

GANIL

Development of a new SPIRAL1 fragmentation target to enhance and expand radioactive isotope production at GANIL

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¹Grand Accélérateur National d'Ions Lourds (GANIL), France

0 Outline

- ➊ Introduction - SPIRAL1-GANIL projectile fragmentation targets
- ➋ New fragmentation targets
- ➌ Beam impact on a niobium target
- ➍ Conclusion & Outlook

1 Outline

- 1 Introduction - SPIRAL1-GANIL projectile fragmentation targets
- 2 New fragmentation targets
- 3 Beam impact on a niobium target
- 4 Conclusion & Outlook

1 GANIL installation

SPIRAL2

- Experimental areas:
e.g. S^3 (In-flight)
- LINAC
(p^+ 33 MeV, $^2H^+$ 40 MeV,
heavy ions < 14.5 MeV/A)

DESIR

Historic GANIL

- Experimental areas
- Cyclotrons
- Beam: C to U
Energies < 95 MeV/A

SPIRAL1 (ISOL)

- TISS (e.g. FEBIAD, TULIP)
- CIME (Post-acceleration up to 25 MeV/A)

1 GANIL installation

SPIRAL2

- Experimental areas:
e.g. S^3 (In-flight)
- LINAC



Recent advances of the S3-Low Energy Branch

Sarina Geldhof (GANIL)

Presentation: Tuesday 21/10 17:10

Implementation of Laser Resonance

Chromatography at S3

Mustapha Laatiaoui (GANIL)

Poster: Tuesday 21/10 18:00

The Super Separator Spectrometer (S3) for the very high intensity beams of GANIL/SPIRAL2

Hervé Savajols (GANIL)

Poster: Tuesday 21/10 18:00

DESIR

Historic GANIL

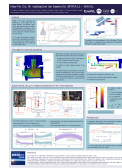
- Experimental areas
- CIME
- BE
- ER



Producing short-lived isotopes by fusion evaporation reactions in the TULIP TISS at GANIL

Pascal JARDIN (GANIL)

Presentation: Friday 24/10 10:30



New Fe, Co, Ni radioactive ion beams for SPIRAL1 - GANIL

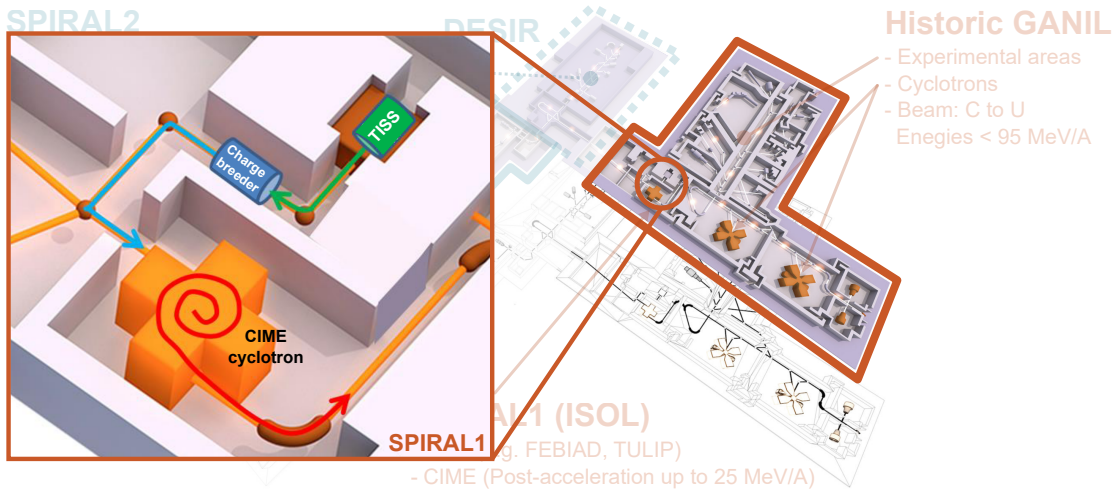
Erwan Le Villain (GANIL)

Poster: Tuesday 21/10 18:00

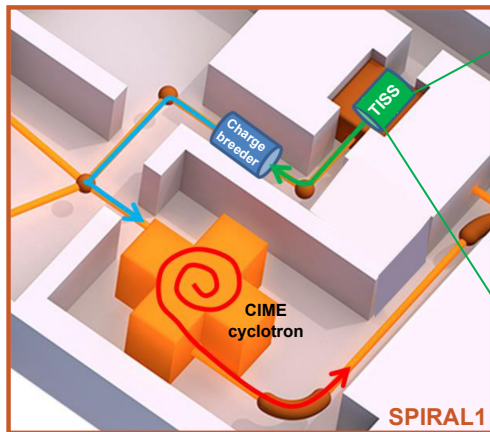
SPIRAL1 (ISOL)

- TISS (e.g. FEBIAD, TULIP)
- CIME (Post-acceleration up to 25 MeV/A)

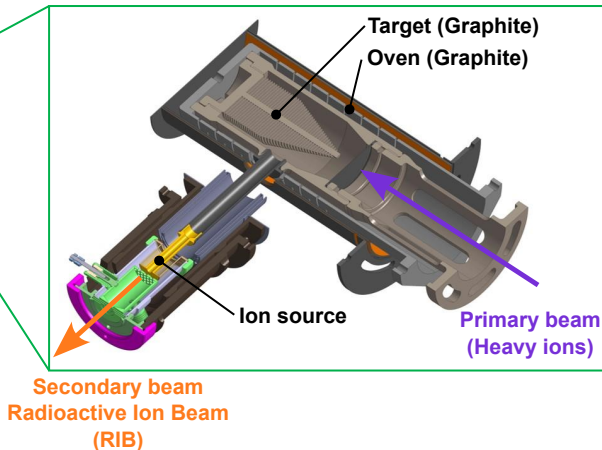
1 GANIL installation



1 Where inside the GANIL? And which target?



TISS: Target Ion Source System

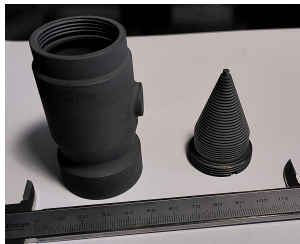


1 Where inside the GANIL? And which target?

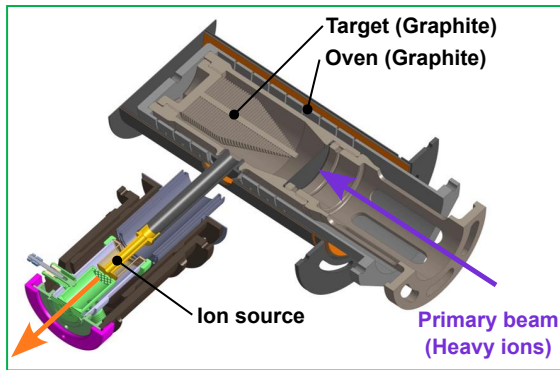
Primary beam (Heavy ions) All SPIRAL1 beams:
 ^{12}C to ^{238}U ($< 95 \text{ MeV/A}$, $< 2 \times 10^{13} \text{ pps}$)

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

... to get beam fragmentation

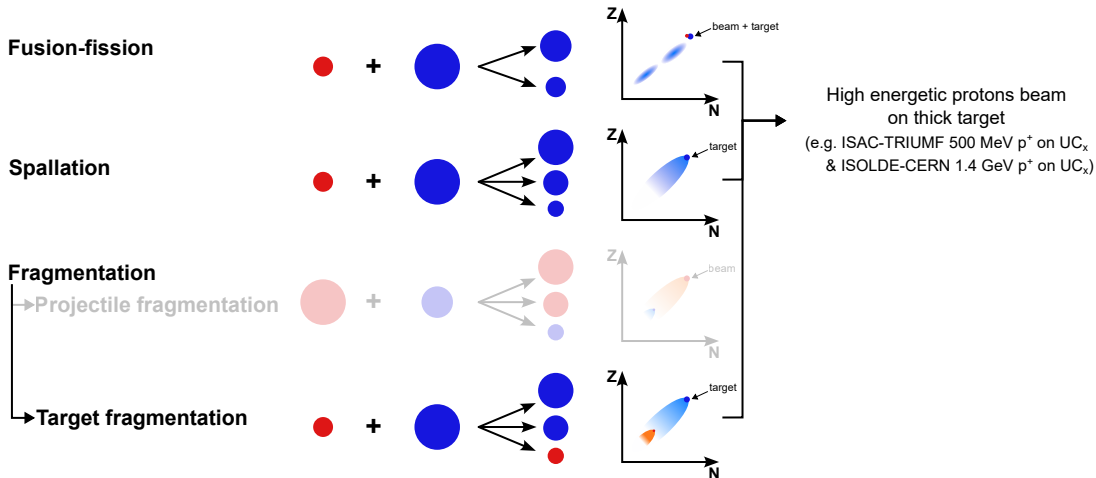


TISS: Target Ion Source System

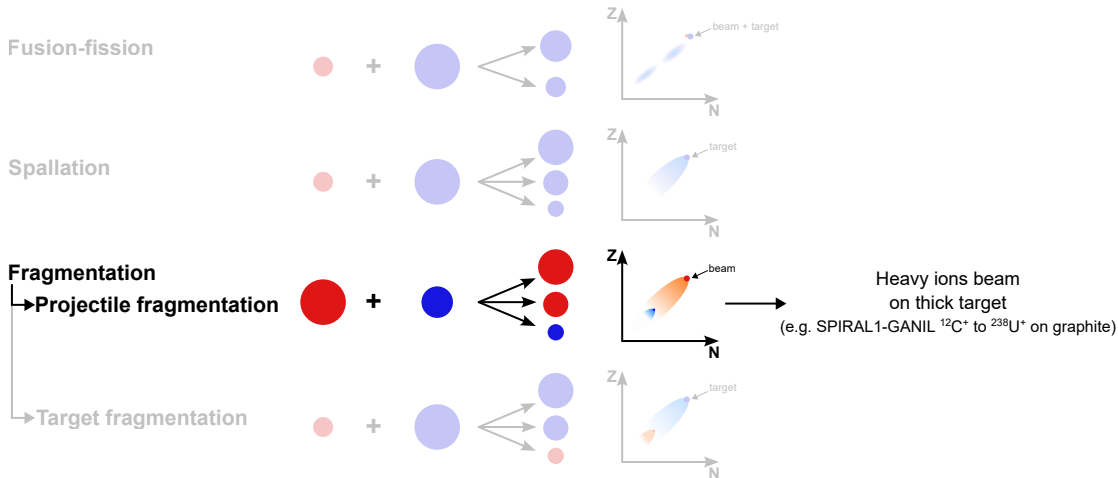


**Secondary beam
Radioactive Ion Beam
(RIB)**

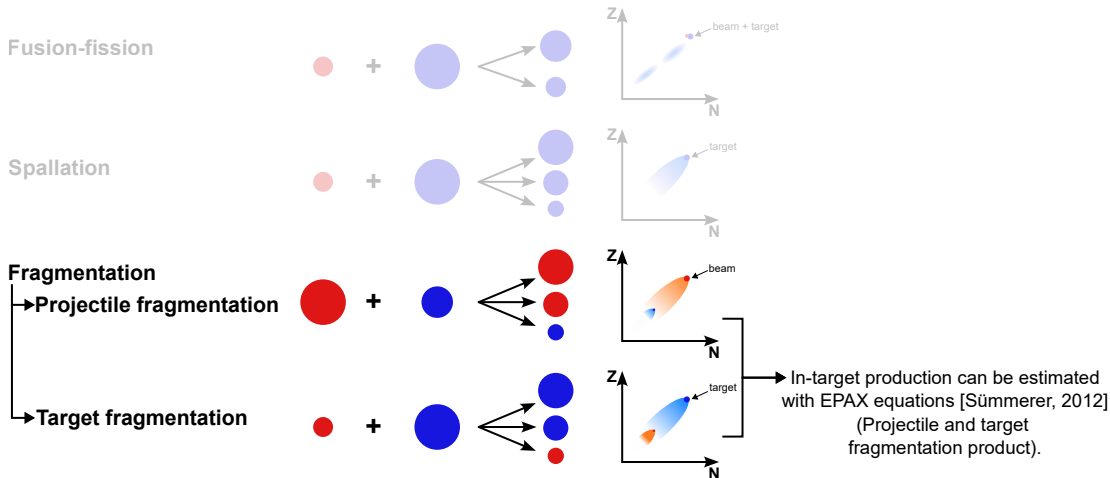
1 Isotope production - Nuclear reaction



1 Isotope production - Nuclear reaction

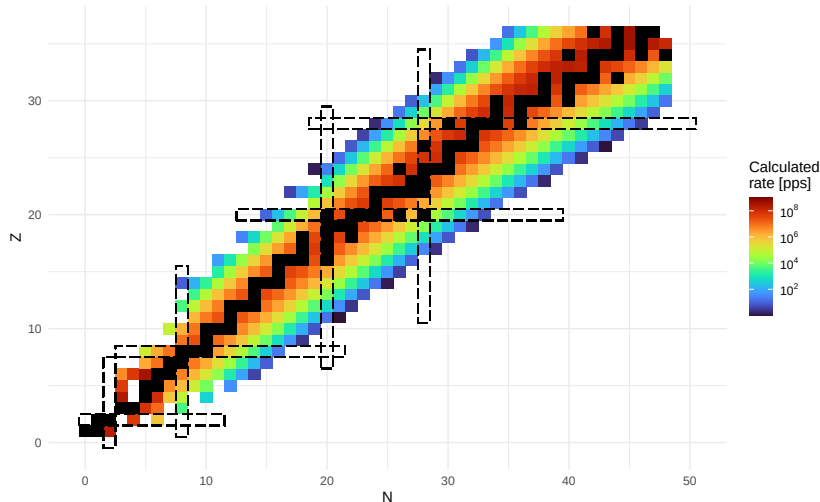


1 Isotope production - Nuclear reaction



1 In-target yields example: Krypton beam

^{84}Kr on ^{12}C



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

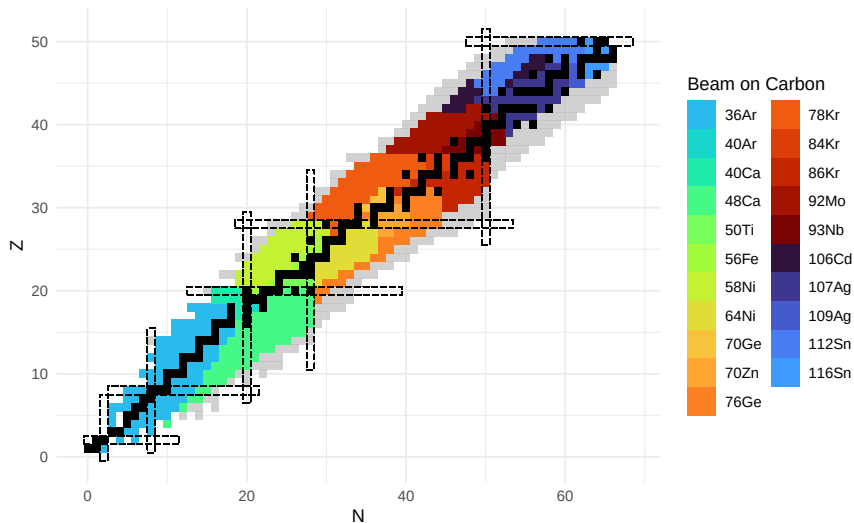
Beam:

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

Target:

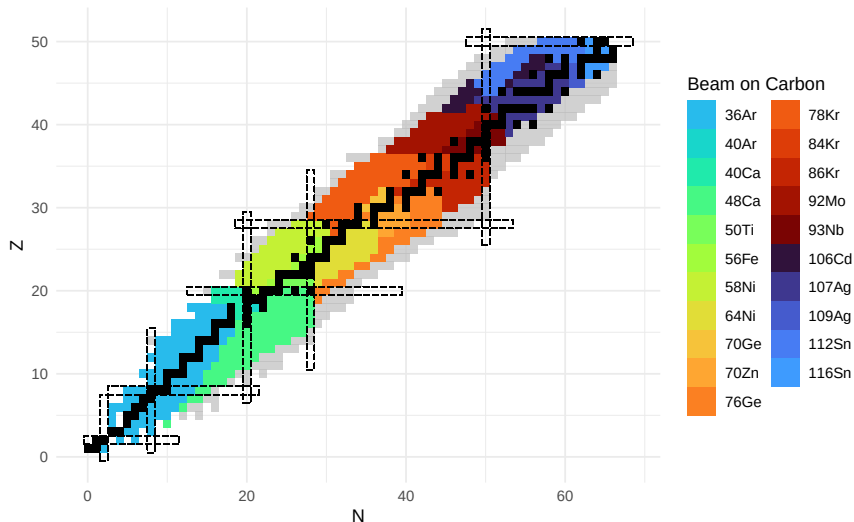
- ▶ ^{12}C

1 Maximum in-target yields: GANIL beams



**GANIL beams:
from Ar to Sn**

1 Maximum in-target yields: GANIL beams



**Beam fragmentation
less efficient
at high masses:**

Lower primary beam
energy and intensity

← **Nb-Sn beams:**

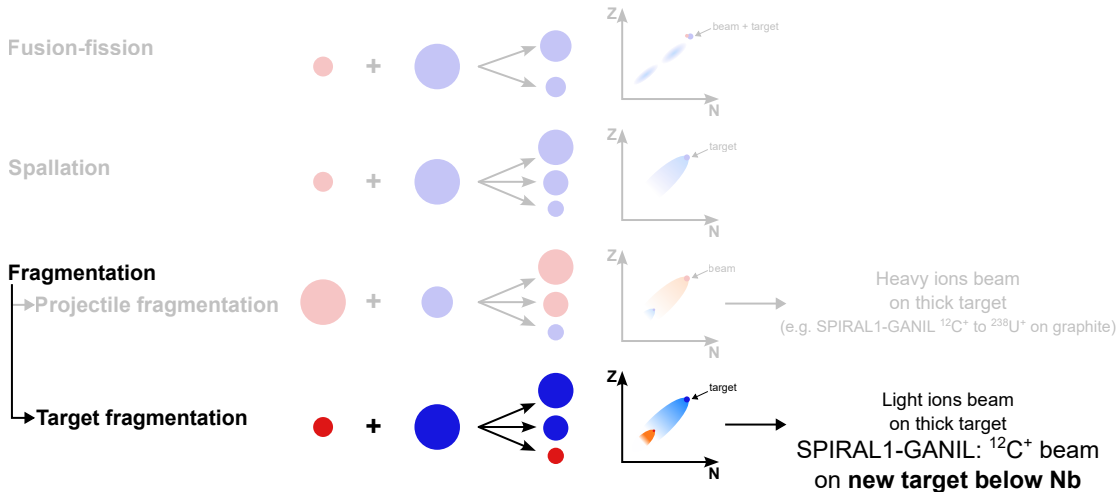
Energy: 30-67 MeV/A

Intensity: $< 50 W$



Solution
New target type

1 Isotope production - Nuclear reaction



2 Outline

- 1 Introduction - SPIRAL1-GANIL projectile fragmentation targets
- 2 New fragmentation targets**
- 3 Beam impact on a niobium target
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2 New target material

Material selection criteria for ISOL targets [Ramos, 2020]:

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

Pure material:

- ▶ Nb
- ▶ Zr
- ▶ Y
- ▶ V

Composite material:

- ▶ ZrC
- ▶ ZrO₂
- ▶ Y₂O₃
- ▶ VC

T_m [Haynes, 2016]

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- ▶ **GANIL facility regulation**: target element below Nb.

Pure material:

- ▶ Nb ($T_m = 2500^\circ\text{C}$) 
- ▶ Zr ($T_m = 1900^\circ\text{C}$) 
- ▶ Y ($T_m = 1500^\circ\text{C}$) 
- ▶ V ($T_m = 1900^\circ\text{C}$) 

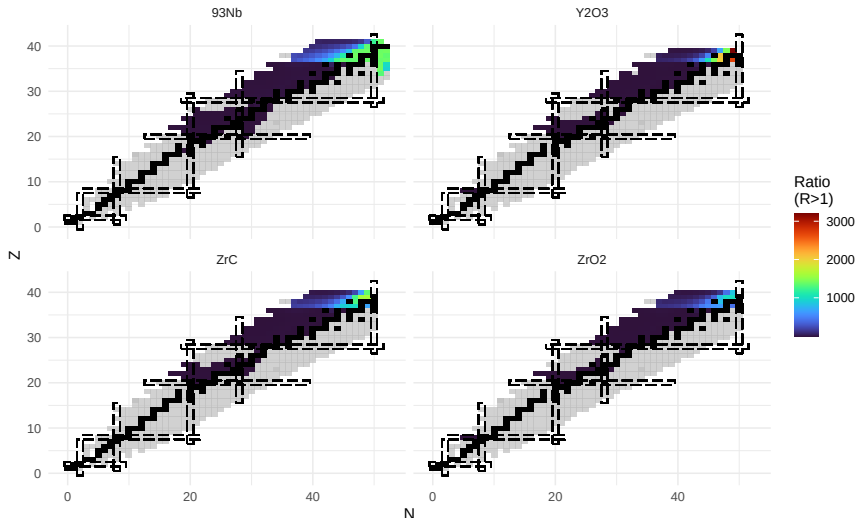
Composite material:

- ▶ ZrC ($T_m = 3500^\circ\text{C}$) 
- ▶ ZrO₂ ($T_m = 2700^\circ\text{C}$) 
- ▶ Y₂O₃ ($T_m = 2400^\circ\text{C}$) 
- ▶ VC ($T_m = 2800^\circ\text{C}$) 

T_m [Haynes, 2016]

2 New targets - In-target production

Estimated in-target yield ratio (New target/Maximum GANIL 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:

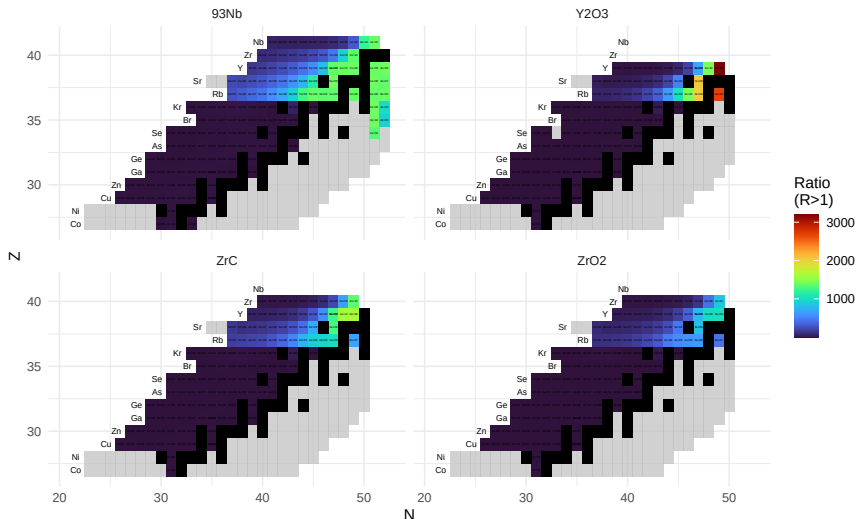
► ^{12}C : 95 MeV/A, 3000 W

Targets:

► ^{93}Nb , Y_2O_3 , ZrC , ZrO_2

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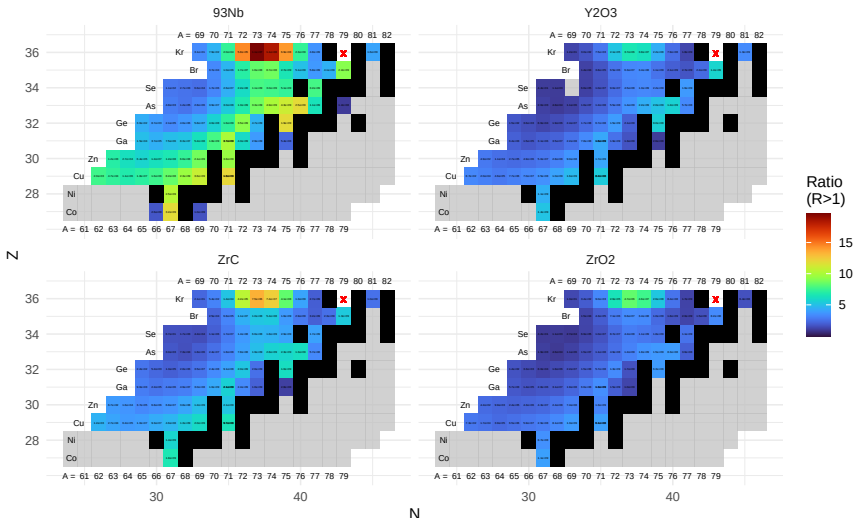
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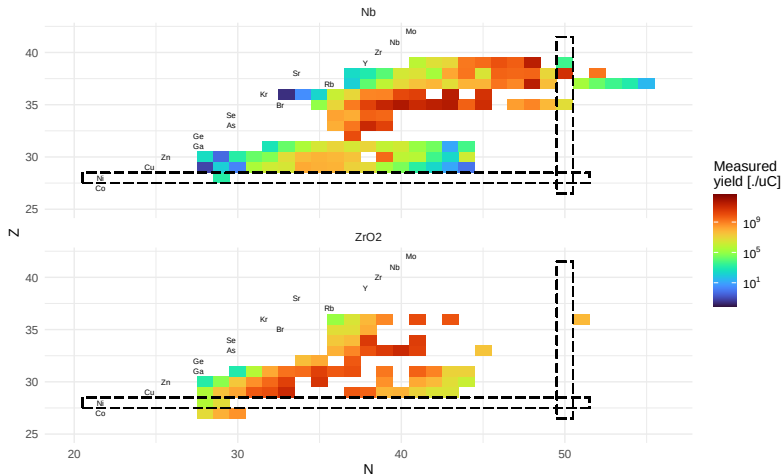
► ^{12}C : 95 MeV/A, 3000 W

Targets:

► ^{93}Nb , Y_2O_3 , ZrC , ZrO_2

2 Isotope extracted - Existing measure

Measured yield (ISOLDE & ISAC Database)



ISOLDE yield database [ISOLDE Website,]

- Nb target: ($> 10^{10} \mu C^{-1}$)
⁷⁹Kr (50s), ⁷⁷Br (57h), ⁷⁶Br (16h),
⁷⁵Br (97m), ⁷¹As (65h), ...
- ZrO₂ target: ($> 10^{10} \mu C^{-1}$)
⁷³As (80d), ⁶⁸Ga (67m), ⁶⁶Ga (9h),
⁶⁵Zn (240d), ⁶³Zn (38m), ...

ISAC yield database [Kunz and et al.,]

- Nb target: ($> 10^{10} s^{-1}$)
^{83g}Sr (1.4d), ^{85g}Sr (65d),
^{83g}Rb (86s), ...

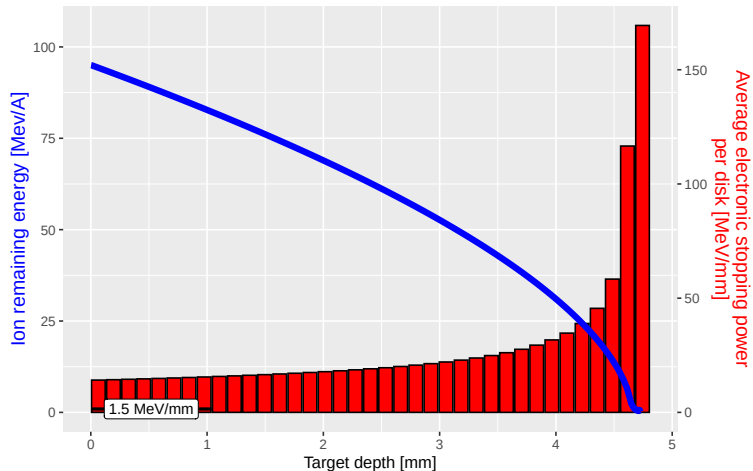
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3 Beam impact on the target

TRIM simulation

Beam: $^{12}\text{C}^+$, 95 MeV/A. Target: ^{93}Nb , 8.57 g/cm³, 130 μm disk thickness



Beam range into a niobium target:

- 1.4 GeV p⁺:
→ 950 mm
- 1.0 GeV p⁺:
→ 600 mm
- 500 MeV p⁺:
→ 225 mm
($\approx 1.5 \text{ MeV/mm}$ in the 1st mm)
- 95 MeV/A $^{12}\text{C}^+$:
→ **4.7 mm**
(147 MeV/mm in the 1st mm)

⚠ Target heating

3 Target shape - Beam range & beam heating

Rolled foils

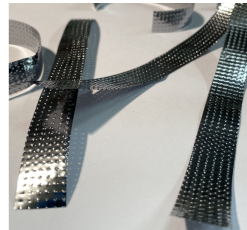
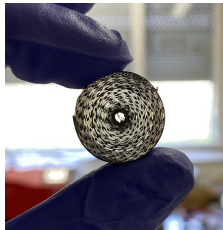
- ❗ **Difficulties:** Precise beam range, element diffusion outside the rolled foils, foils sintering.

Disks

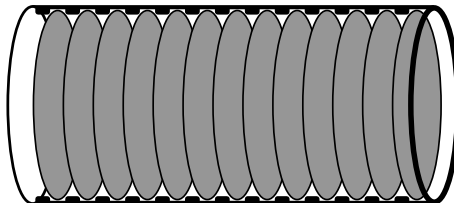
- ❗ **Difficulties:** Need splitting support (temperature inhomogeneity), decreasing the disk thickness increases disk numbers, heat exchange limited.

Bended foils

- 🔧 **Heat radiation:** Increase radiative surface,
- ⬇️ **Beam range:** Increase matter seen by the primary beam,
- 🔧 **Diffusion:** Keep small foil thickness,
- 🔧 **Mechanical:** self support, small contact point between foils, foil height can be adjusted depending on the beam heat deposition.



Embossed Ti and V metallic foils [Mamis et al., 2024]



3 Target shape - Beam range & beam heating

Rolled foils

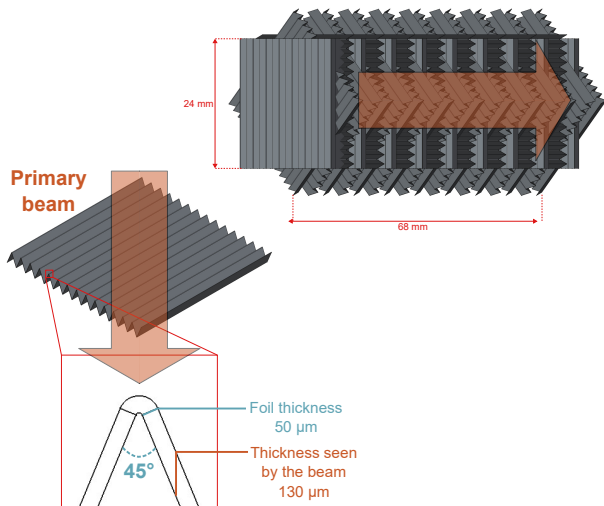
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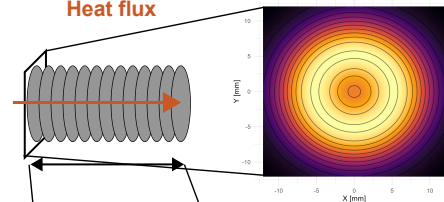
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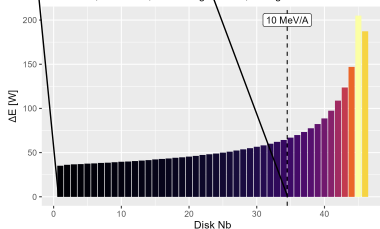
3 Beam heating

Primary beam input:
Heat flux

Beam wobulation: 2D profil
Initial beam power: 35.2 W in disk 1.
Wobulation radius: 6.5 mm. Beam width: 3.4 mm.



TRIM simulation: Energy deposited by disk
Beam: 12C, 95 MeV/A, 3 kW. Target: 93Nb, 8.57 g/cm³

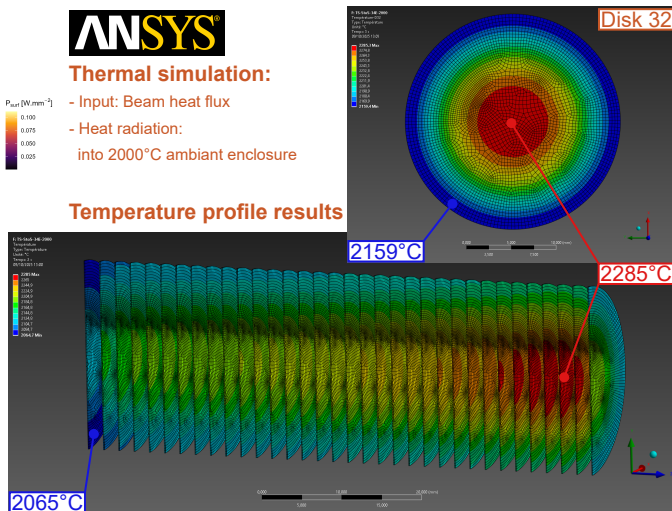


ANSYS®

Thermal simulation:

- Input: Beam heat flux
- Heat radiation:
into 2000°C ambient enclosure

Temperature profile results



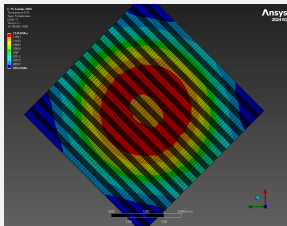
4 Outline

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- ② New fragmentation targets
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4 Conclusion & Outlook

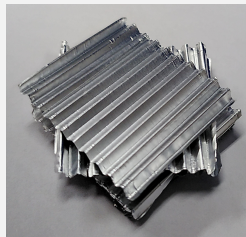
Development of a new fragmentation targets for SPIRAL1-GANIL:

- ▶ From C to U beams on graphite (C) target to C beam on Nb or ZrO_2 targets,
- ▶ Improve the in-target production in Kr-Cu region,
- ▶ Study the beam heating impact on the material (Simulation),
- ▶ Design a new target type (On-going).



In the future

- ▶ Improve the target design with thermal simulation,
- ▶ Target construction: study the foil bending behaviour in room temperature and at high temperature,
- ▶ Experiment: test a full target at high temperature and on-line.



Preliminary mechanical test with aluminium foil



CANIL

Thank you for your attention

5 References

-  [GANIL website.](#)
Chart of ganil ion beams: Currently available and future beams at the GANIL.
<https://u.ganil-spiral2.eu/chartbeams/>.
-  [Haynes, W. \(2016\).](#)
CRC Handbook of Chemistry and Physics.
[CRC Press.](#)
-  [ISOLDE Website.](#)
The ISOLDE yield database.
<http://isoyields2.web.cern.ch>.
-  [Kunz, P. and et al.](#)
ISAC yield database.
<http://mis.triumf.ca/science/planning/yield/beam>.
-  [Mamis, E., Duchemin, C., Berlin, V., Bernerd, C., Bovigny, M., Chevallay, E., Crepieux, B., Gadelshin, V. M., Heinke, R., Hernandez,](#)
[R. M., Johnson, J. D., Kalniņa, P., Koliatos, A., Lambert, L., Rossel, R. E., Rothe, S., Thiboud, J., Weber, F., Wendt, K., Zablockis, R. J., Pajuste, E., and Stora, T. \(2024\).](#)
Target development towards first production of high-molar- activity 44gsc and 47sc by mass separation at cern-medicis.
Pharmaceuticals, 17(3).
-  [Ramos, J. \(2020\).](#)
Thick solid targets for the production and online release of radioisotopes: The importance of the material characteristics – a review.
Nuclear Instruments and Methods in Physics Research Section B: Beam Interactions with Materials and Atoms, 463:201–210.
-  [Sümmerer, K. \(2012\).](#)
Improved empirical parametrization of fragmentation cross sections.
Phys. Rev. C, 86:014601.

[◀ 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	25
⁵⁰ Ti ²	69	700	⁹² Mo ¹	60	35
⁵⁶ Fe ¹	65	700	¹⁰⁷ Ag ¹	52	44
⁵⁸ Ni ¹	74.5	700	¹⁰⁹ Ag ¹	35	12
⁶⁴ Ni ¹	64.6	600	¹⁰⁶ Cd ¹	66.5	22
⁷⁰ Zn ¹	62.5	300	¹¹² Sn ¹	63	34
⁷⁰ Ge ¹	71.8	600	¹¹⁶ Sn ¹	30	17
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 Beam shape

Beam wobulation: Radial profil by disk

Initial beam power: 3 kW. Wobulation radius: 6.5 mm. Beam width: 3.4 mm.

