Recent developments of target and ion sources to produce ISOL beams

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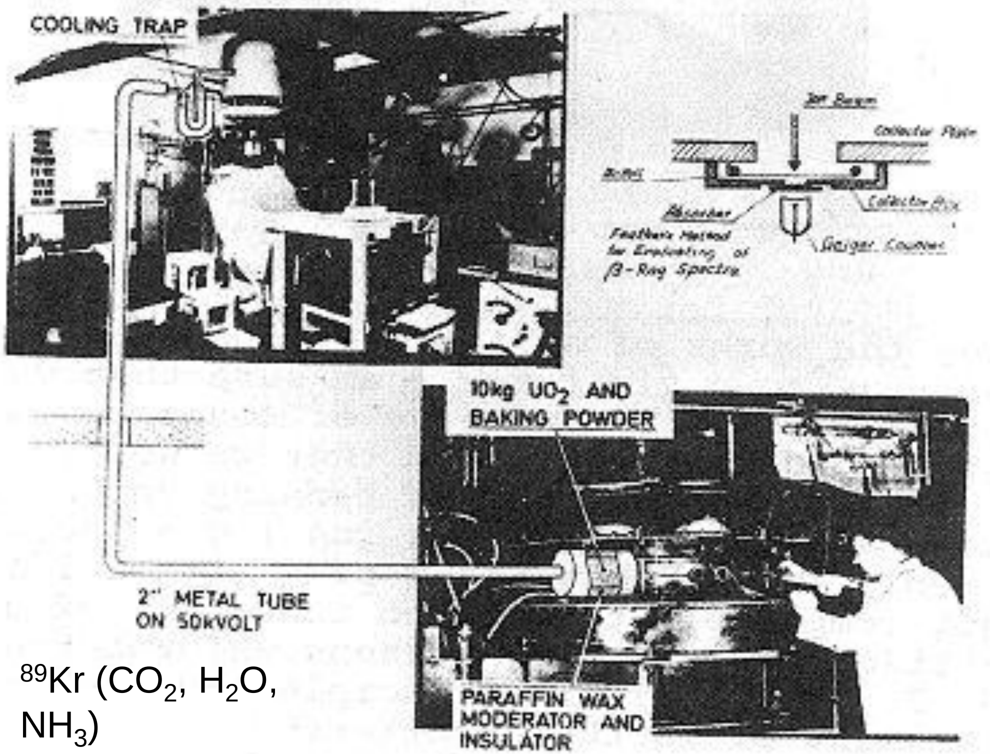
Target and Ion Source Development, ISOLDE (EN-STI-RBS)

(with the contributions of many colleagues)

THE BIRTH OF ON-LINE ISOTOPE SEPARATION

ISOLDE “0”

O.Kofoed-Hansen
K.O. Nielsen
Dan. Mat.Fys.Medd. 26, no. 7 (1951)



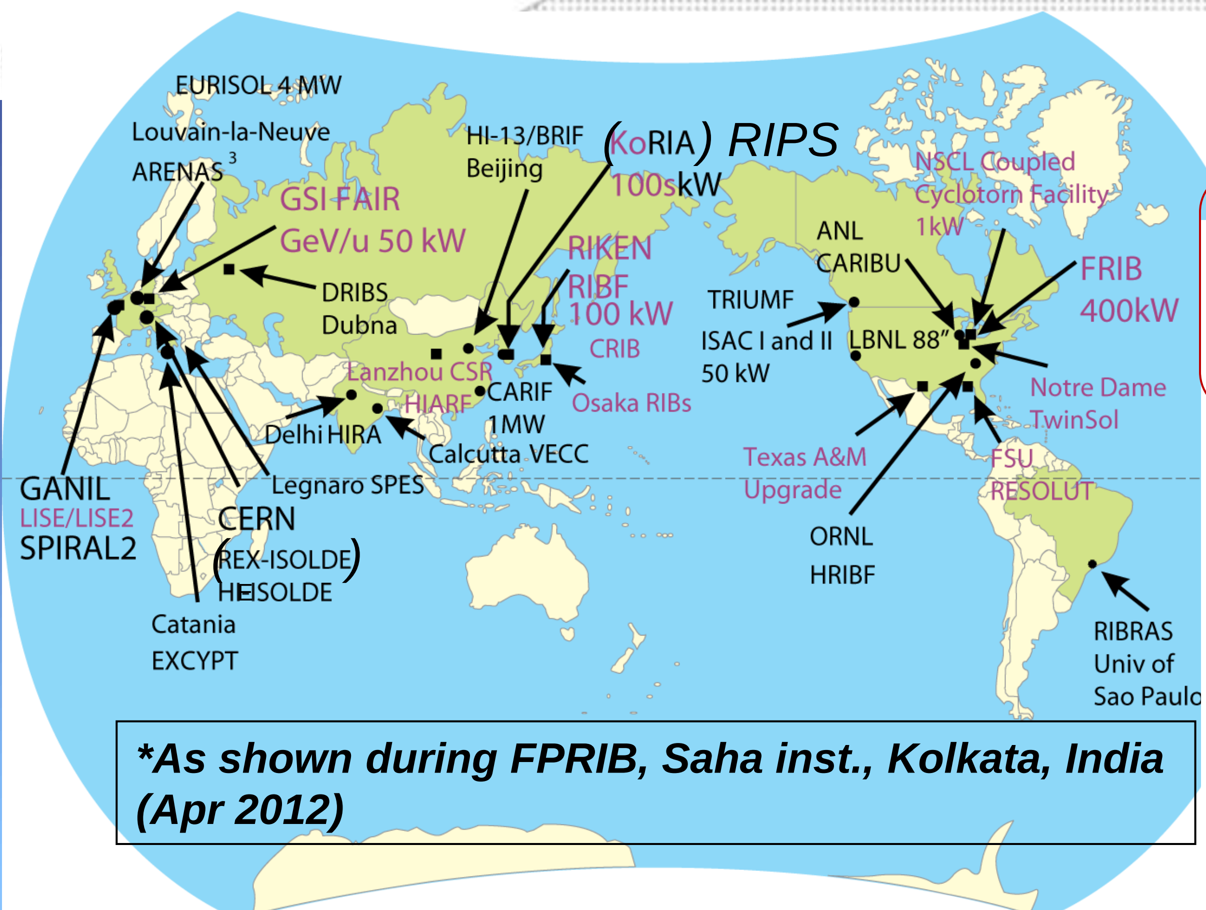
^{89}Kr (CO_2, H_2O, NH_3)

10 MeV deuterons
d-to-n converter (Be)
n moderator (wax)
UO_2 (10 kg)
Baking powder

From CERN 76-13, 3rd conf. nuclei far from stability

What’s new since 2007 ?

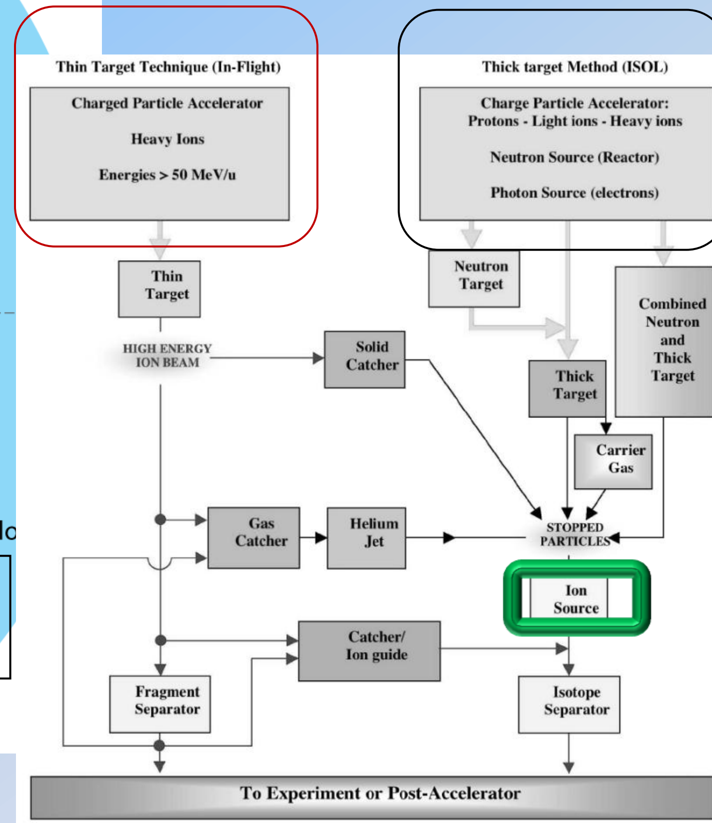
World map of radioisotope ion beam facilities*



As shown during FPRIB, Saha inst., Kolkata, India (Apr 2012)

In-flight Fragmentation Facilities (in red)

Isotope Separation OnLine Facilities ISOL (in black)



ISOL Beam intensity

RIB intensity [$s^{-1}\ \mu A^{-1}$]

Proton beam Intensity [$s^{-1}\ \mu\ A^{-1}$]

Avogadro Numb.

Diffusion+ Effusion Efficiency

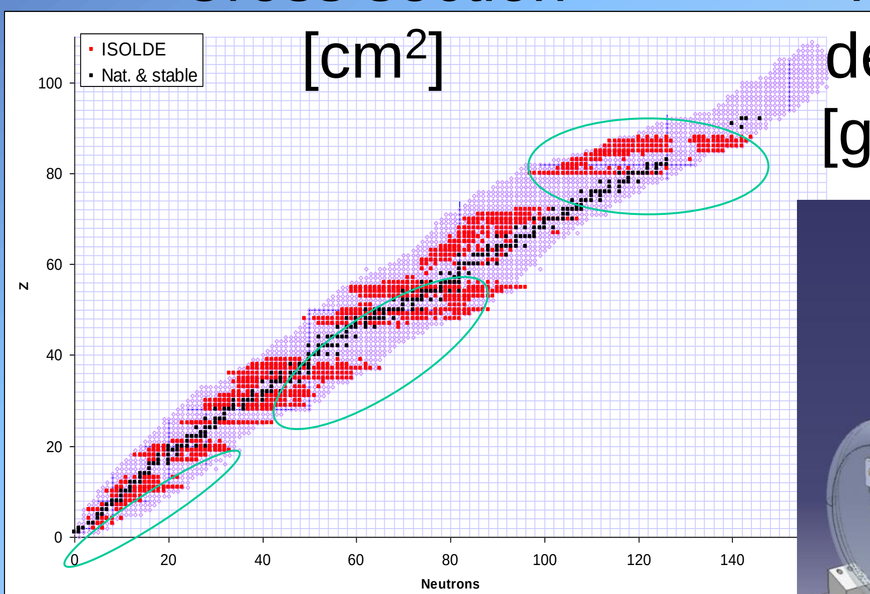
$$I = \int \sigma(E)\ \Phi(E, x)\ \rho(x)\ N/A\ dx\ \varepsilon_{diff+eff}\ \varepsilon_{ion}$$

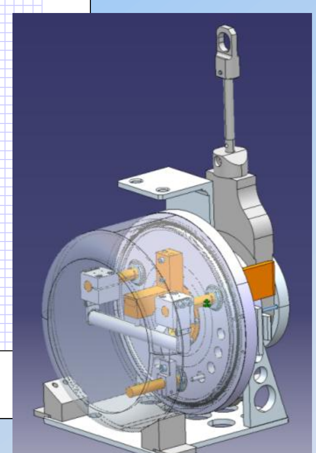
Cross section [cm^2]

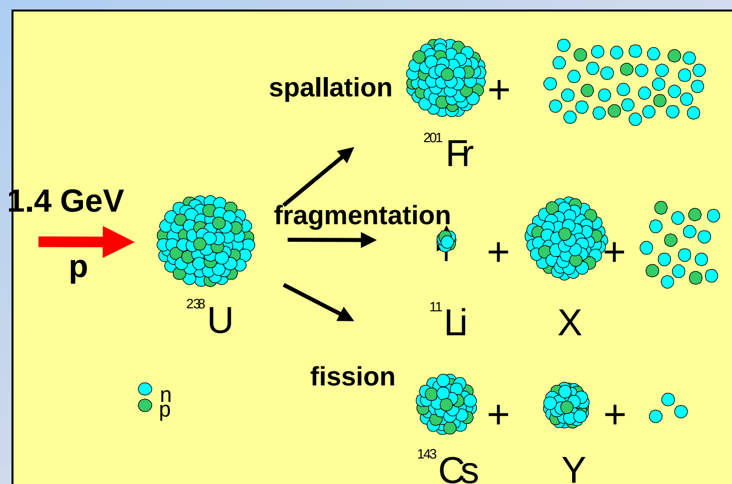
Target density [$g\ cm^{-3}$]

Target Atomic Mass [g]

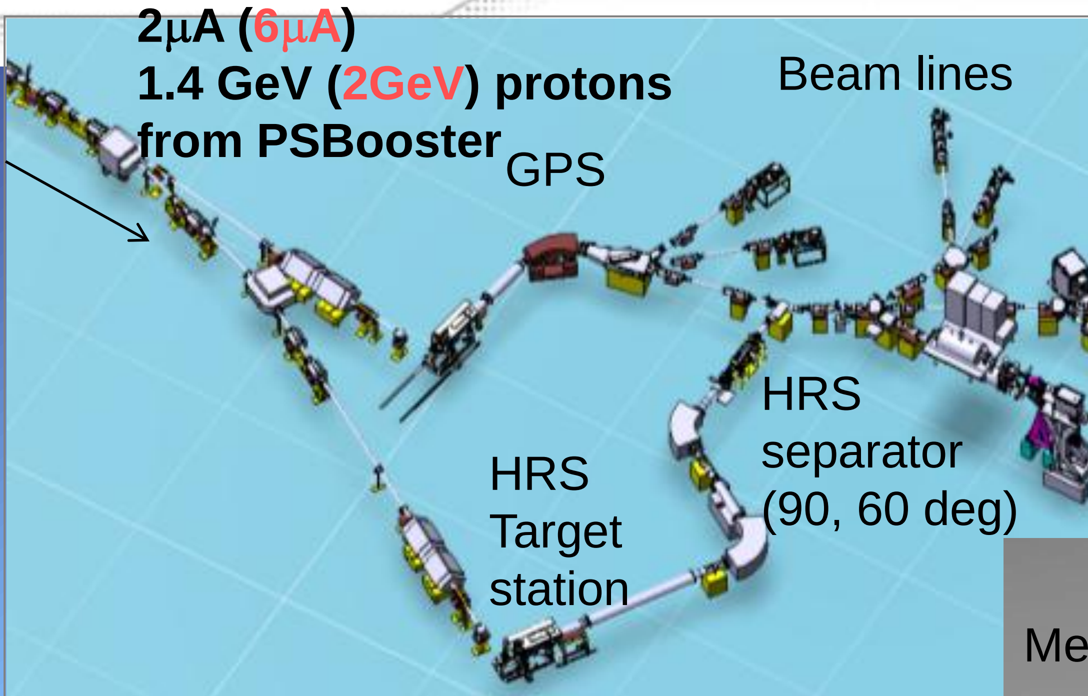
Ionization Efficiency





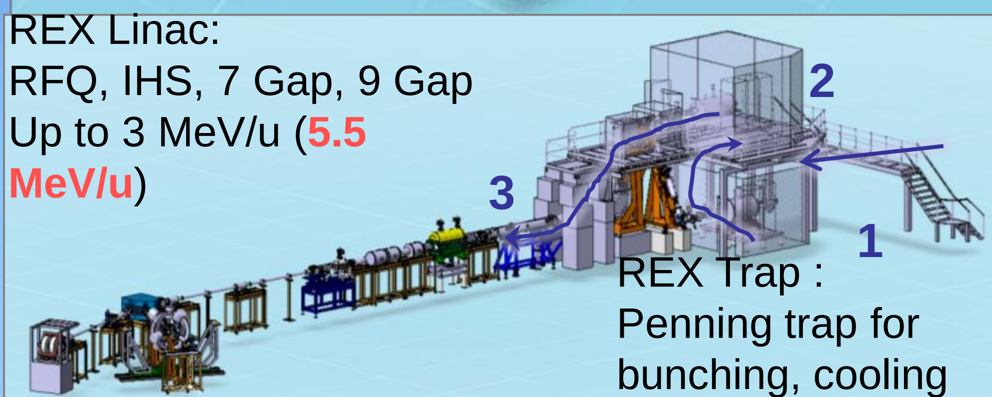


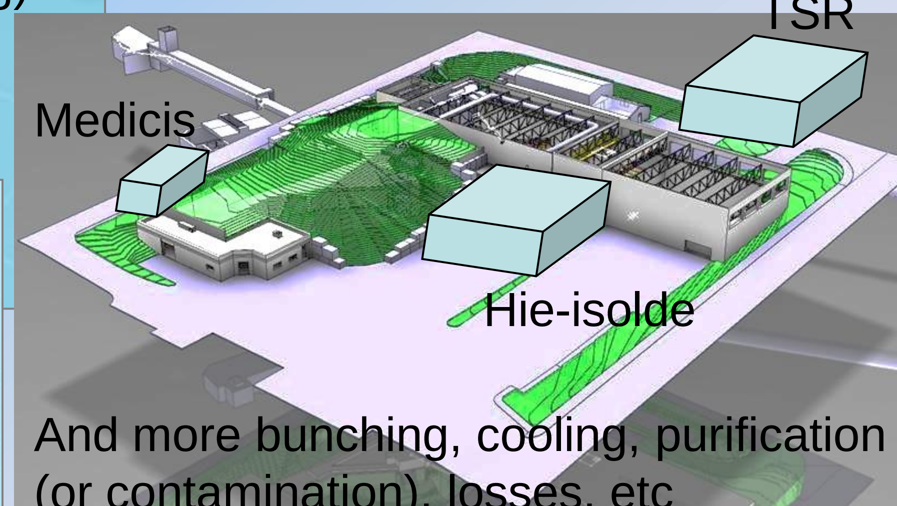
One of the many ISOL facilities…



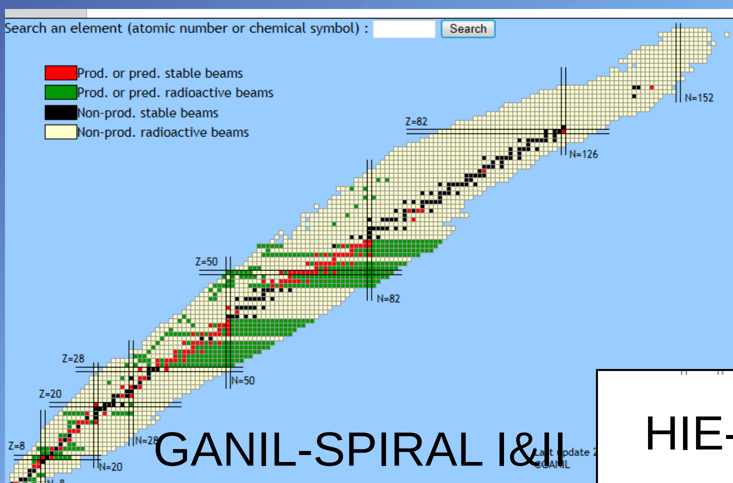
Talks of R. Catherall
T. Nilsson, G. Bollen
Poster S. Essaba

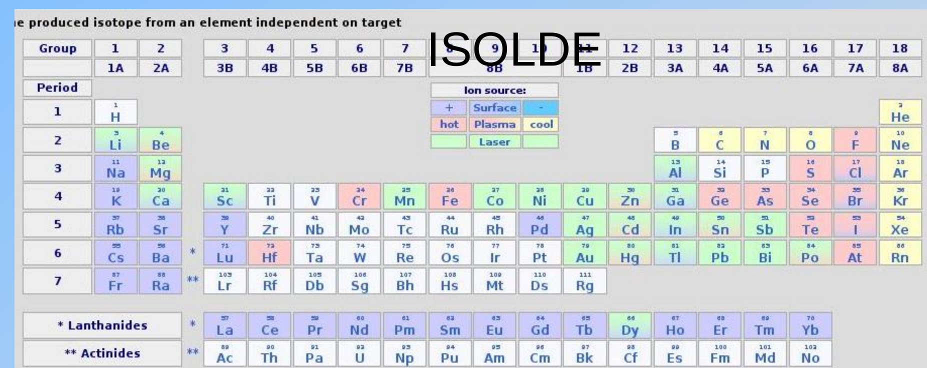
44Ti/Sc recycled from PSI:
→(+CF4°) TiF3+ with FEBIAD
→44Ti13+ in REX
→2-3MeV/u, 3e6pps for (α,p)

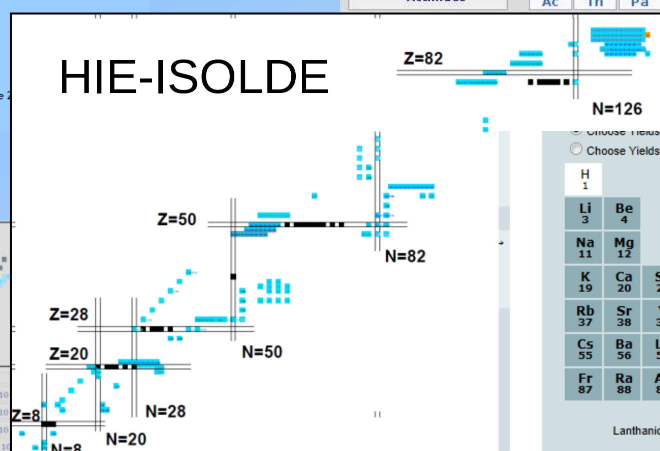


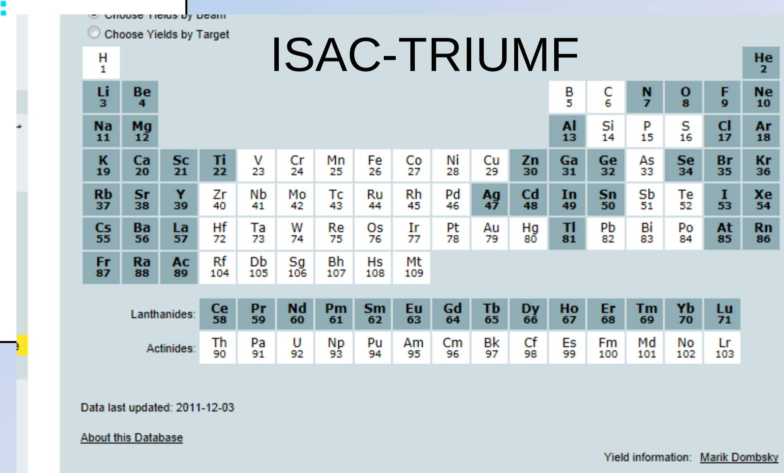


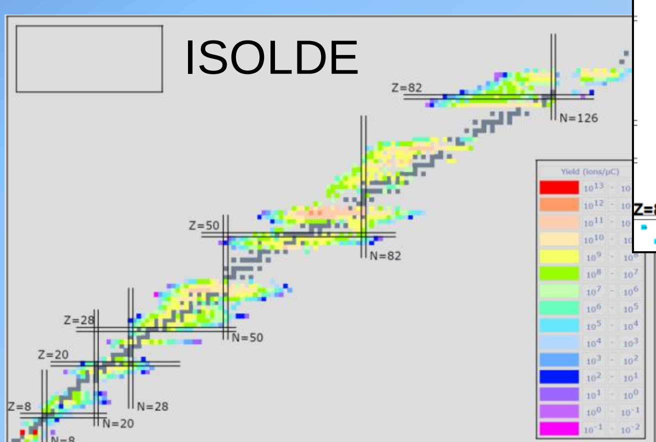
Beams at operating ISOL facilities



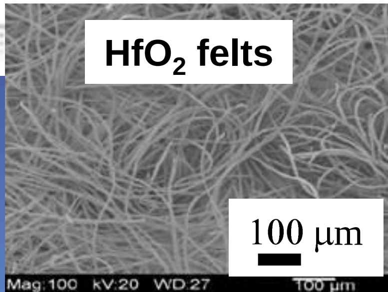




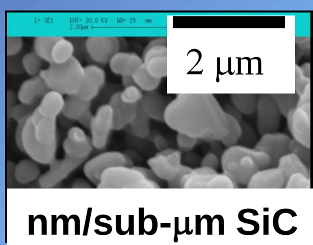




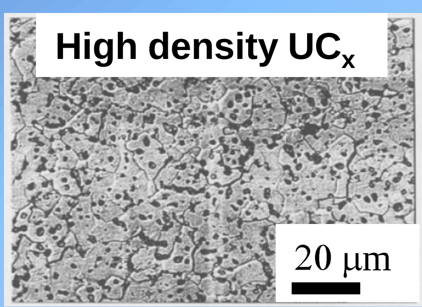
ISOL(DE) targets and ion sources



HfO_2 felts



nm/sub-μm SiC

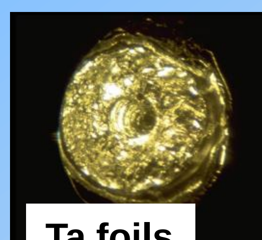


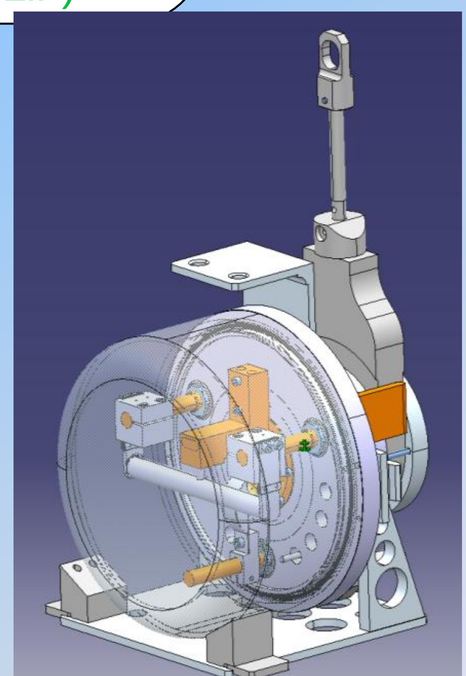
High density UC_x


ISOLDE UC_xpressed pellets

Target materials (30):

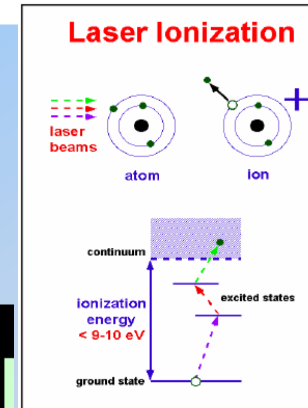
- Refractory oxides carbides (Al_2O_3, SiC, UCx, nano Y2O3)
- Solid metals (Ta, Nb, Mo)
- Molten metals (Pb, La, Sn)
- Molten salt (NaF-LiF)

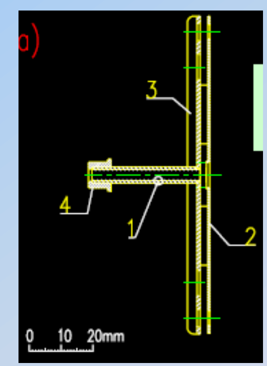

Ta foils

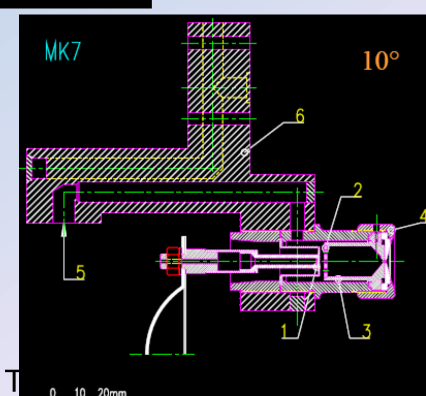


Ion sources (>5):

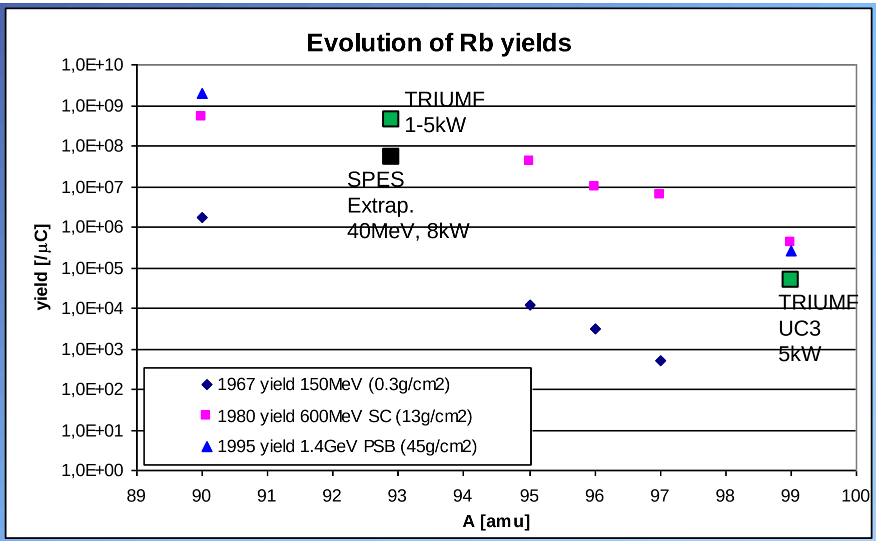
- Surface (W, Re, GdB6)
- FEBIAD, RF Plasma
- LIST (talk D. Fink)

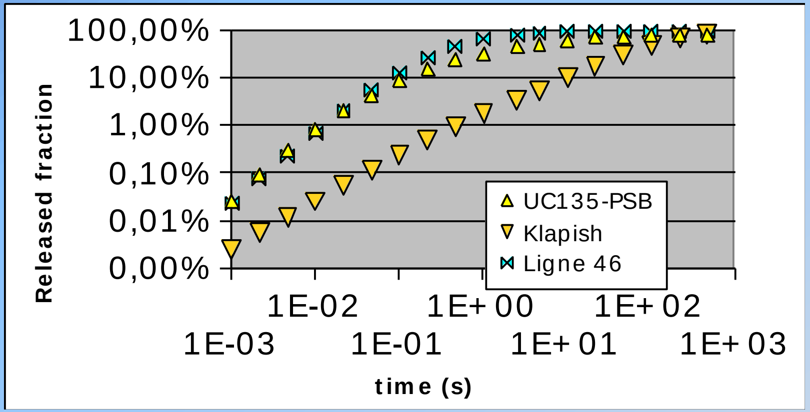


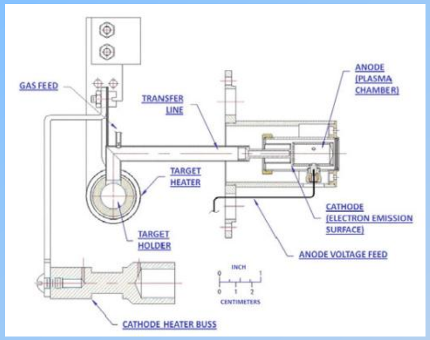


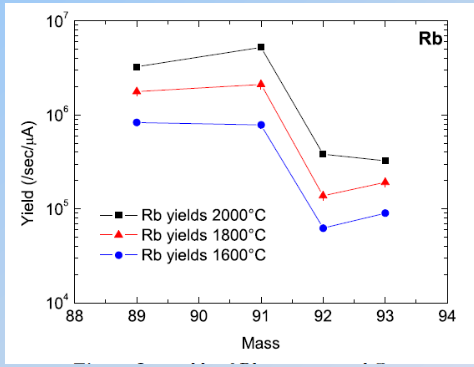


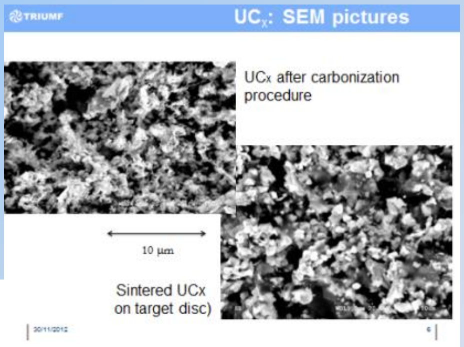
Evolution of yields over years: Rb from UCx







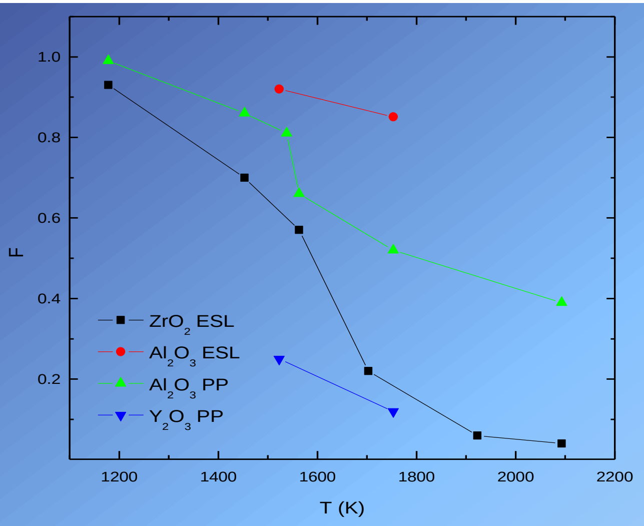


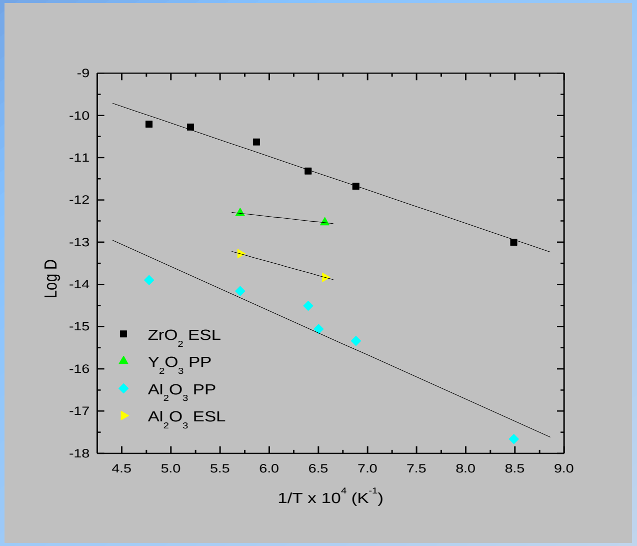


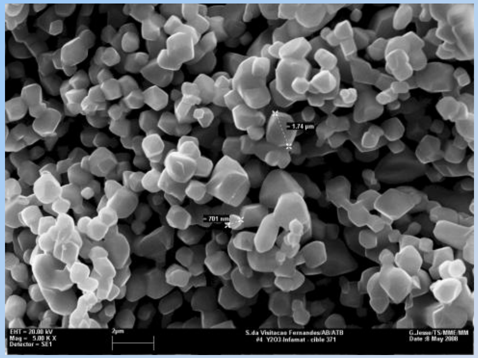
3 C/Ucx targets
Operated
At TRIUMF
(→ 5kW)

EPJ A 47, 119 (2011)
SPES tests @ORNL
See poster M. Monzolaro

Release properties of Kr isotopes from submicron Y_2O_3 target





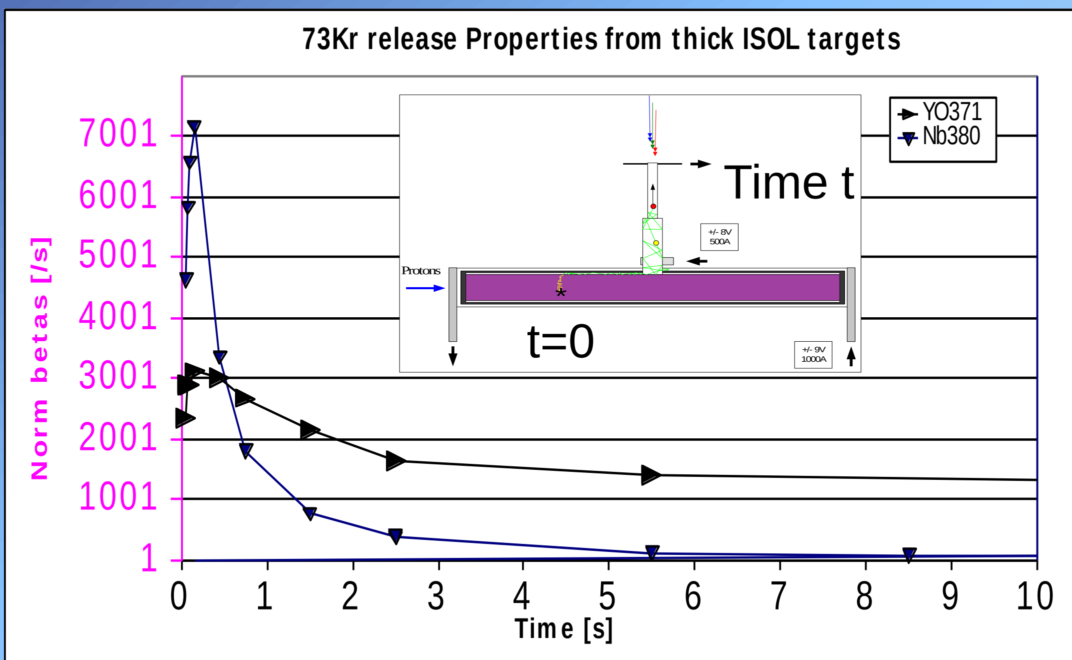


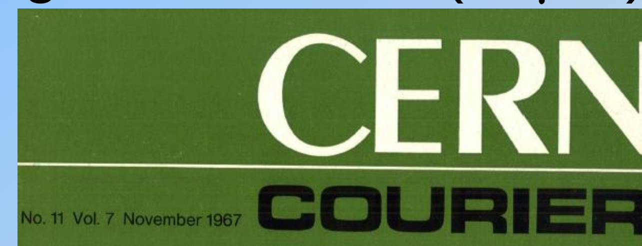
$$(\varepsilon_{target})_{off} = \frac{3}{\pi}\sqrt{\left(\frac{\mu_s}{\lambda}\right)}$$

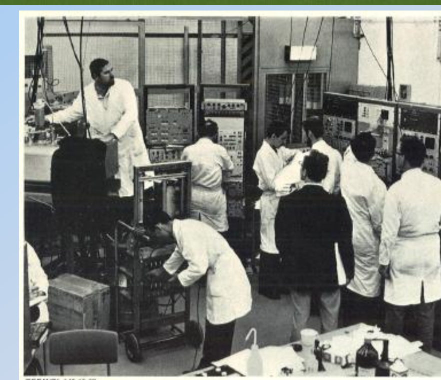
Nuclide	$t_{1/2}$ (s)	λ (s^{-1})	μ_s (s^{-1})	$\varepsilon(target)_{off}$
^{72}Kr	17.2	0.0405	1.766E-3	0.199
^{73}Kr	27.0	0.0265		0.246

Online yield of n-def $^{70\text{-}72}Kr$

Release curve from Y_2O_3 sub-micron target vs Nb foils (30μm)





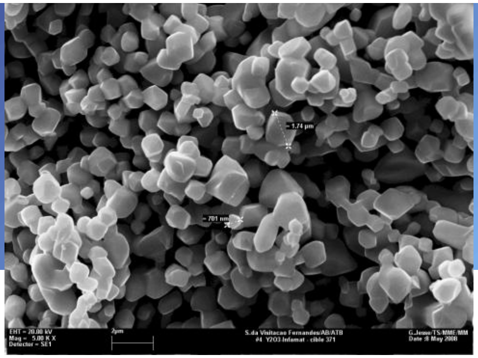


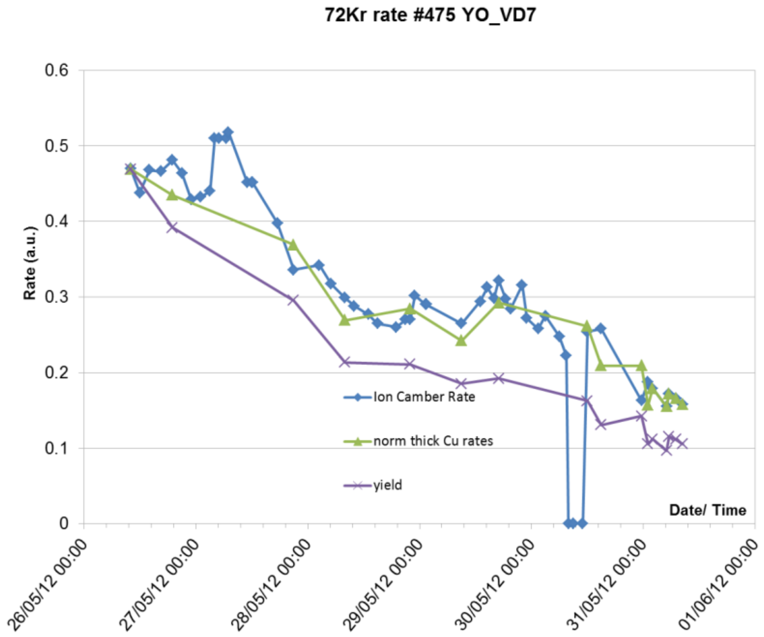
50 s. Traces of another previously unobserved isotope Kr⁷³ were also seen but were insufficient for measurements. The

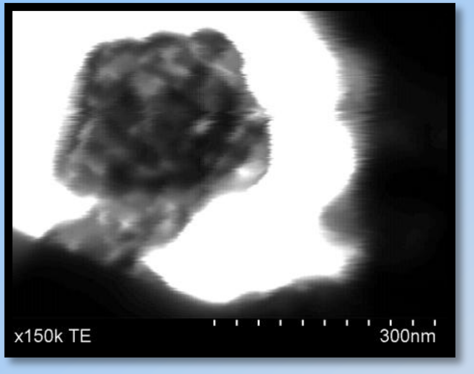
Yields of ^{72}Kr have been improved by x10 from 2 10^3/ μ C to 2 10^4/ μ C (combining prod cross section, target thickness, release efficiency and ion source efficiency)

And what about their stability vs irradiation time

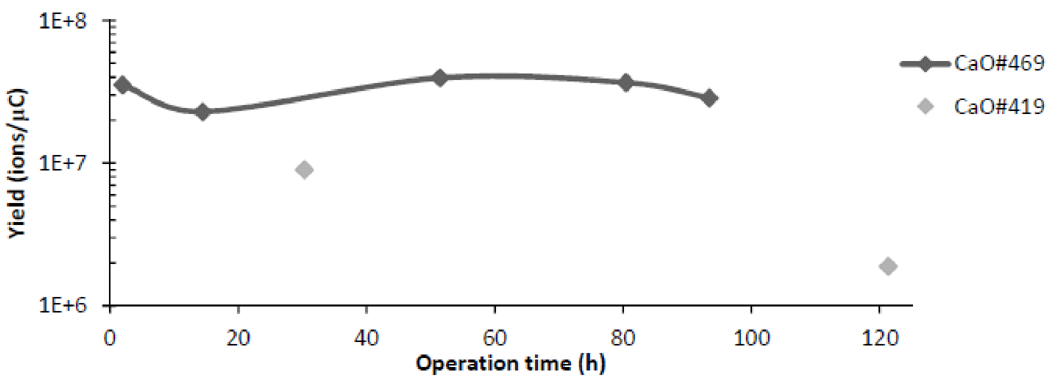
72Kr from nano Y2O3 vs 35Ar from nano CaO





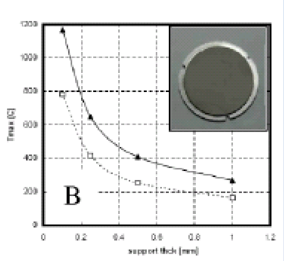


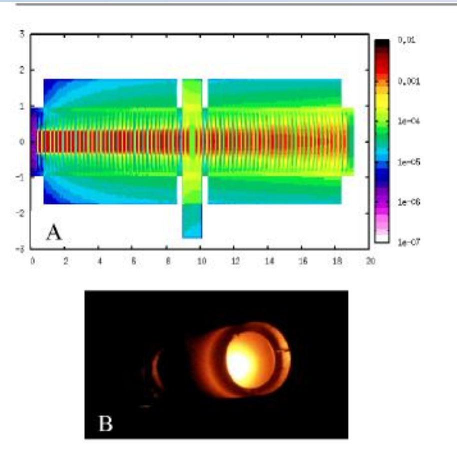
^{35}Ar beam over time



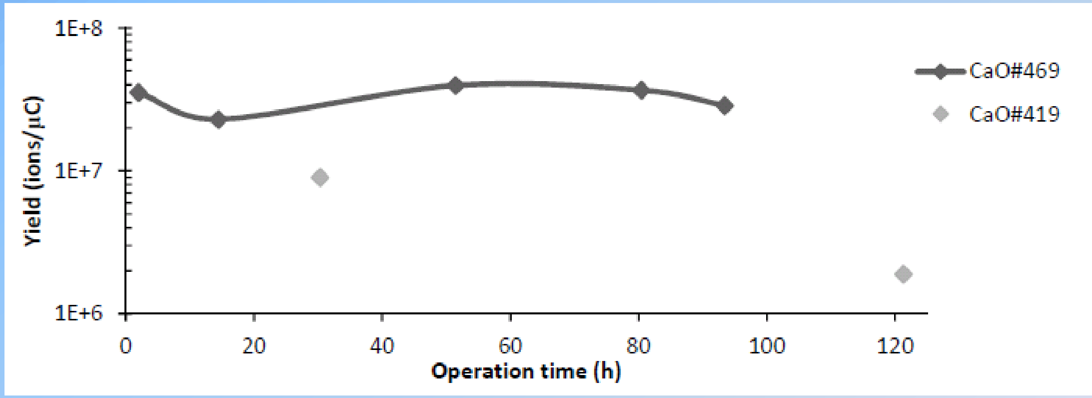
New generation of targets

Have demonstrated increased yields from nano/sub μm SiC, Y_2O_3, CaO targets
Constant yields demonstrated over extended periods
UCx targets under development (ActILab, in FP7 ENSAR program)
High power composite solid targets developped at TRIUMF
(and also for EURISOL)





^{35}Ar beam over time



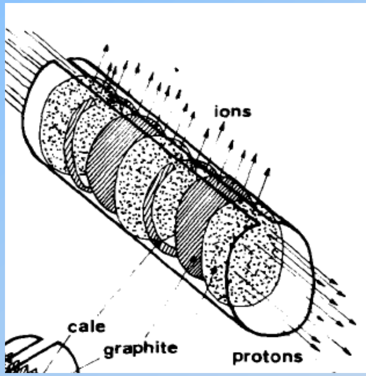
1st Targets used at CERN-PS for alkali metals (p 10-24 GeV)

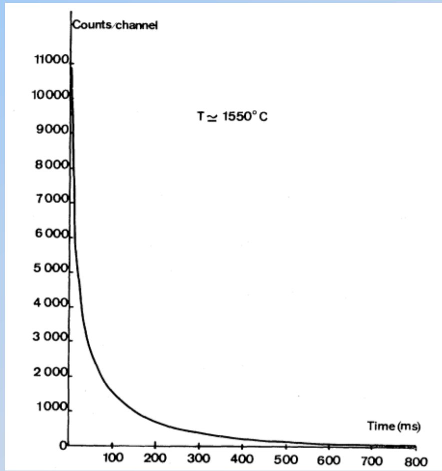
Target preparation:
5cm long, 6mm diameter.
36x 70μm C, 1-10 μ m (1-8mg/cm^2) U compound, 100 μ m gap: tot 0.3g/cm^2 U
Operated at ca 1500°C

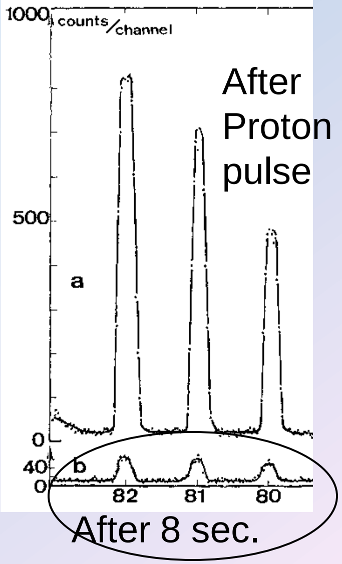
$UO_2(NO_3)_2.6(H_2O)$ layer, converted to UO_3 at 200°C
Heated further to obtain U_3O_8 / UC /UC_2 / oxycarbide

Fission (*10.5GeV p on ThCx*) Rb release

Phys Rev Lett, 1968



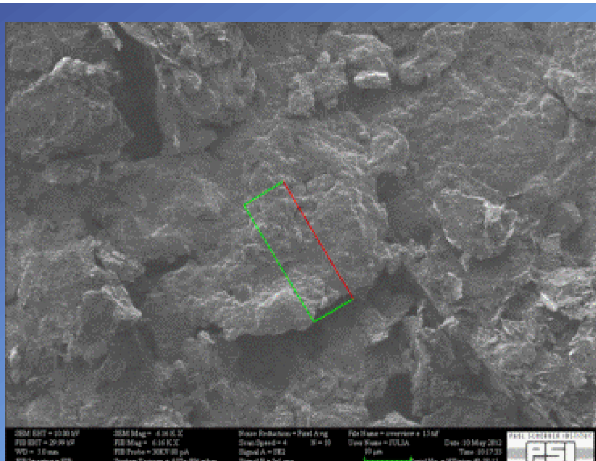


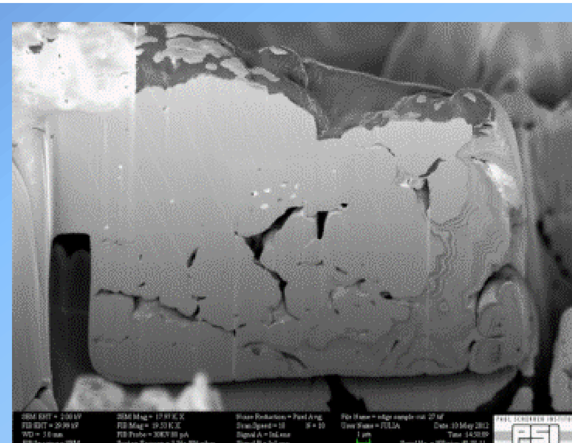


R. Klapish et al.
(UCx at CERN-PS&IPNO/CSNSM, 1967)

Na from Ir/C target

Current UC_x targets : SEM / FIB

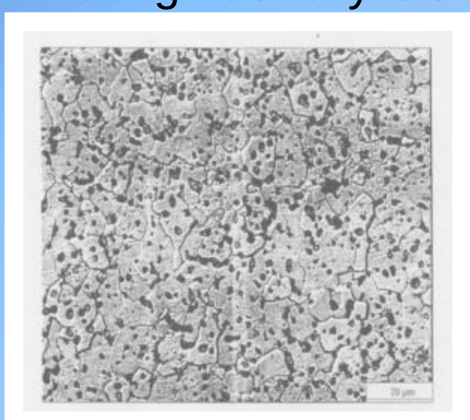


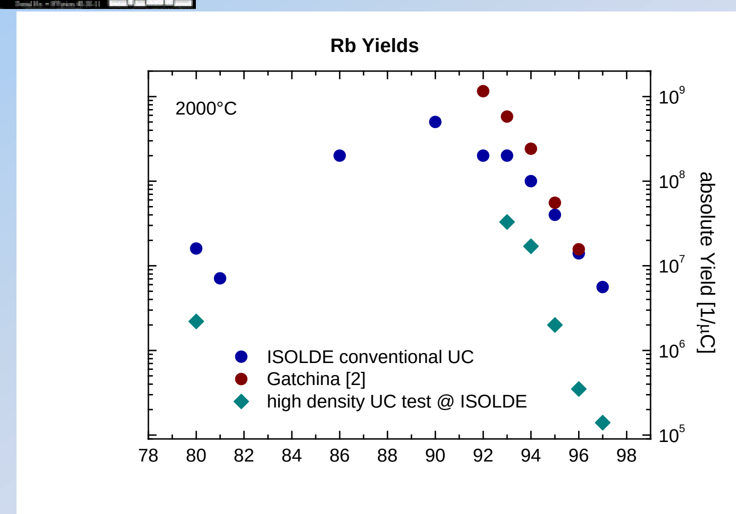


as prepared
(≤1850 ° C)

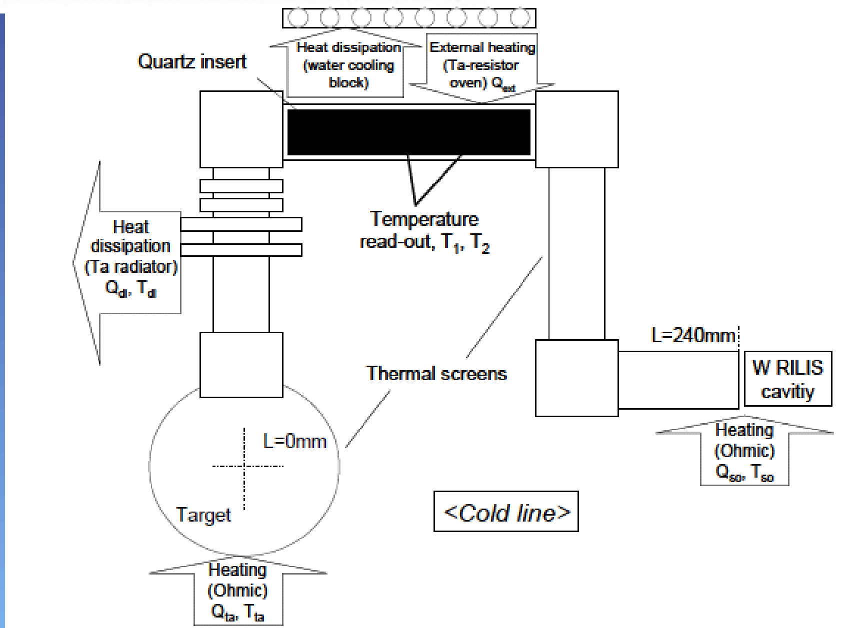
ActILab,
A. Gottberg,
C. Degueldre
Et al

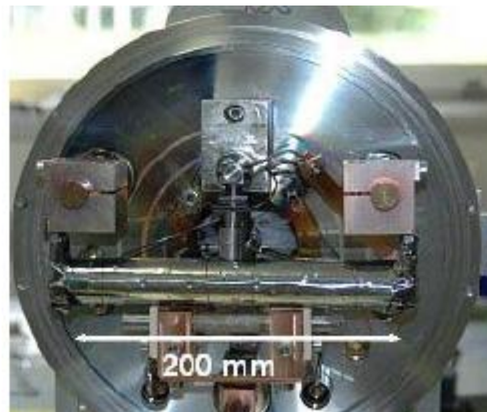
And high density UC targets (ie max # of fissions)

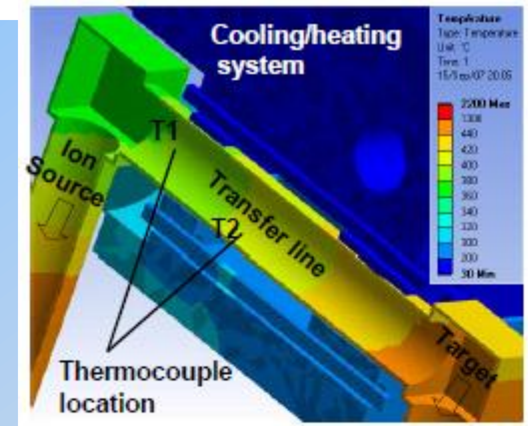


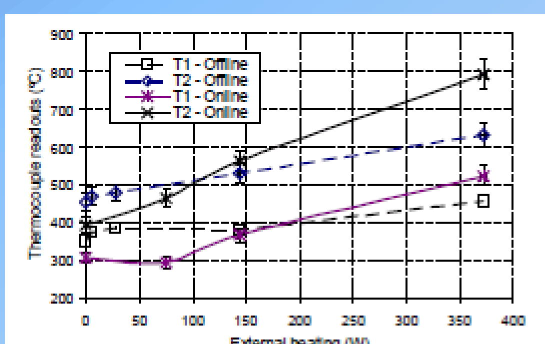


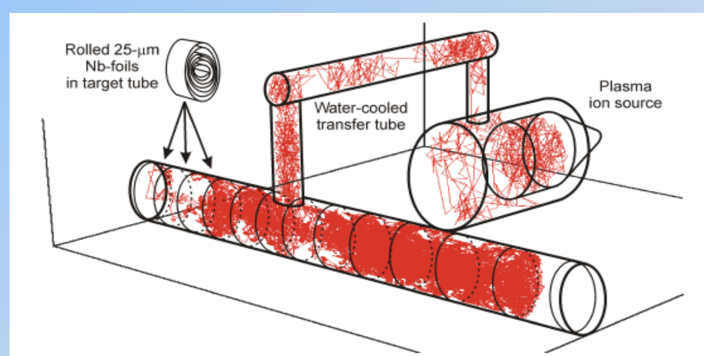
Purification by selective trapping

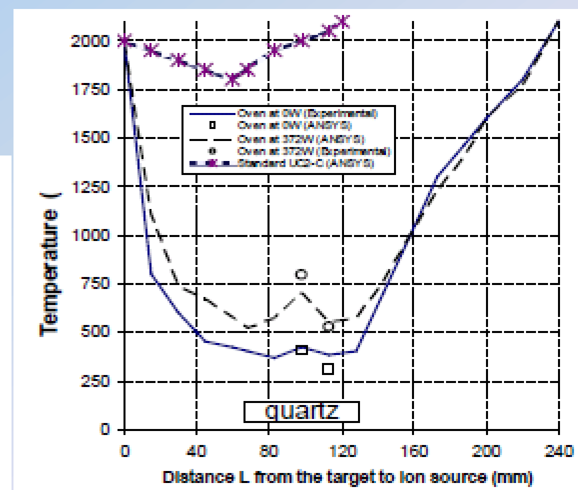




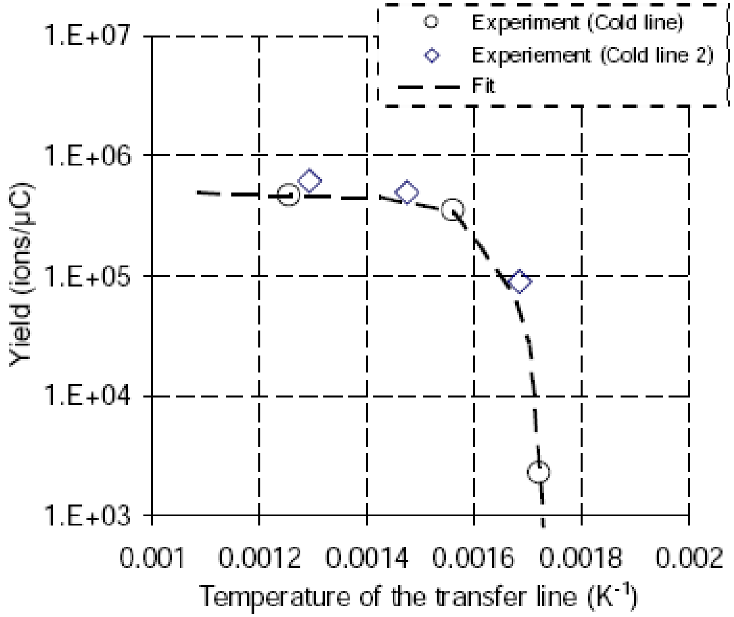


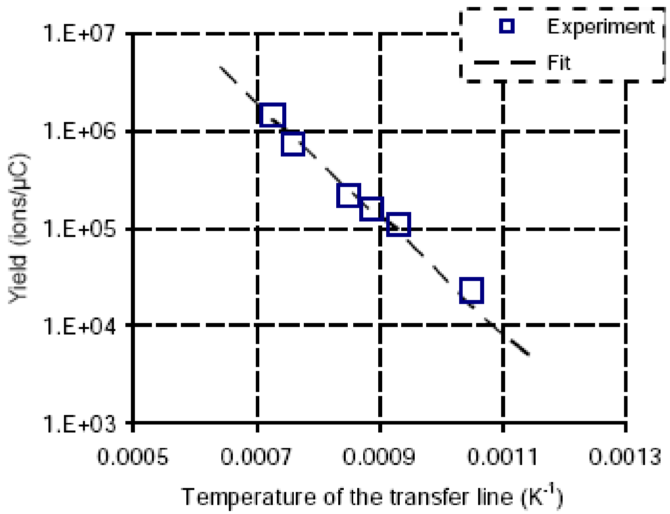






Purification of $^{80-82}$Zn&^{130}Cd beams





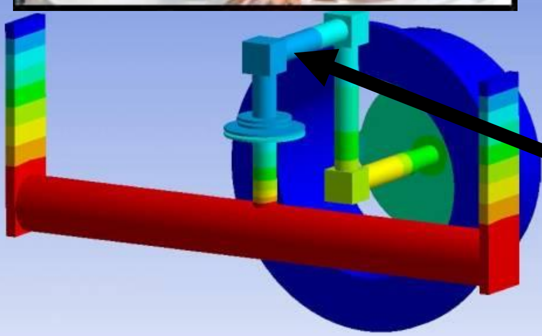
126Cs yield function of quartz temp
Fit with ΔHads = - 145 +- 20 kJ/mol
as only free parameter
Isothermal vacuum chromatography
is ca -180 kJ/mol

80Rb yield function of quartz temp
Fit with ΔHads = - 242 +- 20 kJ/mol
as only free parameter
Isothermal vacuum chromatography
is ca -270kJ/mol

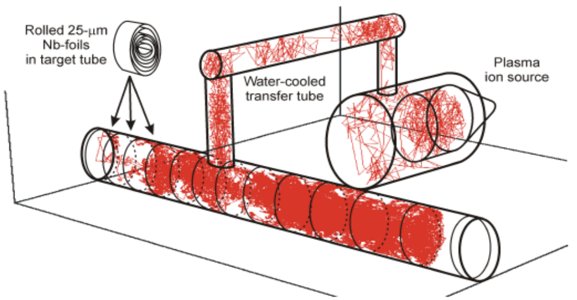
E. Bouquerel et al., Nucl Instr. Meth B266, 4298 (2008)

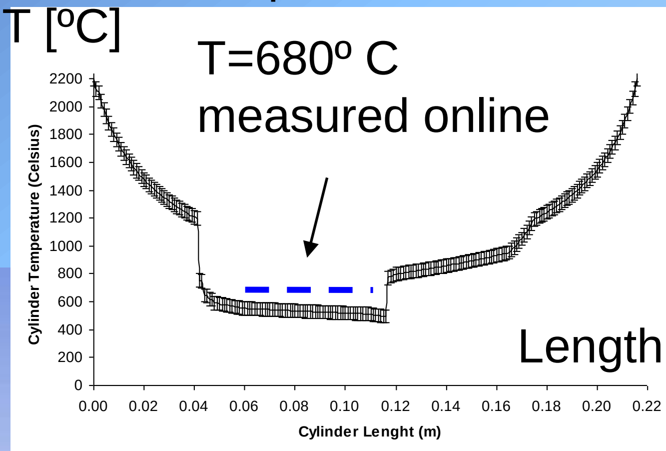
Purification by selective trapping

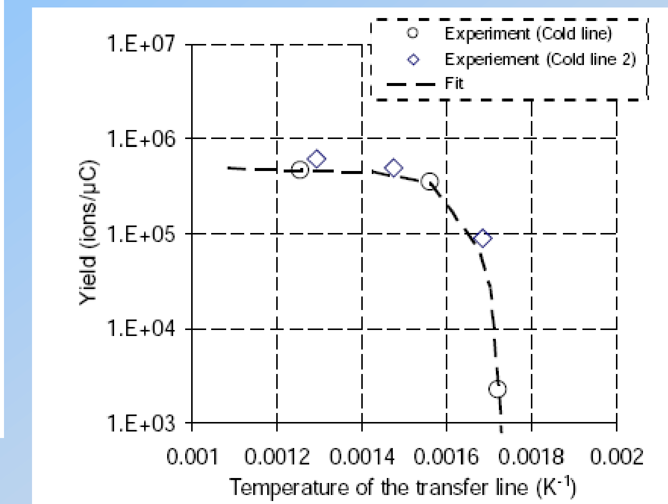
ΔT=200-1400ºC to suppress Alkalis (Cs, Rb)
for pure beams of Cd, Zn



Quartz
inserted here





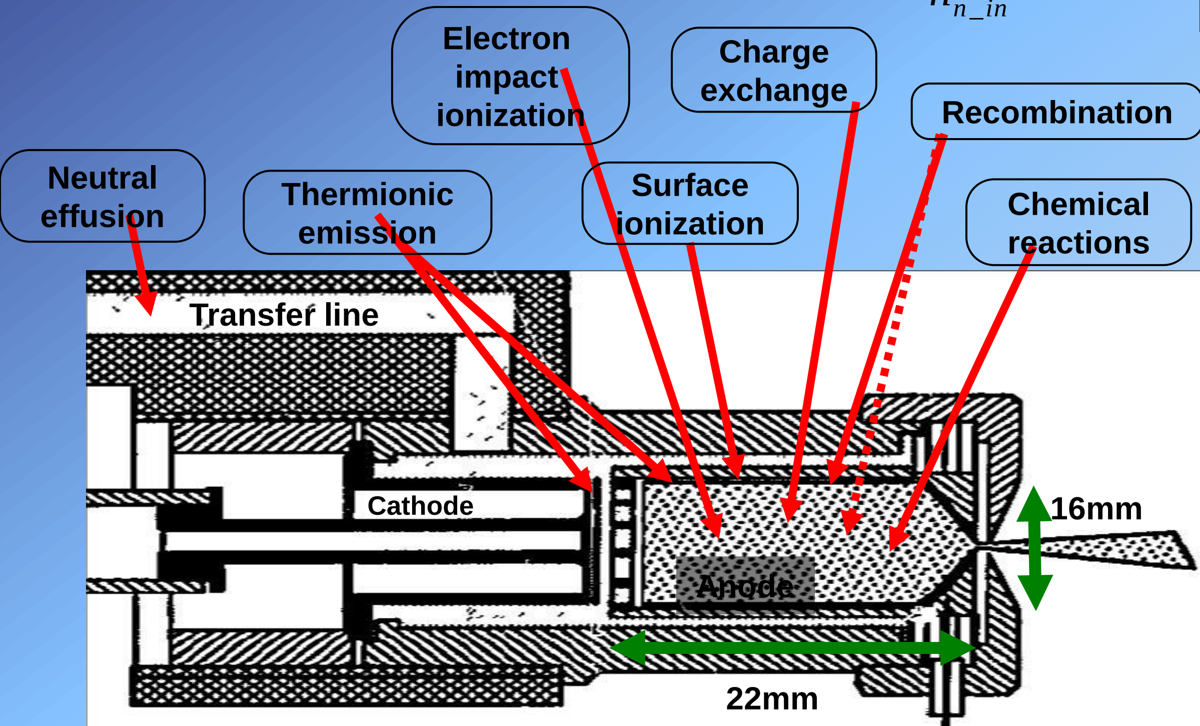


126Cs yield function of quartz temp
Fit with ΔHads = - 145 +- 20 kJ/mol
as only free parameter
Isothermal vacuum chromatography
is ca -180 kJ/mol

E. Bouquerel et al., Nucl Instr. Meth B266, 4298 (2008)

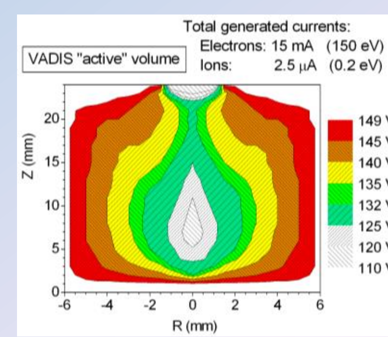
Modeling of the arc discharge plasma

$$\varepsilon = f \times \frac{V_{source} R_{ioniz}}{n_{n\_in}} \quad => \quad \varepsilon = f \times V_{source} \times \frac{n_e \times n_n \times \sigma_{ioniz} \times v_{rel}}{n_{n\_in}}$$



f = the fraction of the produced ions that are extracted before losing their charge on the ion source walls or being pumped.

- 1 electron passage;
- no ion trapping;
- T_e = 150 eV ($e \cdot V_{anode}$, initial energy);
- T_i = 0.17 eV (2300 K, thermal energy);
- n_e = temperature dependent (cathode emission given by Richardson Dushmann);
- n_n = dep. on pressure, n_{n_in}, C_{out}.



- Full cocktail of possible phenomena.
- Not all appearing all over the variation range of the operation parameters.
- Some of them can be neglected at the nominal parameters.
- Application range has been investigated (experiment vs. theory).
- Performance limitations could be pointed out, justified and removed

Yield gains with new VADIS source

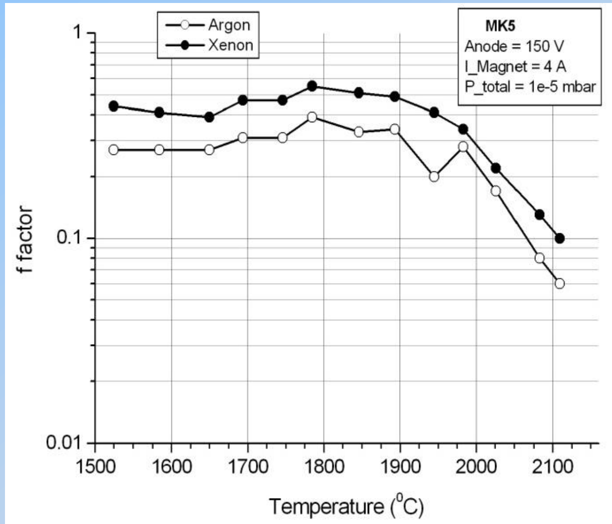
Novel VADIS ion sources

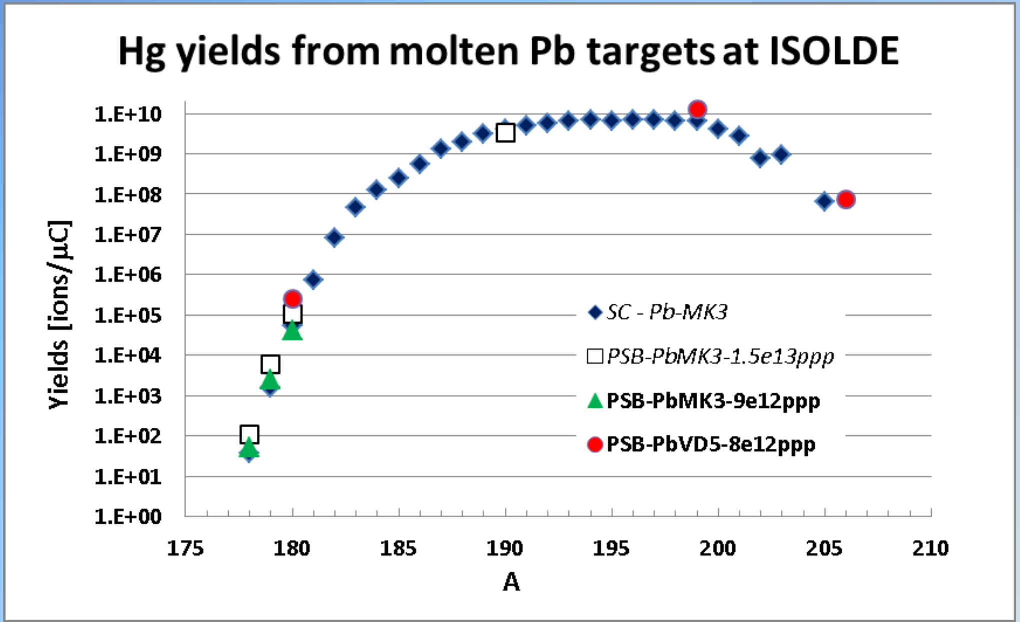
Yields on noble gases: x5-10 vs previous figures

^{229}Rn, D. Neidherr et al., Phys Rev Lett 102, 112501 (2009)

Other elements : improvements, eg Hg and Cd beams : > x5

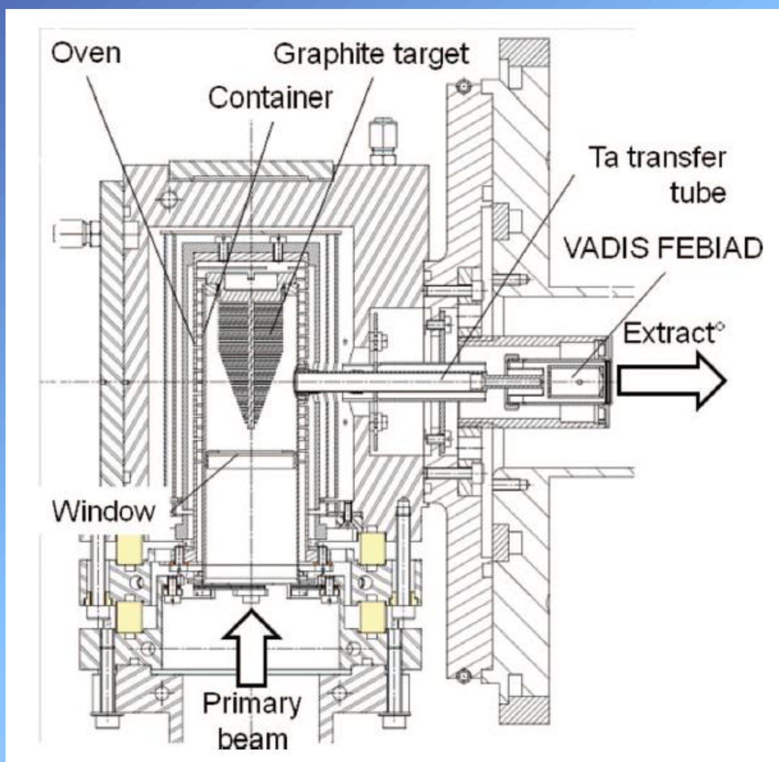
Ongoing tests of laser ion source in VADIS cavity for refractory elements

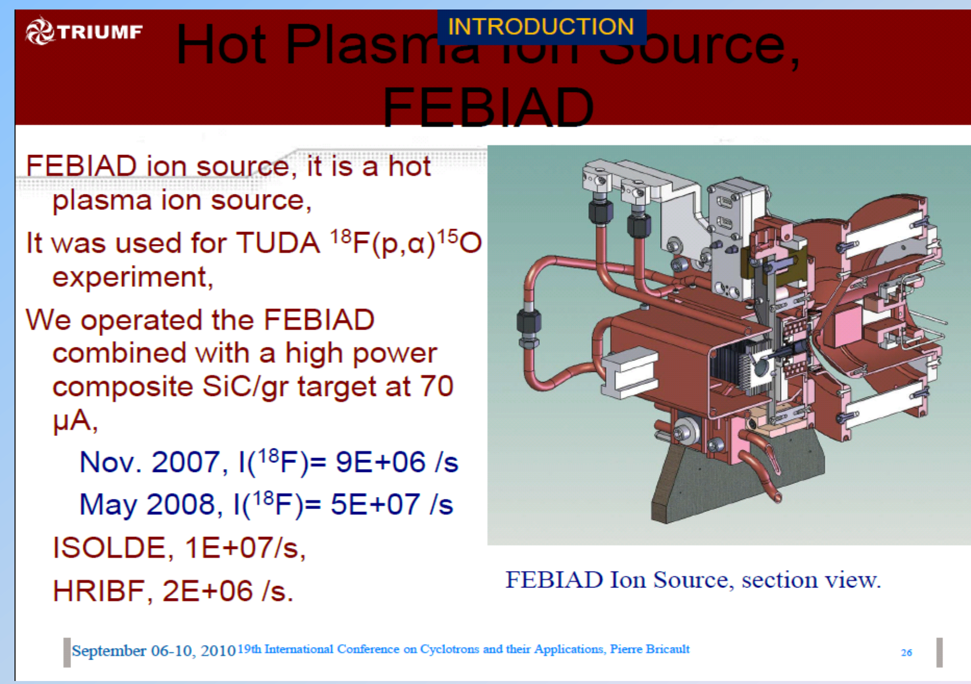




L. Penescu et al.
Rev. Sci. Instr. 81(2), 02A906 (2010)

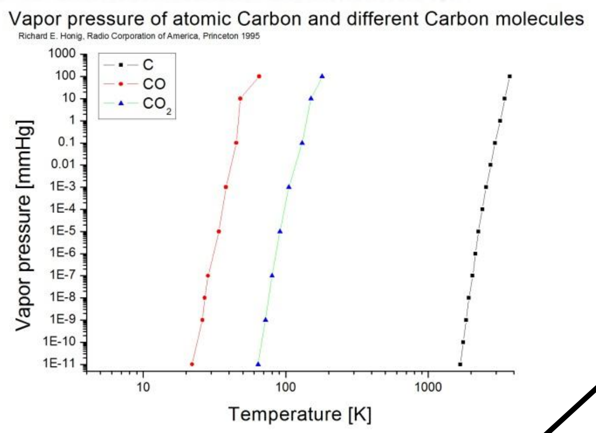
And FEBIADs elsewhere

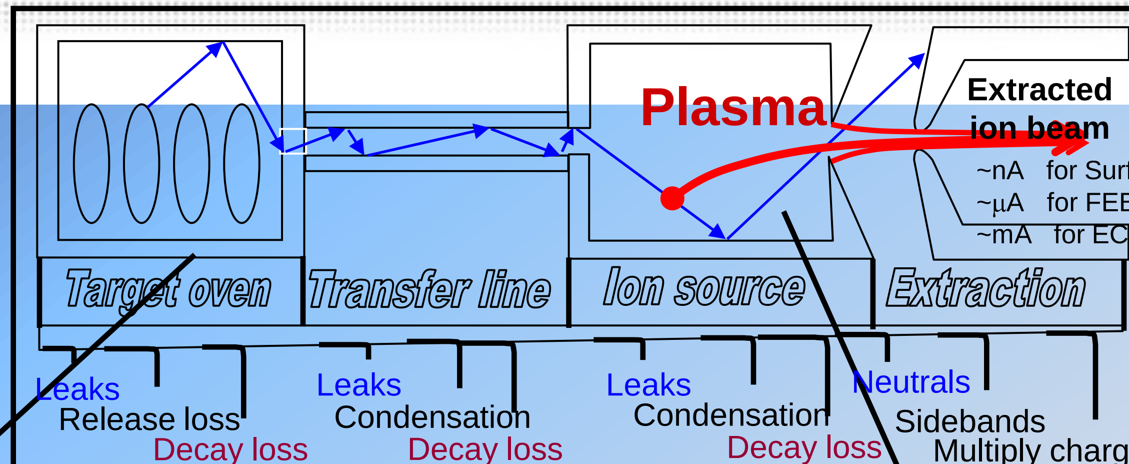


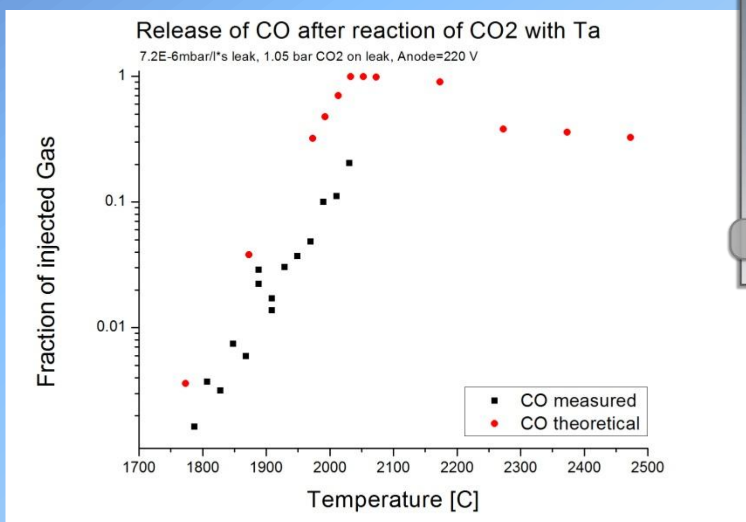


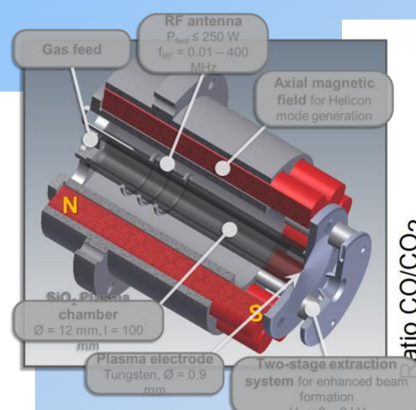
Rev. Sci. Instrum. **83**, 02A911 (2012)
Talk O. Bajeat, Wakasui-San, poster S. Essaba,)

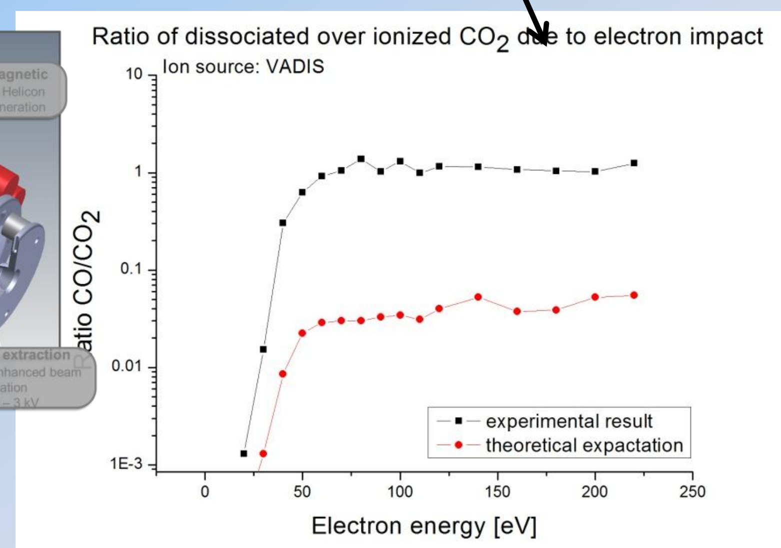
Cold plasma RF sources and chemical aspect sfor C beams as CO^+, CO_2^+







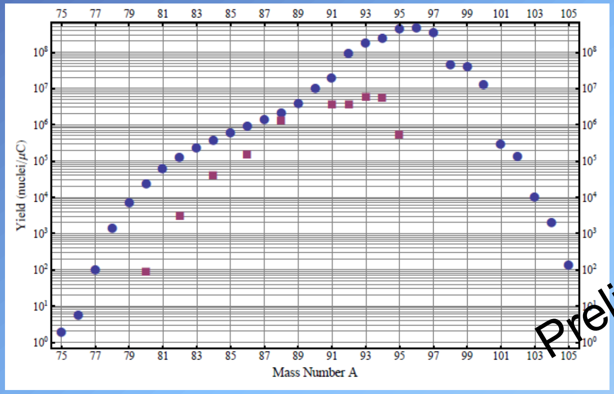




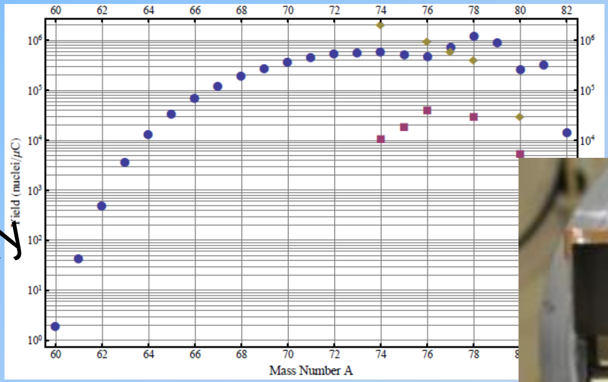
M. Kronberger, C. Seiffert et al.

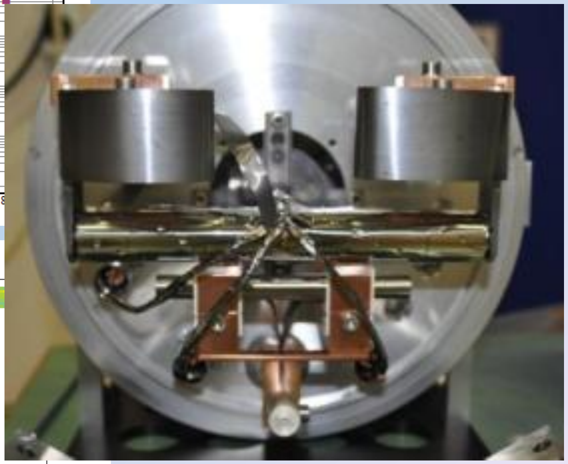
Improvement of solid spallation source for fission fragments

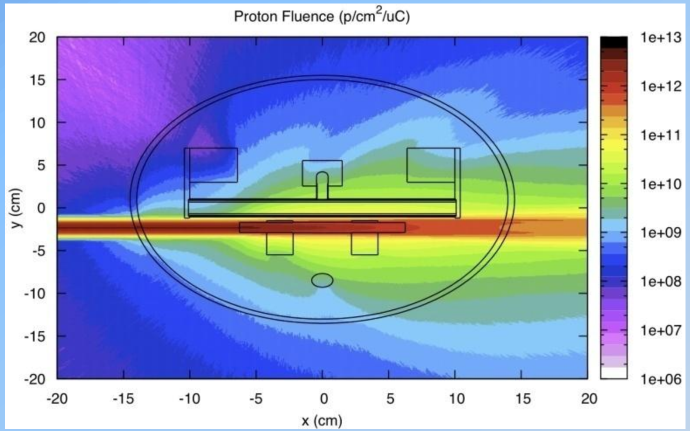
Improvement of fission product yields (for ex. ^{80}Zn, ^{130}Cd) and further reduction of isobaric contaminants (^{80}Rb, ^{130}Cs)

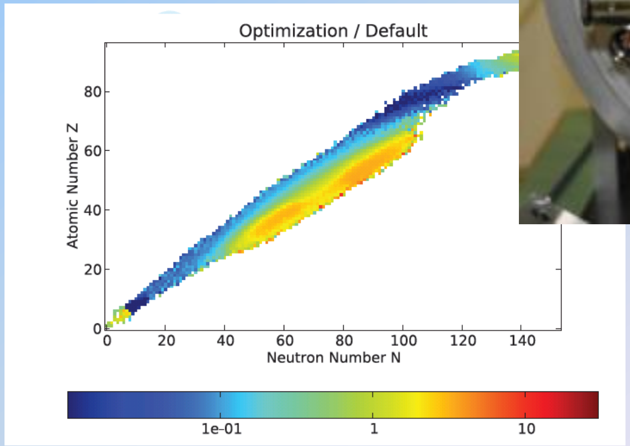


Preliminary



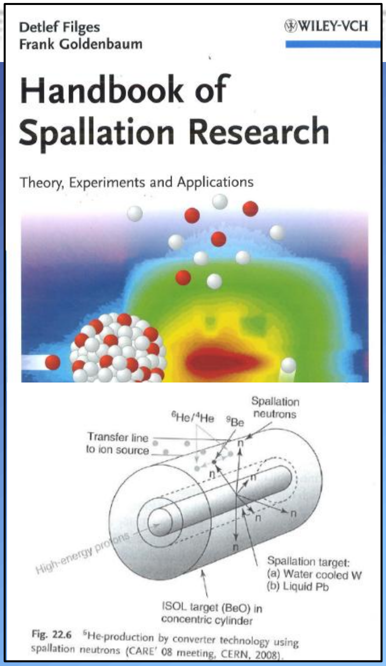




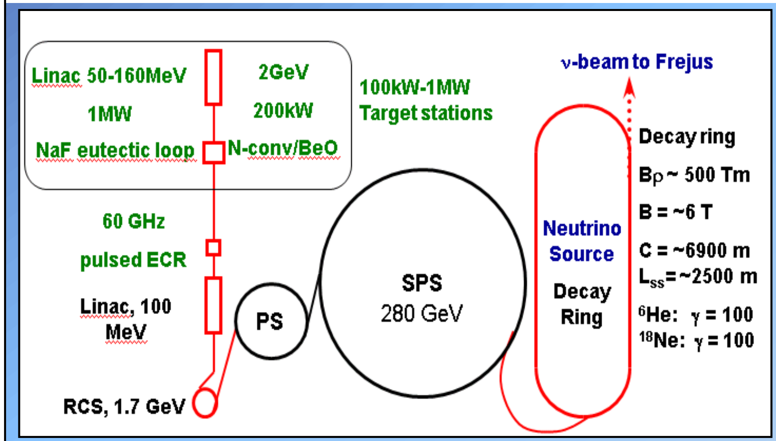


R. Luis et al.
Eur. Phys J. A
2012

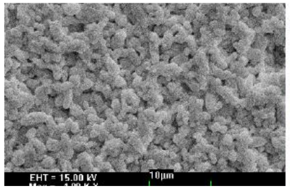
And more spallation sources: High power targets for p.μA RIBs



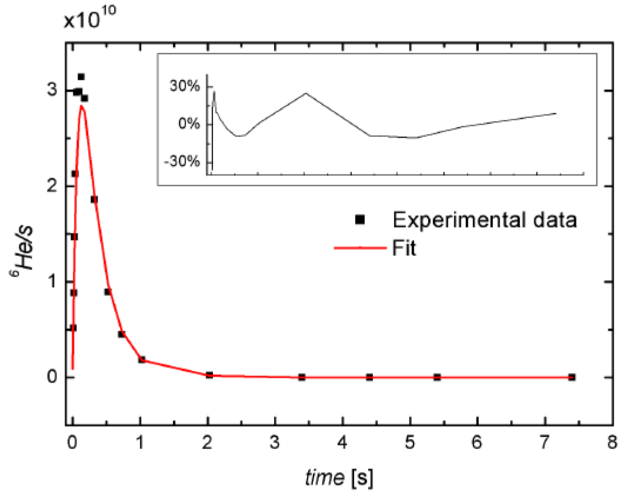
2009



$^{9}Be\ (n,\alpha)\ ^{6}He$



$$p(t) \propto p_{eff}(t) \star p_{diff}(t)$$

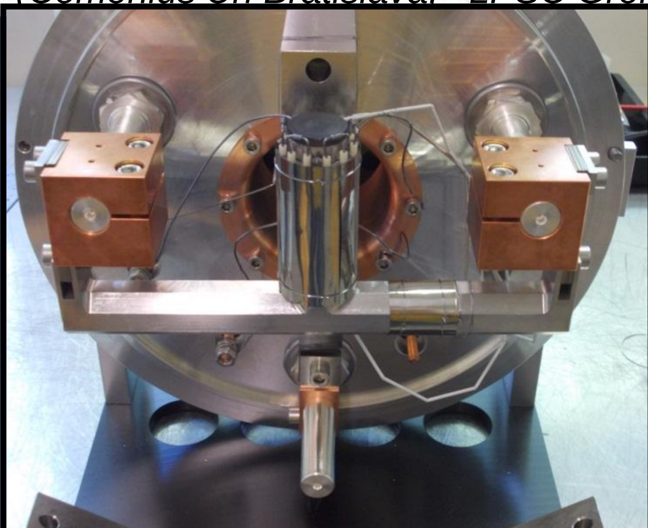


Temperature [°C]	t_{eff1} [ms]	t_{eff2} [ms]	t_{diff} [ms]	Release efficiency [%]	^{6}He production (N_0)
700	5.5	32	320	59	$2.7\ 10^{10}$
800	5.6	28	150	71	$2.6\ 10^{10}$
1000	4.7	28	1600	51	$4.1\ 10^{10}$
1130	3.3	27	190	79	$3.1\ 10^{10}$
1400	1.8	24	270	82	$2.9\ 10^{10}$

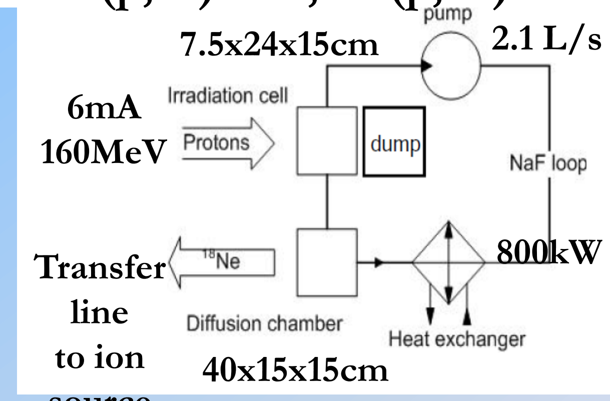
Eur. Phys. Lett. 98, 32001 (2012); Highlighted in Europhysics news

Molten salt target for β-beams 18Ne beams (ν emitter)

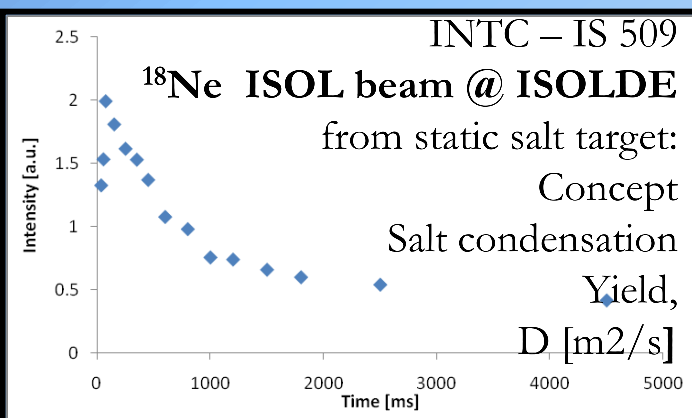
T.M. Mendonça, et al
(Comenius Un Bratislava, [3] LPSC Grenoble, [4] DPN, Univ. Genève)



$^{23}Na(p, X)^{18}Ne$, $^{19}F(p,2n)^{18}Ne$

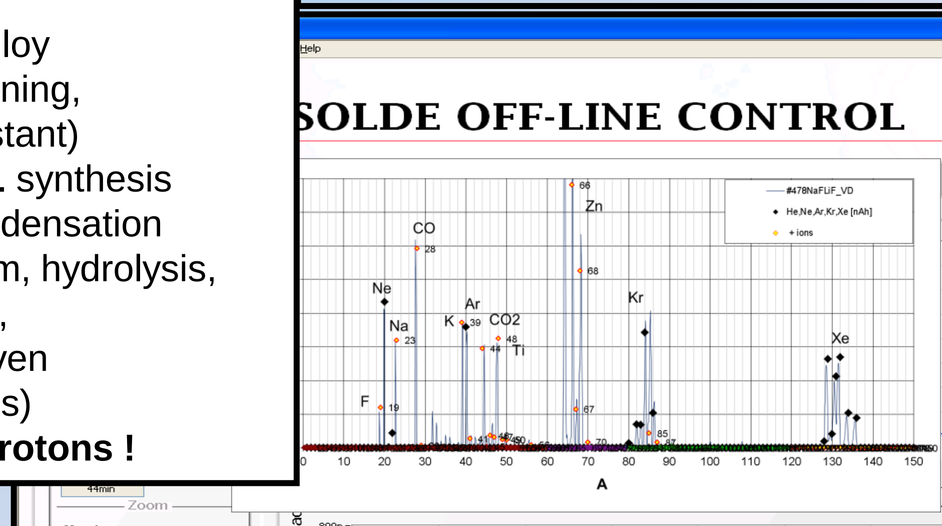


CERN-2010-03 p110



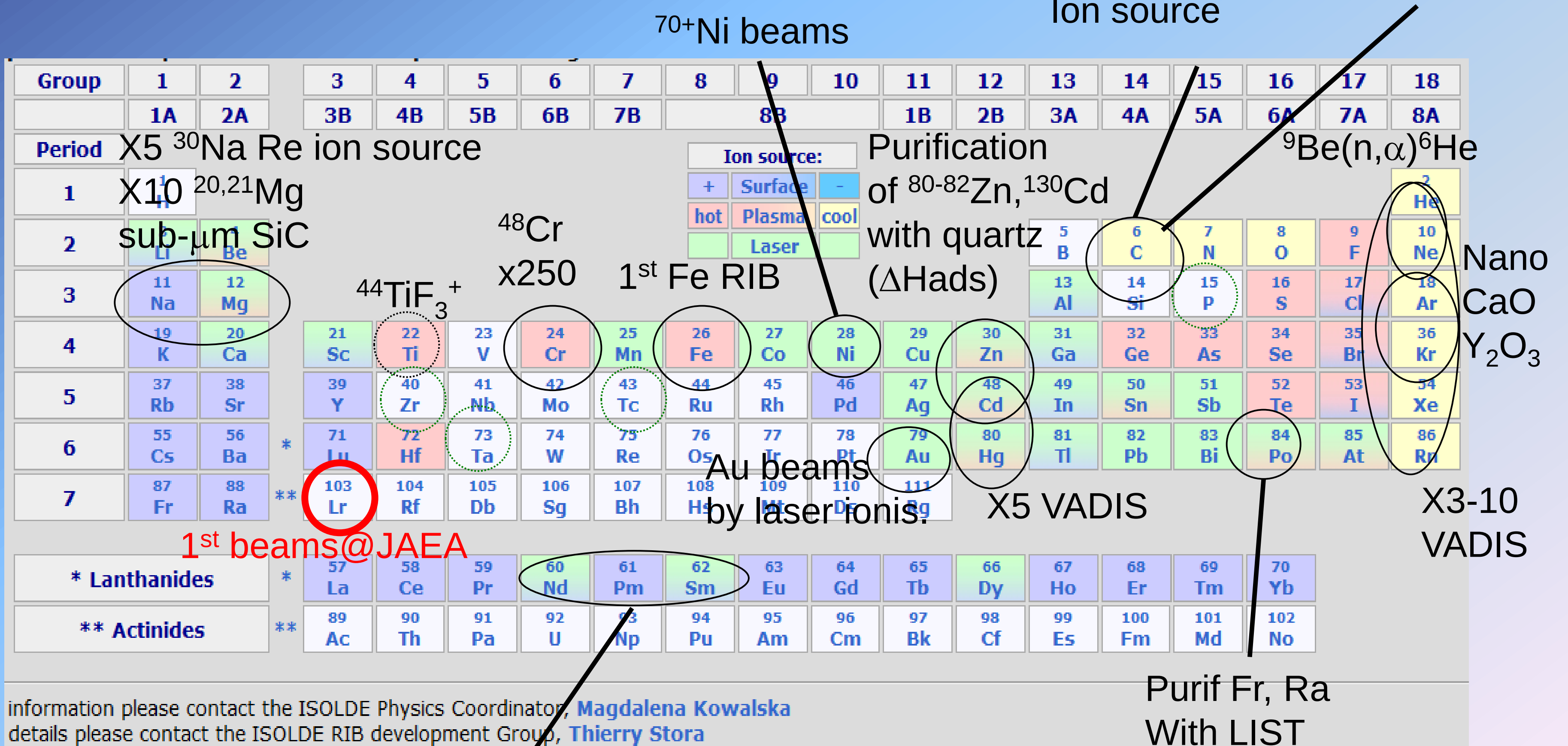
<u>Technical achievements</u>:

Haynes 242 Alloy
(special machining,
corrosion resistant)
NaFLiF eutect. synthesis
Salt vapor condensation
(phase diagram, hydrolysis,
Fluka, ANSYS,
Ta+Alumina oven
Thermocouples)
Online with Protons !



How many ISOL elements will be produced ?
Who said the yields is (only) a question of the driver power) ?

Beam evolution in the past 5 years



Purification of lanthanide beams ^{140}Nd, $^{140-142}$Sm:
GdB$_6$ ion source cavity + RILIS

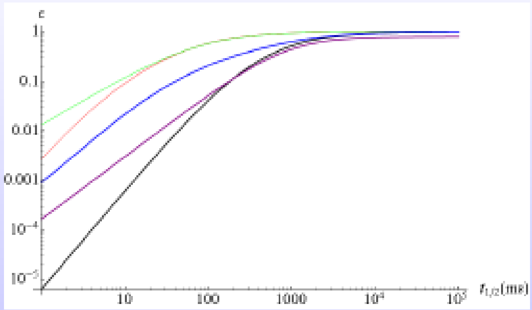
Thank you for your kind attention!

Target mass related to beam intensities

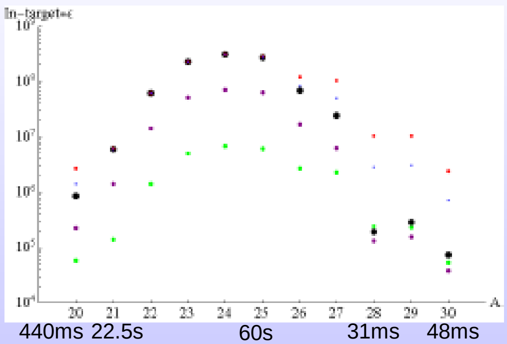
UC_x targets

- Actual stacked pressed powders
  - thickness=46 g/cm^2, W Surface Ion Source, $T_{target} = 2273\ K$, $T_{line} = 2373\ K$, 13-JUL-07
  - thickness=44 g/cm^2, W Surface Ion Source (Quartz Line), 4-OCT-06
  - thickness=46 g/cm^2, W Surface Ion Source [3]
- Stacked impregnates clothes @ SC
  - thickness=13 g/cm^2, W Surface Ion Source [1]
- Initial stacked foils
  - thickness=1 g/cm^2, $T = 1500°C$, 1st target @ PS ('60s) [2]

Release Efficiency



Na Isotope Chain Production



100 8mm diam U/C composite foils, 5-10mg/cm^2 U, tot ~1g/cm^2 U, 1600°C
(C Thibault et al., Phys Rev C, 1975)

References

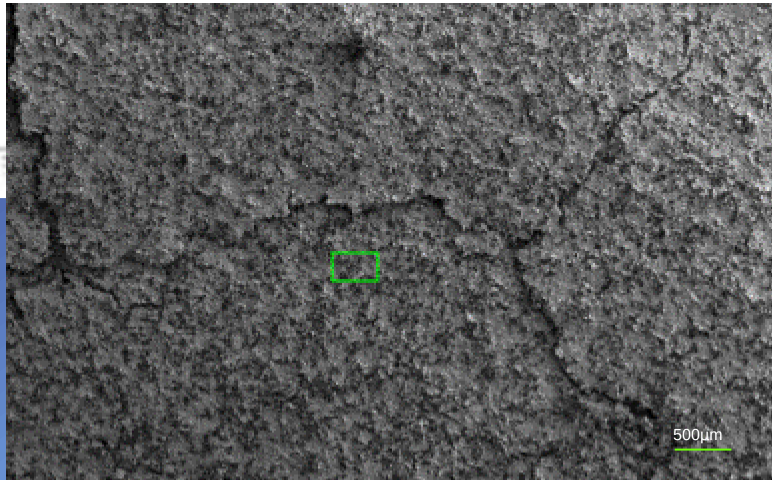
[1] S. Lukic, F. Gevaert, A. Kelic, M. V. Ricciardi, K. H. Schmidt and O. Yordanov, Nucl. Instrum. Meth. A 565 (2006) 784 [arXiv:nucl-ex/0601031].

[2] R. Klapisch, J. Chaumont, C. Philippe, I. Amarel, R. Fergeau, M. Salome, R. Bernas, Nucl. Instrum. Meth. 53 (1967) 216 [http://www.sciencedirect.com/science/article/B73DN-4DSP5KV-18/2/b385cb25e28d03a06d3e87fb754a995c]

[3] http://isolde.web.cern.ch/ISOLDE/

R. Cardinale, T. Stora
EURISOL-DS, poster final town meeting Pisa

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?!