Nuclear Physics Mid Term Plan in Italy

LNF – Session

Frascati, December 1st - 2nd 2022

Nuclear Physics Mid Term Plan in Italy

Innovative targets for new production facilities

- Production target of the SPES ISOL facility at LNL
- Secondary target for the ISOLPHARM project at LNL
- LARAMED targets for direct production of medical radioisotopes at LNL
- Targets for neutrons at LNL
- Target for FraIse facility at LNS

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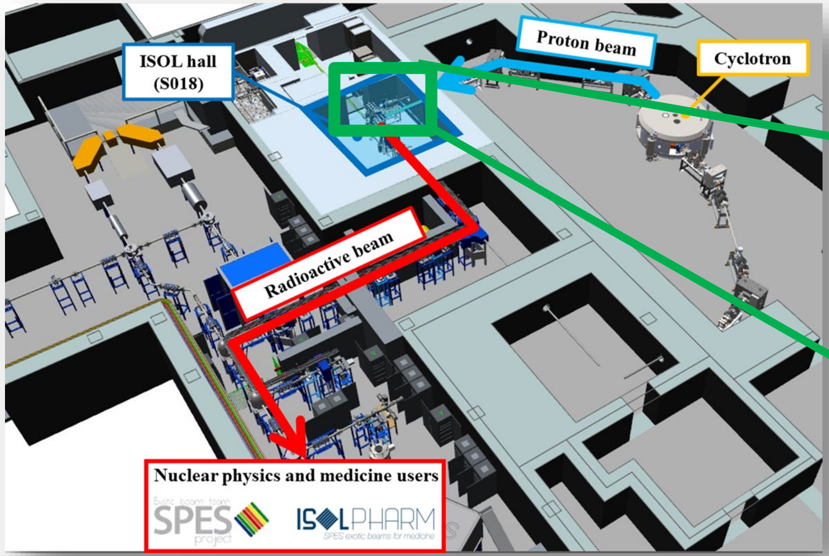
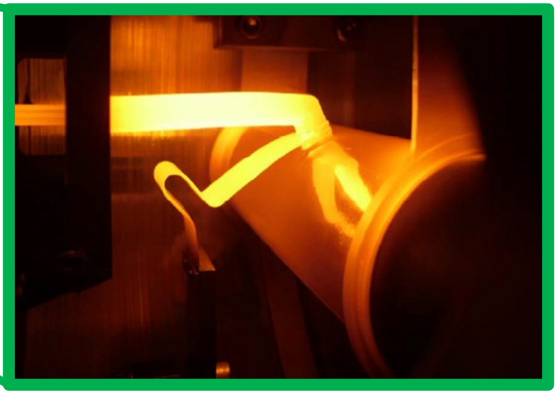
INFN
Istituto Nazionale di Fisica Nucleare

Production target of the SPES facility at LNL



The SPES target-ion source



Stefano Corradetti, Alberto Andrighetto, Mattia Manzolaro, Michele Ballan, Alberto Monetti, Lisa Centofante, Giordano Lilli, Daniele Scarpa (INFN-LNL)
Sara Carturan (University of Padova, DFA)
Alice Zanini, Giorgia Franchin, Paolo Colombo (University of Padova, DII)
Lisa Biasetto (University of Padova, DTG)
Francesca Servadei, Diletta Sciti, Laura Silvestroni, Luca Zoli (CNR-ISSMC)

SPES (ISOL) target requirements

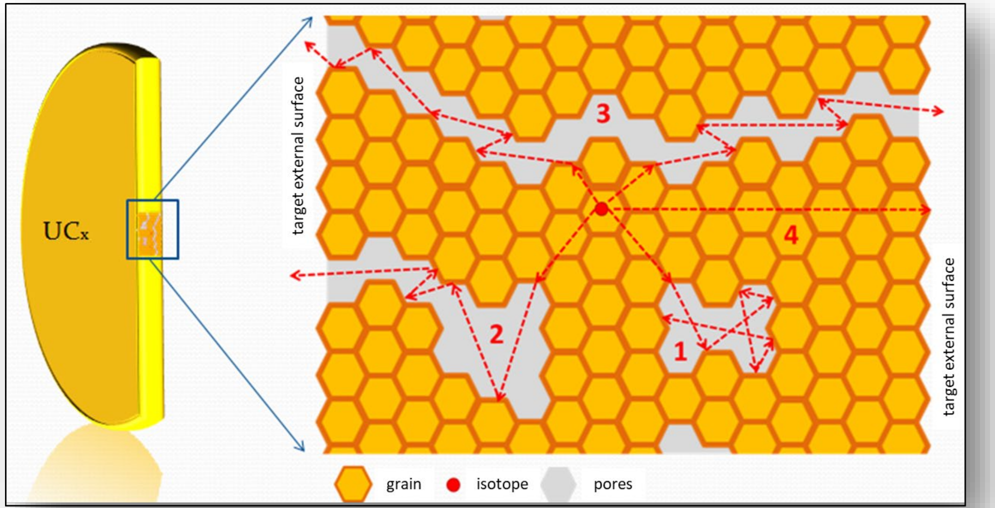
Target working conditions:

- Many days of continuous operation (10 ÷ 15)
- T = 1600 ÷ 2000 °C, even more in some cases
- 10 kW power
- High vacuum
- Radiation (p, n, g, a, b, …)

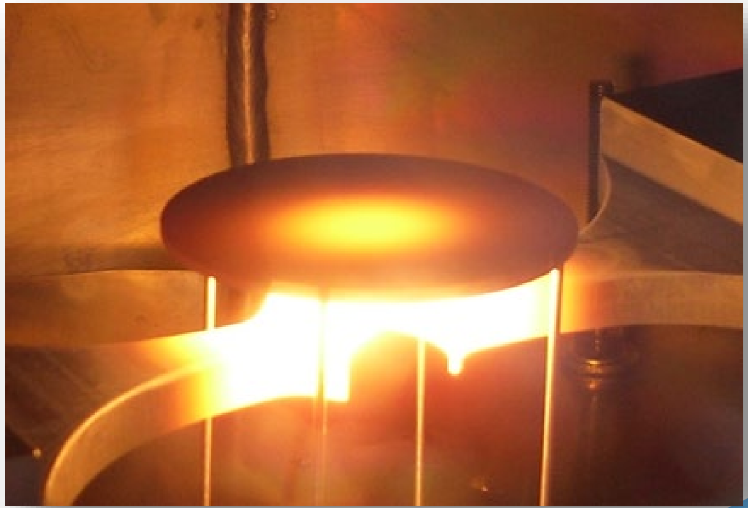
Carbide/carbon composites (UC_2+2C, TiC+2C, ThC_2+2C, …)

Two sets of properties to optimize: porosity and thermo-mechanical

Micro-meso-macroporosity to obtain fast release of isotopes



High thermal properties to efficiently dissipate heat



State of the art: the standard production (carbothermal reduction)

Weighing raw materials

↓

Mixing

↓

Grinding

↓

Pressing

↓

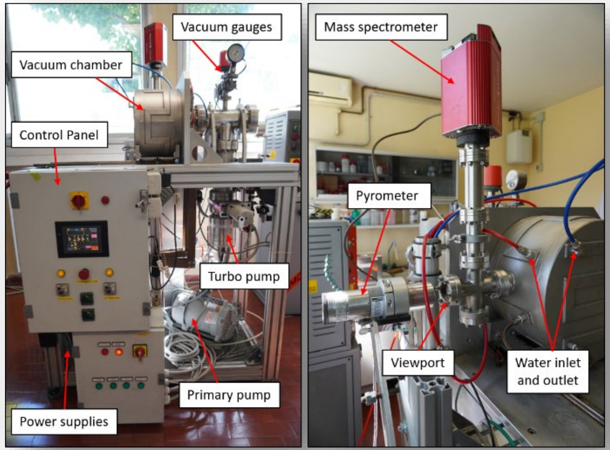
Heat treatment(s) in high vacuum furnaces

La_2O_3 + C after pressing

LaC_2 + 2C after heat treatment

Optimization of properties by:

- Choice of carbon/metal precursors and additives
- Heat treatment parameters



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

Total porosity	60 %
Porosity type	Mainly open, macro
Specific Surface Area	Negligible

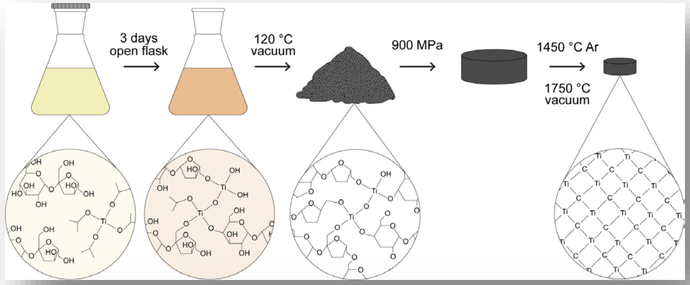
Activity in collaboration with UNIPD: DFA, DII, DTG

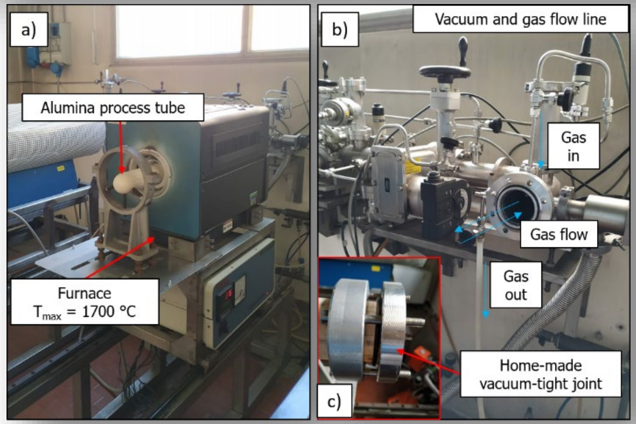
S. Corradetti et al., Nuclear Instruments and Methods in Physics Research B 488 (2021) 12–22

Example of innovative production techniques: sol-gel and use of innovative carbon sources

Synthesis of microporous Carbide/Carbon composites via sol-gel

Ti alkoxide sol
↓
Gel
↓
Drying
↓
Pressing
↓
Heat treatment(s) in gas and/or high vacuum





TiiP + sucrose ⟶ TiC + 2C

Total porosity	65 %
Porosity type	Totally open, micro
Specific Surface Area	Very high (650 m^2/g)

Optimization of properties by:

- Choice of initial reagents type, amount and proportions
- Temperature, pH of each production phase
- Heat treatments parameters

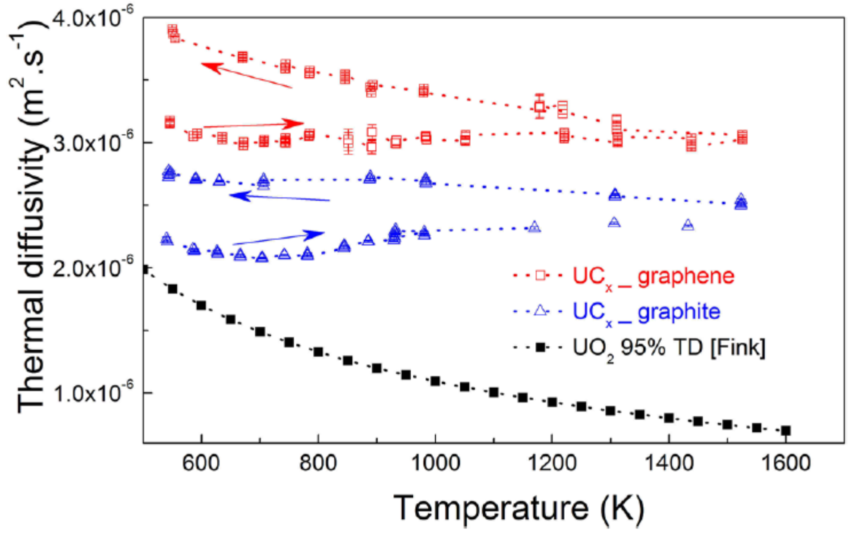
Activity in collaboration with UNIPD: DFA, DII

A. Zanini et al., Microporous and Mesoporous Materials 337 (2022) 111917;
S. Corradetti et al., Ceramics International 46 (2020) 9596

Graphene as a carbon source for U and Th carbides

$$UO_2 + 6C \longrightarrow UC_2 + 2C + 2CO$$
$$ThO_2 + 6C \longrightarrow ThC_2 + 2C + 2CO$$

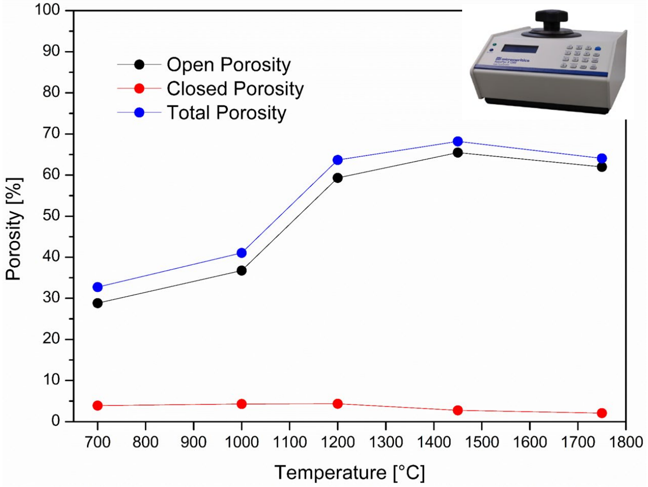
Use of graphene as a carbon source leads to improved thermal properties with respect to standard (graphite) in carbide/C composites



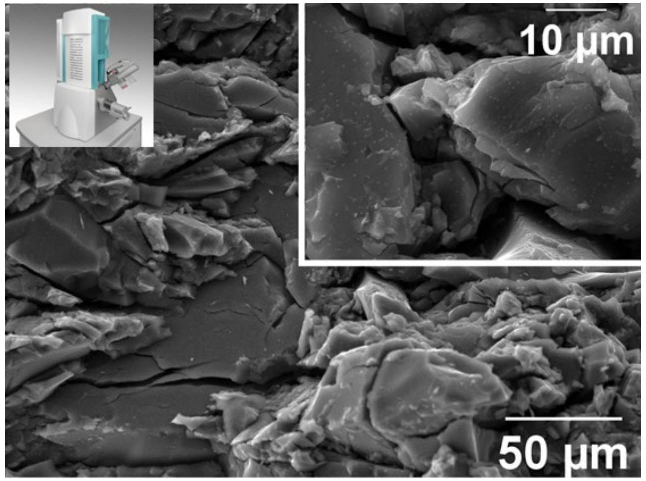
Activity in collaboration with JRC-Karlsruhe and UNIPD: DFA, DTG

S. Corradetti et al., Scientific Reports 11 (2021) 9058
L. Biasetto et al., Scientific Reports 8 (2018) 8272

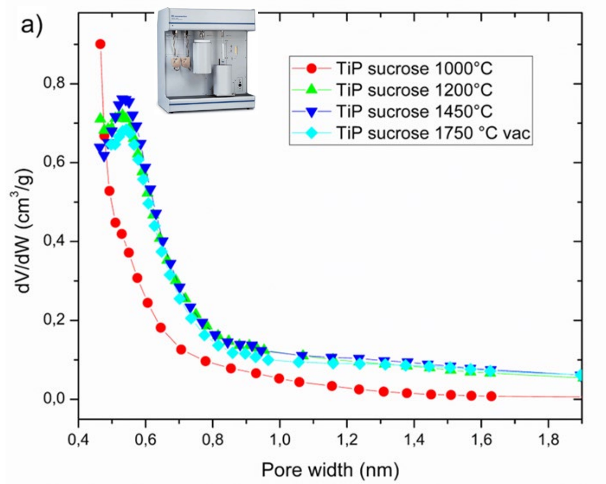
Characterization techniques: microstructure and porosity



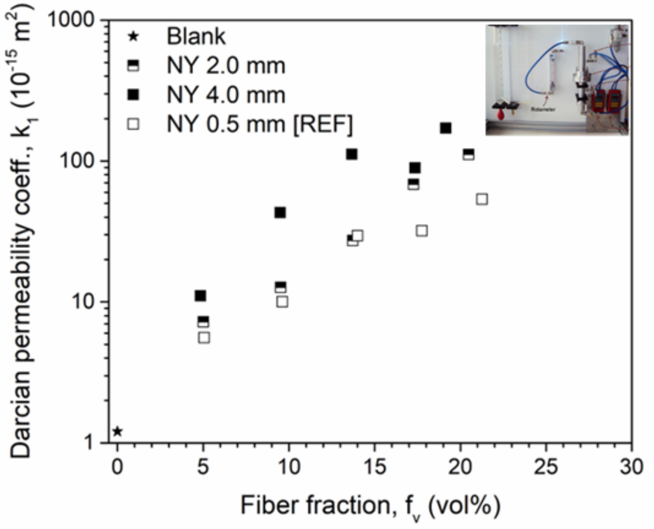
Helium pycnometry to characterize open-closed porosity



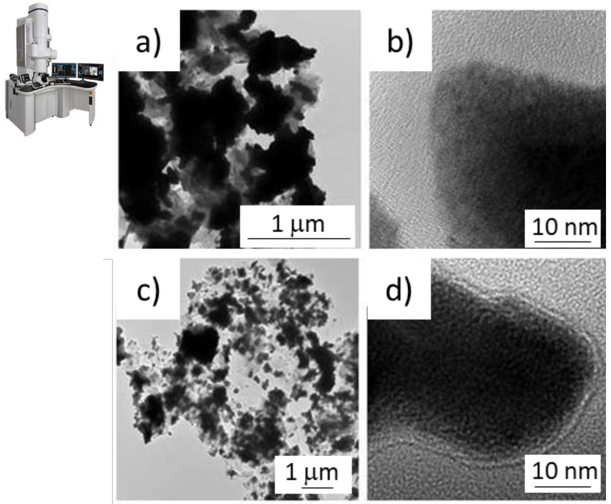
Scanning electron microscopy to study microstructure



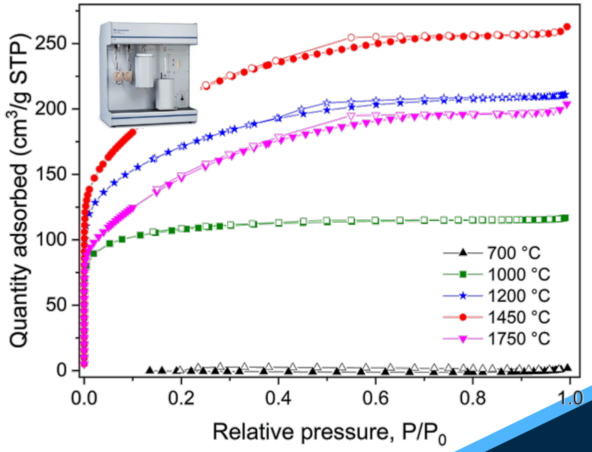
Gas physisorption to calculate pore size



Gas permeability to characterize open porosity

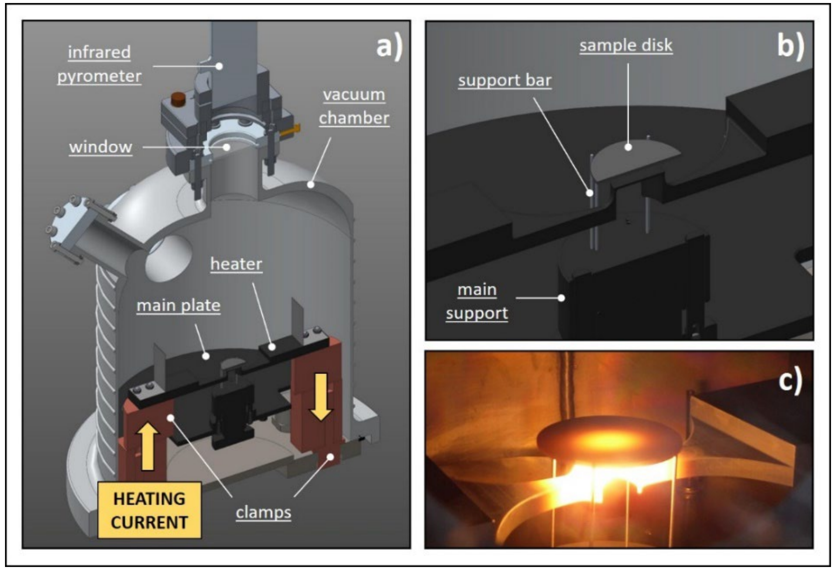


Transmission electron microscopy to study nanostructure

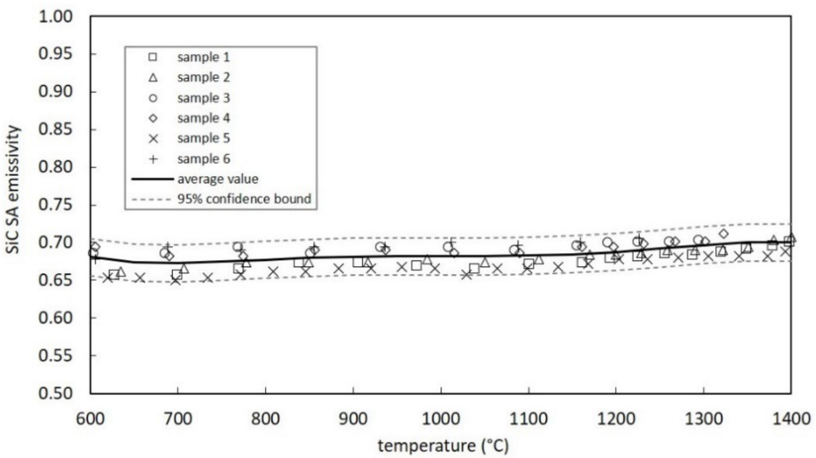


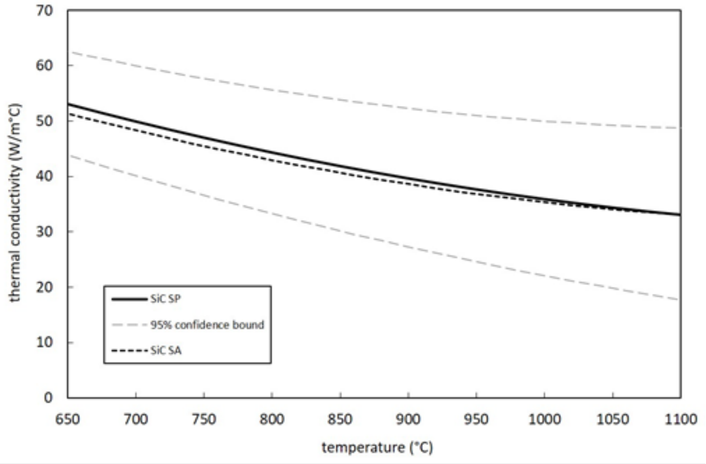
Gas physisorption to calculate specific surface area

Characterization techniques: thermomechanical properties

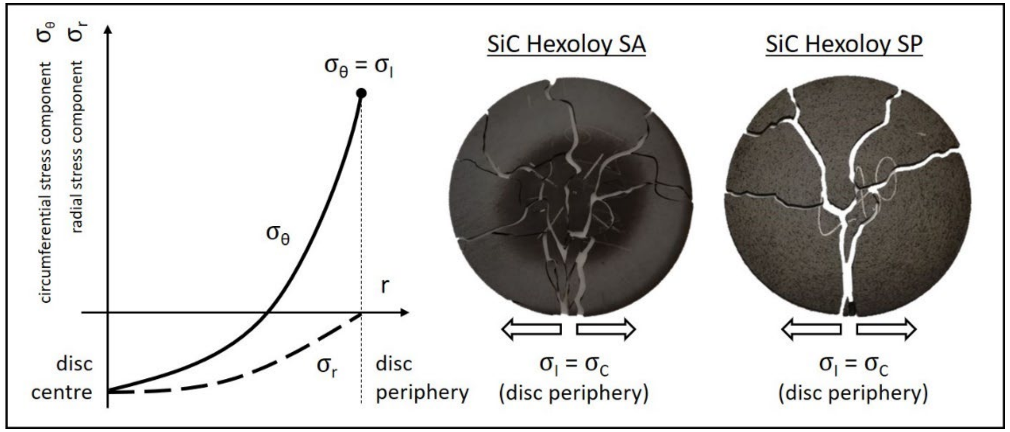


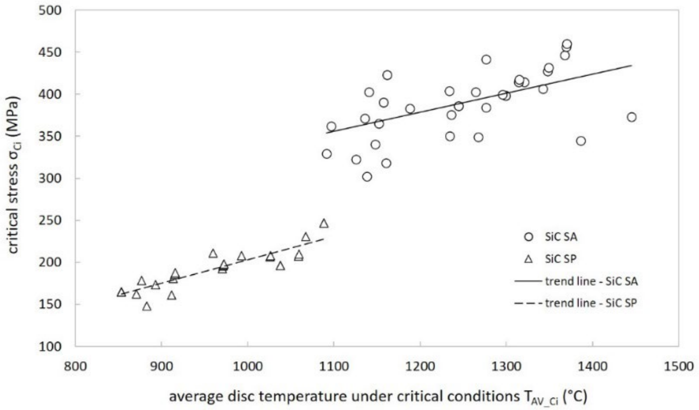
Thermal characterization - Obtainable data: emissivity and thermal conductivity





Structural characterization - Obtainable data: critical stress under irradiation, probability of survival under irradiation without undergoing failure



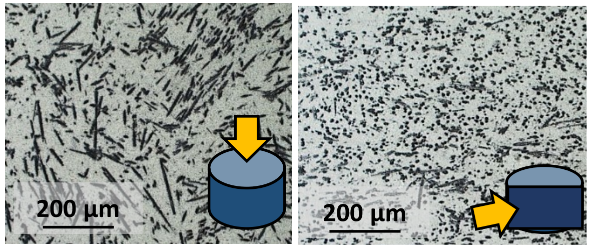


M. Manzolaro et al., Review of Scientific Instruments 84 (2013) 054902;
M. Manzolaro et al., Materials 14 (2021) 2689

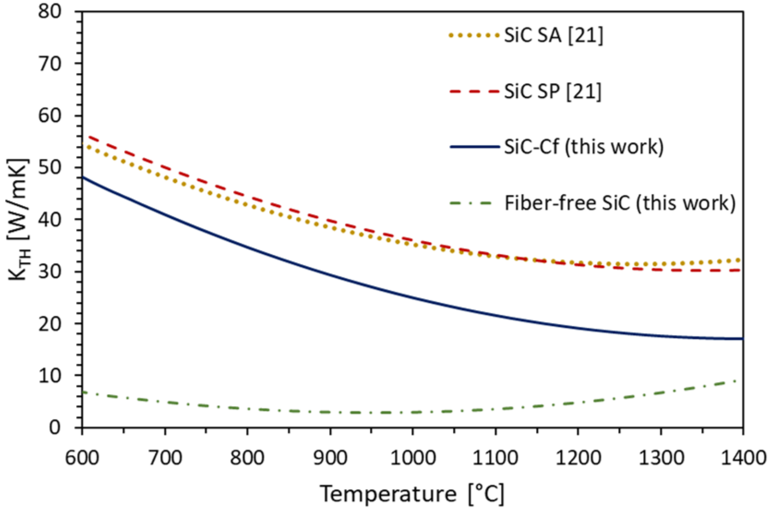
Activity in collaboration with UNIPD: DII

New ideas for the future

Improving thermo-mechanical properties using fibers



Use of dispersed carbon fibers (Cf) in SPES targets leads to porosity AND good thermal properties AND improved survival under thermal induced stresses

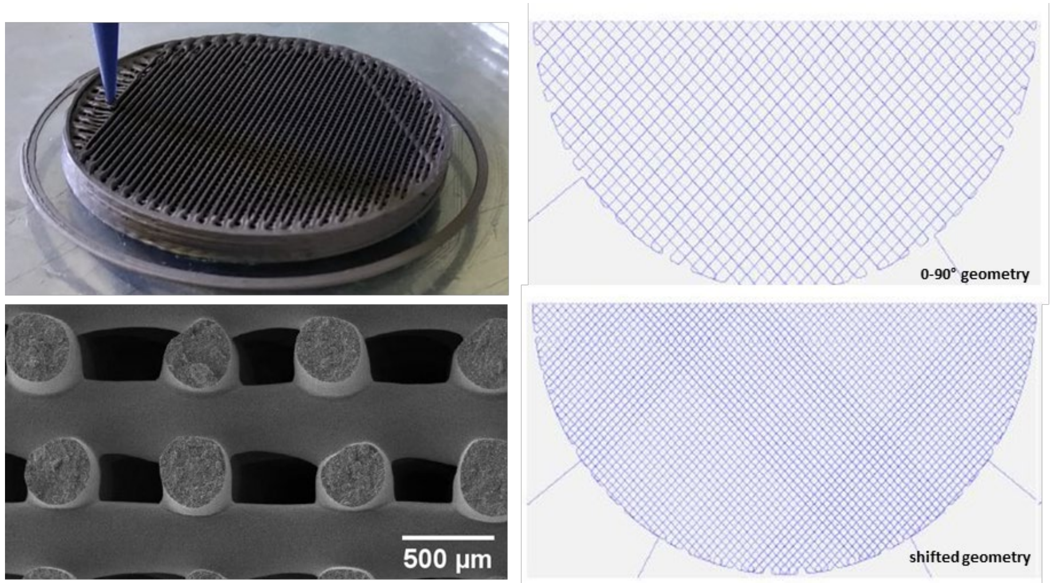


Dense SiC SA   Porous SiC-Cf   Porous fiber-free SiC

Activity in collaboration with CNR-ISSMC

L. Silvestroni et al., Journal of the European Ceramic Society 42 (2022) 6750

Optimizing porosity by using additive manufacturing



Material precursor: commercial TiC powder
Fabrication process: Direct Ink Writing

Preliminary data (AM4INFN and HISOL experiments):

- **permeability coefficients** shifted geometry > 0-90° geometry
- **specific surface area** < 1 m^2/g → low value: to be increased to ensure good release of radioisotopes → future works will focus on the use of the sol-gel approach to tailor the textural properties of the material

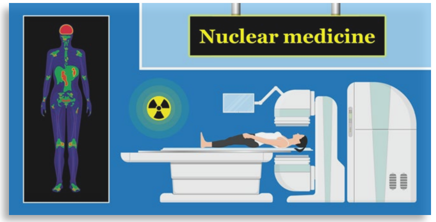
Activity in collaboration with UNIPD: DFA, DII

SPES γ: radionuclides for nuclear medicine

"Radioisotope Service for Medicine and Applications" @LNL

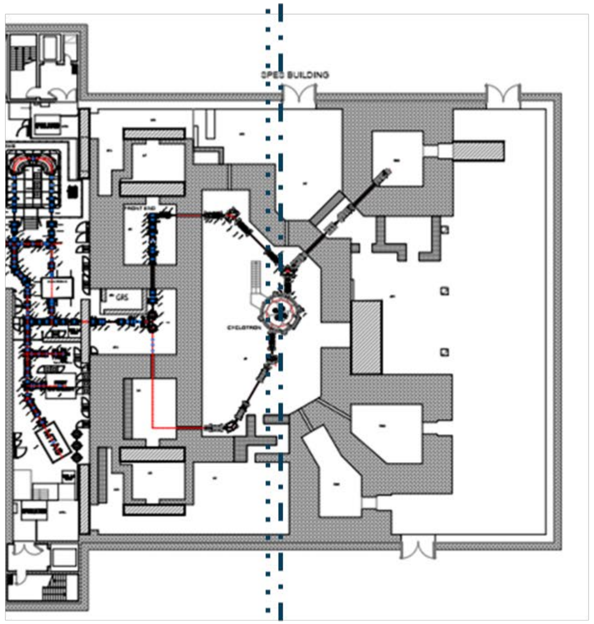
Functional and metabolic organ informations for

- early **diagnosis**
  SPECT – Single Photon Emission Computed Tomography
  PET – Positron Emission Tomography
- **specific therapies**
- **Theranostic**



ISOLPHARM
SPES exotic beams for medicine

ISOL technique
A. Andrighetto
Resp. ISOLPHARM



LARAMED

Direct activation
J. Esposito
Resp. LARAMED

https://isolpharm.pd.infn.it/web/

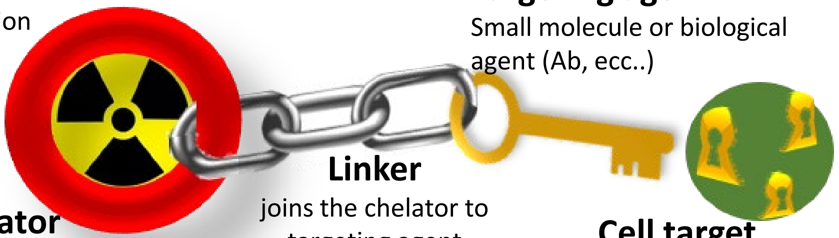
https://www.lnl.infn.it/en/spes-laramed-range

through the use of **radiopharmaceutical**

Radionuclide
responsible of signal emission

γ , β^+

β^- , α, Auger electrons



Chelator
molecule holding the radioisotope

Linker
joins the chelator to targeting agent

Targeting agent
Small molecule or biological agent (Ab, ecc..)

Cell target
Better if overexpressed by the target cells

Medical Radionuclide production @LNL

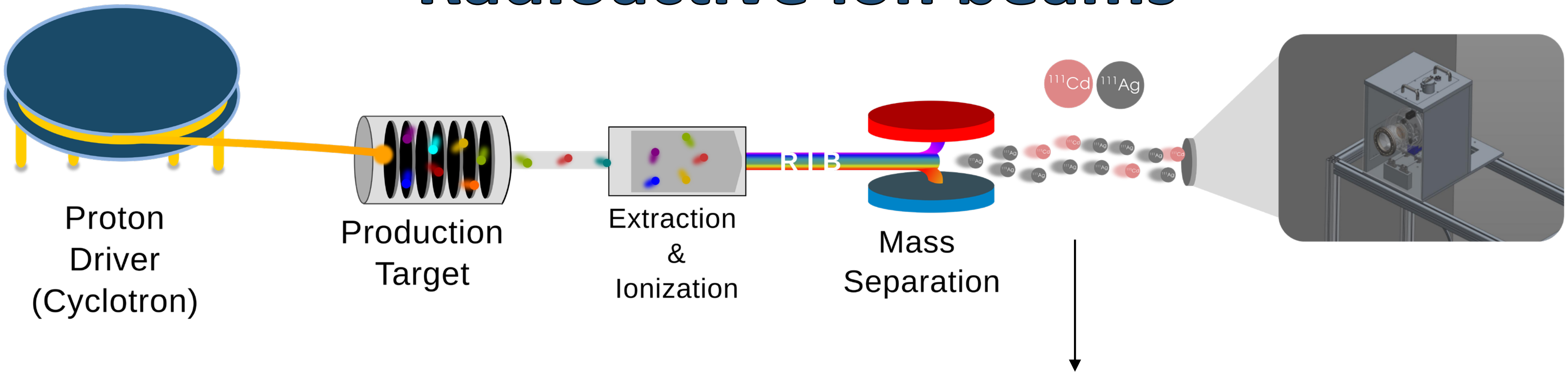
ISOLPHARM SPES exotic beams for medicine

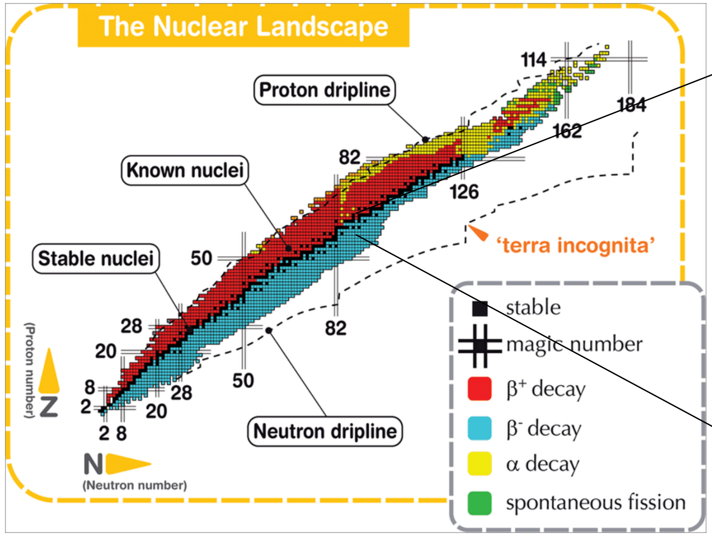
INFN LNL Istituto Nazionale di Fisica Nucleare Laboratori Nazionali di Legnaro

Secondary target for the ISOLPHARM project at LNL

Michele Ballan (INFN-LNL), Elisa Vettorato (INFN-LNL and University of Padova),
Luca Morselli (INFN-LNL)
Nicola Realdon, Francesca Mastrotto (University of Padova)
Marcello Lunardon (INFN-PD and University of Padova)

Radioactive ion beams

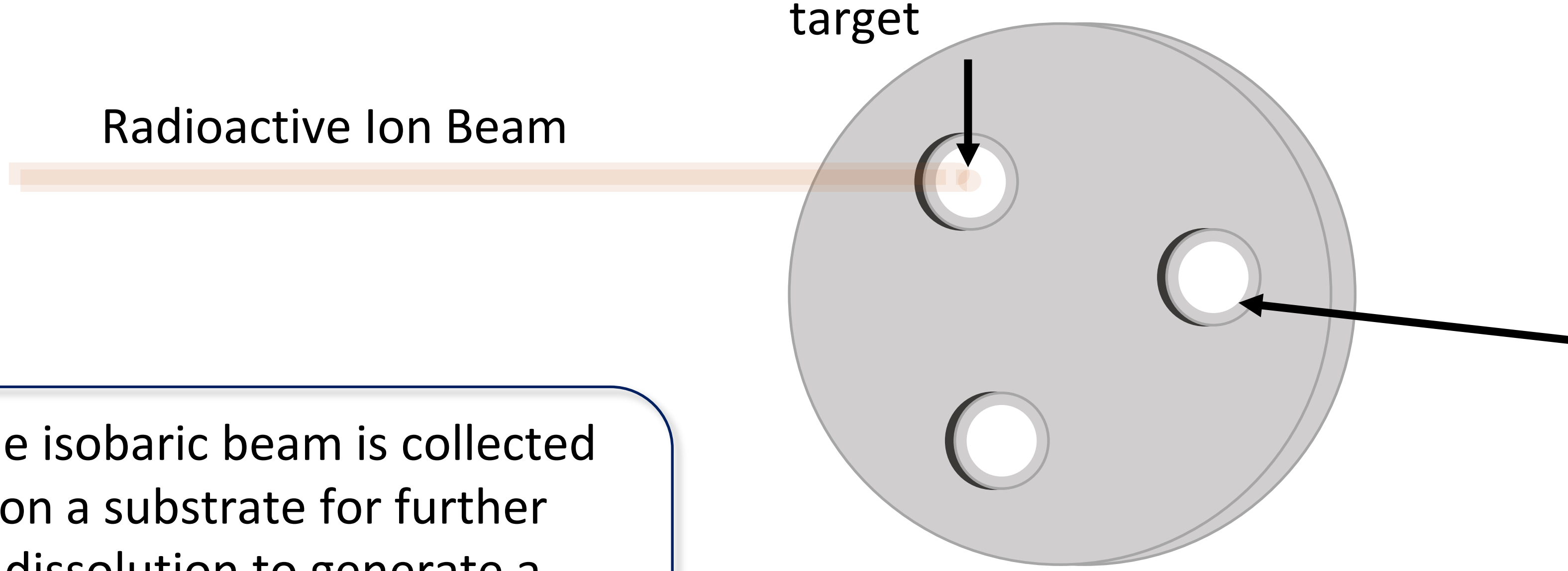


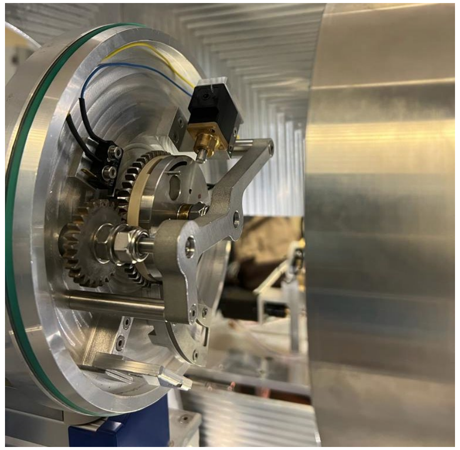


Isobaric Radioactive Ion Beam
- excellent radionuclide purity -

Targets handling - IRIS

ISOL(PHARM) Radionuclide Implantation Station (IRIS)



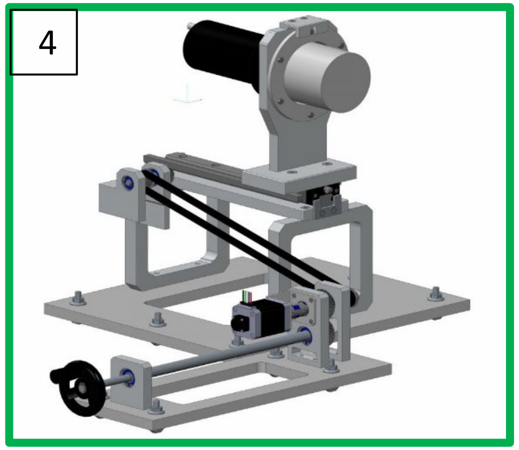


The isobaric beam is collected on a substrate for further dissolution to generate a solution for radiolabelling of pharmaceuticals

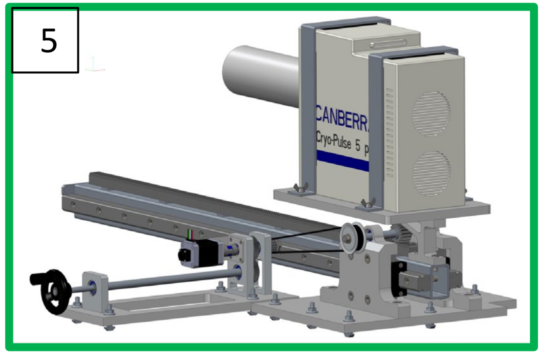
✅ Deposition test on different implantation substrates.

IRIS (ISOLPHARM Radionuclide Implantation Station)

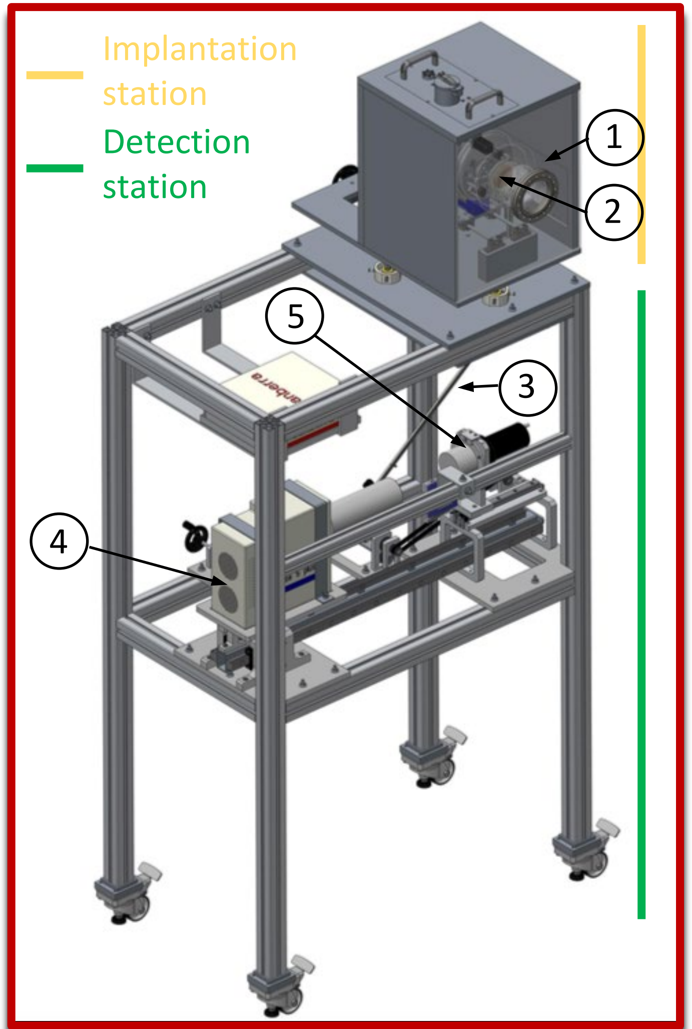
LaBr3 Detector



HPGe detector



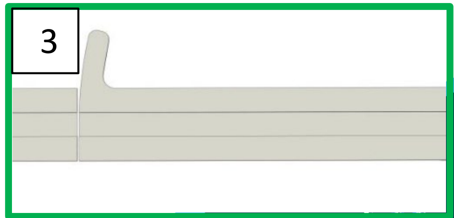
IRIS



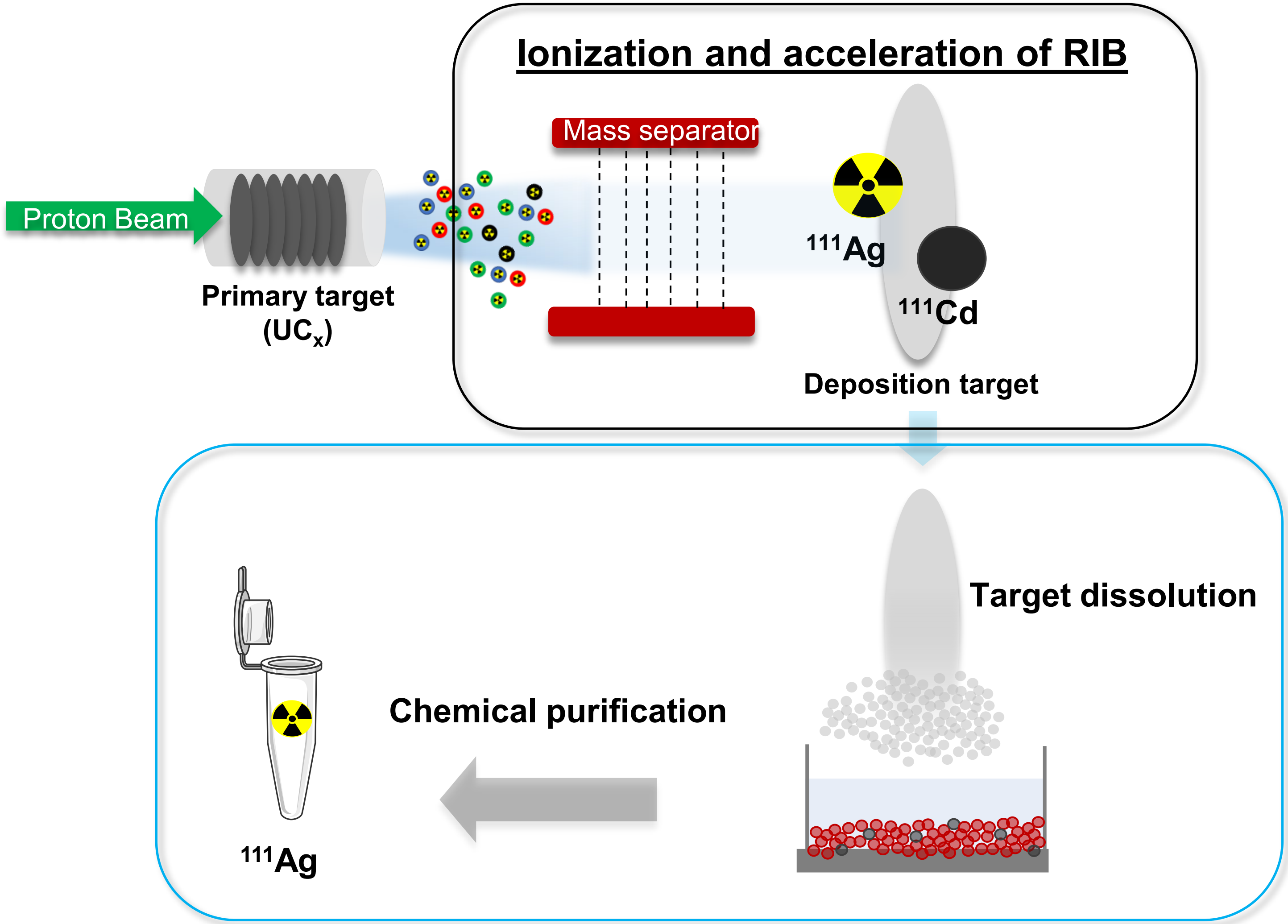
Target rotating support

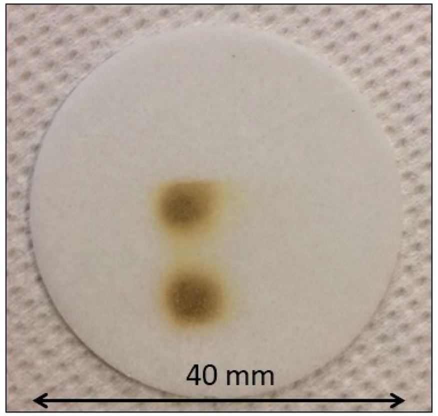
Target refill system

Discharge guide

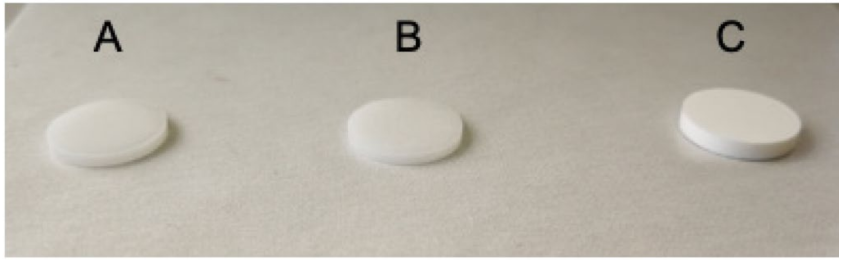


Ion Recovery





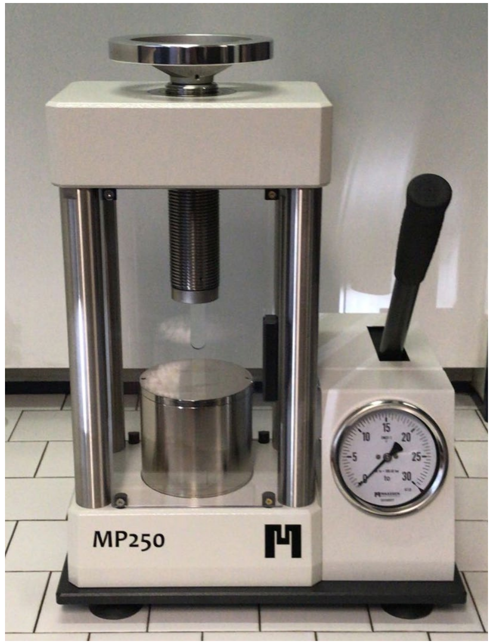
107-Ag and 109-Ag

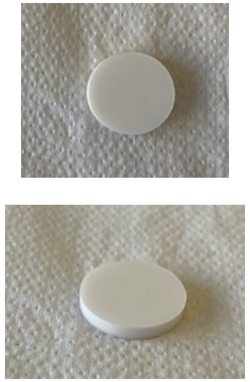


Different materials to get high resistance and radionuclide recovery

Production method

Targets production





- Sodium chloride
- Sodium nitrate

Saline

- Dextrates
- Cellulose

Pharma

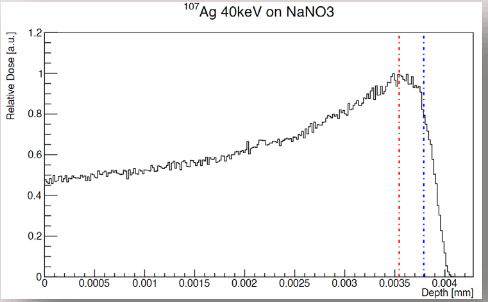
Production conditions

Mass variation

Pressure force variation

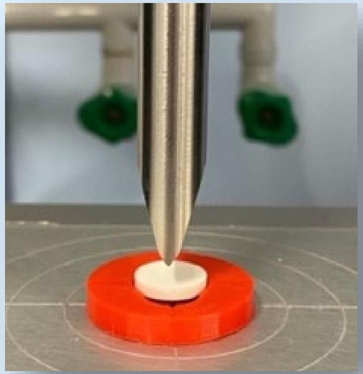
Pressing time variation

Characterization



Implantation depth

Porosity



Breaking load

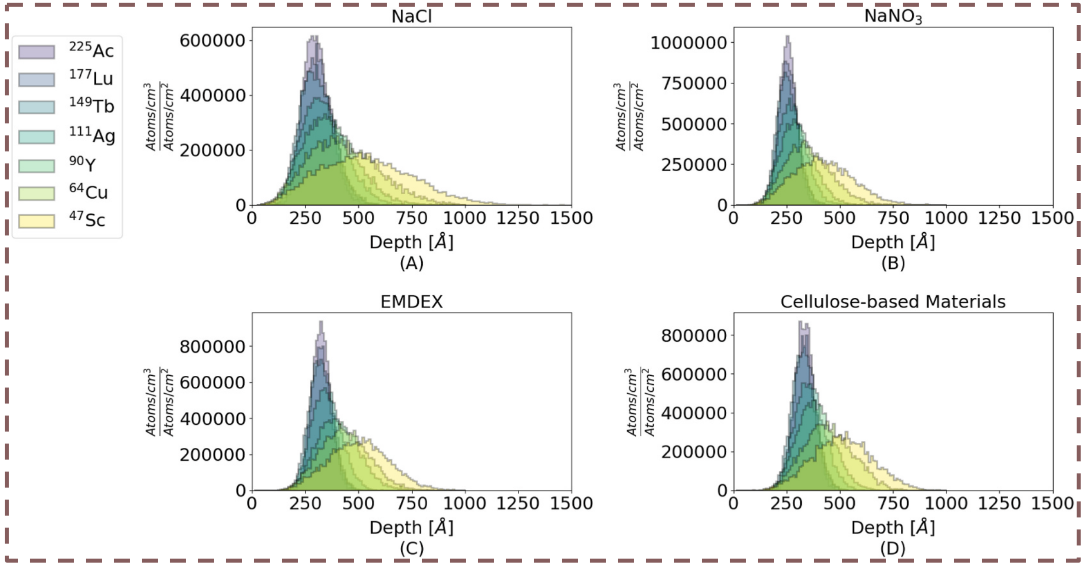
Disaggregation

Metals deposition

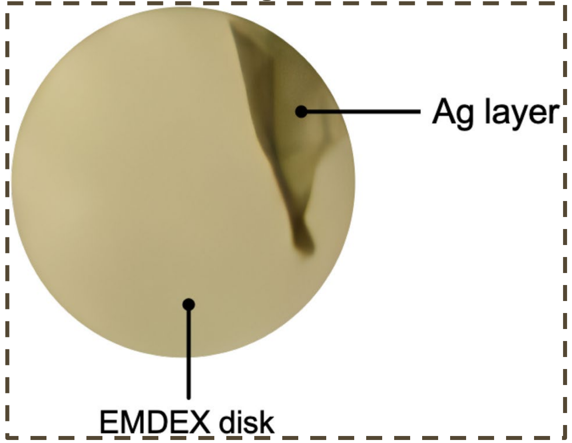
Manuscript: Ballan M, Vettorato E, *et al. Appl Radiat.*2021;175:109795

Results and future works

Implantation depth

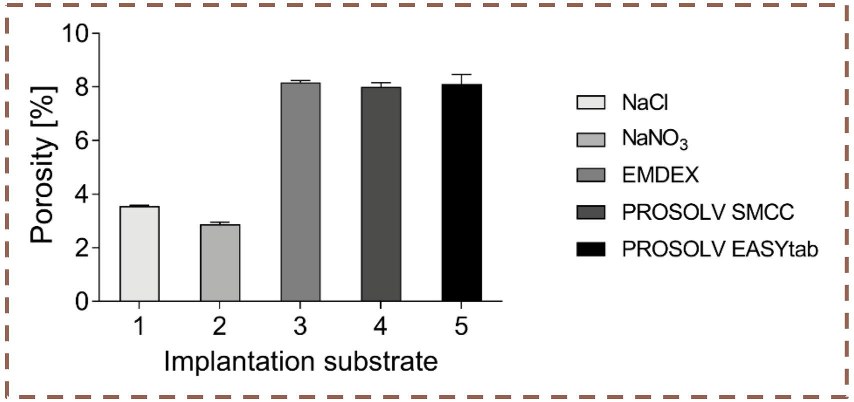


Metals deposition

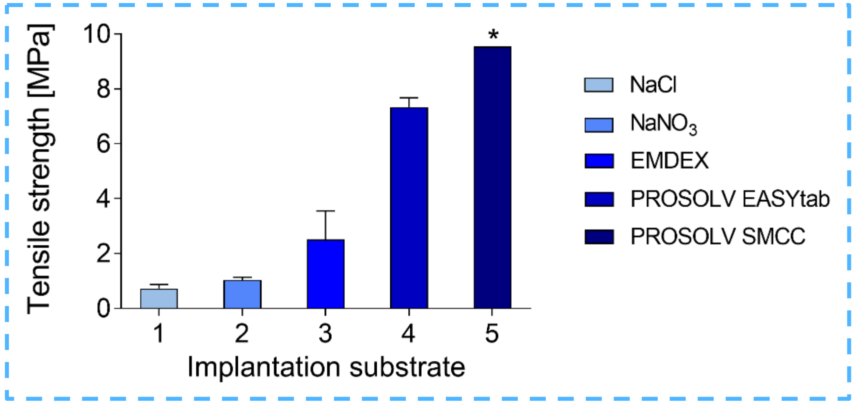


Pharma materials are more promising→ **deposition compatibility studies with different material beyond Cu and Ag**

Porosity



Breaking load

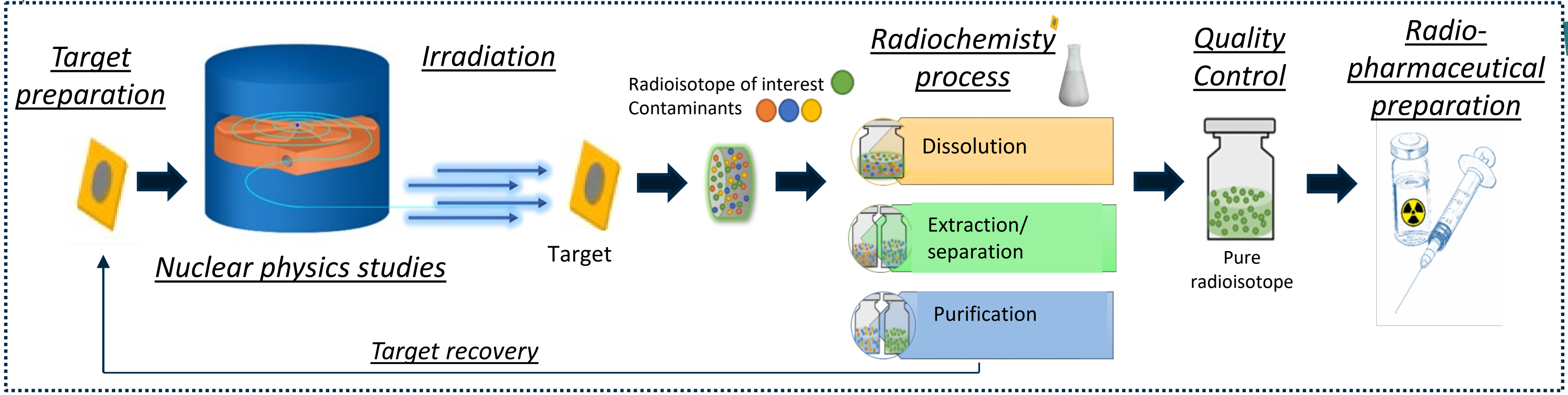


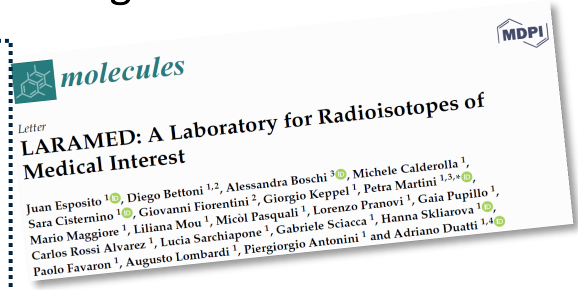
LARAMED targets for direct production of medical radioisotopes at LNL

Sara Cisternino, Juan Esposito, Gaia Pupillo, Liliana Mou, Gabriele Sciacca, Giorgio Keppel, Oscar Azzolini, Mourad El Idrissi (INFN-LNL)
Alisa Kotliarenko (INFN-LNL and University of Ferrara)
Lucia De Dominicis (INFN-LNL and University of Padova)
Petra Martini (University of Ferrara and INFN-FE)

LARAMED → LAboratory of RAdionuclides for MEDicine

Research and development for the production of innovative medical radioisotopes by direct target activation



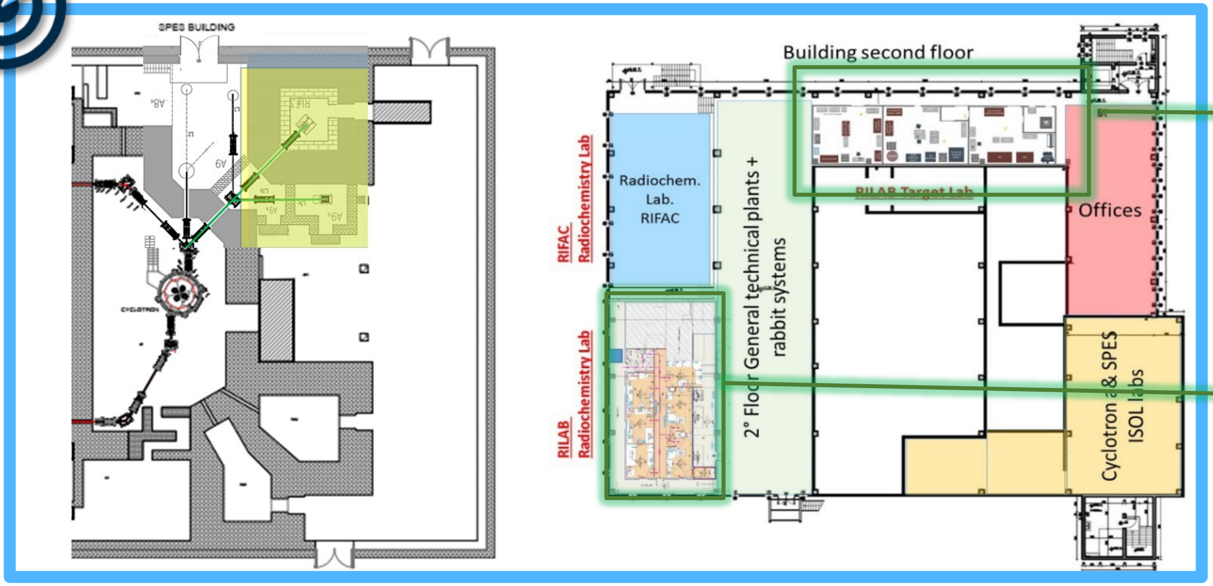

molecules

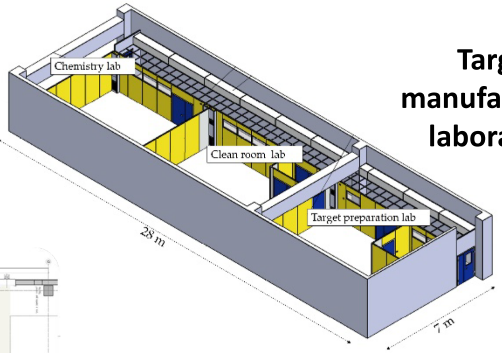
MDPI

Letter

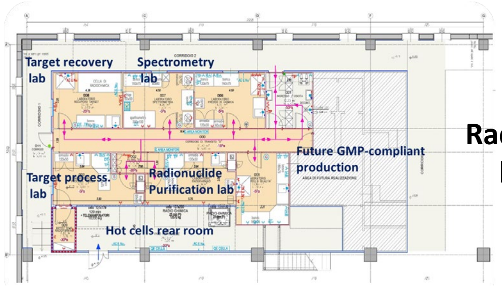
LARAMED: A Laboratory for Radioisotopes of Medical Interest

Juan Esposito [1], Diego Bettoni [1,2], Alessandra Boschi [3], Michele Calderolla [1], Sara Cisternino [1], Giovanni Fiorentini [2], Giorgio Keppel [1], Petra Martini [1,3,*], Mario Maggiore [1], Liliana Mou [1], Micòl Pasquali [1], Lorenzo Pranovi [1], Gaia Pupillo [1], Carlos Rossi Alvarez [1], Lucia Sarchiapone [1], Gabriele Sciacca [1], Hanna Skliarova [1], Paolo Favaron [1], Augusto Lombardi [1], Piergiorgio Antonini [1] and Adriano Duatti [1,4]





Target manufacturing laboratory



Radiochemistry laboratory

Solid targets:

What is needed - absolutely necessary - for successful medical RI production or nuclear-cross section measurements?

→ A target with specific **requirements**

- **Target material**

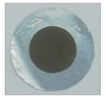
decided based on nuclear physics reaction chosen for the production of the specific radionuclide

Often isotopically enriched material→ very expensive!

- **Optimal thickness**

estimated based on nuclear physics calculations to exploit the best energy range

Nuclear Cross-section measurements



100s μg/cm² – 10s mg/cm²

Radionuclide production

100s mg/cm² – g/cm²

- **Easy handling**

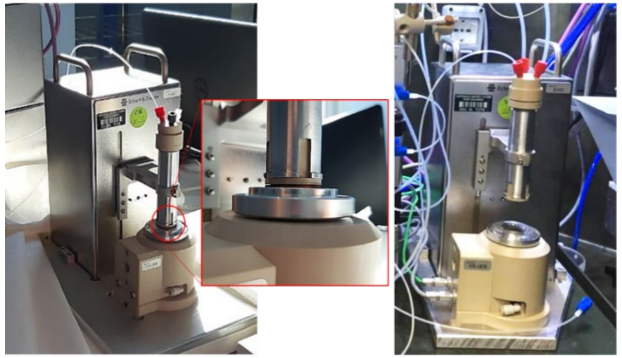
for safe radiochemistry process

- **Thermo-mechanical strenght**

To withstand the thermal power deposited during the irradiation

- **Selected backing material**

based on its
- chemical inertness
- thermal conductivity
- mechanical strenght
- activation under the beam

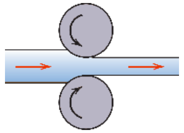


Dissolutin reactor with bottom opened vial (Sciacca et al., Molecules 2021)

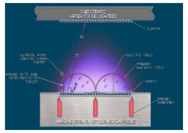
What is needed - absolutely necessary - for a successful target?

→ Tailored **manufacturing techniques**

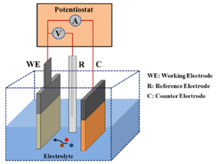
Mechanical



Physical



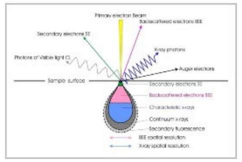
Chemical



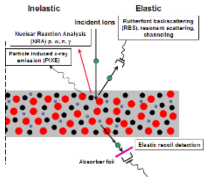
others…

→ **Target characterization, tests and simulations**

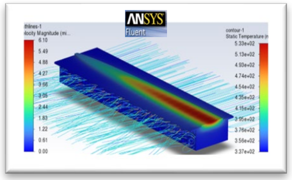
Microscopy



Ion Beam Analysis



others…

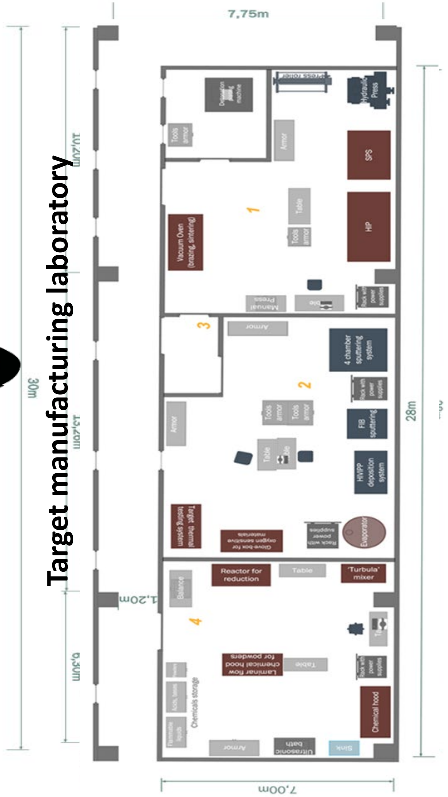


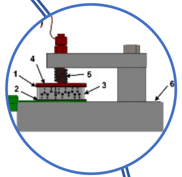
Thermo-mehanical simulations

R&D on innovative target manufacturing techniques

in the framework of the LARAMED project

to overcome the limits of standard techniques



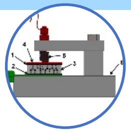


High Energy Vibrational Powder Plating → Thin targets for nuclear XS studies

Spark Plasma Sintering

Magnetron Sputtering

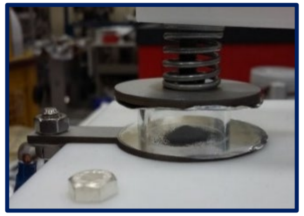
Spark Plasma Sintering and Magnetron Sputtering → Thick targets for RI production



High Energy Vibrational Powder Plating (HIVIPP)

Solution for thin target for nuclear xs measurements

This deposition technique exploits the phenomenon of **vibrational motion** of metallic **powder in a static electric field**



Advantages

- ✓ Starting material→ **powder**
- ✓ Efficiency 95-98%: **no losses of material**
- ✓ Two targets are deposited simultaneously
- ✓ Low amout of starting material is needed
- ✓ Thickness: 0.1-20 µm
- ✓ Glove-bag to work in protective atmosphere
- ✓ Automatic control of power supply

Requirements:

- Metal substrates
- Metal powder (irregular shape and small size <20 µm)

Suitable for Ti targets for the nuclear cross-section mesurements for the production of the theranostic radionuclide ^{47}Sc at high energy (30-70 MeV)

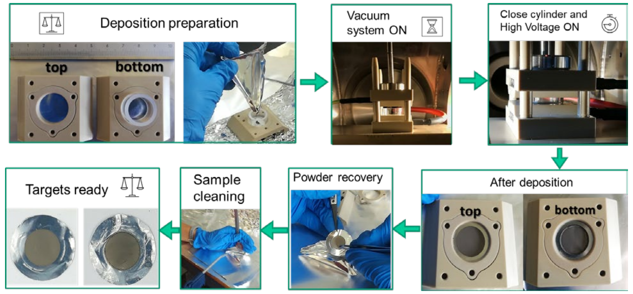
- **know-how**
- **HIVIPP apparatus**
- **technology**

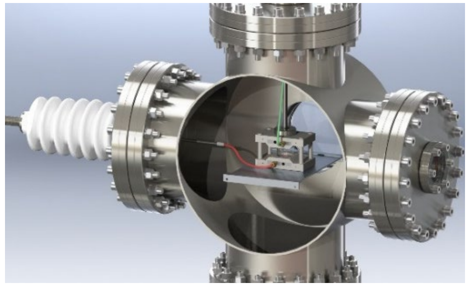
available @ LNL for future target request for

- ➢ nuclear cross-section measurements for medical RI production (Irradiation @ LNL - 2023)
- ➢ and other..

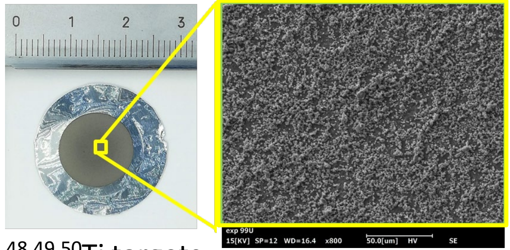
E-PLATE, PASTA and REMIX projects (CSN5)

✓ New set-up apparatus and deposition procedure





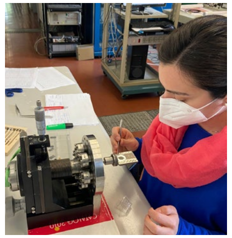
✓ Realization and characterization of enriched Ti targets

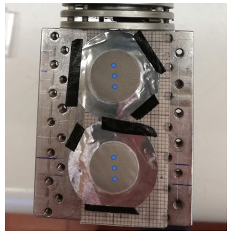


^{48,49,50}Ti targets

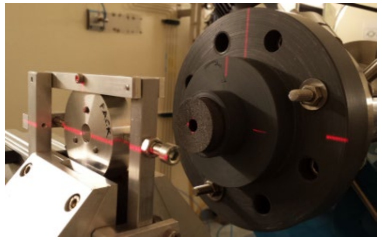
Uniform thickness ≈500 µg/cm^2

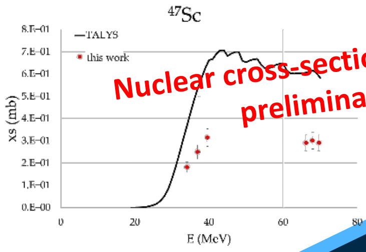
EBS analysis (with AN2000 accelerator at LNL)





✓ Irradiation at ARRONAX facility (with proton beam)





Nuclear cross-section measurements: preliminary results

S. Cisternino et al. Instruments, 3,3, 23, 2022; ***H. Skliarova et al.*** Nucl. Inst. Met. A, 2020,164371; ***H. Skliarova et al.*** Journal of Physics: Conference Series1548 (2020) 012022

Spark Plasma Sintering (SPS)

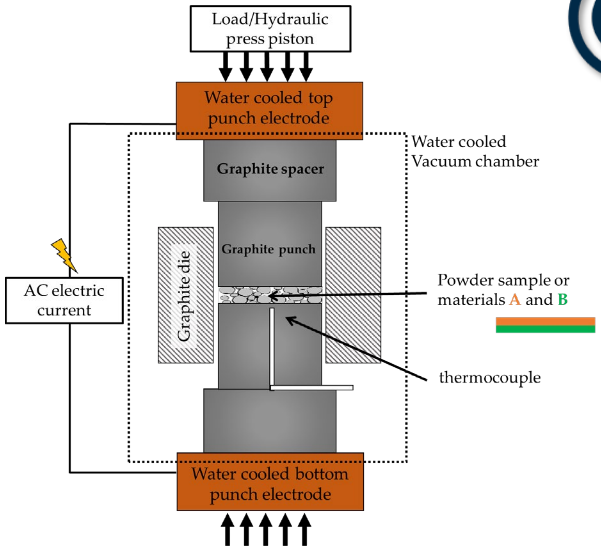
Solution for thick target for RI production

Simultaneous application of load and temperature

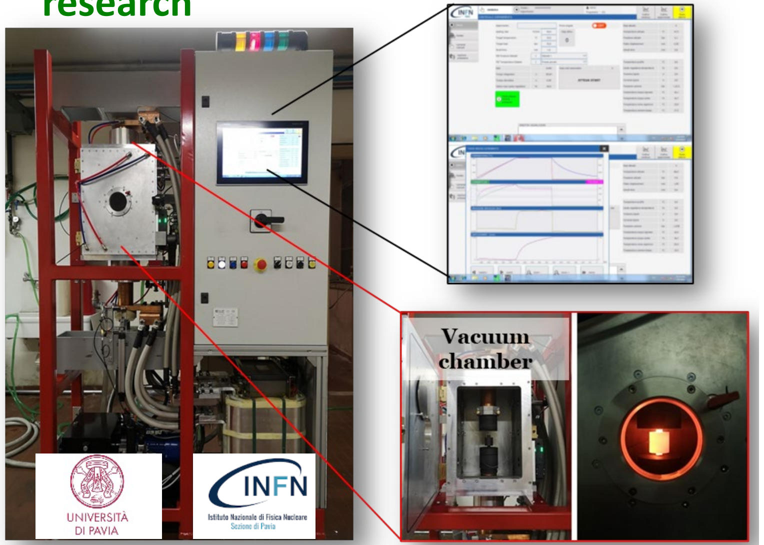
Advantages

- ✓ High heating rates (up to 1000 °C/min)
- ✓ Very short sintering times (min instead of hours)
- ✓ Sintering of high melting point materials (metal or oxide)
- ✓ 99% efficiency→ No loss of isotope-enriched material during manufacturing
- ✓ Starting materials→ powder or foils
- ✓ Directly bonding of different materials→ (target and backing)
  - ▪ Au protective thin layer in between instead of costly Au backings
- ✓ 200 μm - mm thickness pellet→ targets for production

Typical experimental conditions:
Voltage 5-10 V
Current intensity 10^3-10^4 A
Pressure 5-100 MPa



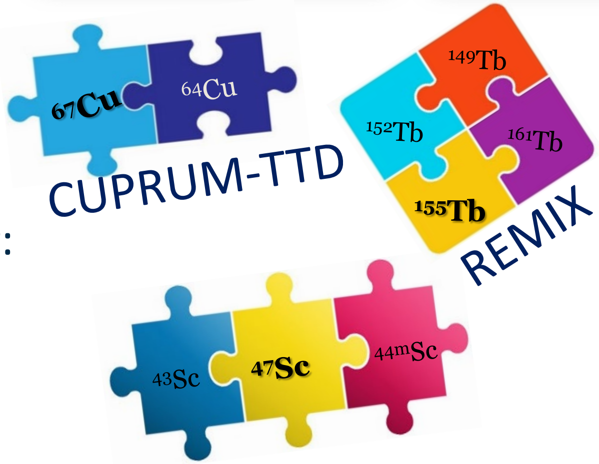
✓ TT_Sinter → dedicated SPS machine tailored for targets manufacturing for research



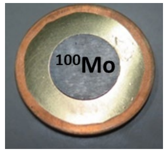
- **know-how**
- **SPS machine**
- **technology**

to manufacture targets for:

- ➢ Emerging Medical RI
- ➢ Other applications

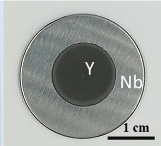


✓ Several targets realized and tested with medical cyclotron



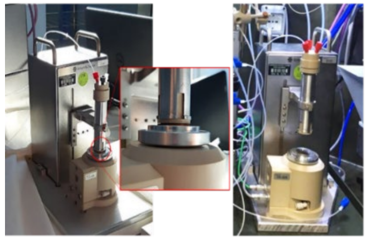
TECHNOSP: ^{100}Mo targets for ^{99m}Tc production

METRICS: ^{52}Cr targets for ^{52}Mn production



Collaboration with hospital: Y targets for ^{89}Zr production

INTEFF_TOTEM: ^{nat}ZnO pellet for ^{67}Cu production



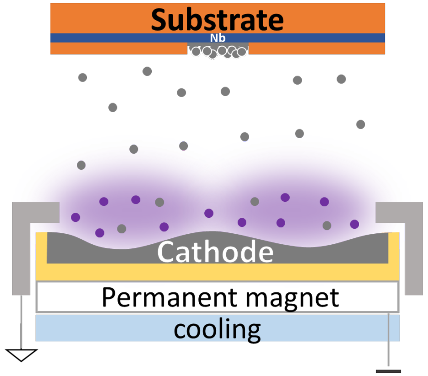
Automated dissolution module for coin targets developed

S. Cisternino et al., Nuclear Medicine and Biology, 104-105, 38-46, 2022; **G. Sciacca** et al., Molecules 2021; **H. Skliarova** et al., J. Phys.: Conf. Ser., 1548, 012022, 2020

Magnetron Sputtering (MS)

Physical Vapor Deposition plasma-based coating process

Advantages
- ✓ Deposition of metals or oxides
- ✓ High adhesion to any substrate
- ✓ High-purity film
- ✓ Multi-target preparation

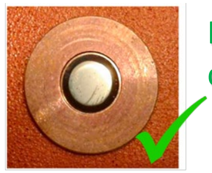


Magnetron sputtering standard configuration

Patent WO 2019/053570
METHOD FOR OBTAINING A SOLID TARGET FOR RADIOPHARMACEUTICALS PRODUCTION
V. Palmieri, H. Skliarova, S. Cisternino, M. Marengo, G. Cicoria

Medical Cyclotron target | **After irradiation**

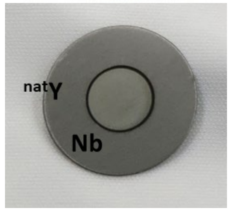
Mo target to produce ^{99m}Tc

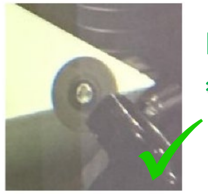



Heat power density >1 kW/cm²

POLICLINICO DI SANT'ORSOLA – SERVIZIO SANITARIO REGIONALE EMILIA-ROMAGNA, Azienda Ospedaliero - Universitaria di Bologna

Y target to produce ^{89}Zr





Heat power density ≈1 kW/cm²

SACRO CUORE DON CALABRIA I R C C S

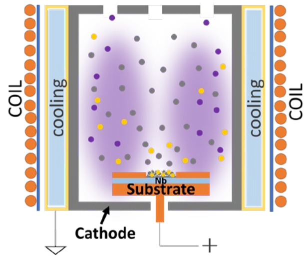
Material saving approach:

INTEFF_TOTEM

Advantages to the standard MS:
- ✓ Reduced material losses during the deposition
- ✓ Possible facilitation in the reactive sputtering deposition
- ✓ Possible more efficient cathode utilization

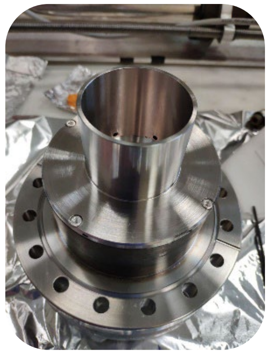
Recovering shield *and* ***Inverted magnetron***

allows to collect 55% of the sputtered material



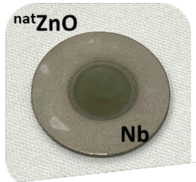
Preliminary thermo-mechanical resistivity test

Recovering shield



Sample holder with nat-Cr target

As prepared



After irradiation

SACRO CUORE DON CALABRIA I R C C S

H. Skliarova et al., Molecules, 24, 1, 25, 2018; *A. Kotliarenko* et al., Applied Science, 11, 19, 9219, 2021

High power targetry development

Scarce availability of emerging radionuclides for nuclear medicine

↓

Yield proportional to beam power

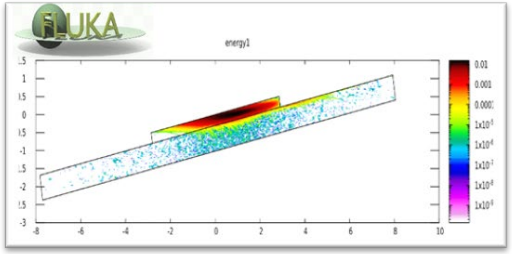
↓

Development of efficient target cooling system (e.g. novel heat sink configurations)

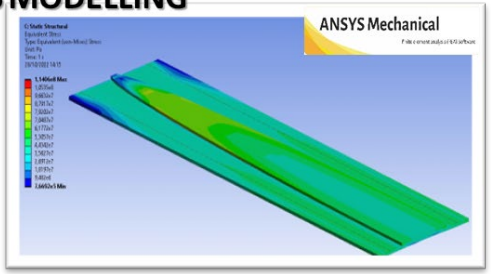
↓

Optimization through thermo-fluid dynamical simulations

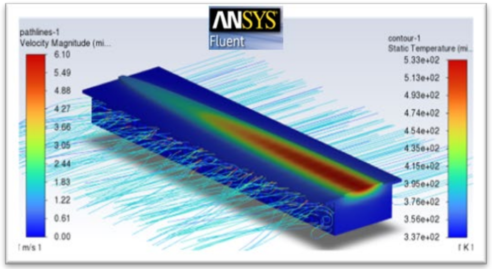
HIGH-POWER TARGETS MODELLING



Beam energy deposition modelling



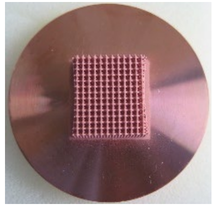
Calculation of thermal stresses



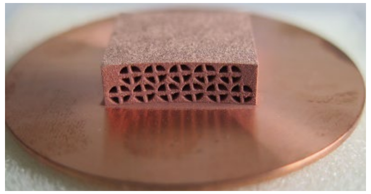
Determination of temperature distribution

ADDITIVELY MANUFACTURED PURE COPPER HEAT SINKS

Grid configuration



Helical channels configuration



- R&D on **different target configurations** with SPS and MS techniques (national and internation collaborations)
- test under **high energy cyclotron** – @ ARRONAX facility, others in Europe or worldwide; @ LNL – SPES (2025) –

G. Sciacca et al., Materials and design, 214, 110415, 2022

Targets development for neutrons at LNL

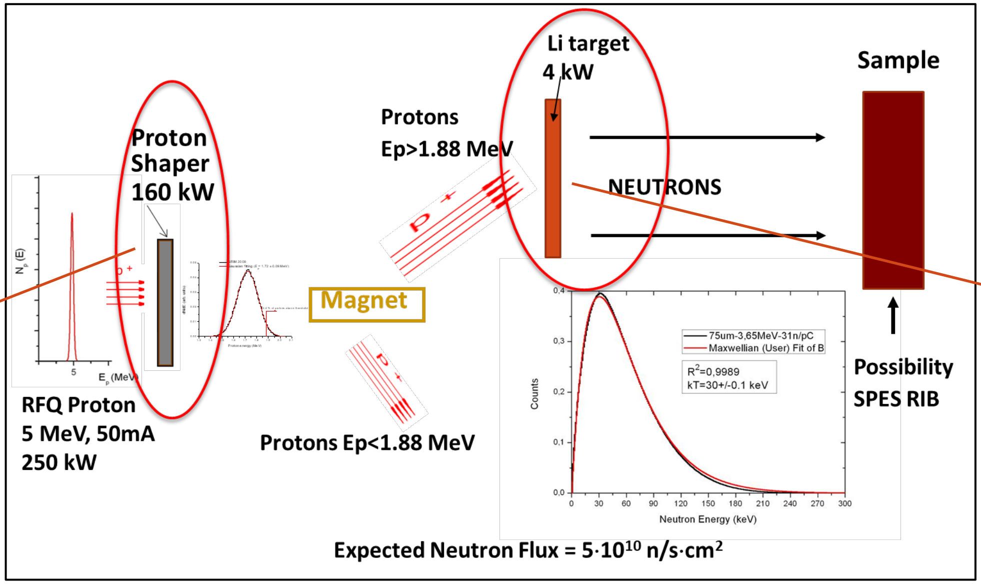
Pierfrancesco Mastinu, Alberto Monetti, Elizabeth Musacchio-Gonzalez (INFN-LNL)
Jeffery Wyss (University of Cassino and Southern Lazio)
Luca Silvestrin (UNIPD)
Gianfranco Prete (INFN-LNL)

LENOS Layout: for astrophysics experiments

SPES/LENOS: Energy Shaper

Rotating target

Energy straggling and stopping power of charge particles when interact with a thin foil of material. General method: **multilayer energy shaper.**



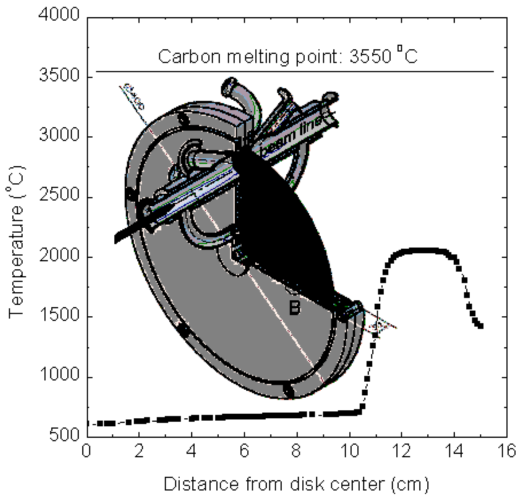
micro-channel targets

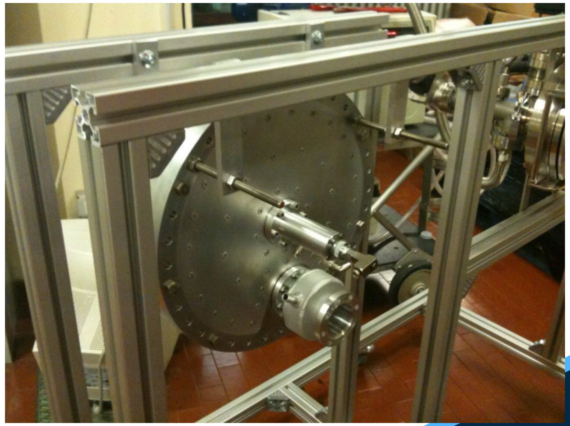
LENOS foil material requirements :

- low atomic number, low density, high melting point, high emissivity, high thermal conductivity, high tensile strength.

→ GRAPHITE foil

- Graphite disk 70 μm thickness.
- Power to be dissipated about 50 kW, mainly by radiation.
- Working temperature <2000°C
- Construction material Al Ergal alloy



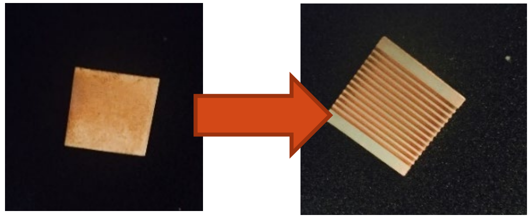


prototype

New version of micro-channel targets

Micro-channels are produced through micro-tubes

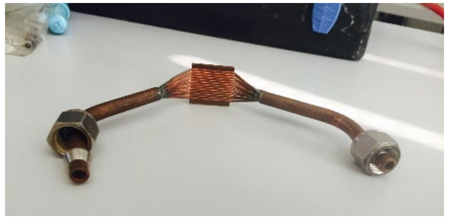
Grooves are produced in the target backing (one or both faces)



INFN international patent APPLICATION n. PCT/IB2014/067156

Micro-tubes are then inserted in the grooves

Interference is produced in order to have a full thermal contact

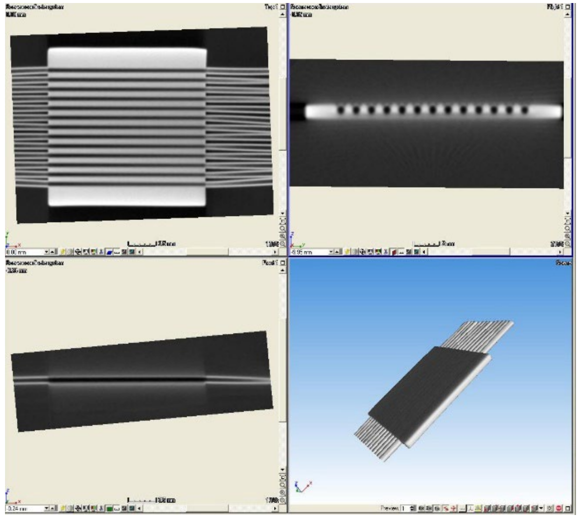


tubes:
- 0.6 mm internal diameter
- 0.8 mm external diameter

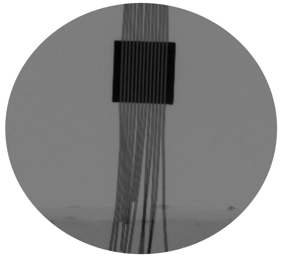
Cu substrate 1.2 mm thickness, 2x2 cm
Wall thickness tube distance 0.5 mm
Number of tubes: 13

- Validation of the target **with metal Li layer**
- Other improvement using different materials for tubes and backing (**Poly Crystalline Diamond)**
- Wide range of **applications**: - SPES beam dump (50kW) - radioisotope production - BNCT - CPU heat sink etc

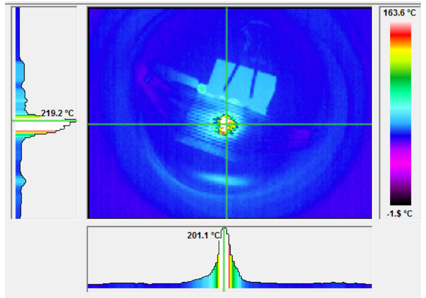
Tomography

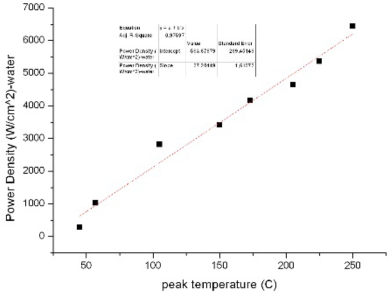


Certified an almost perfect contact: no defect at the 1 µm level precision



Target : beam tests at Birmingham University





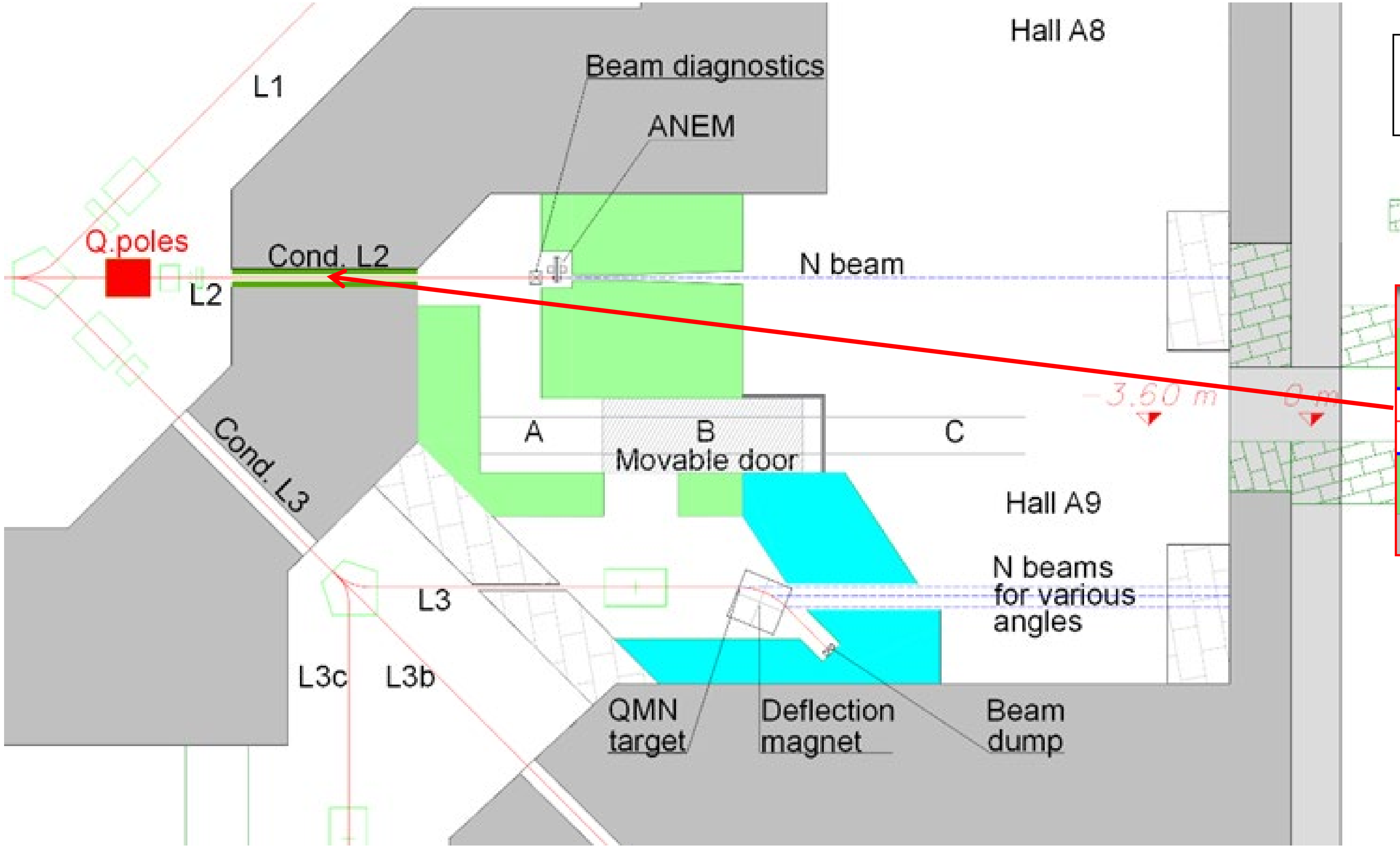
Mass flow: 2.94 l/min T^{in}_{water}=13.0 °C 250<P<1360 W

0.064<beam spot area<0.2 cm^2

specific power of 3.5 kW/cm^2
peak surface temperature<150 °C
(Li target application)

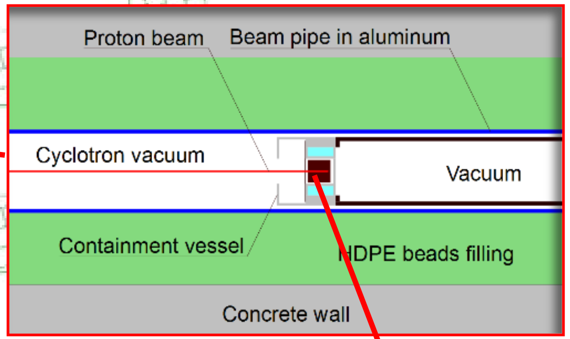
SPES neutron facility

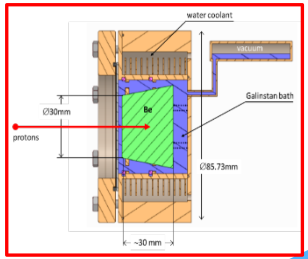
NEPIR: neutron irradiation facility at SPES for studing Single Event Effect in microelectronics



Phase 0→ maximum proton current: 1 μA (P = 70 W).

In this phase, the collimator in the bunker wall (green) towards Hall A9 is closed off.

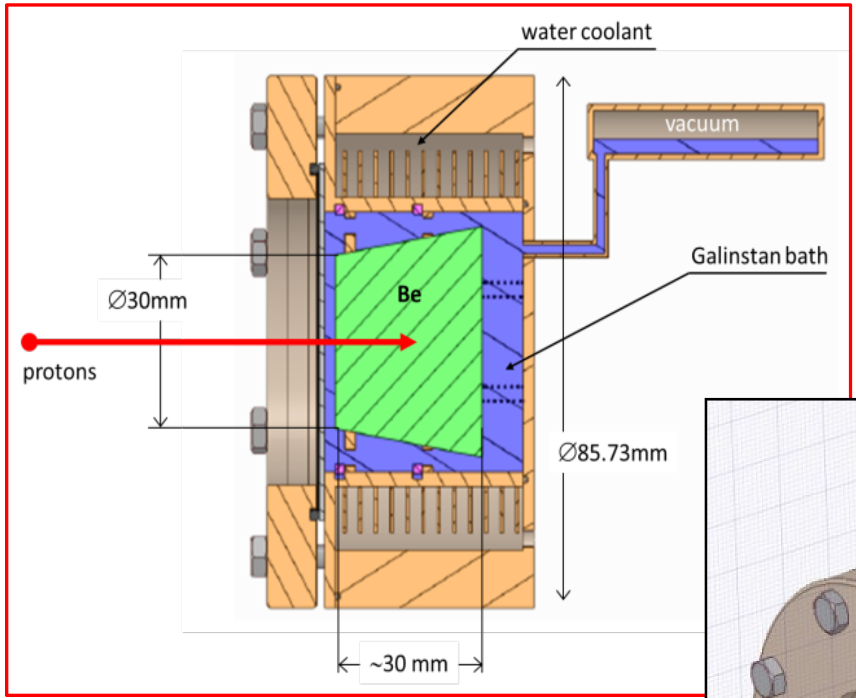




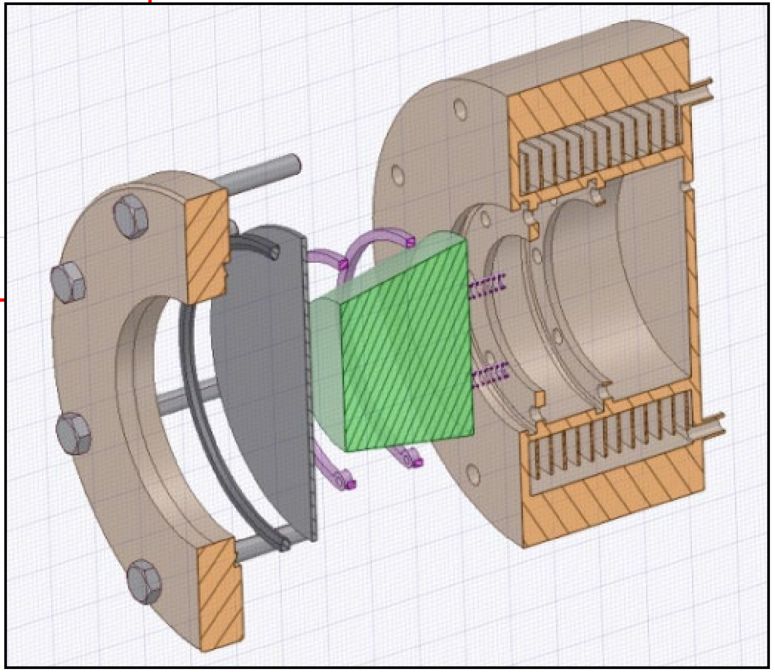
target

NEPIR Initial Phase-0 with “CoolGal” target

A novel liquid GALINSTAN cooled target: COOLGAL



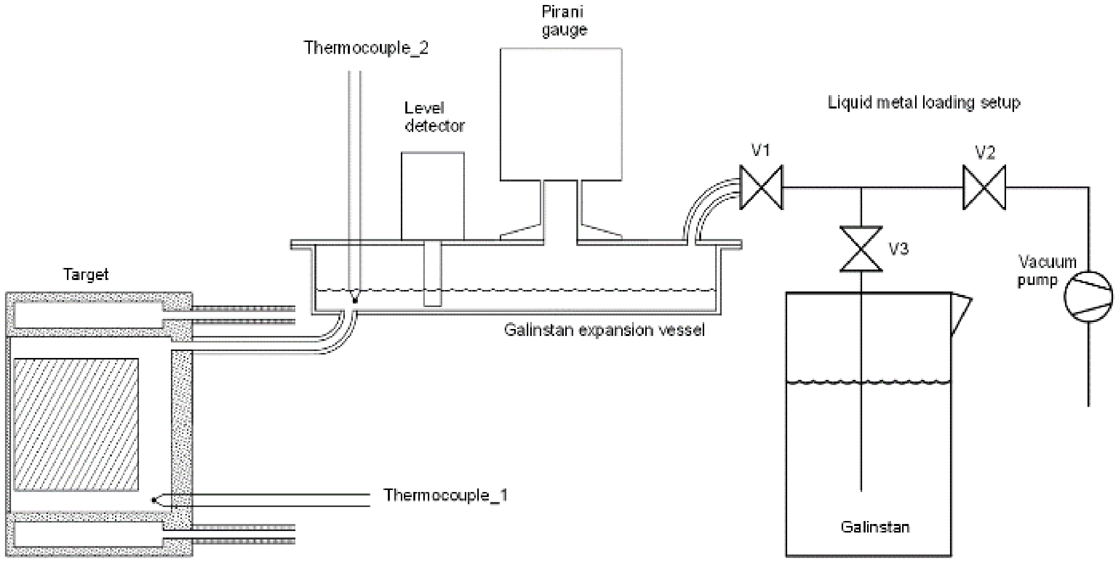
- 30 mm **thick Be cylinder** is immersed in a **bath of GALINSTAN** contained by an outer **copper cladding**.
- The *liquid metal* ensures a good *thermal contact* with the external area of the cladding, where the water cooling circuit is used.
- A **thin havar membrane** separates the liquid metal from the beamline vacuum.



- The containent cladding is made of Cu with Au layer deposited to prevent corrosion and erosion effects from the liquid metal.
- The machined copper includes a closed circuit water-cooling sustem and cooling fins.

NEPIR Initial Phase-0 with “CoolGal” target

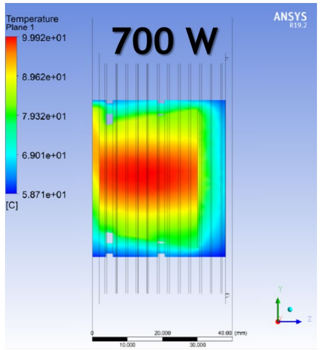
A novel liquid GALINSTAN cooled target: COOLGAL



Safety requirement

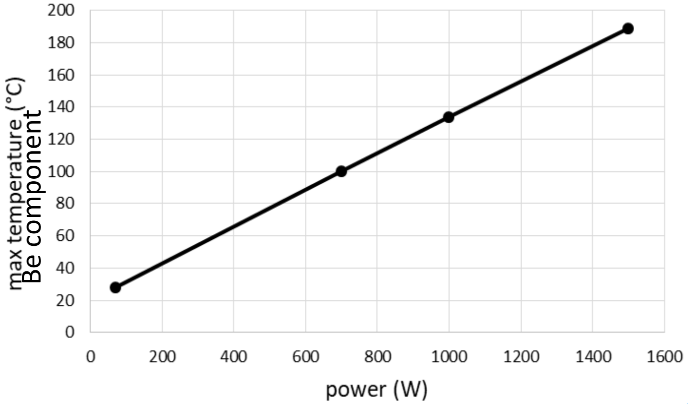
- The liquid metal alloy has a **reservoir tank** which works as expansion volume. *The temperature of the liquid, the pressure of the reservoir and the level of the liquid is monitored* and the data used to interlock the beam.
- The liquid metal provide:
  - To cool down the Havar window
  - To ensure a good thermal contact and heat transfer to the cladding for conduction
  - To keep the debris of beryllium if/when blistering occurs because no pressure difference is present
  - Allow thermal dilatation of the beryllium
  - Thanks to natural convection, distribute the heat on the whole surface of the cladding.

CoolGal: ANSYS CFX/simulations



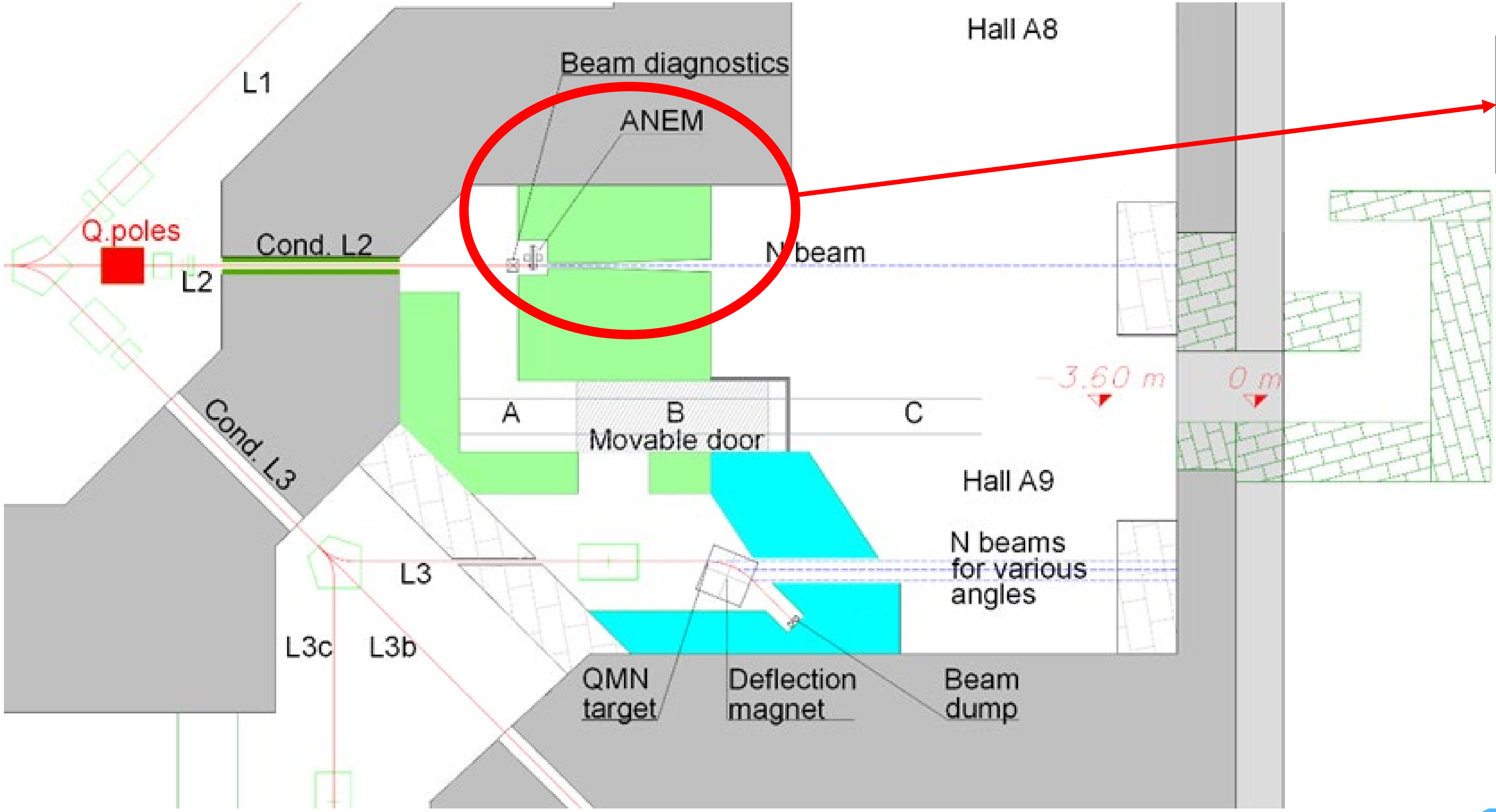
Temperature map of the Be and Galinstan of a preliminary ANSYS model of CoolGal with water coolant (v=2m/s) for 700 W (10 uA current of 70 MeV protons).

The maximum temperature of the Be component is 100°C.



SPES neutron facility

NEPIR: neutron irradiation facility at SPES for studing Single Event Effect in microelectronics



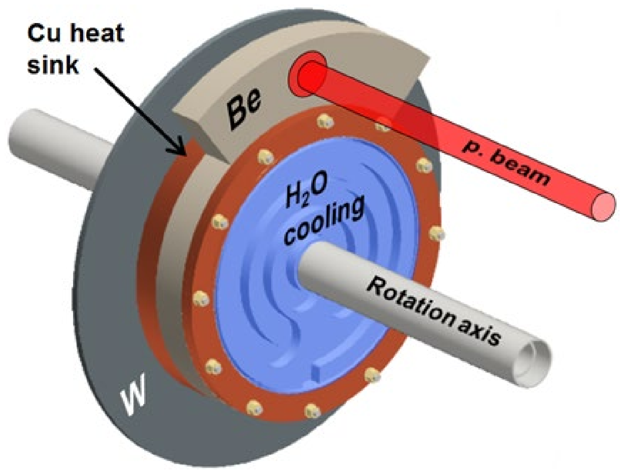
Phase 1→
Atmospheric **NE**utron **EM**ulator

SPES/ANEM: a continuous energy neutron production target

The ANEM target is designed to handle a maximum current I_{beam} = 30 μA (**2.1 kW**)

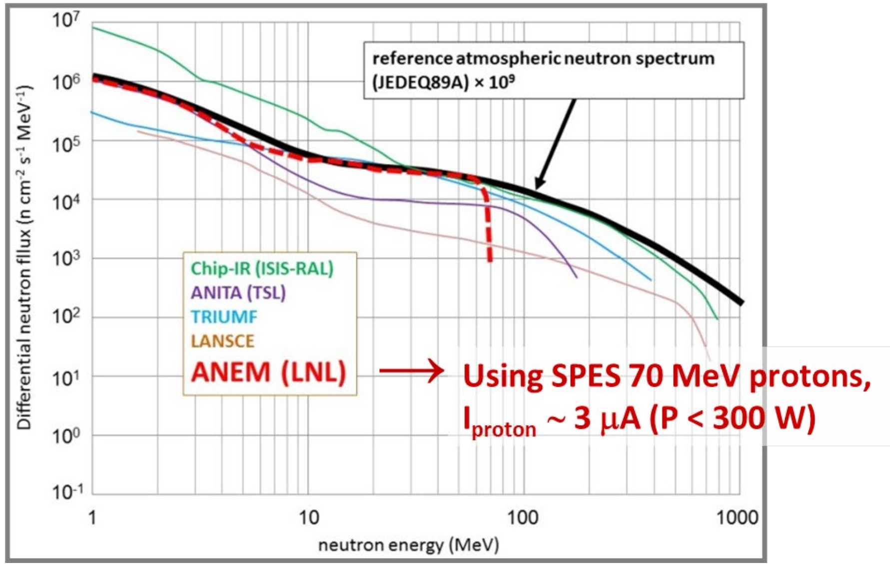
A novel rotating composite target made of thick Be and W

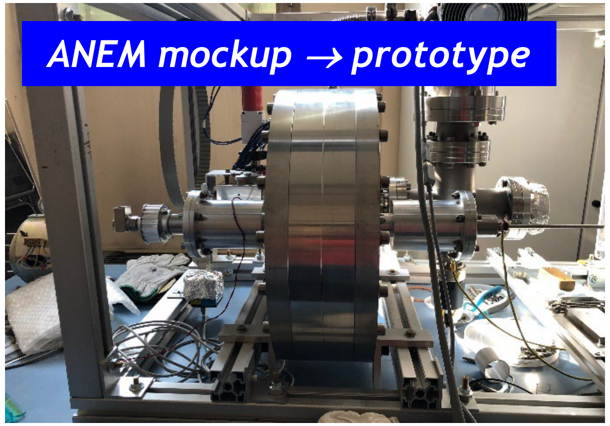
A W disk and a Be circular sector rotate on a common water-cooled hub and alternatively intercept a 70 MeV proton beam

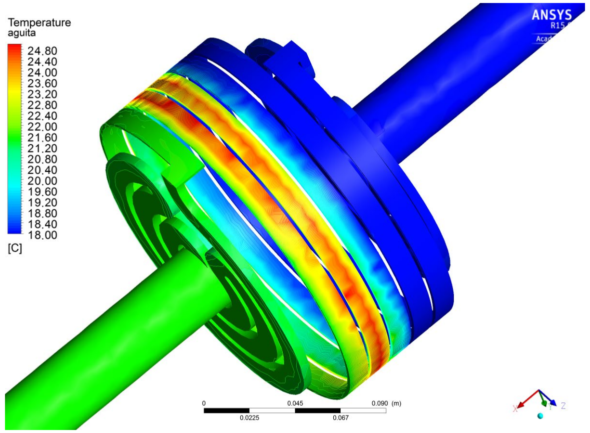


Thickness→
Be: 24 mm (*)
W: 5 mm

(*) The Be sector does not stop the protons (to avoid damage); most of the protons pass through without causing nuclear reactions. The emerging low energy protons are stopped by the W disk.







- Water inlet temperature : 18°C;
- Water inlet velocity 1m/s
- rotating beam (10 rev/sec)

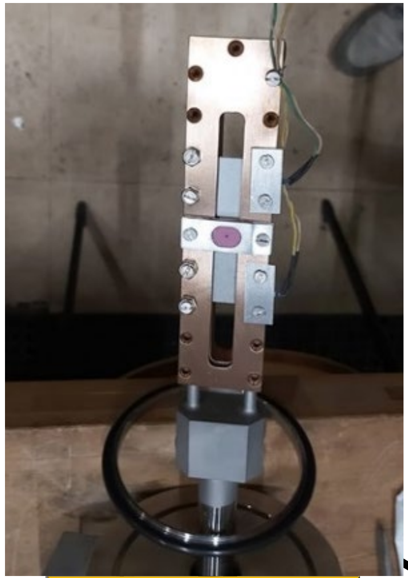
Target for FraISe facility at LNS

Paolo Russotto, Antonio Domenico Russo, S. Cavallaro, M. Costa, Emanuele Vincenzo Pagano, S. Passarello, S. Pulvirenti (INFN-LNS)
Nunzia Simona Martorana (INFN-LNS, University of Catania)

FRIBs facility

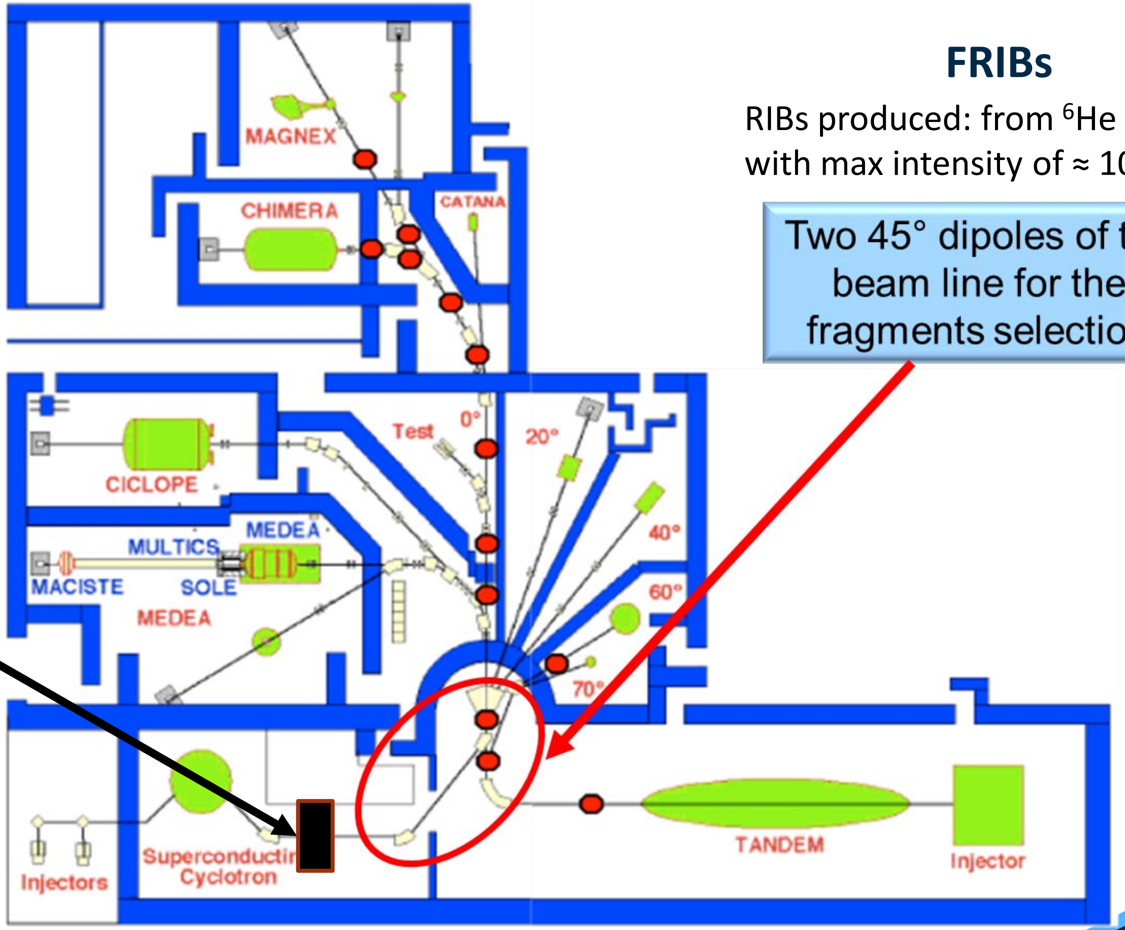
At INFN-LNS RIBs were produced, **since 2001**, using the FRIBs (in Flight Radioactive Ion Beams at LNS) facility through the In-Flight fragmentation method (primary beam accelerated by CS + ^{9}Be target), employing a maximum beam power of 100 W

Water cooled copper support holding two Be foils with typical thickness 250-1500 µm



production target

Alumina target mounted on the production target system and watched by a camera to better focus the beam



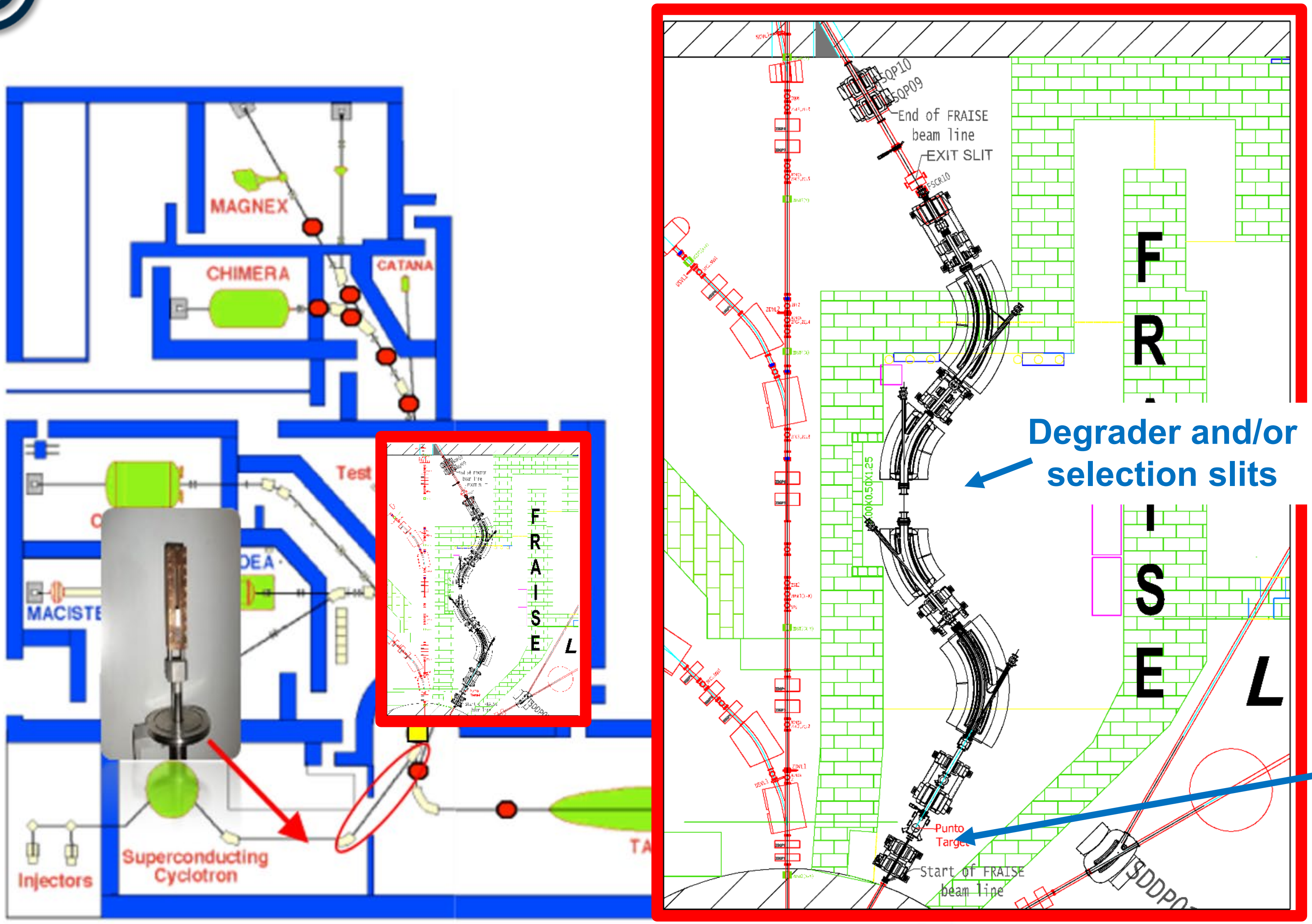
FRIBs

RIBs produced: from ^{6}He to ^{68}Ni with max intensity of ≈ 10^{5} pps

Two 45° dipoles of the beam line for the fragments selection

G. D'Agostino, et al., J. Phys. Conf. Ser. 1350 (2019) 1, 012099***; L. Calabretta*** et al., Mod.Phys.Lett.A 32 (2017) 17, 1740009;
D.J. Morrissey*, et al., Lect. Notes Phys. 651, 113–135 (2004).*

Future development: FraISe



Main features:

- 4 dipoles, 6 quadrupoles and 2 sextupoles, arranged in two symmetric branches, to ensure optimal achromatic condition
- maximum magnetic rigidity 3.2 *Tm*
- momentum acceptance ±1.2%
- solid angle acceptance ±2.5 *msr*
- 5 m dispersion at symmetry plane, energy resolving power

$$\mathrm{RP} = \left|\frac{R_{16}}{2x_0 R_{11}}\right| = 2600$$

(beam spot ±1 mm)

- thanks to high energy dispersion value at the symmetry plane, it will allow to deliver stable beams with an energy spread of 0.1 %

New production target able to work at higher intensity

P. Russotto, et al., J. Phys. Conf. Ser. 1014(1):012016, 2018; ***A.D. Russo*** et al., Nucl. Instr. and Met. B, 463:418, 420, 2020; ***N. S. Martorana,*** IL NUOVO CIMENTO44 C, 44:1-10, 2021

FraISe beams

Primary CS beams

Ion	Energy (MeV/u)
^{12}C	30
^{12}C	45
^{12}C	60
^{18}O	20
^{18}O	29
^{18}O	45
^{18}O	60
^{18}O	70
^{20}Ne	28
^{20}Ne	70
^{40}Ar	60

Expectation using 2kW primary beams and an Al 100 µm homogenous degrader on the symmetry plane

				^{17}Ne 8.7E5 53	^{18}Ne 3.1E7 51	^{19}Ne 6.0E8 52	^{20}Ne	^{21}Ne	^{22}Ne
					^{17}F 1.7E8 50	^{18}F	^{19}F	^{20}F 9.5E6 55	^{21}F
		^{13}O 7.2E4 54	^{14}O 1.4E6 40	^{15}O 2.8E7 54	^{16}O	^{17}O	^{18}O	^{19}O 2.3E6 39	^{20}O
		^{12}N 1.2E6 49	^{13}N 2.3E7 50	^{14}N	^{15}N	^{16}N 6.9E8 53	^{17}N 3.2E8 57	^{18}N 3.7E6 57	^{19}N
^{9}C 4.0E5 45	^{10}C 1.1E7 43	^{11}C 2.2E8 44	^{12}C	^{13}C	^{14}C 1.1E8 59	^{15}C 4.0E7 59	^{16}C 1.4E7 60	^{17}C 1.2E5 58	^{18}C 4.8E2 55
^{8}B 3.1E6 42		^{10}B	^{11}B	^{12}B 2.6E7 57	^{13}B 7.5E6 58	^{14}B 1.4E6 60	^{15}B 2.6E5 51		^{17}B
^{7}Be 1.5E7 43		^{9}Be	^{10}Be 1.6E7 50	^{11}Be 1.5E6 58	^{12}Be 2.8E5 60		^{14}Be 3.0E3 63		
^{6}Li	^{7}Li	^{8}Li 4.2E6 50	^{9}Li 8.9E5 51		^{11}Li 3.3E3 60				
	^{6}He 2.1E6 51		^{8}He 1.8E4 51						

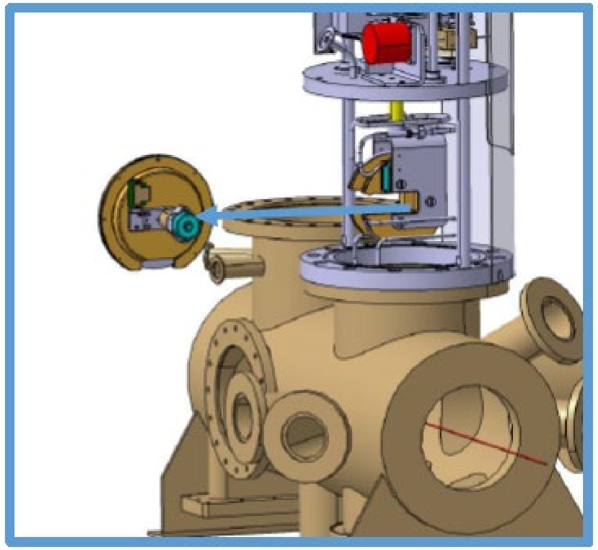
← Expected yield (pps)
← Energy at the exit slit (AMeV)

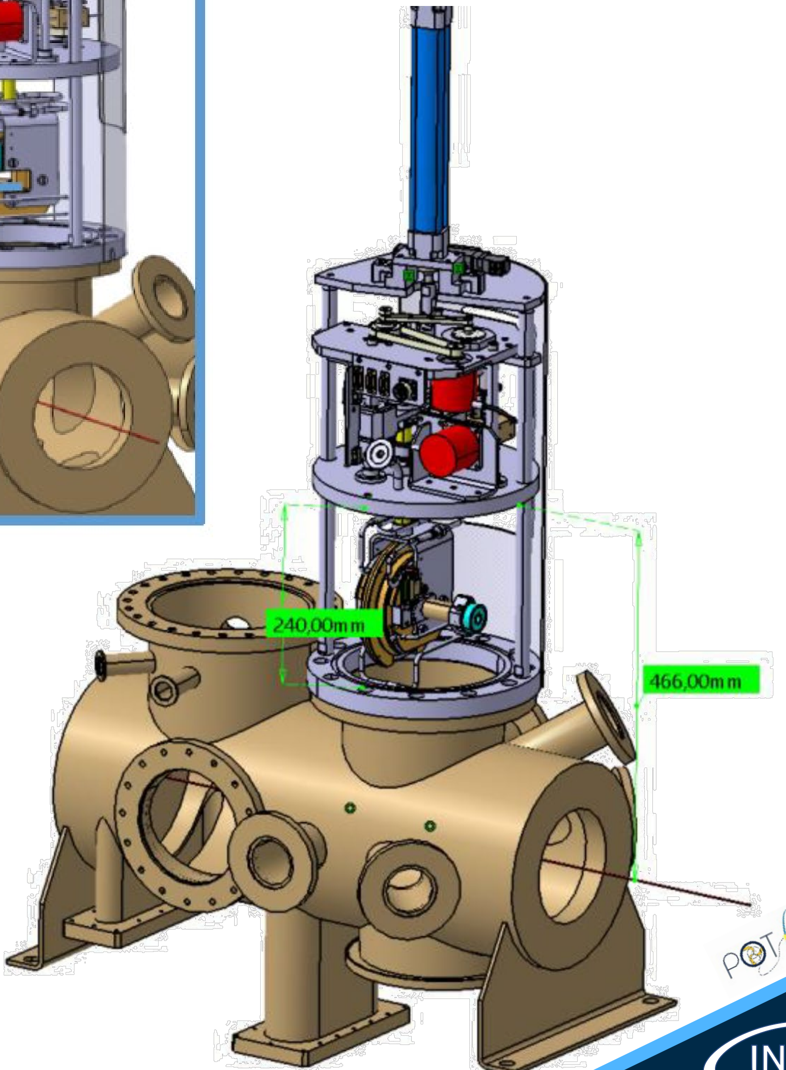
N.S. Martorana et al., Frontiers, in press (2022); ***Martorana NS,*** et al. Il Nuovo Cimento 45 C (2022)390 63.; ***Risitano F.*** Il Nuovo Cimento 45 C (2022) 68.;

CLIM target (from GANIL)

Specifications

- Material target: Beryllium or Carbon ;
- Thickness : 100 to 1500 µm ;
- Max beam power : 3kW ;
- Max beam power deposited in target : **500 W** ;
- Beam spot size : σ= 0.5 mm ; → Ø beam at ± 3 σ = 3mm.
- Ø target 150mm
- Ø impact of the beam on the target : Ø 136mm (nominal) (Ø 130mm to Ø 147mm).
- Target rotation speed :2000tr/min
- Vacuum level : 10^{-6} mbar
- Tilting angle from 0° to 40°.





TimeLine

1st test at LNS	Mounting and set-up in FraiSe line	Commsioning with upagred CS beams
≈ March 2023	≈ Jun 2023	≈ Jan 2024

G. Raciti, et al., Nucl. Instr. and Met. B, 266(19):4632-4636, 2008

CLIM target (from GANIL)

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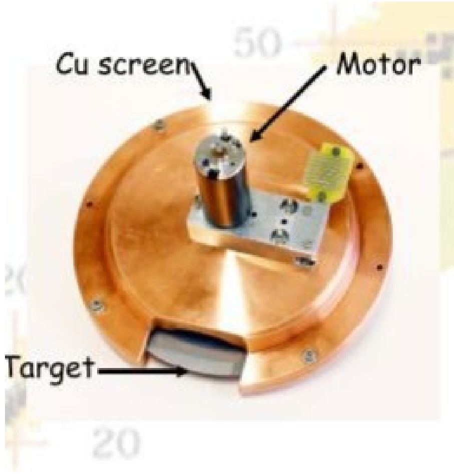
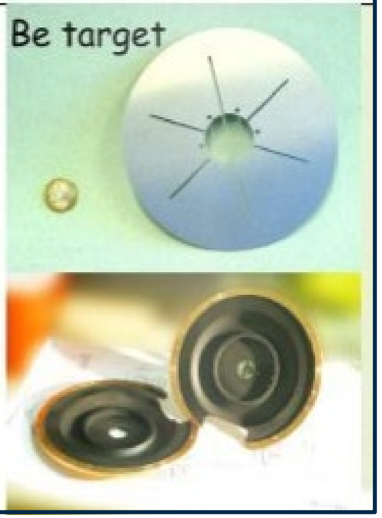
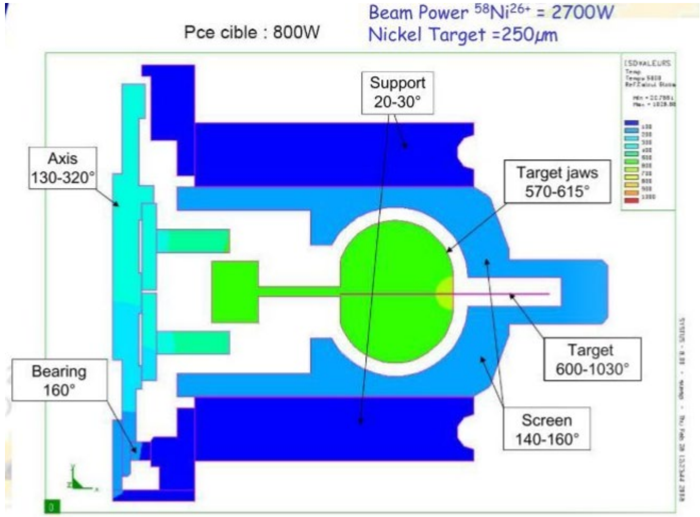
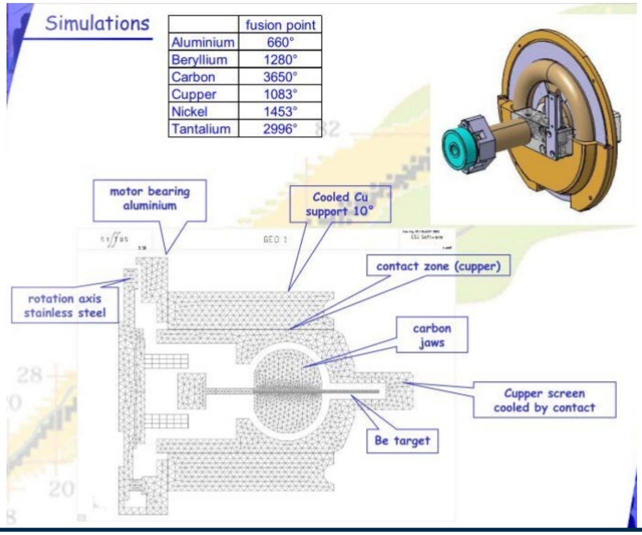
CLIM target: more details



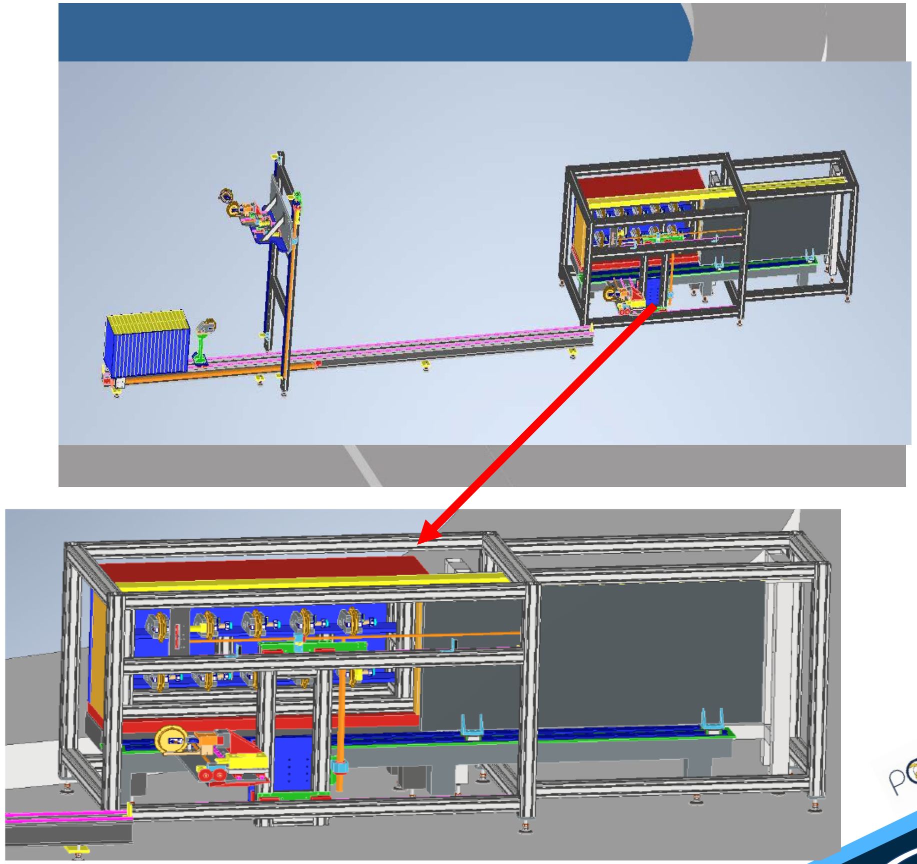


Thermal simulations





Automatized system for targets storage and change



R. Anne et al., NIM A257, 215 (1987); **R. Anne and A.C. Mueller**, NIM B70, 276 (1992); ***S. Grévy et al.,*** INTDS2008, Sep 2008, Caen, France

WG: Innovative targets for new production facilities

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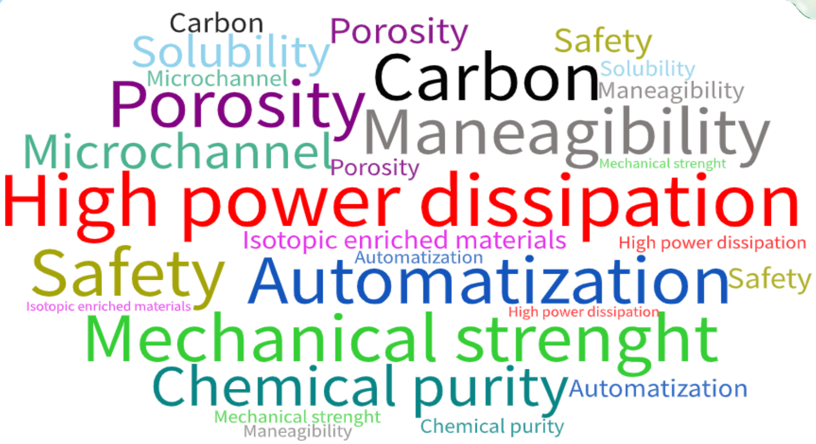

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Thanks for your attention