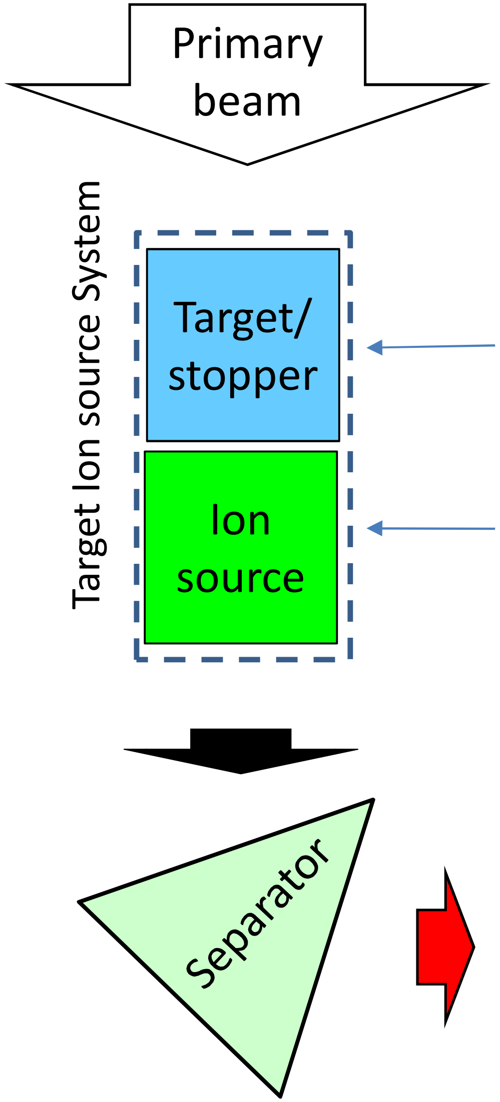
Development of Ion-Source Systems for the production of (short-lived) radioactive ion beams by the ISOL method:

How could the design be more efficient ?

P. Jardin, GCS (Groupe Cible Source, GANIL)

ISOL production principle



Solid, liquid or gaseous material. Adapted to the primary beam and to the element to produce and release

Adapted to the physico-chemical features of the element to ionize

Towards experimental area or post-acceleration

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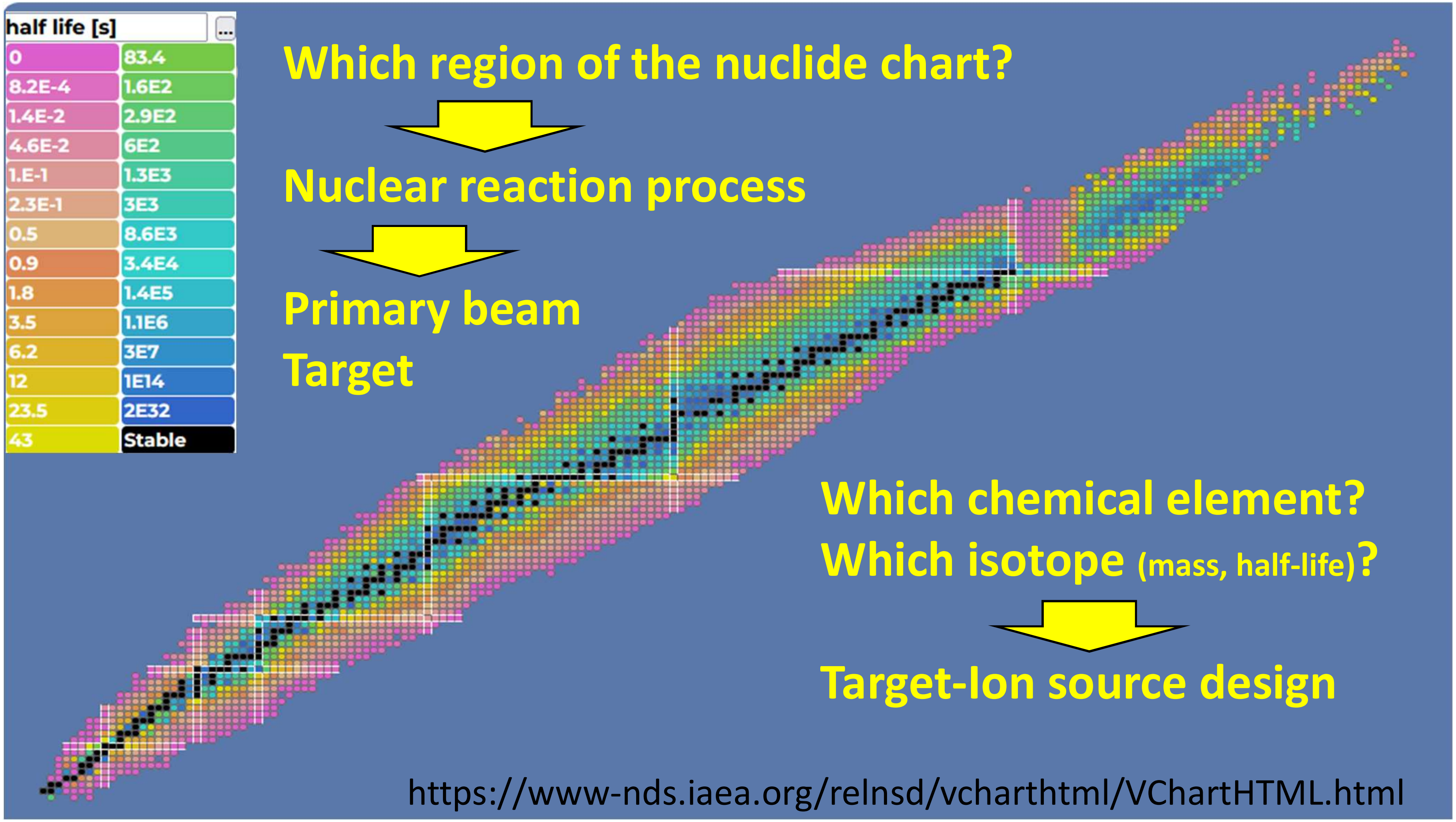
The design of a production system is guided by the objective



Which region of the nuclide chart?

↓

Nuclear reaction process

↓

Primary beam

Target

Which chemical element?

Which isotope (mass, half-life)**?**

↓

Target-Ion source design

https://www-nds.iaea.org/relnsd/vcharthtml/VChartHTML.html

Usual radioactive ion beam specifications

To study the possibility of producing the radioactive ion beam (RIB) , engineers have to know

- Its final energy
- The intensity expected
- The purity of the beam
- Its fluency
- The time structure of the RIB (pulsed or CW)
- The stability of the beam intensity

Technical constraints

- Aging of materials due to high temperature and dose rate
- Safety rules (dose rate, artificial radioactivity)

ISOL design strongly depends on the driver

Electrons, neutrons, high energy protons => In-target production by induced-fission or spallation

Targets: long, and often made of “heavy” materials

Large production area over the nuclide chart thus non-selective production. Important production of artificial radioactivity, which management is time and resource consuming

~10 - 100 MeV/A ions => In-target production by target or beam fragmentation, or by nucleon-transfer

Primary beam and target depend on the radioactive ion beam to produce

Production area limited to isotopes with Z < or = to Z beam or target

~5 MeV/A => In-target production by Fusion-evaporation

Primary beam and target strongly inter-dependent due to the peaked nuclear reaction cross-sections

Production area limited to isotopes around Z,A compound nuclei minus 2p, 2n. Best production selectivity but low production

➔ **Targets are strongly related to the driver.** Difficult to export a TISS from one ISOL facility to another in case of different primary beams.

So what are the issues on which we could work together to make the TISS design more efficient?

How to maximize the RIB intensity ?

$I_{RIB} = \varepsilon_{\text{atom-to-ion transformation}} \times I_{\text{in-target production}}$

Release efficiency out of the target
Transport efficiency up to the ion source
Ionization efficiency

Efficiencies limited by the competition between the Atom-to-Ion Transformation Time and the radioactive half-life

Must be addressed during the design of the target ion source systems

Nuclear reaction cross-section
Target material
Beam energy and intensity
Target design

Limited by the physics, by the beam driver performances and by the safety rules

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All predictions should be possible Off-line

Finally, On-line studies should only be done to verify off-line predictions

→ (Interest of the SIRa device?)

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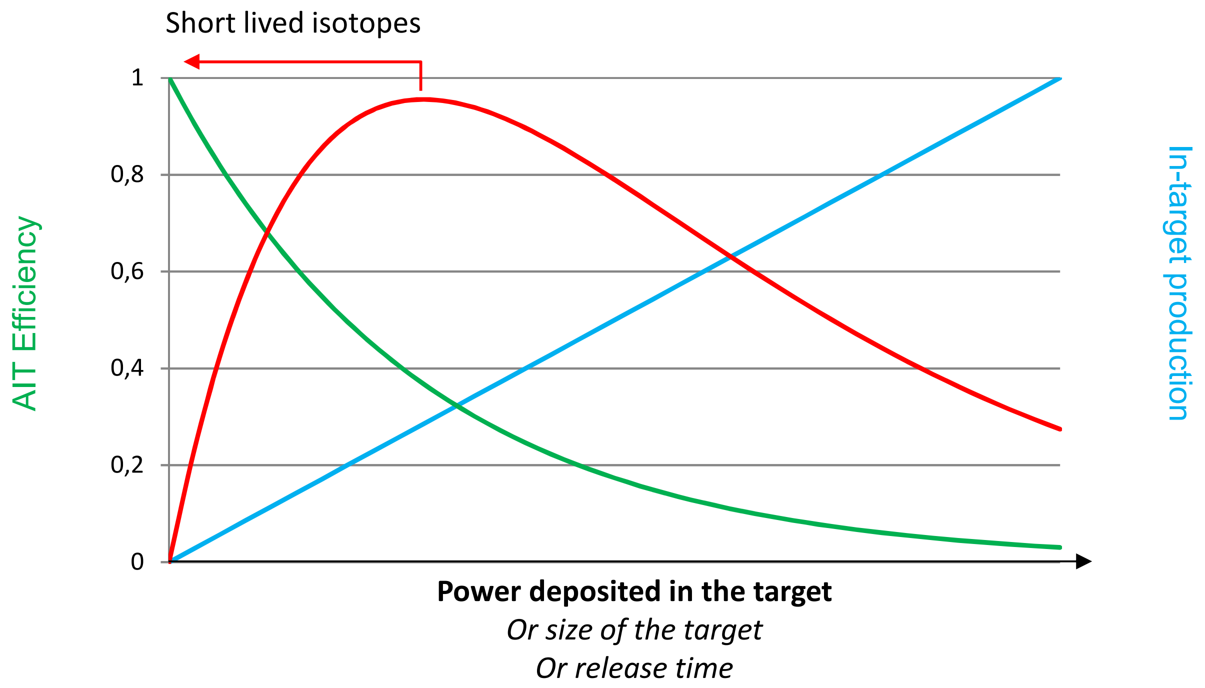
Why increasing the power or the intensity of the primary beam can be a wrong “good idea”?

In-target Production and Atom-to-ion transformation (AIT) Efficiency are **dependent**



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"Target ion source systems must be designed to shorten the Atom-to-Ion transformation time"

How?

TISS largely dependent on the driver ➔ all different

Despite the driver differences, two processes are common to all Target Ion Source Systems (TISS)

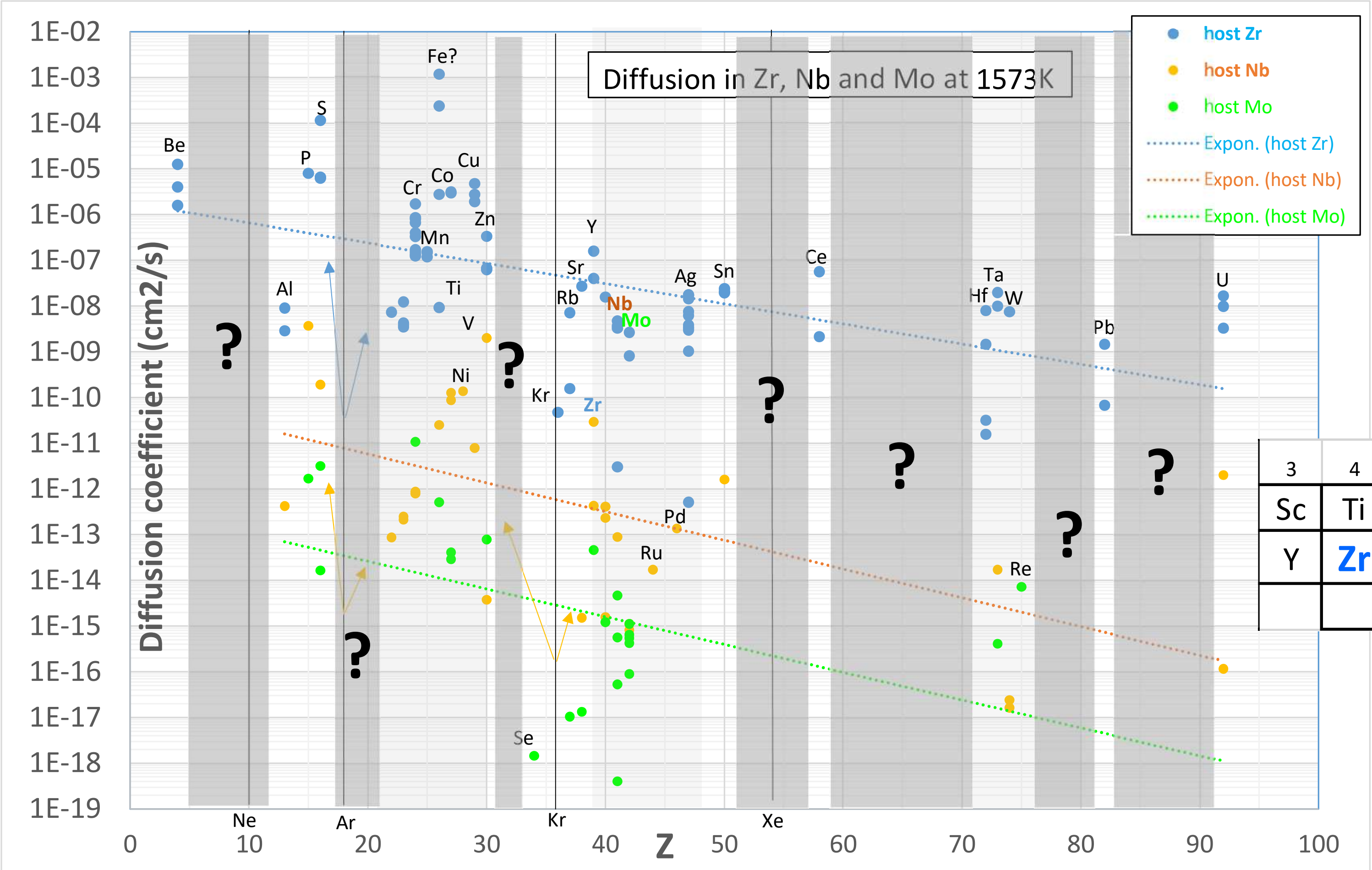
- Diffusion out of target or/and catcher materials
- Effusion in the TISS cavity (sticking)

Rk : Working at high temperature can speed up these processes, but can also contribute to transform or damage the materials by sintering, phase change, shrinking, swelling, deformation, diffusion, chemical reaction evaporation, migration, tearing and fusion !

➔ The optimization of the TISS design requires experimental data about the diffusion and sticking times versus temperature

Diffusion coefficient of atoms in a material

HANDBOOK OF SELF-DIFFUSION AND IMPURITY DIFFUSION IN PURE METALS » G. NEUMANN AND G.J. BEYER ET AL., NIM B 204 (2003) 225-234



Many gaps in the litterature

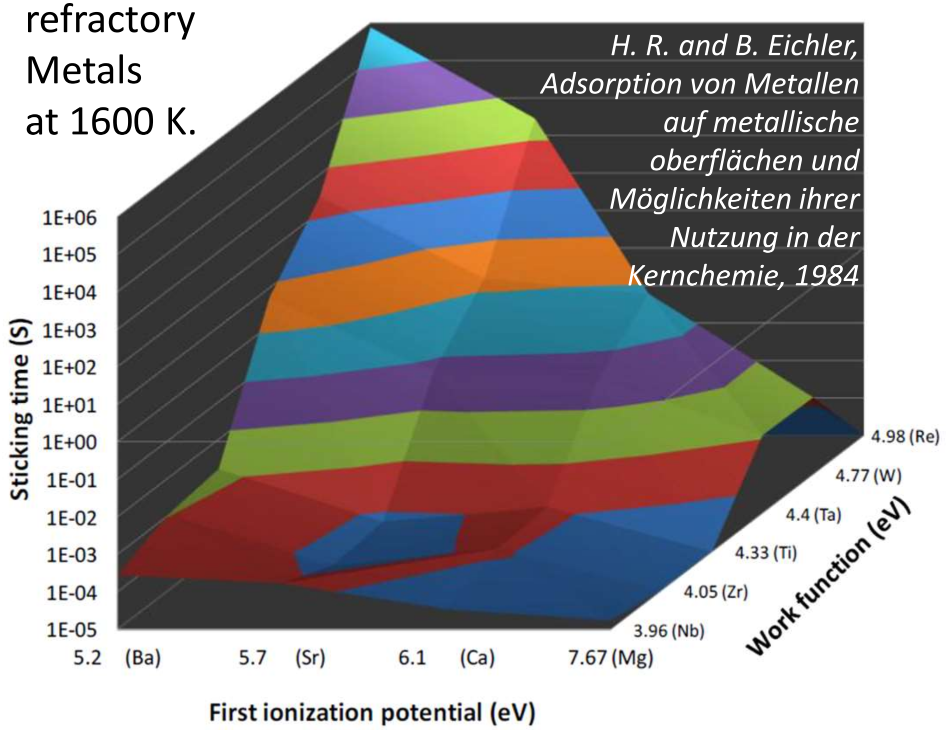
3	4	5	6	7
Sc	Ti	V	Cr	
Y	Zr	Nb	Mo	Tc
		Ta	W	Re

How to estimate the sticking time of atoms on the surface of a material?

Using :

- Bibliographique data : poor, and experimental results obtained in particular conditions: rarely transferable to ours
- Simulation : can help, if the code can take into account all our experimental conditions…do we know them?

Sticking time of alkaline-earth atoms on different refractory Metals at 1600 K.



How to efficiently get data on diffusion and effusion to design the TISSs?

By creating a common data base

Alexis Ribet, Post-doctorant, recently recruited at GANIL within the framework of the TULIP ANR, is in charge of such database.

Main objective: create a database, friendly user :

- *no specific application required,*
- *easy to fill with new data by all contributors,*
- *linked to bibliographic references and/or not published results,*
- *possible to use to easily select and plot relevant parameters, and extract some empirical rules*

Contribution of other laboratories could indeed help in the construction of a common database.

Former attempt: TargISOL European collaboration (HPRI-CT-2001-50033), 2001-2005

Eur. Phys. J. A 25, s01, 763–764 (2005), DOI: 10.1140/epjad/i2005-06-146-5

- Objectives : to build a database gathering diffusion coefficients. Built and accessible (in theory) at http://www.targisol.csic.es : link expired…?

➔ Would it be possible to exhume the data base from the CERN archives? And merge it with the work of Alexis?

How to get missing diffusion and effusion data to design the TISSs?

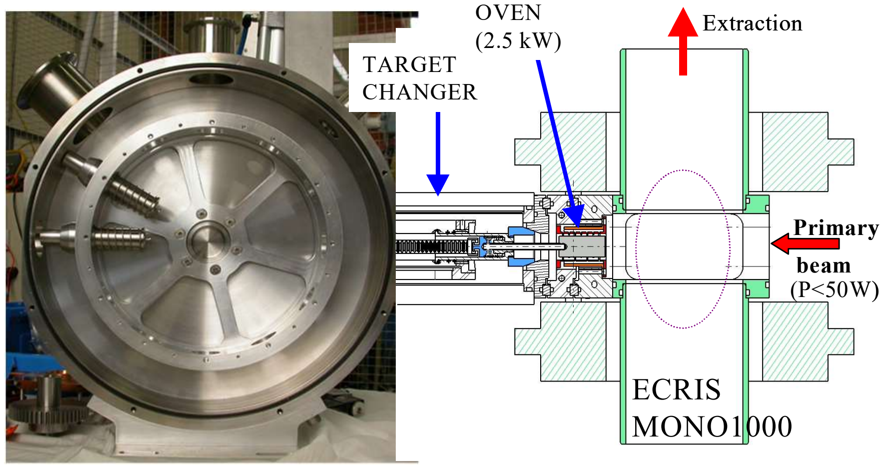
By designing dedicated instruments to systematically measure diffusion and effusion parameters in well defined and relevant experimental conditions

Previous attempt at GANIL within the TargISOL European collaboration

Release of seven targets (graphite, HfO2, MgO, C-W) compared in identical conditions

Issues:

- *Implantation of a radioactive ion beam => needs a primary radioactive ion beam, and an identification station*
  Indirect extraction of the release parameters => rough absolute diffusion coefficients
- *Irradiation of the device => residual activation, maintenance and modification restricted*



Can be improved designing a device as simple as possible to minimize the extraction process of the results, and so maximize their reliability (using a stable beam at low energy, a low intensity detector and release time measurement)

"MELODICA" device studied by Mathieu Lalande (post-doctorant) in 2022. Presently on standby.

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What do we need to move forward?

Support of GANIL and IN2P3 to this upstream study

Experimental area where a large variety of stable primary beams is available, with energies under the Coulomb barrier

Collaborators :

- ISOL laboratories to contribute to the building of the data base, and to the expression of the needs in terms of target materials to test
- Laboratories expert in diffusion and effusion
- Laboratories expert in material characterization

Human ressources

- R&D Engineer in materials, chemistry, condensed matter. Permanent position. In charge of the material characterization, the diffusion and the sticking tests.
- R&D Engineer in instrumentation for physics to develop and build the « MELODICA » test bench. 3 years, up to validation tests.
- Technical support staff (for mechanical design, vacuum, fabrication,services, *i.e.* electrical design, cabling, water circuits)

- **And you.**

Thank you for your attention

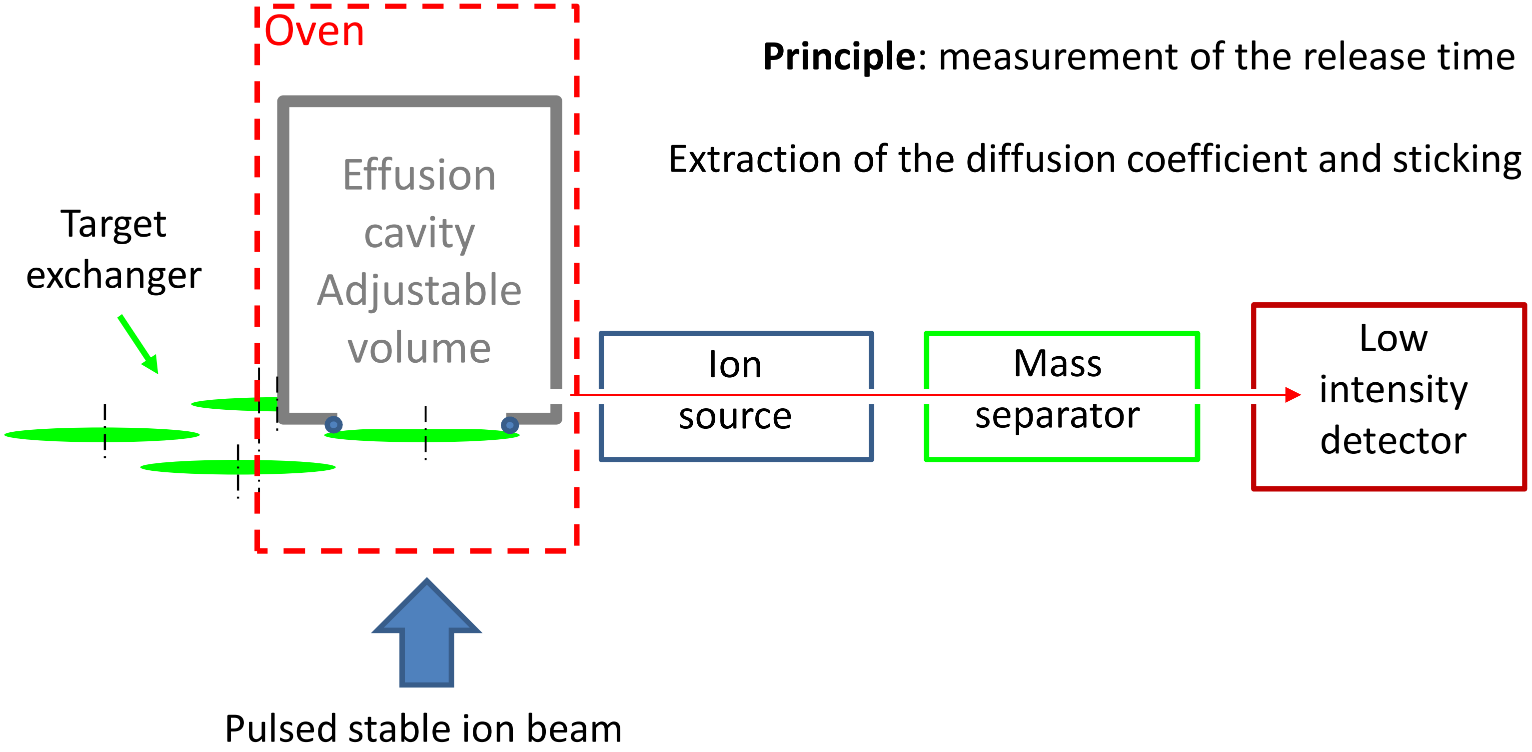
MELODICA Project
(initially part of the TULIP project)

MEsure en **L**igne de c**O**efficients de **D**iffusion et de temps de **C**ollage **A**tomique

MELODICA : Systematic measurement of the release of stable atom out of material and/or from the surface

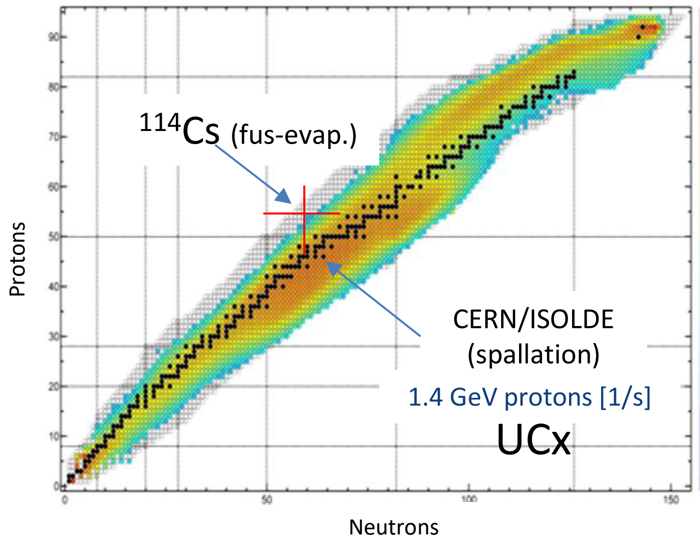
Principle: measurement of the release time

Extraction of the diffusion coefficient and sticking time



Production of ^{114}Cs ($T_{1/2}$ = 0,57 s)

	Produced at ISOLDE	Expected with TULIP on SPIRAL1 at GANIL
Primary beam power	Proton (600 MeV) **1200 W**	^{58}Ni (4 MeV/A) **115 W**
Target	La	^{58}Ni
Reaction	Spallation	Fusion-evaporation
In target production	3.4.10^5	2.4.10^4
Efficiency	0.005%	10%?
SIS material	Tantalum (Ta)	Graphite
RIB intensity (pps)	**17**	2.1.10^3?



Cross-sections calculated with PACE code