Fusion Generation of Therapeutic Radionuclides

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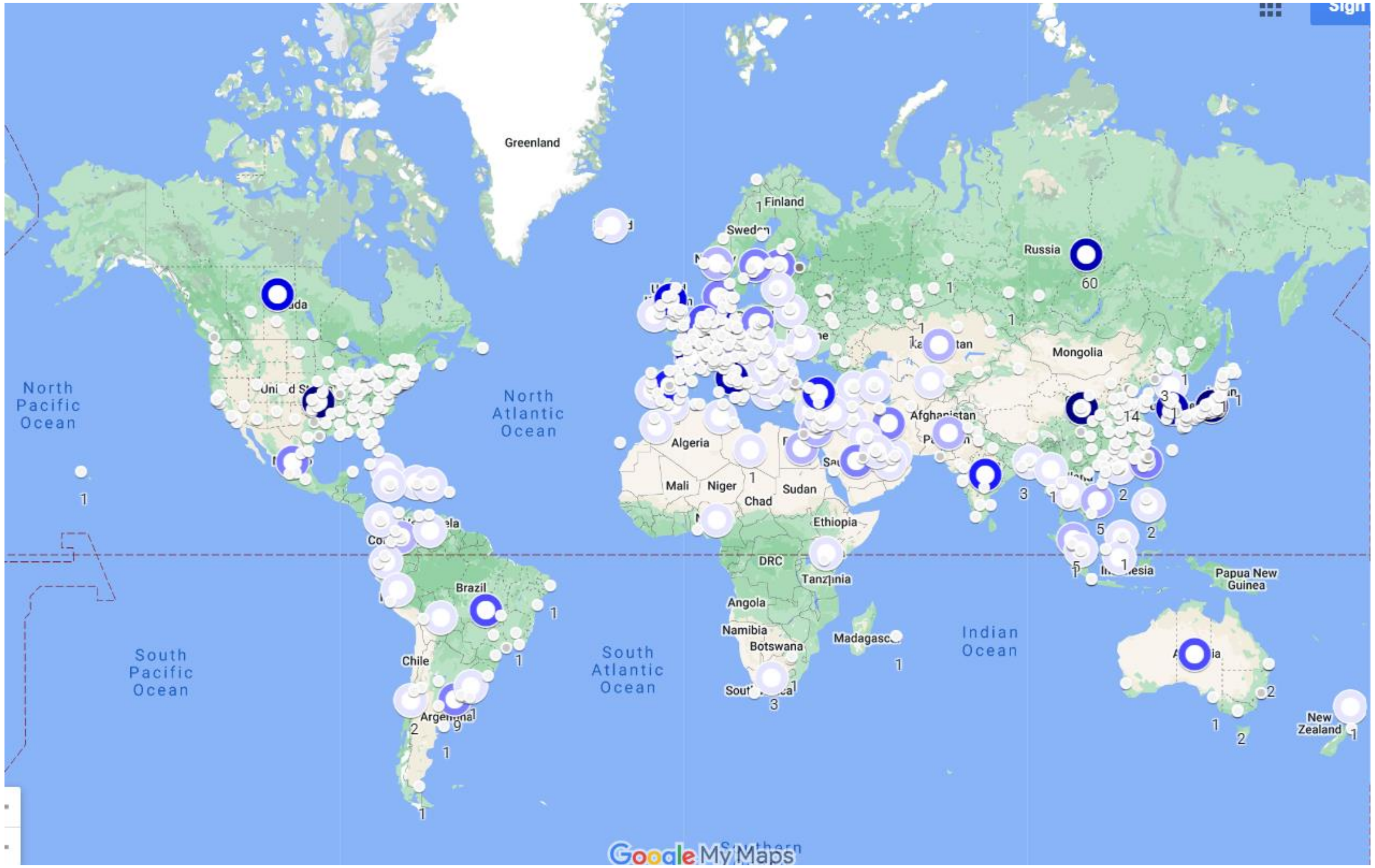
Worldwide cyclotron locations



https://nucleus.iaea.org/sites/accelerators/Pages/Cyclotron.aspx

Half-life of diagnostics

- The prevalence of cyclotrons around the world and proximity to imaging centres allows short lived isotopes
- It is important to match the half- life of the isotope with the half-life of the tracer molecule

Isotope	Half-life
O-15	2.03 min
N-13	10 min
C-11	20.3 min
Ga-68	68 min
F-18	109 min
Cu-64	12.7 h
Zr-89	78.4 h

Half-life of therapeutics

- By contrast therapeutic isotopes typically have much longer half-lives
- Some cyclotron and generator produced isotopes have shorter half-lives

Isotope	Half-life
At-211	7.2 hours
Pb-212	10.6 hours
Cu- 67	2.6 days
Tb-161	7 days
Lu-177	7 days
I-131	8 days
Ac-225	10 days

Location of medical isotope producing fusion reactors

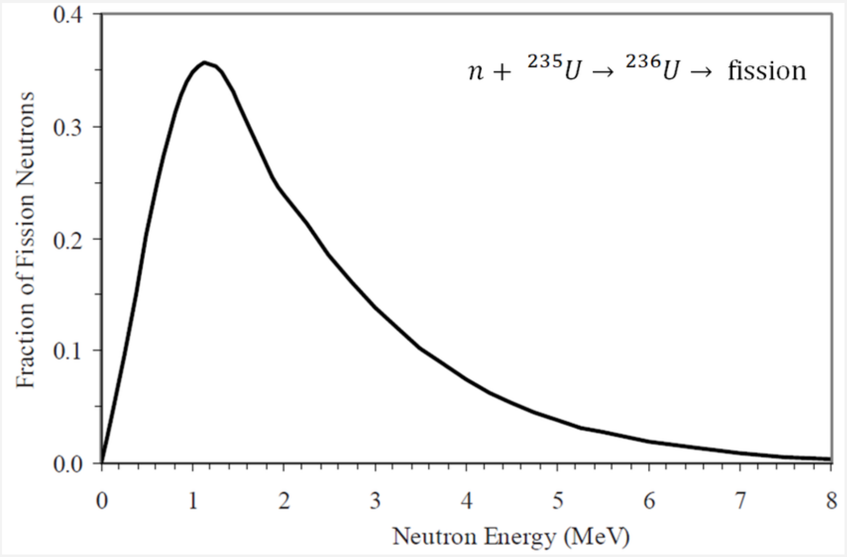
- Reactors sparsely spread across the world
- Non- comprehensive list
- Many scheduled for decommissioning
- 85% of medical isotopes are produced in 6 reactors

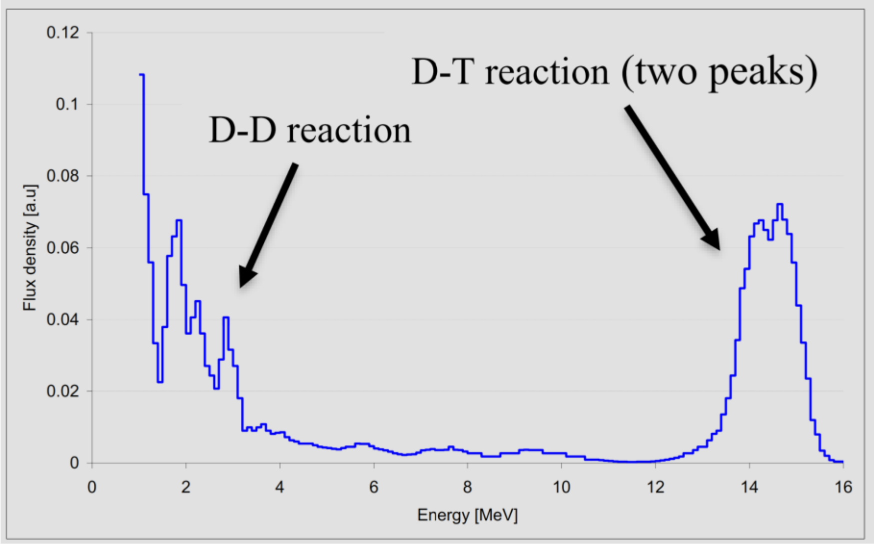
Paradigm shift in production of therapeutic isotopes

- Our goal is to enable local production of neutron produced isotopes in the way that cyclotron have done for proton produced isotopes
- Small modular reactors which are low cost and low risk
- We can fit them into facilities with existing radiochemistry capability
- Ultimately, we hope that this technology will phase out fission produced isotopes

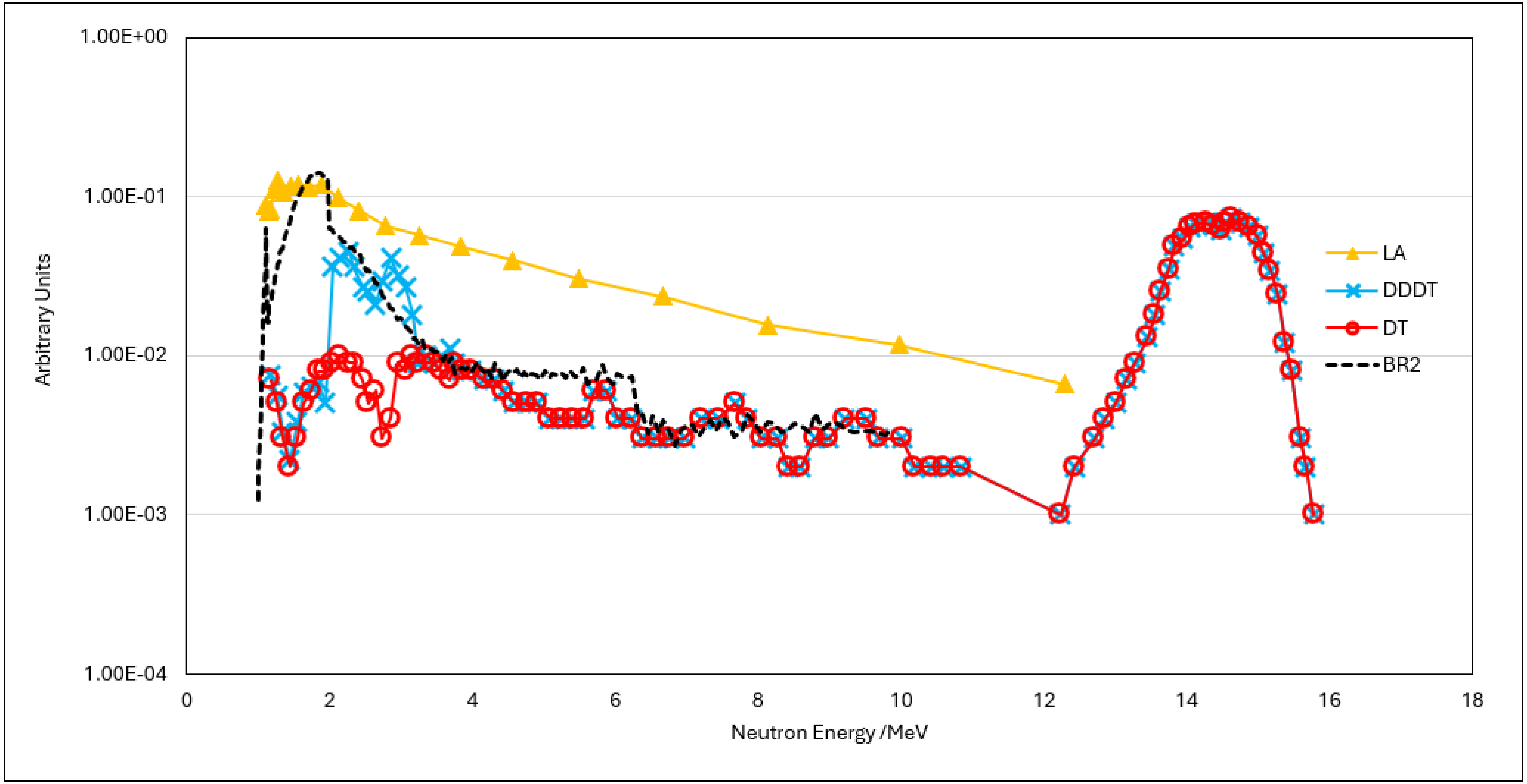
Energy of Fission vs fusion neutrons

- While we are able to produce isotopes in our fusion reactor typically produced in a fission reactor there are differences
  - Some obvious, others less obvious
  - A key difference is neutron energy output



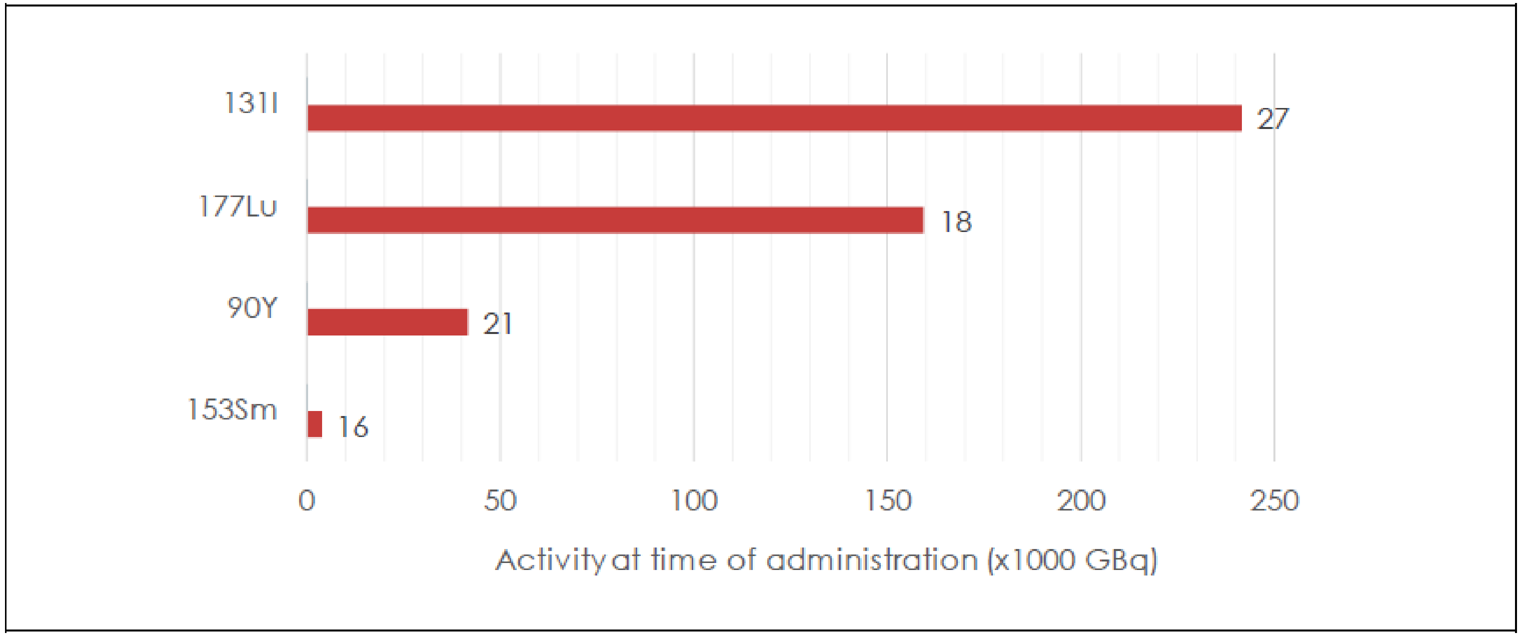


Energy of Fission vs fusion neutrons



Iodine – 131 demand

- Despite the more recent popularity of Lu-177 and other alpha emitting isotopes I-131 is still the most used therapeutic isotope



https://publications.jrc.ec.europa.eu/repository/handle/JRC124565

Iodine-131 Supply Chain

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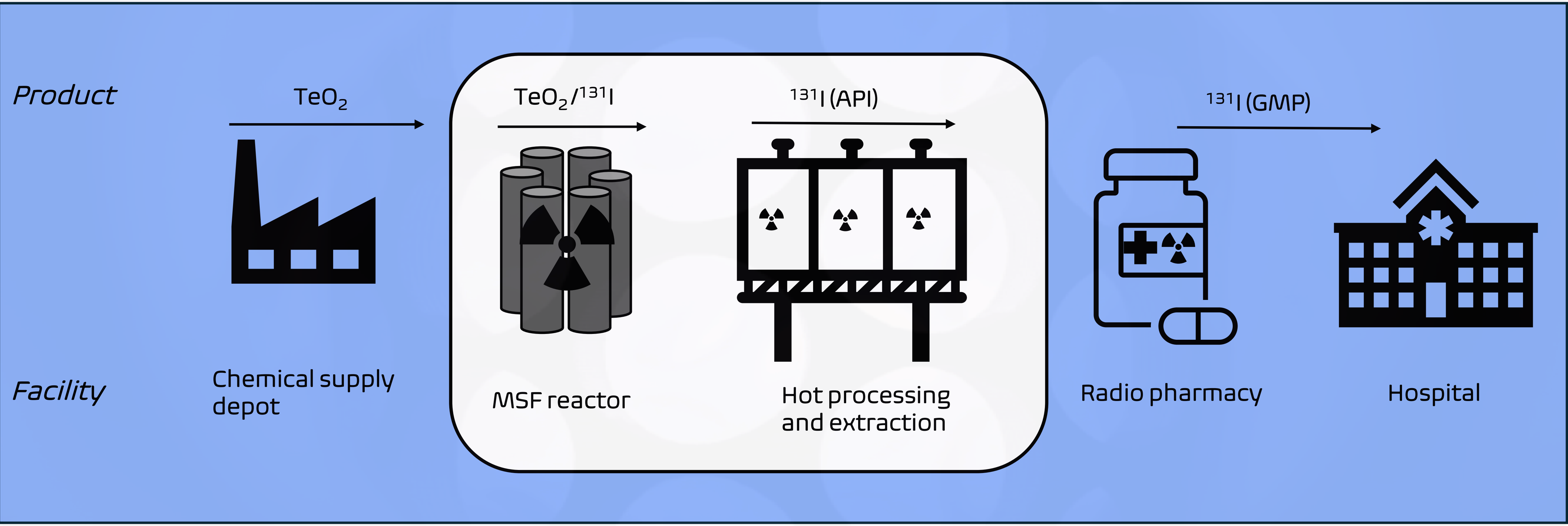

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Iodine production

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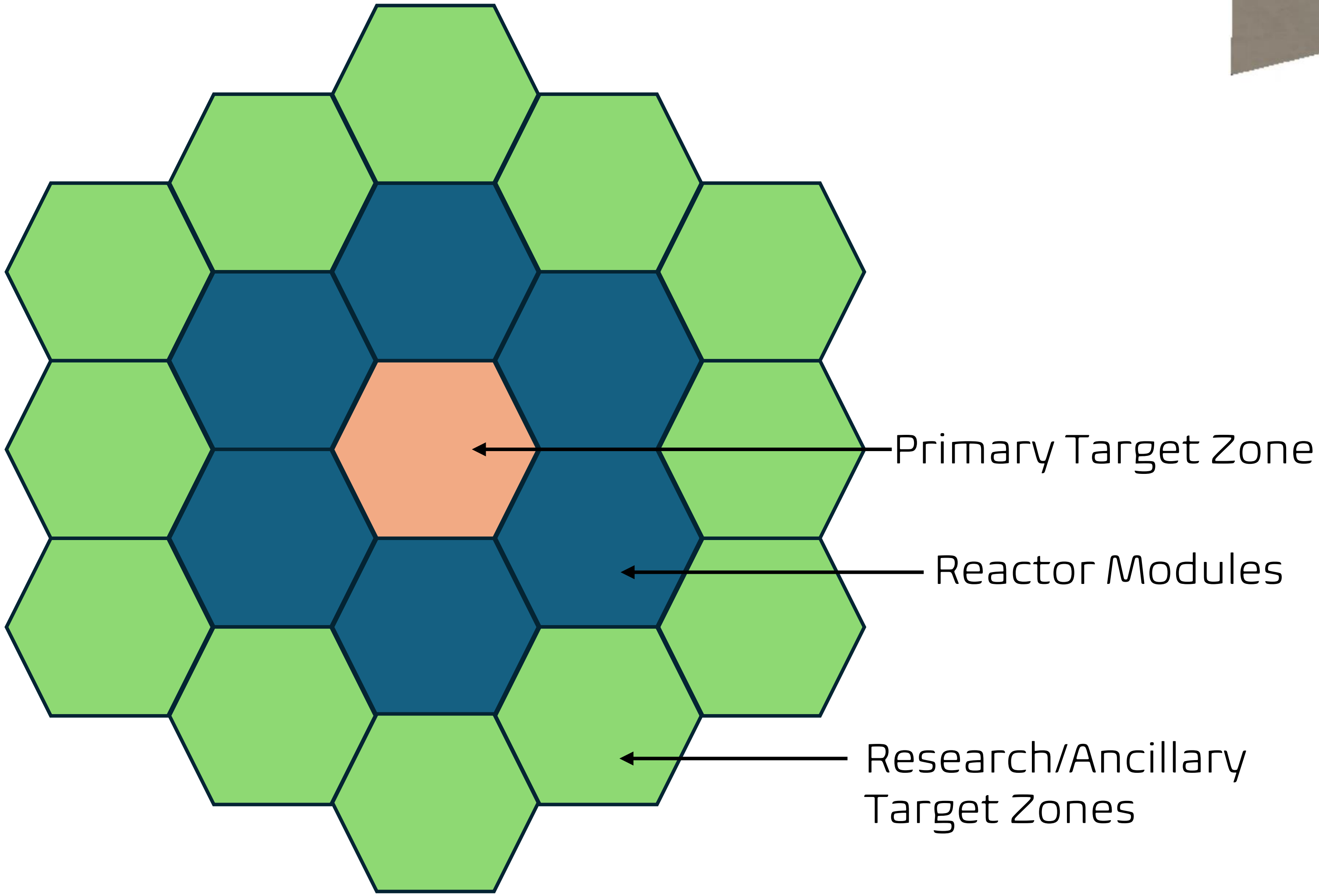
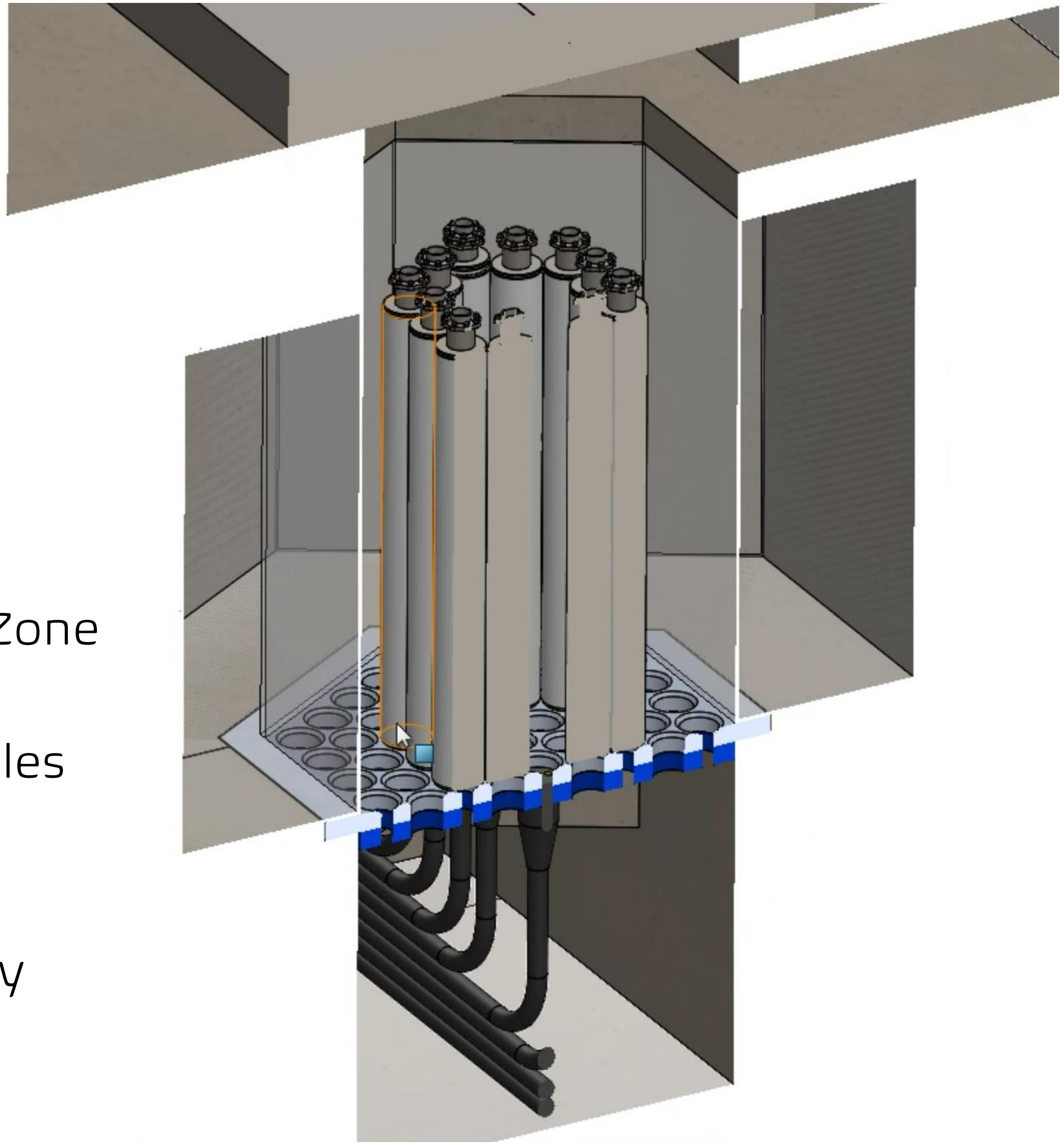
- Iodine is produced through the bombardment of TeO_2
  - Te-130(n,γ)Te-131
    - Te-131 ($t_{1/2}$ 25 min)
  - Te-131 $\xrightarrow{\beta-}$ I-131
  - Due to the mixture of Te isotopes in the target material other short lived Iodine isotopes are also produced. Storage for 3-4 days allows these to decay away

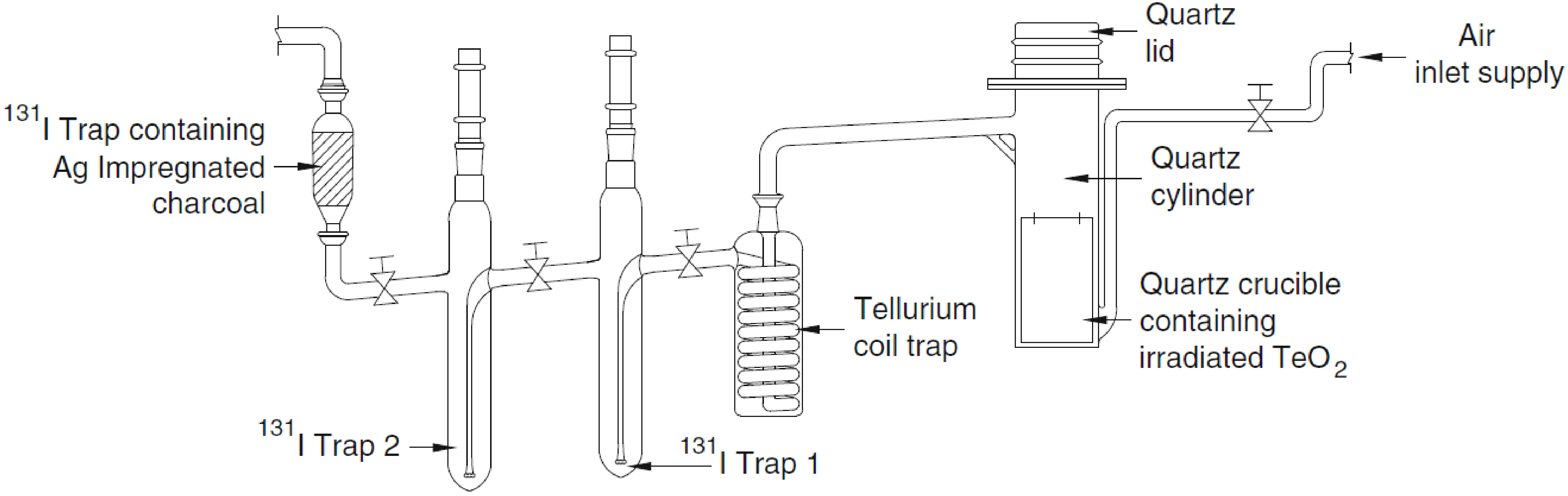
Array design





Iodine – 131 extraction

- Iodine is separated from tellurium oxide target material through dry distillation



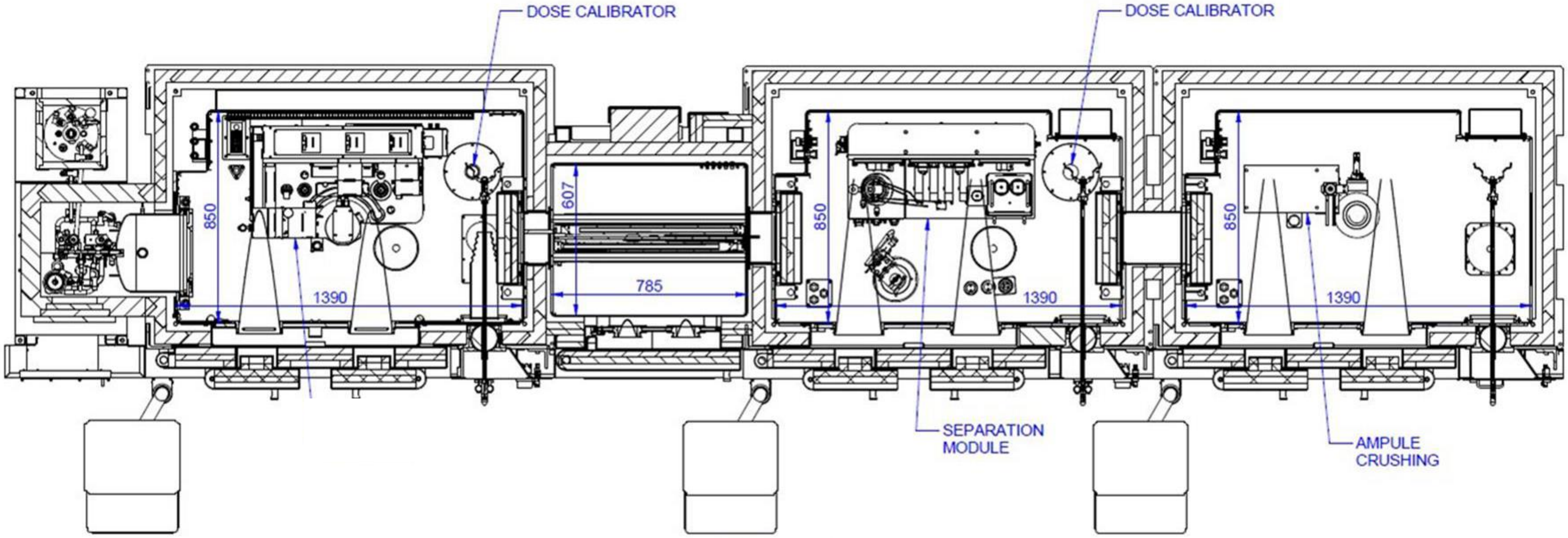
Ambad, 2014, *J. Radioanal. Nucl. Chem.*

Hot cell set up

Dispensing

Processing

Receiving



Process

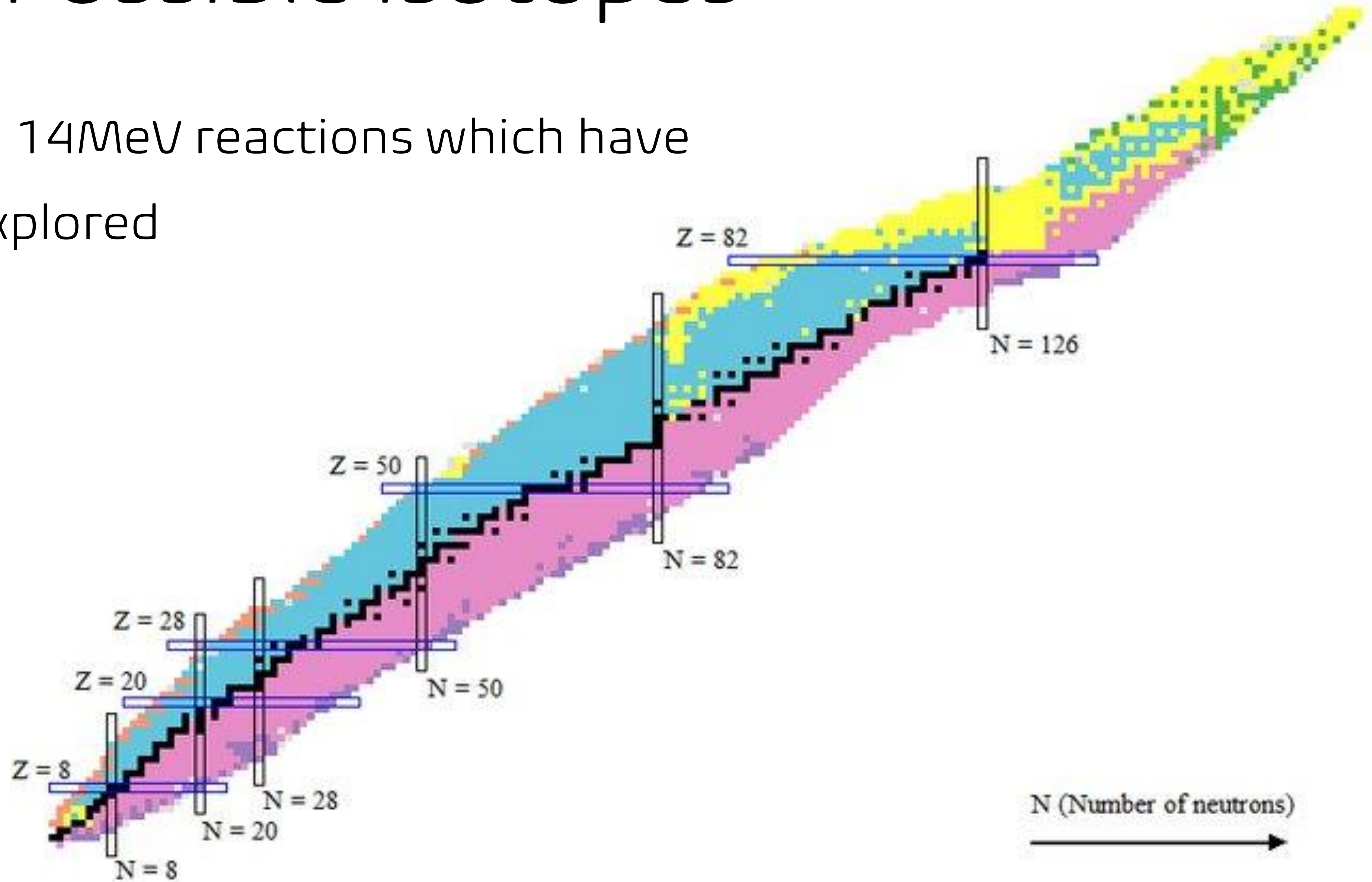
Production Rates

- Radioisotope production numbers are the calculated activity through Monte Carlo simulations.
- Required footprint includes shielding and ancillary systems.
- Irradiation period equal to twice the half-life of the radionuclide.
- Using a 15L target volume of TeO_2 for I-131

System	DT NPR(ns^{-1})	Flux $(nsm^{-2}s)^{-1}$	Delivery year	Required Footprint (m^2)	I-131/2$t^{1/2}$ (16 days)
Mark 1	1e11	1e9	2024	40	3.5 GBq (100mCi)
Mark 2	1e12	1e10	2025	40	35 GBq (1Ci)
Mark 2 - Array	~5e13	~4e11	2027	200	~1 TBq (27Ci)

Other Possible Isotopes

- Threshold 14MeV reactions which have not been explored
- n,2n
- n,3n
- n,p
- n,α
- n, γ



Potential Existing Isotopes

- Sc-44
- Sc-47
- Va-48
- Cr-51
- Cu-64
- Cu-67
- Br-77
- Sr-89
- Y-90
- Ag-111

- I-123
- I-124
- Sm-153
- Tb-161
- Lu-177
- Re-186
- Re-188
- Au-199
- Pb-212
- Ac-225

- Isotopes here have been used in published nuclear medicine research, from animal models through to approved drugs
- Those in Green are of greatest interest to us
- Blue are high priority but require active target material

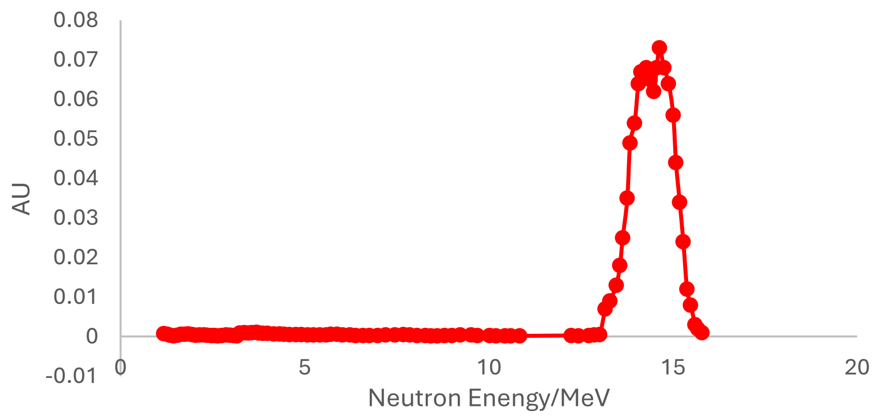
Ac-225 and Pb-212

- Production of Ac-225 from Ra-226
  - Ra-226 (n,2n) Ra-225
  - Ra-225 ->$^{(t1/2\ 15\ days)}$ Ac-225
- Production of Pb-212 from Ra-226
  - Ra-226 (n,3n) Ra-224
  - Ra-224 ->$^{(t1/2\ 3.6\ days)}$ Rn-220 ->$^{(t1/2\ 55\ s)}$ Po-216 ->$^{(t1/2\ 145\ ms)}$ Pb-212

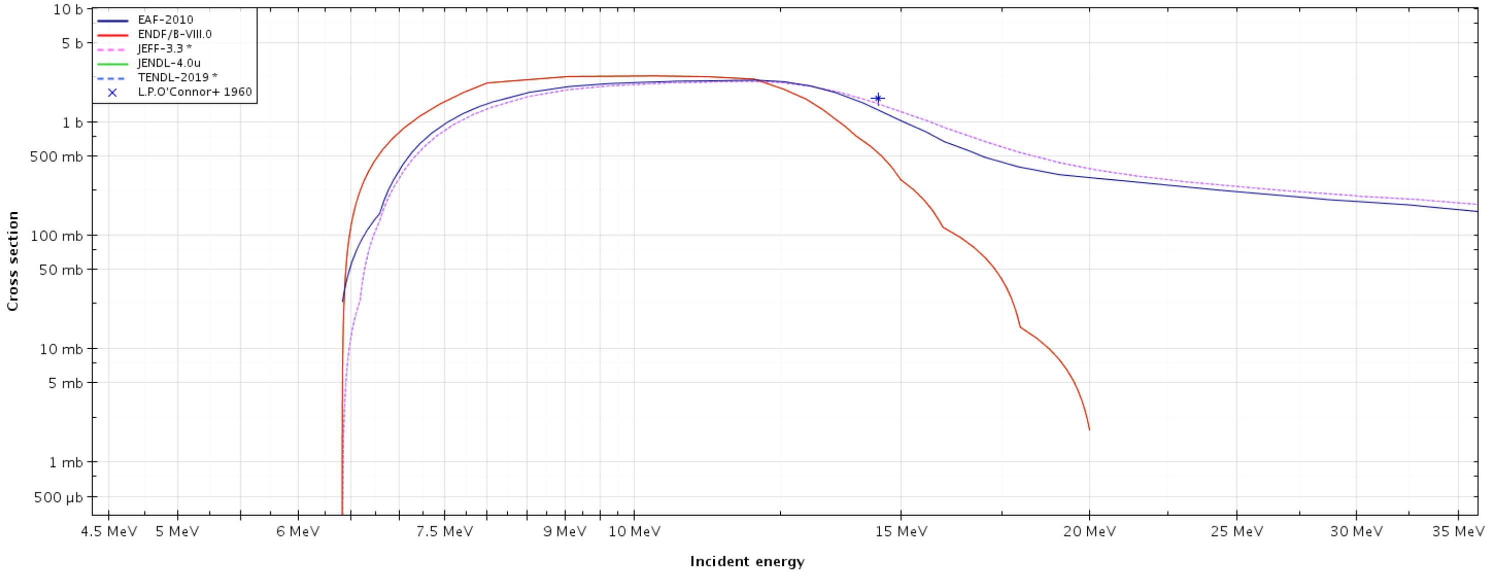
Patent filed on production of Ac-225 and Pb-212 using fusion neutrons

Key cross sections

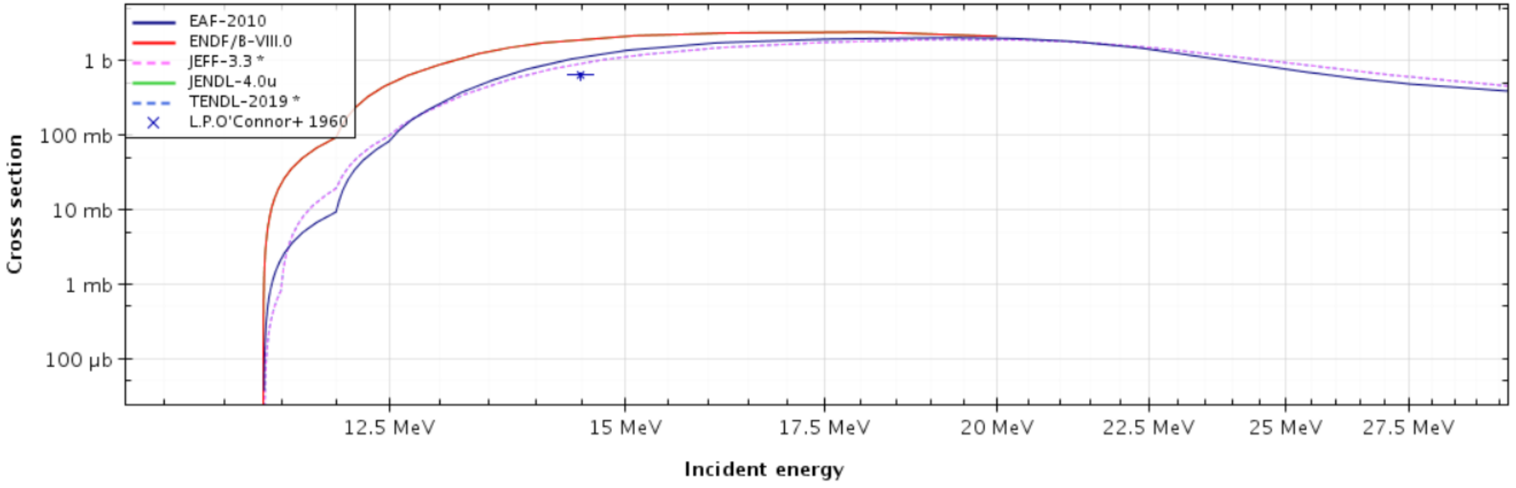
DT



Ra226 (n,2n) or Ra225 production



Ra226 (n,3n) or Ra224 production



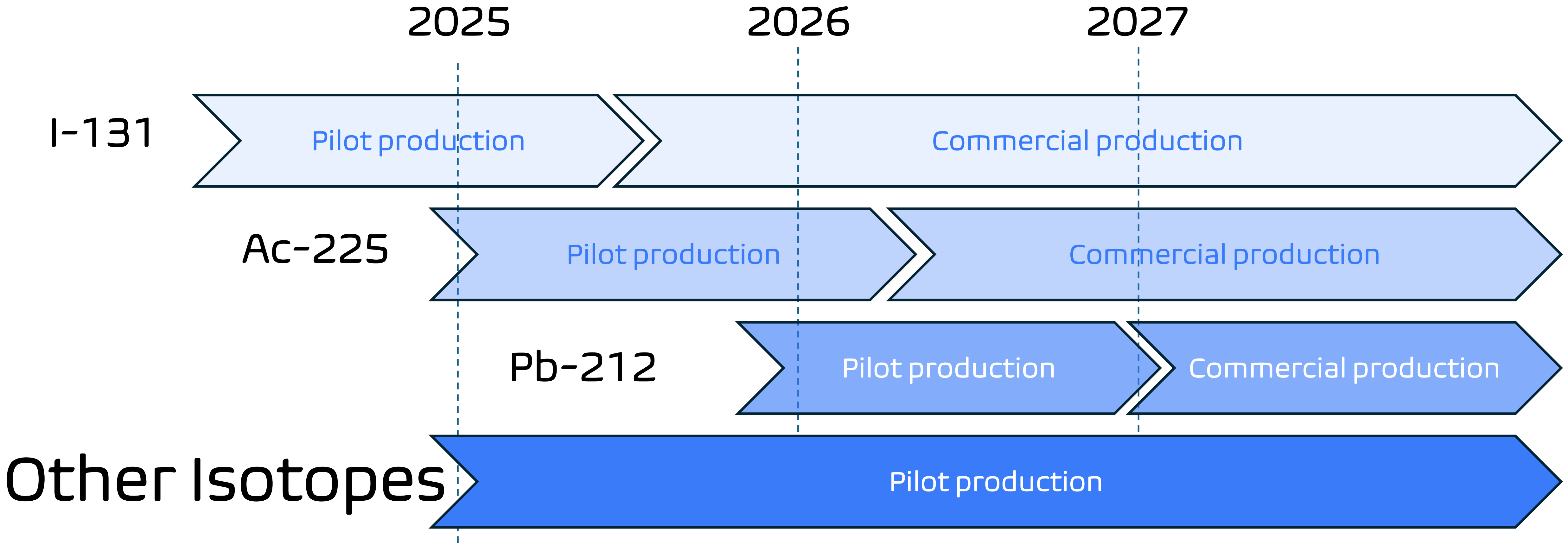
Production rates

System	DT NPR (ns^{-1})	Flux ($(nsm^{-2}s)^{-1}$)	Ac-225 (MBq/month, (mCi/month))	Ac-225 (GBq/Yr, (Ci/Yr))	Pb-212 (MBq/month, (mCi/month))	Pb-212 (GBq/Yr, (Ci/Yr))
Mark 1	1e11	1e9	164 (4.4)	1.97 (0.05)	762 (20.6)	9.1 (0.25)
Mark 2	1e12	1e10	1,640 (44.3)	19.68 (0.5)	7,620 (205.9)	91.4 (2.5)
Mark 3	1e13	1e11	16,400 (443.2)	196.8 (5)	76,200 (2059.5)	914.4 (25)

Pb-212 activities already account for a 1/10 reduction due to processing time in the Ci/yr numbers

Target for both is 24.75 grams, Ac-225 is 1mm thick and looped once around the chamber, Pb-212 is 5mm thick and is 9cm2 (so 20% of a full loop)

Isotope Production Pipeline



Research Collaboration Projects

- **Novel Isotope Production**
  - Exploring therapeutic isotopes not previously explored.
- **Isotope Purification**
  - Purification and isolation of fusion produced isotopes.

**Co-Founder Tom Wallace Smith visiting Kings College University Hospital London.*

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Thank You!

Any Questions?