Recent Nuclear Data Research at RPI

Report to CSEWG November, 2013

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Measurements Completed This Year

- **Transmission**
  - $^{92/94}$Mo, 5-600 keV, 30m, 100m flight path
- **Capture**
  - Fe, 100 eV - 500 keV, 45m flight path (as a system test)
- **Fission**
  - Prompt fission neutron spectra of ^{252}Cf and ^{238}U.

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Planned Measurements

- **Scattering**
  - H_2O, Thermal neutron scattering at several temperatures
- **Transmission**
  - ^{236}U, concentrate on the 5.45 eV resonance
  - Fission neutrons spectrum ^{235}U or ^{238}U
- **Capture**
  - $^{92,94}Mo$, 45m station 1 keV to 500 keV.

Data Analysis

Sample	Status
Be, C	High energy (0.5-20MeV) transmission, Published in NSE M.J. Rapp, Y. Danon, F.J. Saglime, R.M. Bahran and D.G. Williams, G. Leinweber, D.P. Barry and R.C. Block, "Beryllium and Graphite Neutron Total Cross Section Measurements from 0.4 to 20 MeV", Nuclear Science and Engineering, Vol. 172, No. 3. Pages 268-277, November, (2012)
Zr,	Neutron Scattering (0.2-20 Mev) Published in NSE D. P. Barry, G. Leinweber, R. C. Block, and T. J. Donovan, Y. Danon, F. J. Saglime, A. M. Daskalakis, M. J. Rapp, and R. M. Bahran, "Quasi-differential Neutron Scattering in Zirconium from 0.5 MeV to 20 MeV", Nuclear Science and Engineering, 174, 188–201, (2013).
Ti, Ta, Zr, $^{92/94,95,96,98,100,nat}Mo$	High energy (0.5-20MeV) publication in preparation
^{235}U	Capture and fission in the energy range thermal to 5 keV (thesis in progress), keV data analyzed by ORNL, Results Presented in ND2013
$^{92/94,95,96,98,100,nat}Mo$, $^{153,nat}Eu$, $^{161,162,163,164}Dy$ $^{155,156,157,158,160}Gd$, Re	Gd, Eu publications are in preparation Dy, $^{92/94}Mo$ Resonance parameters analysis in progress Re – resonance analysis completed.

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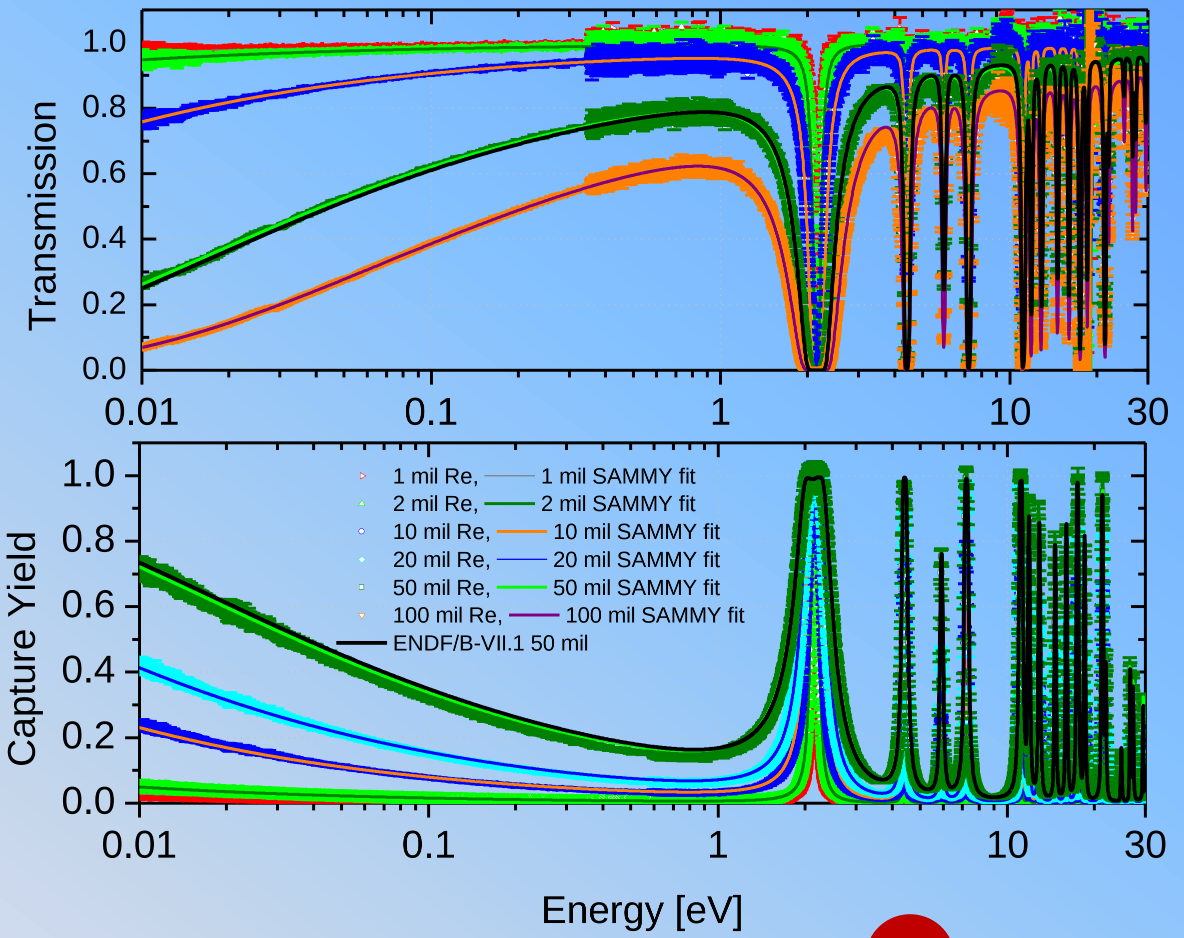
Re – Thermal Transmission and Capture Measurements

- Multiple sample thicknesses 1-100 mils
- Corrected for gamma attenuations (density=12.02 g/cm^3)
- Simultaneous SAMMY fit to all data sets.
- Slightly lower thermal cross section compared to ENDF/B-VII.0
- MS Thesis nearly completed.



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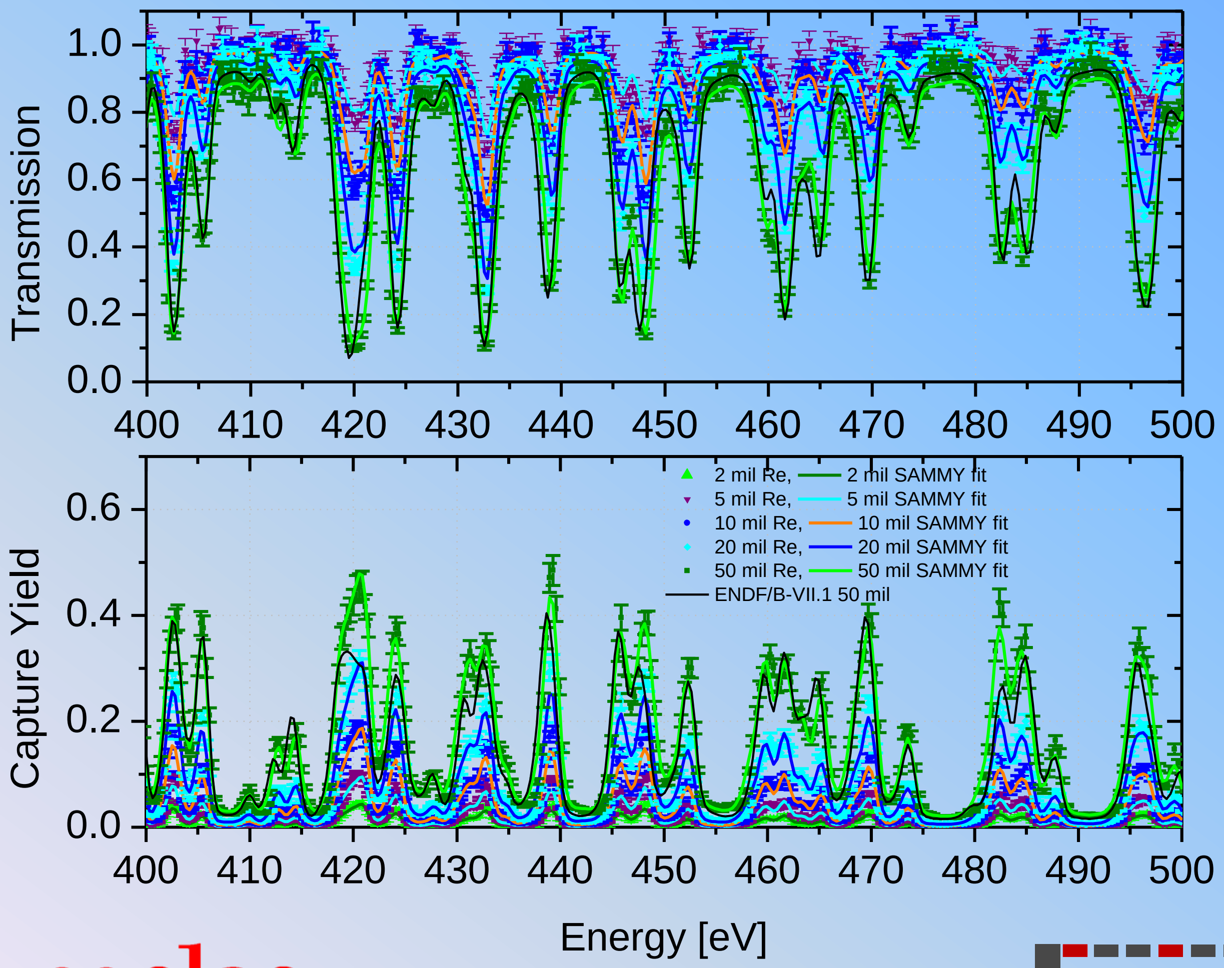
Re - Epithermal Measurements

- Capture corrected for gamma attenuation (2nd densest element)
- Transmission data analyzed to 1 keV, capture data to 600 eV.



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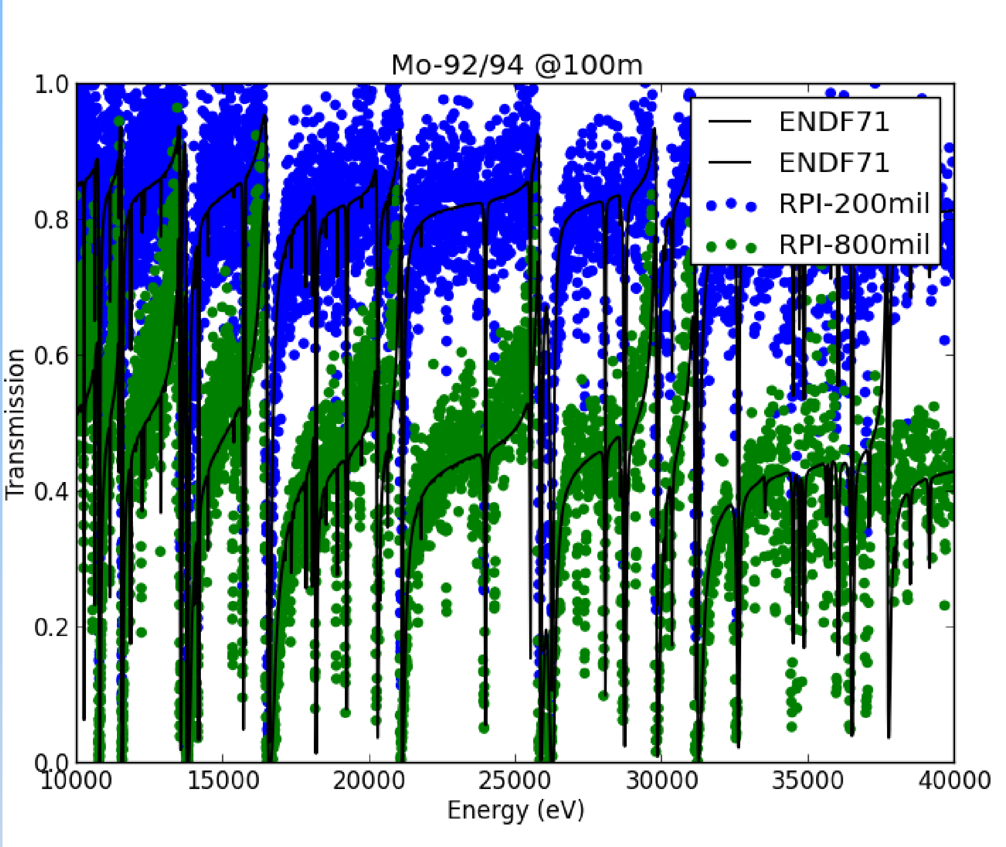
Measurements of $^{92/94}$Mo Transmission at 100m Flight Path

- Enriched Mo samples were prepared by Bettis Atomic Power Lab (75.63% ^{92}Mo, 23.78% ^{94}Mo)
- High resolution (100m flight path) transmission was measured from 5 keV to 200 keV
- Resonance analysis currently being performed between 10 keV and 40 keV. New resonances have been identified.
- Transmission above 40 keV will be treated as URR.



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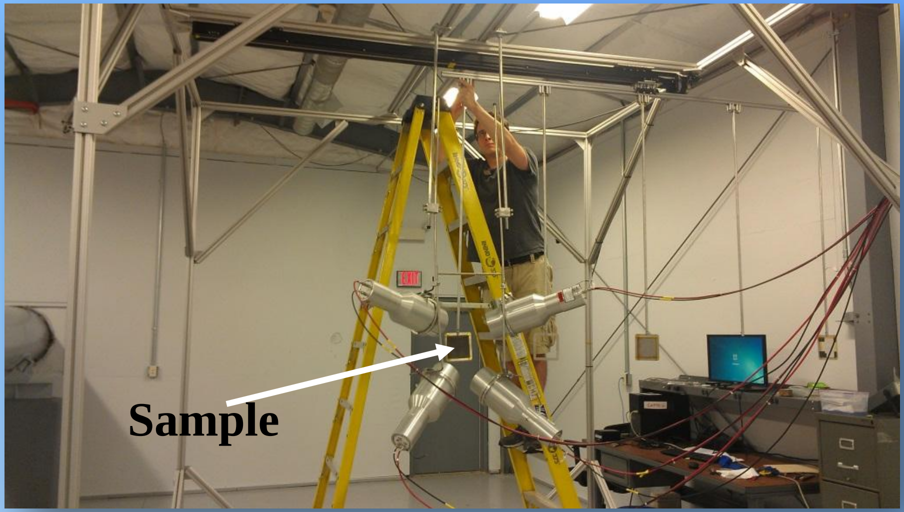
Mid-Energy Capture Detector

- 4 deuterated benzene (C_6D_6) liquid scintillators with low neutron sensitivity
- Located at newly constructed 40m flight station
- 10-bit, 8 channel Struck Systems SIS3305 digital data acquisition system allows for low dead time operation
- Low mass design to minimize background contributions from neutrons captured in detector and surrounding structural materials

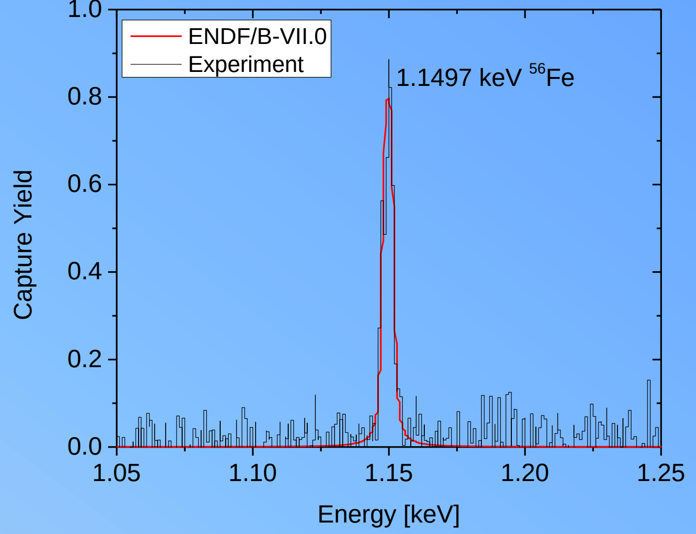


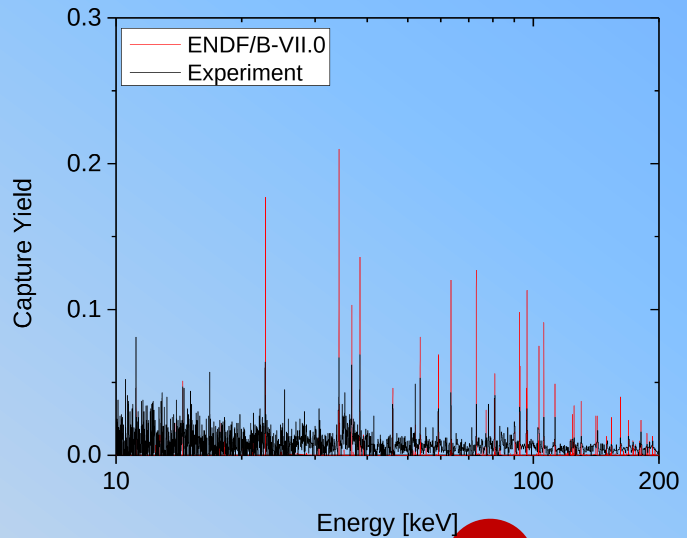
Brian is setting up the new detector system

A picture of flight path station

Test Measurement of Fe capture

- Capture measurements on a 1 cm thick Fe sample
- Three detectors were connected to digitizers
- One detector was connected to an analog system
- Data on Fe sample was taken for about 17 hours.
- Resonances in the keV region are resolved.
- A problem with the energy resolution of three detectors was identified, the detectors were returned to the vendor for repair





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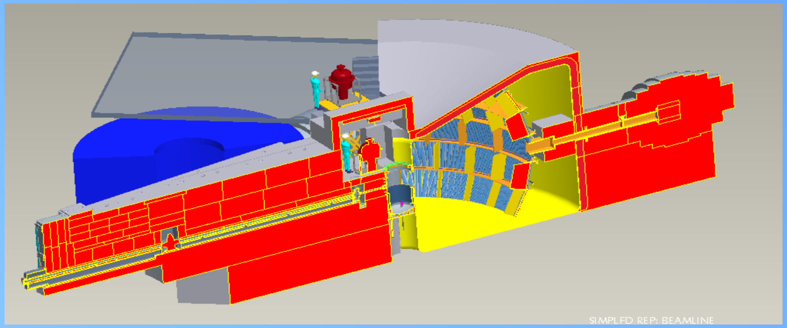
Thermal Scattering Experiment at SEQUOIA (SNS)

- SEQUOIA:
  - Fine-Resolution Fermi Chopper Spectrometer at SNS
  - E_i = 10 to 2000 meV
  - 900 ^{3}He detector tubes
  - Scattering angles: -30° to -3° horizontal and 3° to 60° vertical
  - Flux: > 1×10^5 neutrons/cm^2/s
  - Resolution: $\Delta E/E_i \sim 1\%$



- Double differential scattering cross section for inelastic scattering:

$$\frac{d^2\sigma}{d\Omega dE'}\left(E\rightarrow E',\Omega\rightarrow\Omega'\right)=\frac{\sigma_b}{4\pi kT}\sqrt{\frac{E'}{E}}e^{-\frac{\beta}{2}}S(\alpha,\beta)$$

$$\alpha=\frac{E'+E-2\sqrt{E'E}\cos\theta}{AkT}=\frac{\hbar^2\kappa^2}{2MkT} \qquad \beta=\frac{E'-E}{kT}=\frac{\varepsilon}{kT}$$

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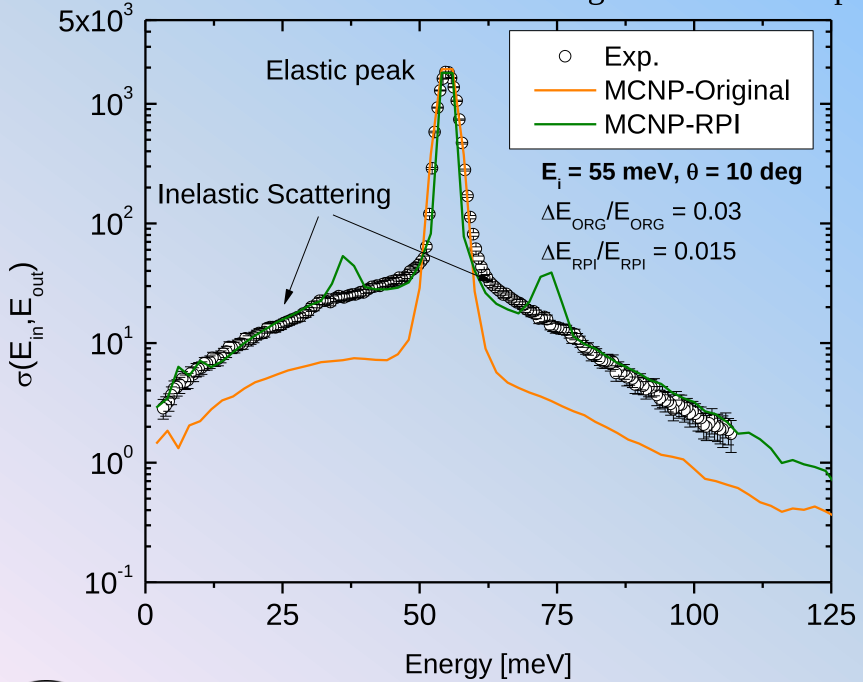
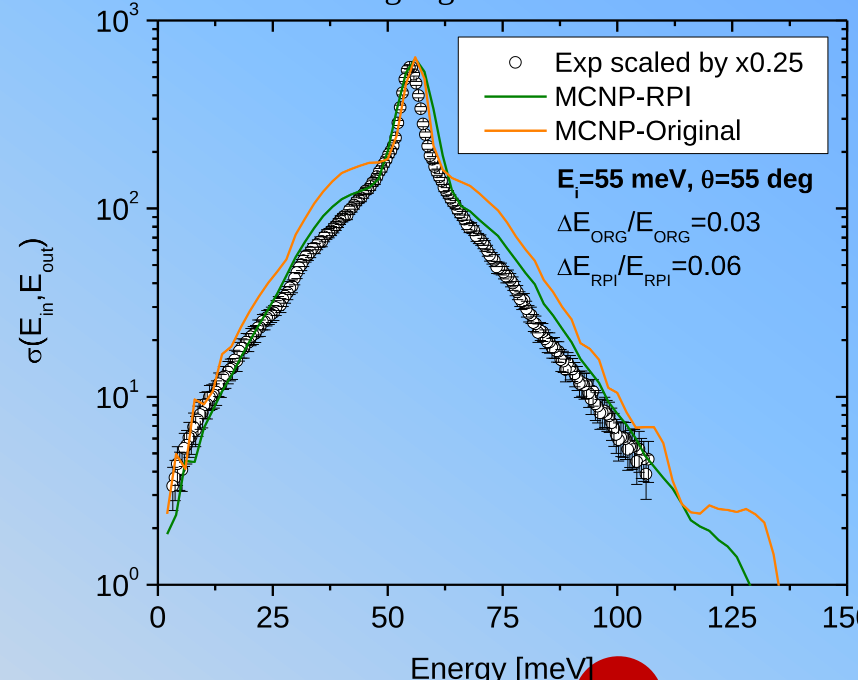
Thermal Scattering Measurements
Mid Density Polyethylene

- Samples: H_2O, **Polyethylene**, Empty Can, Vanadium
- Data were measured for several incident energies, E_i (eV): 0.055, 0.16, 0.25, 0.6, 1, 3, 5
- Use the MCNP provided scattering kernel and our own generated kernel to simulate the experiment using MCNP
  - Included spectrometer incident energy resolution.
  - Data were normalized at the elastic scattering peak
  - The MCNP included scattering kernel does not perform well in the inelastic scattering region.





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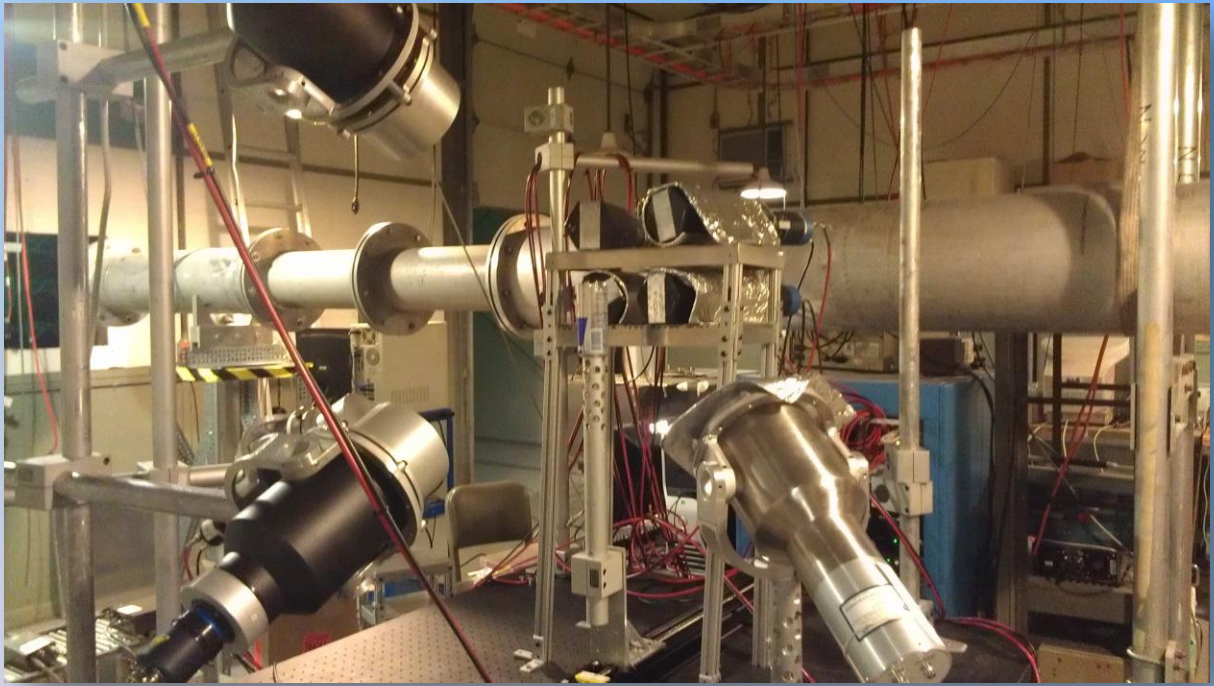
Prompt Fission Neutron Spectra



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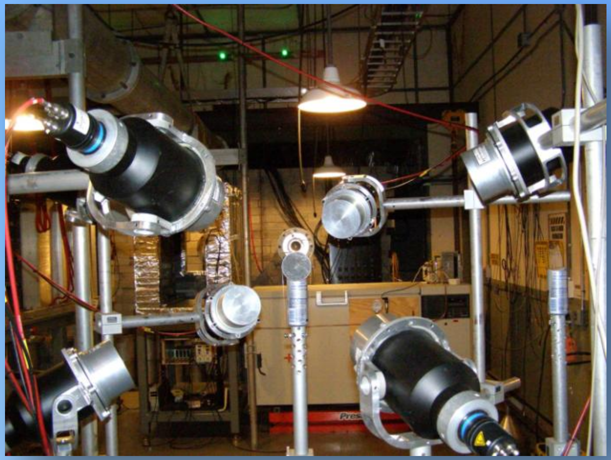
Gamma Tagging

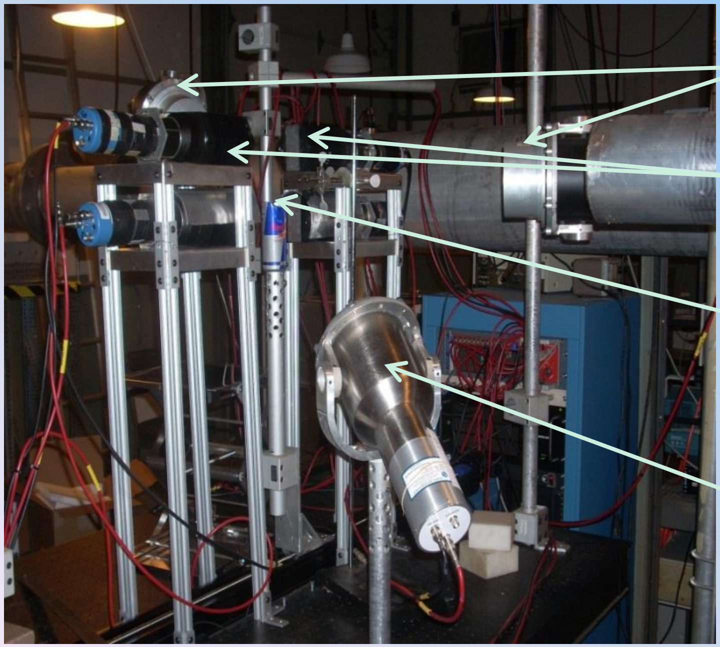
- Advantages
  - Eliminated the need to construct a complicated multiplate fission chamber
  - Simpler sample preparation
  - Can use relatively large samples
  - Can increase the detected fission rate
- Disadvantages
  - False fission detection due to:
    - Random coincidence for radioactive decay
    - Neutron interactions with the gamma detector
    - Beam related:
      - Gamma capture
      - Inelastic Scattering
      - Increased background



Fast neutrons scattering detector array

Experimental Setup

- Neutron Detectors
  - EJ-204 Plastic Scintillator
    - 0.5" x 5"
    - 47 cm away from center of sample
  - 2 EJ-301 Liquid Scintillators
    - 3" x 5"
    - 50 cm away from center of sample



- Gamma Detectors
  - 4 BaF_2 detectors on loan from ORNL
  - Hexagonal detectors 2" x 5"
  - 10 cm from center of sample
  - ¼" lead shield between detectors
    - Reducing scattering between detectors

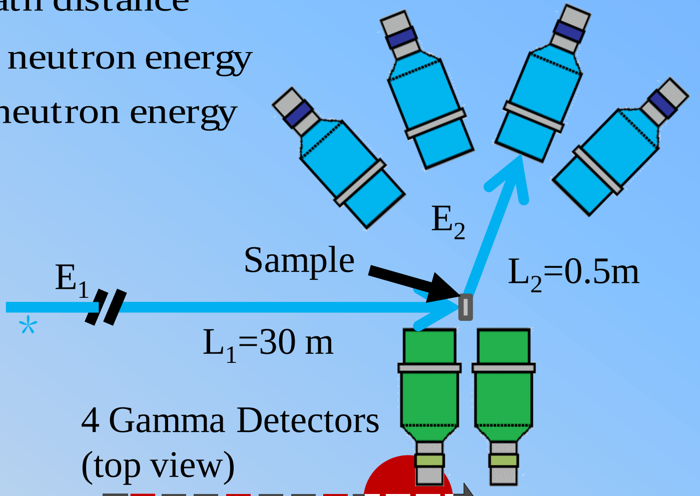
$$ToF = \frac{kL_1}{\sqrt{E_1}} + \frac{kL_2}{\sqrt{E_2}}$$

$$k \approx 72.3 \frac{\mu s\, eV^{1/2}}{m}$$

$L_{1,2}$ – flightpath distance

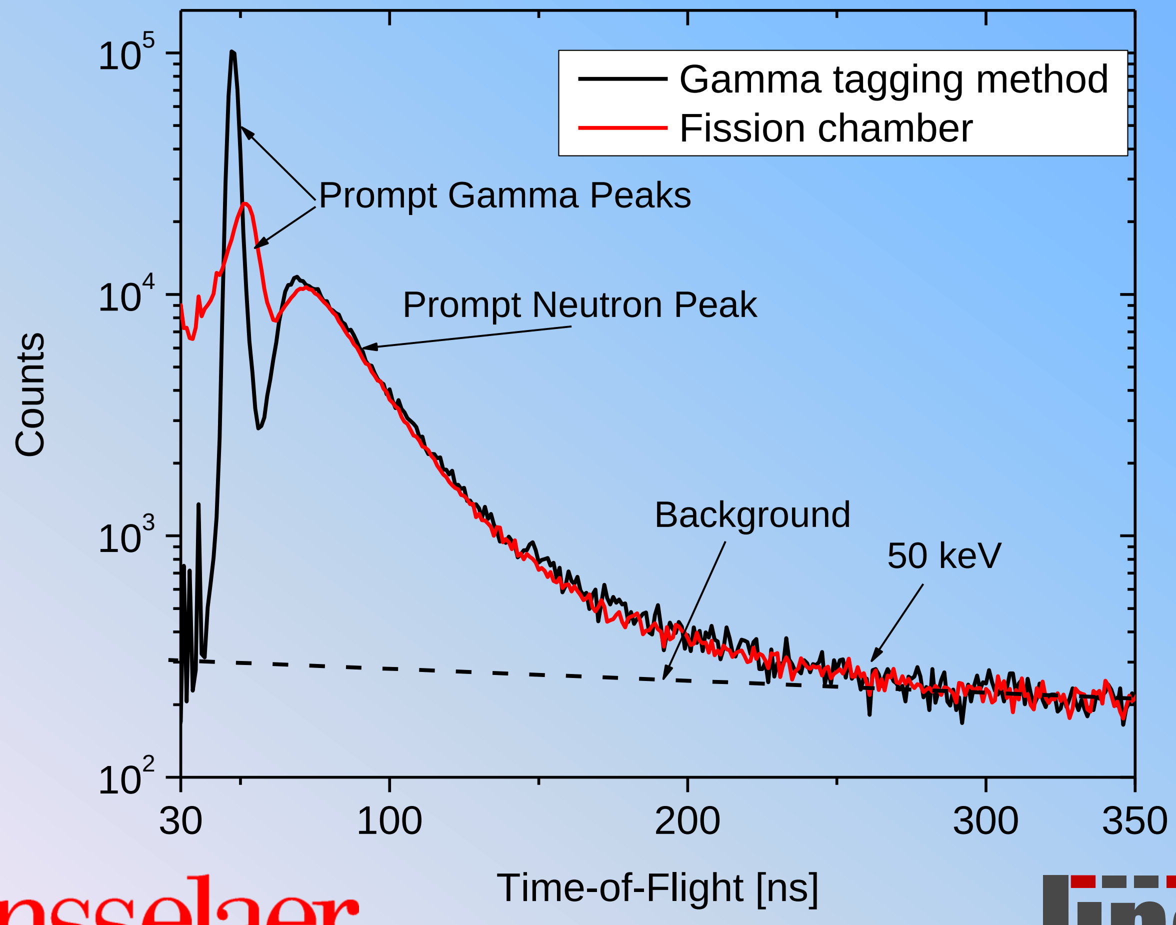
E_1 – incident neutron energy

E_2 – fission neutron energy



Gamma Tagging - EJ-204

- Gamma tagging method corrected for 30% detection efficiency compared to 83% detection efficiency with fission chamber



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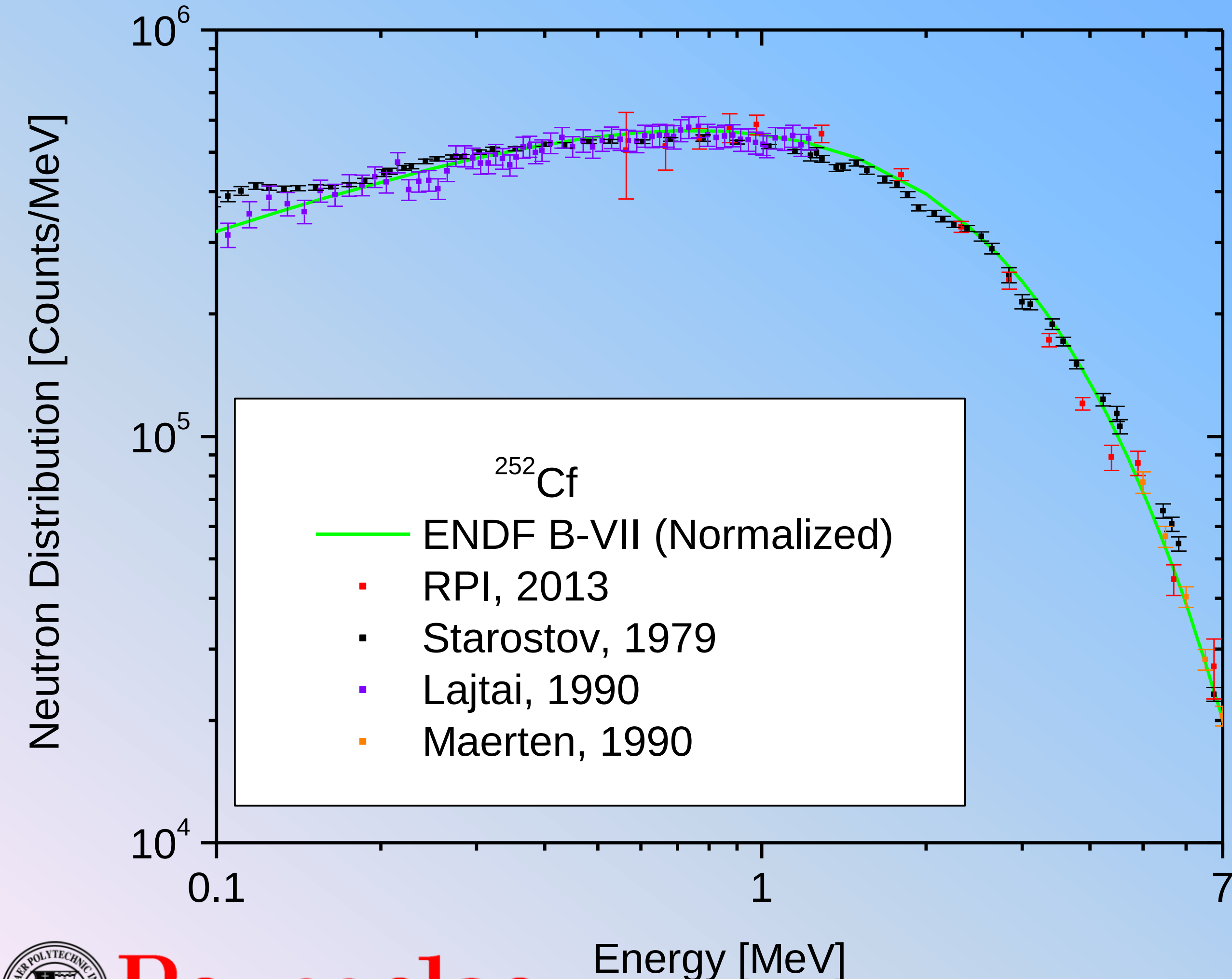
^{252}Cf Prompt Fission Neutron Spectrum High Energy



- High Energy spectrum taken with EJ-301 liquid scintillator
- The gamma tagging method shows good agreement to ENDF/B-VII in the energy range from 0.6 MeV to 7 MeV

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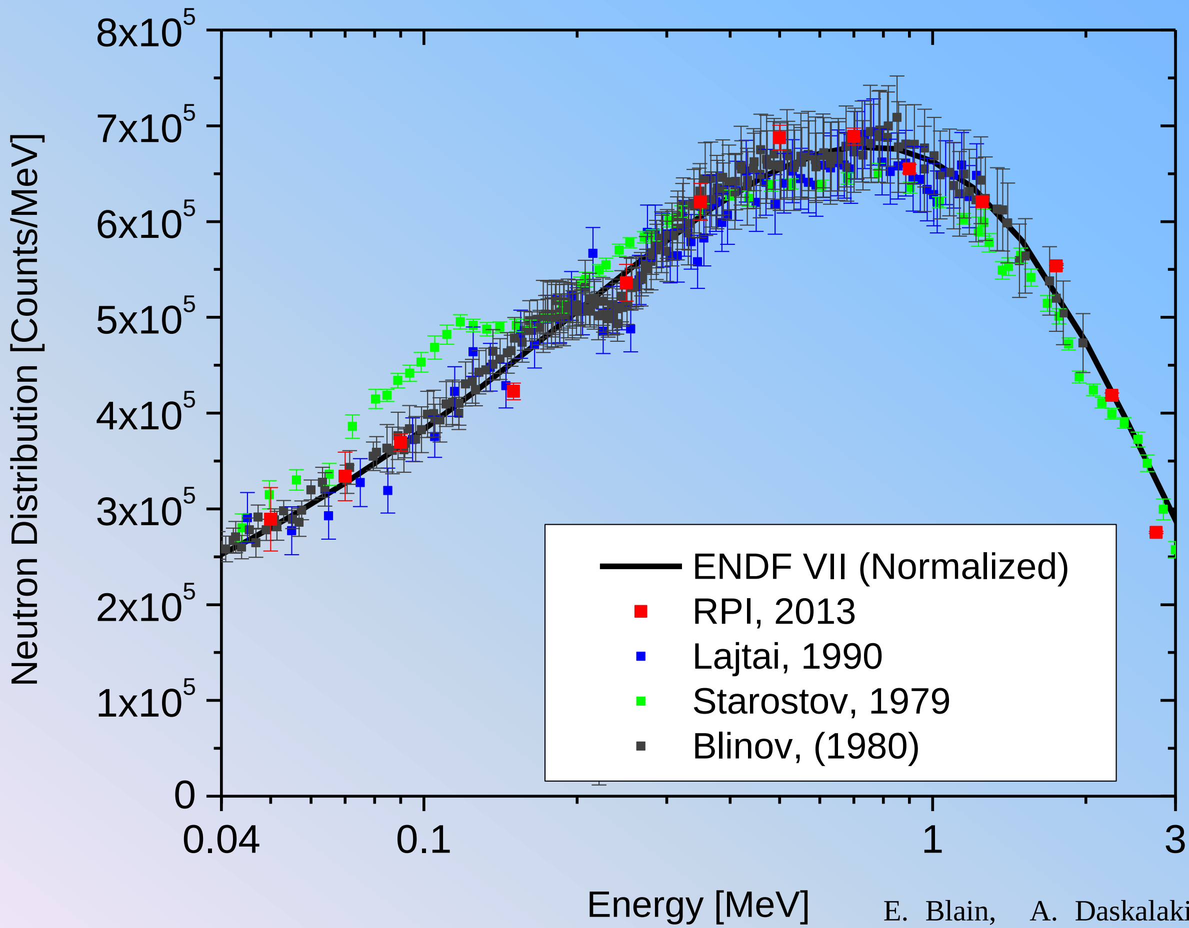
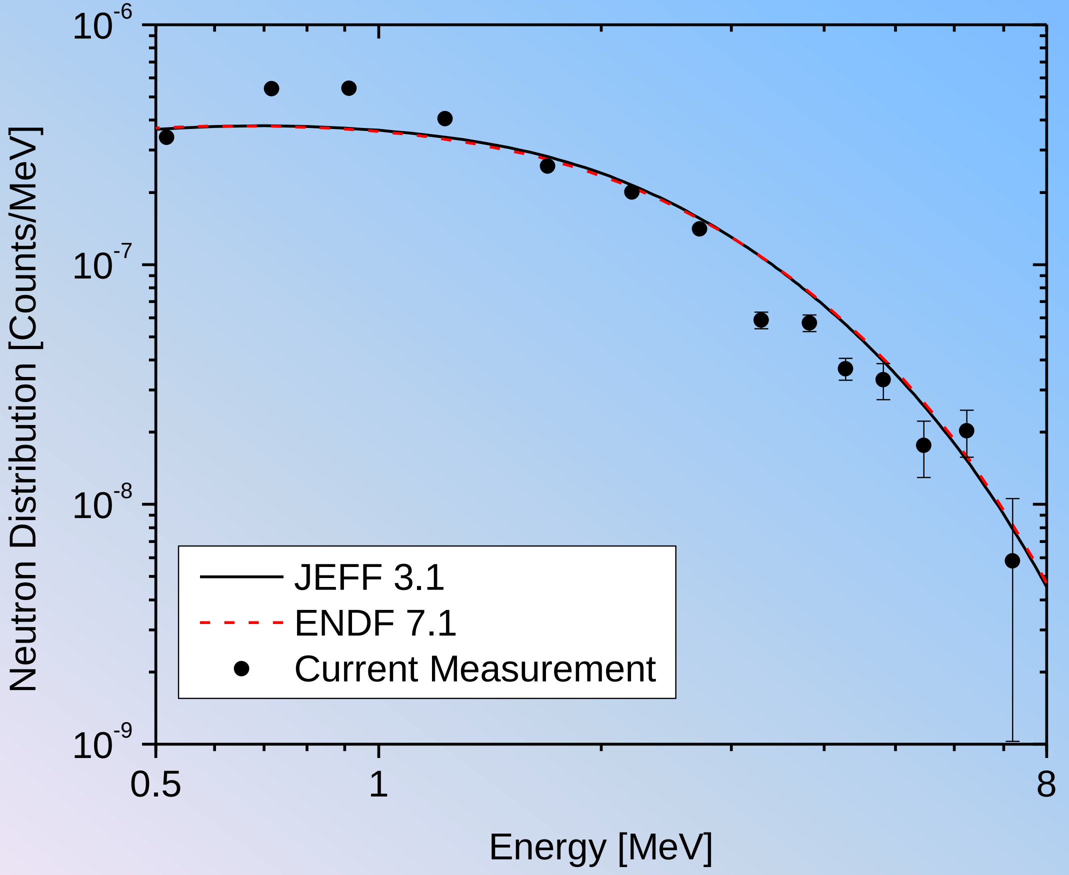
^{252}Cf Prompt Fission Neutron Spectrum Low Energy



- Low energy data taken with 0.5" EJ-204 plastic scintillator
- RPI data show good agreement to Lajtai, Blinov data and ENDF evaluation
- Thin plastic detector allows for measurement down to 50 keV
- Gamma tagging method accurately reproduces PFNS for ^{252}Cf

E. Blain, A. Daskalakis, and Y. Danon, "Measurement of Fission Neutron Spectrum and Multiplicity using a Gamma Tag Double Time-of-Flight Setup", **invited talk**, International Conference on Nuclear Data for Science and Technology, New York, New York, March 4-8, 2013.

^{238}U Prompt Fission Neutron Spectrum
Preliminary Results



- Spectrum is normalized to ENDF at 2 MeV
- Spectrum is integrated over from 0.5 MeV to 20 MeV
- Only statistical uncertainty was plotted.
- Preliminary data show reasonable agreement with current evaluations

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EXFOR meeting at IAEA

- A meeting of several experimentalists was held at IAEA in Vienna to discuss EXFOR reporting for resonance region experimental data (mostly transmission and capture).
  - Experientialists: Guber (ORNL) ,Gunsing (CEA/nTOF), Kimura (JPARC), Noguere (CEA), Schillebeeckx (IRMM), Danon (RPI)
- The result of the meeting is a new template that capture the essential parameters of the different experiments
- Example: JPARC experiment (small part is shown here)

Template for Submission of Time-of-Flight Spectra (EXFOR 23141.003)

Edited by IAEA Nuclear Data Section (Rev., 11 October 2013)

A. EXPERIMENT DESCRIPTION

1. Main Reference		1
2. Facility	ANNRI	2,3,4
3. Neutron production		5
Neutron production beam	Proton	
Nominal beam energy	3 GeV	
Repetition rate (pulse/sec)		
Pulse width	Two bunches, each with a width of 100 ns, at intervals of 600 ns	5
Pulse frequency	25 Hz	
Nominal beam power	120 kW	4
Primary neutron production target	Mercury	
Neutron source position in moderator		
4. Moderator		
Material	Para H	
Dimension (thickness, height×width×depth,…)	140 mm thick	
Mass		
Temperature (K)	19.7 K	

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Summary

- **Publications since the last CSEWG meeting**
  - Eu sample x-ray characterization (Journal of X-Ray Science and Technology)
  - High energy scattering from Zr (NSE)
  - High energy transmission for Be and C (NSE)
  - "Monte Carlo Hauser-Feshbach Predictions of Prompt Fission Gamma Rays", Phys Rev C
- **Analysis in progress**
  - Ti, Ta, Zr and $^{92/94,95,96,98,100,nat}$Mo high energy (0.5-20 MeV) transmission
  - Eu, ^{153}Eu, ^{161,162,163,164}Dy, ^{155,156,157,158,160}Gd
  - ^{238}U, ^{56}Fe neutron scattering
- **Measurements since the last CSEWG meeting**
  - $^{92/94}$Mo Transmission, 5-600 keV, 30m, 100m flight path
  - ^{56}Fe Capture, 1 keV - 500 keV, 45m flight path (as system test)
  - Prompt fission neutron spectra of ^{252}Cf and ^{238}U.
- **Planned measurements**
  - ^{236}U, Transmission, 15m flight path, concentrate on the 5.45 eV resonance
  - Fission neutron spectra ^{238}U, (possibly ^{235}U)
  - H_2O, Thermal neutron scattering
  - $^{92/94}$Mo mid energy capture