Accelerator-Based Isotope Production at TRIUMF

CAP Conference

June 16th, 2015

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TRIUMF
Accelerators at TRIUMF

- ISAC (RIB linac)
- ARIEL (50 MeV electron linac)
- 2 x TR30, CP42, TR13 H\(^-\) cyclotrons
- 500MeV H\(^-\) cyclotron

New addition: TR24; to be installed
TRIUMF Capabilities:

• **CP42**: up to 42 MeV and 200 µA, installed 1980

• **TR30-1**: up to 30 MeV and 900 µA, installed 1990
  - first TR30 designed, assembled by TRIUMF, components manufactured by EBCO, commissioned by TRIUMF

• **TR30-2**: up to 30 MeV and 1000 µA, installed 2003
  - Manufactured, installed by EBCO, commissioned by TRIUMF

• **TR13**: 13 MeV, 25µA, installed 1986 (UBC Neurology)
  - Capable of $^{11}\text{C}$, $^{18}\text{F}$, $^{13}\text{N}$, $^{68}\text{Ga}$, $^{89}\text{Zr}$, $^{64}\text{Cu}$, $^{44}\text{Sc}$, $^{86}\text{Y}$, $^{55}\text{Co}$, $^{52}\text{Mn}$…solid, liquid, gas targets

• **TR24**: 24 MeV, 500+ µA, to be installed

Overall

- 5 solid target, 3 gas stations operating at 30 MeV
  - Commercial production: $^{67}\text{Ga}$, $^{111}\text{In}$, $^{123}\text{I}$, $^{103}\text{Pd}$, $^{201}\text{Tl}$
  - Future commercial production: $^{99m}\text{Tc}$
Direct, multi-Curie production of $^{99m}$Tc on three different cyclotrons

1) TRIUMF
2) University of British Columbia;
3) BC Cancer Agency;
4) Lawson Health Research Institute;
5) Centre for Probe Development and Commercialization
Tc-99m Alternatives: Many options

- $^{99}\text{Mo}/^{99m}\text{Tc}$ in high demand (~40M doses/yr)
- Gov’t owned reactors produce majority of $^{99}\text{Mo}$ supply
- NRU going offline Oct. 2016 (~40% of global supply)
- Capacity emerging (existing reactors, new technology)
- Projections range from oversupply to shortages\(^1\)
- Must move to full-cost recovery

Alternatives:
- $^{98}\text{Mo}(n,\gamma)^{99}\text{Mo}$
- $^{238}\text{U}(\gamma,F)^{99}\text{Mo}$
- LEU $^{235}\text{U}(n,F)$
- $^{100}\text{Mo}(\gamma,n)^{99}\text{Mo}$
- $^{100}\text{Mo}(p,2n)^{99m}\text{Tc}$

\(^1\) OECD - NEA/SEN/HLGMR(2014)2

graphic from http://www.covidien.com/
Cyclotrons By the Numbers

Estimated global cyclotron numbers by various manufacturers (with data from ACSI, GE, IBA and Siemens, Sumitomo data estimated)

Direct Production of $^{99m}$Tc

Goals:
- Demonstrate routine, reliable, commercial-scale production of $^{99m}$Tc via $^{100}$Mo(p,2n) at multiple sites, multiple brands;
- Obtain regulatory approval for clinical use in humans;
- Establish a business plan;
- Disseminate, commercialize the technology

Hypothesis: Future production will be from variety of sources (neutron, proton, electron) and market driven

Maximizing $^{99m}$Tc production, minimizing impurities:

- $<19$ MeV proton energy entering $^{100}$Mo
- $>8$ MeV proton energy exiting $^{100}$Mo

Stopping power of Mo: Requires $<1.2$ g of metal
Reduce density, balance thermal conductivity

Bénard et al., J. Nucl. Med. 2014, 55, 1017-1022

Zeisler et al. WTTC 2014
Retrofit Existing Infrastructure

- $^{100}$Mo Target
- Cyclotron Modification
- Optimize Irradiation
- Purify $^{99m}$TcO$_4$
- Regulatory QA/QC
- $^{100}$Mo Recovery

TR19
TR30
PETtrace
Target Type vs. Cyclotron Power

100Mo Target
Cyclotron Modification
Optimize Irradiation
Purify 99mTcO4
Regulatory QA/QC
100Mo Recovery

TR30 (@24 MeV) target power: 10.8 kW @ 0.6 kW/cm²
TR19 target power: 5.4 kW @ 0.3 kW/cm²
PETtrace target power: 2.1 kW @ ~1.2 kW/cm²
Real and Projected Yields of $^{99m}$Tc

100Mo Target  | Cyclotron Modification  | Optimize Irradiation  | Purify $^{99m}$TcO$_4$  | Regulatory QA/QC  | 100Mo Recovery

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Production Yields

**GE PETtrace**
16.5 MeV, 130 μA
Theoretical 4.9 Ci (6h)
Achieved 4.7 Ci
Sat$^n$: 75.6 mCi/μA

**TR19**
18 MeV, 300 μA
Theoretical 15.4 Ci (6h)
Achieved 9.4 Ci (@ 240 μA)
Sat$^n$: 103 mCi/μA

**TR30 (@24 MeV)**
24 MeV, 500 μA
Theoretical 39 Ci (6h)
Achieved ~32 Ci (@ 450 μA)
Sat$^n$: TBD
Purification of $^{99m}$Tc

100Mo Target | Cyclotron Modification | Optimize Irradiation | Purify $^{99m}$TcO$_4$ | Regulatory QA/QC | 100Mo Recovery

- SPE-based method:
  - original work: Dowex™ vs ABEC
  - new alternative resin: ChemMatrix™
- Process Time: complete in <90 min.
- Efficiency Range: 92.7 ± 1.1%
- Radiochemical Purity: >99.99% TcO$_4$
- Trace analysis: <10 Bq Mo-99, <5 ppm Al$^{3+}$
- non-Tc impurities removed

Disposable fluid path for GMP

Inherent Resin Versatility: Vendor Agnostic

Bénard et al., J. Nucl. Med. 2014, 55, 1017-1022
Regulatory Process: CTA nearly complete

- Not currently approved by Health Canada, FDA, etc.
- CTA preparation underway:
  - GLP preclinical rodent data (complete);
  - documentation (complete),
  - acceptance criteria: RNP, RCP, Al, Mo, H₂O₂ (complete);
  - process validation (complete)
- Shelf life (18 hrs), irradiation parameters are based on projected patient dose (objective <10% add’l vs. pure ⁹⁹ᵐTc)
  - Enrichment and irradiation parameters are interrelated and should not be considered independently
- CTA submission – June 2015 (60 patient trial)
- Fall 2015 - NDS submission
## 100Mo Raw Material/Irradiation Specifications

<table>
<thead>
<tr>
<th>Isotope</th>
<th>Proposed max. isotopic impurity to maintain patient dose increase of ~10% compared to pure $^{99m}$TcO$_4$</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>$\leq$ 20 MeV$^1$</td>
</tr>
<tr>
<td>$^{92}$Mo</td>
<td>0.03</td>
</tr>
<tr>
<td>$^{94}$Mo</td>
<td>0.03</td>
</tr>
<tr>
<td>$^{95}$Mo</td>
<td>0.03</td>
</tr>
<tr>
<td>$^{96}$Mo</td>
<td>0.03</td>
</tr>
<tr>
<td>$^{97}$Mo</td>
<td>0.03</td>
</tr>
<tr>
<td>$^{98}$Mo</td>
<td>7</td>
</tr>
</tbody>
</table>

$^1$Maximum increase in patient dose of 9.8 % at 20 MeV, 18 hours after EOB.
$^2$Maximum increase in patient dose of 10.1% at 22 MeV, 18 hours after EOB.
$^3$Maximum increase in patient dose of 10.6% at 24 MeV, 18 hours after EOB.

- Based on theoretical yield calculations with $^{99m}$Tc pertechnetate
- Mitigates the impact of dose due to $^{98}$Mo(p,3n)$^{96}$Tc reaction at higher E

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We Recycle

- High efficiency recovery process for multi-gram quantities of $^{100}\text{MoO}_4^{2-}$ required
- Some trace long-lived radionuclidic impurities
- Target dissolution waste stream (liquid, 10’s of mL/batch)
- Original method: ion exchange
  >90% efficiency (non-optimized), large column volumes, slow
- Currently using acidic precipitation, thermal decomp. process
- Routine recovery yields >99%
- Analysis of recovered $^{100}\text{Mo}$ underway
Remaining Challenges for Cyclotron Production of $^{99m}$Tc

- Process: Long-term reliability (machine and target)
- Quality Control: Decentralized production inherently leads to a greater likelihood of product variability, dose uncertainty
- Regulatory: Considerations need to include target isotopic enrichment, but also batch-to-batch target consistency, irradiation energy/duration, shelf-life (patient dose)
- Economic: Arguments in one region may not apply in others but FCR must apply
- Availability: A viable alternative/backup needs to be used regularly
Production, Purification and Radiolabelling of Radiometals Produced in a Liquid Target on a 13 or 19 MeV Medical Cyclotron
Proposal

• **Hypothesis:** Established cyclotron centers can obtain research, and possibly clinical quantities of various radiometals by irradiating salt solutions in modified liquid targets
  • Leverage existing liquid target infrastructure for the production of other PET isotopes ($^{18}$F)

**Accepted trade-off:**
Lower production yields in exchange for isotope versatility

Vogg ATJ, et al. Proceedings of the Sixth International Conference on Nuclear and Radiochemistry, 2004; Aachen, Germany.
Project Goals

• **Goals:**
  • Allow broader access to a variety of radiometallic isotopes
  • Radiometal production without generators, solid-target installation
  • Enable faster optimization of vector-isotope pairing
Isotope-Biomolecule Pairing

- **Proposed application:** labeling and *in vivo* analysis of novel proteins/peptides targeted toward HER2 variants/isoforms
  - Larger/slower-clearing constructs $\rightarrow$ longer-lived isotopes
  - Smaller/faster-clearing constructs $\rightarrow$ shorter-lived isotopes

• Specific Interests:
  • $^{94}\text{Mo}(p,n)^{94m}\text{Tc}$ (half-life: 52.5 min)
  • $^{44}\text{Ca}(p,n)^{44}\text{Sc}$ (half-life: 3.9 h)
  • $^{86}\text{Sr}(p,n)^{86}\text{Y}$ (half-life: 14.7 h)
  • $^{89}\text{Y}(p,n)^{89}\text{Zr}$ (half-life: 78.5 h)
  • $^{68}\text{Zn}(p,n)^{68}\text{Ga}$ (half-life: 68 min)

• Approach:
  • TRIUMF: TR13 (13 MeV, 20 µA), standard water target (testing, feasibility)
  • BCCA: TR19 (19 MeV, 300 µA), large volume water target (application: HER2Δ16 binders)
  • New target design (i.e. syphon targets)
Assessing Feasibility: Cross-sectional Considerations

$^{68}\text{Zn}(p,n)^{68}\text{Ga}$

$T_{1/2} = 68$ min

$^{44}\text{Ca}(p,n)^{44}\text{Sc}$

$T_{1/2} = 3.9$ h

$^{86}\text{Sr}(p,n)^{86}\text{Y}$

$T_{1/2} = 14.7$ h

$^{89}\text{Y}(p,n)^{89}\text{Zr}$

$T_{1/2} = 78.5$ h
<table>
<thead>
<tr>
<th>Prod</th>
<th>Production route</th>
<th>Metal salt</th>
<th>Density (g/mL)</th>
<th>Beam current (μA)</th>
<th>Time (min)</th>
<th>Yield (MBq)</th>
<th>Sat. yield (MBq/μA)</th>
</tr>
</thead>
<tbody>
<tr>
<td>$^{94m}$Tc</td>
<td>$^{94}$Mo(p,n)$^{94m}$Tc</td>
<td>$(\text{NH}_4)_6\text{Mo}<em>7\text{O}</em>{24}$</td>
<td>1.66</td>
<td>5</td>
<td>60</td>
<td>110±20</td>
<td>40±6</td>
</tr>
<tr>
<td>$^{44}$Sc</td>
<td>$^{44}$Ca(p,n)$^{44}$Sc</td>
<td>Ca(NO$_3$)$_2$</td>
<td>1.55</td>
<td>7.6</td>
<td>60</td>
<td>5.55±0.22</td>
<td>4.6±0.3</td>
</tr>
<tr>
<td>$^{68}$Ga</td>
<td>$^{68}$Zn(p,n)$^{68}$Ga</td>
<td>Zn(NO$_3$)$_2$</td>
<td>1.65</td>
<td>6.8</td>
<td>60</td>
<td>275±1</td>
<td>68±5</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>1.56</td>
<td>6.96</td>
<td>60</td>
<td>480±30</td>
<td>141±6</td>
</tr>
<tr>
<td>$^{89}$Zr</td>
<td>$^{89}$Y(p,n)$^{89}$Zr</td>
<td>Y(NO$_3$)$_3$ x HNO$_3$</td>
<td>1.49</td>
<td>7.3</td>
<td>60</td>
<td>32±2</td>
<td>360±9</td>
</tr>
<tr>
<td>$^{86}$Y</td>
<td>$^{86}$Sr(p,n)$^{86}$Y</td>
<td>Sr(NO$_3$)$_2$</td>
<td>1.43</td>
<td>4.6</td>
<td>60</td>
<td>7.4±0.5</td>
<td>31±1</td>
</tr>
</tbody>
</table>
## Purification – All metals

<table>
<thead>
<tr>
<th>Prod.</th>
<th>Irradiated metal salt</th>
<th>Column 1</th>
<th>Column 2</th>
<th>Final Eluate</th>
<th>Activity received from target (%)</th>
<th>Vol. (mL)</th>
<th>Eluent</th>
</tr>
</thead>
<tbody>
<tr>
<td>$^{44}\text{Sc}$</td>
<td>Ca(NO$_3$)$_2$</td>
<td>DGA</td>
<td>-</td>
<td></td>
<td>88 ± 6 (n = 5)</td>
<td>2.5</td>
<td>0.05M HCl</td>
</tr>
<tr>
<td>$^{68}\text{Ga}$</td>
<td>Zn(NO$_3$)$_2$</td>
<td>AG 50W-X8</td>
<td>DGA</td>
<td></td>
<td>92 ± 8 (n = 3)</td>
<td>1.0</td>
<td>H$_2$O</td>
</tr>
<tr>
<td>$^{89}\text{Zr}$</td>
<td>Y(NO$_3$)$_3$</td>
<td>Hydroxamate resin</td>
<td>-</td>
<td></td>
<td>82 ± 5 (n = 4)</td>
<td>0.75</td>
<td>1M Oxalic Acid</td>
</tr>
<tr>
<td>$^{86}\text{Y}$</td>
<td>Sr(NO$_3$)$_2$</td>
<td>DGA</td>
<td>-</td>
<td></td>
<td>99 ± 4 (n = 3)</td>
<td>1.0</td>
<td>H$_2$O</td>
</tr>
<tr>
<td>$^{94m}\text{Tc}$</td>
<td>(NH$_4$)$_6$Mo$<em>7$O$</em>{24}$</td>
<td>ABEC-2000</td>
<td>SCX/Alumina</td>
<td></td>
<td>70.9 ± 0.7 (n = 4)</td>
<td>6.0</td>
<td>saline</td>
</tr>
</tbody>
</table>

Specific activity: $^{44}\text{Sc}$ (1.4 TBq/µmol), $^{68}\text{Ga}$ (5.2TBq/µmol), $^{89}\text{Zr}$ (0.015 TBq/µmol), $^{86}\text{Y}$ (0.41 GBq/µmol), $^{94m}\text{Tc}$ ()
Radiolabelling chemistry

### Radiolabelling conditions

<table>
<thead>
<tr>
<th>Isotope</th>
<th>Temperature</th>
<th>Time</th>
<th>pH</th>
<th>Buffer</th>
</tr>
</thead>
<tbody>
<tr>
<td>Y-86</td>
<td>95 °C</td>
<td>30 min</td>
<td>pH=6</td>
<td>0.33M HEPES</td>
</tr>
<tr>
<td>Zr-89</td>
<td>r.t.</td>
<td>15 min</td>
<td>pH=7</td>
<td></td>
</tr>
<tr>
<td>Ga-68</td>
<td>95 °C</td>
<td>10 min</td>
<td>pH=4</td>
<td>0.33M HEPES</td>
</tr>
</tbody>
</table>
Preparation of Liquid Target Solutions

- **Gas evolution during irradiation = high target pressures in a closed target body**
  - Radiolysis of water, O\(_2\), H\(_2\)
  - 1M nitric acid for \(^{nat}\)Zn and \(^{nat}\)Sr salt irradiations*

- **Compatibility between salt solutions and target components**
  - Havar foil (Co-based, Cr, Ni, Fe, W, Mo, Mn)
    - Failed with Cl\(^-\) salts (etching evident)
  - Al vacuum foil (failed in boil tests)
  - Target body (Al) – evidence of corrosion
    - Switch to Nb target body

- **Precipitation**
  - Need thorough flushing protocol between runs

Summary

• A simple method for the production of research quantities of various radiometals using a modified liquid-target system.
• Salt solutions of natural isotopic abundance were irradiated in a standard water target on our 13 MeV cyclotron for 60 min. After irradiation, all solutions were withdrawn from the target and purified using cation exchange or chelating resins.
• Several isotopes ($^{68}$Ga, $^{89}$Zr, $^{44}$Sc, $^{89}$Y, $^{94m}$Tc) were produced in a standard water target on our 13 MeV cyclotron.
• **Future work:** labeling and biodistribution analysis of breast cancer (HER2) binders; novel target designs (higher production)
Production and assessment of radiotherapeutic isotopes
500 MeV Cyclotron Capabilities

Previous decade: routine operation at 220-250μA

Recently achieved:
- Materials science, 500 MeV isotopes:
  - BL1A (100μA)
- ISAC program:
  - BL2A (100μA)
- Sr production:
  - BL2C (100μA)
  - Total (300μA)
Isotope Accelerator Program (ISAC): 50 kW ISOL Facility

Isotope production via spallation of uranium:

Implementation of ISOL technique:

• Uranium carbide, thorium oxide
• 480 MeV protons, 10 µA
• Various available ion sources
• ~2500:1 mass separation resolution (~10^6–10^9 ions/s)
• Ion energy = ~20-60 keV
# Candidate $\alpha$-emitters for therapy

<table>
<thead>
<tr>
<th>Isotope</th>
<th>Half-life</th>
<th>Considerations</th>
<th>Production</th>
</tr>
</thead>
<tbody>
<tr>
<td>$^{149}\text{Tb}$</td>
<td>4.2 h</td>
<td>Good chemistry, alt. isotopes</td>
<td>Spallation, heavy-particle accelerator</td>
</tr>
<tr>
<td>$^{211}\text{At}$</td>
<td>7.2 h</td>
<td>No stable isotope, Thyroid uptake</td>
<td>$\alpha$-cyclotron</td>
</tr>
<tr>
<td>$^{212}\text{Bi}$</td>
<td>1.0 h</td>
<td>Renal uptake</td>
<td>Generator ($^{224}\text{Ra}/^{212}\text{Bi}$)</td>
</tr>
<tr>
<td>$^{213}\text{Bi}$</td>
<td>0.76 h</td>
<td>Renal uptake</td>
<td>Generator ($^{225}\text{Ac}/^{213}\text{Bi}$)</td>
</tr>
<tr>
<td>$^{223}\text{Ra}$</td>
<td>10 d</td>
<td>4 $\alpha$-decays, bone targeting</td>
<td>Generator ($^{227}\text{Ac}/^{223}\text{Ra}$)</td>
</tr>
<tr>
<td>$^{225}\text{Ac}$</td>
<td>10 d</td>
<td>4 $\alpha$-decays,</td>
<td>Generator ($^{229}\text{Th}/^{225}\text{Ac}$)</td>
</tr>
</tbody>
</table>
209At-based imaging to establish 211At α-therapy

209At identified as novel SPECT isotope

**Therapy**

\[ ^{211}\text{At} \quad t_{1/2} = 7.2 \text{ h} \]

(α-emitter)

**Imaging**

\[ ^{209}\text{At} \quad t_{1/2} = 5.4 \text{ h} \]

(γ-emitter)

209At collected from 213Fr ion beams
**Ion beams of therapeutic $\alpha$-emitters**

<table>
<thead>
<tr>
<th>Isotope</th>
<th>$1^{\text{st}}$ Ionization energy</th>
<th>Ion Source</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td><strong>TANTALUM TARGET</strong></td>
<td></td>
</tr>
<tr>
<td>$^{149}\text{Tb}$</td>
<td>5.86 eV</td>
<td>Re surface ionizing</td>
</tr>
<tr>
<td></td>
<td><strong>URANIUM TARGET:</strong></td>
<td></td>
</tr>
<tr>
<td>$^{211}\text{At}$</td>
<td>9.54 eV</td>
<td>Plasma/Resonance ionization laser</td>
</tr>
<tr>
<td>$^{212/213}\text{Bi}$</td>
<td>7.29 eV</td>
<td>Plasma (aka FEBIAD)</td>
</tr>
<tr>
<td>$^{223/225}\text{Ra}$</td>
<td>5.28 eV</td>
<td>Re surface ionizing</td>
</tr>
<tr>
<td>$^{225}\text{Ac}$</td>
<td>5.28 eV</td>
<td>Re surface ionizing</td>
</tr>
<tr>
<td></td>
<td><strong>Note:</strong></td>
<td></td>
</tr>
<tr>
<td>$^{211/213}\text{Fr}$</td>
<td><strong>3.94 eV</strong></td>
<td>Re surface ionizing <em>(Most Intense!)</em></td>
</tr>
</tbody>
</table>
ISOL pilot study: $^{209}$At

Implantation chamber

Sample holder (with current monitor)

Candidate foil

$\text{NaCl foil} \sim 250 \text{ nm}$

I.D. = 20 mm

Aluminum Bracket = 30 mm

Credit to: Peter Kunz, TRIUMF
From bench to (pre-clinical) bedside

10^9 ions/s of $^{213}$Fr collected for up to 9.5 h

$^{209}$At recovered by dissolving NaCl targets in 0.1 N NaOH (< 300 µL)

Up to 8.9 mCi $^{209}$At (EOB)
(Measured by $\gamma$-ray spectroscopy)

Labeling Chemistry

$^{209}$At: 80 keV peak  $^{123}$I: 159 keV peak
211Rn/211At generator system from 211Fr ion beams (>10^9 ions/s)

211Rn/211At generator could increase 211At supply and opportunities for distribution

The 211Fr decay chain provided a novel approach to 211Rn production

211Rn was isolated in dodecane, other radioactive inventory was washed away with aqueous solution

211At progeny recovered after several hours of grow-in
\[^{211}\text{Rn isolation design}\]

**Implant \(^{211}\text{Fr}\) in NaCl**

\[\downarrow\]

Submerge target in dodecane

\[\downarrow\]

Dissolve NaCl in dilute NaOH

\[\downarrow\]

Mix and remove aqueous solution (Pb/Bi/At/Po)

\[\downarrow\]

\(^{211}\text{Rn isolated in dodecane} \rightarrow ^{211}\text{A}\]

Adapted from Maeda et al, 2015 Radioanal Nucl Chem, 303:1465-1468 (Kanazawa U.)
Moving on to feasibility of $^{225}$Ra/$^{225}$Ac

Add 0.1 ml 0.1 N HCl

Evaporate

Add and Retrieve 0.1 ml 0.1 N HCl

Extraction using 0.1N HCl solution

Residual Activity (Bq)

Evap.-Rinse Cycles

Recoil transfer in vacuum

Source

Catcher

Efficiency ~30%

$^{225}$Ac $^{221}$Fr $^{217}$At $^{213}$Po

$^{213}$Bi $^{221}$Fr $^{217}$At $^{213}$Po
Future Direction: \( ^{225}\text{Ac}/^{213}\text{Bi} \)

- ISOL and Target Dissolution/Extraction

\[ \text{225Ac, 213Bi, many other options} \]


- TRIUMF capable of producing large (Ci) quantities of isotopes such as \( ^{225}\text{Ac}, ^{223,225}\text{Ra}, ^{213}\text{Bi}, ^{211}\text{Rn} \)

- Possible to ship targets for off-site processing (short-term)

- Effort in early stages, infrastructure, regulatory capabilities being pursued/implemented (long-term)
Medical Isotopes from ISAC/ISOL

- Generators: $^{211}\text{Rn}/^{211}\text{At}$; $^{225}\text{Ra}/^{225}\text{Ac}$; $^{225}\text{Ac}/^{213}\text{Bi}$

Feasibility/Chemistry in lead up to full target harvest:
Acknowledgements: Tc-99m

• **The Team:**
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