Targets for production of research quantities of the medical radioisotopes with α and p/d beams

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HEAVY ION LABORATORY (HIL)

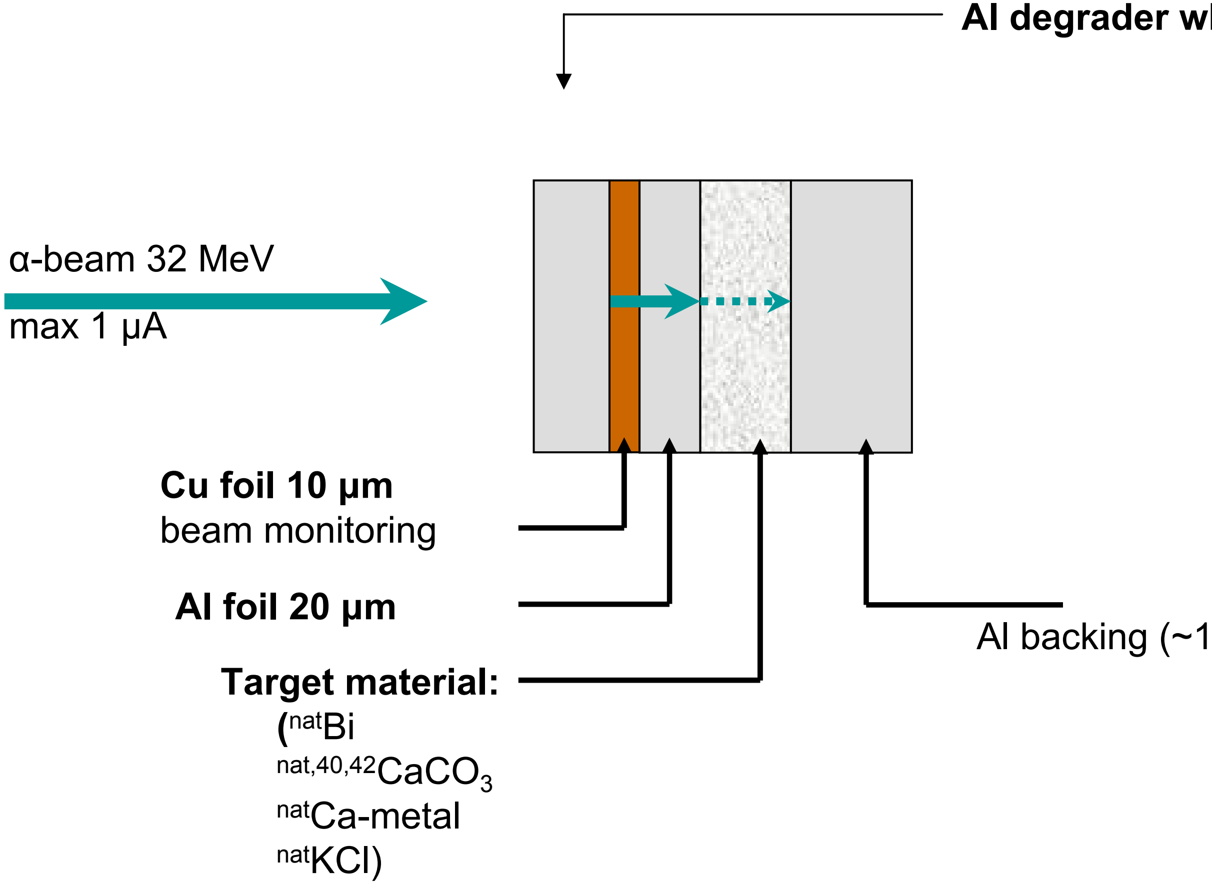
The Laboratory is an interdepartmental unit of the University of Warsaw

Main equipment located at HIL UW	*heavy ion isochronous cyclotron, accelerating ions up to mass 40 to the energies E/A ~10 MeV/A* *Providing Alpha internal beam, 32 MeV*
	PETtrace p/d medical cyclotron (16 MeV/ 8MeV) *Providing protons or deuterons*
Cyclotron C30 *located at NCBJ, Świerk, home made*	*delivering p with low intensities with energies (up to 28 MeV)*

Radioisotopes presently investigated

	U200P (α) / energy	PETtrace (p and d) and C30 (p)
^{211}At (natBi)	^{209}Bi(α,2n) / 29 MeV	
^{43}Sc (^{nat} and ^{40}Ca-99.99%)	^{40}Ca(α,n) / 20 MeV	^{42}Ca(d,n) / 8 MeV ^{43}Ca(p,n) / 16 MeV
^{44}Sc (^{42}Ca- 68% and ^{nat}K)	^{42}Ca(α,2n) / 29 MeV ^{41}K(α,n) / 15 MeV	^{44}Ca(p,n) / 16 MeV
^{47}Sc (^{nat}Ca)	^{44}Ca(α,p)	
$^{44m/44g}$Sc *in-vivo* generator	^{42}Ca(α,2n) possibility of generator production with α beam was presented at ICTR-PHE 2016, Geneva, and in paper available on line at App Rad Isotop	^{44}Ca(p,n) / 16 MeV ^{44}Ca(d,2n) / 8 MeV
^{72}Se/^{72}As (natGe)	^{70}Ge(α,2n) / 30 MeV	
^{99m}Tc		^{100}Mo(p,2n) / 16 and 25 MeV

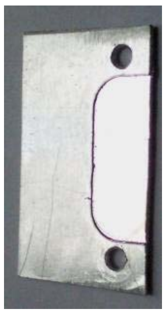
Radioisotopes production with internal α beam

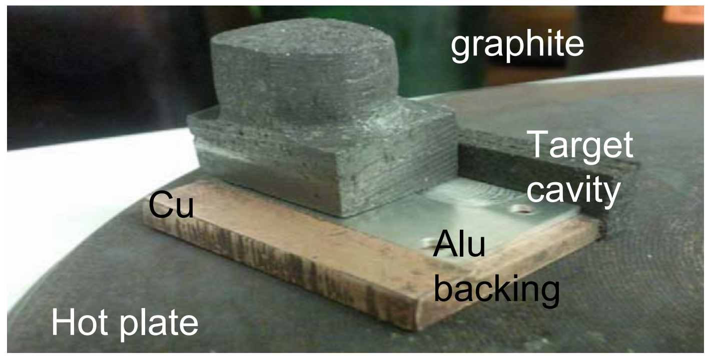


^{211}At production

^{211}At produced at ^{209}Bi(He^{+},2n)^{211}At reaction, Bomb. en. 29 - 31 MeV

Target: 99.95 % Bi, 100 μm (~113 mg/cm^{2}) by direct melting on Al backing, wrapped with 20 μm Al foil and covered with 10 μm Cu foil





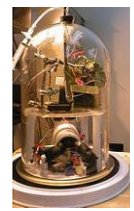
- With 500 pnA beam (recent limitation) ~130 MBq of 211At is produced during ~10 h of irradiation.
- The produced activity is transported to the Institute of Nuclear Chemistry and Technology, where the ^{211}At is extracted from the Bi target and chemical research consisting of binding the ^{211}At e.g. to substance P, a peptide with high affinity to the receptors of glioma cancer cells, are conducted.

Sc isotopes production with α, protons or deuterons in reaction with Ca

Targets material: enriched material is available in form of $CaCO_3$
it can be converted into Ca in multistep vacuum process:

$$CaCO_3 \Rightarrow CaO + CO_2$$

$$2CaO + Zr \Rightarrow Ca + ZrO_2$$



and Ca-metal further reshaped into foil by rolling under the inert atmosphere
but: this is time consuming process and …..

So it is better to stay with $CaCO_3$ form

Sc radioisotopes production with alpha particles

Target for α irradiation

^{nat}Ca-met 99.87 %

$CaCO_3$ nat 99.995 %

$^{40,42,43,44}CaCO_3$

* Calcium carbonate distribution over the pre-shaped aluminium foil
* wrapping the material in this foil forming 'candy'
* and pressing with force of ~120-150 bar forming thin but stable layer of the target material.
* The 'candy' covered with 10 μm Cu foil for beam monitoring is mounted to the target holder

isotope production with *p* or *d*

PETtrace cyclotron


Staying with $CaCO_3$

- pressing the $CaCO_3$ (10 mg) placed on a top of the graphite powder (160 mg) into a pellet (N.P. van der Meulen et al., 2015)
or pressing the $CaCO_3$ powder into pre-pressed graphite disk (2013, C. Muller)
and further encapsulating the received pellet into Al container.

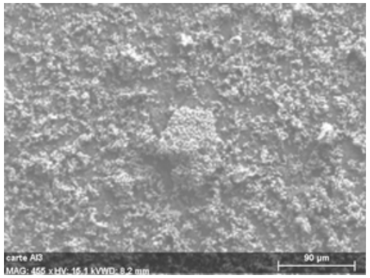
Target prepared this way has very random ‘spot’ of target material (area/shape and thickness) in the graphite bed




Sc radioisotopes production with p or d

- powder loading into and encapsulating in the container
  + easy
  - energy loss on the beam entrance window
  - opening container after irradiation (challenge for automatisation)

- C.Duchemin et all (2015) in their work on ^{44}Sc production reported use of the target prepared by forced powder sedimentation (centrifuge speeding).
  - The mentioned method for layers at the listed thickness of 2.5 mg/cm^2 gives target full of voids



SEM image of the 2 mg/cm^2 of Mo target
Preparation of molybdenum target by centrifugal method
A.Durnez ,V.Petitbon-Thévenet
Journal of Radioanalitycal and Nuclear Chemistry, 2014

Sc isotopes production with protons or deuterons in reaction with Ca

Staying with $CaCO_3$

targets can be prepared

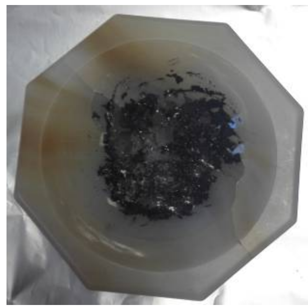
- 'self-supporting' pellet … with addition of the binder
  + easy, controlling the thickness
  - needs of 'foreign' material which can be easily separated from the matrix during isotopes extraction

Taking into account the heat transport from the bombarded target material the best would be to use the powder of the metal with high heat transfer coefficient such as Au, Ag, Cu but they are excluded due to the high activation under the proton beam.

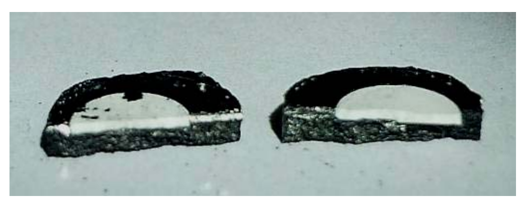
From metals only Al (250 W/(m K) can be considered, as only very short lived (4.16 s) ^{27}Si is produced in reaction (p,n) or (2.24 min) ^{28}Al in reaction (d,p)

The other option is a graphite. Natural graphite material is highly anisotropic, with a thermal conductivity ranging from 140-1800 W/mK along the axes parallel to the layer planes and from 3-10 W/mK along the axis perpendicular to the planes.

Target prepared as a pellet mixed homogenously with graphite or Al powder



In case of mix with graphite there is a problem of a hard inner part requiring its mechanical smashing to get the complete dissolving of the target material. Problem can be avoided by forming the $CaCO_3$ pellet, with defined diameter and thickness, further mounted into the C layer.



Targets made as homogenous mix with Al powder (e.g. 1:1, ~130:130 mg was dissolved

in HNO_3 (~1 min, very easy but ....

or

in Acetic Acid (longer, ~5 min in elevated temp.(~50 °C)

The analyses of the Al contain in the solutions showed

300 µg / g of Al in HNO_3 solution (e.g. 39 µg per 10 GBq in case of target made with 130 mg of Al)

5 µg / g of Al in acetic acid solution (e.g. 0.65 µg per 10 GBq)

Both are below safe limitation per dose of vaccination ....
which is 0.85-1.25 mg/dose according to the Federal regulation
Some other sources show 25 µg /ml as limitation per dose.

Cyclotron production of ^{99m}Tc

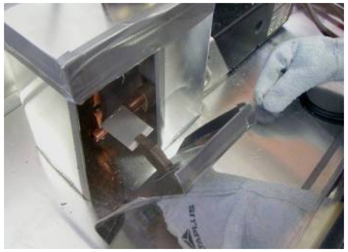
- The accelerator production of the radioisotope of ^{99m}Tc is carried by the Heavy Ion Laboratory of the University of Warsaw in collaboration with POLATOM and Institute of Nuclear Chemistry and Technology.

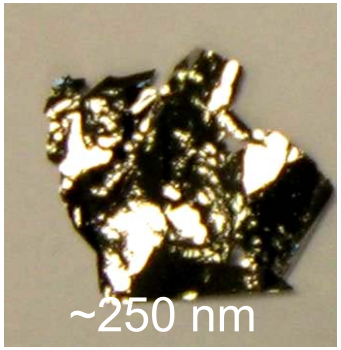
- Samples were irradiated with 16 MeV (PETtrace) and with 27 MeV (C-30) protons and we carry long-term measurements of impurities after irradiation.

- Experimental program covers:
  - determination of parameters for reaction $^{100}Mo(p,xn)^{99m}Tc$ allowing high yield of ^{99m}Tc production with the minimum of impurities;
  - rapid, simple and efficient methods of target dissolution and isolation of ^{99m}Tc
  - and also development of methods of ^{100}Mo recovery from the irradiated targets.

Targets used for ^{99m}Tc production were in form of powder pellet and in form of foils.

The production of the last ones was reported in 2014 at 26th INTDS conference in Tokyo (and is published at J Radioanal Nucl Chem., 305/3 (2015) 947), It consists of powder melting in the high vacuum, production of material disc at high temp. followed by classical rolling technique under the inert atmosphere.





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International projects

- Coordinated Research Project IAEA,
  ”***Accelerator-based Alternatives to Non-HEU production of 99Mo/99mTc***”
  2012-2015,
- French-Polish, COPIN, GANIL/SPIRAL2
  ”***Radioactive Nuclei for Medical Applications”,*** 2013…
- ENSAR2, WP15,
  “***Matched pair of scandium isotopes for Theranostics”***

Polish grants awarded by NCBiR

Alternative method of 99mTc production,
POLATOM, and INCT/IChTJ, HIL UW/ŚLCJ UW
2012-2016

Production of the Sc-based radiopharmaceuticals for PET diagnostic,
IChTJ/INCT, and POLATOM, HIL UW/ŚLCJ UW, NCBCH UW;
2016 - 2018

Conclusions

1. The targets for radioisotopes production not always require sophisticated techniques
2. The target preparation techniques depends on the final goal: research (reaction parameters) or activity production; the target stability and heat dissipation have to be considered
3. Some Sc radioisotopes (43Sc) can be produced with a high efficiency using alpha irradiation and natural target material (not I.E)
   The irradiation with α particle allows as well production of the $^{44m/44g}$Sc generator with much higher isomeric ratio than for deuterons (5 times higher) and protons (20 times higher)
   [more details in K.Szkliniarz et al, *Production of medical Sc radioisotopes with an alpha particle beam*, ARI, 2016

Thank you very much for your attention