Introduction to IPF

Isotope Production Facility (IPF)
- Location: Los Alamos Neutron Science Center (LANSCE)
  - First beamline after DTL
- 100 MeV H\(^+\), \(~250 \mu\text{A}\) (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
st = ci.Stack('iodine_example.csv', E0=100)
st.plot('C_slot')
```

<table>
<thead>
<tr>
<th>compound</th>
<th>thickness</th>
<th>name</th>
</tr>
</thead>
<tbody>
<tr>
<td>H₂O</td>
<td>5</td>
<td>A_slot</td>
</tr>
<tr>
<td>Al</td>
<td>12</td>
<td>B_slot</td>
</tr>
<tr>
<td>H₂O</td>
<td>5</td>
<td>C_slot</td>
</tr>
<tr>
<td>Te</td>
<td>3</td>
<td></td>
</tr>
</tbody>
</table>
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)
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

(NO DATA FOUND) (p,6n) is even worse!
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)

- **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

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

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
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
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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