Harvesting Isotopes For Neutron Cross-section Measurements at RIA

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ACS Symposium on Radiochemistry at RIA
New Orleans, CA
March 27, 2003

This work has been performed under the auspices of the US DOE by UC-LLNL under contract W-7504-ENG-48.
Science Based Stockpile Stewardship (SBSS) has science interest in RIA, namely neutron cross section measurements on short lived nuclei.

Certain elements used as neutron flux monitors in brief, intense neutron flux environments.

Example – Zirconium
1. Begin with only $^{90}\text{Zr}$.
3. Measuring ratios such as $^{88}\text{Zr}/^{89}\text{Zr}$ gives info on neutron flux

Neutron cross-sections must be known accurately!
Guide for Making Neutron Cross-section Measurements

Assumes $10^{11}-10^{12}$ pps production rate and $10^{10}-10^{11}$ n/s on target
Direct Measurement of Neutron Cross Sections

Prompt Method – Must handle high gamma ray background from target

- (n,2n) – Freuhaut method\(^1\) (liquid scintillator ball)
- (n,\(\gamma\)) – DANCE\(^2\) (half-life limit of target?)
- (n,px) – Charged particle spectrometer

Delayed (Radchem) Method – Needs High Purity Target

- Count gamma rays after irradiation
- May involve chemical separation after irradiation

Pre-RIA Example – $^{89}\text{Zr}(n,2n)$ and $^{89}\text{Zr}(n,np)$

1. Production Reaction: $^{89}\text{Y}(p,n)^{89}\text{Zr}$
2. Chemical separation: Zr from Y target
3. Irradiate with neutrons: $10^{10-11}$ n/sec
4. Wait for $^{89}\text{Zr}$ to decay to countable levels (75 days).
5. Count $^{89}\text{Zr}$ (909 keV) and measure half life.
6. 100 days after neutron radiation count $^{88}\text{Zr}$ (393 keV) and $^{88}\text{Y}$ (898 and 1836 keV).

Part of Academic Alliance, UC-Berkeley, LBNL, and LLNL collaborating.

For 1-2% (n,2n) and 5% (n,np) measurements, requires 0.2 Curie $^{89}\text{Zr}$ target.
Target Requirements

For (n,2n) measurement, given target life time and neutron flux…

\[ \Rightarrow \quad ^{89}\text{Zr target must be free of } ^{88}\text{Zr contamination at } 10^{-9} \text{ level.} \]

Cannot chemically separate isotopes.

\[ \Rightarrow \quad \text{Implies production method cannot produce } ^{88}\text{Zr.} \]

\[ \Rightarrow \quad \text{Proton energy must stay below } (p,2n) \text{ threshold – (13.08 MeV).} \]

For (n,np) measurement, \(^{89}\text{Y(n,2n)}\) will contribute background

\[ \Rightarrow \quad \text{Implies chemical separation must leave } < 1\% \quad ^{89}\text{Y in } ^{89}\text{Zr target.} \]

These are general conclusions for all radiochemistry measurements
Light ion direct reactions, such as (p,n), work better for production of low mass nuclei.

As mass number increases...

- One particle out reactions fall below coulomb barrier – cross section decreases.
- Two particle out reactions can be used, but more products are produced.
- More stable isotopes.
- More nearly stable isotopes.

RIA has best potential for producing large mass number isotopes for target fabrication.
Performing Neutron Cross Section Measurements at RIA

- Light Ion Direct Reaction
- ISOL
- Fragmentation
- Rigidity Separation
- Acceleration
- Neutron Irradiation and Prompt Measurements
- Indirect, Inverse Kinematics Measurements
- Chemical Separation And Radchem Measurements

Isotope Harvesting

Measurement
**Harvesting Isotopes at RIA**

1. Production at first stripper – Direct Reactions
2. ISOL with Mass Separator
3. Fragmentation with IGISOL system

HI(RIB,xn) or (p/α,n) reaction
In inverse kinematics

Experimental Areas:
1: < 12 MeV/u  2: < 1.5 MeV/u  3: Nonaccelerated  4: In-flight fragments
Using RIA for isotope production parasitically to other users is desirable, but...

Need high production rates to produce sufficient quantities for target fabrication.

- May need to optimize production beam for fragmentation or target of ISOL to achieve desired production rates.

Given half-life of desired nuclei, cutting production rate can not always be made up by extending running time.

- \( N = \frac{P(1-\exp(-\lambda t))}{\lambda} \): \( P \) is production rate

Most direct production runs will be a few days to at a week.

- Never makes sense for production run to last longer than 1-2 half lives.

For at least some cases will need to run as primary user for production.
Directs Reactions at First Stripper

- Use \((p/d,\text{etc}...,X)\) reactions or \((HI,X)\) reactions on low Z targets to produce nuclei.
  - 100’s of microamps of beam current
  - 50+ MeV protons and about 10’s MeV/A ions
- No possible charge to mass separation for p,d, etc... beams on heavy targets. Some possibilities for heavy ion beams.
- Probably only used in primary user mode (maximize production rates).
- Medical Isotope community will also be interested in this production method.
- Method works well only for near stability nuclei.
# ISOL Versus Fragmentation

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<thead>
<tr>
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<th>ISOL</th>
<th>Fragmentation</th>
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<tbody>
<tr>
<td><strong>Production Rate</strong></td>
<td>As high as $10^{12}$</td>
<td>~$10^{11}$ at target: Limited to $10^9$ by IGISOL</td>
</tr>
<tr>
<td><strong>Variety</strong></td>
<td>Very chemistry dependent</td>
<td>Very Flexible</td>
</tr>
<tr>
<td><strong>Mass Separation</strong></td>
<td>Done on 60 keV ion beams</td>
<td>Done on ~350 MeV/A ion beams</td>
</tr>
<tr>
<td><strong>Ion Collection</strong></td>
<td>Stopping does not produce reactions</td>
<td>Stopping produces nuclear reactions, affecting purity</td>
</tr>
<tr>
<td><strong>Impact as Primary User</strong></td>
<td>Other ISOL target and low energy post acceleration line available</td>
<td>Choice of driver beam limited and only in-flight line available</td>
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Neutron Source Facility at RIA

1. Co-located but separate facility.
2. Mono-energetic neutrons from ~10 keV to 20 MeV.
3. High neutron fluxes, up to $10^{11}$ neutrons/sec on target.
4. Radiochemistry facility for processing targets.

Different production mechanisms are appropriate for different energies.
- $^3\text{H}(^2\text{H},n)^4\text{He}$: 14+ MeV
- Deuteron Breakup: 7+ MeV
- $^2\text{H}(^2\text{H},n)^3\text{He}$: 2-9 MeV
- $^3\text{H}(\text{p},n)^3\text{He}$ or $^7\text{Li}(\text{p},n)^7\text{Be}$: 0.1-2 MeV
- Moderated reactions: Below 100 keV

Strawman design completed and working with MSU and ANL to incorporate into RIA designs.
First Design of Neutron Source Facility

0.05-3 MeV Dynamitron
2-30 MeV Linac
Radiochemistry Facilities

Experimental Halls

Approximate Foot Print
80 x 60 m
1. Further development of ISOL targets
   • Beam power issues
   • Target chemistry issues (larger variety of isotopes)
2. Development of a fragment catcher for target formation
   • Not limited to $10^9$ pps
   • Maintain high purity mass separation
3. Further development on parasitic mode
4. Transportation from production area to radiochemistry area
5. Further development of neutron source facility
Summary

- Given production rates of RIA, targets of nuclei with a half life of around 1 day can be made.
- An isotope production area at first stripper will be valuable tool at RIA.
- Harvesting isotopes in parasitic mode is desirable, but short runs in primary user mode may be preferred method and sometime necessary.
- No clear preference for ISOL or fragmentation line as the preferred isotope production method.