



UNIVERSITÉ DE NANTES

Radioactive isotopes produced for medical applications: setting up an accurate measurement method for production cross section

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• How radionuclides can be useful for medicine ?

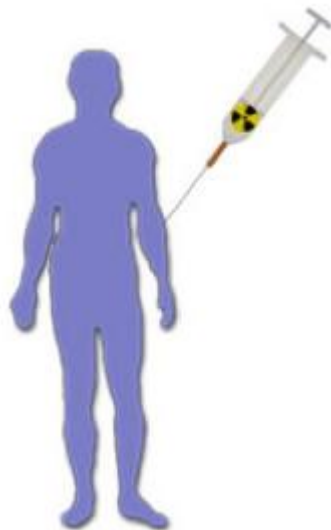
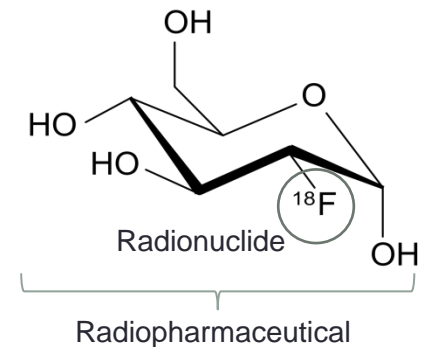
- Physics properties :

- Particle or radiation emitted by decay of the radionuclide ($\alpha, \beta, \gamma, e_{\text{Auger}}$)
- Energy
- Half life of the radionuclide

- Chemical properties :

- Extraction of the radionuclide from the target
- Radionuclide labelling ...

The radionuclides are coupled with a vector to do **imagery** or **therapy**. Indeed, the tracers have an affinity with the interest area which allows to bring them to the cancer cells.



Injection of the radiopharmaceutical into the patient to make a **diagnosis** or a **treatment**.

Imagery

Therapy

- How radionuclides can be useful for medicine ?

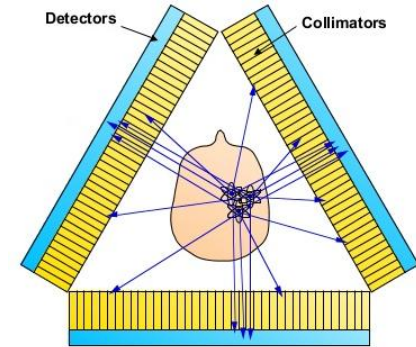
Imagery

➔ Low energy gamma emissions (~100 keV)

- SPECT (Single photon emission computed tomography)

Radionuclide decay by emitting a photon.

Detectors with collimators allow to deduce the emission source



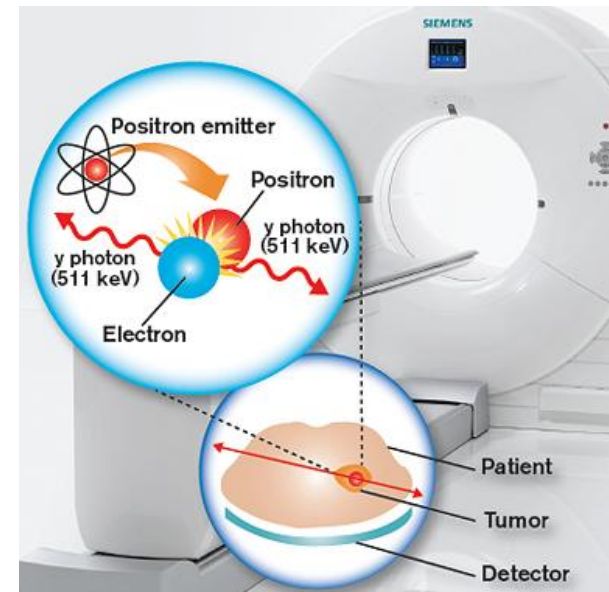
- PET (Positron emission tomography)

Radionuclide decay by emitting a positron.

Annihilation with an electron near the tumour.

Two 511keV photons are created and emitted in opposite direction.

Detectors allow to deduce the emission source



- How radionuclides can be useful for medicine ?

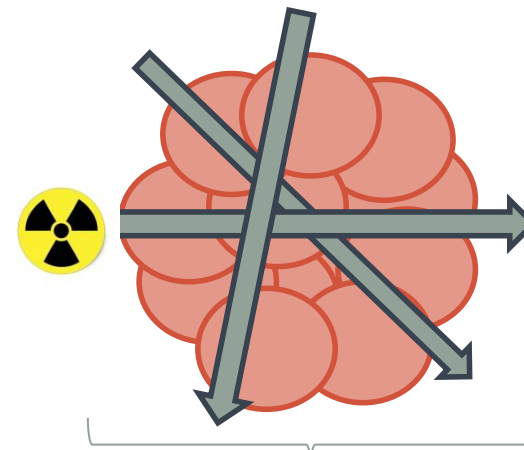
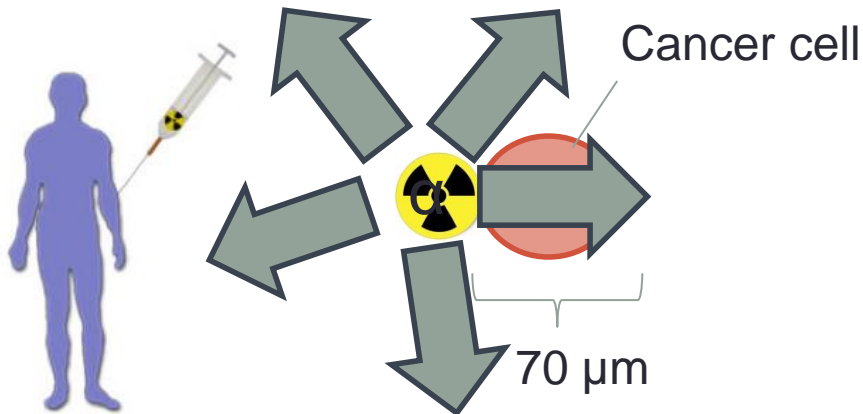
Nuclear Medicine → Linear energy transfer

- Brachytherapy

When it is possible, a sealed source can be placed near to the tumour for treat it.



- Vectorised internal radiotherapy



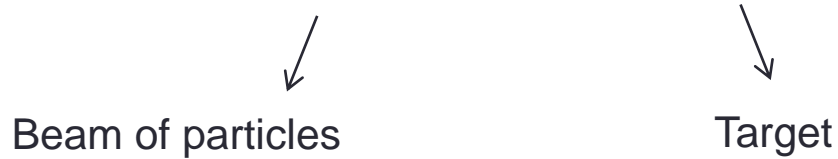
Two kinds of radiation

1000 μm

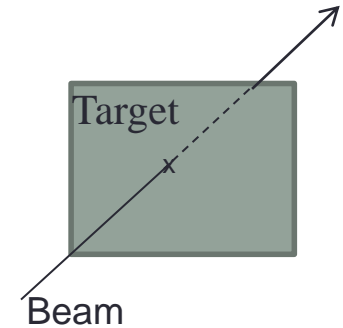
→ How can we produce radionuclides?

- Production of radionuclides

- Nuclear reaction between a projectile and a nucleus



➡ Different nuclear reactions possible.



- Each reaction has a probability to take place in the target

➡ Physic value: the **production cross section** $\sigma(\text{cm}^2)$

Dependence with the incident particle energy.

- Accurate knowledge of the cross section allows :
 - Optimize the radionuclide production.
 - Lower the contaminants production.

• Production of radionuclides

²¹¹At

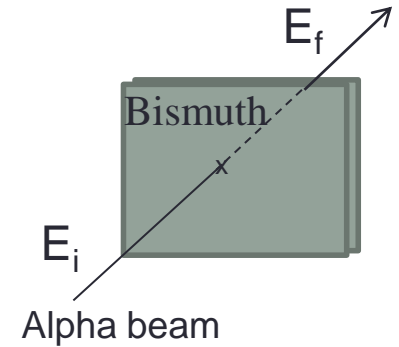
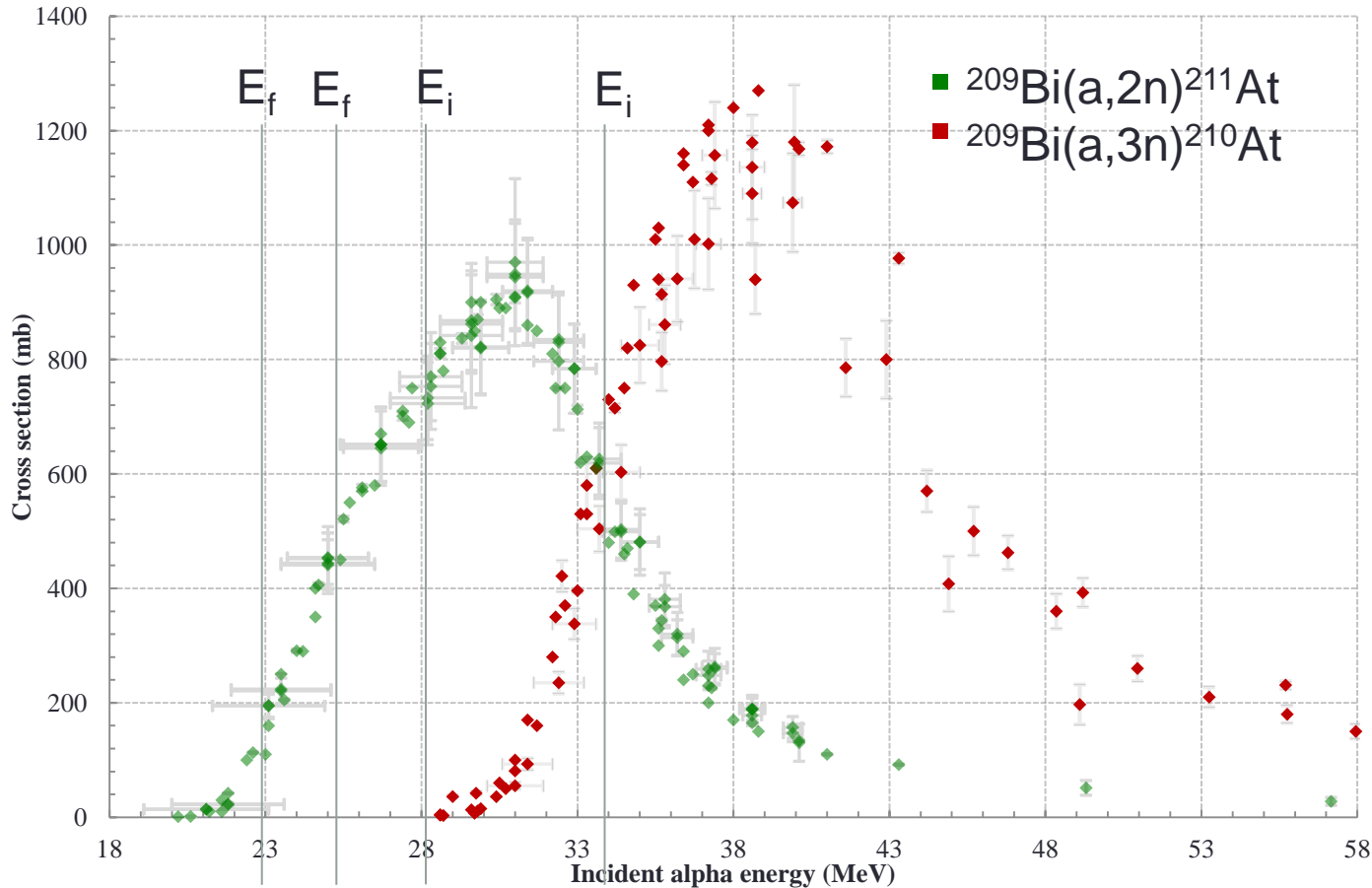
- Alpha emitter
- T_{1/2} = 7,2 hours

²¹⁰At

- T_{1/2} = 8,1 hours
- Decay to ²¹⁰Po

²¹⁰Po

- Alpha emitter
- T_{1/2} = 138,37 days



➡ How can we calculate the cross section?

• Activation formula

$$\text{Act} = \varphi \chi \frac{N_a \rho}{A} (1 - e^{-\lambda t_{\text{irr}}}) \int_{E_f}^{E_i} \frac{\sigma(E)}{\frac{dE}{dx}} dE \quad (1)$$

• Parameters of the **target** :

- A : atomic mass (g.mol⁻¹)
- ρ : density (g.cm⁻³)
- $\frac{dE}{dx}$: linear energy transfer of the incident particle in the target (MeV.cm⁻¹)
- χ : chemical and isotopic purity (only chemical in the case of natural target)

• Parameters of the **beam** :

- φ : incident particles flux (particles.s⁻¹)
- t_{irr} : irradiation time (s)
- E_i et E_f, Incident energy of the particle and the final energy (MeV)

• Parameters of the **radionuclide produced** :

- λ : decay constant (s⁻¹)
- Act : Activity of the radionuclide produced (Bq)
- σ(E) : production cross section at the energy E varying between E_i and E_f (cm²)
- N_a : Avogadro constant (mol⁻¹)

- Activation formula with thin target (~10 μm)

- \Rightarrow Energy loss of the incident particle is negligible

$$Act = \varphi \chi \sigma(E) \frac{N_a \rho e}{A} (1 - e^{-\lambda t_{irr}})$$

- e : target thickness (cm)

- σ : production cross section for the energy particle in the middle of the target (cm²)

$$\sigma(E) = \frac{A \text{ Act}}{N_a \rho e \varphi \chi (1 - e^{-\lambda t_{irr}})} \quad (2)$$

To measure cross section

- **Act** : activity (Bq)

- φ : the number of projectiles/s (proj.s⁻¹)

\Rightarrow Parameters measured during the experiments

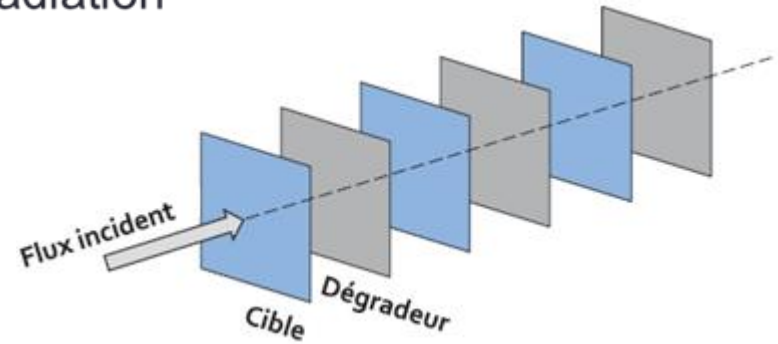
• Stacked foils technique

➡ Several measurements for one irradiation

Pattern

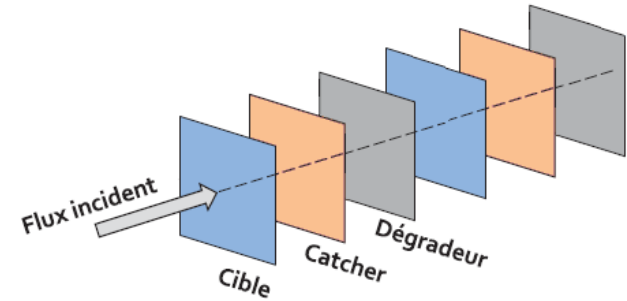
Target : produce the interest radionuclide

Degrader : adapt the beam energy



➡ Possibility of nucleus being ejected

Catcher : catch the recoil nuclei

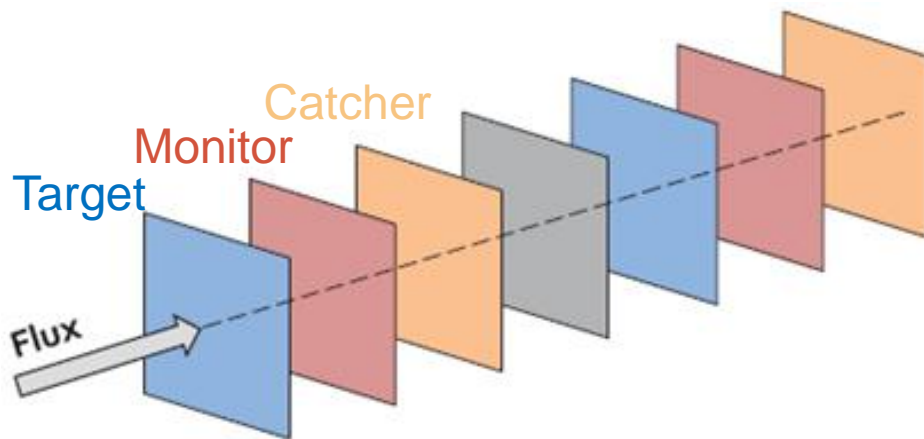


Two methods of **incident flux φ** measurement

- Relative : using monitor foil
- Absolute : measure the number of charges crossing the stack

• Two methods of incident flux φ measurement

- **Relative** method using **monitor foil** : Main error source with relative measurements \rightarrow the monitor reaction ($\sim 10\%$)



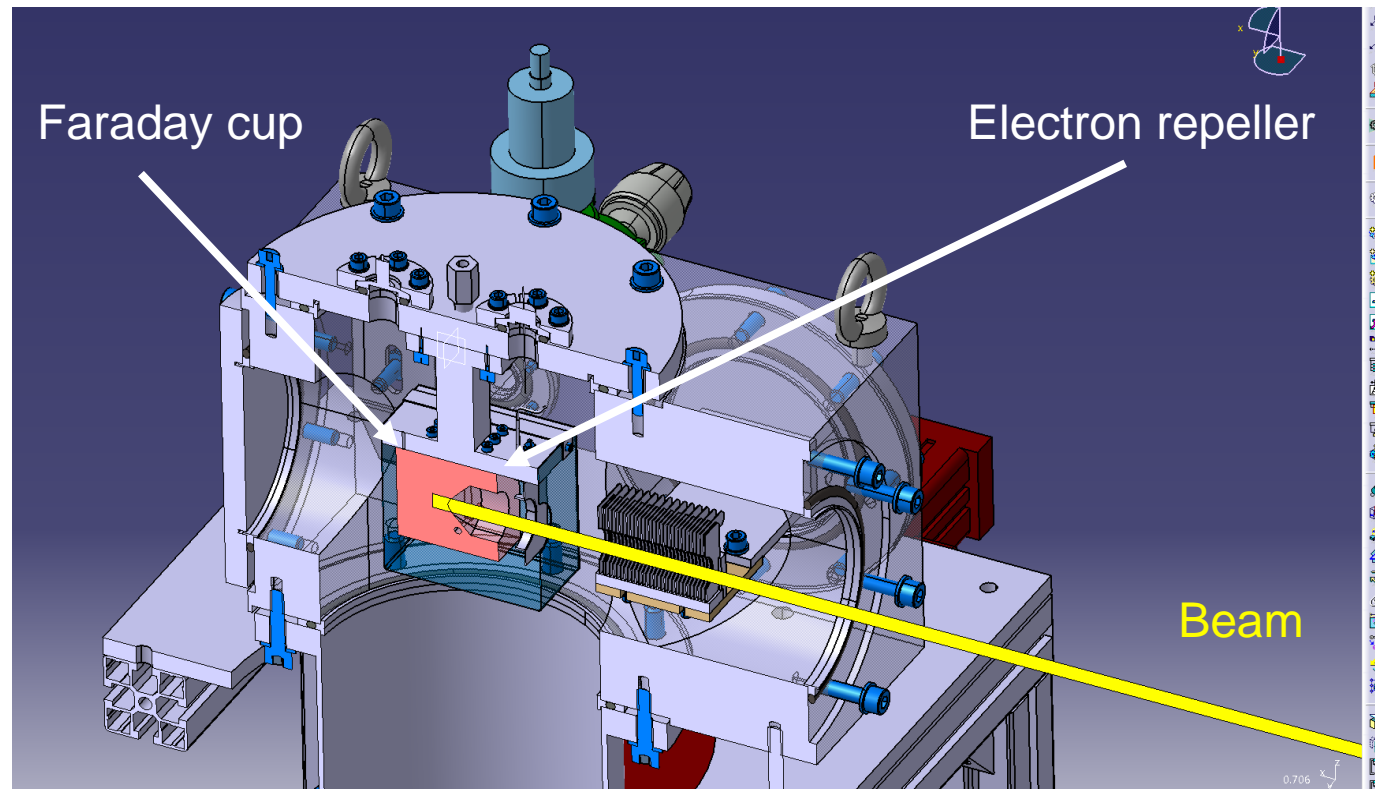
➡ Values recommended by IAEA^[1]

Hypothesis: $\varphi_{\text{target}} = \varphi_{\text{monitor}}$

[1] International Atomic Energy Agency (IAEA), Summary Report Second Research Coordination Meeting on Nuclear Data for C charged-particle Monitor Reactions and Medical Isotope Production, technical report April 2015

• Two methods of incident flux ϕ measurement

- **Absolute** : direct measurement of the number of charges crossing the stack using a **Faraday cup**: error estimate less than 3%



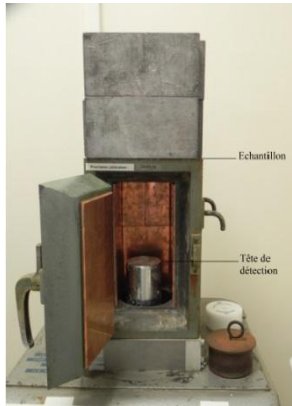
• The measure of the **activity** : gamma spectrometry

Spectrum : number of gamma photons according to their energy

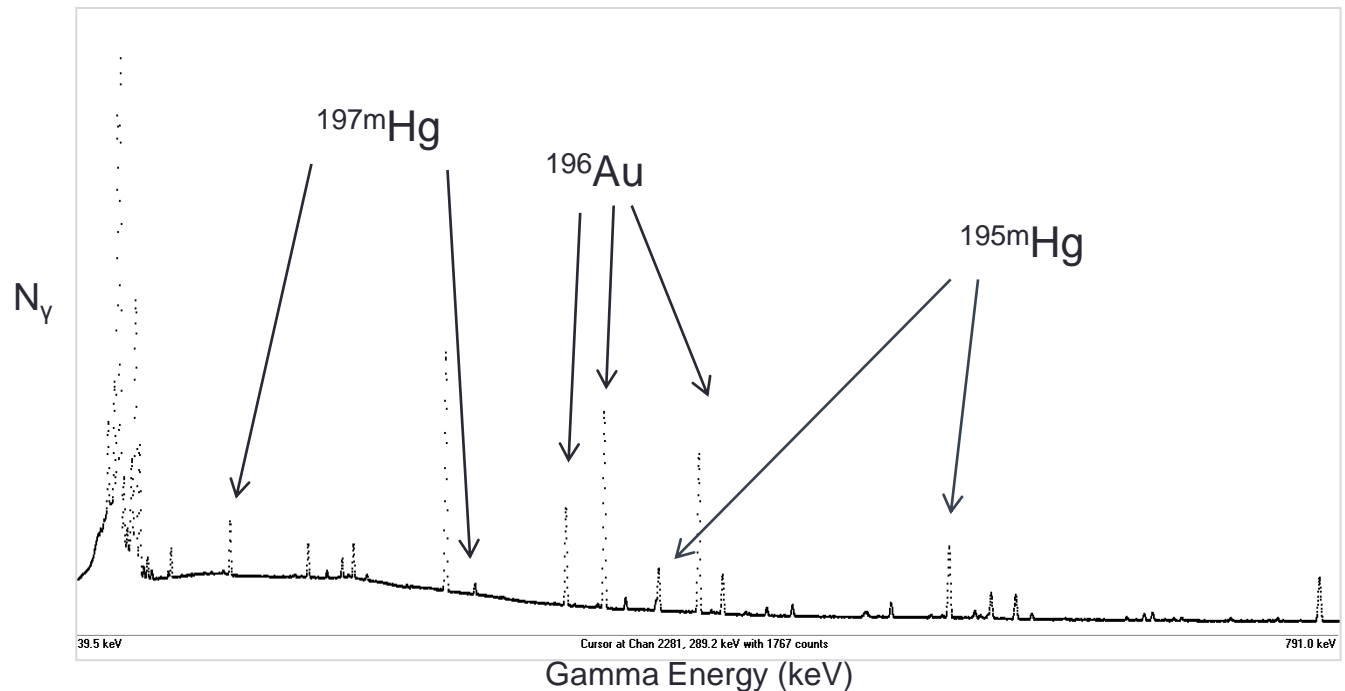
After Irradiation : activity measure of all radionuclides present in the foils

- Short counting to sort short lived radionuclides (<10h)
- Long counting to sort long lived radionuclides (>10h)

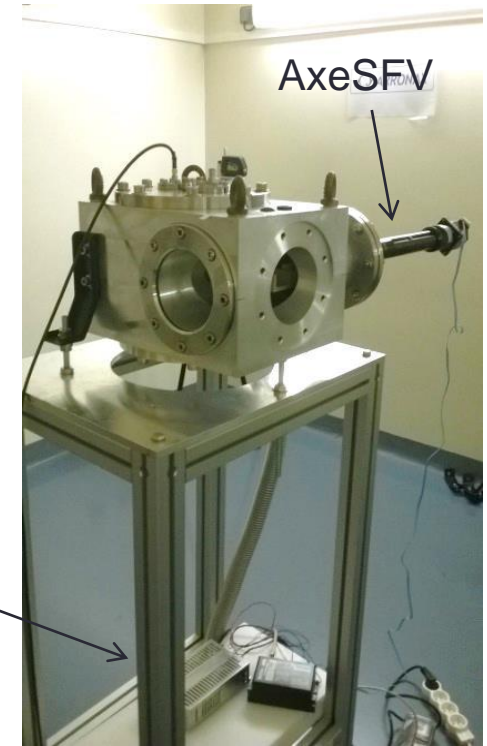
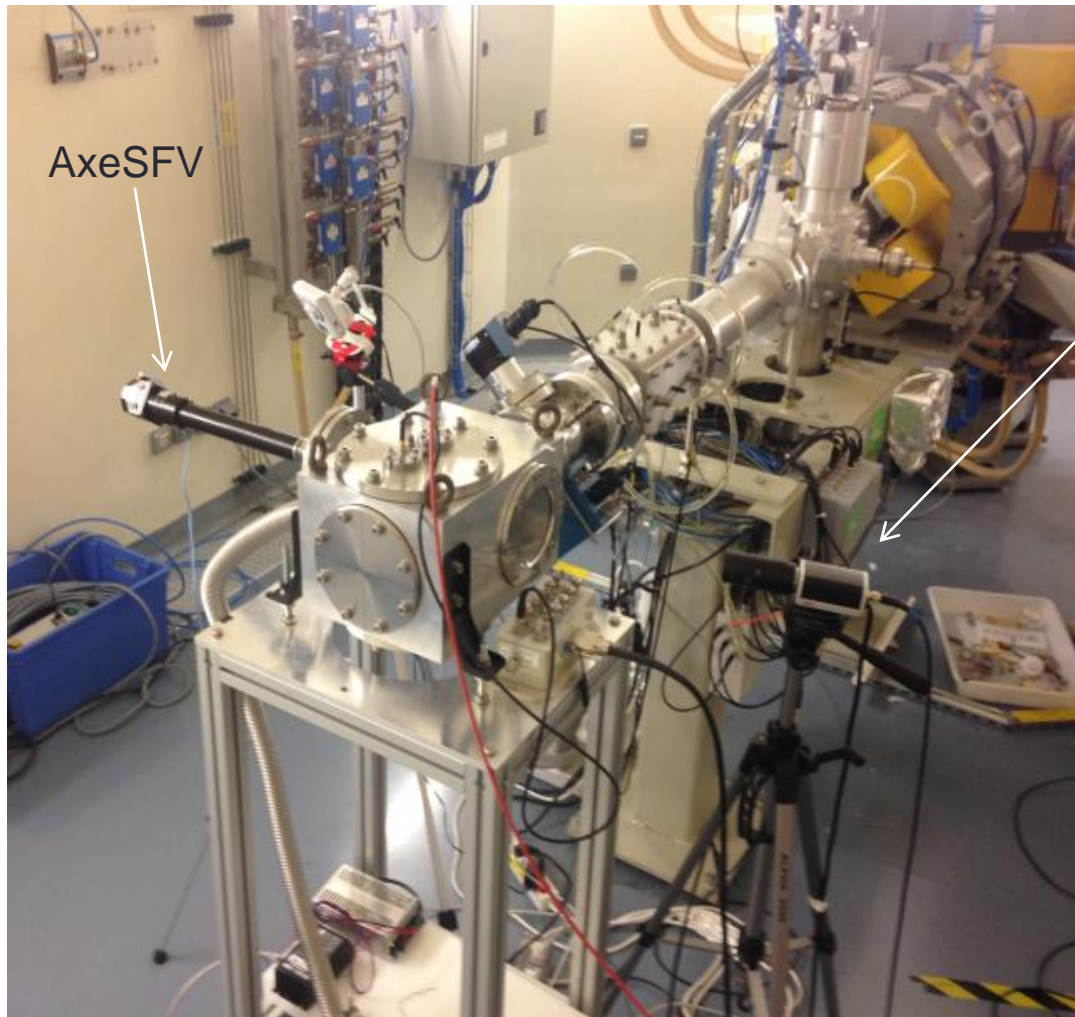
Radionuclides identification by the energy of gamma photon emissions



Reaction: $^{197}\text{Au}(d,x)$
27 MeV



• Experimental set up

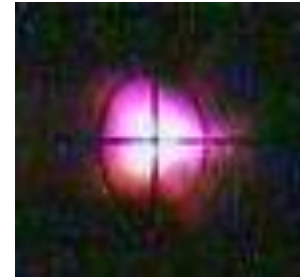


- Vacuum enclosure
- Alignment with the beam output

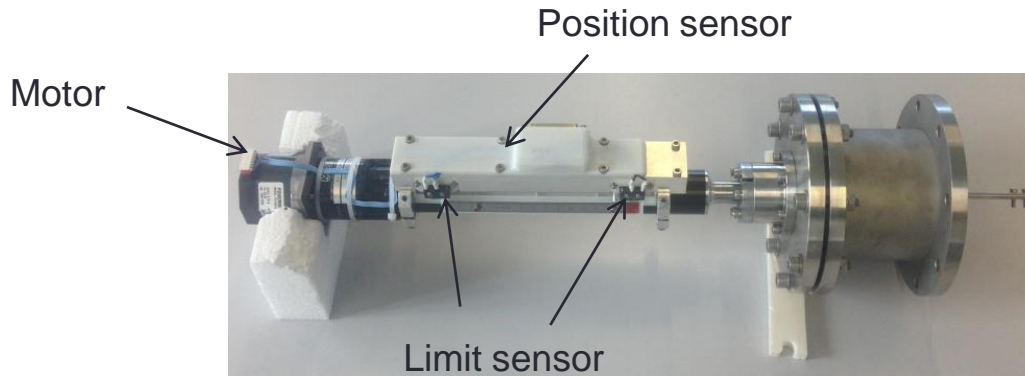
• AxeSFV : a motorized axis

Automate the movement of the axis

- Exposing the alumina then the stack to the beam
- Saving time and upholding the vacuum
- Reduction of radiation exposure

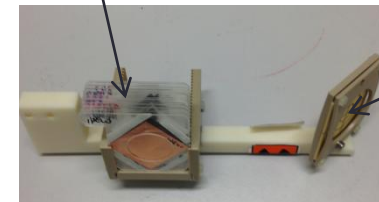


Alumina under beam



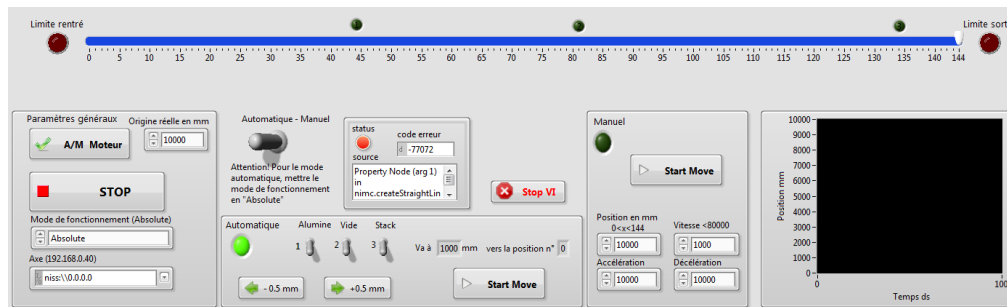
“AxeSFV”

Stacked-foils



Alumina

Stacked foils support



The device has made in collaboration with the mechanical department of SUBATECH laboratory.

• Results on the production of the ^{197m}Hg

ID card

^{197m}Hg ($T_{1/2} = 23,8\text{h}$)

Main gamma emissions :

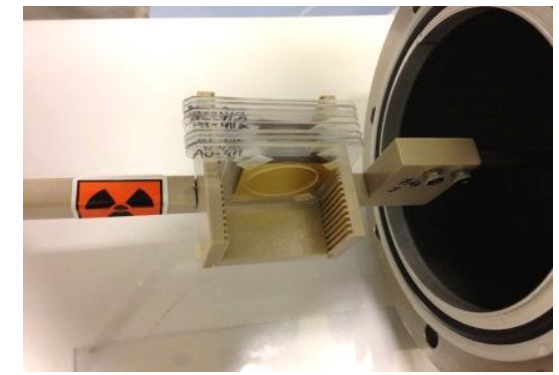
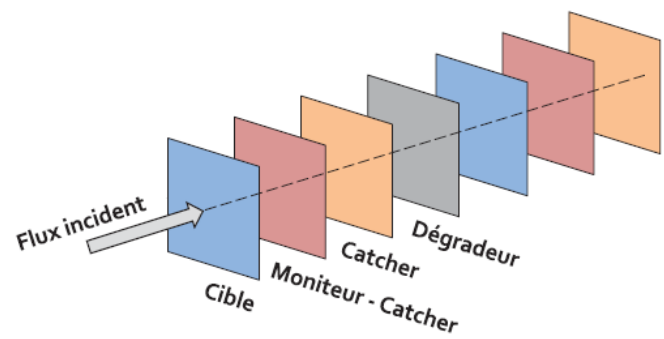
- 134 keV 33%
- 279 keV 6%

➔ SPECT Imaging

Hg extraction
by dry distillation

The best production route is $^{197}\text{Au}(d,2n)$

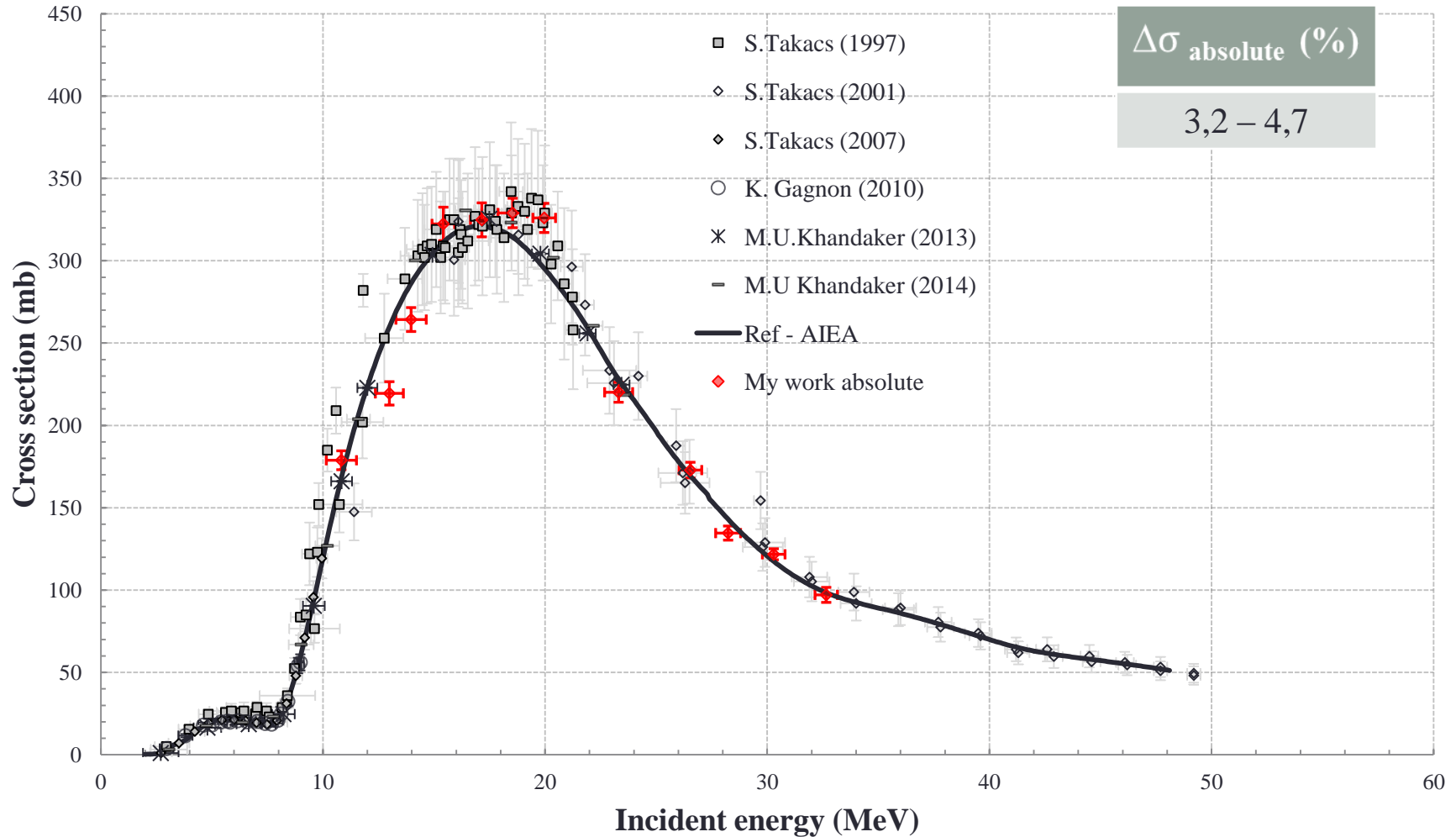
Pattern of the stack : Au – Ti - Al



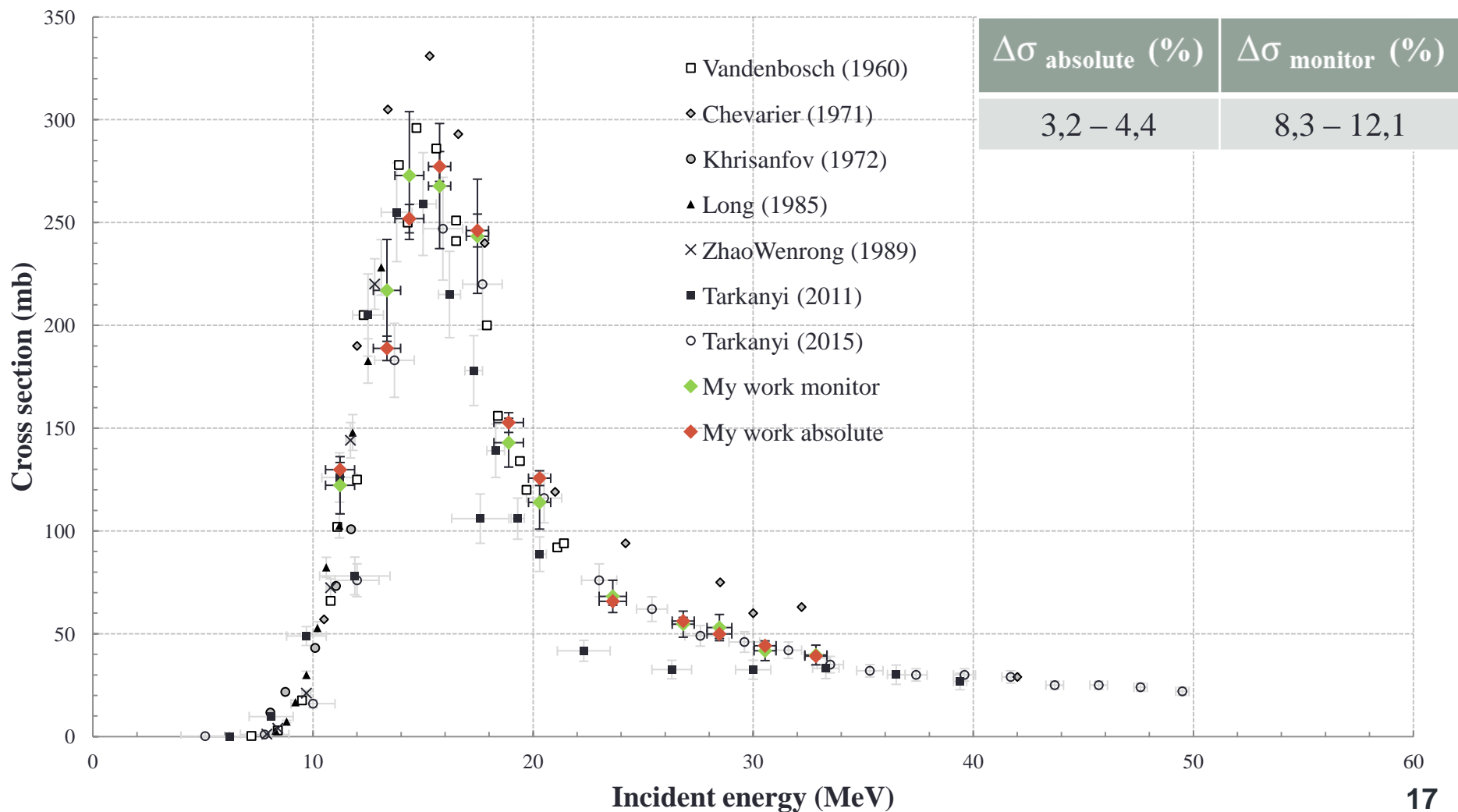
Two kind of values acquired after the experiments :

- σ_{charge} (mb) : measure the number of charges crossing the stack with the Faraday cup
- σ_{monitor} (mb) : using **Titanium** monitor foil

• Monitor reaction : ${}^{\text{nat}}\text{Ti}(d,x){}^{48}\text{V}$



• Reaction of interest : $^{197}\text{Au}(d,2n)^{197\text{m}}\text{Hg}$



• Conclusions

- ^{197m}Hg is a good candidate to be use for **SPECT imaging**
- The results obtained for the monitor reactions show that the new **experimental set-up works well.**
- Our results are in **good agreement** with the IAEA recommended cross section values and other available data in the literature

• Perspectives

- Our new set of data will also help extending the accuracy of databases and can be used to **constrain theoretical calculations**
- Study a new radionuclide of interest for medicine and its ways to produce it
- Study of alternative ways of production – Cu67 & project with Orano.

- Acknowledgements

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My research group **PRISMA**:

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Thanks for your attention

