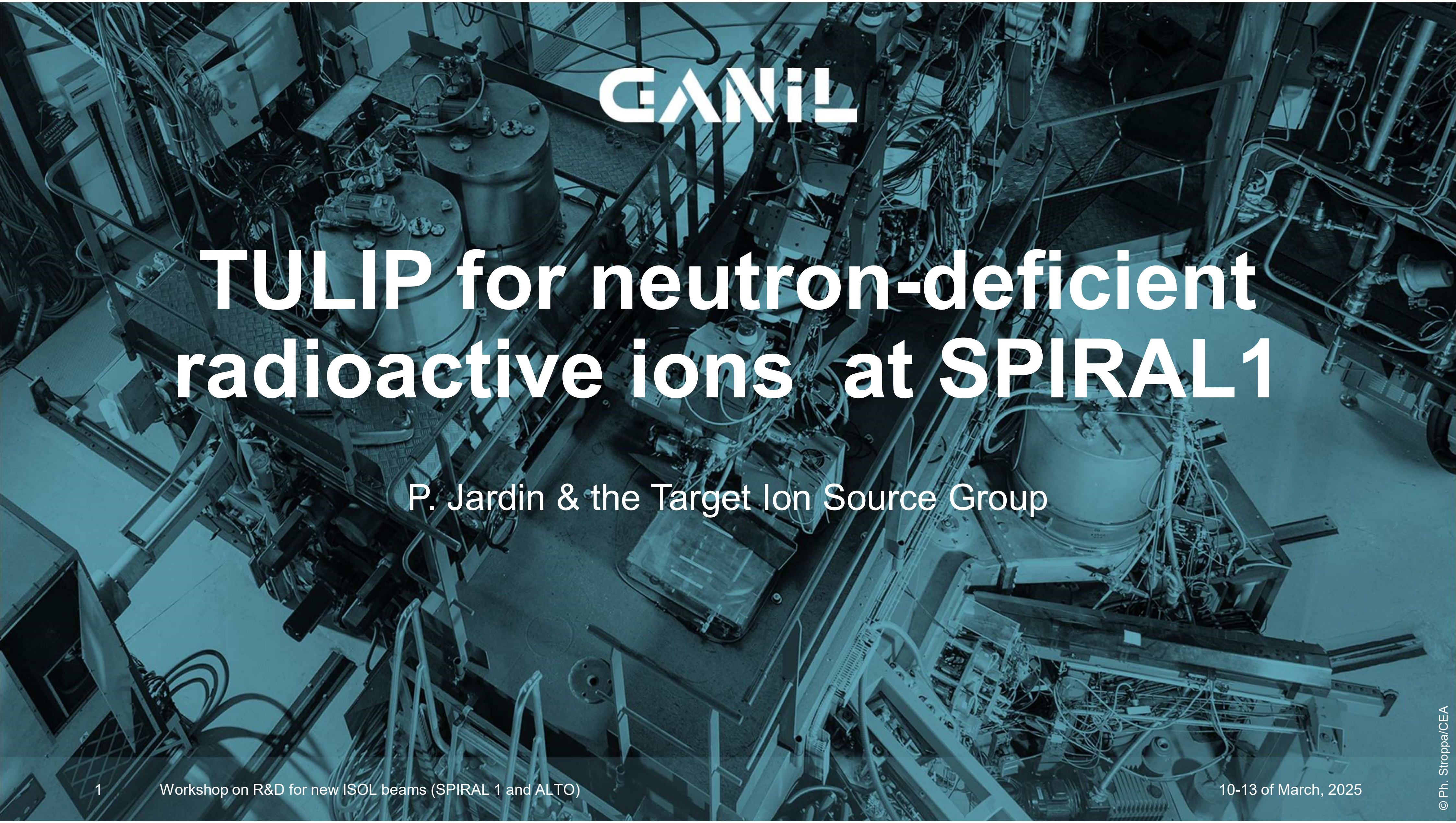
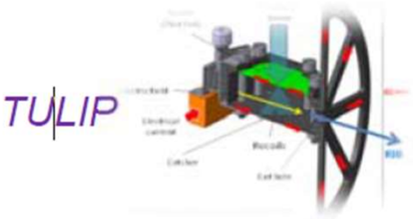


TULIP for neutron-deficient radioactive ions at SPIRAL1

P. Jardin & the Target Ion Source Group

© Ph. Stroppa/CEA



CES 31: Physique Subatomique (PRC)

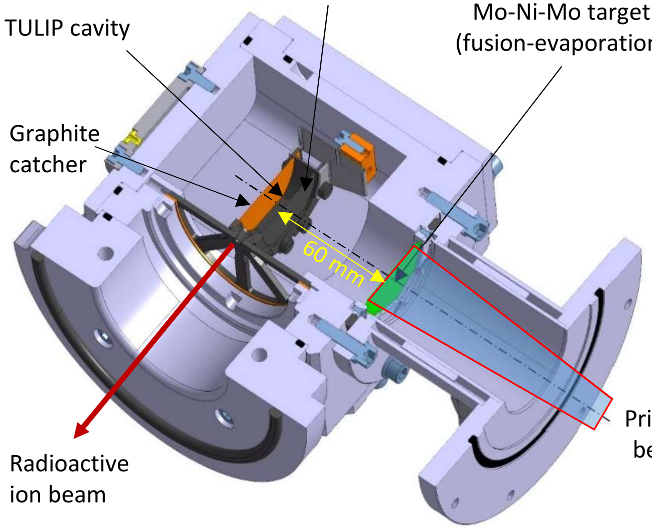
AAPG ANR 2018

TULIP (Target Ion Source for Short-Lived Isotope Production)

Would it be possible to efficiently produce neutron-deficient short-lived isotopes at SPIRAL1?

- **Step 1: proof of principle with Rb+ ions**
- **Step 2: production of metallic ions around 100Sn**

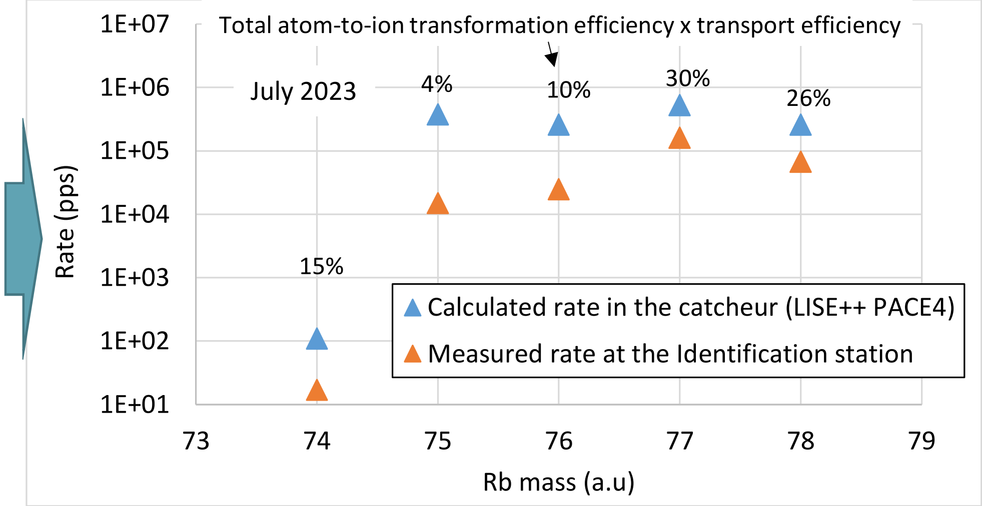
TULIP for alkali



On-line test : production of $^{74-78}$Rb^{+} ions

Rb Mass	$T_{1/2}$	ID station rate (pps)	
		March 22 ^{22}Ne+^{nat}Ni	July 23 ^{20}Ne+^{nat}Ni
74	64,76 ms		1,7E+01
75	19 s		1,5E+04
76	36,8 s	3,80E+03	2,5E+04
77	3,78 m		1,6E+05
78	5,74m/ 17,7 m	5,80E+04	6,8E+04

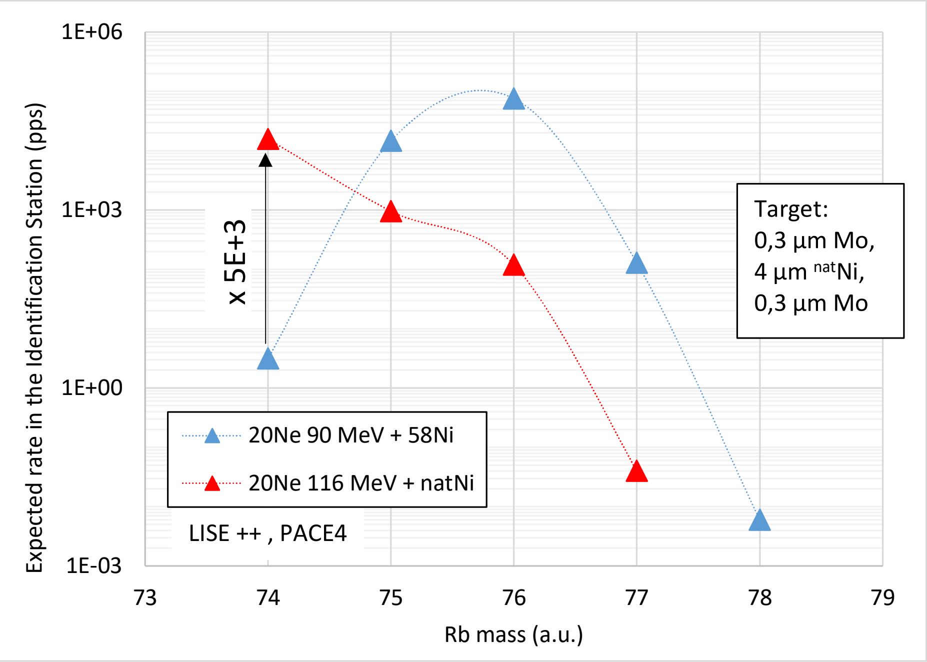
Suggests a short atom-to-ion transformation time



TULIP for alkali

Next on-line production test : September 2025.
Focussed on the production of ^{74}Rb$^+$ ions

- An important gain (5000) is expected using a primary beam energy allowing to maximize the ^{74}Rb production XS
- ~10^4 pps of ^{74}Rb$^+$ are expected on the identification station, assuming the same atom-to-ion transformation efficiencies as the one observed in 2023
- An additional gain (factor 5 to 10) seems to be realistic by increasing the TISS temperature, by optimizing the beam transport and the beam intensity.
- Effect of the release time on the ^{74}Rb$^+$ production efficiency is presently difficult to estimate with precision, but expected to be strongly lower than in the standard graphite target due to the short range of residus in the catcheur.



TULIP for alkali:
Beyond the anr project

Association of the TULIP cavity to a more efficient surface ion source

- **If MonoNaKe demonstrates its ability to ionise elements having a first ionisation potential up to ~6 eV, the same ioniser could be associated to the TULIP cavity**

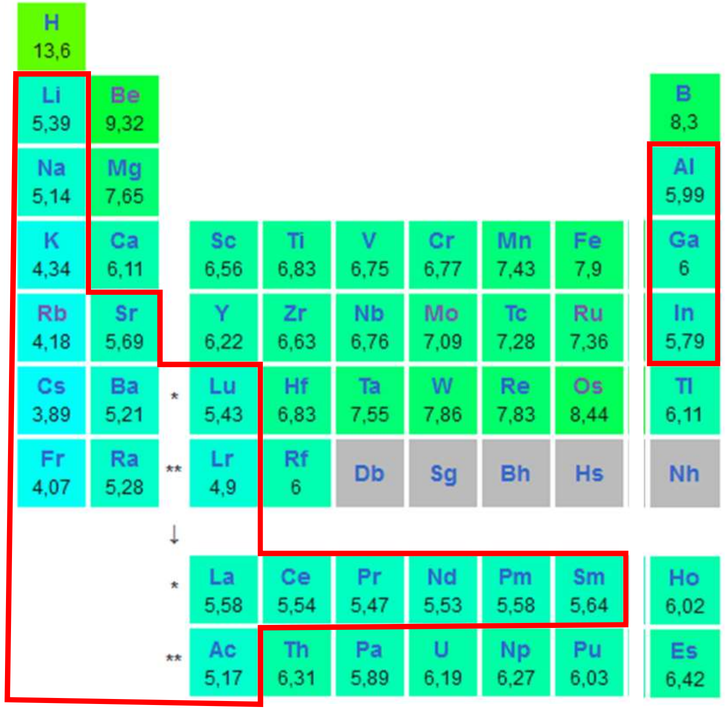
➔ extension of the region of ionisable elements while conserving a selectivity

Graphite and rhenium ionisers common to MonoNaKe and TULIP are under realisation

If MonoNaKe tests are satisfying (efficiencies ≥ % for Al, Ga or In), the most performing ionizing material (graphite or rhenium) will be implemented on TULIP.

➔ Access to non-alkali neutron-deficient short-lived elements

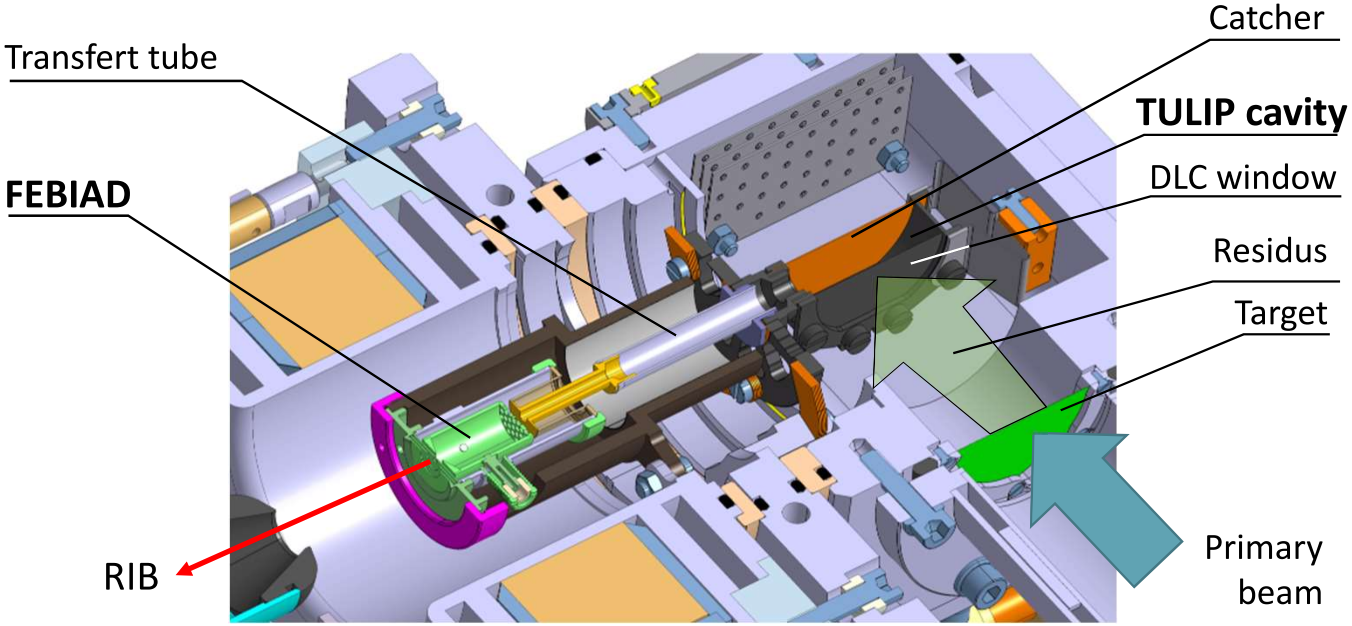
^{61}Ga (167 ms) from ^{14}N+^{54}Fe , ^{22}Al (91 ms) from ^{16}O+^{12}C ?



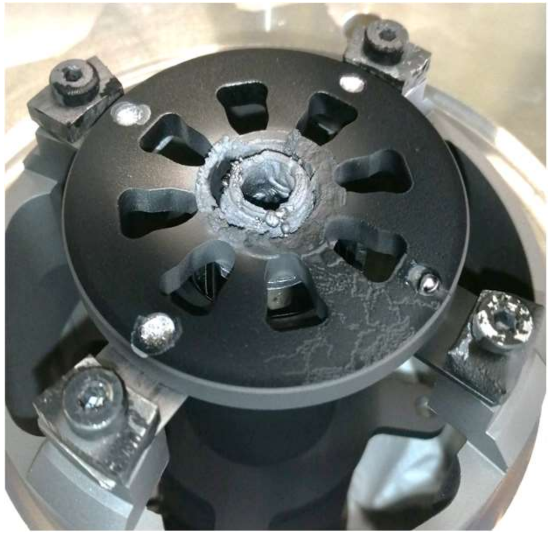
H 13,6										
Li 5,39	Be 9,32									B 8,3
Na 5,14	Mg 7,65									Al 5,99
K 4,34	Ca 6,11		Sc 6,56	Ti 6,83	V 6,75	Cr 6,77	Mn 7,43	Fe 7,9		Ga 6
Rb 4,18	Sr 5,69		Y 6,22	Zr 6,63	Nb 6,76	Mo 7,09	Tc 7,28	Ru 7,36		In 5,79
Cs 3,89	Ba 5,21	*	Lu 5,43	Hf 6,83	Ta 7,55	W 7,86	Re 7,83	Os 8,44		Tl 6,11
Fr 4,07	Ra 5,28	**	Lr 4,9	Rf 6	Db	Sg	Bh	Hs		Nh
		↓								
		*	La 5,58	Ce 5,54	Pr 5,47	Nd 5,53	Pm 5,58	Sm 5,64		Ho 6,02
		**	Ac 5,17	Th 6,31	Pa 5,89	U 6,19	Np 6,27	Pu 6,03		Es 6,42

TULIP for metals

Coupling of the TULIP cavity to a FEBIAD ion source



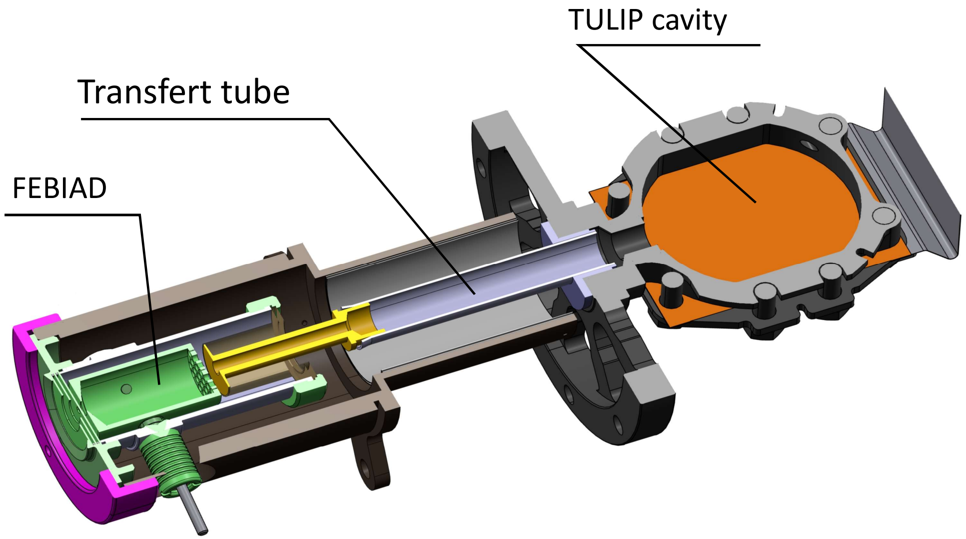
The first test was a failure.
The second too….



The fifth works!

TULIP for metals

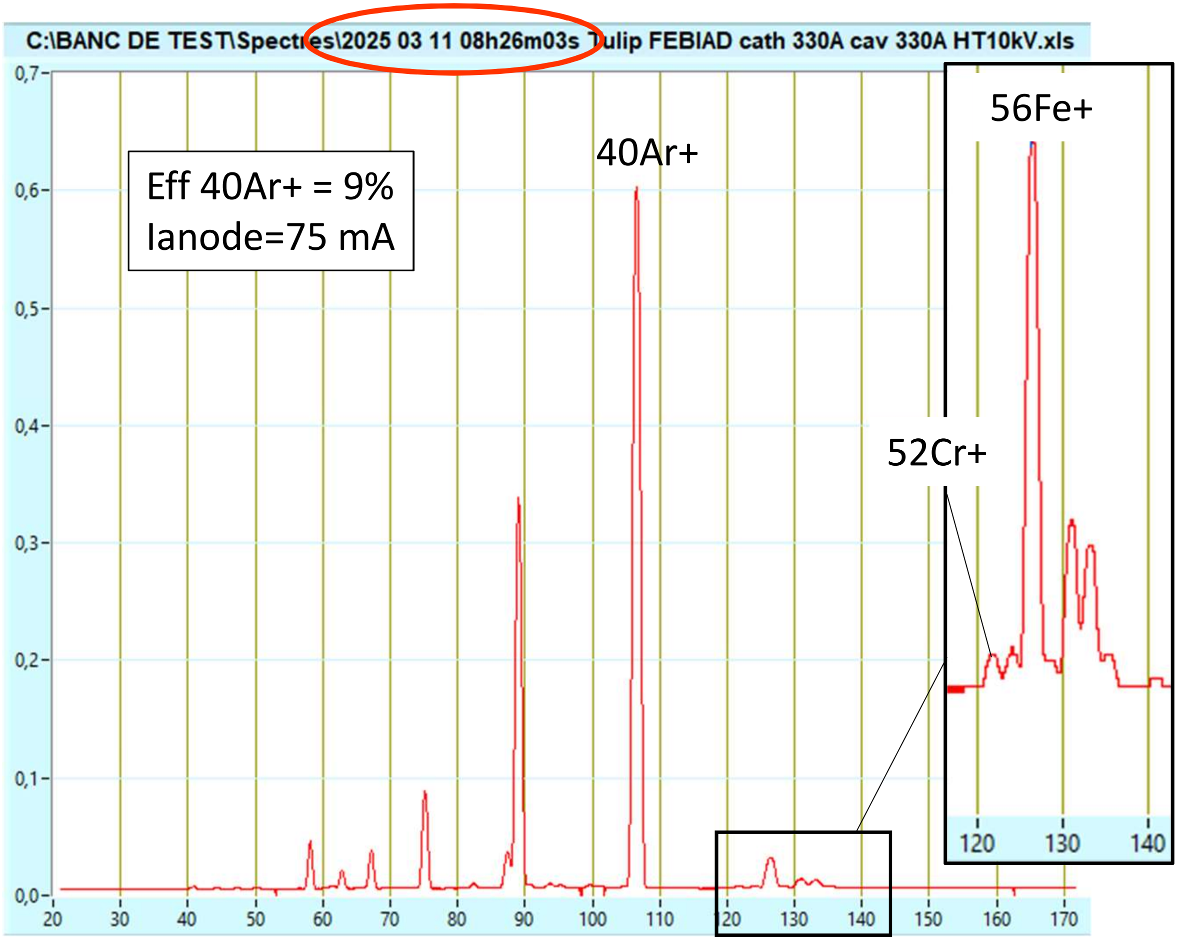
Coupling of the TULIP cavity to a FEBIAD ion source: new design



Objective:

- Producing the same metallic elements as the ones produced in the thick graphite target+FEBIAD,
- but for shorter half-lives isotopes

TULIP for metals



Currently on the test bench

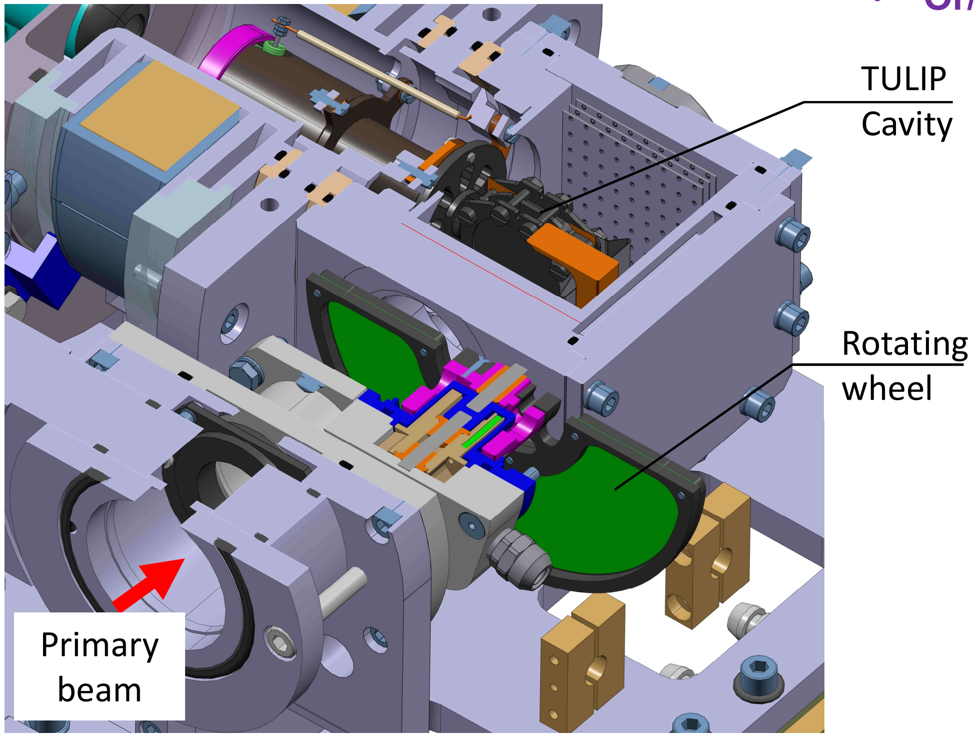
- No failure for 2 days at maximum power
- Improvements are under study:
  - ➢ Minimum temperature of the cavity, presently equal to 1340°C
  - ➢ Homogeneity of the temperature, to limit the cold traps

Next tests will focus on the ionisation of Sn, In, Cd, Ag and Pb

TULIP for more intense primary beams

Design of a rotating wheel

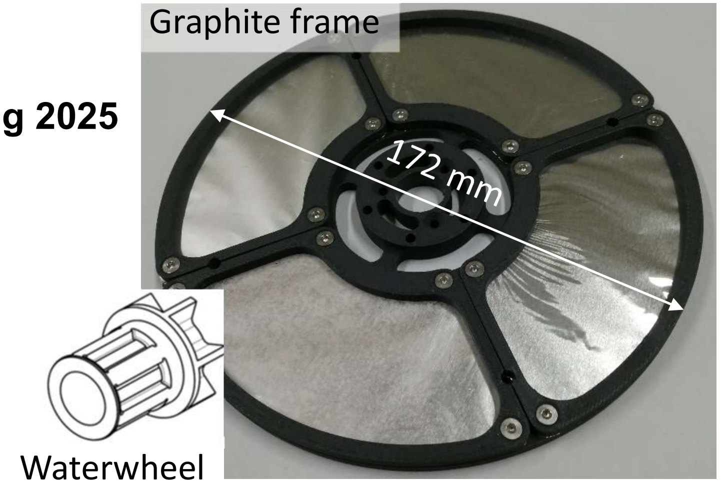
- To increase the possible primary beam intensity by a factor of 7
- Or/and to increase the target lifespan



Design requirements: simplicity and radiation hard.
➔ Graphite bearing, waterwheel drive, magnetic coupling

Present status:
It works but the rotating speed is limited to ~20Hz by eddy current (Courant de Foucault in French)
New design under process to reach ~50Hz.

- **Next test by Spring 2025**



TULIP-FEBIAD for metals

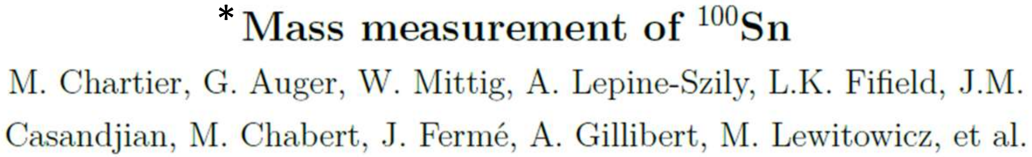
Final objective of the anr project

Production of metals around ^{100}Sn (In, Cd, Ag…)

- Using ^{46}Ti (207 MeV@3E+12 pps) or 50Cr (289 MeV@3E+12 pps) on ^{nat}Ni target,
- 3 orders of magnitude between the PACE XS and the M. Chartier* XS: who is right?
- Assuming PACE XS /1000
- Assuming an atom-to-ion transformation efficiency of 10%,

the production rate at the exit of the TISS should be close to 1 pps.

Physics will decide.



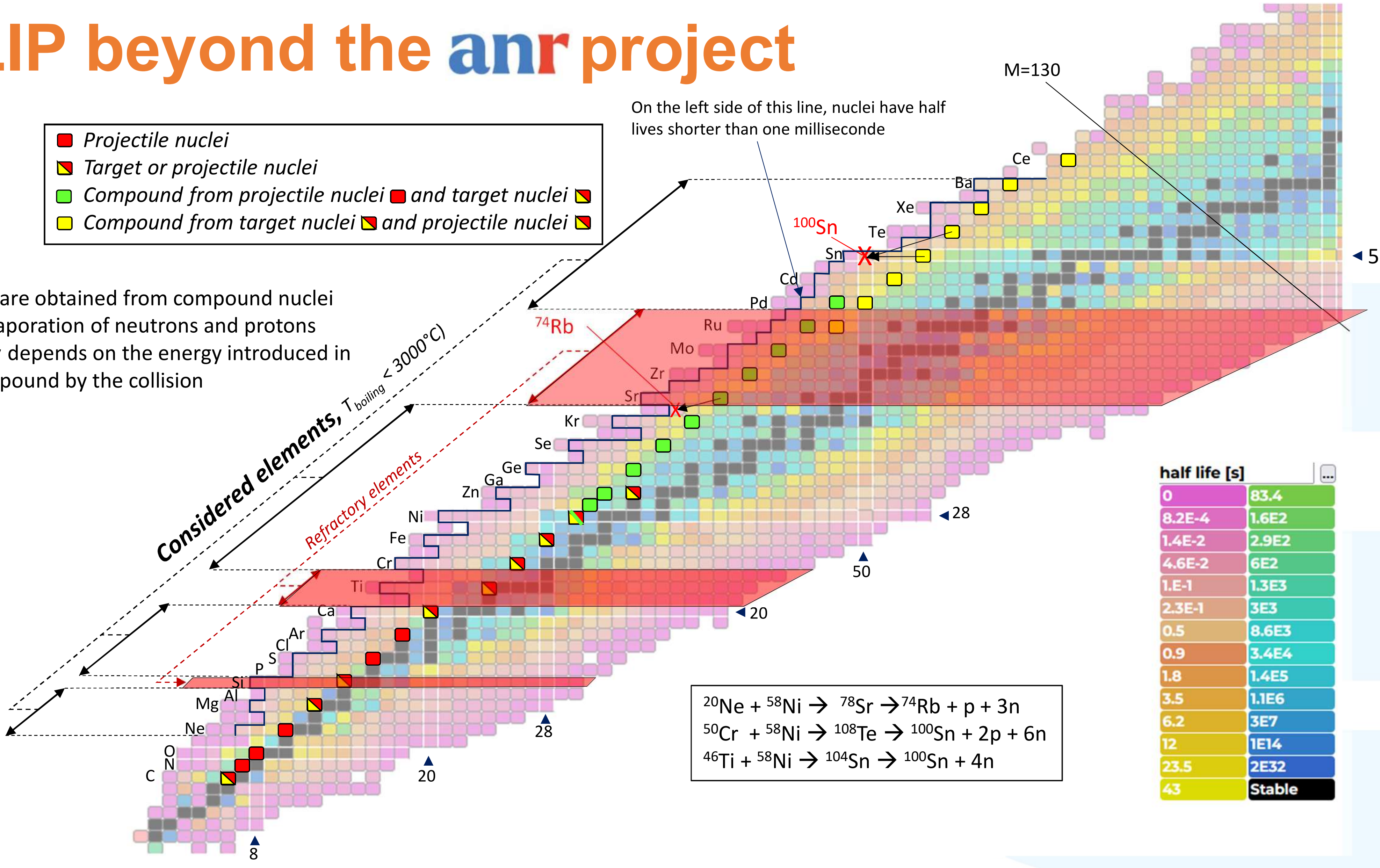
* Mass measurement of ^{100}Sn

M. Chartier, G. Auger, W. Mittig, A. Lepine-Szily, L.K. Fifield, J.M. Casandjian, M. Chabert, J. Fermé, A. Gillibert, M. Lewitowicz, et al.

TULIP beyond the anr project

- 🟥 *Projectile nuclei*
- ◩ *Target or projectile nuclei*
- 🟩 *Compound from projectile nuclei 🟥 and target nuclei ◩*
- 🟨 *Compound from target nuclei ◩ and projectile nuclei ◩*

- Residus are obtained from compound nuclei after evaporation of neutrons and protons
- Exoticity depends on the energy introduced in the compound by the collision

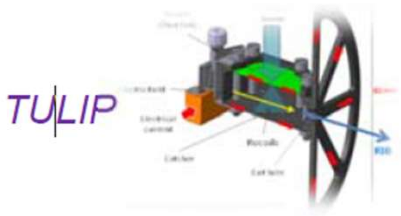


On the left side of this line, nuclei have half lives shorter than one milliseconde

$^{20}Ne + ^{58}Ni \rightarrow ^{78}Sr \rightarrow ^{74}Rb + p + 3n$

$^{50}Cr + ^{58}Ni \rightarrow ^{108}Te \rightarrow ^{100}Sn + 2p + 6n$

$^{46}Ti + ^{58}Ni \rightarrow ^{104}Sn \rightarrow ^{100}Sn + 4n$

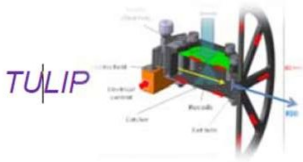


AAPG ANR 2018

Diffusion data base

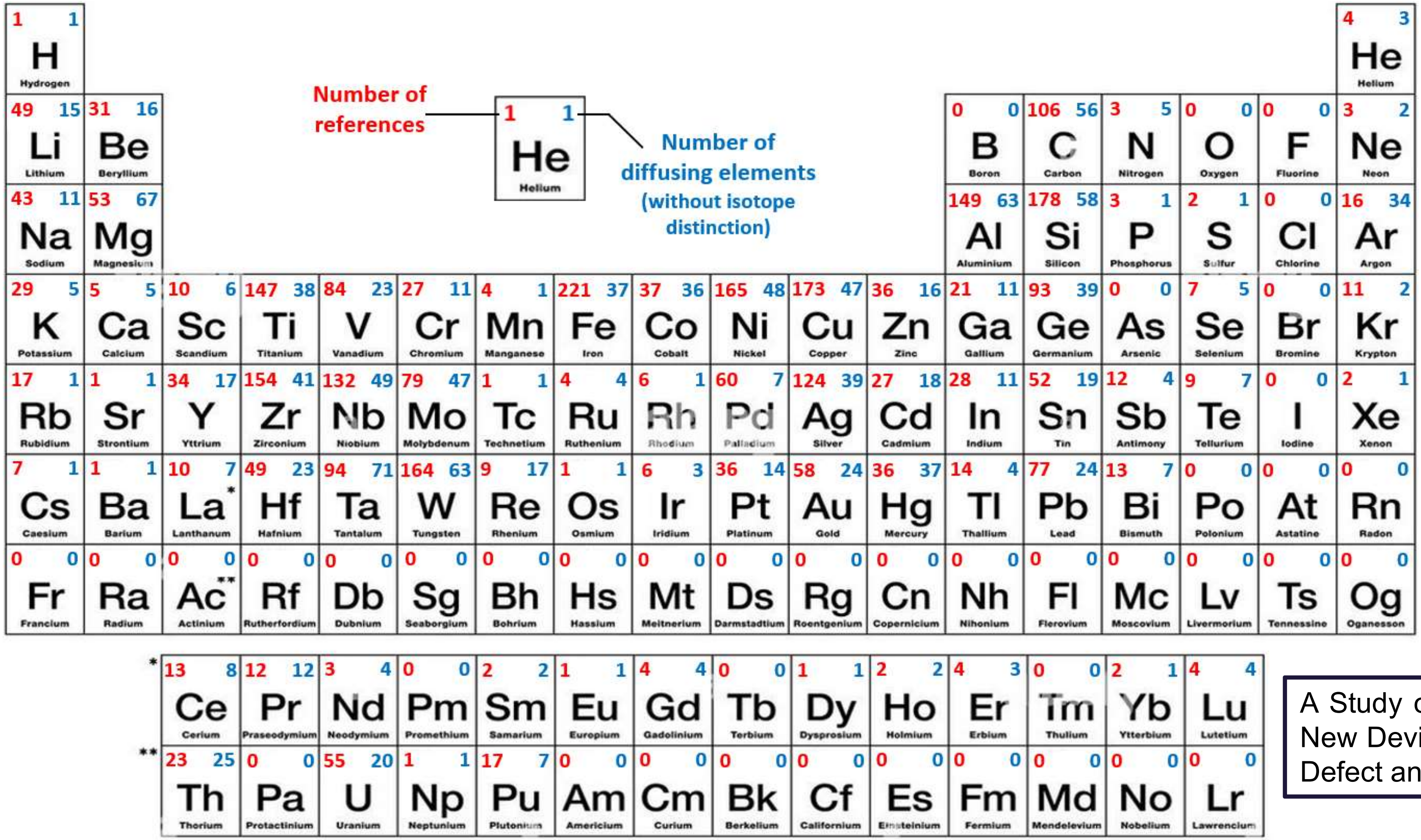
(Alexis Ribet, post-doc)

- Atom-to-ion transformation efficiency in Target-Ion Source Systems depends on release time of radioactive atoms
- Prediction and improvement of production system performances requires the knowledge of diffusion coefficients of atoms in matter at high temperature
- A global view of the diffusion coefficients of atoms in the different target materials is necessary, to directly use them or to extra-interpolate to missing values
- The availability of a diffusion coefficient database was necessary
- Therefore, an important bibliographical work has been done to collect as much as possible **diffusion parameters** concerning a large variety of target-element combinations and for broad temperature range



AAPG ANR 2018

*CES 31: Physique Subatomique **(PRC)***



Number of references — 1 1
He
Helium — Number of diffusing elements (without isotope distinction)

1 1 H Hydrogen																	4 3 He Helium
49 15 Li Lithium	31 16 Be Beryllium											0 0 B Boron	106 56 C Carbon	3 5 N Nitrogen	0 0 O Oxygen	0 0 F Fluorine	3 2 Ne Neon
43 11 Na Sodium	53 67 Mg Magnesium											149 63 Al Aluminium	178 58 Si Silicon	3 1 P Phosphorus	2 1 S Sulfur	0 0 Cl Chlorine	16 34 Ar Argon
29 5 K Potassium	5 5 Ca Calcium	10 6 Sc Scandium	147 38 Ti Titanium	84 23 V Vanadium	27 11 Cr Chromium	4 1 Mn Manganese	221 37 Fe Iron	37 36 Co Cobalt	165 48 Ni Nickel	173 47 Cu Copper	36 16 Zn Zinc	21 11 Ga Gallium	93 39 Ge Germanium	0 0 As Arsenic	7 5 Se Selenium	0 0 Br Bromine	11 2 Kr Krypton
17 1 Rb Rubidium	1 1 Sr Strontium	34 17 Y Yttrium	154 41 Zr Zirconium	132 49 Nb Niobium	79 47 Mo Molybdenum	1 1 Tc Technetium	4 4 Ru Ruthenium	6 1 Rh Rhodium	60 7 Pd Palladium	124 39 Ag Silver	27 18 Cd Cadmium	28 11 In Indium	52 19 Sn Tin	12 4 Sb Antimony	9 7 Te Tellurium	0 0 I Iodine	2 1 Xe Xenon
7 1 Cs Caesium	1 1 Ba Barium	10 7 La* Lanthanum	49 23 Hf Hafnium	94 71 Ta Tantalum	164 63 W Tungsten	9 17 Re Rhenium	1 1 Os Osmium	6 3 Ir Iridium	36 14 Pt Platinum	58 24 Au Gold	36 37 Hg Mercury	14 4 Tl Thallium	77 24 Pb Lead	13 7 Bi Bismuth	0 0 Po Polonium	0 0 At Astatine	0 0 Rn Radon
0 0 Fr Francium	0 0 Ra Radium	0 0 Ac** Actinium	0 0 Rf Rutherfordium	0 0 Db Dubnium	0 0 Sg Seaborgium	0 0 Bh Bohrium	0 0 Hs Hassium	0 0 Mt Meitnerium	0 0 Ds Darmstadtium	0 0 Rg Roentgenium	0 0 Cn Copernicium	0 0 Nh Nihonium	0 0 Fl Flerovium	0 0 Mc Moscovium	0 0 Lv Livermorium	0 0 Ts Tennessine	0 0 Og Oganesson
	*	13 8 Ce Cerium	12 12 Pr Praseodymium	3 4 Nd Neodymium	0 0 Pm Promethium	2 2 Sm Samarium	1 1 Eu Europium	4 4 Gd Gadolinium	0 0 Tb Terbium	1 1 Dy Dysprosium	2 2 Ho Holmium	4 3 Er Erbium	0 0 Tm Thulium	2 1 Yb Ytterbium	4 4 Lu Lutetium		
	**	23 25 Th Thorium	0 0 Pa Protactinium	55 20 U Uranium	1 1 Np Neptunium	17 7 Pu Plutonium	0 0 Am Americium	0 0 Cm Curium	0 0 Bk Berkelium	0 0 Cf Californium	0 0 Es Einsteinium	0 0 Fm Fermium	0 0 Md Mendelevium	0 0 No Nobelium	0 0 Lr Lawrencium		

- **More than 2000** publications studied for pure elements: Fe (221), Si (178), Cu (173), …
- Bibliography for some binary alloys → candidate target materials
- Graphical interface to make it easier to use

A Study of Diffusion Coefficients: Database and New Device. A. Ribet, P. Jardin and M. Lalande. Defect and Diffusion Forum, 439 (2025) 139-146

TULIP conclusions

Within the framework of SPIRAL1, TULIP

Gives an access to neutron-deficient RIBs,
- with shorter half-lives than the RIBs produced by fragmentation
- with a more selective in-target production process

Is not competitive in terms of rates for RIBs close to the stability valley, so complementary to the production of RIB by fragmentation

Is a mature principle for neutron-deficient short-lived isotopes of alkali. Nevertheless, the technique can still be improved to extend the production of elements having higher first ionisation potentials.

TULIP for metals works off-line. Must soon be tested on-line. Planned in 2026 for metals around ^{100}Sn

Use for isotopes from Mg to Ba can be studied, except refractory elements.

Optimisation of the primary beam–target material couple is essential to optimize the production XS
- This optimisation is facilitated by the number of primary beams available at GANIL
- Graphite targets must be favoured, as far more simple to design.
- Presently, a Mo / Ni 4 µm / Mo target is available
- A ^{54}Fe target is under development
- A rotating wheel is also under development to reduce the target damage

Would it be possible to use the MNT reactions in TULIP?

GANIL

Thank you for your attention

Neutron deficient Rb$^+$ production