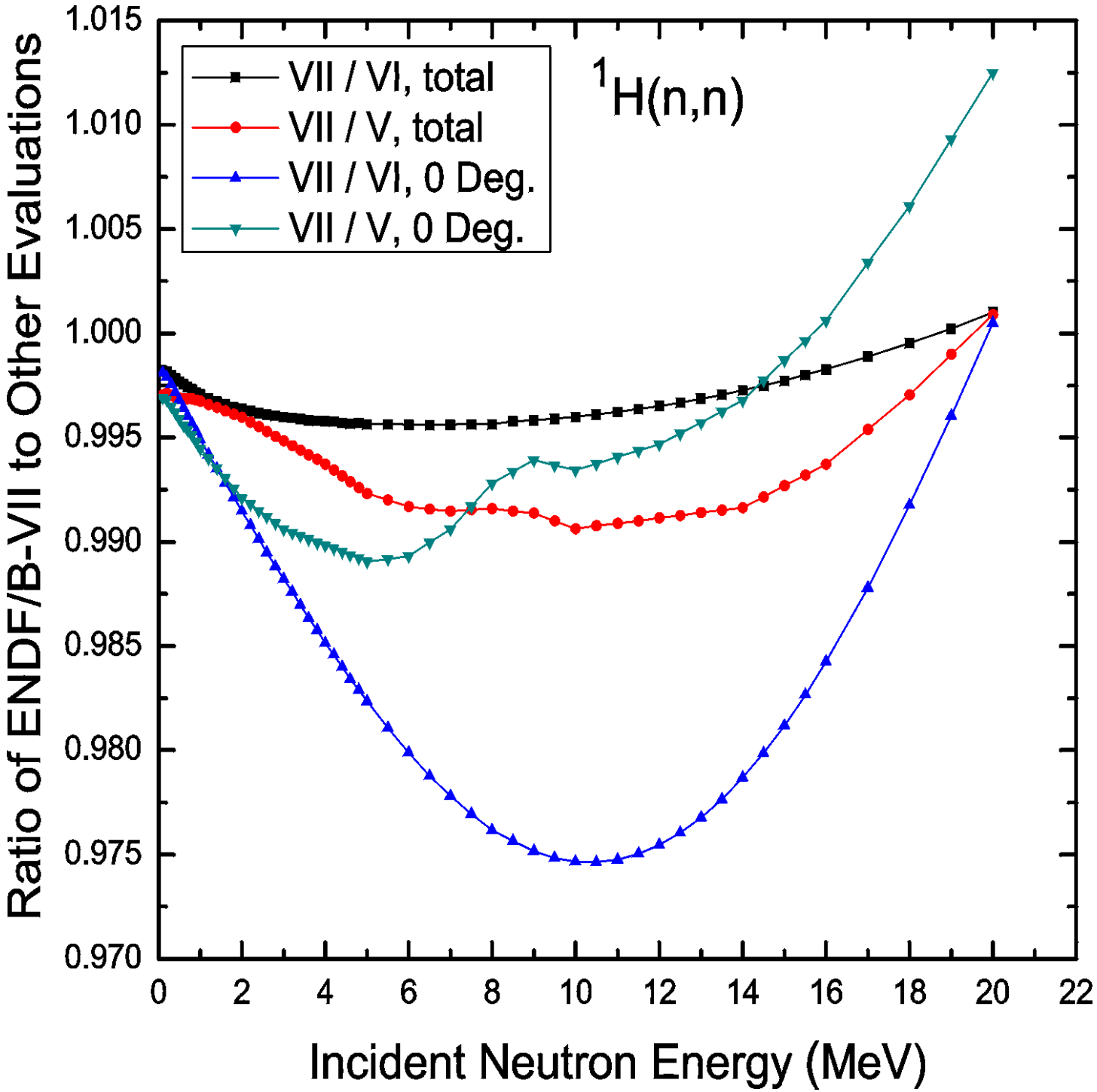
- Successfully coordinated an IAEA/WPEC/CSEWG combined effort leading to the completion of an international evaluation of the neutron cross section standards.
  - The standards are the basis for the neutron reaction cross section libraries.
    - These standards are being used as the standards for the ENDF/B-VII sub-library

THE NEUTRON CROSS SECTION STANDARDS

Reaction	Energy Range
H(n,n)	1 keV to 20 MeV
^{3}He(n,p)	thermal to 50 keV
^{6}Li(n,t)	thermal to 1 MeV
^{10}B(n,α)	thermal to 1 MeV
^{10}B(n,$\alpha_1\gamma$)	thermal to 1 MeV
C(n,n)	thermal to 1.8 MeV
^{197}Au(n,γ)	thermal, 0.2 to 2.5 MeV
^{235}U(n,f)	thermal, 0.15 to 200 MeV
^{238}U(n,f)	2 to 200 MeV

Standard Cross Section Results

- H(n,n)
  - Changes to the capture cross section of the first ENDF/B-VII hydrogen R-matrix evaluation were suggested to improve the calculation of thermal criticals. The re-evaluation led to small changes (as large as 0.1% to 0.2%) in the standard. The R-matrix evaluation in ENDF/B-VII is a complete neutron reaction evaluation.
  - The energy range of the standard is 1 keV to 20 MeV.
  - The extension to 200 MeV was not completed.
  - New measurements and analyses are underway which should improve this cross section

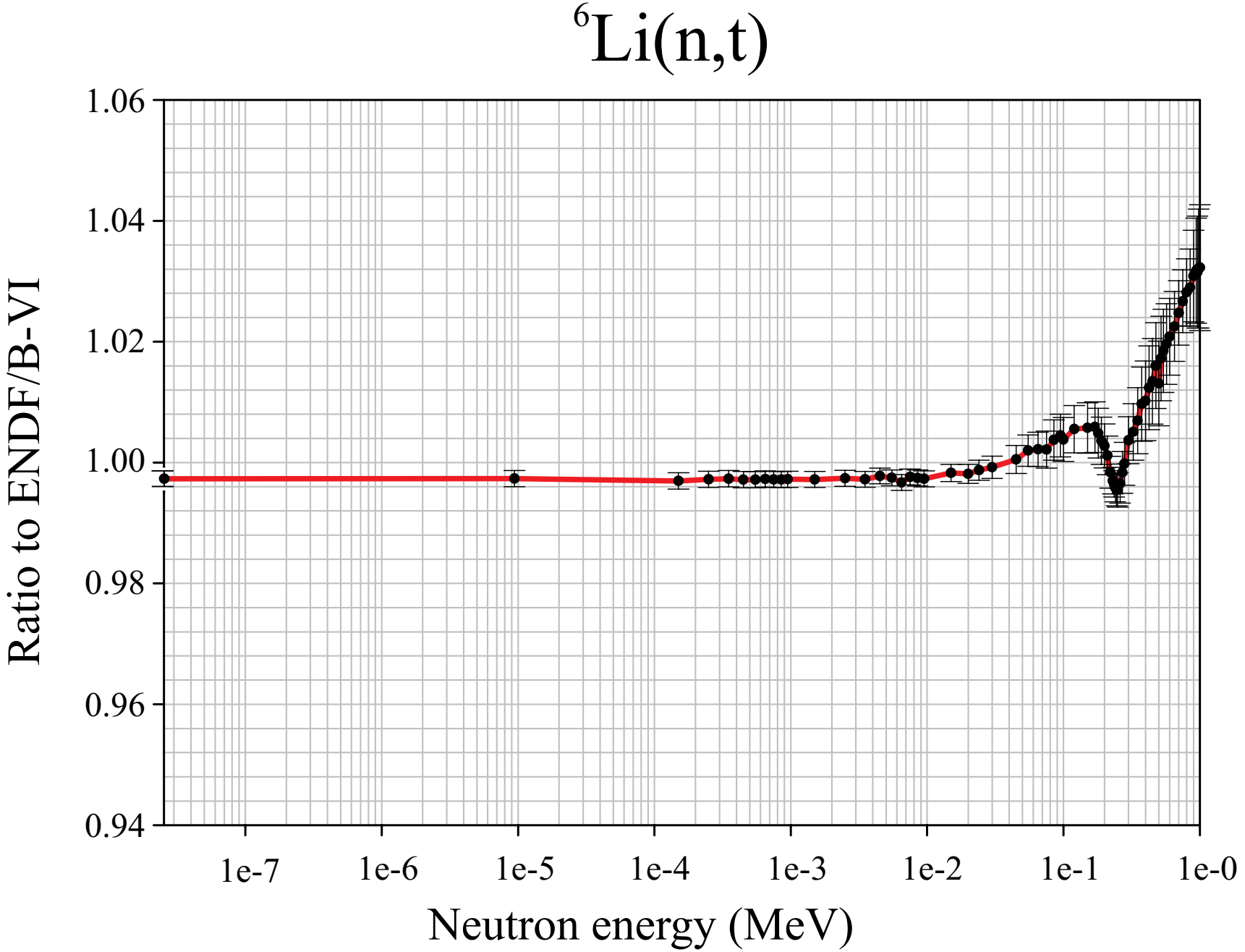

VII / VI, total
VII / V, total
VII / VI, 0 Deg.
VII / V, 0 Deg.
^{1}H(n,n)
Ratio of ENDF/B-VII to Other Evaluations
Incident Neutron Energy (MeV)
1.015
1.010
1.005
1.000
0.995
0.990
0.985
0.980
0.975
0.970
0
2
4
6
8
10
12
14
16
18
20
22

Standard Cross Section Results (cont.)

- ^{3}He(n,p)
  - An evaluation of this cross section was not completed. The evaluation was carried over from ENDF/B-VI.
  - The energy range of the standard is thermal to 50 keV.
  - This standard is not actively used in measurements at the present time. It is used for conversion of previous measurements made relative to this standard.
  - This is the only ENDF standard that is not included in the INDC/NEANDC Nuclear Standards File.
  - Measurements of the total cross section and coherent scattering length have been made recently, which can be used to improve the quality of the standard through R-matrix analyses.

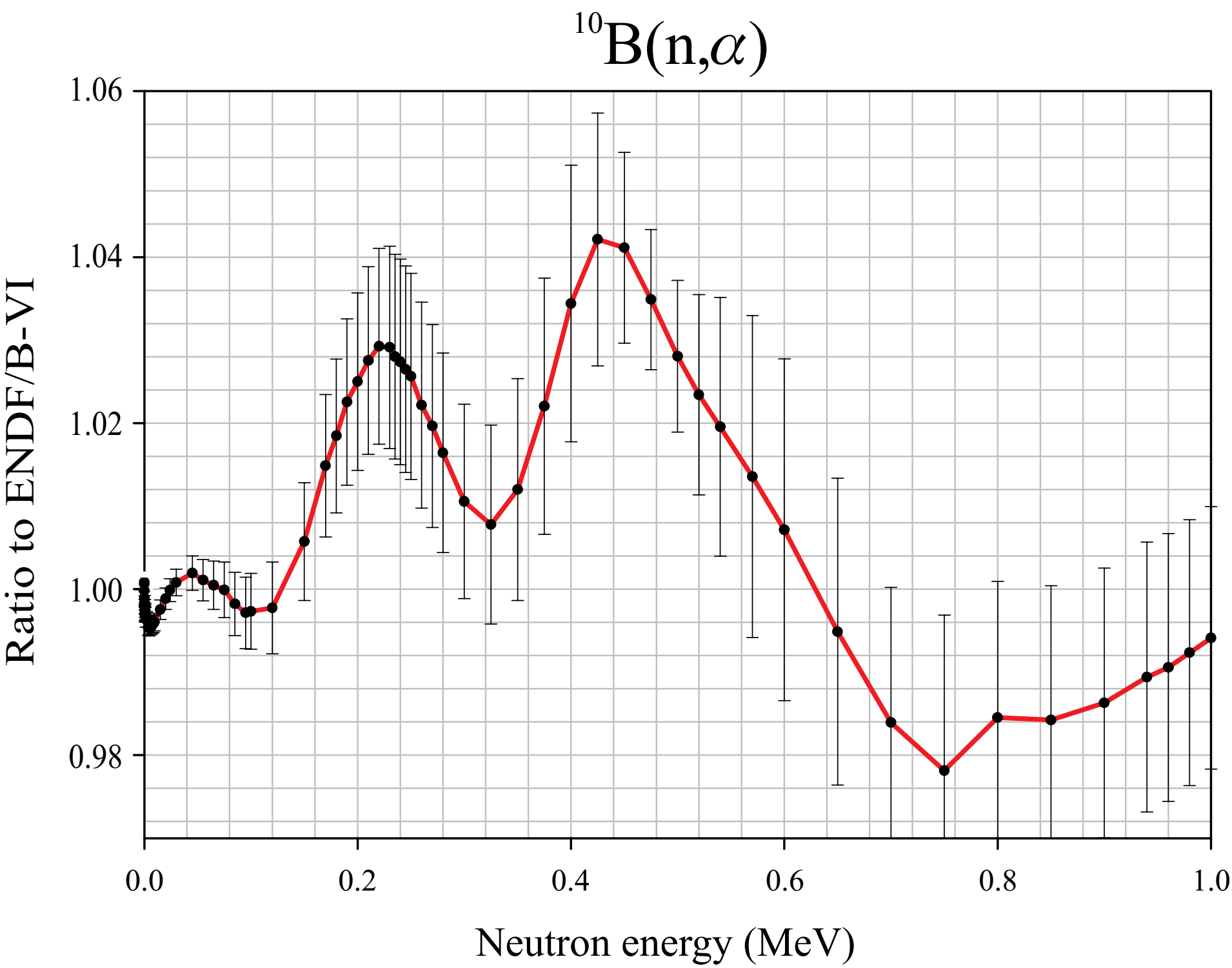
Standard Cross Section Results (cont.)

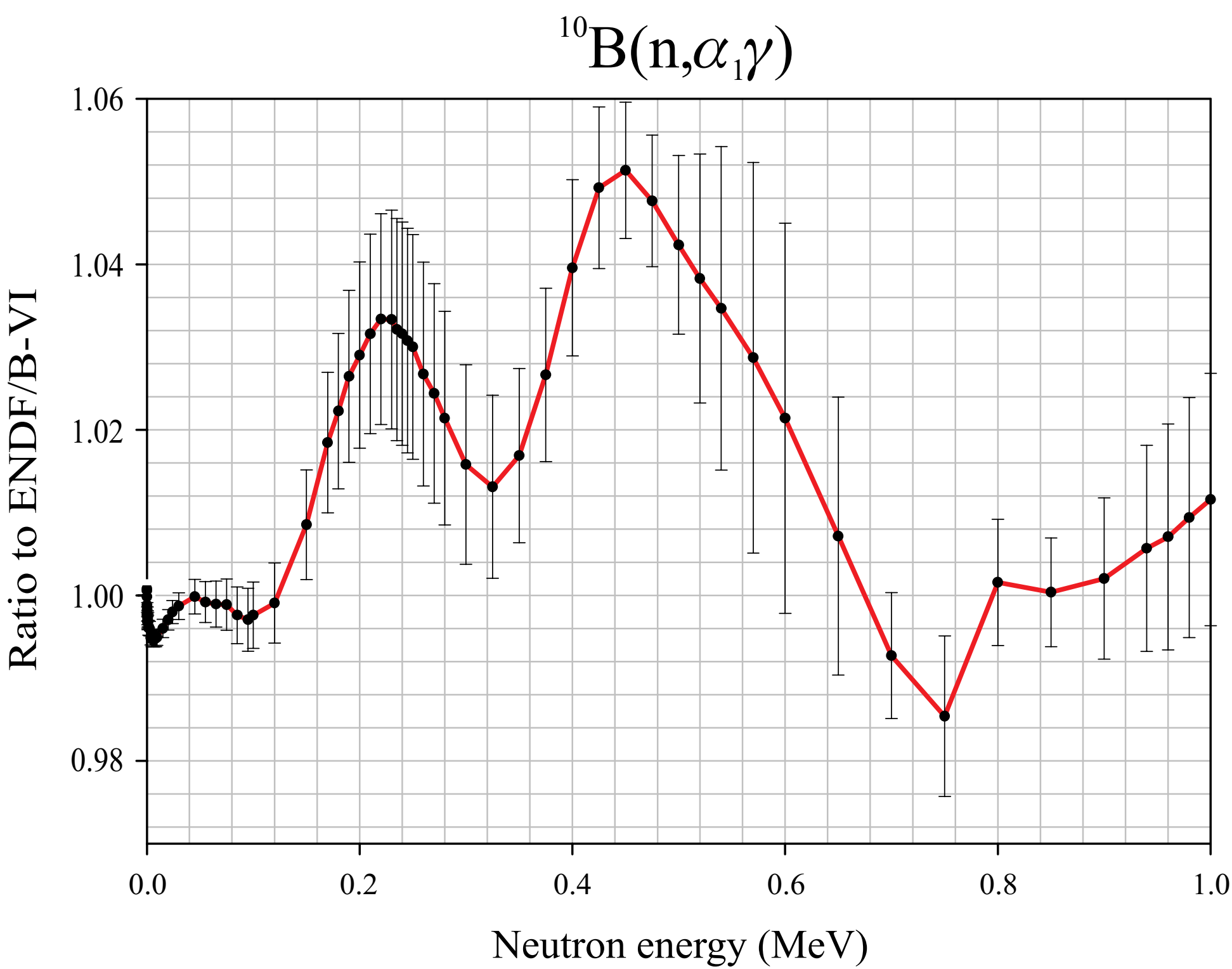
- ^{6}Li(n,t)
  - The energy range of the standard is thermal to 1 MeV.
  - Users are cautioned about using this as a standard near the resonance at ~240 KeV due to the rapid change of the cross section with energy.
  - The standard cross section was completely adopted into the neutron reaction sublibrary.
  - New measurements are underway of this standard.


^{6}Li(n,t)
Ratio to ENDF/B-VI
1.06
1.04
1.02
1.00
0.98
0.96
0.94
1e-7
1e-6
1e-5
1e-4
1e-3
1e-2
1e-1
1e-0
Neutron energy (MeV)

Standard Cross Section Results (cont.)

- $^{10}B(n,\alpha)$ and $^{10}B(n,\alpha_1\gamma)$
  - The energy range of the standards is thermal to 1 MeV.
  - These standard cross sections were completely adopted into the neutron reaction sublibrary.
  - The uncertainties are larger at the highest energies partially due to differences in R-matrix analyses used in obtaining the final evaluated results.
  - Measurements are underway on these standards.


^{10}B(n,α)
Ratio to ENDF/B-VI
1.06
1.04
1.02
1.00
0.98
0.0
0.2
0.4
0.6
0.8
1.0
Neutron energy (MeV)

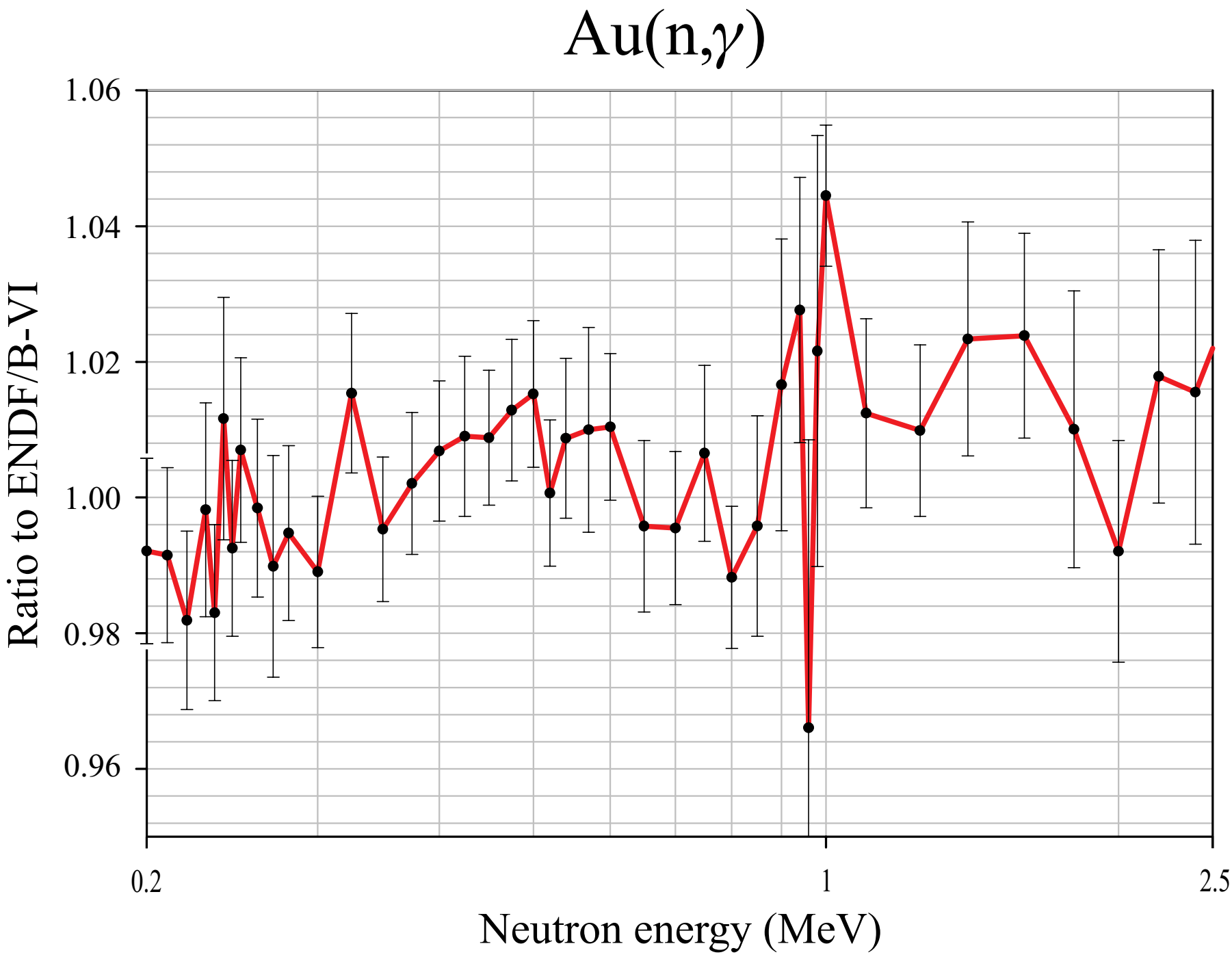

$^{10}B(n,\alpha_1\gamma)$
Ratio to ENDF/B-VI
1.06
1.04
1.02
1.00
0.98
0.0
0.2
0.4
0.6
0.8
1.0
Neutron energy (MeV)

Standard Cross Section Results (cont.)

- C(n,n)
  - Only a few new measurements have been made of this standard and they agree very well with the ENDF/B-VI evaluation.
  - This evaluation was carried over from ENDF/B-VI.
  - The energy range of the standard is thermal to 1.8 MeV.

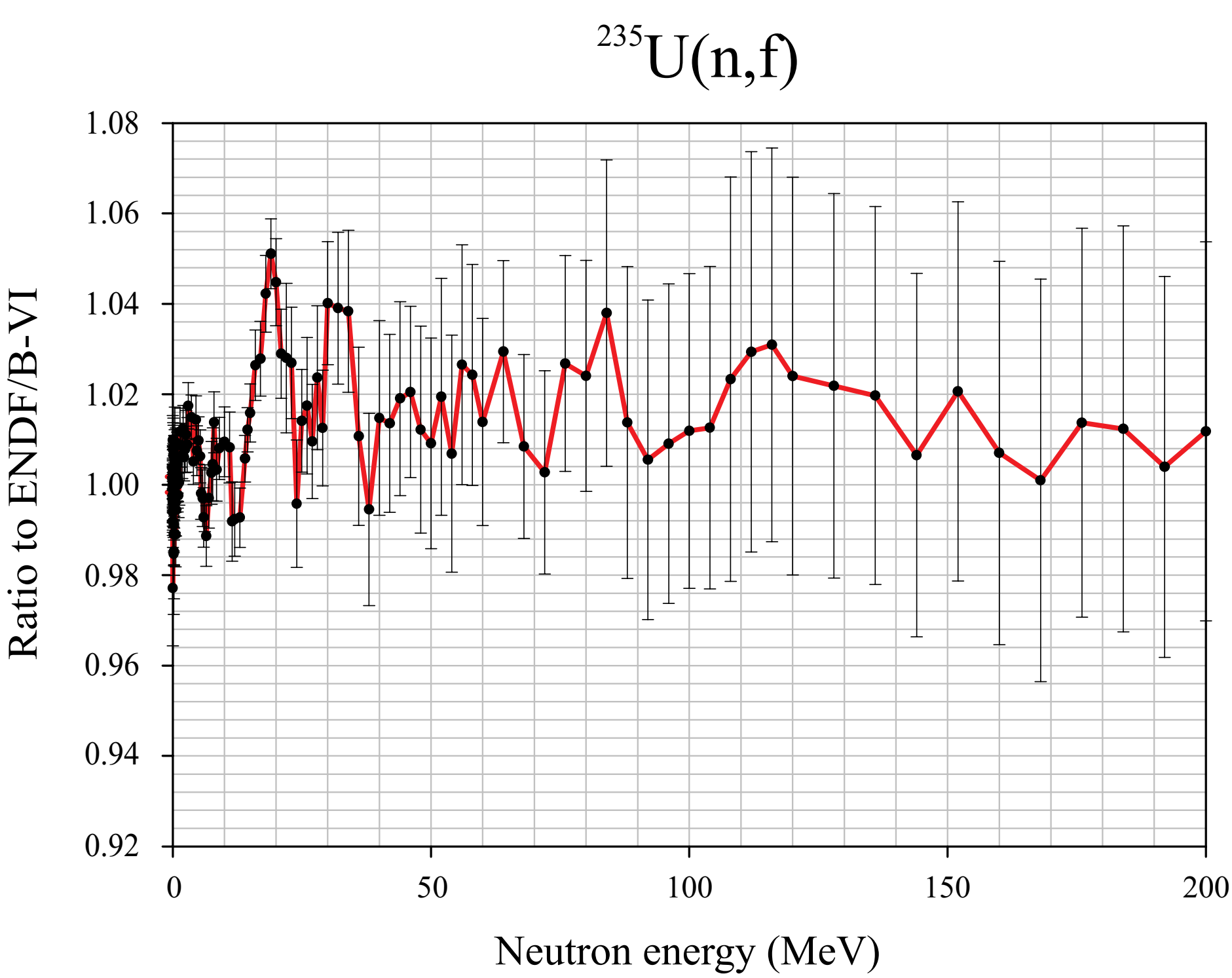
Standard Cross Section Results (cont.)

- Au(n,γ)
  - This is the only capture standard.
  - The energy range of the standard is thermal and 0.2 MeV to 2.5 MeV.
  - The standard cross section was completely adopted into the neutron reaction sublibrary.


Au(n,γ)
Ratio to ENDF/B-VI
1.06
1.04
1.02
1.00
0.98
0.96
0.2
1
2.5
Neutron energy (MeV)

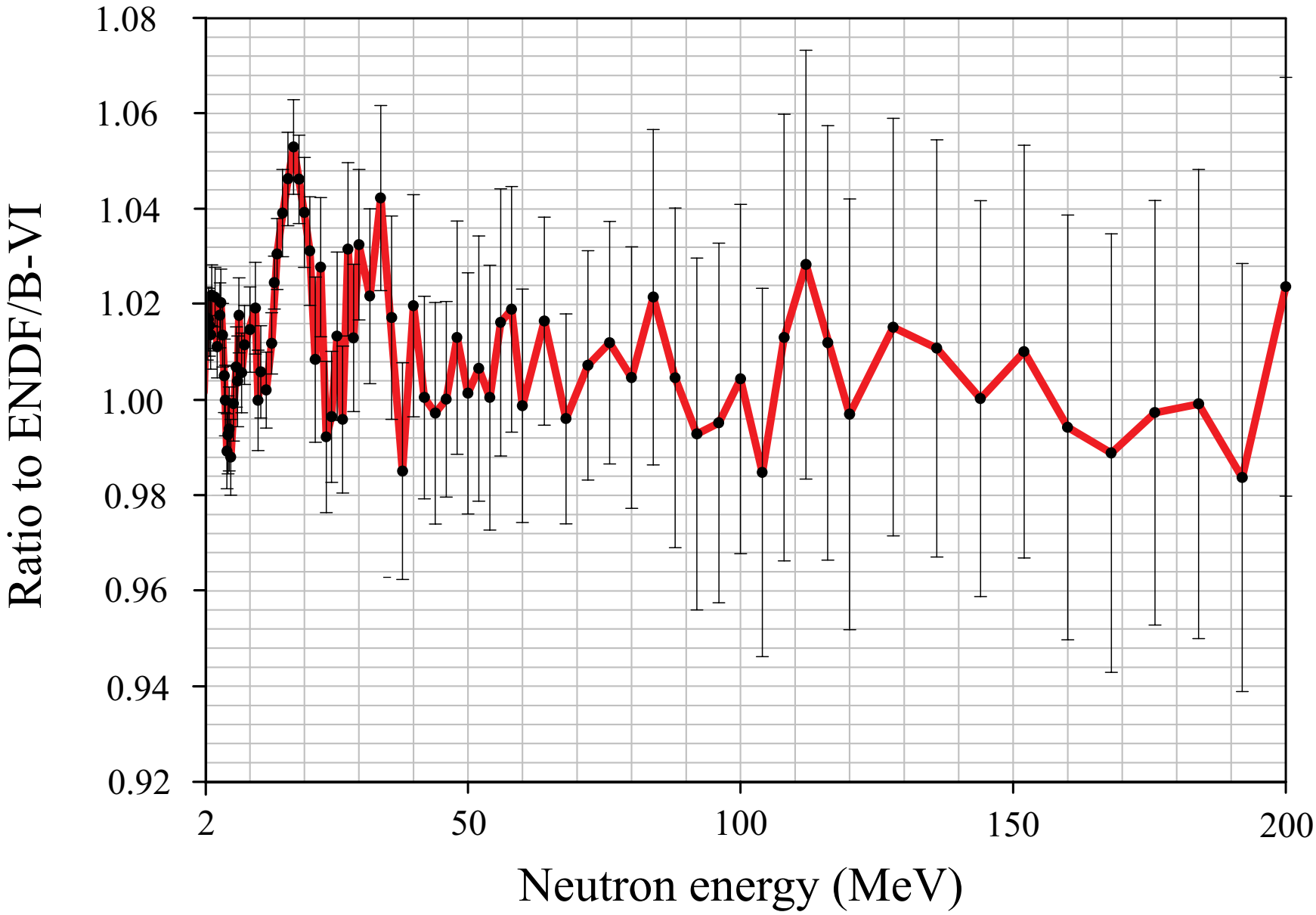
Standard Cross Section Results (cont.)

- $^{235}U(n,f)$
  - The energy range of the standard is thermal and 0.15 MeV to 200 MeV.
  - Except for the thermal value where a slight change was made to satisfy thermal data testing, the standard cross section was completely adopted into the neutron reaction sublibrary.
  - Measurements are being considered for this standard.


^{235}U(n,f)
Ratio to ENDF/B-VI
1.08
1.06
1.04
1.02
1.00
0.98
0.96
0.94
0.92
0
50
100
150
200
Neutron energy (MeV)

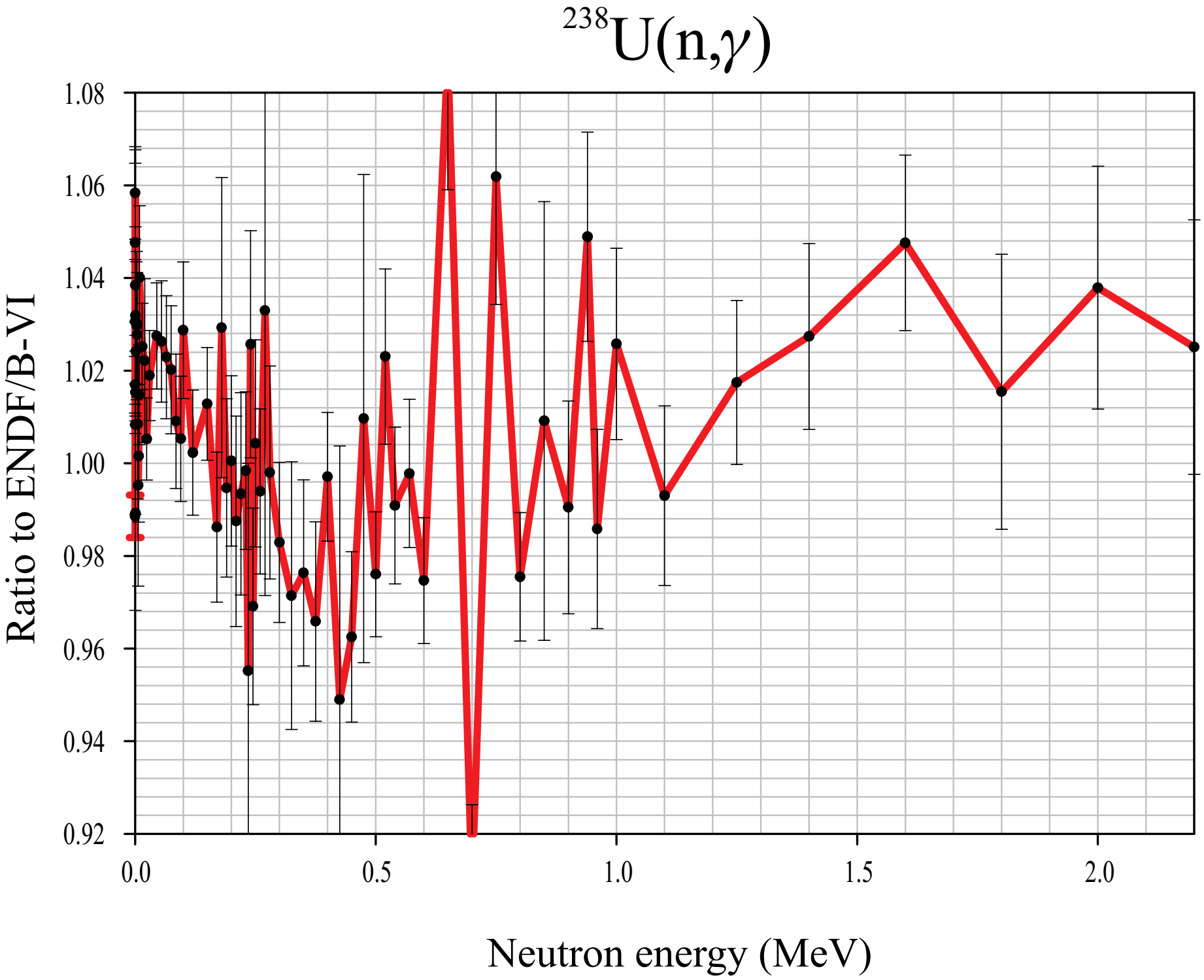
Standard Cross Section Results (cont.)

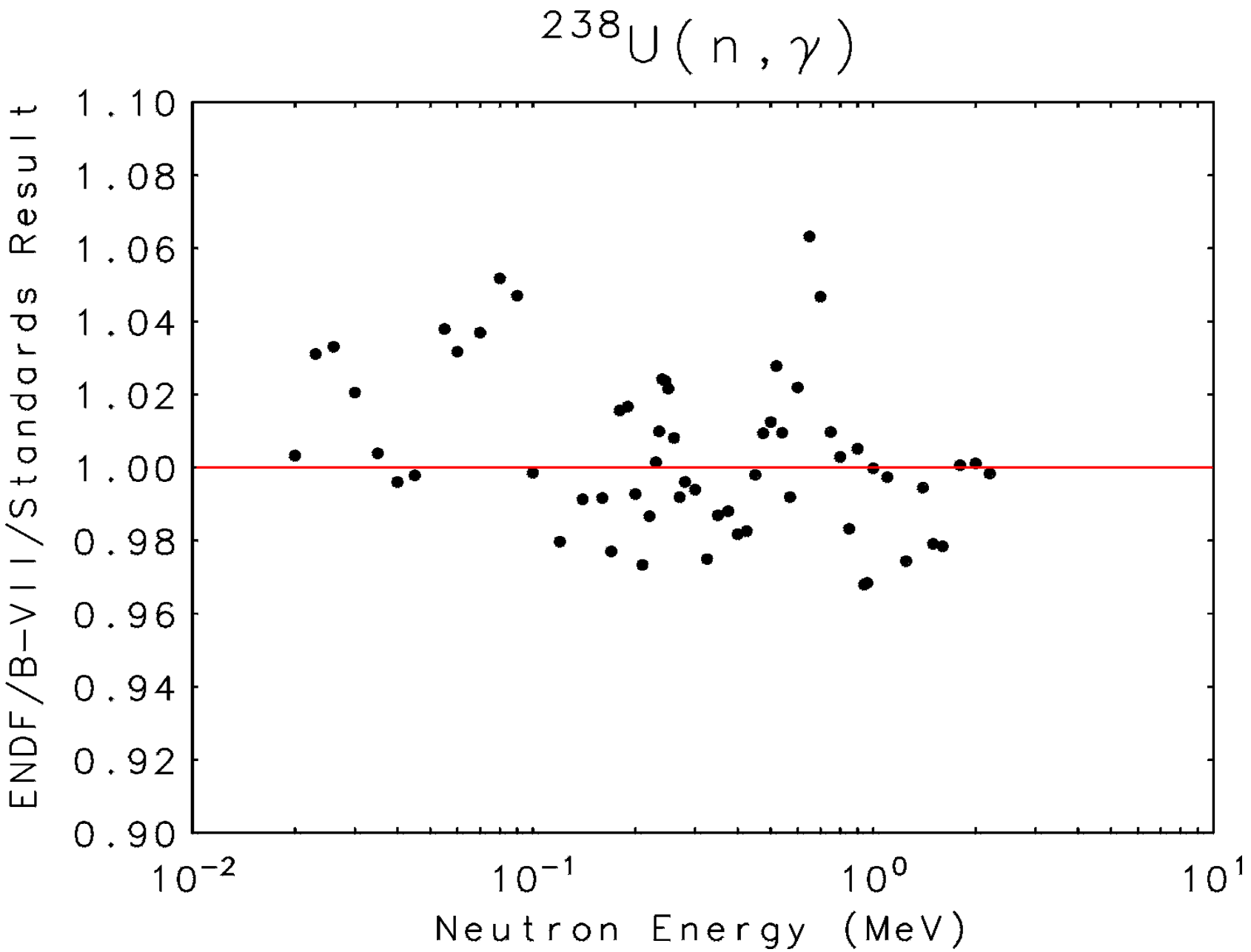
- $^{238}U(n,f)$
  - It was accepted as an ENDF/B-VII standard by the CSEWG.
  - It was recommended that the lower energy bound for use as a standard be changed to 2 MeV.
  - The energy range of the standard is 2 MeV to 200 MeV.
  - The standard cross section was completely adopted into the neutron reaction sublibrary.
  - Measurements are being made on this standard.


^{238}U(n,f)
Ratio to ENDF/B-VI
1.08
1.06
1.04
1.02
1.00
0.98
0.96
0.94
0.92
2
50
100
150
200
Neutron energy (MeV)

Additional Results of the Standards Evaluation Process

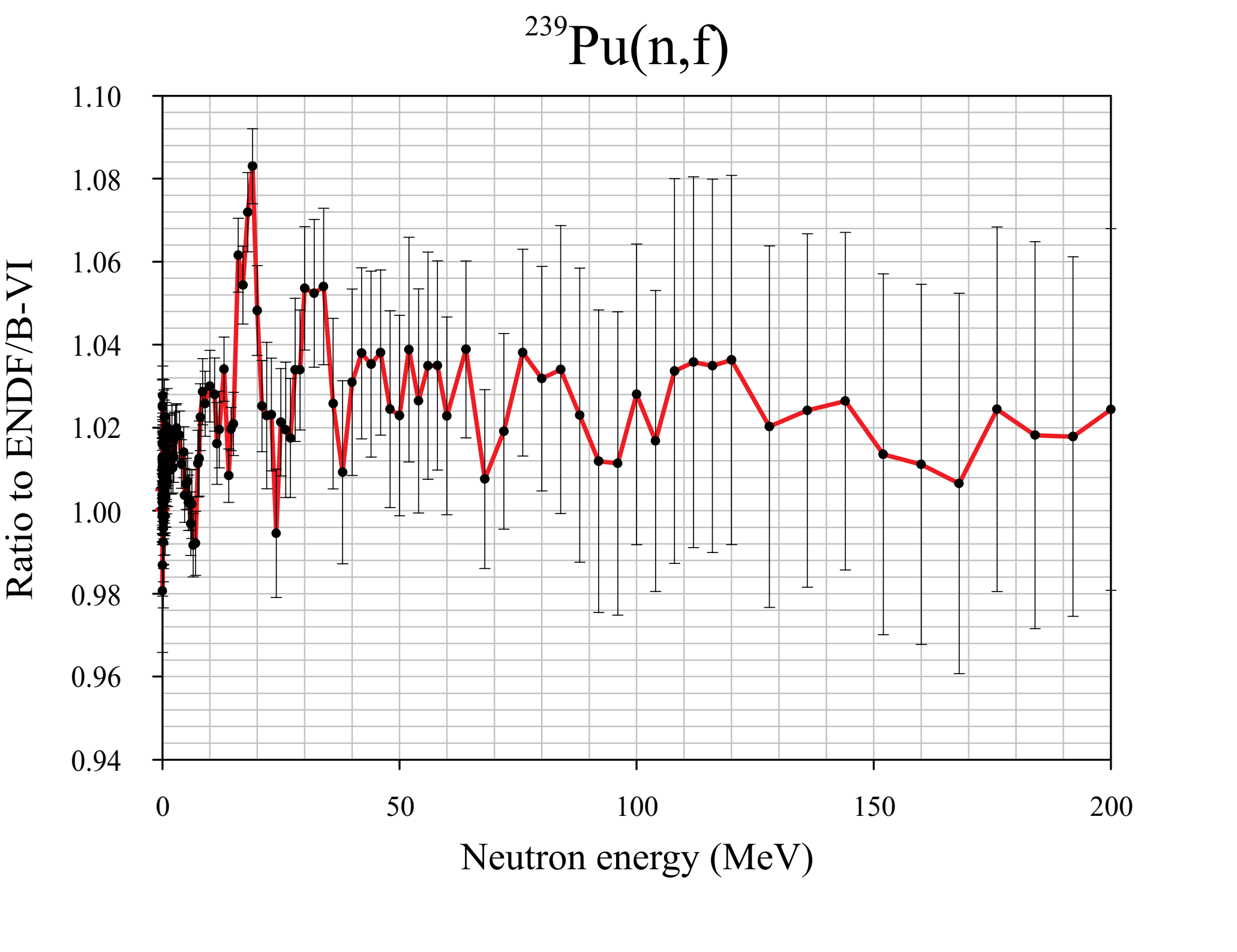
- $^{238}U(n,\gamma)$
  - This is not a standard cross section.
  - The evaluation extends to 2.2 MeV.
  - These data were the basis for the ENDF/B-VII $^{238}U(n,\gamma)$ evaluation.
  - Small cross section changes were made by the ^{238}U evaluators to optimize the performance of some criticality benchmarks.


^{238}U(n,γ)
Ratio to ENDF/B-VI
1.08
1.06
1.04
1.02
1.00
0.98
0.96
0.94
0.92
0.0
0.5
1.0
1.5
2.0
Neutron energy (MeV)


^{238}U(n,γ)
ENDF/B-VII/Standards Result
1.10
1.08
1.06
1.04
1.02
1.00
0.98
0.96
0.94
0.92
0.90
10^{-2}
10^{-1}
10^{0}
10^{1}
Neutron Energy (MeV)

Additional Results of the Standards Evaluation Process (cont.)

- ^{239}Pu(n,f)
  - This is not a standard cross section.
  - The evaluation extends to 200 MeV.
  - The cross section was completely adopted into the neutron reaction sublibrary.


^{239}Pu(n,f)
Ratio to ENDF/B-VI
1.10
1.08
1.06
1.04
1.02
1.00
0.98
0.96
0.94
0
50
100
150
200
Neutron energy (MeV)

The Thermal (0.0253 eV) Constants Obtained from the Standards Evaluation

(values in parenthesis correspond to the values actually in the ENDF/B-VII file, which were allowed to differ slightly so as to optimize performance in the integral data testings.)

Quantity	^{233}U	^{235}U	^{239}Pu	^{241}Pu
σ_{nf} (b)	531.22 (531.22) ± 0.25 %	584.33 (585.09) ± 0.17 %	750.00 (747.40) ± 0.24 %	1013.96 (1011.85) ± 0.65 %
$\sigma_{n\gamma}$ (b)	45.56 (45.24) ± 1.50 %	99.40 (98.69) ± 0.72 %	271.50 (270.33) ± 0.79 %	361.79 (363.05) ± 1.37 %
σ_{nn} (b)	12.11 (12.15) ± 5.48 %	14.087 (15.08) ± 1.56 %	7.800 (7.975) ± 12.30 %	12.13 (11.24) ± 21.50 %
g_f	0.9956 (0.9966) ± 0.14 %	0.9773 (0.9764) ± 0.08 %	1.0554 (1.0542) ± 0.20 %	1.0454 (1.046) ± 0.53 %
g_a	0.9996 (0.9994) ± 0.11 %	0.9788 (0.9785) ± 0.08 %	1.0780 (1.0782) ± 0.22 %	1.0440 (1.042) ± 0.19 %
ν-bar	2.497 (2.504) ± 0.14 %	2.4355 (2.4367) ± 0.09 %	2.8836 (2.8789) ± 0.16 %	2.9479 (2.9453) ± 0.18 %

^{252}Cf ν-bar 3.7692 ± 0.125 %

Standards Evaluation Activities

- Final standard cross sections, covariance data and summary documentation were provided for the standards sublibrary of ENDF/B-VII.
- A final report on the activities of WPEC Subgroup 7 on nuclear data standards was written.
- A contribution was written on the standards and the standards sublibrary for the comprehensive ENDF/B-VII article to be published in Nuclear Data Sheets.
- A proposal for an IAEA nuclear data development project "maintenance of the neutron cross section standards" was approved. This project will update the standards so they are available for new versions of a library.
- Improvements continue to be made to the experimental data in the standards database as a result of NIST involvement or encouragement.
- The work on the IAEA coordinated research project on the international evaluation of the neutron cross section standards has been completed. A detailed IAEA technical report has been written documenting the evaluation activities.

IAEA Technical Report on the International Evaluation of the Neutron Cross Section Standards

Topics to be addressed in this report include the following:

- Methods used for the evaluations/codes.
  - Justification for the Poenitz method adopted for ENDF/B-VI being used for the new evaluations.
  - Improvements in the Poenitz method.
  - Uncertainties of discrepant data.
  - PPP effects.
  - Method for combining the R-matrix and simultaneous evaluations.
  - Discussion of codes used in the evaluations (EDA, RAC, SAMMY, GLUCS, GMA).
  - Intercomparisons and tests of codes used in the evaluations.

IAEA Technical Report (cont.)

- Experimental database :
  - Original ENDF/B-VI database.
  - Additional experiments since the ENDF/B-VI evaluation.
  - Corrections for “particle leaking” with Frisch-gridded ionization chambers.
  - Extending the database to energies above 20 MeV.
  - Revision of uncertainties of “discrepant” data.
- Microscopic nuclear models for the light element standard cross-sections.
  - RGM, RRGM, NN, NNN.
  - Intercomparison of the methods.
  - Methods for improving R-matrix analyses.
  - Results for ^{4}He and ^{7}Li systems.

IAEA Technical Report (cont.)

- R-matrix theory and evaluation of the light element standards.
  - Use of charged-particle database.
  - Comparison of EDA and RAC results for ^{7}Li and ^{11}B systems-consistency.
  - Uncertainties of results with R-matrix fits.
  - Problems with positive definiteness of the covariance matrix.
- Peelle's Pertinent Puzzle (PPP).
  - History and reasons for PPP.
  - Presence of PPP in fits to multi-point data sets from the GMA database.
  - Methods to reduce PPP.
  - Updating of codes to minimize PPP.
  - Comparison of different methods to reduce PPP (consistent results).

IAEA Technical Report (cont.)

- Evaluation of the standards and the combining procedure.
  - Use of GMA with R-matrix evaluations treated like data sets in the GMA fit.
  - Handling of additional components of the uncertainty.
  - R-matrix numerical solution uncertainty.
  - Uncertainty of the method used to minimize PPP.
  - Results of the evaluation: central values, uncertainties, cross-energy and cross-reaction correlations.
- Comparison and presentation of results.
  - Original results.
  - Smoothed results.
  - Thinned covariance matrices (more easily readable).
  - Plots of new standards compared with previous standards.
- Justification for the recommended uncertainties.

Experimental and other work

- Data continues to be accumulated at the Ohio University accelerator facility for the Hydrogen scattering angular distribution experiment. The data are being obtained at 15 MeV neutron energy. Data are being obtained with two different hydrogenous sample thicknesses. Measurements are being made at angles of 0 degrees, ± 12 degrees (one on each side of the beam direction), ± 24 degrees, ± 36 degrees, ± 48 and ± 60 degrees. A paper on this work will be given at the ND2007 conference. (collaboration with Ohio University and LANL)

- NIST measurements of the ^{3}He total cross section and coherent scattering length have been published in the Physical Review. An experiment employing polarized neutrons and a polarized ^{3}He beam is being designed. This measurement will allow separation of the real part of the two spin channels of this interaction. All of these types of data can be used in R-matrix evaluations to improve the ^{3}He(n,p) standard cross section.

Experimental and other work (cont.)

•New measurements have been made of the ^{6}Li(n,t) cross section standard at ~ 4 meV neutron energy. Three different means of determining the neutron fluence are used for this measurement:

- •One method employs the accurately known nu-bar of ^{252}Cf (uncertainty of 0.12%) . by using precise solid angle counting of fission fragments, the amount of ^{252}Cf in a thin deposit can be accurately determined. Using nu-bar, the neutron emission rate (fluence) can then be calculated.
- •The second method, which is absolute, is based on α-γ coincidences using the ^{10}B(n,$\alpha_1\gamma$) reaction. It is anticipated that this method can achieve an accuracy of 0.1% for neutron fluence.
- •The third method employs a cryogenic radiometer to measure the heat produced by neutrons being absorbed by the ^{6}Li(n,t) reaction in a thick lithium target.

Experimental and other work (cont.)

- In addition to the ^{6}Li(n,t) cross section determination, this effort will be used to provide an improved determination of the standard neutron source, NBS-I. A paper on this subject will be given at the ND2007 conference.
- It may be possible to improve the accuracy of the determination of nu-bar for ^{252}Cf based on the results of this work.
- The NIST National Repository for Fissionable Isotope Mass Standards continues to acquire and monitor samples.
- NIST has members on the International Program Committees for both the ND2007 and International Symposium on Radiation Dosimetry (2008) meetings, who are actively involved in the planning details.

Recommendations

- It is important to maintain an active program of measurements and evaluations of the neutron cross section standards. The international standards evaluation has been completed, but there there are still important standards activities that need to be continued, some of which were initiated but not completed in the standards evaluation process. These activities could be done under the IAEA nuclear data development project "maintenance of the neutron cross section standards". This project will periodically update the standards so they are available for new versions of a nuclear data library. New experiments will be encouraged and the experimental results obtained will be carefully investigated so that an improved database will be available for future evaluations. Also standards evaluation codes will be maintained and improved. Maintaining a close relationship with the WPEC and CSEWG communities will make this a more effective project.
- It should be stressed that improved use and understanding of the covariances is essential for proper use of nuclear data.