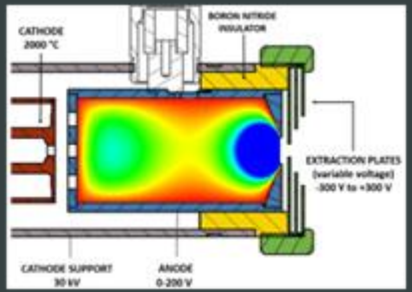
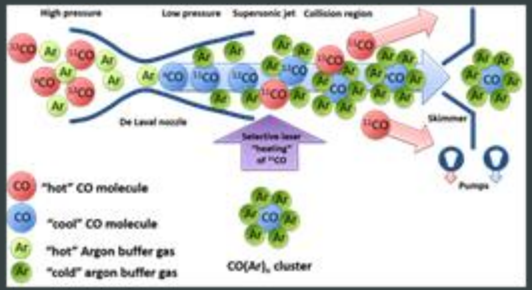
27 PRISMAP EU
Medical Radionuclides

CONSORTIUM MEETING 9

WP10, JRA2 - Ion sources, targets and isotope separation techniques

Mattia Manzolaro





18 - 21 November 2025 - Warsaw, Poland

WP10-JRA2 organization

Task 1- Target design and characterisation: **INFN**, IST-ID, ARRONAX, GANIL

- **Optimisation** of **target designs** and **target materials** for the **production of medical radionuclides.**
- **Characterisation** of **target materials.**

Task 2- Ion sources: **KULeuven**, MedAustron, CERN + INFN + SCK-CEN

- **Optimisation** of **ISOL ion sources** in terms of **efficiency** and **selectivity** in conditions that are appropriate for the **production of medical radioinuclides.**
- **Realisation of high-throughput ion sources** for **medical radionuclides** that may be **integrated in radionuclide production facilities** as well as **within medical infrastructures.**

Task 3- Isotope separation techniques: **CERN, KULeuven**

- Application of the **laser-enhanced isotopically selective condensation method** for the **enrichment** of **Ca** and **Ti isotopes.**

Outline of the presentation

Task 1- Target design and characterisation

- Targets for Direct Production
- ISOL Targets
- Outlook & PRISMAP+

Task 2- Ion sources

- Developments in hot-cavity ion-source technology
- Developments in FEBIAD ion-source technology
- Ion Sources for C-11 beam production
- Outlook & PRISMAP+

Task 3- Isotope separation techniques

- Laser-enhanced isotopically selective condensation: enrichment of Ca and Ti radionuclides

General notes

- WP10-JRA2 Deliverables
- WP10-JRA2 Publications

Task 1- Target design and characterisation: Targets for Direct Production

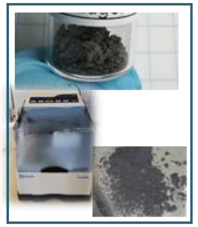
Solid target technologies available at INFN-LNL (Gaia Pupillo, Liliana Mou, Sara Cisternino, INFN)

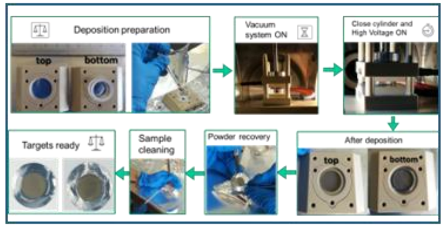
High Energy Vibrational Powder Plating

E-PLATE, PASTA and REMIX projects (INFN CSN5)

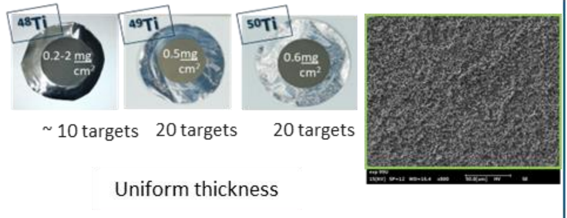
Solution for thin target for nuclear xs measurements

Powder preparation, new set-up apparatus and deposition procedure





Realization and characterization of enriched Ti targets

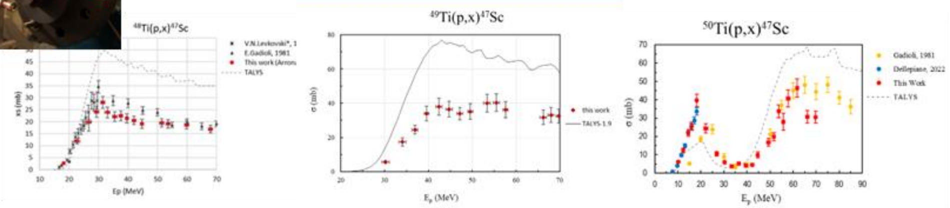


EBS analysis

(with AN2000 accelerator at LNL)

Irradiation at ARRONAX facility (with proton beam)

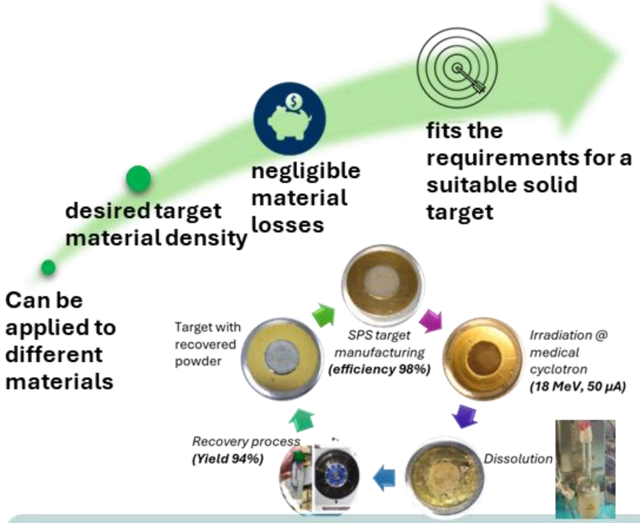
Cross-section measurements for ^{47}Sc produciton



Spark Plasma Sintering

METRICS, CUPRUM-TTD projects (INFN CSN5), APHRODITE-155 project (PRIN-PNRR), collaboration with IRCCS Sacro Cuore Don Calabria Hospital (Negrar (VR)

For thick target for radionuclide production



^{100}Mo on Au/Cu backing	^{nat}Cr on Au/Cu backing	^{nat}Cr on Nb backing	^{52}Cr on Au/Nb backing	^{89}Y on Nb backing	^{70}ZnO on Au/Nb backing	$^{155}Gd_2O_3$ target

- *Cisternino et al., PRISMAP Deliverable D10.1 - Report on Gd target production, 10.5281/zenodo.11110642*

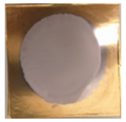
Cu-67 Tb-155

Task 1- Target design and characterisation: Targets for Direct Production

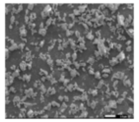
Production of Tb-155 at ARRONAX (Ferid Haddad, Thomas Sounalet, ARRONAX)

The measure of cross sections to produce Tb-155 from EMMC : Gd_2O_3 in Ni matrix

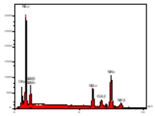
Technique 1 : Co-electrodeposition -> the particles of Gd are trapped in the Ni deposit.



13 µm of coating containing 2-3 mg of gadolinium in nickel matrix on gold substrate



SEM with x1000 magnitude.
The distribution of the particules are homogenous on the entire surface

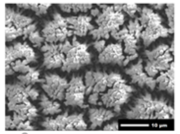


EDX : presence only Gd and Ni atoms, without others impureties

Even if the of cross section measurements were performed successfully, the yield of co-electrodeposition is low, below 1%. Consequently, we have initiated the study of other techniques based on Molecular Plating and Molten salt. The latter one is at the bibliographic stage whereas for the former first results have been obtained.

Technique 2 : molecular plating -> electrodeposition in organic media, especially in alcoholic media, with Gd in the form of nitrate salt

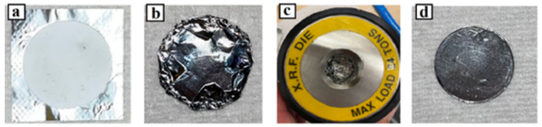
Picture of Gd deposit on Ti foil



SEM of Gd deposit

- We have achieved initial results with a yield exceeding 70%.
- This technique will be used for the measure of cross sections

pellet of Gd_2O_3 for the route production of Tb-155



A compressed Gd_2O_3 pellet with a diameter of 20mm and a thickness of 390 µm
This pellet is wrapped with Al

First irradiation for 1h with
$E_{incident}$ = 15.1 MeV
E_{out} = 8.6 MeV
500 nA

Experimental yield:
- ^{155}Tb: 10.2 ± 0.7 MBq/µA/h
- ^{156g}Tb: 1.3 ± 0.1 MBq/µA/h

Purity of ^{155}Tb: 88% at 9 d after EOB

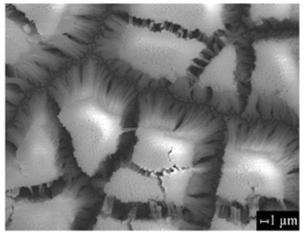
Publications:
- Electrochemical co-deposition of Ni-Gd_2O_3 for composite thin targets preparation : Production of ^{155}Tb as a case study. Applied Radiation and Isotopes 186 (2022)110287
- Publication : Study of terbium production from enriched Gd targets via the reaction ^{155}Gd(d,2n)^{155}Tb.Applied Radiation and Isotopes. Volume 201, November 2023, 110996
- PRISMAP deliverable 10.1

Task 1- Target design and characterisation: Targets for Direct Production

Production of Tb-155 at ARRONAX (Ferid Haddad, Thomas Sounalet, ARRONAX)

Molecular plating : Electrodeposition in isopropanol

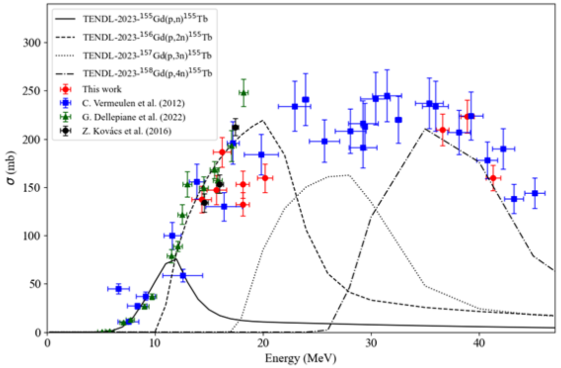
Natural Gd was deposited on a Ti substrate.
A deposition yield can be reached 100%

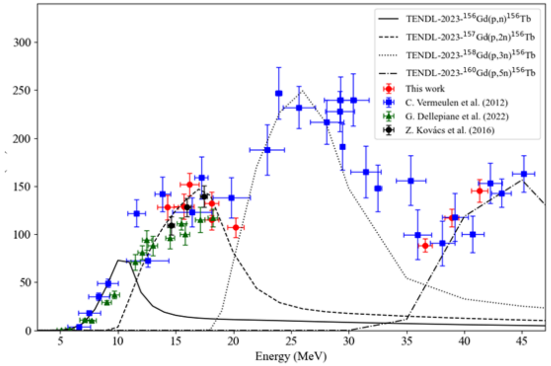


- ✓ Strong adhesion on Ti substrate
- ✓ Deposit structure : filamentous clusters, but homogenuous over the surface

cross section measurements of Tb-155 and Tb-156

Cross section measurements are performed with proton particles on natural gadolinium.





- ✓ Good agreement with different authors
- ✓ Molecular plating is suited for cross section measurements
- ✓ The publication is in progress

➡ We plan to irradiate Gd-152, Gd-155 and Gd-156 targets to measure the cross sections for the production of Tb-149 and Tb-155

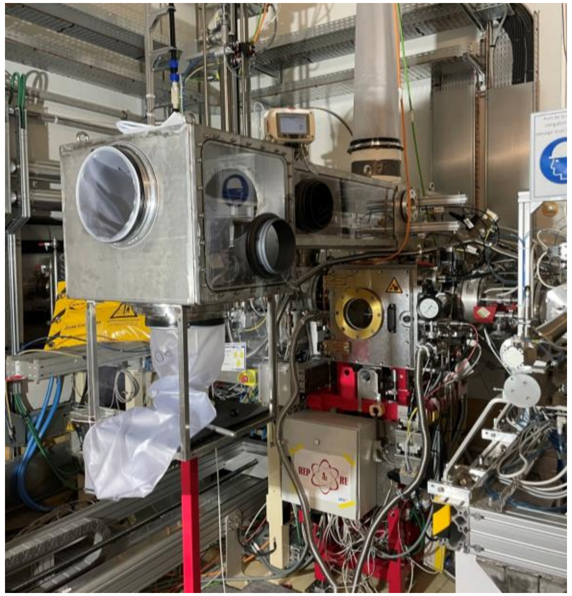
Manufacture exploration of different elements using molecular plating

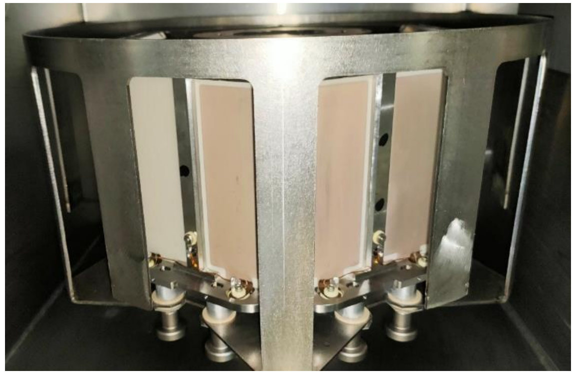
Different lanthanides have been succefully manufactured using molecular plating : Dy, Yb, Eu and Tb.

The results are presented by Vanessa Rhoden, 3th years PhD student

Task 1- Target design and characterisation: Targets for Direct Production

High power targetry at GANIL (Gilles Defrance, GANIL)





High Power (10 kW) Bismuth Target

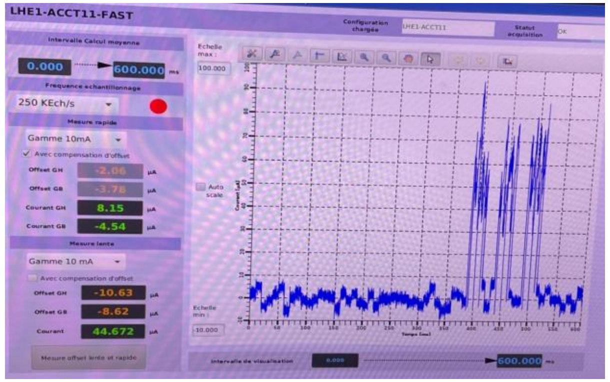
(^{211}At prod. via alpha+^{209}Bi reaction channel)

- 2023: preliminary tests
- September 2024: main test
  - α **beam**, 7MeV/A, 2 kW beam power: 3 targets irradiated during 12 h
  - 100 rpm (target rotational speed)
  - ~1 GBq each target

Task 1- Target design and characterisation: Targets for Direct Production

High power targetry at GANIL (Gilles Defrance, GANIL)

- Online continuous beam on target current reading
- Two targets shipped to ARRONAX
- Very successful run…
- … but unexpected detection of gaseous form of At after the run:
  - Very little (estimated to 15 kBq)
  - Not allowed in our authorization (gaseous alpha emitter in environment)
  - Need to understand at which stage
  - Tests at ARRONAX under analysis



For the future:

- Need to ensure no At gas (maybe request autorization to safety authority but long term process)
- Install the station in a place where it can be used on a more regular basis
- Push the beam intensity step by step
- Deliver ^{211}At to CYCERON (extraction)+labelling of antibody VLA-4 (ISTCT): approved project

Part of the team after shipment to ARRONAX!

Task 1- Target design and characterisation: ISOL Targets

UNIVERSITÀ DEGLI STUDI DI PADOVA

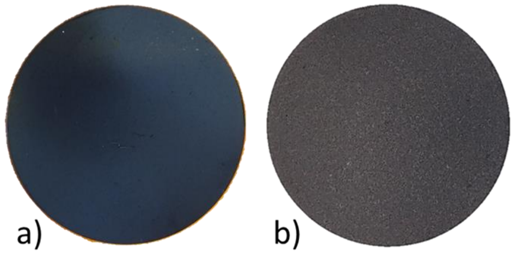
HISOL-NEXT
(INFN-CSN5)

TiC ISOL targets for Sc-47 and Sc-44 production (Michele Ballan, Stefano Corradetti, Mattia Manzolaro, INFN-LNL)

Standard Disks: carbothermal reaction with titanium oxide (TiO2) as precursor and graphite powder as carbon source

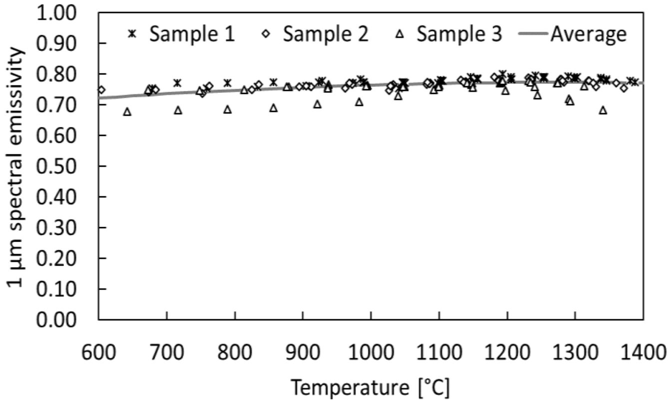
$$TiO_2 + 5C \rightarrow TiC + 2C + 2CO$$

Thermal characterization at high temperature (600-1400°C)

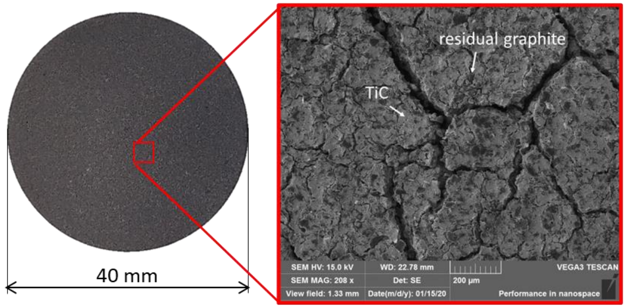


Green pellet
(Before carbothermal reduction – sintering process)

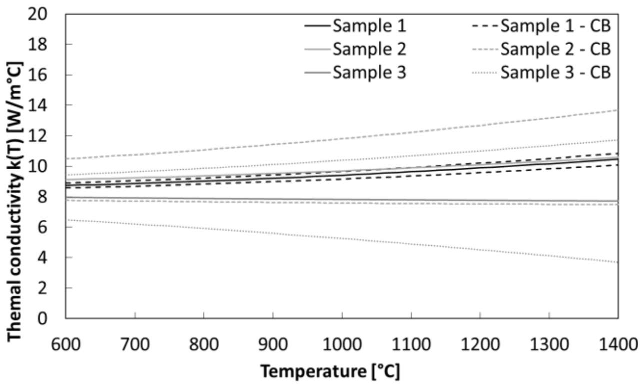
Sintered pellet
(After carbothermal reduction – sintering process)

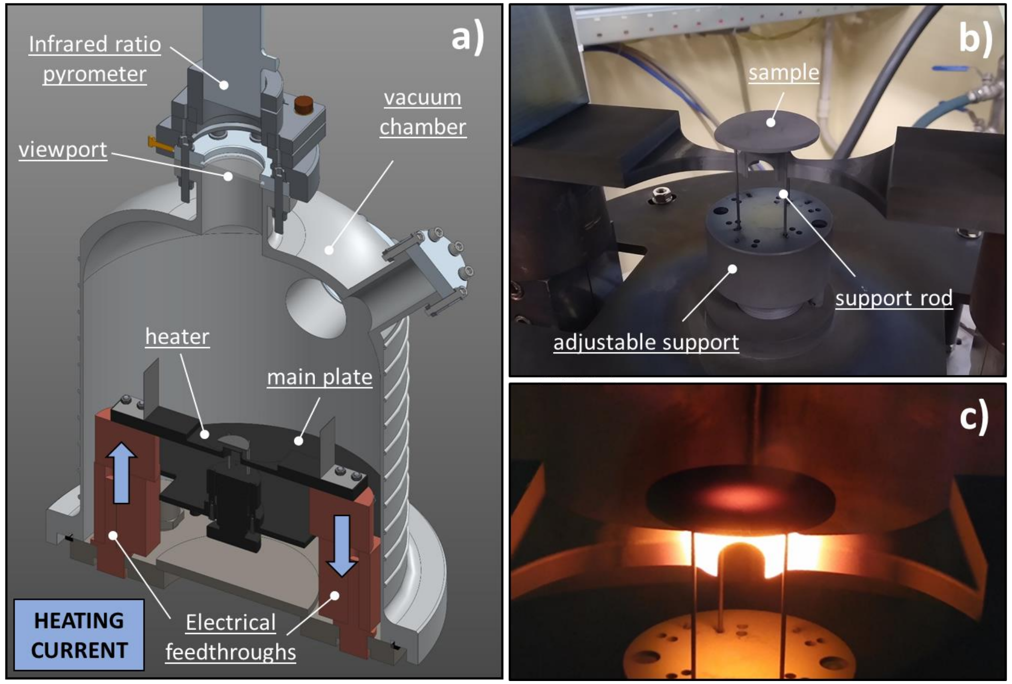


Microstructural characterization



Average achieved porosity: 58±3%





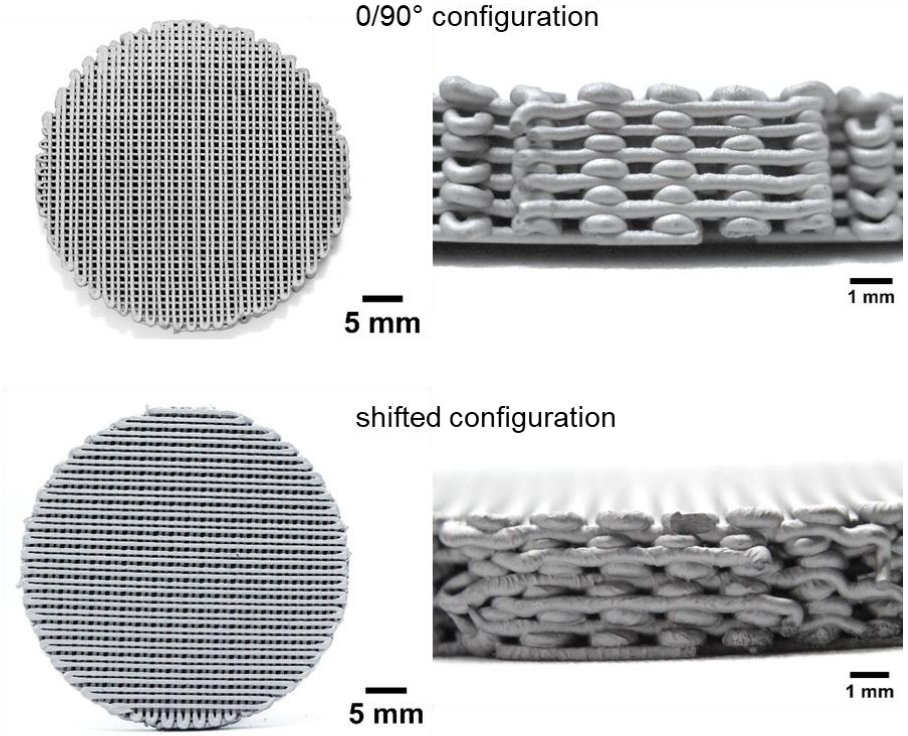
*General CAD view of the test bench for thermal characterization (**a**), detailed view of the sample and heater (**b**), pictures of the components at high temperature during a test (**c**).*

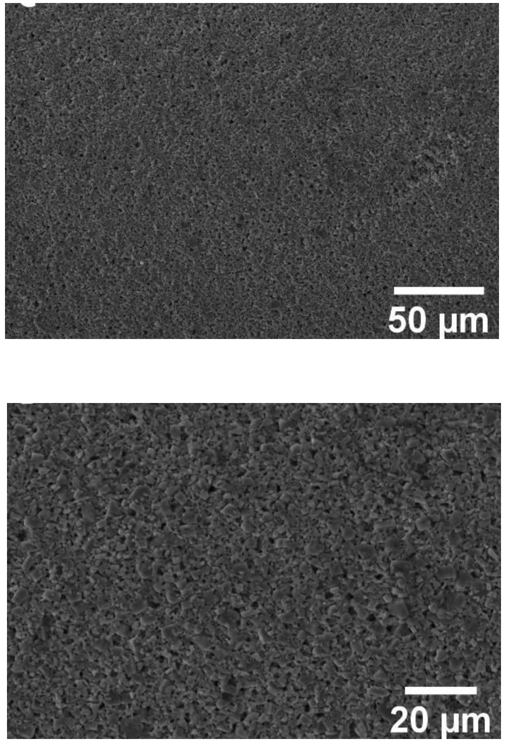
Task 1- Target design and characterisation: ISOL Targets

TiC ISOL targets for Sc-47 and Sc-44 production (Michele Ballan, Stefano Corradetti, Mattia Manzolaro, INFN-LNL)

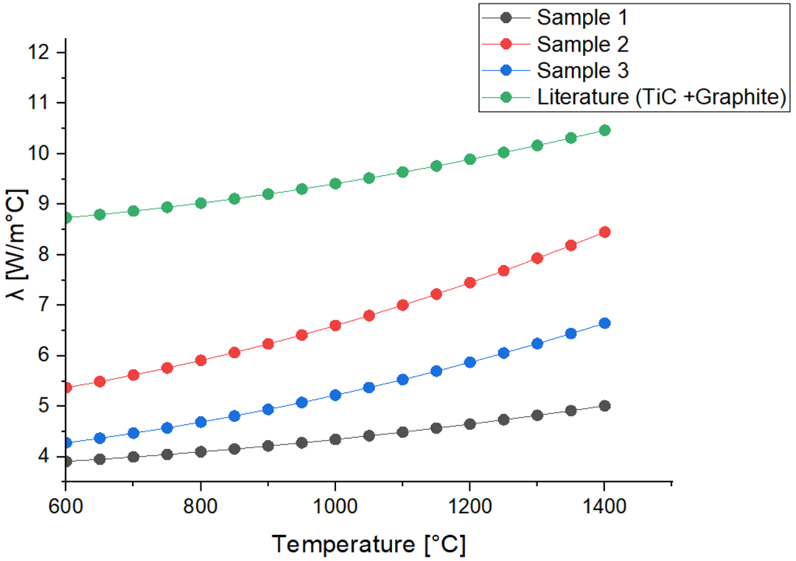
Direct Ink Writing (DIW) Disks: production and characterization at high temperature

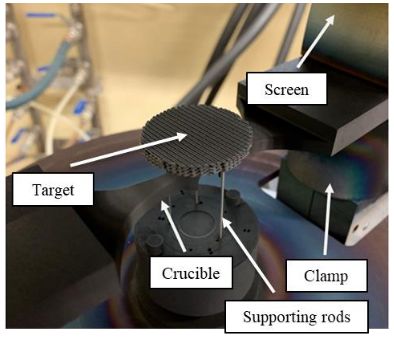
Higher **Specific Surface Area**

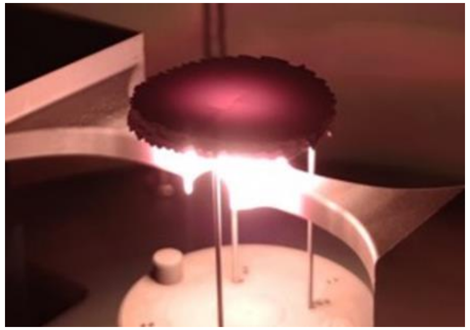




Average achieved porosity:
57.8 vol%







Task 1- Target design and characterisation: ISOL Targets

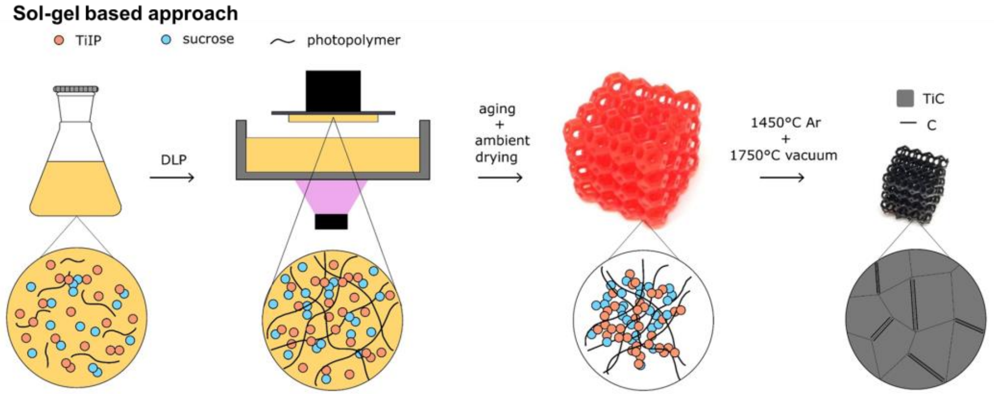
Università degli Studi di Padova

HISOL-NEXT
(INFN-CSN5)

TiC ISOL targets for Sc-47 and Sc-44 production (Michele Ballan, Stefano Corradetti, Mattia Manzolaro, INFN-LNL)

Digital Light Processing (DLP) Disks : production and characterization at high temperature

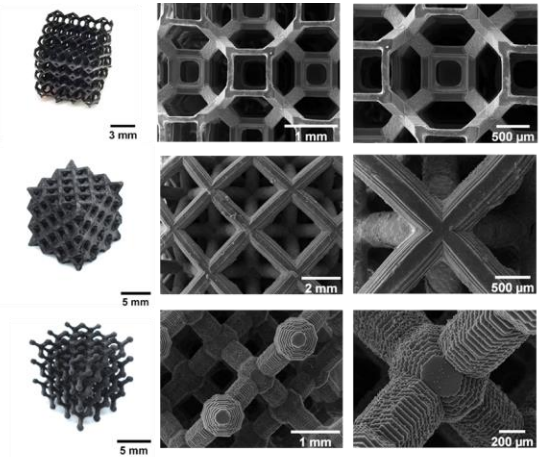
Higher **Specific Surface Area**



- textural control and design of bimodal porosity:
  - aerogel route → mesopores > micropores
  - xerogel route → mesopores < micropores

fabrication route	SSA_{BET} [m^2/g]	V_{micro} [%]
xerogel	149	71
xerogel + template	328	57
aerogel	391	21
aerogel + template	403	18

fabrication route	TiC size [nm]	C size [nm]
xerogel	12	7
xerogel + template	13	7
aerogel	13	7
aerogel + template	13	7



- crack-free samples upon sintering at 1750°C
- dense struts and no residual porosity
- homogeneous shrinkage along x-y and z direction

weight loss [%]	91.13 ± 0.66
x-y shrinkage [%]	56.65 ± 0.09
z shrinkage [%]	56.72 ± 0.09
volumetric shrinkage [%]	91.87 ± 0.04

Printed structures are compatible with typical ISOL target holders; different materials are ready to be tested on-line (UCx, …).

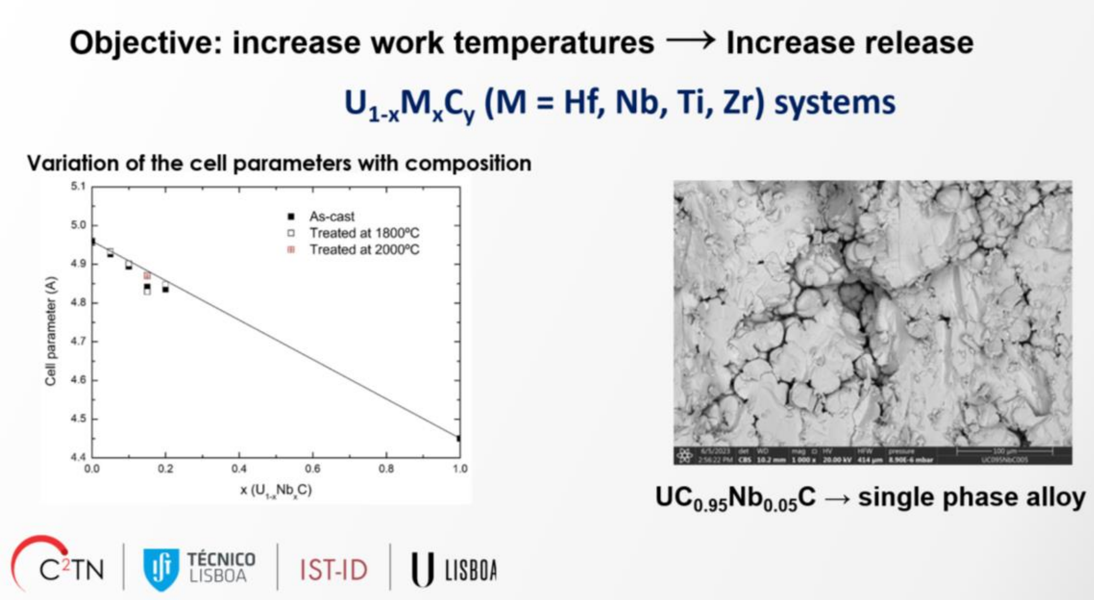
RESEARCH ARTICLE — ADVANCED FUNCTIONAL MATERIALS www.afm-journal.de

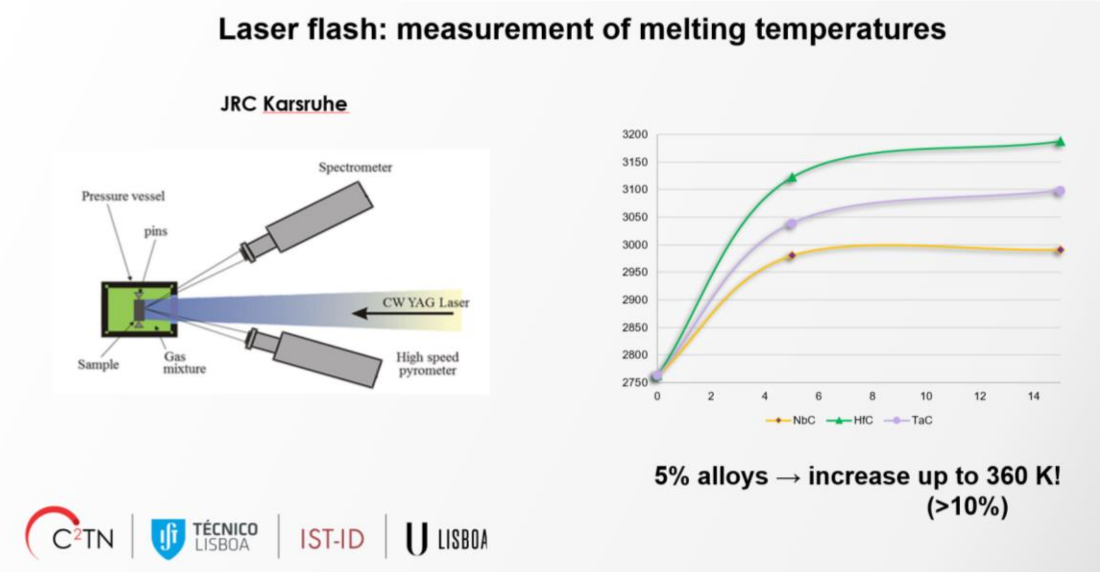
First Structured Uranium-Based Monoliths Produced via Vat Photopolymerization for Nuclear Applications

Alice Zanini, Pedro Amador Celdran, Olaf Walter, Sara Maria Carturan, Jacobus Boshoven, Antonio Bulgheroni, Lisa Biasetto, Mattia Manzolaro, Rachel Eloirdi, Stefano Corradetti,* and Giorgia Franchin**

Task 1- Target design and characterisation: <u>ISOL Targets</u>

Uranium solid solutions with refractory carbides - Ta, Nb, Hf (Antonio Pereira Goncalves, IST-ID)





<u>Uranium solid solutions with refractory carbides</u> <u>(Ta, Nb, Hf)</u>

The addition of <u>refractory metal carbides</u> to <u>uranium carbide</u>, UC, promoted an <u>increase on the melting temperature</u> of all tested compositions. A minimum raise of 8 % with 0.05 atomic percentage (at.%) doping was observed for samples with NbC, TaC and HfC. The latter exhibited **the highest melting temperature, exceeding 3100 K** according to a preliminary analysis.

Task 1- Target design and characterisation: Outlook & PRISMAP+

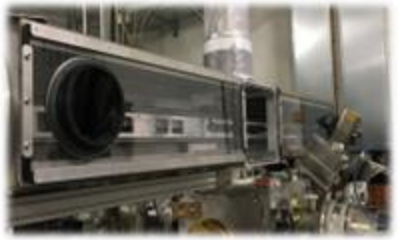
INFN-LNL & ARRONAX: consolidation of the collaboration activities on direct production

- Strong collaboration on target development, cross-section measurements, and production/separation workflows
- Mutual enrichment through staff exchange and publication of papers (INFN-LNL as emerging facility and ARRONAX as expert and consolidated production facility)

Picture of Gd deposit on Ti foil

IST-ID, INFN, CERN, SCK-CEN, KU-Leuven: good prospects for ISOL target materials developments in the coming years

- Solid Solutions with Refractory Carbides, Nano-materials, Additive Manufacturing, …
- Characterization at High Temperature (microstructural, structural, thermal characterization activities)
- Emerging Facilities & Yield Measurements: comparison among different materials at low intensities (first part of PRISMAP+) while preparing for future high intensity productions (end of PRISMAP+)



GANIL: strong know-how for design, manufacturing and operation of High Power Targets

- The High-power **bismuth target** for the synthesis of **At-211** is a clear example

Strong and consolidated network for future **PRISMAP+** target developments

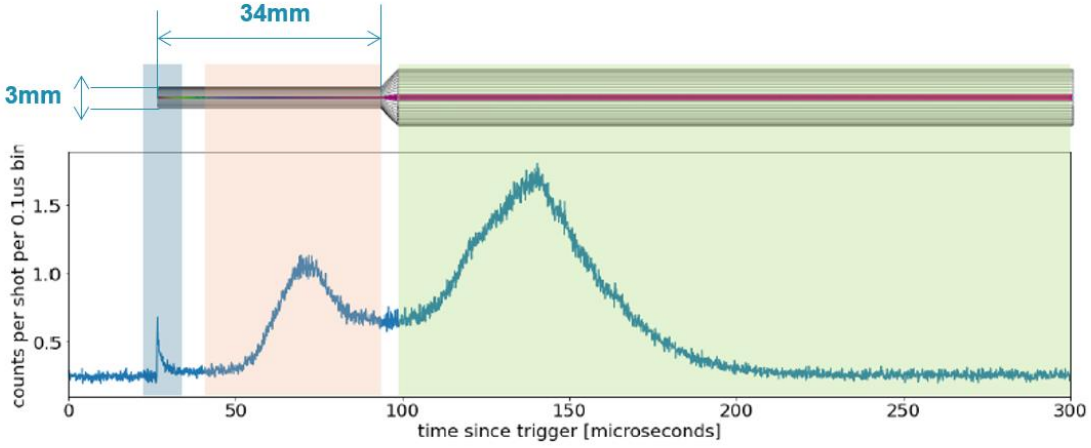
Task 2- Ion Sources: Developments in hot-cavity ion-source technology

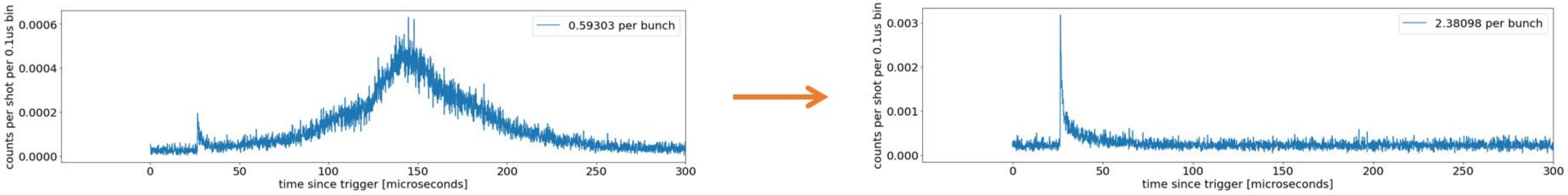
ISOLDE/MEDICIS hot-cavity ion source (surface / laser ionization) (Ralitsa Mancheva, CERN)

MEDICIS operation: pre-irradiated sample evaporated, ionised and mass separated

The high ion throughput problem

- Laser ion extraction reduced at high ion load (hundreds on nA ion beam)
- In some cases, no laser effect is present
- Confinement potential breakdown
- Ions from the back of the source are not extracted efficiently
- MEDICIS operates at high ion loads





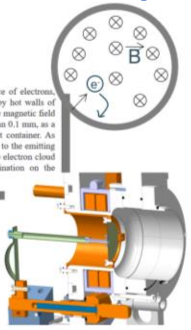
Task 2- Ion Sources: Developments in hot-cavity ion-source technology

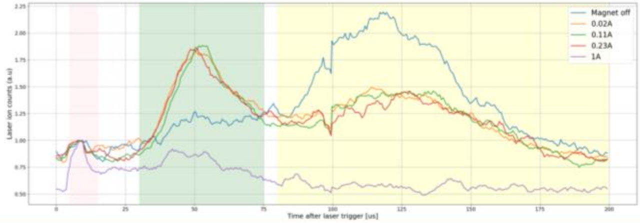
ISOLDE/MEDICIS hot-cavity ion source (surface / laser ionization) (Ralitsa Mancheva, CERN)

Axial magnetic field application

- Introducing the confining potential externally with an axial magnetic field[2]
- RILIS standard ion source design with VADIS base plate (already contains magnet)
- Long, **heated** transfer line, magnet only around ion source
- ➢ The ratio between the ion source bunch (green) and transfer line bunch (yellow) changes with increasing magnetic field
- ➢ It **could** mean better ion confinement in ion source region
- ➢ Inconclusive for overall ion source efficiency

That effect can be explained by the influence of electrons, which are emitted inside the target volume by hot walls of the target or target material. They move in the magnetic field in spiral trajectories with a diameter lower than 0.1 mm, as a voltage of 2–3 V is applied along the target container. As those electrons mainly concentrate very close to the emitting surface, ions can be trapped by a rather dense electron cloud that gives them protection against recombination on the walls.





[2] V. Penteleev. *Enhancement of ionization efficiency of surface, electron bombardment and laser ion sources by axial magnetic field application* https://doi.org/10.1063/1.1691515

Department of Physics and Astronomy, IKS — KU LEUVEN

Gas injection

- Injecting inert gas into the ion source to reduce the mean free path of the ions and thus improve ion survival[1]
- RILIS standard ion source design (also used for axial magnetic field)
- Long, **heated** transfer line
- ➢ No effect was observed with up to 1bar of Ar
- ➢ Higher pressure is required

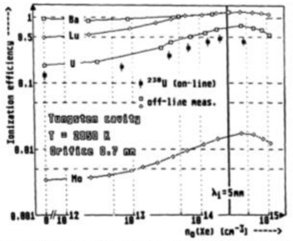
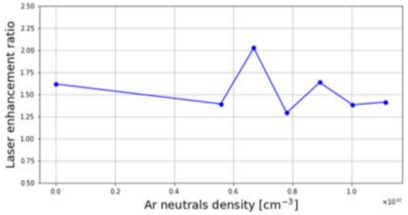


Fig. 4. Ionization efficiencies for various trace elements as function of the neutral density, which is varied and determined by feeding known fluxes of xenon into the cavity. The on-line



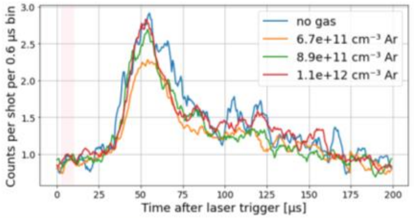
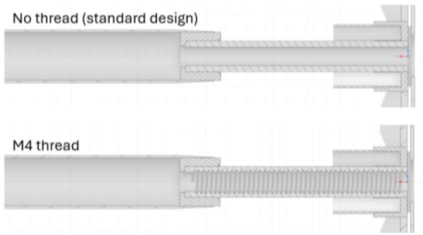


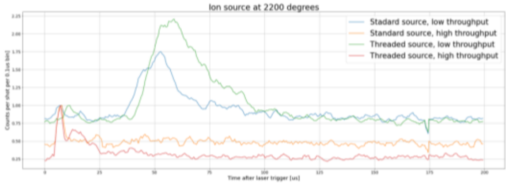
Fig. 4 from R Kirchner. *On the thermoionization in hot cavities.* 1990 https://doi.org/10.1016/0168-9002(90)90377-I

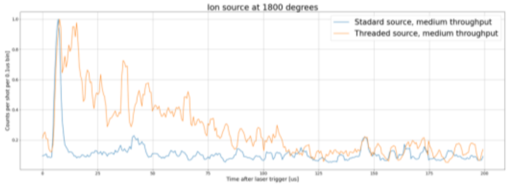
Department of Physics and Astronomy, IKS — KU LEUVEN

Threaded ion source

- Standard Ta ion source with an M4 thread on the inner surface, no transfer line
- Increase of surface area increases **thermionic emission** of electrons and thus improves confinement
- Increase in **surface ionization** is a competing mechanism
- ➢ Threaded source shows **increase** in the number of ions in the time structure compared to standard source
- ➢ Efficiency measurements are necessary to assess overall performance comparison







more details available here:

Deliverable D10.3

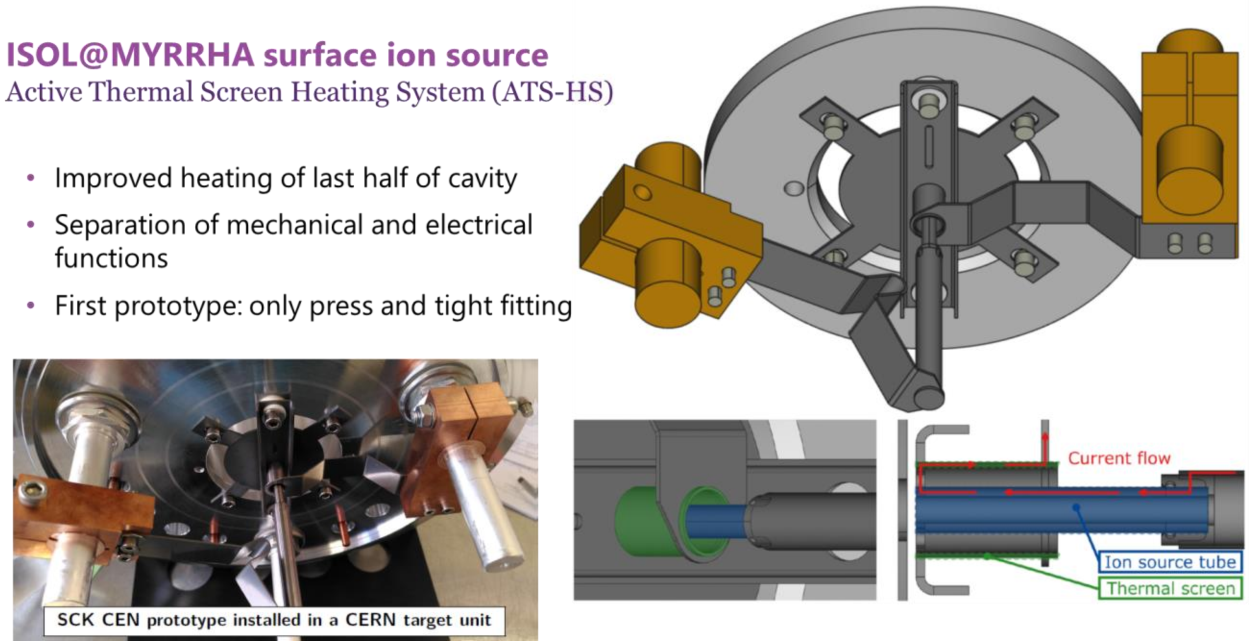
Report on ion source with increased throughput

Task 2- Ion Sources: Developments in hot-cavity ion-source technology

ISOL@MYRRHA hot-cavity ion source (surface / laser ionization) (Thomas Cocolios - KU-Leuven, Kim Rijpstra - SCK CEN)

The Leuven Isotope Separator has restarted the operation with ion beams.

Main developments for the ISOL@MYRRHA ion source (for surface and laser ionization) in partnership with CERN.

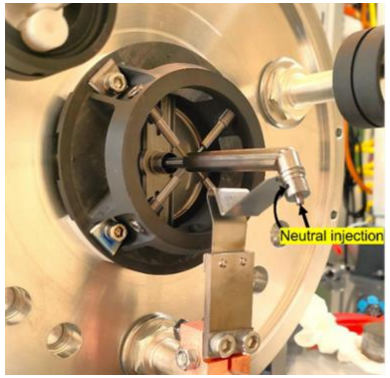


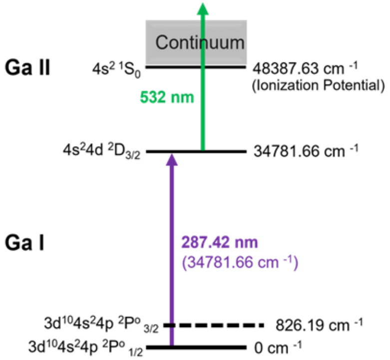
In 2025, characterisation at CERN yielded a preliminary ionisation efficiency of ~ 28.9 % for gallium, similar to SPES benchmarks (27.18 % ± 1.18 % [https://doi.org/10.1088/1742-6596/2743/1/012066]). The laser enhancement ratio (LER) was also characterised under total ion loads from 10 nA to 1 µA. A threefold decrease in LER was observed up to 200 nA, followed by saturation at higher loads.

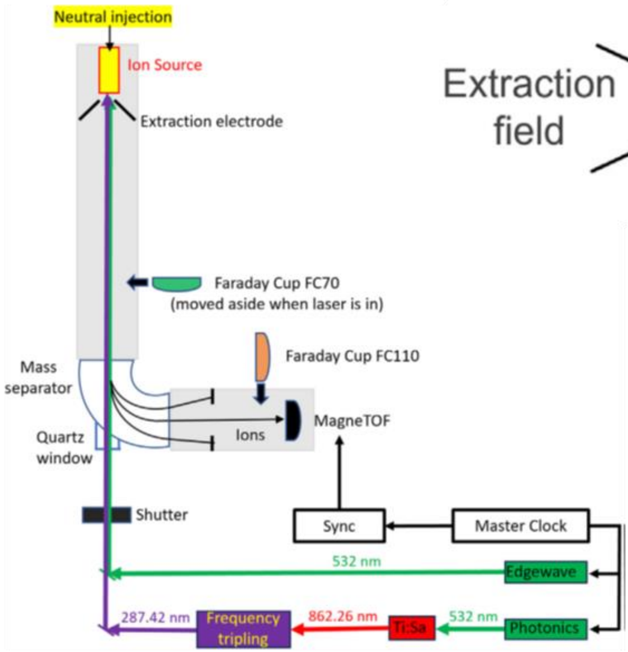
Sophie Hurier, Kim Rijpstra, Thomas Elias Cocolios, João Pedro Ramos, Philip Creemers, Lucia Popescu, Jurgen Verlinden, Ralitsa Mancheva, Katerina Chrysalidis, Sebastian Rothe, Mia Au, Alexandros Koliatos

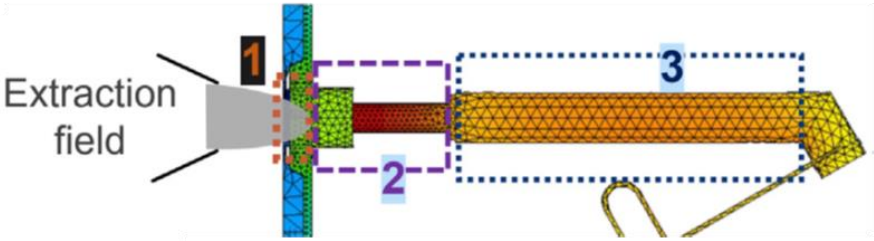
Task 2- Ion Sources: Developments in hot-cavity ion-source technology

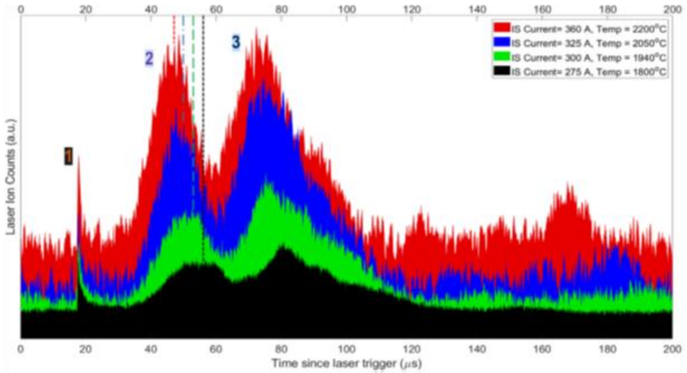
SPES hot-cavity ion source (surface / laser ionization) (O. Khwairakpam, D. Scarpa, M. Manzolaro, INFN-LNL)











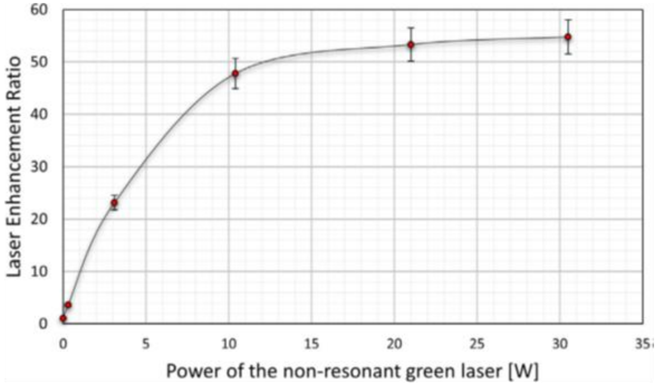


Table 2
Measured ionization efficiency values of gallium at ion source temperature 2200 °C.

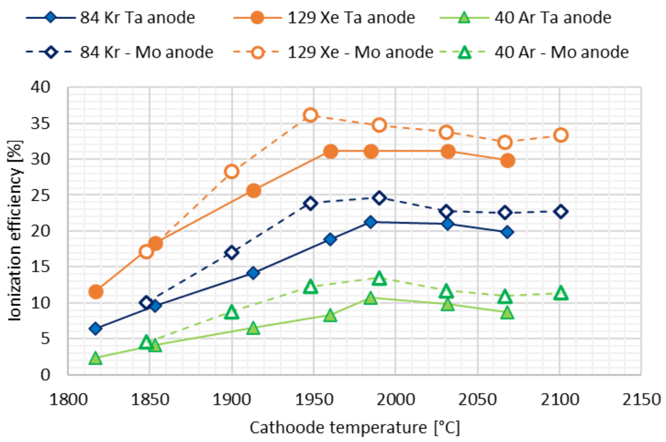
Test no.	Type	Efficiency (%)	Mean efficiency (%)
1	Surface	0.49 ± 0.04	0.49 ± 0.04
2	Laser	27.66 ± 2.07	
3	Laser	27.64 ± 2.07	27.18 ± 1.18
4	Laser	26.23 ± 1.97	

O.S. Khwairakpam et al., Nuclear Inst. and Methods in Physics Research, B 548 (2024) 165249 - https://doi.org/10.1016/j.nimb.2024.165249
O.S. Khwairakpam et al., 20th International Conference on Ion Sources, Journal of Physics: Conference Series 2743 (2024) 012066 - https://doi.org/10.1088/1742-6596/2743/1/012066

The **MEDICIS/ISOLDE**, **ISOL@MYRRHA** and **SPES hot-cavity ion sources** are being developed in parallel by different groups, but **characterized at the same test-bench** (ISOLDE off-line) and **sharing results** > <u>This context is ideal for improving performance!</u>

Task 2- Ion Sources: Developments in FEBIAD ion-source technology

SPES AM FEBIAD ion source (M. Ballan, P. Rebesan, A. Monetti, G. Voltan, M. Manzolaro, INFN-LNL)

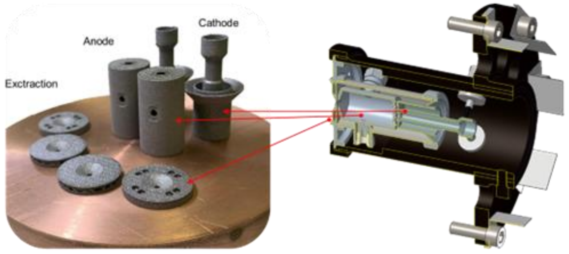


STANDARD Cathode (produced by ext. Companies)

AM (LPBF) Cathode (produced by INFN section of Padova)

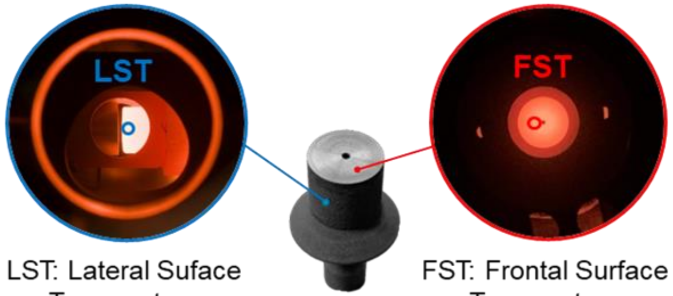
Production and **Characterization** (with Beams) of **Ion Source Components (Cathode, Anode, Extraction Unit)** with **Complex Shapes** manufactured via **Laser Powder Bed Fusion (LPBF)**:

- Testing of geometrical accuracy / repeatability ✓
- High Temperature Testing and validation of Electrical - Thermal FE models implemented for the design process ✓
- 2 months operation @ 2000 °C producing stable beams ✓
- Ionization Efficiency Measurements ✓



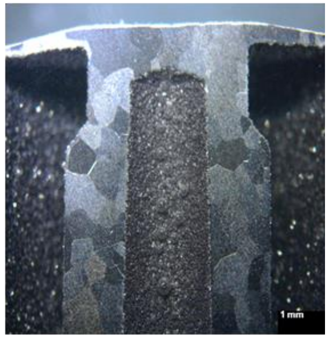
CERN ISOLDE

ISOLDE offline 1: ion source reference test facility



LST: Lateral Suface Temperature

FST: Frontal Surface Temperature

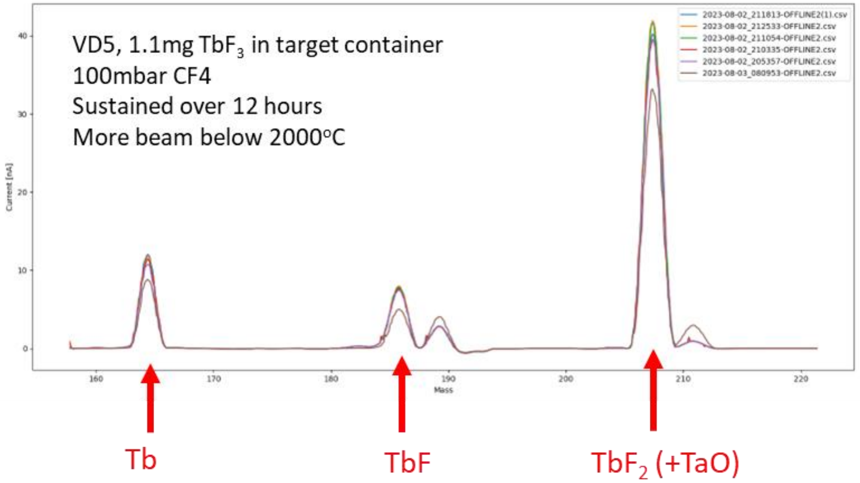


A dedicated R&D effort demonstrated the feasibility of producing a **FEBIAD ion source** cathode via **Laser Powder Bed Fusion (LPBF) additive manufacturing**, leading to a component with reduced postprocessing requirements, **improved geometrical stability under high-temperature operation**, and performance comparable to standard counterparts, as confirmed through extensive testing and successful deployment at CERN ISOLDE's offline test bench.

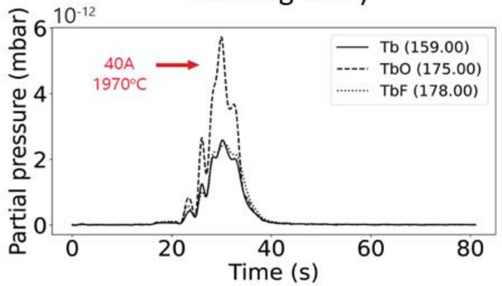
Task 2- Ion Sources: Developments in FEBIAD ion-source technology

Molecular Terbium extraction by means of a VD5 FEBIAD (Wiktoria Wojtaczka, KU-Leuven, CERN)

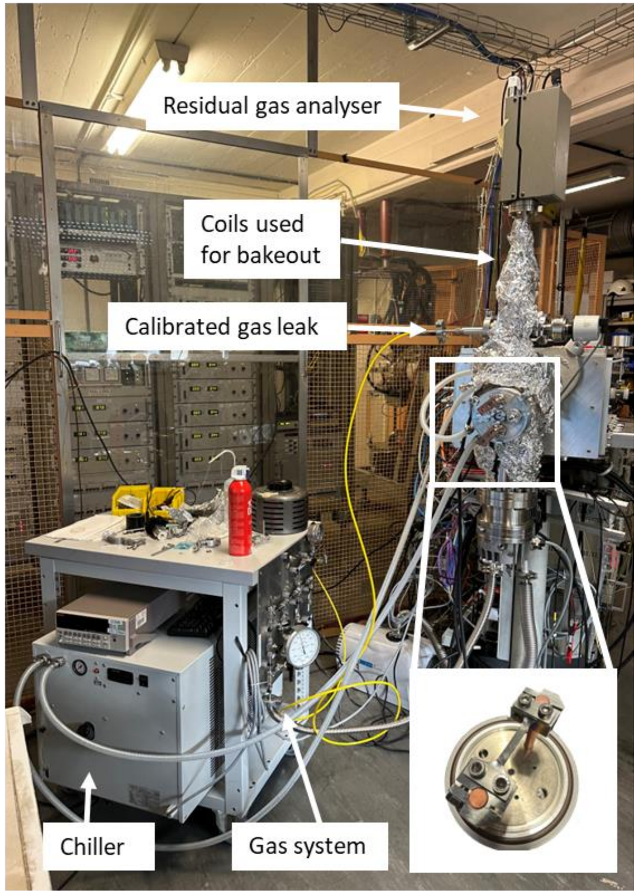
Offline development @ CERN



First diffusion results (CF_4 not injected but present in the chamber)
- TbF in competition with TbO (issues with Tb condensing before reaching RGA)



Diffusion from Ta under investigation



Observations:
- Tb peaks appear below 1500°C (with and without CF_4)
- TbF_2 peaks strongest (even at high anode voltage)

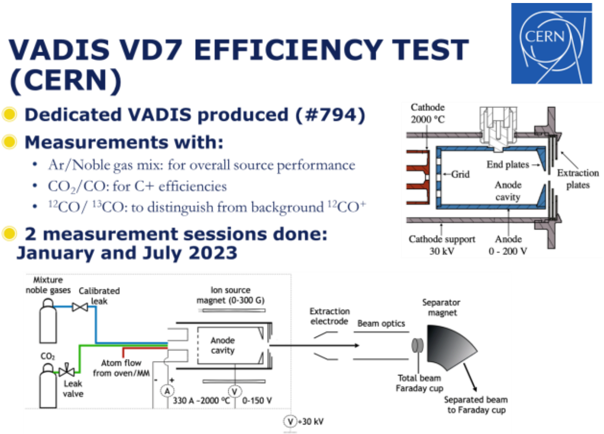
Next steps:
- Characterize diffusion out of Ta in a target unit
- Measure appearance potential
- Find best conditions for TbFx beam extracted from irradiated Ta (ISOLDE)

Task 2- Ion Sources: Ion sources for the production of C-11 beams

Characterization of ion sources in terms of C-11 production capability (C. Schmitzer, N. Gambino, MedAustron)

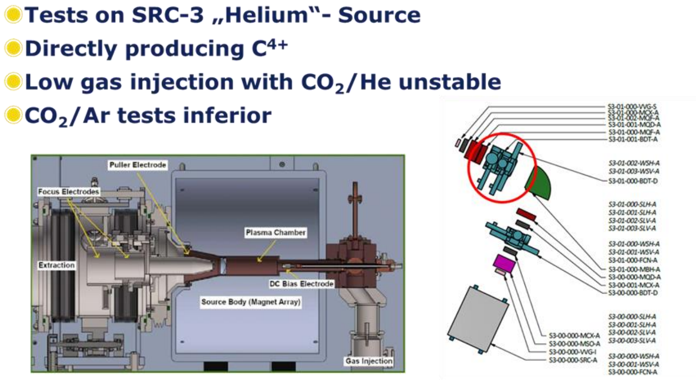
- Particle-based radiation therapy: it is important to verify the 3-dimensional location of the Bragg peak.
- Positron emitter C-11 (produced by means of a Boron Nitride (BN) target, via $^{11}B(p,n)^{11}C$ nuclear reaction, ^{11}CO gas output of 6×10^{10} [s^{-1}]) would thus enable the use of standard PET-CTs for direct correlation between the PET signal and the deployed dose distribution.
- High efficiency ion sources are required to ionise the small amount of C-11 produced > **3 different ion source types were tested**

FEBIAD VADIS MK7 (CERN)



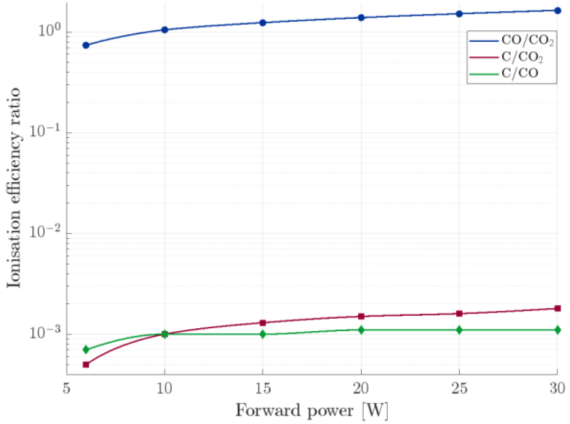
- high ionization efficiency
- 1+ beams (charge breeder required)
- developments and extensive tests required

Supernanogan ECR source (MedAustron)



- operational simplicity and high charge state
- low ionization efficiency
- there is room for improvement

COMIC source (The University of Manchester)



- low ionization efficiency values
- low beam intensity values

Task 2- Ion Sources: Ion sources for the production of C-11 beams

Characterization of ion sources in terms of C-11 production capability (C. Schmitzer, N. Gambino, MedAustron)

Ion source type	Ion source efficiency *(measured)*	Charge breeding efficiency *(estimated)*	Total efficiency
VADIS	5.4%	5%	0.27%
Supernanogan	0.6%	(not needed)	0.6%
COMIC	0.35%	5%	0.02%

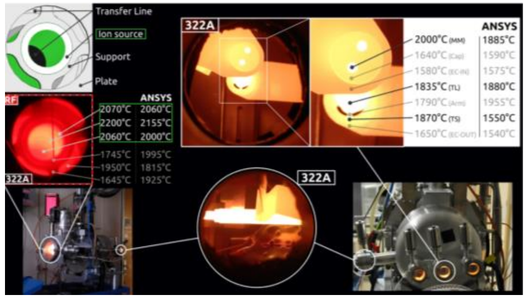
- **Ion source efficiency**
  - Supernanogan is best option when considering full chain:
    - Best overall efficiency
    - No additional accelerator components needed for charge breeding
  - The Supernanogan ionization efficiency can be further improved via design optimisation
- **Facility integration**
  - The best available gas input + Supernanogan do not provide enough beam intensity for treatment; only possible for diagnostics purposes
  - Intensities sufficient for treatment could be obtained by equiping a Supernanogan with a cryogenic trap (for accumulation + pulsed sublimation release)
  - Alternate options (but lower overall efficiencies expected):
    - Cryogenic trap + EBIS source
    - Cryogenic trap + a high-performance electron string ion source (TESIS)

Task 2- Ion Sources: Outlook & PRISMAP+

KU-Leuven, CERN, SCK-CEN, INFN: important developments on ISOL ion-sources

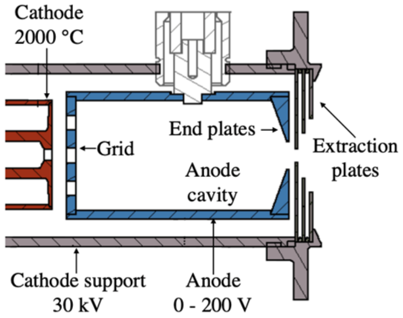
- Comparison of the performance among MEDICIS/ISOLDE, SPES and ISOL@MYRRHA ion sources
- Sharing of the same test-bench / front-end (@ ISOLDE off-line) is a fundamental added value
- Numerous papers published and under development
- DELIVERABLE D10.3: Report on ion source with increased throughput

ISOL@MYRRHA surface ion source
Pump stand tests at ISOLDE



MedAustron: Characterization of ion sources in terms of C-11 production capability

- Structured work completed (comparison among SUPERNANOGAN ECR, FEBIAD, COMIC ECR)
- DELIVERABLE D10.4: Report on ion source efficiency for a C-11 PET ISOL beam



Important basis for future **PRISMAP+** ion source developments

Task 3- Isotope separation techniques: Laser-enhanced isotopically selective condensation for the enrichment of Ca and Ti radionuclides

Enrichment of Ca and Ti isotopes for theranostic Sc isotope production

(Thomas Cocolios - KU-Leuven / CERN)

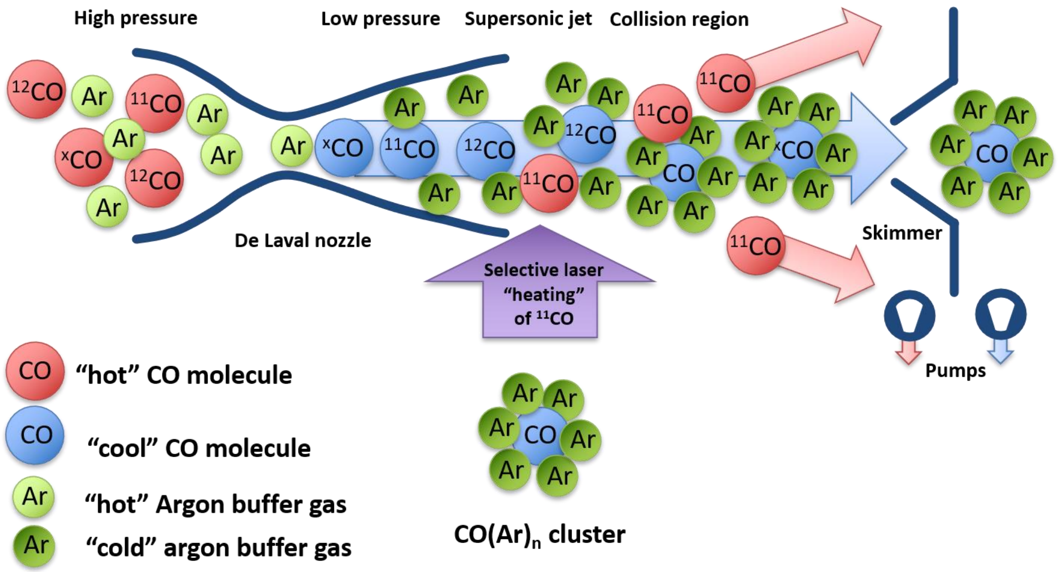
Deliverable D10.6

Report on precursor synthesis

and related infrared spectroscopy measurements

- D10.6 is dedicated to the "**Synthesis of the appropriate molecular precursors containing Ca and Ti and the related FTIR spectra measurements**", towards the application of **laser-enhanced isotopically selective condensation** for the **enrichment of Ca and Ti radionuclides**.
- As **calcium hexafluoroacetylacetonate ($C_{10}H_2CaF_{12}O_4$)** is **commercially available**, it has been **procured externally** for this purpose and **characterised** towards its planned use.

Selective condensation and aerodynamic separation



Task 3- Isotope separation techniques: Laser-enhanced isotopically selective condensation for the enrichment of Ca and Ti radionuclides

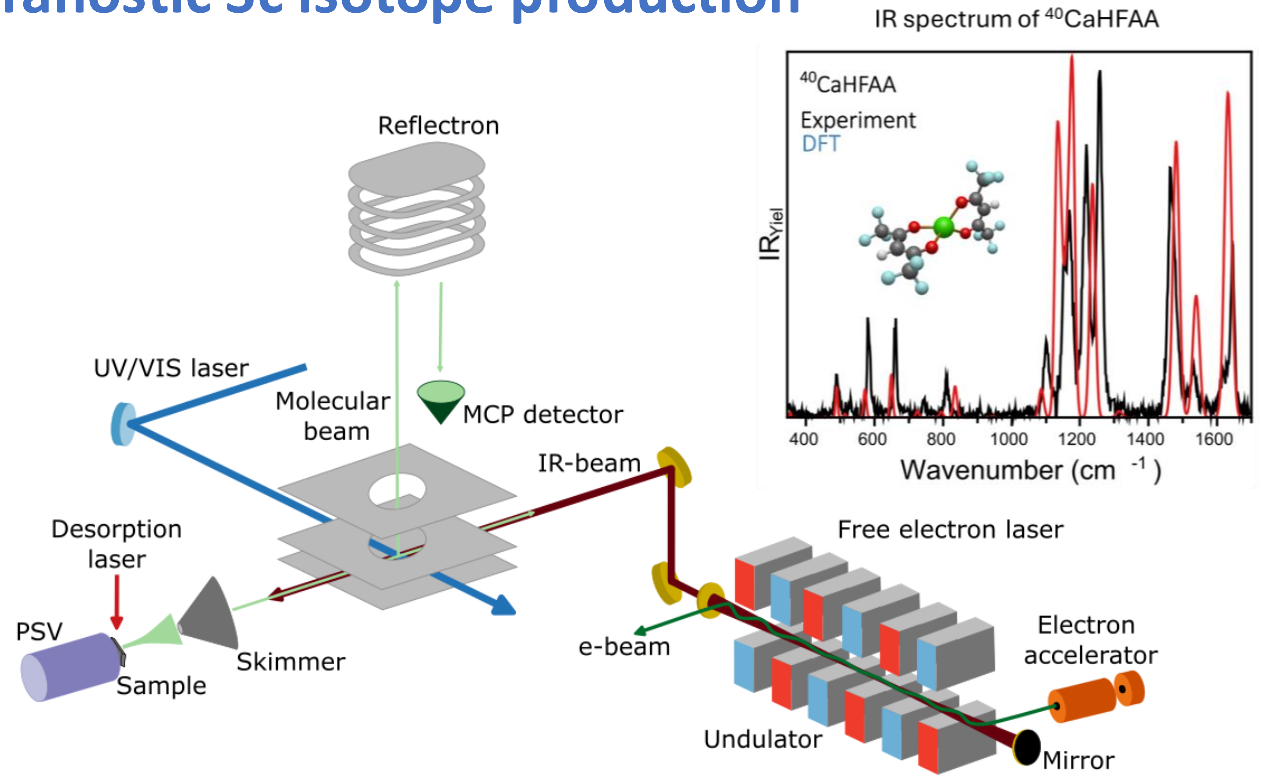
Enrichment of Ca and Ti isotopes for theranostic Sc isotope production

(Thomas Cocolios - KU-Leuven / CERN)

Deliverable D10.6

Report on precursor synthesis and related infrared spectroscopy measurements

- **Gas-phase infrared spectroscopy** was employed to investigate the **vibrational modes** of **calcium hexafluoroacetylacetonate** **($C_{10}H_2CaF_{12}O_4$)** in the wide wavenumber range from 550 to 1700 cm^{-1}.
- The **measured spectrum agrees well with previous** density functional theory **(DFT) calculations**, allowing a targeted laser excitation within PRISMAP at 490 cm^{-1}, in order to resonantly excite a Ca isotope sensitive vibration.



- This demonstrates that this **commercially available compound is appropriate** for the sought-out application and that dedicated synthesis is thus not required.
- **A similar approach may be followed for Ti-containing molecules**, where we need first to identify a suitable stable molecule, then perform the associated DFT calculations, perform the synthesis if no commercial compound can be identified, and finally verify those with infrared light spectroscopy.

General notes: WP10-JRA2 Deliverables

Deliverables		Date
D10.1	**Report on Gd target production**. Comparison between different production methods.	M36
D10.2	**Report on target material characterisation**. Reporting the microstructure information (grain size, porosity), thermal and structural stability.	M42
D10.3	**Report on ion source with increased throughput.** Optimising the geometry, electrical connections and materials of surface and laser ion sources for the ionisation of long-lived radionuclides with high throughput compared to those of existing ISOL ion sources.	M48
D10.4	**Report on ion source efficiency for a ^{11}C PET ISOL beam.** Feasibility and optimisation of the source efficiency for a ^{11}C PET-aided hadron therapy production facility.	M48
D10.5	**DFT calculations for Ca and Ti containing molecules.** Report on the DFT calculations of IR excitations and their isotope shifts for Ca and Ti containing molecules.	M12
D10.6	**Report on precursor synthesis.** Synthesis of the appropriate molecular precursors containing Ca and Ti and on the related FTIR spectra measurements.	M30

General notes: WP10-JRA2 Publications

C. Bernerd et al, **Production of innovative radionuclides for medical applications at the CERN-MEDICIS facility**, NIMB 542 (2023) 137-143
https://doi.org/10.1016/j.nimb.2023.05.008

B. Leenders et al, **On the feasibility of online terbium extraction at ISOL@MYRRHA**, NIMB 541 (2023) 249-252
https://doi.org/10.1016/j.nimb.2023.05.034

C. Bernerd et al, **DFT calculations of Ti-based molecules clustering with Ar for laser-based enrichment of stable isotopes**, NIMB 541 (2023) 141-143
https://doi.org/10.1016/j.nimb.2023.05.040

R. Heinke et al, **First on-line application of the high-resolution spectroscopy laser ion source PI-LIST at ISOLDE**, NIMB 541 (2023) 8-12
https://doi.org/10.1016/j.nimb.2023.04.057

J.D. Johnson et al, **Resonant laser ionization and mass separation of 225Ac**, Scientific Reports 13 (2023) 1347
https://doi.org/10.1038/s41598-023-28299-4

R. Heinke et al, **Efficient production of high specific activity thulium-167 at Paul Scherrer Institute and CERN MEDICIS**, Frontiers in Medicine 8 (2021) 712374
https://doi.org/10.3389/fmed.2021.712374

M. Ballan et al, **Thermal and Structural Characterization of a Titanium Carbide/Carbon Composite for Nuclear Applications**. Materials 2022, 15, 8358
https://doi.org/10.3390/ma15238358

A. Breda et al, **Production and mechanical characterization of Titanium Carbide ISOL target disks fabricated by direct ink writing**, Ceramics International 2023, 49, 19, Pages 31666-31678
https://doi.org/10.1016/j.ceramint.2023.07.121

L. Mou et al, **67Cu Production Capabilities: A Mini Review**, Molecules

Y. Wang et al, **Study of terbium production from enriched Gd targets via the reaction 155Gd(d,2n)155Tb**, ARI
https://doi.org/10.1016/j.apradiso.2023.110996

O.S. Khwairakpam et al, **The SPES Laser Ion Source: Time Structure, Laser Enhancement and Efficiency Measurements with Gallium at ISOLDE Offline 2**, Nuclear Instruments and Methods in Physics Research B.
10.1016/j.nimb.2024.165249

E. Mamis et al, **Target Development towards First Production of High-Molar- Activity 44gSc and 47Sc by Mass Separation at CERN-MEDICIS**. Pharmaceuticals 2024, 17, 390.
https://doi.org/10.3390/ph17030390

… and many more > see https://www.prismap.eu/members/dissemination/publications/

Many Thanks for Your Attention!

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PRISMAP PROJECT

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