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ISOTOPE PRODUCTION SOLUTIONS

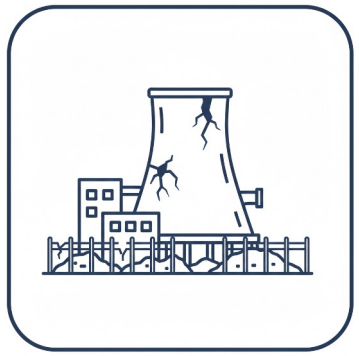
High-yield, standard cyclotron-based production system for Actinium-225 and Lead-212

Non-Confidential Technical Summary

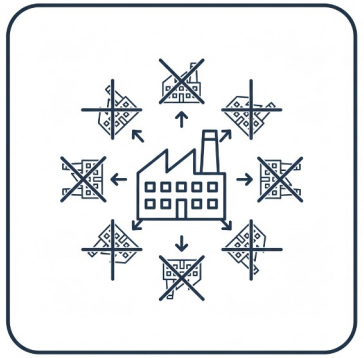
September 2026

Targeted Alpha Therapy Trials are Stalling Due to Limited Ac-225 and Pb-212

Current Production Methods



Large cyclotron or aging reactor required



Requires centralized (non-redundant) manufacturing



Inefficient production methods, difficult to scale



Ac-227 contamination co-produced in spallation



Radon release, radium fire risk in proton or gamma irradiation

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EnVoy-LAB Solution

A safe, scalable, high-yield production process for **Ac-225 and Pb-212** using fast neutrons from ***existing*** standard cyclotrons

- **18-30 MeV standard cyclotron**
- **Produces Ra-225 (Ac-225 precursor) & Pb-212 simultaneously or solo**
  - **Ra-225 yield : 18 → 120+ mCi/week**
  - **Pb-212 yield: 5 → 120+ mCi/day**
- **<1 g radium with 96-100% recovery for Ac-225**
- ***No radium consumption for Pb-212***
- **Integrates seamlessly in existing production processes**

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What are we NOT?

- We are NOT commissioning cyclotrons
- We are NOT building production facilities

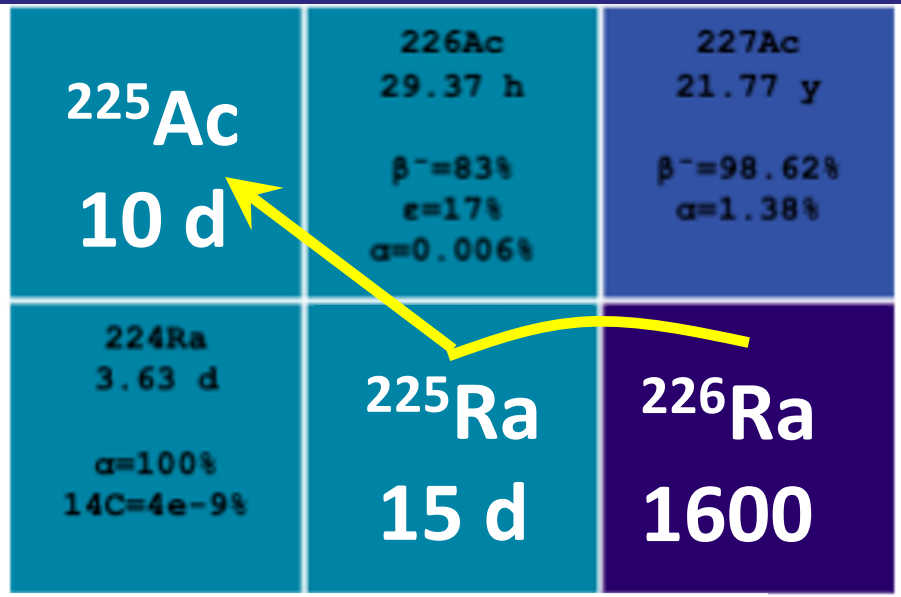
- *We partner nonexclusively to deploy our platform to existing production facilities, increasing supply of $^{225}Ac/^{212}Pb$ as quickly and cost-effectively as possible*
- *We provide bespoke target platforms optimized for **YOUR** specific facility and radium inventory*
- *We provide technical competency to your staff in commissioning, operating, and supporting our platform*

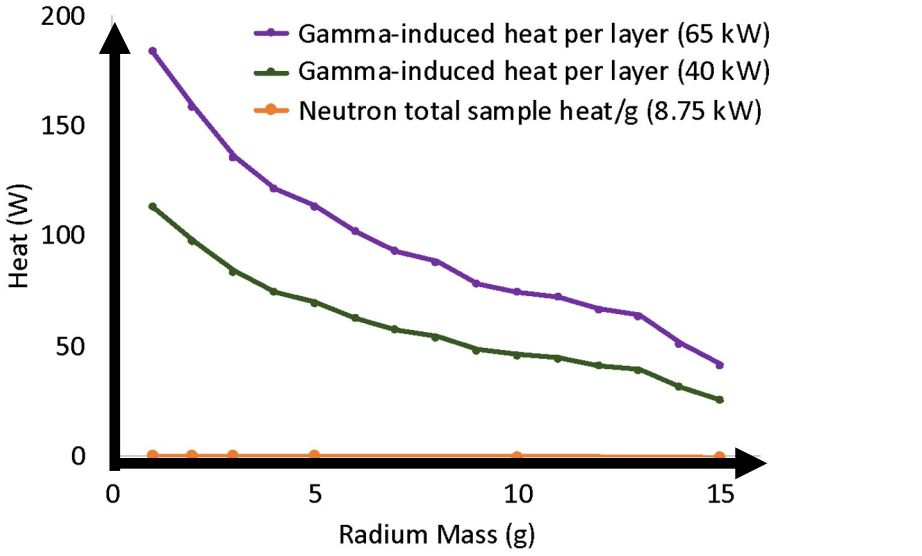
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^{225}Ac production via ^{226}Ra(n,2n)^{225}Ra

- ***INdirectly*** irradiating ^{226}Ra with ***secondary fast neutrons*** from energetic protons (19-30 MeV) will induce ^{226}Ra(n,2n)^{225}Ra
- Possible with machines as low as 16 MeV, but viable for >19 MeV
- Up to ≈120 mCi ^{225}Ra/week could be made with 1 g of ^{226}Ra using a high-power proton machine, using a hermetically-sealed Ra capsule
  - mCi-scale yields per week with as little as 100 mg of ^{226}Ra
- **FUNCTIONALLY NO TARGET HEATING – Safest possible operation**
  - Neutrons: ~8 uW/uA (of protons)
  - Photonuclear: ~ 0.1 W/uA (of electrons)
  - Protons: ~ 18 W/uA
- ^{225}Ra / ^{225}Ac separation frequency determined by client needs

We demonstrated the success of this approach in 2018 and tested an optimized breakup target in 2024

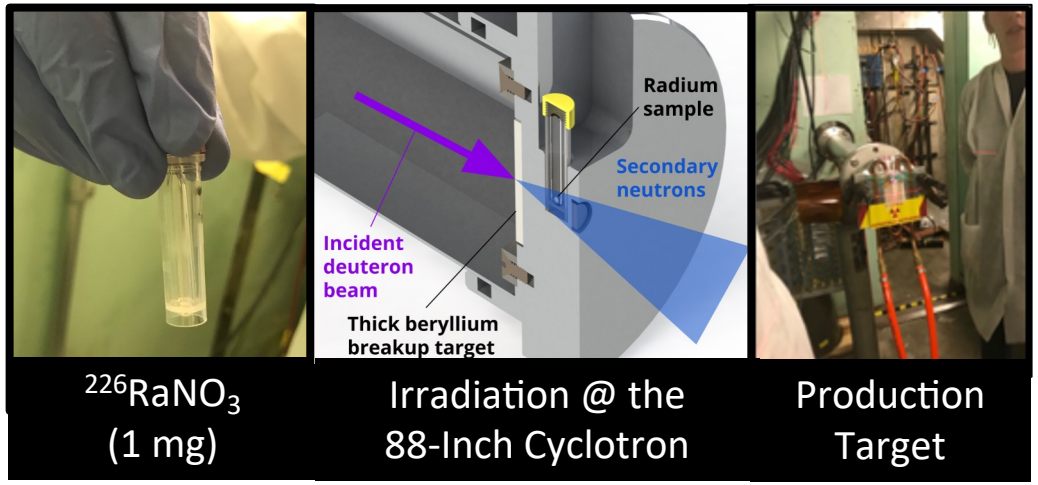




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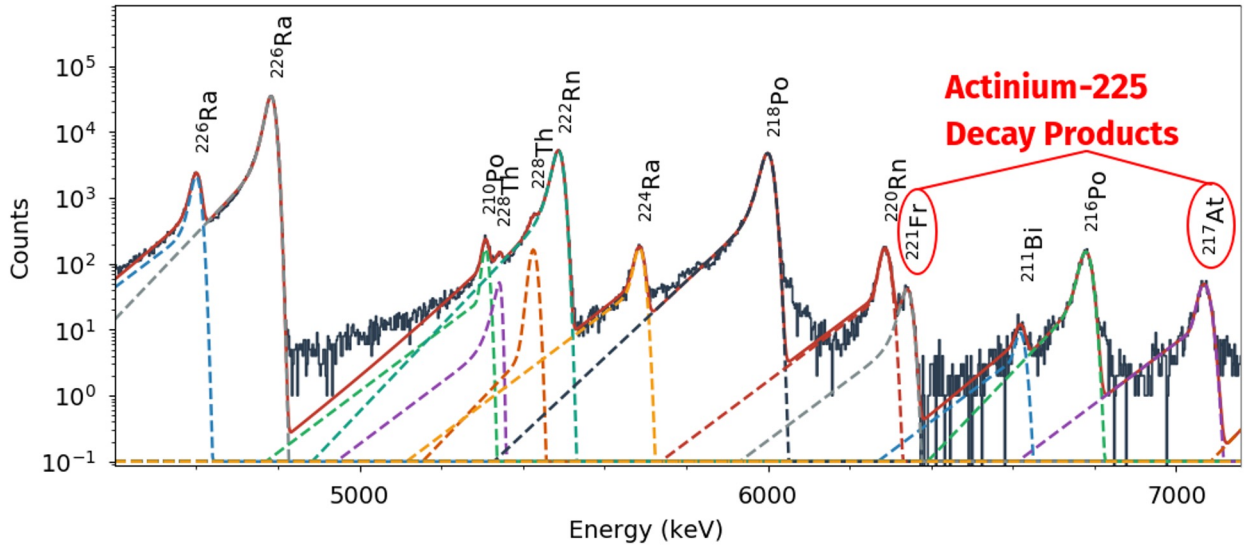
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^{225}Ac production: 2018 Proof-of-Concept



^{225}Ac production R&D using fast neutrons[1,2]

- Gamma-ray and alpha spectroscopy was performed 20 days after the end of bombardment.
- No ^{227}Ac or fission fragment contamination was observed.
- ^{225}Ac production rate at 33 MeV: **2.1 ± 0.2 mCi/mAh/g**
- IP owned by UC Berkeley, EnVoy has exclusive rights



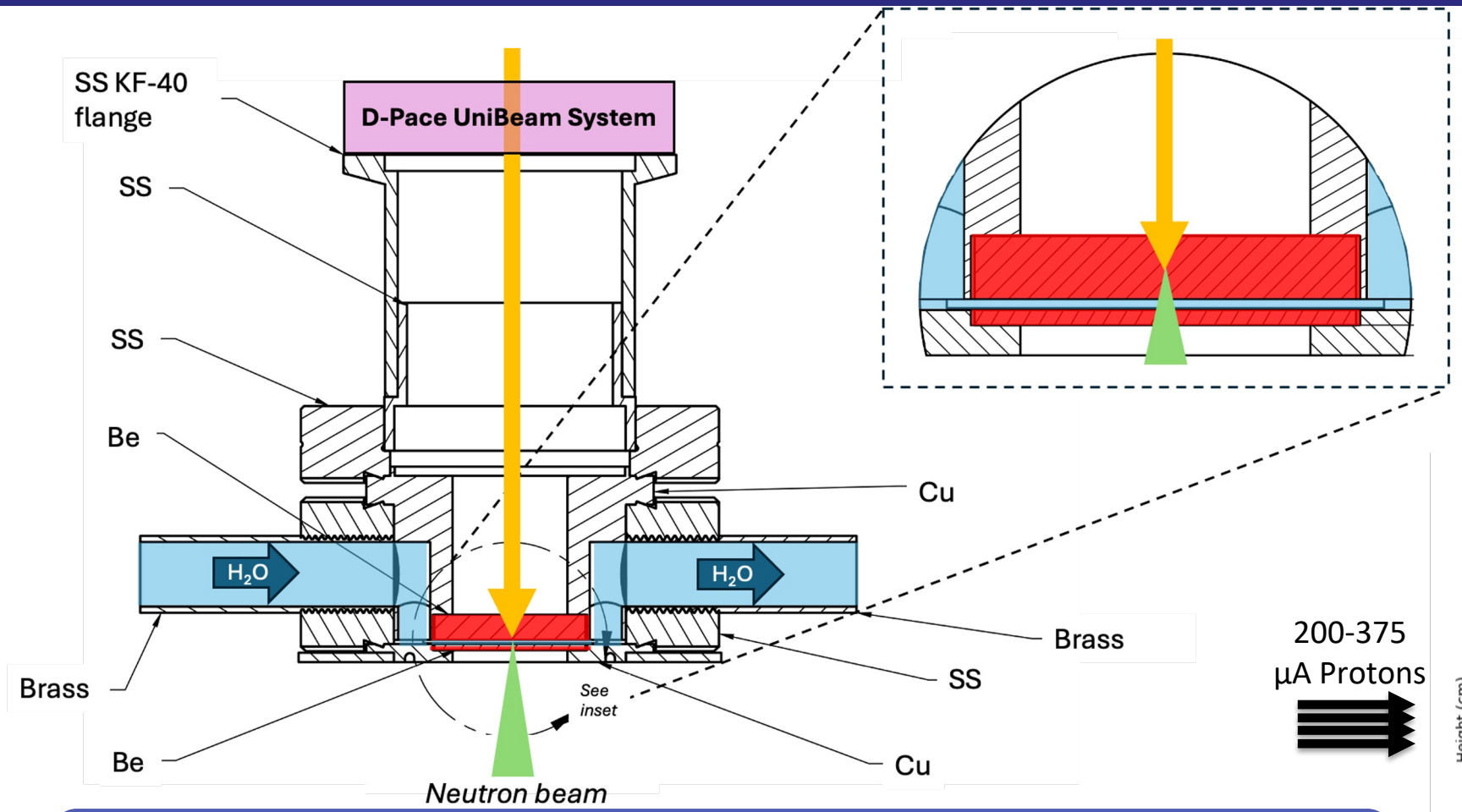
Extension to Commercialization using p+Be

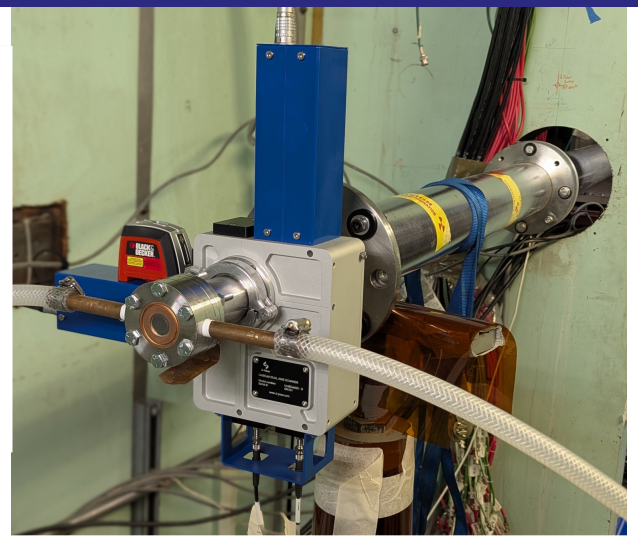
- Brede *et al.*,[3] has measured the neutron production from thick target *proton* irradiation of beryllium[3]
- We performed p+Be neutron spectral measurements using activation and and ToF spectroscopy in 2024-2025
- High-current proton machines are abundant, scalable

[1]J.T. Morrell *et al.,* Phys. Rev. C 108, 024616 (2023).
J. Morrell, (2021). Next-Generation Isotope Production via Deuteron Breakup. :
[2]Lee Bernstein, Jon Batchelder, Jonathan T Morrell, Andrew Voyles. Systems and methods for producing actinium-225. WO2020210147A1. (2020)
[3]H.J. Brede *et al.,* Nucl. Intrum. Meth. A274 (1989) 332-344

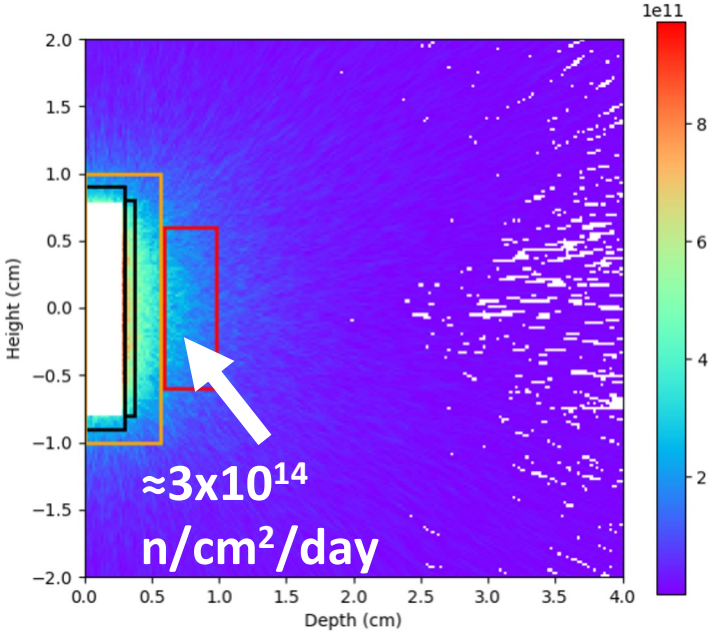
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The EnVoy 1st Generation Target Platform





200-375 µA Protons



A compact, modular target platform which connects via standard vacuum flanges to commercial cyclotrons, coupled beam diagnostics

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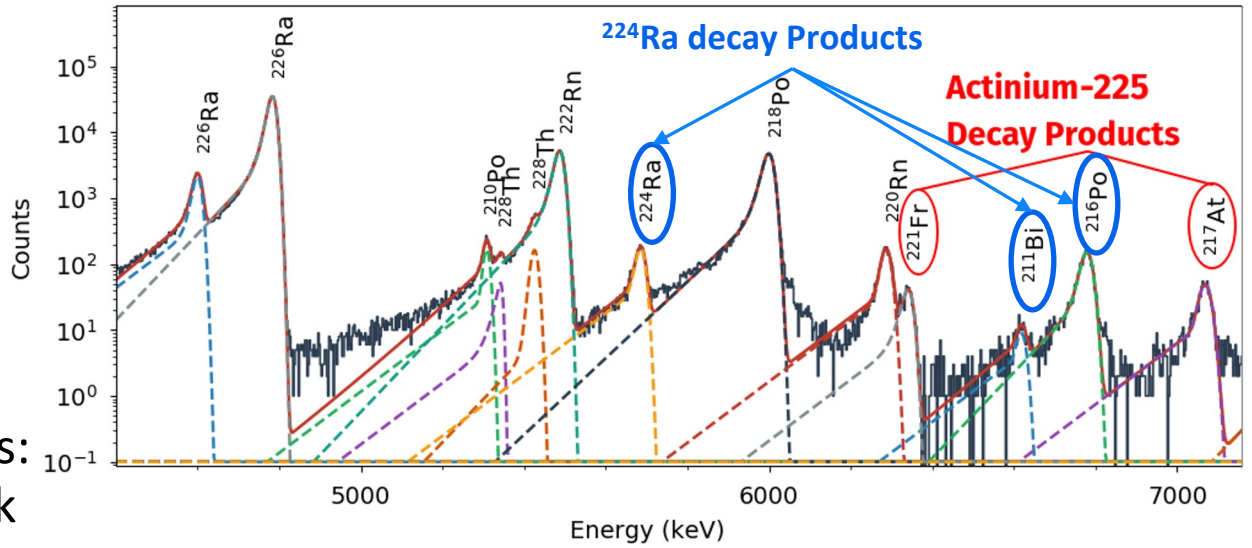
Above 19 MeV, we simultaneously make the ^{212}Pb precursor ^{224}Ra, via ^{226}Ra(n,3n)

- The same EnVoy target platform can be operated at >19 MeV beam energies to make the ^{212}Pb precursor ^{224}Ra, via ^{226}Ra(n,3n)

- Recoil of the ^{224}Ra ($t_{1/2}$= 3.6 d) daughter ^{220}Rn ($t_{1/2}$=55.6 s) allows for collection via emanation, without the need for separation chemistry

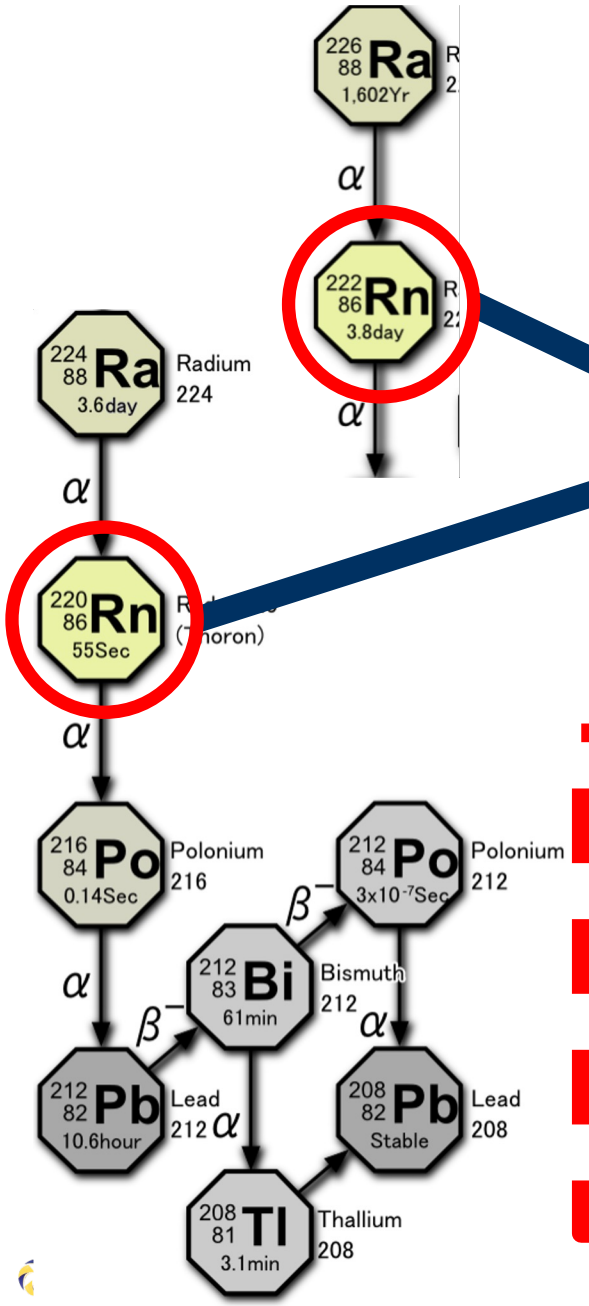
- Two Ra target options for different production modes:
  - "^{212}Pb Only" – a sealed gas loop with holdup tank for collecting ^{212}Pb, no chemistry needed, no radium handling needed after installation
  - "Hybrid ^{212}Pb/^{225}Ac" – continuous collection of ^{212}Pb during operation, and batch-mode harvest of ^{225}Ac based on user needs. Radium must be recycled prior to next irradiation cycle

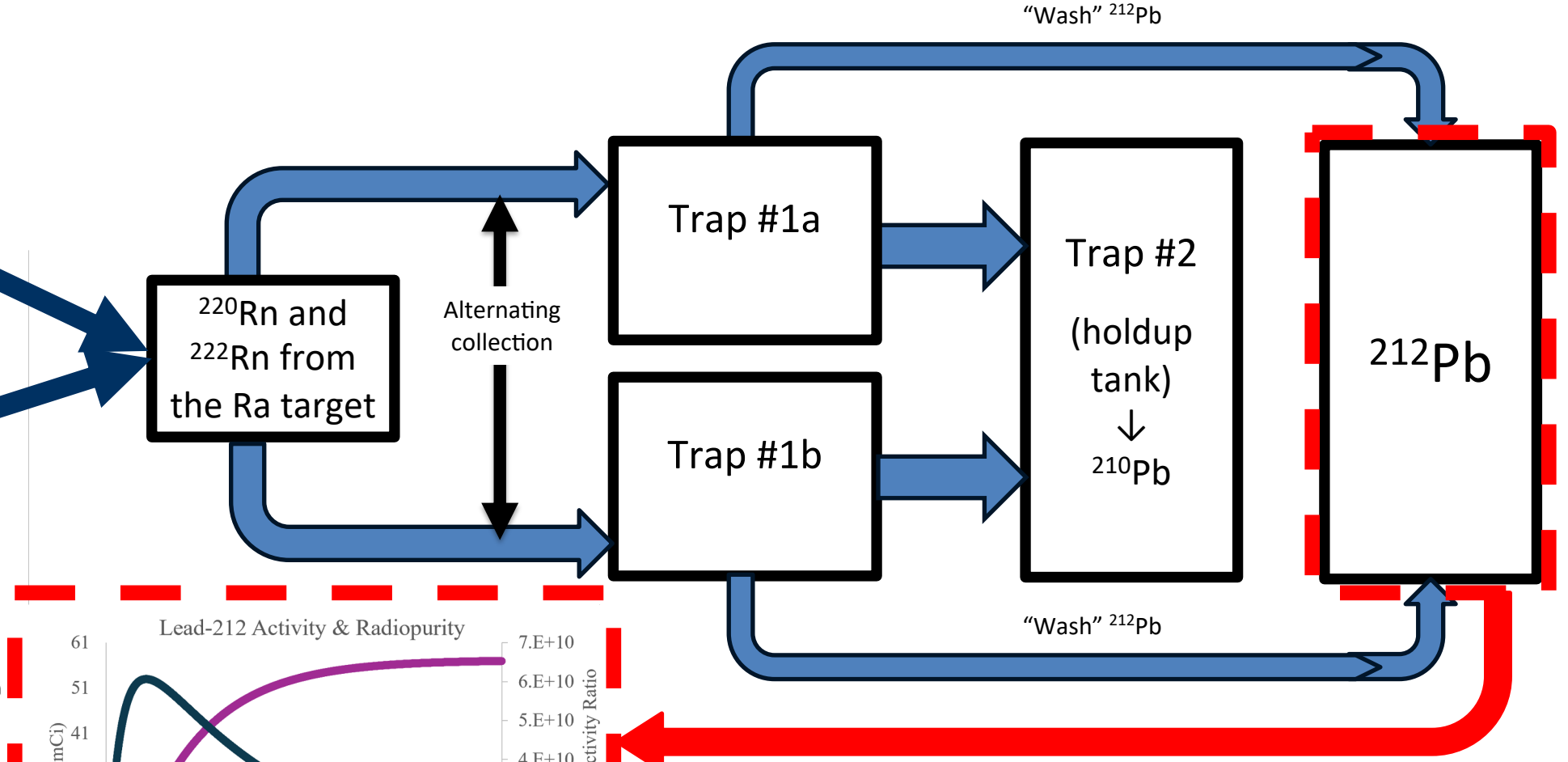
- ^{212}Pb collects continuously on a glass wool cold trap – harvesting is a simple on-demand wash with dilute HCl

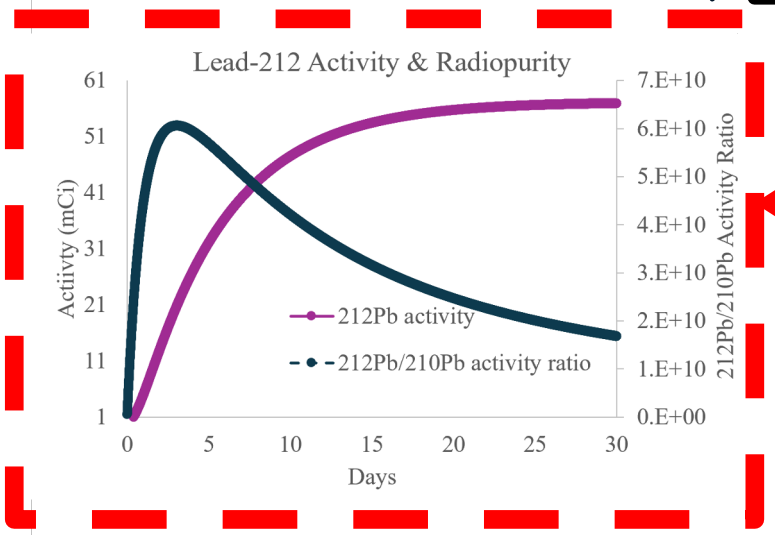


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Pure ^{212}Pb can be harvested using a two-stage gas separation approach*







Physical separations mean no chemistry or radium handling is needed after installation – **^{212}Pb on tap, with no radium losses in processing!**

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*Method for Production of the Medical Radioisotope Lead-212 US Patent # 63/873190

How Much ^{225}Ac, ^{212}Pb can Be Produced with the EnVoy Platform?

		Demonstrated (mCi)		Projected (mCi)		
		Weekly	Daily	Weekly	Daily	
Beam	**Max Current (uA)**	**Ra-225 Production***	**Pb-212 Production***	**Ra-225 Production***	**Pb-212 Production***	**Suitable Machines**
22 MeV protons @ 375 µA	385	**59 (1g ^{226}Ra)** **35 (500 mg ^{226}Ra)** **9 (100 mg ^{226}Ra)**	**58 (1g ^{226}Ra)** **34 (500 mg ^{226}Ra)** **8 (100 mg ^{226}Ra)**	260 (1g ^{226}Ra) 155 (500 mg ^{226}Ra) 40 (100 mg ^{226}Ra)	255 (1g ^{226}Ra) 150 (500 mg ^{226}Ra) 36 (100 mg ^{226}Ra)	IBA Ikon ACSI TR-Flex
19 MeV Protons @ 200 µA	446	**18 (1g ^{226}Ra)** **9 (500 mg ^{226}Ra)** **3 (100 mg ^{226}Ra)**	**5 (1g ^{226}Ra)** **3 (500 mg ^{226}Ra)** **1 (100 mg ^{226}Ra)**	80 (1g ^{226}Ra) 40 (500 mg ^{226}Ra) 13 (100 mg ^{226}Ra)	22 (1g ^{226}Ra) 13 (500 mg ^{226}Ra) 4 (100 mg ^{226}Ra)	IBA KIUBE ACSI TR-19
35 MeV Deuterons @ ***50 µA***	***1695***	**120 (1g ^{226}Ra)** **71 (500 mg ^{226}Ra)** **23 (100 mg ^{226}Ra)**	**118 (1g ^{226}Ra)** **69 (500 mg ^{226}Ra)** **20 (100 mg ^{226}Ra)**	1144 (1g ^{226}Ra) 682 (500 mg ^{226}Ra) 176 (100 mg ^{226}Ra)	1122 (1g ^{226}Ra) 660 (500 mg ^{226}Ra) 159 (100 mg ^{226}Ra)	IBA Cyclone-70 ***"Cyclone-XD"?***

Yields at 24-30 MeV are expected to be >30+% higher than 22 MeV

Recent R&D will soon increase existing yields by a factor of ~4-15

*Illustrative values, yields may vary based on machine and local configuration

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Key Platform Advantages

Compatible with widely installed machines

Use standard cyclotrons widely used in nuclear medicine facilities

Two target configurations available, both keeping radon completely sealed

Hermetically-sealed ^{225}Ac-only, or sealed-loop ^{225}Ac+^{212}Pb

Multiple ^{225}Ac separations per irradiation plus continuous ^{212}Pb separations

The two most promising α-emitters produced *simultaneously*

High efficiency of radium, with safe, scalable solid targets

Yields scale better than linearly with radium mass, and EnVoy works with you to optimize a target for your facility

Modular target platform

User-serviceable modular target to change beam energy based on ^{225}Ac/^{212}Pb needs

Integrate into existing production processes and programs

An EnVoy target station can operate simultaneously to other beamlines, or independently

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