GCS-2024-018

SPIRAL1 radioactive ion production

***P.* Jardin,** V. Bosquet, P. Chauveau, M. Dubois, S. Damoy, P. Delahaye, G. Frémont, R. Frigot, S. Hormigos, M. Lalande, E. Levillain, C. Michel, F. Pérocheau, A. Ribet, J-C. Thomas*. GANIL, Grand Accélérateur National d'Ions Lourds, Bvd H. Becquerel, BP55027 14076 Caen cedex5, France*

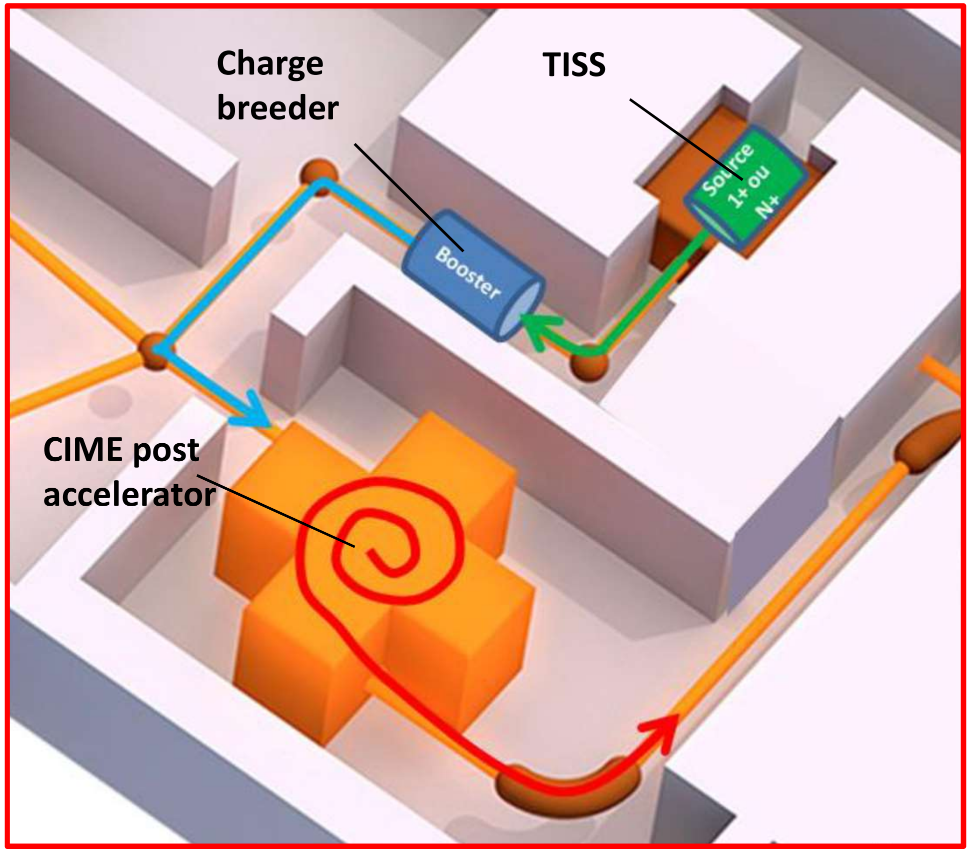
M. MacCormick, J. Guillot, B. Roussière, *IJCLab, Institut Joliot Curie Laboratory, 15 Rue Georges Clémenceau, 91400 Orsay, France*

SPIRAL1 Installation

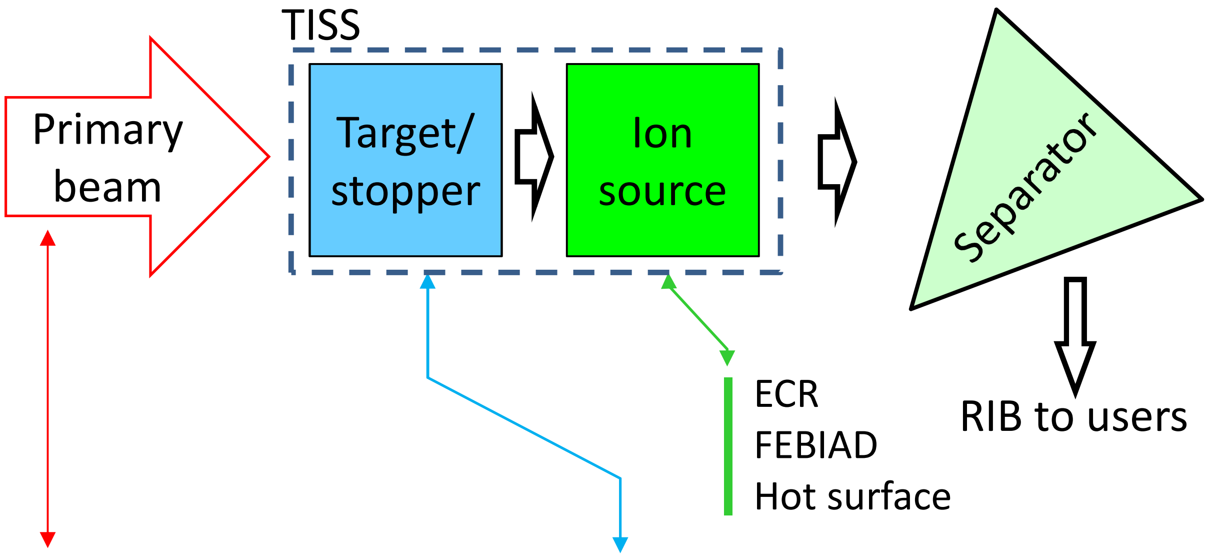
Objective
- To deliver low energy radioactive ion beams for DESIR
- To deliver post-accelerated ion beam intensities from 1E+3 pps to 1E+4 pps

Transport, charge breeding and post-acceleration efficiency (from the TISS exit to the post-accelerator exit) : ~1 to 2 %
➔ **Minimum intensity at the exit of the TISS : 1E+5 to 1E+6 pps**

Purity of the beams : depends on
- The production reaction
- The contaminants present in the TISS
- The mass separator and post-accelerator



Primary ion beam and target combinations at SPIRAL1

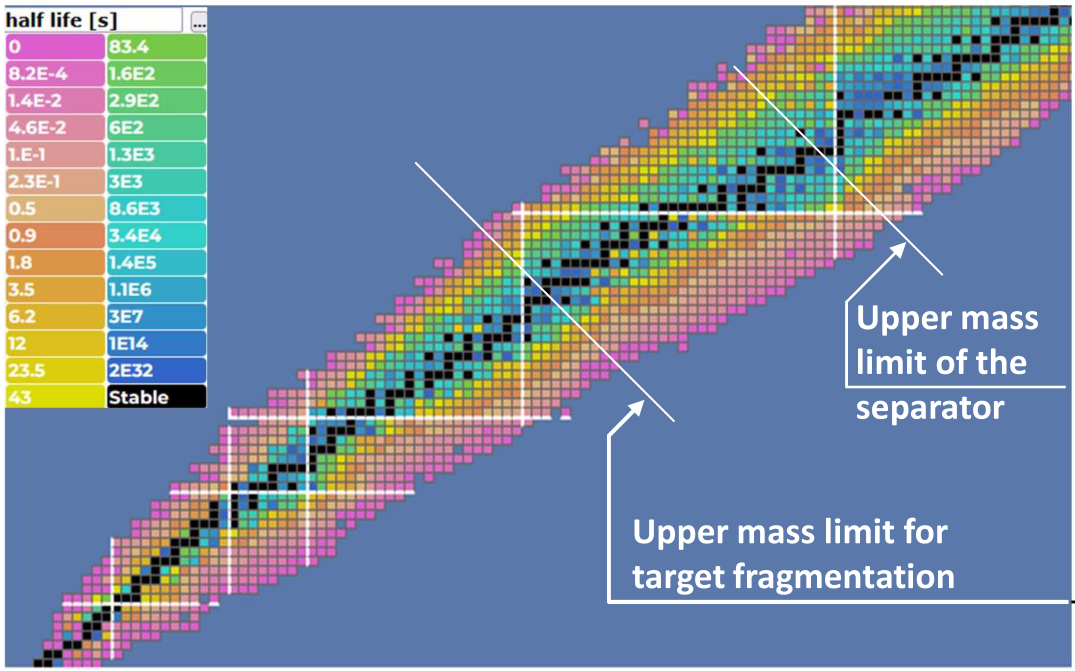


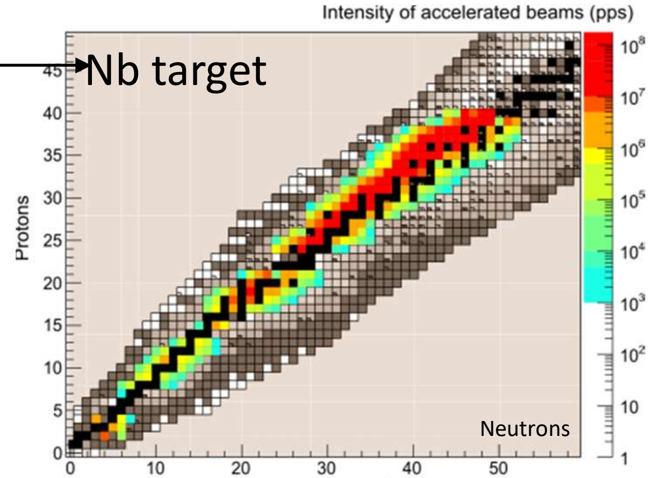
C to U, *E* up to 95 MeV/A +
C, *E* up to 95 MeV/A +
C to U, *E* up to 95 MeV/A +

thick carbon target
thick target for material with mass up to Nb
thin target. Submitted to safety authorization

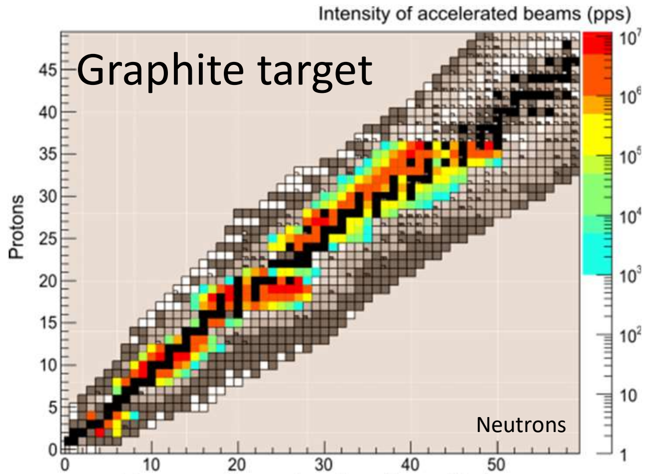
Significant flexibility
But
Limited to primary beam energies lower than 95 MeV/A

Regions of the nuclide chart are presently accessible with SPIRAL1





Expected production from Nb target fragmentation induced by 12C beam



Expected production from Kr beam fragmentation on graphite target

And after in-target production…

Are required

- An efficient diffusion of the atoms out of the target materiel. ➔ Need of experimental data about diffusion at high temperature
- An efficient effusion to transport the atoms up to the ion source. ➔ Need of experimental data about sticking at high temperature
- An efficient atom-to-ion transformation

Not available at SPIRAL1

	ECR	FEBIAD	Surf. Ion	Laser
Elements	Gas	All except refractories	Alkali	All except noble gases and refractories
Efficiency	Up to 100%	Up to 50%	Up to 100%	Up to 30%
Selectivity	Yes	no	yes	yes

Graphite target + ECR ion source (NanoGan)

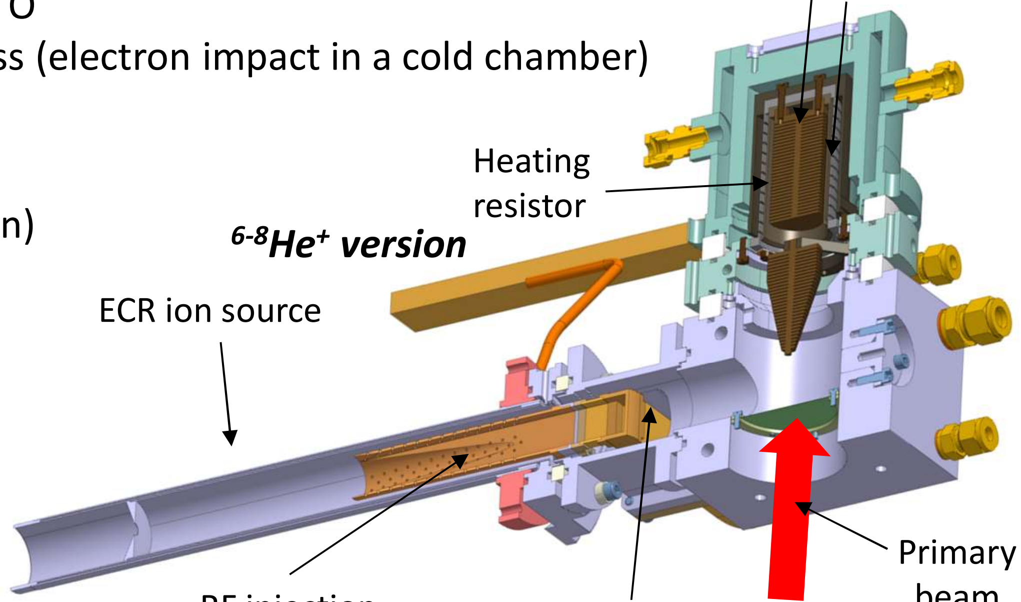
Objective: multicharged RIBs from gaseous elements (mainly noble gases).

Designed and optimized from 1990 to 2004 at GANIL

- Under regular operation since 2001 (~50 TISSs). Technical configuration fixed
- Production of RIBs from He, Ne, Ar, Kr and O
- Selectivity insured by the ionisation process (electron impact in a cold chamber)

Original concept (+ some years of optimisation)

- Several attempts to copy ➔ aborted
- Sufficient intensities and charge states for efficient post-acceleration



Possible improvements

- Target design for Xe isotopes
- Improvement of the performances for the short-lived isotopes by improving the homogeneity of the target temperature

Graphite target + FEBIAD ion source

Objective: singly-charged RIBs from non refractory elements

Designed in the seventies (R. Kirchner)

- Several slight evolutions since its first design.
- Almost no selectivity due to the ionisation process (electron impact in a hot chamber)
- Efficiency strongly depends on the mass and on the chemistry

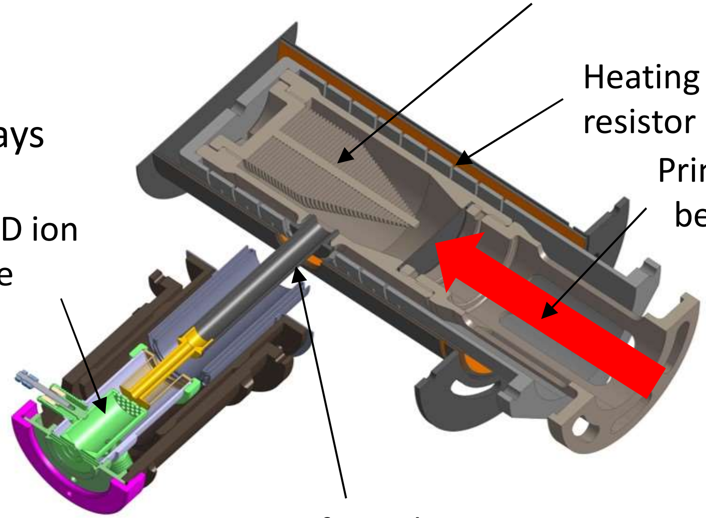
Last significant upgrade performed at GANIL in 2021-2022

- Thermal configuration modified

➔ Ar ionisation efficiency of 20 to 25% for more than 15 days without failure

Next changes

- Thermal configuration of the target to improve its temperature homogeneity (under study)
- Use of another target material



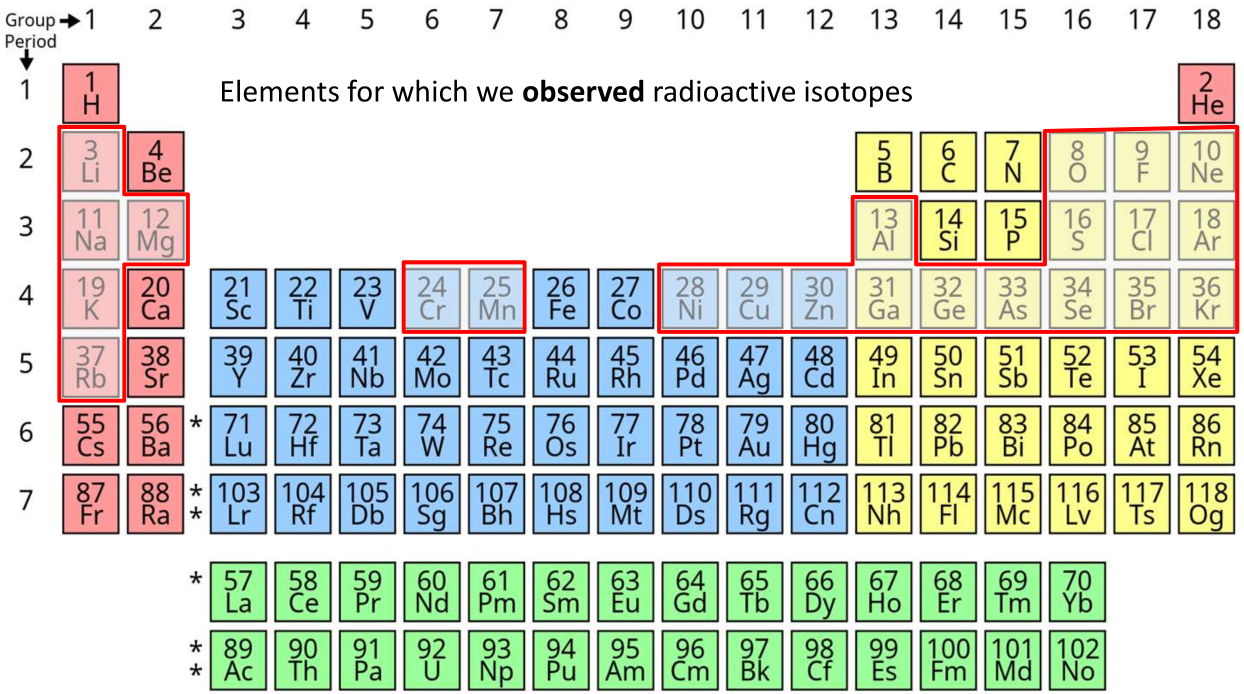
Graphite target + FEBIAD ion source

Recent results

- 10 tests/experiments with radioactive beams
- Laste primary beams send on the graphite target :
  ^{48}Ca (2021), ^{84}Kr (2022) and ^{50}Cr (2023)
- 2 post accelerated beams : ^{38m}K (2019), ^{47}K (2021)
- More than 90 radioactive isotopes/isomers **seen**, including around 50 at post-accelerable intensities (>5^{E}+5 pps).

Last test (^{50}Cr primary beam)

- ^{48}Cr ($T_{1/2}$=21 h) rate ok (1.2^{E}+4 pps/W) but very slow release (46 min) at low beam power (30 W)



Post-accelerable beams (>5E+5 pps)

Graphite target + FEBIAD ion source

https://www.ganil-spiral2.eu/scientists/ganil-spiral-2-facilities/available-beams/

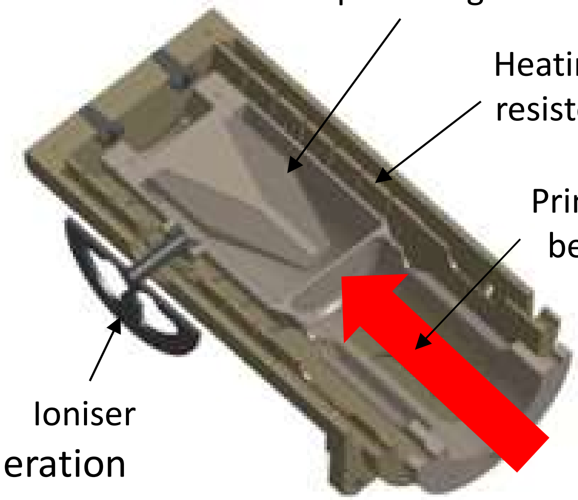
Contact: chartbeams-spiral1@ganil.fr

	Mass	Isotope(s)	T1/2	Expected rate with the best primary beam
Year: 2021	47	47K	17,5	2,7E+08
Target Ion Source n°53	45	45Ar	21,48	5,7E+06
Target : Graphite		45K	1038	4,9E+08
Source : FEBIAD	43	43Cl	3,3	6,8E+04
Primary beam		43Ar	322,2	3,9E+07
48Ca 60MeV/A	42	42K	44496	6,2E+08
Power : 200W		H41Cl	38,4	3,5E+05
Maximum power		42Cl	6,8	3,2E+05
available : 700W	37	37S	303	1,4E+05
	80	80Rb	34	7,2E+07
	79	79mKr	50	3,0E+07
		79Kr	126144	3,5E+07
		79Rb	1374	1,1E+07
		79mBr	4,85	8,1E+06
	78	78mRb	344,4	1,9E+06
		78Rb	1059,6	3,0[illegible]
		78Br	387	[illegible]
	77	77Rb	226,8	[illegible]
		77Kr	427[illegible]	[illegible]08
		77mBr	[illegible]	2,0E+08
Year: 2022		77Br	[illegible]	2,1E+08
		77[illegible]	[illegible]36	1,8E+04
	76	[illegible]	36,5	1,8E+04
Target Ion Source n°55		76[illegible]	53280	1,9E+08
Target : Graphite		76Br	58320	7,1E+08
Source : FEBIAD		76mBr	1,31	2,6E+07
	75	75Kr	276	7,8E+05
Primary beam		75Br	5802	6,7E+08
84Kr 67MeV/A		75Ga	126	2,8E+06
Power : 10W	71	71Se	284,4	5,2E+05
		71As	235080	8,2E+07
Maximum power		71Zn	147	6,6E+05
available : 500W		71mZn	14256	5,3E+06
	69	69As	912	2,3E+06
		69Ge	140580	1,4E+08
		69mZn	49521,6	2,3E+07
		69Cu	171	1,1E+06
	68	68mCu	225	1,5E+06
		68Ga	4062,6	3,0E+08
	67	67Ge	1134	8,0E+05
		67Ga	281811	2,2E+08
	65	65Ga	912	4,1E+07
		65Ni	9061,88	2,8E+05

	Mass	Isotope(s)	T1/2	Expected rate with the best primary beam
	35	35Ar	1,7756	2,3E+08
		H34mCl	1919,4	2,9E+07
	34	34Ar	0,8438	1,1E+07
		34Cl	1,5266	3,6E+07
		34mCl	1919,4	1,2E+08
	33	33Ar	0,173	1,5E+05
		[illegible]Cl	2,511	3,4E+06
	[illegible]	32Ar	0,098	1,7E+03
Year: 202[illegible]		32Cl	0,298	1,3E+05
	31	31Cl	0,19	1,2E+03
		C19O	26,91	2,9E+03
T[illegible]e n°55	30	30Al	3,62	1,9E+04
[illegible]Graphite	29	29Al	394	7,1E+05
[illegible]rce : FEBIAD		29Mg	1,3	4,3E+04
	28	28Al	134,7	9,5E+06
Primary beam	27	27Mg	567,5	1,3E+06
36Ar 74MeV/A	26	26Na	1,07128	1,5E+06
Power : 850W		26mAl	6,346	1,3E+05
	25	25Al	7,183	5,7E+04
Maximum power		25Na	59,1	3,7E+07
available : 850W		25Ne	0,602	5,9E+04
	24	24Ne	202,8	3,8E+06
		24Na	53989,2	9,1E+08
		24mNa	0,0202	2,8E+06
		24Al	2,053	1,4E+03
	23	23Ne	37,25	1,6E+07
		23Mg	11,3046	8,8E+07
	21	21Na	22,49	1,0E+08
		1H20F	11	2,0E+05
	20	20Na	0,4479	1,3E+07
	8	8Li	0,84	1,9E+06
Year: 2023	50	50mMn*	105	3,8E+05
Target Ion Source n°55	48	48Cr*	77616	5,9E+06
Target : Graphite				
Source : FEBIAD				
Primary beam				
50Cr 72MeV/A				
Power : 20W				
Maximum power				
available : 500W				

Graphite target + surface ion source (MonoNaKe TISS)

Objective: RIB from low first ionization potential elements with a selective ionization.



Designed in 2006 (*C. Eléon, PhD 2007, GANIL*)

- Tested on-line on SIRa (2006) for Li^+, Na^+, K^+ production.
- Pending since 2007.

Tested and qualified from 2022 to 2024 with ^{7}Li (stable)

- Encouraging off-line results

On-line production test of $^{8-9}$Li+ in April 2024

- Rate of ~2E+7 pps of $^{8}Li^+$ obtained, sufficient for a post-acceleration
- Rate of ~1E+5 pps of $^{9}Li^+$
- Rates seems to be improvable by a factor of ~10 (high sensitivity of the production rate to the target temperature)

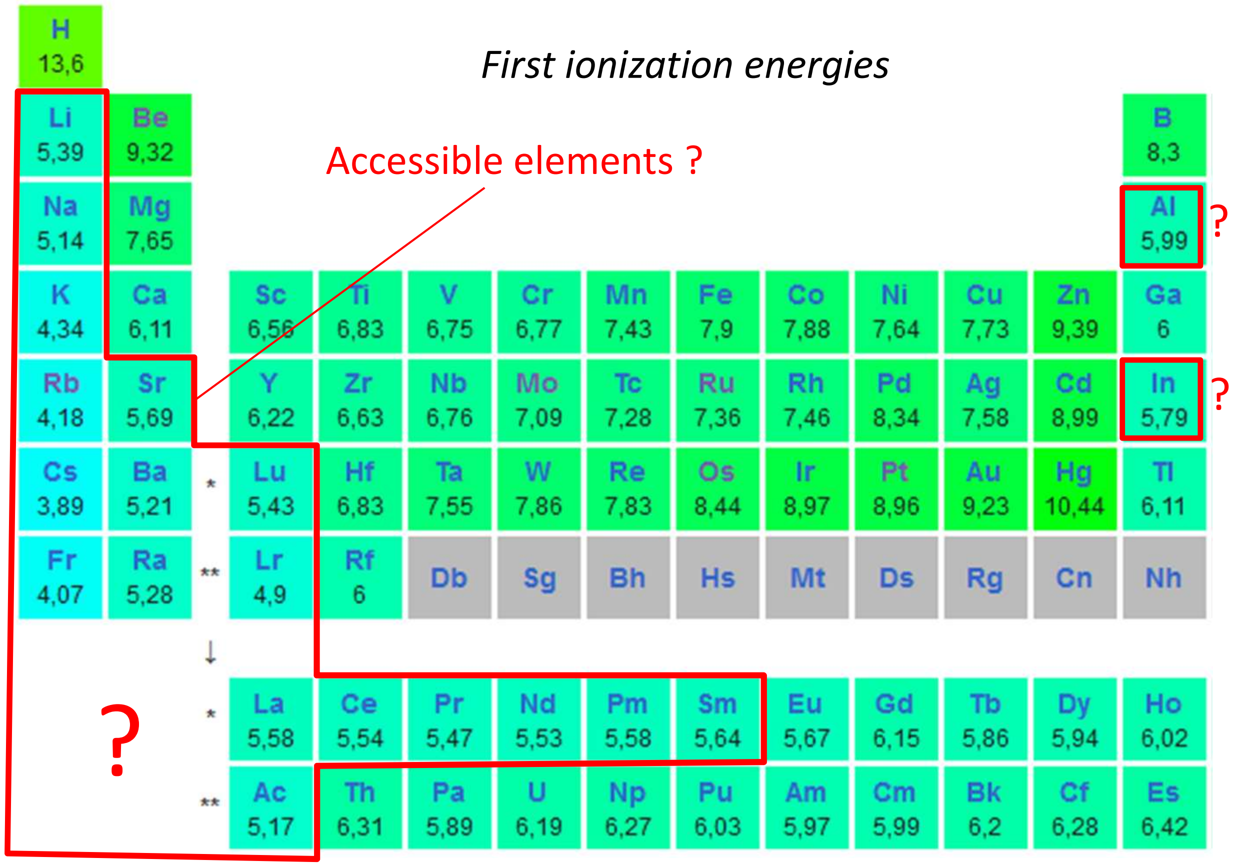
Results explained by the electric field in the ioniser

➔ Less dependant on the first ionisation potential of the atoms

➔ Atoms with first ionisation potential up to 6 eV could be accessible: to be tested.

Graphite target + surface ion source (MonoNaKe TISS)

Expansion of the production to low first ionization potential elements.



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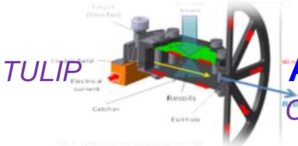

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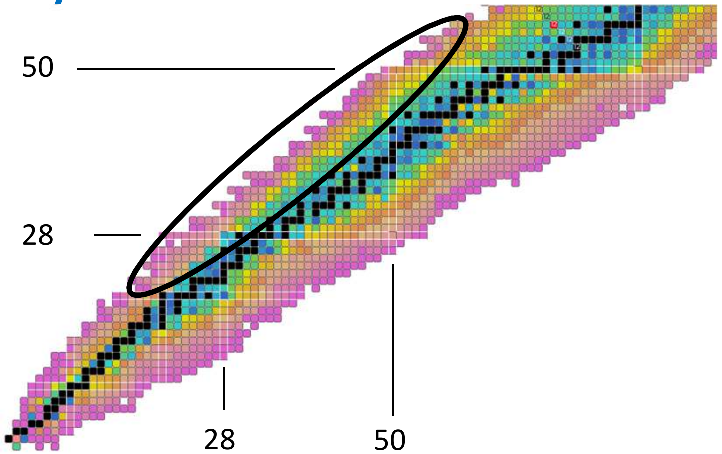
TULIP project (2019-2025)

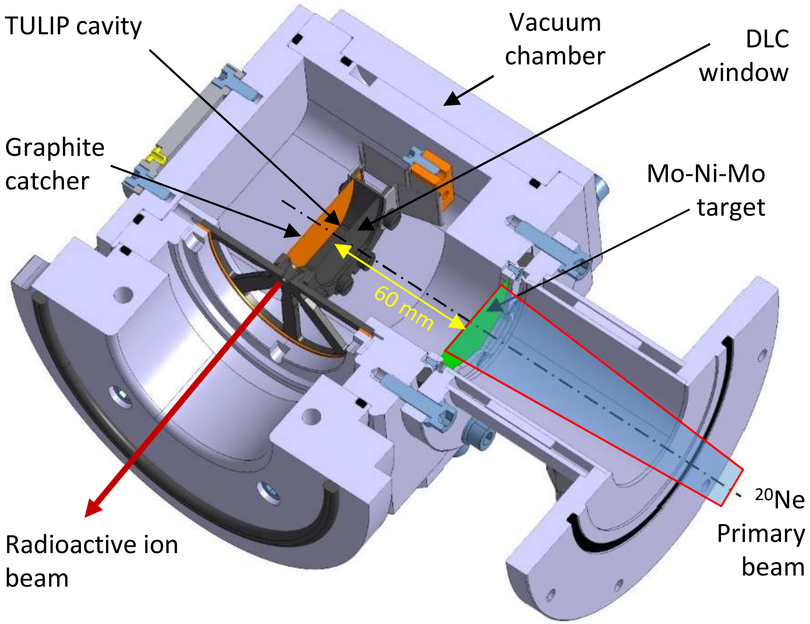
Ni target + SIS or electron impact

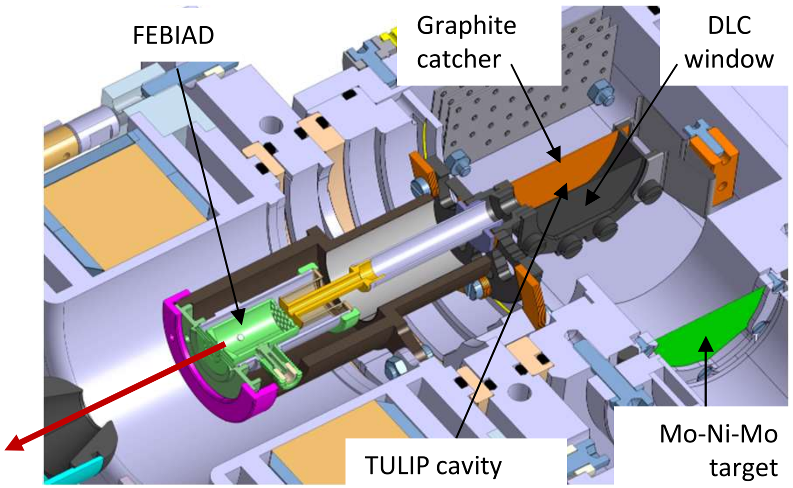


Objective: Neutron deficient short-lived ions from Rb and Sn

Initially designed in 2015 (*V. Kuchi, PhD 2015-2018, GANIL*)

TULIP configuration for Rb$^+$





TULIP configuration for Sn$^+$

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TULIP

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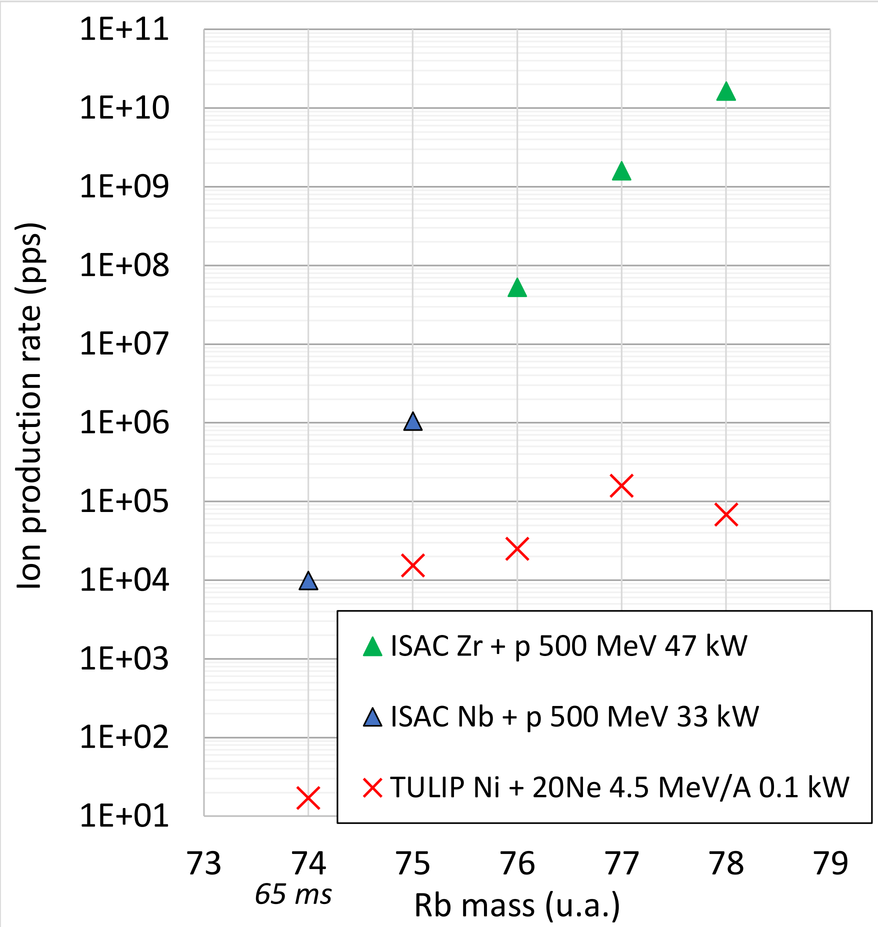
TULIP project (2019-2025)

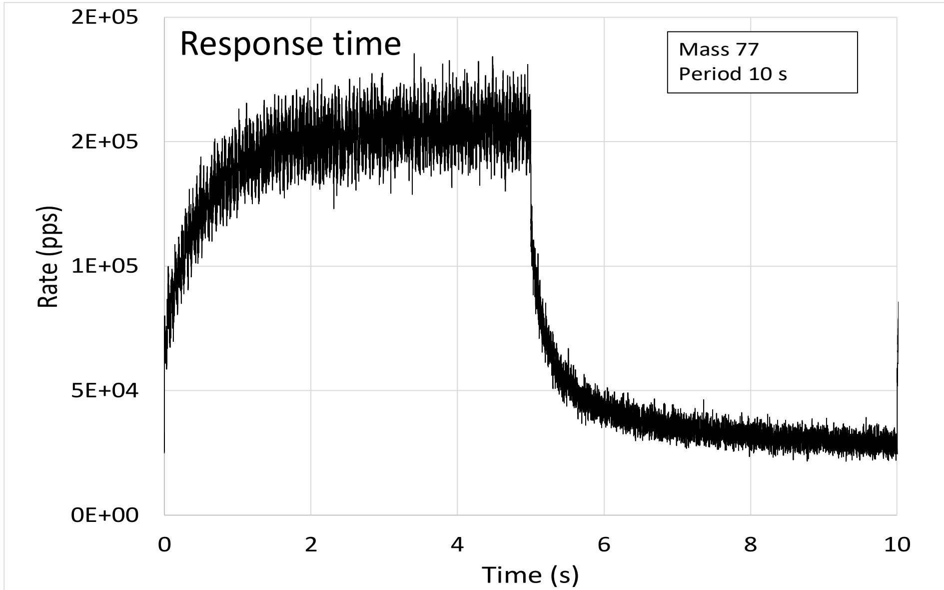
Ni target + Surface Ionisation Source for $^{74\text{-}78}Rb^+$ production, July 2022



^{74}Rb not released due to a too long response time at 1200°C. Need to increase the cavity temperature

- Made possible by the all-carbon cavity
- Made possible (without risk for the target) by a rotating target (under construction)

Off-line test scheduled for June 2024



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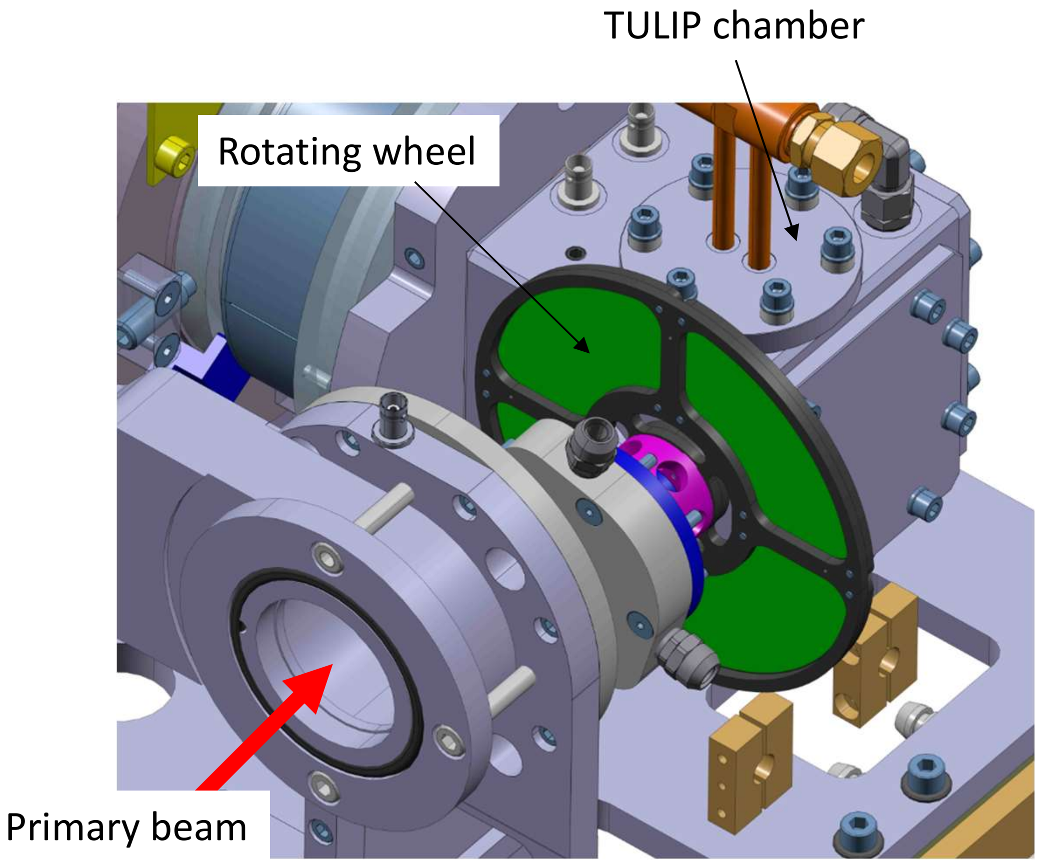
TULIP project (2019-2025)

- **Ni target + FEBIAD Ion Source, off-line test scheduled for July 2024**
- **Ni target + FEBIAD Ion Source + rotating target, off-line test scheduled for July 2024**
- **Ni target + FEBIAD Ion Source + rotating target, ON-line test expected for Spring 2025 to produce isotopes close to ^{100}Sn**



How to extend the production to other elements?

Change the primary beam-target couple

=> Verify the temperature of the target

=> Estimate the production

=> Obtain the authorisation to use the target material

Batch Mode Ion source at FRIB

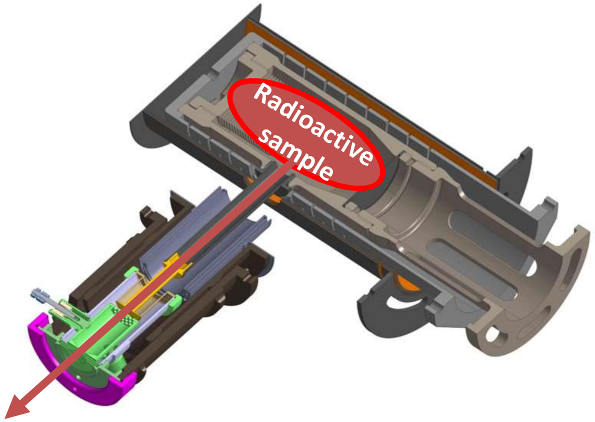
Beams for experiments already delivered:

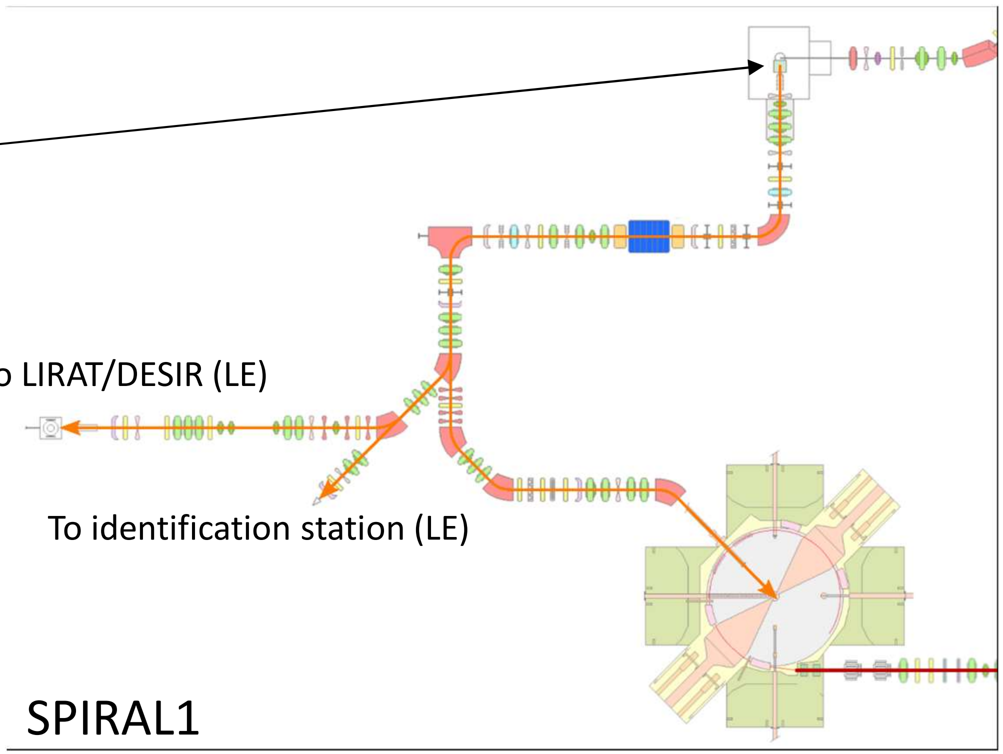
^{7,10}Be, ^{26}Al, ^{32}Si, ^{73}As – delivered for experiments

^{229}Th, ^{44}Ti and other isotopes under development

Under study

Batch Mode Ion source at GANIL/SPIRAL1 ?





CYREN anticipation:

- No cyclo run3/run4 in 2025-2028
- No cyclo at all in 2029

Opportunities for Batch-mode ions (LE)
to DESIR?

Conclusions

- Three innovative and performing Target Ion Source Systems are today available at SPIRAL1
- With them, SPIRAL1 can compete in regions hardly accessible to other installations
- ~50 Radioactive Ion Beams can be post-accelerated with a final ion intensity higher than 1E+4 pps
- Other radioactive beams could be delivered at short term (6 months-2 years) if demanded (see https://u.ganil-spiral2.eu/chartbeams/)

Thank you for your attention