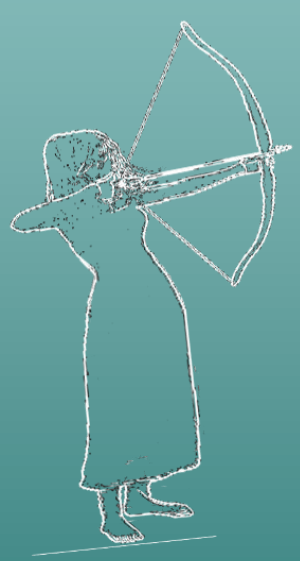
Targets for nuclear studies and production of the medical isotopes



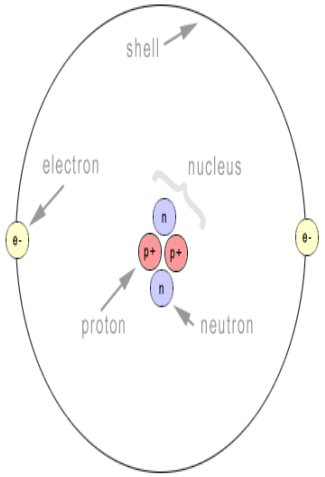


Anna Stolarz

Heavy Ion Laboratory, University of Warsaw

3rd Workshop on Research & Innovation in Poland dedicated to Particle Accelerator Applications; October 2026, Kraków

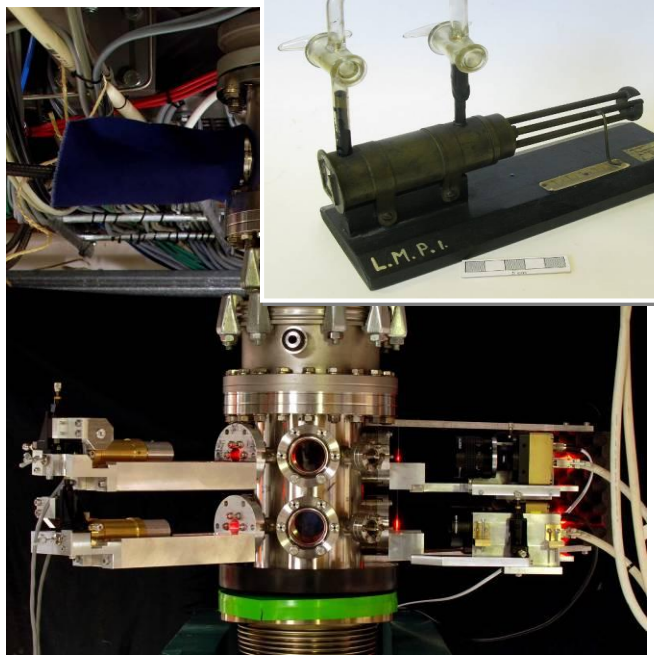


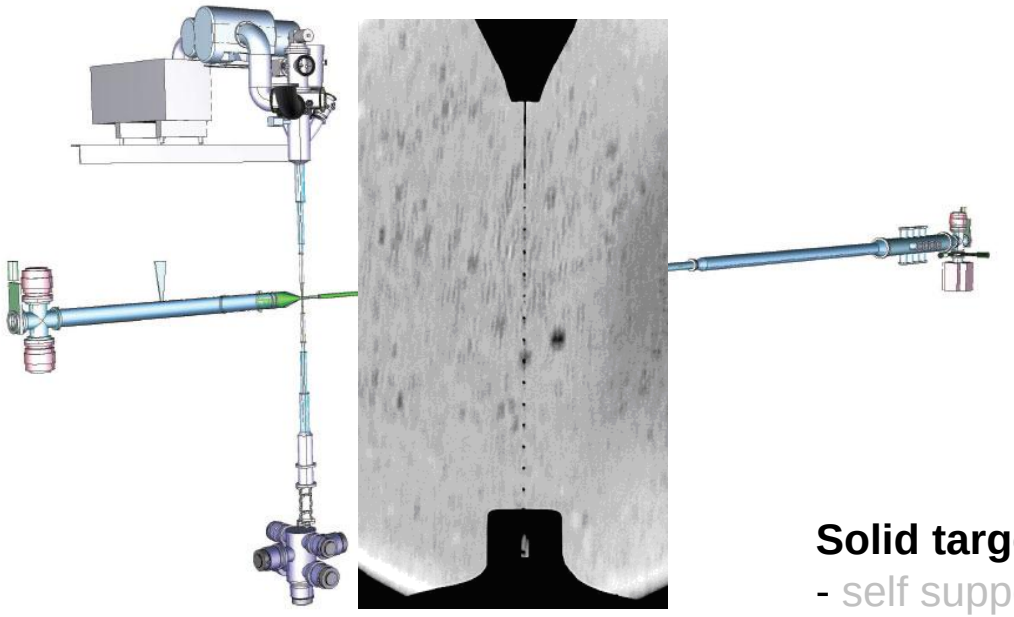


The target can be defined as a substance, object, or system subjected to bombardment by particles such as electron, proton etc, or to irradiation.

Gaseous or liquid

- material loaded into the chamber kept at a low temperature
- gas or liquid flow (the melted metals as well)
- in case of gaseous elements:
  implantation into the solid backing/carrier

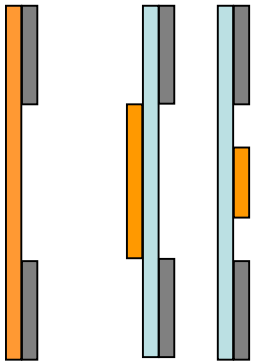


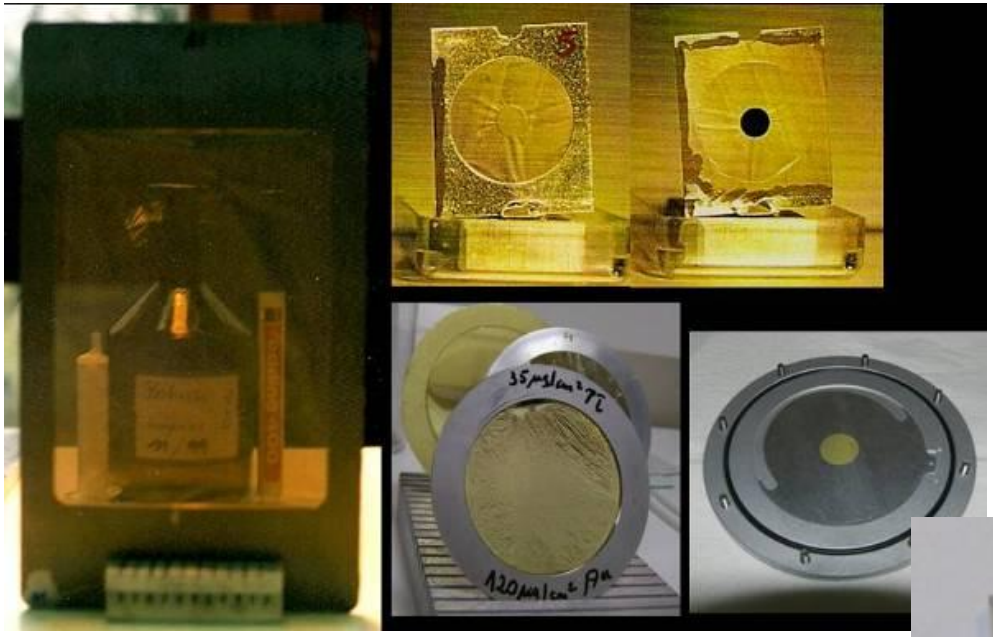


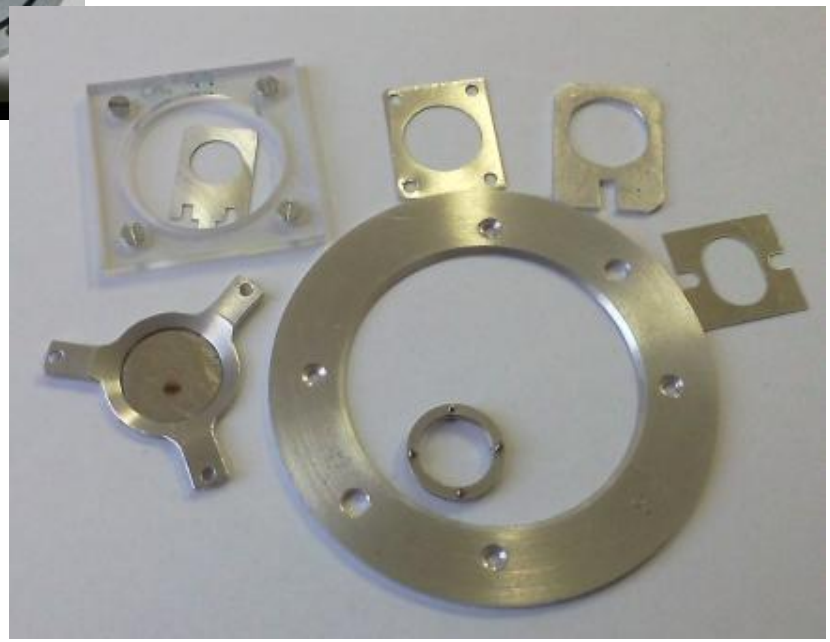
Gaseous/solid target in
form of frozen hydrogen

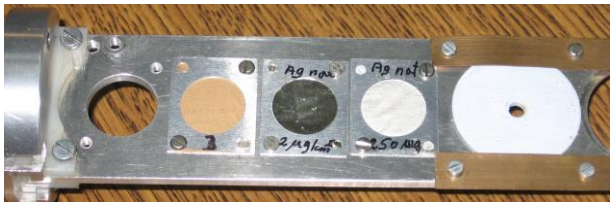
Solid targets

- self supporting
- on the backing









How to make them?

The nuclear physics studies
der
~1 μg/cm^2 up

Regardless of the type of exper
target shou
chemical
available







In general t

Physical

Therma

Cold: sp

Mechanic

rolling,
sedimer
HIVIPP
Plating)
imposed

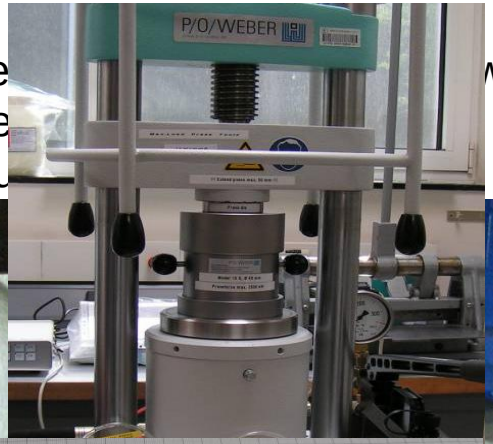
Chemical: electrodeposition

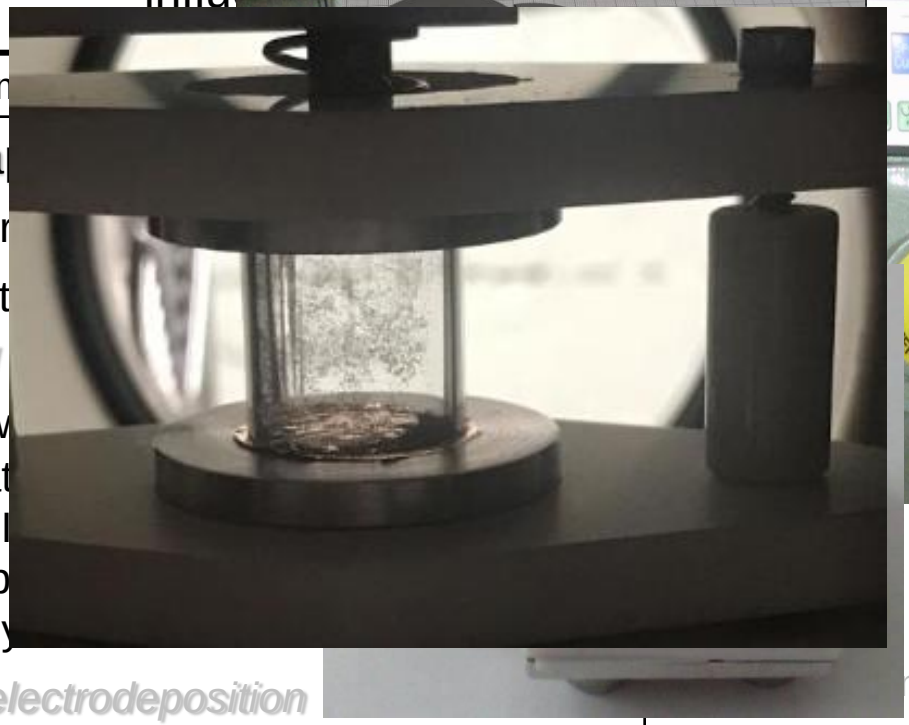
few ug/cm2 to mg/cm2

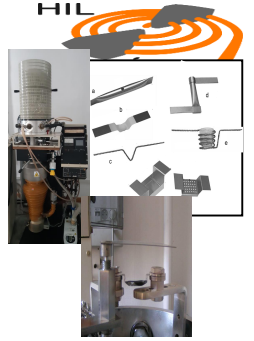
How to make them?

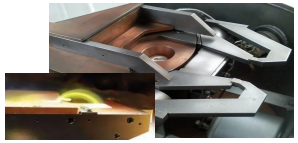
The nuclear physics studie … with areal de…
~1 μg/cm² u…

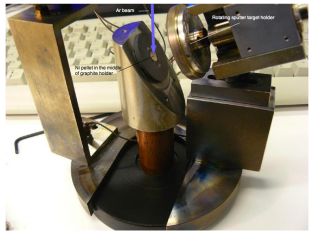
Regardless of the type of e… …ts thickness, the target sh… mechanical strength, chemi… …he enrichment of the avail… influ…











In general the r… …as

Physical Va…

Thermal: r…

Cold: sputt…

Mechanical …

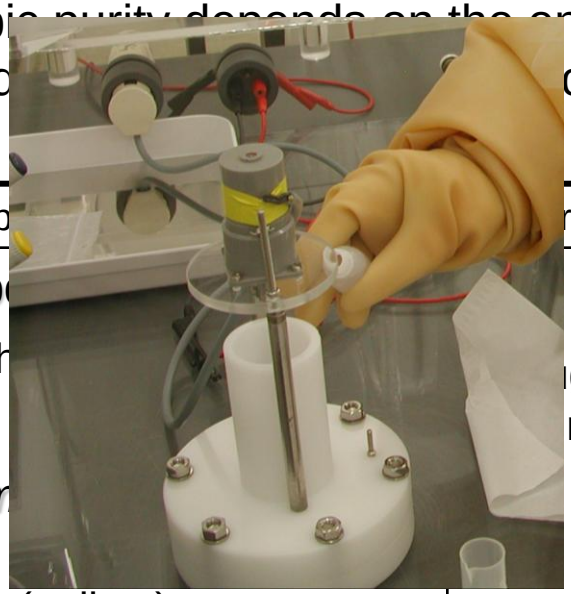
rolling, pow… …²
sedimentat…
HIVIPP (HI…
Plating) - p…
imposed by…

Chemical: electrodeposition … mg/cm²

How to make them?

The nuclear physics studies usually require targets with areal density from
~1 μg/cm^2 up to 10-20 mg/cm^2.

Regardless of the type of experiment, apart from its thickness, the target should ensure: uniform thickness, good mechanical strength, chemical purity (isotopic purity depends on the enrichment of the available material) and ce of the beam.

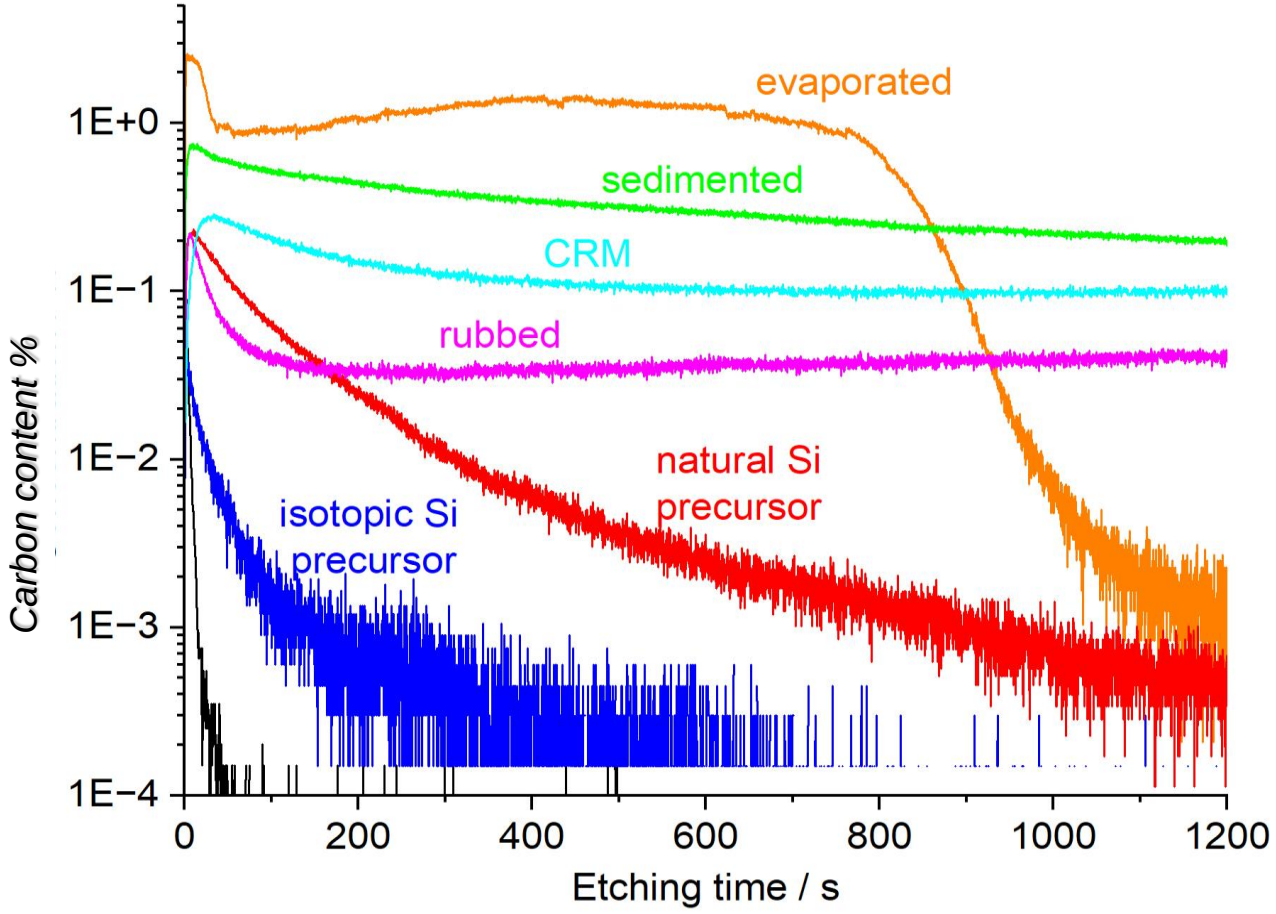


In general the methods app	roughly classified as
Physical Vapour Dep	
**Thermal:* resistant h	g/cm^2 (if on the
**Cold:* sputtering	ng) to mg/cm^2
Mechanical transform	
*rolling, *powder compacting (pellets), *sedimentation (gravimetrical or imposed), *HIVIPP (HIgh energy VIbrational Powder Plating) - powder depossition by vibrations imposed by electric field	0.5 mg/cm^2 - > g/cm^2
Chemical: electrodeposition	few μg/cm^2 to mg/cm^2



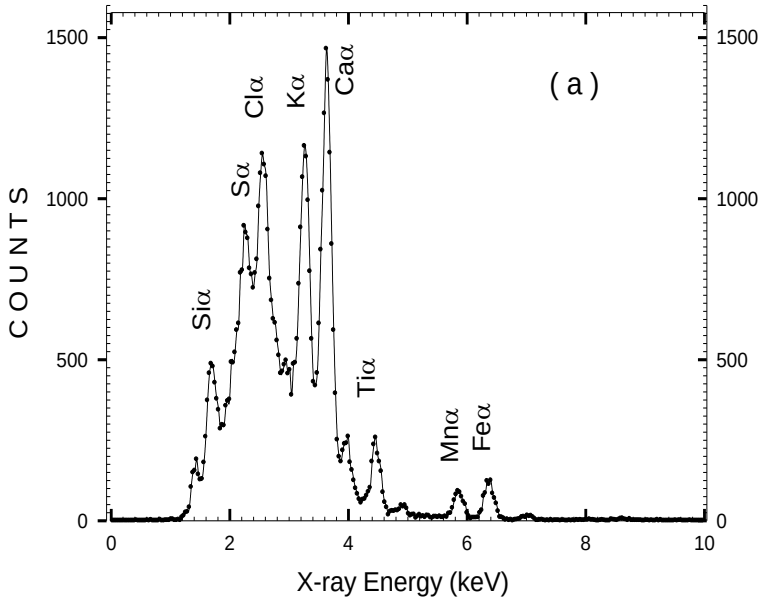
The methods which should be considered as preferable

method	thickness limitation	conditions	efficiency
rolling	0.5 - ∞ mg/cm^2 soft metals >1.5 mg/cm^2	material has to be malleable	~ 90 %
pellet	~20 - ∞ mg/cm^2	excluded - very hard materials unless the addition of the binder is accepted	>95%
sedimentation	few - ∞ mg/cm^2	additional material-binder	95 - 98%
electrodepo	µg/cm^2 – mg/cm^2	always on the backing	80 - 90%
HIVIPP	µg/cm^2 – mg/cm^2	on the backing or without	95 - 98 %
high vac evap	µg/cm^2 – mg/cm^2	self-supporting or on the backing	2 - 10 % (could be higher if .....)

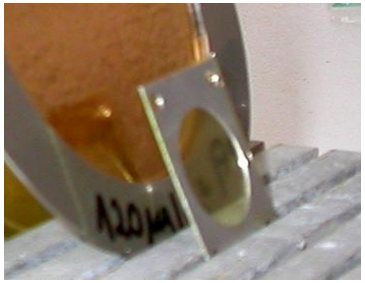


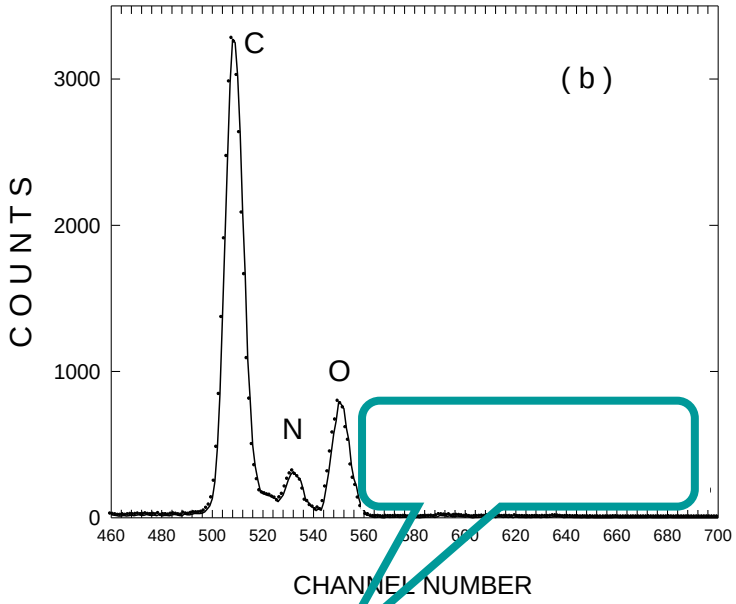
SIMS analisis of ^{28}Si targets prepered by various methods

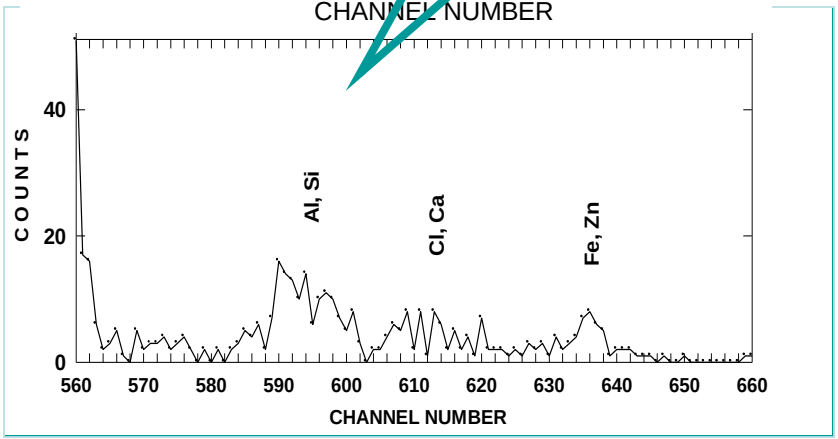
Target purity



PIXE spectrum (polyimid foil)







Thickness estimation

mm-μm / g-mg-μg/cm^2 ??

* Mechanically or electrically i.e.
  caliper, micrometer (screw??) or induction thickness gauge

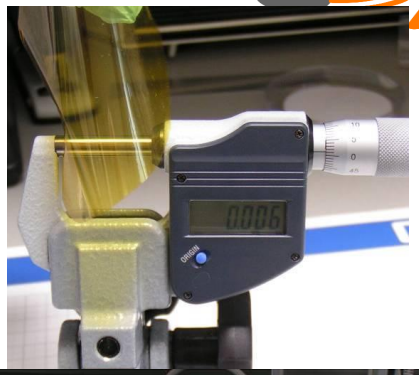
* weighing the defined area

* spectrophotometrically

* measurement of the α particles energy loss

•profilometers
  working in a contact or non-contact modes

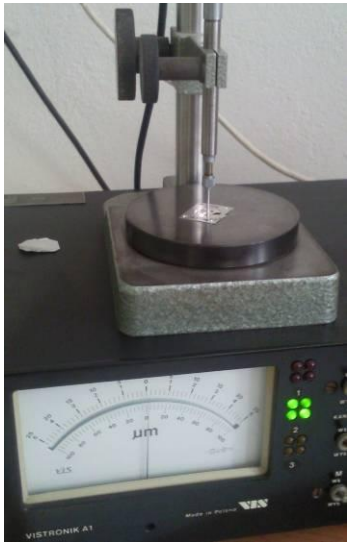
* in-situ during the vapour deposition process
  using the quartz microbalance













Radioisotope production (Medical application) October, 2026
H+ and 4He2+ beams can produce radioisotopes

Purpose	Order	Short	Long	Reactions	Energies [MeV]	References
PET	1	^{64}Cu	Copper-64	^{64}Ni(p,n) ^{64}Cu	9 - 12	[1][2]
				^{64}Ni(p,n) ^{64}Cu	11	[3]
	2	^{18}F	Flourine-18	^{16}O(α, np) ^{18}F	40	[4]
	3	^{68}Ga	Gallium-68	^{68}Zn(p, 2n) ^{68}Ga	12.5	[5][6]
	4	^{124}I	Iodine-124	^{124}Te(p, n) ^{124}I	12.5	[1][7]
	5	^{89}Zr	Zirconium-89	^{89}Y(p, n) ^{89}Zr	12.5	[8]
SPECT	6	^{67}Ga	Gallium-67	^{65}Cu(α, 2n) ^{67}Ga	28	[9]
	7	^{111}In	Indium-111	^{109}Ag(α, 2n) ^{111}In	27, 30	[10][11]
	8	^{203}Pb	Lead-203	^{203}Tl(p, n) ^{203}Pb	12.5	[12]
THERAPEUTICS	9	^{211}At	Astatine-211	^{209}Bi(α, 2n) ^{211}At	28	[1]
	10	^{131}Cs	Cesium-131	^{nat}Xe(α, xn) ^{131}Ba → ^{131}Cs	50	[13]
	11	^{131}I	Iodine-131	^{121}Sb(α, 2n) ^{123}I	26	[14]
	12	^{192}Ir	Iridium-192	^{192}Os(p, n) ^{192}Ir	12.5	[15]
	13	^{212}Pb	Lead-212	^{228}Th → ^{212}Pb	12.5	[16]
	14	^{186}Re	Rhenium-186	^{186}W(p, n) ^{186g}Re	12	[17]
				^{186}W(α, x) ^{186g}Re	43	
	15	^{117m}Sn	Tin-117m	^{116}Cd (α, 3n) ^{117m}Sn	42	[18]

64Cu	Copper-64	64Ni(p,n)64Cu	7-12	**187 µm**	**167 mg/cm2**
68Ga	Gallium-68	68Zn(p,2n)68Ga	7 -15	**440 µm**	**314 mg/cm2**
203Pb	Lead-203	203Tl(p,n)203Pb	7 - 80	**125 µm**	**148 mg/cm2**
44m/44gSc		44Ca(p,n)44m/gSc	5 - 15	**912 µm**	**263 mg/cm2 $CaCO_3$**
			7.5-13.5	**710 µm**	**159 mg/cm2 $CaCO_3$**
67Ga	Gallium-67	65Cu(α,2n)67Ga	15 - 45	**250 µm**	**222 mg/cm2**
211At	Astatine-211	209Bi(α,2n)211At	25 - 33	**92 µm**	**90 mg/cm2**
117mSn	Tin-117m	116Cd(α,3n)117mSn	7.5 - 80	**936 µm**	**809 mg/cm2**

nuclear studies

- rather thin (μg/cm^2 up to few mg/cm^2
- Homogenous thickness
- High purity

Methods
mechanical, physical, chemical

PVD
Thermal: (resistant heating, e-gun);
Cold: sputtering

Mechanical reshaping: rolling, powder forming (pellet forming, powder deposit), HIVIPP

Chemical: electrodeposition

medical isotopes production – research level

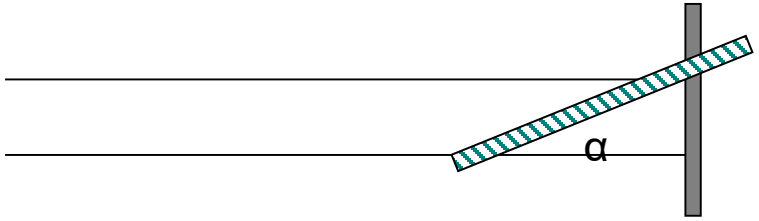
- thick (tens - hundreds mg/cm^2)
- The thickness homogeneity unimportant
- Very high purity

Methods
- mechanical, chemical

Mechanical reshaping: rolling, powder forming, (pellet forming, powder deposit), HIVIPP

Chemical: electrodeposition

64Cu	Copper-64	64Ni(p,n)64Cu	7-12	**187 µm**	**167 mg/cm2**
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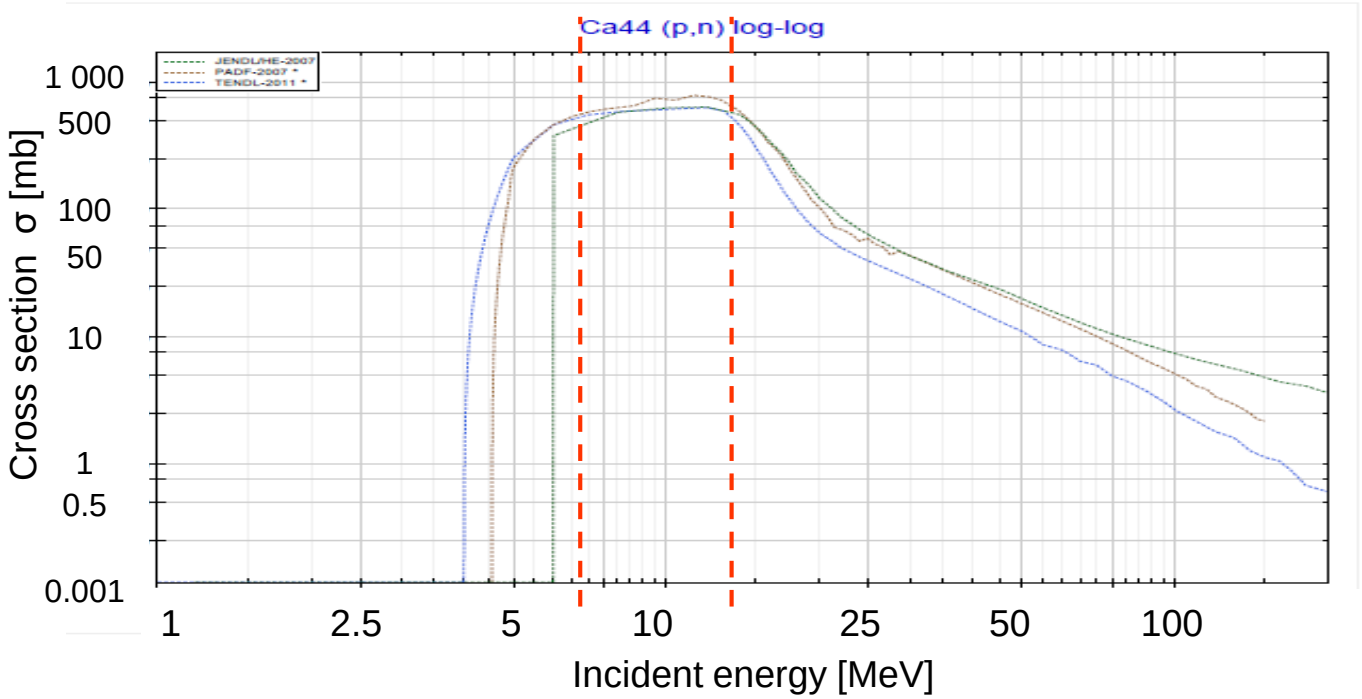


Beam fi 1 cm;
the same ‘physical’ target but beam is passing through: 100/sin α ->

e.g. for 30 º we have double thickness

Beam fi 1 cm > 0.7854 cm2
target 100 µm

	$^{44m/44g}$Sc	Scandium-44	^{44}Ca(p,n)$^{44m/g}$Sc	5-15 MeV	912 µm 263 mg/cm^2
				7-13 MeV	552 µm 159 mg/cm^2



56.2 mg
Target $^{44}CaCO_3$
198.77 mg/cm^2
6 mm diameter

13.5 -> 7.5 MeV

4 h of irradiation,
p 9.4 µA

Reported: 42 h
after EOB
~46 MBq /29 MBq

Simulation: 13.5 -> 7.5 MeV,
9.4 µA target 198 mg/cm^2

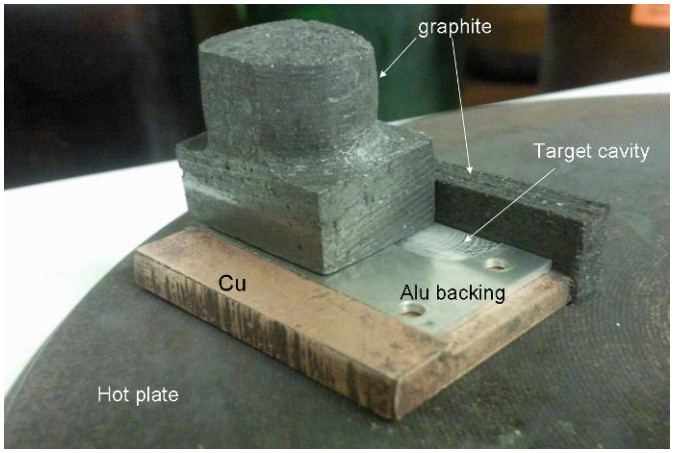
	total 44Sc	44mSc
for fi 6 mm (0.2827 cm^2)		
0 h (EOB)	12.6 GBq	50 MBq ^{44m}Sc
42 h after EOB	47.50 MBq	31.7 MBq ^{44m}Sc

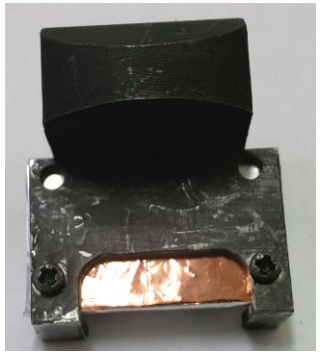
Simulation: 16 -> 5 MeV,
9.4 µA target 325 mg/cm^2

total 44Sc	44mSc
18.8 GBq	79 MBq
67.0 MBq	49 MBq

with internal α beam (~30 MeV)

$^{209}Bi\ (\alpha,2n)^{211}At$ target ~100 mg/cm²

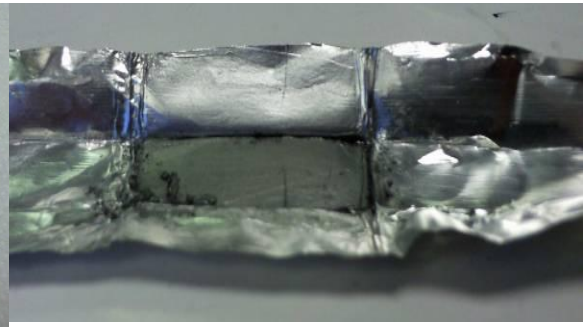




$^{40}Ca(\alpha,p)^{43}Sc$ or $^{40}Ca(\alpha,n)^{43}Ti \rightarrow {}^{43}Sc$

$^{nat}CaCO_3$ ~50-60 mg/cm²







Targets for medical radioisotopes production

with protons 16 MeV

$^{100}Mo(p,2n)^{99m}Tc$ ~370 mg/cm^2









Targets as pellets produced by compacting the Mo powder with hydraulic press

w ramach grantu ALTECH from NCBIR

Targets for medical radioisotopes production

with 16 MeV protons

$^{43}Ca(p,n)^{43}Sc$ ~ 250-300 mg/cm^2

$^{42}Ca(d,n)^{43}Sc$ ~ 55 mg/cm^2

$CaCO_3$ ~300 mg/cm^2

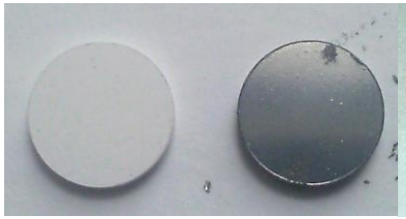








$CaCO_3$ + 5-10% graphite







$CaCO_3$ ~300 mg/cm^2, fi 6 mm in graphite bed

Heat dissipation???

dissipation of the heat (W=ΔE × I) deposited in the target:
conduction + radiation + convection

by *conductive heat transfer* can be estimated from:

$$q = k\,A\,dT\,/\,s$$

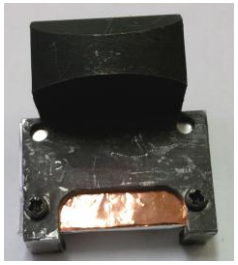
where
- A = heat transfer area (m^2)
- k = thermal conductivity of the material (W/(m K)
- dT = temperature difference across the material (K)
- s = material thickness (m)

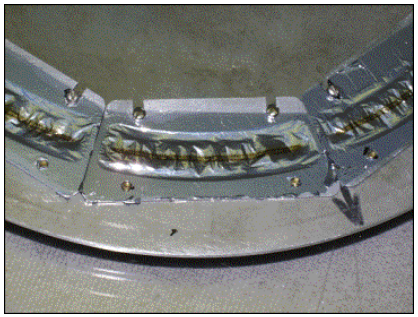
by *radiation* can be estimated from expression

$$q = \varepsilon\,\sigma\,T^4\,A$$

where
- ε - emissivity of the object (one for a black body)
- σ - Stefan-Boltzman constant [$W\,m^{-2}K^{-4}$]
- A - area of the object [m^2]
- T - temp of the object [K]

To decrease the thermal impact of the beam:
- target wheel
- beam wobbling
- backing with higher thermal conductivity
- blackening of the target materials







target wheels used
by SHE, Argonne Lab *or* by TASCA, GSI
(Transactinide Separator and Chemistry Apparatus)
projects



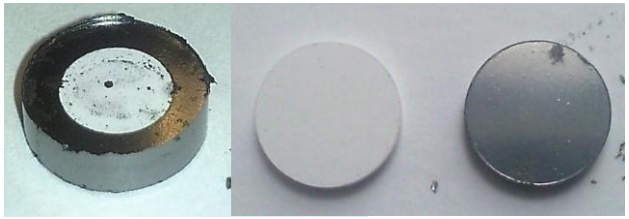
Thank you

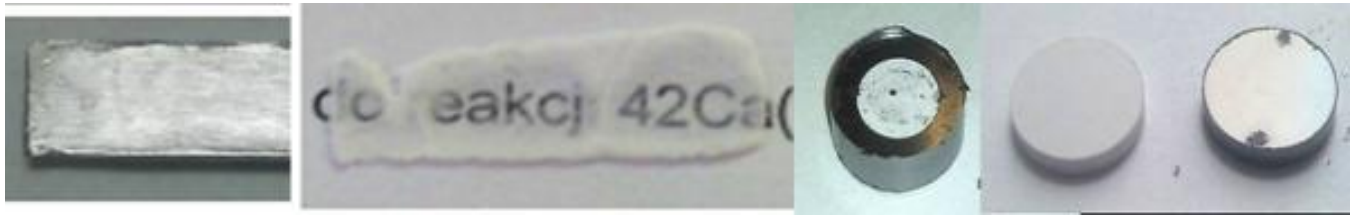




International Nuclear Target Development Society
www.intds.org

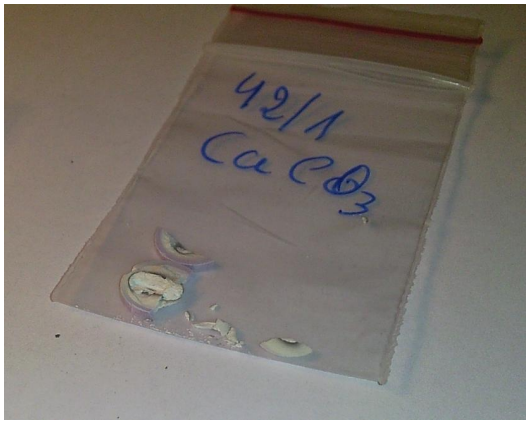





eakcj 42Ca





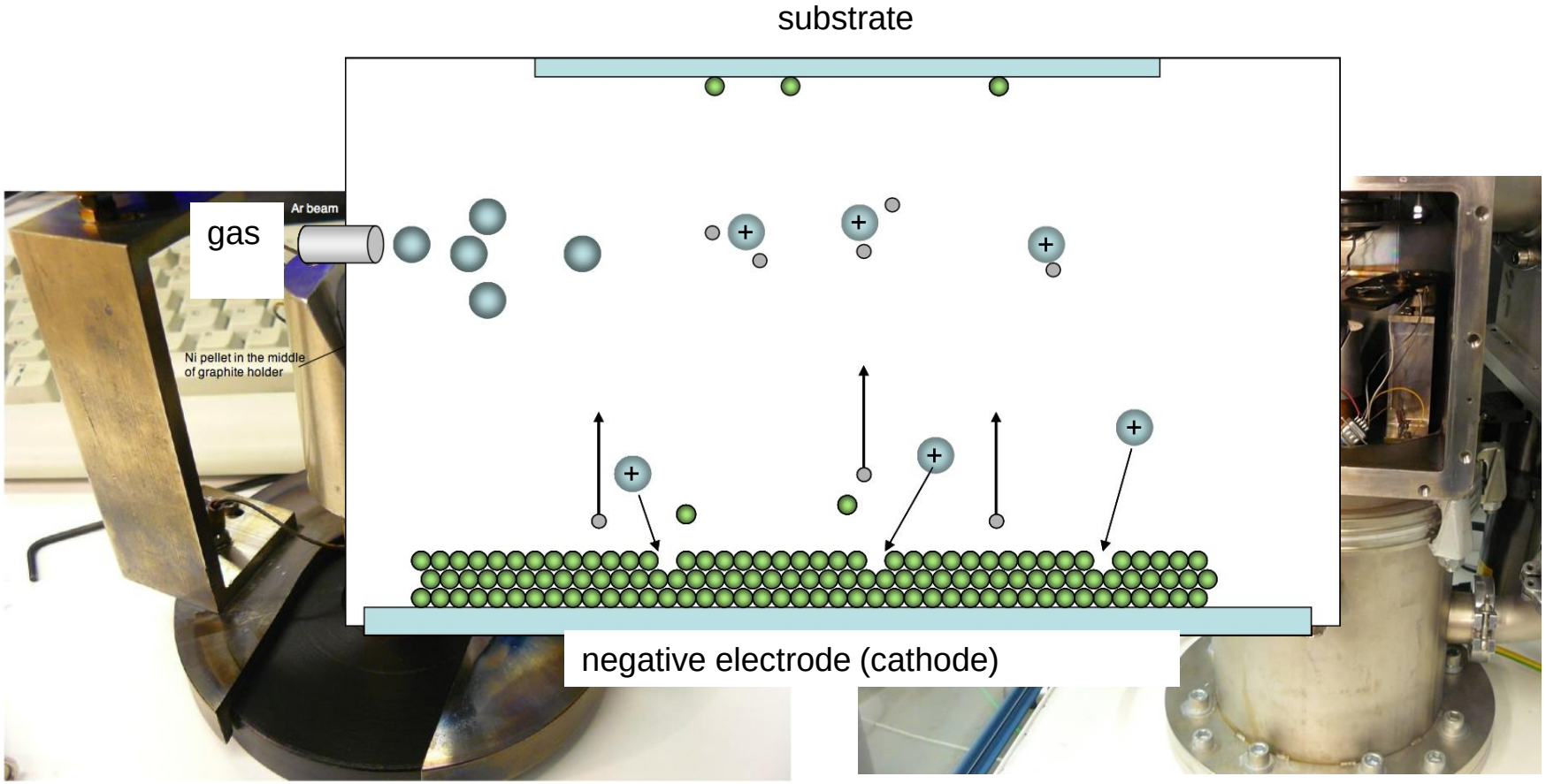

42/1
CaCO3

Sa jeszcze inne interesujące DYSK: backup 22-run with jj



sputtering

particles of a solid material (cathode) are ejected from its surface, by accelerated ions of the nobel gas

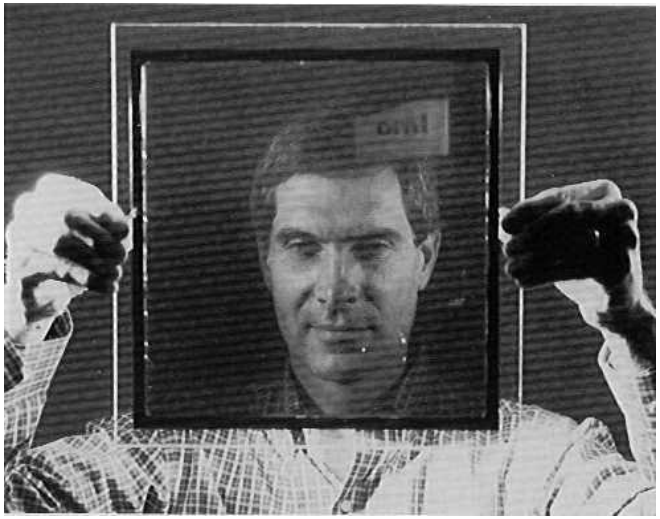


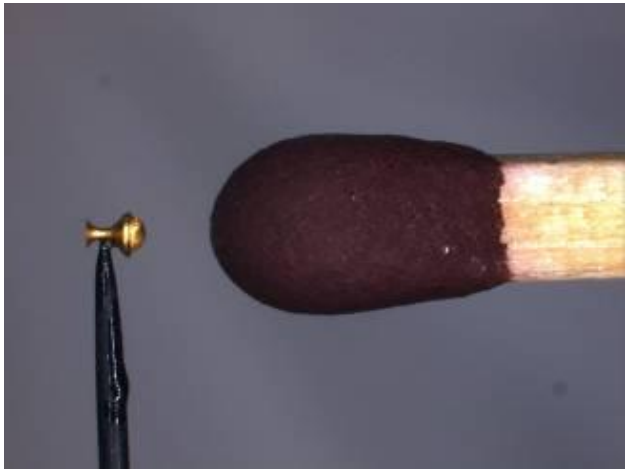
Alpha particle energy attenuation

The method is based on the change of the energy of the alpha particle passing the material.
The areal density for the thin foils can be determined form the relation between the lost energy and stopping power for the given energy of the alpha particle in studied material
th = ΔE/S(E)
where: th is the measured thickness, ΔE is the measured energy loss, MeV
S is the stopping power of the material at the E energy of the alpha particle MeV /cm2/g
Since S is energy dependent in case of the thick foils the total energy loss has to be splitted [[i]] and thickness is expressed as:
th =
The upper limit of the method is considered as around the 5 mg/cm2 . The lower limit of the method depends on sensitivity of the applied detectors i.e. on the precision of measurability of the alpha energy peak shift.
The method is relatively simple and can be applied to all materail with known value of sropping power our-days easily availbale from the TRIM or SRIM programmes

COMPARISON

- Rutherford Scattering:
  6.25 mg/cm^2
  6.00 mg/cm^2
- Energy loss of α particles:
  5.88 mg/cm^2
- Induction gauge method:
  5.72 mg/cm^2

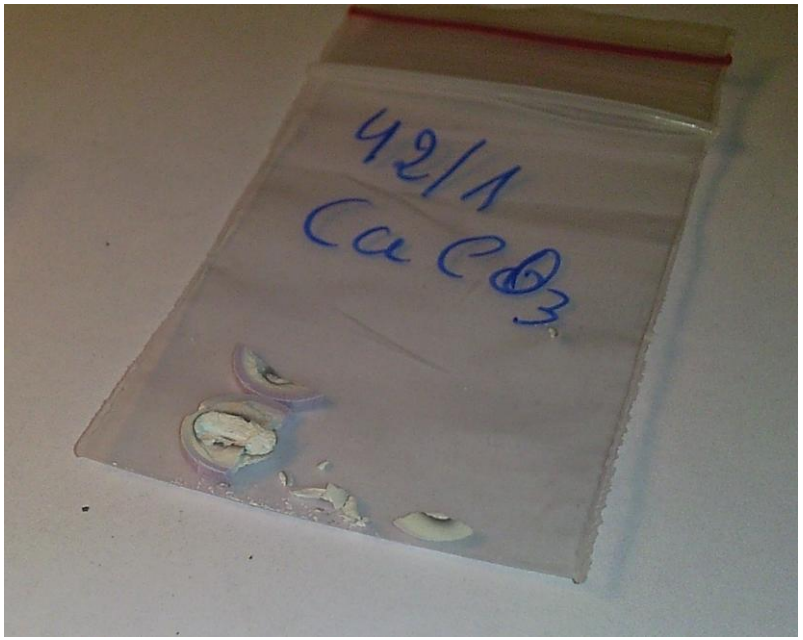





42/5
CaCO3


CaCO3
42/5


42/1


42/1
CaCO3

Gas targets

The ‘gas target’ is used in the ambiguous way. Some when talking about the gas target meant target in the gaseous state while others meant just the targets composed of/containing the gaseous element such as hydrogen, oxide etc.

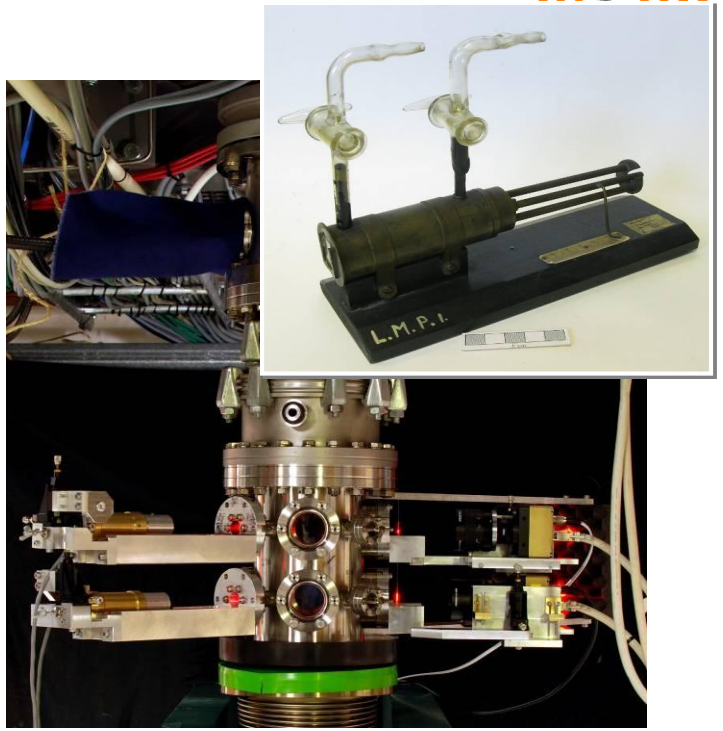
- gas container with entrance window made of thin foil.

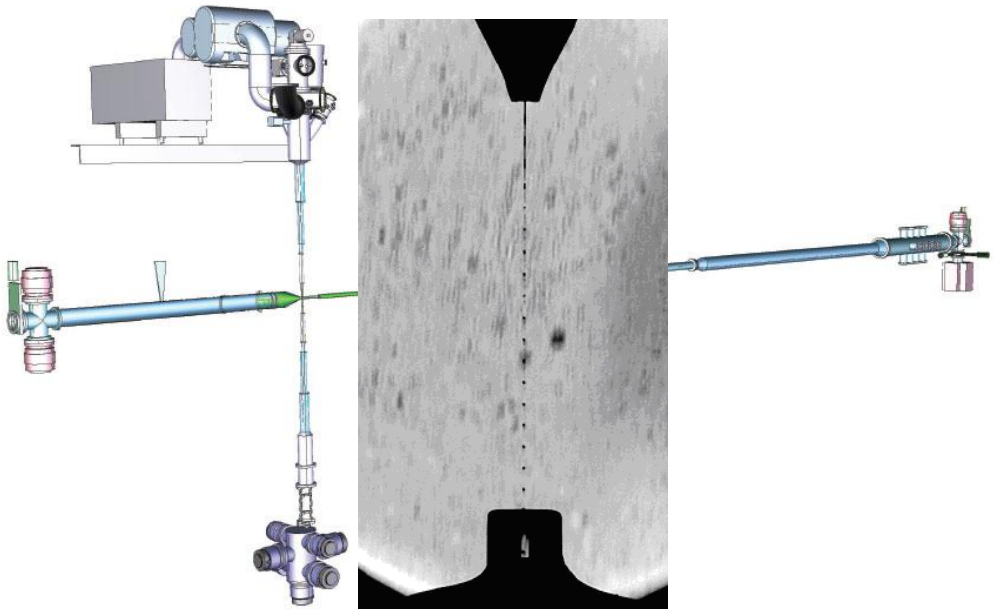
This windows means the limitation of projectiles beam power to avoid the window rupture Nevertheless, especially the heavy ions when passing through the entrance window they loos energy and thus the beam contain projectiles of different energy, The other important disadvantage of such target is aging of the window material and in consequence cousing the vacuum problem or the gas leak out of the target chamber. The mentioned drawbacks can be overcome with widowless high-density gas targets using the gas jets

sorption
implementation
solid compounds with gasous elements
cryotargets

Gaseous or liquid

- material loaded into the chamber kept at a low temperature
- gas or liquid flow (the melted metals as well)
- in case of gaseous elements:
  implantation into the solid backing/carrier

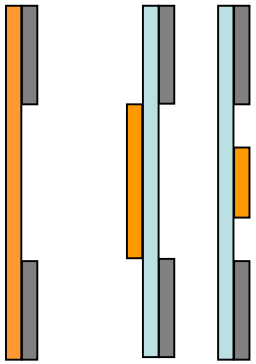




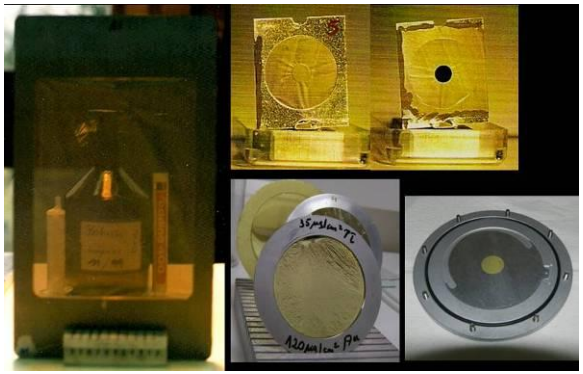
Gaseous/solid target in form of frozen hydrogen

Solid targets

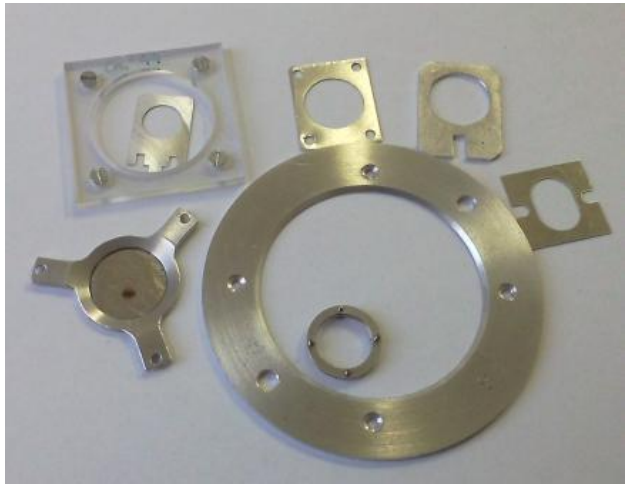
- self supporting
- on the backing



31

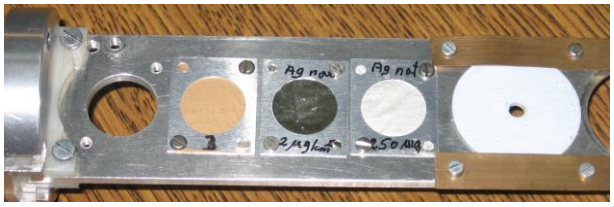






Compact solid target system for production of 123-I, 124-I, 86-Y, 64-Cu, etc
(commercial solution)

http://www.elexcomm.com/nirta-eng.html









blackening the wheels material or covering the targtes with thin layer of the carbon to enhance the heat dissipation by radiation

The bench water-cooled rotating target

For experiment performed for search of the super heavy elements the gas-cooled rotating targets are used



Thank you

International Nuclear Target Development Society
www.intds.org