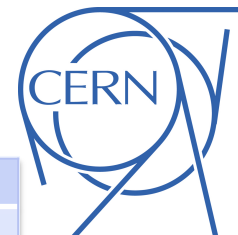




Radioactive Beams at ISOLDE in 2011



Mass	Element
6	He
8	He
8	Li
8	LiO
9	Li
10	C
10	CO
11	CO
13	NO ₂
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

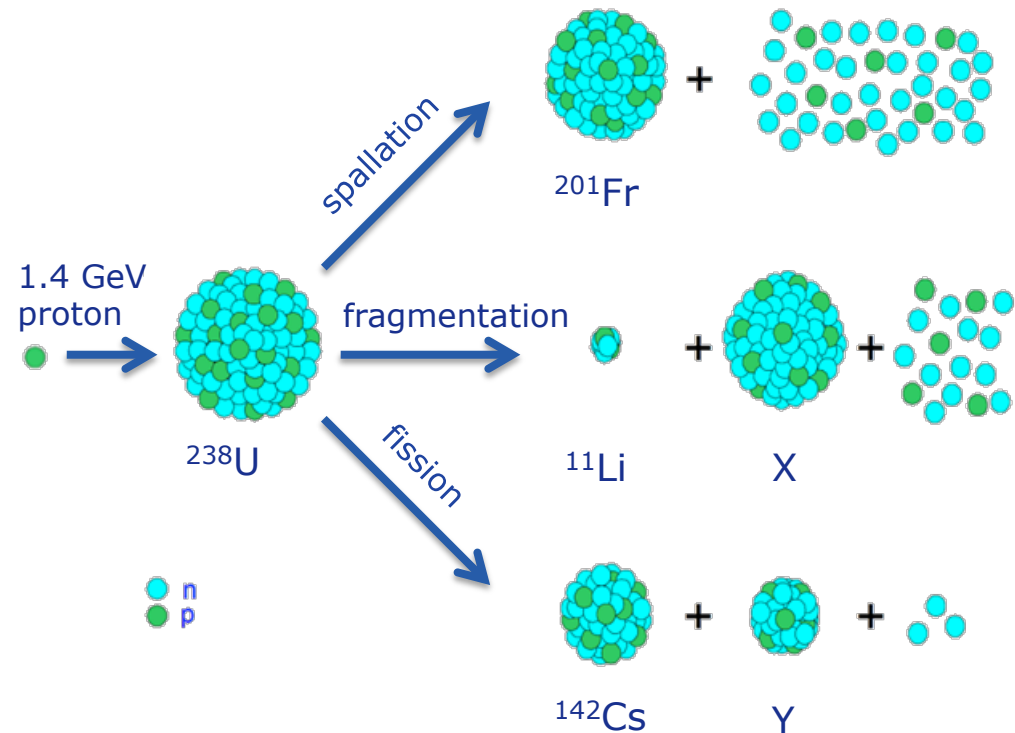
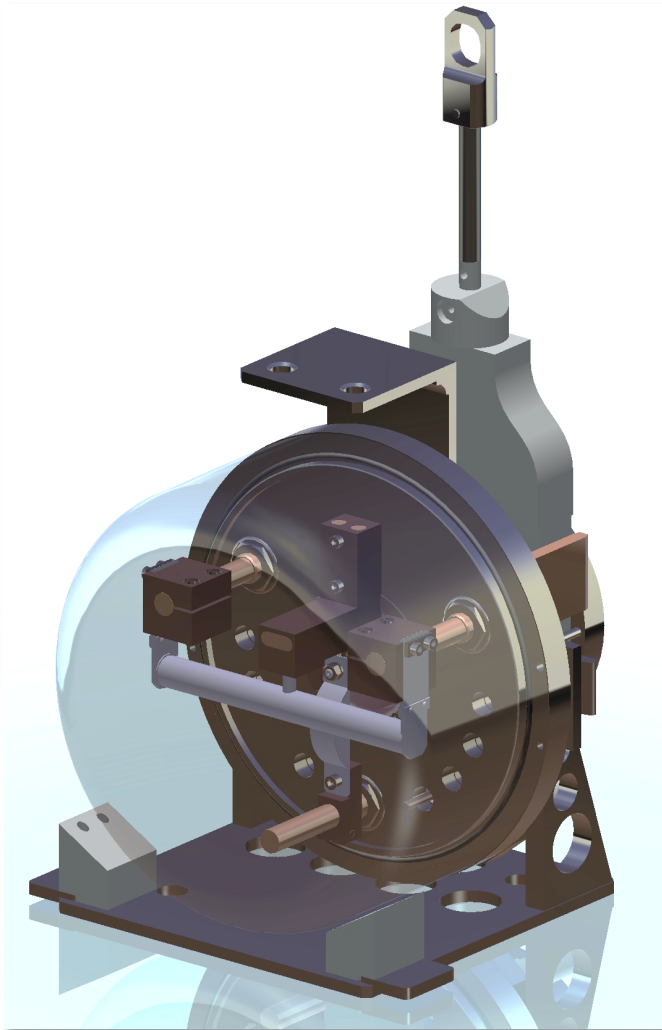
Mass	Element
68	Ni
69	Ge
69	Ni
70	As
70	Ga
71	As
71	Kr
71	Ni
71	Zn
72	Kr
72	Ni
72	Se
72	Zn
73	As
73	Ga
73	Kr
74	As
74	Kr
74	Zn
76	Zn
77	Br
77	Zn
78	Zn
79	Zn
80	As
80	Rb
80	Zn
81	Rb
81	Zn
82	Rb
82	Zn
83	Br
83	Zn
84	Kr
86	Kr
91	Kr
93	Rb

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

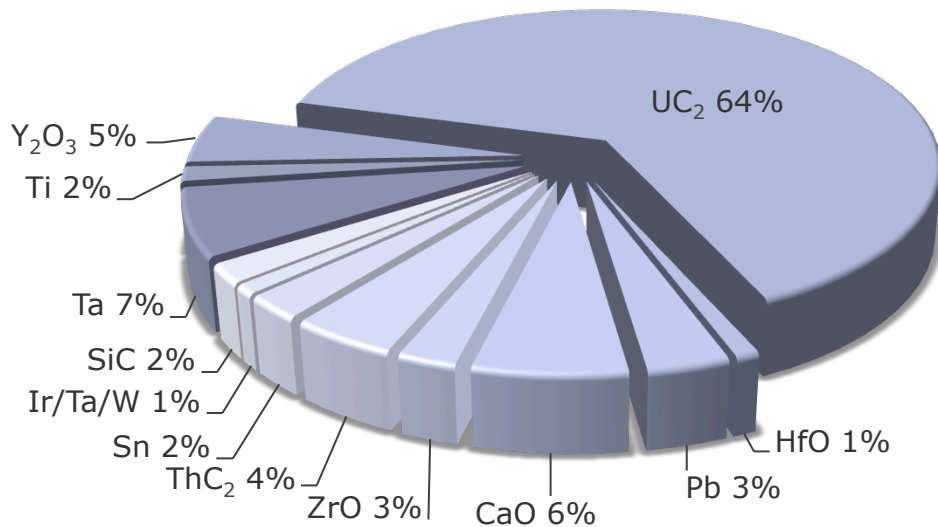


- diffusion through target material $\rightarrow \epsilon_{D\ 1,2,\dots}$
- effusion to ion source $\rightarrow \epsilon_{E\ 1,2,\dots}$
- ionization $\rightarrow \epsilon_{I\ 1,2,\dots}$
- extraction/transport $\rightarrow \epsilon_{T\ 1,2,\dots}$

Target Material Distribution

Target materials at ISOLDE in 2011 (2010)

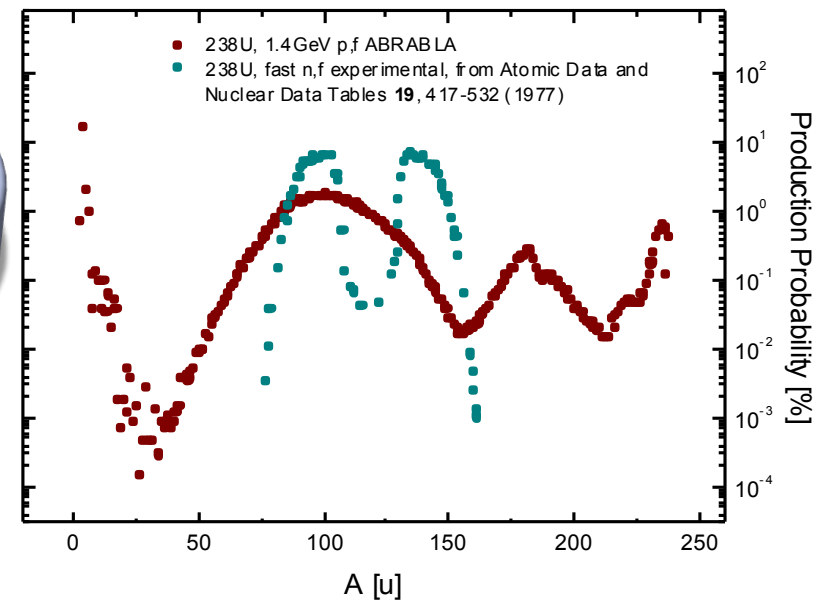
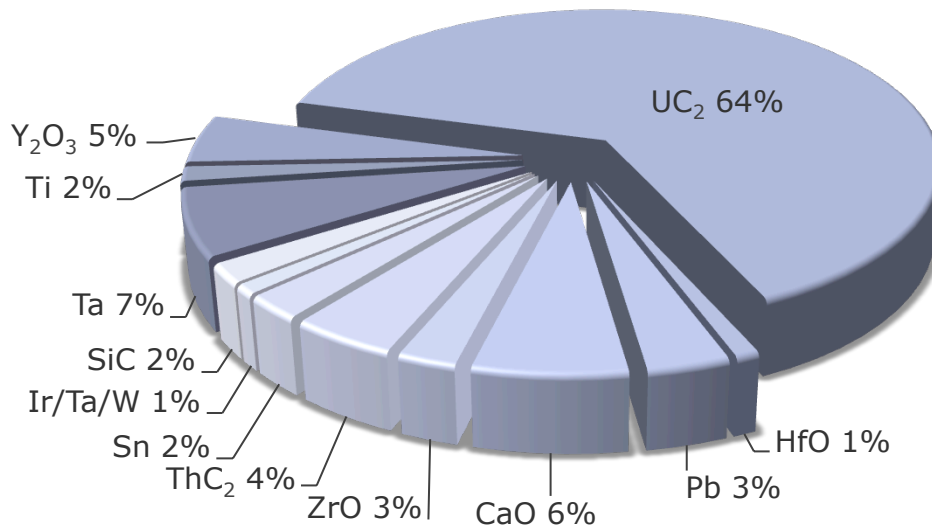
- Actinides: 249 shifts out of 396 → 68% of total (72%)
- Actinides: 13 new units (12 new, 2 old)



Target Material Distribution

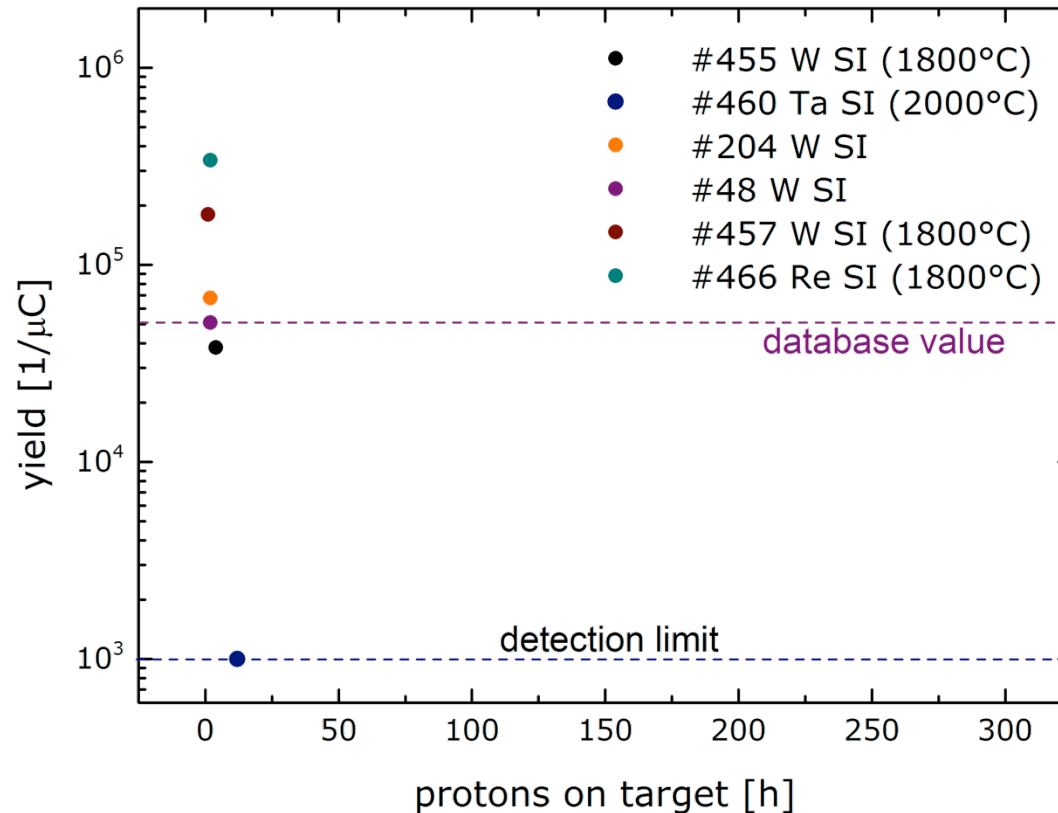
Target materials at ISOLDE in 2011 (2010)

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



Extraction of Short-Lived Alkali Isotopes

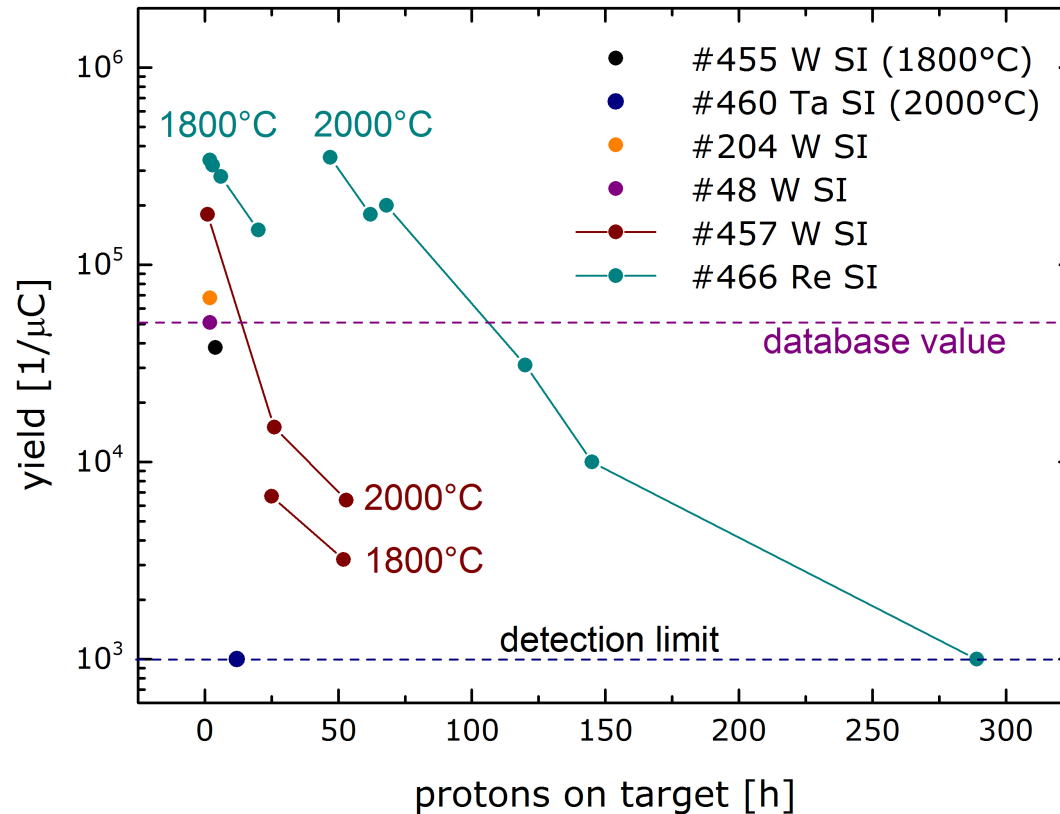
short-lived ^{30}Na (48ms) from bulk Re surface ion source



Mg 28 20.9 h β^- 0.5; 0.9... γ 31; 1342; 401; 942...	Mg 29 1.30 s β^- 4.3; 7.5... γ 2224; 1398; 960...	Mg 30 335 ms β^- 6.1... γ 244; 444...	Mg 31 230 ms β^- γ 1613; 947; 1626; 666... βn
Na 27 304 ms β^- 8.0... γ 985; 1698... βn 0.46...	Na 28 30.5 ms β^- 13.9... γ 1474; 2389... βn	Na 29 44.9 ms β^- 10.8; 13.4... γ 55; 2560; 1474... βn 4.13; 1.70...	Na 30 48 ms β^- 12.2; 15.7... γ 1482; 1040*; 1978... βn ; $\beta 2n$; $\beta \alpha$
Ne 26 197 ms β^- γ 83; 233... βn	Ne 27 31.5 ms β^- 12.6... γ 63; 3019; 2736; 2225... βn	Ne 28 20.0 ms β^- 12.2... γ 2063; 663... βn ; $\beta 2n$	Ne 29 15.8 ms β^- 15.3... γ 72; 1516; 1249; 1588... βn ; $\beta 2n$

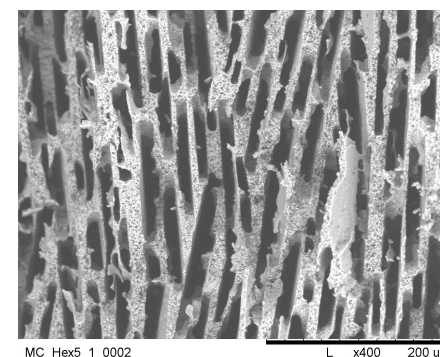
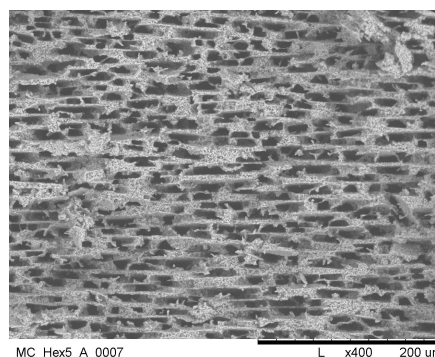
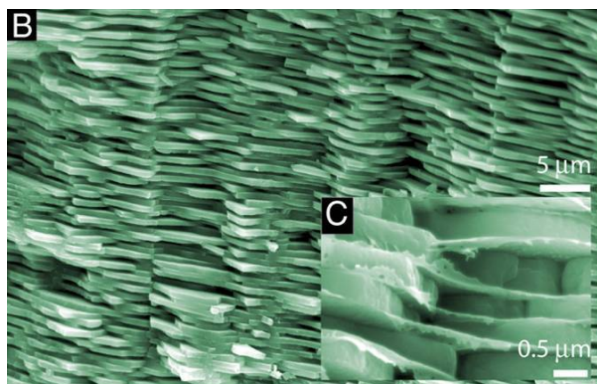
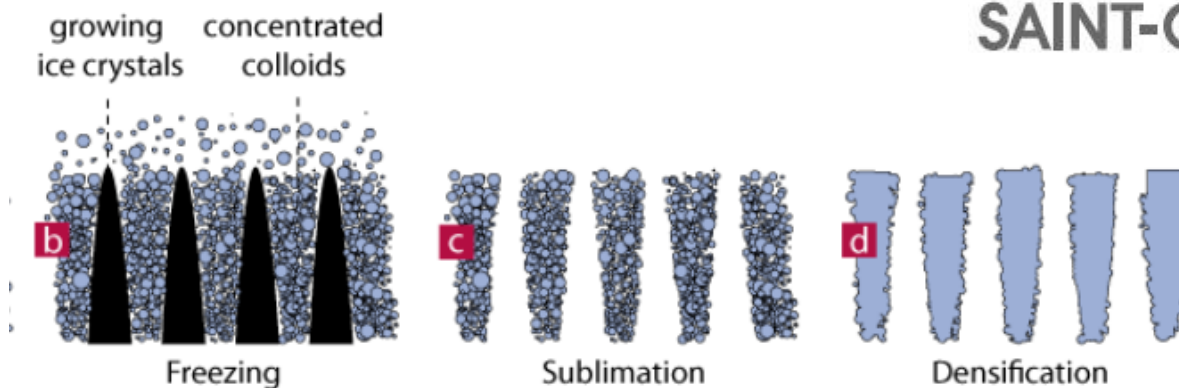
Extraction of Short-Lived Alkali Isotopes

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



Mg 28 20.9 h β^- 0.5; 0.9... γ 31; 1342; 401; 942...	Mg 29 1.30 s β^- 4.3; 7.5... γ 2224; 1398; 960...	Mg 30 335 ms β^- 6.1... γ 244; 444...	Mg 31 230 ms β^- γ 1613; 947; 1626; 666... βn
Na 27 304 ms β^- 8.0... γ 985; 1698... βn 0.46...	Na 28 30.5 ms β^- 13.9... γ 1474; 2389... βn	Na 29 44.9 ms β^- 10.8; 13.4... γ 55; 2560; 1474... βn 4.13; 1.70...	Na 30 48 ms β^- 12.2; 15.7... γ 1482; 1040*; 1978... βn ; $\beta 2n$; $\beta \alpha$
Ne 26 197 ms β^- γ 83; 233... βn	Ne 27 31.5 ms β^- 12.6... γ 63; 3019; 2736; 2225... βn	Ne 28 20.0 ms β^- 12.2... γ 2063; 663... βn ; $\beta 2n$	Ne 29 15.8 ms β^- 15.3... γ 72; 1516; 1249; 1568... βn ; $\beta 2n$

ICE-TEMPLATING METHOD (CNRS/SG CREE* patent)



Open porosity
30 – 70 %

*European R&D center of the market leader in SiC production

Material studies

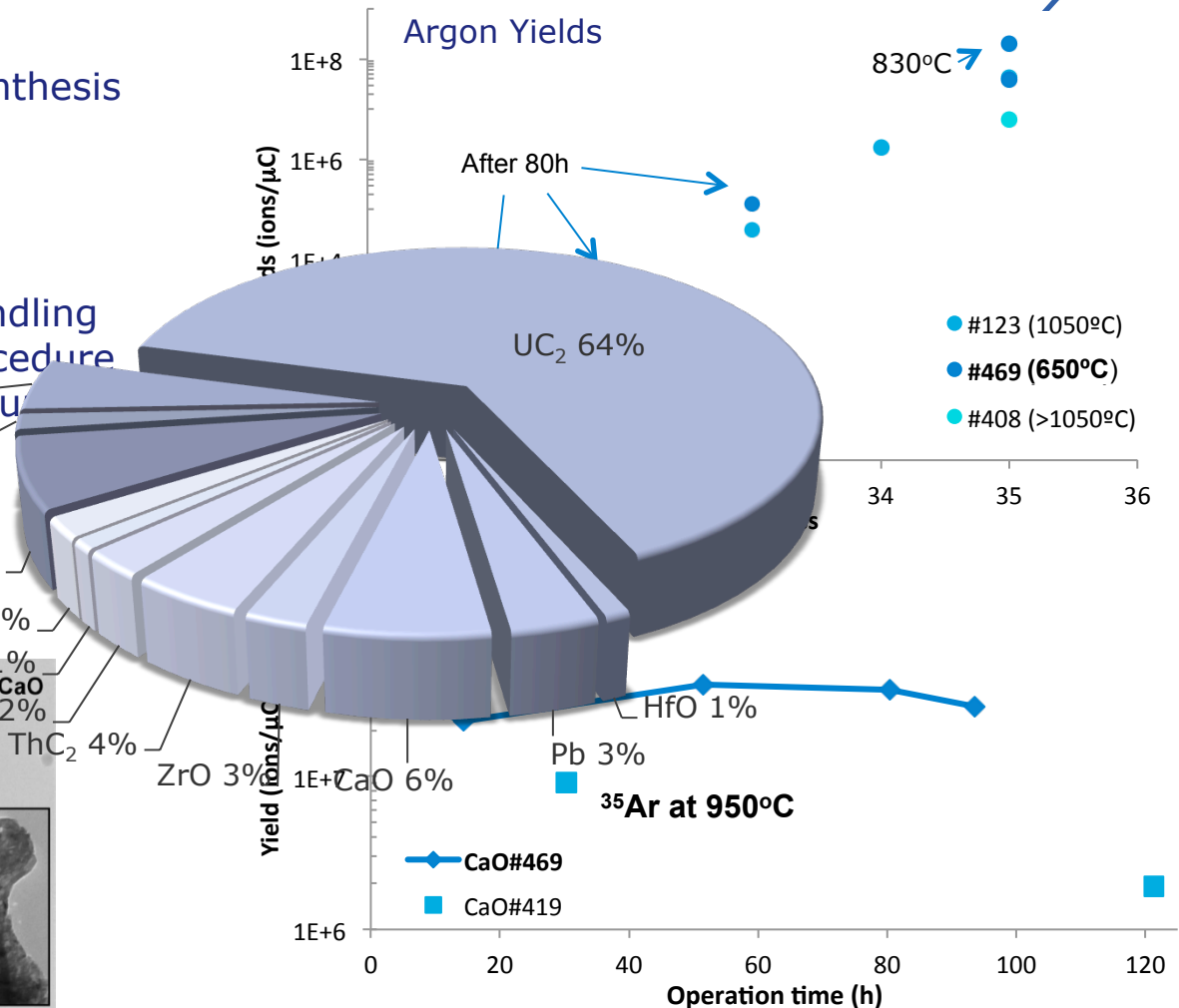
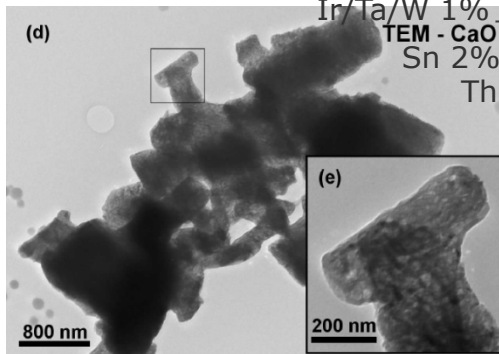
- Nanometric CaO Synthesis
- Sintering studies
- CaO reactivity

New CaO target

- Correct material handling
- New production procedure
- ↓ Operation Temperature
- ↓ Proton Intensity

Online tests

- Stable yields
- Higher Yields



Yields on ^{31,32}Ar measured by ISOLDE experiment IS476 – H. Fynbo and B. Blank.

Turron, M.; Urszula, H.-I. ISOLDE Yield Database. https://oraweb.cern.ch/pls/isolde/query_tgt (accessed December 1st, 2011)

Done for CaO, Y₂O₃, SiC, but...



Task 1: Synthesis of new actinide targets (CERN, INFN, IPNO)

Subtask 1: Sol-gel synthesis in complex fluids

Subtask 2: Nanostructures

Task 2: Characterization of actinide targets (CERN, INFN)

Subtask 1: Microstructure, porosity, specific surface, crystalline phase

Subtask 2: Emissivity, thermal conductivity at high temperature

Task 3: Actinide targets properties after irradiation (CERN, PSI)

Subtask 1: Post-irradiation examination of target prototypes

Task 4: Online tests of actinide targets (CERN, GANIL, IPNO)

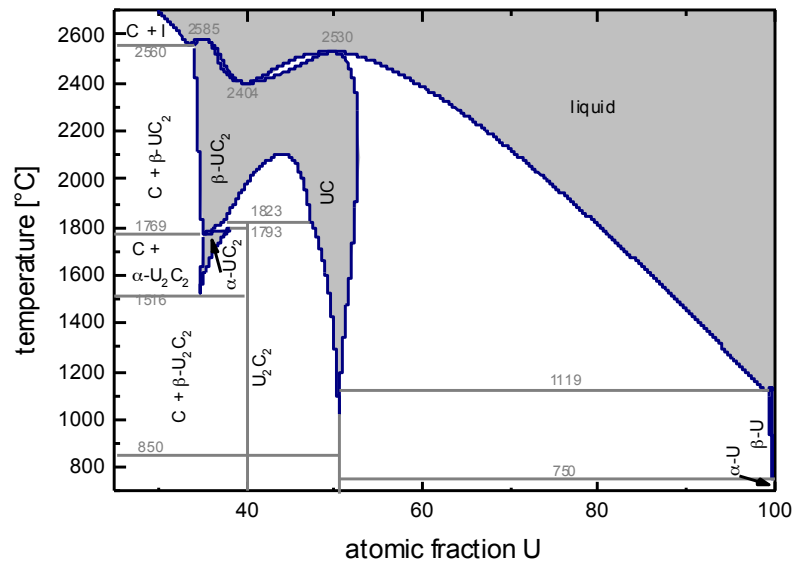
Subtask 1: Impact of pulse time structure on release and ageing properties

Subtask 2: Analysis of the results-effusion and diffusion phenomena



Production Process:

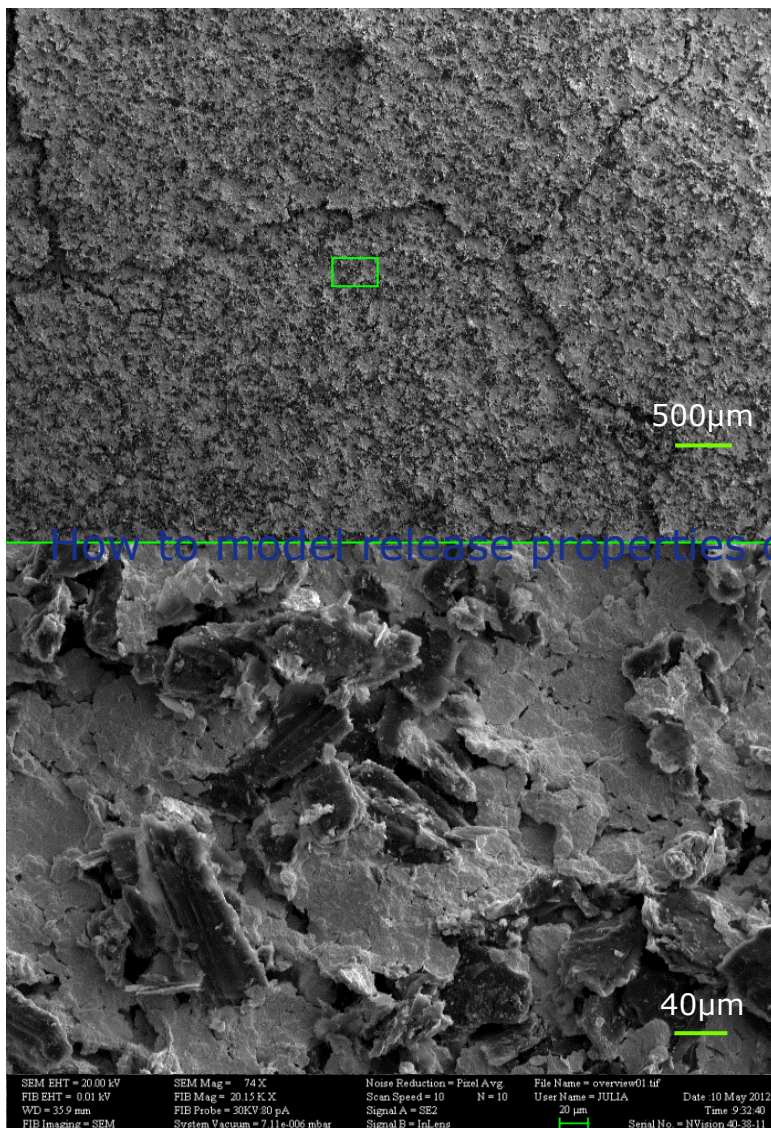
1. Blending UO_2 and C powder
2. Cold pressing into pills
3. Carbothermic reduction of UO_2



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



Current UC_x at ISOLDE

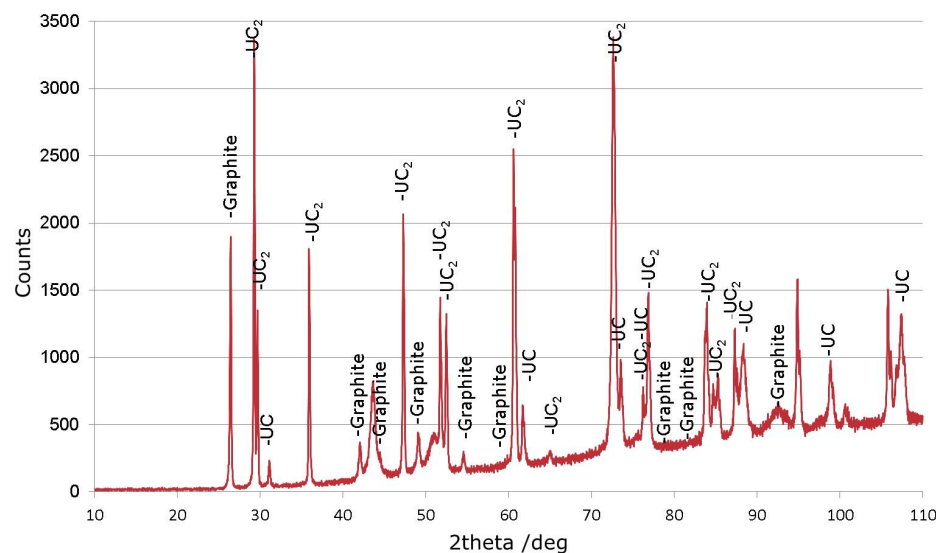


$$\rho_{\text{bulk}} = 3.5 \pm 0.8 \text{ g/cm}^3$$

$$11.3 \text{ g/cm}^3 \text{ (TD)}$$

$$\text{BET: } 2.6 \pm 0.9 \text{ m}^2/\text{g}$$

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

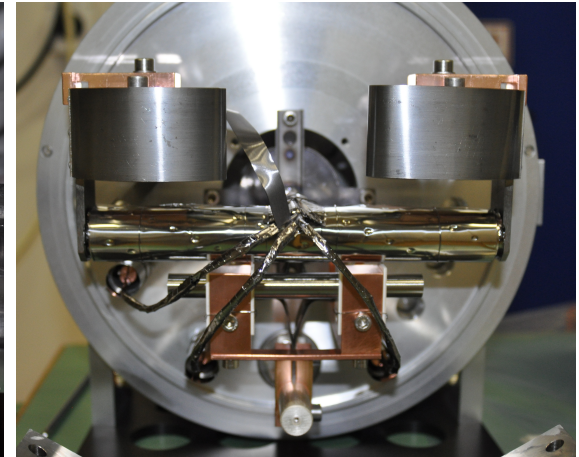
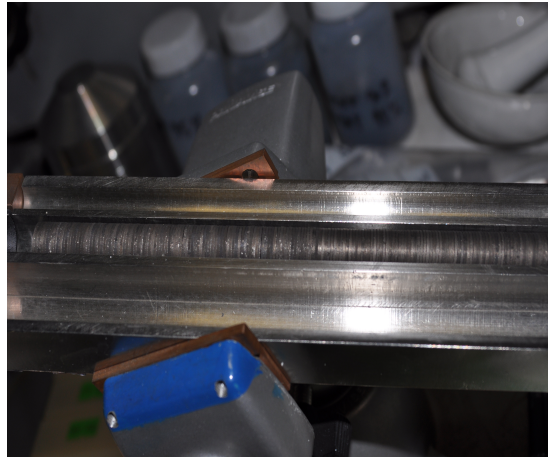


see also: C. Lau et al., NIM B, **204**, 246 (2003)

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

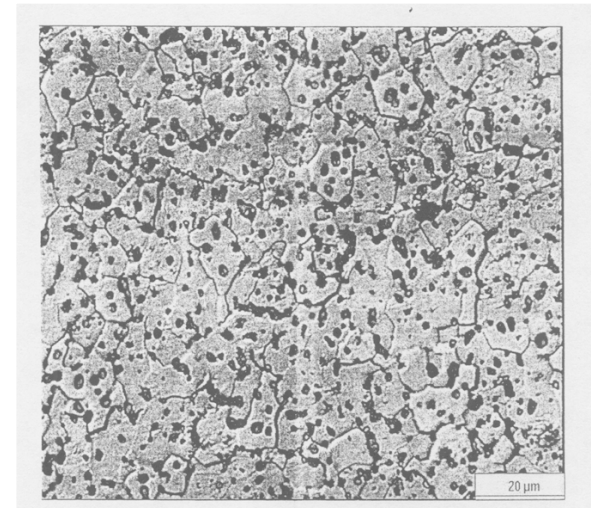
High Density UC Target at CERN

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

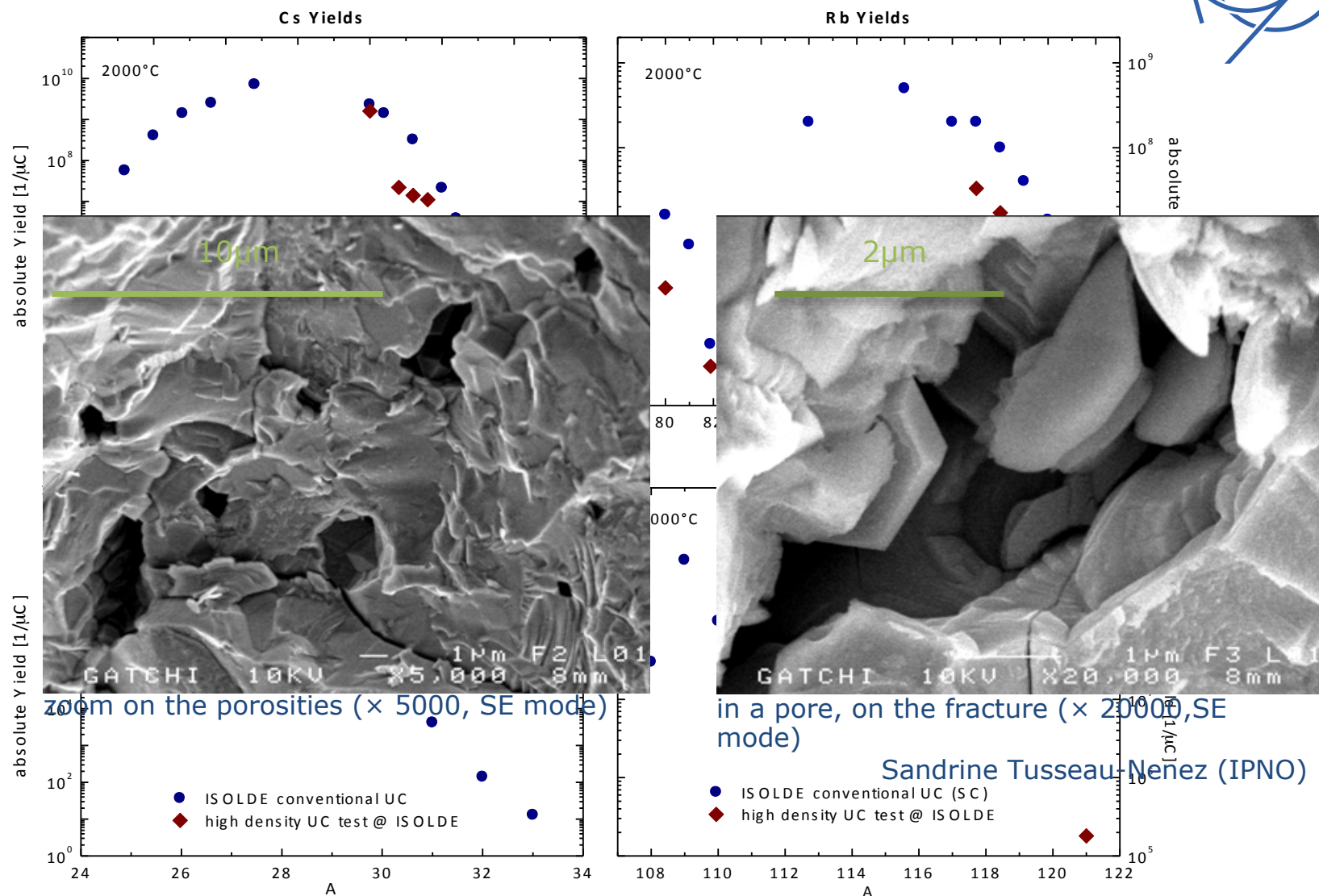


300 pills

- UC (^{235}U :0.38%), 13.2mm diam., 1mm thick, 12.7g/cm³, avg. grain 6 μm , UC₂<4%



Yields from HD UC



teleev,
Phys.
A **42**,
95-501
(2009)
teleev,
ne 25,
(2007)

Sandrine Tusseau-Nenez (IPNO)

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

Swiss Light Source (SLS)

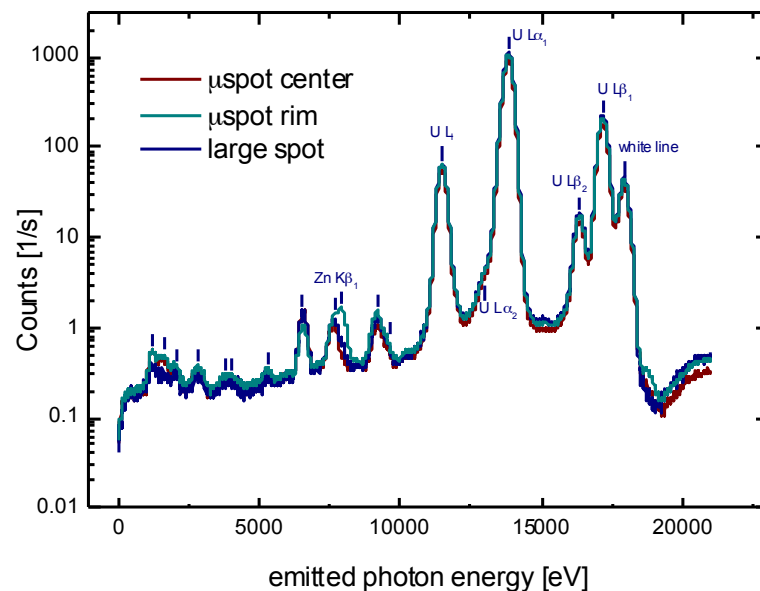


Micro Spot Material Mapping at SLS

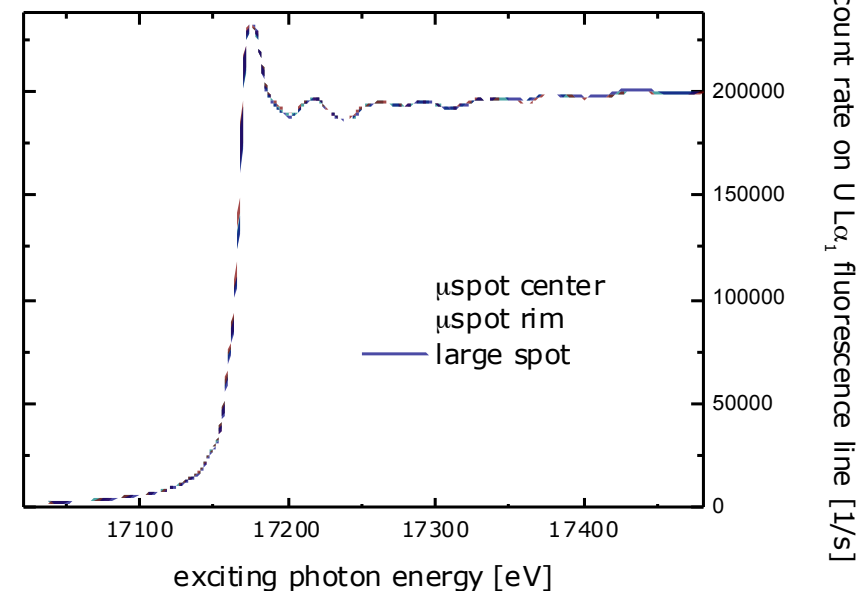
Beamline X05LA @ SLS, PSI offers: $h\nu = 5 - 20 \text{ keV}$, $\Delta E/E = 2 \cdot 10^{-4}$, $1 \times 1 \mu\text{m}^2$

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

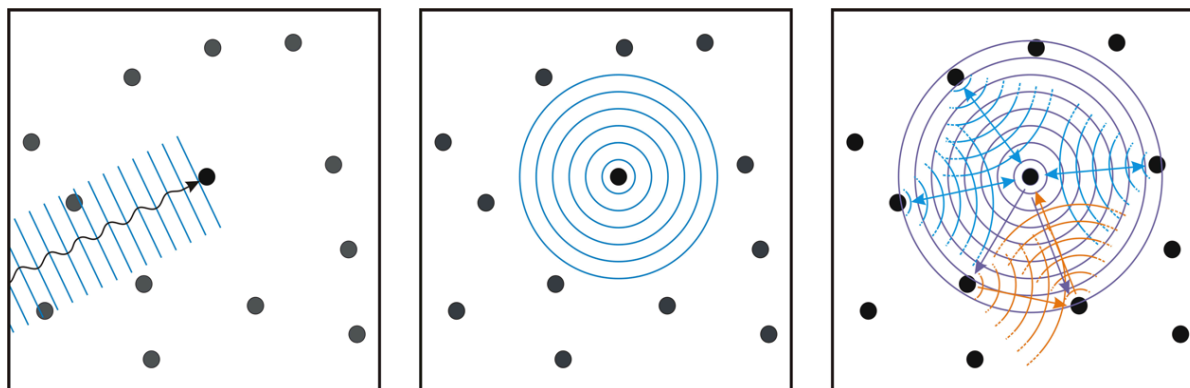
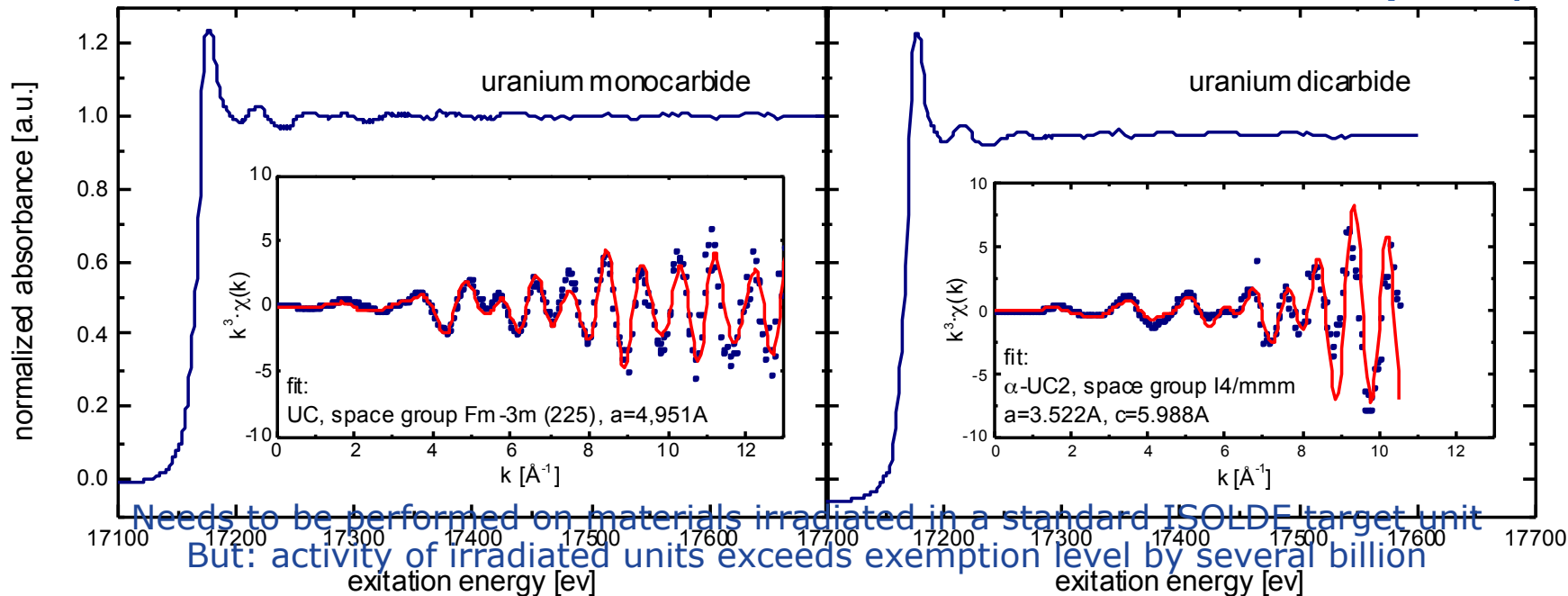
Fluorescence

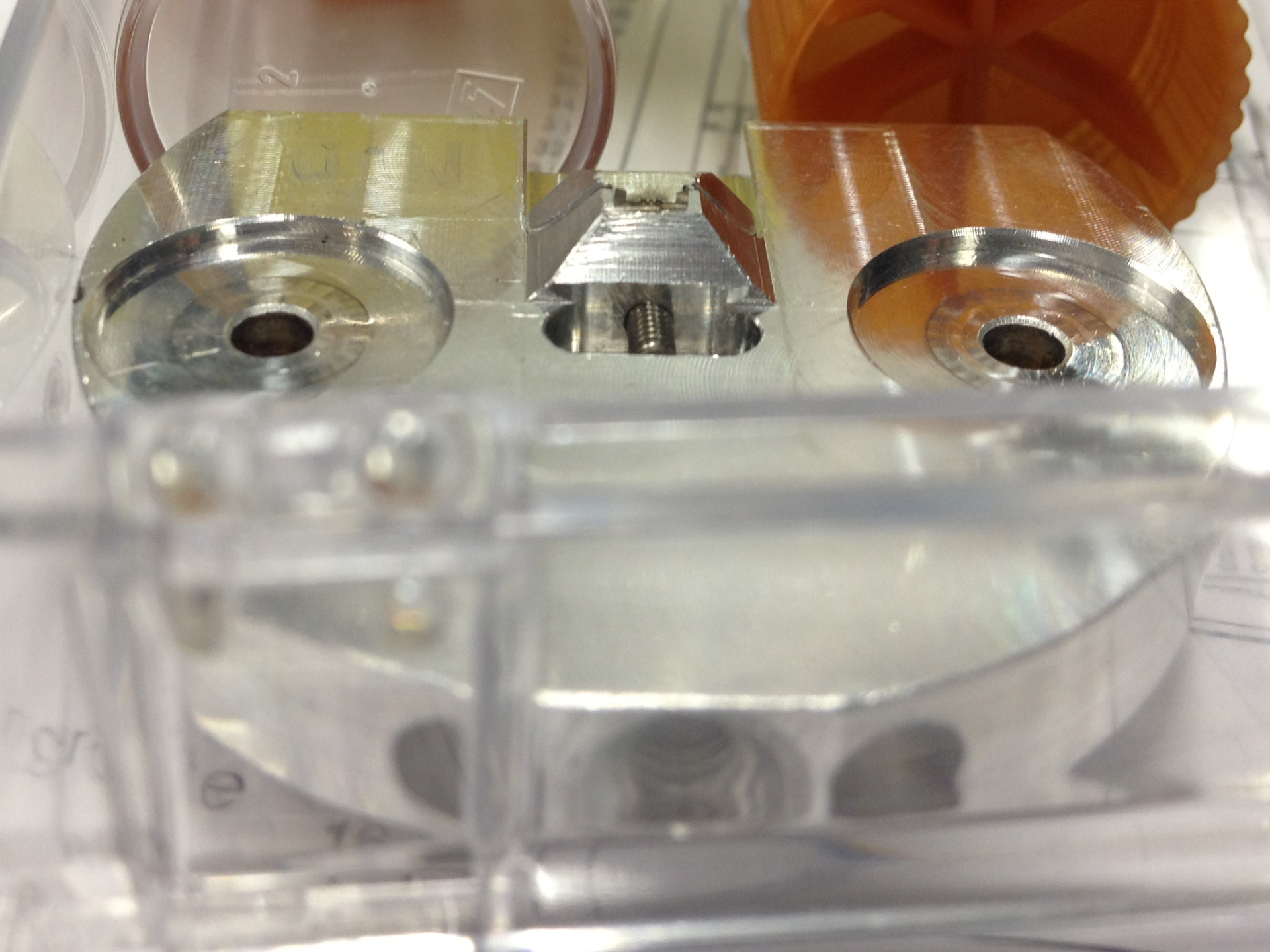


EXAFS

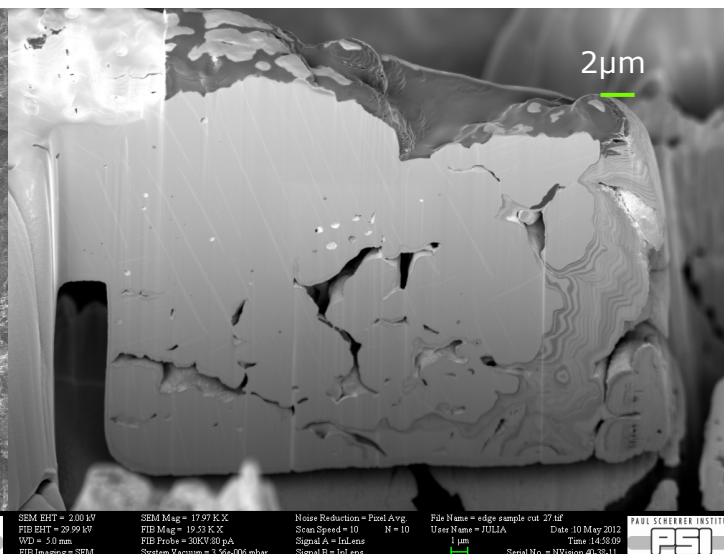
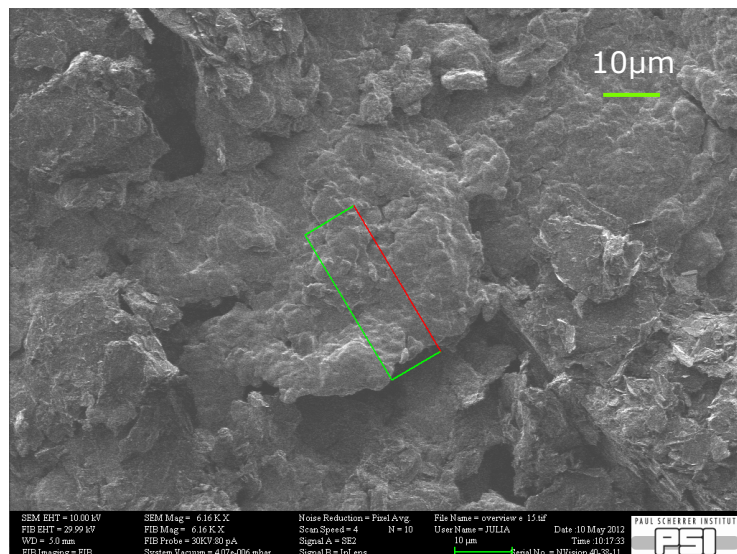


Results from first X-ray absorption experiments on UC

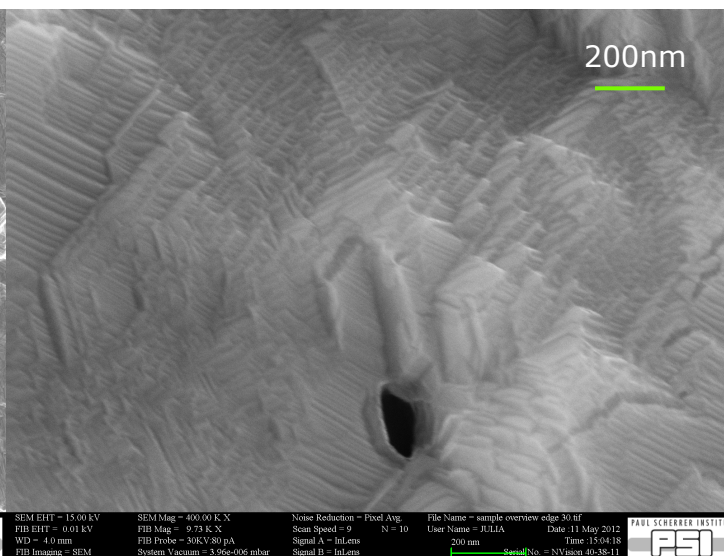
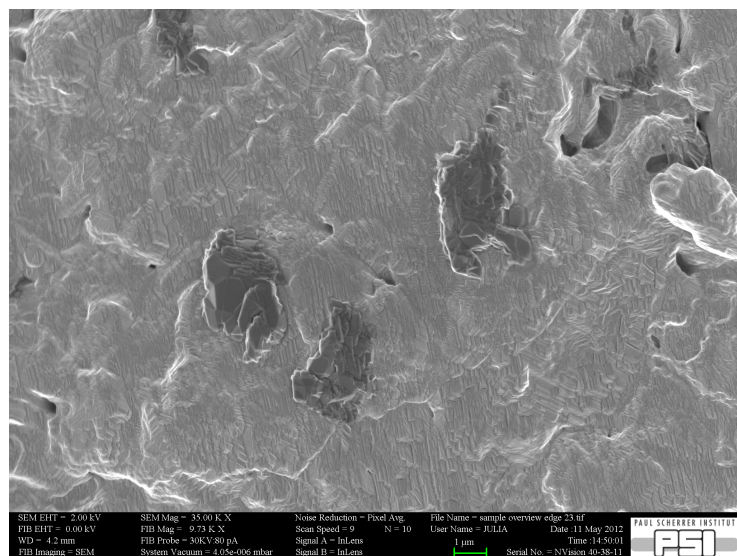




Current UC_x at ISOLDE: SEM / FIB



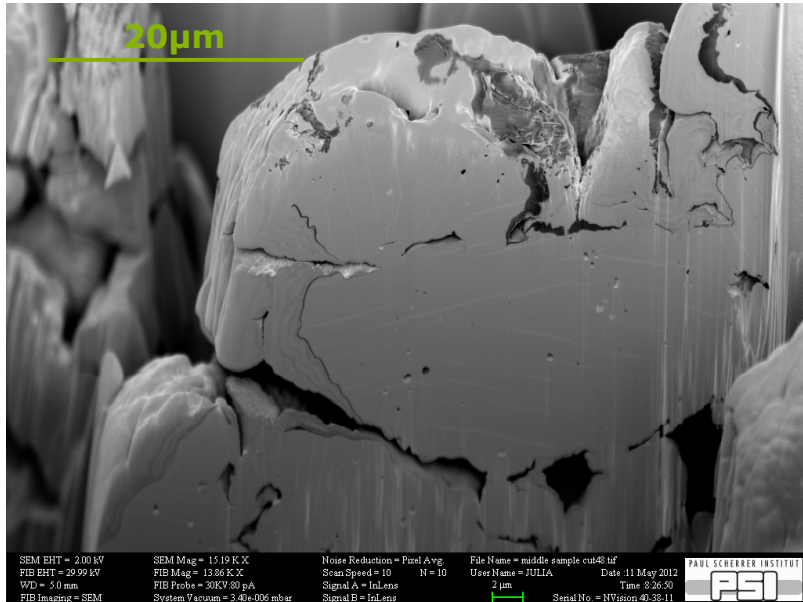
as prepared
($\leq 1850^\circ\text{C}$)



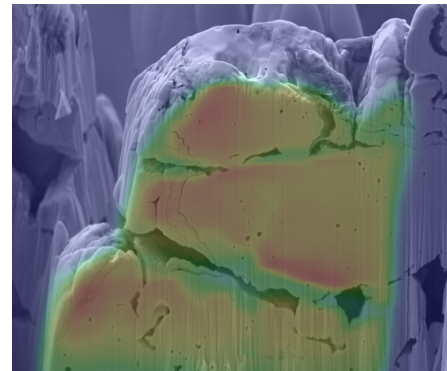
as operated
(2100°C for
5 days)

Micro Spot Material Mapping at SLS

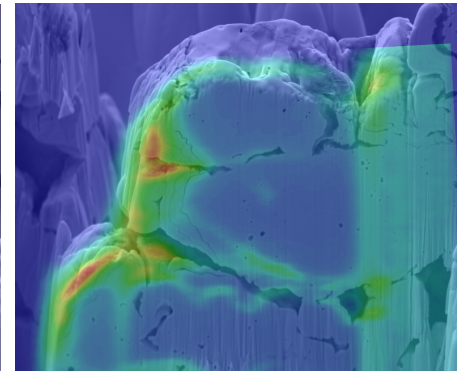
SEM Uranium



μ -spot X-ray fluorescence mapping



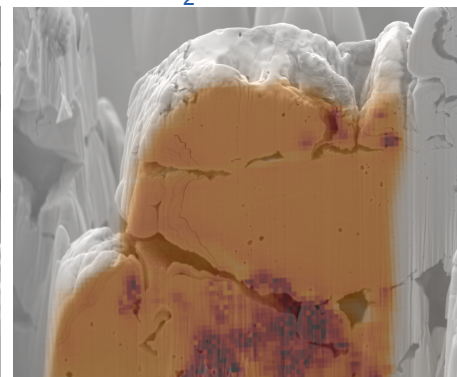
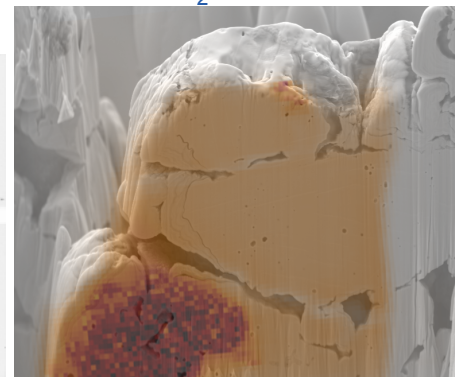
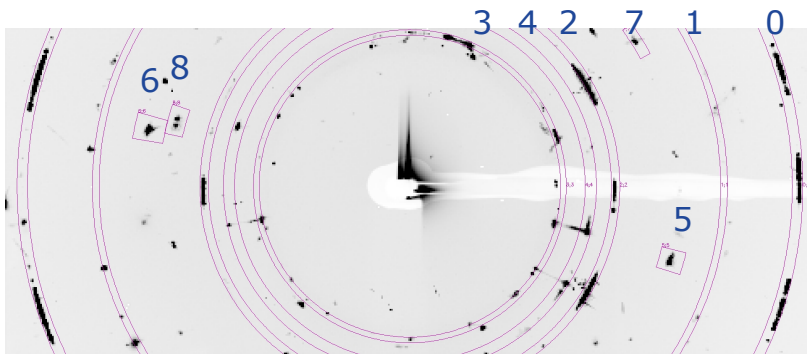
Uranium



Gallium

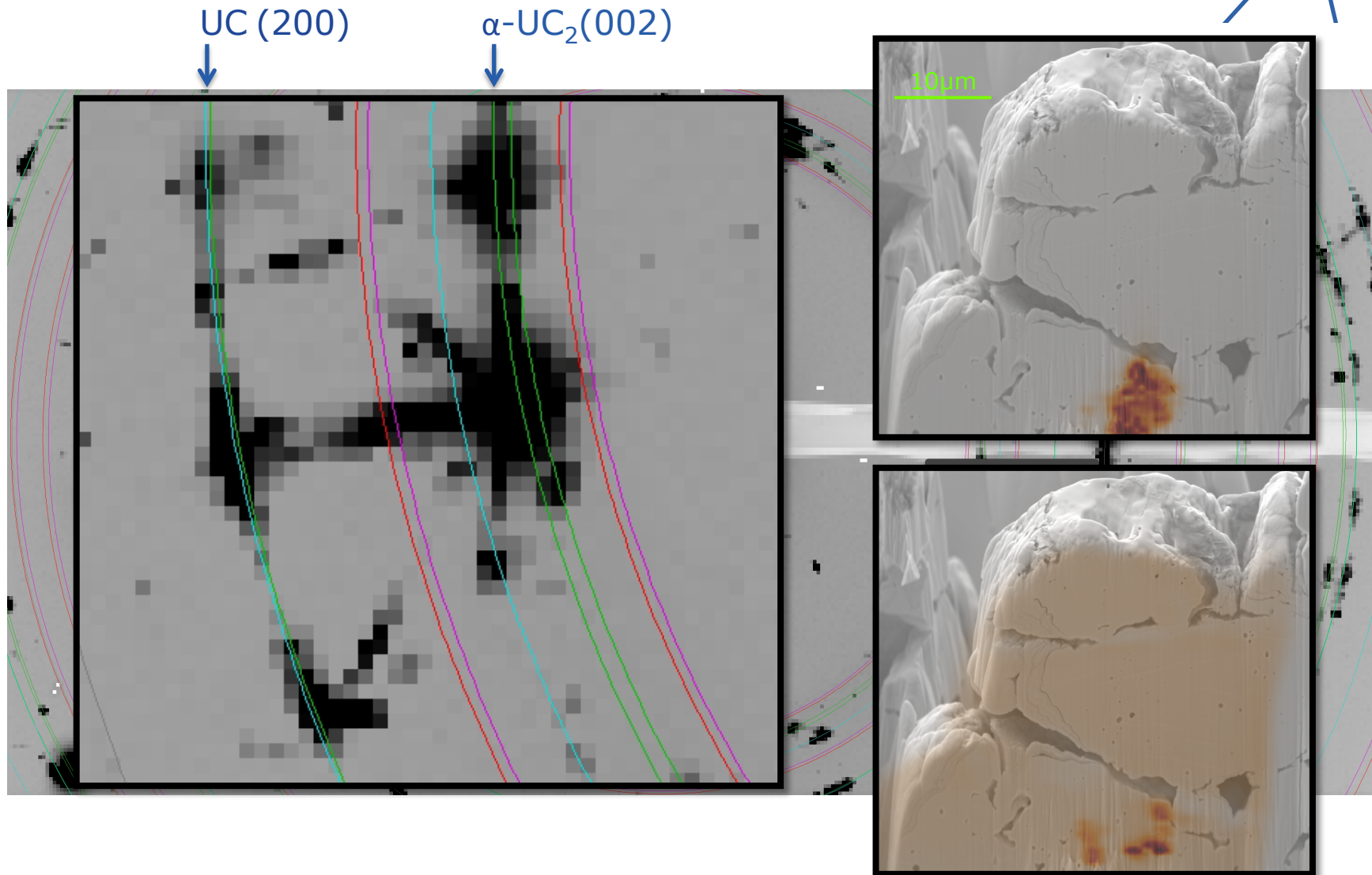
UC₂ reflex 1

UC₂ reflex 3



μ -spot X-ray diffraction

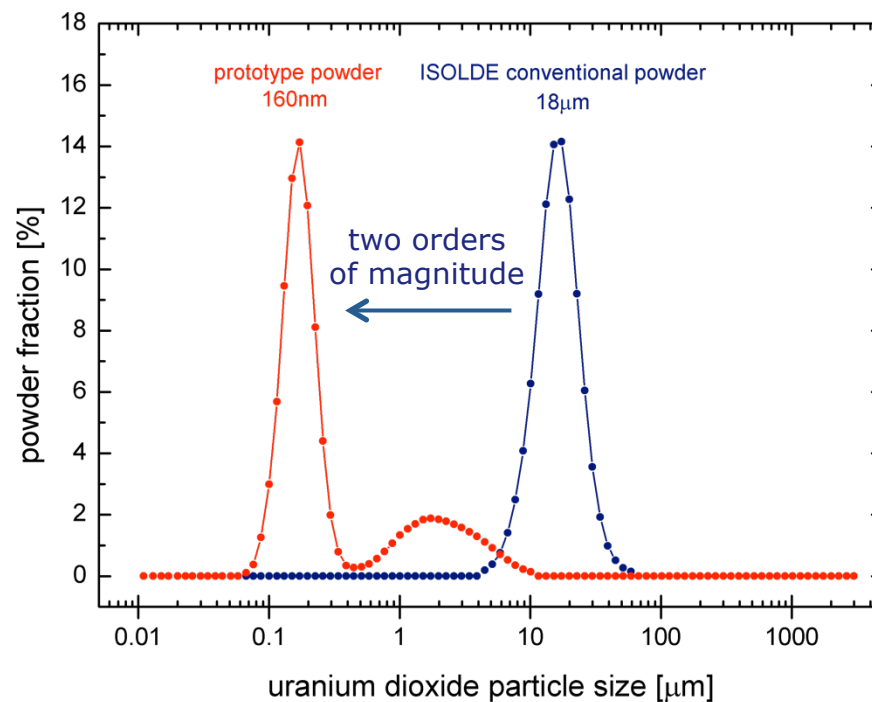
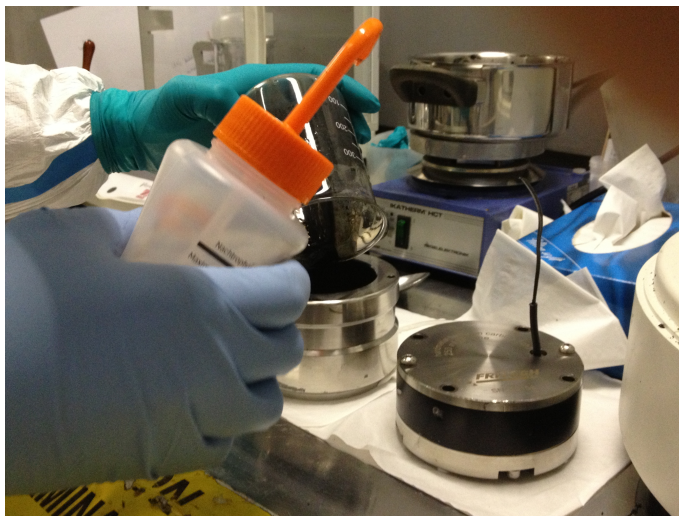
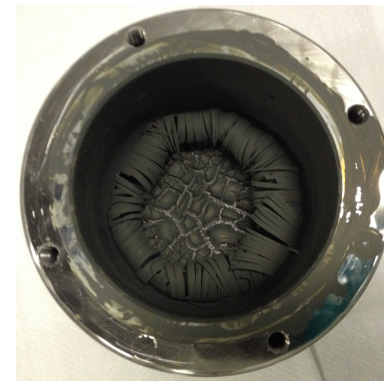
Why is UC_x such successful target material?



Composing a Procedure for Nano-Grained UO_2



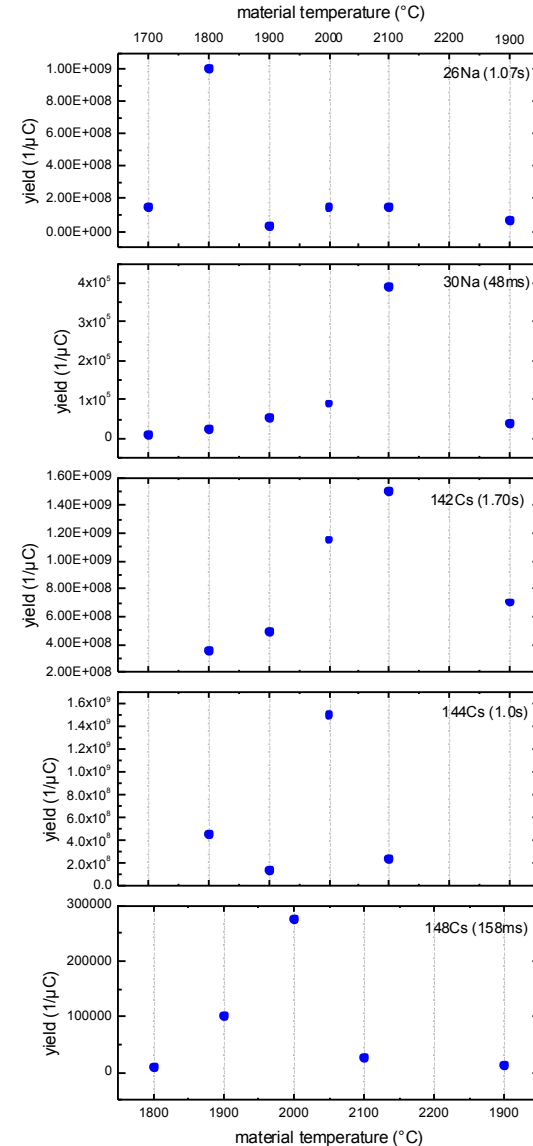
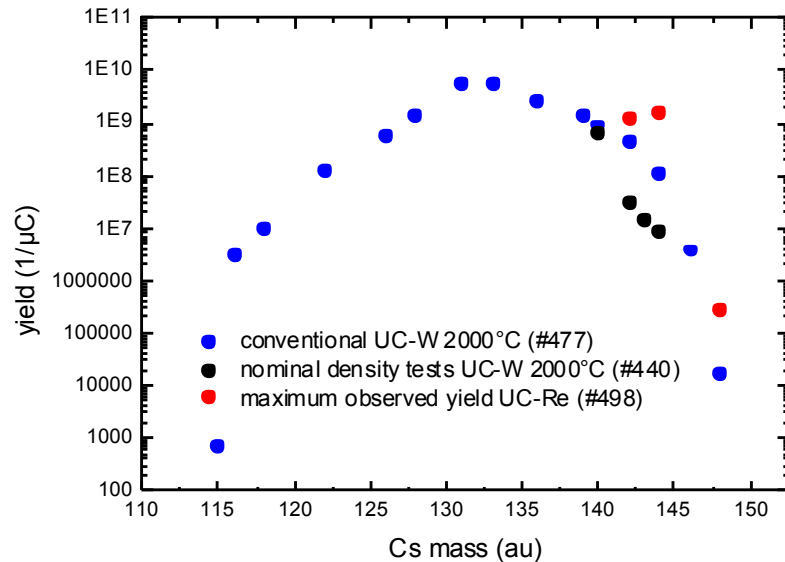
- Purchase, tests and safety clearance for high speed planetary WC ball mill
- Particle size limit for dry grinding: 600nm
- Identifying a suitable liquid with low surface tension
- Identifying the best grinding parameters (speed, temperature, liquid to powder to balls ratio, grinding time, grinding cycle)



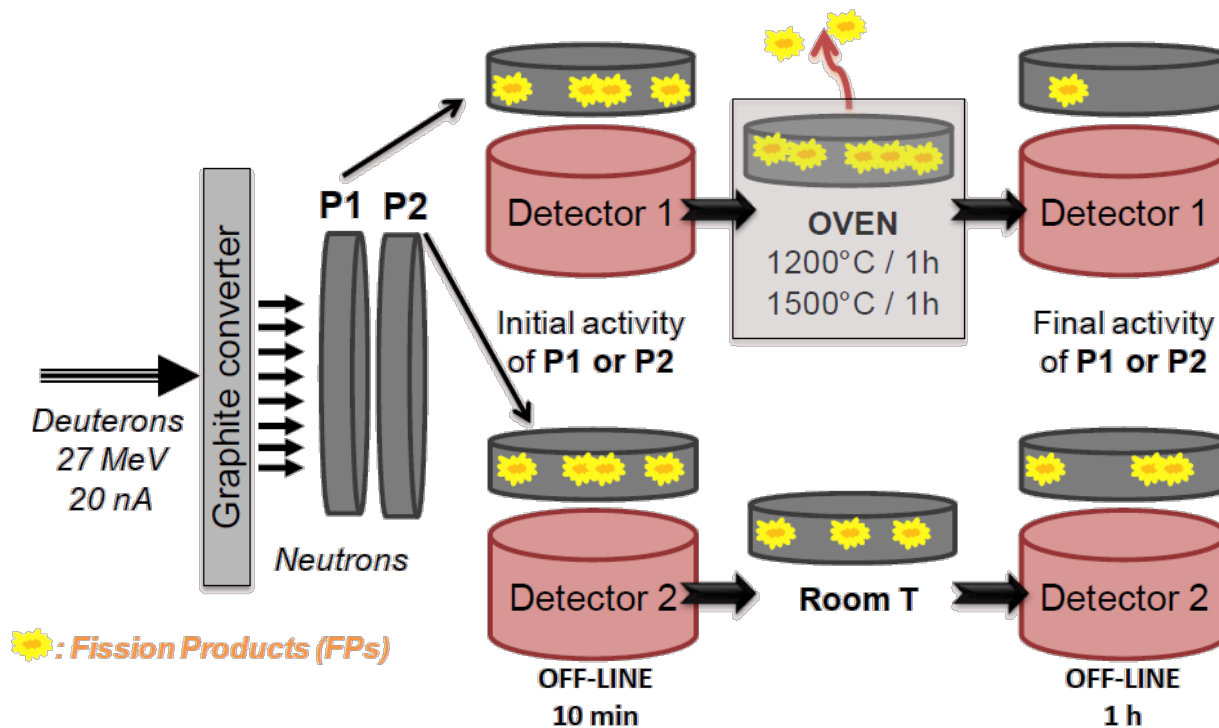
Online Results (preliminary)

Despite major technical difficulties:

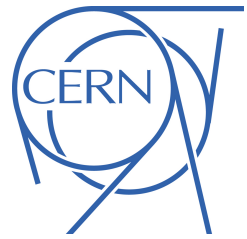
- ^{11}Be : 6.0×10^7 1/ μC , database: 7×10^6 1/ μC
- Record yields for Cs
- Structure seems widely conserved over time and temperature



Contributions by: Pierre Delahaye, Marie-Geneviève Saint-Laurent, Joanna Grinyer (GANIL)

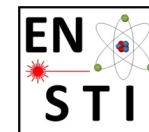


Data analysis from tests on high density UC, conventional UC_x, nano-structured UC_x ongoing.



- 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
 - understanding the significant ageing effects for some isotopes, finally solved
 - realizing longer target lifetime
- ActiLab in FP7-ENSAR:
 - Material analysis before irradiation revealed first unexpected results
 - Online tests of a HD-UC target was performed in 2010/2011
 - Online tests of a tailored UC_x in December 2012
 - Post-irradiation tests are arranged and will take place as of July 2013 at PSI
 - Irradiation tests on several prototypes at IPN-Orsay in May, December 2013

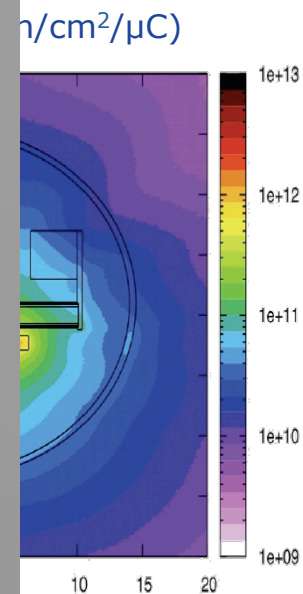
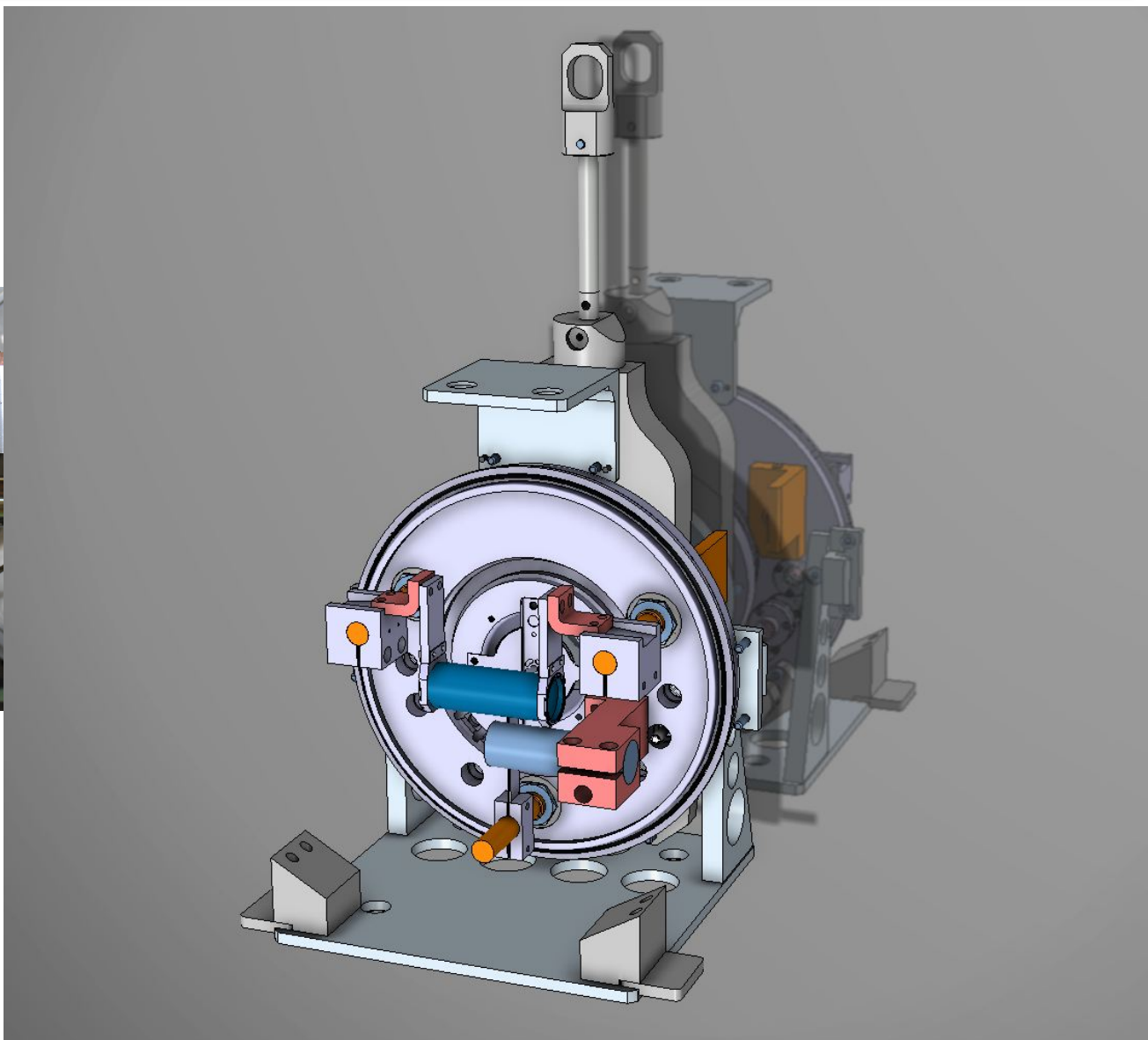
Collaboration and Acknowledgement



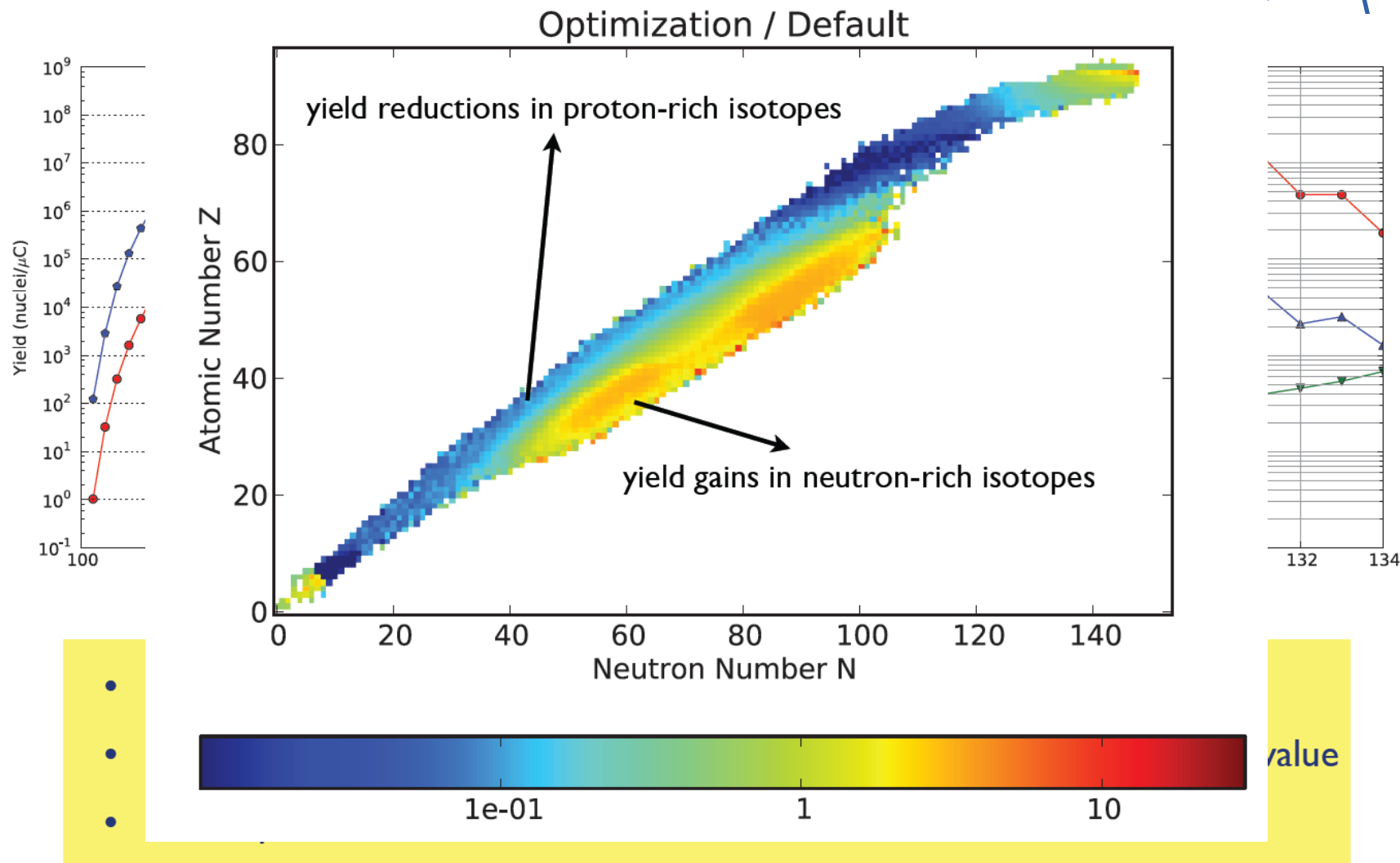
Thank you for your attention!



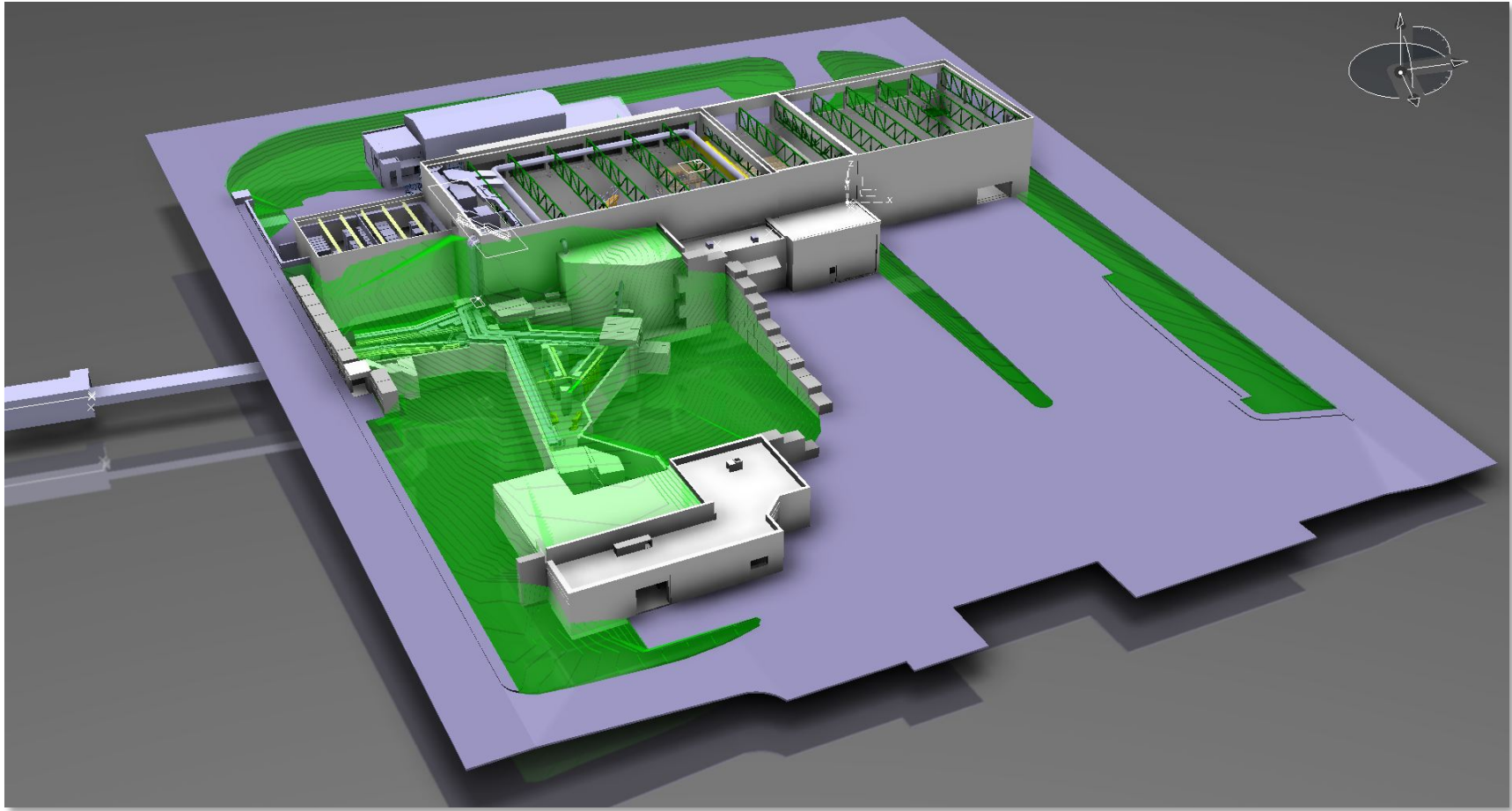
Proton to Neutron Converter Prototype (R. Luis)

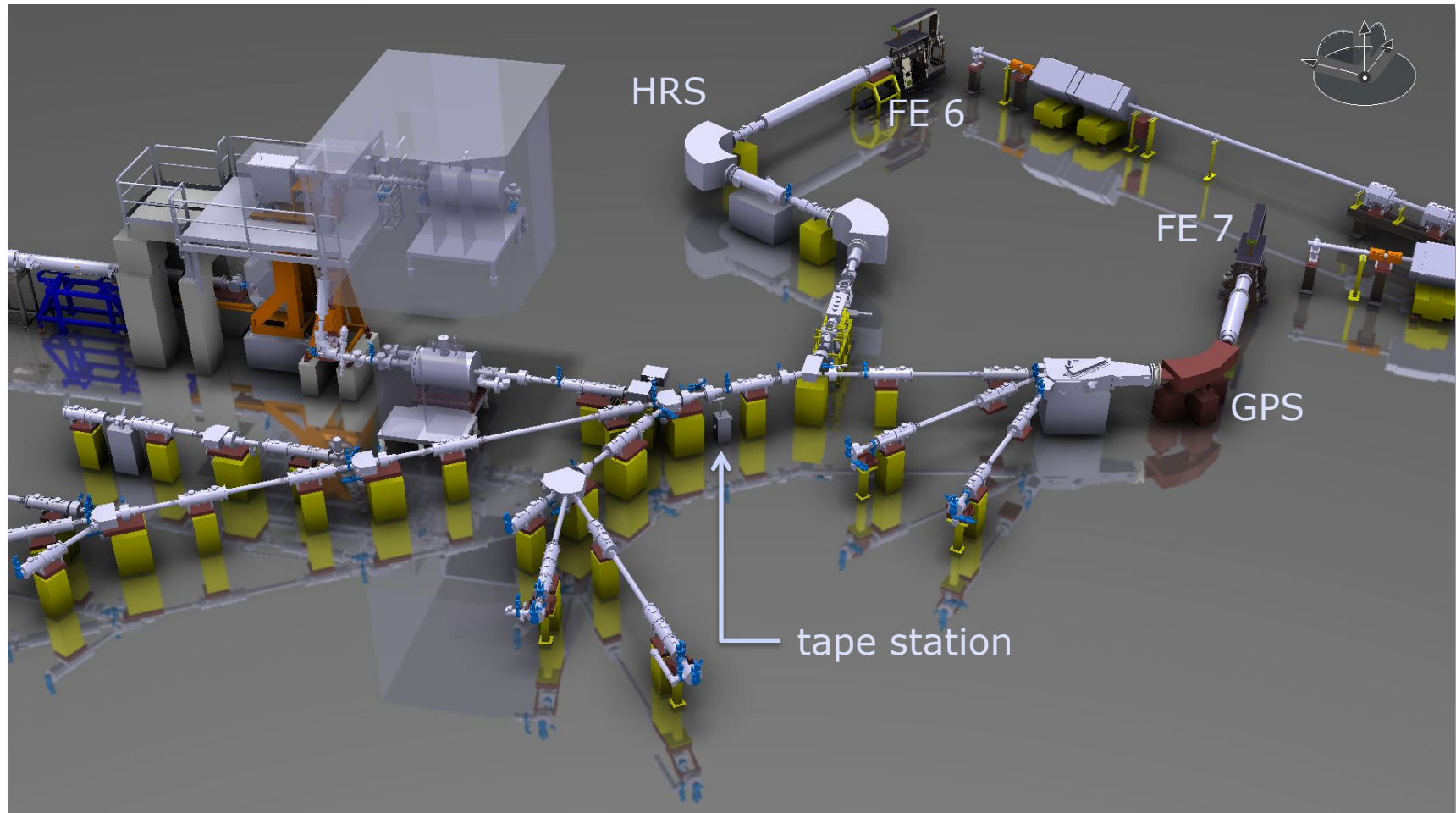


Proton to Neutron Converter Prototype (R. Luis)









CERN Accelerator Complex

