Capabilities for Isotope Production Nuclear Data Measurements at LBNL

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Berkeley
UNIVERSITY OF CALIFORNIA

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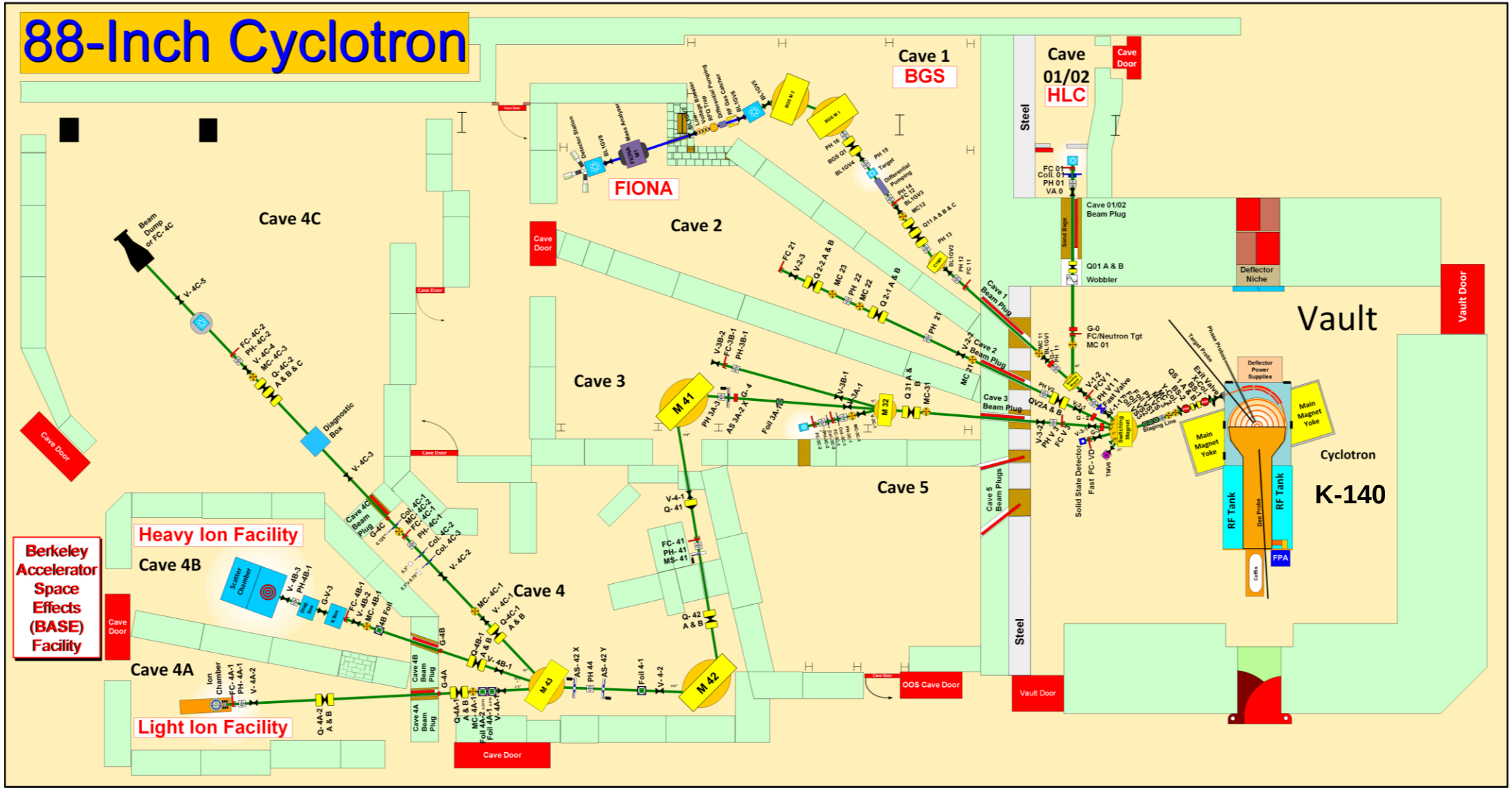
The 88-Inch Cyclotron: Variable-Beam, Variable-Energy



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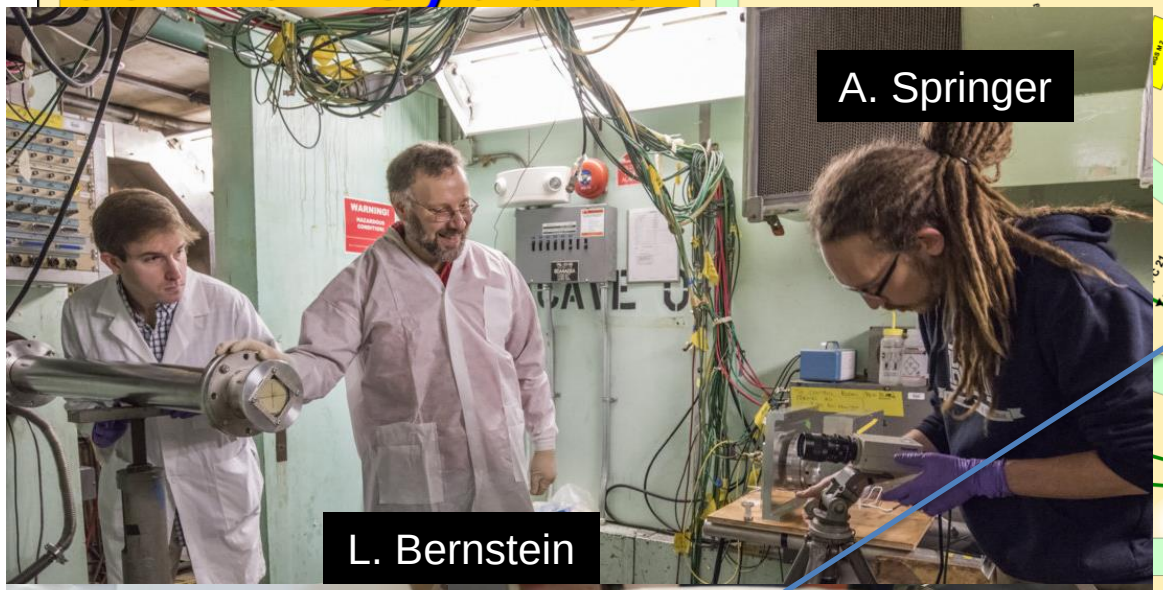
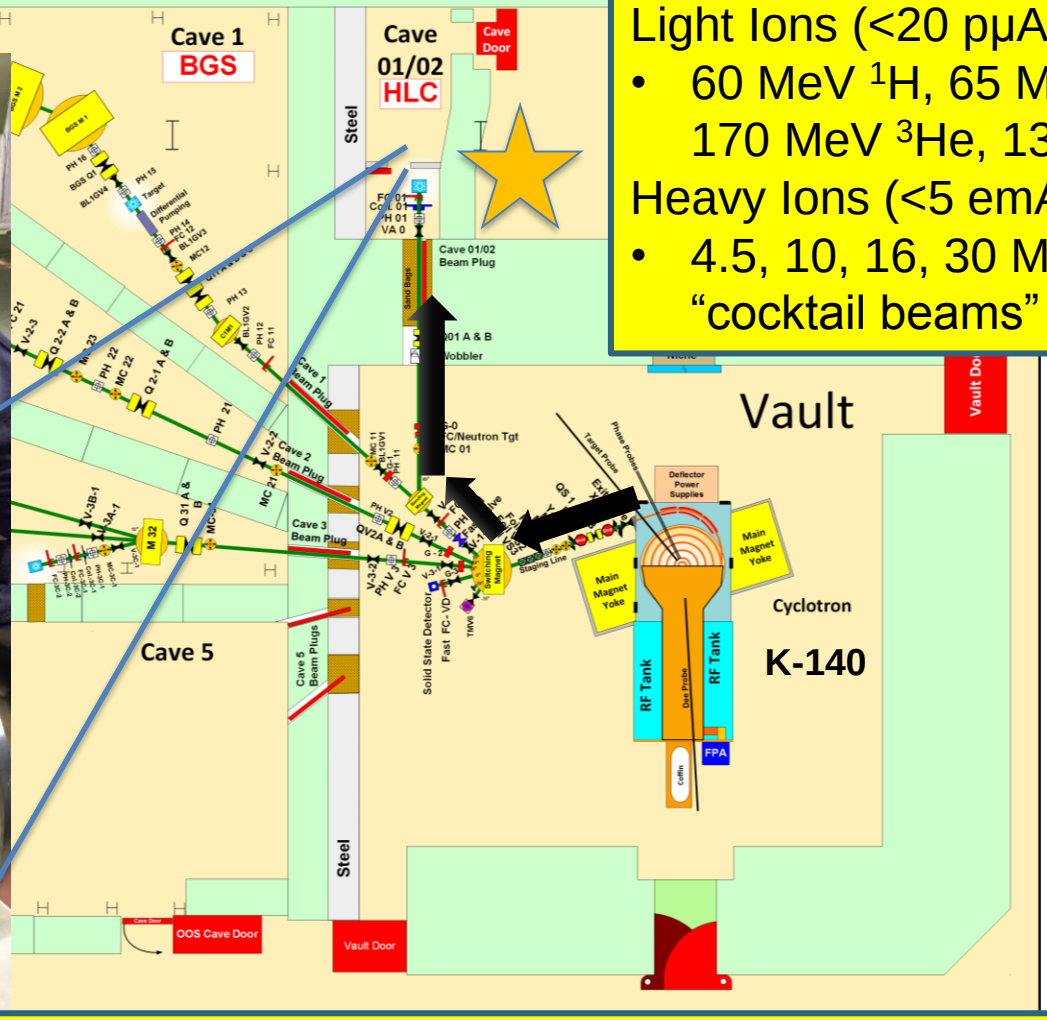
88-Inch Cyclotron



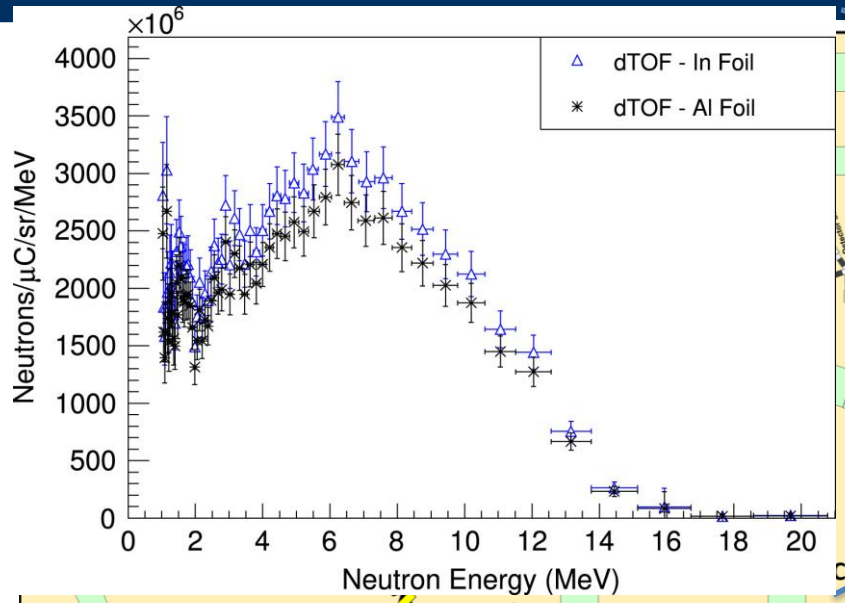


Light Ions (<20 pμA)
- 60 MeV ^{1}H, 65 MeV ^{2}H, 170 MeV ^{3}He, 130 MeV ^{4}He

Heavy Ions (<5 emA, up to $^{238}U^{56+}$)
- 4.5, 10, 16, 30 MeV/A "cocktail beams"

2016: Launched a targeted nuclear data measurement campaign at the LBNL 88-Inch cyclotron to address gaps in high-priority reaction data

Tunable Neutron Sources



Thick-target Deuteron Breakup[1]

- Intense, **focused** (≈10°) source
- Breakup neutrons from 0-***50*** MeV, peaked ≈ $0.5*E_d$
- May be paired with upstream (d,x) target for simultaneous production

Quasi-monoenergetic neutrons (QMN)

- Inconel-clad Li targets (LANL LDRD)
- (p,n) Neutrons from 0-***60*** MeV
- Unreacted beam dumped in Cave 0
- Flux from $10^{6\text{-}4}$ /MeV/sr/s (decreases w/E_n)

Jon Engle

≤ 65 MeV deuterons

Unreacted deuterons

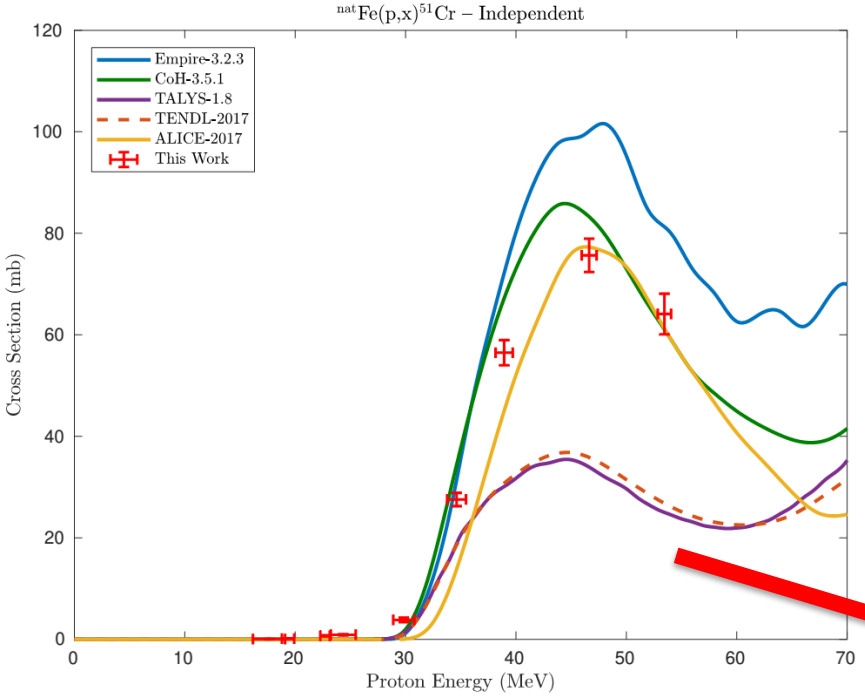
Energetic secondary neutrons

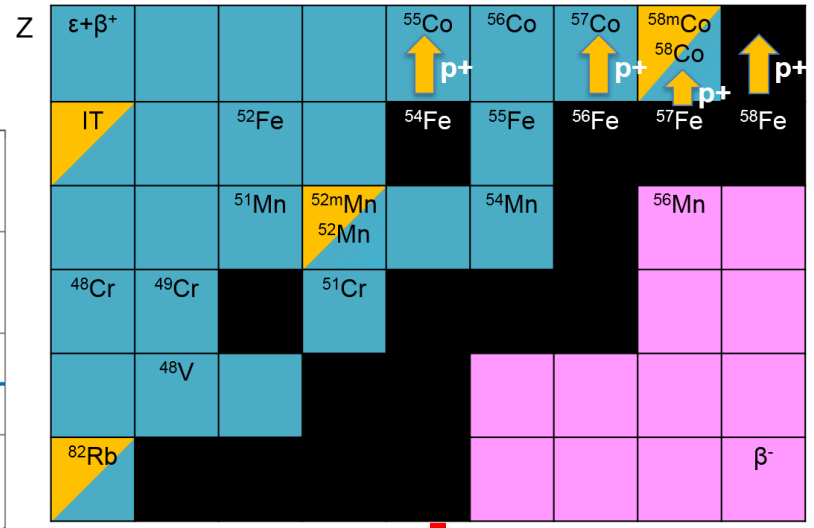
[1] K. P. Harrig, *et al.*, "Neutron Spectroscopy for pulsed beams with frame overlap using a double time-of-flight technique," *NIM A*, 877, pp. 359–366, 2018.

Precision Charged Particle Excitation Functions

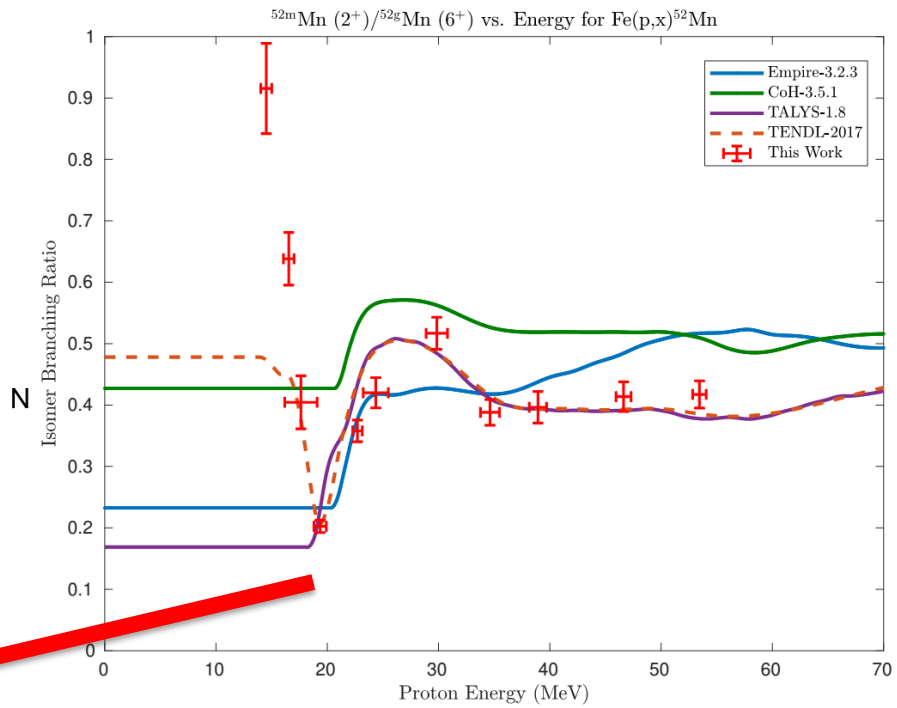
Multiple independent reaction channels

Precision excitation functions





Behavior of excited nuclear states



Measurements across wide ranges of energy and product mass provide ideal inputs for improving predictive capabilities of reaction modeling

Training and Retaining the Next Generation…

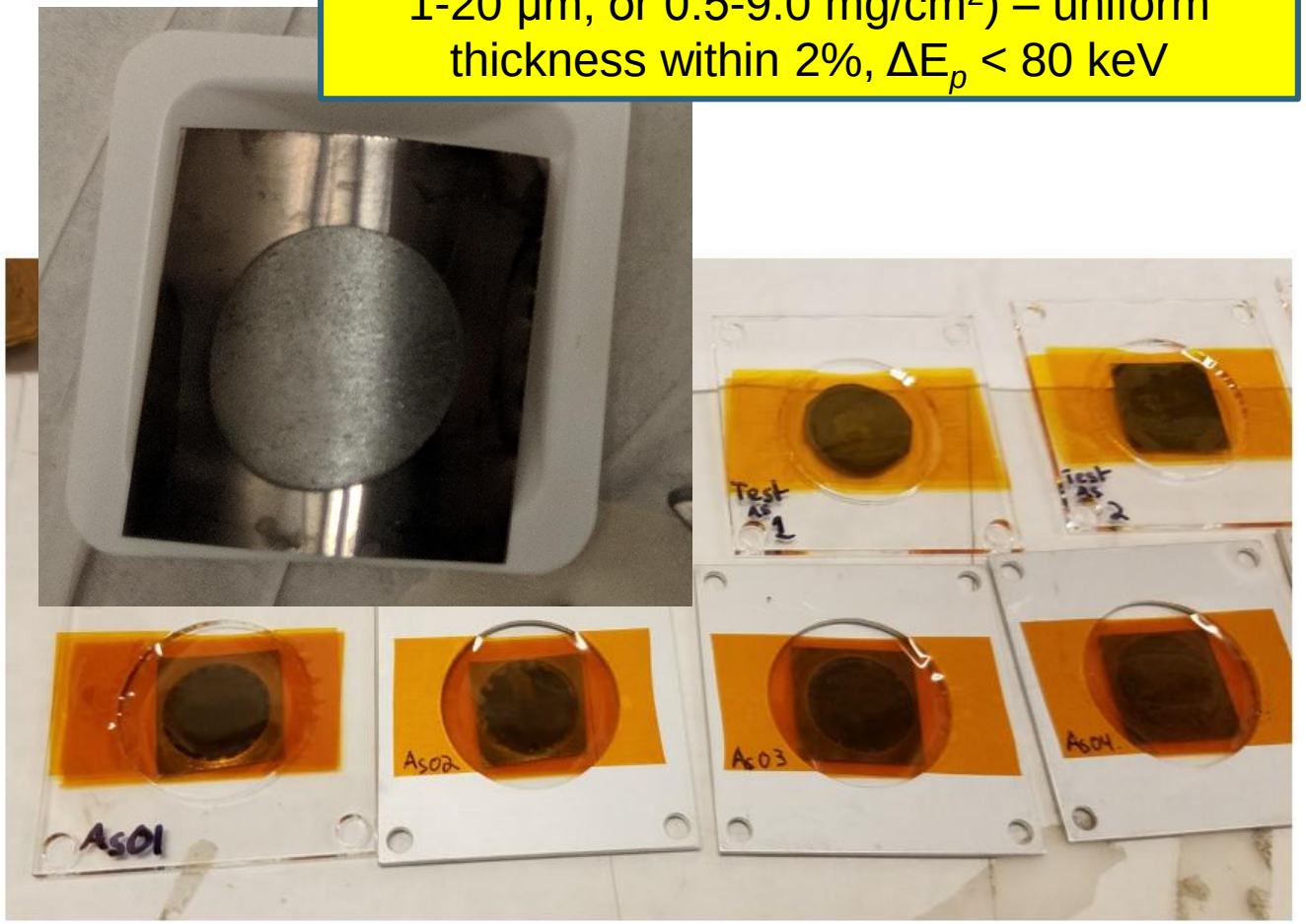
Project	Status	Degree
$Fe(p,x)^{51,52m,52g}Mn$	Manuscript Preparation	PhD, MSc
$Zn(n,x)^{64,67}Cu$	Analysis Underway	MSc
$Ir(d,x)^{193m}Pt$	Scheduled: March 2019	MSc
$La(p,x)^{134}Ce$	Manuscript Preparation	PhD
$^{235}U(d,x)^{236m}Np$, $Tm(d,x)^{169}Yb$	Analysis Underway	n/a
$As(p,x)^{72}Se,^{68}Ge$	Analysis Underway	PhD
$^{86}Sr(p,x)^{86}Y$, $^{86}Sr(d,x)^{86}Y$	Scheduled: Feb 2019	MSc
QMN Development	Analysis Underway	PhD

In addition to measurements, we train our students in dissemination of nuclear data to the user and evaluation communities → compiling each publication into EXFOR, including uncertainty analysis!

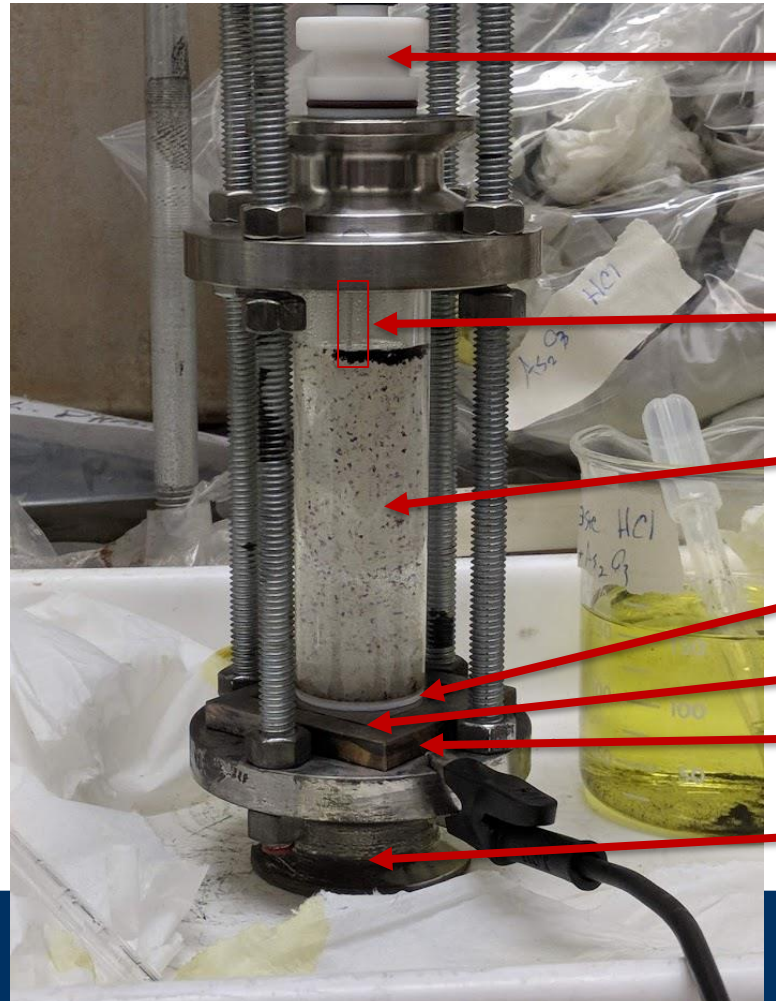
Since 2016, this student-led program has generated 1 PhD and 1 MSc, with an additional 3 PhD's and 2 MSc's in progress!

As Target Fabrication

Developed capabilities to plate targets with masses ranging 2-37 mg (approximately 1-20 μm, or 0.5-9.0 mg/cm^2) – uniform thickness within 2%, ΔE_p < 80 keV



- Two deposition methods on 10um titanium foil:
  - As_2O_3 (12.5 g/L) in 7M HCl, @ 130 mA
  - As_2O_3 (0.2M) in 1:2 molar choline chloride : ethylene glycol deep eutectic solvent, @ 46 mA



Collaborators on this work

M.S. Basunia[1], L.A. Bernstein[1,2], E.R. Birnbaum[3], J.W. Engle[3,4], M. Fox[2], S.A. Graves[5], T. Kawano[3], A.M. Lewis[2], E.F. Matthews[2], J.T. Morrell[2], F.M. Nortier[3], A. Springer[6], C. Vermeulen[3], A.S. Voyles[2]

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[4] University of Wisconsin – Madison
[5] University of Iowa – Department of Radiation Oncology
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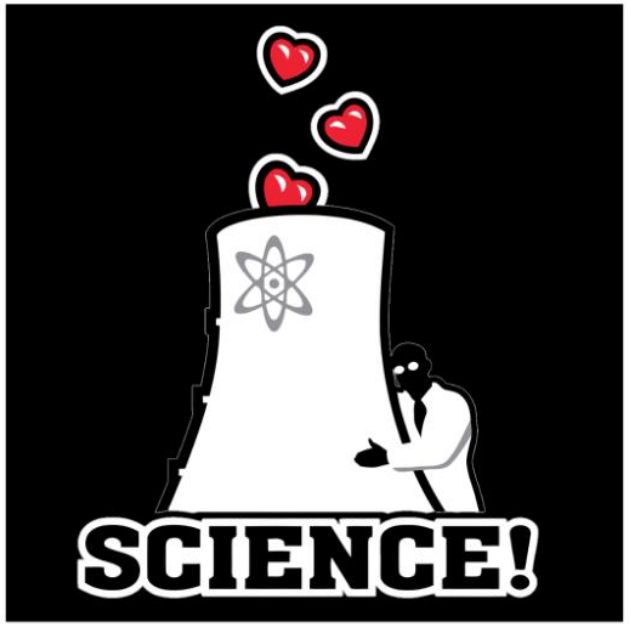

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