

# Nuclear Data Measurements, from LBNL & UC Berkeley



7 November 2018

**US National Nuclear Data Week**

Jonathan Morrell



# Summary of Cross Sections Measured

## UC Berkeley (Nuc. Eng.) High-Flux Neutron Generator

- $^{35}\text{Cl}(n,p)$  &  $^{35}\text{Cl}(n,a)$  - *Fast reactor coolant*
- $^{58}\text{Ni}(n,p)^{58}\text{Co}$  - *High energy neutron monitor*
- $^{39}\text{K}(n,p)^{39}\text{Ar}$  - *Geochronology*

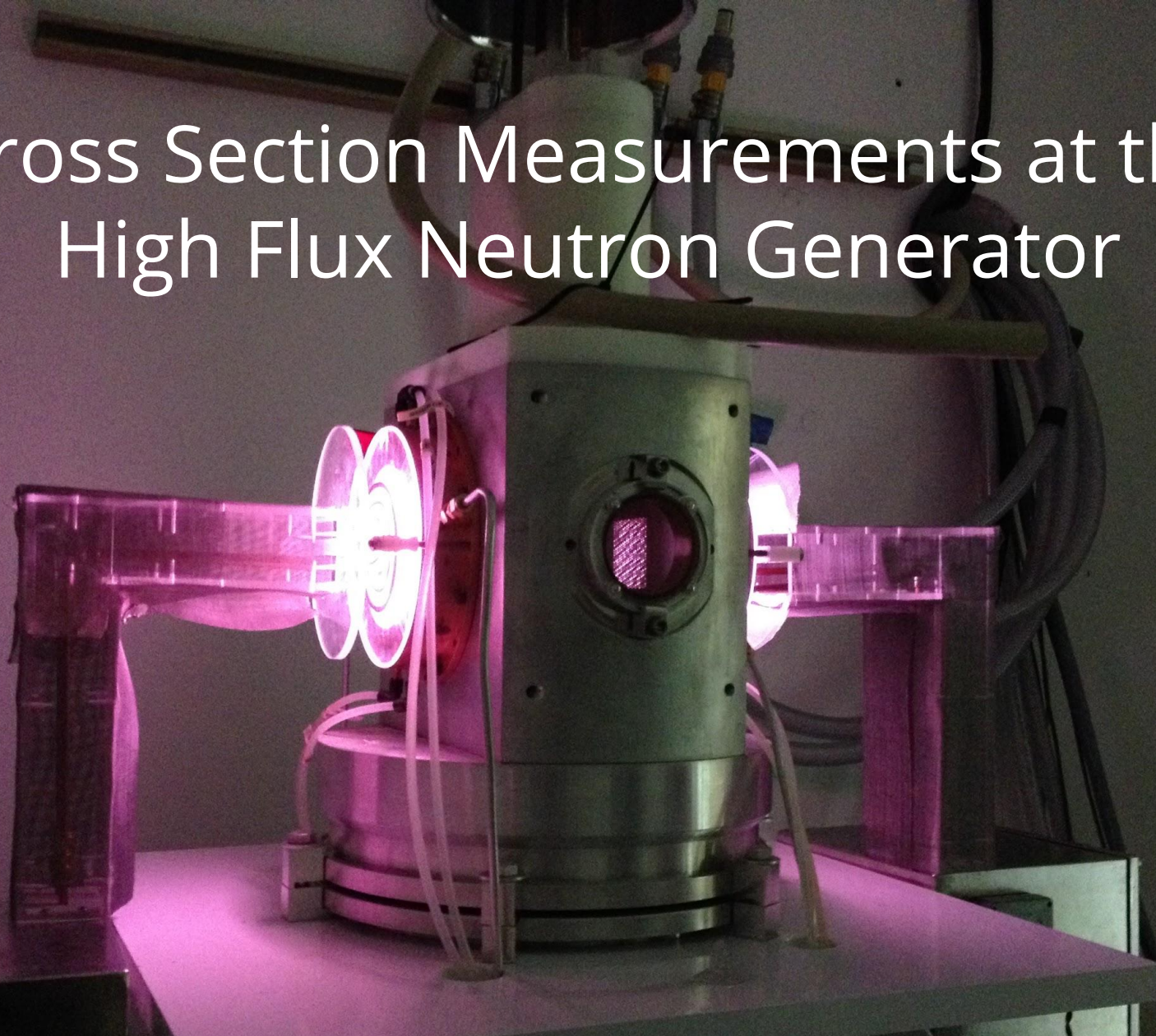
## LBNL 88" Cyclotron

- $^{139}\text{La}(p,6n)^{134}\text{Ce}$  (and contaminants) - *PET Isotope*
- $^{64}\text{Zn}(n,p)^{64}\text{Cu}$  &  $^{67}\text{Zn}(n,p)^{67}\text{Cu}$  - *Therapeutic/Diagnostic pair*
- $^{235}\text{U}(d,n)^{236}\text{Np}$  - *Mass Spectrometry Spike*
- $^{169}\text{Tm}(d,2n)^{169}\text{Yb}$  - *Cryo-bolometer calibration source*
- $^{226}\text{Ra}(n,2n)^{225}\text{Ra} \rightarrow ^{225}\text{Ac}$  - *Targeted Alpha Therapy*





# Cross Section Measurements at the High Flux Neutron Generator



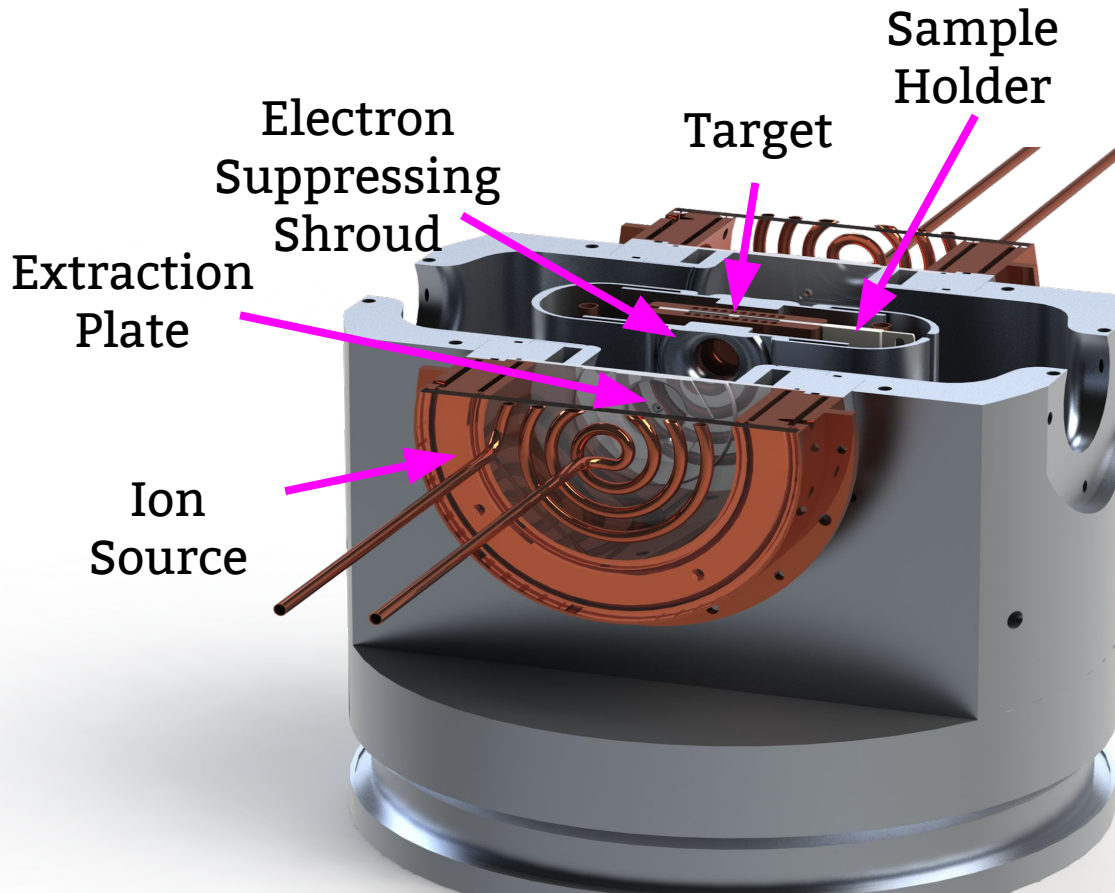
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# Design, Capabilities & Goals

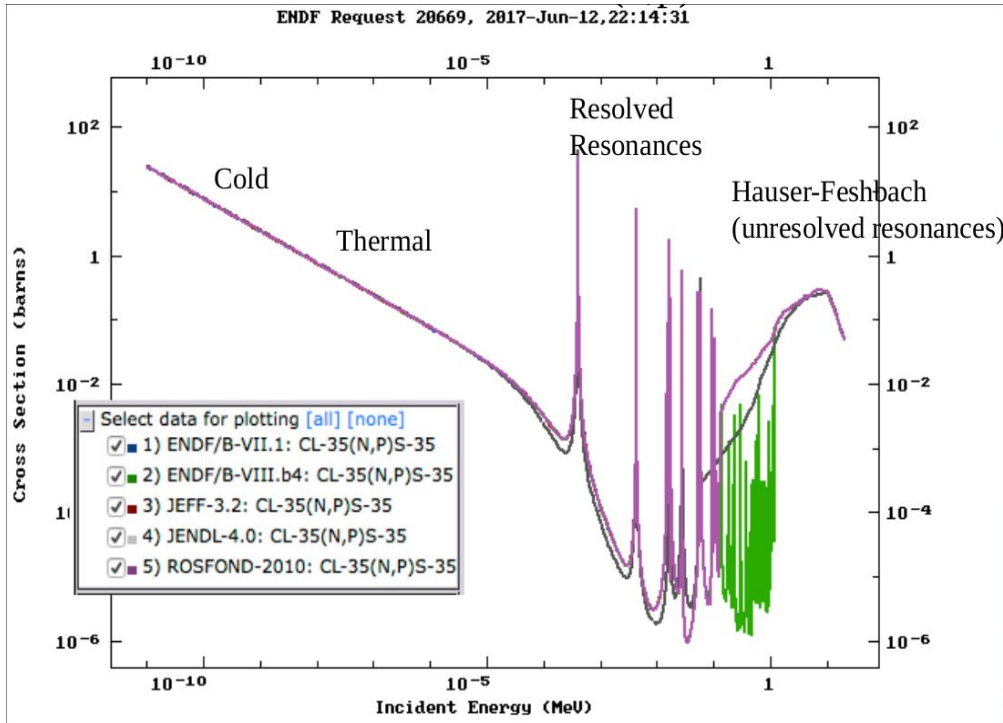


- Attempt to maximize flux on samples ( $\sim 3 \cdot 10^7$  n/cm<sup>2</sup>/s)
- High neutron utilization factor
- Well known energy-angle correlation
- Tuneable neutron energy on sample
- Gamma/beta counting

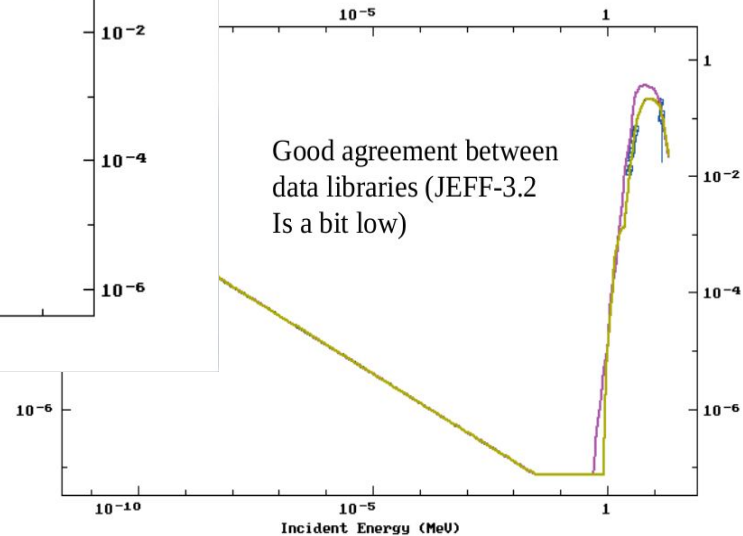




# $^{35}\text{Cl}(n,p)$ & $^{35}\text{Cl}(n,a)$



ENDF Request 542, 2017-Jun-13, 16:43:25  
Request: 37350/1, 2017-Jun-13 16:43:38



Select data for plotting [all] [none]

- 1) 17-CL-35(N,A)15-P-32,,SIG
- 2) ENDF/B-VII.1: CL-35(N,A)P-32
- 3) ENDF/B-VIII.b4: CL-35(N,A)P-32
- 4) JEFF-3.2: CL-35(N,A)P-32
- 5) JENDL-4.0: CL-35(N,A)P-32
- 6) ROSFOND-2010: CL-35(N,A)P-32
- 7) Use my data [example]

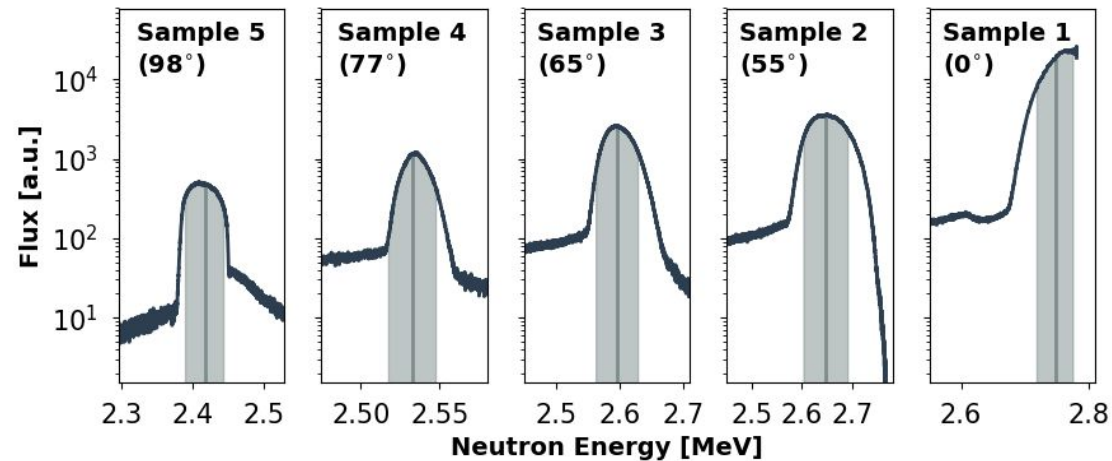
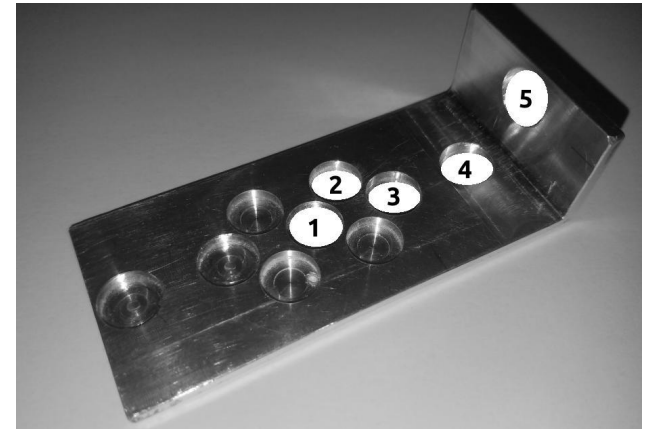
See: plotted data (68Kb)

Well measured  
3-4 & ~14 MeV

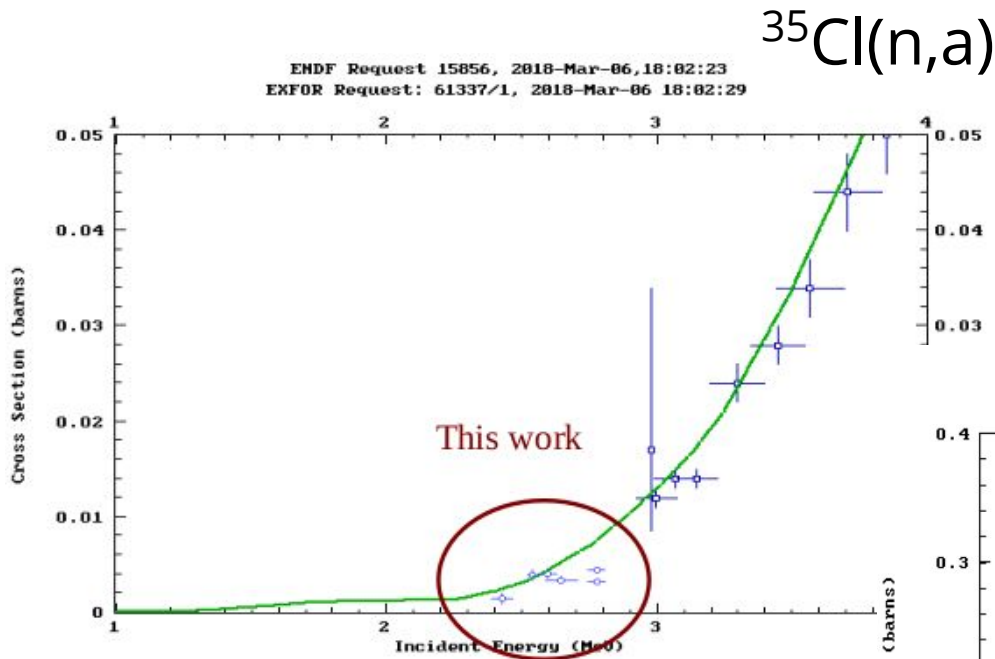


# Experiment Design

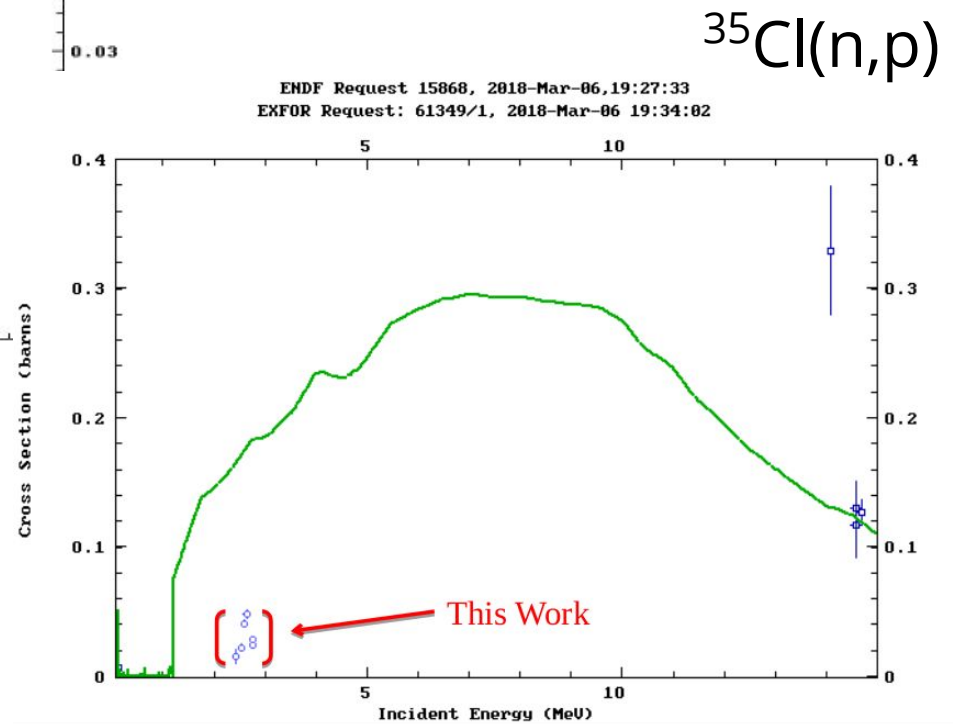
- Neutron spectrum determined by angle
- 5 NaCl samples
- Flux monitored by In/Ni foils
- Activity determined by LSC (beta) counting



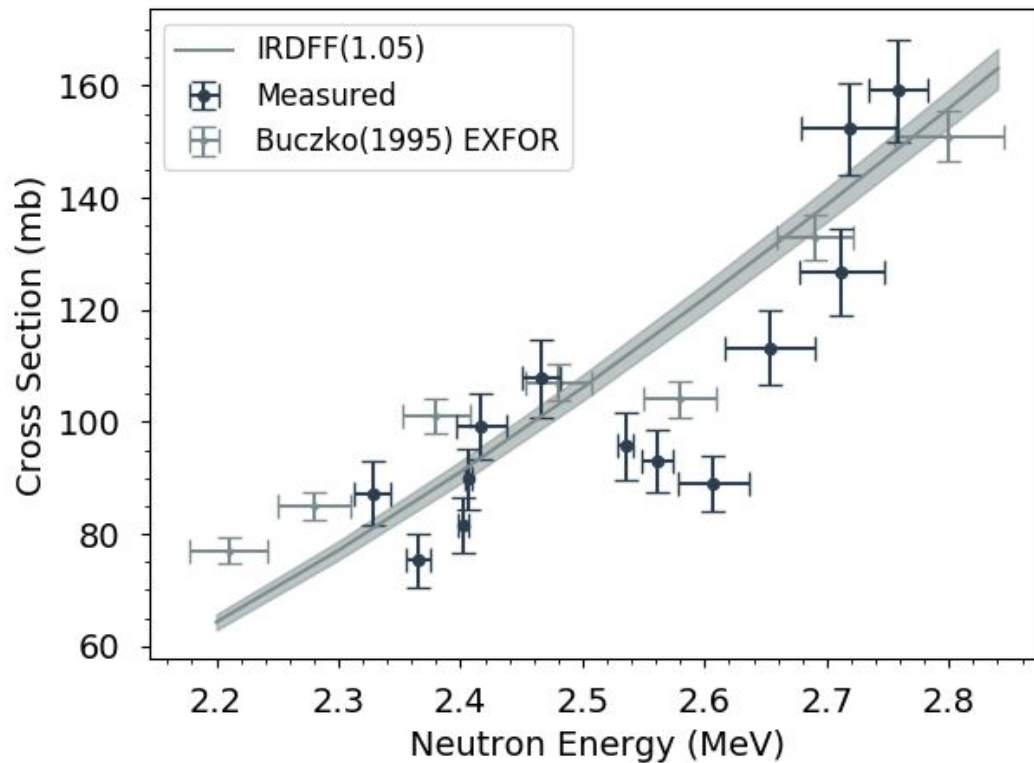
# Results



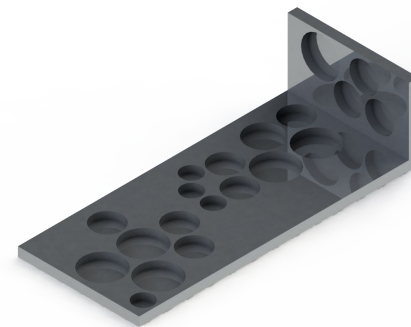
- Significant deviation from evaluation
- Resonance(s) in (n,p)



# $^{58}\text{Ni}(n,p)^{58}\text{Co}$ Cross Section



- New sample holder designed
- Increased resolution
- Greater energy range
- Test using monitor reaction (Ni)





# Cross Section Measurements at the LBNL 88" Cyclotron



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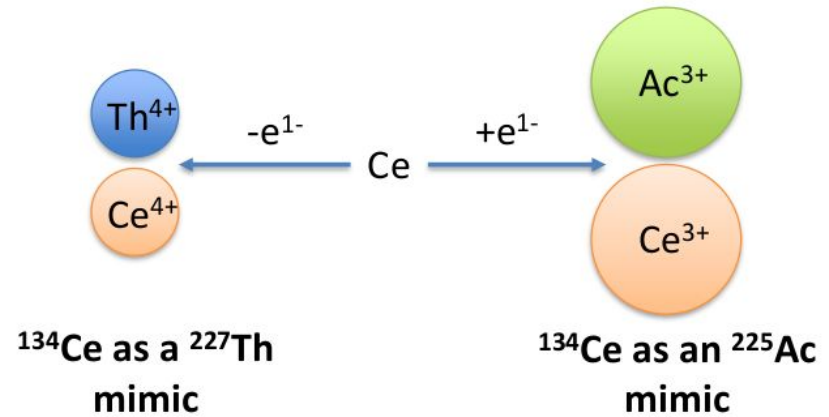
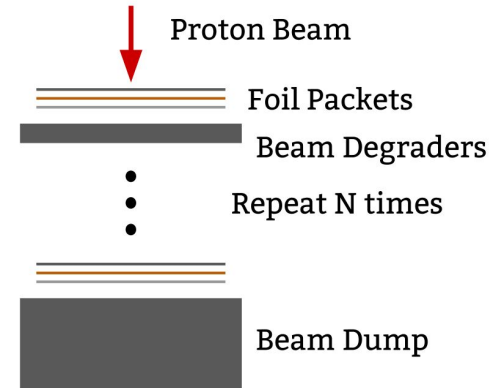
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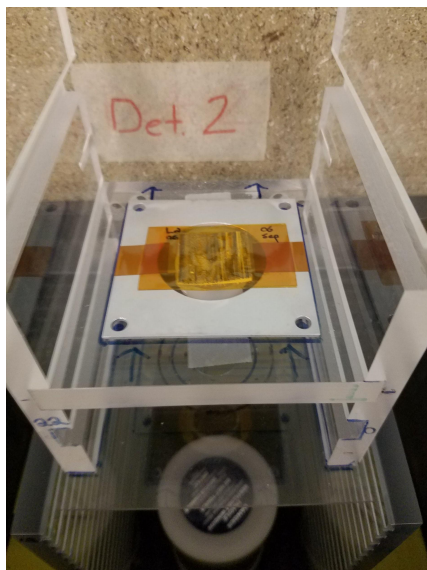
# $^{139}\text{La}(p,6n)^{134}\text{Ce}$ Cross Sections

- $^{134}\text{Ce}$  - PET analogue of  $^{225}\text{Ac}$
- $^{134}\text{Ce}/^{134}\text{La}$ :  $t_{1/2} = 75.9\text{h}/6.67\text{m}$ , 2.7 MeV  $\beta^+$  (62.0%)
- Stacked foil activation measurement (< 60 MeV)

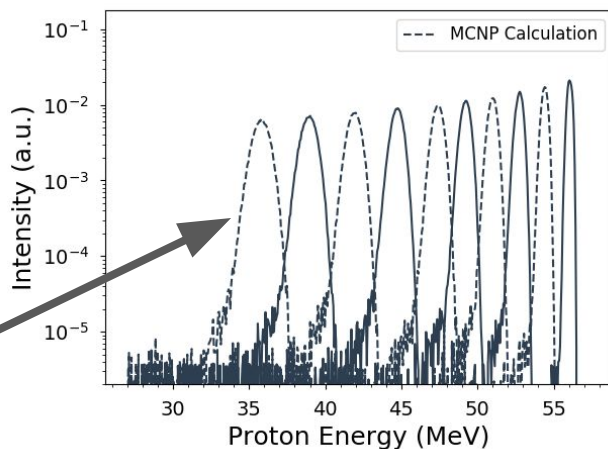
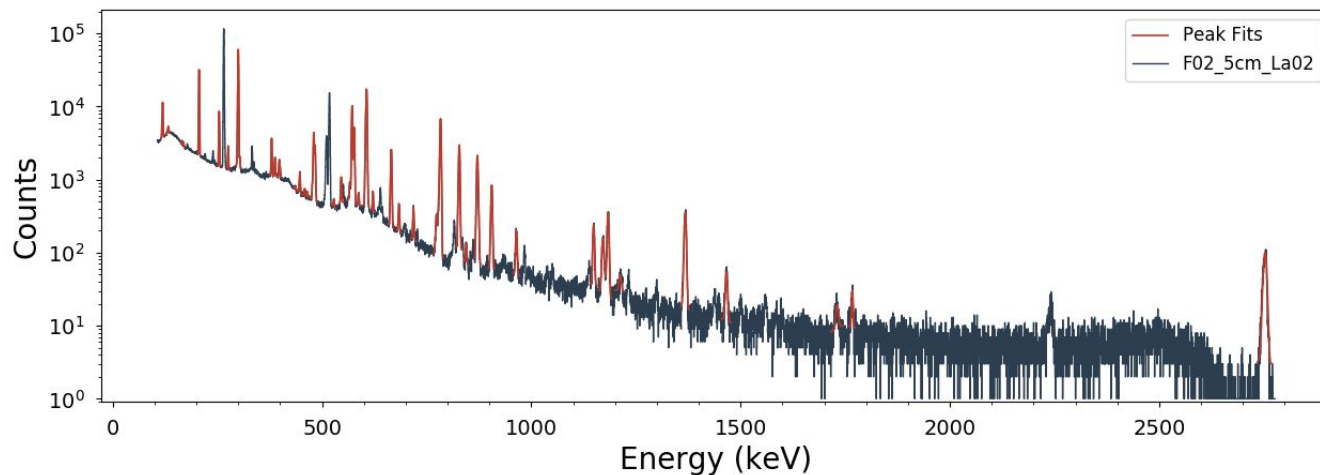




# Measurement



Proton spectrum in each foil



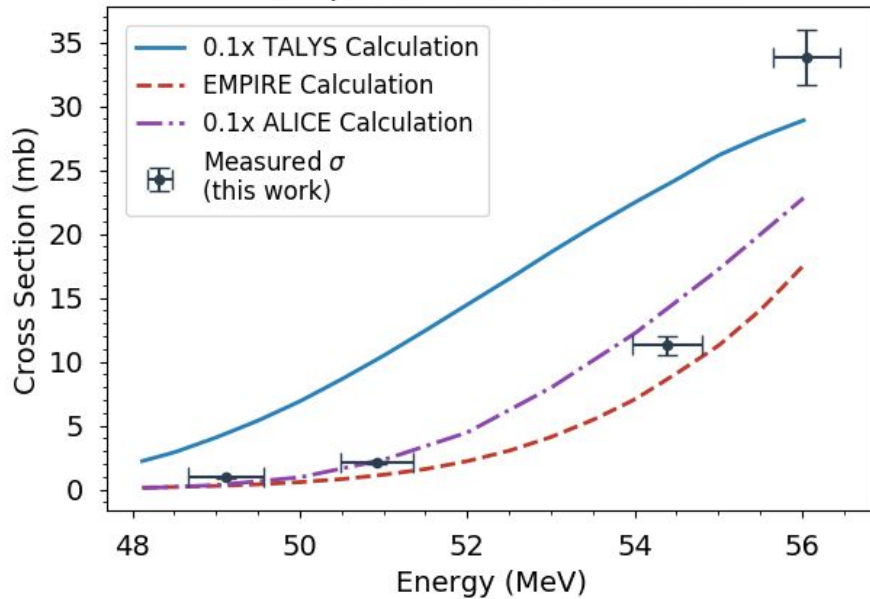
- Measure activity of reaction channels
- Measure current with monitor foils
- MCNP/AZ Energy Assignments



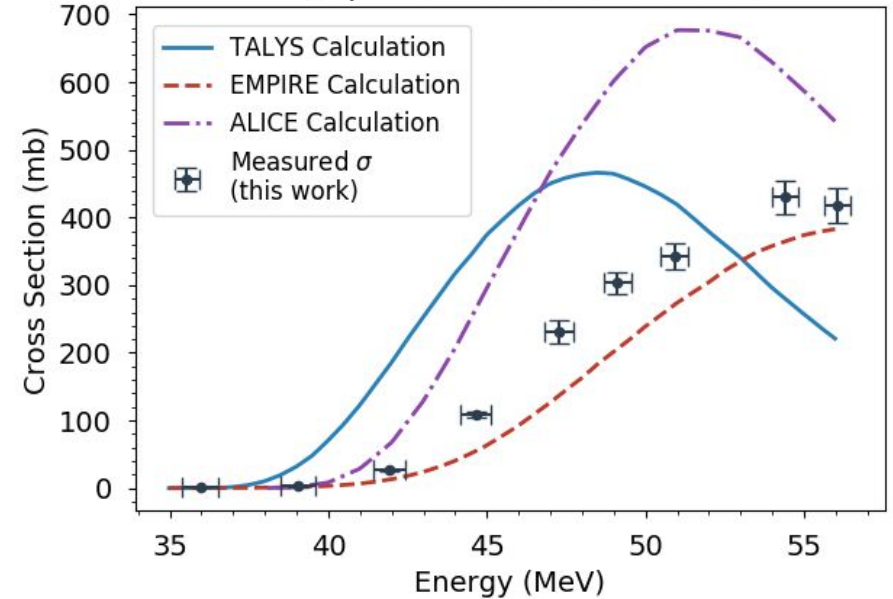


# Deviation from XS Calculations

$^{nat}\text{La}(p,6n)^{134}\text{Ce}$  Cross Section



$^{nat}\text{La}(p,5n)^{135}\text{Ce}$  Cross Section



- TALYS & ALICE (Exciton) overpredict by ~10x, EMPIRE (HMS) close to measurement
- Implications for production/target design

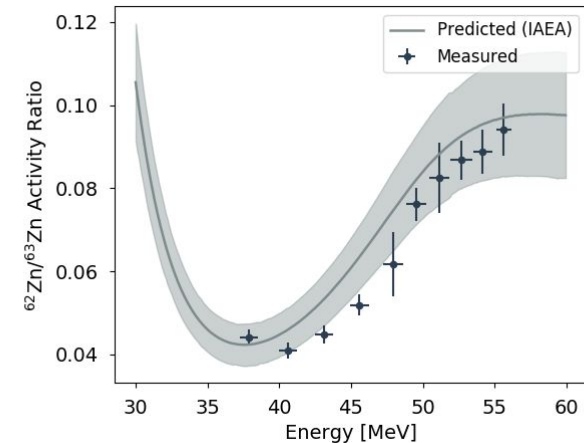
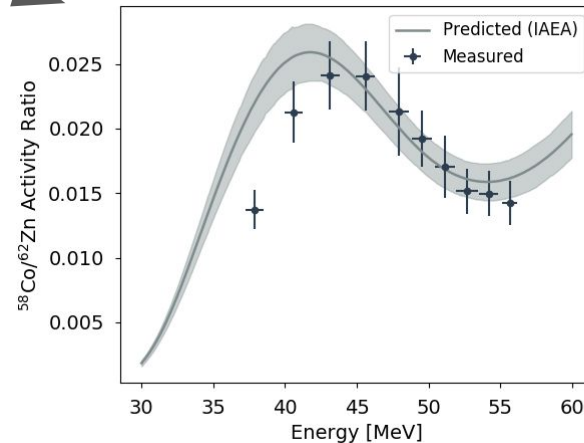
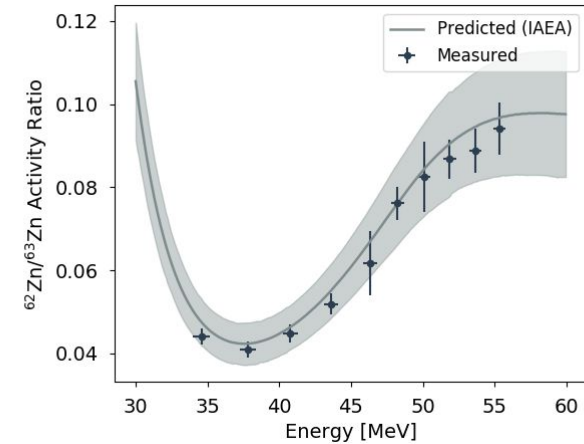
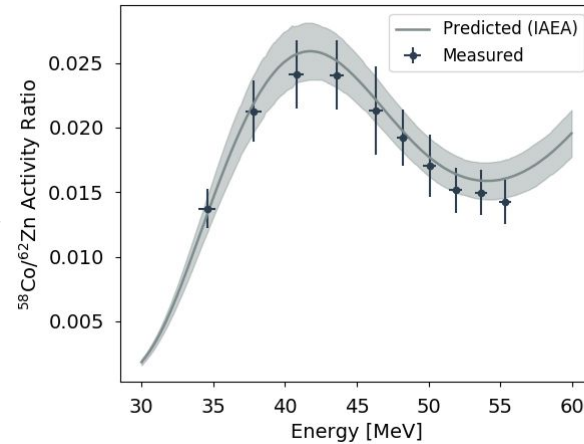


# Deviation from Stopping Powers

Anderson &  
Ziegler (SRIM)  
calculations

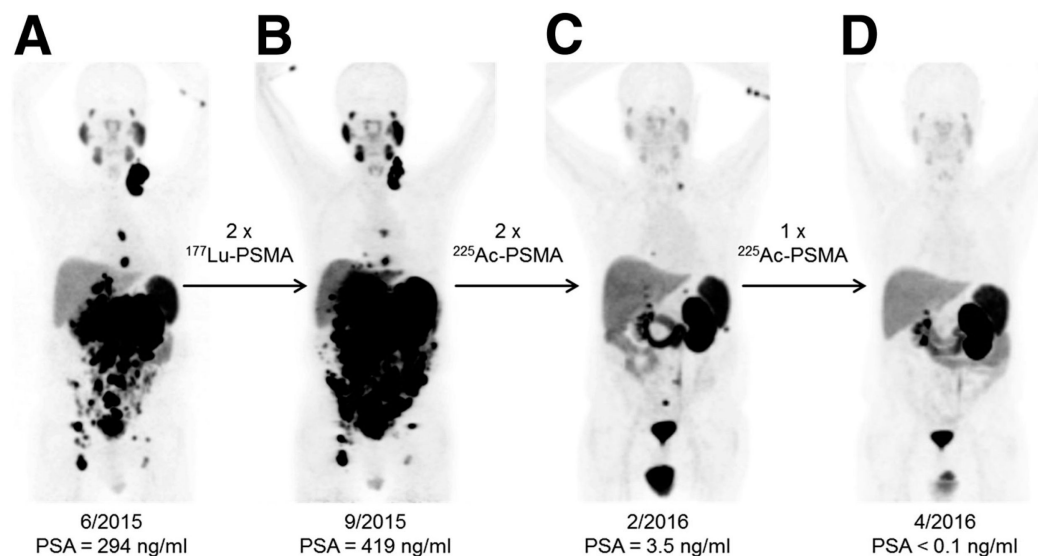
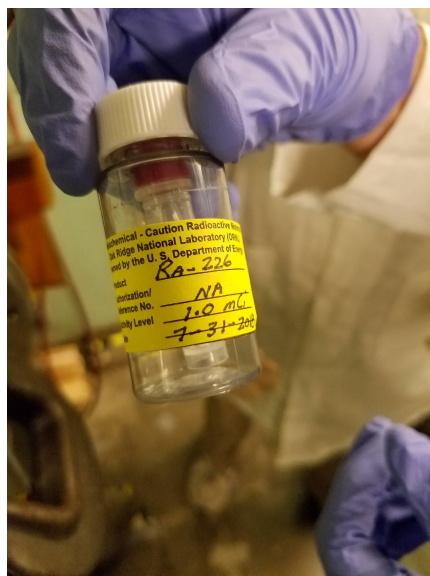
MCNP  
calculations

- MCNP energy assignments (stopping power) 20% off!



# $^{225}\text{Ac}$ Production from $^{226}\text{Ra}(n,2n)$

- Extremely promising for targeted alpha therapy
- Every production pathway is challenging (Th/Ra targets)
- $^{226}\text{Ra}(n,2n)$  followed by  $\text{B}^-$  decay utilizes high-intensity D-breakup beam at 88" cyclotron

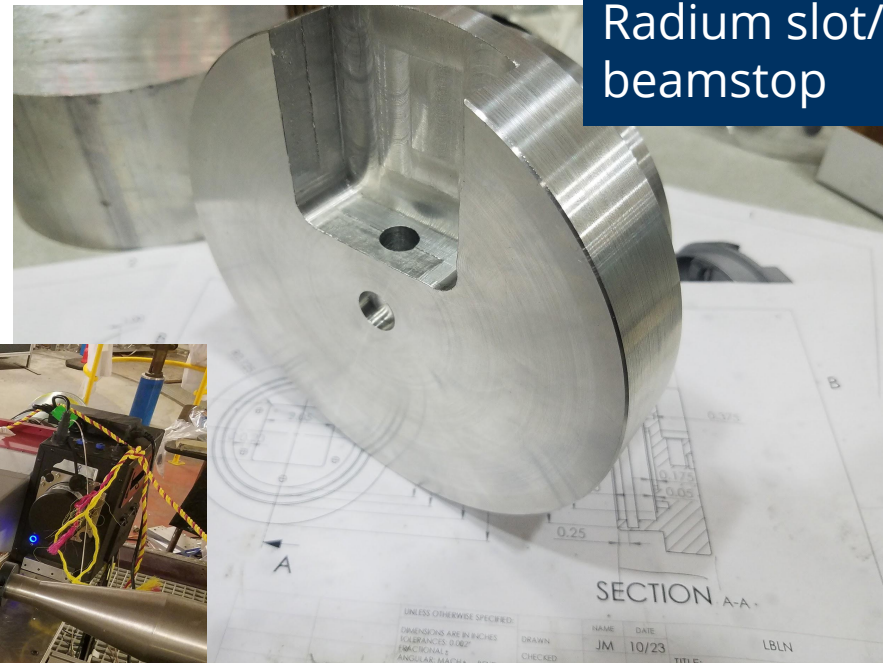




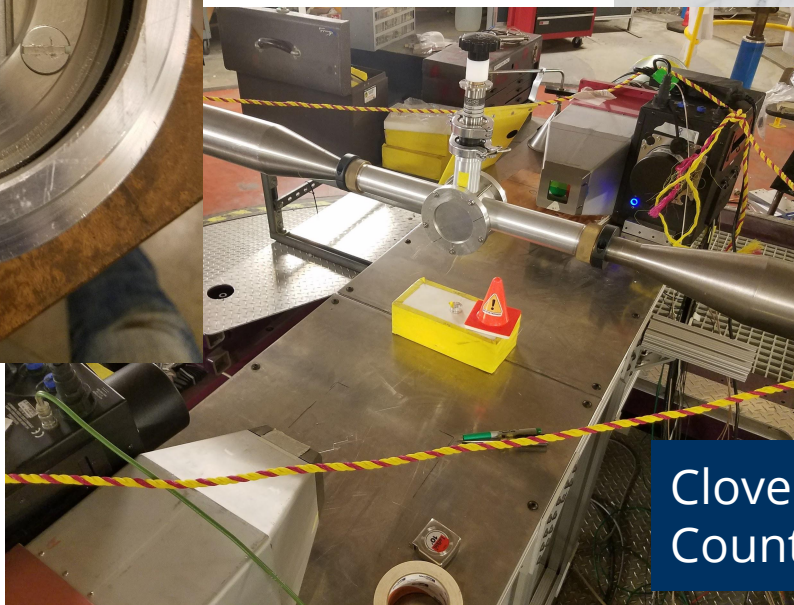
# $^{225}\text{Ac}$ Production from $^{226}\text{Ra}(n,2n)$



Be breakup target



Radium slot/  
beamstop



Clover HPGE  
Counting Array



# Questions?



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