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TISD activities during LS1

Update from last report

22 Oct 2013

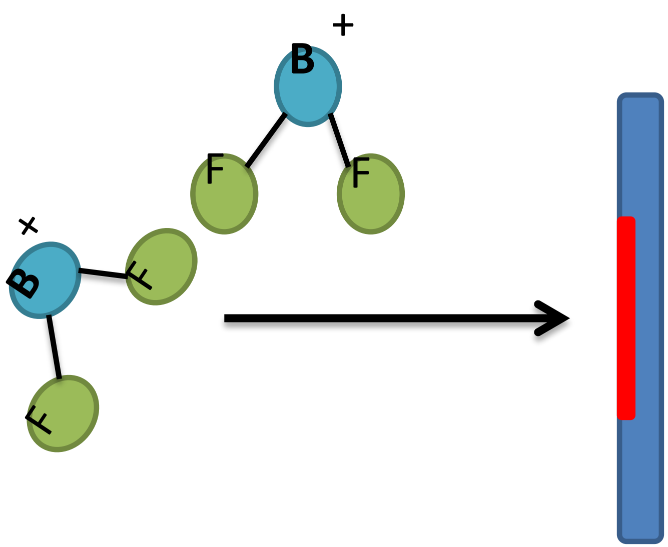
T. Stora

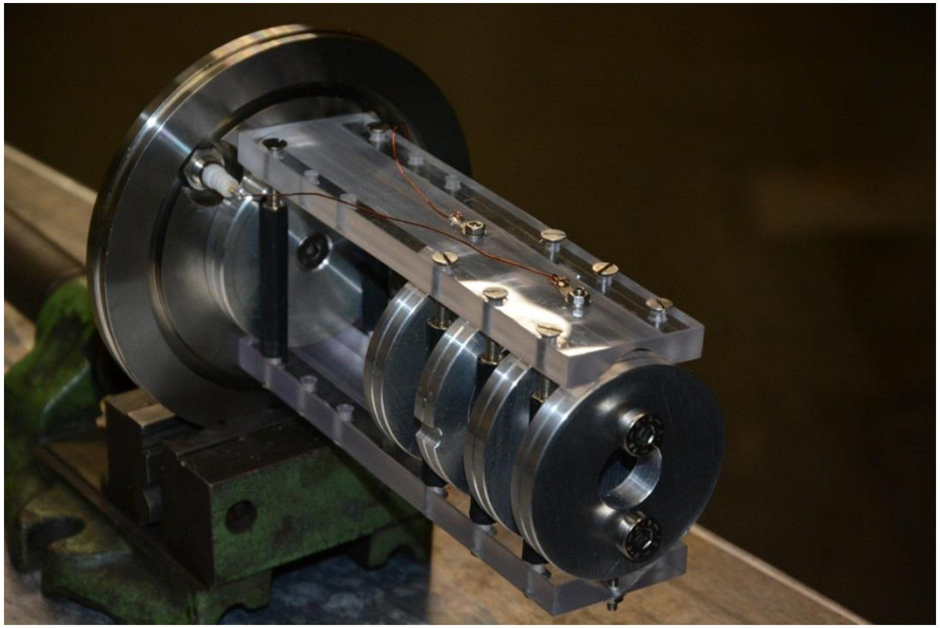
Reminder

- 8B
- 9C
- 37K
- LIEBE (LBE loop)
- ActILab ENSAR (nanoUCx)
- Ba beams
- Neutron converter
- (RILIS in VADIS) molecular beams

- ISOLDE
  - Diffusion studies of boron in possible target materials
  - Implantation of ^{10}B as $^{10}BF_2$ into pressed pills of Al_2O_3, CNT, $MgF_{2[1]}$;
  - HV=70kV-80kV

- SARAF
  - Characterisation of neutron beam
  - Implantation of ^{10}B as $^{10}BF_2$ into Al (200ug/cm2) foil, r_{coll}=1.5mm,
  - HV=32kV
  - $n_{BF2}{}^{+}$=4*10^16

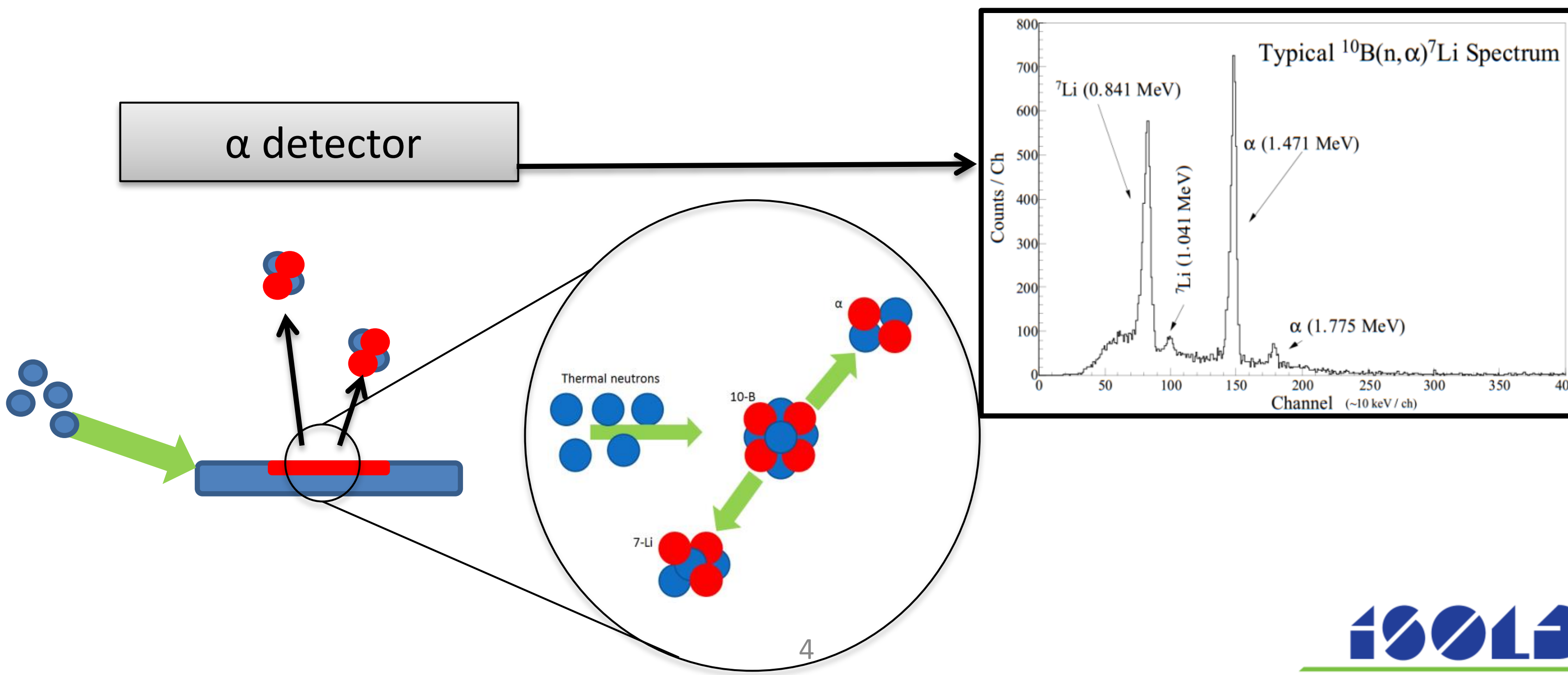




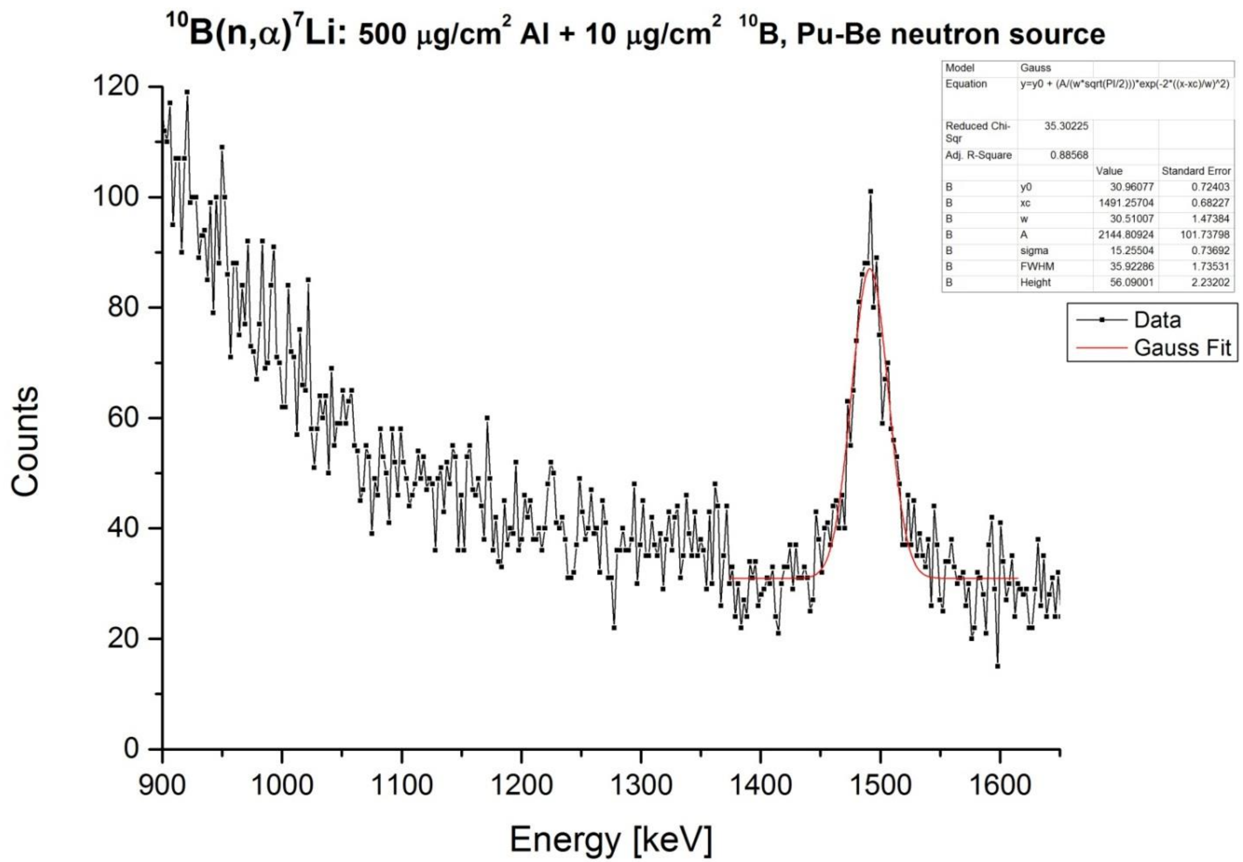
[1] J. Vacik et al, On Boron diffusion in MgF2, CP1099, Application of Accelerators in Research and Industry: 20th international Conferene

- Principle
  - Irradiation of sample with thermal neutrons:
  - For diffusion measurements: Pu-Be Source $1.1*10^8$ n/s @4π, (before moderation)
  - Neutron capture cross section of ^{10}B: σ_{th}=3840 barn
  - Detection of produced ^7Li and α from $^{10}B(n,\alpha)^7Li$

^{10}**B+n** →
6%: 7Li (1.015MeV + α (1.777MeV)
94%: 7Li (0.840MeV + α (1.470MeV) +γ(0.478MeV)



- Measurement with calibration sample, done with Pu-Be source



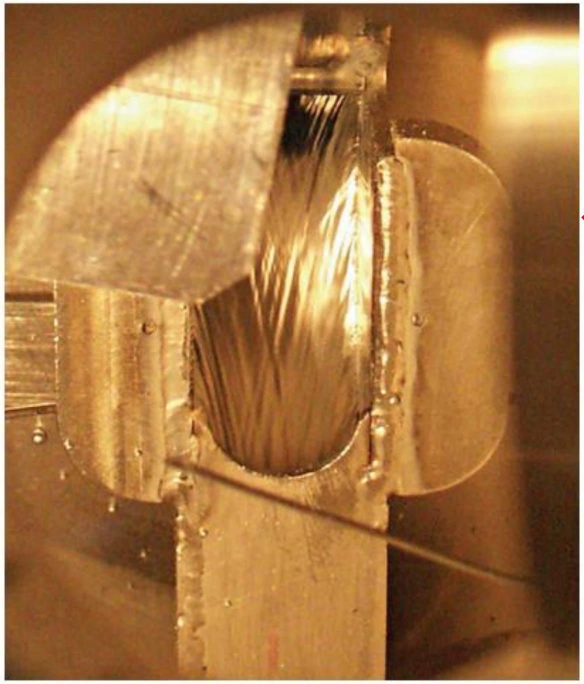
Model	Gauss		
Equation	y=y0 + (A/(w*sqrt(PI/2)))*exp(-2*((x-xc)/w)^2)		
Reduced Chi-Sqr	35.30225		
Adj. R-Square	0.88568		
		Value	Standard Error
B	y0	30.96077	0.72403
B	xc	1491.25704	0.68227
B	w	30.51007	1.47384
B	A	2144.80924	101.73798
B	sigma	15.25504	0.73692
B	FWHM	35.92286	1.73531
B	Height	56.09001	2.23202

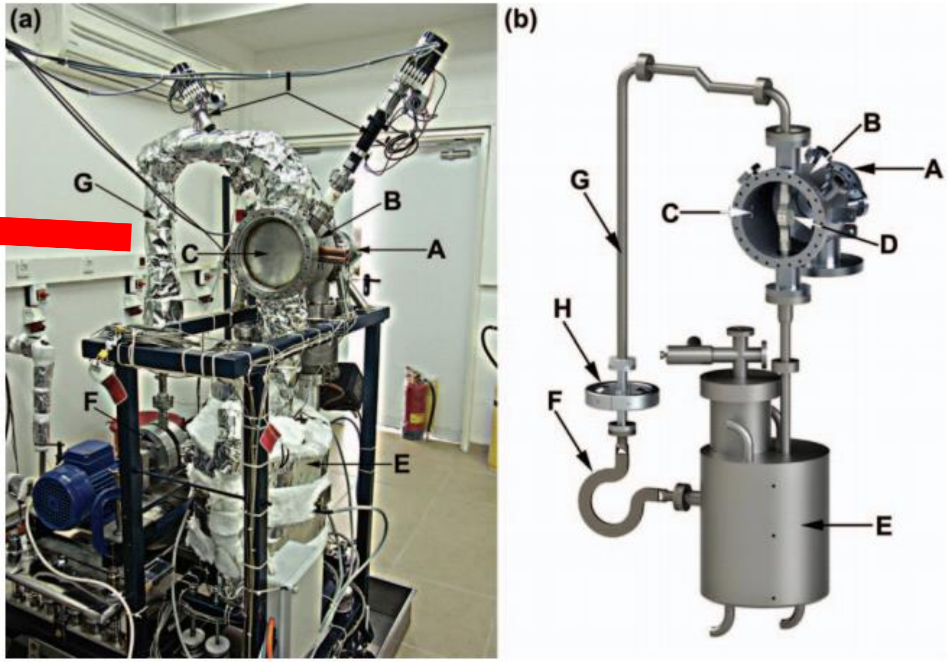
http://www.soreq.gov.il/default_EN.asp

- SARAF@Soreq
  - Located near Yavne, Israel
  - Proton beam (E=1.91MeV) from Soreq Applied Research Accelerator Facility (SARAF) hits liquid lithium target (LiLiT) ,T~200◦C
  - Production of 10-100keV neutrons: $^{7}Li(p,n)^{7}Be$
  - Irradiation of ^{10}B sample with fast neutrons
  - Coincidence detection of produced ^{7}Li and α from $^{10}B(n,\alpha)^{7}Li$

Rev. Sci. Instrum. **84**, 123507 (2013)

Rev. Sci. Instrum. **84**, 123507 (2013)





LIEBE: Liquid Lead Bismuth Eutectic Loop target for Eurisol

Validation of the conceptual design of EURISOL direct target by prototyping at Cern-ISOLDE

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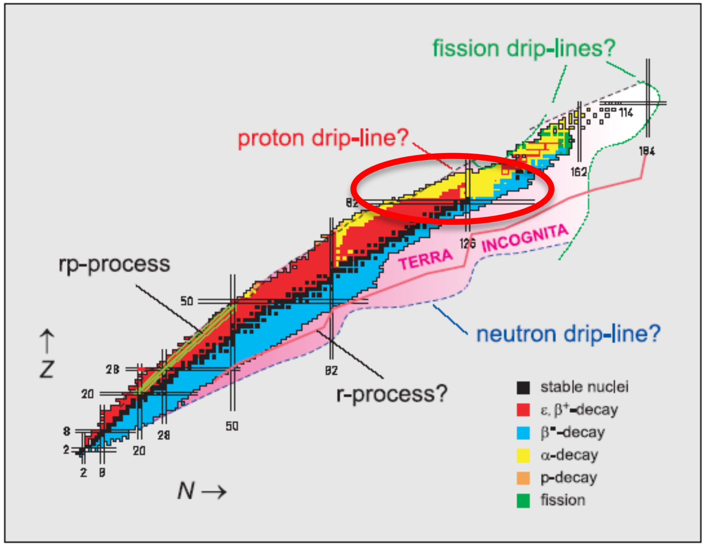
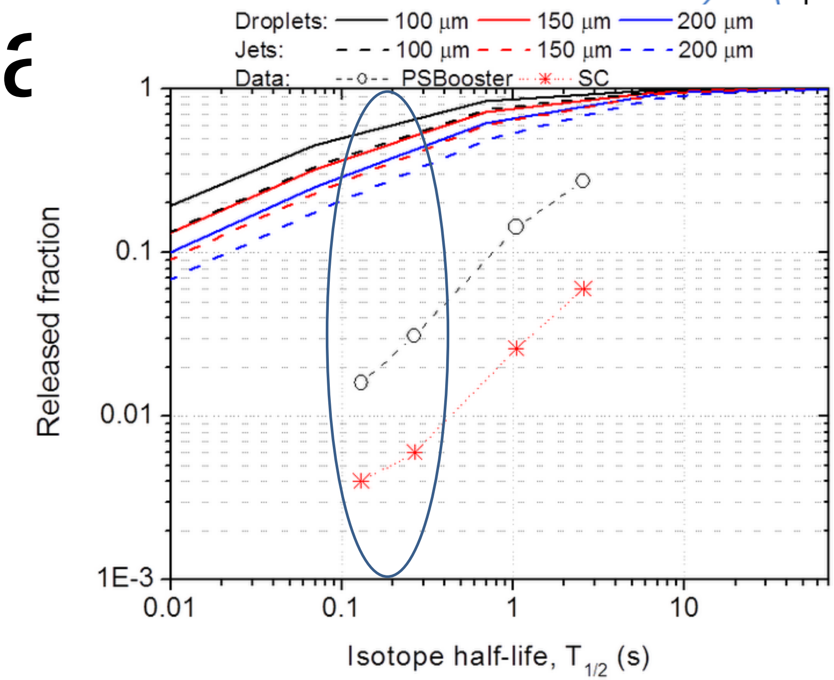
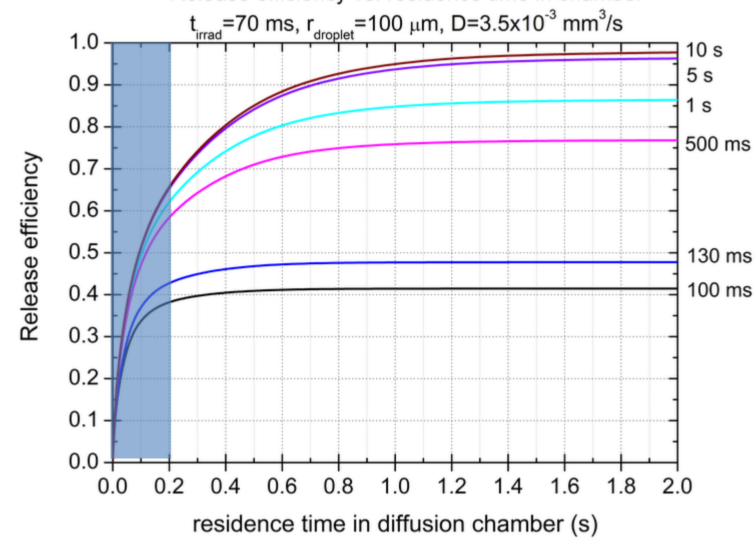
Motivation: Improvement of yields of short-lived Hg isotopes





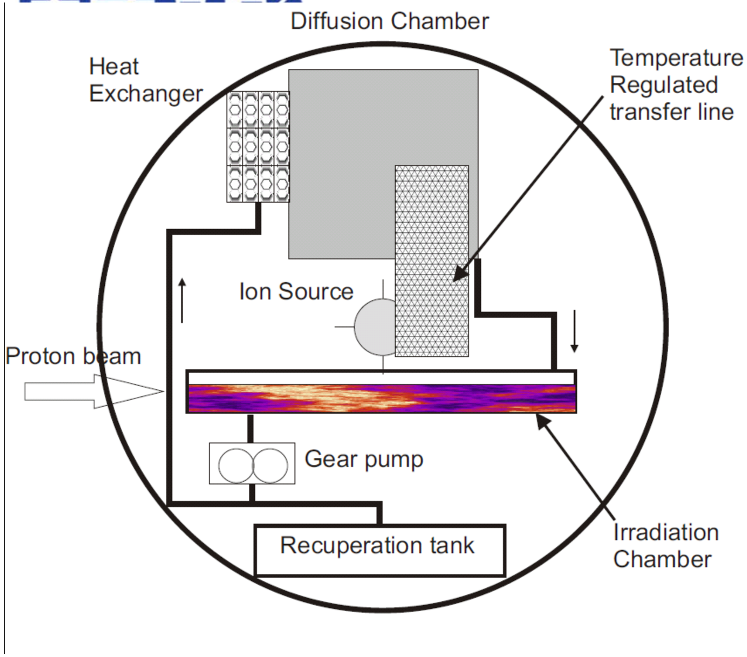
Diffusion: model from Fujioka et al. (NIM 186 (1981) 409)
Data: Lettry et al. (NIM B 126 (1997) 170)



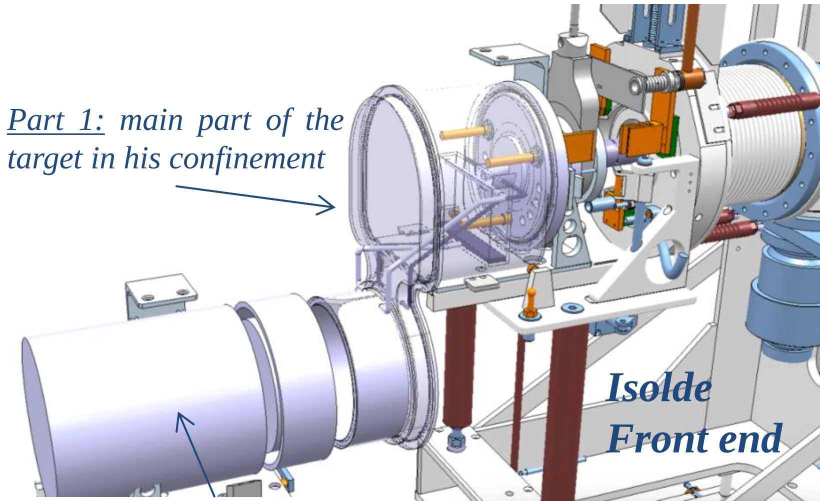
Total time till the post acceleration: < 300 ms.

Diffusion of isotope when the LBE is on droplets shape which require the use of a grid, a diffusion chamber and a pump to recirculate the liquid.

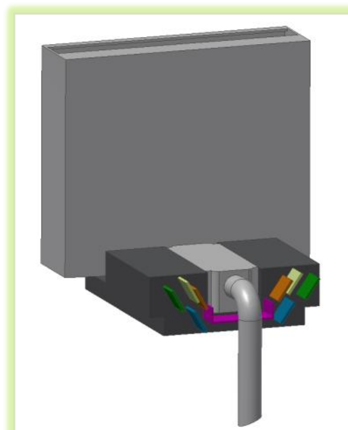
Proposed layout:



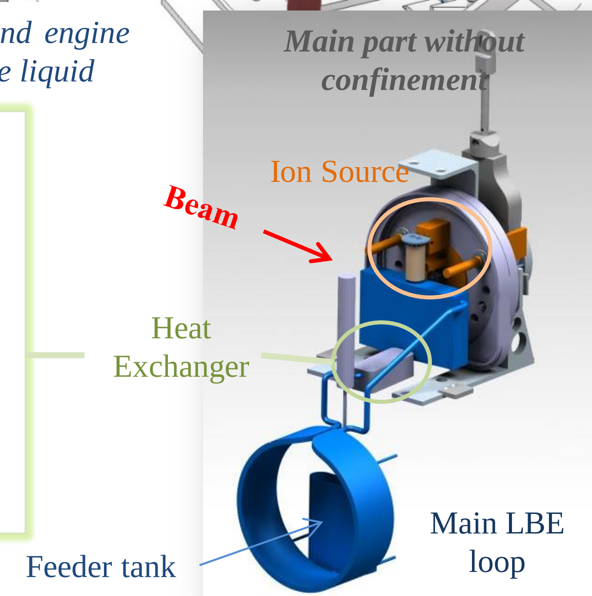
Development: integration of a liquid loop target, working at high temperature (from 200 deg C up to 600 deg C) in the Cern-Isolde environment.



Part 2: pump and engine to recirculate the liquid



Proposed design

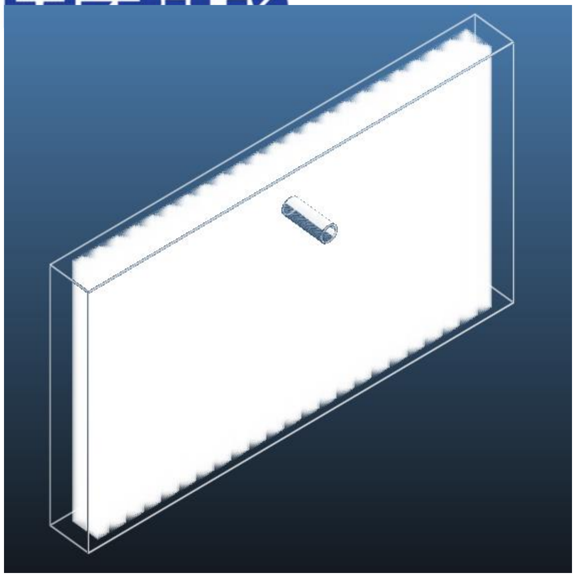


Main challenges:

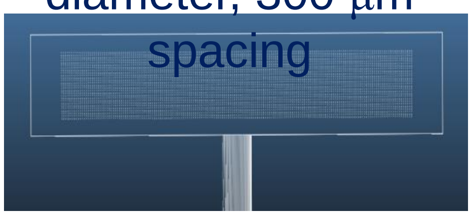
- High power deposited on target to be evacuated (HEX to dimension at various T)
- Recirculation of liquid through a compatible LBE pump
- High temperature of use (up to 600 deg C)
- Integration in already existing (relatively small) environment
- Monitoring and control

Offline tests: Shower formation, pore size and spacing

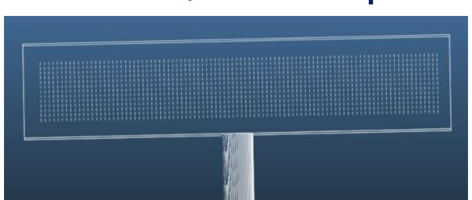
Model: Shower inside diffusion chamber

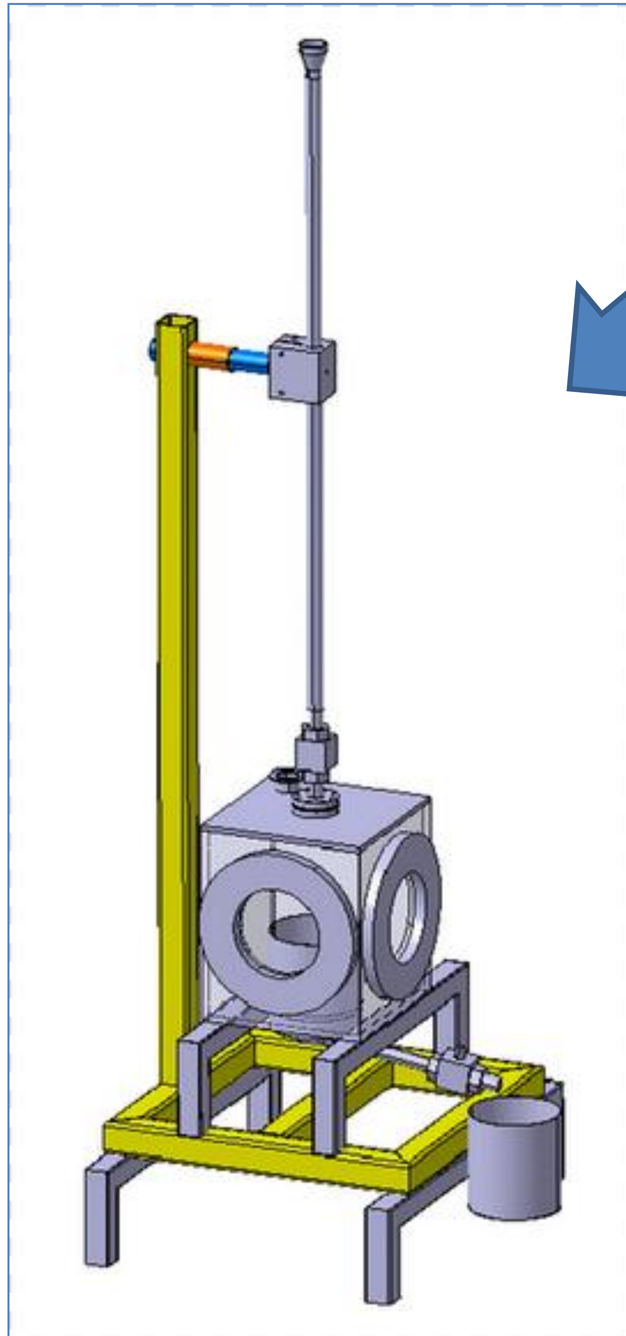


Grid: 200µm pore diameter, 300 µm spacing



Grid: 200µm pore diameter, 1 mm spacing





Test stand to investigate shower formation in vacuum

Tests ongoing

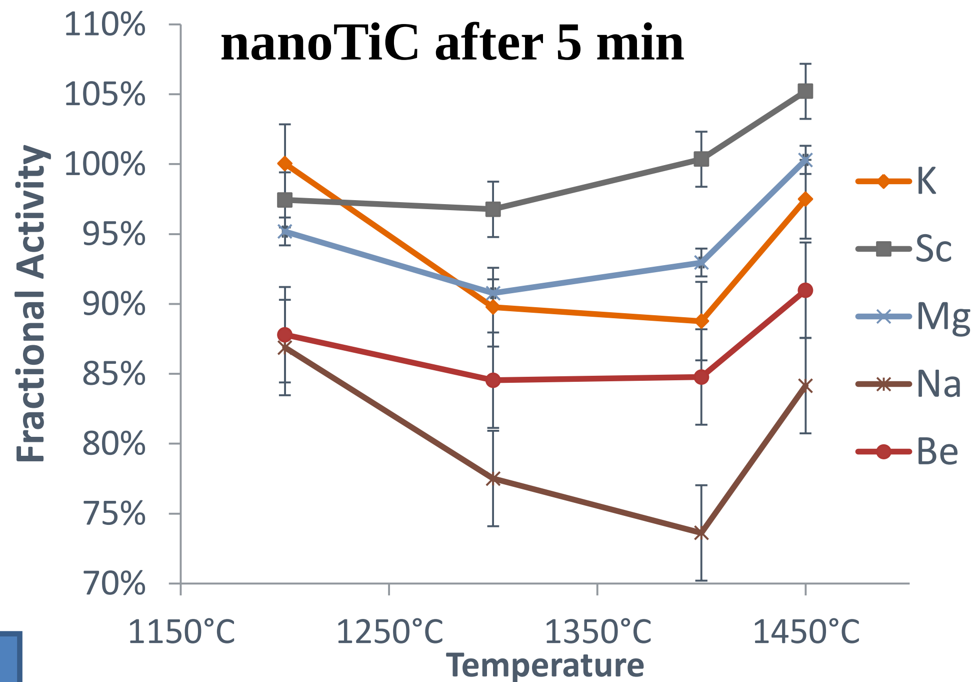
LBE shower in air @ISOLDE-Jan 2014

nanoTiC - motivation

Release studies

High Melting point – 3160 °C

- Sintering studies done, shows that TiC can maintain a <u>submicron</u> structure at least until 1500°C
- Operation temperature has to be at least 1500°C (Ca, K, Sc beams)



- Avoid oxidation of TiC
- Improve nanostructure stability => Essencial for good release
- TRIUMF shows release of Ca and K from TiC

Fractional activity rise at 1450°C is attributed to a an oxide layer in the samples at higher sintering temperatures.

nanoTiC – ongoing studies

How to hinder sintering of TiC?

- Doping
- **Add (a higher melting point) second phase**
- ~~Lower temperature and time~~

Graphite → TiC
Carbon Nanotubes → TiC
Carbon Black → TiC

- Study the effect of the different carbon polymorphs
- Study the volume ratio of carbon

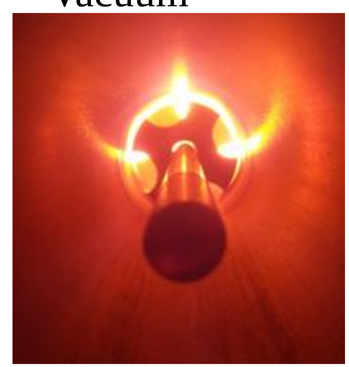
Powder Suspension → Wet mixing → Pellet Preparation → Sintering → Characterization

Powder Suspension
- Isopropanol
- Polymeric dispersant

Wet mixing
- Attrition mill
- Zirconia milling elements

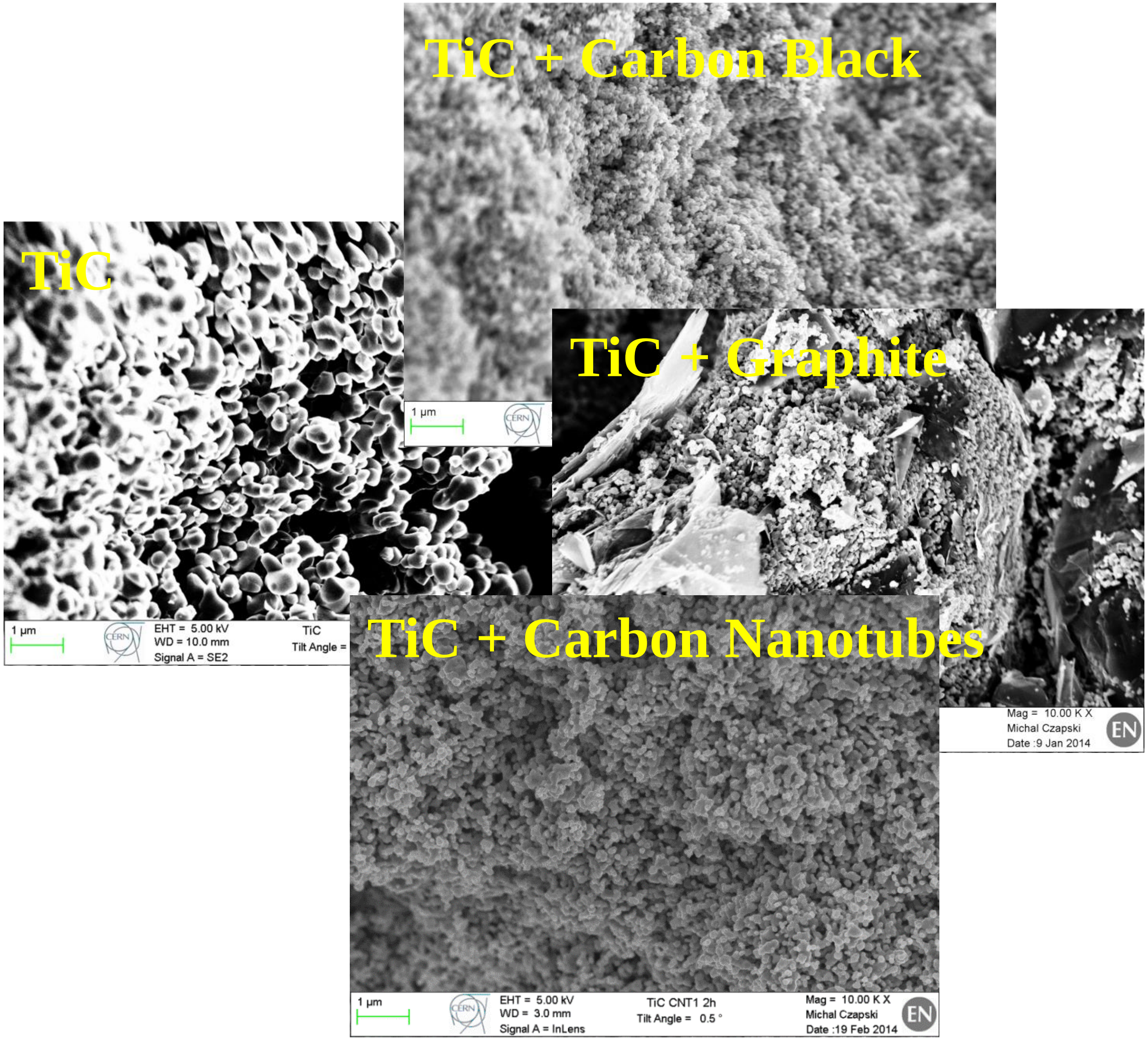
Pellet Preparation
- Drying
- Deagglomerate
- Pressing

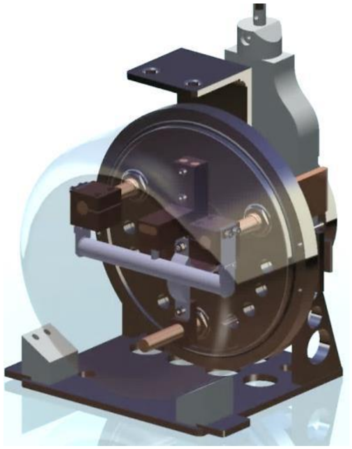
Sintering
- 1500ºC for 2 and 10h
- Vacuum



Characterization
- Morphology
- Density
- Porosity
- Specific sufrace area

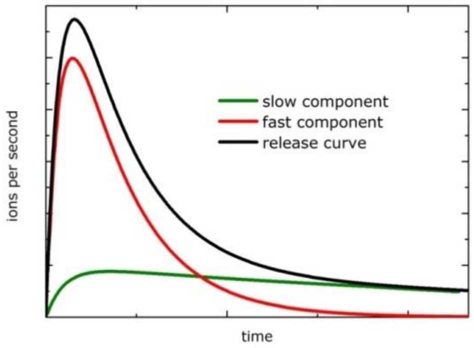
nanoTiC – results and future studies





Future work:

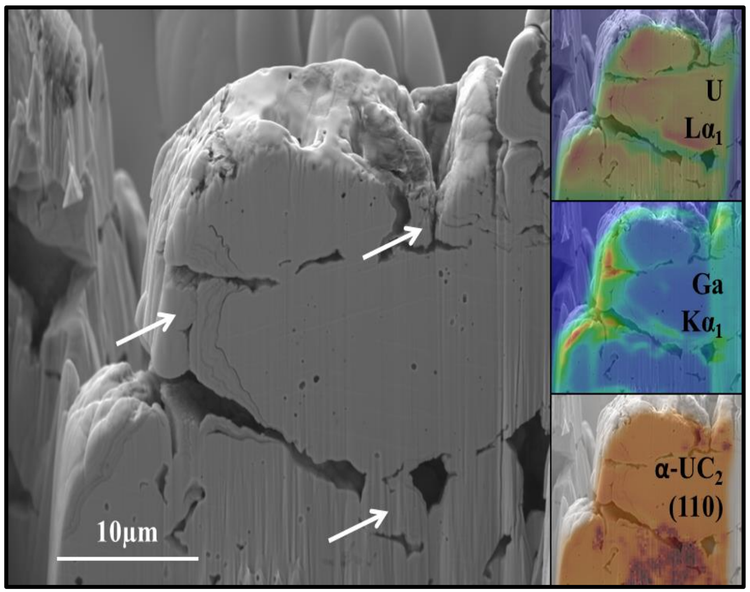
- Release studies
- Target prototype
- Modeling



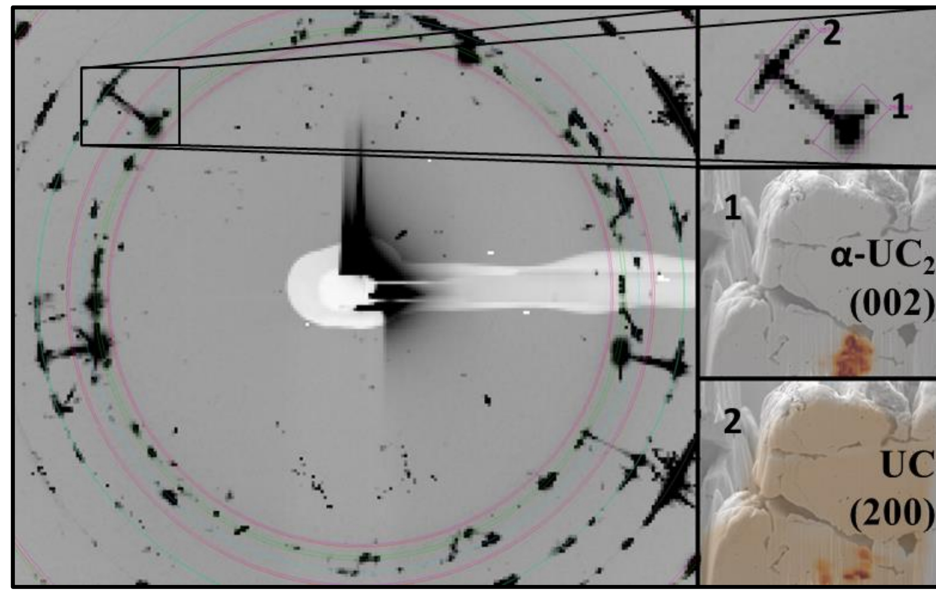
UC_x prototype target tests for ActILab-ENSAR

Characterization of conventional UC_x using synchrotron-based micro-beam analysis:

Microscopic morphology – buried porosity & chemistry



Kinetic stabilization by sub-microscopic UC – UC_2 phase competition



- Grain size of material is smaller than previously estimated; global phase transition observed at 2100°C
- Phase competition between UC and α-UC_2 as yet missing explanation of performance and durability of this material

A. Gottberg, et al., submitted

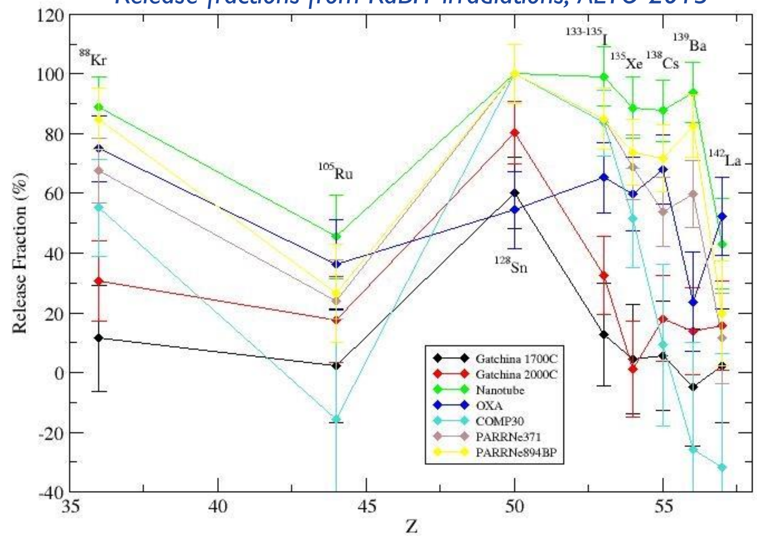
UC_x prototype target tests for ActILab-ENSAR

Online tests and synthesis of de-novo designed uranium carbide matrixes:

Different microstructures, densities, grain sizes, crystal structures tested → tailor-made matrix:

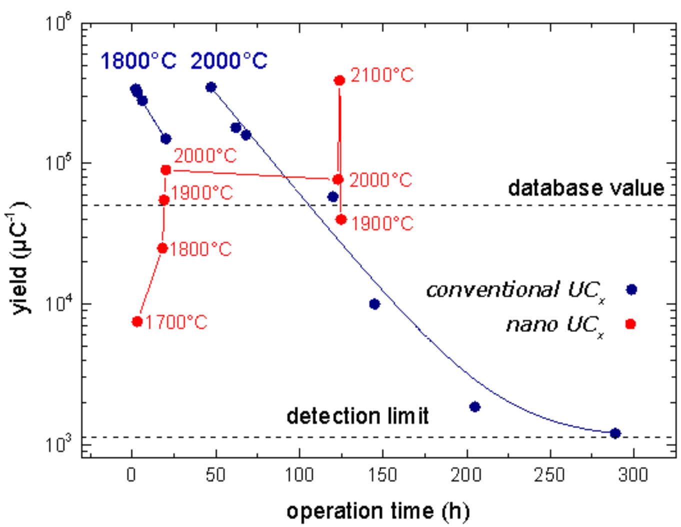
- Suspension grinding of UO_2 powder to 160 nm average particle size
- Ultrasound-assisted mixing with multi-walled carbon nanotubes
- Pressing to 1.6 g/cm^3 pellets
- Optimized reactive sintering to mixed uranium carbide inside carbon nanotube matrix

Release fractions from RaBIT irradiations, ALTO 2013



Ch. Lau, et al. , in preparation

^{30}Na beam intensity evolution



ISOLDE online tests:

Despites major technical difficulties (RFQ, tape station, separator):

- record yield of ^{11}Be: 6.0x10^7 /μC, database: 7x10^6 /μC (confirmed)
- Structure appears to be widely conserved over time and temperature

Repeat tests at ISOLDE and at ALTO within ActILab in 2014

A. Gottberg et al. submitted

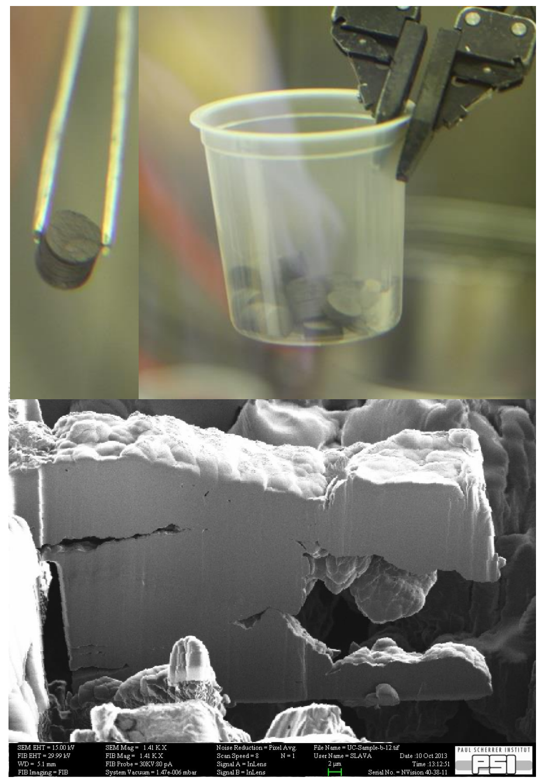
UC_X Post-Irradiation Studies for ActILab-ENSAR

Post-irradiation analysis:

- First analysis of an irradiated UC_X target in the history of ISOLDE (important to understand ageing processes and for upcoming waste campaign)
- Opening target unit #466 ($8.8 \cdot 10^{18}$ protons in 2011) in inert-gas hot-cell at PSI, 19 mSv/h on contact with Ta beam window

before irradiation

after irradiation

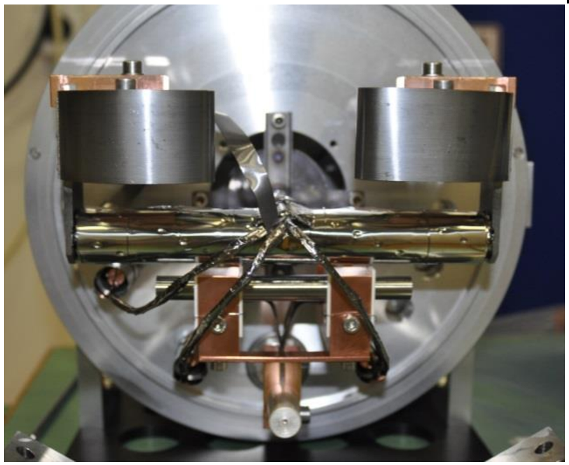


- Pellets appear macroscopically unchanged
- Microscopic evolution of pore distribution and grain size under irradiation observable
- 500 μSv/h on contact with single pellet

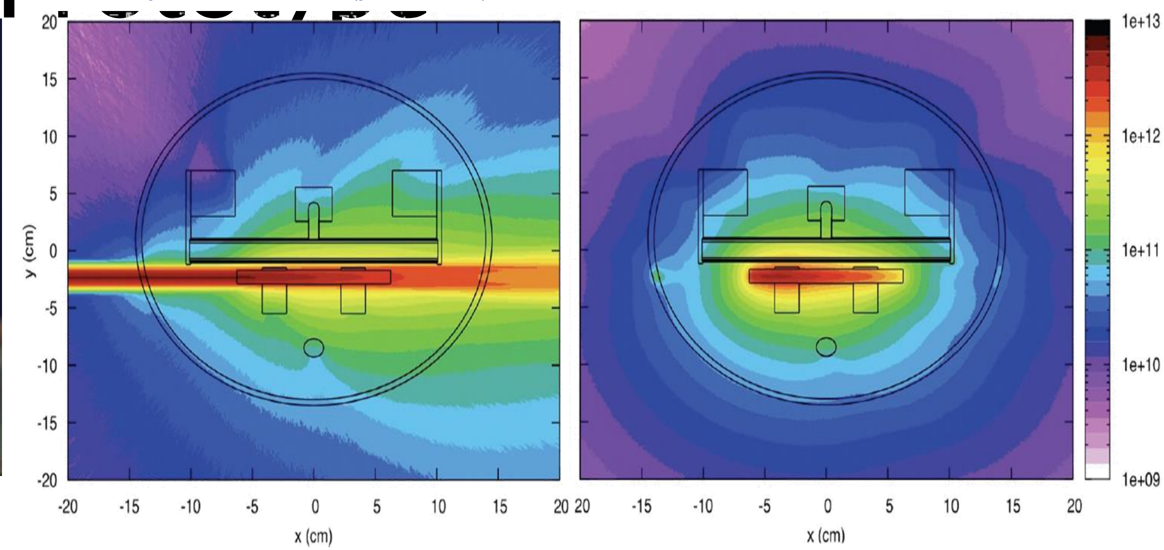
- Results of synchrotron investigations under analysis
- Ceramography and electron micro-probe analysis scheduled for April
- Perform full suite of investigations on nano UC

Proton-to-Neutron Converter Prototype

current design



proton fluence (p/cm^2/μC) — neutron fluence (n/cm^2/μC)



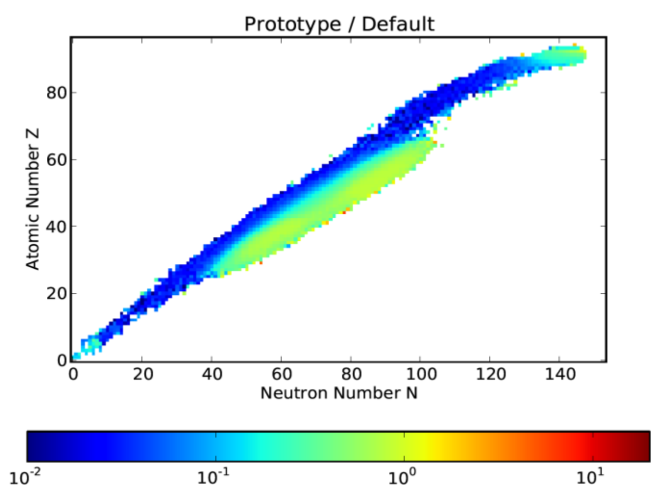
ISOLDE compatible

geometry optimization

max high-energy neutrons

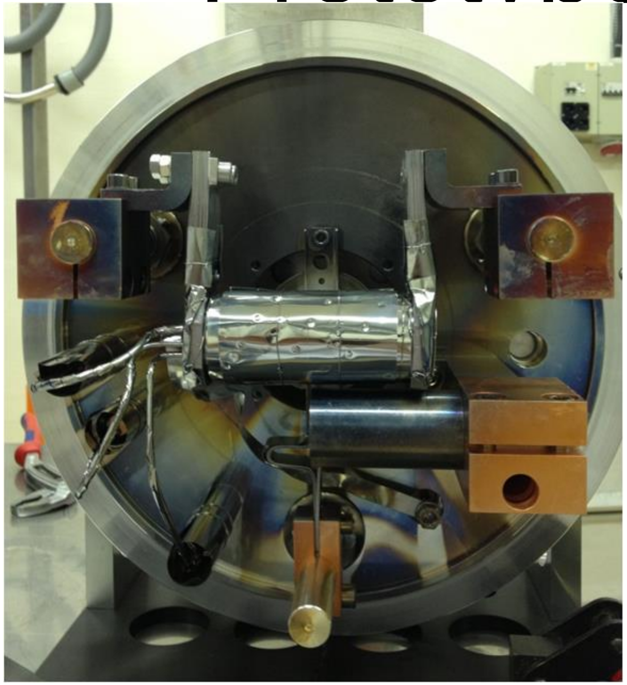
min proton

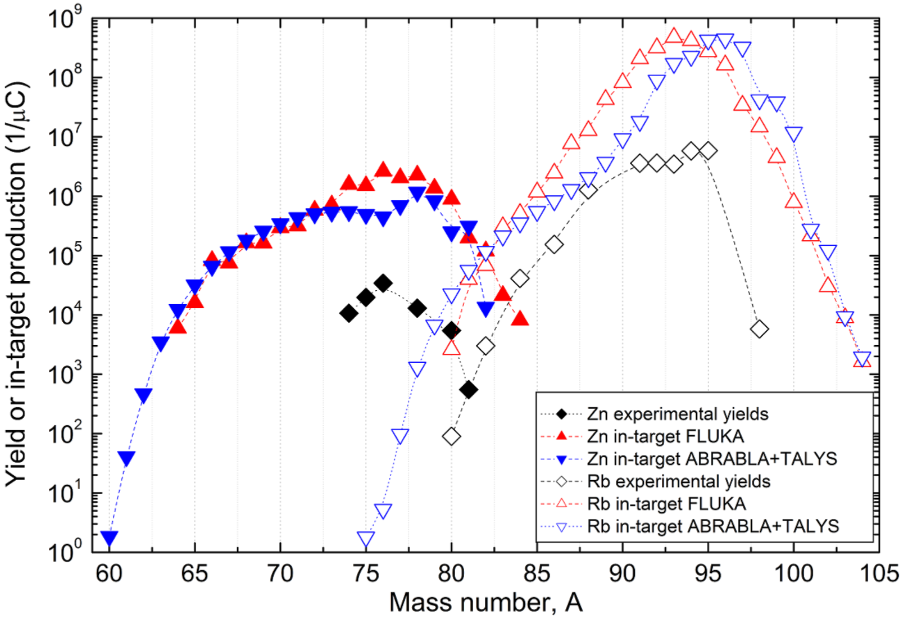
in UC_x



R. Luis et al., European Physics Journal A, 48 (2012) 90
A. Gottberg et al. submitted to Nucl. Instr. Meth. B (2014)

Proton-to-Neutron Converter Prototype Online Tests

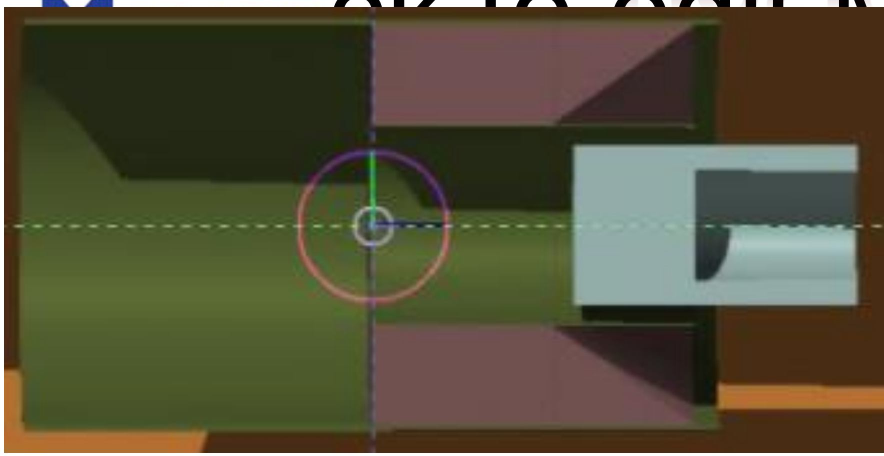




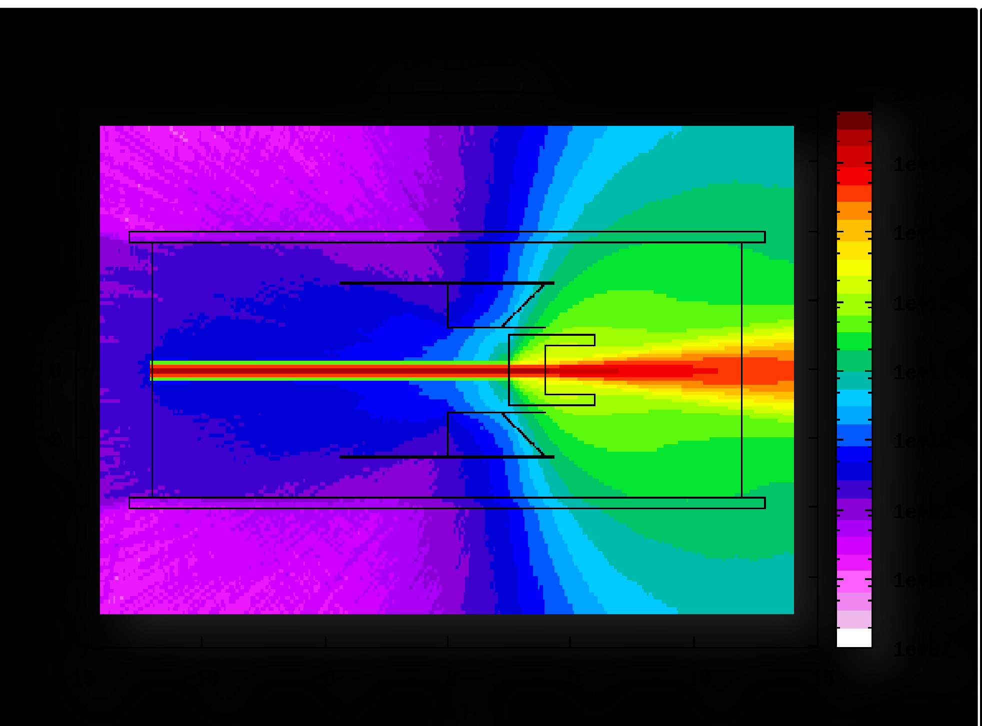
- Strong suppression of contaminations compared to conventional converter confirmed (10^4 for ^{80}Rb)
- Experimental ratio of n-rich species to contamination improved (200 for ^{80}Zn/^{80}Rb)
- Poor extraction efficiencies due to low operational temperatures (caused by structural failure)

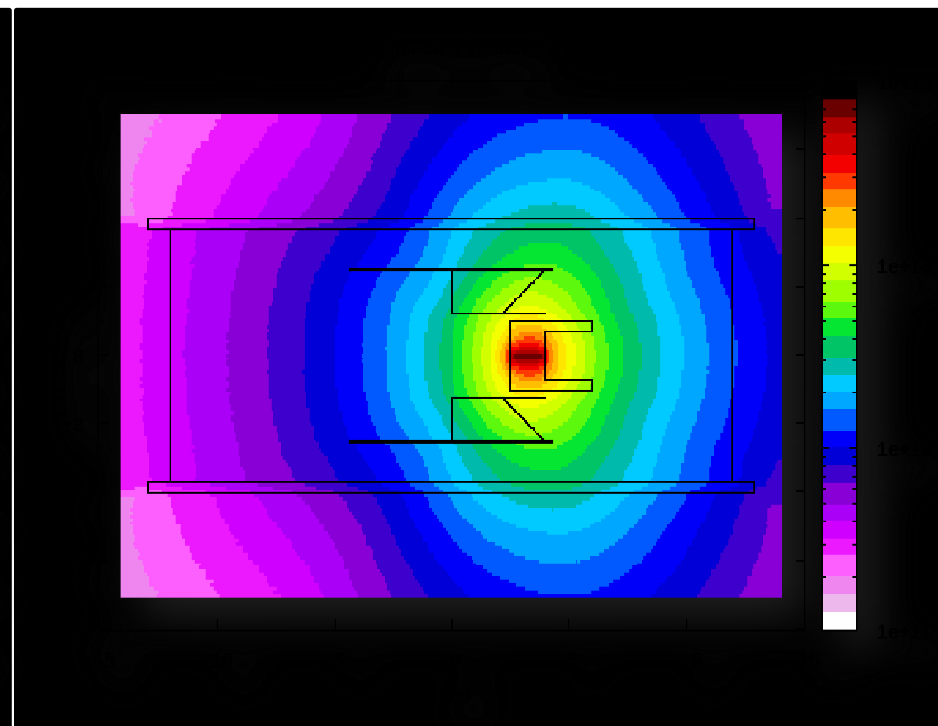
A. Gottberg et al. submitted to Nucl. Instr. Meth. B (2014)

*Design Study



- Beam Energy: 500 MeV;
- Beam Intensity: 100μA;
- FWHM: 3mm;
- Particles per second: 6.242 E14;
- UCx density: 3.63g/cm3





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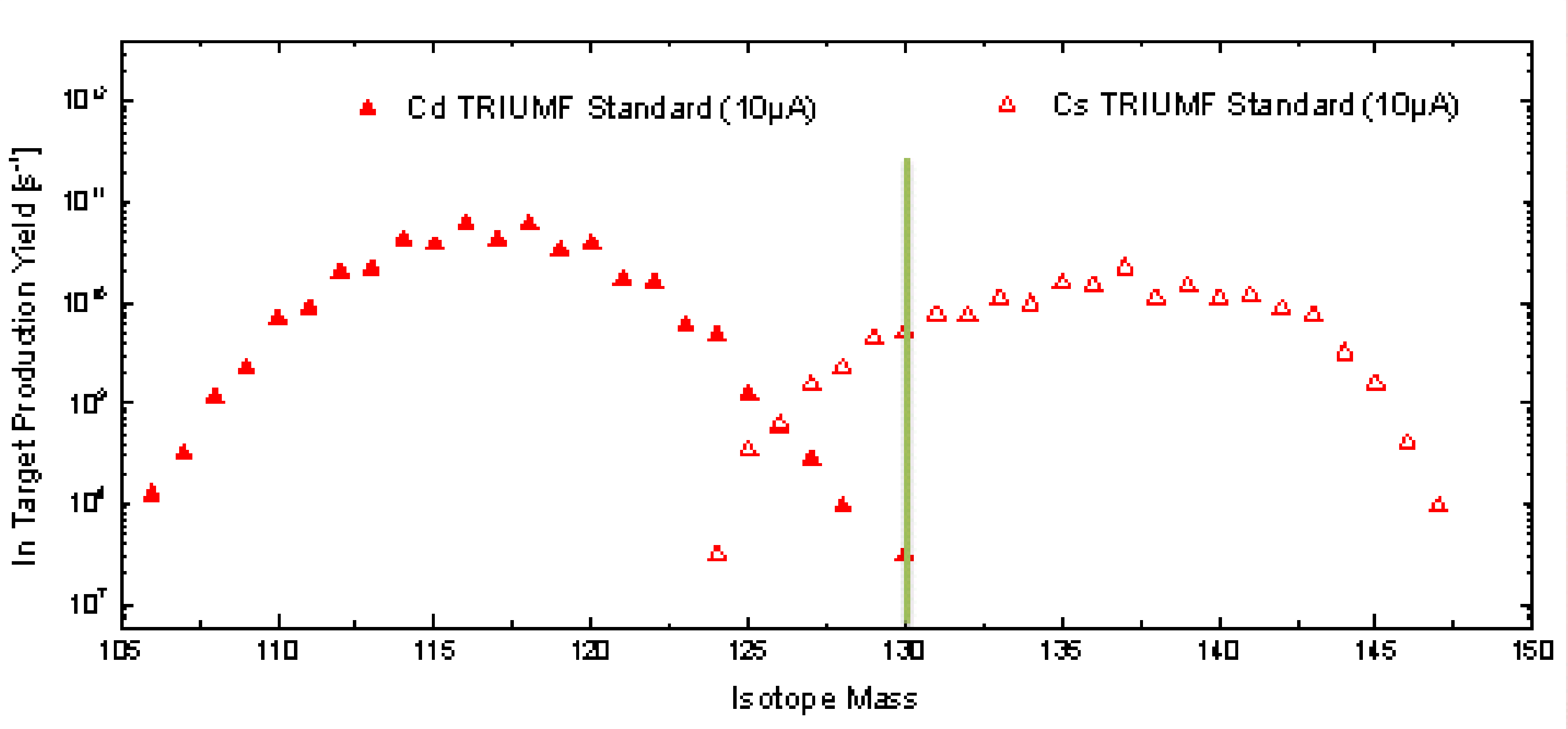
Production Comparison



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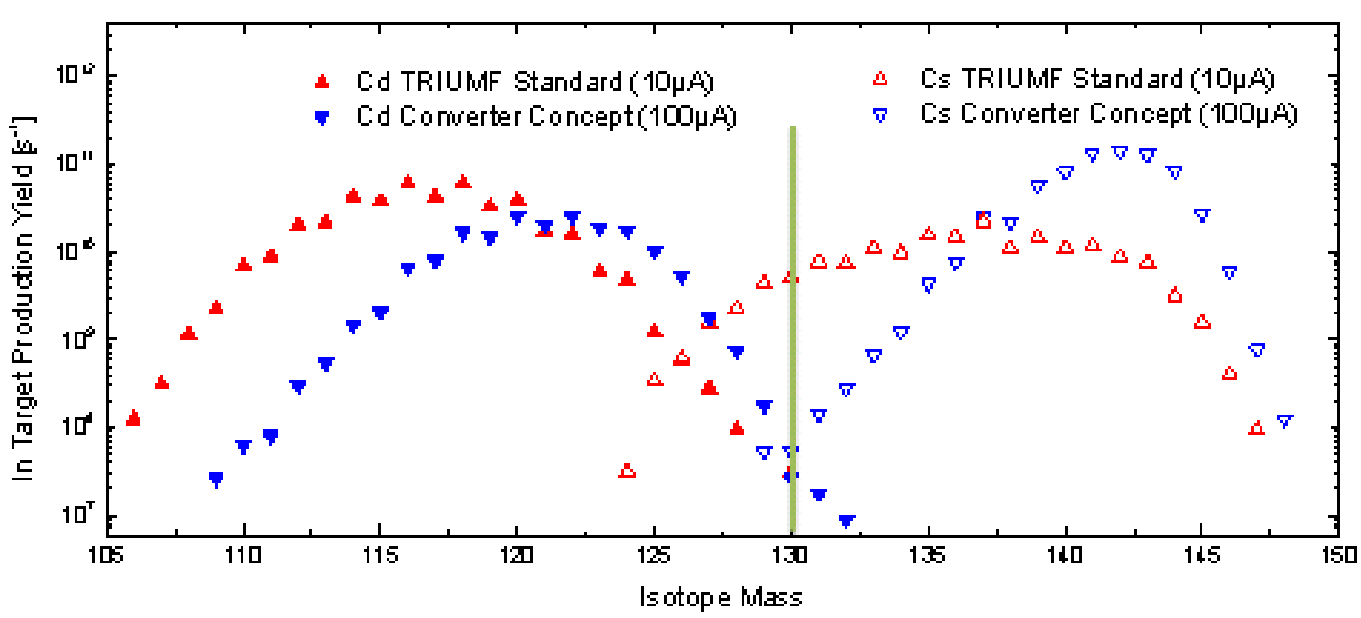
Production Comparison



3

Preliminary Thermal Analysis

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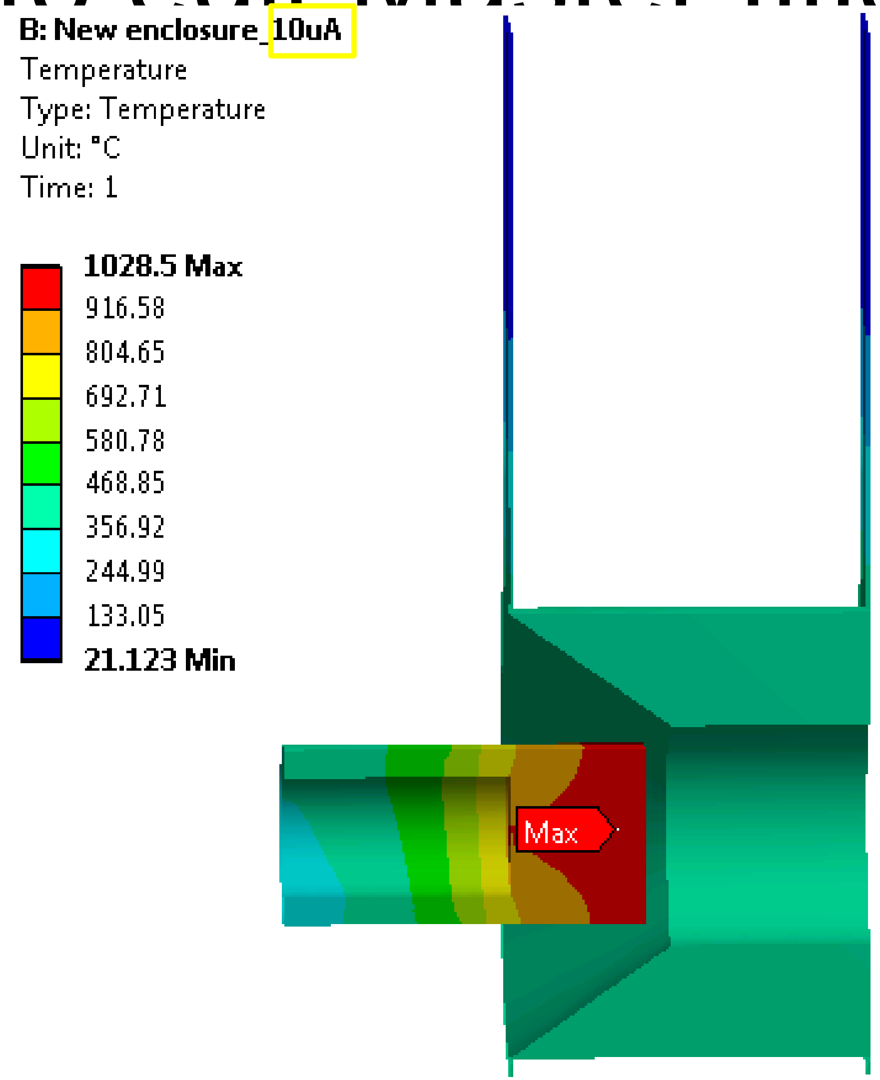


Synthesis of lanthanum carbide pellets

Work in IPNO: Use LaCx as chemical homologue to UCx

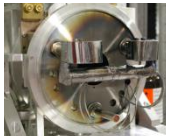
	LaC_2	UC_2
Theoretical density (g/cm^3)	5.20	11.28
Crystal structure	HT β: FCC LT α: Tetragonal	HT β: FCC LT α: Tetragonal
Lattice parameter	β: a_0 = 6.02 Å α: a = 4.00 Å, c = 6.58 Å	β: a_0 = 5.49 Å α: a = 3.52 Å, c = 5.99 Å
α → β $T_{transition}$ (°C)	1060	1777

La_2O_3 is very hygroscopic and quicly turns into in $La(OH)_3$

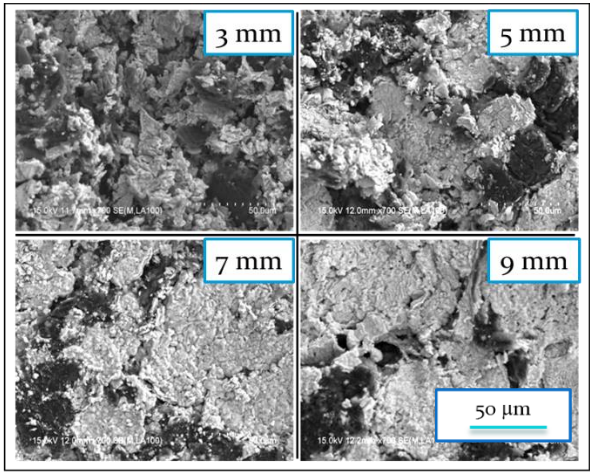
Choice to start with graphite and $La(OH)_3$:

- lanthanum hydroxide stable in the air
- strong degassing during sintering = porosity↑

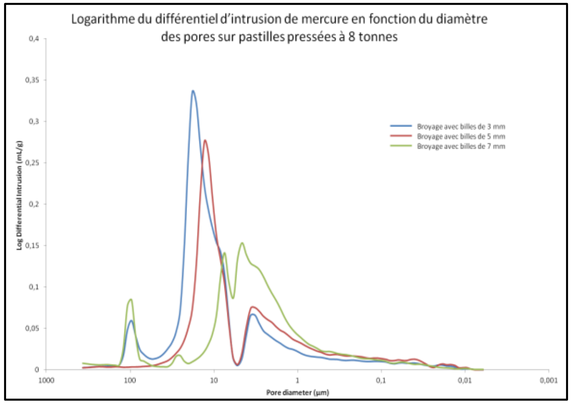
Precursor powder → Grinding → Pressing → Sintering → Characterisations



He pycnometry
SEM
XRD
Hg porosimetry



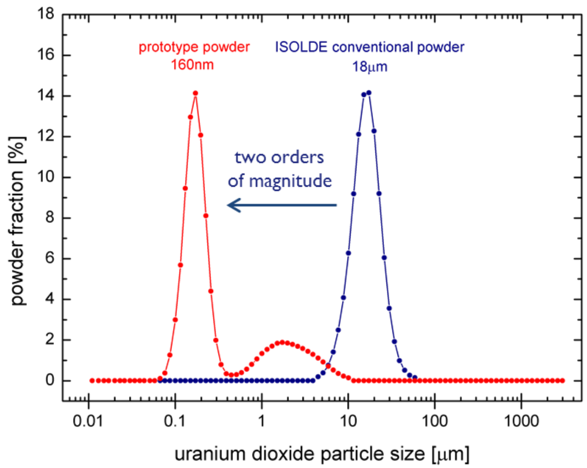
SEM Hitachi modèle S-4800 (LSI- Palaiseau). Observation backscattered electrons



Smaller beads produce:

- Finer powder
- Larger pores

○ Grinding with planetary mill :



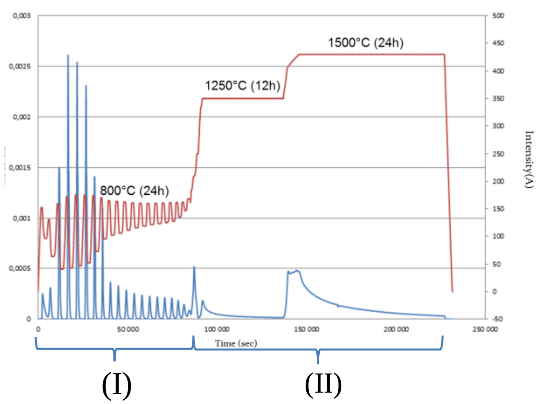
ISOLDE experience with nanoUCx shall be translated to LaCx.
Milled powders would allow to produce smaller grains by two orders of magnitude.
Smaller grains together with carbon nanotubes can be engineered for better preservation of microstrure at high temperature .
Having small grains of the target increases the efficiency of diffusion of the isotope out of the target material.
This program can be used to manufacture LaC_2 targets.

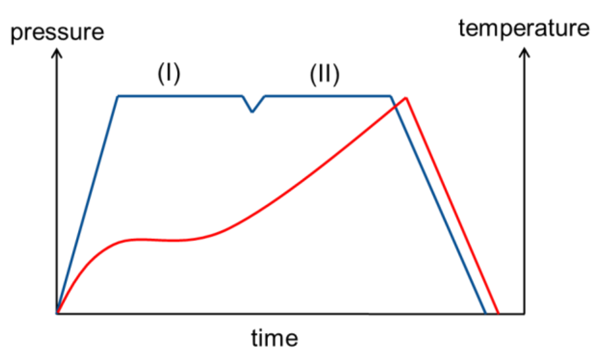
AIMS:
- **Reducing grain size**
- **Improving homogeneity in shape and grain size**

○ Reactions during sintering:

$$La(OH)_3 \rightarrow La_2O_3 + 3H_2O\uparrow \qquad \text{(I)}$$

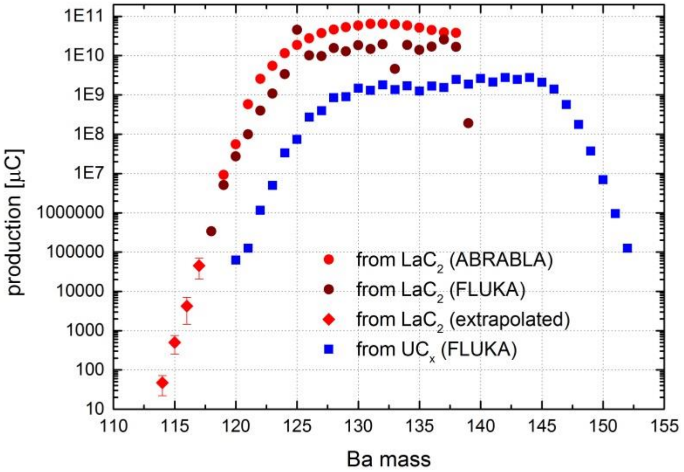
$$La_2O_3 + 11C \rightarrow 2\,LaC_2 + 4\,C + 3\,CO\uparrow \qquad \text{(II)}$$





Choice of new outgassing program
- reduces the dwell time at high temperature
- limit sintering responsible for the decrease of the porosity
- limit the change in the microstructure (grain growth ...)

- Choice of LaC2 for the production of i.e. neutron-deficient Barium beam



FLUKA simulations of the production of Ba isotopes from LaC_2 targets at ISOLDE

- neutron-deficient isotopes of Ba (Cs, Xe, etc.) isotopes LaC_2 shows higher production cross-sections thanUCx
- For Ba with A<120 the production decreases rapidly and good extraction efficiencies are necessary for decent isotope beams

LaC_2 is a better candidate than UC_2

- Purchase of material:

Start with La(OH)3 :
- lanthanum hydroxide stable in the air
- grinding in isopropanol
- strong degassing during sintering = porosity↑

Start with carbon nanotubes :
- Size
- Thermostability
- Diffusion

Grinding equipment (Jar+Beads) in Tungten Cabide:
- high density
- high hardness and high abrasion resistance
- high melting point (2900°C> work temperature ~ 2000°C)

Thank you !! Hungry ?