Development of Terbium Fluoride Beams for Medical Applications

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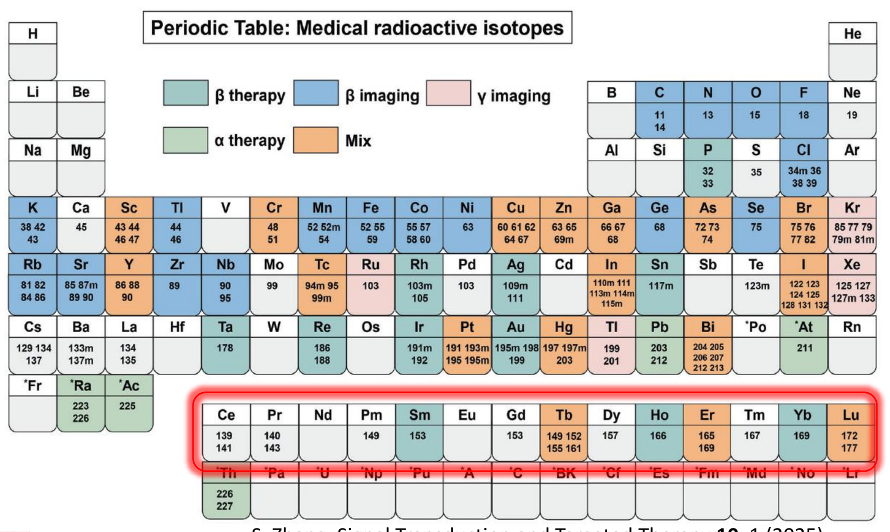
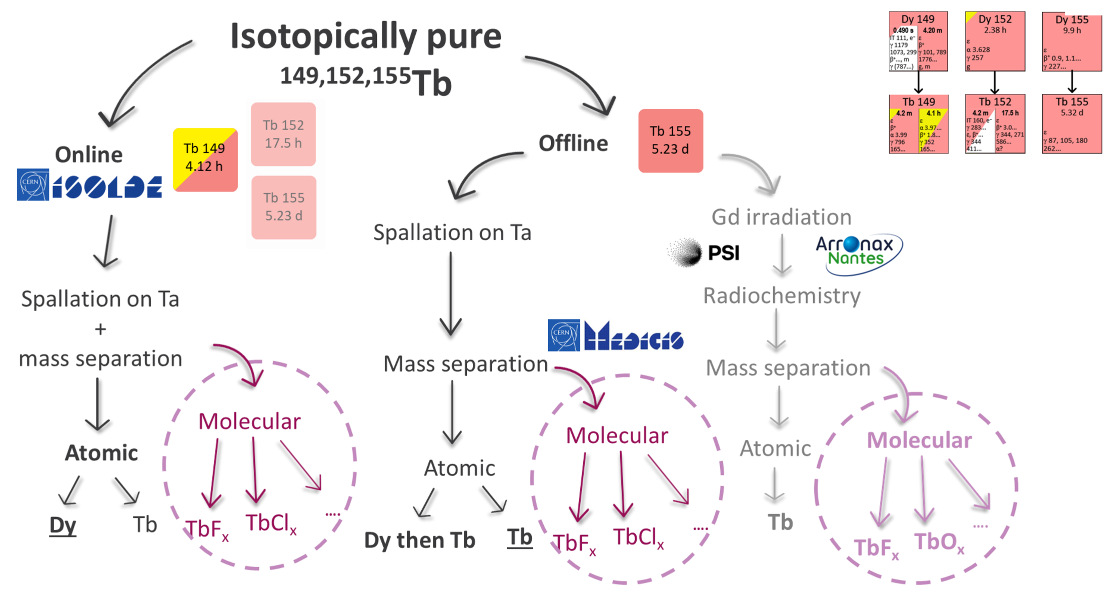
Terbium quadruplet

^{149}Tb, ^{152}Tb, ^{155}Tb and ^{161}Tb, show particular promise for molecular imagining and targeted cancer therapies, enabling a true theragnostic approach [1]. This includes the attractive but hard to access α-emitter ^{149}Tb.



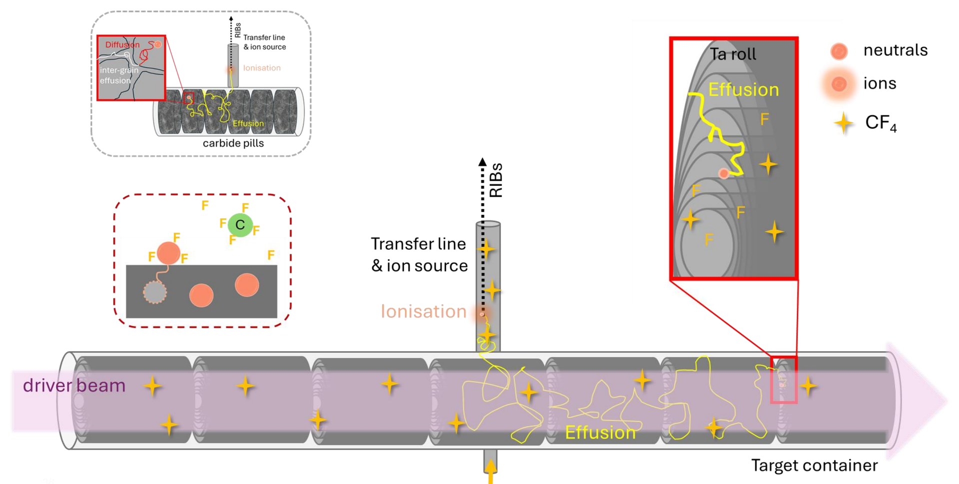
S. Zhang, Signal Transduction and Targeted Therapy **10**, 1 (2025)



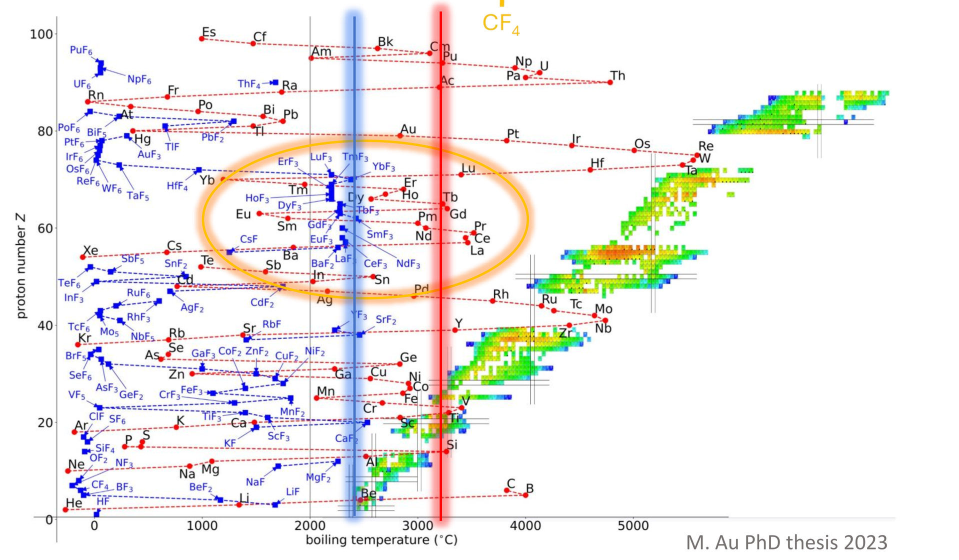
With the exception of reactor-produced ^{161}Tb, large-scale production of radioisotopically pure Tb isotopes remains challenging, and current methods cannot yet sustain the needs of preclinical research [2].

Isotope Separation Online (ISOL)

Direct extraction of Tb from Ta targets is hindered by its low volatility and strong chemical interaction with the target material.



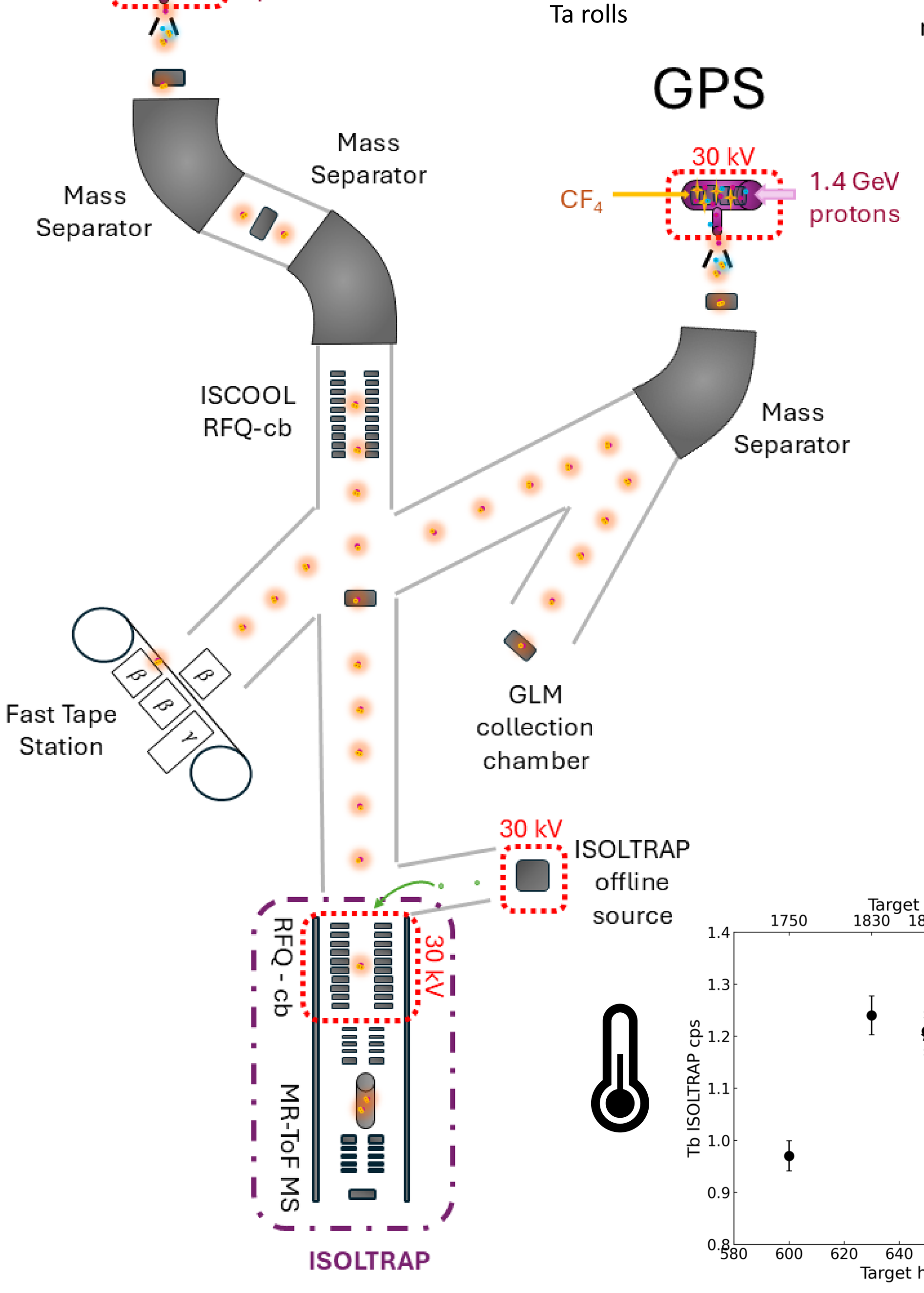
This work explores molecular extraction as a strategy to enhance Tb volatility and improve release.

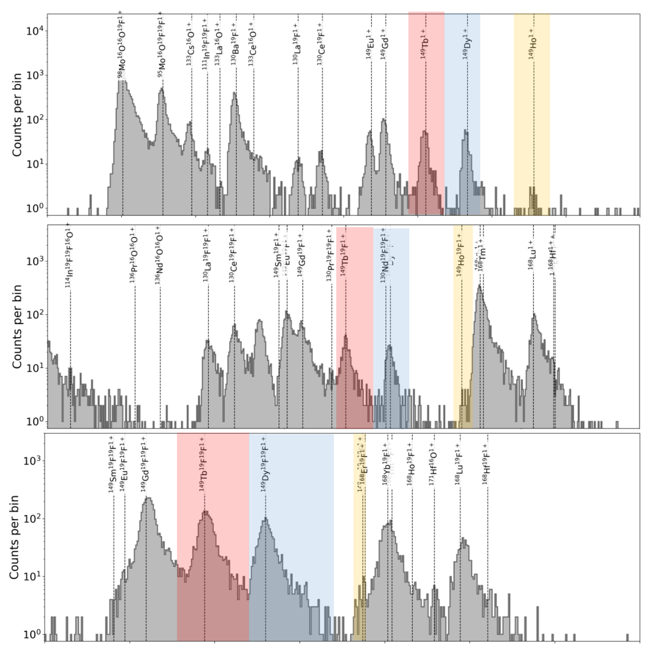


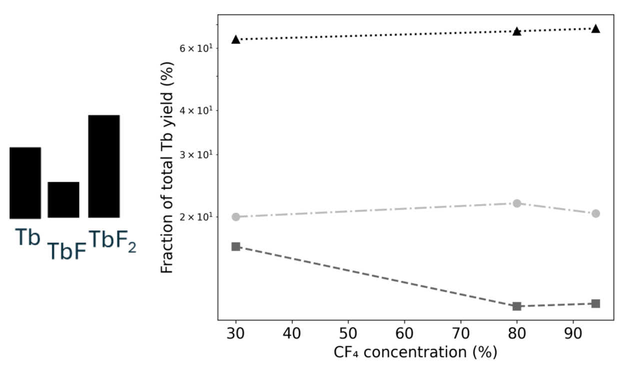
Target and Ion Source Development

Online development campaign @ ISOLDE

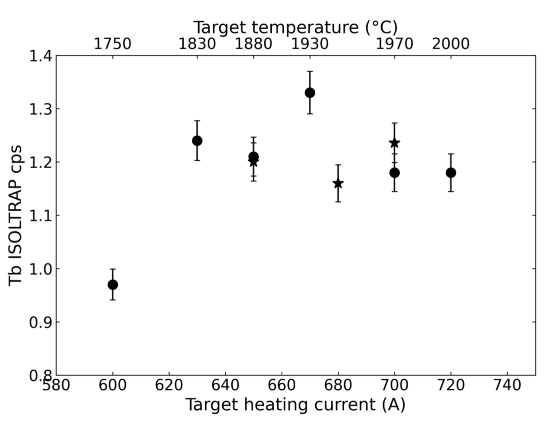
Ion beam composition was studied as a function of target, ion source, and gas injection conditions to optimise the delivery of Tb beams.



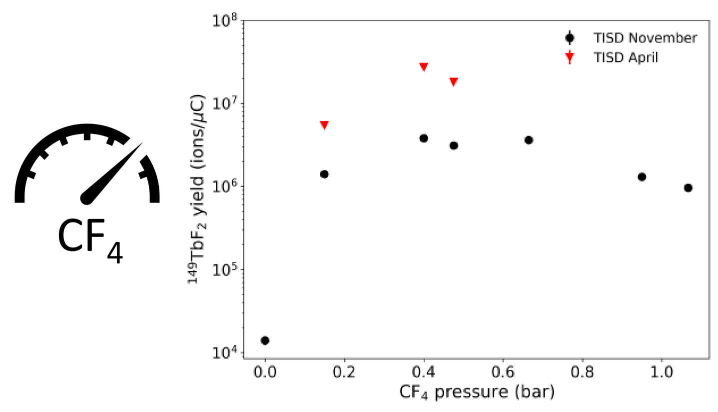




TbF$_2$ strongest
(& cleanest) sideband



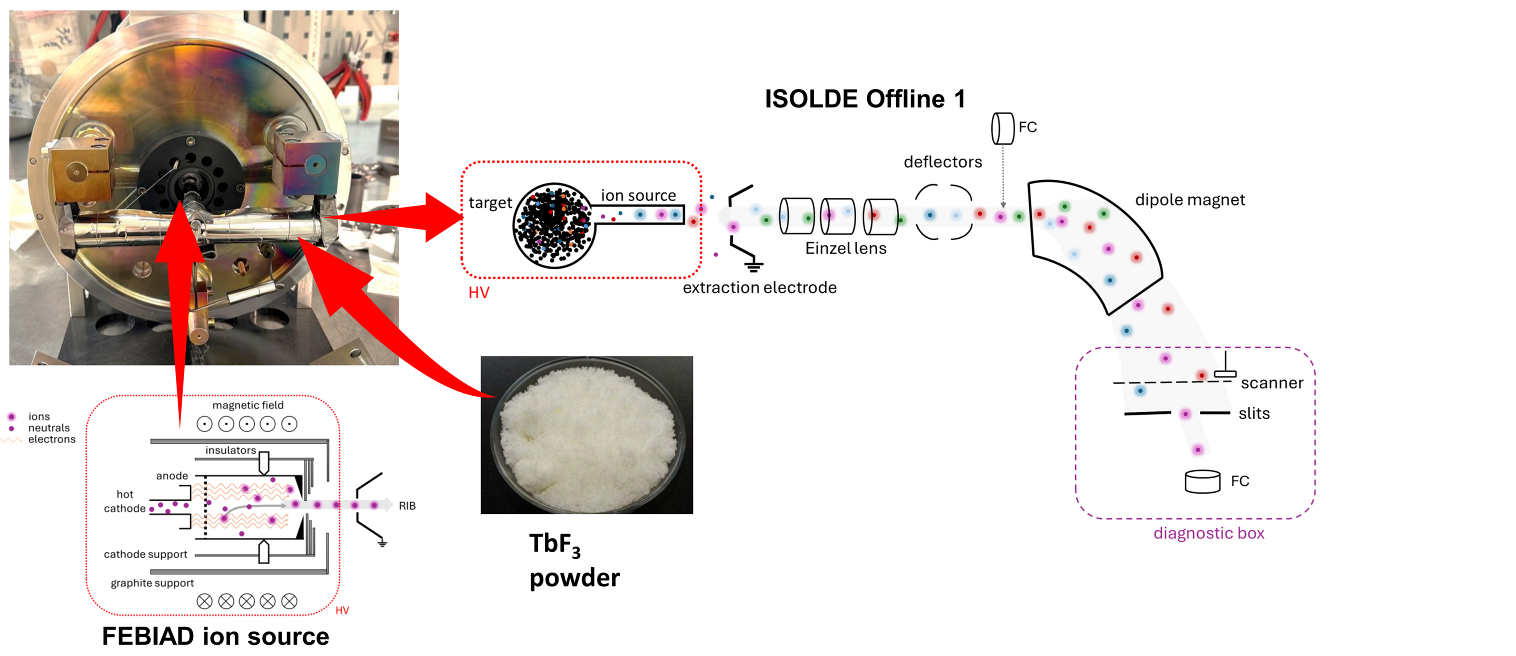
Tb beam <1900°C
Dependence on fluorine concentration

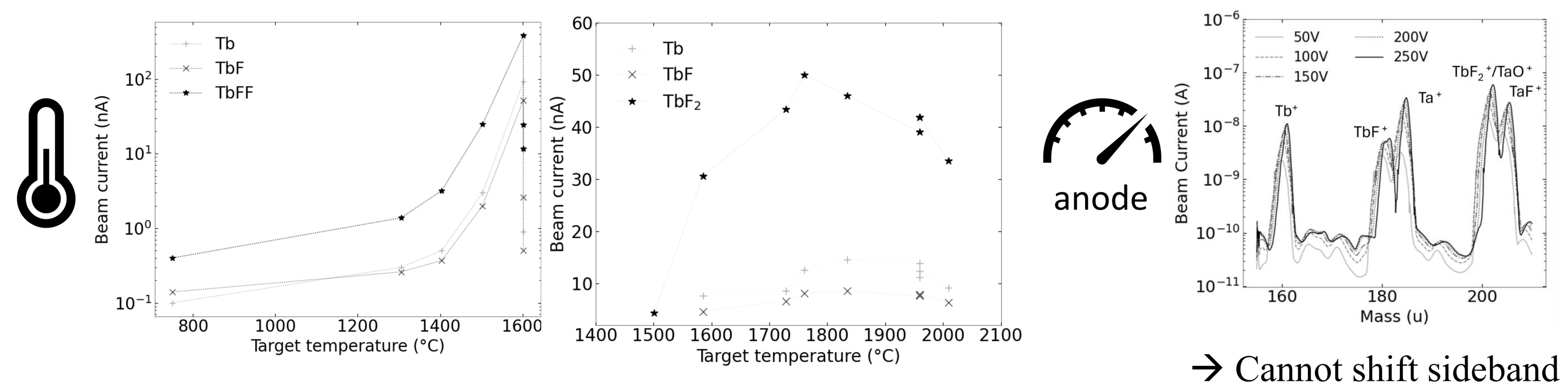


Existence of optimal fluorine concentration

Offline tests with stable compounds

Offline development with stable compounds allowed for exploration of the stability of the molecule and its behavior in the ISOL-like conditions.



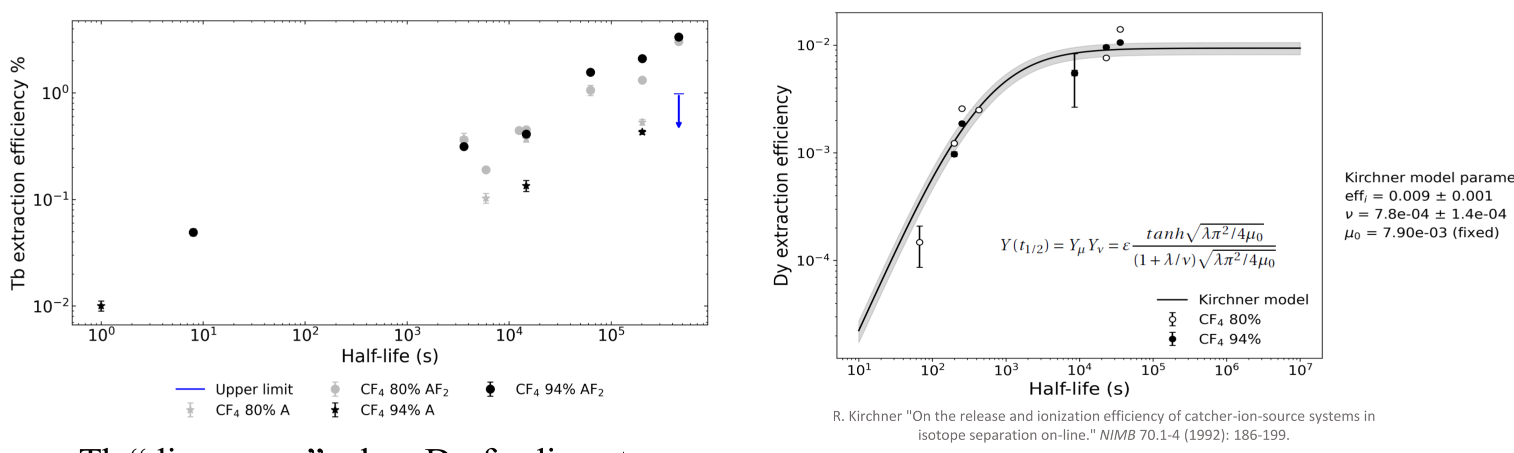


→Already observed <1500°C

→ Appearance temp. depends on oxygen content and CF$_4$ saturation

→ Cannot shift sideband distribution

Extraction efficiencies



Tb "disappears" when Dy feeding stops
Highest efficiency 3.5% for ^{155}Tb
No ^{156}Tb observed

Highest efficiency 1.4% for ^{155}Dy
Shape indicates effusion limit

What is limiting the release?

Production limit or effusion limit

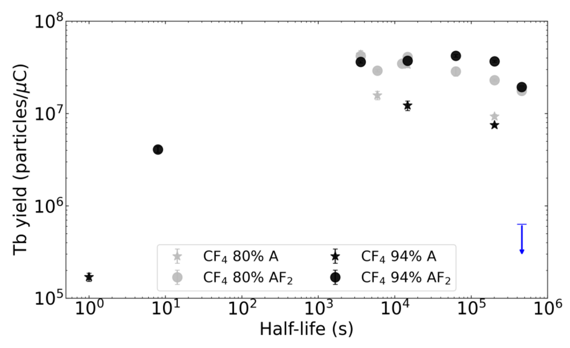
- No ^{156}Tb observed
- No n-rich Tb observed
- No stable or long-lived Tb observed when there is no feeding from Dy

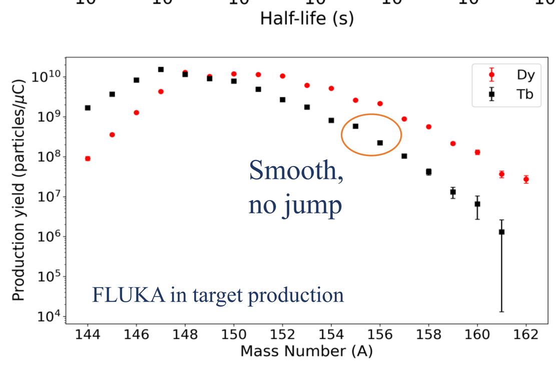
Effusion limit

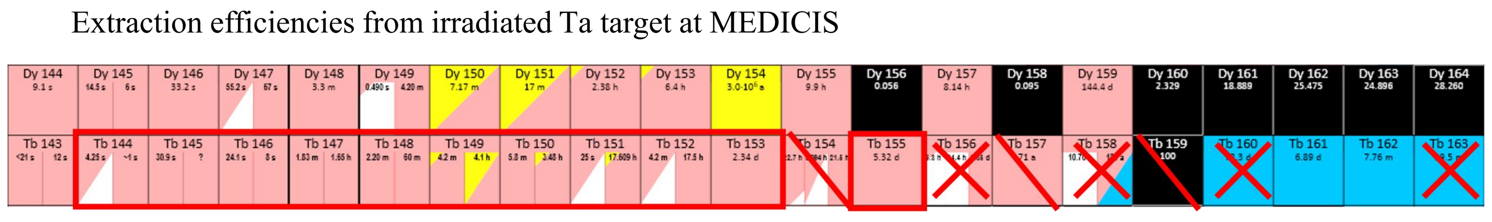
- Offline extraction:
  ^{149}TbF$_2$ efficiency: 0.0005(1)%
  ^{155}TbF$_2$ efficiency: 0.11(3)%

Isotope	Sideband	A/q	$A_{in-target}$ [MBq]	A_{foil} [MBq]	$A_{collimator}$ [MBq]	Efficiency %
Gd-149	GdF$_2$	187	748 (11)	1.27 (7)	5.45 (2)	0.17 (1)
Tb-149	TbF$_2$	187	3090 (90)	0.015 (3)	0.045 (6)	0.0005 (1)
Tb-155	TbF$_2$	193	1130 (20)	1.25 (4)	–	0.11 (3)

Extraction efficiencies from irradiated Ta target at MEDICIS





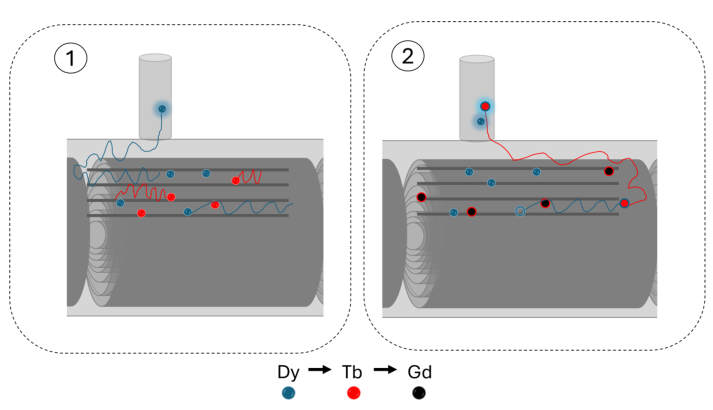


Positive ID   Negative ID   Unable to ID

Effusion limit

- Tb produced in the foil is not released
- Tb we see is the decay product of Dy
  → Dy completed part of the pathway

Proposed mechanism:
Dy assisted release



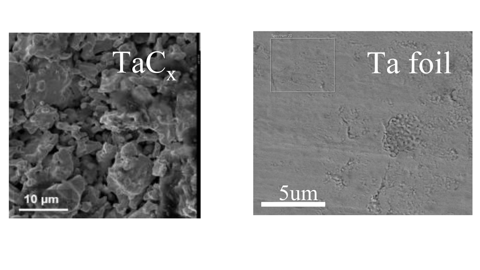
>> 60 000 collisions in a Ta target
Tb 0.03s sticking time at 2400°C for Ta*
→ average delay on the order of **hours**
(Dy ~0.0003s sticking time – 100x faster)

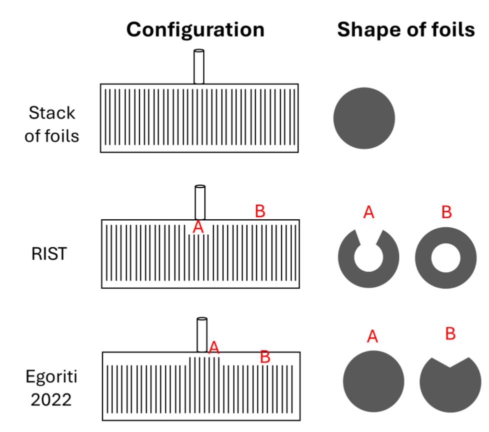
*lower limit! Estimated through Eichler systematics. U. Köster PhD thesis 2000

What's next?

We need to rethink the target itself

- New materials – TaC? Others?
- New geometries





We need to redefine what is needed for medical production

"standard" ISOL	medical mass separation
Efficiency	Efficiency
Rapidity	~~Rapidity~~
Selectivity	Selectivity
Versatility	~~Versatility~~
	Scalability

[1] Müller C., et al. (2012) "A unique matched quadruplet of terbium radioisotopes for PET and SPECT and for α-and β-radionuclide therapy." Journal of Nuc. Med. 53.12: 1951-1959.
[2] Moiseeva, A. N., et al. (2024) "Terbium sisters: current development status and upscaling opportunities." Frontiers in Nuclear Medicine 4 (2024): 1472500.