GANIL

Fragmentation targets at SPIRAL1

Workshop on R&D for new ISOL beams

S. Hurier, GANIL

11/03/2025

0 Outline

1. Introduction - GANIL fragmentation targets
2. In-target production estimation: GANIL beams
3. In-target production estimation: new fragmentation targets
4. Setup: Characterization of material properties as a function of the temperature

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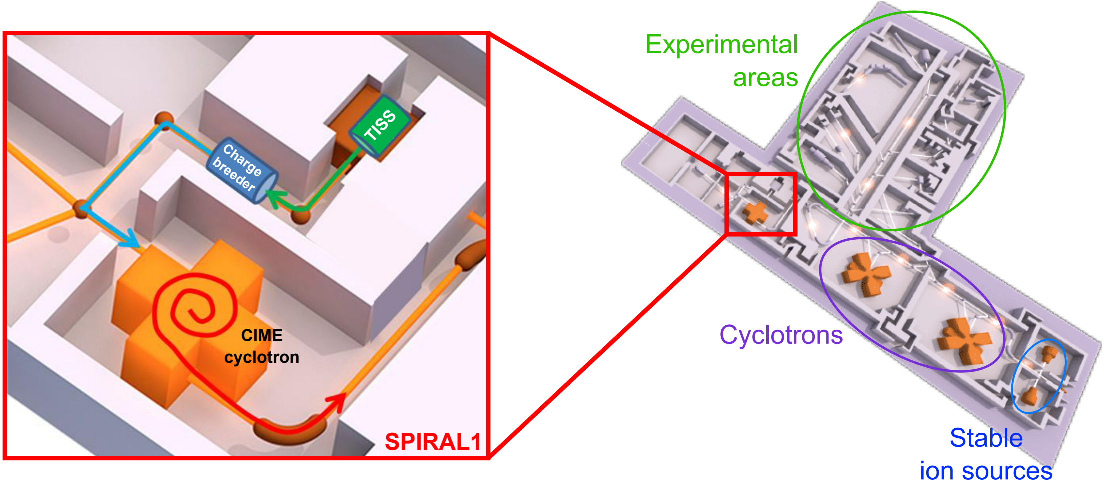
1 Where inside the GANIL? And which target?



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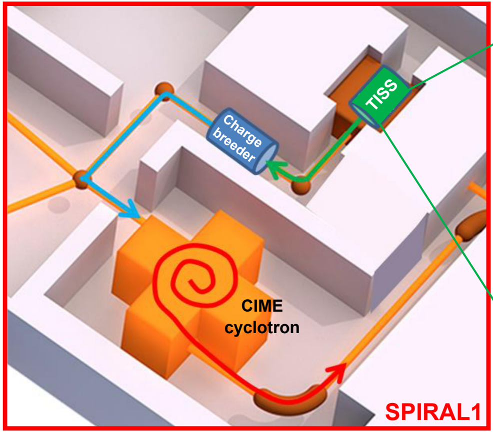
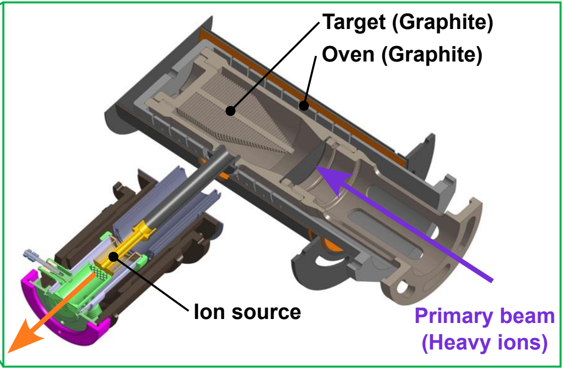


TISS: Target Ion Source System



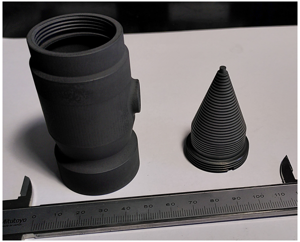
1 Where inside the GANIL? And which target?

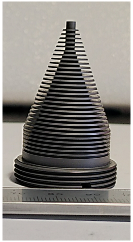
Primary beam (Heavy ions) All GANIL beams:
^{12}C to ^{238}U (< 95 MeV/u, < 2×10^{13} pps)

↓

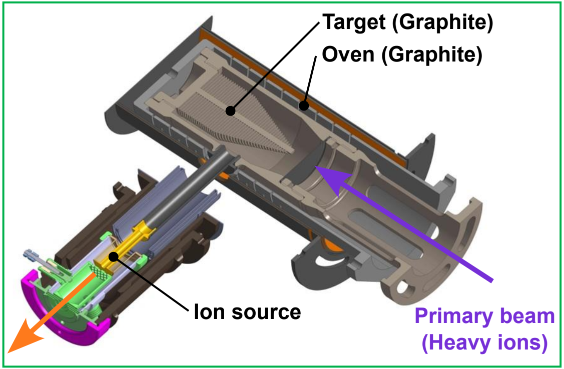
Target (Graphite) ... on ^{12}C target

→ ... to get beam fragmentation





TISS: Target Ion Source System



Secondary beam
Radioactive Ion Beam
(RIB)

1 Nuclear reaction & fragmentation principle

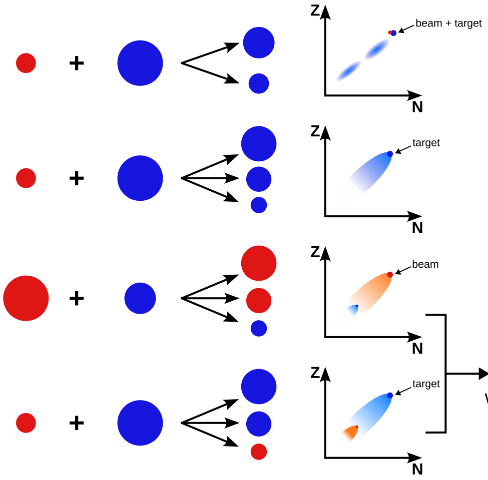
Fusion-fission

Spallation

Fragmentation

→Projectile fragmentation

→Target fragmentation



→ In-target production can be estimated with EPAX equations [Sümmerer, 2012] (Projectile and target fragmentation product).

2 Outline

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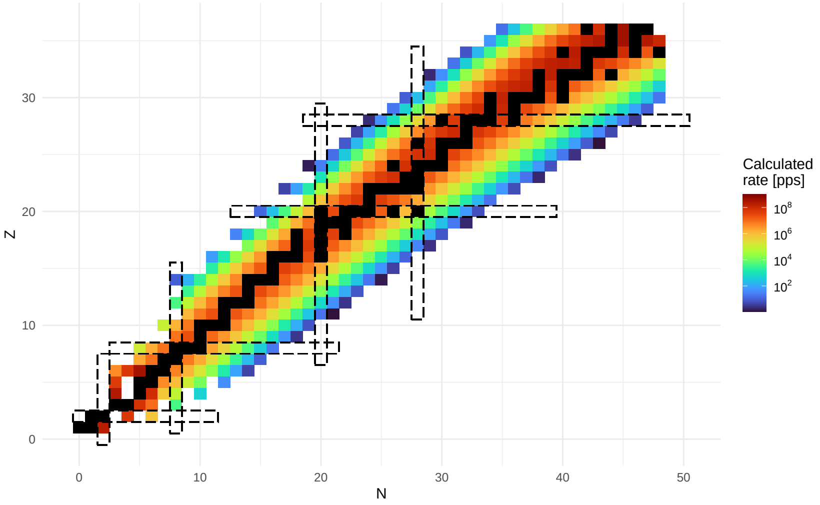
2 In-target yields: Krypton beam

84Kr on 12C



In-target yields estimated with EPAX equations [Sümmerer, 2012]:

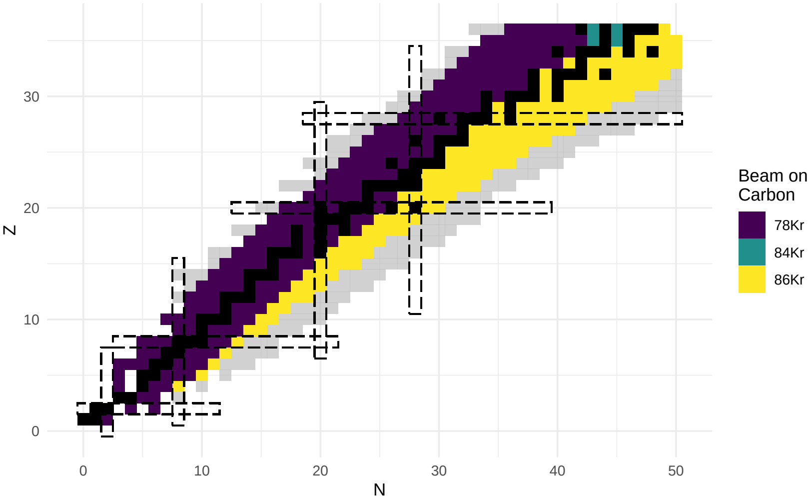
Beam:

- ^{84}Kr:
  - Energy: 66.8 MeV/A
  - Intensity: $600\ W$

Target:

- ^{12}C

2 Maximum in-target yields: Krypton beams



In-target yields estimated with EPAX equations [Sümmerer, 2012]:

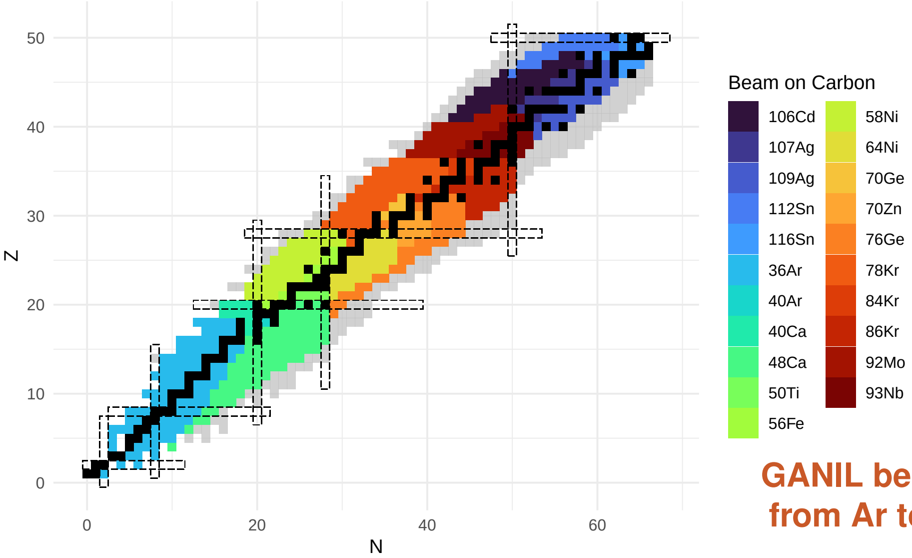
Beam:

- ^{78}Kr: 70.4 MeV/A, 1200 W
- ^{84}Kr: 66.8 MeV/A, 600 W
- ^{86}Kr: 57.9 MeV/A, 700 W

Target:

- ^{12}C

2 Maximum in-target yields: GANIL beams



GANIL beams: from Ar to Sn

3 Outline

3 New target material

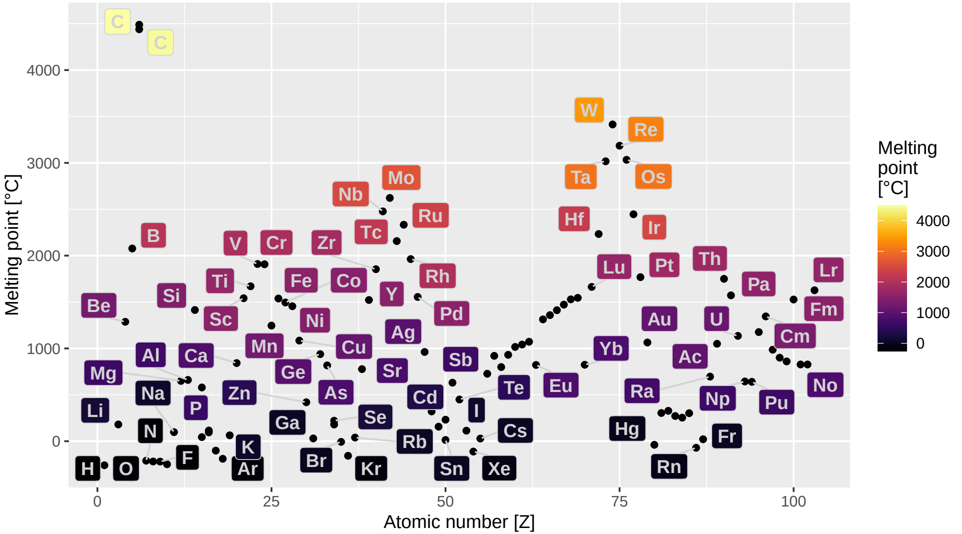
The main material selection criteria for ISOL targets [Ramos, 2020]:

- target element(s) for the **highest isotope production cross-section**,
- **high melting point** with **rapid diffusion/effusion of the radioisotopes of interest** (often tens of μm and porous)
- high radiation damage resistance,
- **low vapor pressure** to be compatible with ion source operation,
- compatibility with target structural materials,
- and eventually material shape, for e.g. foils, rods, powder, etc.

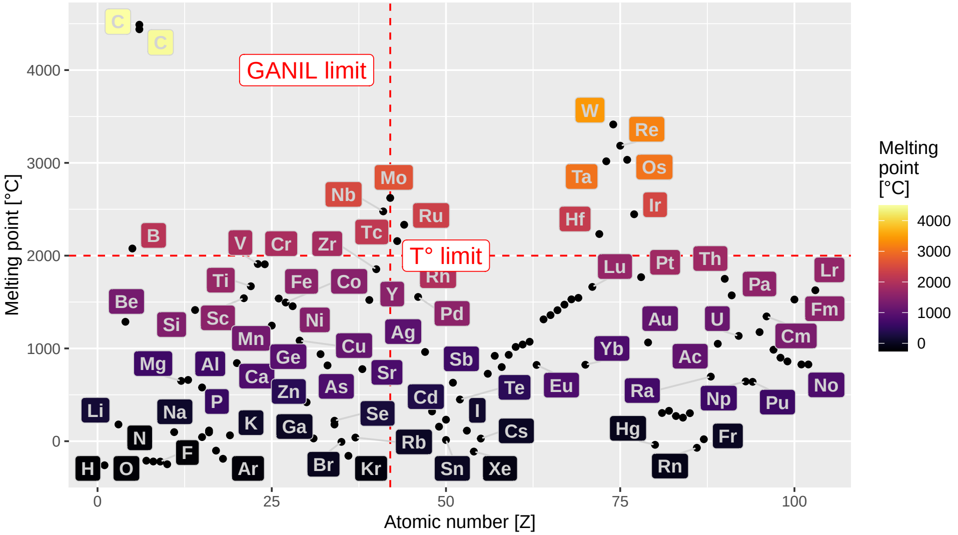
GANIL beam/target possibilities:

- All GANIL beams on ^{12}C target (^{12}C to ^{238}U beams, $<$ 95 MeV/u, $<$ 2E13 pps) $\rightarrow$ beam fragmentation
- **^{12}C beam on any target material up to Nb** $\rightarrow$ target fragmentation

3 Melting point of pure material



3 Melting point of pure material



3 New target: Temperature limit of pure material

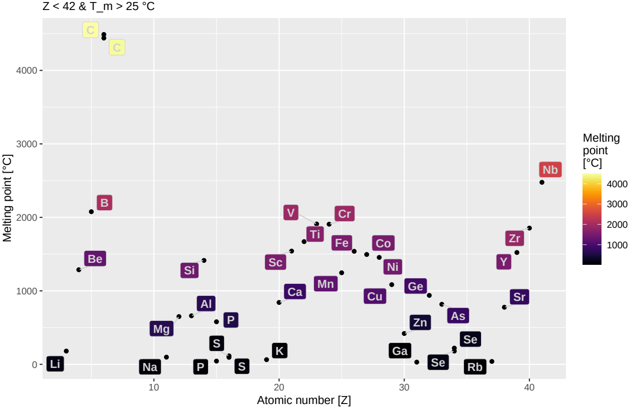


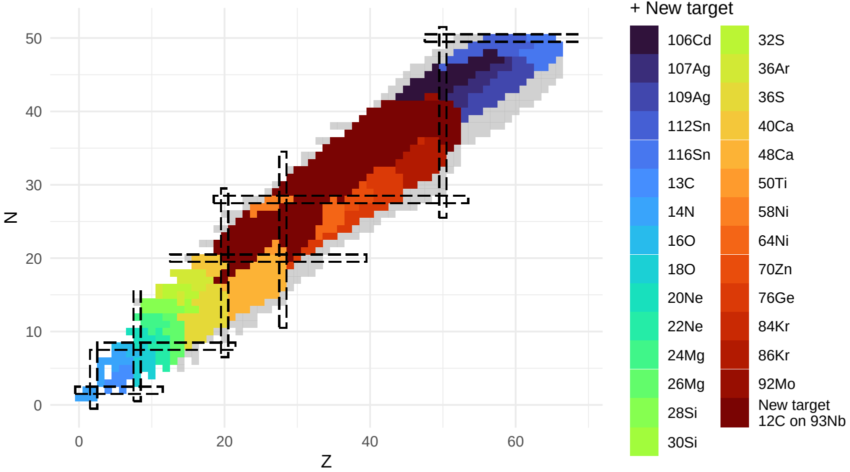
Table: Melting (T_m) and boiling (T_b) point of pure material below the Niobium element. Data from [Haynes, 2016].

Z		Element	T_m [℃]	T_b [℃]
6	C	Carbon	4489	3825
41	Nb	Niobium	2477	4741
5	B	Boron	2077	4000
23	V	Vanadium	1910	3407
24	Cr	Chromium	1907	2671
40	Zr	Zirconium	1854	4406
22	Ti	Titanium	1670	3287
21	Sc	Scandium	1541	2836
26	Fe	Iron	1538	2861
39	Y	Yttrium	1522	3345

3 New niobium target

Maximum in−target yield:

GANIL beams + new niobium target (4 kW 12C beam)



In-target yields estimated with EPAX equations [Sümmerer, 2012]:

GANIL beam fragmentation:

GANIL beams from Ar to Sn

Target: ^{12}C

GANIL target fragmentation:

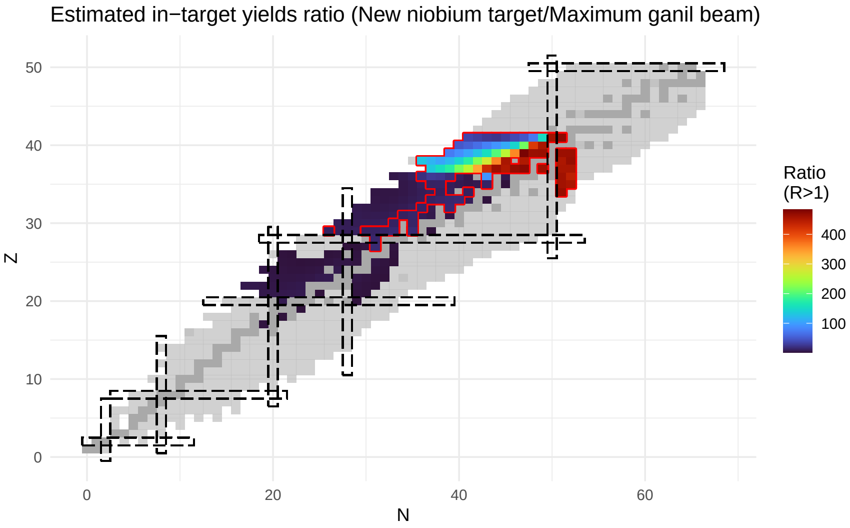
Beam:

- ^{12}C: 95 MeV/A, 4000 W

Target:

- ^{93}Nb

3 New niobium target



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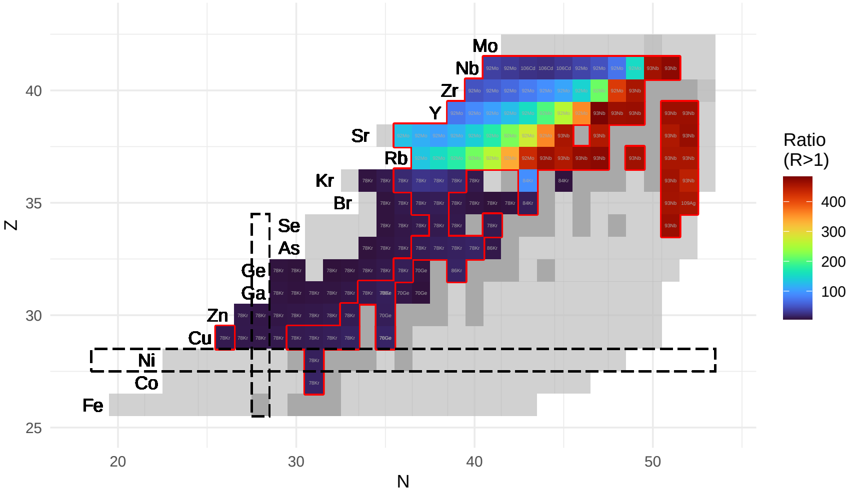
3 New niobium target

Estimated in−target yields ratio (New niobium target/Maximum ganil beam)



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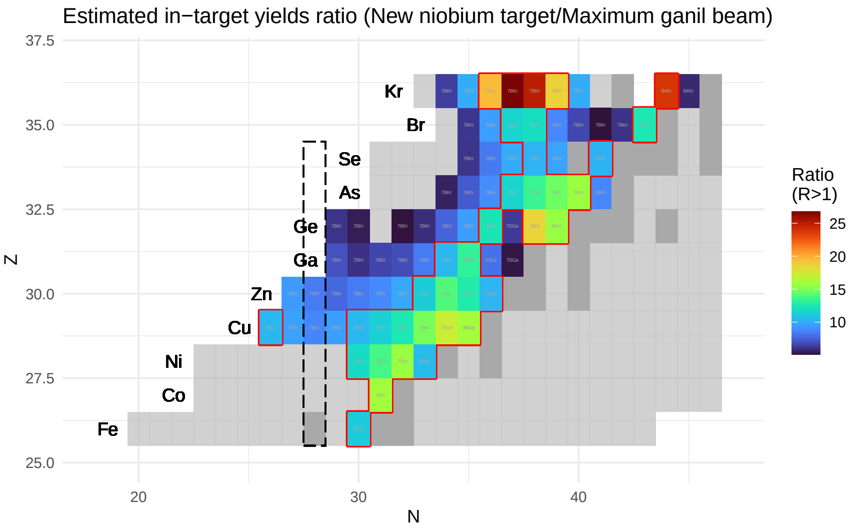

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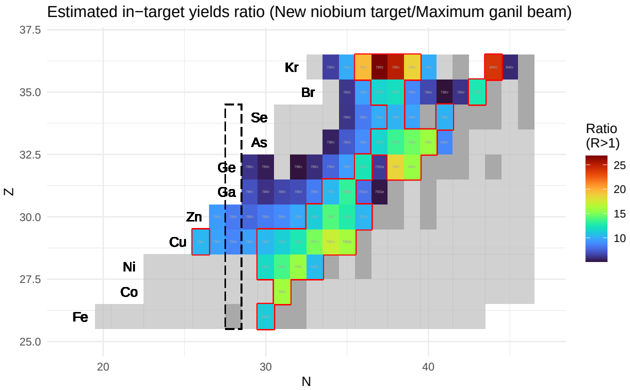


Limitations of in-target production estimation with EPAX:

- ^{12}C beam on Nb target: **outside the domain of validity of EPAX equations** (designed for beams between Ar-Pb)
- Alternative approaches needed for more accurate in-target production estimation

3 Niobium target: other ISOL facility

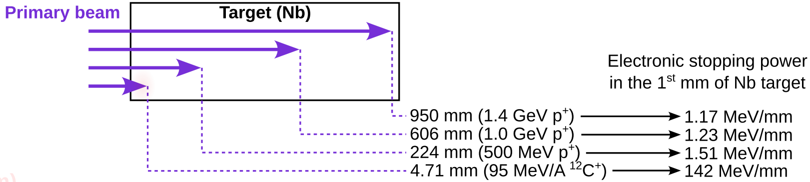
ISOLDE CERN: 1.0/1.4 GeV protons beam on Nb foil target [ISOLDE website,].
Yield results example:

- ^{54}Mn (312.3d), Surf-W: Yield = 1.10e+9 [μC]
- ^{77}Br (57.036 h) 1.4 GeV, Surf-Neg-Ir5Ce: Yield = 2.00e+9 [μC]
- ^{79}Kr (50 s), 1 GeV, Plasma-Cold-MK7: Yield = 2.30e+9 [μC]
- ...

ISAC TRIUMF: 500 MeV protons beam on Nb target [Kunz and et al.,].
Yield Results example:

- ^{83g}Sr (1.35 d), TRILIS Re surface: Yield = 1.440e+11 [1/s]
- ^{85g}Sr (64.85 d), TRILIS Re surface: Yield = 1.220e+11 [1/s]
- ^{83g}Rb (86.20 d), Re surface: Yield = 5.500e+10 [1/s]
- ...

3 New niobium target: beam impact



Disk target type (10x0.5 mm)

Energy deposition in the target

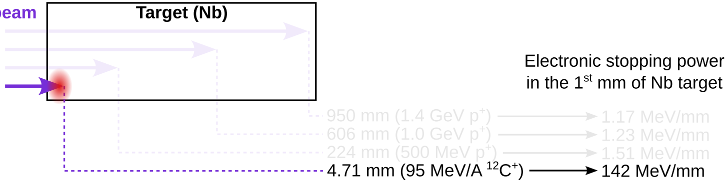
ANSYS

Beam heat flux

Temperature in target disks

Temperature in the target with the beam and target Ohmic heating

3 New niobium target: beam impact



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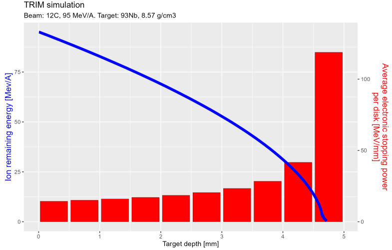
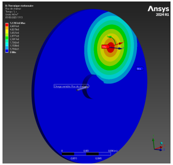
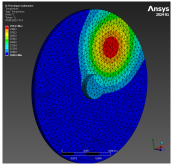


Energy deposition in the target

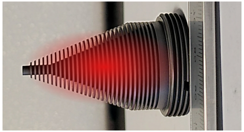
ANSYS



Beam heat flux



Temperature in target disks



Temperature in the target with the beam and target Ohmic heating

3 New target: possible material

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Pure metal:

- Niobium (disk or rolled foils, ...)

Composite material:

- e.g. yttrium carbide, zirconium oxide/carbide, silicon carbide
- ??

To correctly estimate the impact of the beam on the target and the target temperature under Ohmic heating via simulations (ANSYS, ...) :

- Needs material properties as function of the temperature: Electrical resistance, emissivity, thermal conduction, etc.

$\Rightarrow$ Usually incorrect, incomplete and/or unavailable at high temperature (> 300 ℃),

$\Rightarrow$ Need a way to measure those properties!

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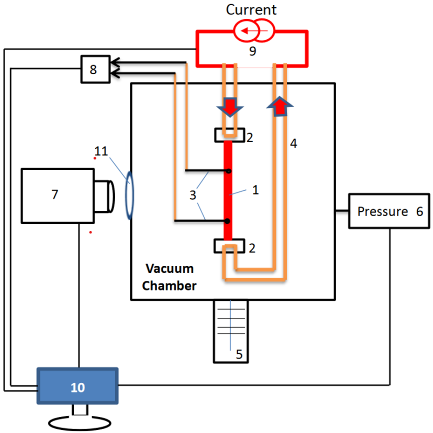


Figure 87: Schematic overview of the experimental set-up.

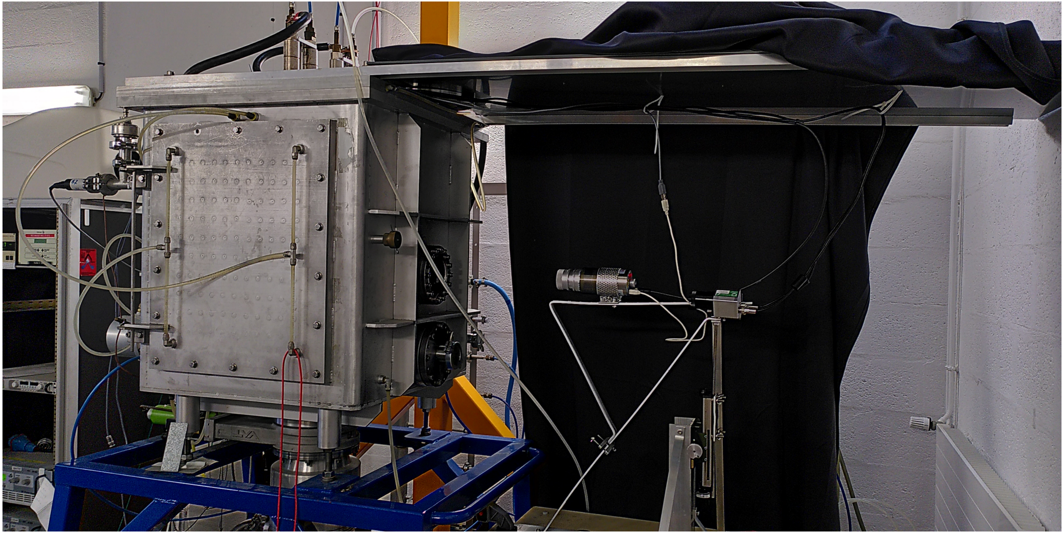
1. Metallic band
2. Tantalum clamps
3. Tantalum Wires
4. Cooled copper tubes
5. Turbo pump
6. Pressure gauge
7. Pyrometer
8. Voltmeter
9. Power supply
10. PC
11. Window

[Kuchi, 2018]

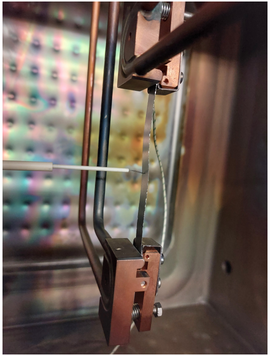
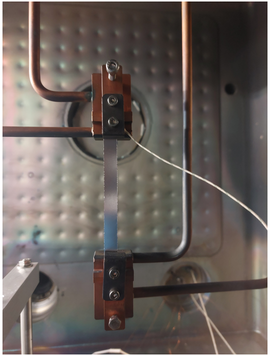
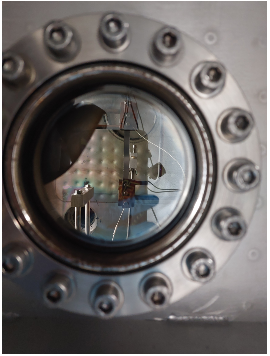
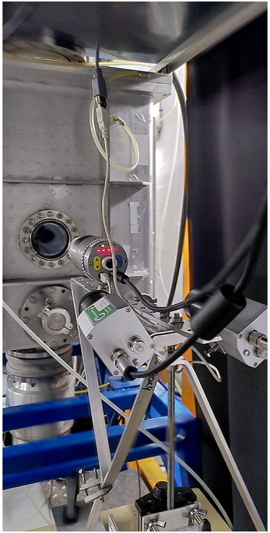
Characterization of the electrical resistance and the emissivity of various material, used for V. Kuchi PhD thesis:

- Chamber under vacuum ($> 10^{-6}\ mbar$),
- System with two clamps (100 mm separation) to hold the material sample (water-cooled) connected to an electrical power supply ($I_{max} = 500\ A$ and $V_{max} = 30\ V$),
- Set of wire connected to the sample to measure potential difference along the sample (**4 wires**),
- **Thermocouples installed** on the clamps which holds the sample,
- A window to look at the sample and measure the temperature with a bi-chromatic pyrometer and **two thermal cameras**.

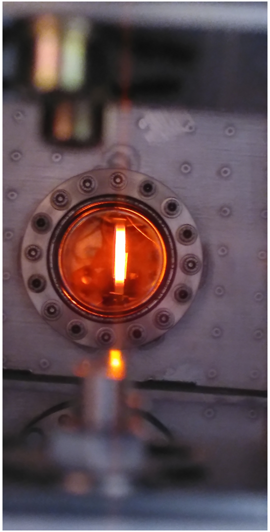
4 Setup (Photos)

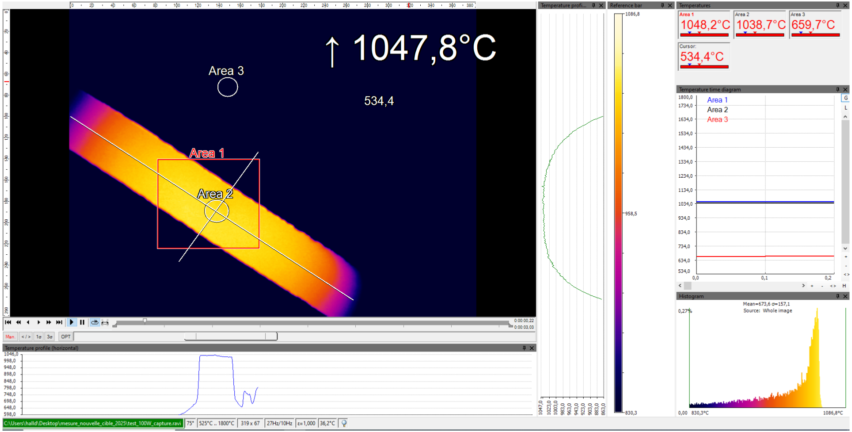


4 Setup (Photos)

4 Setup test with a tungsten sample





Thermal camera

4 Conclusion

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New fragmentation target possibilities at GANIL:

- ^{12}**C beam on target materials up to Nb** for target fragmentation studies:

⇒ Niobium targets
or composite materials (yttrium carbide, zirconium oxide/carbide, silicon carbide)

Future work on ^{12}C beam impact on new fragmentation targets:

- Energy deposition analysis and estimation of beam-induced temperature increase
- SRIM/TRIM simulations coupled with ANSYS thermal-electric analyses
  to evaluate multiple target designs
- Precise characterisation of temperature-dependent material properties
  for the new target materials

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Thank you for your attention

5 References

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Chart of ganil ion beams: Currently available and future beams at the GANIL.
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Back to Outline

Appendix

5 In-target yields: GANIL beams (Ar to Sn)

Beam	Energy [MeV/A]	Intensity [W]	Beam	Energy [MeV/A]	Intensity [W]
^{36}Ar[1]	95	2000	^{78}Kr[1]	70.4	1200
^{40}Ar[1]	35	400	^{84}Kr	66.8	600
^{40}Ca[1]	95	800	^{86}Kr[1]	57.9	700
^{48}Ca[1]	60.3	700	^{93}Nb[1]	56	100
^{50}Ti[2]	69	700	^{92}Mo[1]	60	100
^{56}Fe[1]	65	700	^{107}Ag[1]	52	100
^{58}Ni[1]	74.5	700	^{109}Ag[1]	35	100
^{64}Ni[1]	64.6	600	^{106}Cd[1]	66.5	100
^{70}Zn[1]	62.5	300	^{112}Sn[1]	63	100
^{70}Ge[1]	71.8	600	^{116}Sn[1]	30	100
^{76}Ge[1]	61.1	500			

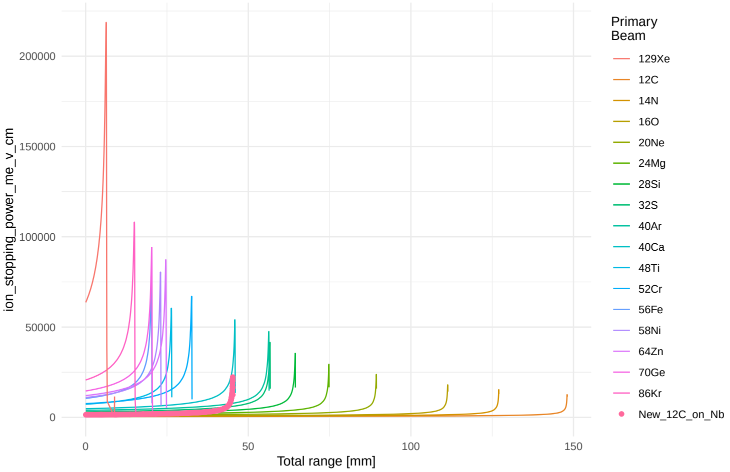
[1]: Beams done and accelerated in GANIL

[2]: Tested at the ion source and extrapolated, still not done for an experiment

[GANIL website,]

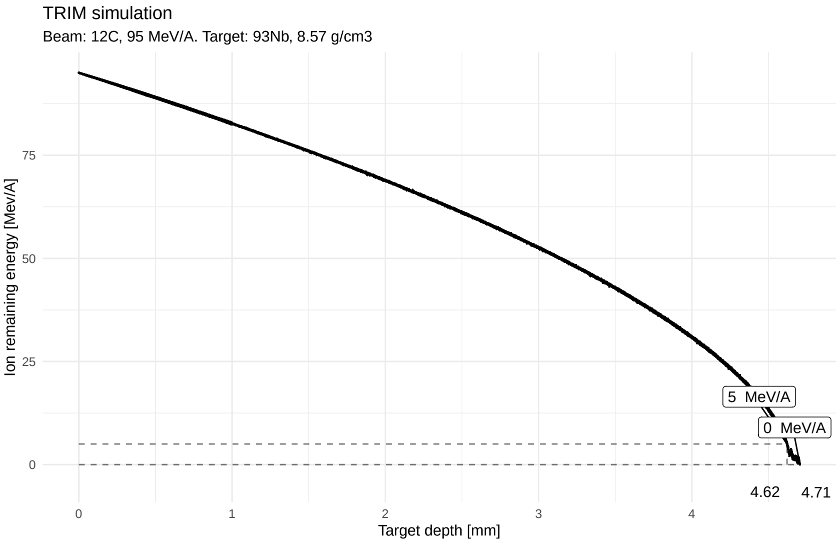
Target	Density ρ
^{12}C	2.267 $g.cm^{-3}$

5 Stopping power - GANIL Beam



[Estimated via SigmaSira]

5 SRIM/TRIM: Carbon on Niobium target



5 Recherche bibliographique

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A. Gottberg / Nuclear Instruments and Methods in Physics Research B 376 (2016) 8–15

Table 2
Overview (not exhaustive) of studied ISOL target materials. Underlined are materials that are currently, or have been recently, used for operations. (*) Engineered micro- or nano-structures have been developed for this material.

ISOL target materials				
Molten	Solid metals	Oxides	Carbides	Others
Au [24,25]	Cm [26]	Al_2O_3* [27,28]	AlC_2 [29]	AlN [28]
Ag [25]	Hf [30]	B_2O_3 [29]	B_4C [29]	BaB_6 [31]
Bi [24]	Ir [32,29]	BaO [33]	C (gr) [29,28]	$BaZrO_3$ [31]
Cd [34]	Ir/C [35]	BeO [36,29,28]	C (MWCNT)* [37–39]	BN [28]
Ce [25]	Ir/Ta [37]	CaO* [33,42,45]	CaC_2 [43]	Ca-zeolite [40]
Ce_3S_4 [31]	Mo [41]	CeO_2 [48]	CmC_x [26]	CaB_6 [33]
Er:Cu [24,25]	Nb [35,44]	Cr_2O_3 [32]	GdC_x [49]	$Ce(OH)_4$ [46]
Ge [47,34]	Os [32]	HfO_2* [50]	LaC_2* [33]	CaF_2 [43]
Gd:Cu [25]	Pu	La_2O_3 [48]	ScC_2 [35,33]	CeB_6 [31]
Hg [34]	Pt/C [44]	MgO [33,45,28]	SiC* [32,44,27,28]	CeS [31,28]
La [34,51]	Re [35,32]	NiO [54]	TaC_x [32,33]	LuF_3 [52]
La:Th [34]	Re/C [30]	SrO [55]	ThC_2 [44,33,26,56]	Na-zeolite [40]
La:X [34]	Ru [32]	Ta_2O_3 [30,32]	TiC* [32,38]	Ta_5Si_3 [32]
NaF:LiF [53]	Ru/C [30]	ThO_2* [48,32,50]	UC_x* [58,31,26,56]	Hf_5Ge_3 [32]
NaF:ZrF_4 [53]	Si layers [41]	TiO_2* [50]	VC [31,32]	Hf_5Si_3 [29]
Nd [25]	Sn/C [44]	UO_2 [59]	ZrC [32,59,49]	Hf_5Sn_3 [32]
Ni [25]	Ta* [35,57,29]	Y_2O_3* [61]		Ta_5Si_3 [32]
Pr [25]	Ti [35,44]	ZrO_2 [34,32,50]		Tl-zeolite [40]
Pt:B [24]	Th [41,26]			$Th(OH)_4$ [46]
Sc:La [34]	Th/Nb [35]			Zr_5Ge_3 [32,28]
Sn [34,60]	U [26]			Zr_5Si_3 [32,28]
Tb [34]	U/C [32]			
TeO_2:KCl:LiCl [32]	V [35,31]			
ThF_4:LiF [24]	W [31]			
Pb [34,51]	Zr [35,59]			
Pb:Bi [62]				
Y:La [34]				
U [63]				
U:Cr [34]				
Zn [34]				

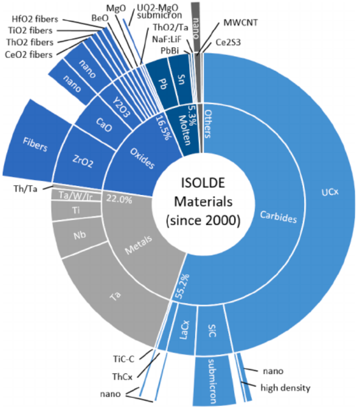

Fig. 1. Sunburst plot of the number of operated target materials at ISOLDE for the past 19 years (since the year 2000) – total of 395 target – showing the material classes (1s level), material compounds (2nd level) and engineered microstructure materials (3rd level – total of 18.5%).

[Gottberg, 2016] [Ramos, 2020]

5 Recherche bibliographique

Matériaux de cible ISOL :

- Molten: Pb, Sn
- Metals: Ta, Nb
- Oxides: CaO, ZrO_2
- Carbides: UCx
- Others: Ce_2S_3

Formes :

- Foil
- Powder/Pellet
- Fiber/Felt

Tailles :

- macro
- micro
- nano

Z		Molten	Solid metals				Oxides					Carbides			Others
			--	Foil	Powder	Fiber	--	Powder	Pellet	Fiber	Felt	--	Powder	Pellet	
31	Ga														
32	Ge	Gott16													Alt96(Ge)
33	As														
34	Se														
35	Br														
36	Kr														
37	Rb														
38	Sr						Gott16(SrO)		Pera03(SrZrO3)		Pera03(SrO)				
39	Y	Gott16(Y:La)					Gott16(Y2O	Ram20(Y2O	Pera03(Y2O3)		Pera03(Y2O3), Ram20(Y2O3)				
40	Zr		Gott16	Dom90, Pera03			Hoff83(ZrO2), Gott16(ZrO		Pera03(ZrO2	Ram20(ZrO2	Hag92(ZrO2)	Barz97(ZrCx),	Hoff83(ZrC-C3), Dom90(ZrC		Hoff83(Zr5Ge
41	Nb		Gott16	Dom90, Hag92, Pera03								Ram20(NbC)			
42	Mo		Gott16	Pera03											
43	Tc	Gott16(TcO2:KCl:LiCl)													
44	Ru		Gott16(Ru)		Hoff83(Ru)							Hoff83(Ru/graphite), Gott16(Ru/C)			
45	Rh														
46	Pd														
47	Ag	Gott16													
48	Cd	Gott16(Cd, Cd:Cu)													
49															
50	Sn	Gott16, Ram	Gott16(Sn/C)		Hag92(Sn/Graphite mix)										
51															