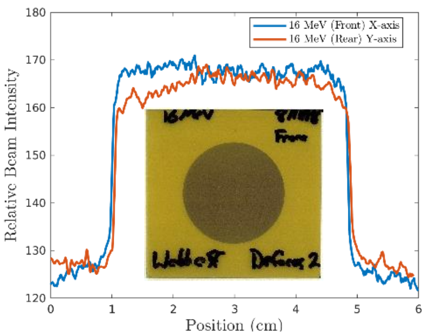
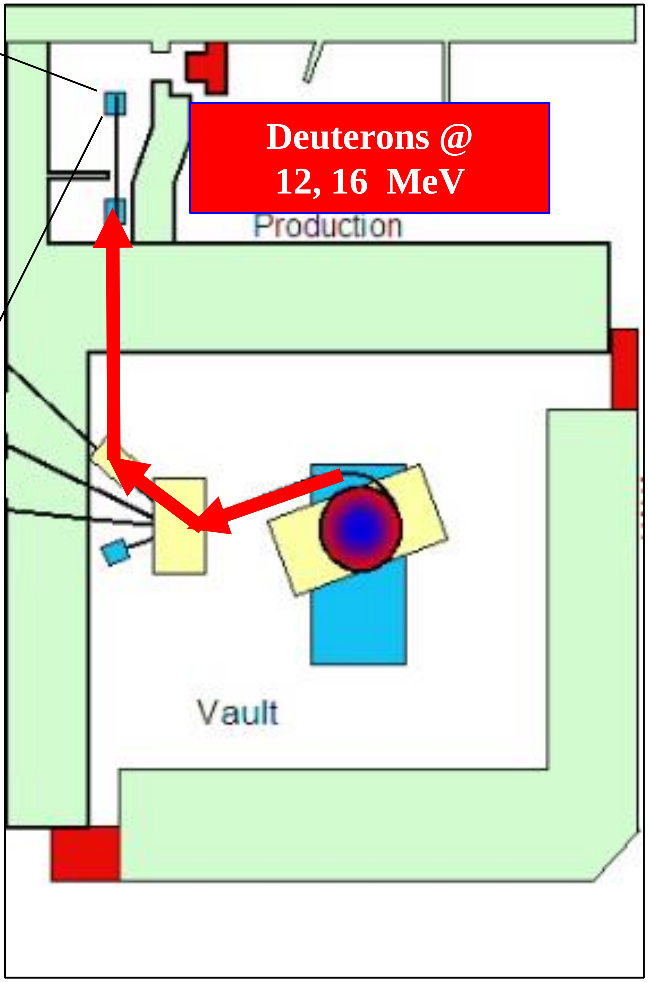
Two≈200 mg 93% ^{235}U samples were irradiated at the LBNL 88-Inch cyclotron in 12 and 16 MeV deuteron beams

Beam profile measured
Using GAFChromic film

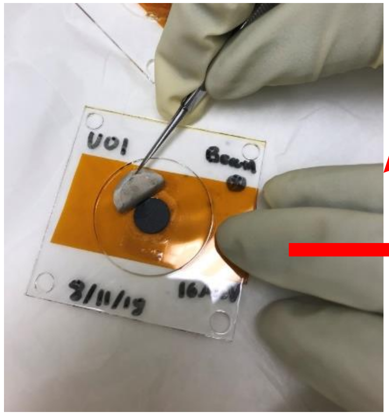


Stacked Target Holder

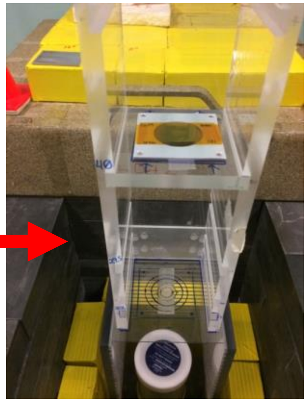


$$A = \sigma N \Phi \Delta t$$

The ^{235}U sample was "overfilled" with beam shifting "areal" distribution from target to beam



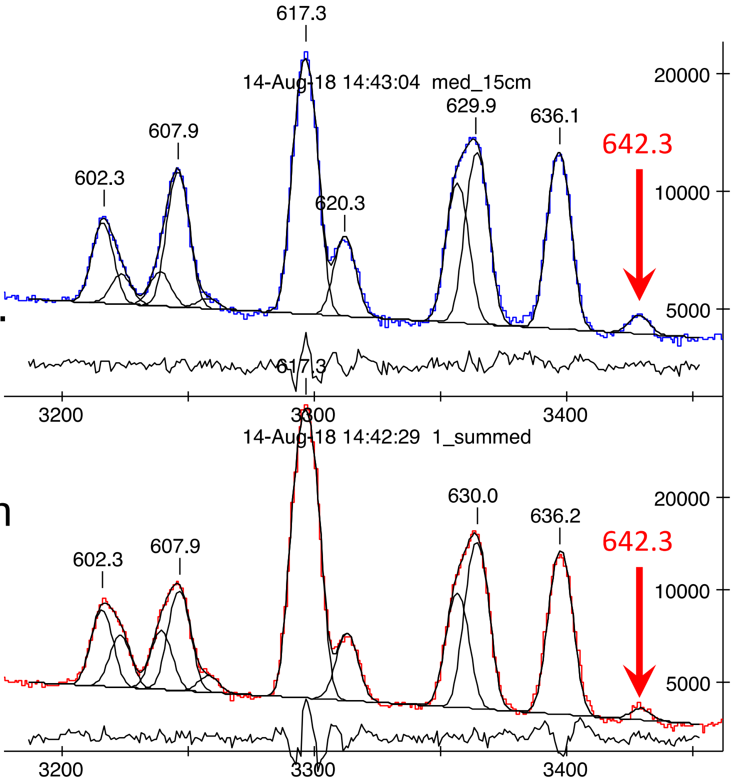
HPGe counter



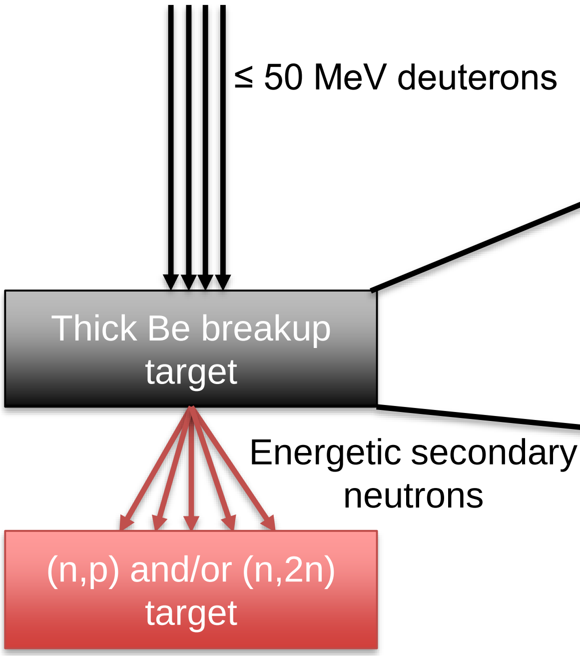
Post-irradiation counting shows the 642.3 keV g-ray from the decay of the ^{236}Np isomeric state ($t_{½}$=22.5 h)

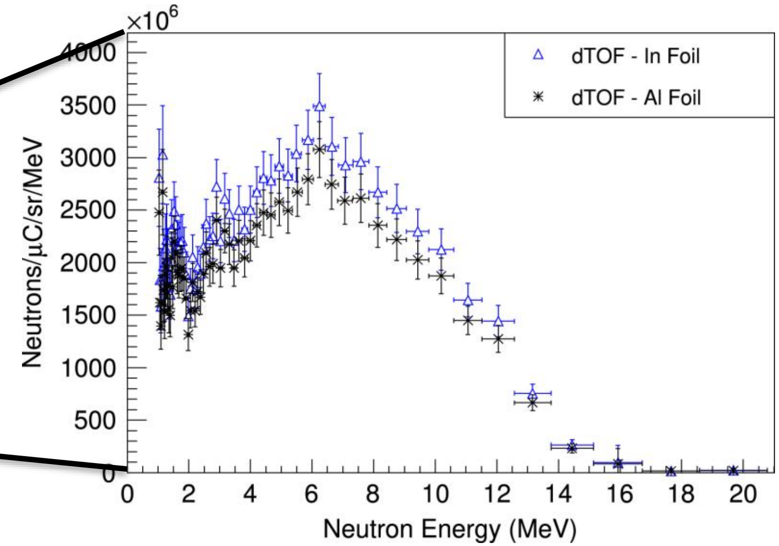
- Neptunium-236g ($t_{1/2}$=1.5 · 10^5 a) is used for IDMS determination of ^{237}Np ($t_{1/2}$=2.14 · 10^6 a).
- ^{238}U(p,3n)$^{236m+g}$Np experimental measurements show a **99.9 : 0.1 favoring of ^{237}Np : ^{236g}Np**
- The formation of short-lived isomer ^{263m}Np (22.5h) generated via ^{235}U(d,n) was quantified for two energies non-destructively after 60 minutes (16 MeV) and 9 hours (12 MeV) of deuteron irradiation at LBNL in August 2018.
- Preliminary analysis shows EoB ^{235}U(d,n)^{236m}Np production yields of **29.95 kBq/uAh at 16 MeV** and **5.15 kBq/uAh at 12 MeV**.
- ^{236g}Np and ^{237}Np production cannot be quantified through decay spectroscopy: irradiated ^{235}U foils have been shipped to LANL for ICP-MS analysis.
- ^{238}U(p,3n)$^{236m+g}$Np planned for Spring 2019, to measure the narrow 22 MeV <E_p< 27 MeV window for clean $^{236m+g}$Np production
- Analysis underway by UCB postdoc Andrew Voyles

Gamma-ray spectra from ^{235}U foils irradiated at 12 MeV (top) and 16 MeV



The LBNL/UCB nuclear data group is characterizing the use of "secondary" neutron beams for isotope production



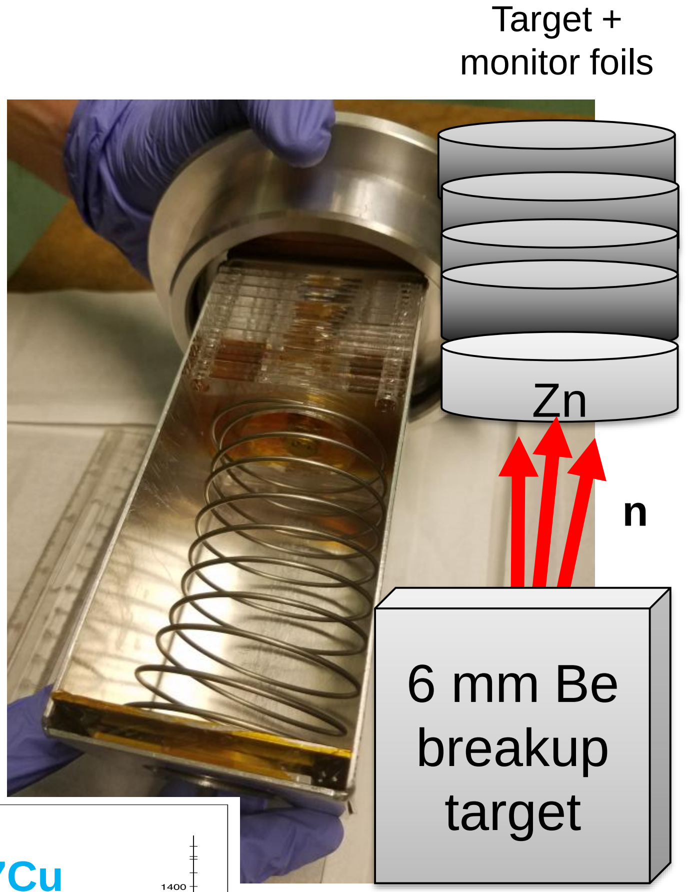


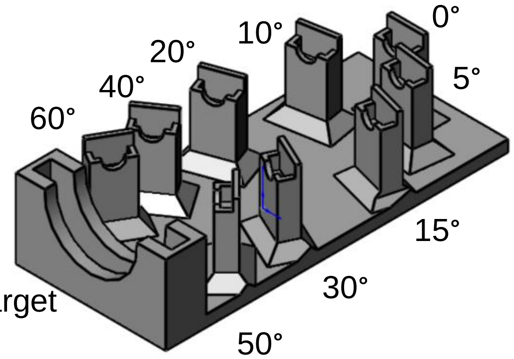
[1] K. P. Harrig, *et al.*, "Neutron Spectroscopy for pulsed beams with frame overlap using a double time-of-flight technique," *NIM A*, 877, pp. 359–366, 2018.

- Produces a focused (~5°), **intense** ($\phi_n/\phi_d \approx$ 3%) energetic secondary neutron flux (ESNF) from breakup of primary deuteron beam.
- ESNF can be used to produce high specific-activity radionuclides via (n,2n), or charge exchange reactions such as (n,p) and (n,α).
- Neutron volumetric range allows for trivial scale-up of production through increased target mass
- Development supported under Research Development and Training in Isotope Production Proposal

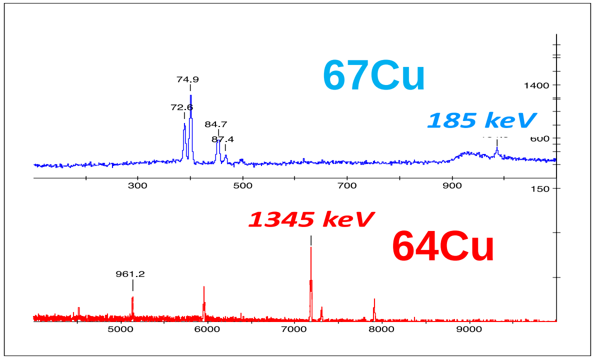
The LBNL/UCB nuclear data group is characterizing the use of "secondary" neutron beams for isotope production

- First development run took place in August 2018: simultaneous production of $^{64,67}Cu$ via energetic Zn(n,x), using 33 and 16 MeV deuteron breakup.
  - $^{64,67}Cu$ are emerging as a "theranostic pair" for simultaneous dose delivery and imaging.
- Preliminary analysis shows EoB production rates of ^{64}Cu:^{67}Cu in an approximately **75:1 ratio at 33 MeV** and an **800:1 ratio at 16 MeV**.
  - Selection of deuteron energy allows co-production of $^{64,67}Cu$ in a tunable ratio for applications!
  - Complete analysis is underway and will form the master thesis for Ms. Nora Pettersen from the University of Oslo.
- Irradiation of targets mounted at 0° to maximize neutron fluence
  - Deuteron breakup neutrons have an energy-angle correlation – the spectrum "hardness" varies with angle off-axis
  - This provides a second "tuning knob" for the ^{64}Cu:^{67}Cu ratio!
  - Experiments in November 2018 and Feb 2019 will better characterize the angular breakup neutron spectrum



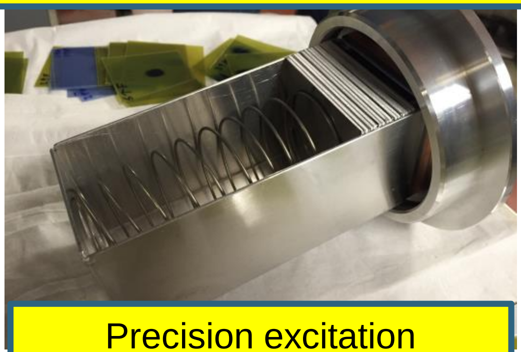


Be breakup target position

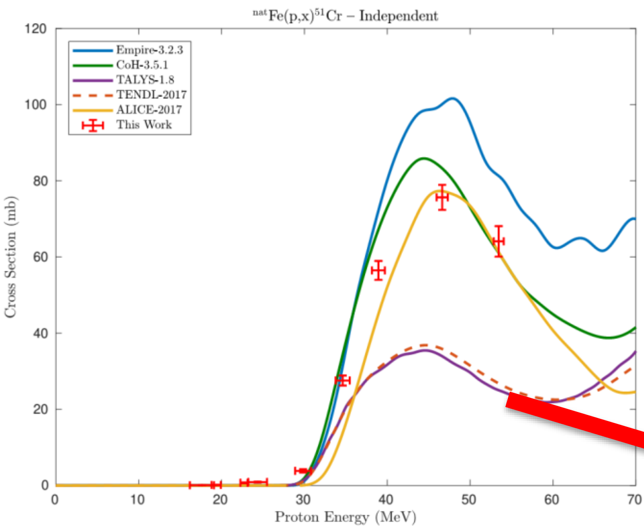


We are also addressing the need for non-standard PET tracers: $^{nat}Fe(p,x)^{51,52}Mn$ – Novel PET imaging

Two overlapping stacks: E_p= 55→15 MeV, 25→0 MeV (120 nA@10 min, 100 nA@20 min)

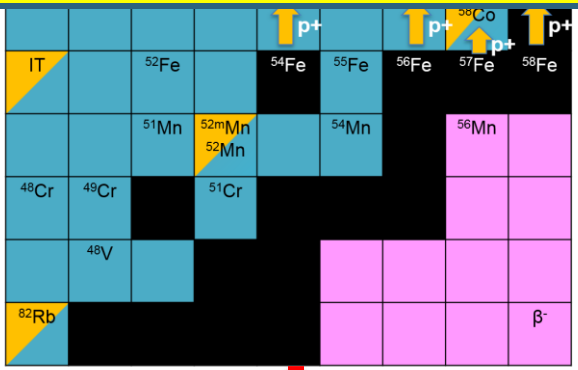


Precision excitation functions

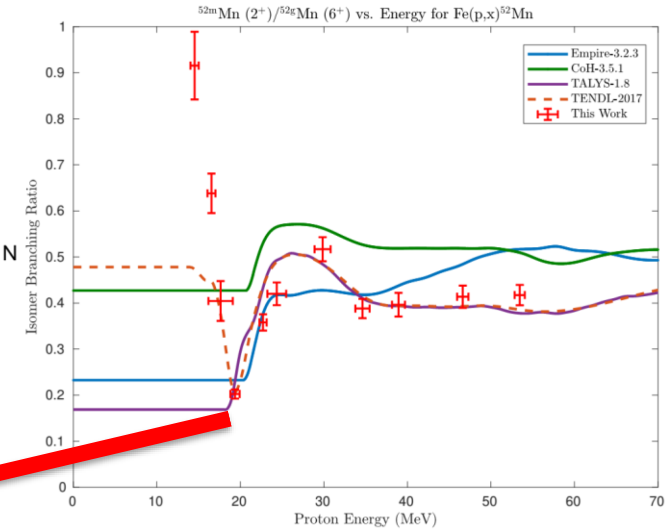


- Emerging medical radionuclides
  - ^{51}Mn ($t_{1/2}$ = 46 min, 97% β^+) – short-lived PET tracer for metabolic studies
  - ^{52g}Mn ($t_{1/2}$ = 5.6 d, 29% β^+) – long-lived PET tracer for neuron tracking, immune studies

Multiple independent reaction channels



Behavior of excited nuclear states



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

…as well as "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: Feb 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!