GANIL

Ion Source and Radioactive Ion Beam Development at SPIRAL1

P. Jardin & the Target Ion Source Group

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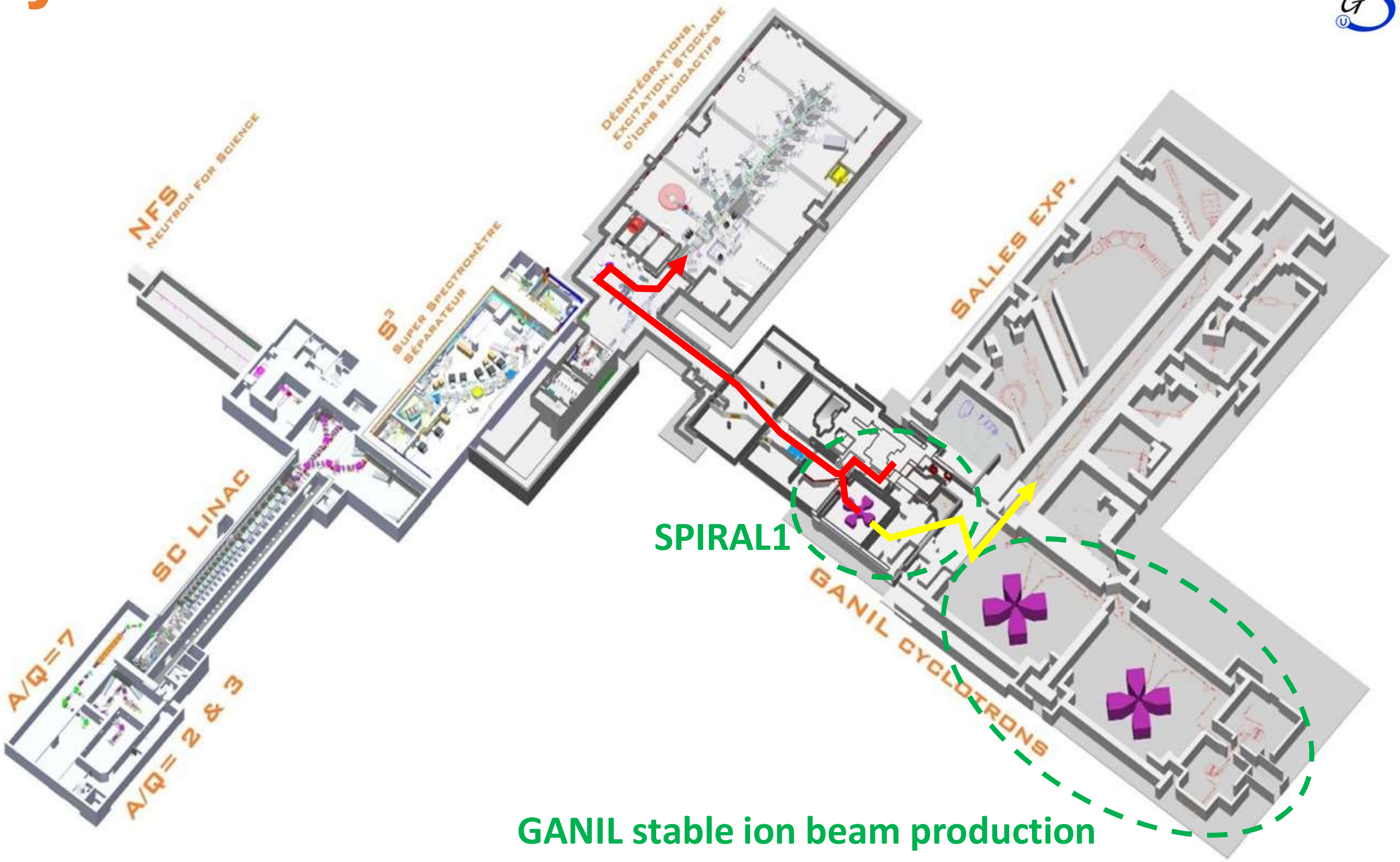
SPIRAL1 Facility



SPIRAL1

GANIL stable ion beam production

SPIRAL1 so far

Primary ion beams

- From ^{12}C to Kr (up to ^{238}U but never used)
- Energy ≤ 95 MeV/A (decreases as the mass increases)
- Intensity on target ≤ 2.10^{13} pps. Rarely obtained. Decreases as the mass increases.

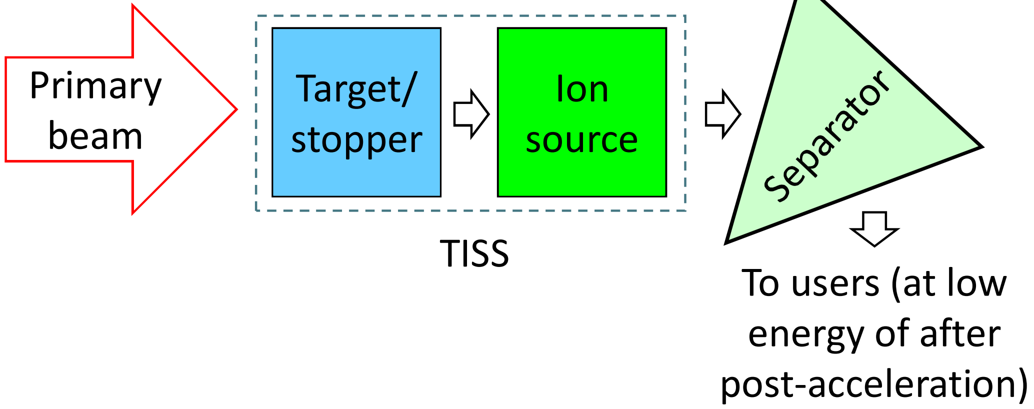
Targets

- Thick : graphite

→ Nuclear reaction

- Beam fragmentation

The ISOL technique



SPIRAL1 : new possible production ways

Primary ion beams

- From ^{12}C to Kr (up to ^{238}U but never used)
- Energy ≤ 95 MeV/A (decreases as the mass increases)
- Intensity on target ≤ 2.10^{13} pps. Rarely obtained. Decreases as the mass increases.

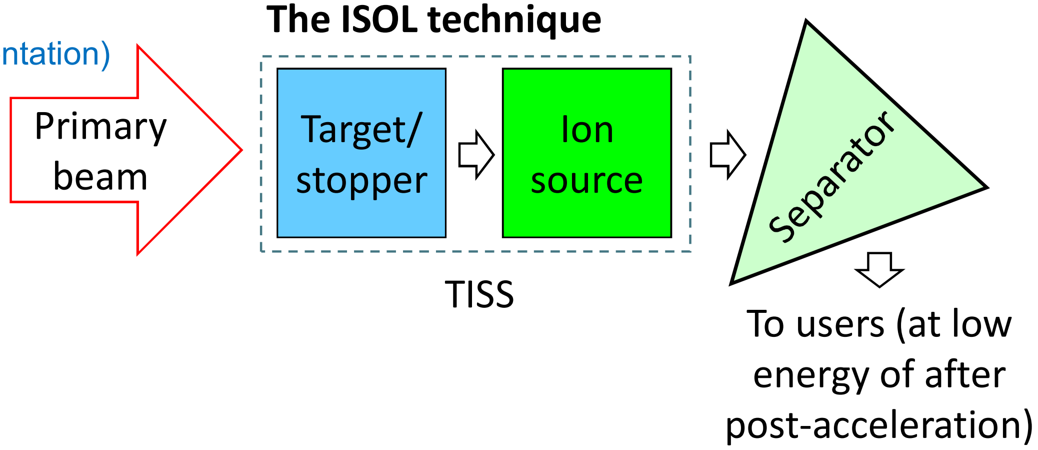
Targets

- Thick target : graphite
- Thin target (few mg/cm2) : Ni, C exist, 54Fe under development
- others can be studied
- « Heavier » Thick target up to Nb (under study, S. Hurier presentation)

→ Nuclear reactions

- Beam Fragmentation
- Fusion-evaporation
- Multi-Nucleon Transfert
- Target Fragmentation (induced by C beam)

The ISOL technique



Ion sources for gases: NanoGan+thick graphite target

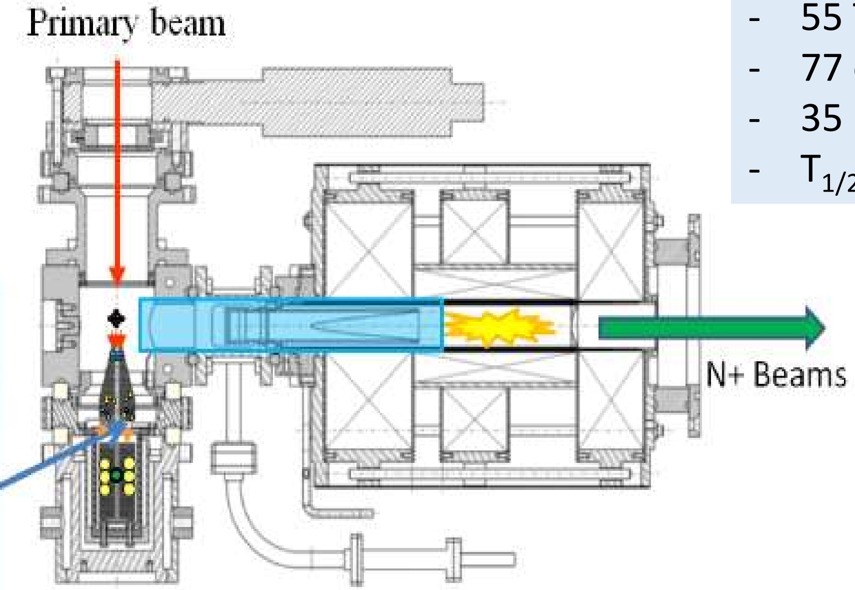
Current graphite Target ECR Ion Source

For Ne, Ar & Kr

4 kW

For He

3 kW ^{12}C beam



Mature system
- 55 Target Ion Source Systems built
- 77 experiments since 2001
- 35 isotopes with intensities > 1E+4pps
- $T_{1/2}$ min ~ 100ms (^{8}He)

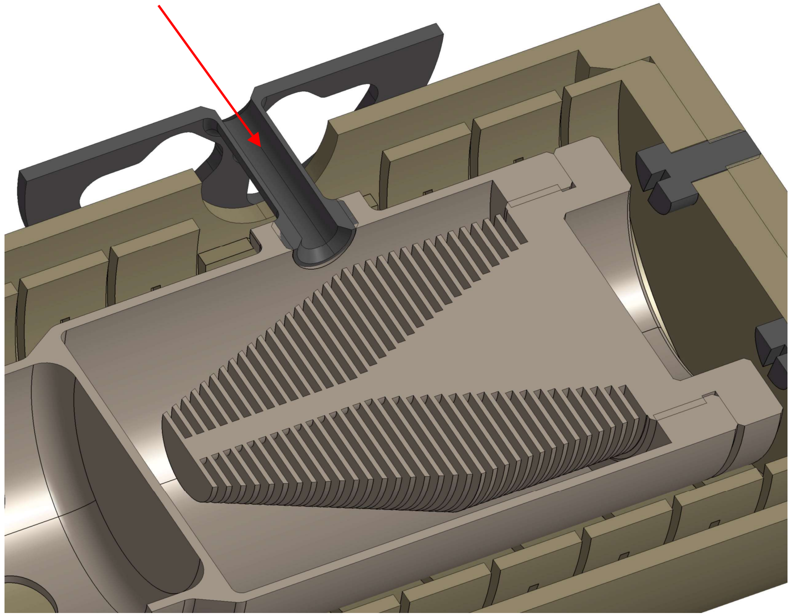
No improvement in progress

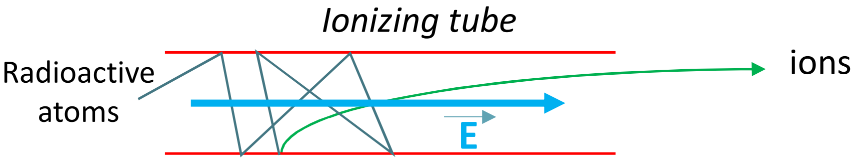
MonoNaKe

Initially designed and tested in 2006 for **Na** and **K**

Graphite

Platinum





Optimum efficiency ⇨
- High work function material
- \+
- Efficient extraction out of the tube
- \+
- High temperature

Comparison of graphite (W_s ~4,75eV) and platinum (W_s ~5,5 eV) for ^{stable}Li ionisation:

Efficiency	graphite / platinum
Per contact (calculated)	1 / 10
Extraction (deduced)	60 / 1
Total (measured)	6 / 1

An efficient extraction from the tube can play an role

MonoNaKe

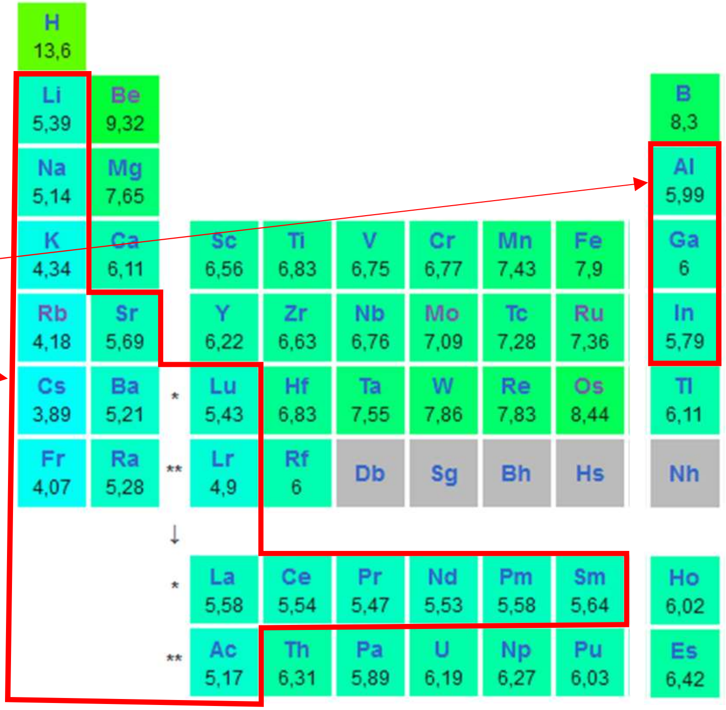
On-line results

- Production test of $^{8}Li^{+}$ (2E+4 pps) with a platinum ionizer in May 2023
- Successful production test of $^{8}Li^{+}$ (2E+7 pps) and $^{9}Li^{+}$ (1E+5 pps) with a graphite ionizer in April 2024
- Successful experiment with post-acc. $^{8}Li^{+}$ (5E+5 pps at 1.2MeV/A) in June 2024
- The TISS behavior suggested a room for improvement

➔ Possibility to efficiently produce ions from elements with a E_i significantly higher than W_s

What are the elements concerned? Ei ≤ 6 eV?

Advantage compared to ECR and FEBIAD : more selective



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

MonoNaKe

What would be the best ionizer design ?

➔ Regarding our technical objectives, graphite and rhenium seems to be the most suitable materials

- A rhenium tube is under construction (delivered by April 2025)
- Systematic measurements will then be performed with graphite and rhenium ionizers for « high » first ionization energy elements, starting with Li, Al, Ga.
- The order of the following tests will depend on your demands

Material candidates	Ws (eV)	Resistivity (Ω.m) at 1727 °C	Temperature (°C) for a vapor pressure of 10^{-5} mbar	Fusion temperature (°C)	Carbon inert	Mechanical feasibility
graphite	4,5-5	900-1400	1927	3500	Y	Y
Zirconium	4,05-4,05-4,1	132	1727	1855	N	N
Niobium	4,01-4,19-4,3	72	2077	2477		Y
Molybdenum	3,9-4,15-4,6	58	1977	2623	Y	NY
Rhodium	4,8-4,98-4,98	47,5	1527	1964		
Tantalum	4,12-4,25	81	2377	3017	N	Y
Rhenium	4,72-4,96	98,9	2327	3185	Y	Y
Irridium	5,27-5,27-5,6		1927	2446		N
Platinum	5,32-5,64-5,65	65	1627	1768	Y	Y
Tungsten	4,4-4,54-4,55	56	2577	3422	N	NY
Ruthenium	4,71-4,71		1877	2333		NY
Osmium	4,83-5,93-5,93		2277	3033		N
	Ws < 4,5 eV	< 80 Ω.m	T < 1900°C	T < 1900°C	N	N
	WSs > 4,5 eV	> 80 Ω.m	T > 1900°C	T > 1900°C	Y	Y

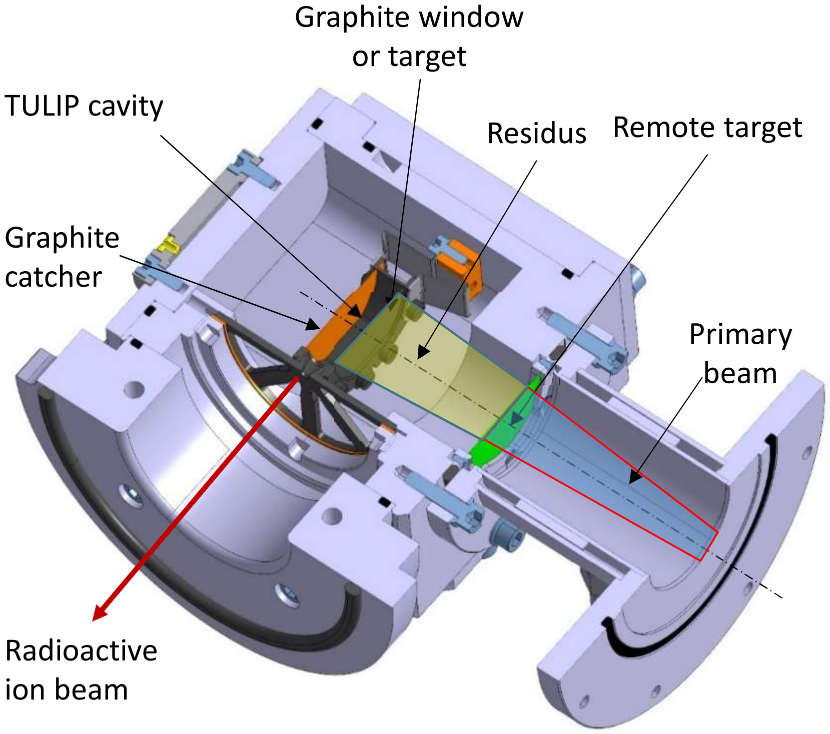
TULIP (ANR project 2020-2025)

Objective: production of neutron-deficient short-lived isotopes of light to intermediary masses

Principle:
Production of residus by fusion-evaporation reactions in a small target cavity to speed up the release of ions

Proof of principle with $^{74\text{-}78}$Rb+ ion production

Final objective: Isotopes around ^{100}Sn

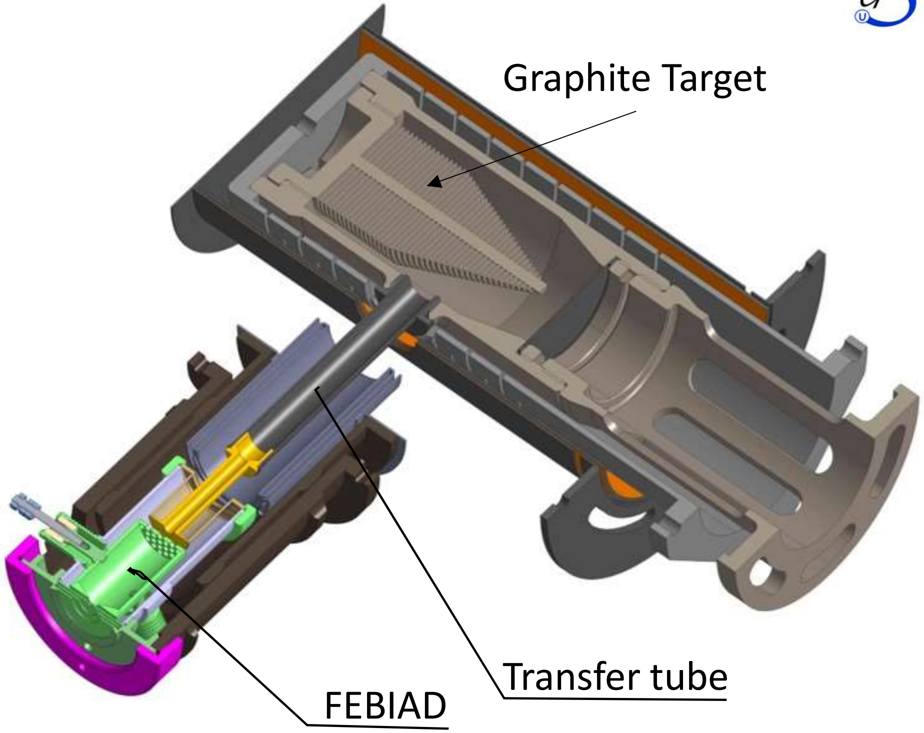


FEBIAD+thick C target

Objective: production of ions from condensable elements

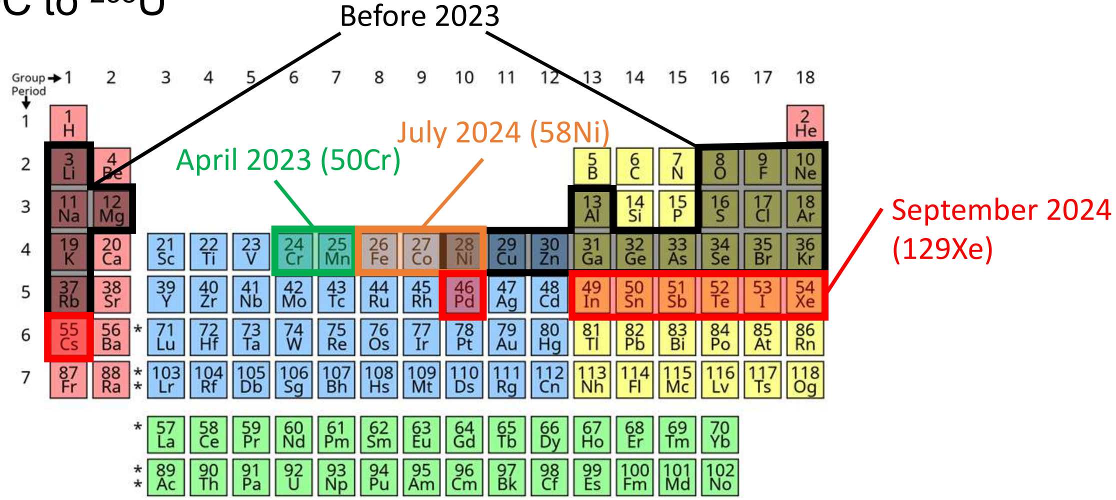
Principle:
Fragments are stopped in the graphite, released at high temperature and ionized in a hot electron impact ion source (FEBIAD)

See presentation of E. Le Villain



Possible Target Ion Source Systems

- 58 primary beams from ^{12}C to ^{238}U
- 5 target-ion sources



Before 2023

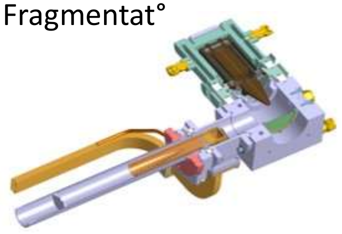
April 2023 (50Cr)

July 2024 (58Ni)

September 2024 (129Xe)

Can be improved or adapted to cope with your needs

Fragmentat°

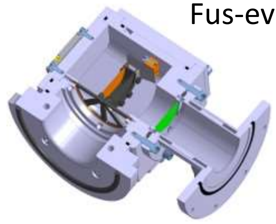


Nanogan
For gas

Fragmentat°

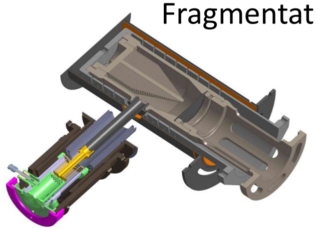
MonoNaKe
For alkaline

Fus-evap



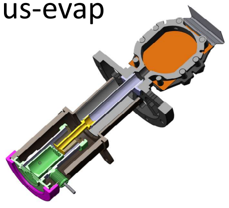
TULIP-alkaline
For neutron-deficient alkaline

Fragmentat°



FEBIAD
For condensable

Fus-evap



TULIP-FEBIAD
For neutron-deficient elements

What about purity?

Depends on

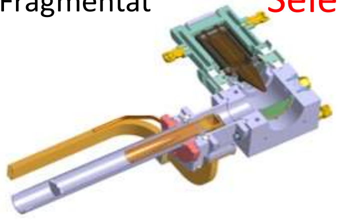
- **The extent of the region of the nuclide chart covered by the nuclear reactions**
    - I. Fusion evaporation : Narrow region, neutron deficient side
    - II. Fragmentation : limited to masses equal or lower than the beam's one
    - III. Fission, mainly leading to neutron rich isotopes around Kr and Xe
    - IV. Spallation: no limit, favouring neutron rich side

MNT reactions?

- **The chemical selectivity of the atom release out of the target material and of the transport up to the ion source**
    - I. Target: material, structure, geometry, temperature
    - II. Chamber: materials, geometry, temperature
- **The ionization method**
    - I. Laser
    - II. Hot surface
    - III. Electron impact in a cold chamber (ECR)
    - IV. Electron impact in a hot chamber (FEBIAD)

↑ Beam purity

Fragmentat° Selective

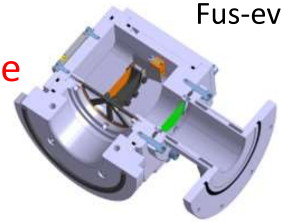


Nanogan
For gas

Fragmentat°

Selective

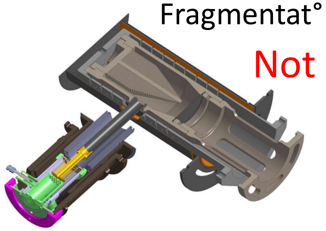
Fus-evap



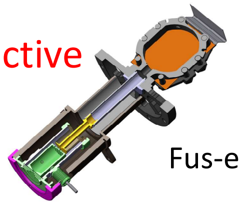
MonoNaKe
For alkaline

TULIP-alkaline
For neutron-deficient alkaline

Fragmentat°



Not selective



Fus-evap

FEBIAD
For condensable

TULIP-FEBIAD
For neutron-deficient elements

Requested beams

T1/2 < 1 s
Seems to be "out of reach"

8Li
10,11,**12**,**13**,**14** Be
10 C
20,21 N
14,15,19,20,**21**,22,**23,24** O
24,25 F
20 Mg
22 Al
23 Si
26,27,28,29,30,32,33,34,35,36,37,**38, 39,40,41,42** P
31,32,33,34, 36, 38,39,40,41,42,43,**44,45,46,47** Cl
31,32,49,50 Ar
35 Ca
43 Cr
58,59,60,61,62,63 Zn
70 Br
74-78 Kr
74 Rb
82,83,84,85,86,87,88,89,90 Zr
94,95 Ag
96,97 Cd
98,99 In
100,101,102,103 Sn

- **SPIRAL 1 offers unique combinations of beam-target- and ion sources, which should allow to give a positive response to many requests in a short to medium term**
- **To get the expected beam, you have to**
  - Question the ion-source group about the possibility to produce it
  - If yes, you have to send a letter of intend
- **After a technical and physical evaluation of your demand, the ion-source group**
  - will study into more details how to produce the beam
  - will adapt the most suitable beam-target-ion source system
  - will test it off-line and on-line to valid its performances
  - will deliver it for a physics experiment

Basic information on beams: https://u.ganil-spiral2.eu/chartbeams/
Inquiries to be sent at chartbeams-spiral1@ganil.fr

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Thank you for your attention