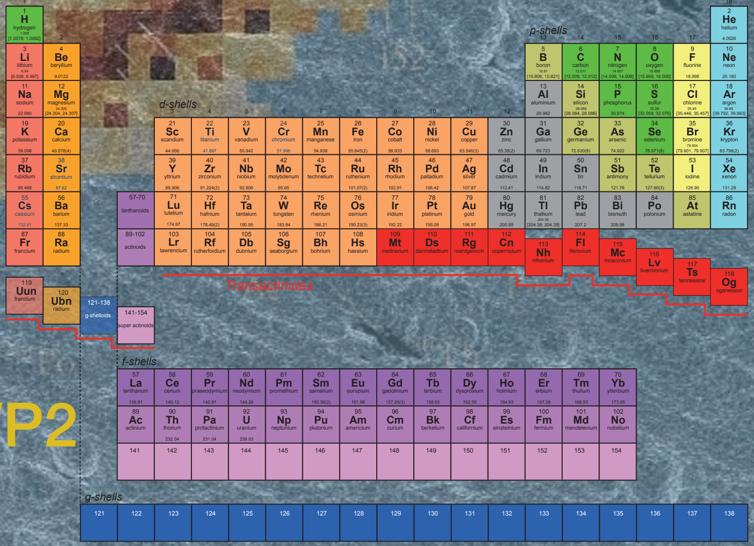
Innovative Target Backing activity @ IPHC Strasbourg

Search for specific target backing material for the highest beam intensities



EUROLABS WP2

2.5.2 Targets

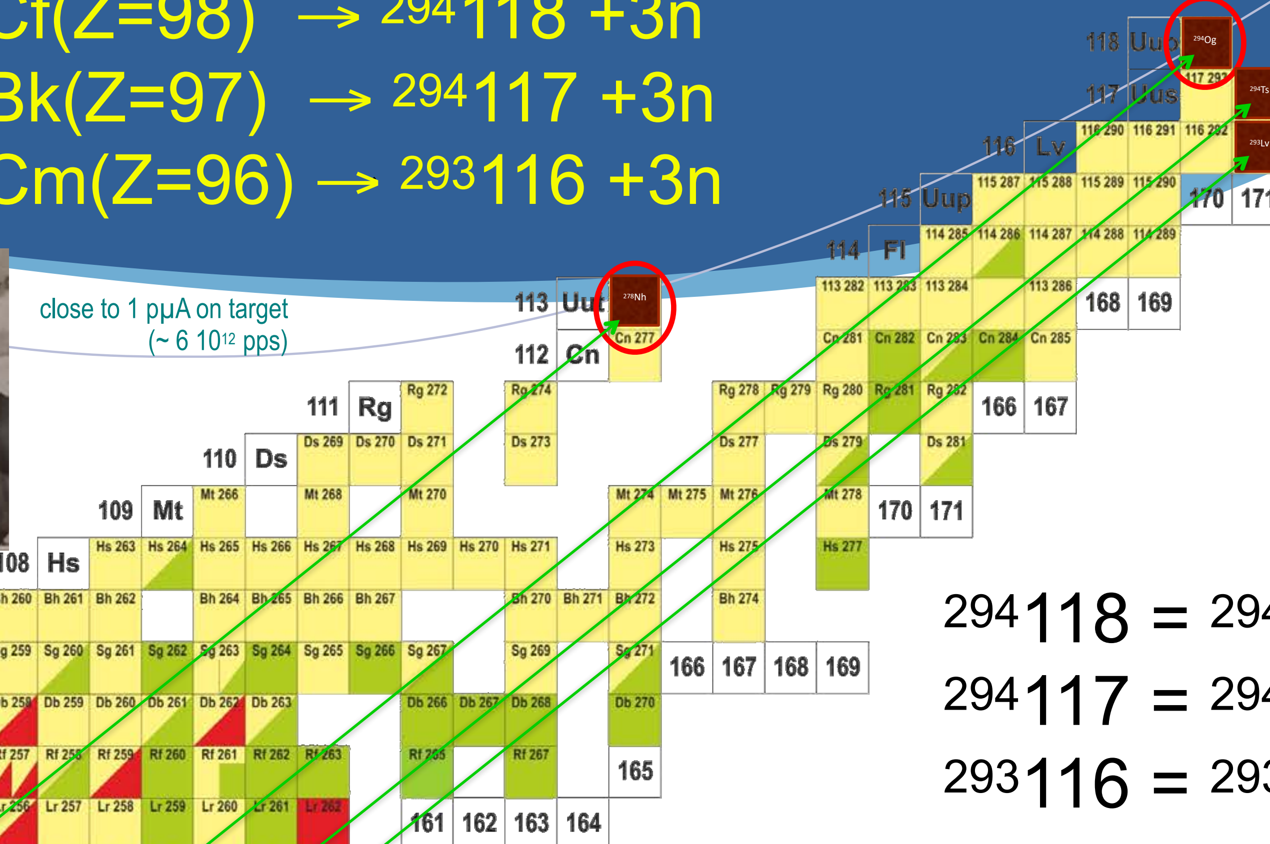
C2 targets for high intensity beams

Cold fusion $^{208}Pb/^{209}Bi$ / hot fusion ^{48}Ca

$^{48}Ca + ^{249}Cf(Z=98) \rightarrow ^{294}118 + 3n$

$^{48}Ca + ^{249}Bk(Z=97) \rightarrow ^{294}117 + 3n$

$^{48}Ca + ^{248}Cm(Z=96) \rightarrow ^{293}116 + 3n$

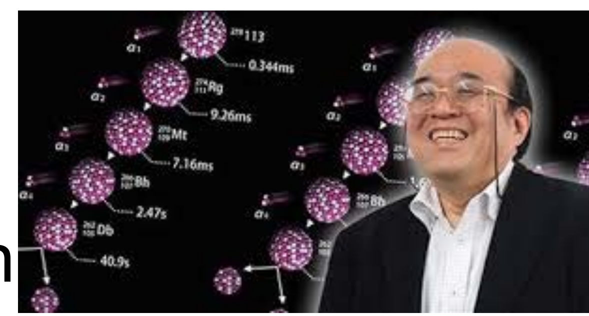


$^{294}118 = ^{294}Og$

$^{294}117 = ^{294}Ts$

$^{293}116 = ^{293}Lv$

$^{278}113 = ^{278}Nh$



$^{70}Zn + ^{209}Bi(Z=83) \rightarrow ^{278}113 + 1n$

IPHC Institut Pluridisciplinaire Hubert CURIEN STRASBOURG

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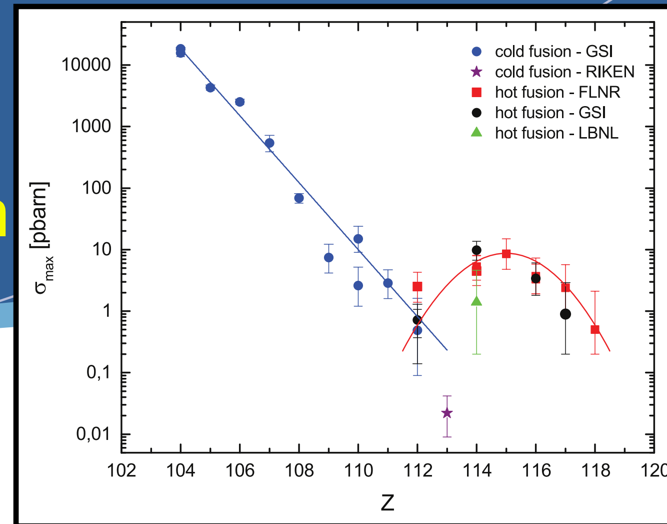

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89 **Ac** actinium	90 **Th** thorium 232.04	91 **Pa** protactinium 231.04	92 **U** uranium 238.03	93 **Np** neptunium	94 **Pu** plutonium	95 **Am** americium	96 **Cm** curium	97 **Bk** berkelium	98 **Cf** californium	99 **Es** einsteinium	100 **Fm** fermium	101 **Md** mendelevium	102 **No** nobelium

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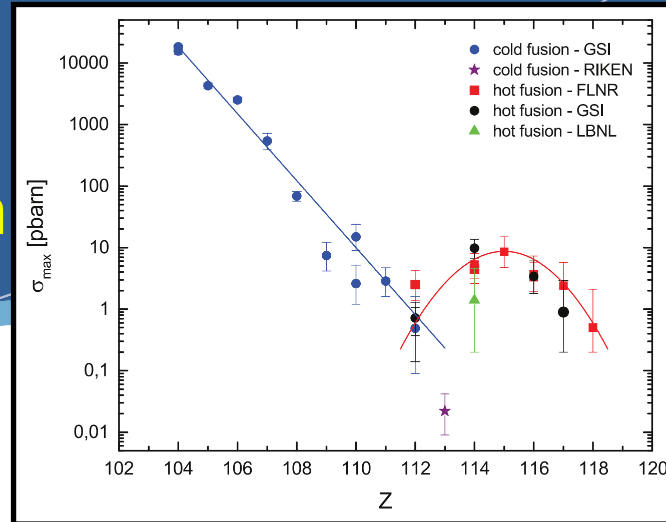

Key:

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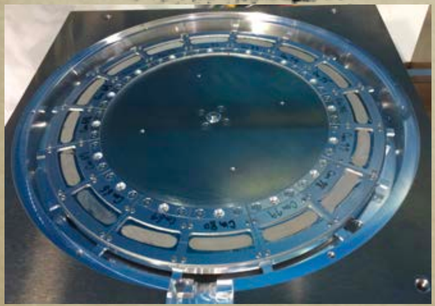
Rare material targets

Target material for SHE



^{248}Cm …

40 mg /wheel (6 M€)

… Rare material

Cannot simply extend the radius of the target wheel

Inventories of selected actinide isotopes at ORNL

(from High flux reactor)

Isotope	Approximate amount (mg)	Isotopic %	Notes
Pu 242	5500	>99%	
Pu 244	2750	Various	650 mg at 8.7%, 2100 mg at 17.8%
Am 241	3500	>99%	
Am 243	1000	>99%	
Cm 244	1000	>90%	
Cm 248	2500	Various	90 mg at > 95%, 1700 mg at > 90%
Bk 249	—	>99%	Requires HFIR production and chemical processing (~20 milligrams per campaign)
Cf 249	170	>99%	
Cf 251	90	10-40%	Requires chemical processing and isotopic separation

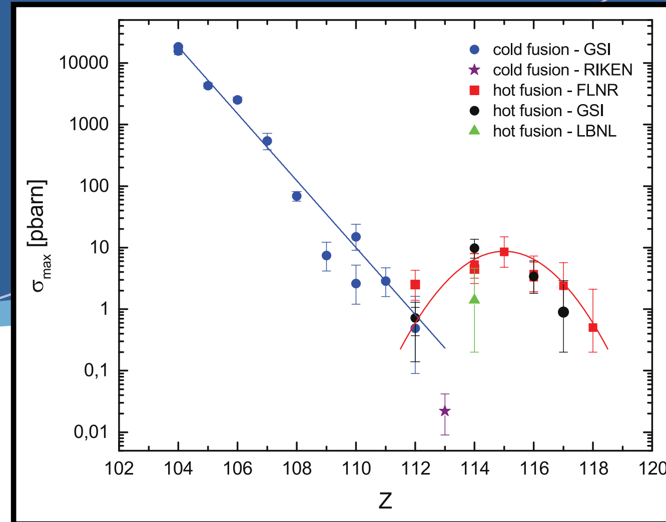
First ^{254}Es target (a few μg) in 2019

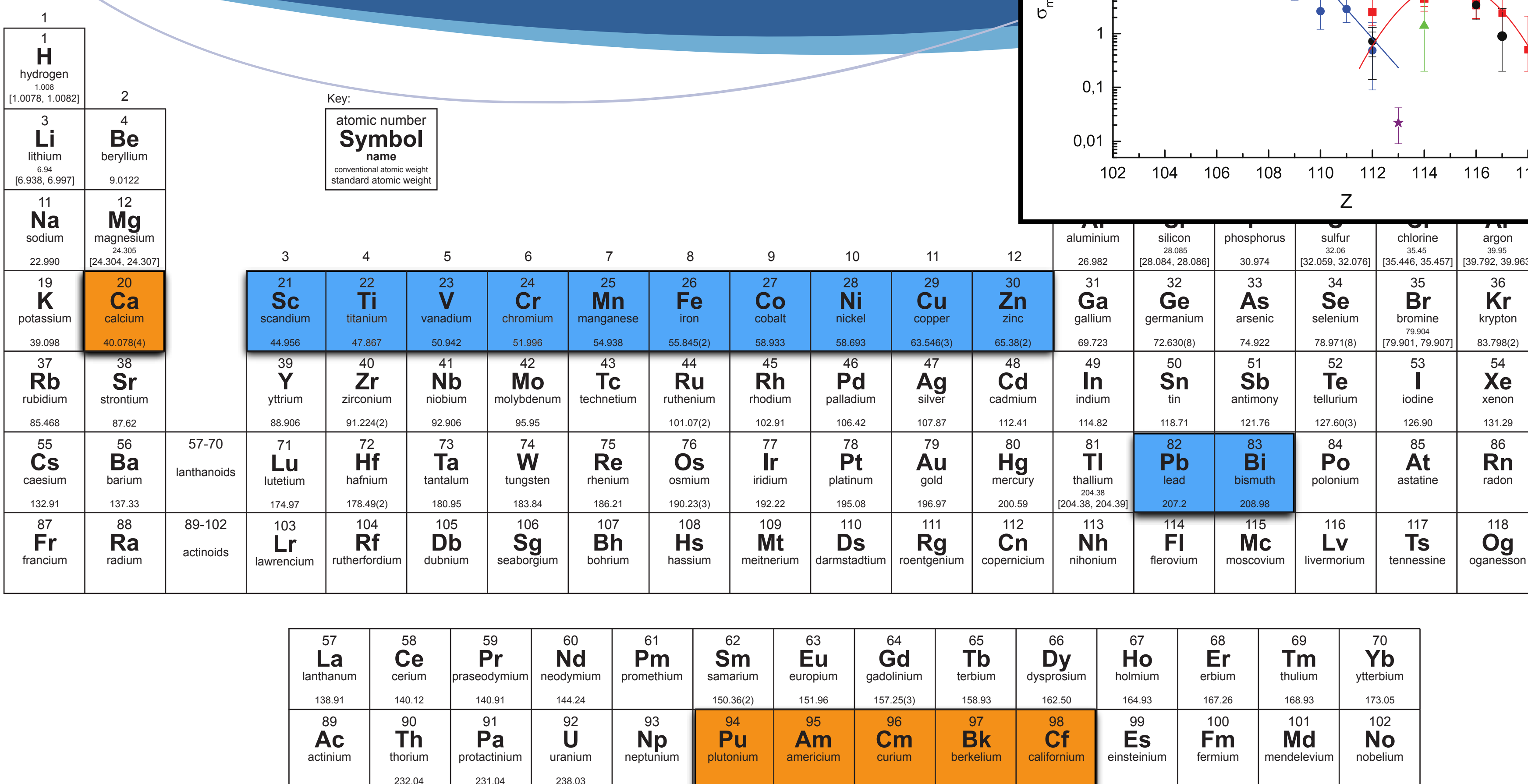
Einsteinium (Z=99) & Fermium (Z=100) targets will need new concepts of targets

Courtesy from J. ROBERTO (ORNL)

Heaviest elements done with ^{48}Ca + actinides …

close to 1 pμA on target (~ 6 10^{12} pps)





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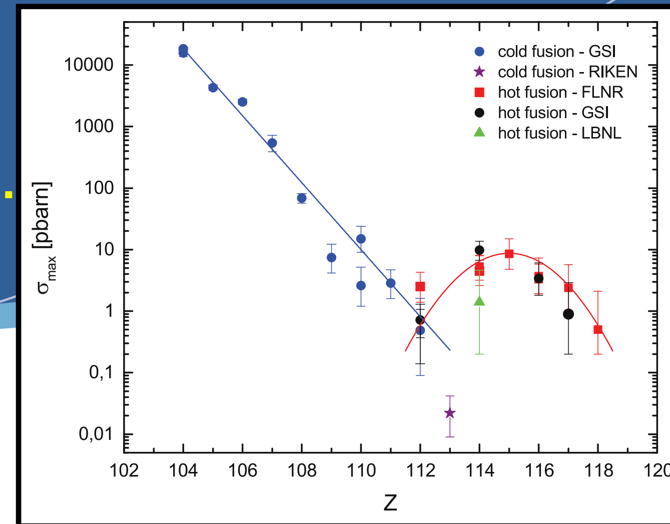

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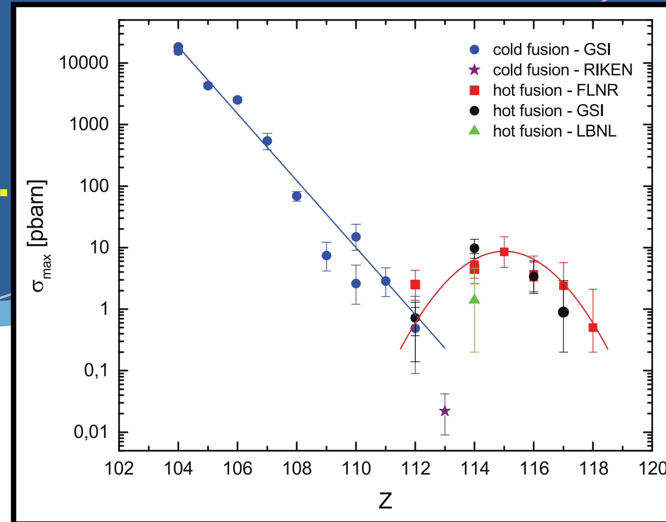

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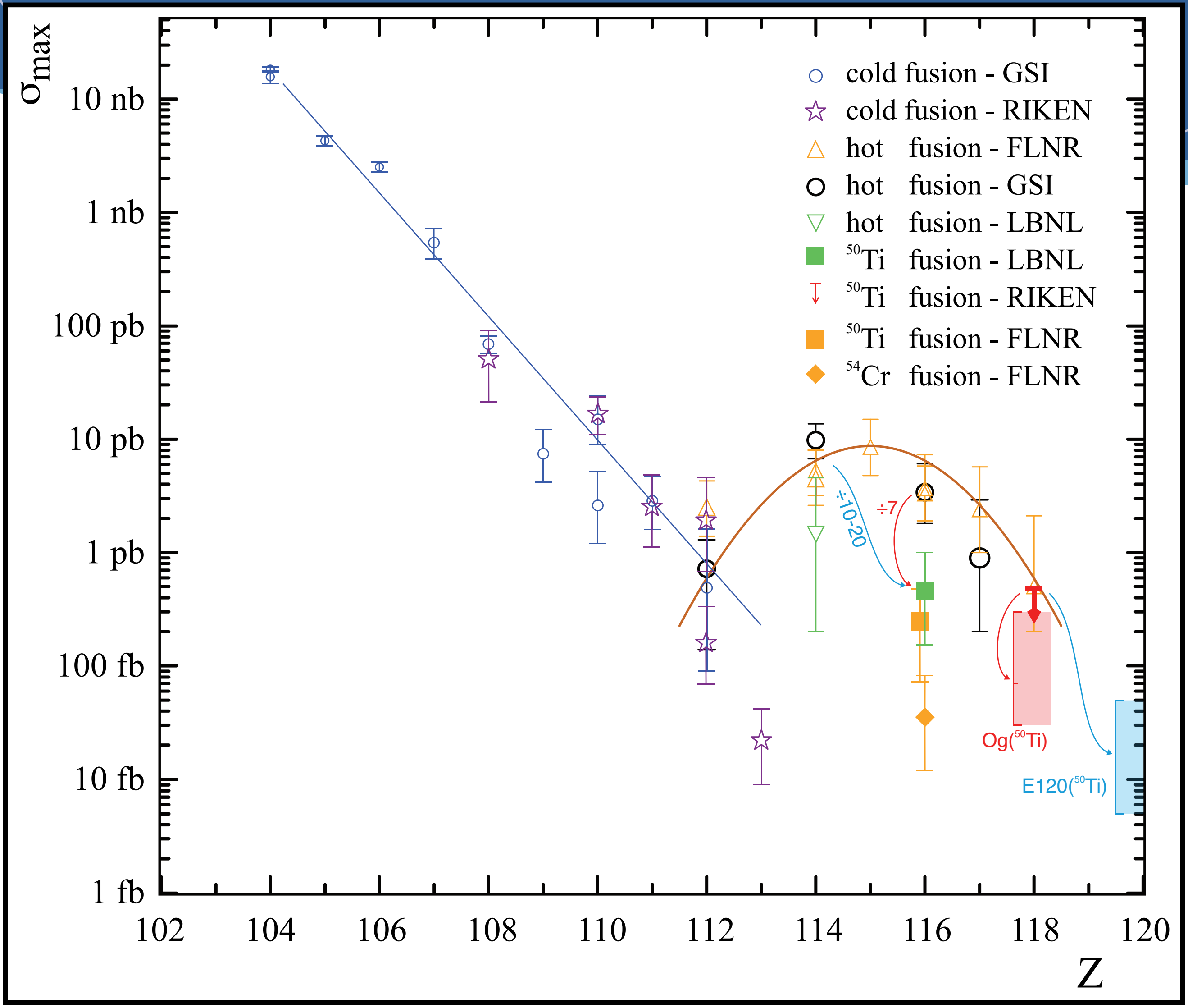
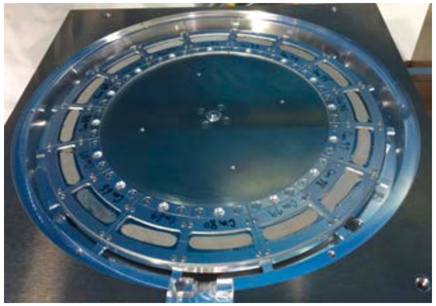
... AND HIGHER INTENSITIES

Heaviest elements done with ^{48}Ca + actinides …

Cross sections drops … => compensate buy intensity…





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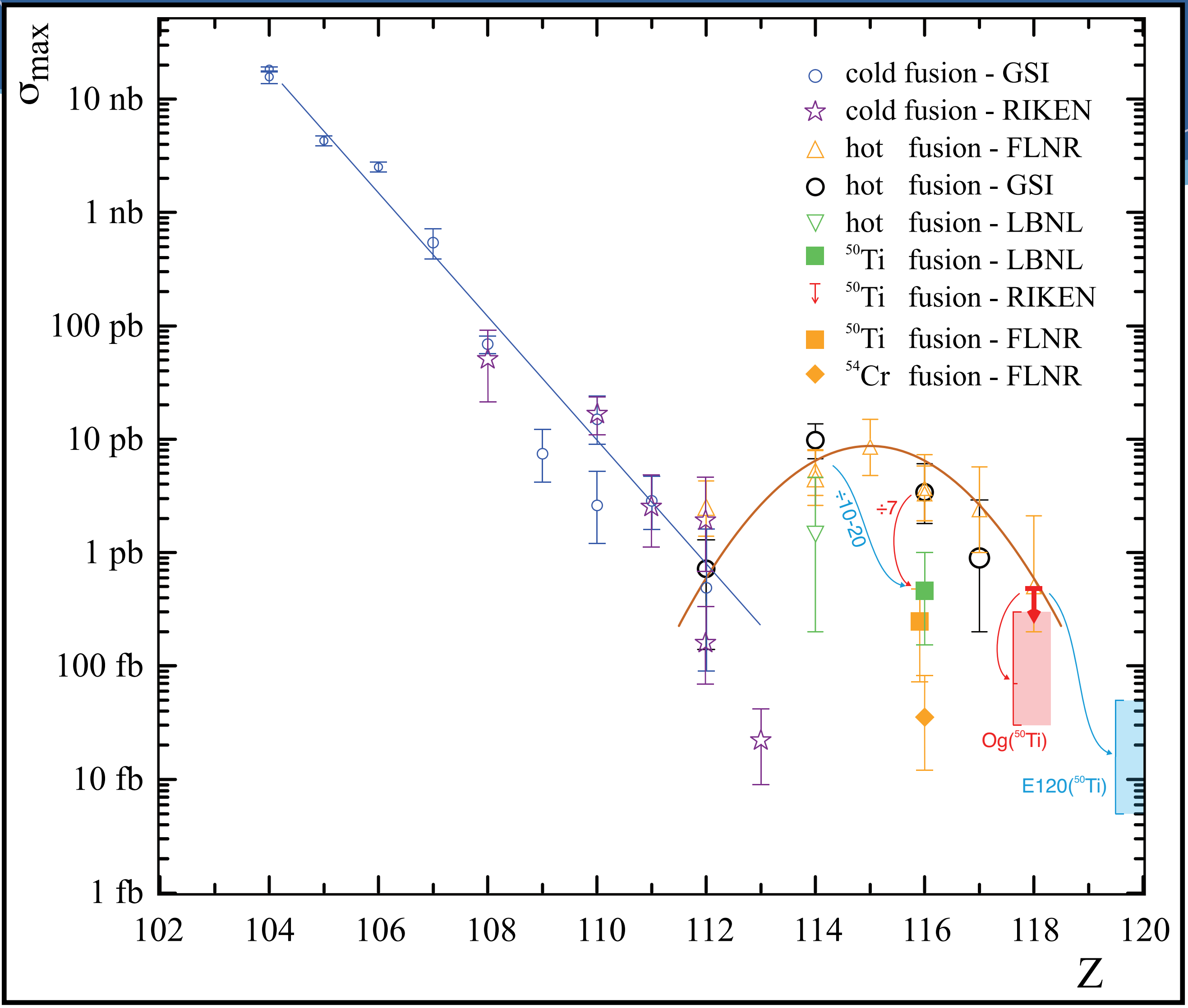
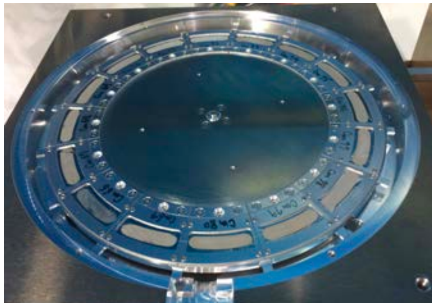
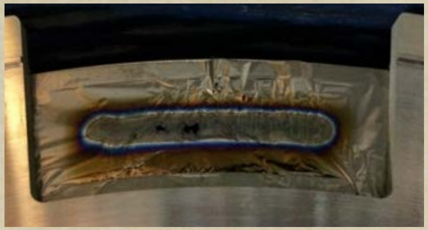


High intensity metallic beams



=> Bigger target wheels !

EURO-LABS Task 2.5 - C2 @ IPHC : HT target backings

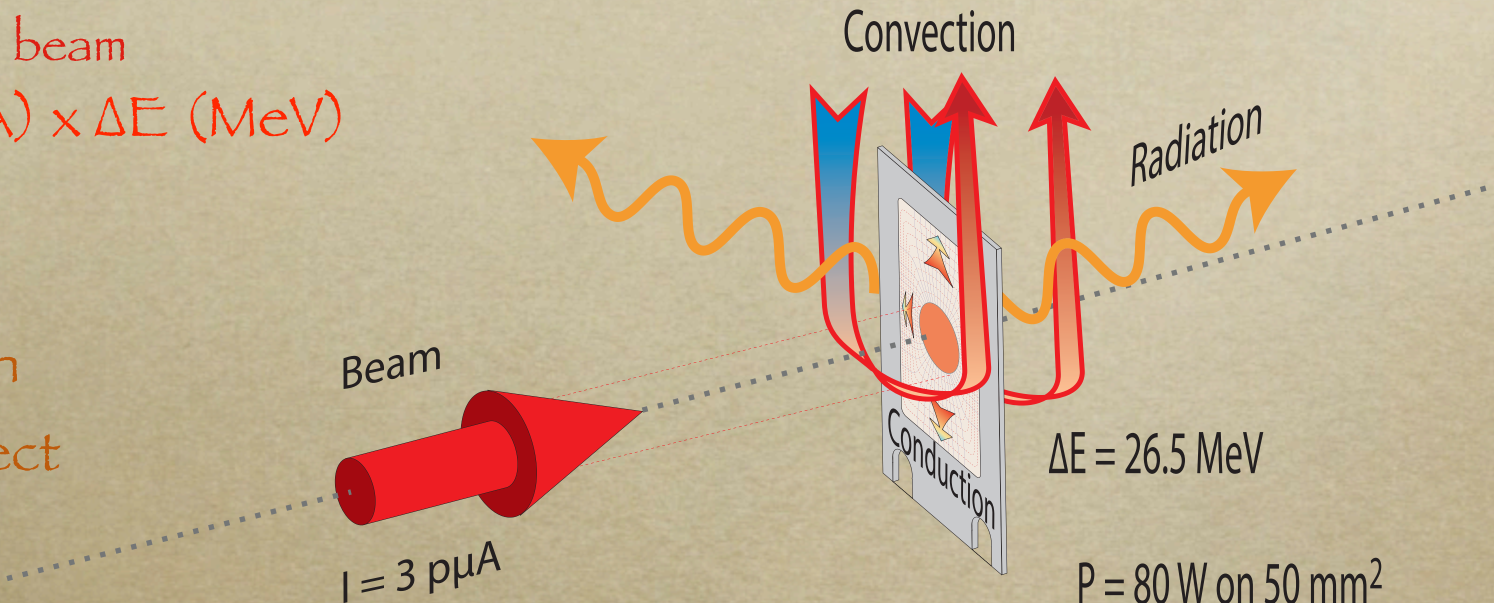


Power brought by beam

P (W) = I (pμA) x ΔE (MeV)

Power dissipation

- Radiation
- Conduction
- He gas effect



-> Higher stress/strain material

-> Higher conductivity (Graphene ...)

Need of new generation of foil material

Need of real conditons test beam

Innovative Materials sustaining extreme beams for rare Targets

IPHC Institut Pluridisciplinaire Hubert CURIEN STRASBOURG

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3 Li lithium 6.94 [6.938, 6.997]	4 Be beryllium 9.0122												5 B boron 10.81 [10.806, 10.821]	6 C carbon 12.011 [12.009, 12.012]	7 N nitrogen 14.007 [14.006, 14.008]	8 O oxygen 15.999 [15.999, 16.000]	9 F fluorine 18.998	10 Ne neon 20.180
11 Na sodium 22.990	12 Mg magnesium 24.305 [24.304, 24.307]												13 Al aluminium 26.982	14 Si silicon 28.085 [28.084, 28.086]	15 P phosphorus 30.974	16 S sulfur 32.06 [32.059, 32.076]	17 Cl chlorine 35.45 [35.446, 35.457]	18 Ar argon 39.95 [39.792, 39.963]
19 K potassium 39.098	20 Ca calcium 40.078(4)		21 Sc scandium 44.956	**22 Ti titanium 47.867**	23 V vanadium 50.942	24 Cr chromium 51.996	25 Mn manganese 54.938	26 Fe iron 55.845(2)	27 Co cobalt 58.933	28 Ni nickel 58.693	29 Cu copper 63.546(3)	30 Zn zinc 65.38(2)	31 Ga gallium 69.723	32 Ge germanium 72.630(8)	33 As arsenic 74.922	34 Se selenium 78.971(8)	35 Br bromine 79.904 [79.901, 79.907]	36 Kr krypton 83.798(2)
37 Rb rubidium 85.468	38 Sr strontium 87.62		39 Y yttrium 88.906	40 Zr zirconium 91.224(2)	41 Nb niobium 92.906	42 Mo molybdenum 95.95	43 Tc technetium	44 Ru ruthenium 101.07(2)	45 Rh rhodium 102.91	46 Pd palladium 106.42	47 Ag silver 107.87	48 Cd cadmium 112.41	49 In indium 114.82	50 Sn tin 118.71	51 Sb antimony 121.76	52 Te tellurium 127.60(3)	53 I iodine 126.90	54 Xe xenon 131.29
55 Cs caesium 132.91	56 Ba barium 137.33	57-70 lanthanoids	71 Lu lutetium 174.97	72 Hf hafnium 178.49(2)	73 Ta tantalum 180.95	74 W tungsten 183.84	75 Re rhenium 186.21	76 Os osmium 190.23(3)	77 Ir iridium 192.22	78 Pt platinum 195.08	79 Au gold 196.97	80 Hg mercury 200.59	81 Tl thallium 204.38 [204.38, 204.39]	82 Pb lead 207.2	83 Bi bismuth 208.98	84 Po polonium	85 At astatine	86 Rn radon
87 Fr francium	88 Ra radium	89-102 actinoids	103 Lr lawrencium	104 Rf rutherfordium	105 Db dubnium	106 Sg seaborgium	107 Bh bohrium	108 Hs hassium	109 Mt meitnerium	110 Ds darmstadtium	111 Rg roentgenium	112 Cn copernicium	113 Nh nihonium	114 Fl flerovium	115 Mc moscovium	116 Lv livermorium	117 Ts tennessine	118 Og oganesson

Key: atomic number **Symbol** name conventional atomic weight standard atomic weight

57 La lanthanum 138.91	58 Ce cerium 140.12	59 Pr praseodymium 140.91	60 Nd neodymium 144.24	61 Pm promethium	62 Sm samarium 150.36(2)	63 Eu europium 151.96	64 Gd gadolinium 157.25(3)	65 Tb terbium 158.93	66 Dy dysprosium 162.50	67 Ho holmium 164.93	68 Er erbium 167.26	69 Tm thulium 168.93	70 Yb ytterbium 173.05
89 Ac actinium	90 Th thorium 232.04	91 Pa protactinium 231.04	92 U uranium 238.03	93 Np neptunium	94 Pu plutonium	95 Am americium	96 Cm curium	97 Bk berkelium	98 Cf californium	99 Es einsteinium	100 Fm fermium	101 Md mendelevium	102 No nobelium

For notes and updates to this table, see www.iupac.org. This version is dated 1 December 2 018.

cnrs INC INEE IN2P3

Université de Strasbourg

PURE TI FOILS

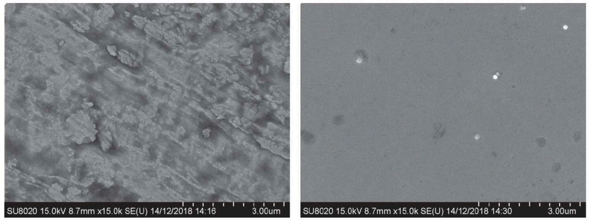
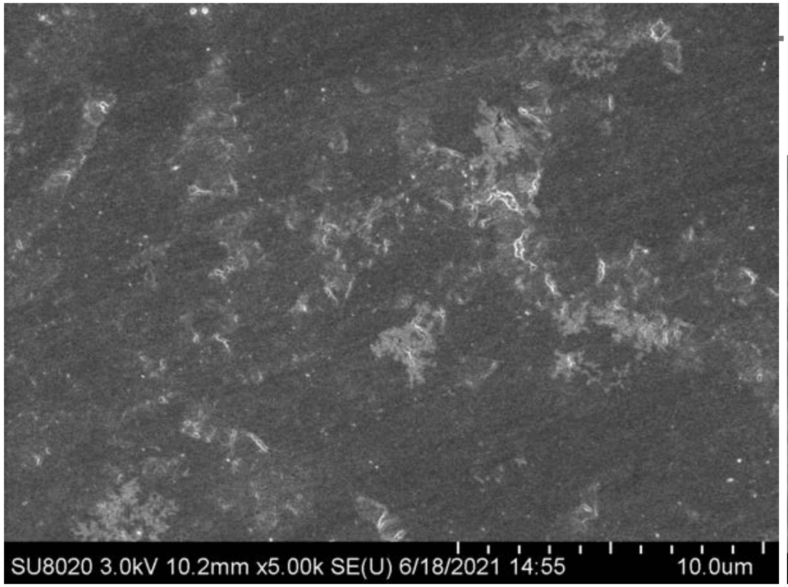
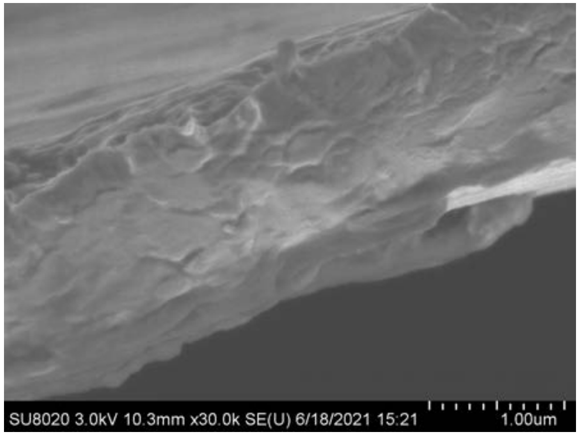


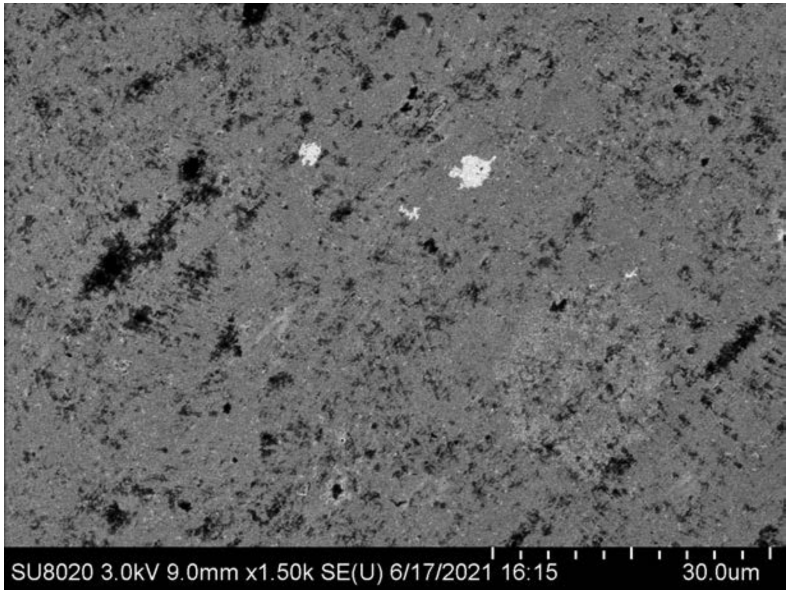
Figure 5. Left panel – scanning electron micrographs of the fresh Ti foil taken from a roll. Right panel – a similar foil after irradiation by 7.9×10^{17} ion/cm^2 beam-dose density of 5.5 MeV/u ^{48}Ca ions (taken from Set #12).

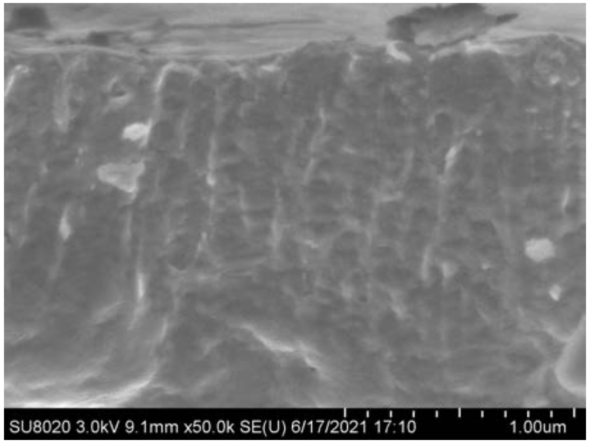
Ti Dubna

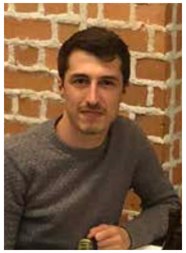




Ti STREM

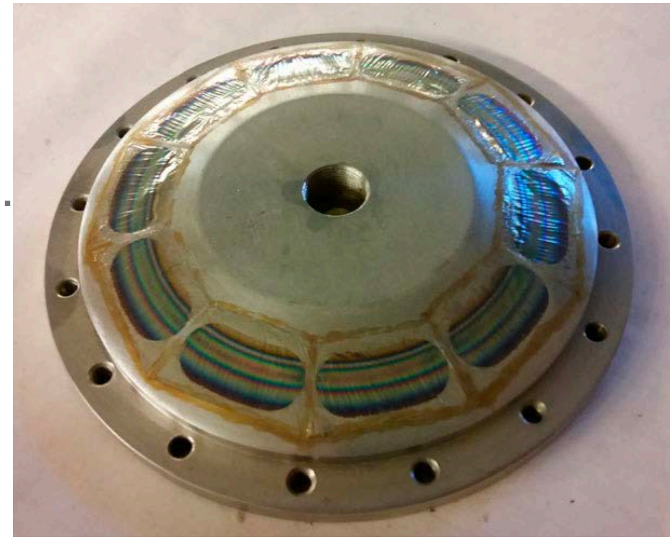






Thanks to Vladimir Skuratov, Oleg Orelovich, Ekaterina Korneeva, Nikolay Lizunov FLNR Sector 8

IS EFFECT OF HEAT ONLY BAD ?



RADIATION EFFECTS & DEFECTS IN SOLIDS
2020, VOL. 175, NOS. 7–8, 704–718
https://doi.org/10.1080/10420150.2020.1756813

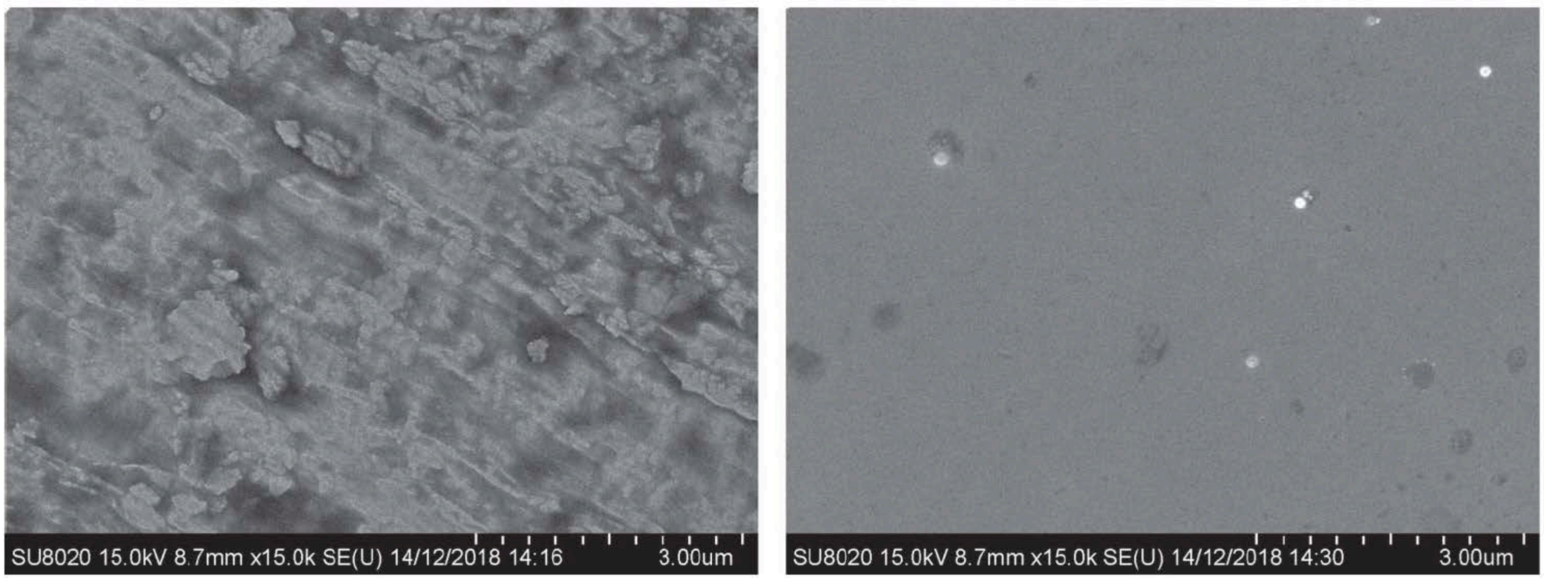
Taylor & Francis
Taylor & Francis Group

Check for updates

Modification of Ti foils irradiated by intense heavy ion beams

R. N. Sagaidak, F. Sh. Abdullin and O. L. Orelovich

Flerov Laboratory of Nuclear Reactions, Joint Institute for Nuclear Research, Dubna, Russia



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Thermal effects

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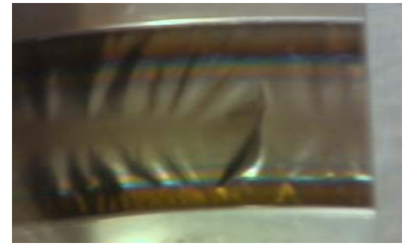
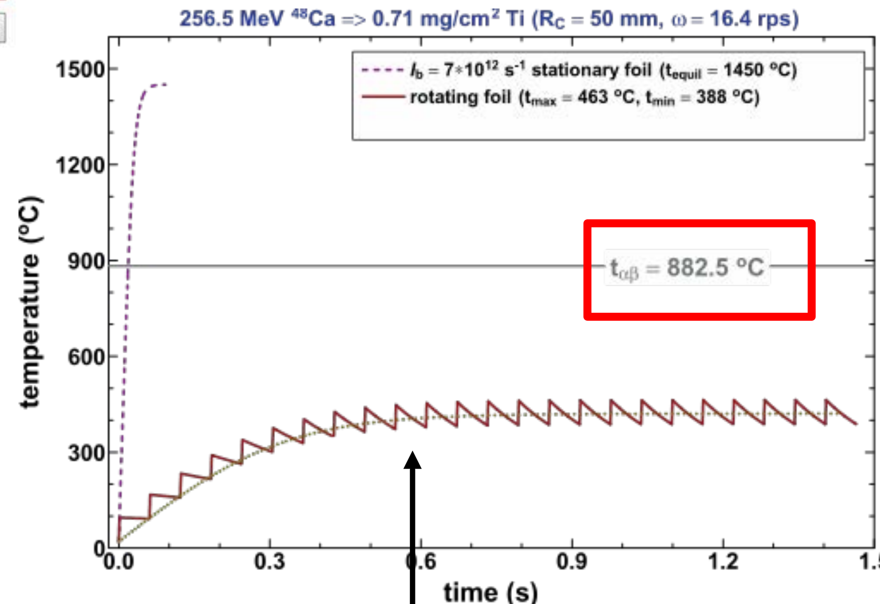
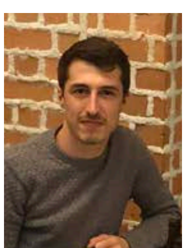
- Pure Titanium α/β phase transition : T=882,5°C
- 1 pμA → microscopic T° α/β cross → deformation

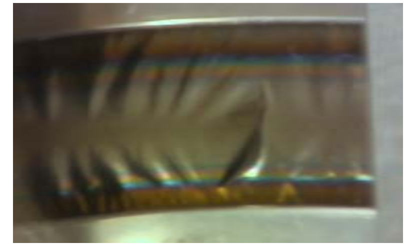




1 pμA



Thermal effects



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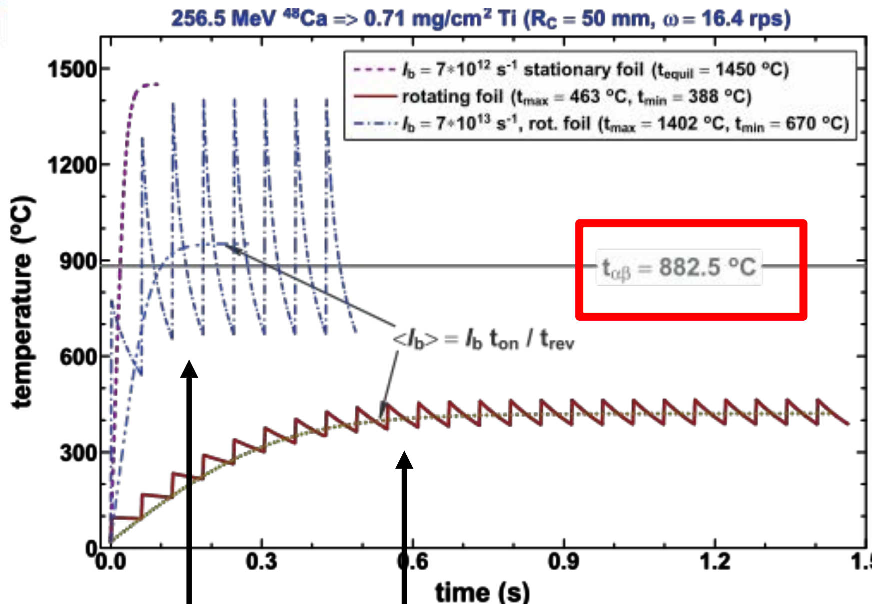
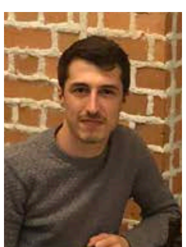
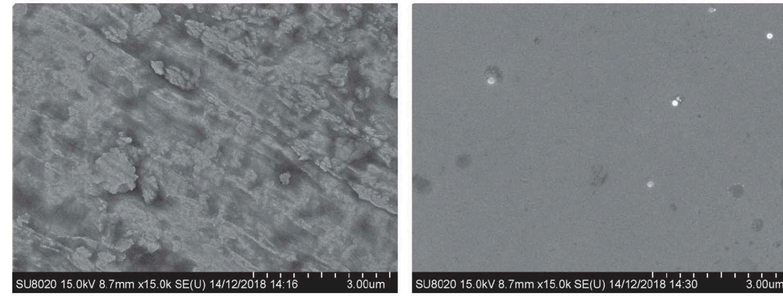


- Pure Titanium α/β phase transition : T=882,5°C
- 1 pμA → microscopic T° α/β cross → deformation
- Oscillations at 10 pμA reach T_{max}=1402°C !!!
- May cause changes in the crystal structure of Ti due to repetitive short-term crossing the α/βtransition T°
- In addition to the thermal deformations → breakage

10 pμA 1 pμA



IS EFFECT OF HEAT ONLY BAD ?



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Temperature effects leads to cristalline phase change

For pure titanium alpha/beta transition is at 882,5°C

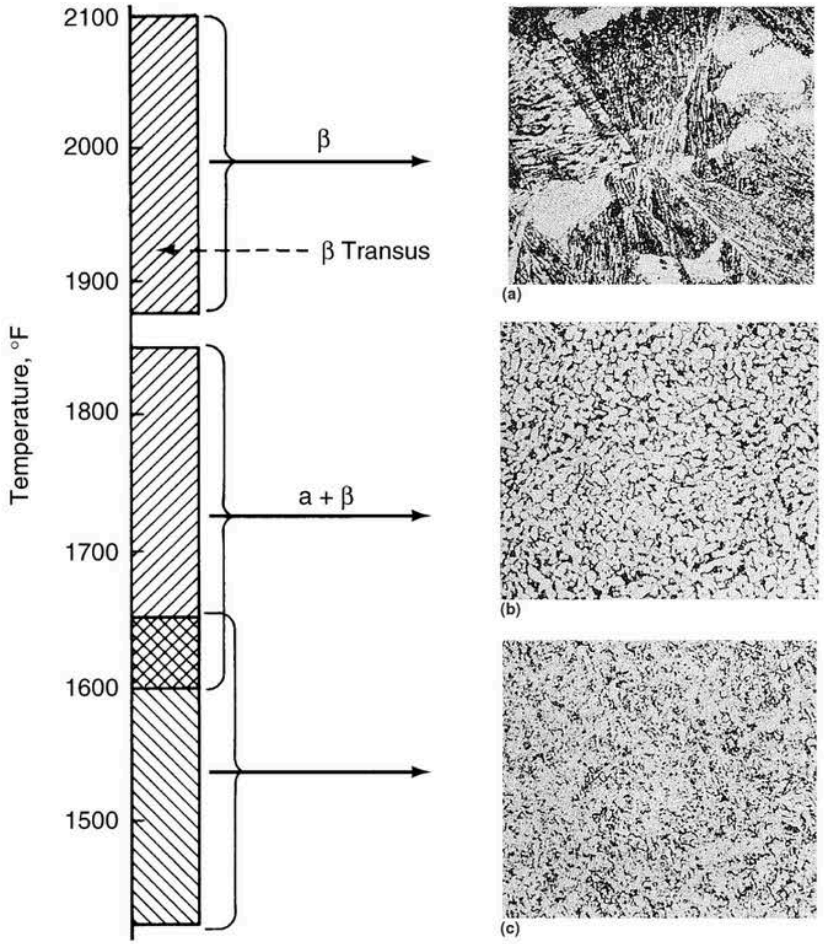
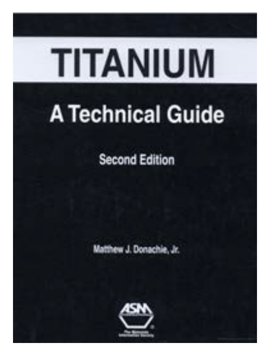


Fig. 3.3 Microstructures of an annealed near-alpha alloy (Ti-8Al-1Mo) after cooling from different areas of the phase field. (a) Acicular alpha. (b) Equiaxed alpha and intergranular beta. (c) Fine alpha-beta structure



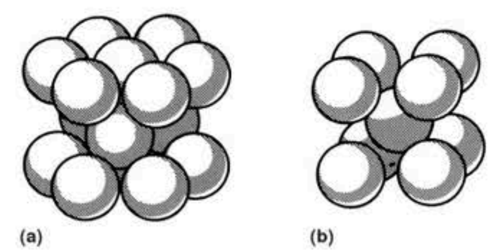
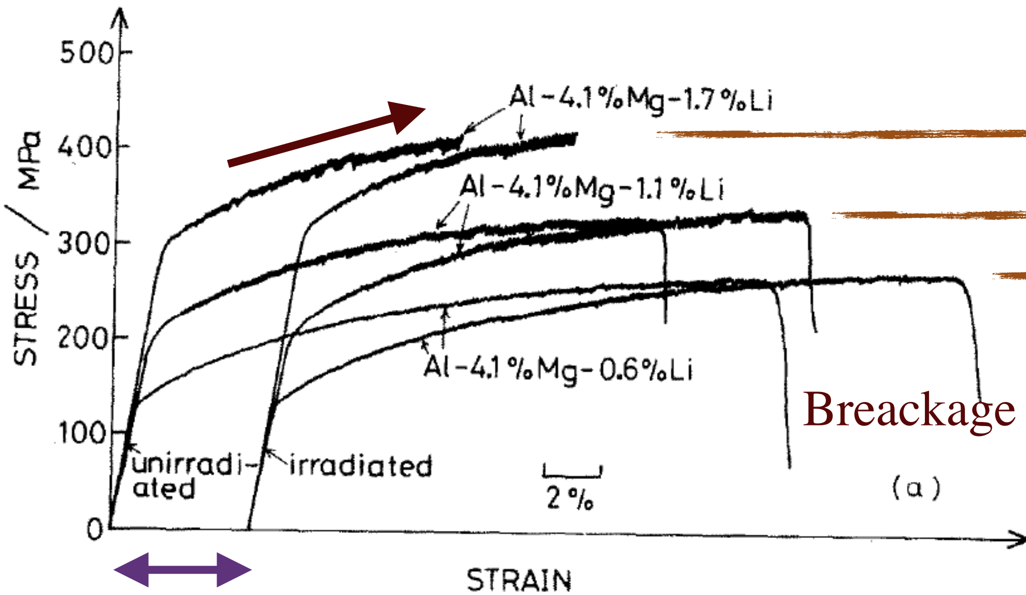
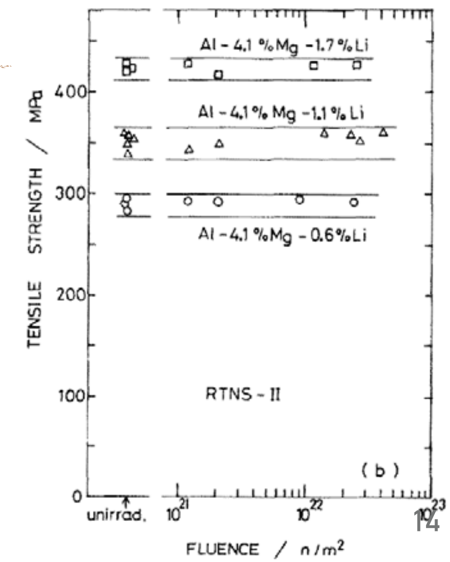


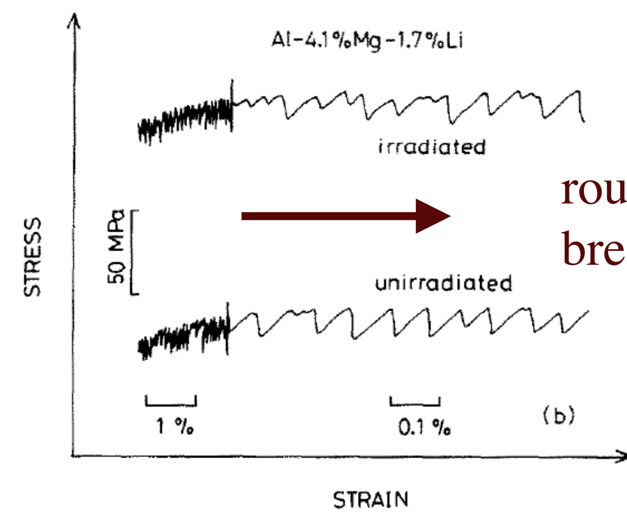
Fig. 1.3 Appearance of crystal structures of titanium at the atomic level. (a) Hexagonal, close packed. (b) Cubic, body centered

STRESS-STRAIN EFFECTS



Permanent deformation





route to breackage

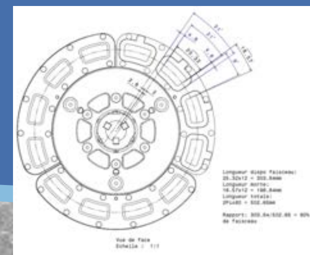
Journal of Nuclear Materials 141–143 (1986) 915–920
North-Holland, Amsterdam
915

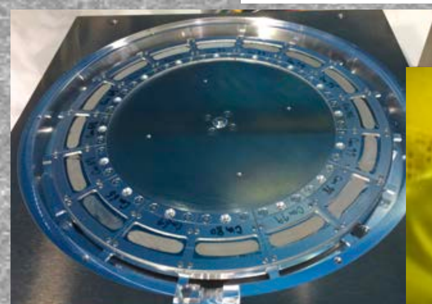
MECHANICAL PROPERTIES AND MICROSCOPIC STRUCTURE OF Al–Mg–Li ALLOYS AFTER 14 MeV NEUTRON IRRADIATION *

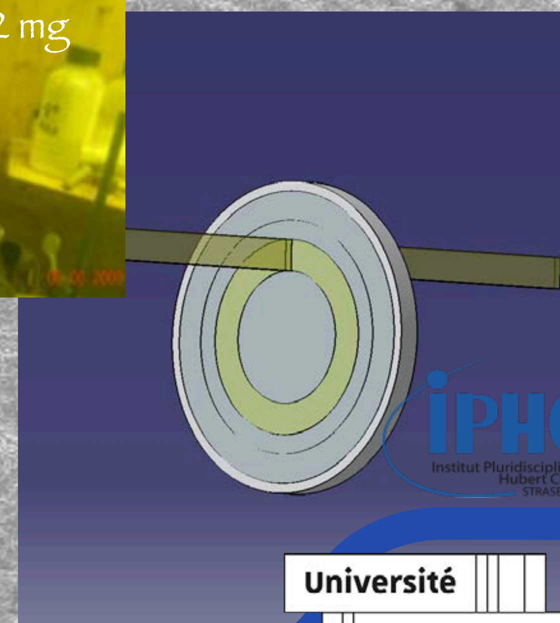
K. ABE [1], I. YOSHIZAWA [2], K. KAMADA [3] and H. KAYANO [4]

[1] *The Research Institute for Iron, Steel and Other Metals, Tohoku University, Sendai 980, Japan*
[2] *Faculty of Education, Ibaraki University, Mito 310, Japan*
[3] *Institute of Plasma Physics, Nagoya University, Nagoya 464, Japan*
[4] *Oarai Branch, The Research Institute for Iron, Steel and Other Metals, Tohoku University, Oarai 311-13, Japan*

FROM 60-80 % DUTY CYCLE TARGETS…



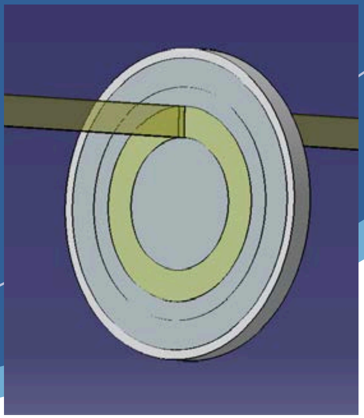




TO 100 % DUTY CYCLE TARGET

What about Target at 5 or 10 pμA ?

We will need target backing developments !!!
... and dedicated beam time allocated



Standard large rotating wheel
- -> test several solutions at the same time & under similar conditions

« Cofee-cup » small rotating wheel
- -> Higher temperature (not the limitation)
- -> Shorter lifetime (max dose /u of surface)
- +> Shorter test time
- +> lower material needed => lower activity
- +> 100% duty-cycle (x 1,6 !)
- +> Split material (can reprocess in //)
- +> solution for ^{254}Es future target ?

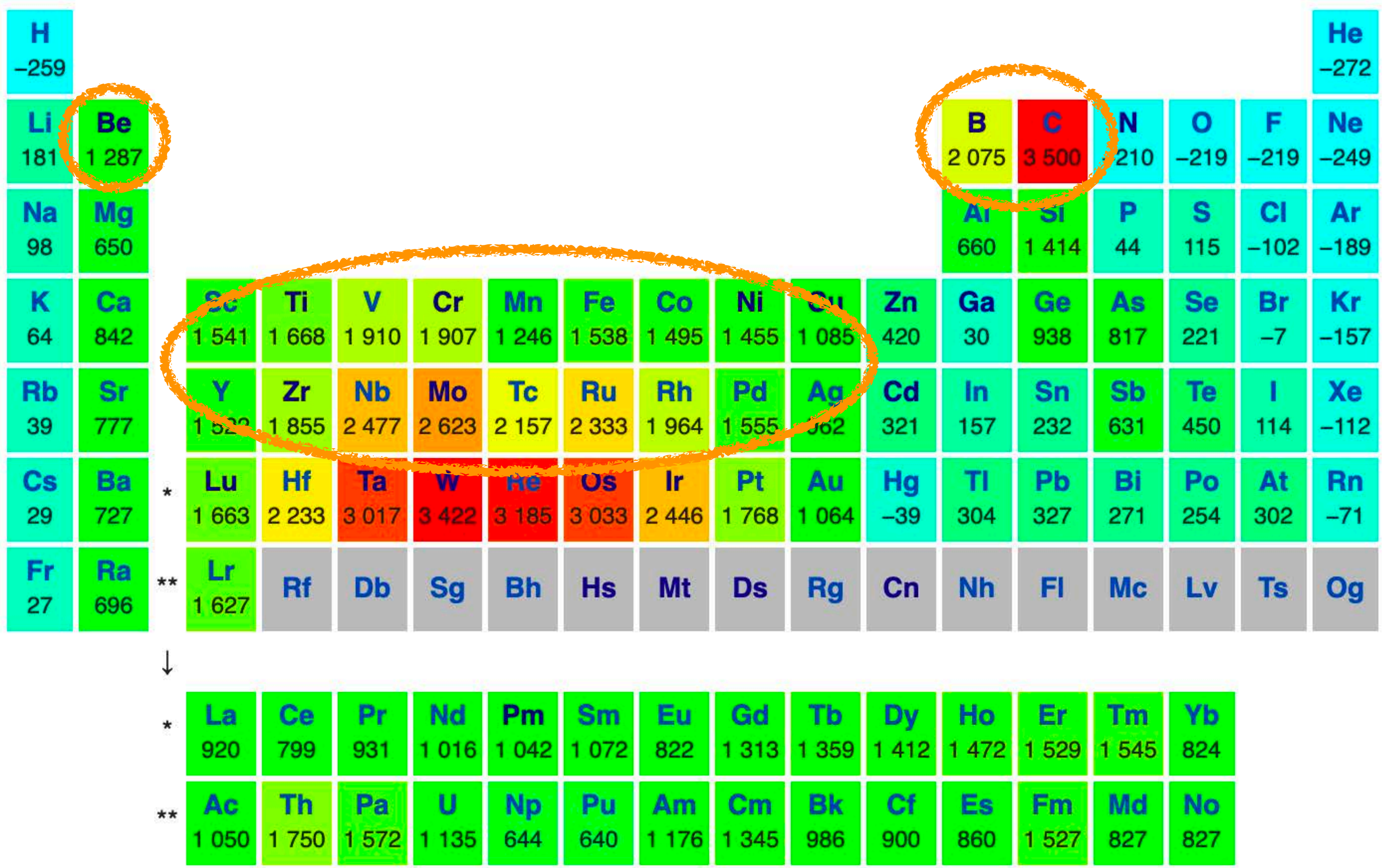
developed @IPHC for JYFL

Innovative Materials sustaining extreme beams for rare Targets

Looking for Advanced backing materials

INC
INEE
IN2P3

PURE MATERIALS : HIGH MELTING POINT MATERIALS



(C) WIKIPEDIA…

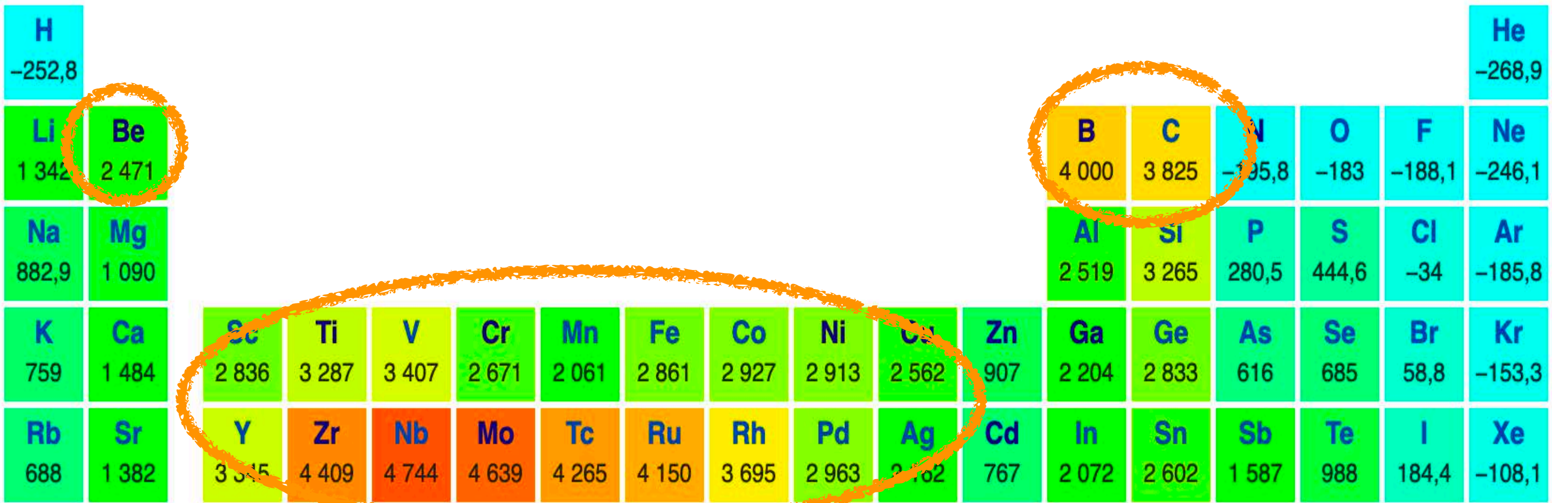
- Pure materials: Be, B, C, Ti, Cr

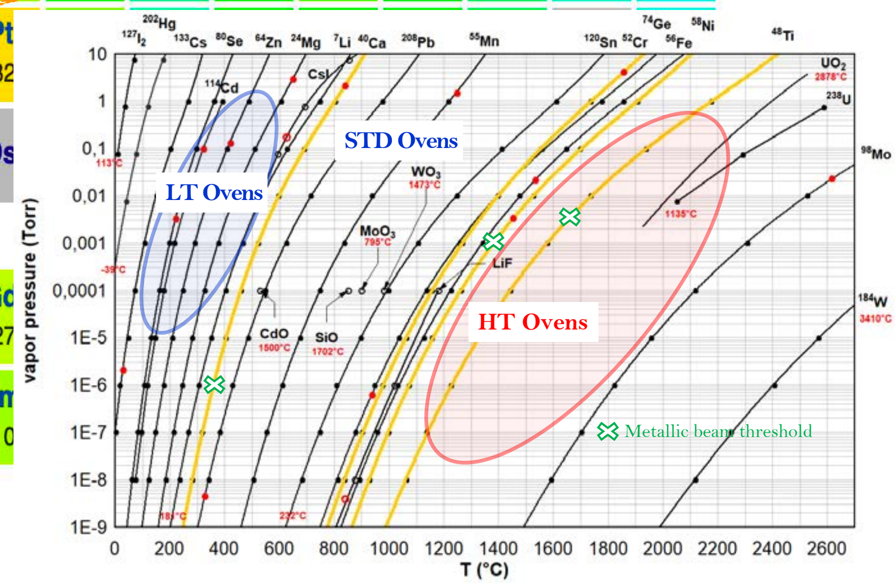
PURE MATERIALS : HIGH BOILING POINT MATERIALS

H −252,8																		He −268,9
Li 1 342	Be 2 471												B 4 000	C 3 825	N −195,8	O −183	F −188,1	Ne −246,1
Na 882,9	Mg 1 090												Al 2 519	Si 3 265	P 280,5	S 444,6	Cl −34	Ar −185,8
K 759	Ca 1 484		Sc 2 836	Ti 3 287	V 3 407	Cr 2 671	Mn 2 061	Fe 2 861	Co 2 927	Ni 2 913	Cu 2 562	Zn 907	Ga 2 204	Ge 2 833	As 616	Se 685	Br 58,8	Kr −153,3
Rb 688	Sr 1 382		Y 3 345	Zr 4 409	Nb 4 744	Mo 4 639	Tc 4 265	Ru 4 150	Rh 3 695	Pd 2 963	Ag 2 162	Cd 767	In 2 072	Sn 2 602	Sb 1 587	Te 988	I 184,4	Xe −108,1
Cs 671	Ba 1 897	*	Lu 3 402	Hf 4 603	Ta 5 458	W 5 555	Re 5 596	Os 5 012	Ir 4 428	Pt 3 825	Au 2 856	Hg 356,6	Tl 1 473	Pb 1 749	Bi 1 564	Po 962	At	Rn −61,7
Fr	Ra	**	Lr	Rf	Db	Sg	Bh	Hs	Mt	Ds	Rg	Cn	Nh	Fl	Mc	Lv	Ts	Og
		↓																
		*	La 3 464	Ce 3 443	Pr 3 520	Nd 3 074	Pm 3 000	Sm 1 794	Eu 1 529	Gd 3 273	Tb 3 230	Dy 2 567	Ho 2 700	Er 2 868	Tm 1 950	Yb 1 196		
		**	Ac 3 198	Th 4 788	Pa	U 4 131	Np	Pu 3 228	Am 2 011	Cm 3 100	Bk	Cf	Es	Fm	Md	No		

(C) WIKIPEDIA…

PURE MATERIALS : HIGH BOILING POINT MATERIALS





USIAS Task 2 : HT target backing

ULTIM

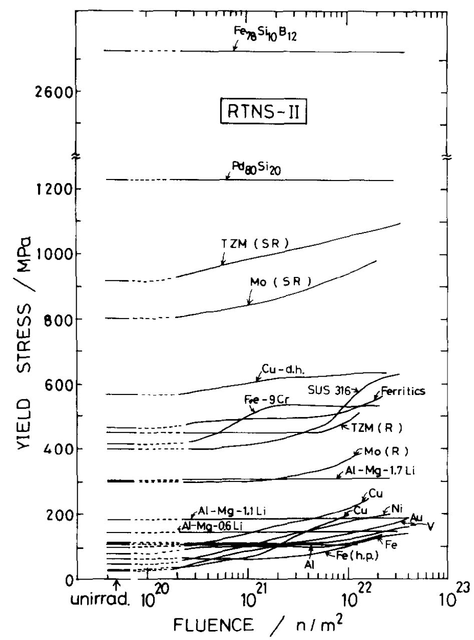


Fig. 5. Summary of yield stress in metals and alloys, irradiated with 14 MeV neutrons to about 4×10^{22} n/m^2 at room temperature and tested at room temperature [15].

K. Abe et al., J. Nucl. Mat. 141-143 (1986) 915-920

—> Pure metals thin* foils

(*) 1 - 5 µm thick

Ti (traditional), B, Be, Mo, … Production issues

—> Carbone based thin* foils

Diamond like Carbon, Graphene, Production & use issues

—> Alloys in thin* deposit ?

Ti based alloys (Ti_6Al_4V, Ti_3Au, Ti_3Al …)

Other alloys (non regular) Not possible or difficult to make foils …

—> Ceramics in thin* deposit ?

TiC, BN, BC … Not possible to make our foils …

Go to 10 pµA is vital and problematic for nuclear physicists…

… It needs a full time solid state physicists

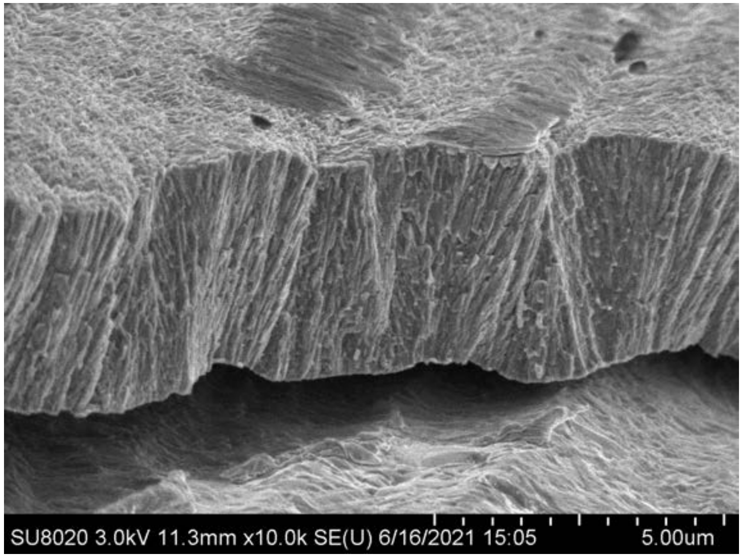
& means to overcome this major limitation

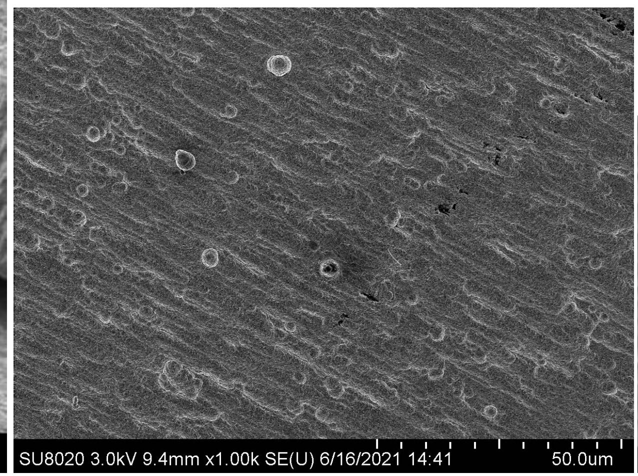
IPHC Institut Pluridisciplinaire Hubert CURIEN STRASBOURG

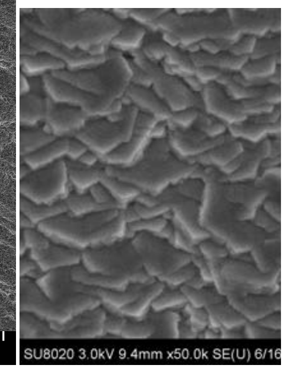
Université de Strasbourg

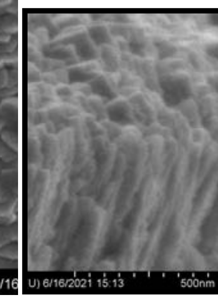
ALLOYS ?

Ti 6Al 4 V

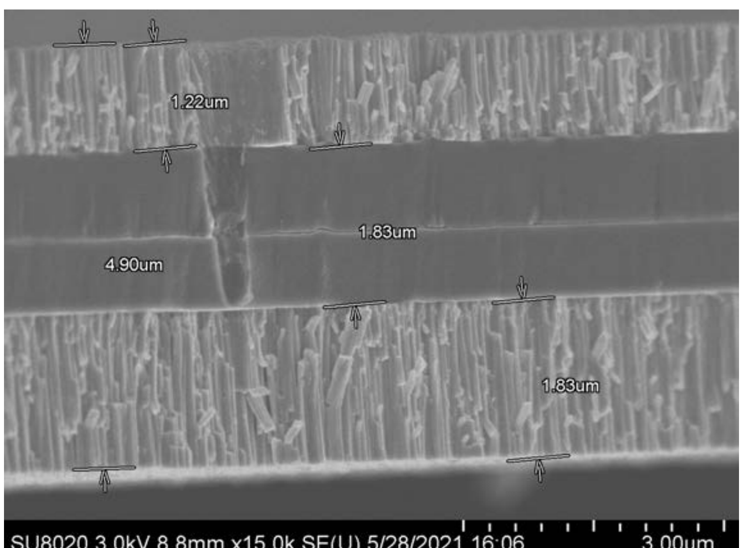


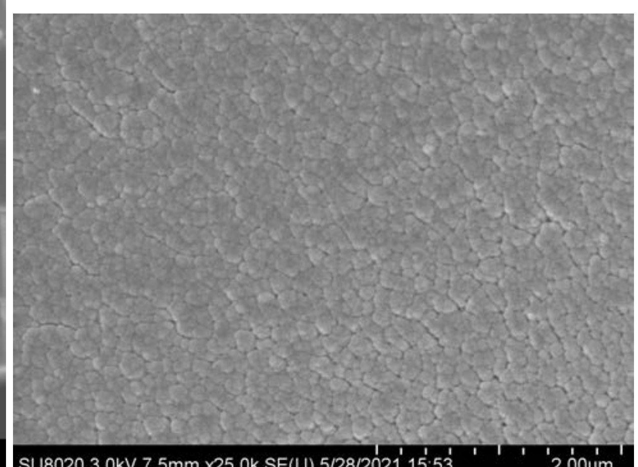


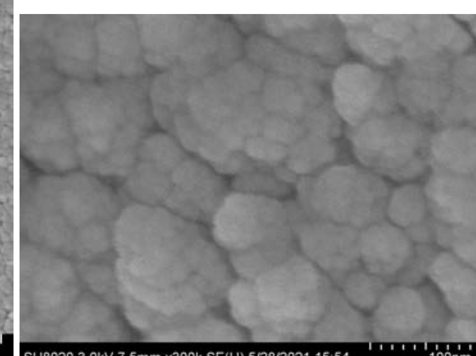




Ti3Al / DLC /Ti3Al

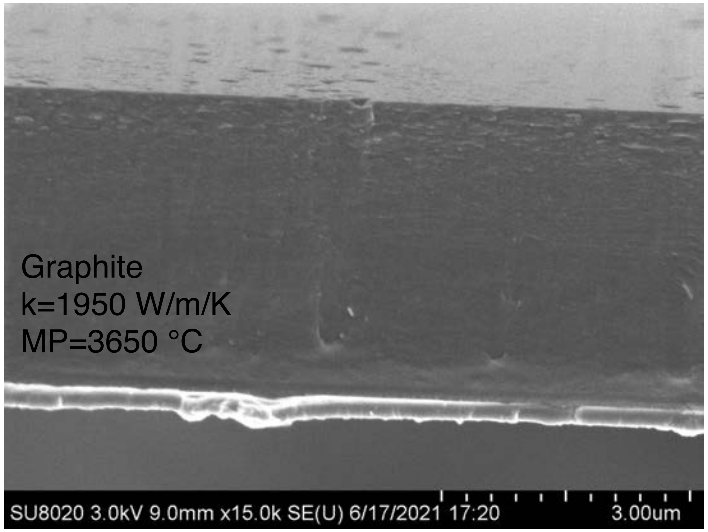


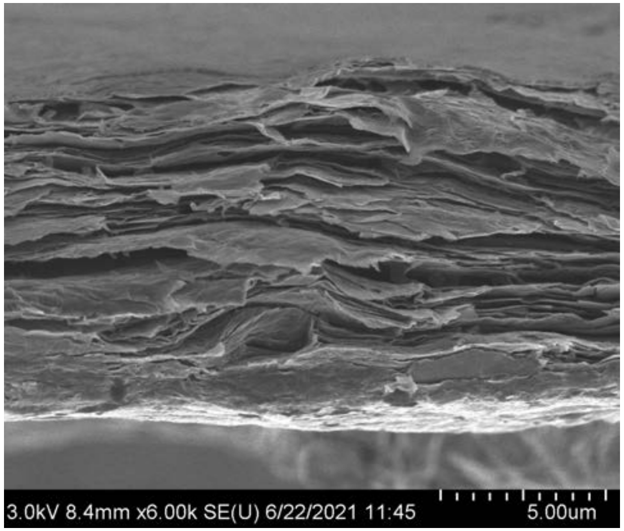




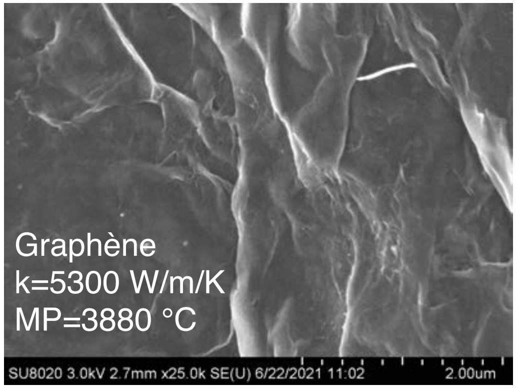
Thanks to Vladimir Skuratov, Oleg Orelovich, Ekaterina Korneeva, Nikolay Lizunov FLNR Sector 8

CARBON BASED MATERIALS



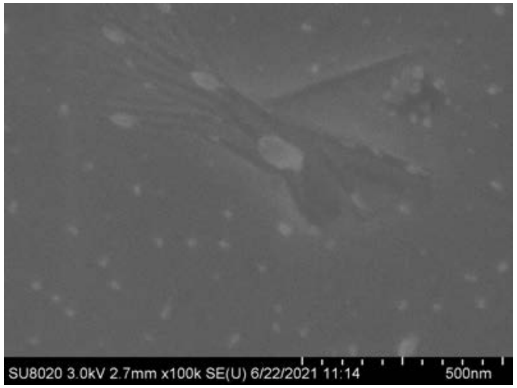


GRAPHENE

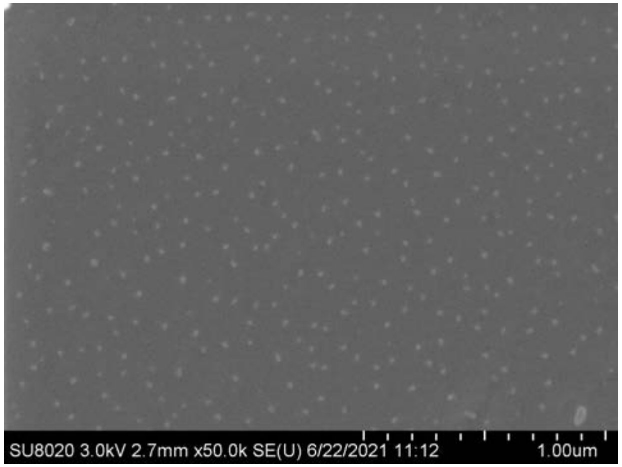


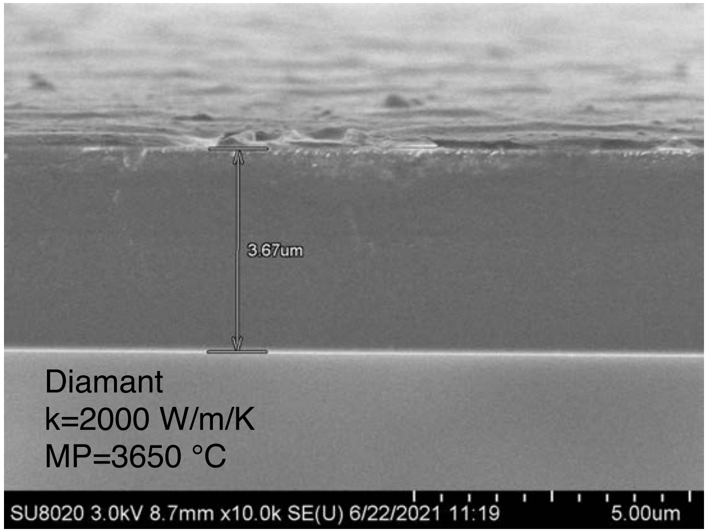
GRAPHITE / B

@ 1700 °C diamant -> Graphite.



DLCH





Thanks to Vladimir Skuratov, Oleg Orelovich, Ekaterina Korneeva, Nikolay Lizunov FLNR Sector 8

CERAMICS

- Very strong materials
- how to make thin foils
- How to handle
- conductive ?

- radiation damages indu tracks
- no repair process

layers of BN, B4C, TiN , …
on existing foils ?

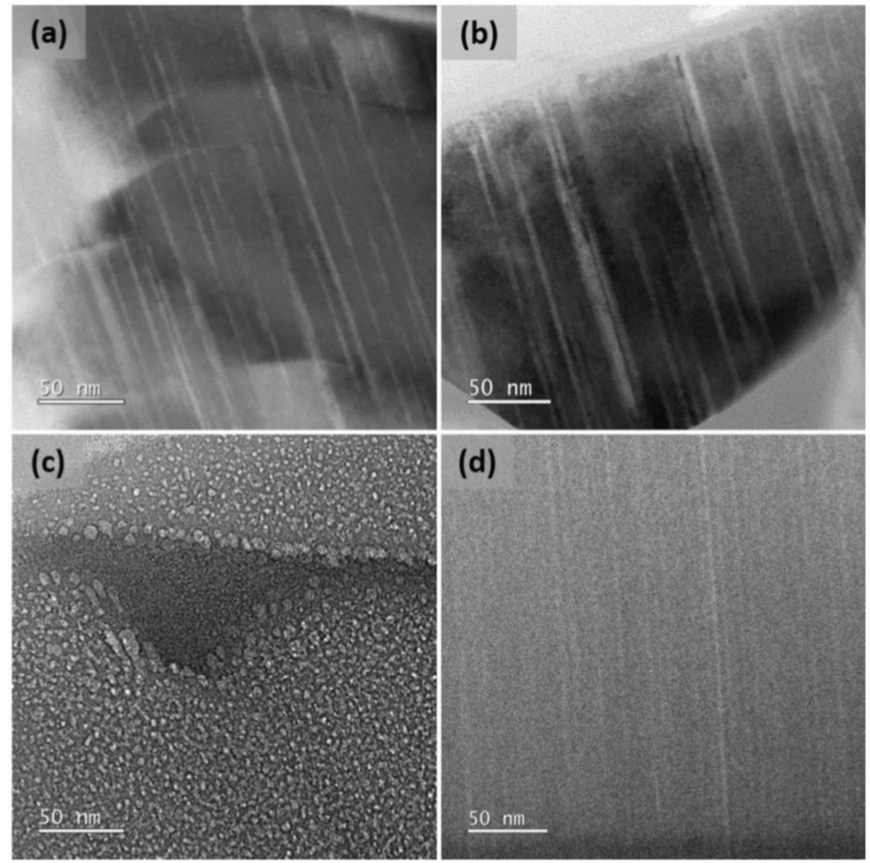


Fig. 6. Bright field TEM images of (a) p-Si_3N_4 irradiated with 220 MeV Xe to a fluence of 5×10^{11} cm^{-2} and (b) p-Si_3N_4 irradiated with 710 MeV Bi to a fluence of 5×10^{11} cm^{-2} and (c) ra-Si_3N_4 irradiated with 220 MeV Xe to a fluence of 2×10^{14} cm^{-2}; and (d) an annular bright field STEM image of a-Si_3N_4 irradiated with 710 MeV Bi to a fluence of 5×10^{11} cm^{-2}.

A. Janse von Vurge, A. D. Ibrayeava et al., NIM B 473 (2020) 16-23

ULTIM

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USIAS Laboratory for Target Innovative Materials

Rolling
Direct deposition

Institut Pluridisciplinaire Hubert CURIEN STRASBOURG

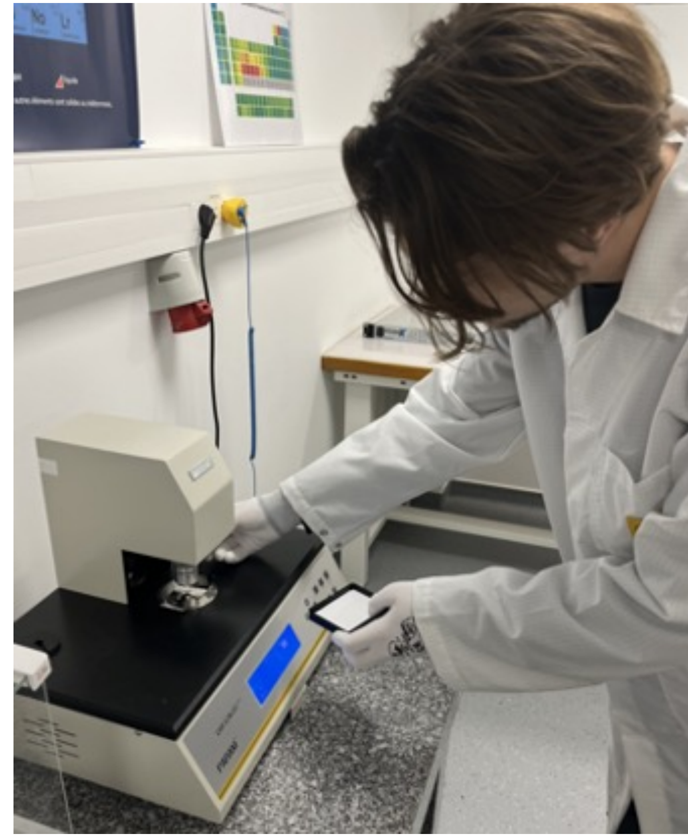
cnrs INC INEE IN2P3

Université de Strasbourg

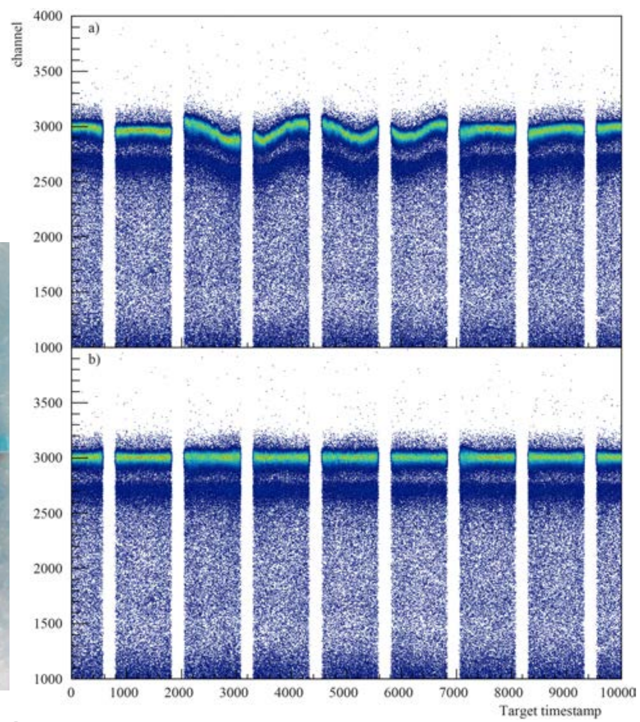
Rolling

We roll to μm when can be done …
Characterize thickness homogeneity

Uniformity



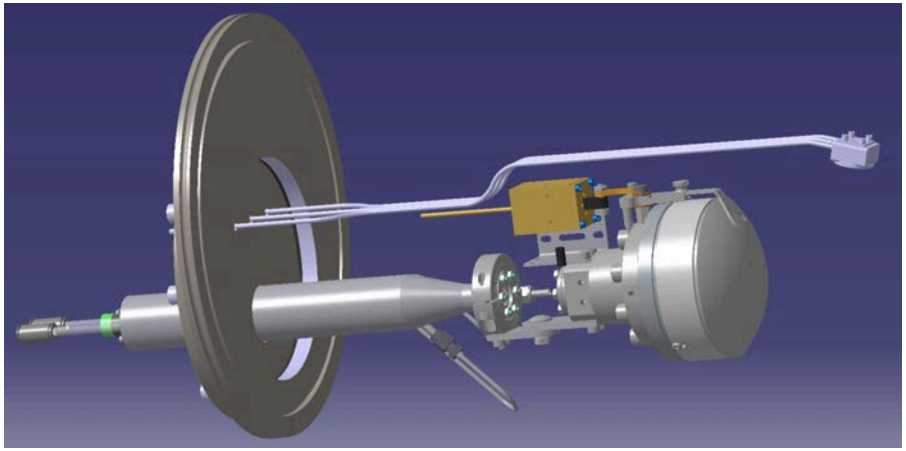
Thickness from weight …
= dangerous !

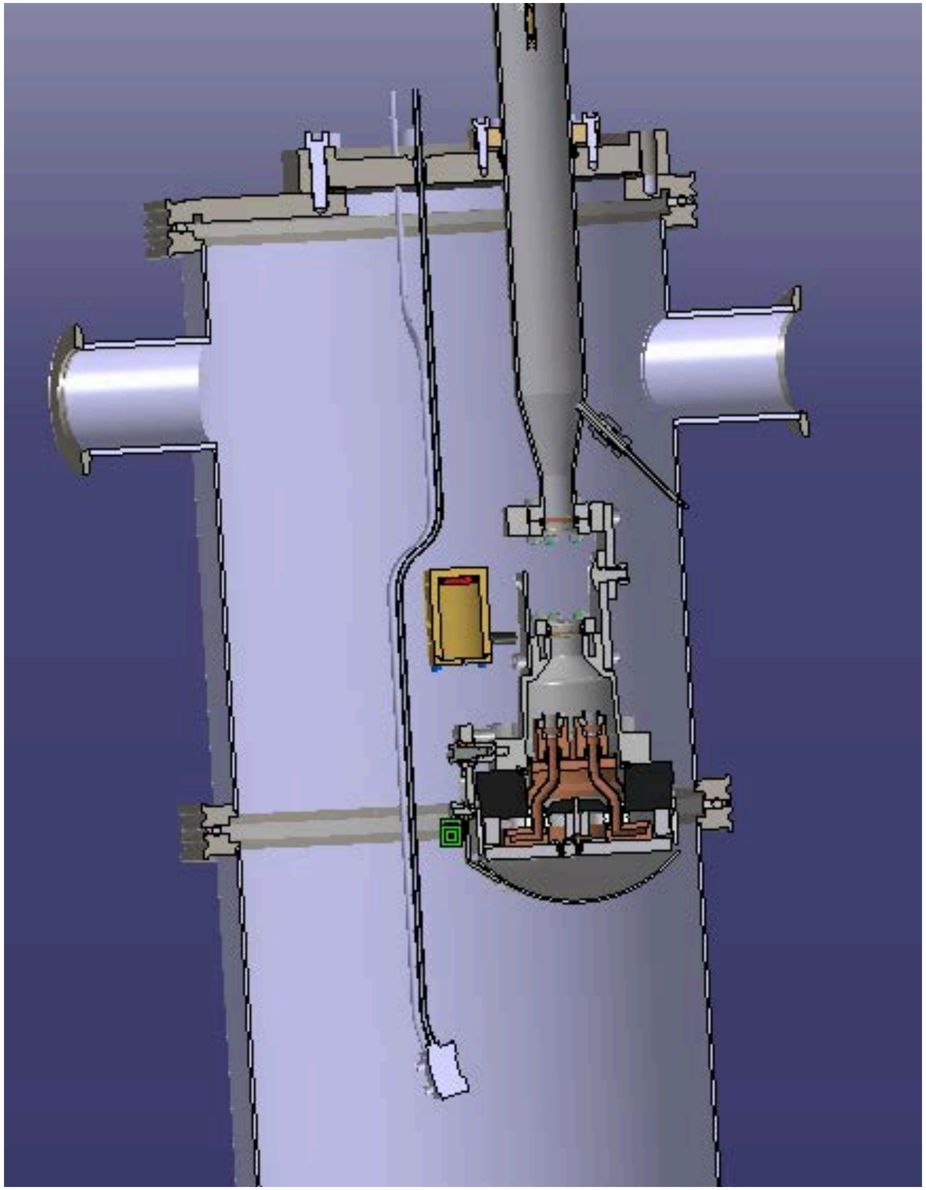


Measure local thickness…

± 0,1 μm …

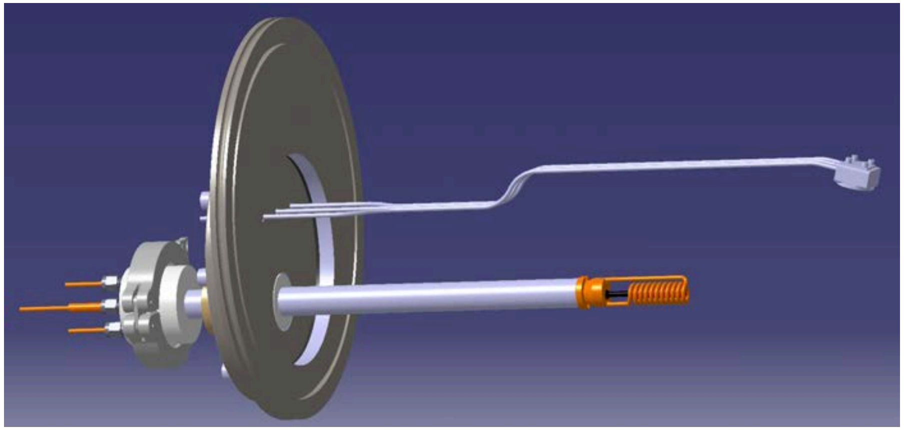
Direct deposition



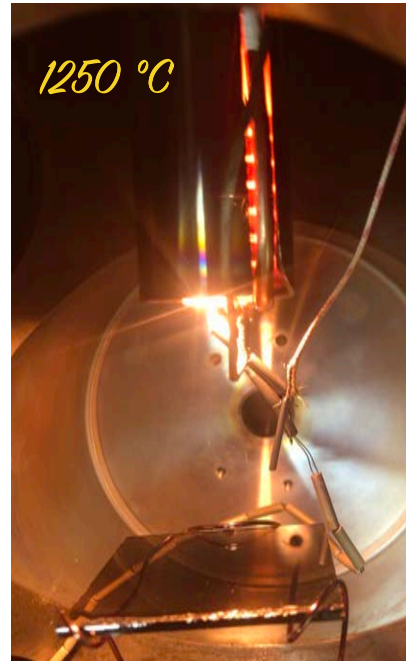


Prepare backing foils
Deposit Ti on existing backings
Try sputtering from alloys discs …

Direct deposition



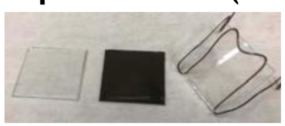
Cr (M) vapor



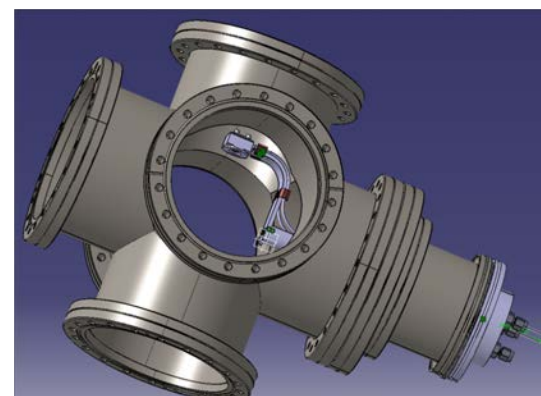
Ti (M) vapor

Evaporation rate : up to several 10 mg/h …

- Multi head deposition device
  - Based on inductive oven
    - All metal deposition possible (Titanium, Boron …)

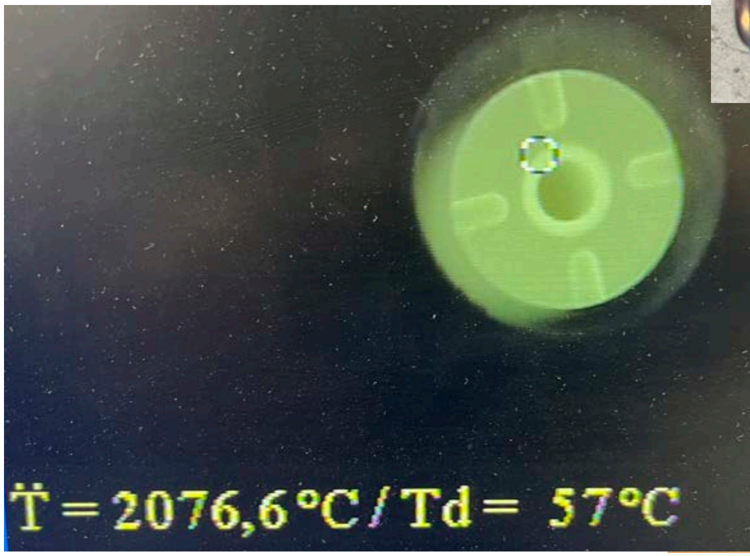


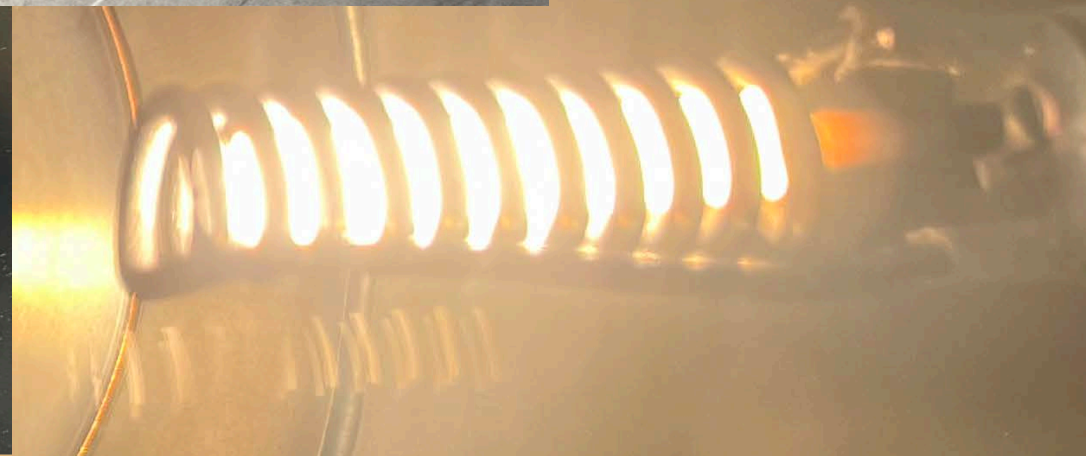
  - Three different head possible
    - Alloys
    - Layered materials
  - Deposition under vacuum or selected gas



Prepare backing foils
from co-deposited materials …alloy foils

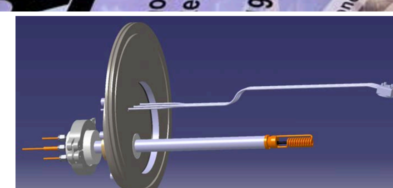
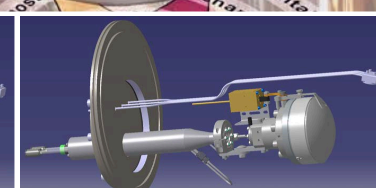
- ø25 oven ready



- Vacuum chambers prepared


- The deposition head will be installed soon

Innovative Materials sustaining extreme beams for rare Targets

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GANIL, RIKEN, DUBNA, GSI

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