

# Berkeley Nuclear Data Measurements Program



30 November 2020

**US National Nuclear Data Week**

Jonathan Morrell



# Measurement Campaigns

## Fission

- FLUFFY - Independent fission product yields for short-lived isotopes
  - See Eric Matthews (spoke earlier today) for more info

## Neutron Scattering

- GENESIS - *Inelastic scattering on  $^{56}\text{Fe}$ ,  $^{238}\text{U}$  for fast-reactor applications*

## Isotope Production

- $^{75}\text{As}(p,x)^{72}\text{Se}$  &  $^{75}\text{As}(p,x)^{68}\text{Se}$  - *PET Imaging*
- $^{nat}\text{Sb}(p,x)^{117m}\text{Sn}$  - *Therapeutic/Diagnostic*
- $^{226}\text{Ra}(n,2n)^{225}\text{Ra} \rightarrow ^{225}\text{Ac}$  - *Targeted Alpha Therapy*
- Secondary Neutrons from Deuteron Breakup
- $^{232}\text{Th}(p,4n)^{229}\text{Pa} \rightarrow ^{229}\text{Th}$  - *Long lived  $^{225}\text{Ac}$  generator*





# Inelastic Neutron Scattering using the GENESIS Array



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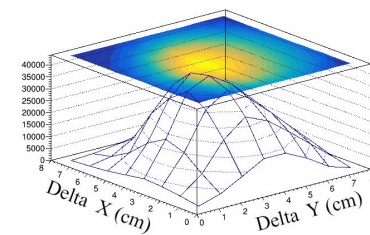
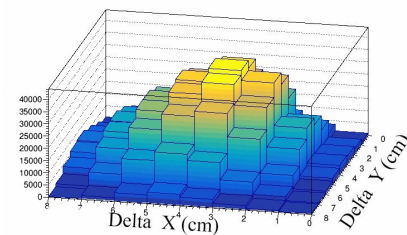
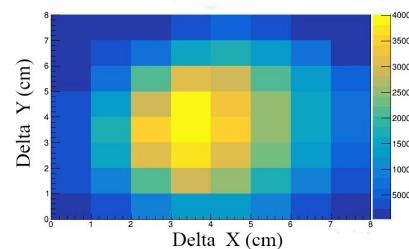
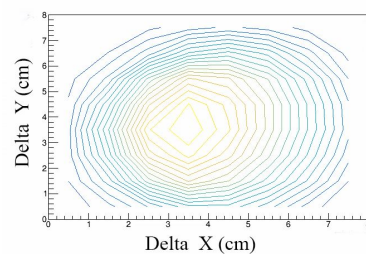
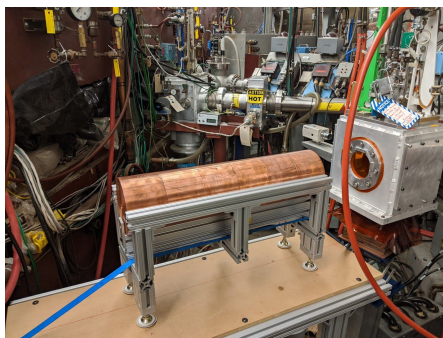
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# Characterizing the Array

- Neutron source: thick target deuteron breakup
- Collimator assembled & characterized for ~4 cm beamspot
- Preliminary runs helped verify design (using GEANT)
- Full measurements this Spring!



# Isotope Production Measurements



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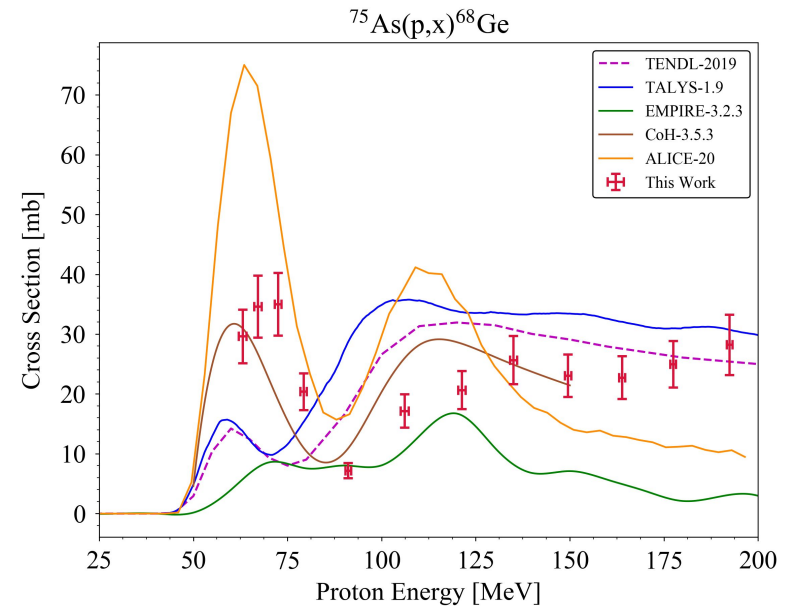
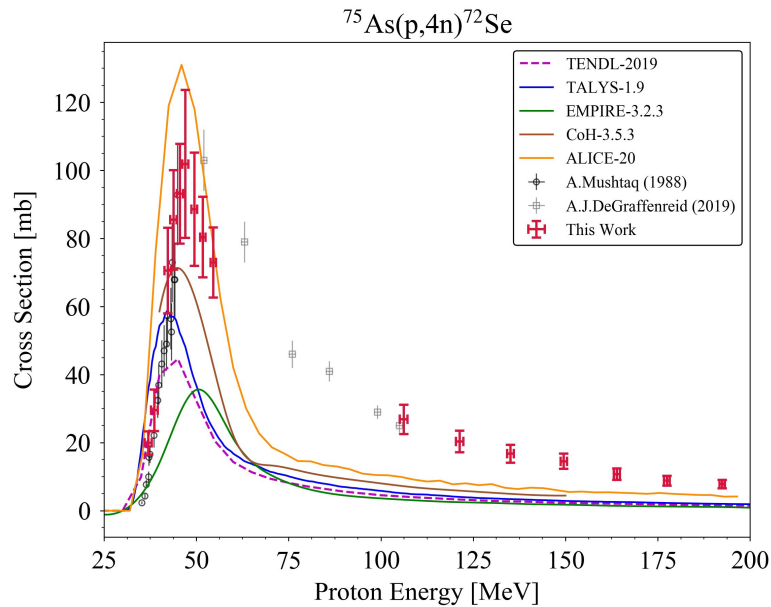


# Tri-Lab Nuclear Data Collaboration

- Collaborators and facilities at LBNL, BNL and LANL
- Analysis by grad. students at LBNL/UCB - 2 PhD theses
- Stacked-target cross section measurements for critical isotope production pathways
  - Mix of thin-target activation foils with energy “degraders”
- Protons from 0-200 MeV
- Funded by DOE Isotope Program



# $^{75}\text{As}(p,x)$ Reactions from 35-200 MeV

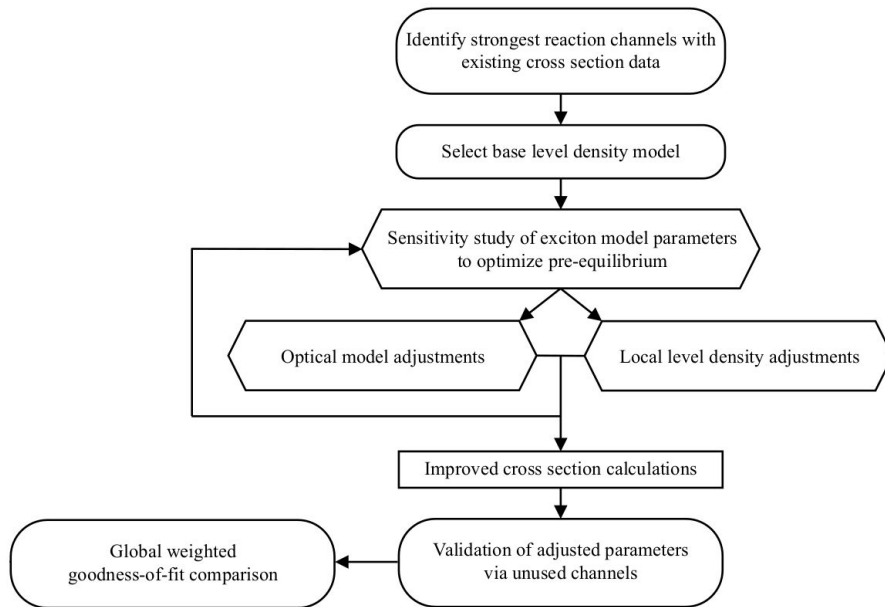


Large body of high-energy reaction data (many channels, up to 200 MeV)

Modeling is particularly sensitive to pre-equilibrium



# Pre-equilibrium Reaction Modeling



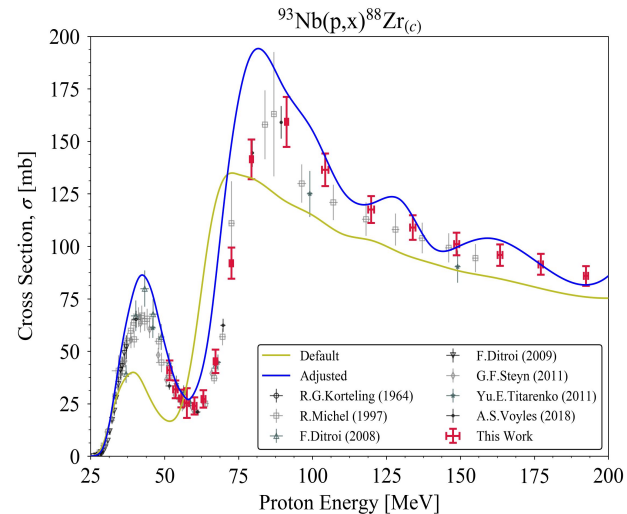
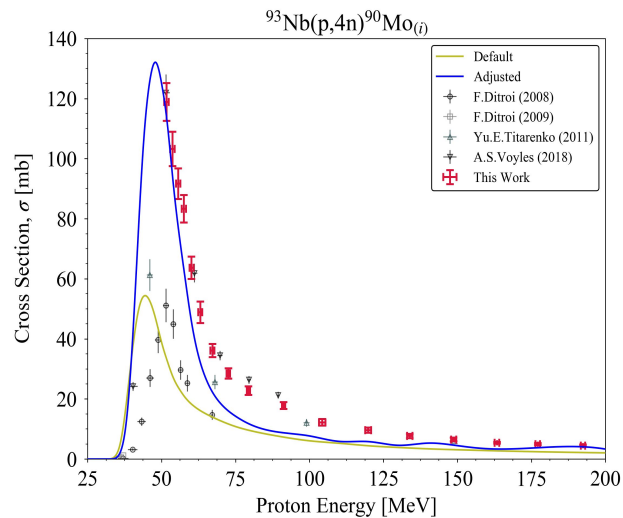
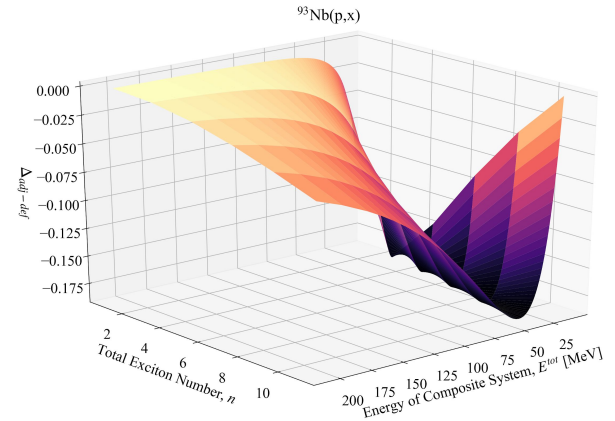
- Parameter adjustment via TALYS (well-documented, easy to use)
- Collaboration with Dr. Arjan Koning (Head of the IAEA Nuclear Data Section)
- Level density and exciton model parameters adjusted to match strongest independent channels
- Validation using cumulative channels





# Procedure Applied to $^{93}\text{Nb}(p,x)$

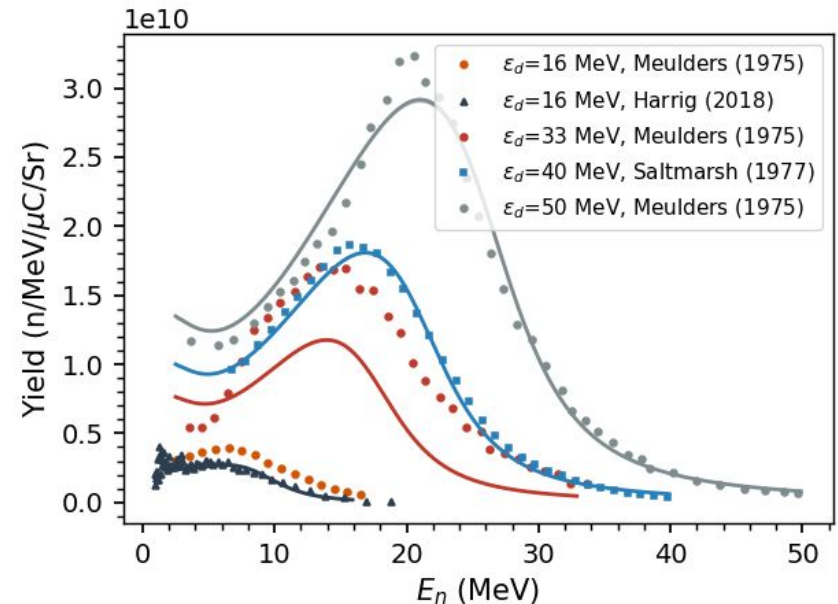
- 2x goodness-of-fit improvement over default
- Extract trends in exciton model parameters



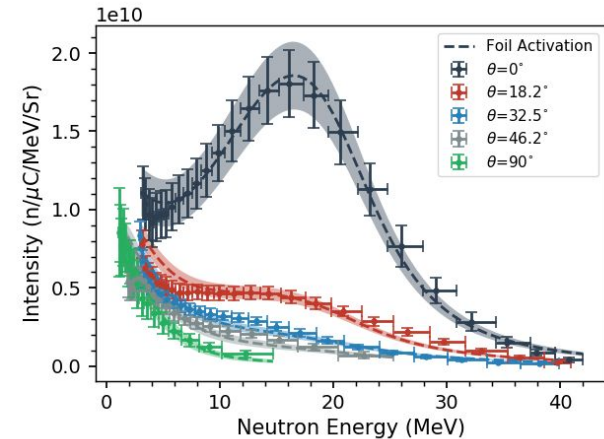
# Deuteron Breakup Modeling

- *Objective*: develop simplified physics-based model that can be adjusted (parameterized) to reproduce experimental data
- Breakup model based on 1947 deuteron “stripping” model by Serber
- 5 adjustable parameters for fitting neutron yield data
- Non-breakup reactions modeled with TALYS
- Good results, but 33 MeV dataset seems off

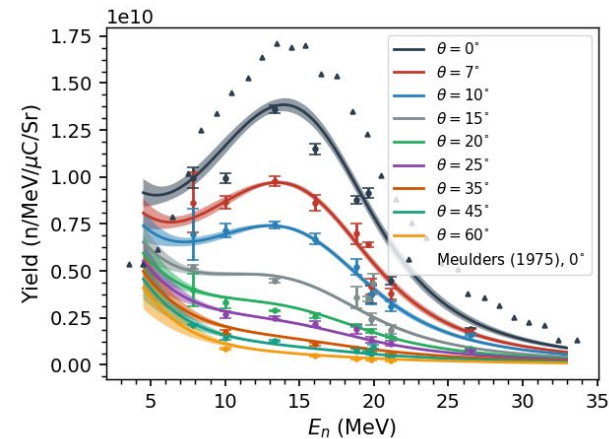
$$\frac{d^2\sigma_{BU}(\epsilon_d)}{d\Omega dE_n} = \sigma_{BU}(\epsilon_d)P(E_n)P(\theta)$$



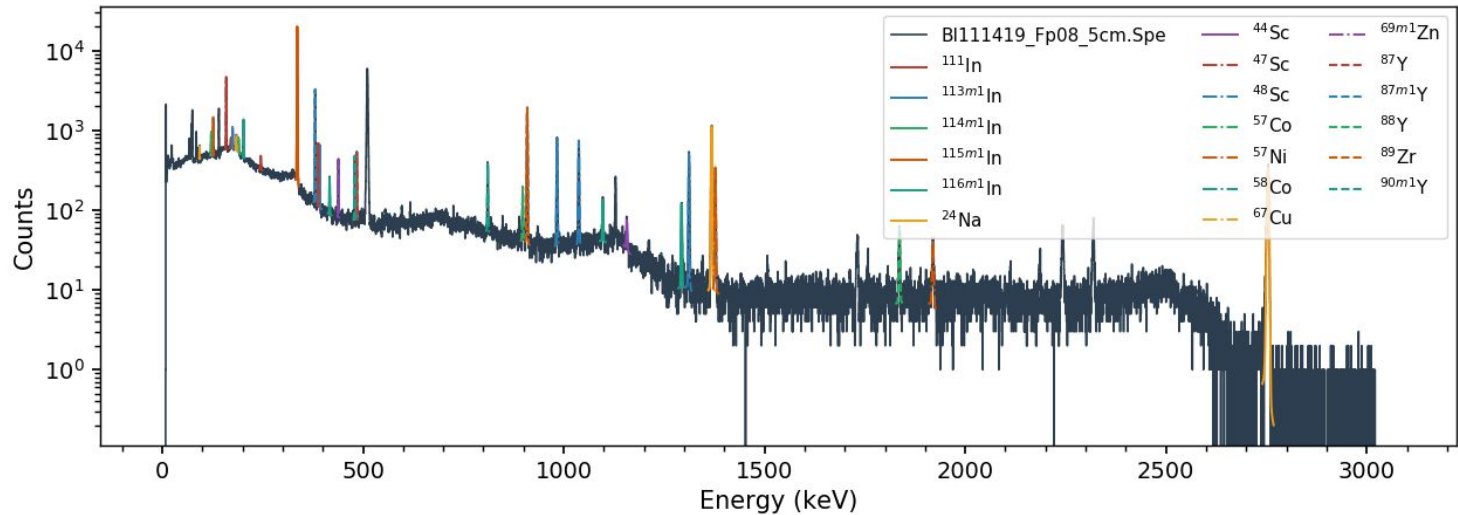
# Deuteron Breakup Measurements



- Measured double-differential neutron spectrum from  $0-90^\circ$  at 33 & 40 MeV (deuteron energy)
- Parameterized breakup model used to “unfold” neutron spectrum with activation
- Confirmed with time-of-flight



# New Activation Analysis Suite: Curie



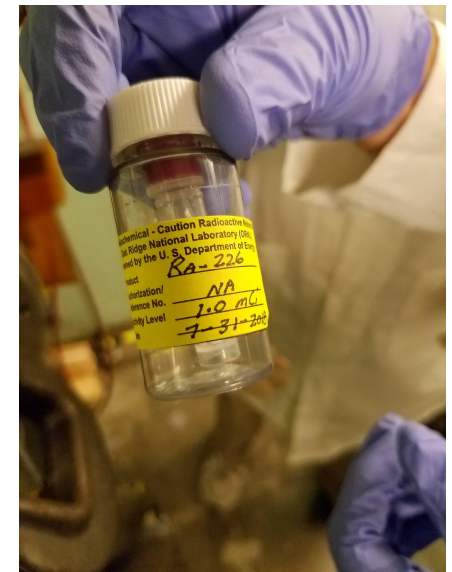
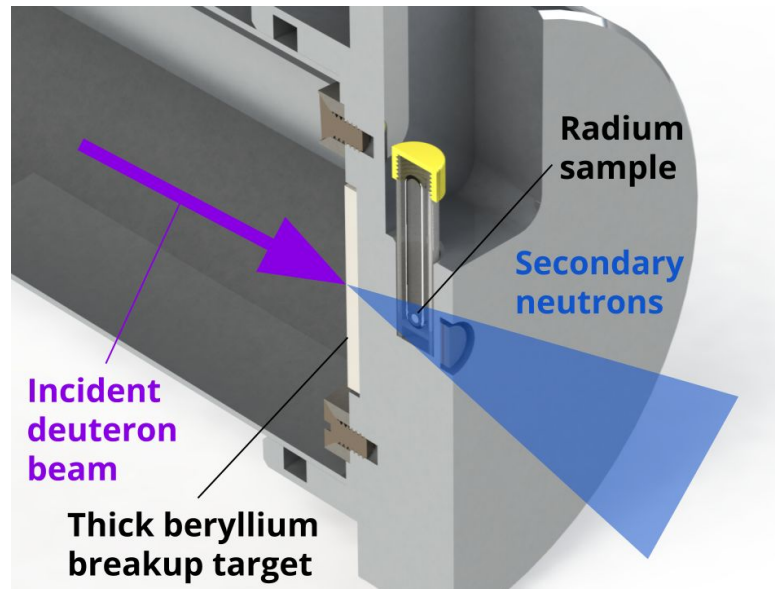
- Open-source python code developed for activation analysis. Includes forward-modeling  $\gamma$ -spectroscopy, Bateman eqn. Decay chain solver (for R meas), physical efficiency model (Vidmar)

Download: <https://github.com/jtmorrell/curie>



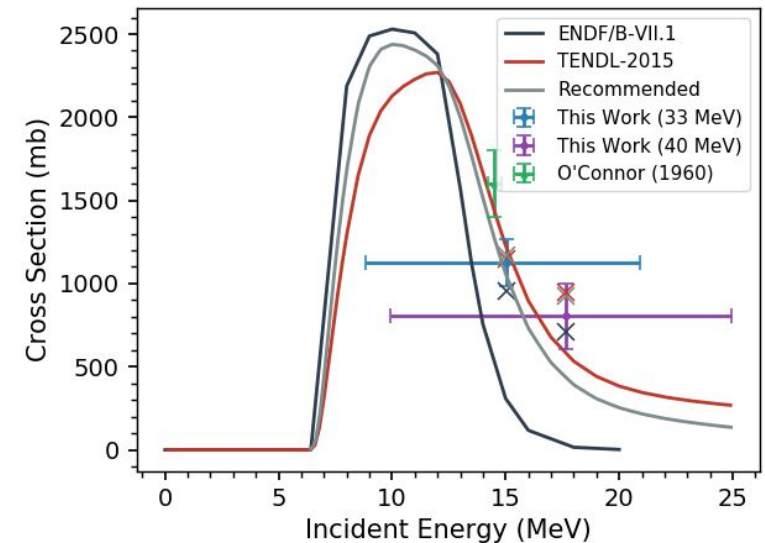
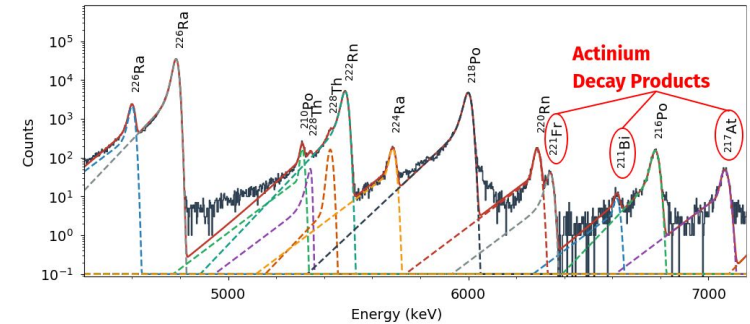
# $^{225}\text{Ac}$ Production from $^{226}\text{Ra}(n,2n)$

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



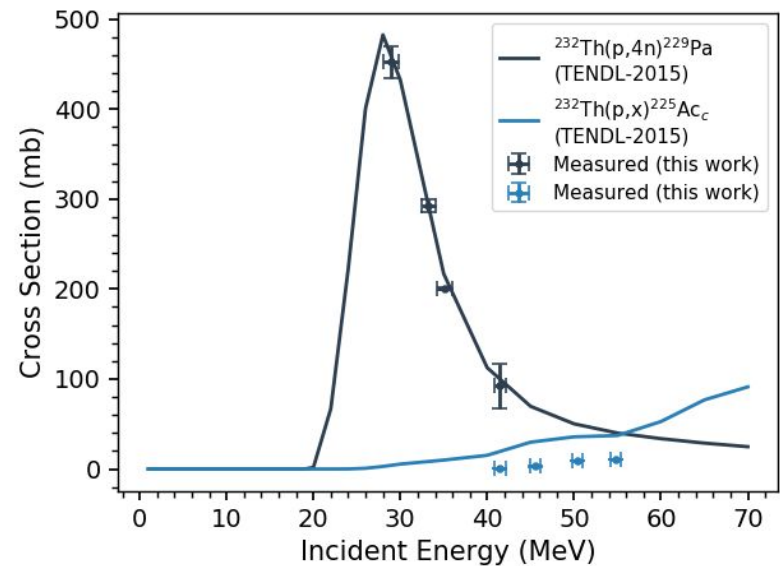
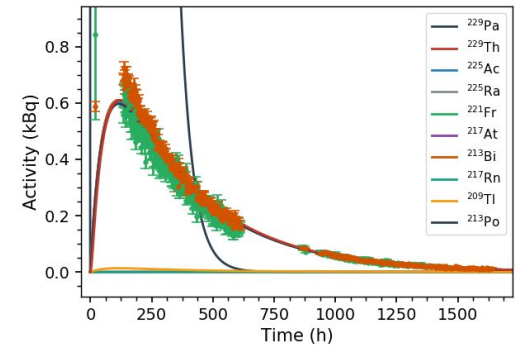
# Measured $^{226}\text{Ra}(n,2n)$ Cross Sections

- Production rate determined through  $\alpha$ -spectroscopy
- Precise characterization of breakup spectrum allows for accurate xs determination
- Measurements show good agreement with TENDL, possible discrepancy with ENDF
- Useful for optimizing production target



# $^{232}\text{Th}(p,4n)^{229}\text{Pa}$ Generator for $^{225}\text{Ac}$

- $^{229}\text{Th}$  ( $t_{1/2} = 7932$  y) could be a useful generator for  $^{225}\text{Ac}$
- Goal to measure  $^{229}\text{Th}/\text{Pa}$  production from  $^{232}/^{230}\text{Th}$  targets
- First stacked-target measurement (on  $^{232}\text{Th}$ ) successful - barely
  - Chem. lab (for Pa/Th separation) shut down day of measurement
  - Channel identified through  $^{225}\text{Ac}$  decay products (with HPGE)
- Future measurements with  $^{230}\text{Th}$



# Questions?



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# Acknowledgements

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