Neutron Cross-Sections for Radionuclide Production

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AT A GLANCE

•.The UC Berkeley High-Flux Neutron Generator has been used to irradiate Zn and Ti at fast fission-like energies.

• Decay spectroscopy following (n,x) reactions provides precise cross sections in ratio to known dosimetry standards.

• (n,p) reactions provide mCi quantities of radionuclides for national security, forensics and medical applications.

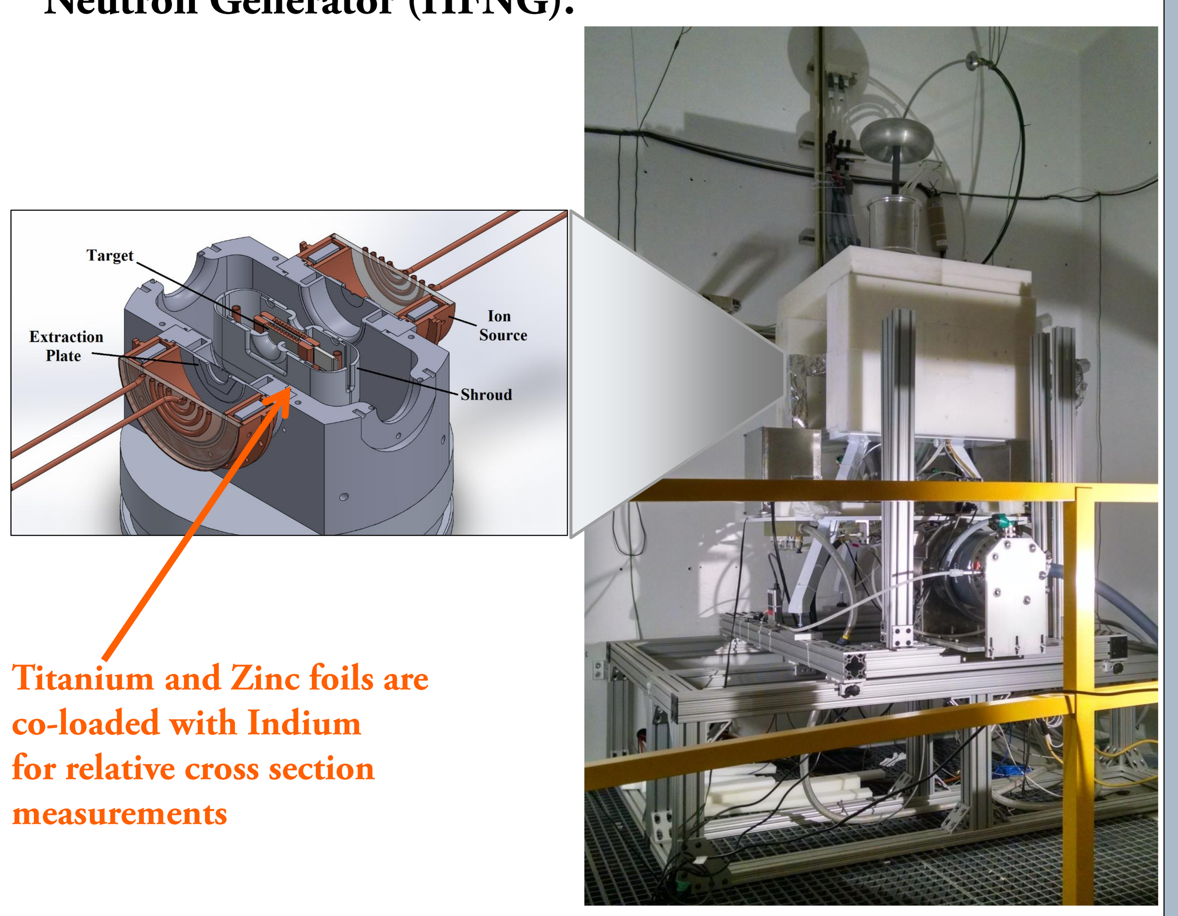
RESEARCH GOALS

Expand cross section libraries for radionuclide production, as a part of the U.S. Nuclear Data Program by measuring production cross sections:

- On structural materials for national security applications (Zn, Ti).
- For emerging medical isotopes and radiochemical tracers, via (n,p).

INTRODUCTION

Production cross sections for many emerging medical radioisotopes currently have unacceptably large uncertainties. Compact neutron generators allow for precise (n,p) cross section measurements, and offer a proliferation-resistant pathway for radioisotope production, with simplified radiochemical product separation. This work focuses on the irradiation of Titanium and Zinc foils using the UC Berkeley High Flux Neutron Generator (HFNG).



Titanium and Zinc foils are co-loaded with Indium for relative cross section measurements

Figure 1. The UC Berkeley High Flux Neutron Generator

SAMPLE IRRADIATION

The HFNG is a D-D fusion neutron generator capable of producing an internal flux of approximately 10^8 neutrons/cm^2s, with a flux-averaged neutron energy of 2.55 MeV for target foils loaded into the generator.

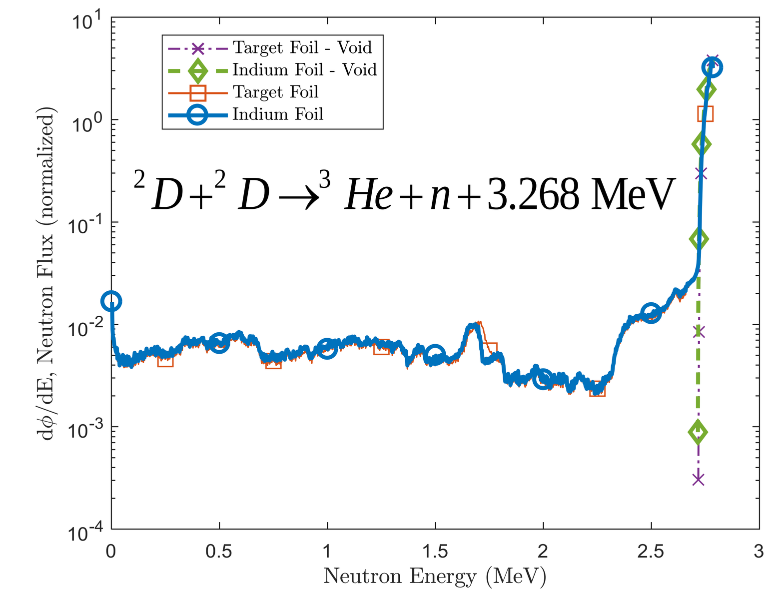


Figure 2. MCNP-modeled neutron energy distribution for the HFNG.

This work focuses on (n,p) production of the emerging medical radionuclides ^{64}Cu and ^{47}Sc:

- ^{64}Cu ($t_{1/2}$ = 12.7 h via β^- and β^+) is a diagnostic and therapeutic radionuclide.
- ^{47}Sc ($t_{1/2}$ = 3.35 d via β^-) production is a potential solution to the ^{99m}Tc shortage, with its similar high-intensity 159-keV gamma.

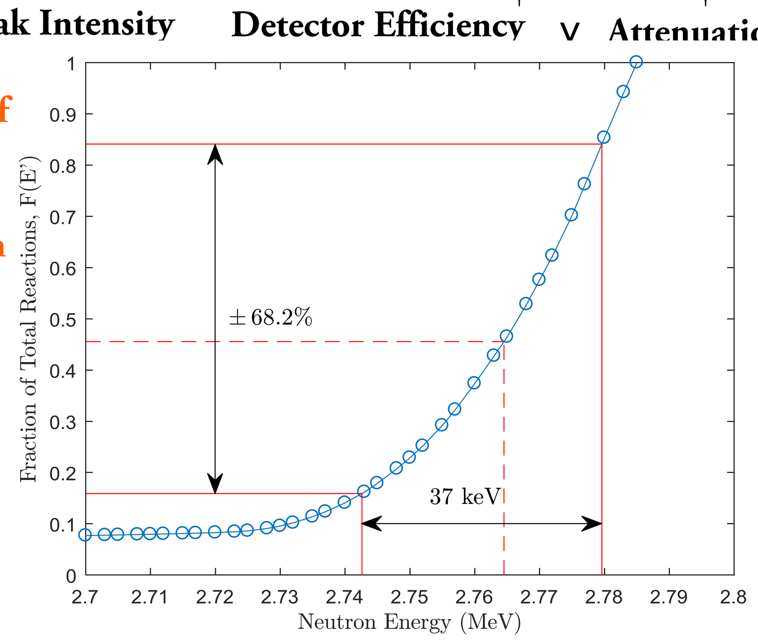
Figure 3. Co-loaded foils for neutron activation.

• Co-loading Indium foils removes flux dependence , allowing for (n,p) activity measurements to within anticipated uncertainties of 10%.

• Decay spectra were used to quantify the (n,p) cross section, relative to the well-characterized $^{113}In(n,n')^{113m}In$ and $^{115}In(n,n')^{115m}In$ dosimetry standards, σ_{In}:

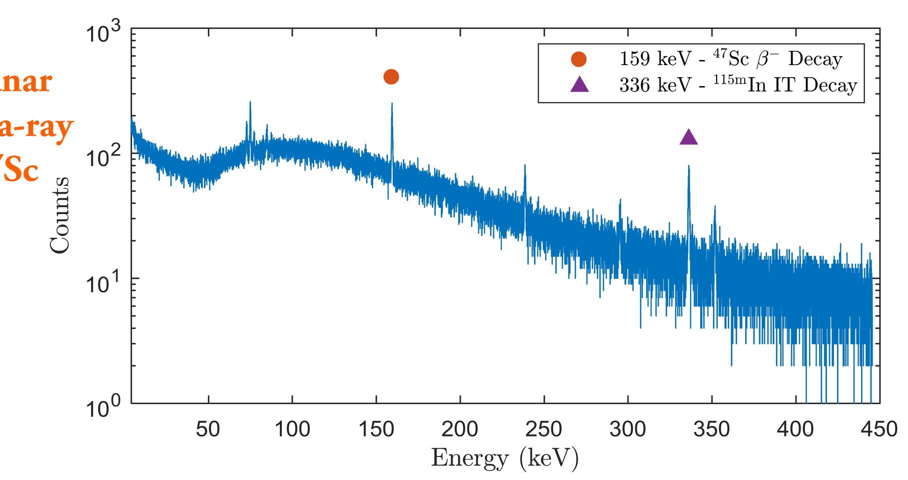
$$\sigma_X = \sigma_{In} \underbrace{\frac{A_X}{A_{In}}}_{\text{Measured Photopeak Intensity}} \overbrace{\frac{N_{In}}{N_X} \frac{\lambda_X}{\lambda_{In}} \left(\frac{1-e^{-\lambda_{In}t_i}}{1-e^{-\lambda_X t_i}}\right)\left(\frac{e^{-\lambda_{In}t_d}}{e^{-\lambda_X t_d}}\right)\left(\frac{1-e^{-\lambda_{In}t_c}}{1-e^{-\lambda_X t_c}}\right)}^{\text{Decay}} \underbrace{\frac{\epsilon_{In}}{\epsilon_X}}_{\text{Detector Efficiency}} \overbrace{\frac{I_{In}}{I_X}}^{\gamma\text{ Branching Ratio}} \underbrace{\frac{e^{-\mu_{In}\frac{d_{In}}{2}} \times e^{-\mu_{In} d_X}}{e^{-\mu_X \frac{d_X}{2}}}}_{\text{Attenuation}}$$

Figure 4. Fraction of total reactions induced in the Indium foil between the energies [0, E']. The solid red boundaries indicate theenergy region that corresponds to 68.2% of the total activation.



(n,p) CROSS SECTIONS

Figure 5. Planar LEPS gamma-ray spectra for ^{47}Sc and ^{115m}In



$^{47}Ti(n,p)^{47}Sc$ and $^{64}Zn(n,p)^{64}Cu$ production cross sections have been successfully measured through neutron activation at the UC Berkeley HFNG.

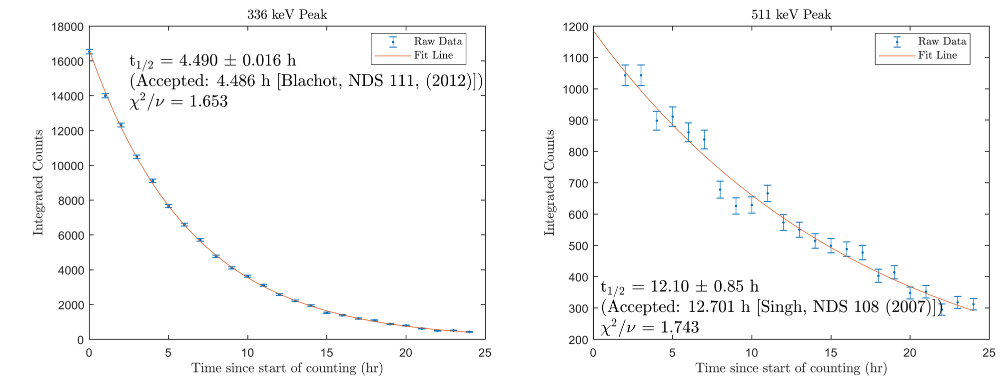
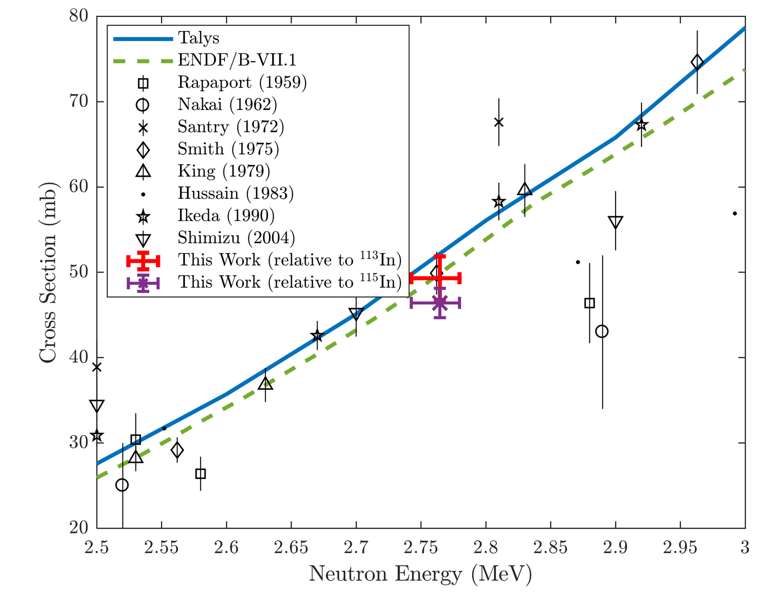


Figure 6. Measured lifetimes show strong agreement with ENSDF.

• Preliminary cross sections are consistent with experimental and evaluated data, as well as reaction modeling results from TALYS.

•Cross sections have been measured for 2.764 MeV, + 0.015 MeV / - 0.022 MeV neutrons, to lower uncertainty than existing data.

Figure 7a. Cross section data for the $^{64}Zn(n,p)^{64}Cu$ reaction.



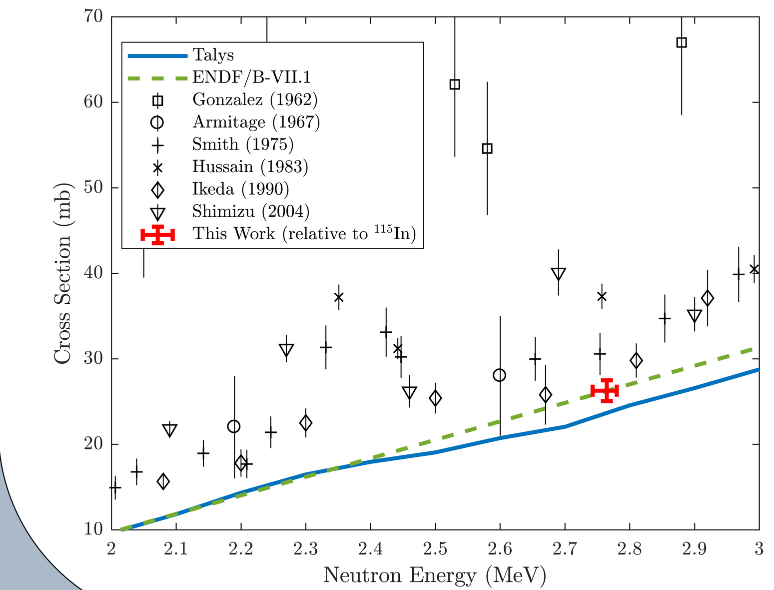


Figure 7b. Cross section data for the $^{47}Ti(n,p)^{47}Sc$ reaction.

FUTURE WORK

•Continue production cross sections measurements for emerging medical radioisotopes: ^{47}Ca, ^{67}Cu, ^{89}Sr, ^{105}Rh, ^{149}Pm, ^{159}Gd, ^{161}Tb, ^{166}Ho, ^{169}Er, ^{175}Yb, ^{177}Lu, ^{193m}Pt.

•Extension of measurements up to 55 MeV by developing $^7Li(p,n)$ capabilities at the LBNL 88 Inch Cyclotron.

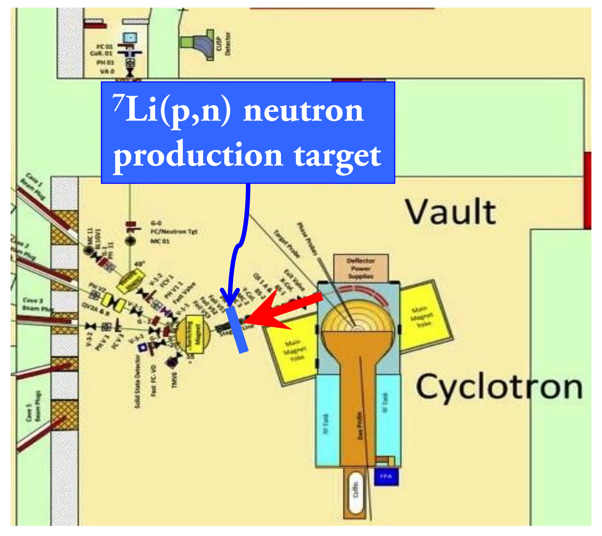
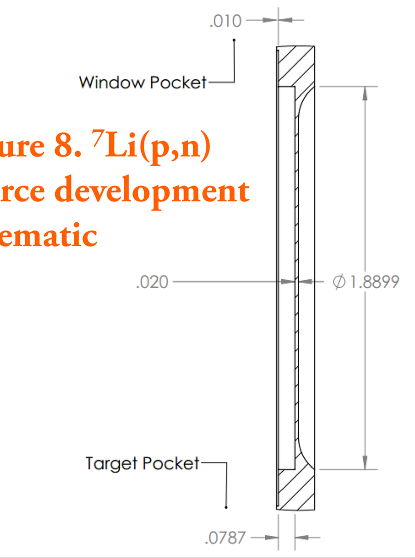


Figure 8. $^7Li(p,n)$ source development schematic



CONCLUSIONS

• The capability to precisely measure relative (n,p) cross sections to within 5% uncertainty has been clearly demonstrated.
  - Measurements are consistent with existing data and models.

• Continued measurement of (n,p) cross sections provides:
  - Valuable activation data at fast fission-like energies, useful for forensics and nonproliferation applications and testing.
  - Expanded nuclear medicine capabilities through precise dose deposition, as well as patient-specific treatments.
  - More efficient and affordable production of radionuclides for various applications, as a proliferation-resistant alternative to production in HEU-fueled reactors.
  - Improved fidelity of reaction modeling codes, used for estimating cross sections by comparison to measured data.

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