Update on Nuclear Data Research at RPI

Report to CSEWG November, 2015

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Mini CSEWG meeting, May 7-8, 2015 at BNL

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Measurements Completed/in Progress

Italics= in progress

- **Transmission**
  - H_2O - 0.5-20 MeV, 250m flight path
  - ^{236}U - 5.45 eV resonance
  - ^{186}W – 1- 5 keV in support or ORNL evaluation
- **Capture**
  - Fe - 500 eV - 500 keV, 45m flight path
  - Ta - 4eV – 20 eV, 500 eV – 1 MeV, 45m flight path
- **Scattering**
  - *Pb – 0.5 – 20 MeV*
  - *Zr <0.5 MeV in development*
- **Thermal Scattering**
  - Quartz at temperatures of 20, 300, 550, 600 °C.
  - Polyethylene at temperatures of 295 K and 5 K.

Planned Measurements

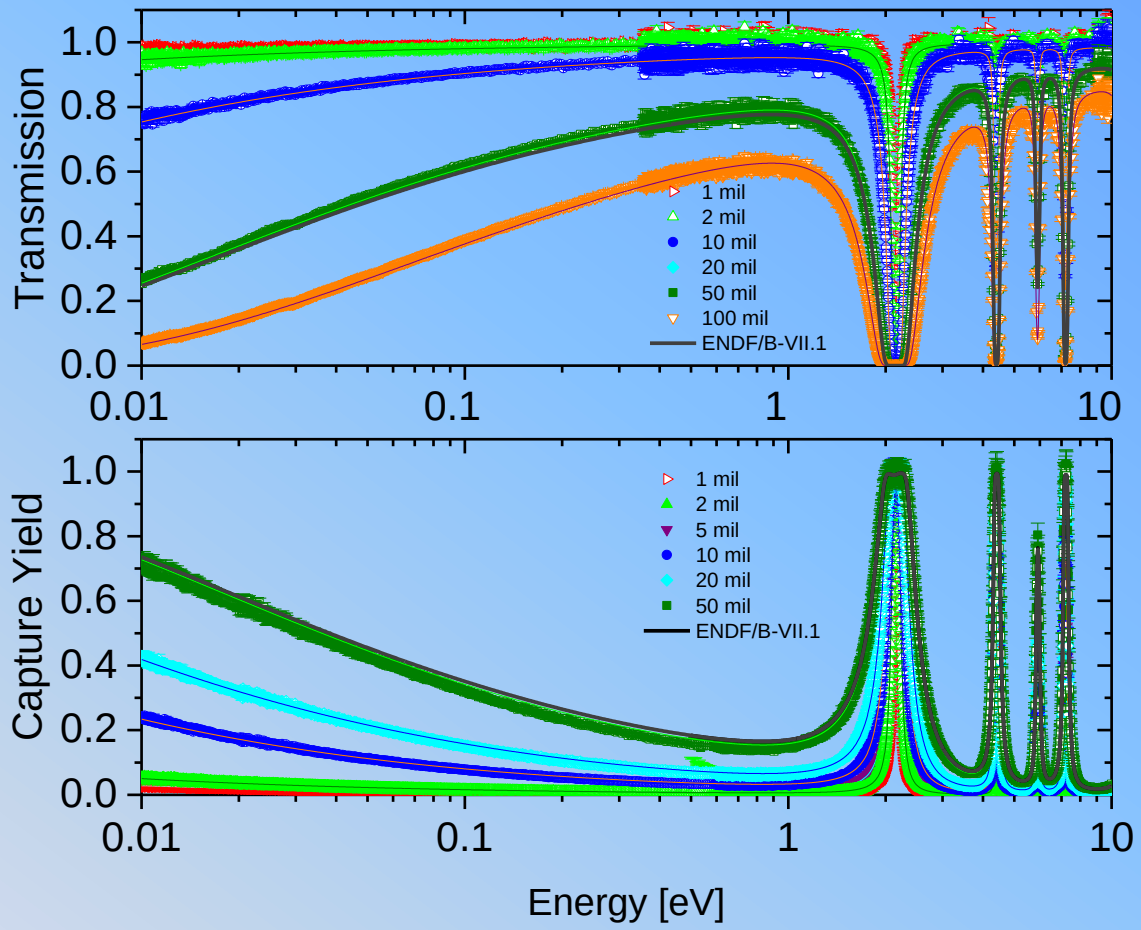
- **Scattering**
  - Pb - complete measurement and analysis
  - Zr - for E<0.5 MeV continue development
  - Hf - resonance scattering (for MC physics models)
- **Transmission**
  - W - 0.5 to 20 MeV
- **Capture**
  - ^{95}Mo, 45m station 1 keV to 500 keV.
    - If unavailable, one of the following ^{92,94}Mo, ^{nat}Zr, ^{nat}Hf

Data Analysis

Measure	Sample	Status
High Energy	Fe, Ti, Ta, Cu, Zr, $^{92/94,95,96,98,100,nat}$Mo	High energy (0.5-20MeV) transmission, publication in preparation
RRR and URR	Cs, Rh , Re, Fe, Ta ^{161,162,163,164}Dy ^{236}U ^{155,156,157,158,160}Gd ^{153,nat}Eu $^{92/94,95,96,98,100,nat}$Mo	Resonance analysis in progress Resonance analysis in progress, ^{164}Dy - publication in internal review ^{236}U - publication submitted to progress in nuclear energy Gd isotopes – published, NSE Vol. 180, Number 1, May 2015. Eu – published , Annals of Nuclear Energy, Vol. 69, pp. 74-89, 2014. ^{95}Mo URR - Accepted to Phys. Rev. C
Scattering	^{238}U Fe	^{238}U – published, Annals of Nuclear Energy, Vol. 73, pp. 455-464, 2014. Fe – analysis in progress
Thermal Scattering	H_2O, polyethylene, quartz	Analysis in progress

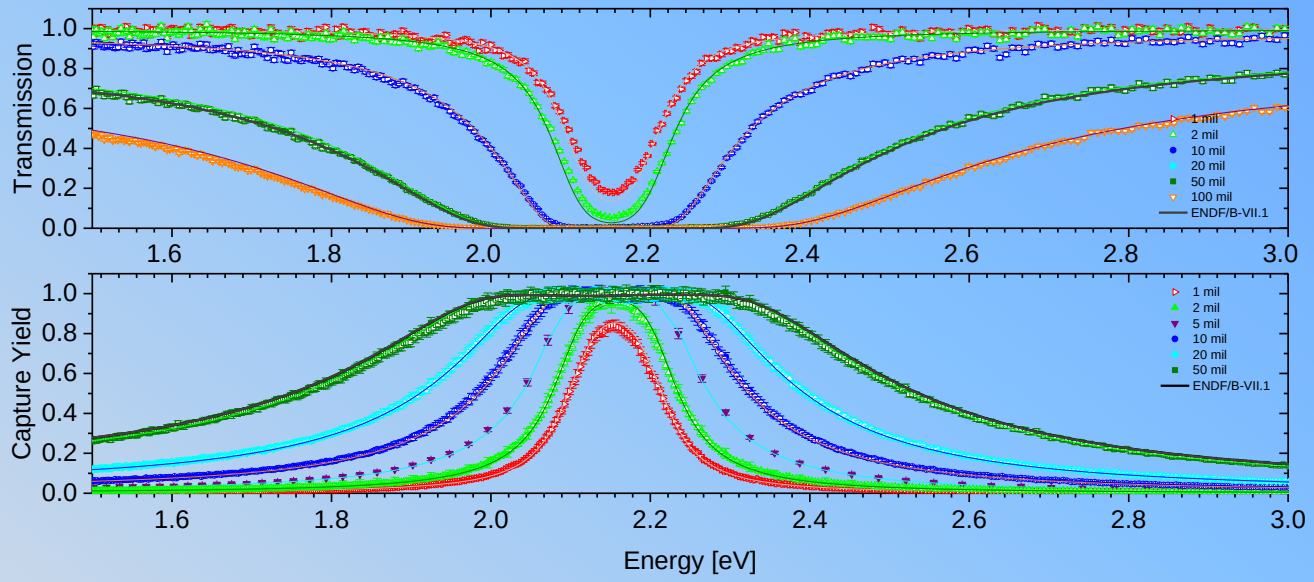
Re – Thermal Transmission and Capture Measurements

- Multiple sample thicknesses 1-100 mils
- Corrected for gamma attenuations (density=12.02 g/cm^3)
- SAMMY fit of all data sets.
- Capture corrected for gamma attenuation (2nd densest element)
- MS Thesis completed.



Re - Summary

- Small change to thermal values and 3% increase in resonance integral for ^{185}Re

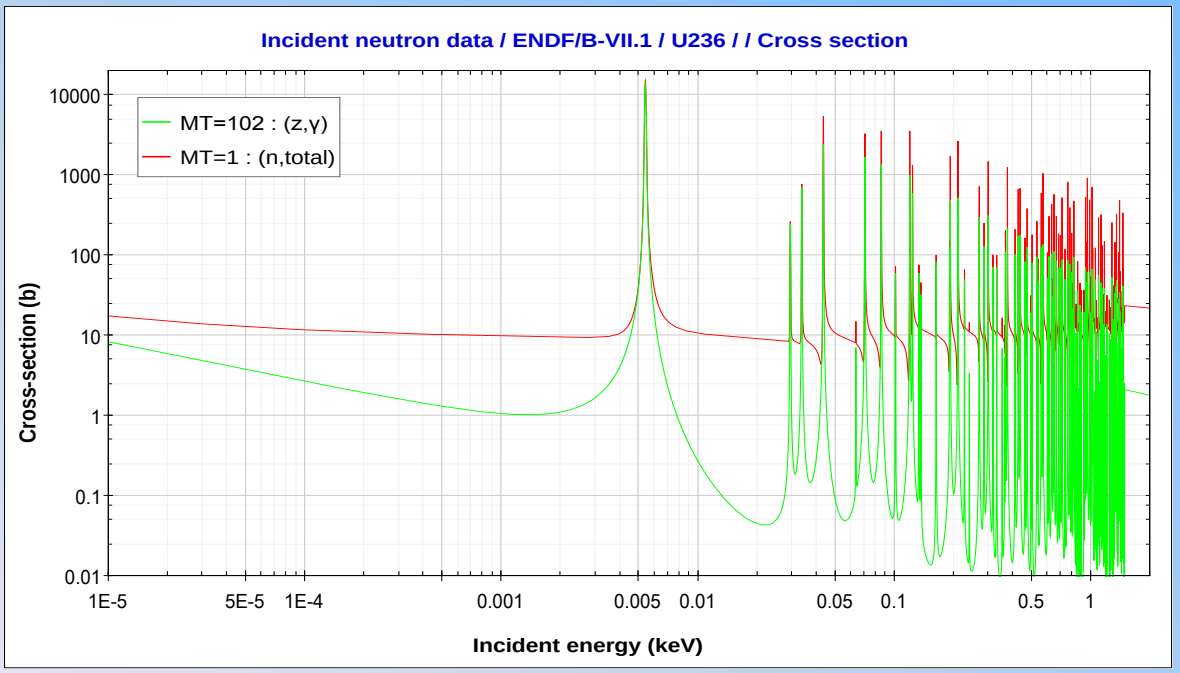


	Energy Range of This Work	Thermal σ_t [b]		Resonance Integral [b]		R` [fm]
Isotope	**N/A**	**Re-185**	**Re-187**	**Re-185**	**Re-187**	**(Combined fit of both isotopes)**
BMPC/RPI	thermal – 1 keV	120	80	1800	310	9.3+/-0.2
ENDF/B-VII.1	RRR ends at 2 keV	121	87	1738	301	8.7*

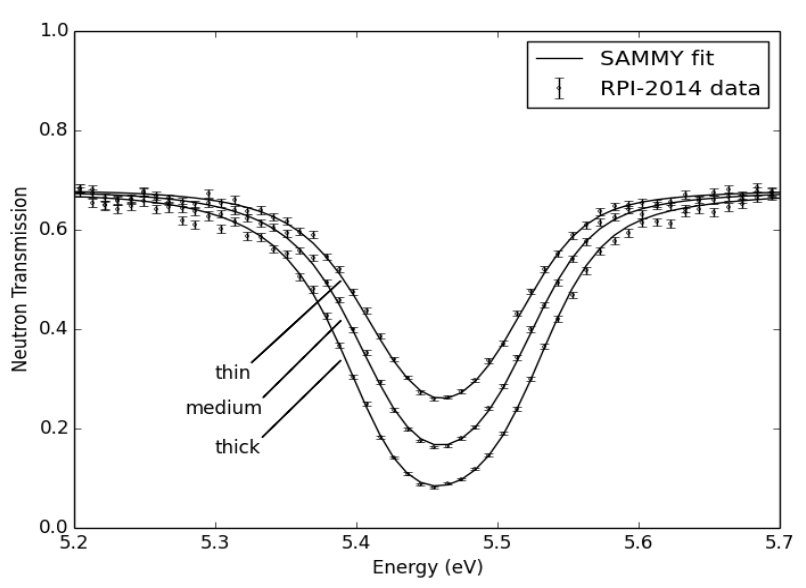
* Use the same R' for both isotopes. This is the value from Mughabghab, ENDF/B-VII.1 has a value of 7.9 fm which was acknowledged by NNDC as a typo.

^{236}U is an important isotope within the ^{235}U fuel cycle

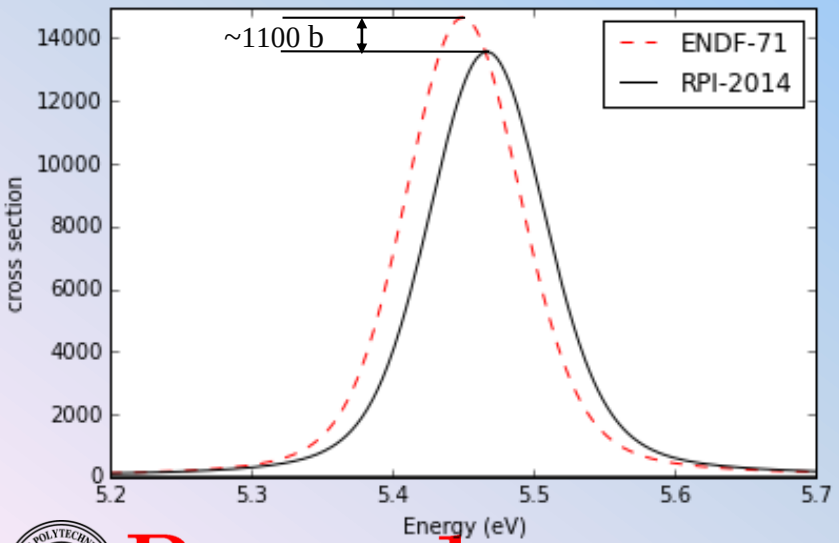
- High yield build-up product
- Strong resonance at 5.467 eV with total cross section over 13,000 barns
  - Difficult to measure since it is hard to make a "thin" ^{236}U sample
    - Used liquid sample
  - Last transmission measurements for ^{236}U was prior to 1960



The ^{236}U Transmission Measurement



Evaluation	E [eV]	Γ_γ [meV]	Γ_n [meV]	σ_t [barns]
JENDL40	5.45	24.5	2.30	15070
ENDF71	5.45	24.5	2.24	14665
Mughabghab (2006)	5.45 ± 0.03	24.7 ± 0.6	2.19 ± 0.08	14316
JEFF32	5.45	24.5	2.16	14152
RPI2014	**5.467 ± 0.01**	**27 ± 1**	**2.13 ± 0.04**	**13571**



- New results indicate lower cross section compared to evaluations
- Uncertainties found by using Monte Carlo approach to data fitting

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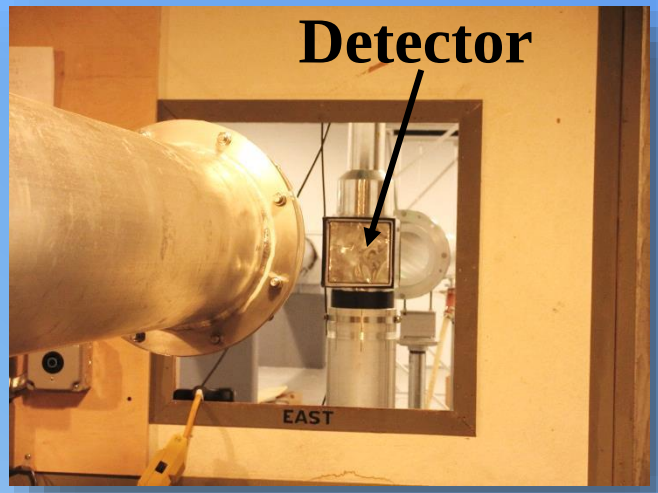
The ^{236}U results show a lower neutron capture resonance integral relative to evaluations

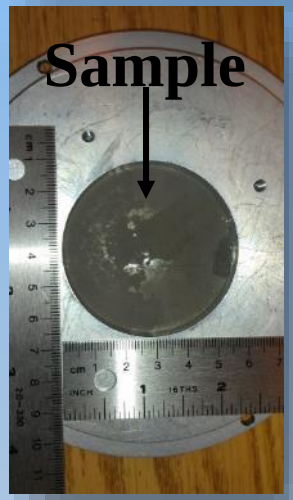
- Method developed to preserve ENDF71 thermal cross sections
- Effect on benchmarks is being assessed

Evaluation	RI [barns]
JENDL40	353
ENDF71	342
Mughabghab	345 ± 15
JEFF32	346
RPI2014	**330 ± 5**

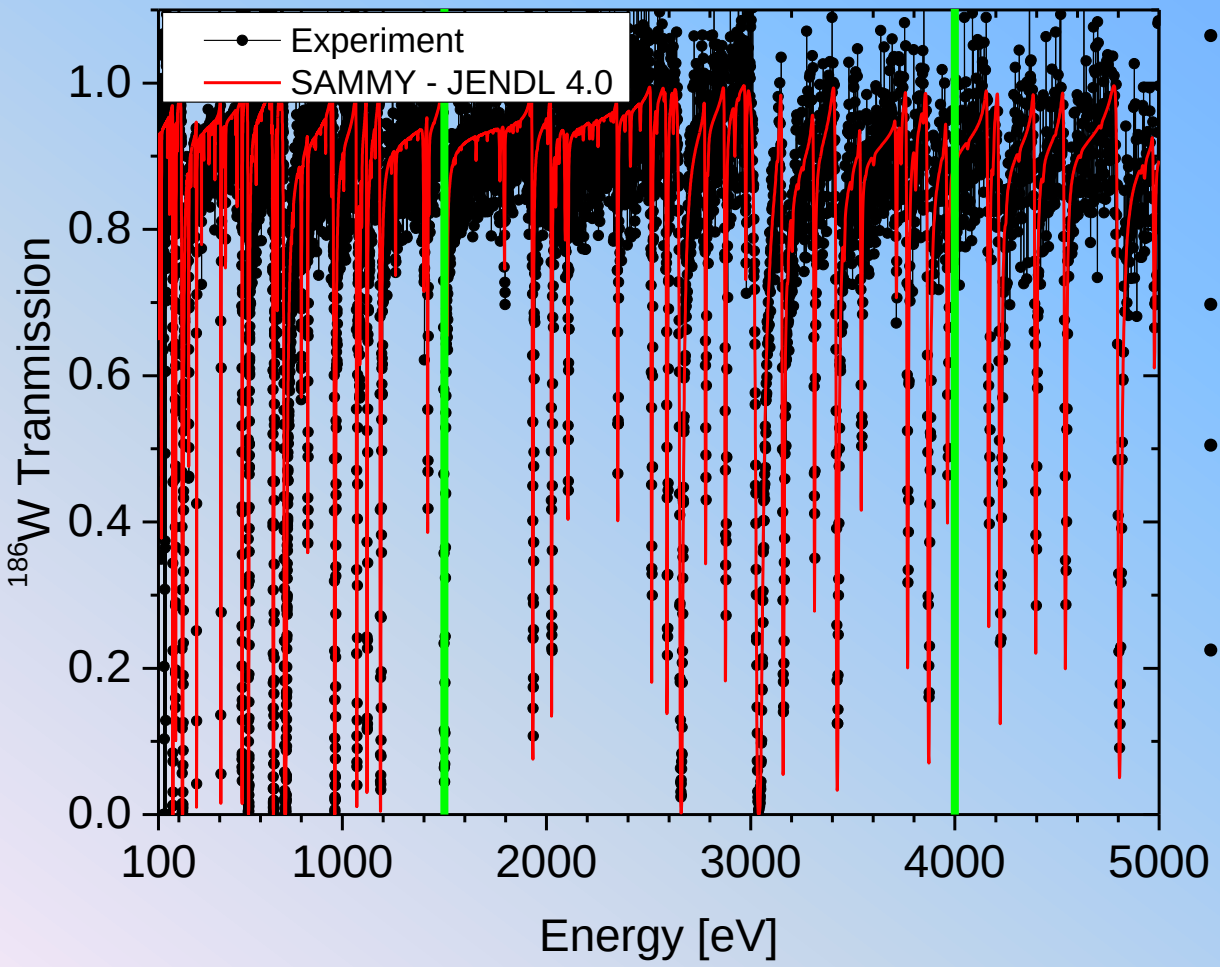
Transmission of ^{186}W

- Experiment was designed to provide data in the energy range from about 2-4 keV (Na fixed filter at Geel)
- Sample provided by ORNL
  - 3 discs, 0.01169 atoms/barn
  - ^{238}U sample for determination of the energy resolution
- Data was collected for 3.5 days.
  - 35 m flight path
  - Pulse width of 10 ns
- Co and Al fixed notches were used for background determination





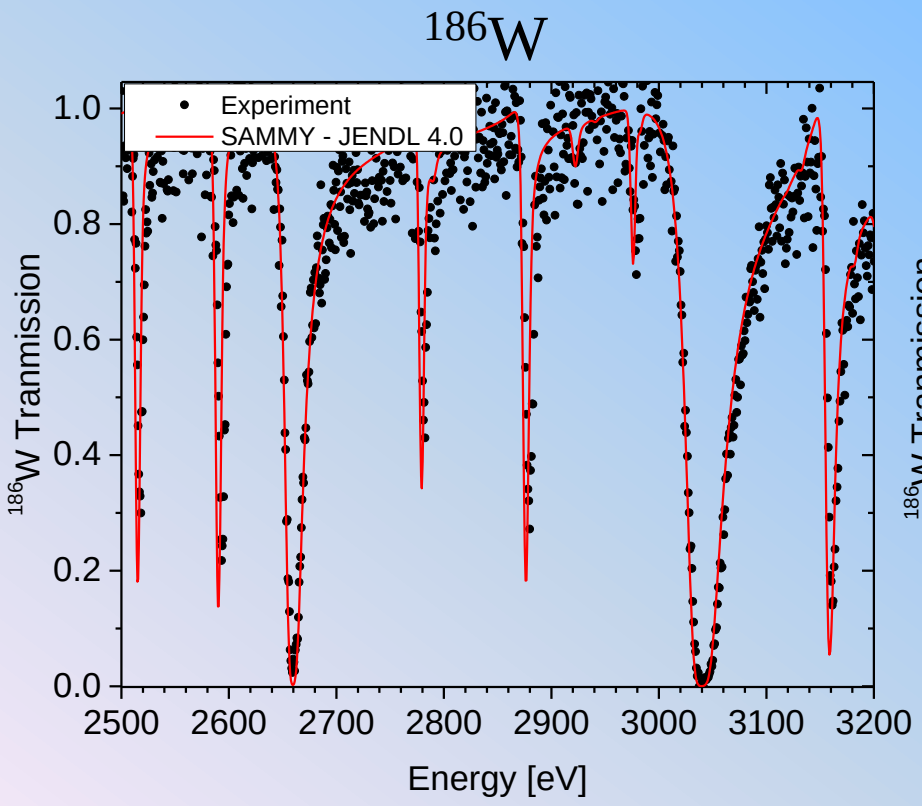
^{186}W Transmission results

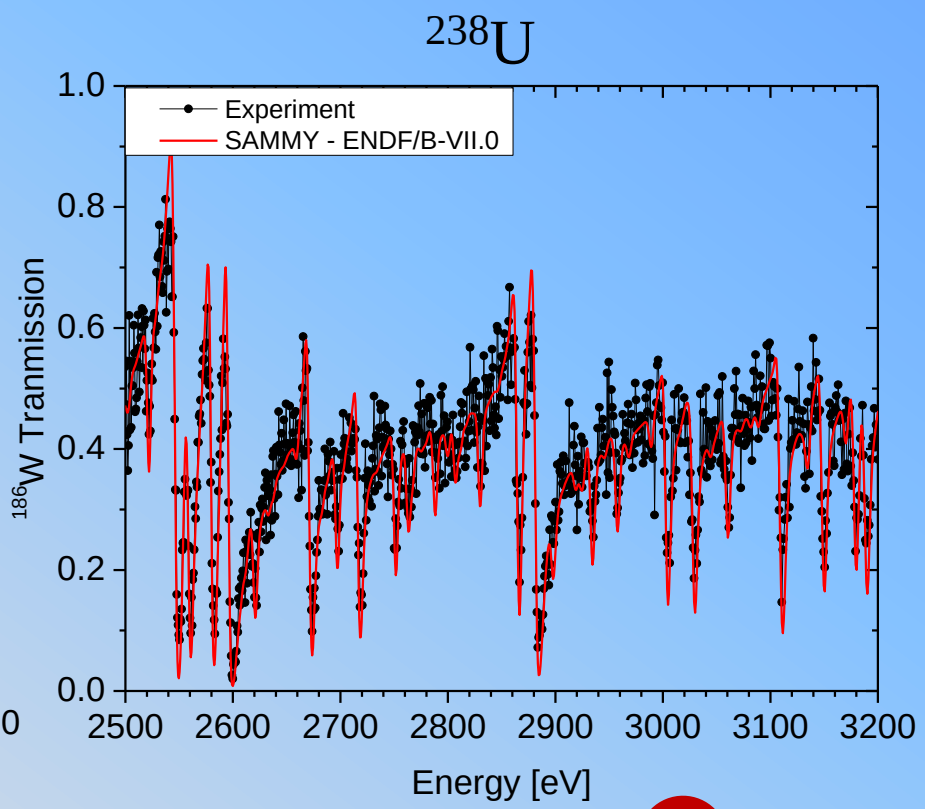


- Transmission was measured in the energy range from a 10 eV to 400 keV
- The region of interest is highlighted in green
- On this scale seems like good agreement with JENDL 4.0
- ENDF/B-VII.1 seemed to have some issue with extra resonances (not shown).

^{186}W Transmission results: 2.5 – 3.2 keV

- Energy resolution was fitted to the ^{238}U sample
- ^{186}W shows energy shifts which are not visible in the ^{238}U
- **Data were delivered to ORNL**





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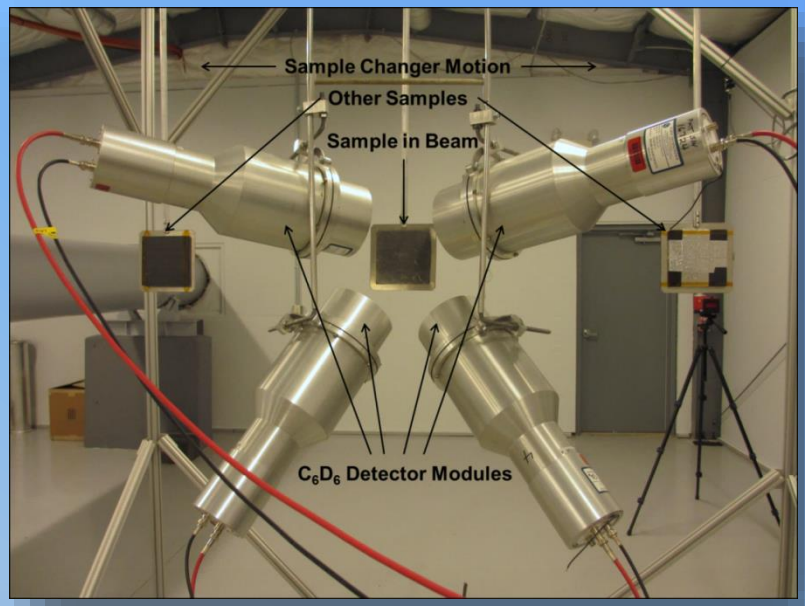
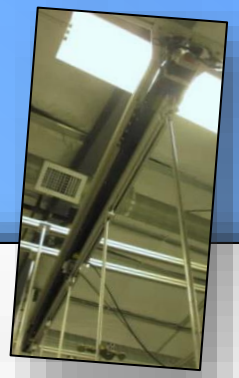
Mid-Energy Capture Detector System Overview

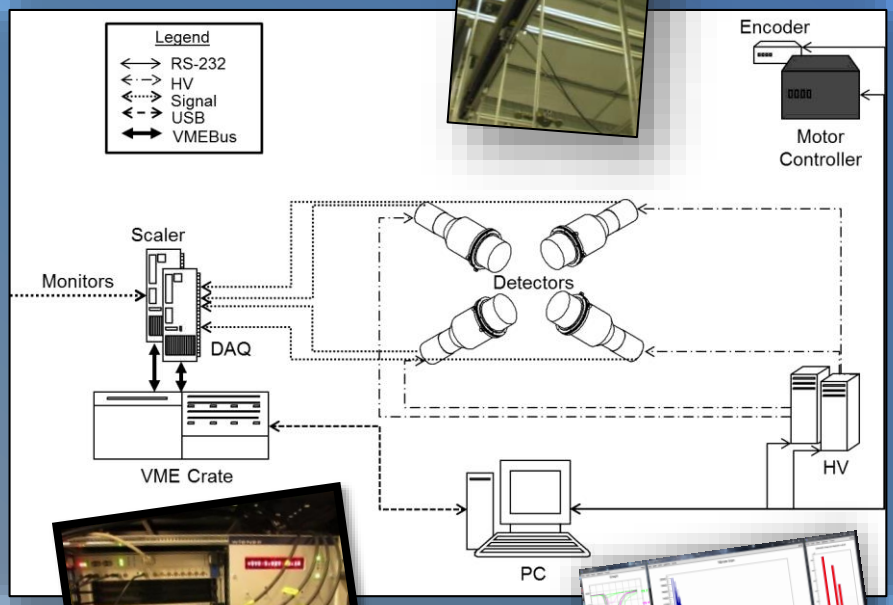
- 4 C_6D_6 detector modules manufactured by Eljen Technology
- **Low mass, low neutron sensitivity design**
- Located at 45m flight path in newly constructed flight station
- Measurements made from 1 eV to 1 MeV



Mid-Energy Capture Detector System Overview

- **Sample Changer**
  - Velmex BiSlide linear translation table w/ stepper motor and magnetic position encoder
- **Data Acquisition**
  - 8-channel SIS3305 digitizer w/ 10-bit, 1.25GHz functionality
- **Beam Flux Monitoring**
  - 8-Channel MDGG-8 Flexible Delay/Gate Generator & Scaler
- **Detector Bias**
  - 2 Dual-channel 3kV NHQ-203M high voltage supplies
- **Software**
  - Custom C/C++ libraries for system control, data acquisition, visualization and data analysis

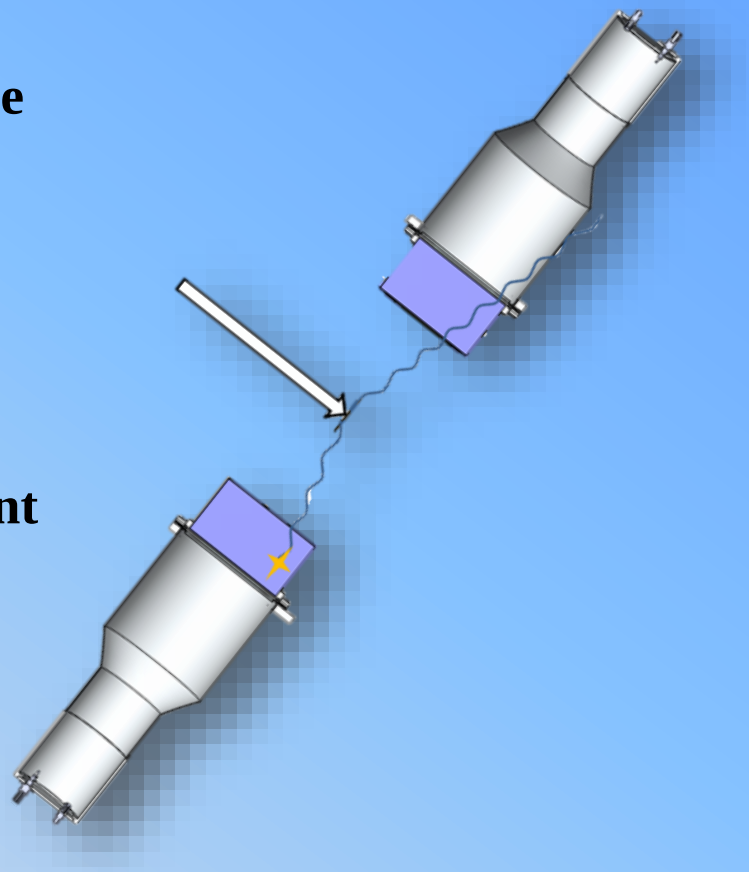




Mid-Energy Capture Detector Principle of Operation

Uses the "**Total Energy**" detection principle:

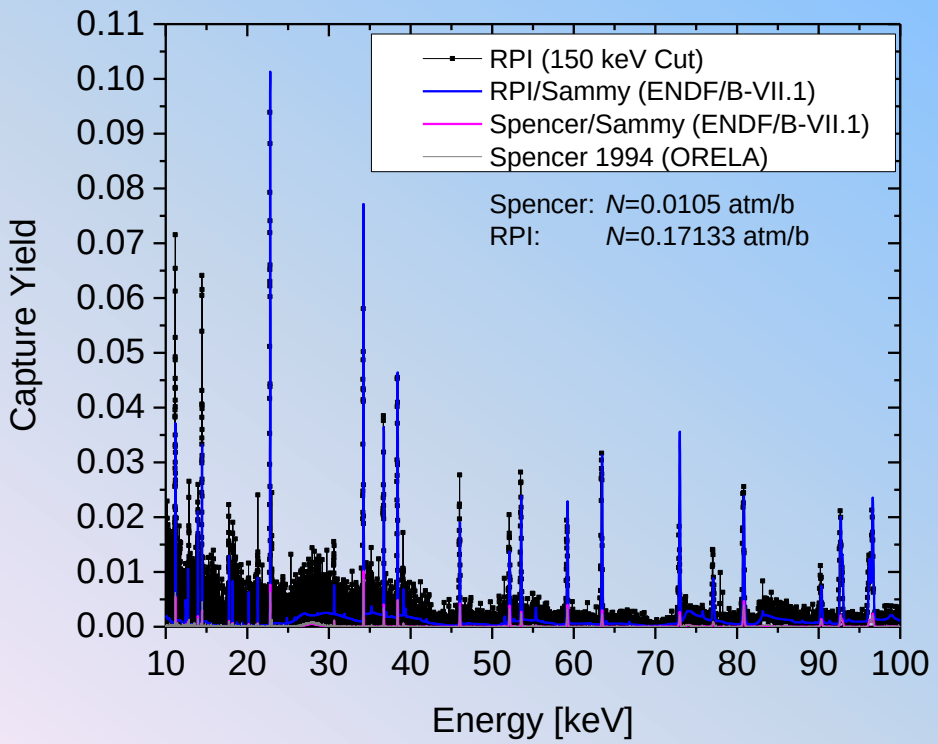
1. Detect only a **single photon per capture** cascade
2. Assert that the detection **efficiency is proportional** to the incident photon energy
3. Given 1 and 2, it can be shown that the total **efficiency to detect a capture event is proportional to the total excitation energy** of the compound nucleus, and insensitive to the cascade.

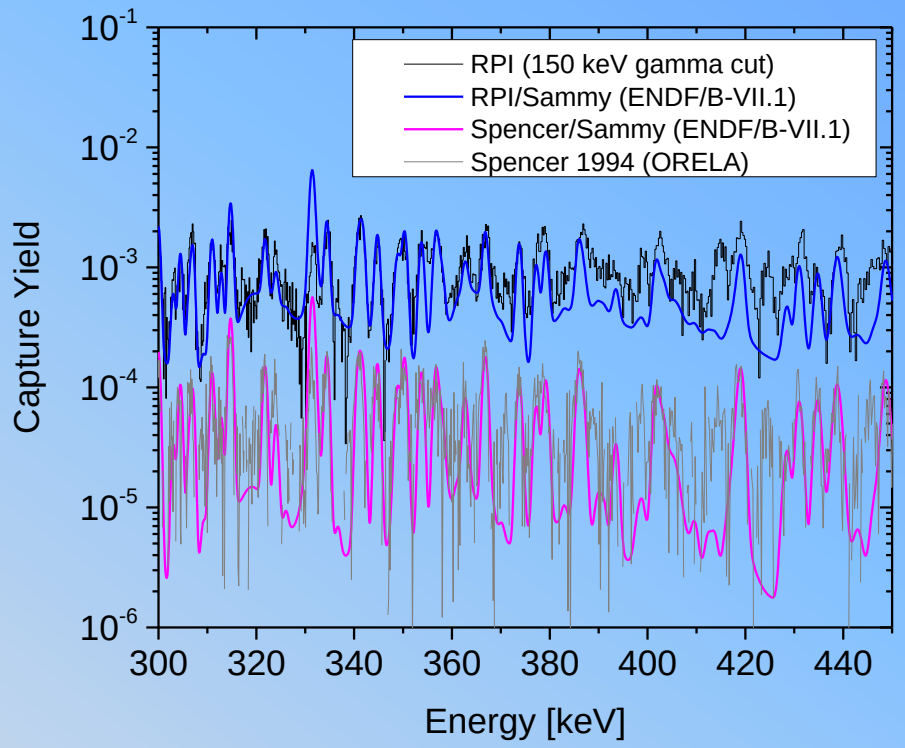


Requires a weighting function

^{nat}Fe Capture measurment

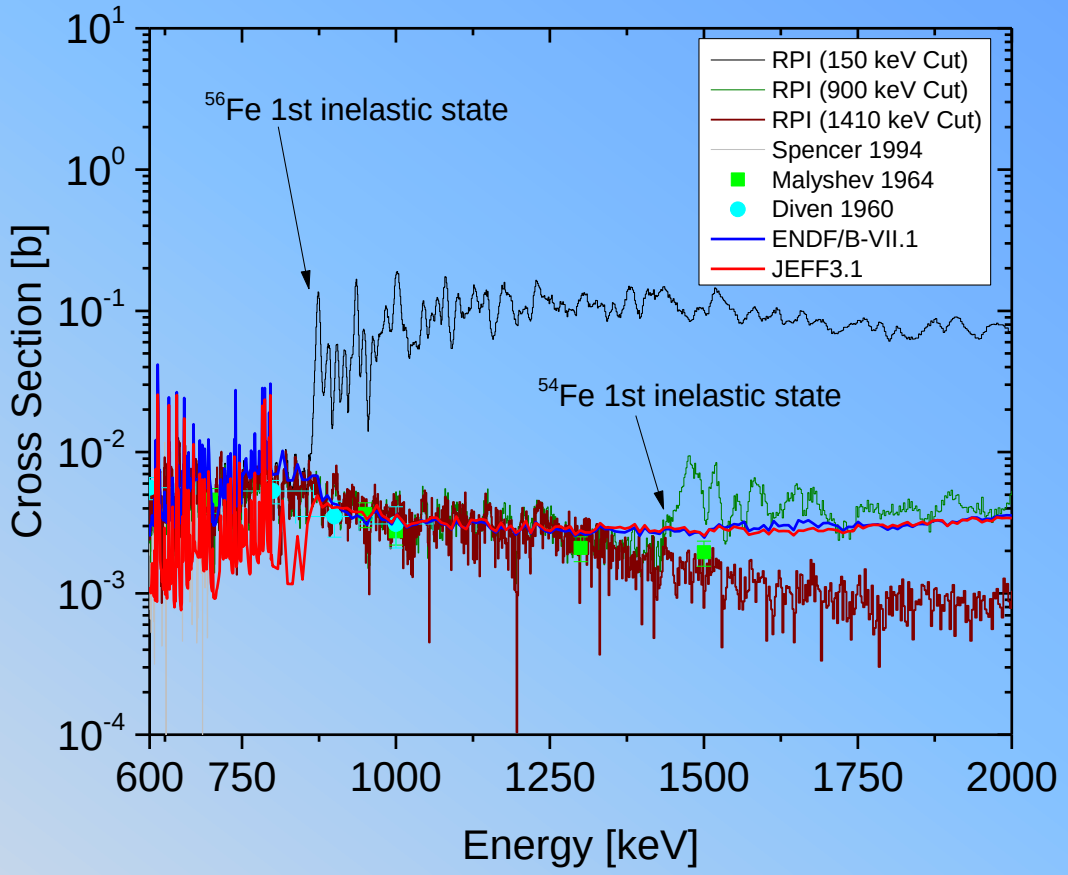
- ^{nat}Fe was used as a test to compare with evaluations and other measurements
  - The RPI data (45m flight path) has good energy resolution compared to the Spencer ORELA data (40m flight path)
  - The RPI data provide information above 700 keV (next slide)





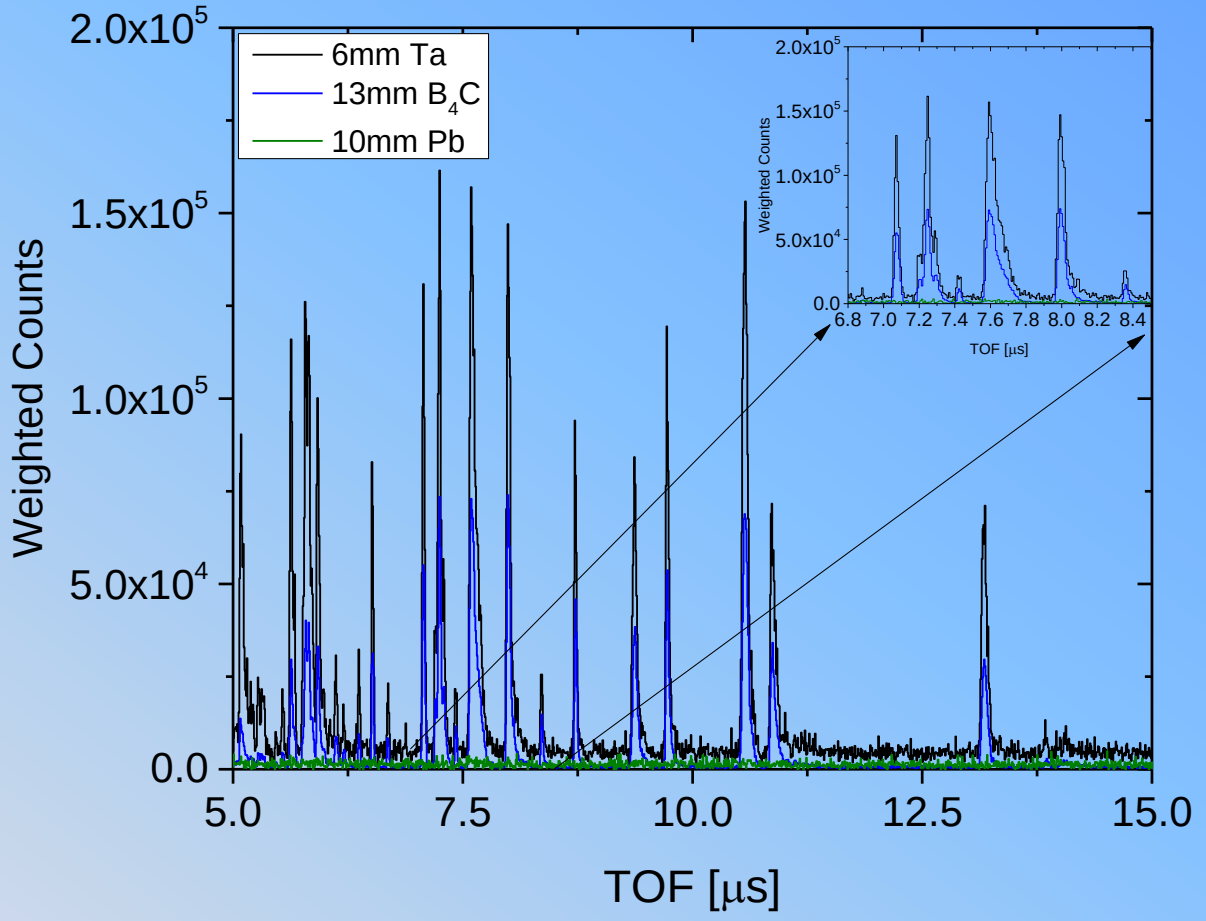
^{nat}Fe Capture Cross Section above 847 keV

- New capture data obtained above 847 keV and 1409 keV inelastic states in ^{56}Fe and ^{54}Fe
- Capture signal separated from inelastic scattering signal by post-processing digitized waveforms with different energy deposition cutoffs
- Good agreement with other experiments
- The data are lower than the evaluations above 1400 MeV



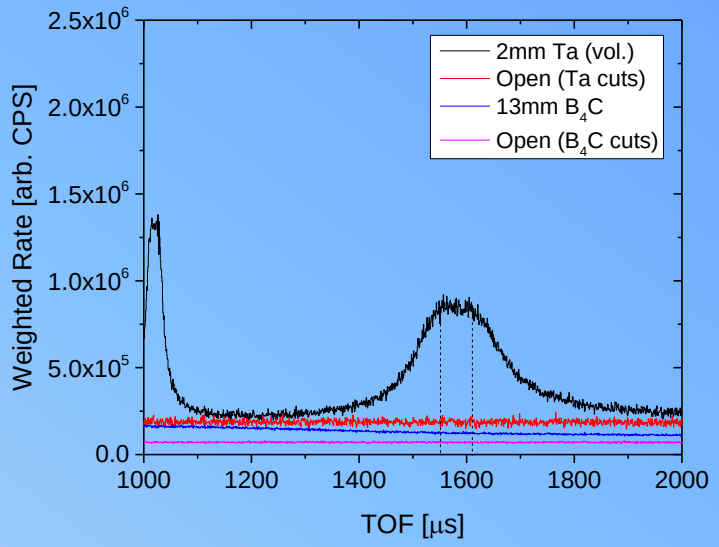
^{181}Ta Iron Filtered Beam Capture Measurement: Method

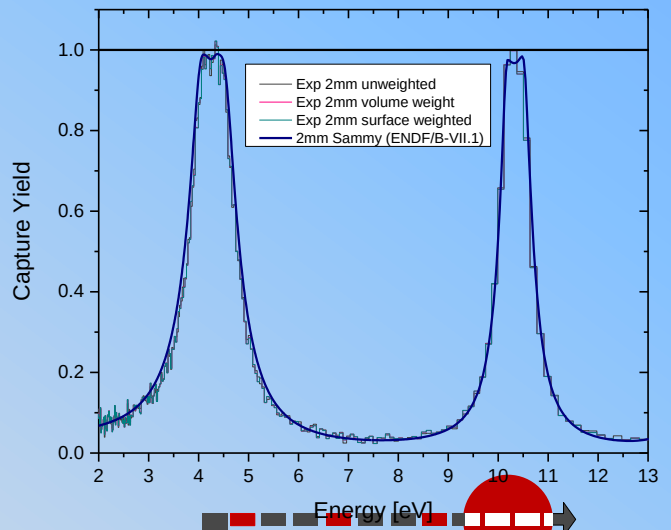
- Count rates for Ta and B_4C samples were summed under each filter transmission peak.
- Pb scattering sample used to confirm negligible neutron background



^{181}Ta Iron Filtered Beam Capture Measurement: Normalization

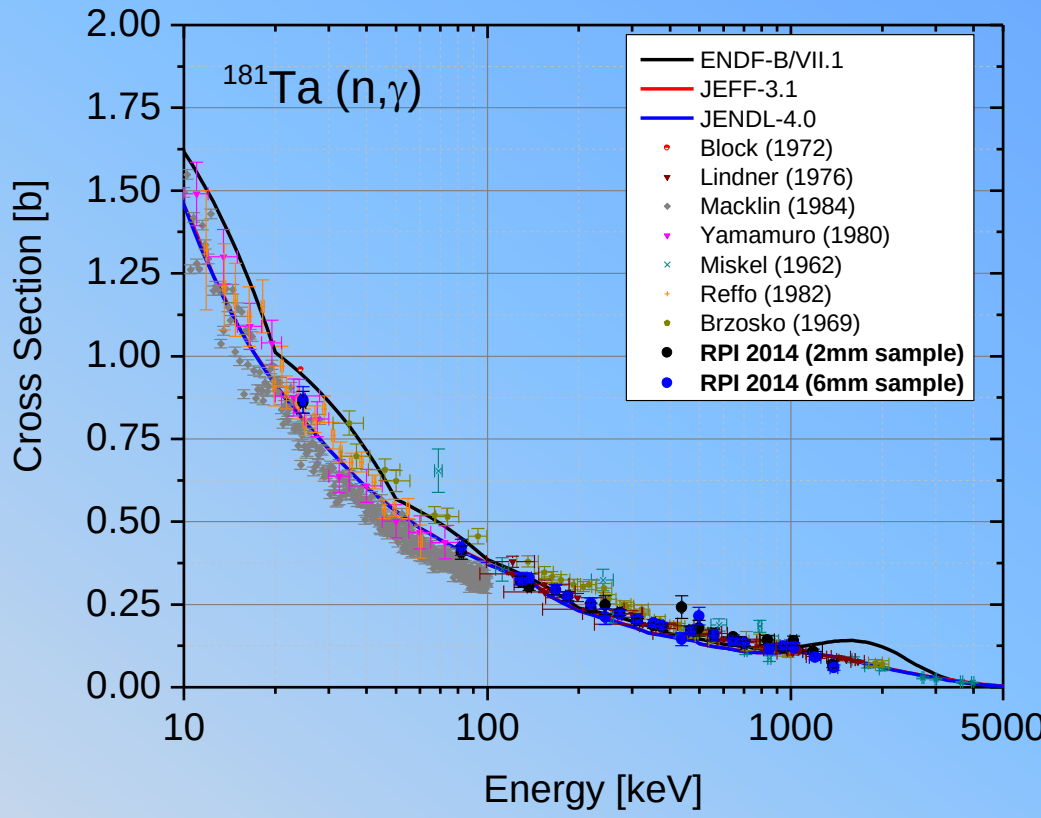
- Unfiltered run performed to determine normalization factor from 4.2 eV saturated resonance
- Normalization factor determined from the ratio of B_4C to Ta counts at the location of the saturated resonance ($Y_\gamma \approx 1$)
- A refinement of the normalization is based on a SAMMY calculations





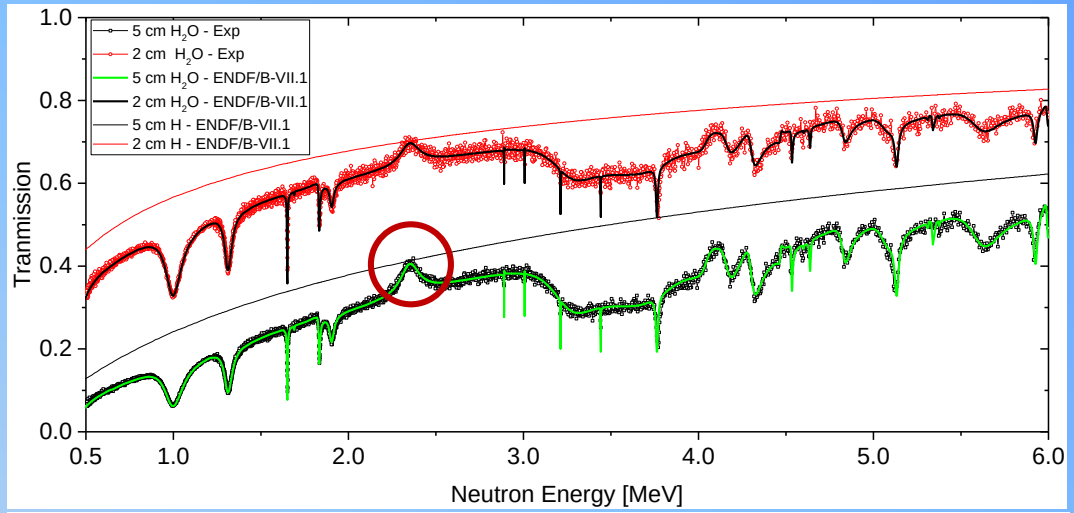
^{181}Ta Iron Filtered Beam Capture Measurement: Cross Section

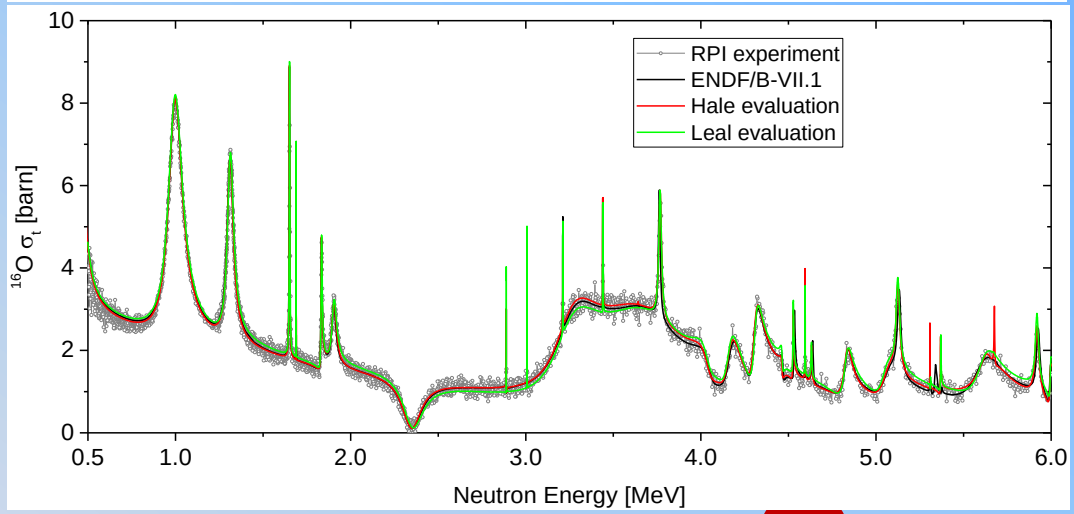
- As expected a thick sample requires larger corrections
  - Self shielding correction is large
  - Multiple scattering correction is large
  - Need to work on better understanding of the weighting function and its validity
- Thin sample data support the JEFF-3.1/3.2 evaluation
- Possible contamination from inelastic scattering apparent in ENDF/B-VII.1



Feasibility of ^{16}O total cross section measurement using H_2O

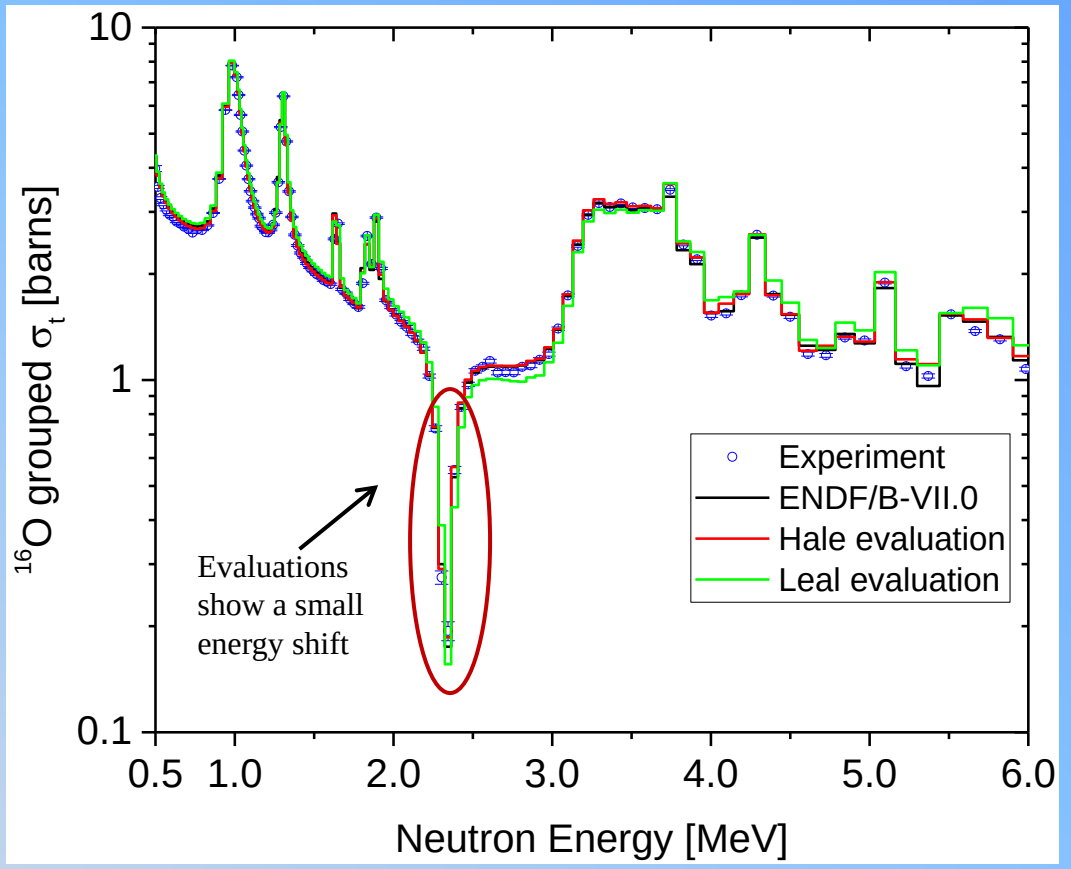
- Measurements of 2cm and 5cm H_2O in thin windows quartz optical cells
- Used 250m TOF and 10 ns pulse width for the feasibility test
- Used 3 fission chambers as beam monitors.
  - The experiment requires good monitor normalization
- In the ^{16}O "hole" at 2.34 MeV only H_2 is measured
  - **Provides verification of the normalization to about 1.5%**
- Used carbon for energy calibration





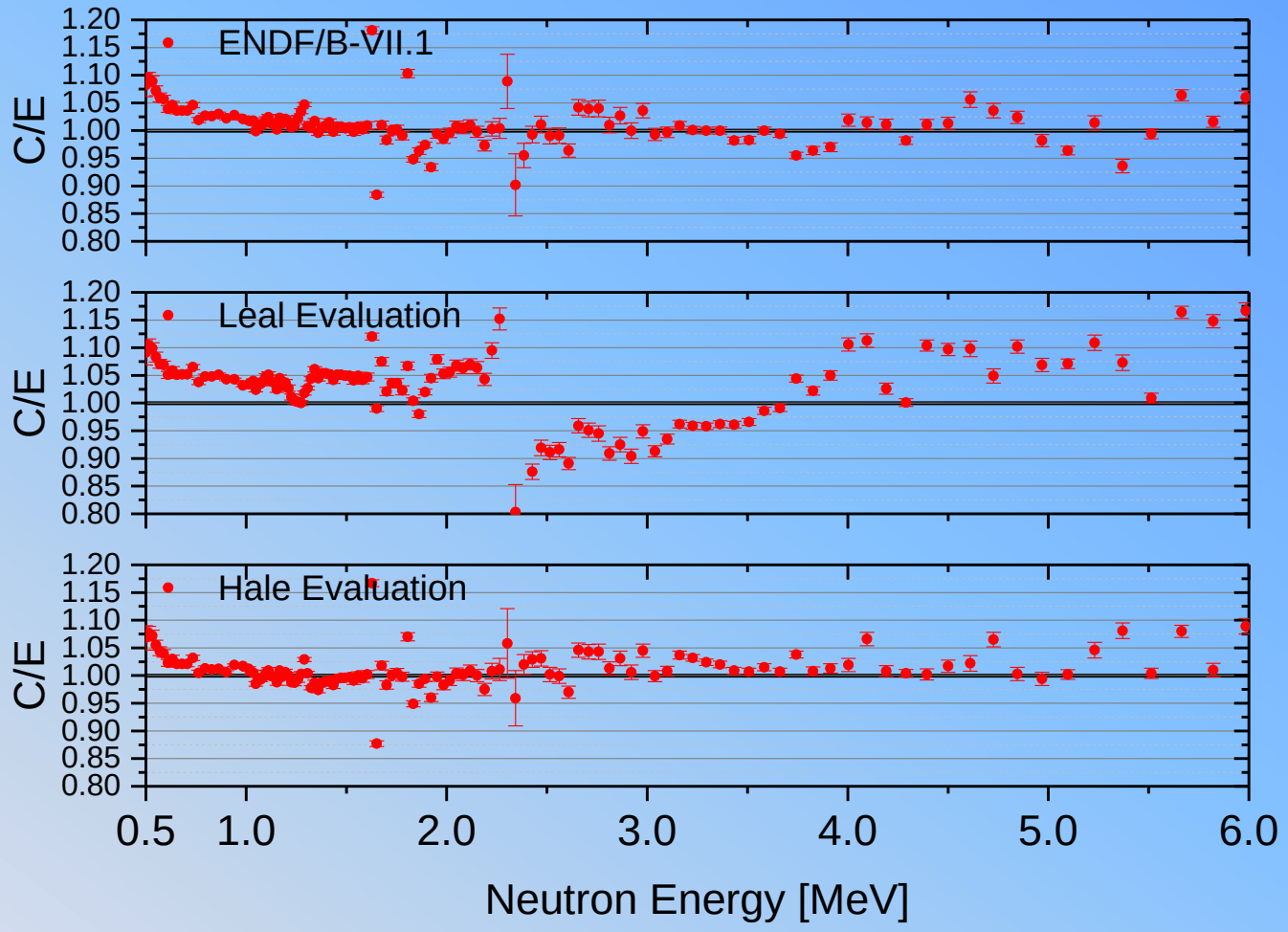
To compare the experiment with evaluation both were grouped

- Grouping reduces the statistical uncertainty
- Grouping preserves the number of neutrons transmitted through the sample
- Grouping can be done in two ways:
  - Group the cross section
  - Group the transmission and then compute the effective cross section
- Both options gave similar results
  - **The grouped cross section is shown**



^{16}O C/E

- Overall the evaluations are higher than the experiment
- Between 3-6 MeV ENDF/B-VII.1 matches the experiment best (ENDF is ~0.5% lower)
- It is feasible to provide new information on ^{16}O
  - Normalization of the experiment is critical
- H normalization is better than 1%



Summary

- **Publications since the last CSEWG meeting**
  - Gd isotopes – published, NSE Vol. 180, Number 1, May 2015.
  - Eu – published , Annals of Nuclear Energy, Vol. 69, pp. 74-89, July 2014.
  - ^{238}U – published, Annals of Nuclear Energy, Vol. 73, pp. 455-464, November 2014.
  - Mo URR - Accepted to Phys. Rev. C
- **Analysis in progress**
  - High energy (0.5-20 MeV) transmission: Fe, Ti, Ta, Cu, Zr and $^{92/94,95,96,98,100,nat}$Mo
  - RRR (capture/transmission) : ^{161,162,163,164}Dy, Cs, Rh , Re, Fe,
  - URR capture: Ta,
  - ^{nat}Fe neutron scattering
  - Thermal scattering H_2O, polyethylene, quartz
- **Measurements since the last CSEWG meeting**
  - Transmission: H_2O, ^{236}U, ^{186}W
  - Capture: Fe, Ta
- **Planned/in progress measurements**
  - Scattering: Pb, Zr
  - Capture: ^{95}Mo