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# Data Needs & Capabilities at the LANL Isotope Production Facility

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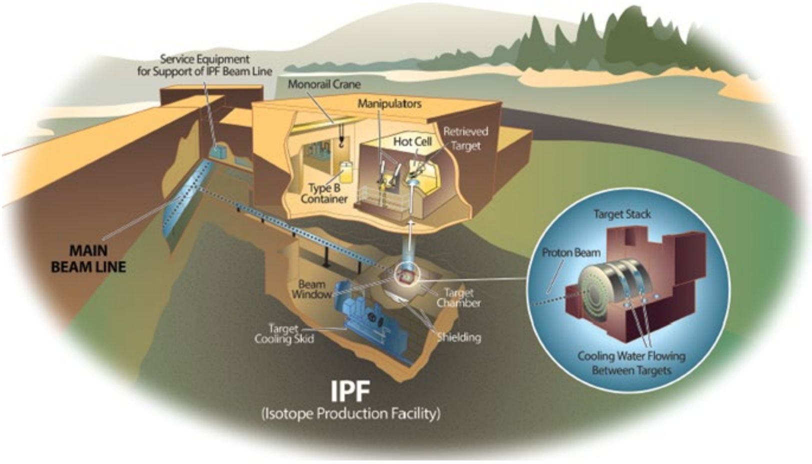
# Introduction to IPF

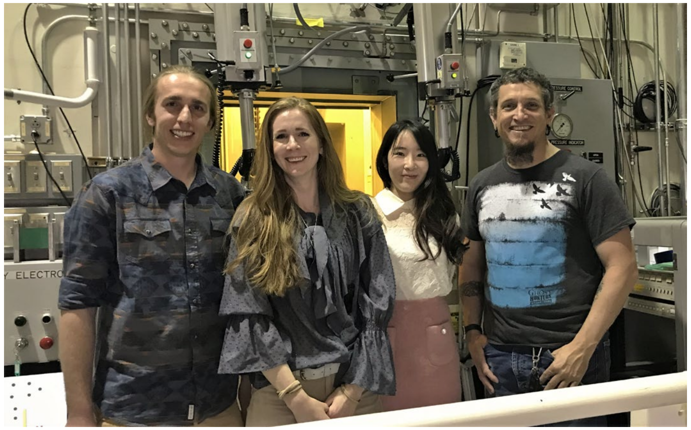
Isotope Production Facility (IPF)

- Location: Los Alamos Neutron Science Center (LANSCE)
  - First beamline after DTL
- 100 MeV $H^+$, ~250 μA (nominal)
- DOE IP production site
  - Mission: supply isotopes (not commercially available) to DOE IP
  - Complemented by BNL BLIP

Scientific Efforts

- **Proton-induced reaction cross sections**
- Beam energy distribution measurements
- Secondary neutron measurements
- Gamma spectroscopy method development



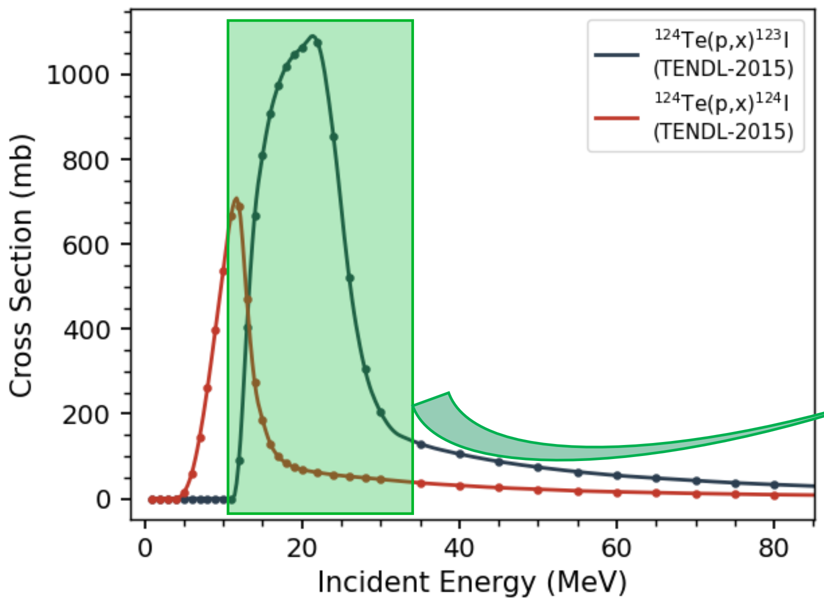



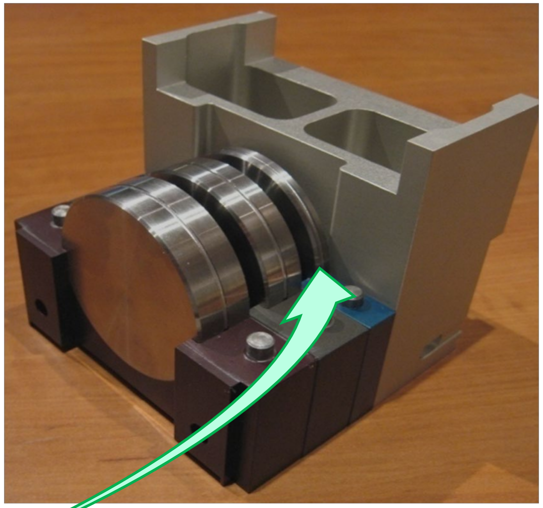
*Science Staff - Isotope Team at LANL IPF*
**Me**, E. O'Brien, J.H. Seong, E. Vermeulen

# Nuclear Data Needs for Isotope Production

Goal: maximize production of isotope X (product), while minimizing Y (impurity)

- Free Parameters:
  - Target thickness + incident energy = **energy window**
    - Select upstream target (or degrader) material, thickness
  - Irradiation + decay times
- Example: production of I-123 illustrates challenges



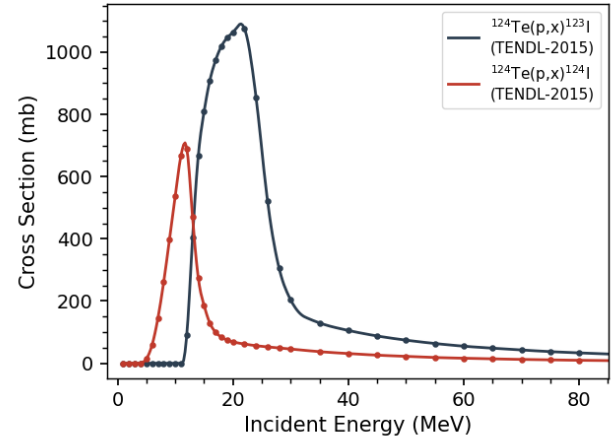
# Production Planning with Curie

Open-Source Python Library

https://jtmorrell.github.io/curie/

Tools for production planning:

- Cross section libraries
- 1D Monte Carlo code (beam energy)
- Bateman equation solver

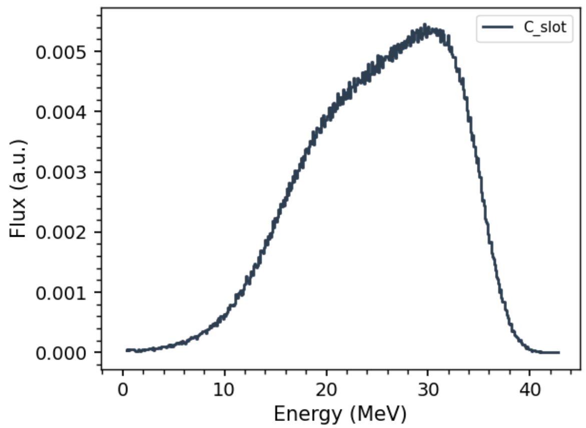


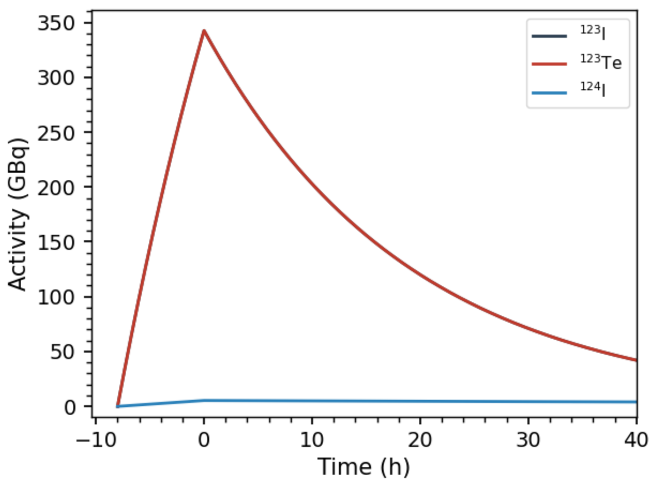

```python
rx = ci.Reaction('Te-124(p,x)I-123')
rx.plot()
```

```python
dc = ci.DecayChain('I-123', R=[[1E12, 8]], units='h')
dc.plot()
```

```python
st = ci.Stack('iodine_example.csv', E0=100)
st.plot('C_slot')
```

| compound | thickness | name |
|---|---|---|
| H2O | 5 | |
| Al | 12 | A_slot |
| H2O | 5 | |
| Al | 12 | B_slot |
| H2O | 5 | |
| Te | 3 | C_slot |



# Example: Producing I-123 from Te-124 (enriched)

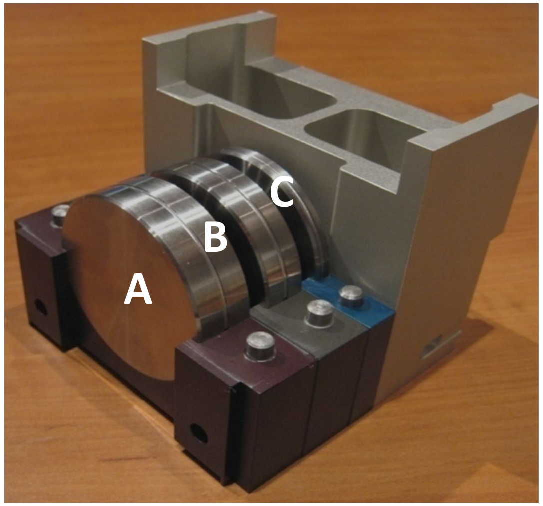
Target 15 – 35 MeV window

- 3 mm (enriched) $^{124}$Te target in C-slot
- 12 mm degraders (A+B)

Consider an 8 hour irradiation, with 12 hours of decay

Using TENDL-2021 XS:

- I-124: 54.2 Ci
- I-123: 2.67 Ci (4.9% impurity)

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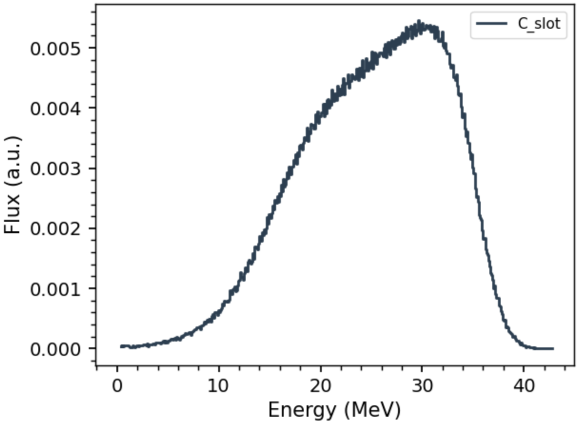


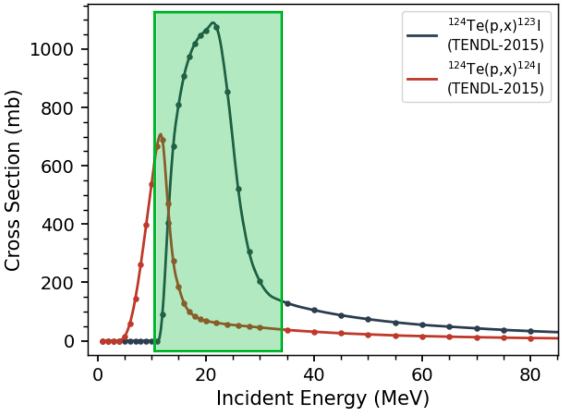


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# The nuclear data challenge

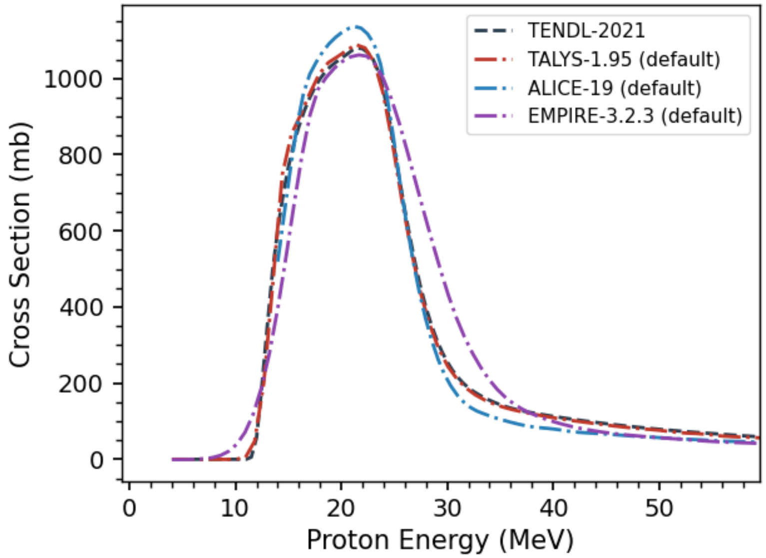
Even for (p,2n) reaction, calculations disagree

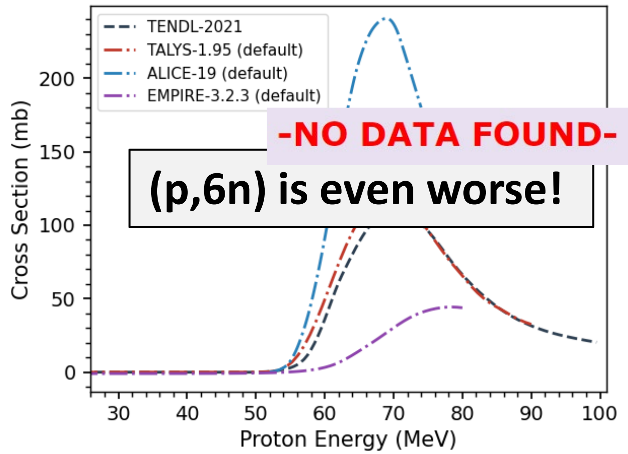
- Yields vary by 12.3%
- Impurities vary by 18.2%

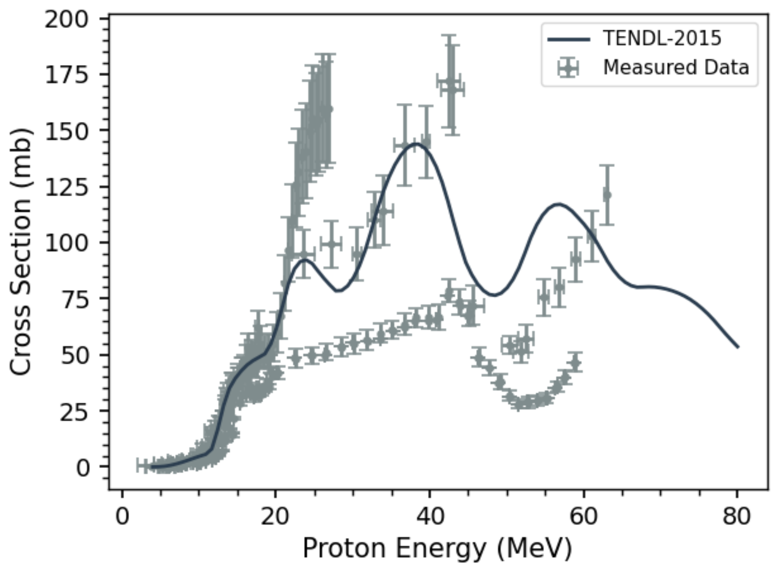
Measured data vary **significantly**

- Difficult to determine which experiments to believe

Broad energy range at IPF is particularly demanding



# List of Data Needs

**Measurement needs:**

- Energy-differential cross sections - proton and (high-energy) neutron induced
  - Enriched targets
  - Rare or “challenging” materials
  - Capability to measure quickly/on-the-fly
- Fission product yields (up to 200 MeV)
  - Thorium a priority (but even W fissions)

**Important Theory:**

- Pre-equilibrium
- Level density
- Angular momentum distribution (isomers)
- High energy fission (Z>88)

**Nuclear Data Utilities:**

- Database for isotope production
  - Curated selection of IAEA/ENDF/TENDL
- Yield calculator (pref. online)
- Data quality assessment tool
  - AI/ML augmented
- **Python** ports/wrappers for existing tools
  - Personal experience:
    - 100% of early-career scientists know python
    - 90% use it primarily
    - 30-40% use C/C++
    - Only 10% can code in Fortran
      - Would probably prefer not to

# Addressing shortcomings in nuclear data for isotope production: TREND (Tri-Lab Effort in Nuclear Data)



LBNL 88-Inch Cyclotron
$E_{p,max} = 60$ MeV

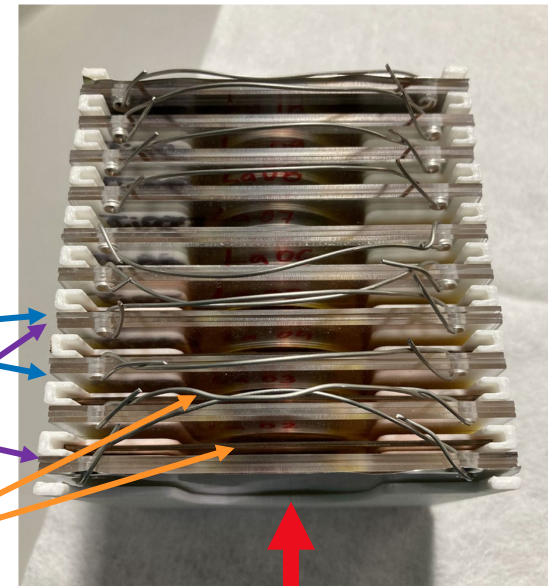
LANL IPF
$E_{p,max} = 100$ MeV

BNL BLIP
$E_{p,max} = 200$ MeV

- Collaboration to measure (p,x) reactions relevant to isotope production applications, from threshold up to 200 MeV
- Goal to measure XS for production isotope(s) + *as many reaction channels as possible* – anchor points, improve the modeling
- Measurements (mostly) via stacked target method

# Stacked Target Method

- Simultaneous irradiation of multiple “stacks” of foils (targets, monitors, degraders)
- Cross sections measured at multiple energies: “degrading” beam (Cu/Al foils)
- Absolute XS from γ-spectroscopy



Monitor foils

Target foils of interest

Multiple energy “degraders”

Incident beam direction

Michael Skulski (BNL post-doc) examines a γ-spectrum, 2021

# Activation Analysis with Curie

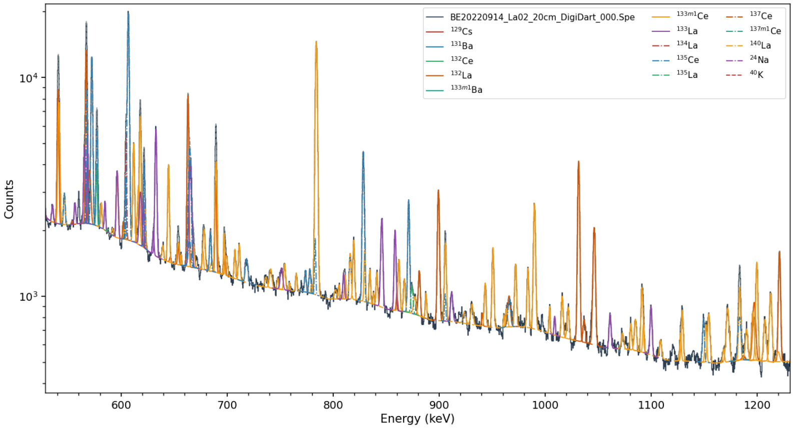
Activation analysis performed using *curie* python library

- Peak fitting
- Production/decay correction
- Stack energy-loss calculation
- Cross section libraries (monitors)

- Convert *measured* production rates, R, to beam current, $I_p$, (for monitor foils) and cross sections (for target foils): $R = (\rho r) I_p \sigma$

Advantages over other methods:

- Forward modeling of gamma spectra
  - Uses detector response function and list of isotopes to fit peaks
  - Advantage when isotopes are unknown
  - Automation of peak fitting




Spectrum with over 400 gamma-rays

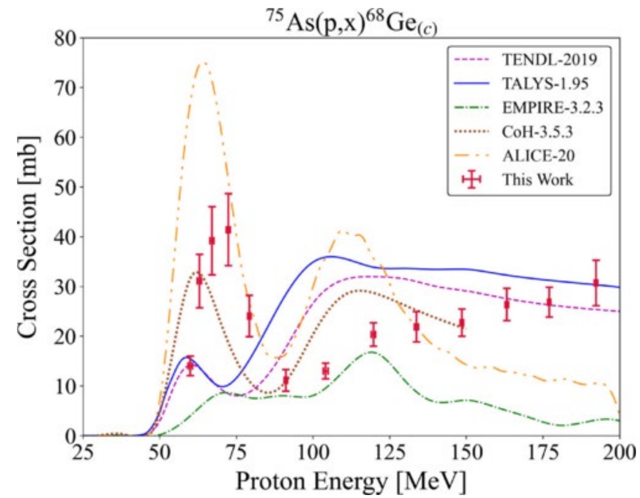
# TREND Measurements at IPF

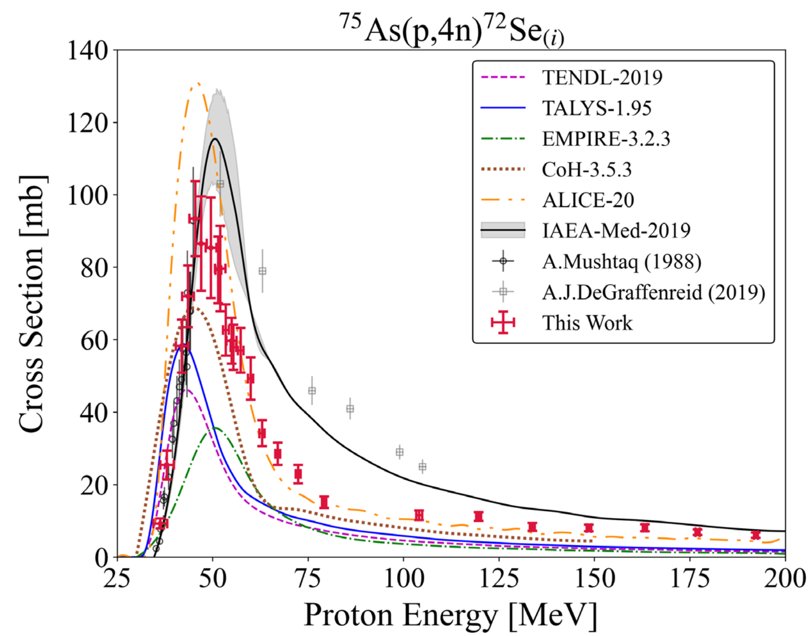
- First TREND campaign: As(p,x), focus on $^{72}$Se production (PET imaging)
  - 21 reaction channels observed in As
  - 27 data points from 30-200 MeV
  - Also measured 34 new reaction channels in (Cu,Ti) monitor foils

Ongoing work:

- Antimony, thallium and lanthanum
  - All from 200 MeV to threshold
  - Sb/Tl included prompt-gamma, secondary particle (LBNL only)

M. B. Fox, A. S. Voyles, J. T. Morrell, L. A. Bernstein, A. M. Lewis, A. J. Koning et al., Measurement and Modeling of Proton-Induced Reactions on Arsenic from 35 to 200 MeV, *Physical Review C, 104:064615* (2021)



# Developing New Capabilities: Counting Facility Upgrades

Recently upgraded IPF counting capabilities (2022)

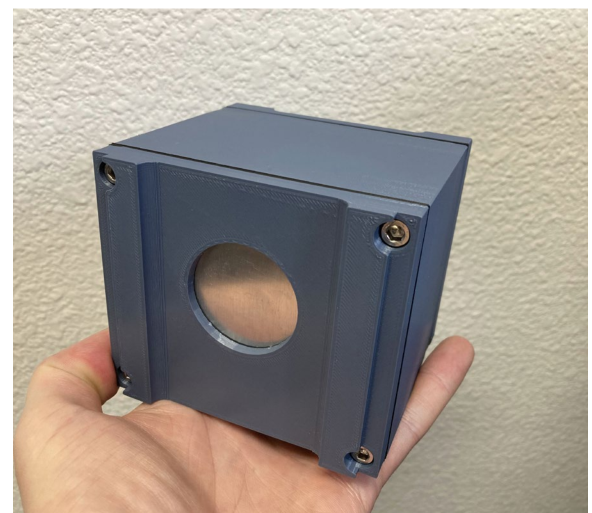
- 2 Ortec GEM (transistor-reset) detectors
- DSPEC-PRO (2-channel)
- Concrete and lead shielding
- Calibrated counting towers (up to 75 cm)
- Dedicated counting space for IPF nuclear data experiments
  - On-site is bonus

*Much of the work was ensuring safety requirements will be met*

# Printing a Nuclear Data Box

Need for rapid (stacked-target) measurements

- Developing 3D printed, disposable test box
- Compared to machined box:
  - **Significantly reduces fabrication time + cost**
    - Cheap plastic vs precision machined aluminum
  - No need for decontamination
    - Box is thrown away after experiment
  - Can have many foil experiments “lined up”
  - Customizable
    - Compartment size + degrader thickness tailored to experiment
    - Could accommodate custom samples



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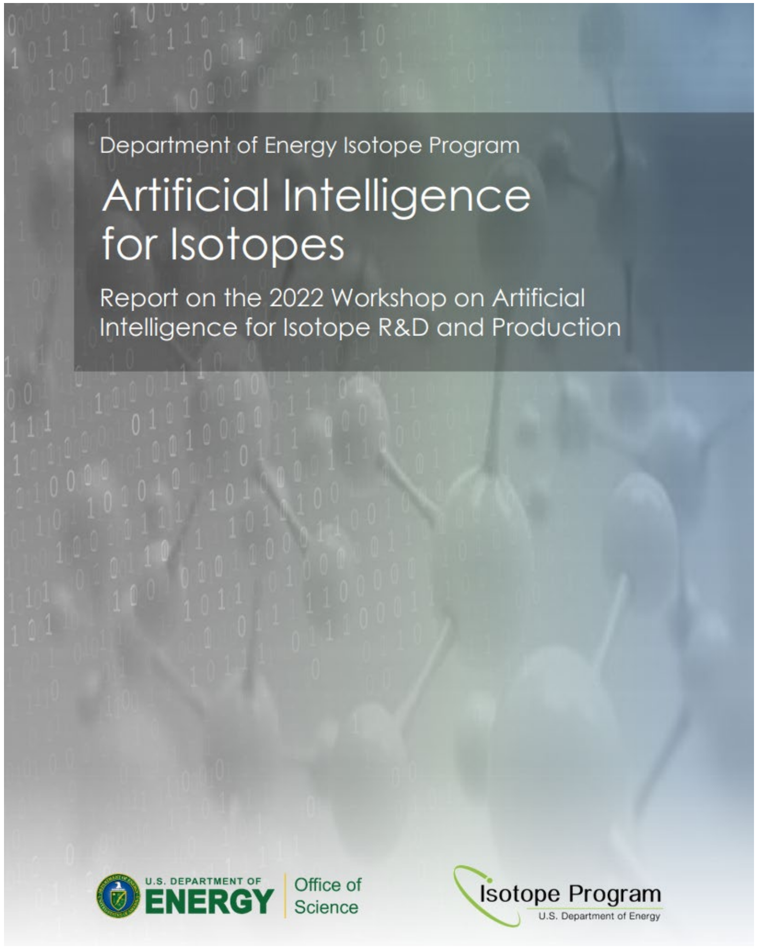
# Machine Learning for Nuclear Data

Recent (2022) workshop on AI Applications for Isotope Production

- Why we want to use AI/ML:
  - Accelerate performance of computationally-heavy tasks
    - >100x speedup over C/C++ for parallel applications
  - Remove human bias
  - Perform global optimizations
  - Outlier rejection
  - Good for working with “noisy” data
- Where AI/ML isn’t appropriate:
  - Replacing physics models
  - Work on small data sets

Recent IPF developments

- New GPU compute workstation
- Use of AI/ML for image analysis



# Workforce Development

**Students are a critical part of the nuclear data pipeline**

Recent updates:

- Participating institution of HIPPO
- Site visit summer 2022
  - Undergrad/Grad Students
  - Taught theory and practice of isotope production
  - Poster session to showcase student projects to the public
- Always looking for students/post-docs
  - Physics, engineering, comp. sci., chemistry, math
  - Contact etienne@lanl.gov

HIPPO

Horizon-Broadening Isotope Production Pipeline Opportunities

# Conclusions & Future Work

- Many nuclear data needs:
  - Cross sections, evaluations, curated data, utilities for isotope production
- Stacked target activation measurements performed for natural targets of: As, Sb, Tl, La (Nb, Cu & Ti products were also observed)
- Many capability improvements complete or ongoing
- Future work: improve pre-equilibrium reaction modeling, incorporate AI/ML into data evaluation procedure

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Isotope Program
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