Recent Work on Neutron Standards Data

Allan D. Carlson
Neutron Physics Group
National Institute of Standards & Technology

Presented at
The CSEWG Meeting
BNL
November 7, 2018

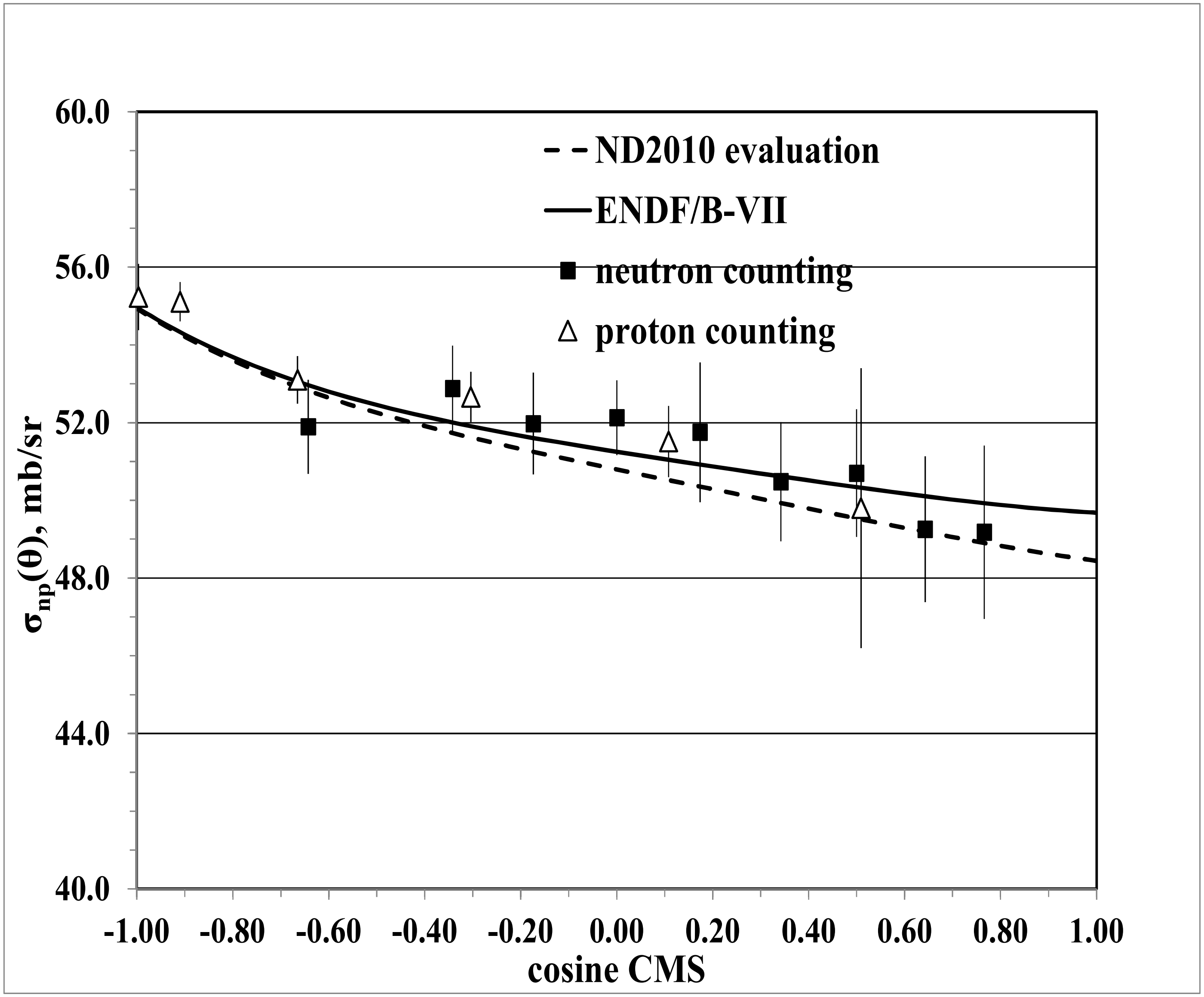
Nuclear Reaction Activities: H(n,n)H Standard Angular Distribution Work

- Measurements were made previously by this collaboration at 10 and 14.9 MeV at the Ohio University accelerator facility. Those data were obtained by detecting the recoil proton.
- New measurements at 14.9 MeV have been made detecting the neutron in coincidence with the associated proton so that data can be obtained at smaller CMS angles. The data were also obtained at the Ohio University accelerator facility.
- The neutron detector efficiency was determined relative to the ^{252}Cf spontaneous fission neutron spectrum with a neutron-fission fragment coincidence.

- Thr present results and those obtained by proton detection are in excellent agreement. There is also excellent agreement with the ENDF/B-VII and ENDF/B-VIII standards evaluations within the uncertainties but there is a trend toward lower values at small CMS angles for both experiments. The results are now nearly final.

- (collaboration of NIST with Ohio University, LANL and the University of Guelma)

Ohio H(n,n)H Standard Measurements



Recent H(n,n)H Standard Measurements

- Concerns about the hydrogen total scattering cross section at low neutron energies led to University of Kentucky Van de Graaff work by Yang from 90 keV to 1.8 MeV with uncertainties of 1-2%. Numerical data has not been available. There are questions about the quality of these data.

- Kovash at the University of Kentucky has plans to measure the hydrogen cross section in the MeV energy region using both his accelerator and the LANSCE facility at LANL.

^{6}Li(n,t) Measurements

- The NIST measurement is the first direct and absolute measurement of this cross section in this neutron energy range using monoenergetic neutrons.

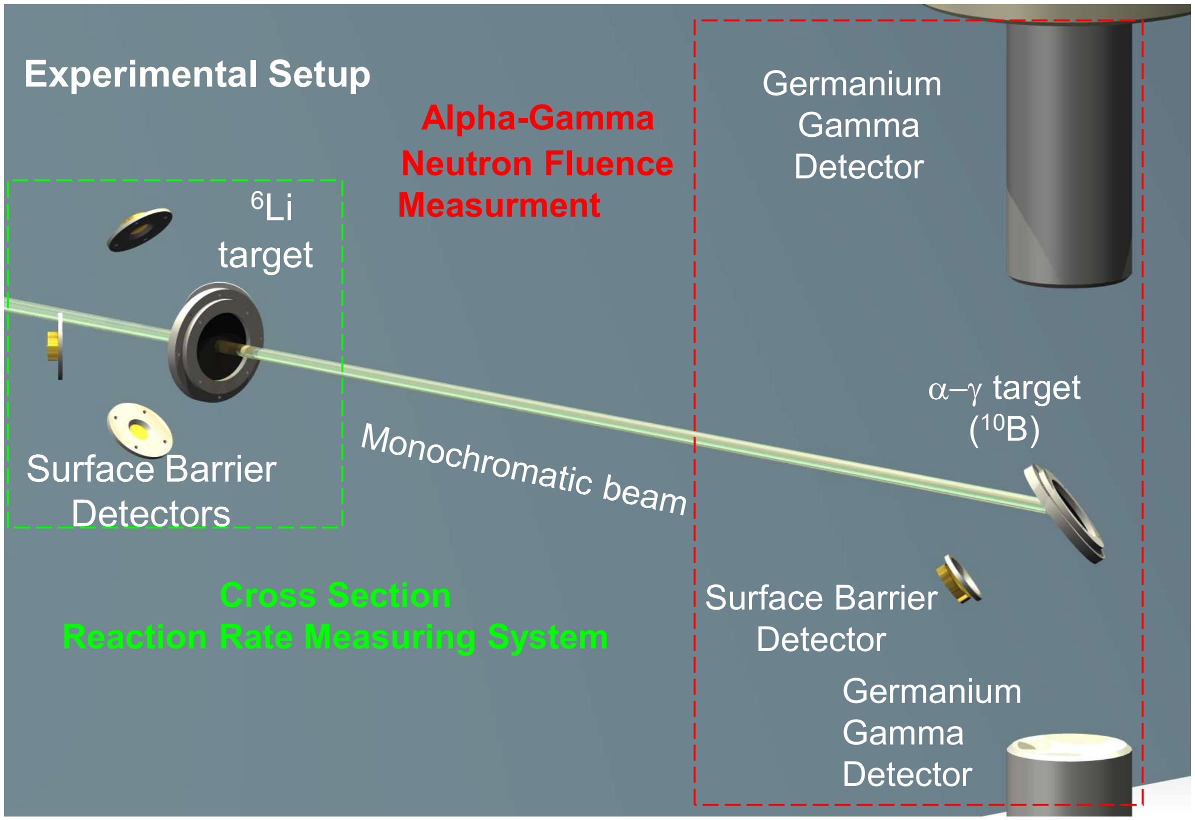
- A primary effort was focused on measuring the neutron fluence accurately. It was determined with an uncertainty of 0.06%.

- Much investigation has gone into the uncertainty of this cross section measurement. The uncertainty is mainly from the uncertainty in the ^{6}Li mass. The deposits were obtained from IRMM. The initial value obtained was in excellent agreement with the ENDF/B-VII standards evaluation. It was recently found that the mass reported by IRMM was in error. Using the new mass value produces a cross section value with an uncertainty of 0.3% that is 1% lower than the ENDF/B-VII value. **Plans have been made to use Isotope Dilution Mass Spectrometry to obtain a very accurate value for the mass this December.**

- **The low energy (thermal) cross section ENDF/B-VII value is largely determined by three measurements made in 1970-1971.**
  - It is not clear how well they determined their ^{6}Li masses.

(collaboration of NIST with the University of Tennessee and Tulane University)

^{6}Li(n,t) Cross Section Measurement

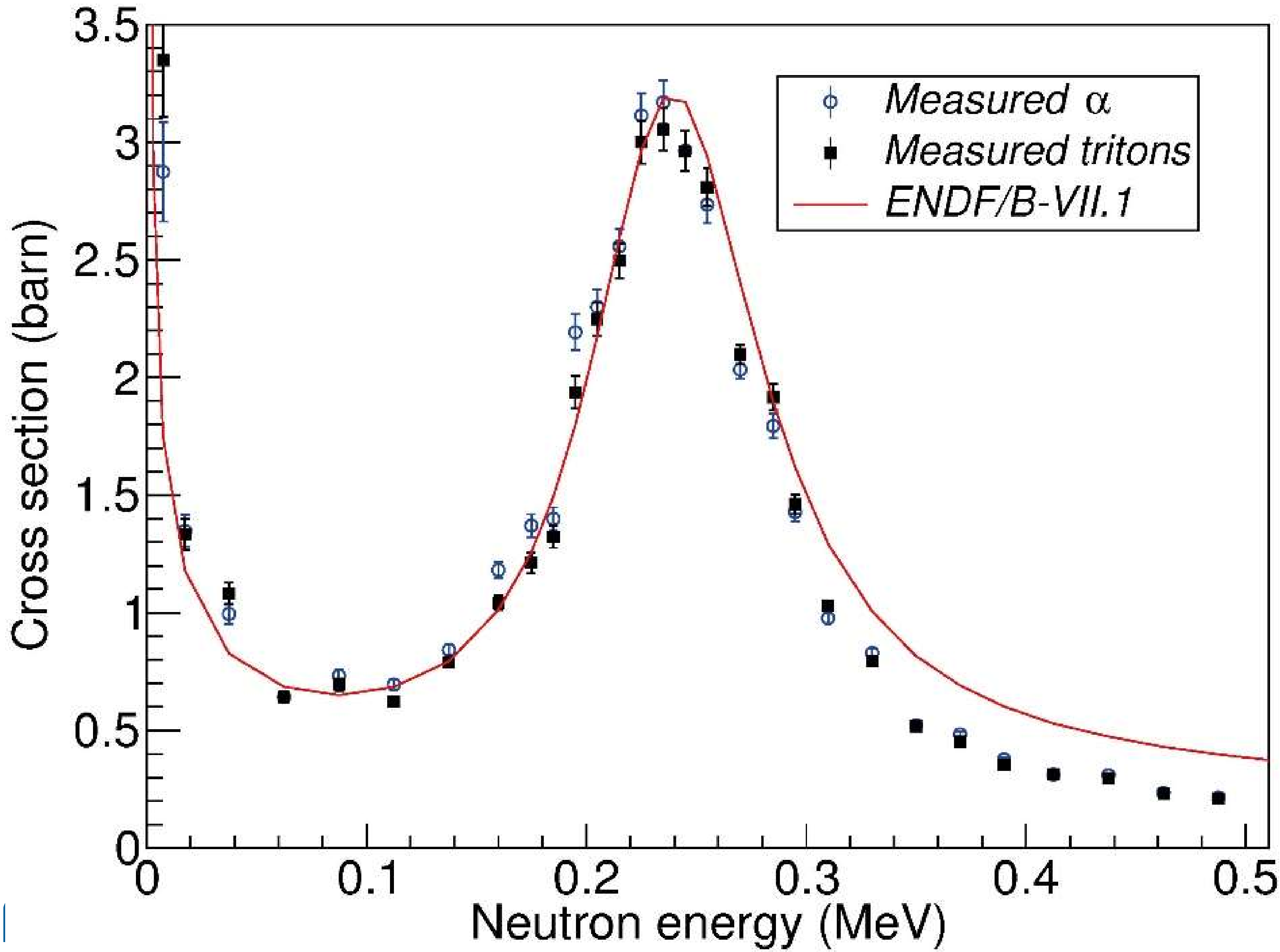


$^{6}Li(n,t)$ Measurements

- Measurements were made of the $^{6}Li(n,t)$ cross section standard at IRMM (JRC..). It was a collaboration that included Josch Hambsch and a graduate student Kai Jansson at Uppsala University. There were a number of problems as outlined in Jansson's thesis. He finally concluded more experimental work is required, but he would not be able to do that work. Hambsch retired and it is not clear if additional work will be done on this standard.

- The $^{6}Li(n,t)$ cross section is one of those standards that we hope could be extended to 2 or 3 MeV with small uncertainties. Then measurements of neutron cross sections (or neutron fluence) when combined with the hydrogen standard could be measured from thermal to high neutron energies.

^{6}Li(n,t) Measurements by Jansson *et al.*



$^{10}B(n,\alpha)$ and $^{10}B(n,\alpha_1\gamma)$ Measurements

- Bevilacqua *et al.* has measurements of the branching ratio, the angular distribution and the $^{10}B(n,\alpha)$ and $^{10}B(n,\alpha_1\gamma)$ cross sections relative to the $^{235}U(n,f)$ standard up to 1 MeV. The data were obtained at GELINA. There appear to be some systematic problems:

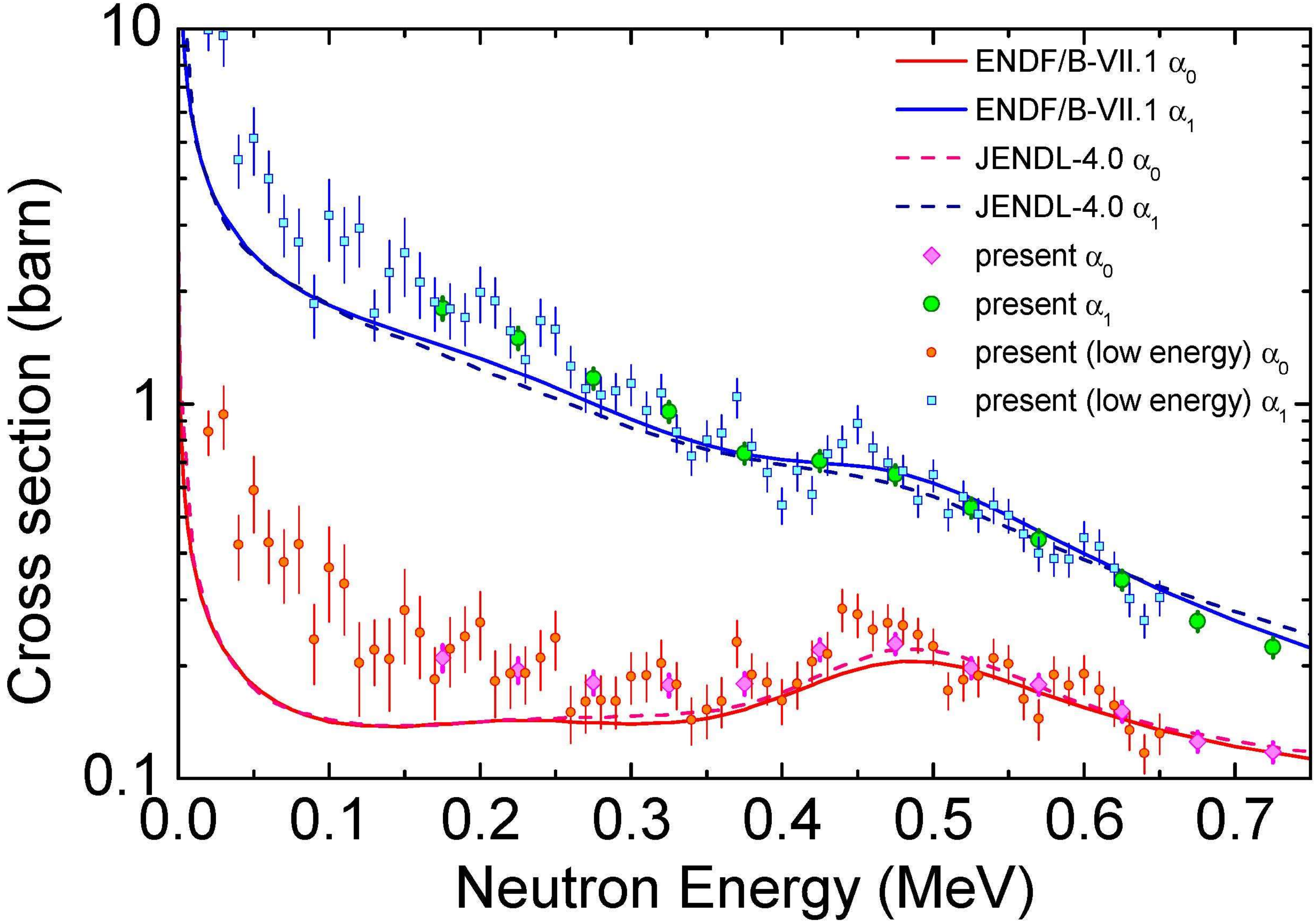
  - The branching ratio measurements look high at the highest energies . Note – that they are independent of the neutron fluence determination.
  - The $^{10}B(n,\alpha)$ and $^{10}B(n,\alpha_1\gamma)$ cross sections used to make that ratio appear to be high below about 0.5 MeV. It could something in common such as the fluence determination.

- In their ND2016 paper, they state more work is needed on these cross sections

- This is a collaboration that included Hambsch who has retired. It is not clear if additional work will be done on this standard at IRMM.

- As with the $^{6}Li(n,t)$ standard, the hope is to extend the boron standards to 2 or 3 MeV with small uncertainties. Then measurements of neutron cross sections (or neutron fluence) when combined with the hydrogen standard could be measured from thermal to high neutron energies.

IRMM Preliminary Measurements of the $^{10}B(n,\alpha_0)$ & $^{10}B(n,\alpha_1)$ Cross Sections

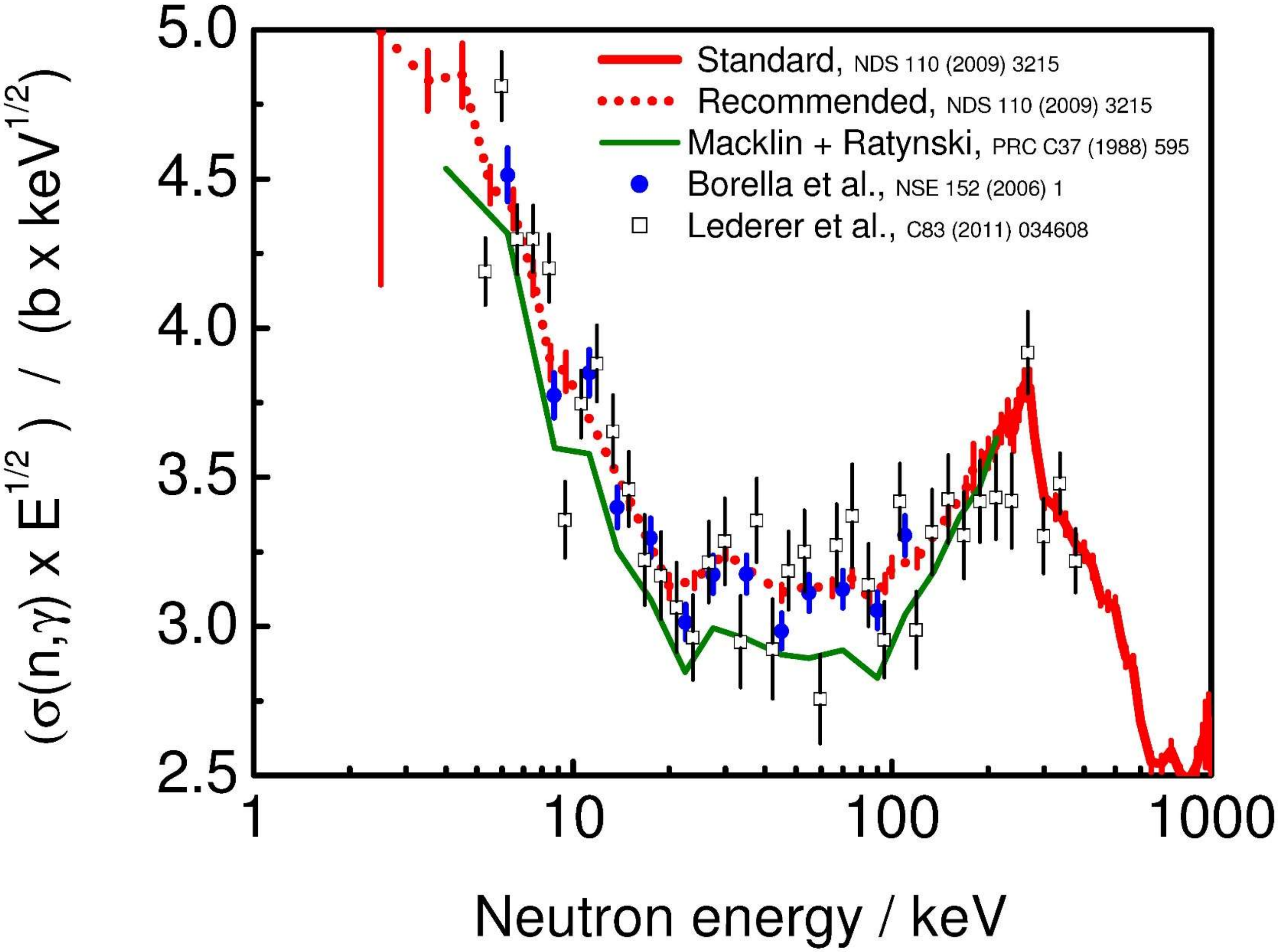


C(n,n) Data

- Yang *et al.* also made measurements of the carbon total cross section from 90 keV to 1.8 MeV since polyethylene samples were used in his measurements. As with his hydrogen work, there are questions about the quality of these data. Numerical data are not available

- Gritzay *et al.* plans to continue her work on the carbon total cross section but she has stated the Kiev research reactor has been down most of the time So she has done no measurements. All her previous measurements are considered preliminary

Low Energy Au(n,γ) Cross Section Problem



Au(n,γ) Data at Low Neutron Energies

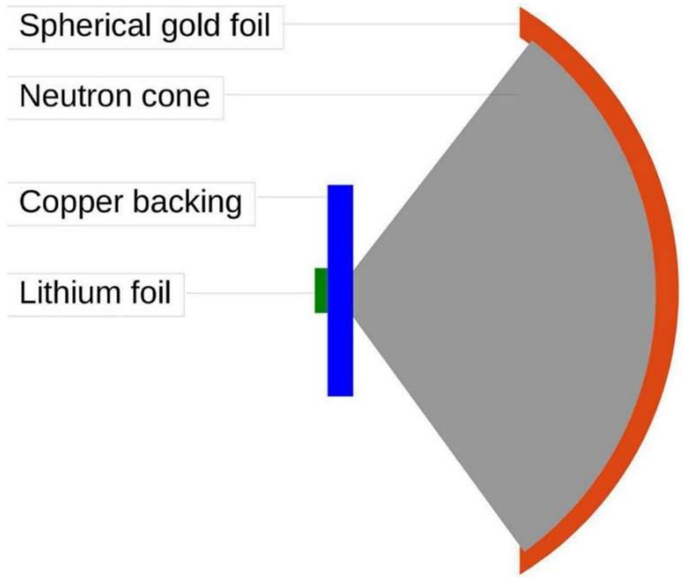
- The 30 keV Au(n,γ) Maxwellian averaged cross section (MACS) is a reference cross section for the KADONIS astrophysics database. The value of that reference was originally from the Ratynski-Käppeler evaluation based on the Ratynski and Käppeler measurements and the Macklin measurement. It is 582 ± 9 mb

  - Several Au(n,γ) cross section measurements have been made since the 2006 standards evaluation (ENDF/B-VII). They all agree within their uncertainties with the standards evaluation. They indicate the Ratynski and Käppeler results are low by about 5-7% near 30 keV.

    - The 30 keV MACS for gold using the 2017 standards evaluation (ENDF/B-VIII) has been accepted as a standard cross section. We have been told that the astrophysical database, KADONIS 1.0, has changed the MACS for the Au(n,γ) cross section. Their new value agrees with the 2017 standards evaluation within one standard deviation. This is not yet shown on their website.

New work on the 30 keV MACS problem with gold capture

Setup of the Ratynski and Kaeppeler Experiment



- Reifarth et al. have recently made Monte Carlo simulations that show that the effect of the copper backing in the experiment of Ratynski and Kaeppeler was not properly taken into account. Using their corrections leads to a corrected experimental result consistent with the standards evaluation.

- In the Reifarth paper (Käppeler is a coauthor), a new evaluation is done of that MACS. They obtain 612 ± 6 mb. The standards value is 620 ± 11 mb. The two now agree within their uncertainties.

High Energy Fission Cross Section Measurements

- New measurements of both the $^{238}U(n,f)/^{235}U(n,f)$ cross section ratio and the $^{239}Pu(n,f)/^{235}U(n,f)$ cross section ratio have been made at LANSCE by the NIFFTE collaboration.

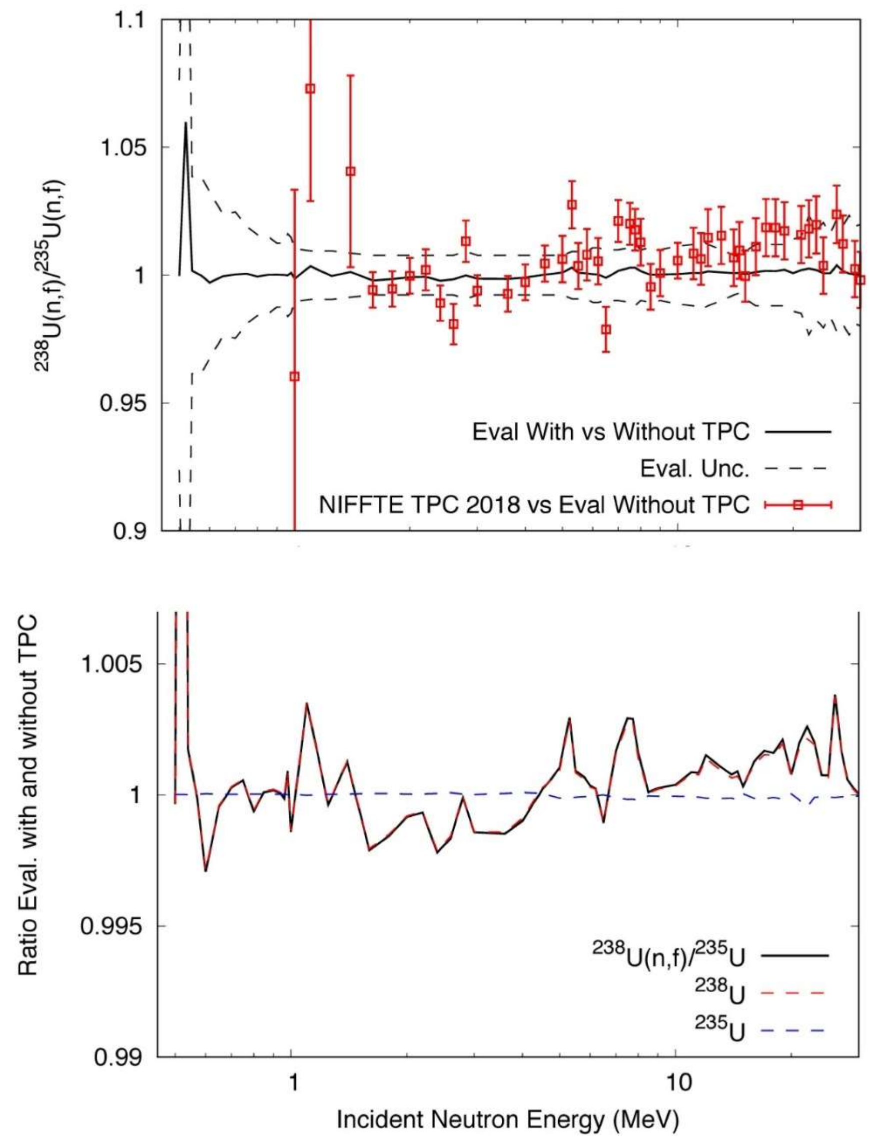
- The $^{238}U(n,f)/^{235}U(n,f)$ cross section ratio work has been published.

  - These are the first TPC results with promising looking results. Overall good agreement with the the ENDF/B-VIII standards evaluation. They are slightly lower in the lower energy region and slightly higher in the high energy region.

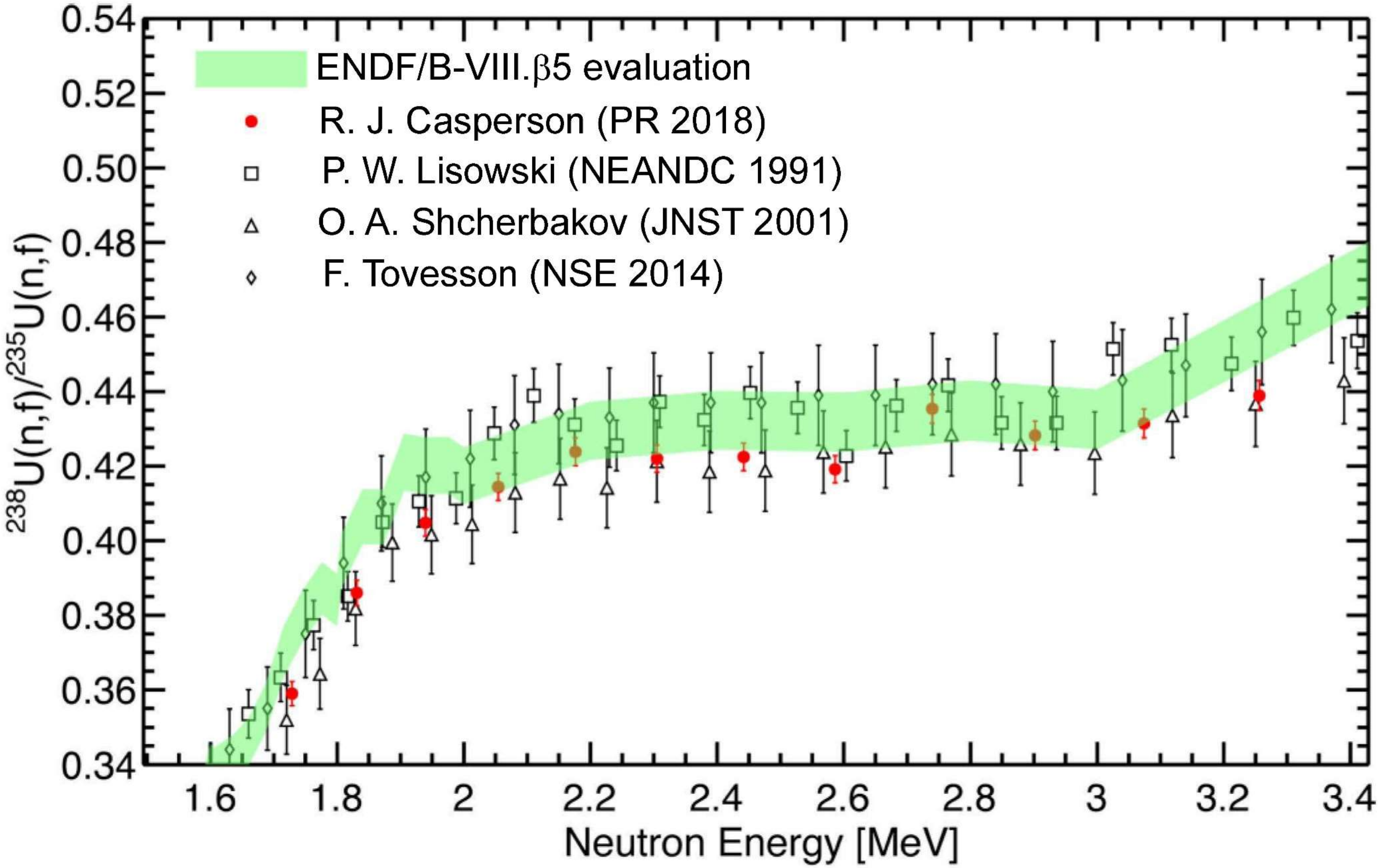
  - The results lead to somewhat smaller uncertainties in the standard from an analysis by Neudecker.

- The $^{239}Pu(n,f)/^{235}U(n,f)$ cross section ratio work is still being analyzed. But the results should also lead to somewhat smaller uncertainties.

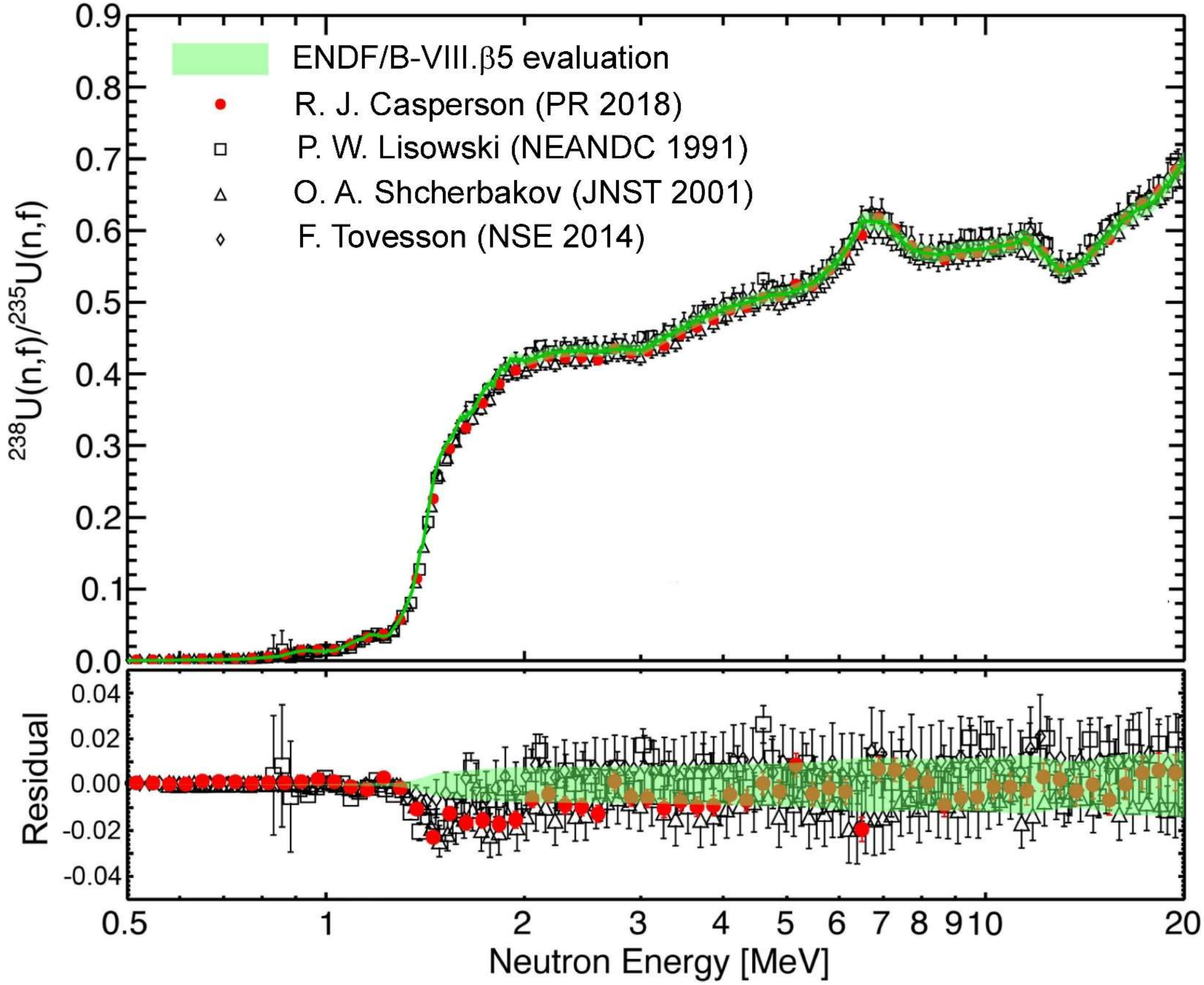
Effect of the NIFFTE TPC ^{238}U(n,f)/ ^{235}U(n,f) Cross Section Ratio data on a GMA Evaluation by Neudecker. The ^{238}U(n,f)/ ^{235}U(n,f) Cross Section Ratio data are from R. J. Casperson *et al*. (Phys. Rev. C 97, 034618 (2018))



^{238}U(n,f)/ ^{235}U(n,f)/ Cross Section Measurement by Casperson et al.



Comparison of Ratio Recent Measurements of the $^{238}U(n,f)/^{235}U(n,f)$ Cross Section Ratio with the NIFFTE Results (Phys. Rev. C 97, 034618 (2018))

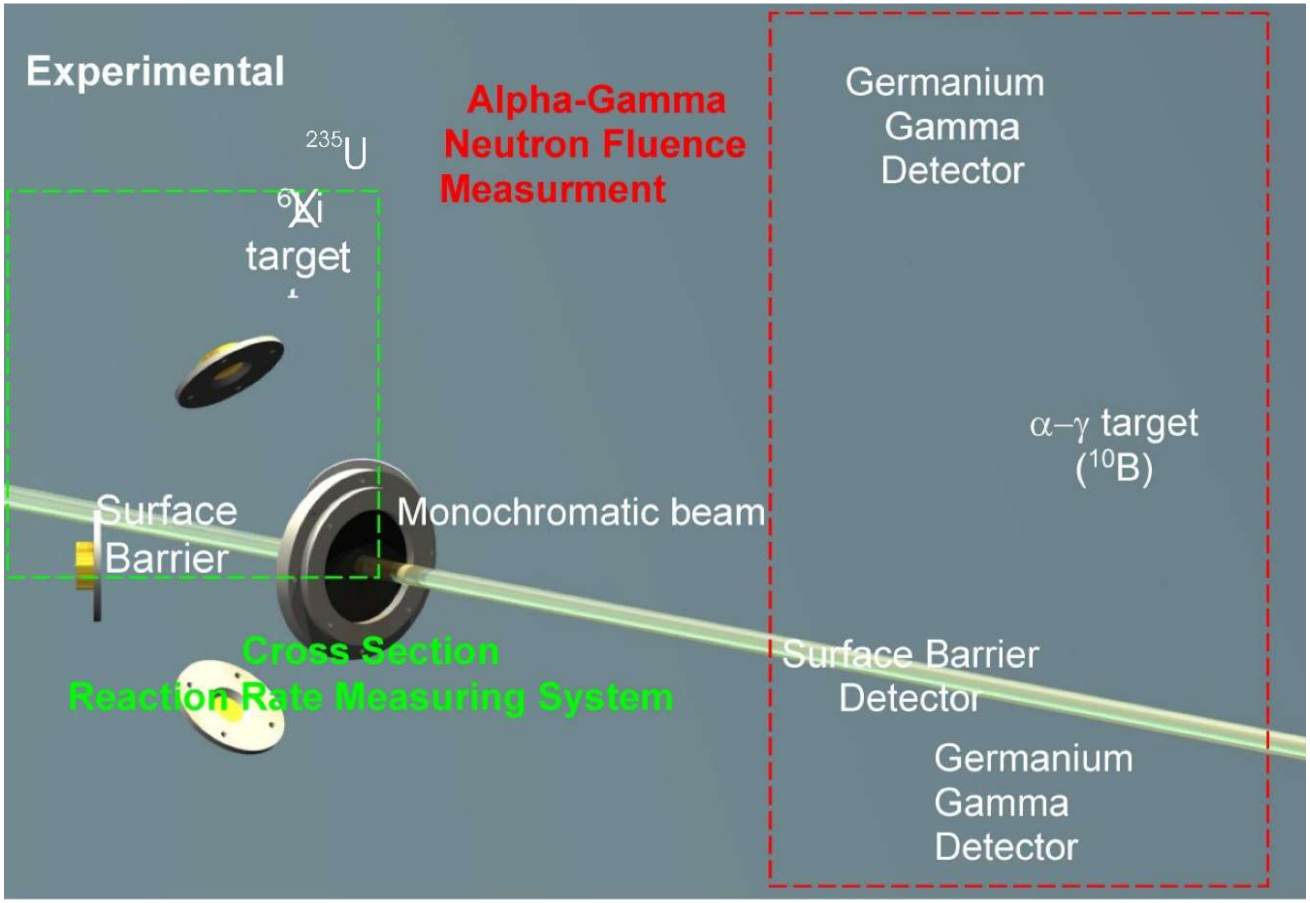


$^{235}U(n,f)$ Cross Section Measurements
(At Thermal – No Maxwellian Data)

Author	Date	CS (b)	DCS (%)	Reference
Saplakoglu	1959	593.17	2.2	*2nd Geneva Conf.* ***4,*** *157*
Raffle	1959	581.97	3.1	*AERE/R-2998*
Deruytter	1961	589.73	1.3	*J. Nucl. Energy* ***15****, 165*
Maslin	1965	583.71	1.4	*Phys. Rev.* ***139****, 852*

- A new measurement is planned at NIST of the $^{235}U(n,f)$ cross section using the same basic setup used for the $^{6}Li(n,t)$ measurement.

$^{235}U(n,f)$ Cross Section Measurement



NBS-I Source Strength Determination Work

- Work continues on improvements in the determination of the neutron source strength for NBS-I, the U.S. national fast-neutron source standard. This work will have an impact on many cross section measurements that have used this source as a standard and any future measurements made using this source.
  - The work requires first that a $MnSO_4$ bath be calibrated using the very accurate measurement of neutron fluence method referred to previously. Then calibration of the NBS-I source can be done by putting it into the calibrated bath.

$MnSO_4$ Bath and NBS-I Calibration