Uranium Carbide Target Material Investigations at ISOLDE/CERN

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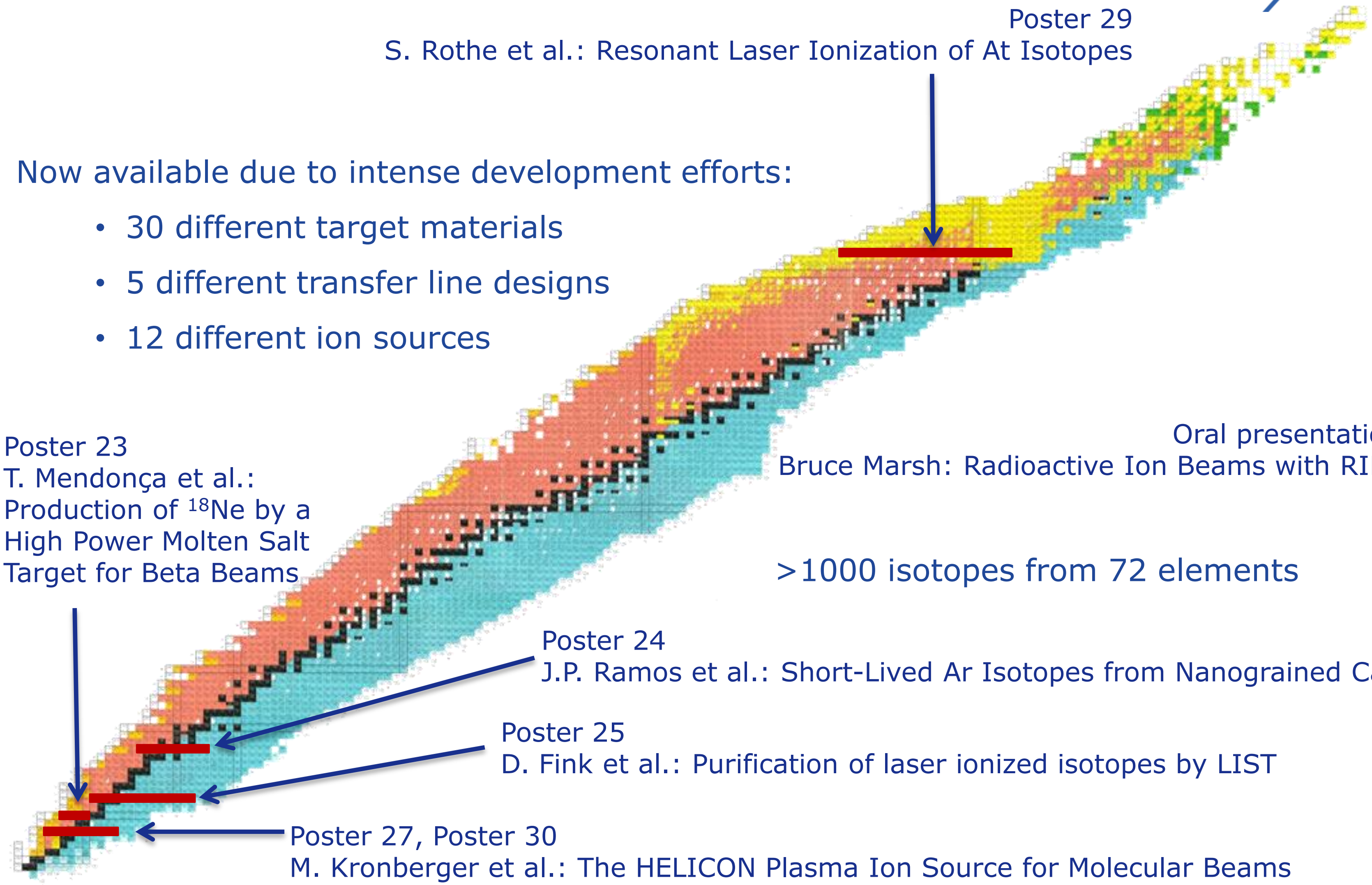
[5)]IPN, Orsay, France, [7)]INFN LNL, Legnaro, Italy

The ISOLDE Isotope Landscape

Now available due to intense development efforts:

- 30 different target materials
- 5 different transfer line designs
- 12 different ion sources

>1000 isotopes from 72 elements



Radioactive Beams at ISOLDE in 2011

Mass	Element
6	He
8	He
8	Li
8	LiO
9	Li
10	C
10	CO
11	CO
13	NO2
15	CO
16	NO
16	CO
17	NO
19	Ne
20	Mg
20	Na
21	Mg
21	Na
22	Mg
22	MgO
23	Mg
24	Al
24	Na
25	Al
25	Na
26	Na
27	Mg
27	Na
28	Mg
30	Mg
30	Na
31	Al
31	Mg
32	Ar
33	Ar
33	Cl
34	Ar

Mass	Element
35	Ar
36	Ar
40	Cl
42	K
43	Ar
45	K
45	Ti
46	Sc
47	K
48	Cr
49	K
49	Ti
50	K
50	Sc
51	K
51	Ti
52	Fe
52	Ti
53	Fe
55	Co
55	Cr
56	Cr
57	Co
57	Cr
58	Cu
60	Co
61	Fe
61	Cu
61	Mn
62	Co
63	Co
63	Ni
65	Ni
66	Ga
66	Ni
67	Cu
67	Ni

Mass	Element
68	Ni
69	Ge
69	Ni
70	As
70	Ga
71	As
71	Kr
71	Ni
71	Zn
72	Kr
72	Ni
72	Se
72	Zn
73	As
73	Ga
73	Kr
74	As
74	Kr
74	Zn
76	Zn
77	Br
77	Zn
78	Zn
79	Zn
80	As
80	Rb
80	Zn
81	Rb
81	Zn
82	Rb
82	Zn
83	Br
83	Zn
84	Kr
86	Kr
91	Kr
93	Rb

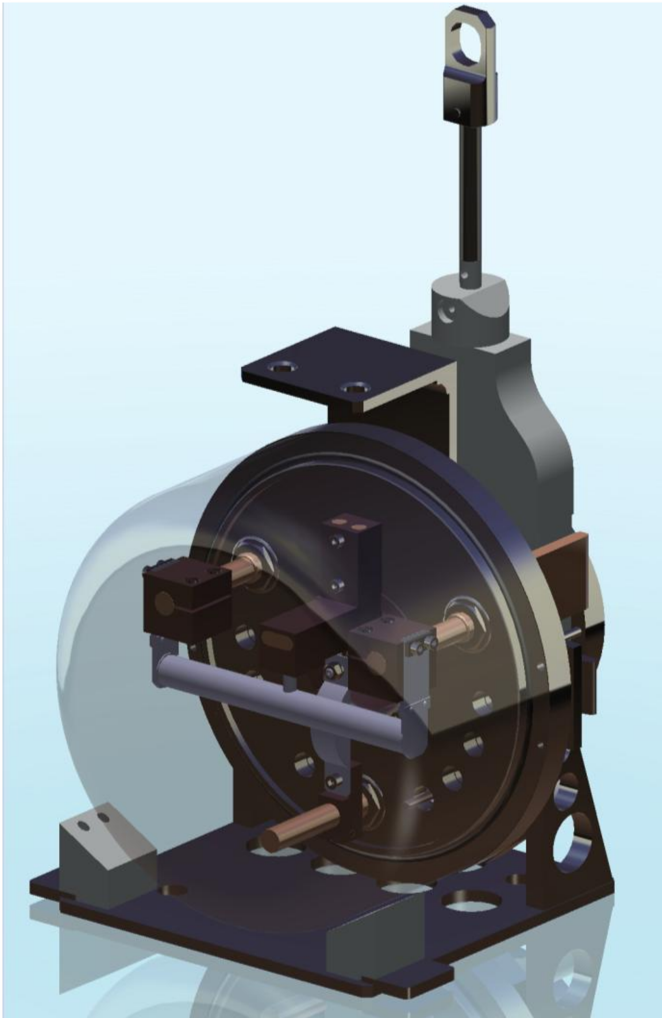
Mass	Element
95	Rb
96	Kr
98	Rb
101	Ag
103	Cd
104	Cd
106	Rh
107	Cd
110	Ag
111	Ag
111	Cd
111	In
112	Pd
113	Ag
114	Ag
114	Cd
115	Ag
117	Ag
118	Cd
118	In
124	In
126	Cd
128	Cd
128	Cs
129	Te
130	Cs
131	Cs
131	Xe
132	Cs
135	Pr
136	Cs
136	Pr
137	Cs
137	Pr
138	Cs
138	Nd
138	Pr

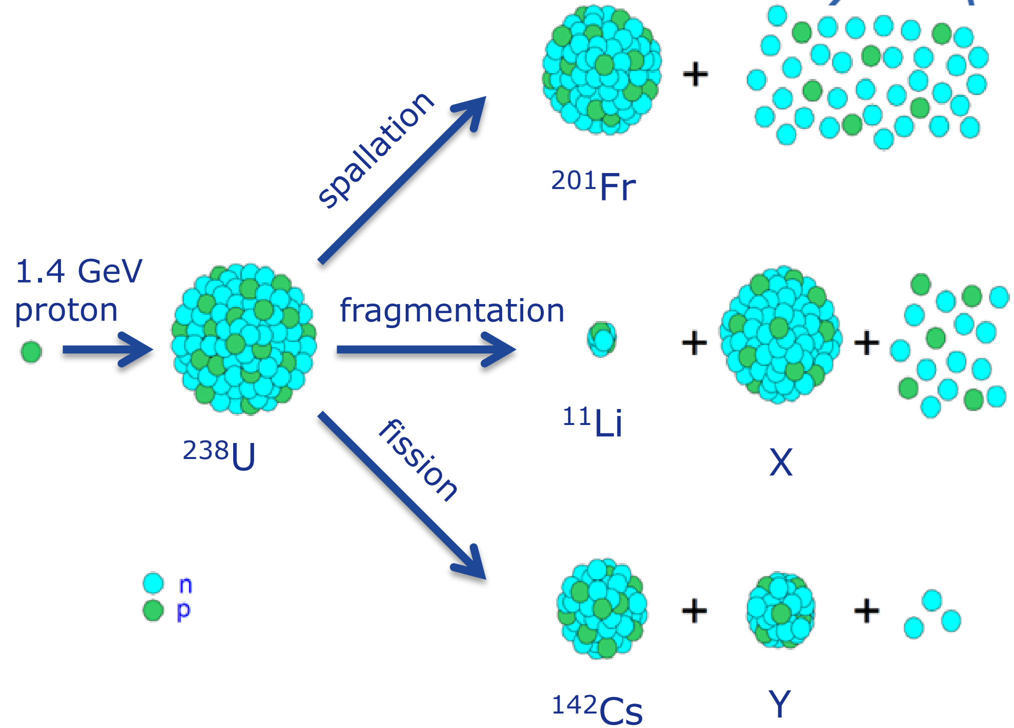
Mass	Element
139	Nd
139	Pr
139	Sm
140	Cs
140	La
140	Nd
140	Pr
140	Sm
141	Nd
141	Sm
142	Cs
142	Dy
142	Pr
142	Sm
143	Sm
147	Nd
149	Tb
151	Dy
152	Dy
152	Nd
152	Tb
157	Dy
157	Eu
165	Dy
167	Dy
168	Dy
168	DyO
169	Yb
172	Er
176	Yb
178	Hg
178	Tl
178	Yb
179	Lu
179	Tl
179	Yb
180	Hf

Mass	Element
180	Hg
180	Tl
180	Yb
181	Tl
182	Tl
183	Tl
184	Tl
186	Pb
186	Tl
188	Hg
188	Pb
188	Tl
189	Hg
190	Pb
190	Tl
191	Hg
192	Hg
193	At
193	Hg
194	At
194	Pb
195	Hg
195	Tl
196	At
196	Pb
197	Hg
198	Ir
199	At
199	Hg
200	Fr
200	Pb
201	Fr
202	Fr
202	Tl
204	At
204	Tl
205	At

Mass	Element
205	Fr
205	Rn
206	Fr
206	Hg
206	Tl
207	Fr
208	Fr
208	Hg
208	Rn
208	Tl
209	At
214	Fr
217	At
218	At
220	At
220	Fr
220	Rn
222	At
222	Fr
222	Rn
223	Fr
224	Fr
226	Fr
227	Fr
228	Fr
229	Fr
230	Fr
231	Fr
232	Fr
232	Th
233	Fr
233	Ra
234	Ra
238	U

Production of Radioisotopes





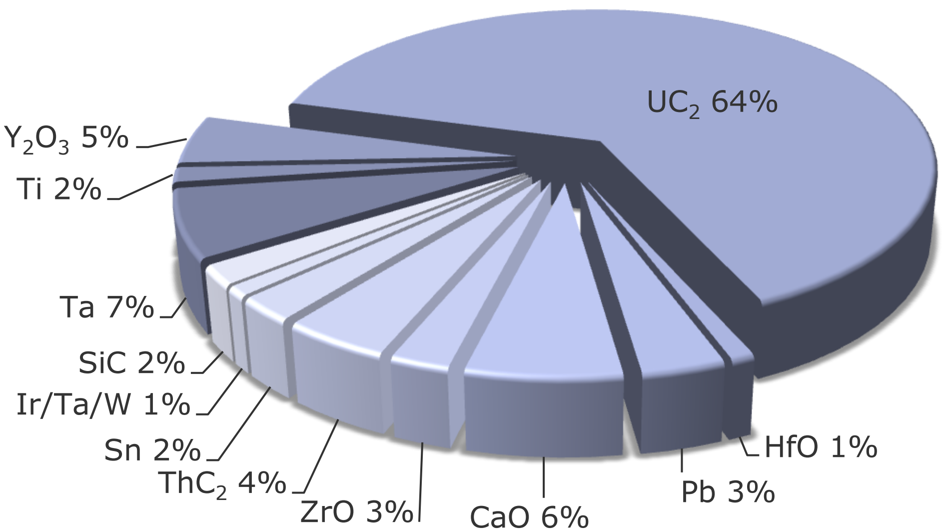
After production:

- diffusion trough target material $\rightarrow \varepsilon_{D\ 1,2,...}$
- effusion to ion source $\rightarrow \varepsilon_{E\ 1,2,...}$
- ionization $\rightarrow \varepsilon_{I\ 1,2,...}$
- transport $\rightarrow \varepsilon_{T\ 1,2,...}$

Target Material Distribution

Actinide targets at ISOLDE in 2011 (2010)

- 249 shifts out of 396 → 68% of total (72%)
- 13 new units (12 new, 2 old)



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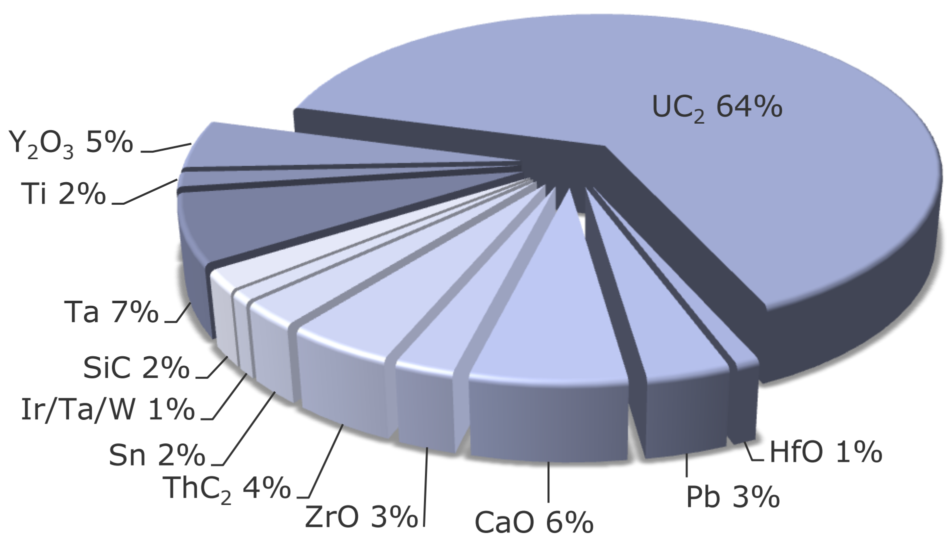
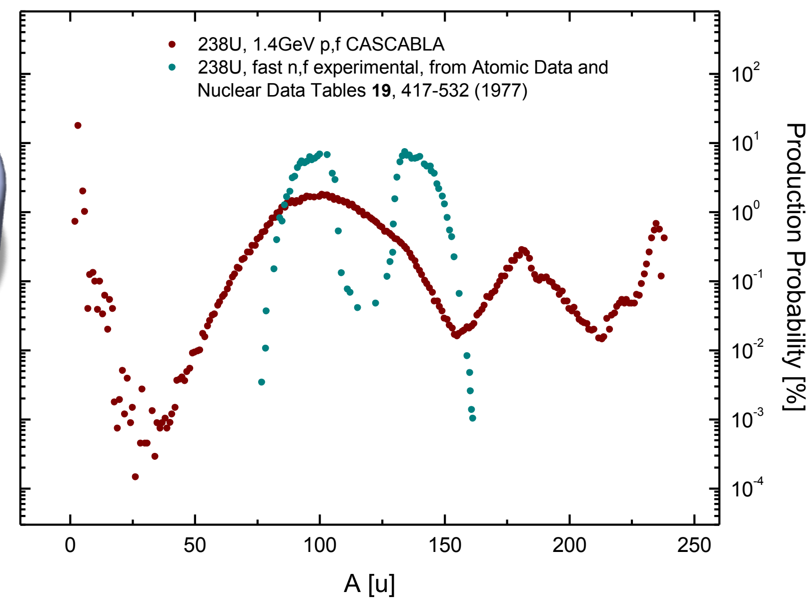
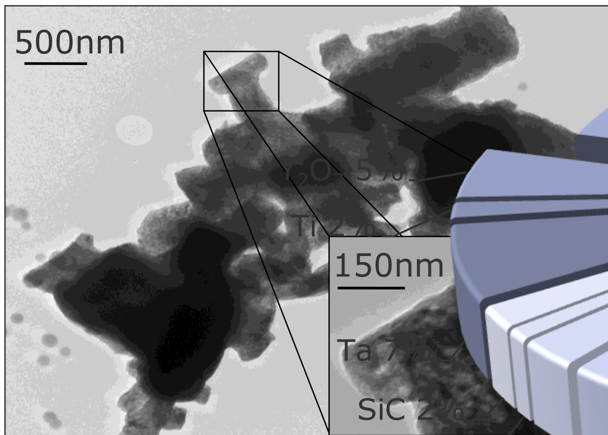




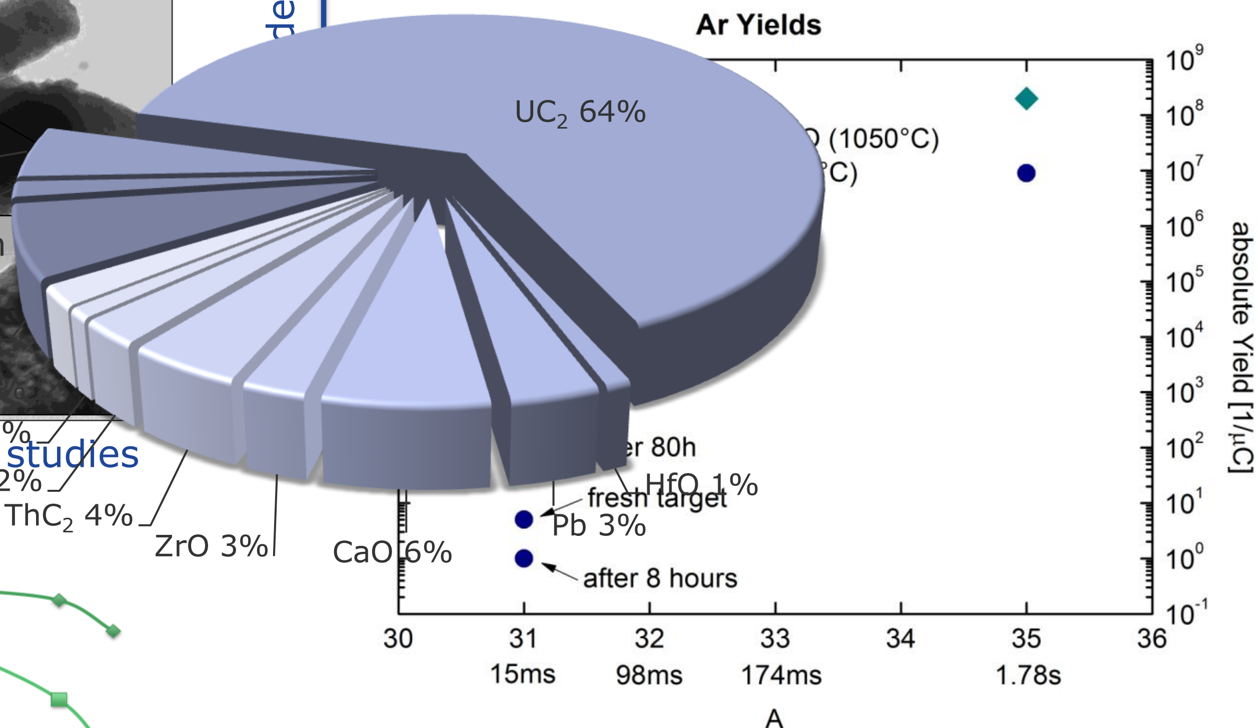
Motivation: CaO (Master thesis of J. P. Ramos, P24)

Microstructure characterization (not known before)

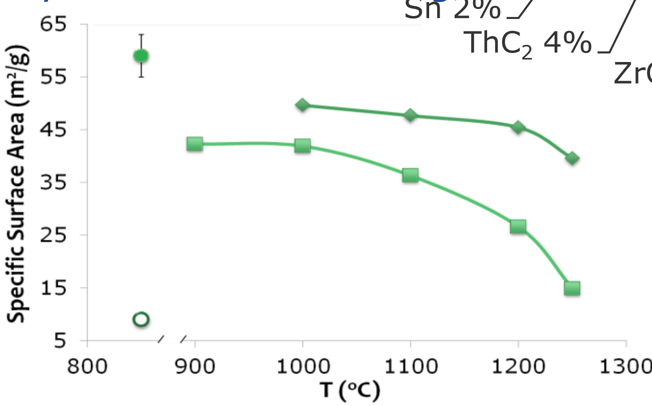
- grain size
- surface area
- porosity
- morphology



improved microstructure
reduced structural degradation



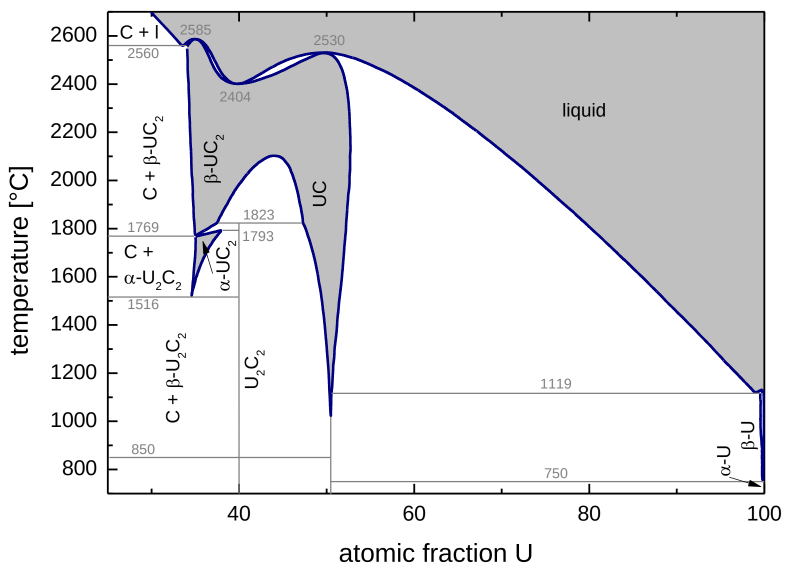
synthesis and sintering studies



Done for CaO, Y_2O_3, SiC, but…

Material Production

$UO_2 + 6C \rightarrow UC_2 + 2C + 2CO_{(g)}$



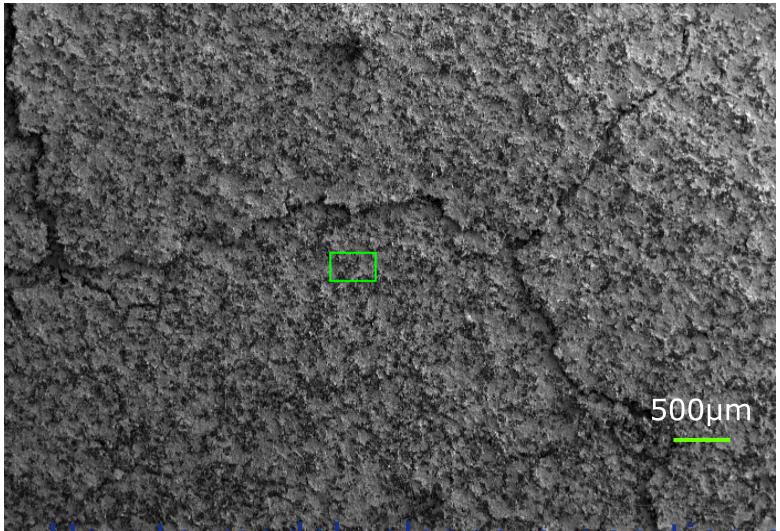
P.Y. Checalier *et al.*, J. Nuc. Mat. 288 (2001) 100-129

conventional UC_x pills used at ISOLDE

Production Process:

1. Blending UO_2 and C powder
2. Cold pressing into pills
3. Carbothermic reduction of UO_2

Current UC_x at ISOLDE

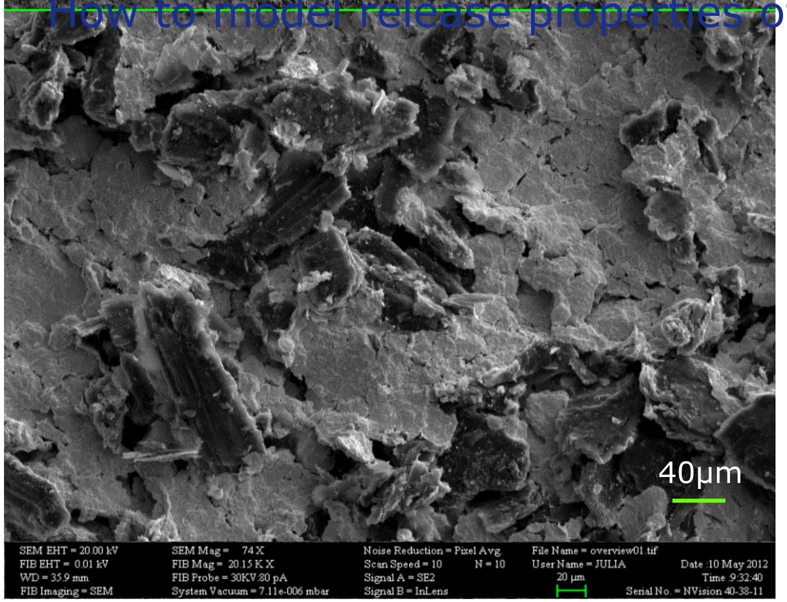


ρ_{bulk}= 3.5±0.8 g/cm^3

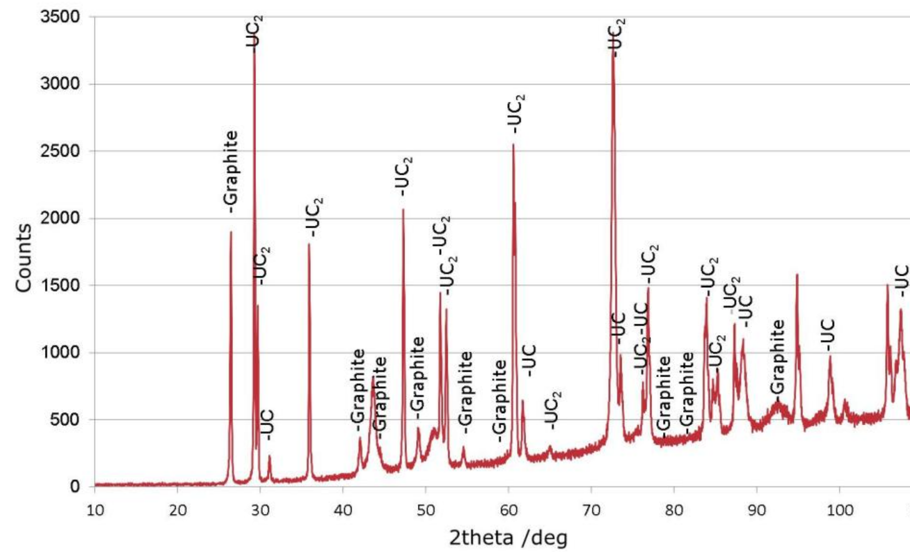
11.3 g/cm^3 (TD)

BET: 2.6±0.9 m^2/g

How to model release properties of radioactive isotopes from this material?!



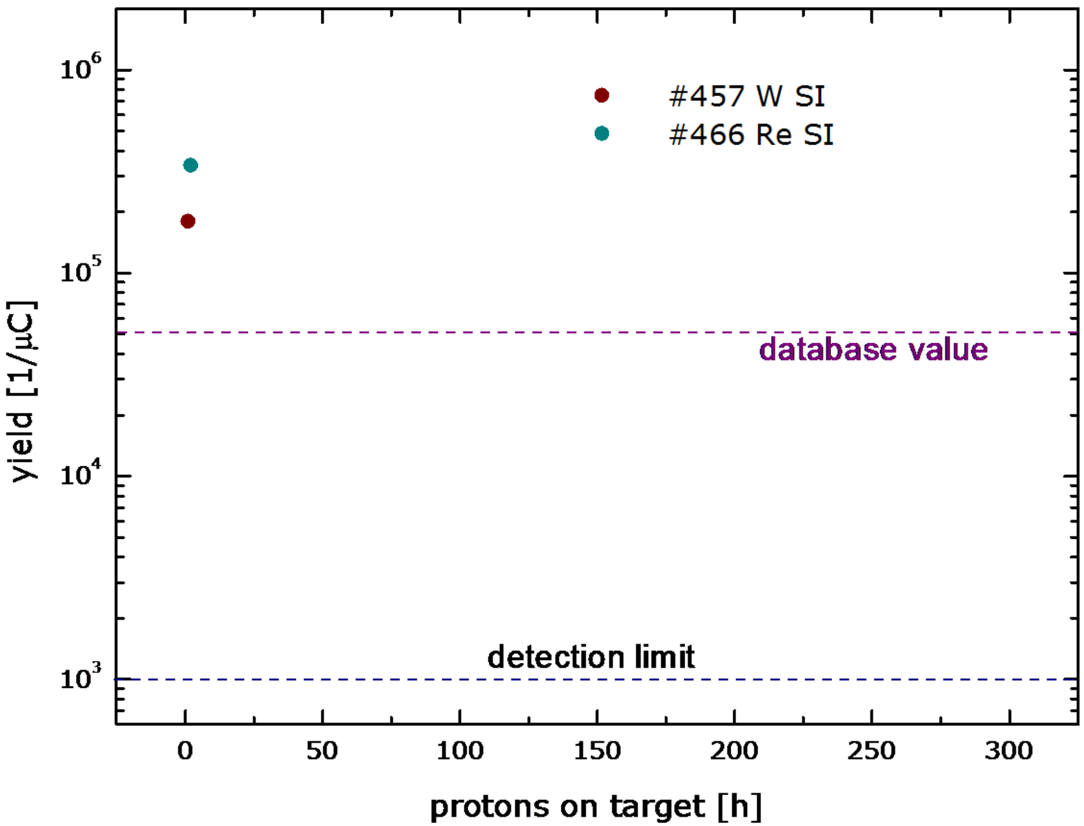
see also: C. Lau et al., NIM B, **204**, 246 (2003)

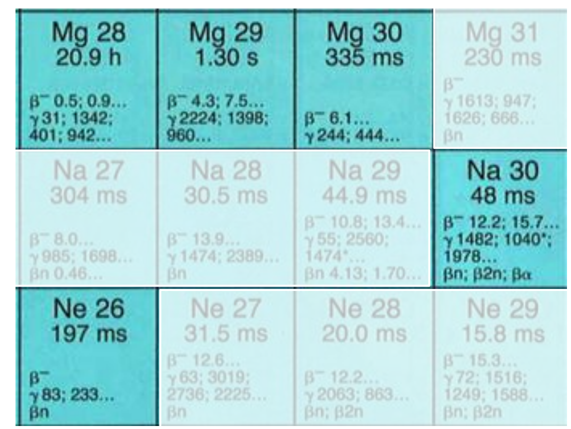


K. Hallam et al., University of Bristol, UK

Extraction of Short-Lived Alkali Isotopes

short-lived ^{30}Na (48ms) from bulk Re surface ion source





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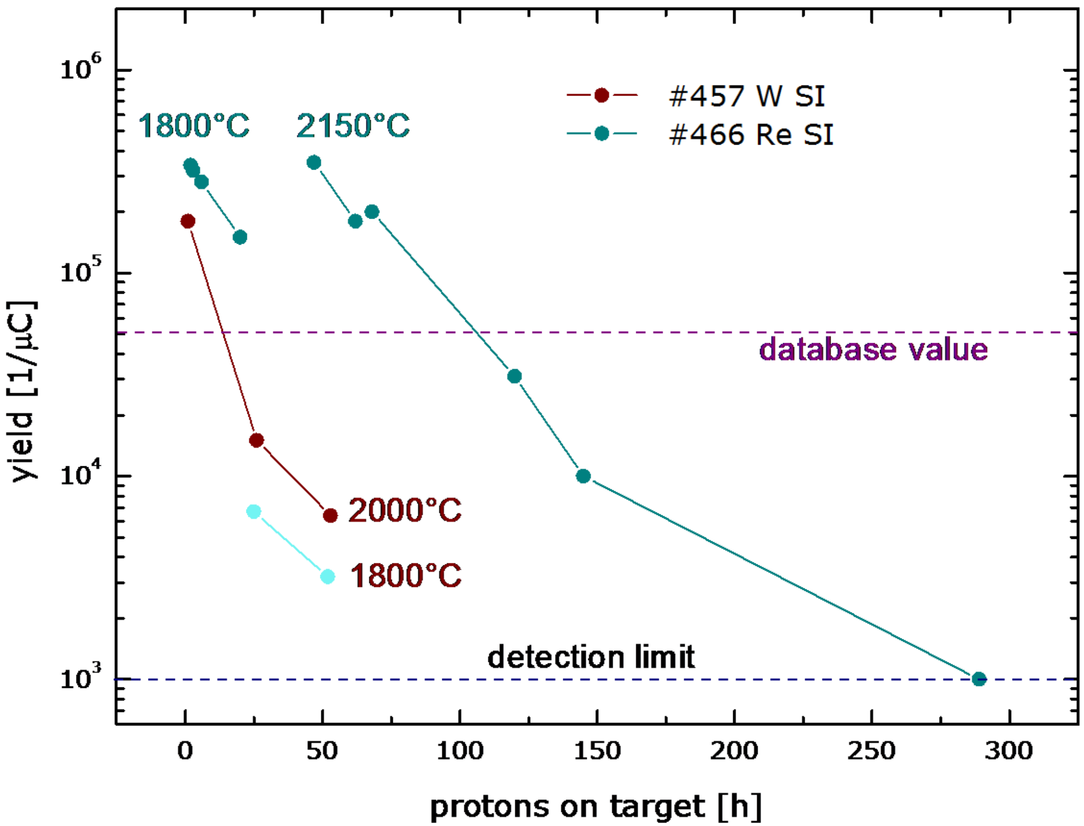
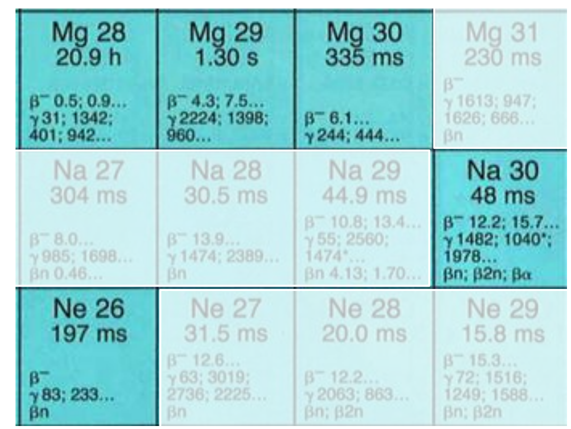




ActiLab in FP7-ENSAR

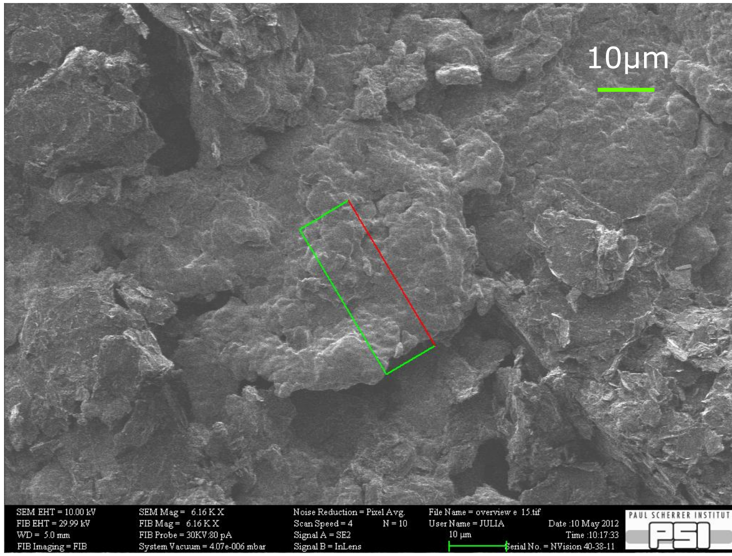
<u>Task 1: Synthesis of new actinide targets (CERN, INFN, IPNO)</u>
Subtask 1: Sol-gel synthesis in complex fluids
Subtask 2: Nanostructures

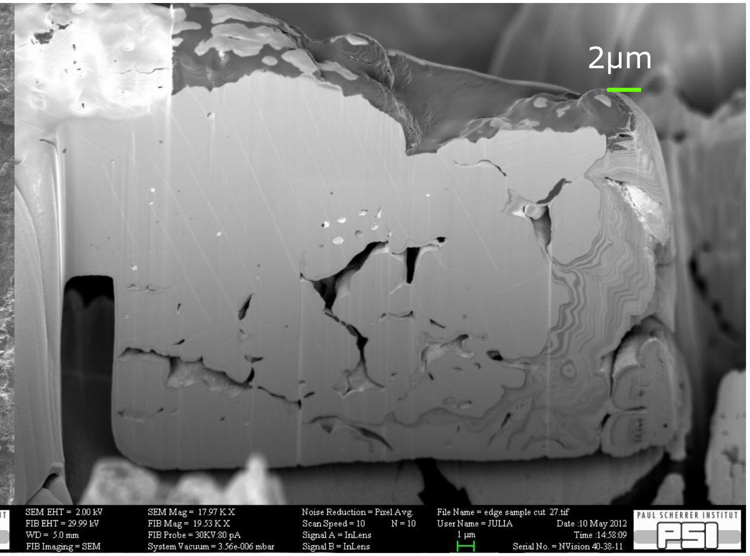
<u>Task 2: Characterization of actinide targets (CERN, INFN)</u>
Subtask 1: Microstructure, porosity, specific surface, crystalline phase
Subtask 2: Emissivity, thermal conductivity at high temperature

<u>Task 3: Actinide targets properties after irradiation (CERN, PSI)</u>
Subtask 1: Post-irradiation examination of target prototypes

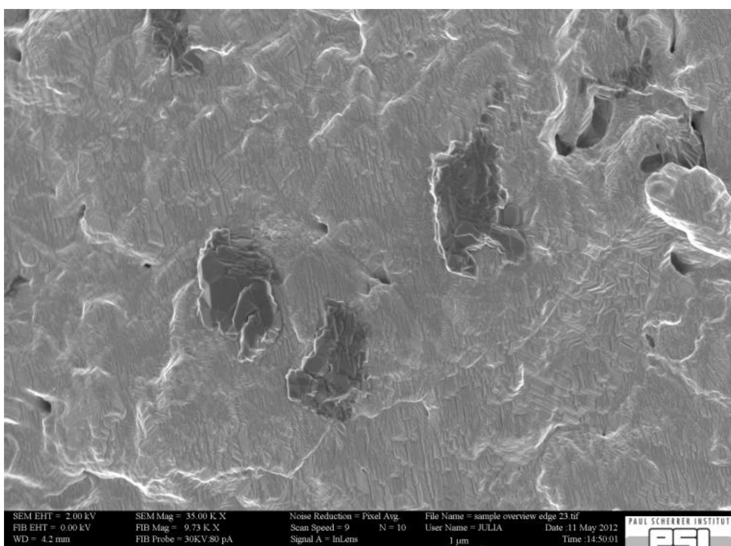
<u>Task 4: Online tests of actinide targets (CERN, GANIL, IPNO)</u>
Subtask 1: Impact of pulse time structure on release and ageing properties
Subtask 2: Analysis of the results-effusion and diffusion phenomena

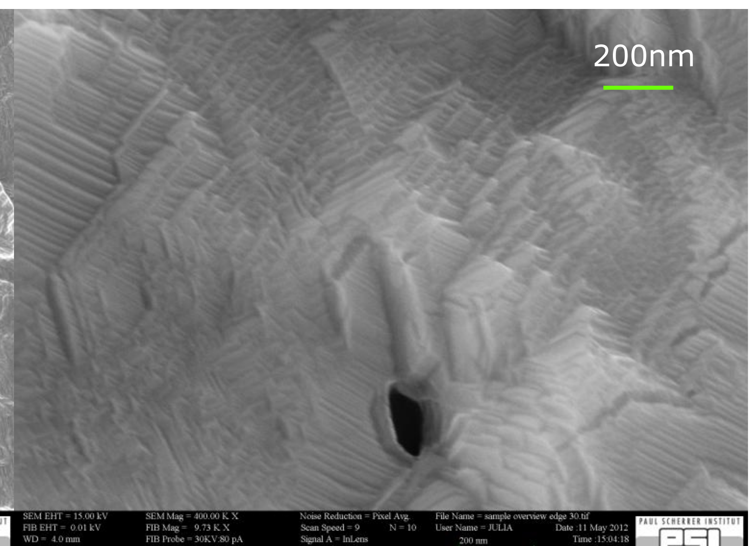
Current UC_x at ISOLDE: SEM / FIB





as prepared
(≤1850°C)

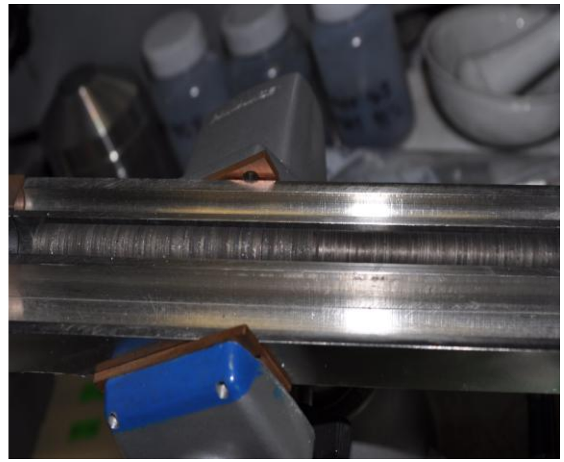
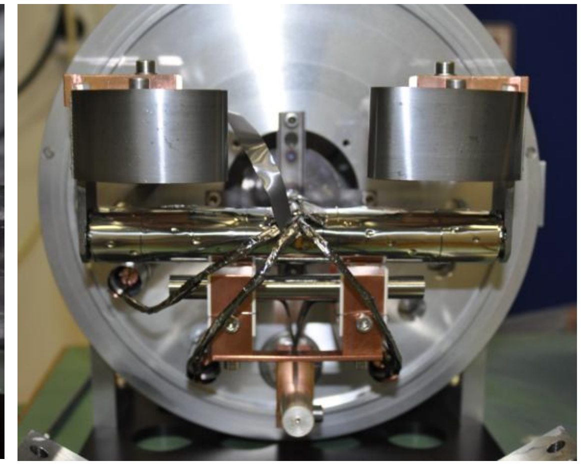


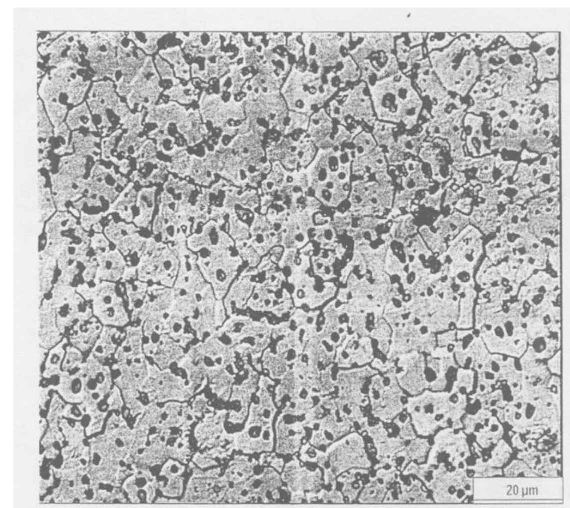


as operated
(2100°C for
5 days)

High Density UC Target at CERN

Importation from Rosatom (Russia) of HD-UC pellets to CERN & online tests in Nov. 2010:

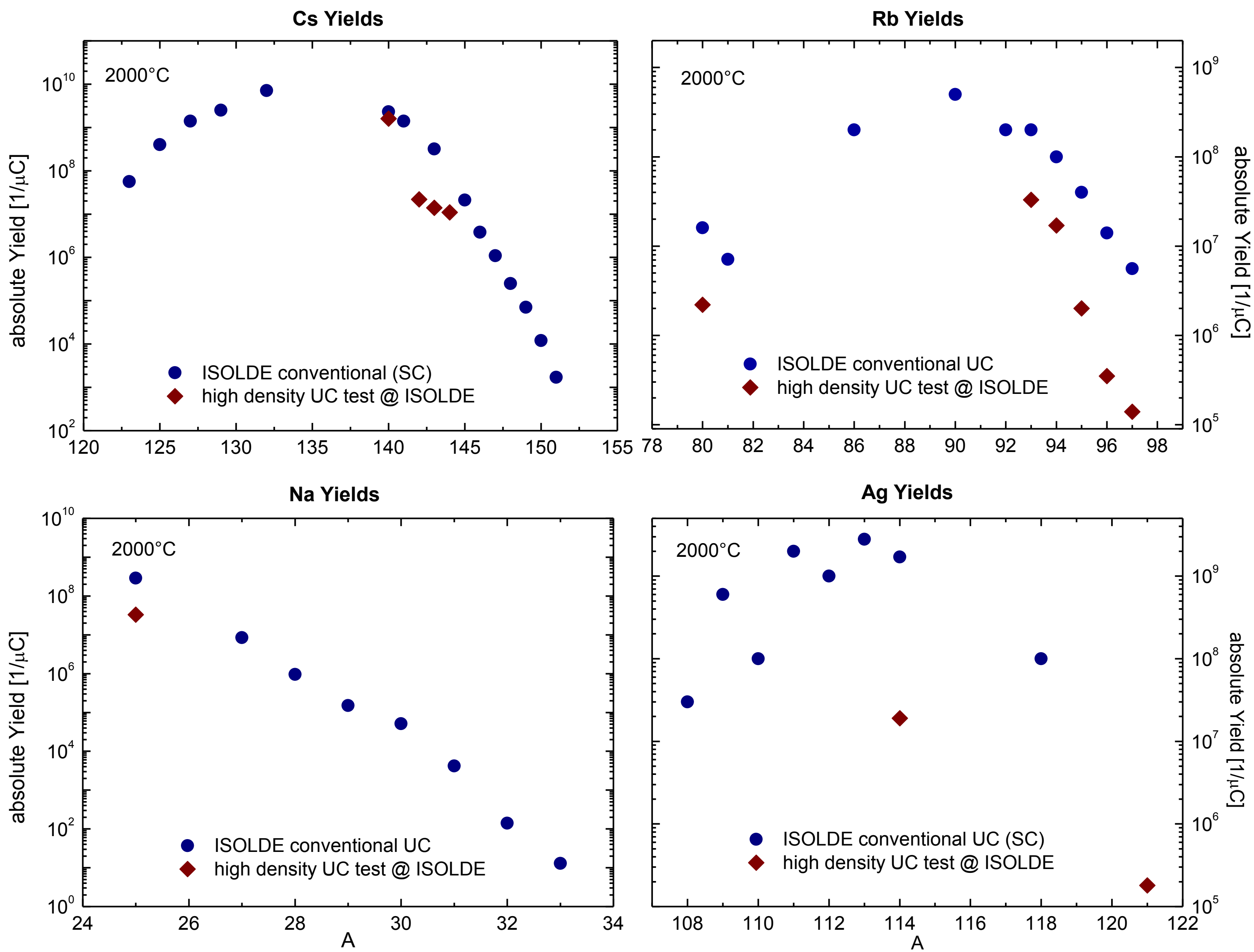






300 pills

- UC (^{235}U:0.38%), 13.2mm diam., 1mm thick, 12.7g/cm^3,
  avg. grain 6 μm , UC_2<4%

Yields from HD UC



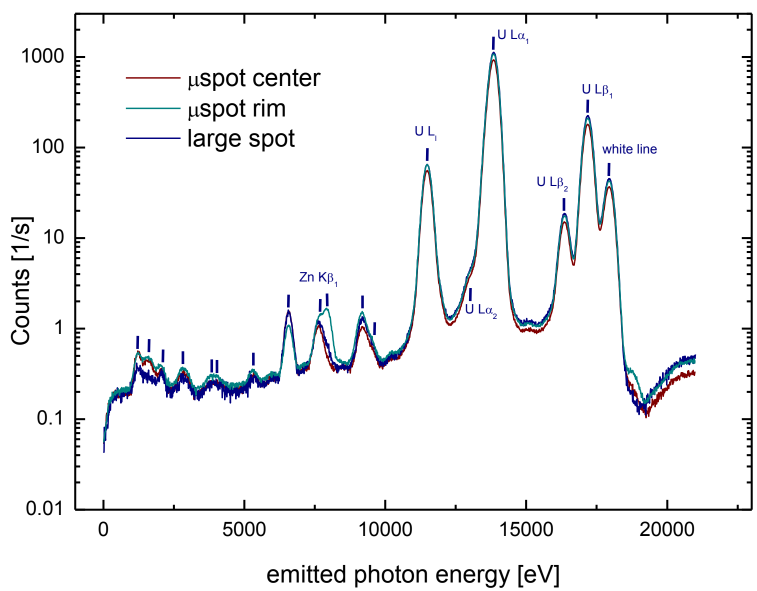
HD absolute yields @ ISOLDE (450g) x2 to x10 lower than from conventional UC targets (≈100g)

Micro Spot Material Mapping at SLS

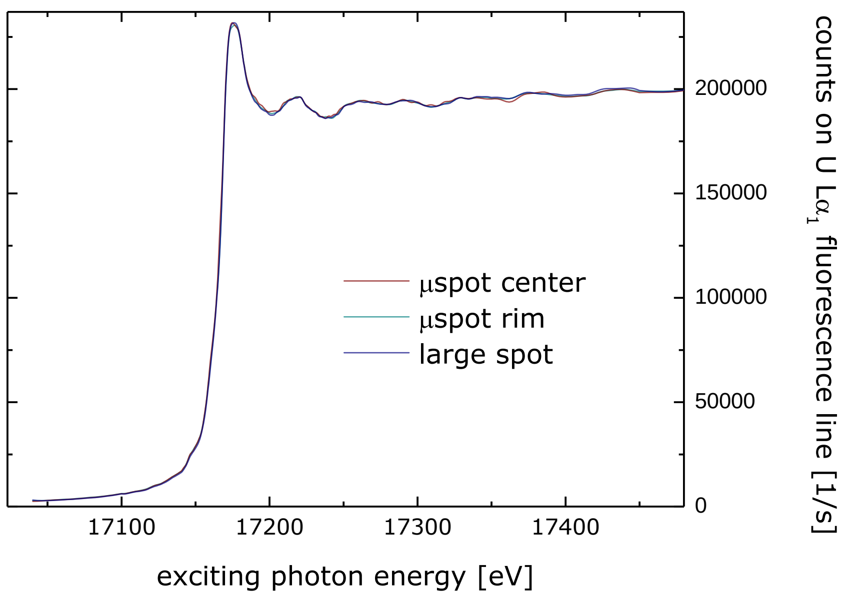
Beamline X05LA @ SLS, PSI offers: $h\nu$= 5 – 20 keV, $\Delta E/E=2\bullet 10^{-4}$, 1 x 1 μm^2

- X-Ray Diffraction (XRD)
- X-Ray Fluorescence Spectroscopy (XFS)
- X-ray absorption fine structure (XAFS, NEXAFS, EXAFS)

Fluorescence

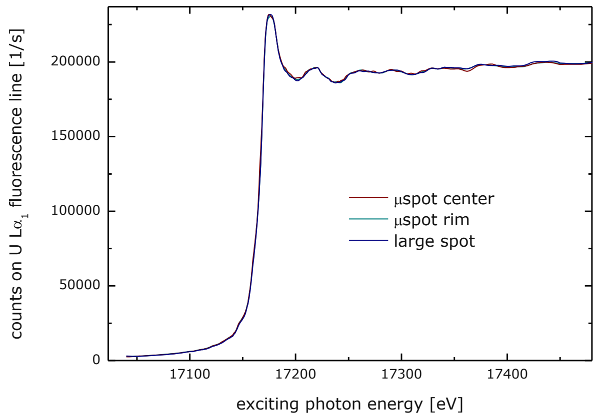


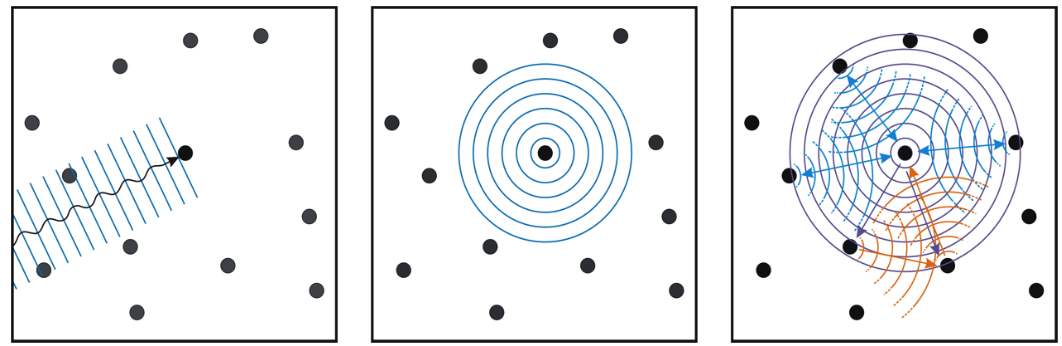
EXAFS



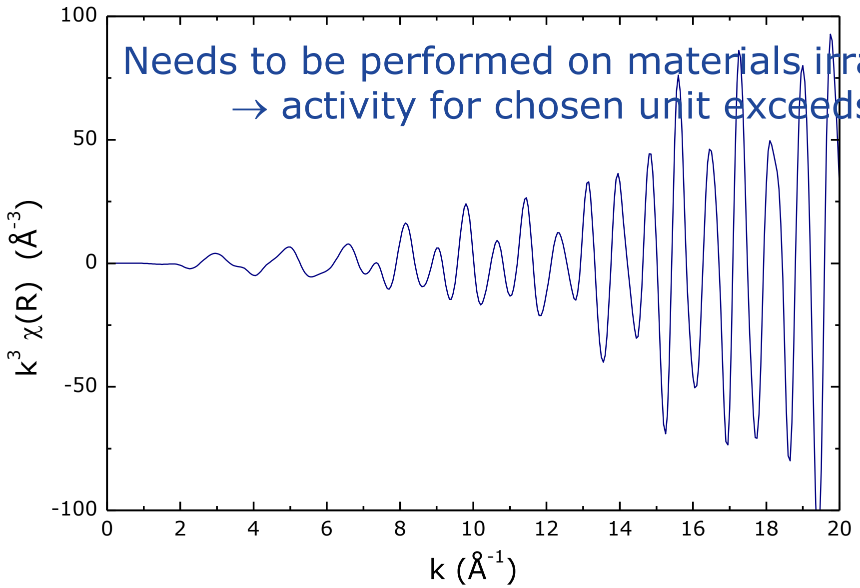
Results from first X-ray absorption experiments on UC

Micro Spot Material Mapping at SLS

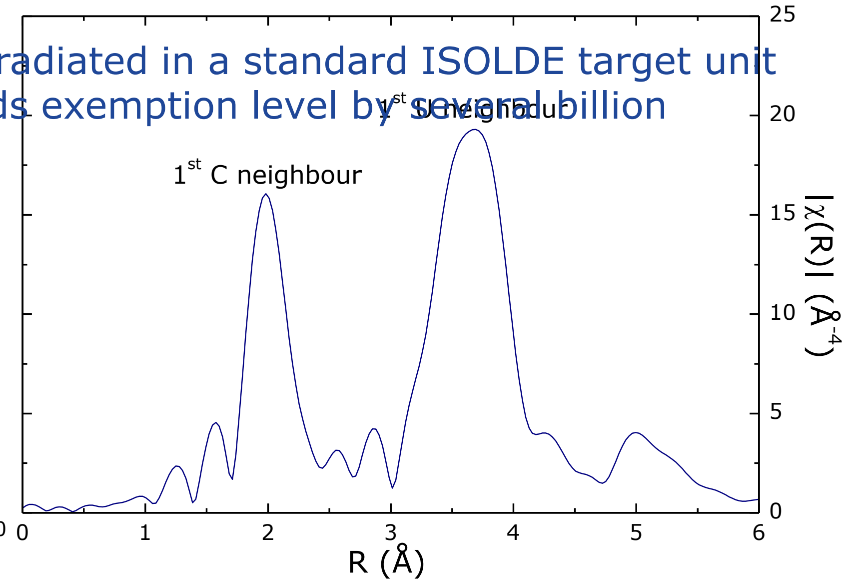




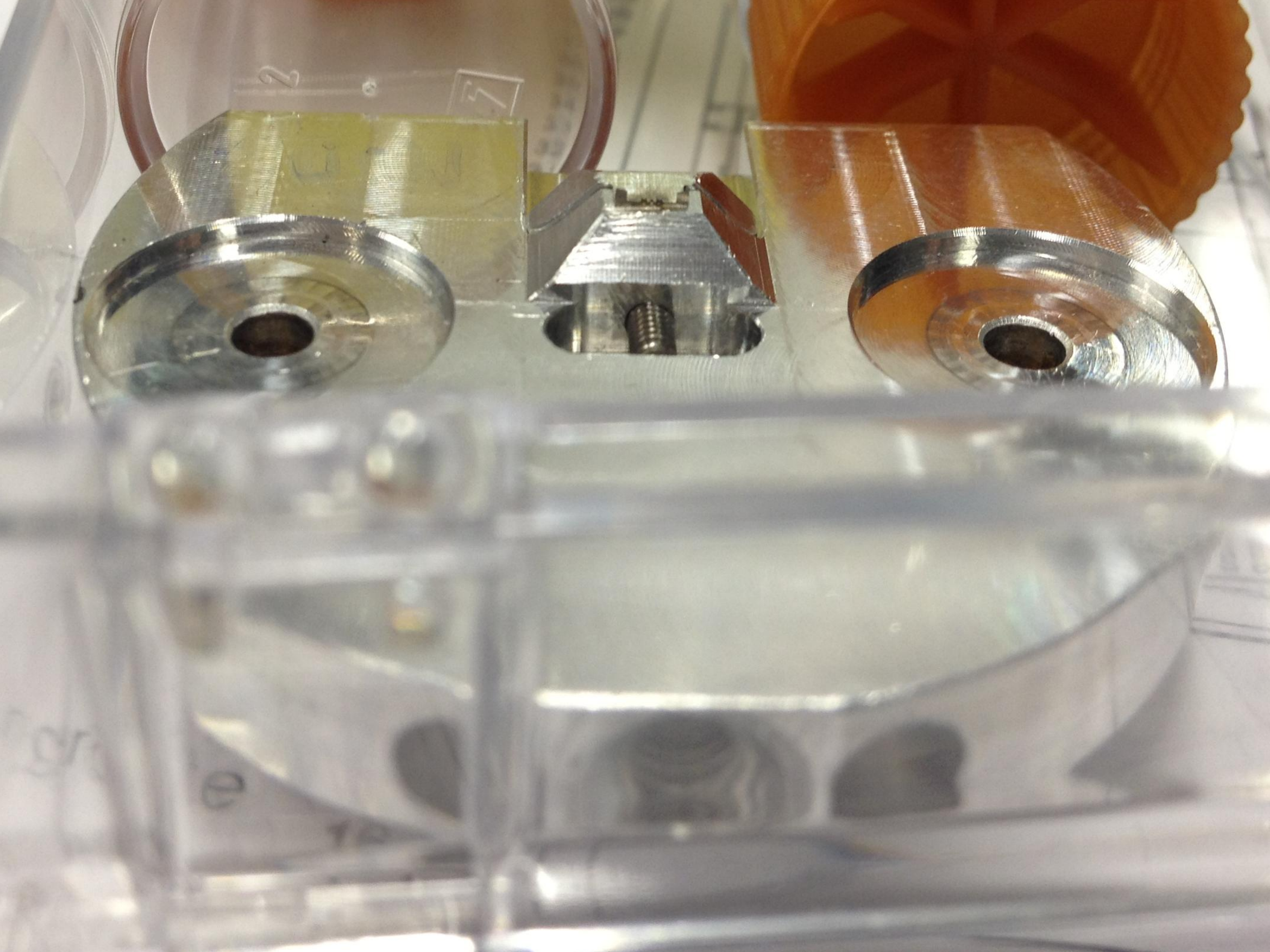
electron momentum



Fourier transform



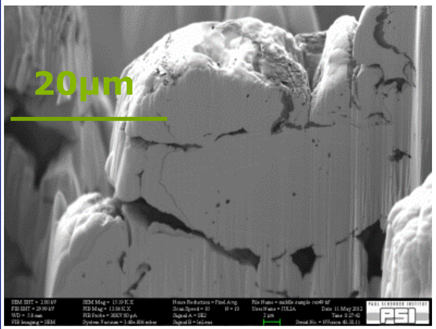
Needs to be performed on materials irradiated in a standard ISOLDE target unit
→ activity for chosen unit exceeds exemption level by several billion



Micro Spot Material Mapping at SLS

Transfer sample to SLS and perform micro spot fluorescence mapping

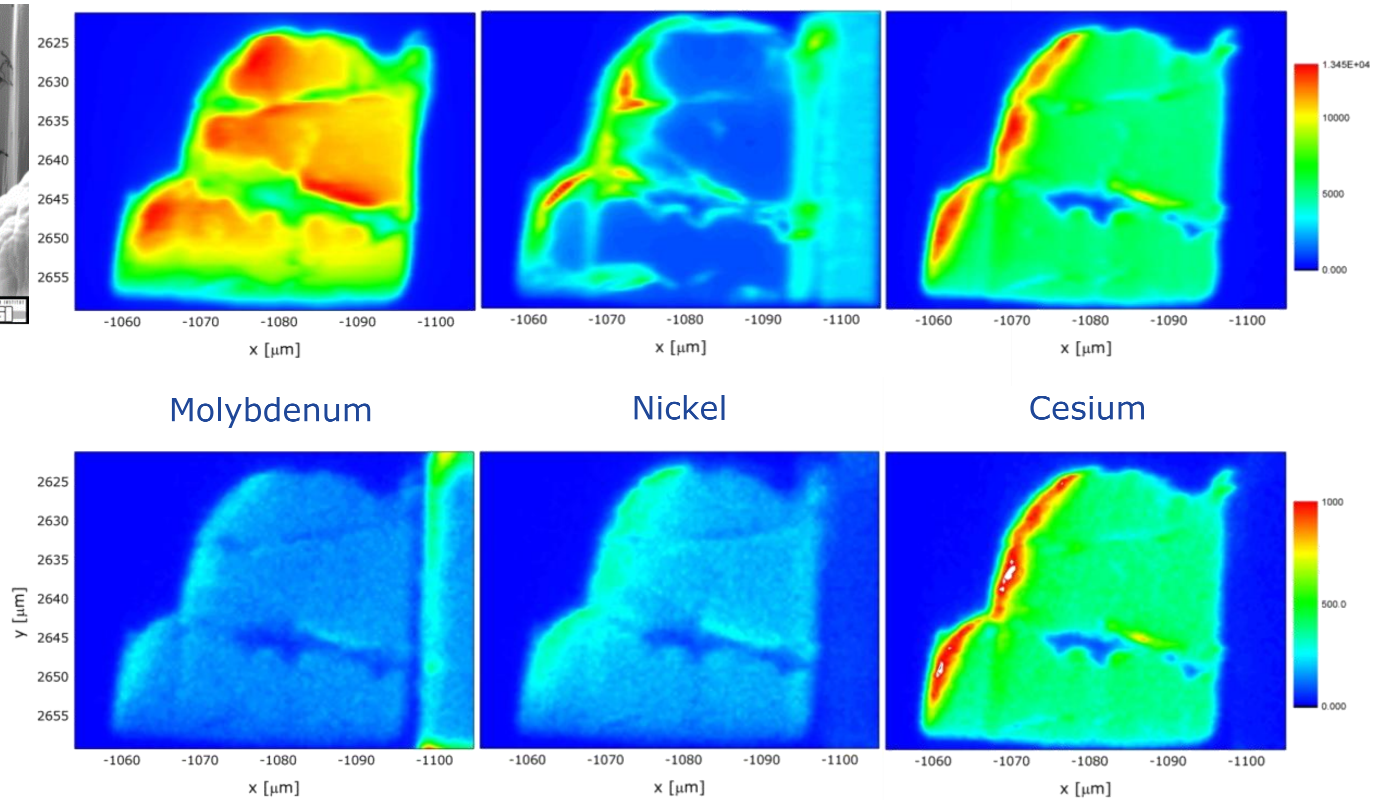
SEM Uranium



non-irradiated

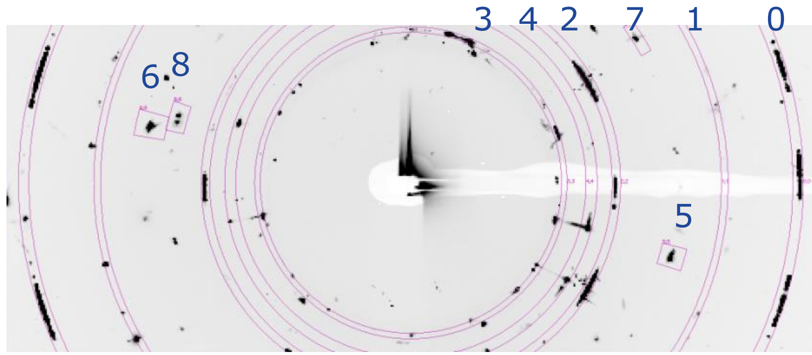
Uranium | Gallium | Potassium

Molybdenum | Nickel | Cesium

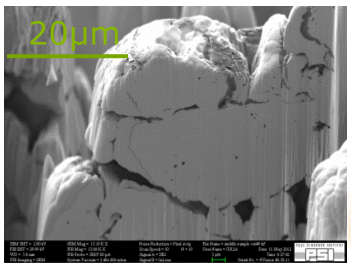


Preliminary data taken last week

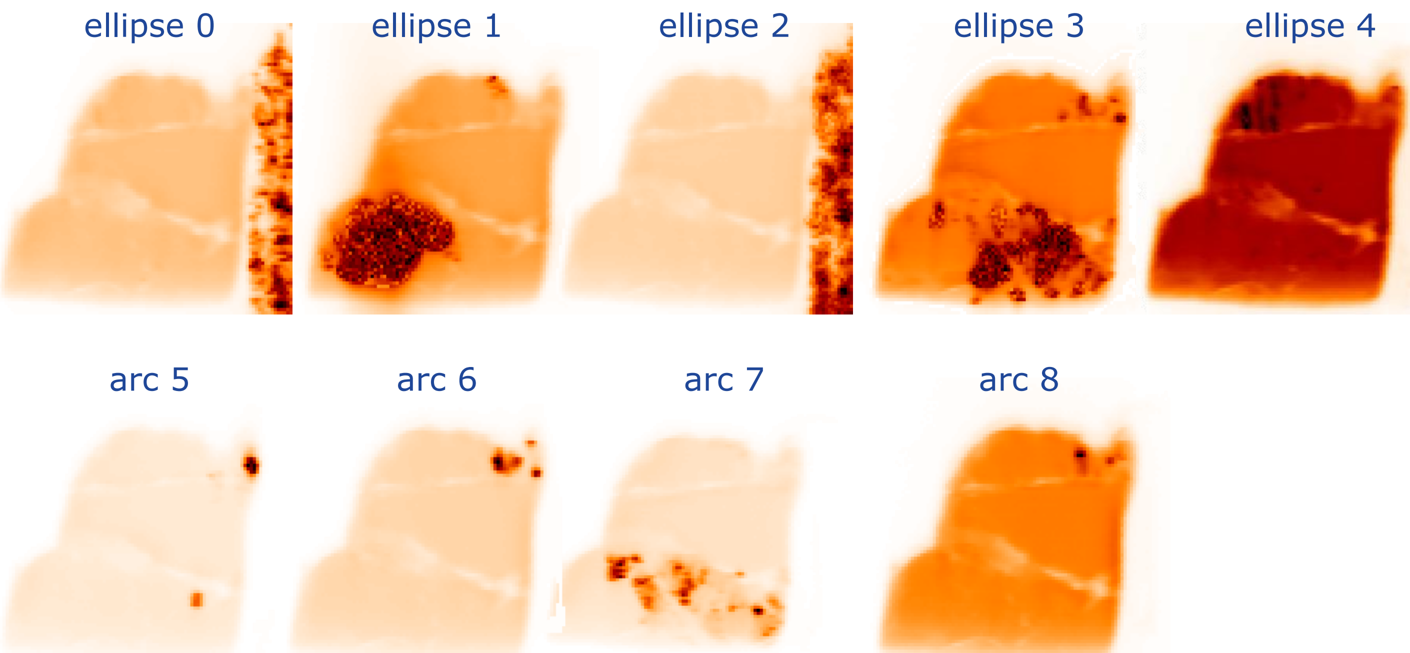
Micro Spot Crystallite Mapping at SLS



SEM Uranium



non-irradiated



Preliminary data taken last week

Post irradiation proposal for SLS beamtime approved by the SLS scientific committee

Conclusion

- UC_x is the by far most used target material for recent and future ISOL facilities

- intense development on UC_x material indispensable, for
  - accessing more exotic isotopes
  - addressing the demanded intensity enhancement
  - overcoming significant ageing effects for some isotopes
  - realizing longer target lifetime

- ActiLab in FP7-ENSAR:
  - Material analysis before irradiation reviled first unexpected results
  - Online tests of a HD-UC target was performed, results will be published soon
  - Online tests of a tailored UC_x is foreseen for the end of this year
  - Post-irradition tests are arranged and will take place in 2013 at PSI
  - Irradiation tests on several prototypes are planned at IPN-Orsay

Collaboration and Acknowledgement

UNIVERSITÉ BORDEAUX 1 Sciences Technologies

CSIC Consejo Superior de Investigaciones Científicas

ISOLDE

EN STI

INFN Istituto Nazionale di Fisica Nucleare

PAUL SCHERRER INSTITUT PSI

GANIL spiral2 laboratoire commun CEA/DSM CNRS/IN2P3

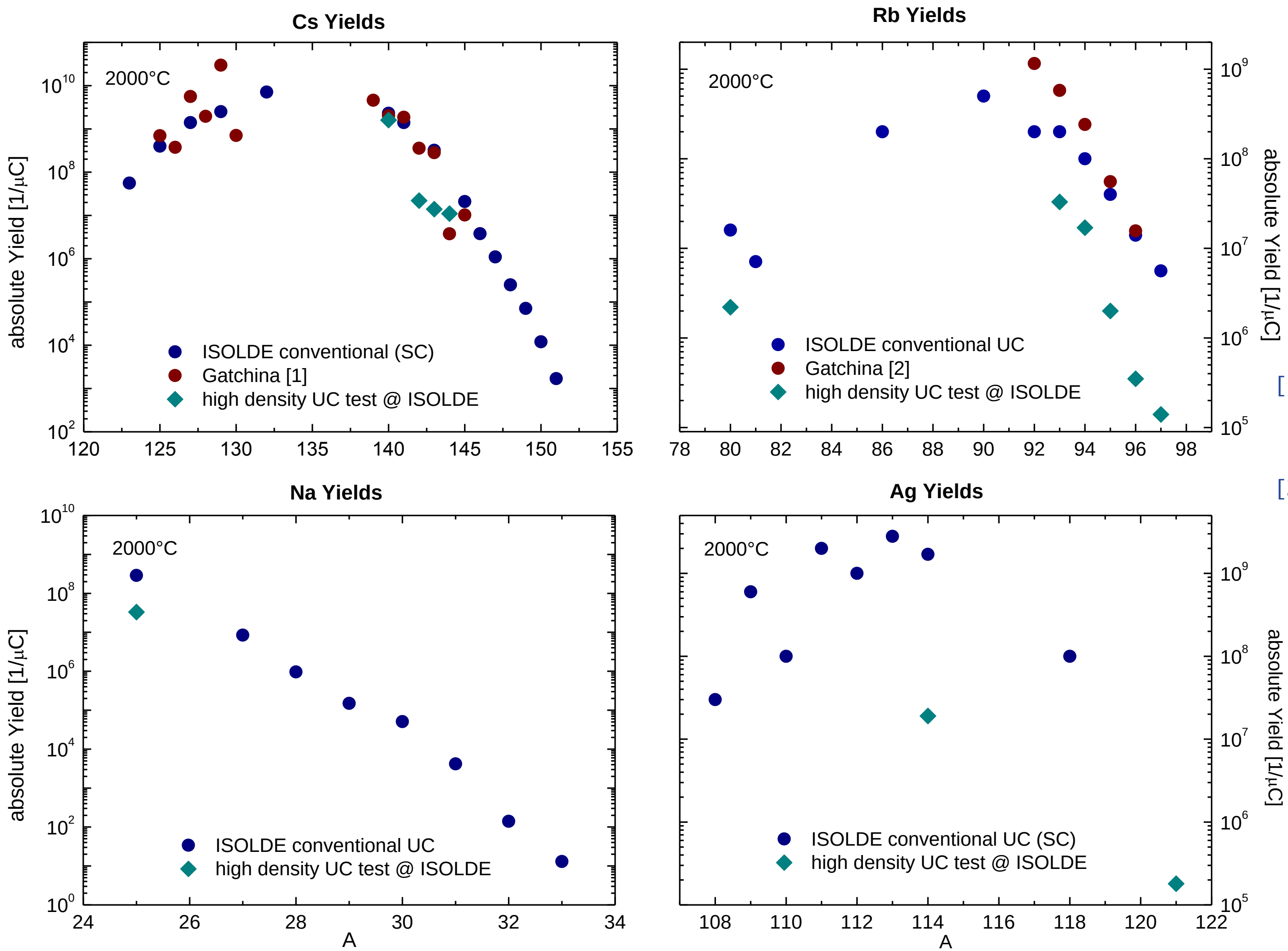
IPN INSTITUT DE PHYSIQUE NUCLÉAIRE ORSAY

Thank you for your attention!

ENSAR

ACTINET i3 Integrated Infrastructure Initiative for Actinide Science

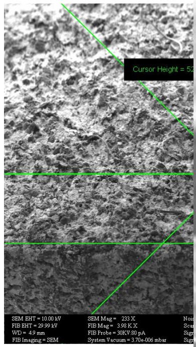
Yields from HD UC

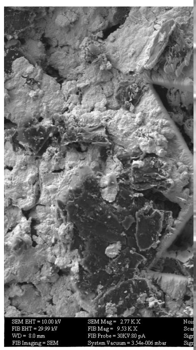


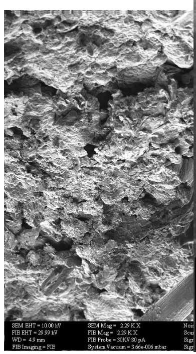
[1] V. N. Panteleev, et al., Eur. Phys. J. A **42**, 495-501 (2009)
[2] V. N. Panteleev, EMIS-15, June 25, (2007)

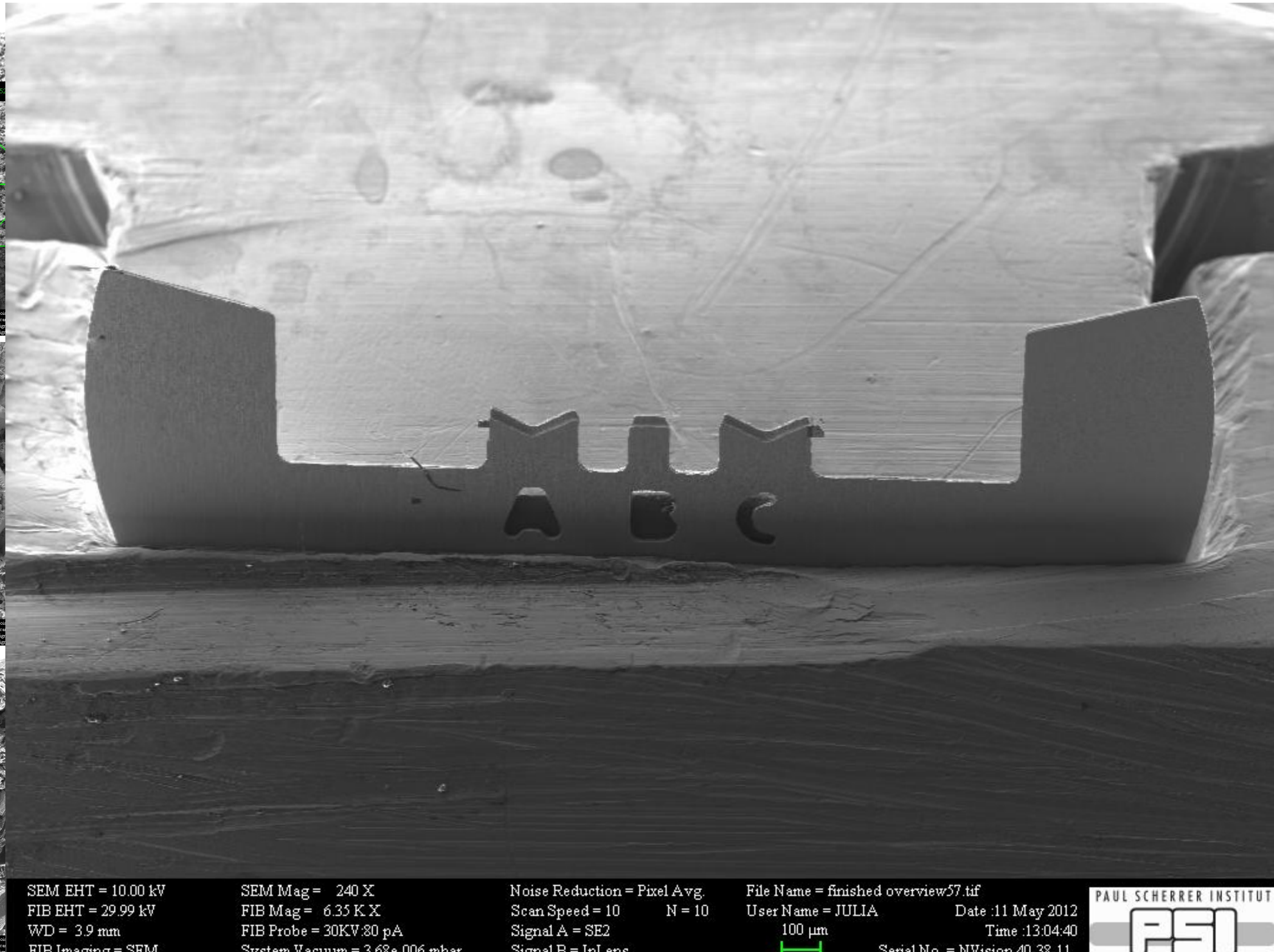
- Comparable absolute yields (Gatchina 91g/cm^2, conventional ISOLDE ≈45g/cm^2)
- HD absolute yields @ ISOLDE (241g/cm^2) x2 to x10 lower than from conventional UC targets

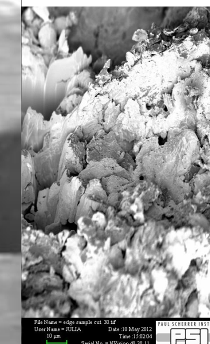
Sample Preparation for Irradiated Actinide Targets

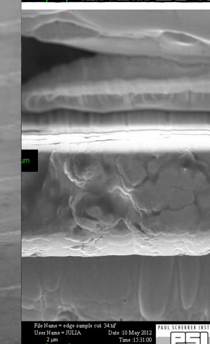


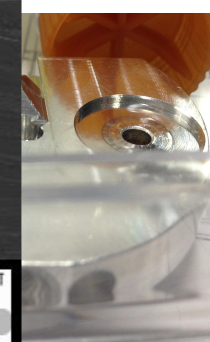






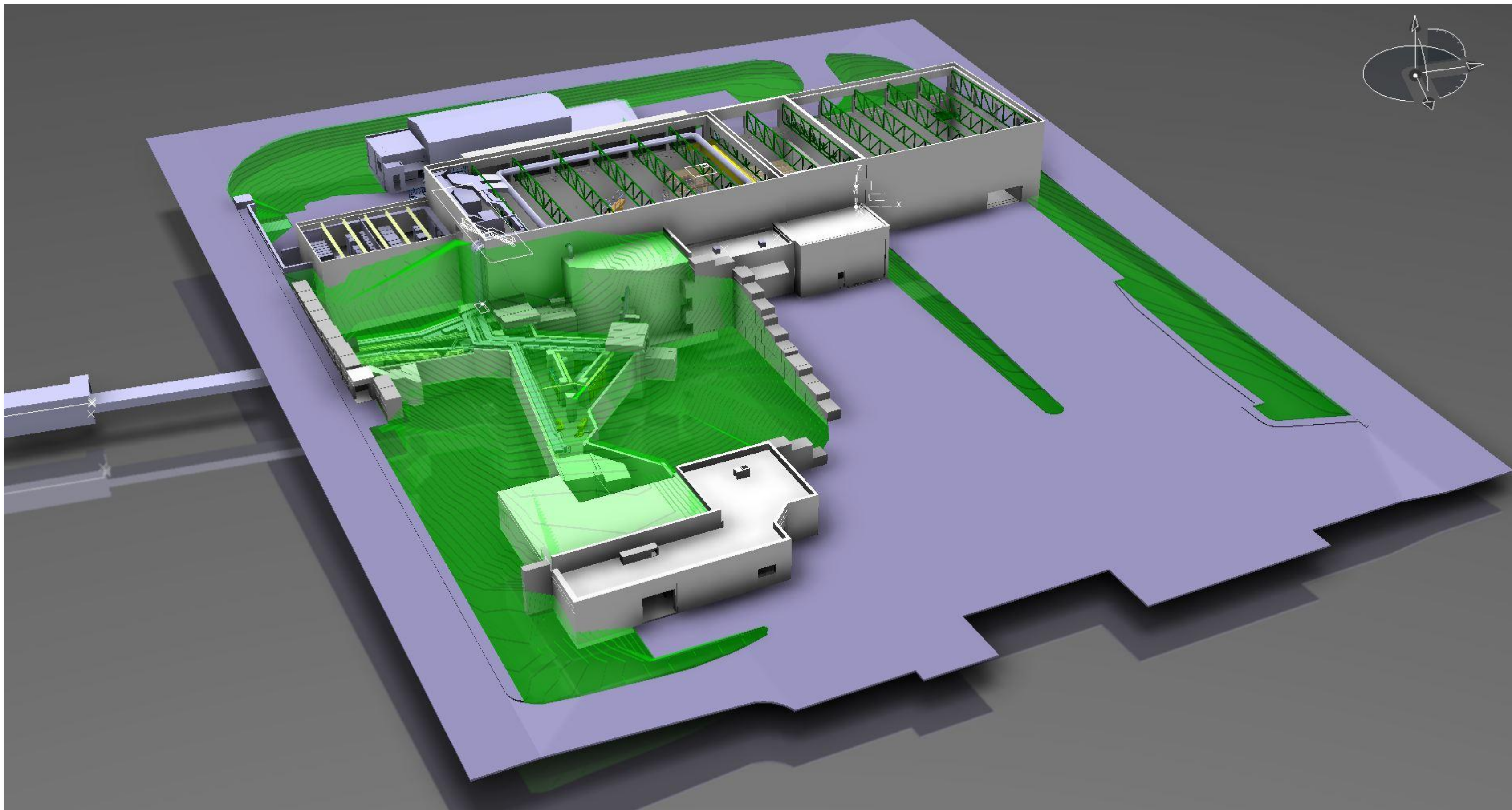




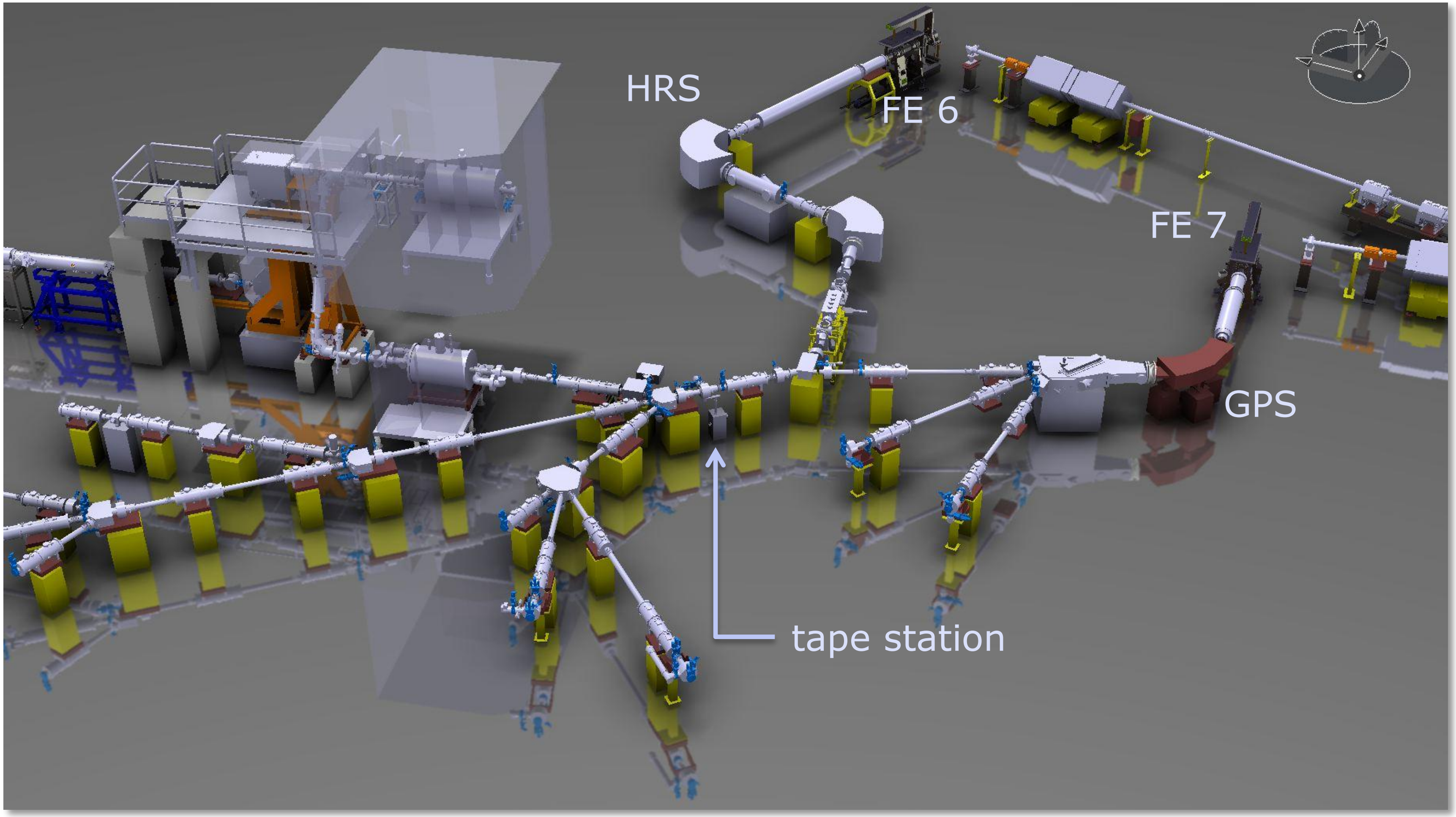


CERN – Meyrin

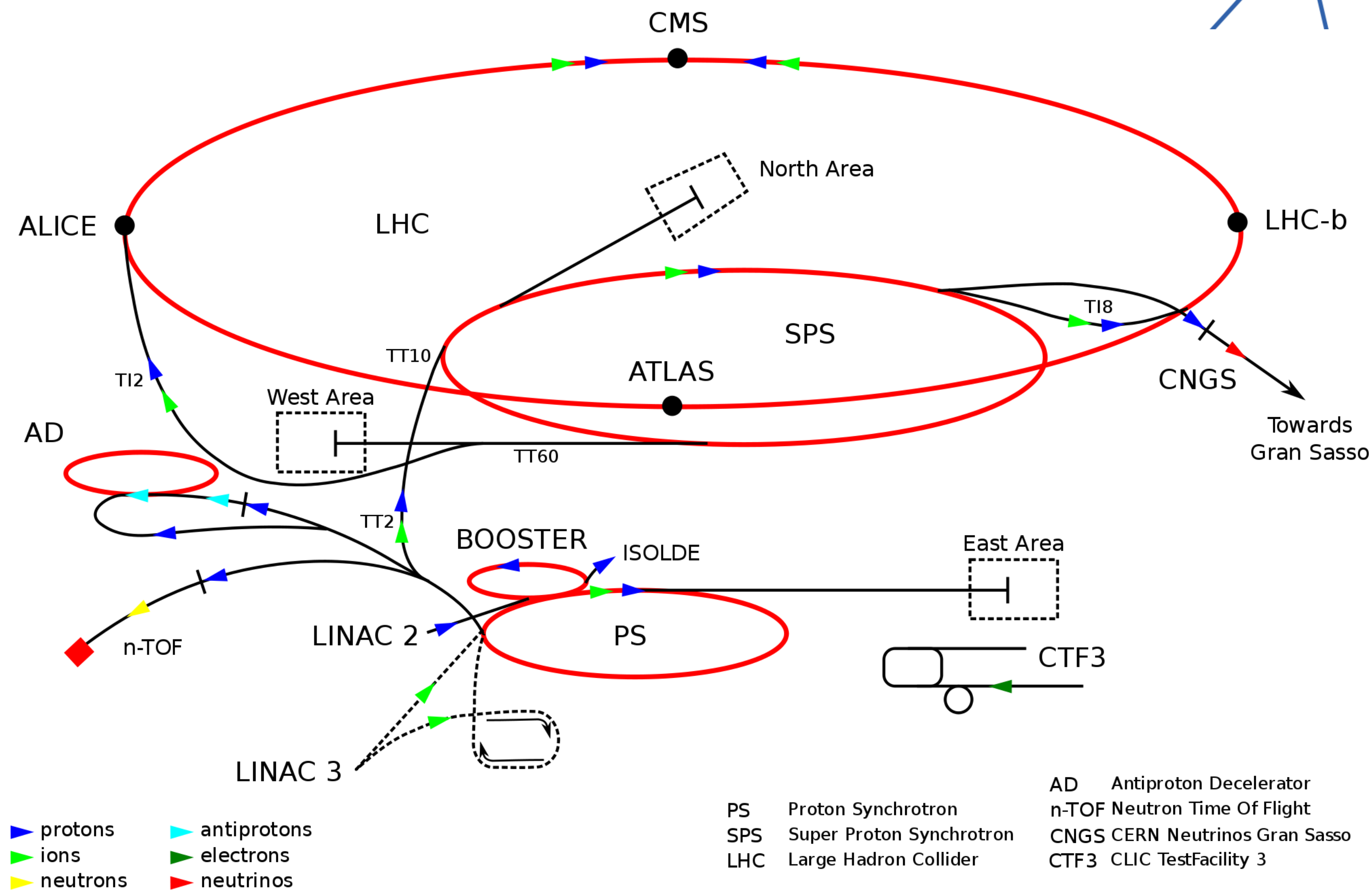
ISOLDE Outside View



ISOLDE – Beamline Overview



CERN Accelerator Complex



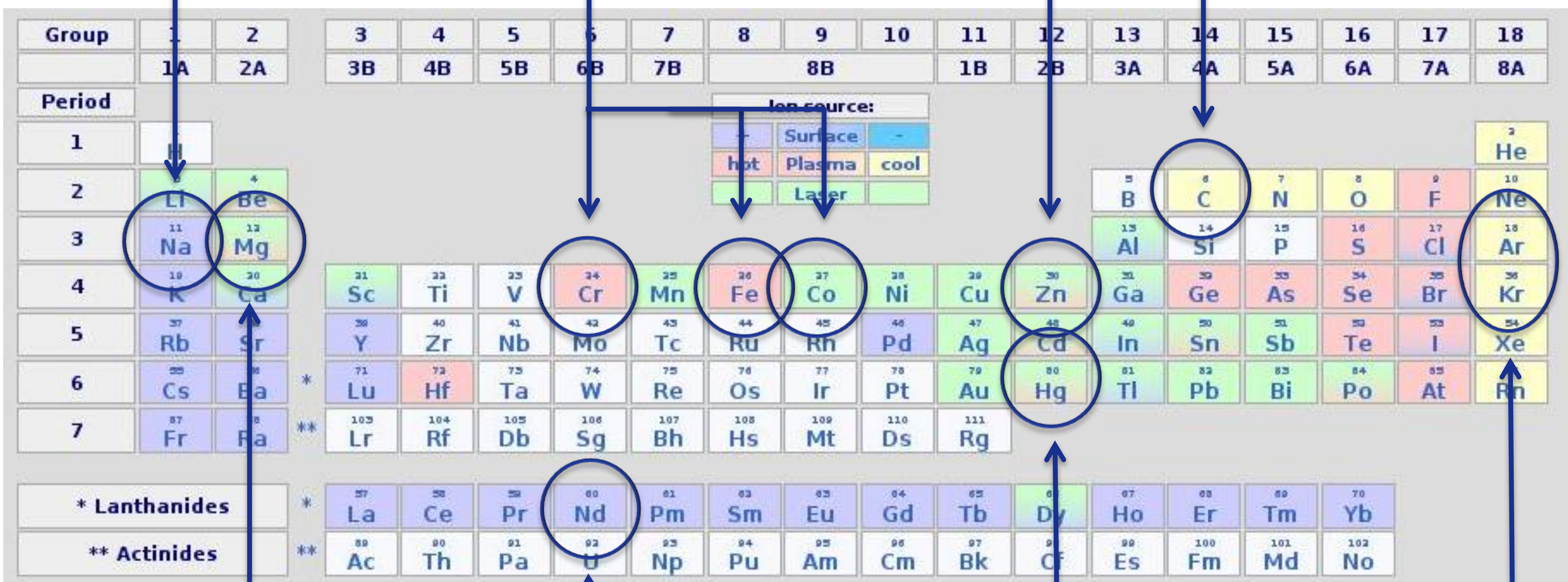
Highlights in 2011

x5 ^{30}Na from Re ion source

confirmation Cr, Fe, Co nano Y_2O_3 VADIS

Purification of ^{82}Zn with quartz

^{17}C as CO^+ helicon ion source



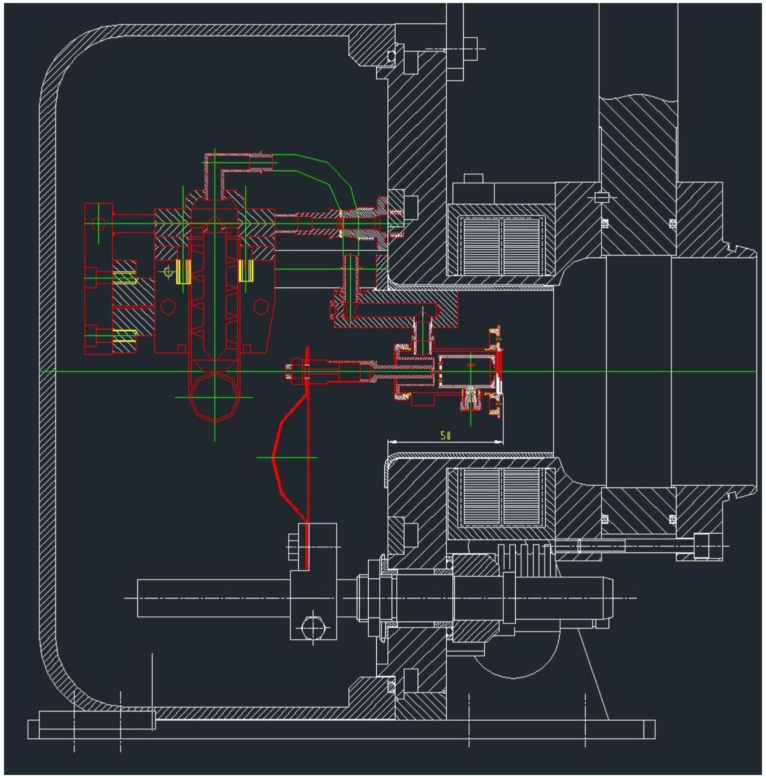
^{20}Mg from sub-µm SiC
^{27}Mg from LIST

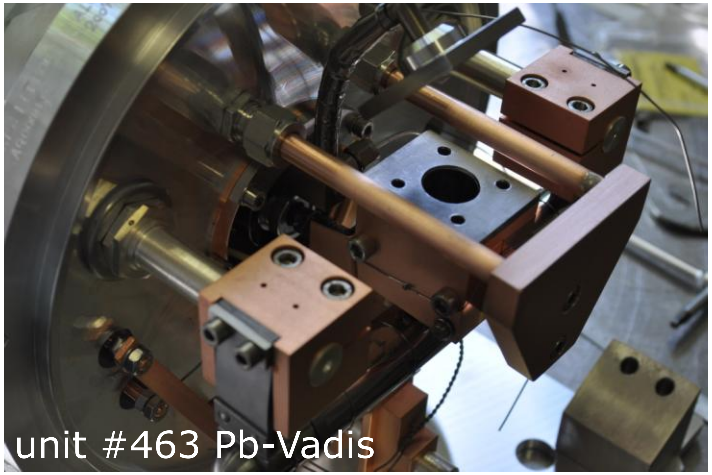
^{140}Nd from GdB_6 /RILIS

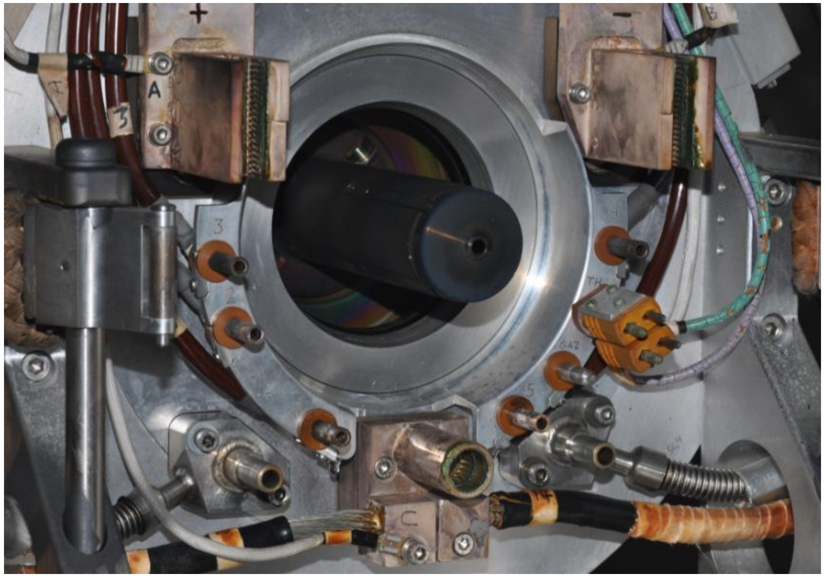
x5 from Pb-VADIS

nano CaO, Y_2O_3 for $^{31\text{-}35}$Ar, ^{72}Kr

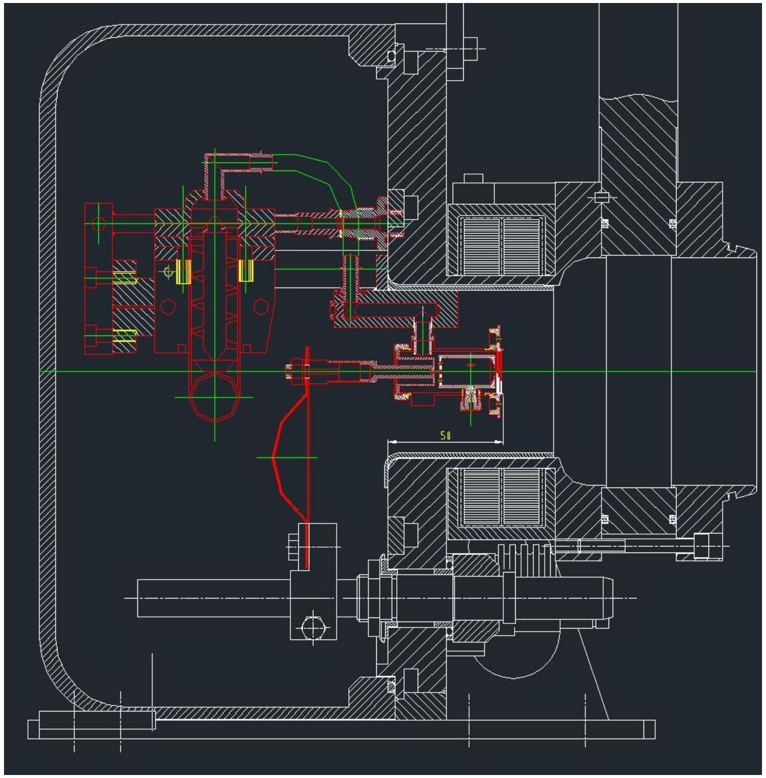
Hg Yield vs. Pb Evaporation Rate & Tl/In Contamination

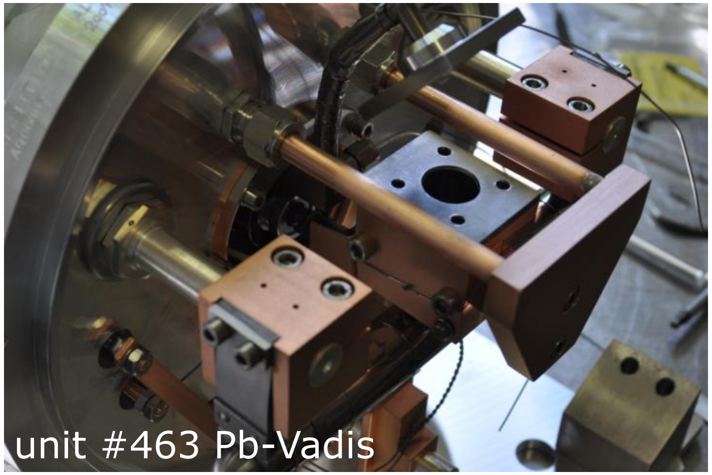


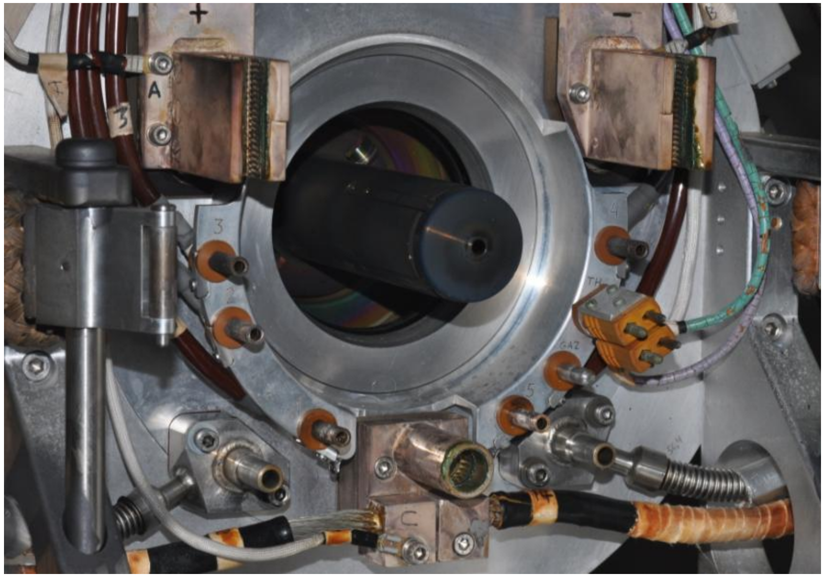




Hg Yield vs. Pb Evaporation Rate & Tl/In Contamination

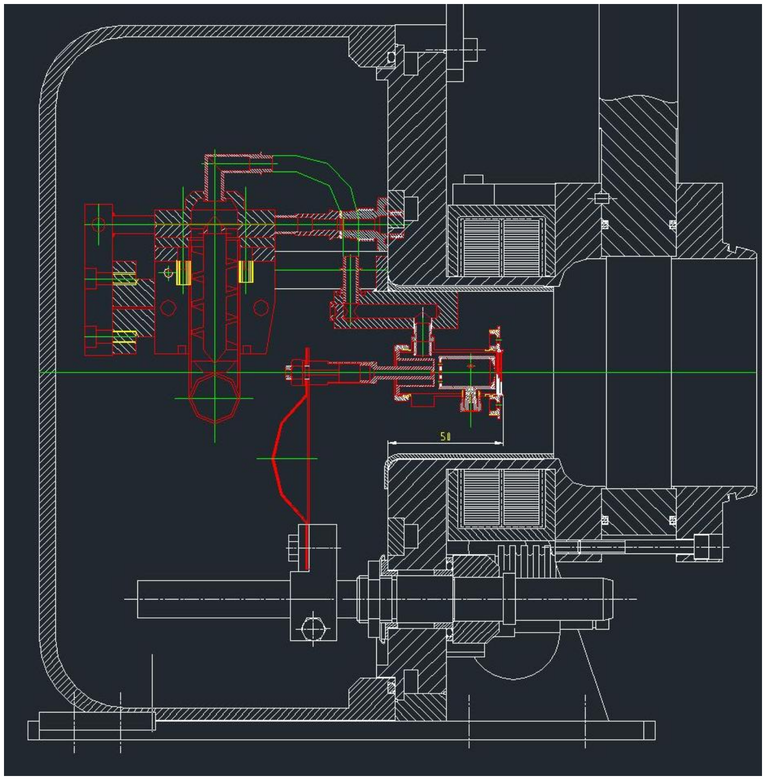


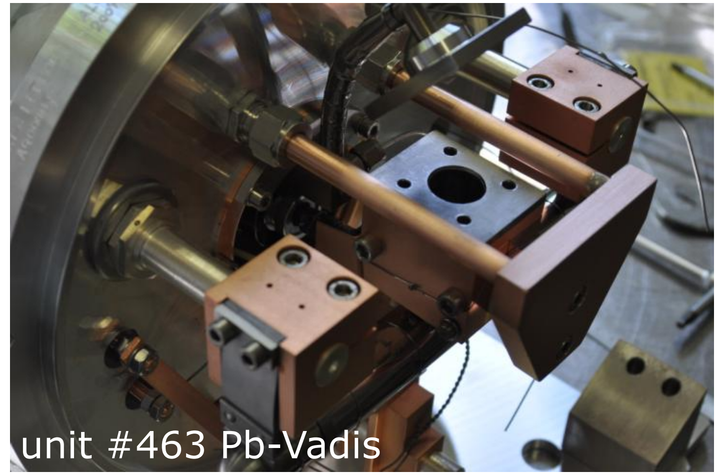


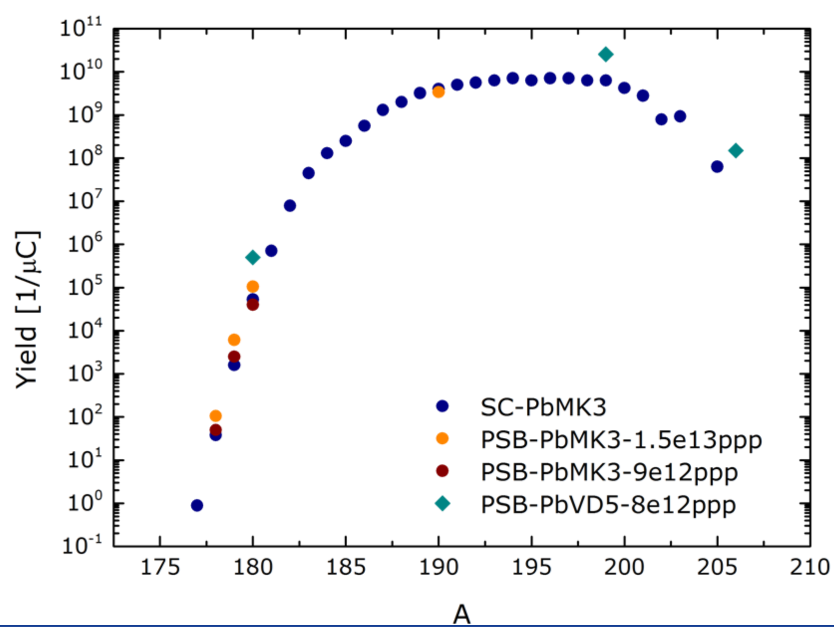


- Tuning target container to 320°C (< Pb melting point 327°C)
  → minimized coating of extraction electrode
- Careful tuning of VADIS ion source
  → Hg ↗, Tl ↘

Hg Yield vs. Pb Evaporation Rate & Tl/In Contamination







- Tuning target container to 320°C (< Pb melting point 327°C) → minimized coating of extraction electrode
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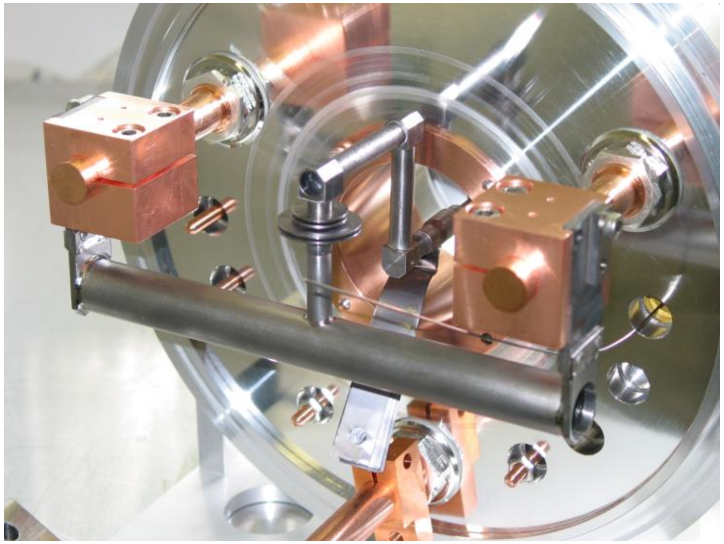
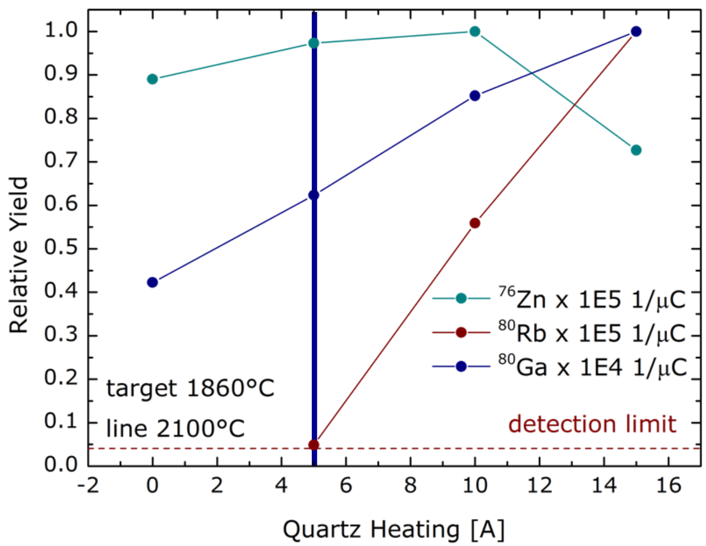
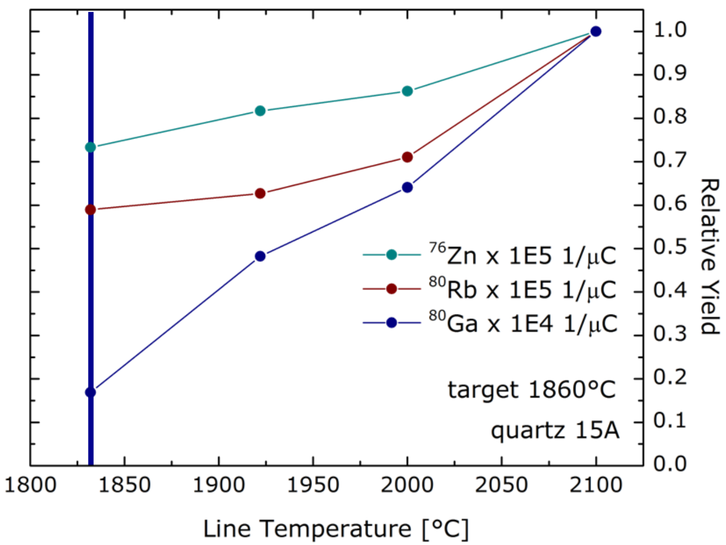
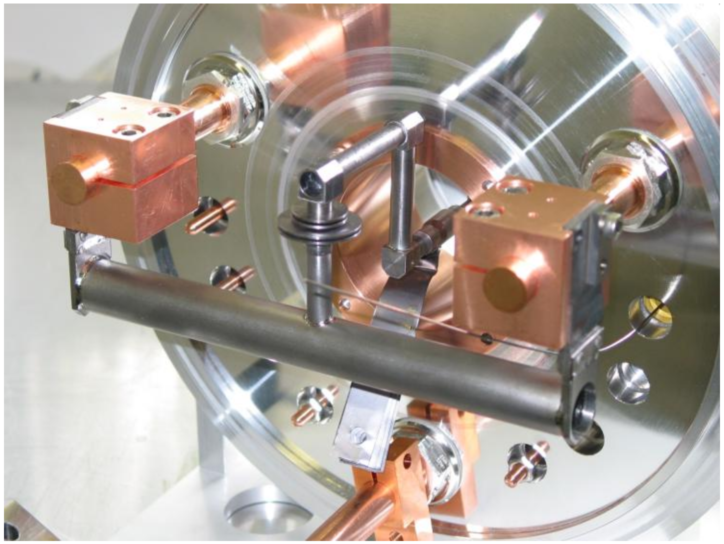
n-Converter and Quartz Line for Purified Zn Beams

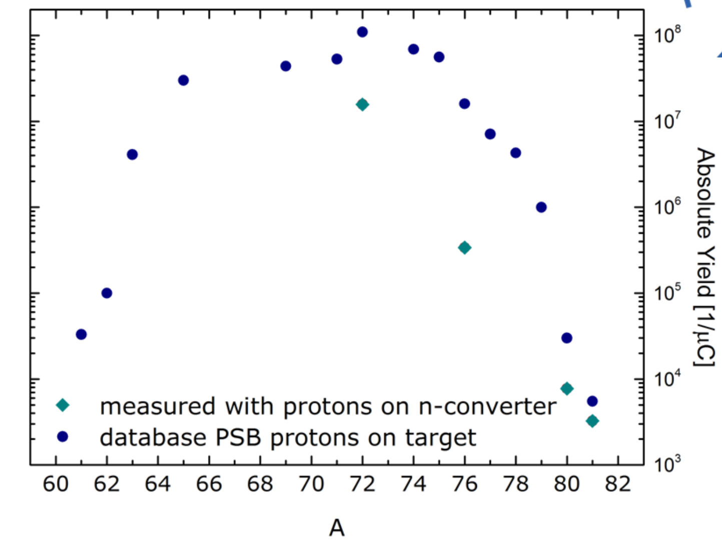


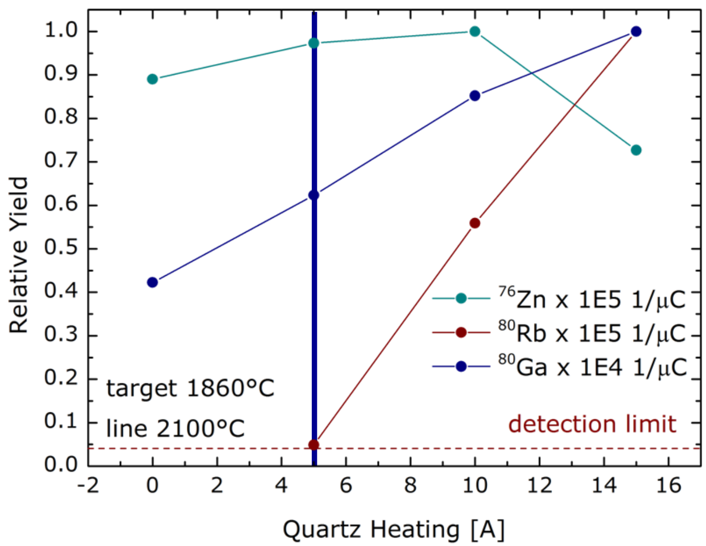


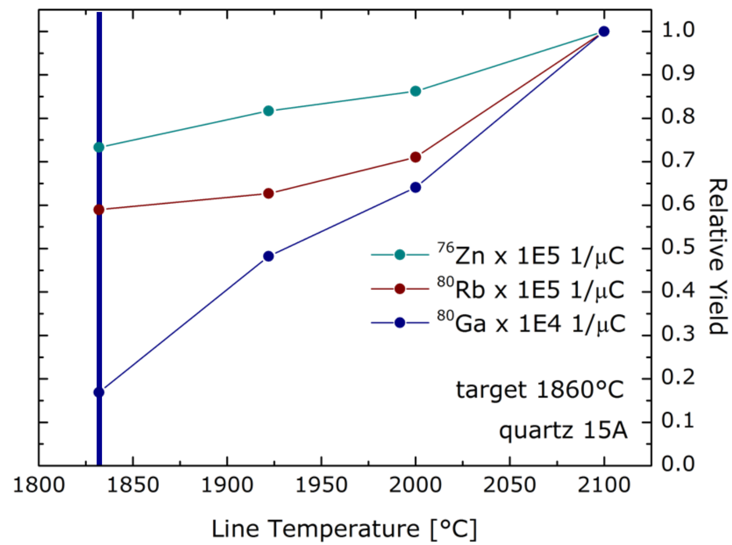


n-Converter and Quartz Line for Purified Zn Beams









TISD Team & Collaborations

- Dr. Thierry Stora

- Dr. M. Kronberger: ion sources (JYFL)
- C. Seiffert: molecule evaporation (U. Darmstadt)

- R. Luis: neutronics (ITN, Lisboa)

- Dr. A. Gottberg: target materials, incl. Uranium (U. Bordeaux, IEM-CSIC Madrid, ENSAR-FP7, ActILab).
- J. P. Ramos: target materials (Univ. Aveiro)
- M. Czapski: material analysis support (CATHI ITN Marie-Curie program)

- T. Mendonça: High power targetry for neutrino physics (CERN PJAS)
- S. Cimino: High power targetry (CATHI ITN Marie-Curie program)

GANIL, IPNO, INFN, PSI (Uranium, ENSAR "ActILab") + ORNL, TRIUMF
ITN (neutronics)
EPFL, Univ. Aveiro, ITN (materials)
ESS, CEA, SCKCEN-Myrrha (high power targetry)

Highlight: Extraction of Co, Fe, Cr

Yields from nano grained Y_2O_3-Vadis (in 2011)

53Fe:	3E4 1/µC
52Mn:	4E7 1/µC
55Cr:	2E4 1/µC
48Cr:	4E6 1/µC
49Cr:	2E5 1/µC
57Co:	3E7 1/µC
56Cr	
56Mn	
72Kr:	2E4 1/µC
73Kr:	7E5 1/µC