Report on U.S. Experimental Activities

WPEC 2015

Yaron Danon

Rensselaer Polytechnic Institute, Troy, NY 12180, USA

CSEWG measurements committee chair

WPEC May 21-22, 2015, NEA Paris, France

Introduction

- **The usual November 2014 CSEWG meeting was dedicated to the CIELO project.**
- **A min-CSEWG meeting was held on May 7-8 at BNL**
  - Resulted in limited updates on US experimental effort.
- **The US experimental effort reported is based the mini-CSEWG meeting reports.**
- **Reports from different laboratories:**
  1. Recent ORNL Neutron Cross-Section Measurements Activities
  2. Recent Nuclear Data Research at RPI
  3. Nuclear Data Experiments at LANSCE, Brief Highlights 2014-2015

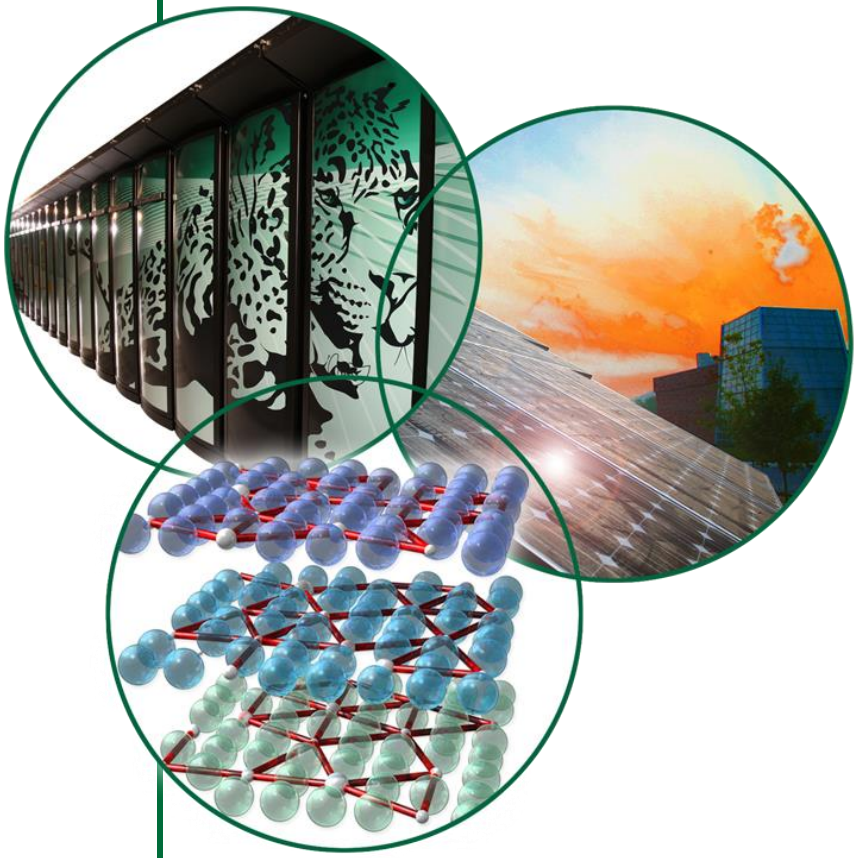
- **This report represents part of the U.S. nuclear data activity.**

Oak Ridge National Laboratory

- **Resonance Region Measurements**
  - **Ca** - Finalized measurements of Ca using metallic samples
    - The samples are in Al canning due to reactivity with air
    - Transmission experiments with 5 cm thick sample using FP4, 50 m
    - Neutron capture of thick sample using detector system at FP14, 60 m
    - Resonances are missing in ENDF file, even though reported in literature.
  - **Ce** - Measurements of Ce using natural metallic samples
    - The samples are in Al canning due to reactivity with air
    - Transmission experiments with different sample thickness are scheduled using FP4, 50 m
    - Neutron capture using detector system at FP14, 60 m
  - **V** - Measurements using metallic samples of different thickness
    - Neutron Transmission experiments with different samples are scheduled using FP4, 50 m
    - Neutron capture using detector system at FP14, 60 m
    - Capture and transmission experiments started
    - Experiments to be continued in FY16.

Recent ORNL Neutron Cross-Section Measurements Activities

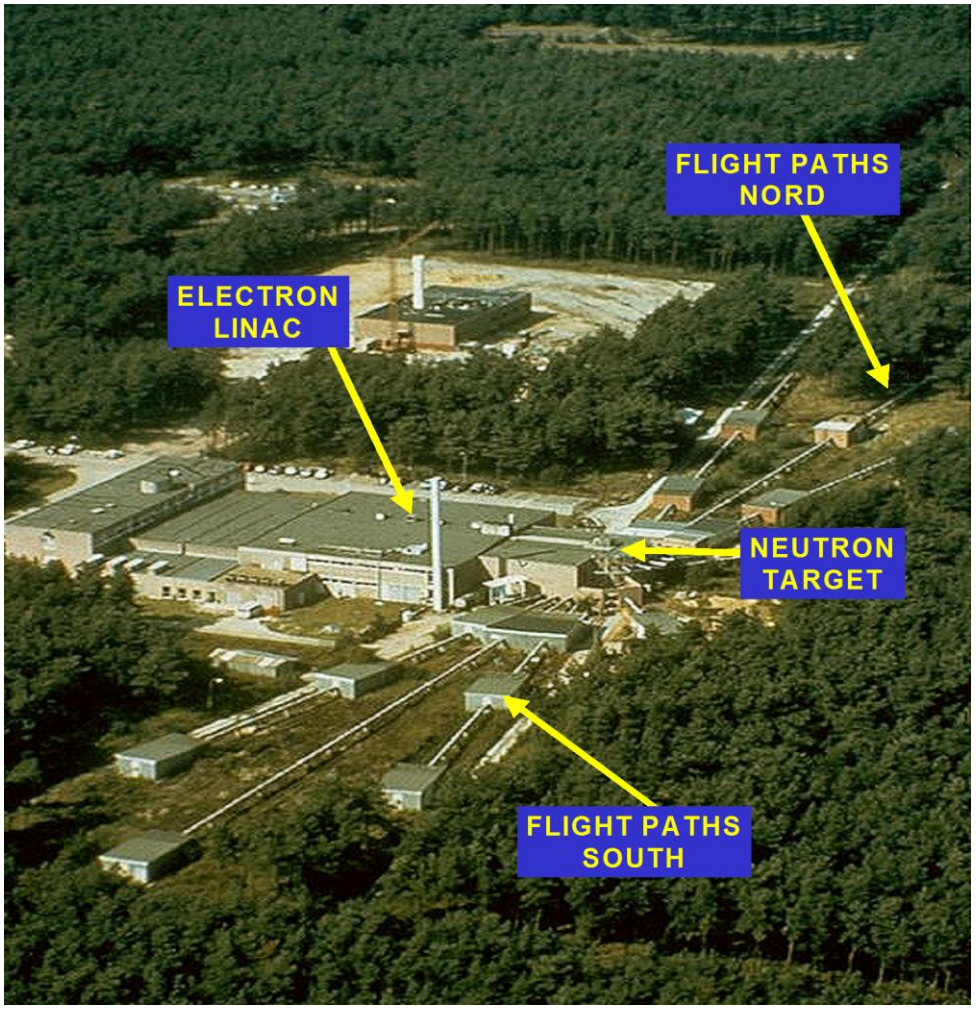
K. H. Guber
Oak Ridge National Laboratory
Oak Ridge, TN, USA



Mini-CSEWG Meeting
May 7-8, 2015

U.S. DEPARTMENT OF ENERGY

OAK RIDGE NATIONAL LABORATORY
MANAGED BY UT-BATTELLE FOR THE DEPARTMENT OF ENERGY



GELINA

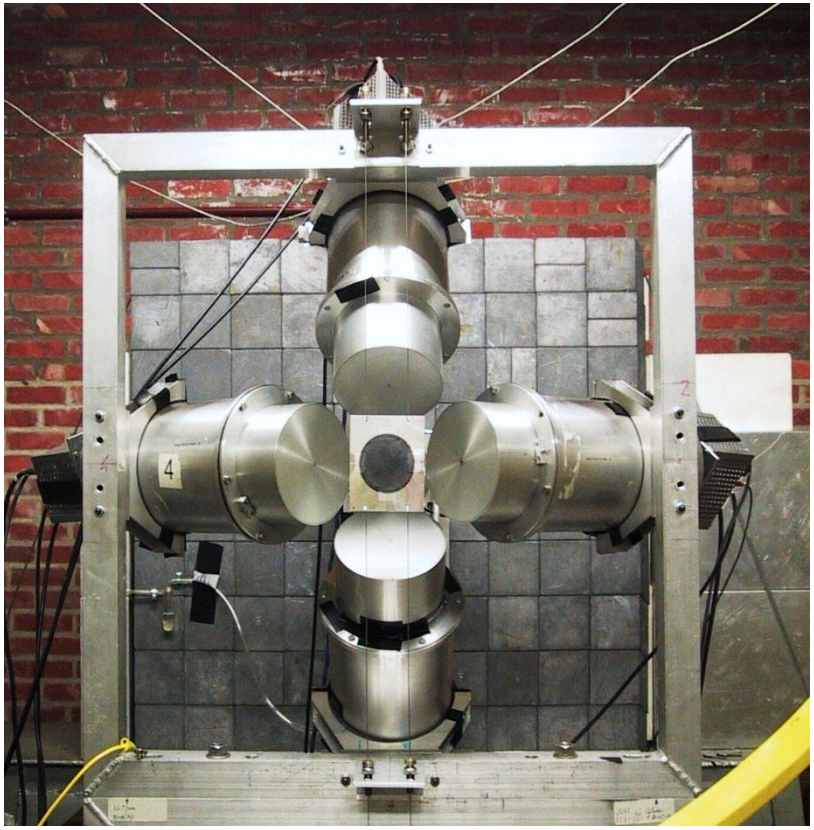
- **Time-of-flight facility**
- **Pulsed white neutron source**

  (10 meV < E_n < 20 MeV)
- **Multi-user facility with 10 flight paths (10 m - 400 m)**
- **The measurement stations have special equipment to perform:**
  - **Total cross section measurements**
  - **Partial cross section measurements**

Pulse Width	: 1ns
Frequency	: 40 Hz – 800 Hz
Average Current	: 4.7 μA – 75 μA
Neutron intensity	: 1.6 10^{12} – 2.5 10^{13} n/s

Capture Cross-Section Measurements at GELINA

L = 10 m, 30 m and 60 m



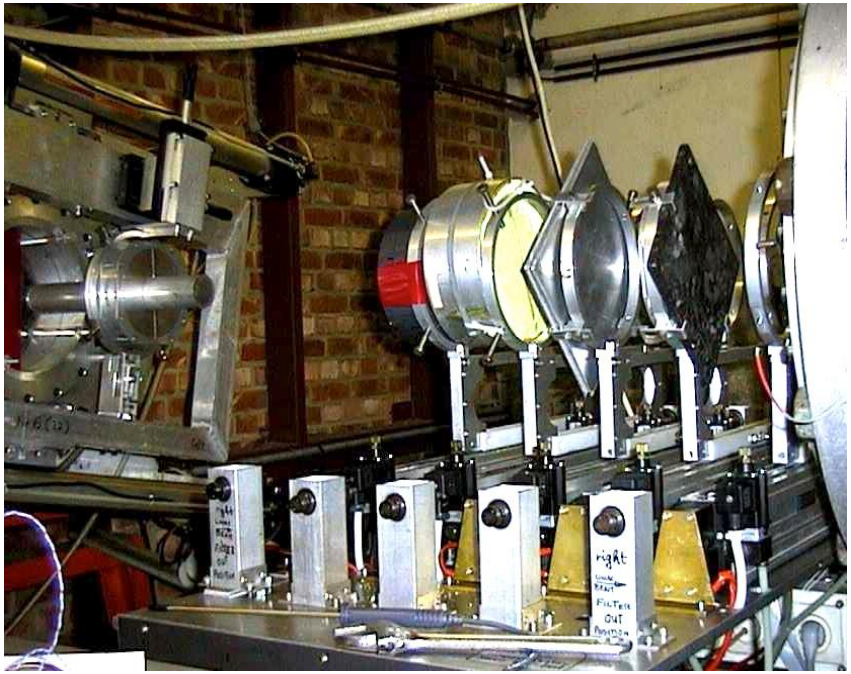
Total energy detection

- C_6D_6 liquid scintillators
  - 125°
  - PHWT
- Flux measurements (IC)
  - $^{10}B(n,\alpha)$
  - $^{235}U(n,f)$

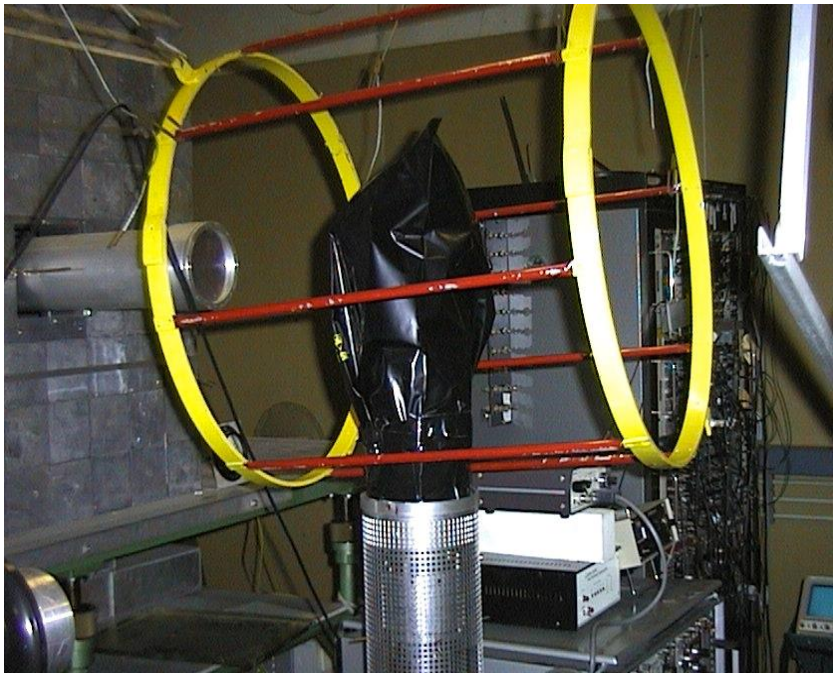
$$Y_{exp} = N\sigma_{\varphi}\frac{C_w - B_w}{C_{\varphi} - B_{\varphi}}$$

Transmission Measurements

Sample & Background Filters



Detector



Detector stations
Moderated: L= 30 m,50 m,(100 m,200 m)
Fast: L= 400 m

Low energy : $^{6}Li(n,t)\alpha$ Li-glass

High energy : H(n,n)H Plastic scintillator

$$T = \frac{C_{in}}{C_{out}} \cong e^{-n\sigma_{tot}}$$

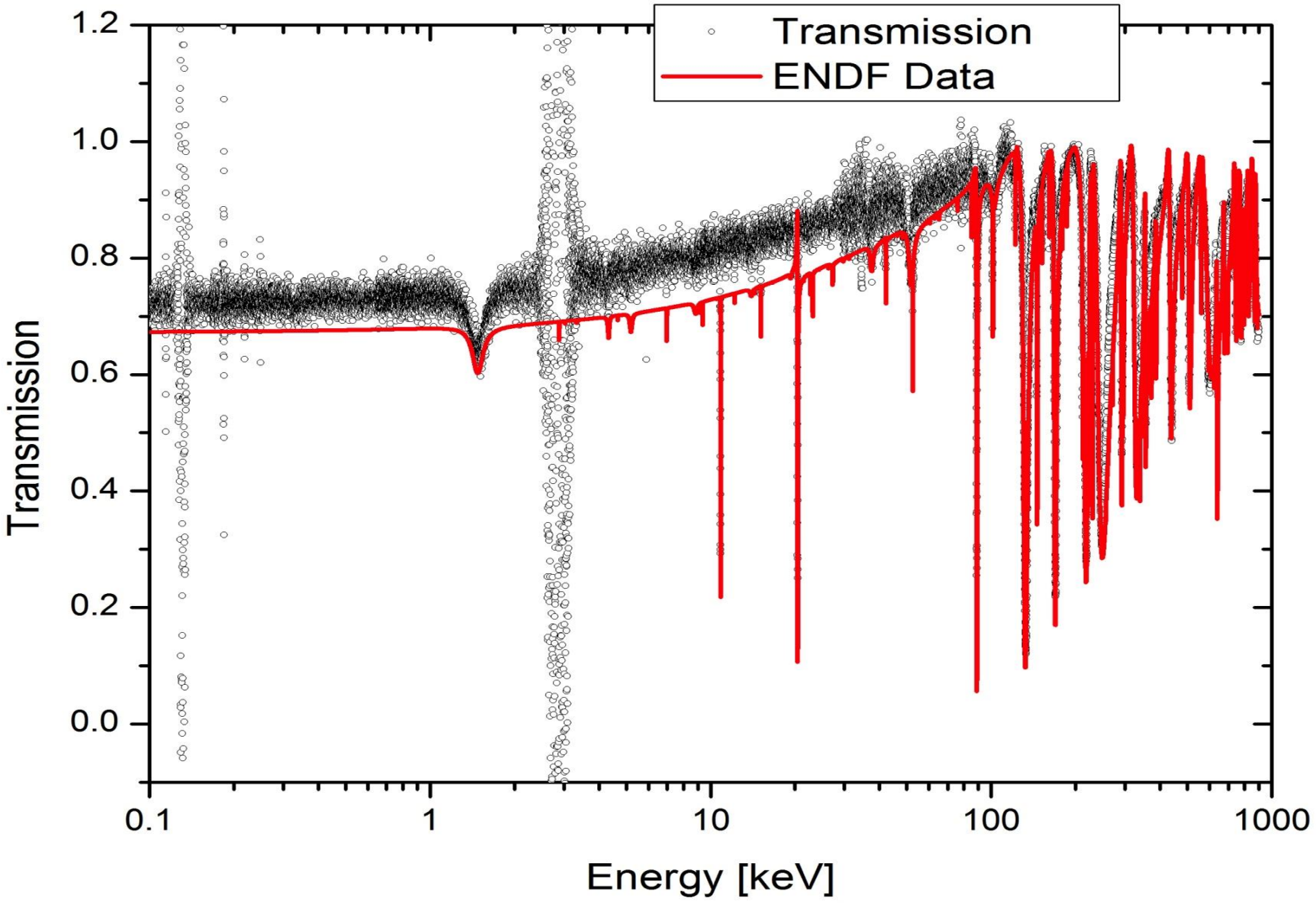
ORNL Measurement Activities for Calcium

- Finalized measurements of Ca using metallic samples
  - The samples are in Al canning due to reactivity with air
  - Transmission experiments with 5 cm thick sample using FP4, 50 m
  - Neutron capture of thick sample using detector system at FP14, 60 m

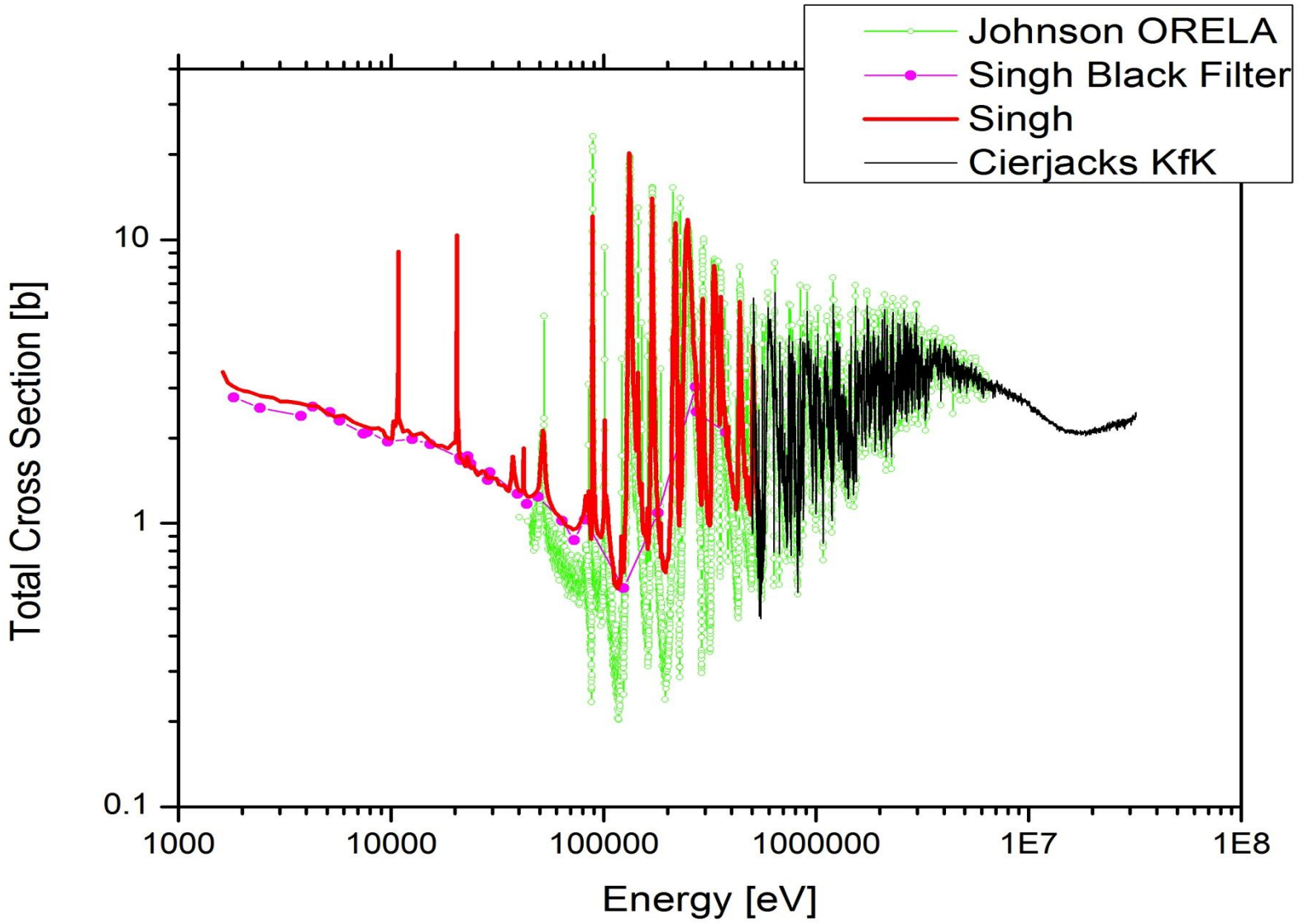
- Observation: Resonances are missing in ENDF file, even though reported in literature.

- Data will be included in the already started analysis and evaluation.

Ca Transmission with Co and Na Filters

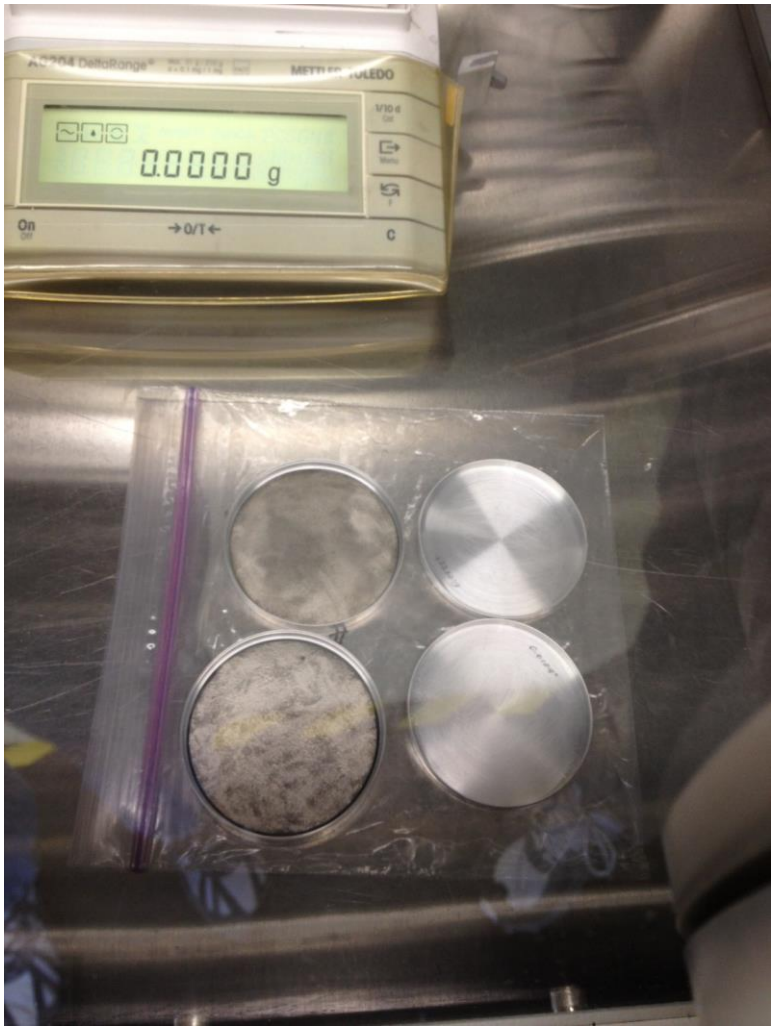


Ca Total Cross Sections from CSISRS to be analyzed and included in Evaluation

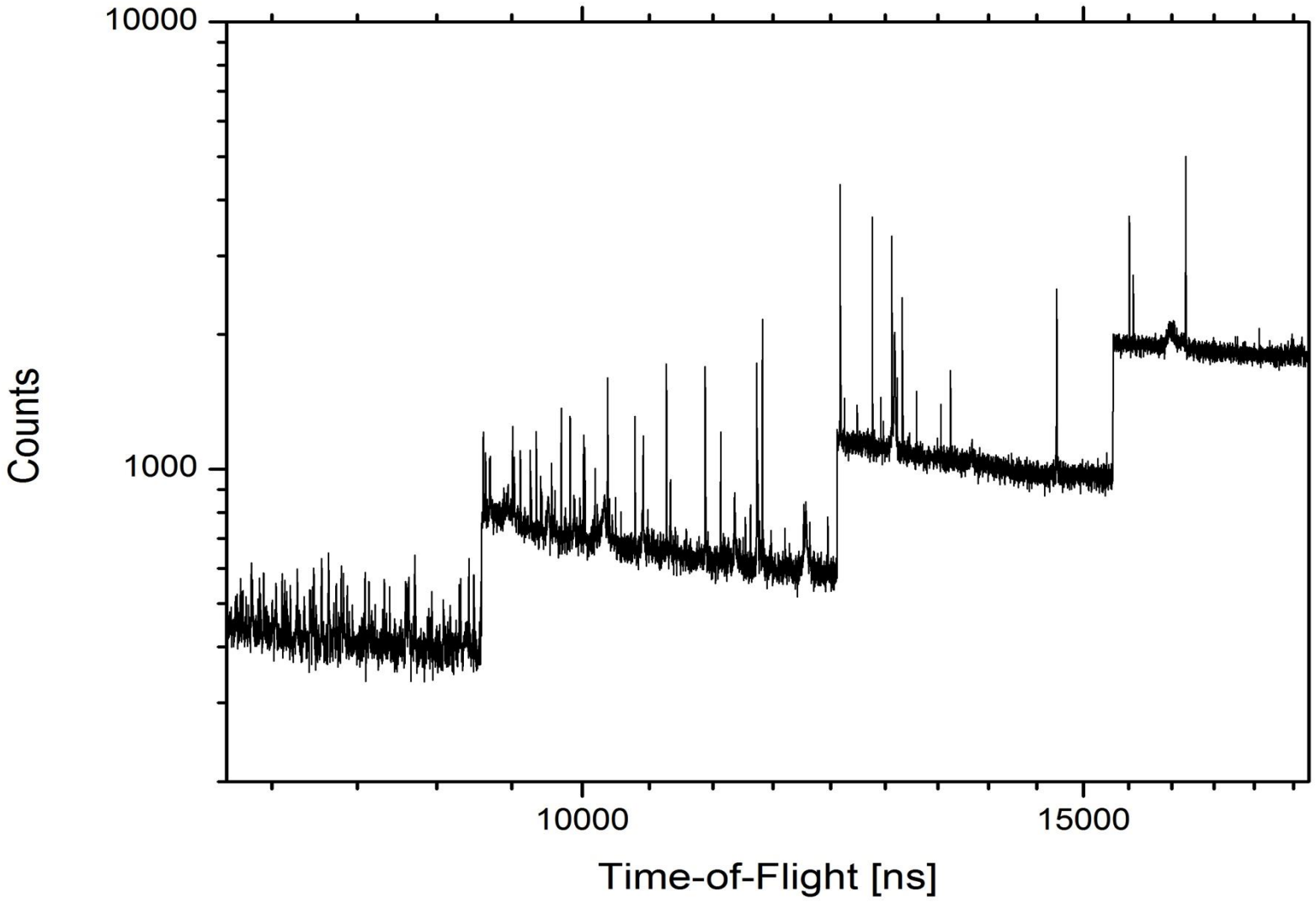


ORNL Measurement Activities for Cerium

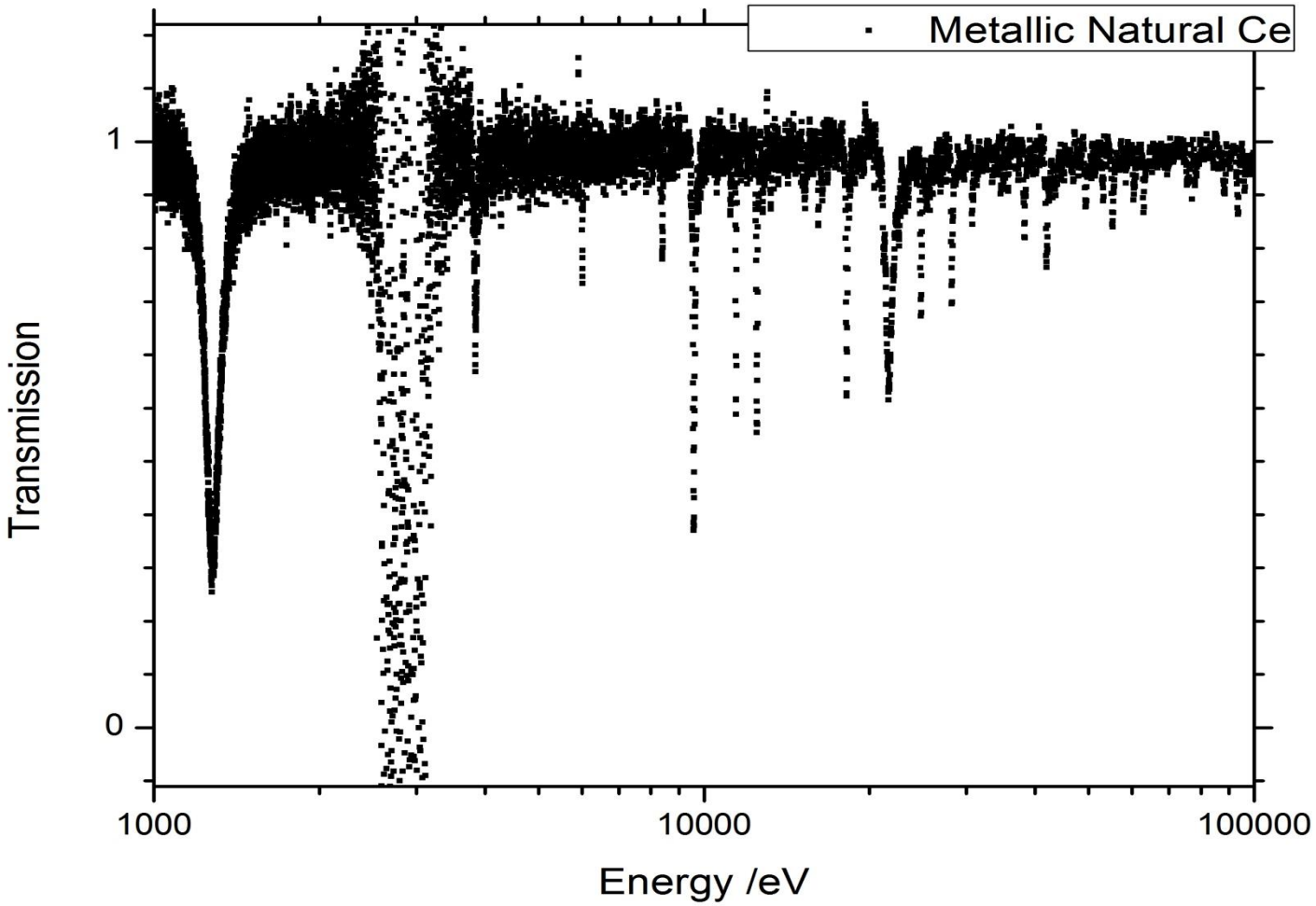
- Measurements of Ce using natural metallic samples
- The samples are in Al canning due to reactivity with air
- Transmission experiments with different sample thickness are scheduled using FP4, 50 m
- Neutron capture using detector system at FP14, 60 m



Natural Ce (n,γ) raw data
Resolving resonances above 200 keV



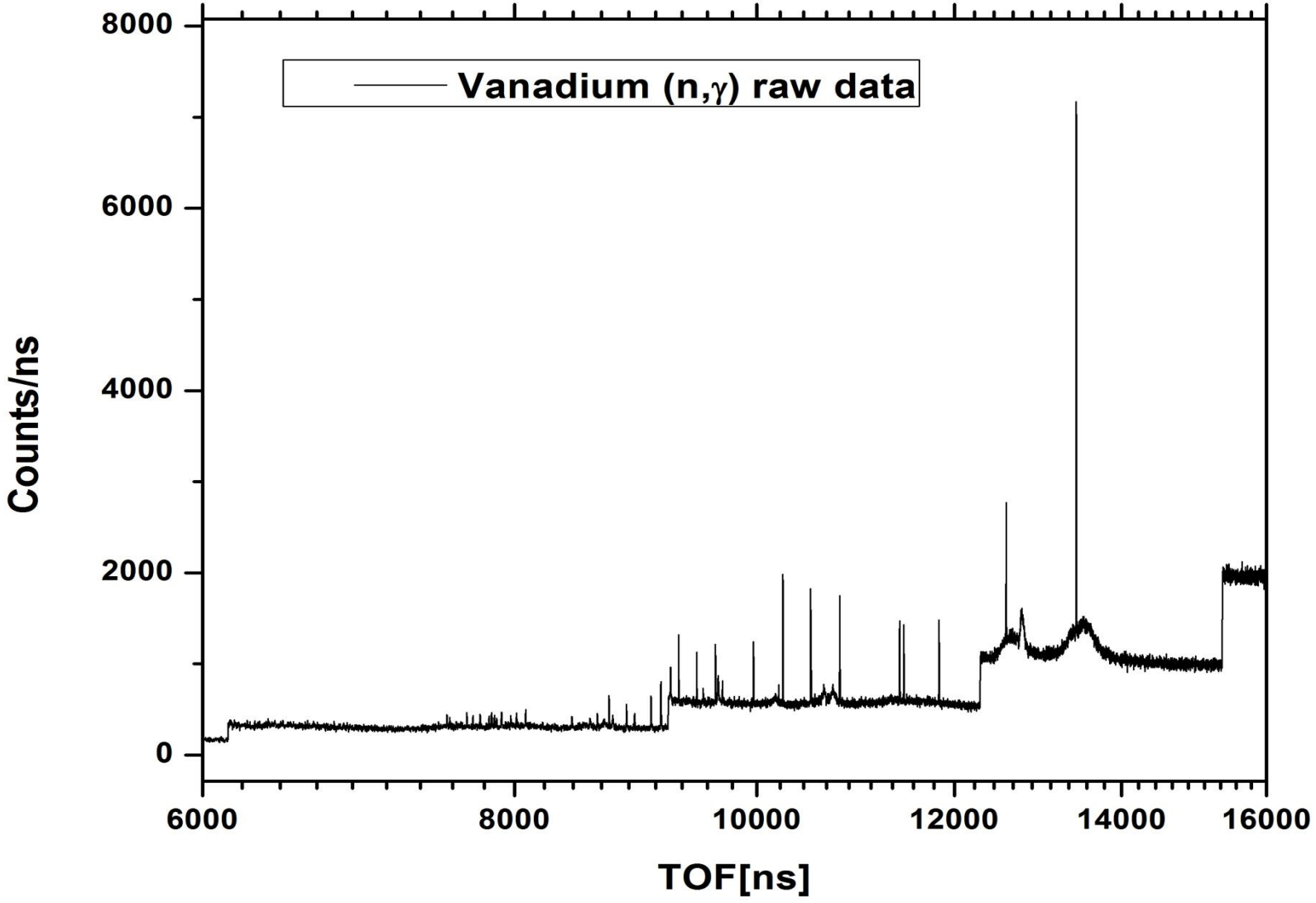
Transmission of thin Natural Ce Sample



ORNL Measurement Activities for Vanadium

- V is mono-isotopic
- Measurements using metallic samples of different thickness
- Transmission experiments with different samples are scheduled using FP4, 50 m
- Neutron capture using detector system at FP14, 60 m
- Capture and transmission experiments started
- Experiments to be continued in FY16.

V (n,γ) raw data for thin sample



Problems obtaining enriched Samples

- Due to contaminations of returned samples, DOE put a halt on leasing enriched isotopes.
- This affects planned experiments for Ce-142 using enriched samples.
- Future experiments for Zr isotopes are delayed.

Upgrades to GELINA

- After upgrade and renovation of the flight stations on the north side in 2011, now upgrade and renovation of the south side flight stations.
- Work started in spring and is to be finished end of this year.
- No experiments on neutron capture are possible.

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Recent Measurements

- **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 – 4 eV – 20 eV, 500 eV – 1 MeV, 45m flight path
- **Scattering**
  - Pb – 0.5 – 20 MeV
  - Zr <0.5 MeV in development
- **Thermal neutron scattering**
  - Quartz at temperatures of 20, 300, 550, 600 °C.
  - Polyethylene at temperatures of 295 K and 5 K.

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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 in internal review 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

Update on Nuclear Data Research at RPI

Report to CSEWG November, 2015

Y. Danon, E. Liu, E. Blain, A. Daskalakis, B. McDermott, K. Ramic, C. Wendorff

Rensselaer Polytechnic Institute, Troy, NY, 12180

and

D. Barry, R. Block, J. Burke, T. Donovan, B. Epping, G. Leinweber, M. Rapp

KAPL, Bechtel Marine Propulsion Corporation, Schenectady, NY ,12301-1072

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

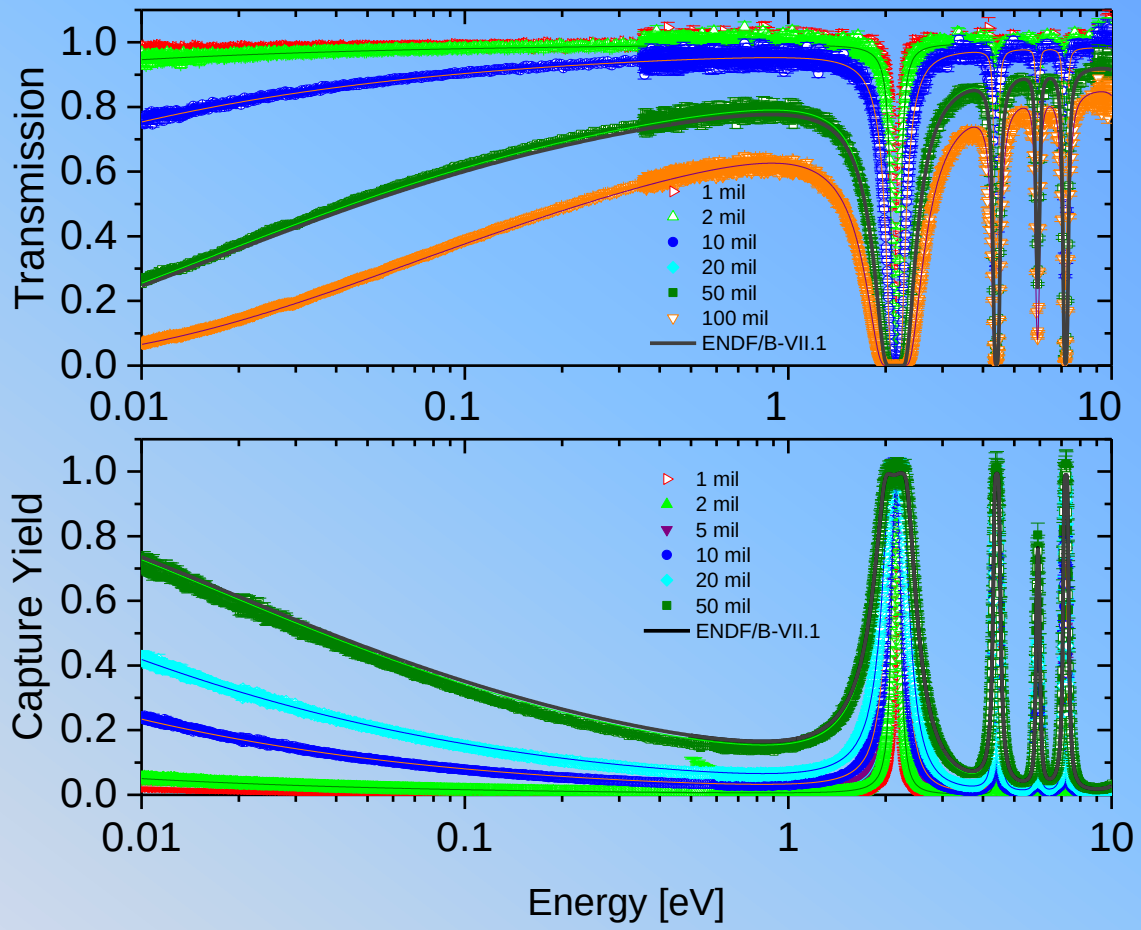
- **Scattering**
  - Pb - complete measurement and analysis
  - Zr - for E<0.5 MeV continue development
  - Hf - resonance scattering (for MC physics models)
- **Transmission**
  - W - 0.5 to 20 MeV
- **Capture**
  - ^{95}Mo, 45m station 1 keV to 500 keV.
    - If unavailable, one of the following ^{92,94}Mo,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

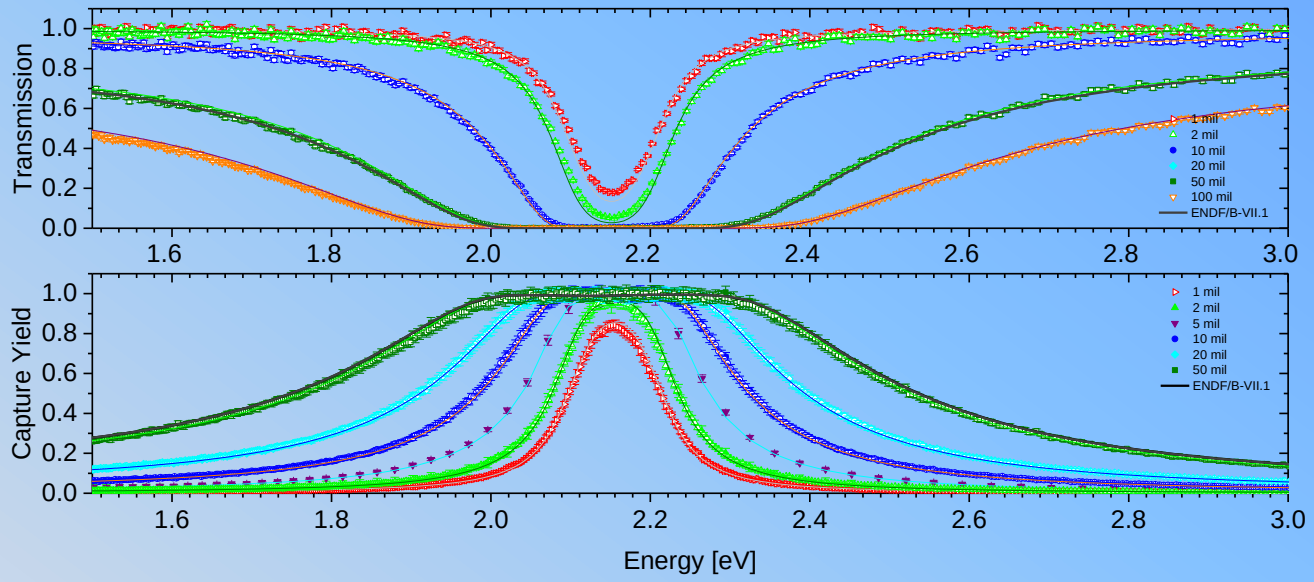
Re – Thermal Transmission and Capture Measurements

- 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

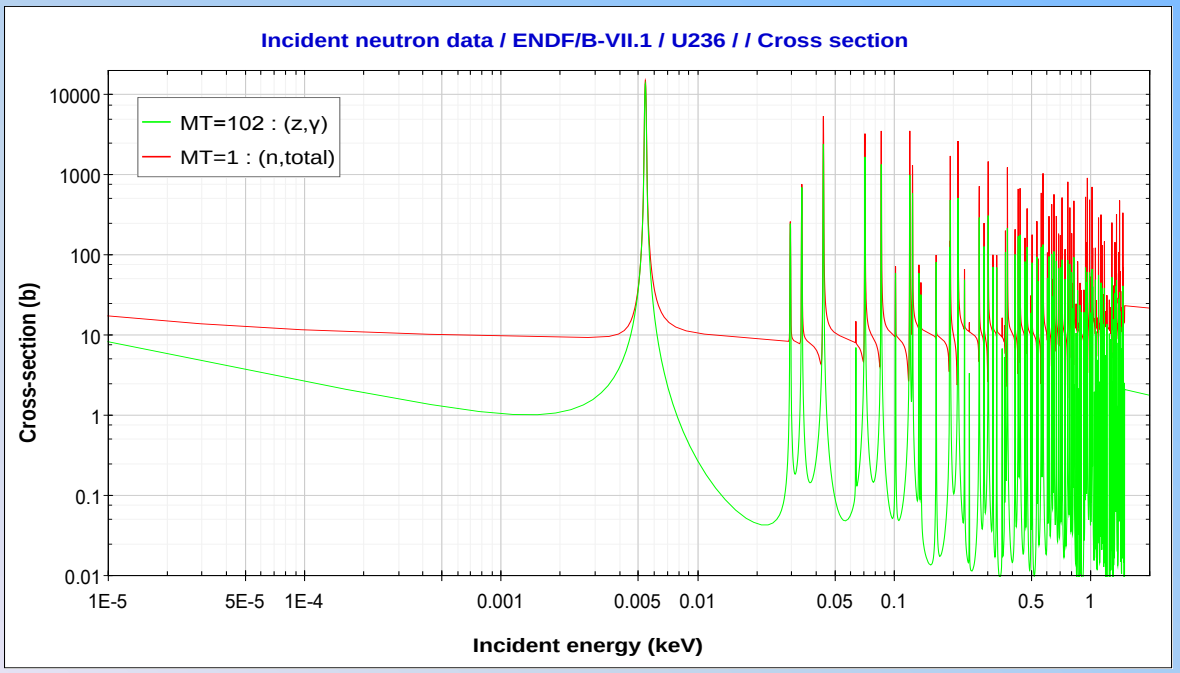


	Energy Range of This Work	Thermal σ_t [b]		Resonance Integral [b]		R` [fm]
Isotope	**N/A**	**Re-185**	**Re-187**	**Re-185**	**Re-187**	**(Combined fit of both isotopes)**
BMPC/RPI	thermal – 1 keV	120	80	1800	310	9.3+/-0.2
ENDF/B-VII.1	RRR ends at 2 keV	121	87	1738	301	8.7*

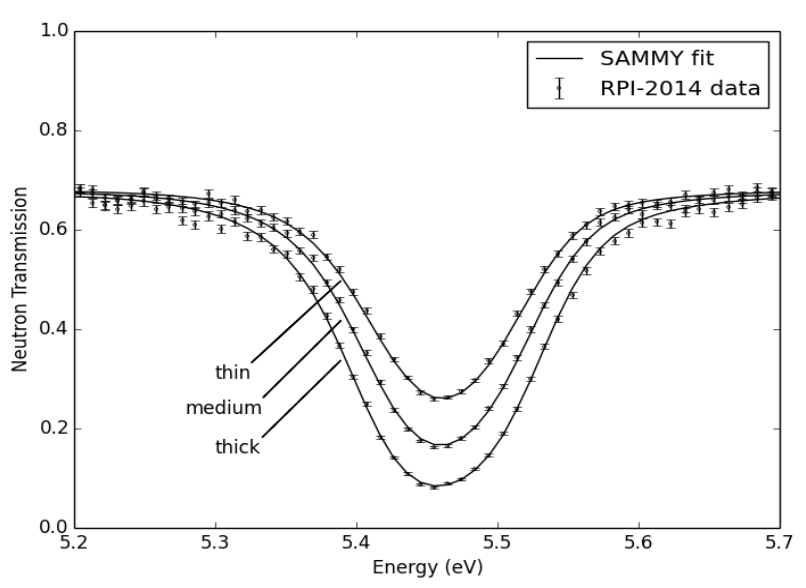
* Use the same R' for both isotopes. This is the value from Mughabghab, ENDF/B-VII.1 has a value of 7.9 fm which was acknowledged by NNDC as a typo.

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

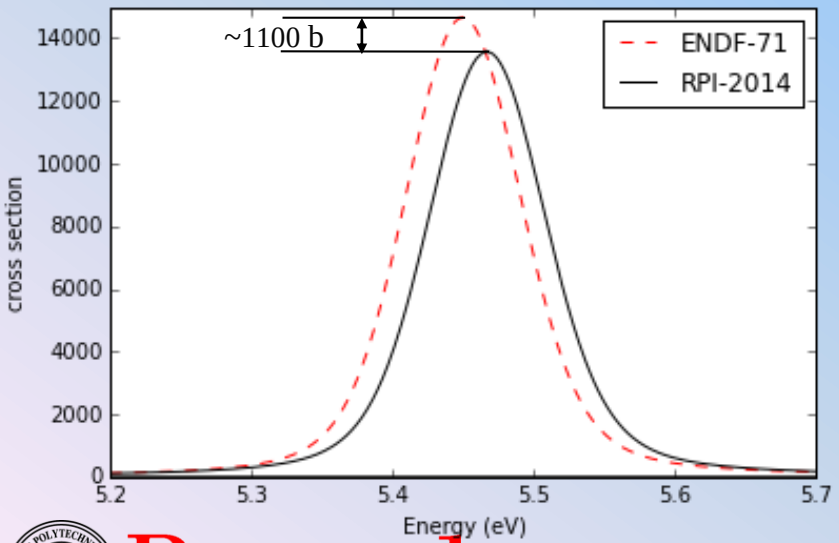
- High yield build-up product
- Strong resonance at 5.467 eV with total cross section over 13,000 barns
  - Difficult to measure since it is hard to make a "thin" ^{236}U sample
    - Used liquid sample
  - Last transmission measurements for ^{236}U was prior to 1960



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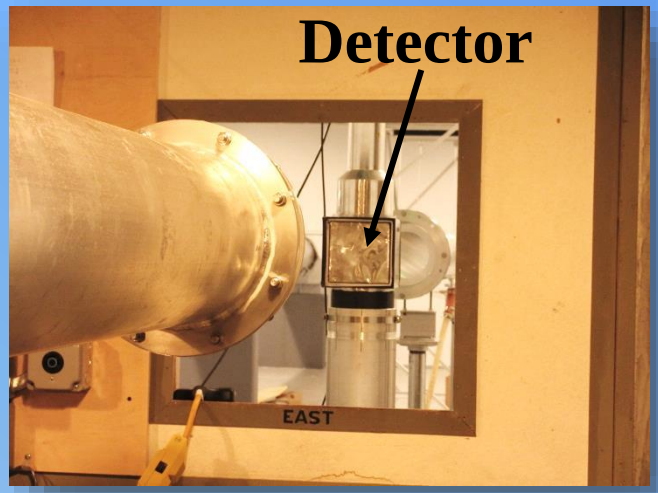
The ^{236}U results show a lower neutron capture resonance integral relative to evaluations

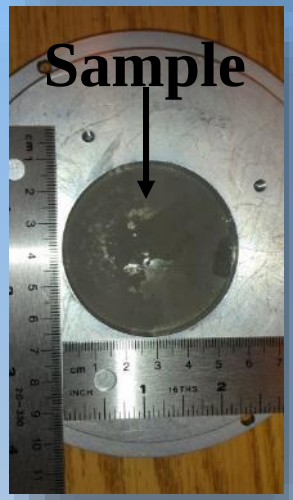
- Method developed to preserve ENDF71 thermal cross sections
- Effect on benchmarks is being assessed

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

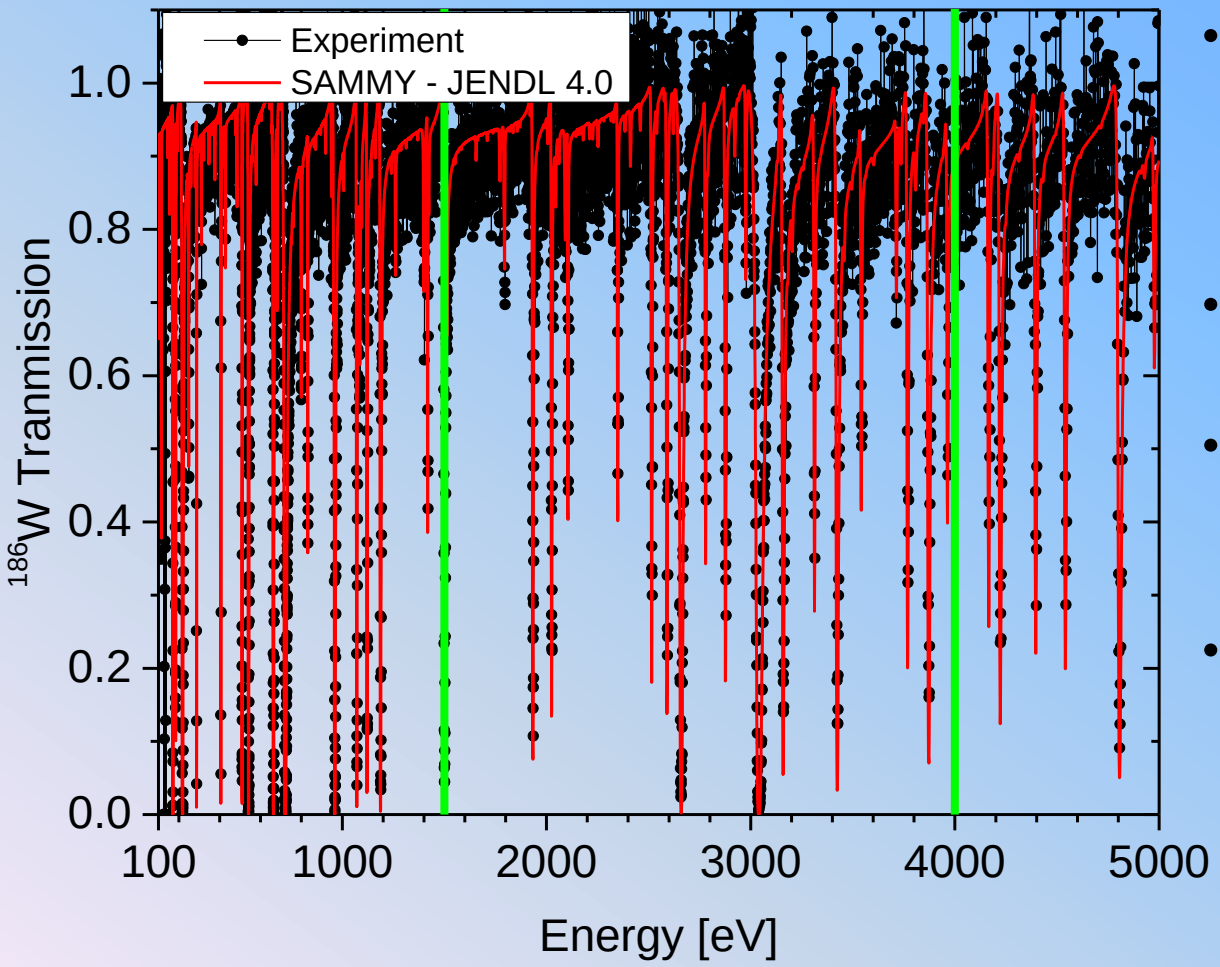
Transmission of ^{186}W

- 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





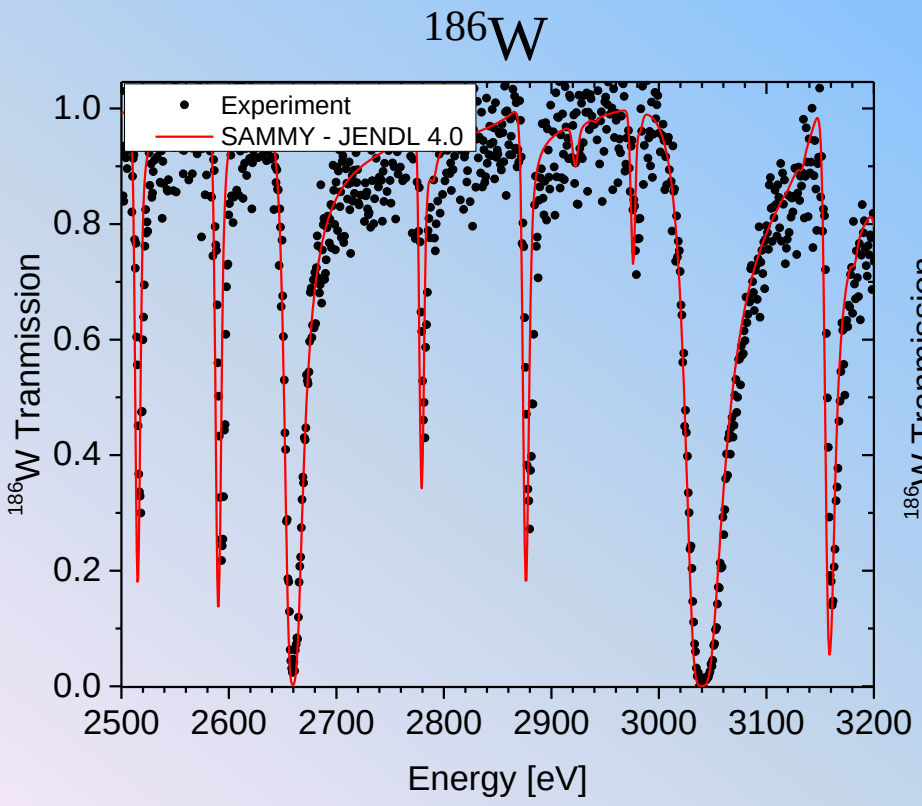
^{186}W Transmission results

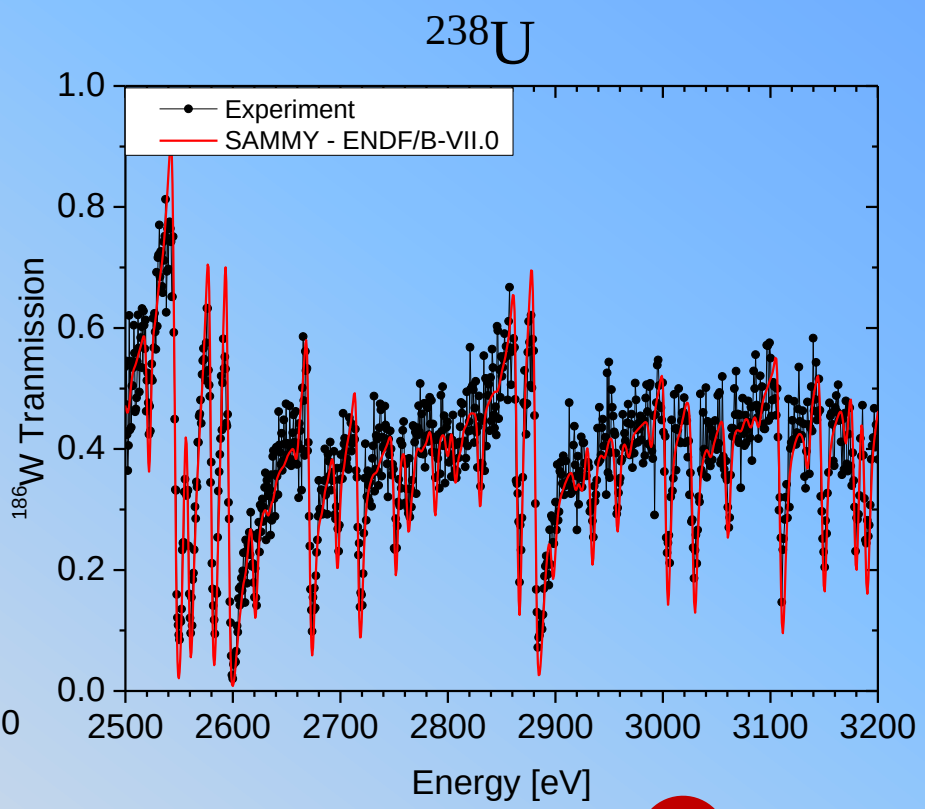


- Transmission was measured in the energy range from a 10 eV to 400 keV
- The region of interest is highlighted in green
- On this scale seems like good agreement with JENDL 4.0
- ENDF/B-VII.1 seemed to have some issue with extra resonances (not shown).

^{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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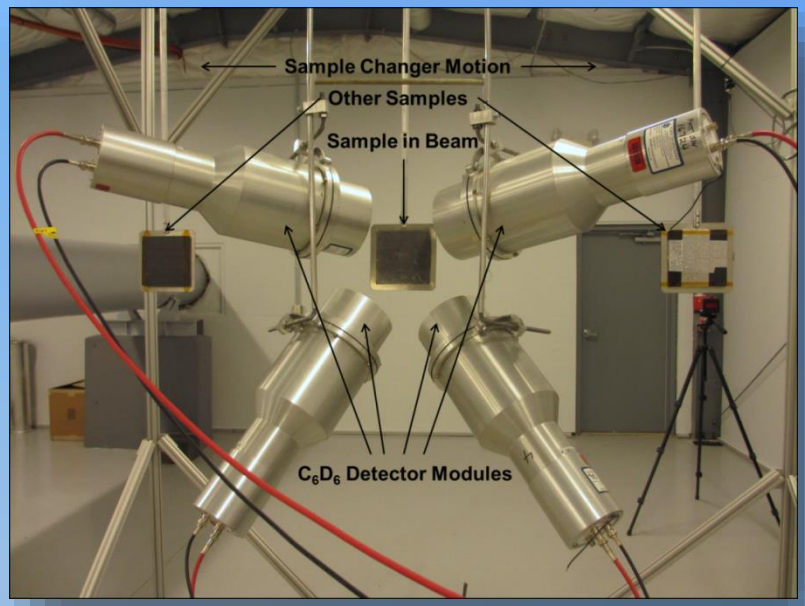
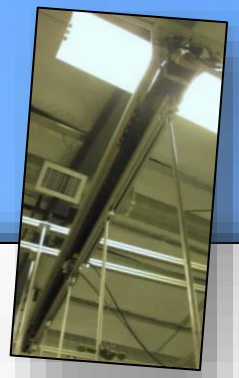
Mid-Energy Capture Detector System Overview

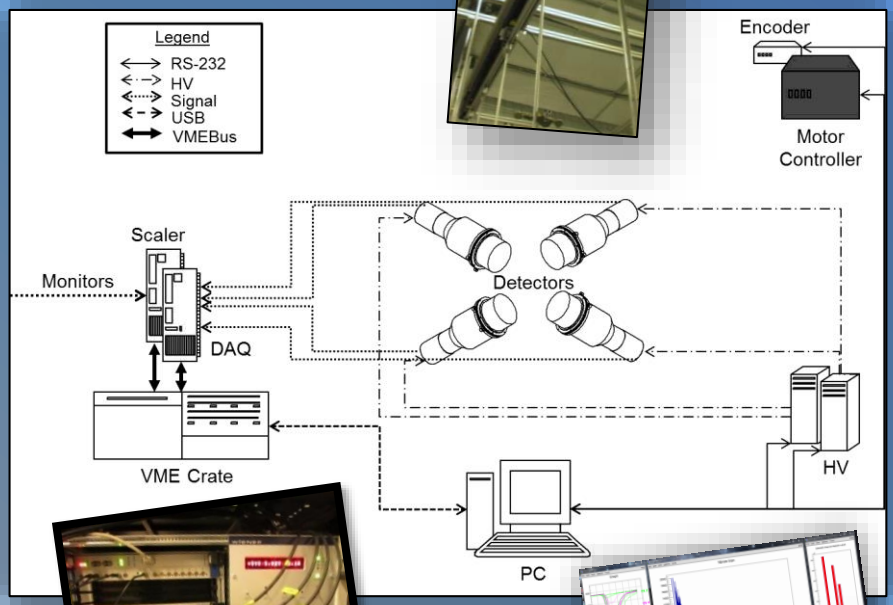
- 4 C_6D_6 detector modules manufactured by Eljen Technology
- **Low mass, low neutron sensitivity design**
- Located at 45m flight path in newly constructed flight station
- Measurements made from 1 eV to 1 MeV



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

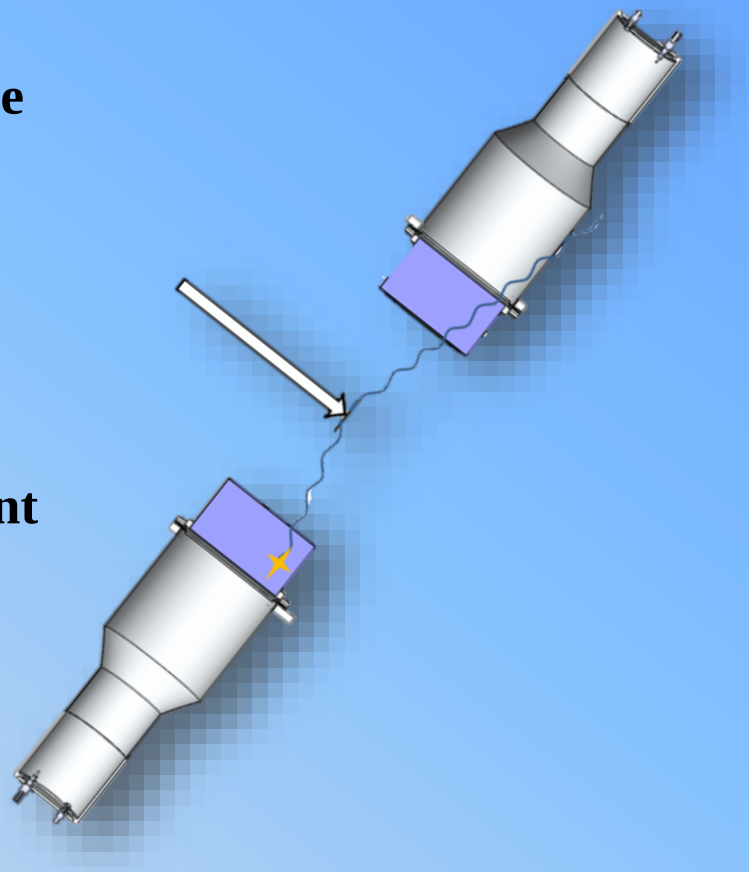




Mid-Energy Capture Detector Principle of Operation

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

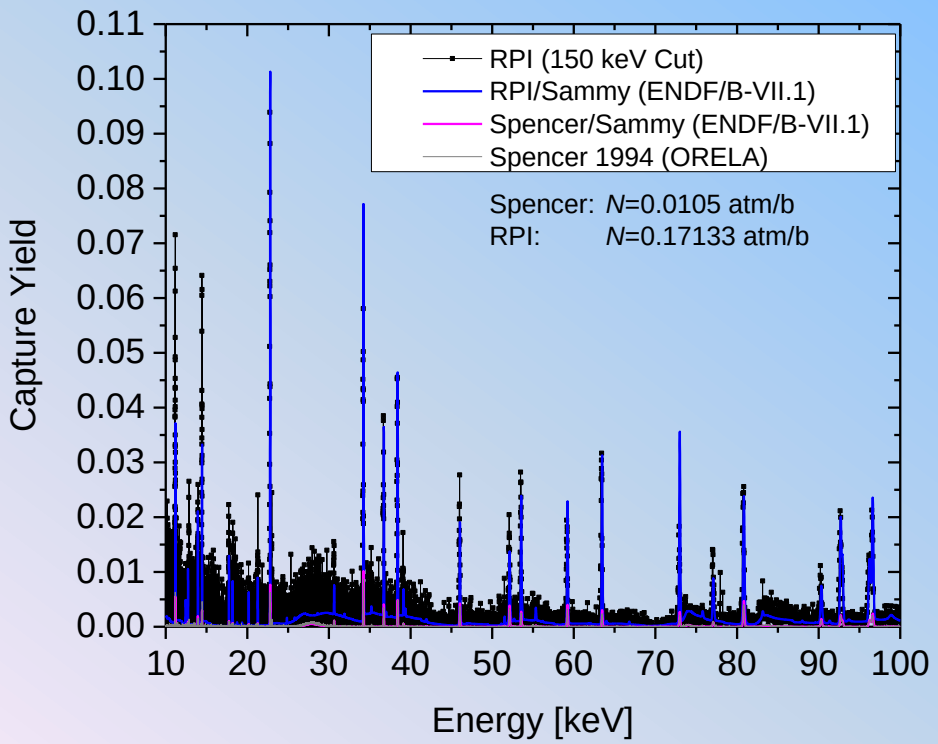
1. Detect only a **single photon per capture** cascade
2. Assert that the detection **efficiency is proportional** to the incident photon energy
3. Given 1 and 2, it can be shown that the total **efficiency to detect a capture event is proportional to the total excitation energy** of the compound nucleus,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

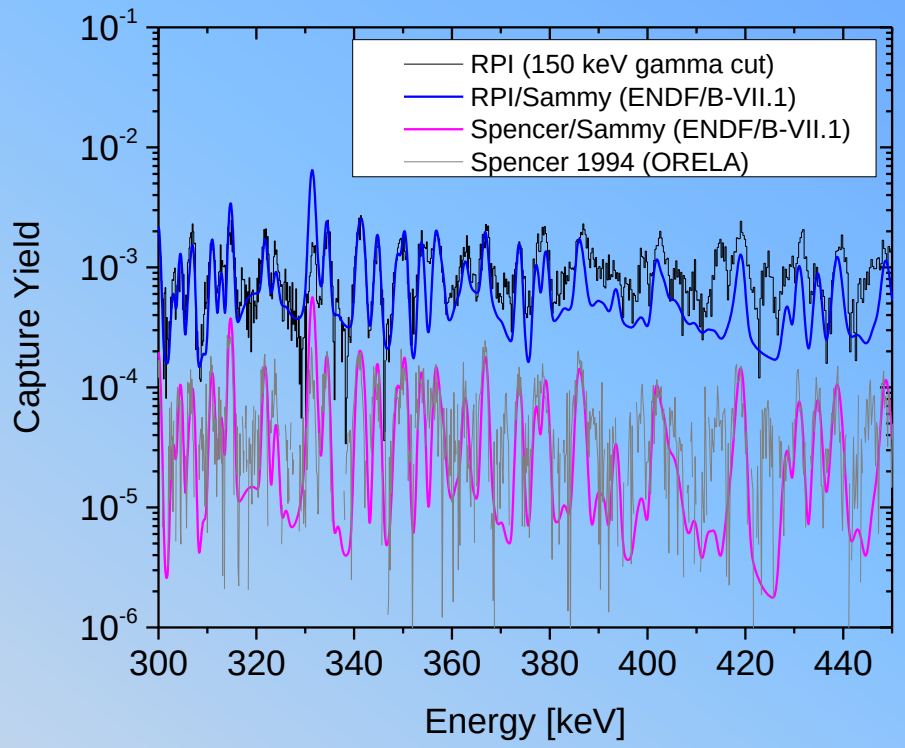


Requires a weighting function

^{nat}Fe Capture measurment

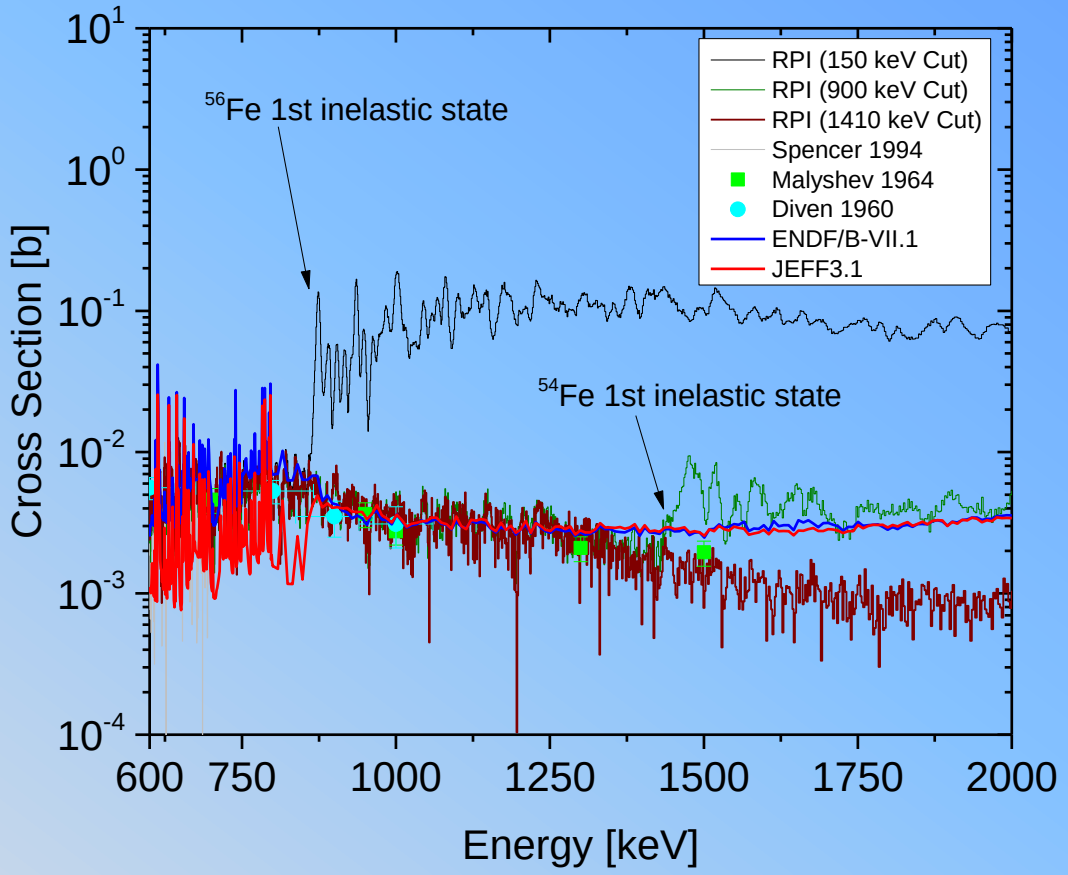
- ^{nat}Fe was used as a test to compare with evaluations and other measurements
  - The RPI data (45m flight path) has good energy resolution compared to the Spencer ORELA data (40m flight path)
  - The RPI data provide information above 700 keV (next slide)





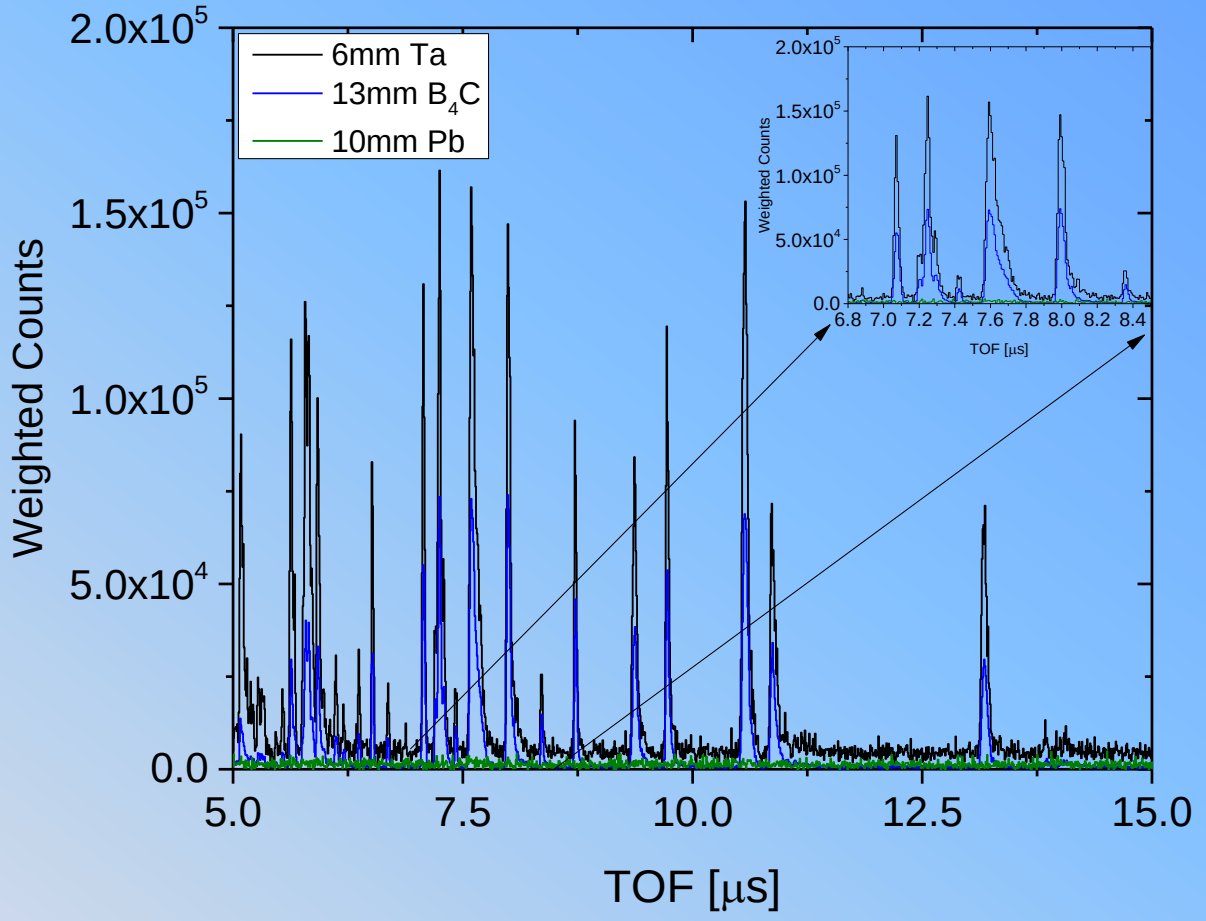
^{nat}Fe Capture Cross Section above 847 keV

- 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



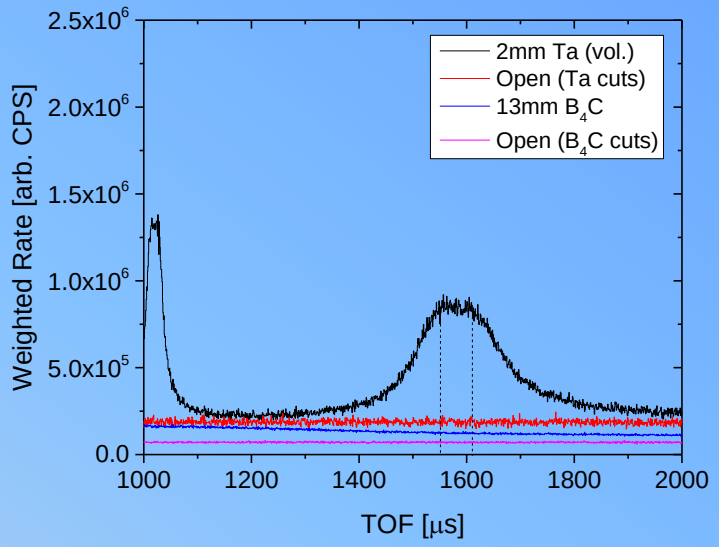
^{181}Ta Iron Filtered Beam Capture Measurement: Method

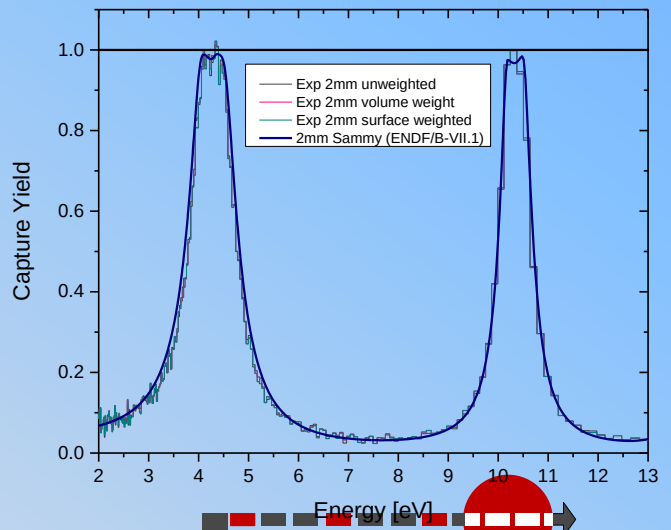
- Count rates for Ta and B_4C samples were summed under each filter transmission peak.
- Pb scattering sample used to confirm negligible neutron background



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

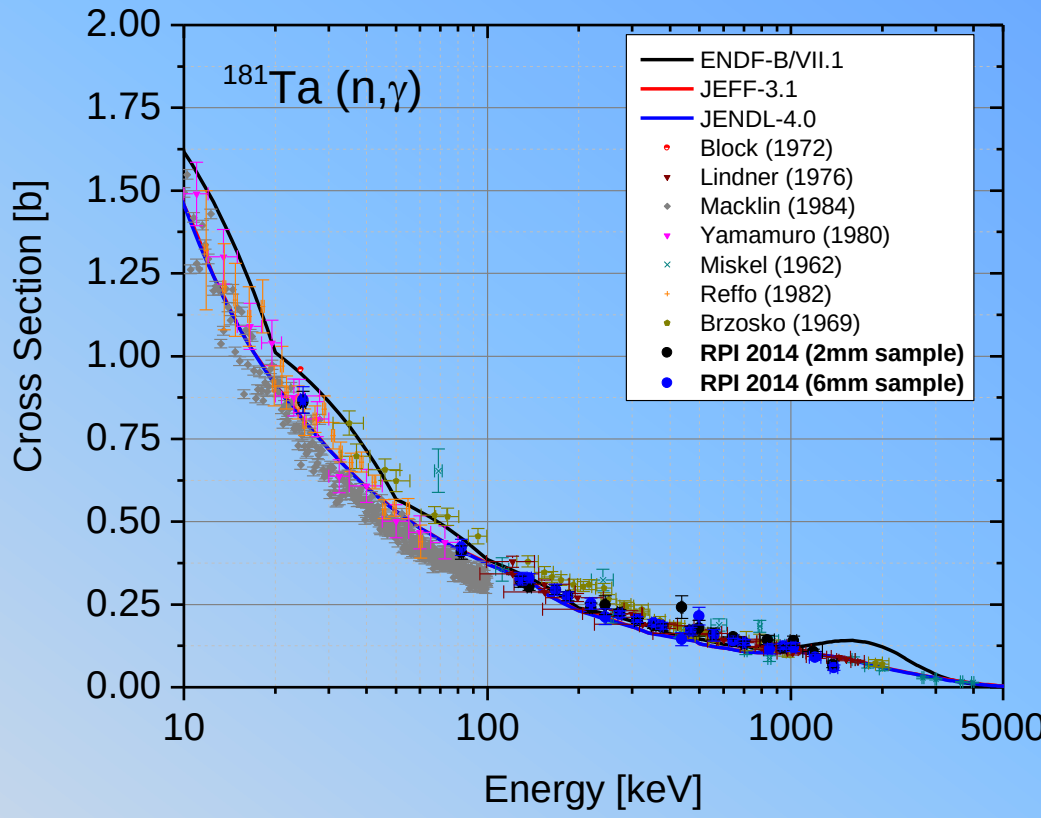
- Unfiltered run performed to determine normalization factor from 4.2 eV saturated resonance
- Normalization factor determined from the ratio of B_4C to Ta counts at the location of the saturated resonance ($Y_\gamma \approx 1$)
- A refinement of the normalization is based on a SAMMY calculations





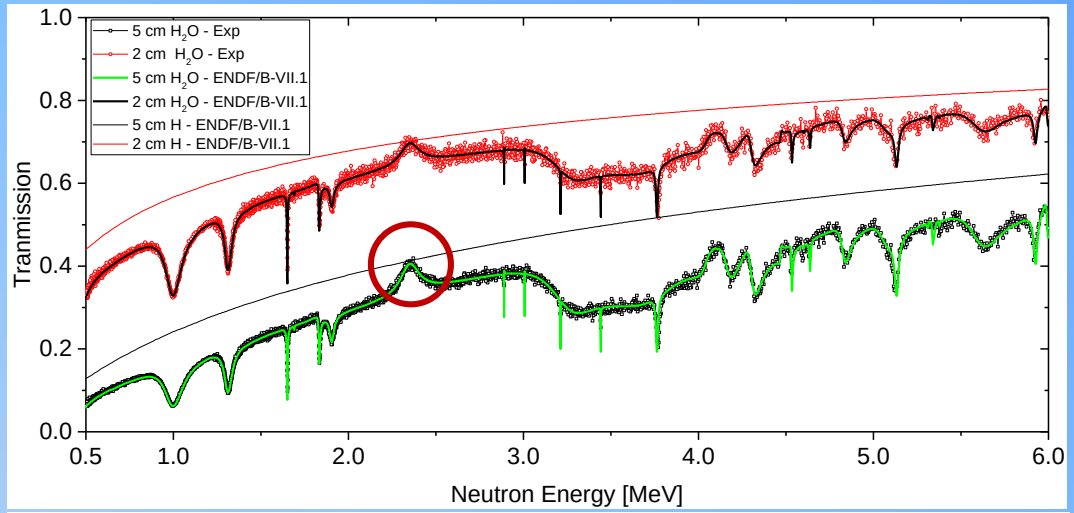
^{181}Ta Iron Filtered Beam Capture Measurement: Cross Section

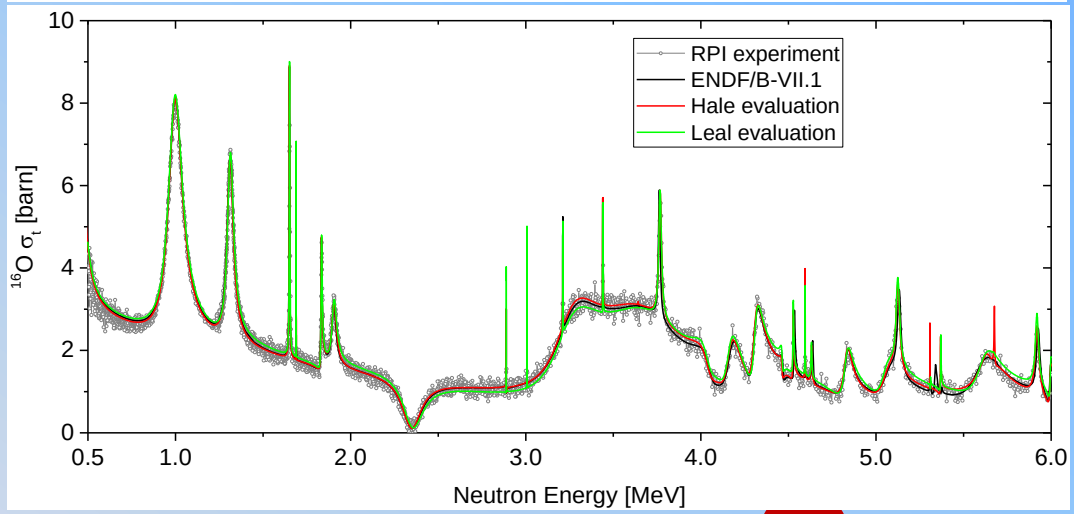
- As expected a thick sample requires larger corrections
  - Self shielding correction is large
  - Multiple scattering correction is large
  - Need to work on better understanding of the weighting function and its validity
- Thin sample data support the JEFF-3.1/3.2 evaluation
- Possible contamination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



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

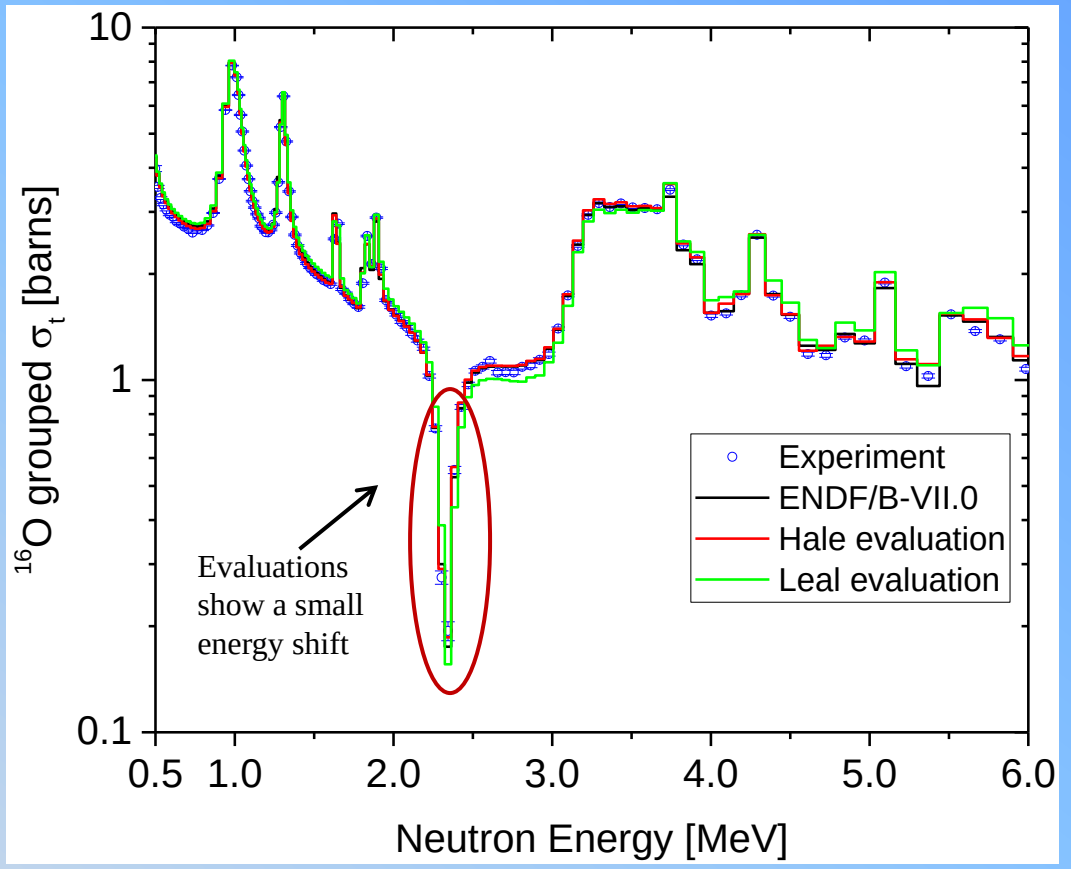
- Measurements of 2cm and 5cm H_2O in thin windows quartz optical cells
- Used 250m TOF and 10 ns pulse width for the feasibility test
- Used 3 fission chambers as beam monitors.
  - The experiment requires good monitor normalization
- In the ^{16}O "hole" at 2.34 MeV only H_2 is measured
  - **Provides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





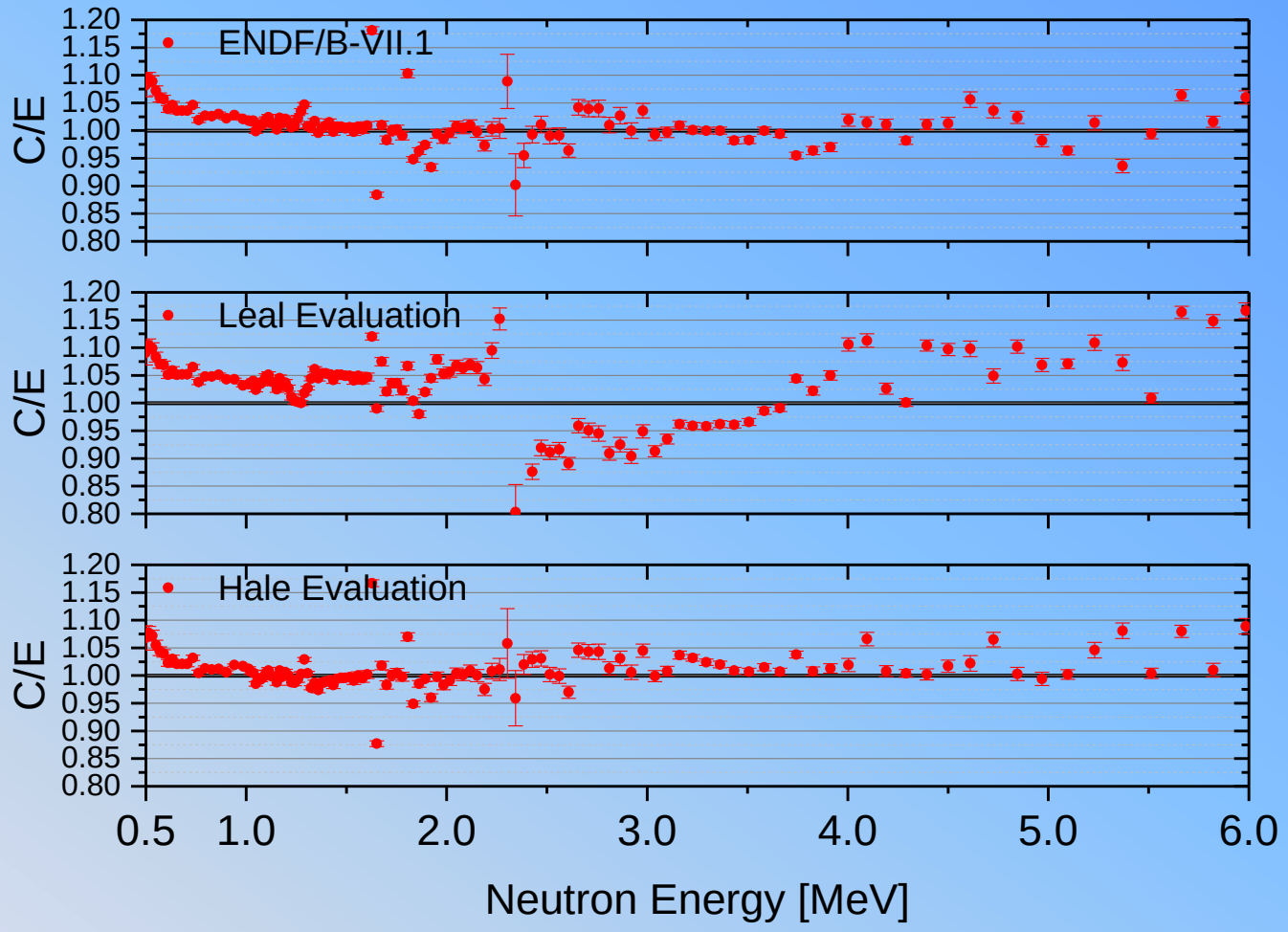
To compare the experiment with evaluation both were grouped

- 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

Los Alamos National Laboratory

- **Capture measurement with DANCE (Detector for Advanced Neutron Capture Experiments)**
  - ^{236,238}U(n,γ) Relative to ^{235}U(n,f) – mixed target, E > 10 keV (M. Jandel DOE ECR)
  - ^{67,68}Zn(n, γ) Astrophysics (with LSU)
  - ^{173,174}Lu(n, γ) Radioactive samples! (With CEA)
  - ^{242}Pu Spontaneous fission – gamma-ray spectra (with LLNL)
  - ^{235}U(n, γ) Capture isomers (requires fission tagging)
  - ^{161,162}Dy(n, γ) Strength functions and resonances (with NCSU, Charles U.)
  - ^{136}Xe(n, γ) Double-Beta decay backgrounds and physics (With IU)
  - ^{191}Ir(n, γ) Capture data > 10 keV

- **GEANIE – (GErmanium Array for Neutron Induced Excitations)**
  - ^{187}Re(n,xn) with Jeff Carroll (NRL) and David Matters (AFIT)
  - ^{136}Xe(n,xn) for 0$\nu\beta\beta$ backgrounds with Josh Albert, Lisa Hoffman, etc (IU)
  - Neutron-induced γ-ray standard measurements: ^{56}Fe, Cr, B, Ti (n,n') γ-ray comparisons as a function of E_n
  - Also: neutron scattering measurements with the UMASS-Lowell CLYC array (P Choudury, N D'Olympia, K Lister, et al.)

LANL (continued)

- **Fission Total kinetic energy (TKE) release in fission E<30 MeV**
  - Results were shown for ^{238}U, ^{235}U, ^{239}Pu
  - Comparison with models was shown, Liston's model provides a reasonable agreement
- **2E method with Frisch-gridded ionization chamber**
  - Results for several incidence energies were shown for ^{235}U
- **SPIDER: measures fission product yields with high mass resolution**
  - SPIDER: Preliminary results were shown for ^{252}Cf and $^{235}U(n,f)$ mass yields measured at thermal.
- **The Chi-Nu project - measure prompt fission neutron spectrum**
  - Two detector arrays: liquid scintillation neutron detectors, and Li-Glass neutron detectors to allow measurement of fission neutrons with E<0.5 MeV.
  - Results for PFNS measurement of ^{235}U were shown
    - Incident energy of 1-6 MeV
    - Fission neutron were measured between 0.01-1 MeV

Nuclear Data Experiments at LANSCE: Brief Highlights 2014-2015

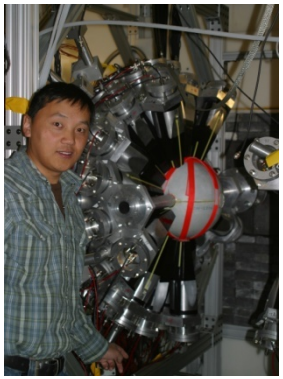
Fredrik Tovesson and Robert Haight
for P-27 and colleagues
Los Alamos National Laboratory

Cross Section Evaluation Working Group Meeting
"Mini-CSEWG"
Brookhaven National Laboratory
May 7-8, 2015

LA-UR-15-23446

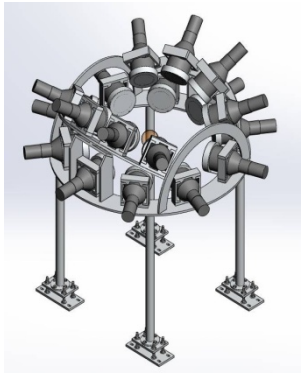
Nuclear data measurements at LANSCE are made with many different instruments

DANCE (n,γ)

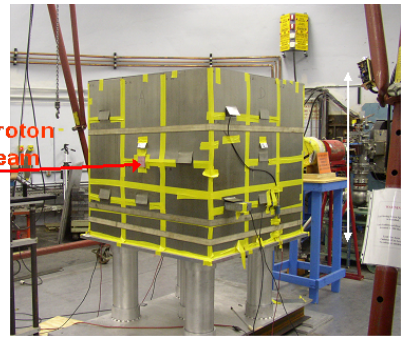


GEANIE (n,xγ)

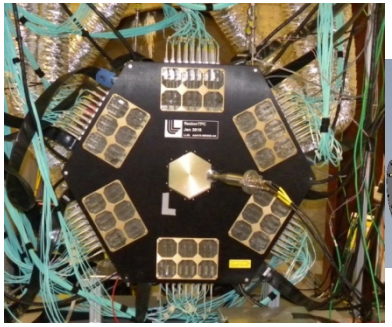
Chi-Nu (n,xn)



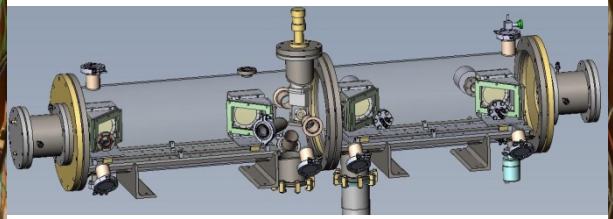
LSDS



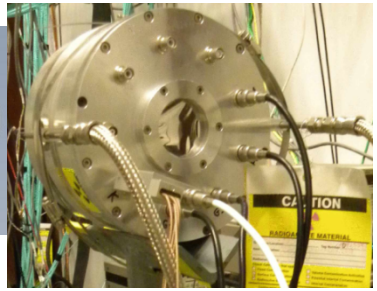
TPC



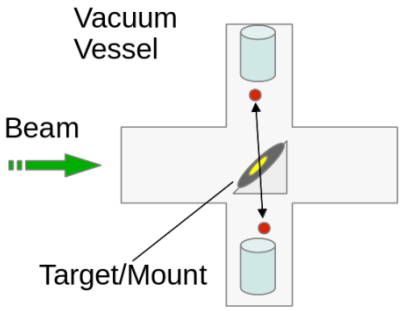
SPIDER



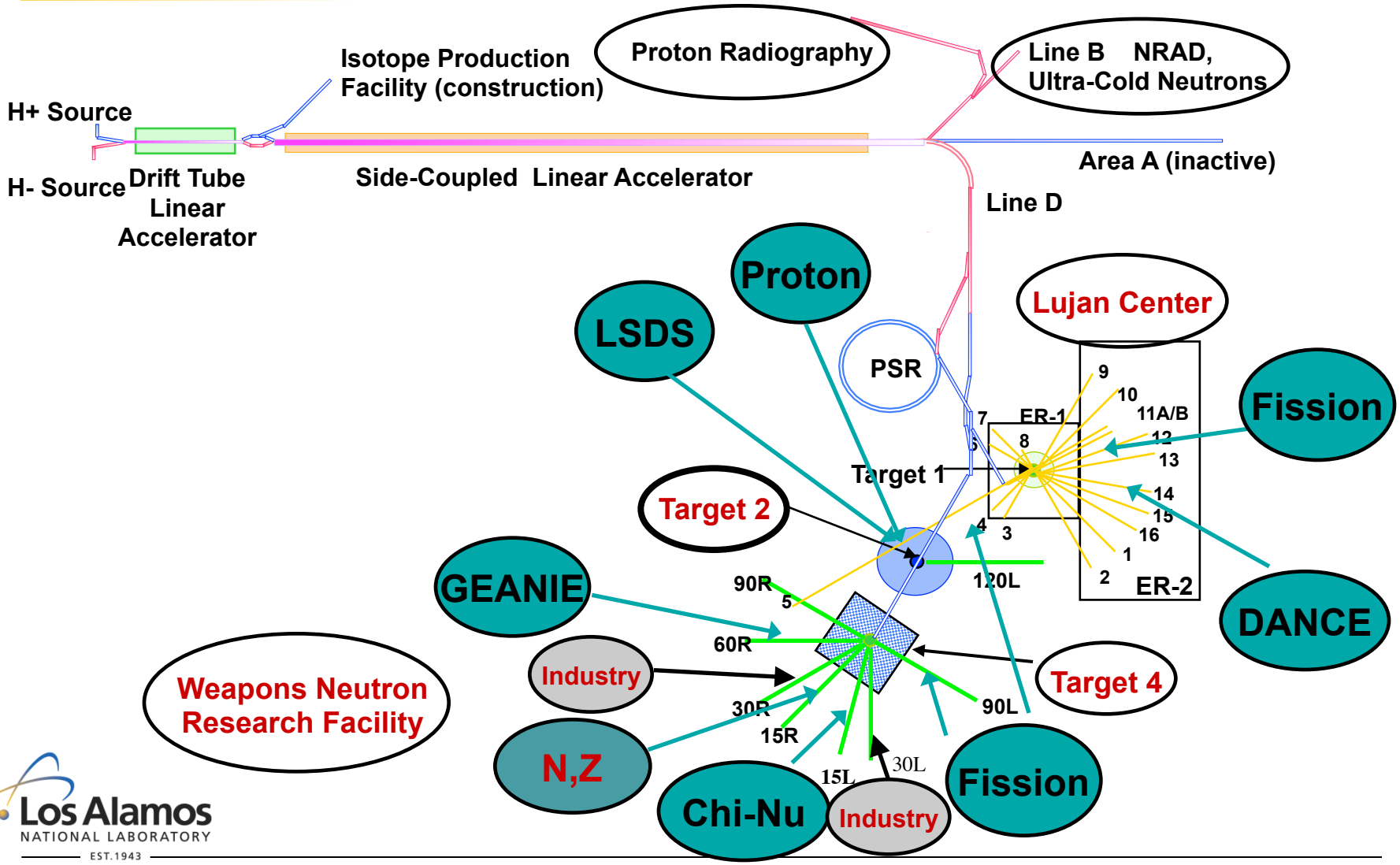
Double gridded ion chamber



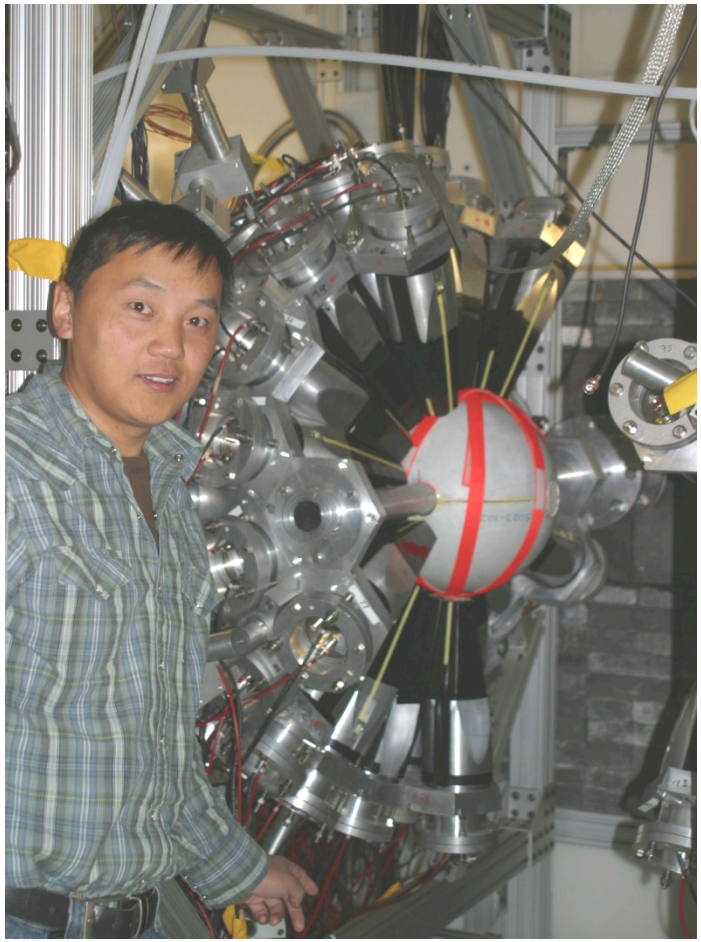
Surface barrier detectors



Nuclear data experiments at LANSCE use neutrons at the Lujan Center, Target 2 and Target 4



DANCE (n,γ)



Contacts:
John Ullmann
Aaron Couture
Marian Jandel

Major DANCE Experiments 2014/2015

- ^{236,238}U(n,γ) Relative to ^{235}U(n,f) – mixed target
  Data > 10 keV (M. Jandel DOE ECR)
- ^{67,68}Zn(n,γ) Astrophysics (with LSU)
- ^{173,174}Lu(n,γ) Radioactive samples! (With CEA)
- ^{242}Pu Spontaneous fission – gamma-ray spectra (with LLNL)
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- ^{136}Xe(n,γ) Double-Beta decay backgrounds and physics (With IU)
- ^{191}Ir(n,γ) Capture data > 10 keV

Recent Publications

Total prompt gamma-ray emission in fission of ^{235}U, ^{239}Pu,^{241}Pu, and ^{252}Cf. A. Chyzh, C.Y. Wu, E. Kwan, R. Henderson, T.A. Bredeweg, R/C/ Haight, A.C. Hayes-Sterbenz, H.-Y. Lee, J.M. O'Donnell, Phys. Rev. C **90**, 014602 (2014).

Improved Neutron Capture Cross Section of ^{239}Pu. S. Mosby, T.A. Bredeweg, A. Chyzh, A. Couture, R. Henderson, M. Jandel, E. Kwan, J.M. O'Donnell, J.L. Ullmann, C.Y. Wu, Phys. Rev. C **89**, 034610 (2014).

Cross Section and γ-ray spectra for ^{238}U(n, γ) measured with the DANCE detector array at the Los Alamos Neutron Science Center. J.L. Ullmann, T. Kawano, T.A. Bredeweg, A. Couture, R.C. Haight, M. Jandel, J.M. O'Donnell, R.S. Rundberg, D.J. Vieira, J.B. Wilhelmy, J.A. Becker, A. Chyzh, C.Y. Wu, B. Baramsai, G.E. Mitchell, M. Krticka, Phys. Rev. C **89,** 034603 (2014).

Cascade gamma rays following capture of thermal neutrons on Cd-113. G. Rusev, M. Jandel, M. Krticka, C.W. Arnold, T.A. Bredeweg, A. Couture, W. Moody, S.M. Mosby, J.L. Ullmann, Phys. Rev C **88**, 057602 (2013).

Precision measurement of the ^{238}Pu(n,γ) Cross section. A. Chyzh, C.Y. Wu, R.A. Henderson, T.A. Bredeweg, R.C. Haight, H.-Y. Lee, J.M. O'Donnell, J.L. Ullmann, Phys. Rev C **88**, 044607 (2013).

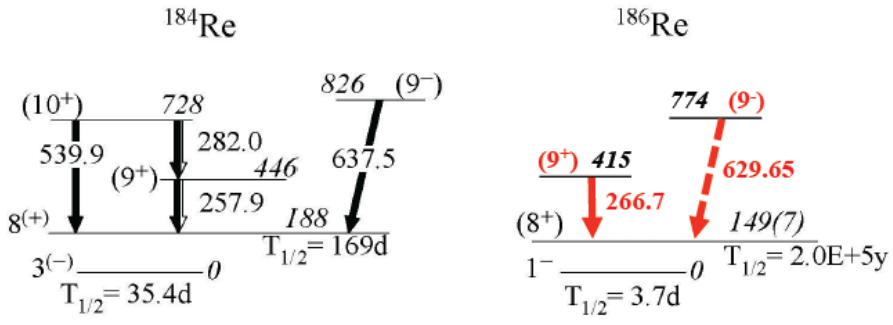
Strength of the scissors mode in odd-mass Gd isotopes from the radiative capture of resonance neutrons. J. Kroll, B. Baramsai, G.E. Mitchell, U. Agvaanluvsan, F. Becvar, T.A. Bredeweg, A. Chyzh, A. Couture, D. Dashdorj, R.C. Haight, M. Jandel, A.L. Keksis, J.M. O'Donnell, W. Parker, R.S. Rundberg, J.L. Ullmann, S. Valenta, D.J. Vieira, C Walker, C.Y. Wu, Phys. Rev C **88**, 034317 (2013).

GEANIE (n,xγ)

Contacts:
Ron Nelson
Nik Fotiades
Matt Devlin

GEANIE @ WNR/LANSCE: experiments in 2014
M Devlin, N Fotiadis, and RO Nelson

- ^{187}Re(n,xn) with Jeff Carroll (NRL) and David Matters (AFIT)



New g-rays feeding the isomer in ^{186}Re, observed with GEANIE from the ^{187}Re(n,2n) reaction. From D Matters, Master's Thesis, Air Force Institute of Technology (2015)

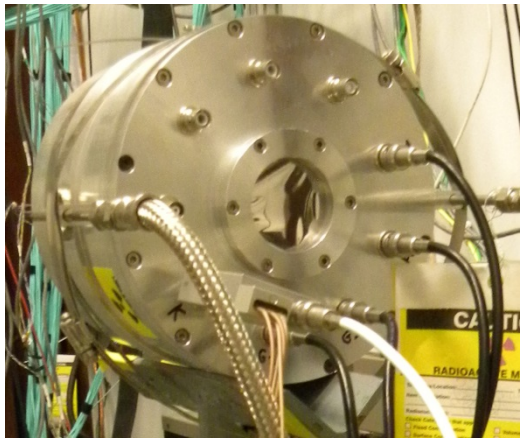
- ^{136}Xe(n,xn) for $0\nu\beta\beta$ backgrounds with Josh Albert, Lisa Hoffman, etc (IU)
- Neutron-induced γ-ray standard measurements: ^{56}Fe, Cr, B, Ti (n,n') γ-ray comparisons as a function of E_n
- Also: neutron scattering measurements with the UMASS-Lowell CLYC array (P Choudury, N D'Olympia, K Lister, et al.)

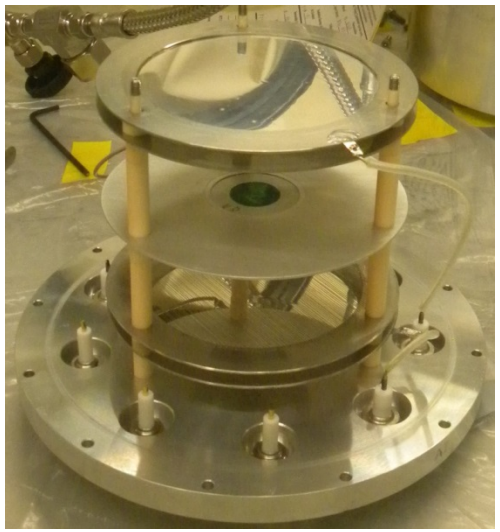
Fission Cross Sections
Fission Total Kinetic Energy
Fission Fragment Yields

Contact:
Fredrik Tovesson

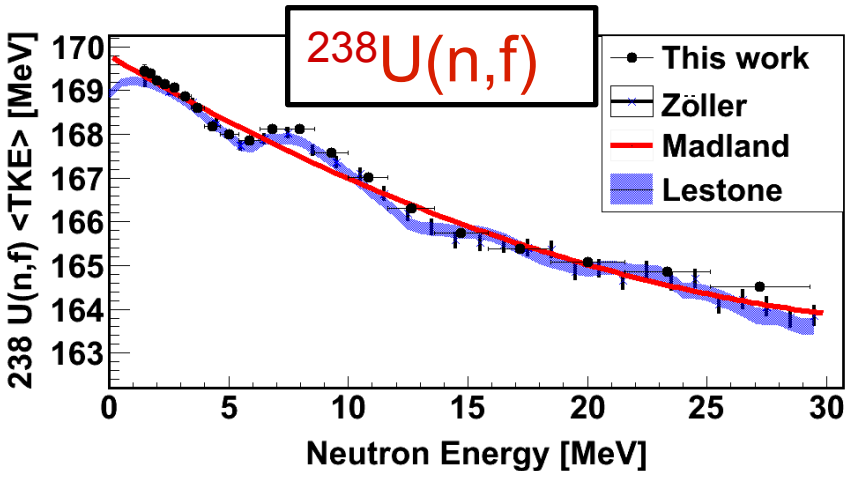
Frisch-gridded ionization chambers are used to measure fission fragment energy

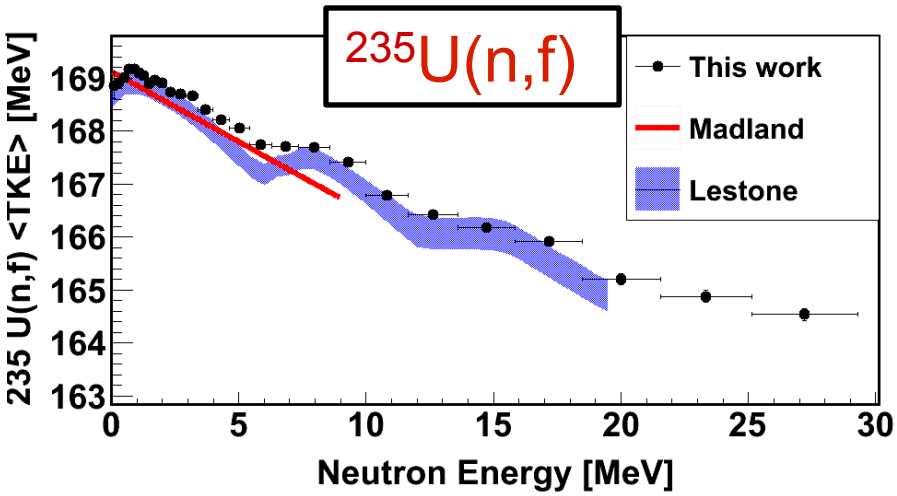
- **Provides excellent energy resolution for fission fragments**
  - Intrinsic resolution is 0.4-0.6%
  - Sample located inside active volume -> No energy loss through window
- **Collaboration with Joint Research Centers and Oregon State University**
  - Chamber built by Josch Hambsch at IRMM, Geel
  - Samples prepared by Walt Loveland at OSU
- **Three experiments at LANSCE with different isotopes**
  - 2012: U-238 measured with participation from IRMM
  - 2013: U-235 successfully measured, attempted Pu-239
  - 2014: Pu-239 successfully measured
- **Fission mass yields can also be calculated with low resolution using “2E” method**

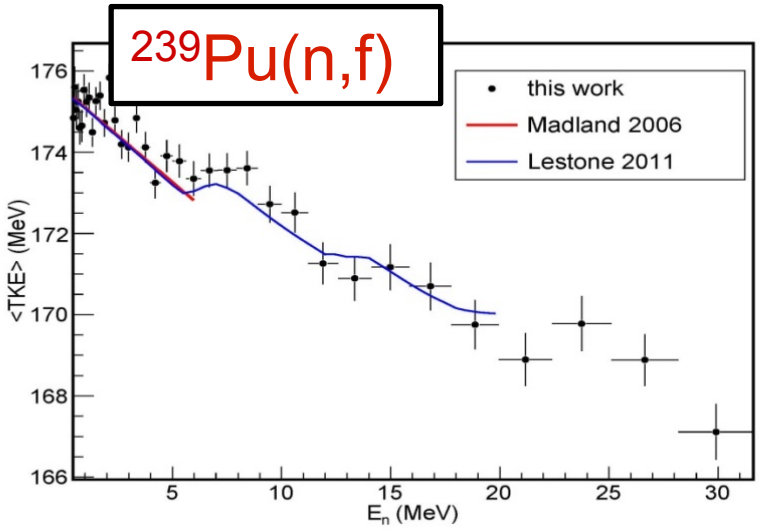




The experimental results are consistent with calculations by Lestone et al.

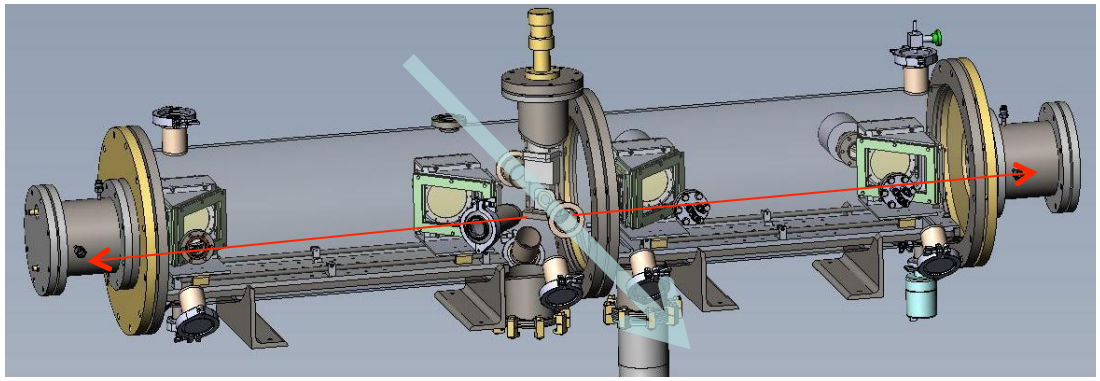




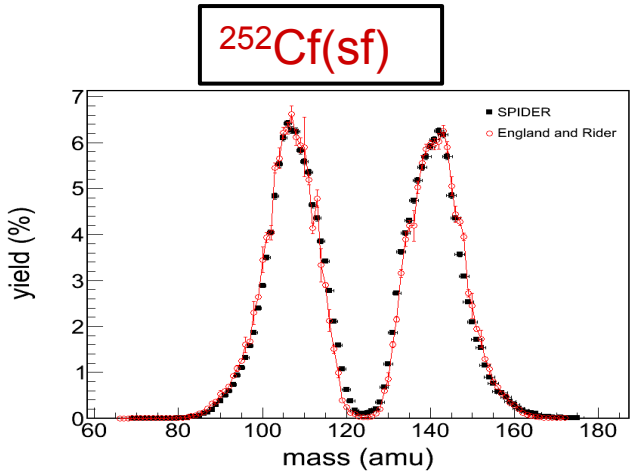


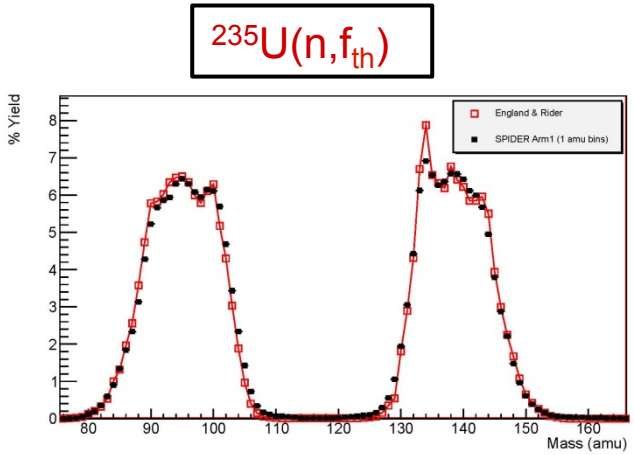
- **Zöller et al. data for U-238 extends beyond 30 MeV**
  - For U-235 no previous data above 9 MeV
  - For Pu-239 no data beyond 5 MeV
- **Madland evaluation is fit to experimental data**
  - Not intended for extrapolation
  - ENDF values for 14 MeV never the less are extrapolations
- **Semi-empirical modeling by Lestone et al. in close agreement with new data**
  - J.P. Lestone, T.T. Strother, Nuclear Data Sheets **118,** 208 (2014)

SPIDER measures fission product yields with high mass resolution



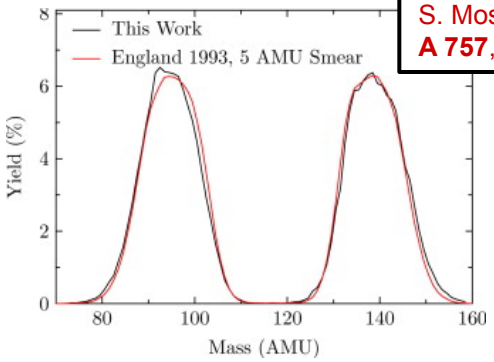
- The 2E-2v method can provide 1 amu resolution for light fragments
  - Demonstrated with Cosi-fan-Tutti at ILL
- SPIDER uses ionization chambers for energy measurement
  - 1% energy resolution for α-particles, 0.5% for fission fragments
  - Thin entrance window (Mylar or SiN)
- Fast, position sensitive TOF detectors
  - Micro-channel plates



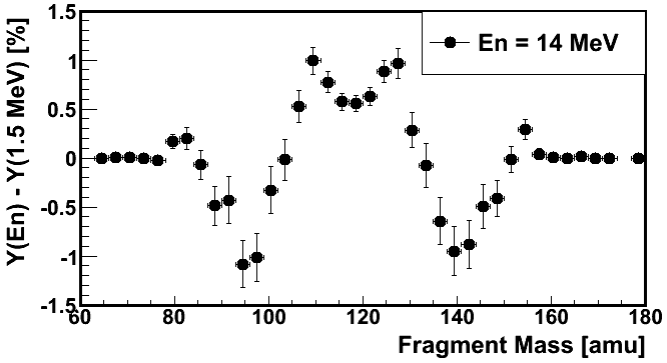


- K. Meierbachtol, F. Tovesson, D. Shields, *et al.*, *The SPIDER fragment spectrometer for fission product yield measurements*, Nucl. Instr. and Meth. A **788**, 59 (2015).
- C.W. Arnold, F. Tovesson, K. Meierbachtol, *et al.*, *Development of position-sensitive time-of-flight spectrometer for fission fragment research*, Nucl. Instr. and Meth. A **764**, 53 (2014).

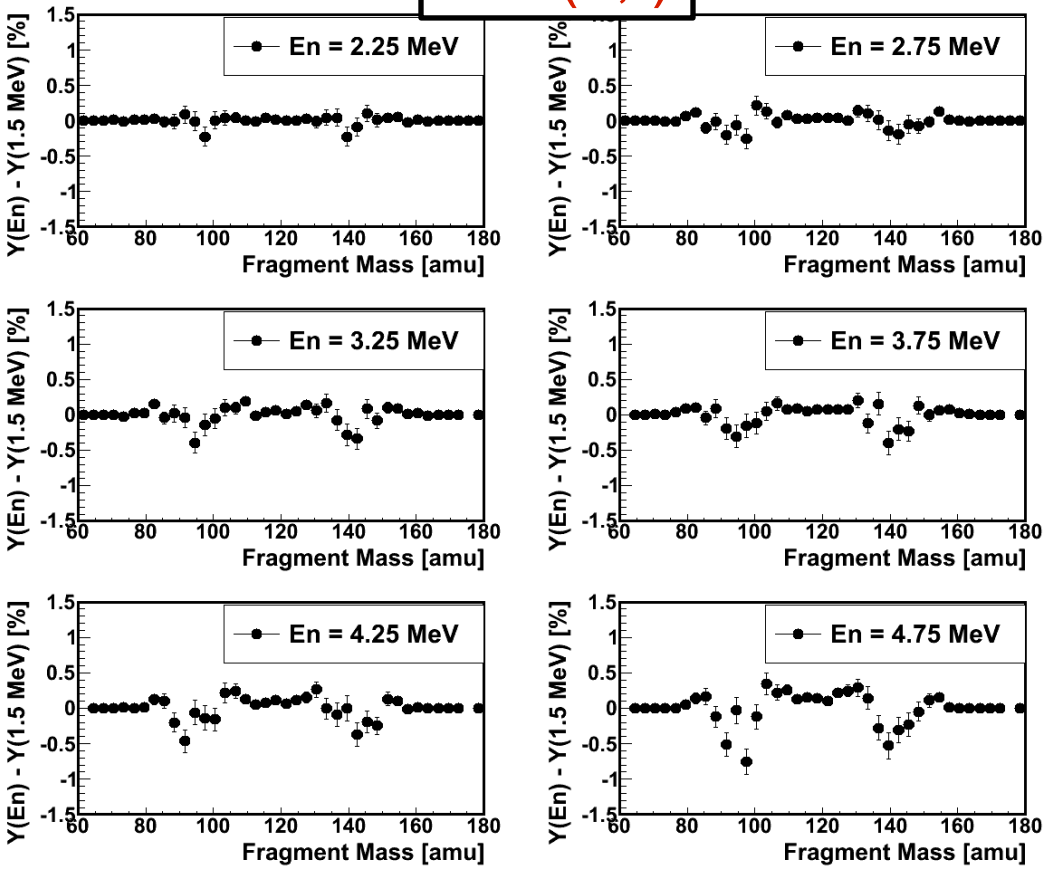
The 2E-method can be used to measure fission yields with low mass resolution



S. Mosby *et al.*, NIM **A 757**, 75 (2014).

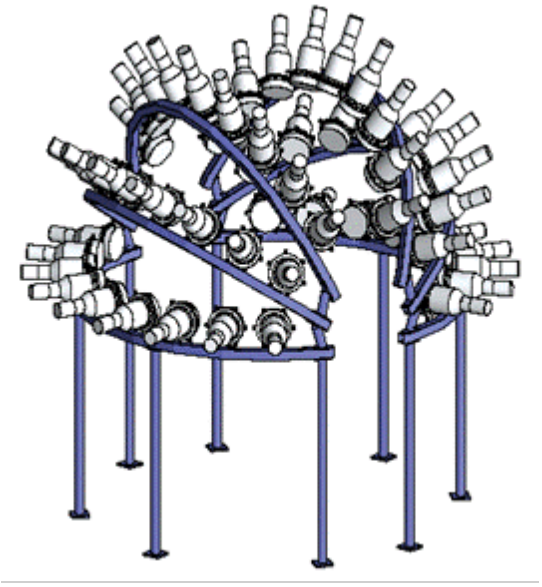


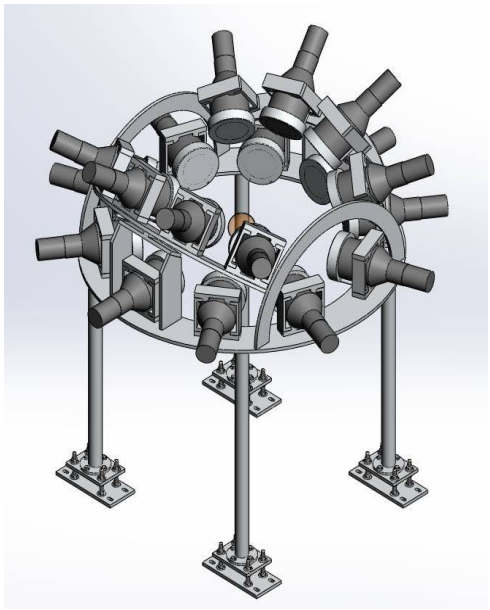
^{235}U(n,f)



- Fission product yields measured with TI chamber
  - ^{238}U: Completed
  - ^{235}U: Preliminary results
  - ^{239}Pu: Analysis in progress

Chi-Nu - Prompt fission neutron spectra





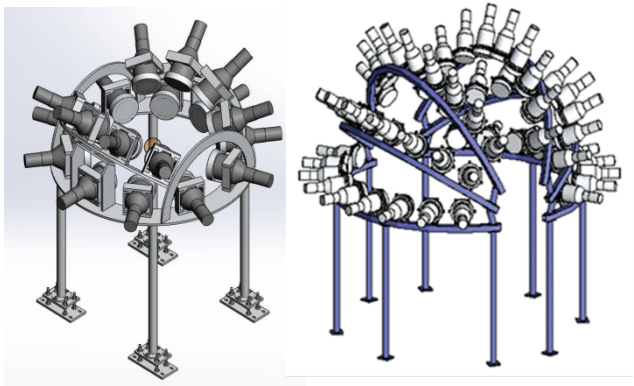
Contacts:
LANL:
Bob Haight
Hye Young Lee
Shea Mosby
Matt Devlin
LLNL:
Ching-Yen Wu

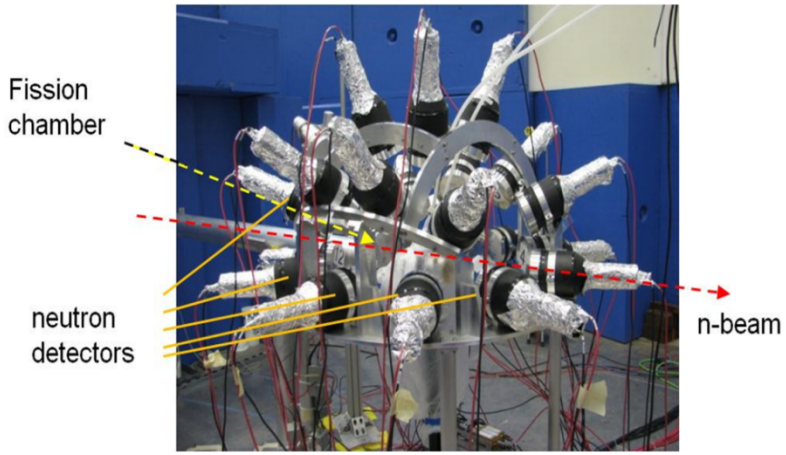
Approach – fast fission counter, two types of neutron detector arrays to cover fission neutron energy range

- WNR/LANSCE spallation neutron source – all neutron energies from 0.5 to 30 MeV and higher
- New building from LANS support
- Double time-of-flight
  - LANSCE spallation source to fission chamber → incident neutron energy
  - Fission chamber to neutron detector → fission neutron energy
- Multi-year project – thru FY2017
- Goal: a significant result for stockpile stewardship (i.e. with respect to the current nuclear data evaluations)

LLNL fission chamber

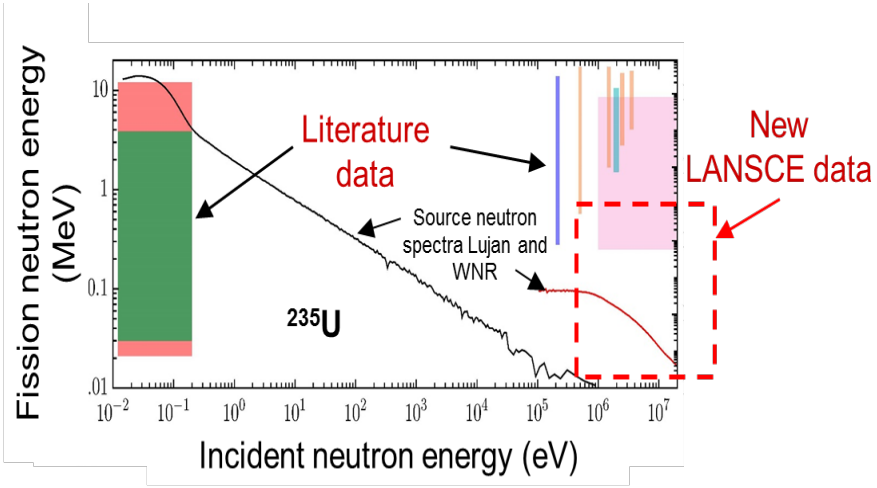
Two LANL neutron detector arrays

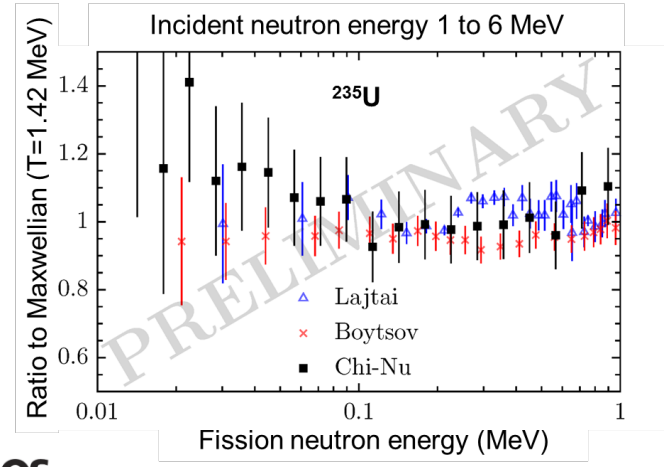




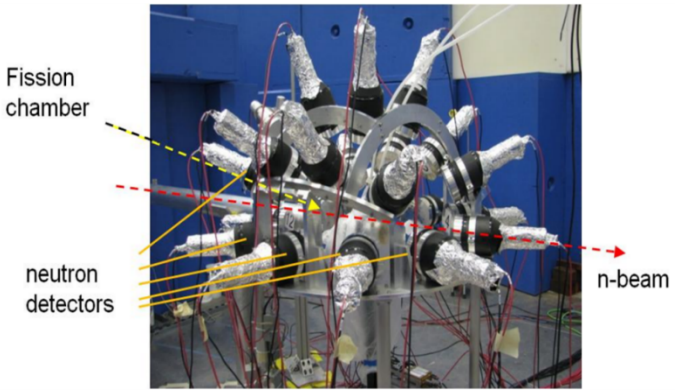
Prompt Fission Neutron Spectra Measurements at LANSCE obtain data in previously unexplored region

- New region of PFNS for fission induced by fast neutrons (above thermal) for ^{235}U(n,f).
- Measured PFNS ~ 50 keV to 1 MeV
- Preliminary analysis shows reasonable agreement with literature data obtained at thermal energy
- Next is full analysis of ^{235}U and then ^{239}Pu





^{6}Li-glass neutron detectors



Recent Publications

The LANL/LLNL Prompt Fission Neutron Spectrum Program at LANSCE and Approach to Uncertainties, D. Neudecker, P. Talou, T.N. Taddeucci, R.C. Haight, T. Kawano, H.Y. Lee, D.L. Smith, R. Capote, M.E. Rising, and M.C. White, R.C. Haight, C.Y. Wu, H.Y. Lee, T.N. Taddeucci, B.A. Perdue, J.M. O'Donnell, N. Fotiades, M. Devlin, J.L. Ullmann, T.A. Bredeweg, M. Jandel, R.O. Nelson, S.A. Wender, D. Neudecker, M.E. Rising, S. Mosby, S. Sjue, M.C. White, B. Bucher, and R. Henderson, Nucl. Data Sheets **123**, 130 (2015).

The LANL/LLNL Prompt Fission Neutron Spectrum Program at LANSCE and Approach to Uncertainties, R.C. Haight, C.Y. Wu, H.Y. Lee, T.N. Taddeucci, B.A. Perdue, J.M. O'Donnell, N. Fotiades, M. Devlin, J.L. Ullmann, T.A. Bredeweg, M. Jandel, R.O. Nelson, S.A. Wender, D. Neudecker, M.E. Rising, S. Mosby, S. Sjue, M.C. White, B. Bucher, and R. Henderson, Nucl. Data Sheets 123, 130 (2015).

Multiple-scattering Corrections to Measurements of the Prompt Fission Neutron Spectrum, T.N. Taddeucci, R.C. Haight, H.Y. Lee, D. Neudecker, J.M. O'Donnell, M.C. White, B.A. Perdue, M. Devlin, N. Fotiadis, J.L. Ullmann, R.O. Nelson, T.A. Bredeweg, M.E. Rising, S.K. Sjue, S.A. Wender, C.Y. Wu, and R. Henderson, Nuclear Data Sheets **123**, 135 (2015).

The need for new and precise experimental data on Prompt Fission Neutron Spectra from neutron-induced fissions of 239Pu, D. Neudecker,T.N. Taddeucci, R.C. Haight, H.Y. Lee, M.C. White, and M.E. Rising, Nuclear Data Sheets (invited, in preparation).

LANL-LLNL Chi-Nu Collaboration Team