

Production cross section of $^{197\text{m}}\text{Hg}$ induced by deuterons on natural gold target

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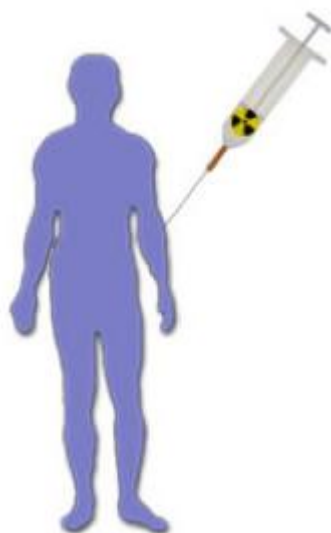
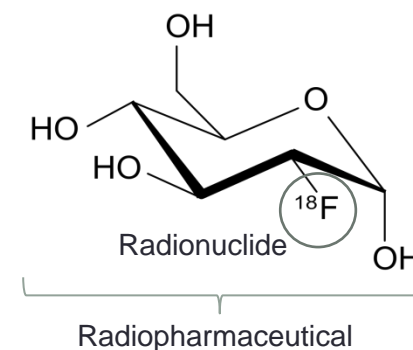
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• Radionuclides in medicine

- 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 tracer 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**.

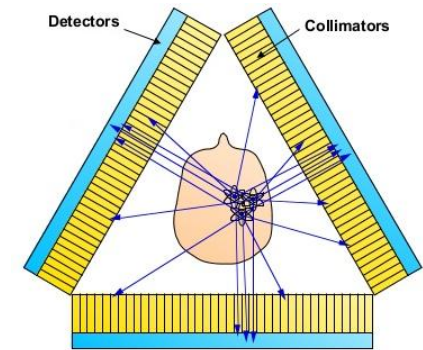
Imagery

Therapy

• Radionuclides in medicine

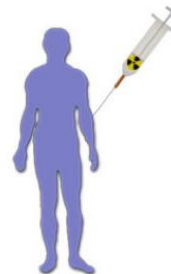
Imagery → Low energy gamma emissions (~ 100 keV)

- SPECT (Single photon emission computed tomography)
- PET (Positron emission tomography)



Therapy → Linear energy transfer

- Brachytherapy
- Vectorised internal radiotherapy



- ^{197m}Hg a potential medical radioisotope

Half life ^{197m}Hg 23,8h

Decay 91,4% IT, 8,6% EC
no β^+

Main gamma emissions

134 keV (33%)

279 keV (6%)

^{195}Hg 10.53 H E: 100.00%	^{196}Hg STABLE 0.15%	^{197}Hg 64.14 H E: 100.00%	^{198}Hg STABLE 9.97%	^{199}Hg STABLE 16.87%	^{200}Hg STABLE 23.10%	^{201}Hg STABLE 13.18%
^{194}Au 38.02 H E: 100.00%	^{195}Au 186.01 D E: 100.00%	^{196}Au 6.1669 D E: 93.00% β^- : 7.00%	^{197}Au STABLE 100%	^{198}Au 2.6941 D β^- : 100.00%	^{199}Au 3.139 D β^- : 100.00%	^{200}Au 48.4 M β^- : 100.00%

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

- Optimise the production → Highest cross section with deuterons
- Limit the number of impurities → Natural gold is monoisotopic

Hg extraction by dry distillation

- ^{197m}Hg can be imaged through the **SPECT technique**
 - To be use as a tracer for gold nanoparticles
 - Use in human with radiopharmaceutical

Stacked foils technique

Several measures for one irradiation

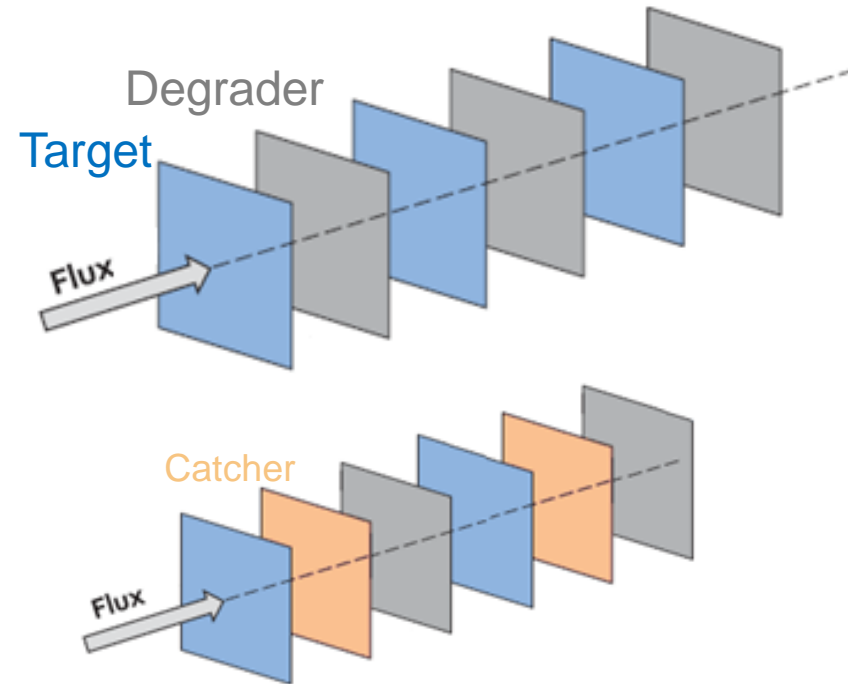
Pattern

Target (thin foil): produce the radionuclide of interest

Degrader : change the beam energy

Possibility of nucleus being ejected

Catcher : catch the recoil nuclei



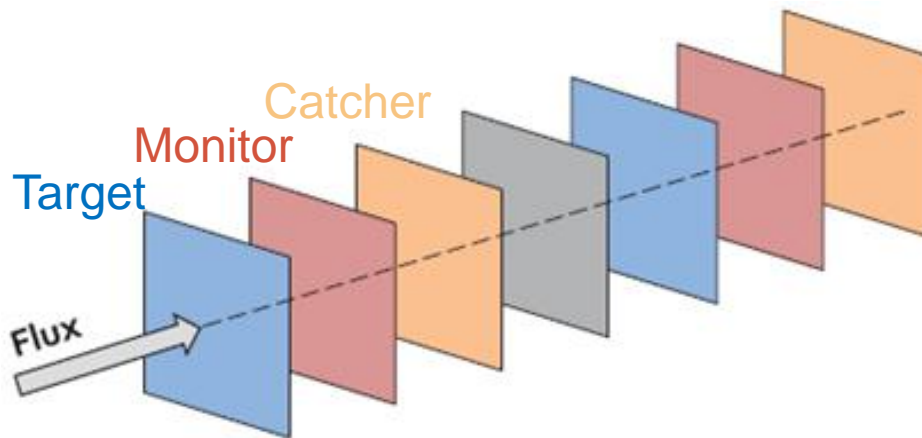
Two methods of **incident flux ϕ** measurement

- Two methods of incident flux φ measurement

- **Relative** method using **monitor foil** : Main error source with relative measurements → the monitor reaction (~ 10%)
- **Absolute** : direct measurement of the number of charges crossing the stack using a **Faraday cup**: error estimate less than 3%

• 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]

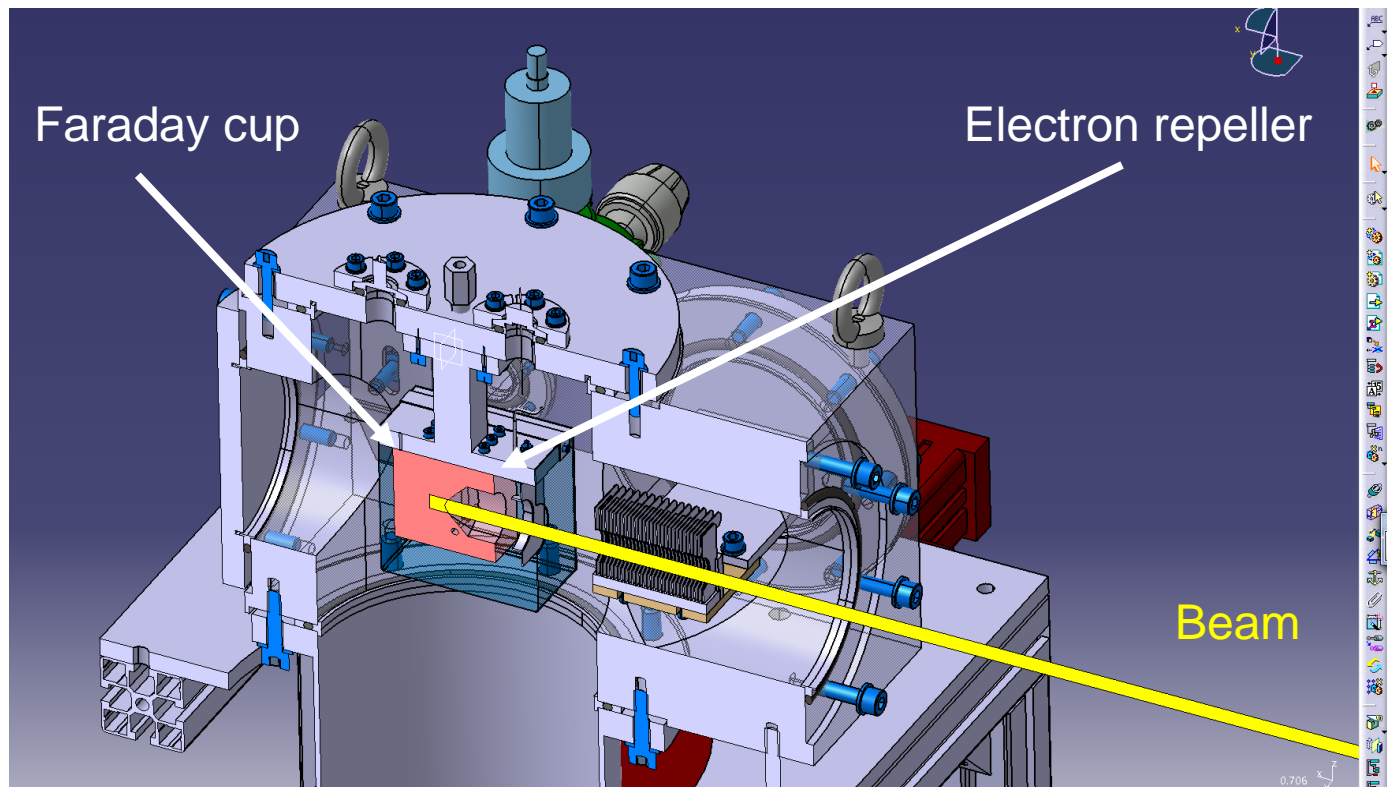
Hypothesis: $\phi_{\text{target}} = \phi_{\text{monitor}}$

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

[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

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

HPGe detector

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

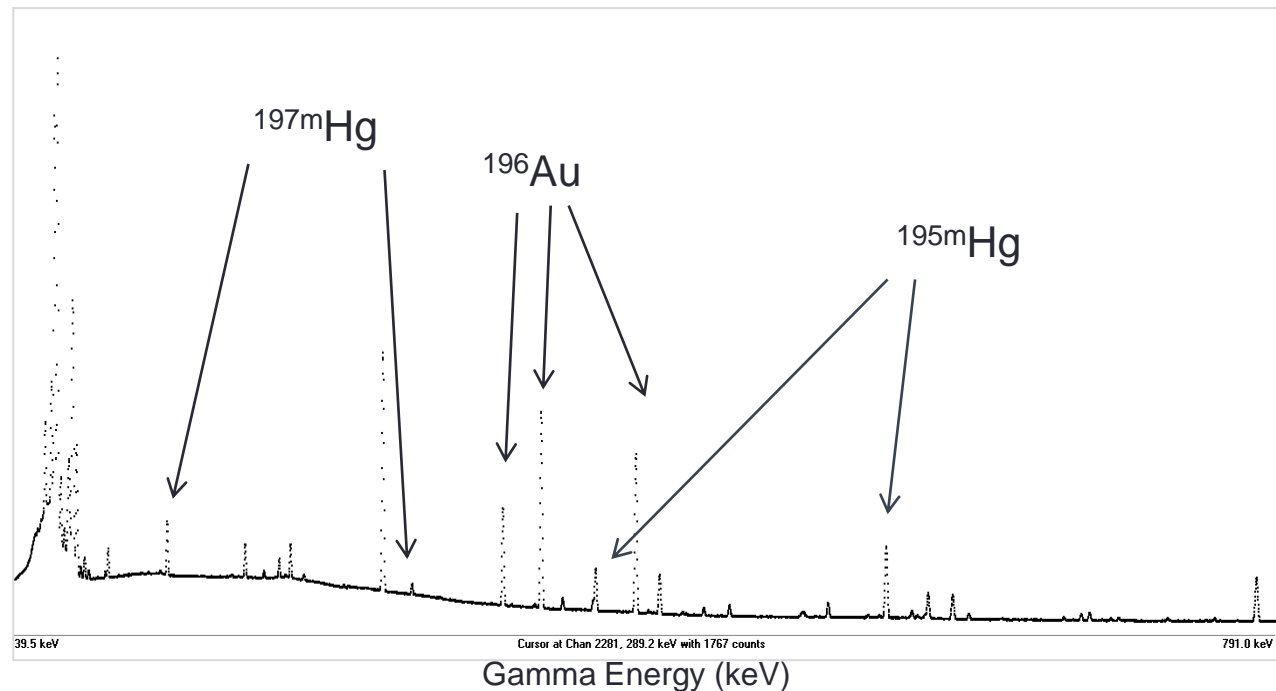
- Short counting to sort short lived radionuclides (<10h)
- Long counting to sort long lived radionuclides (>10h)



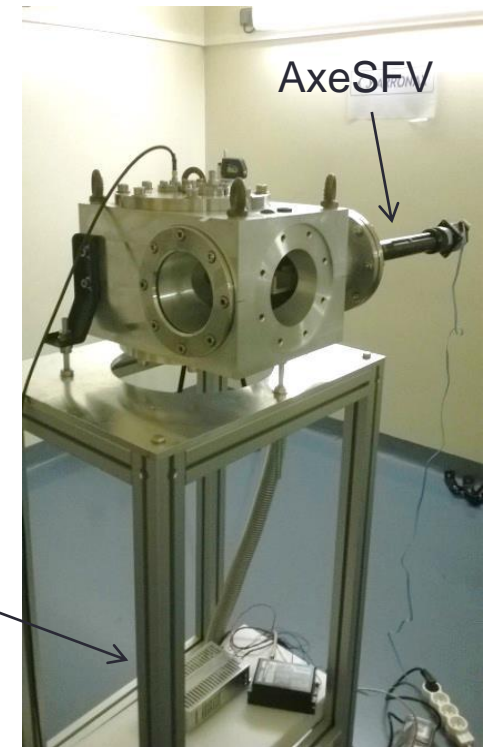
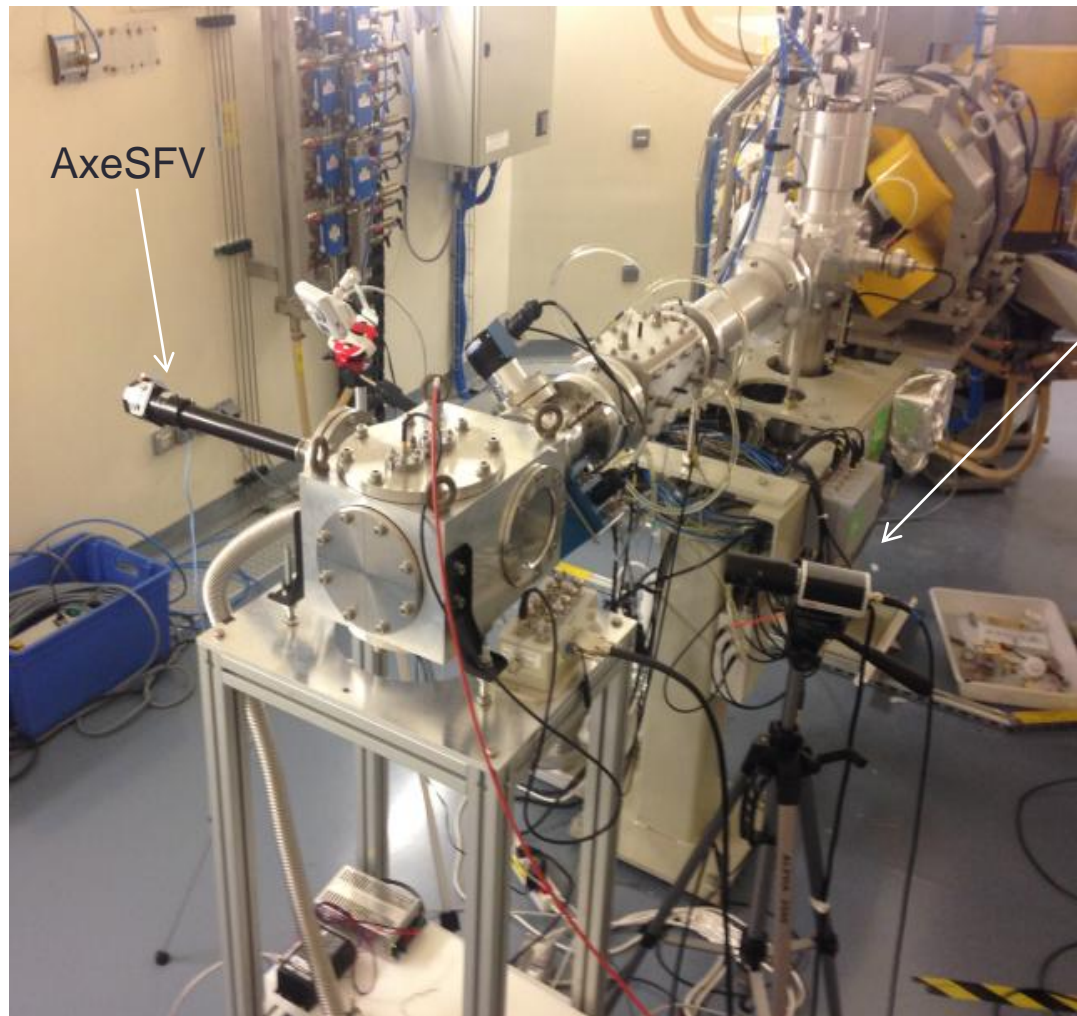
Reaction: $^{197}\text{Au}(d,x)$

27 MeV

N_γ



- The experimental set up



Beam
setting
using a
camera

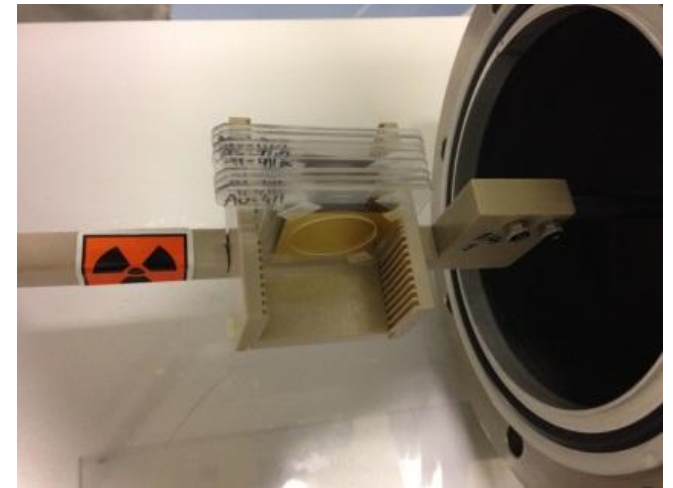
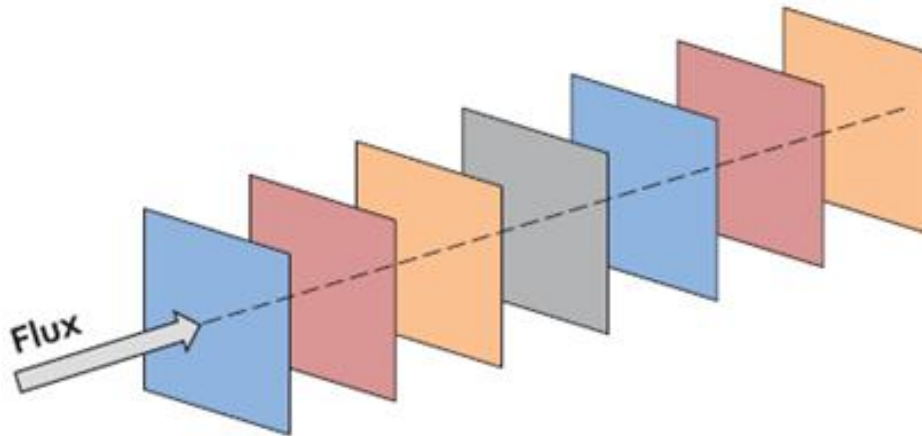
Electronic

- Vacuum enclosure
- Aligned with the beam output

- Our objectives are :

- Acquire new values for the production cross section of ^{197m}Hg
- Compare values obtained using both technique of flux determination

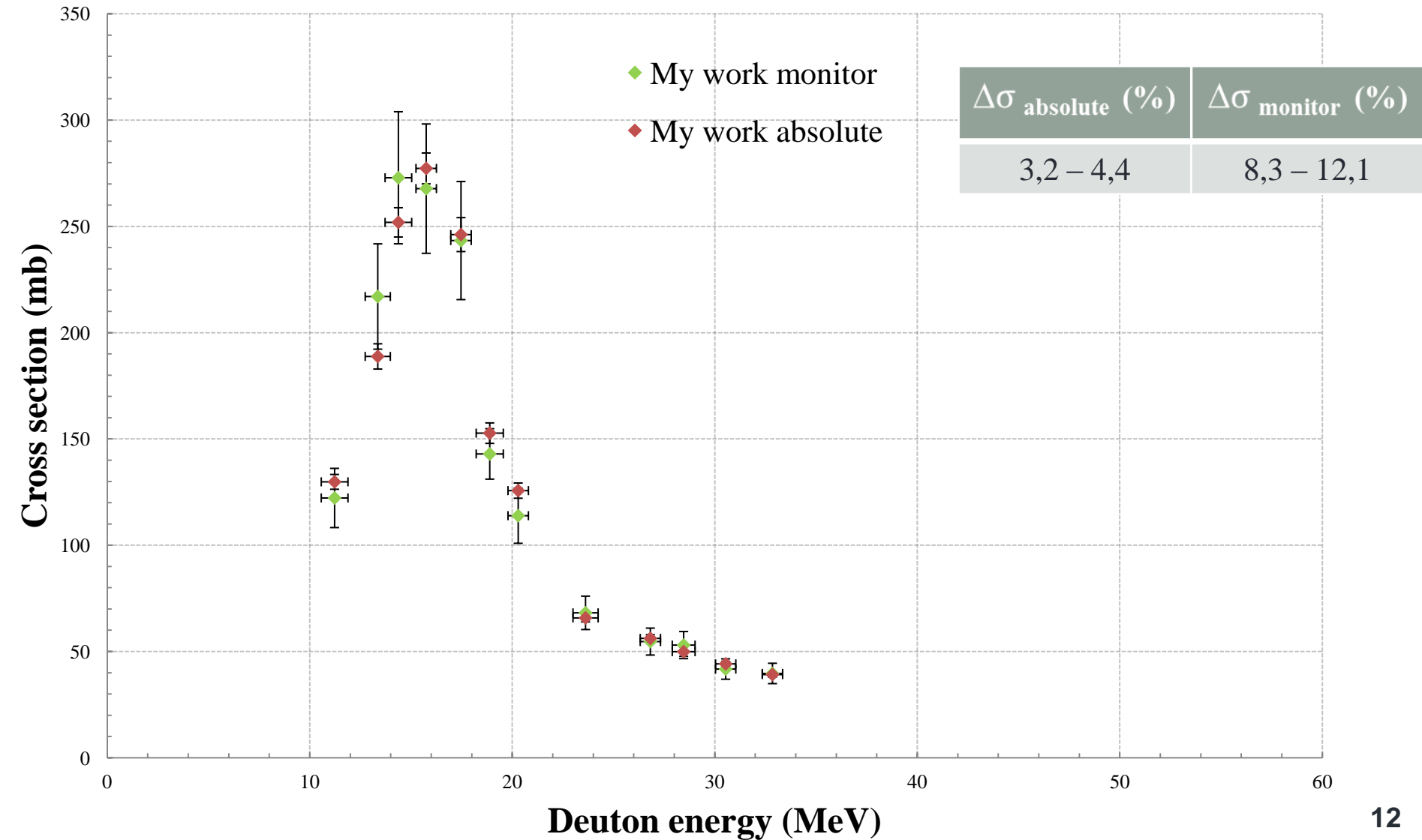
Pattern of the stack : Au – Ti - Al



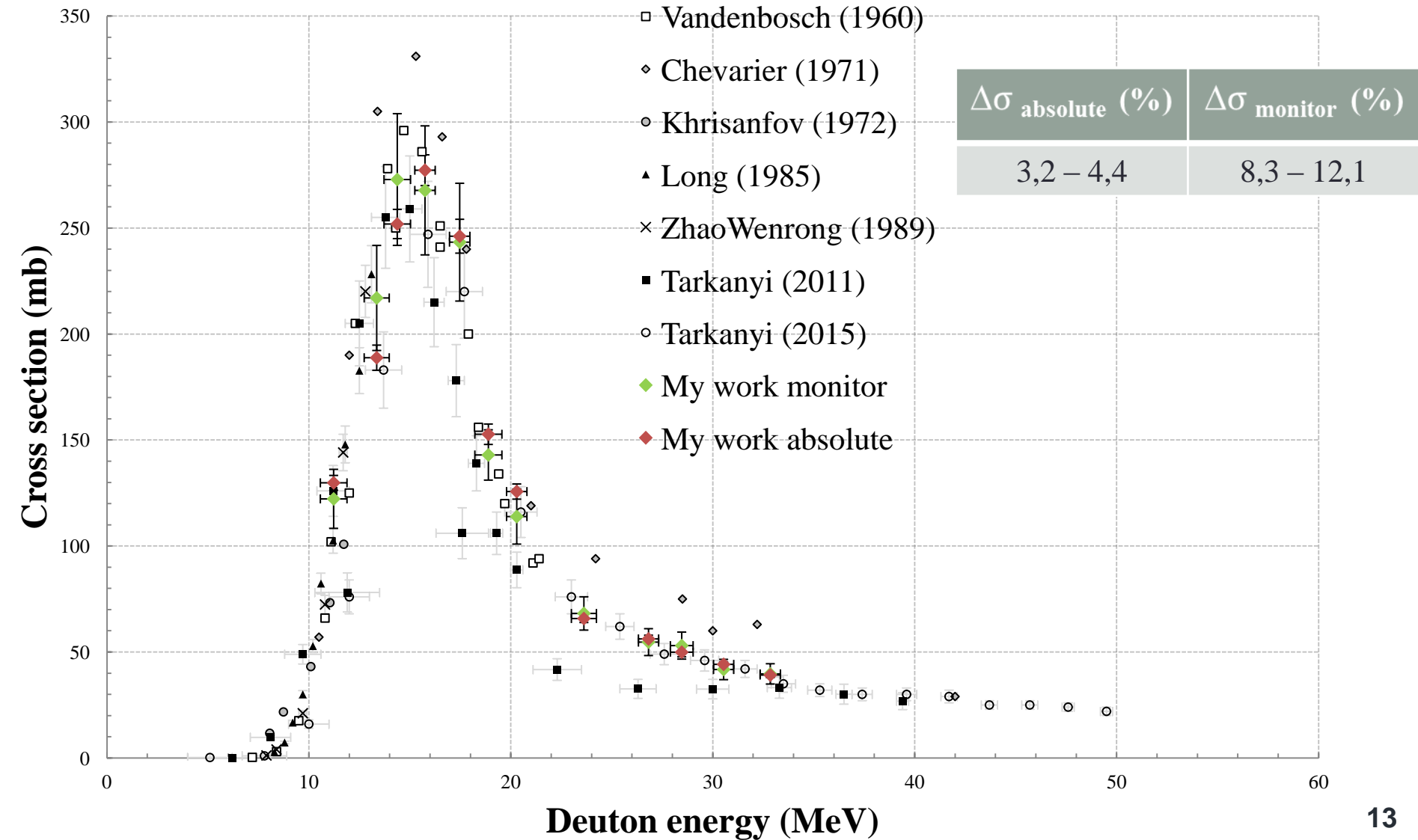
Two kind of values acquired after the experiments :

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

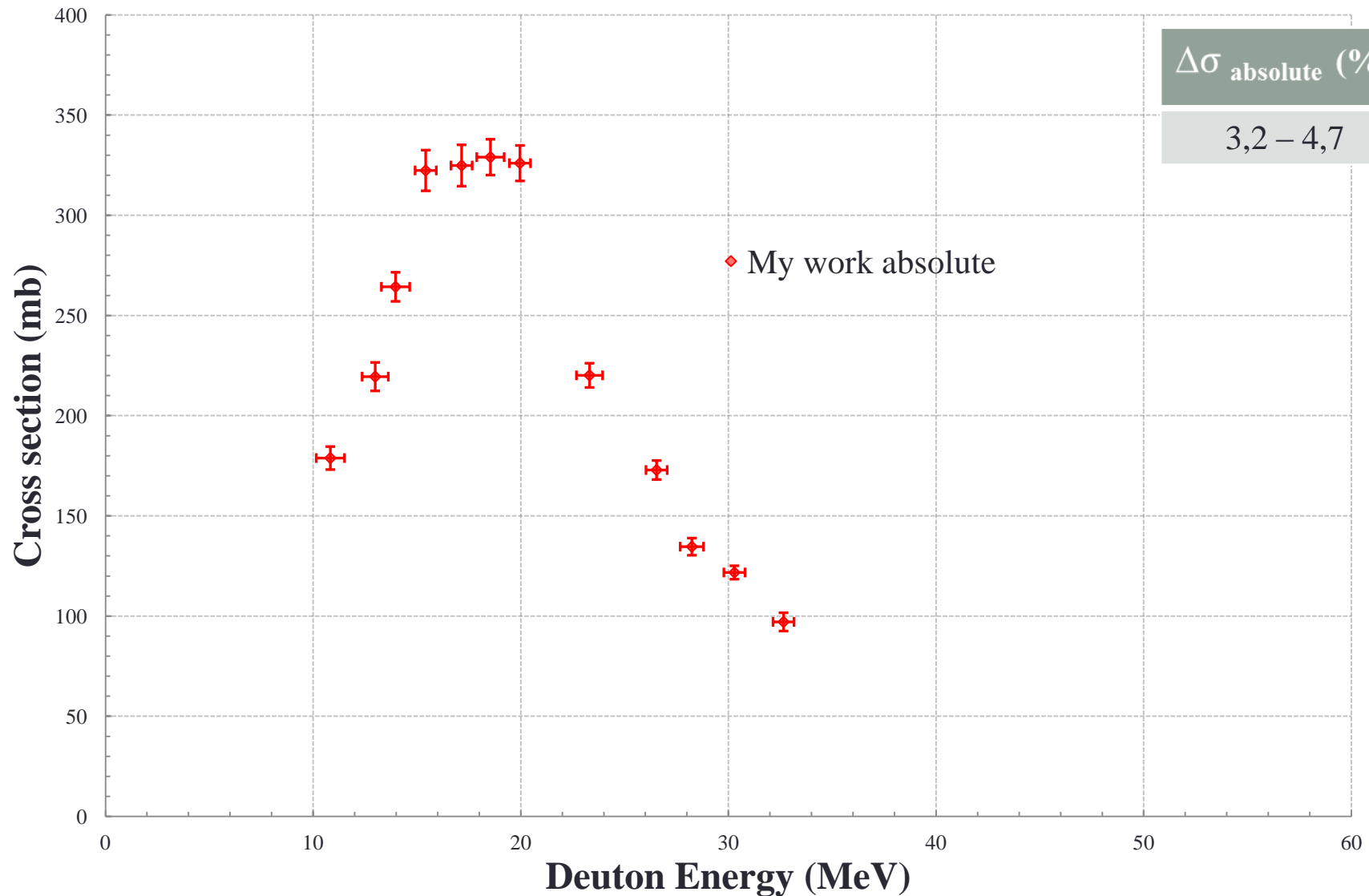
- Reaction of interest : $^{197}\text{Au}(d,2n)^{197\text{m}}\text{Hg}$



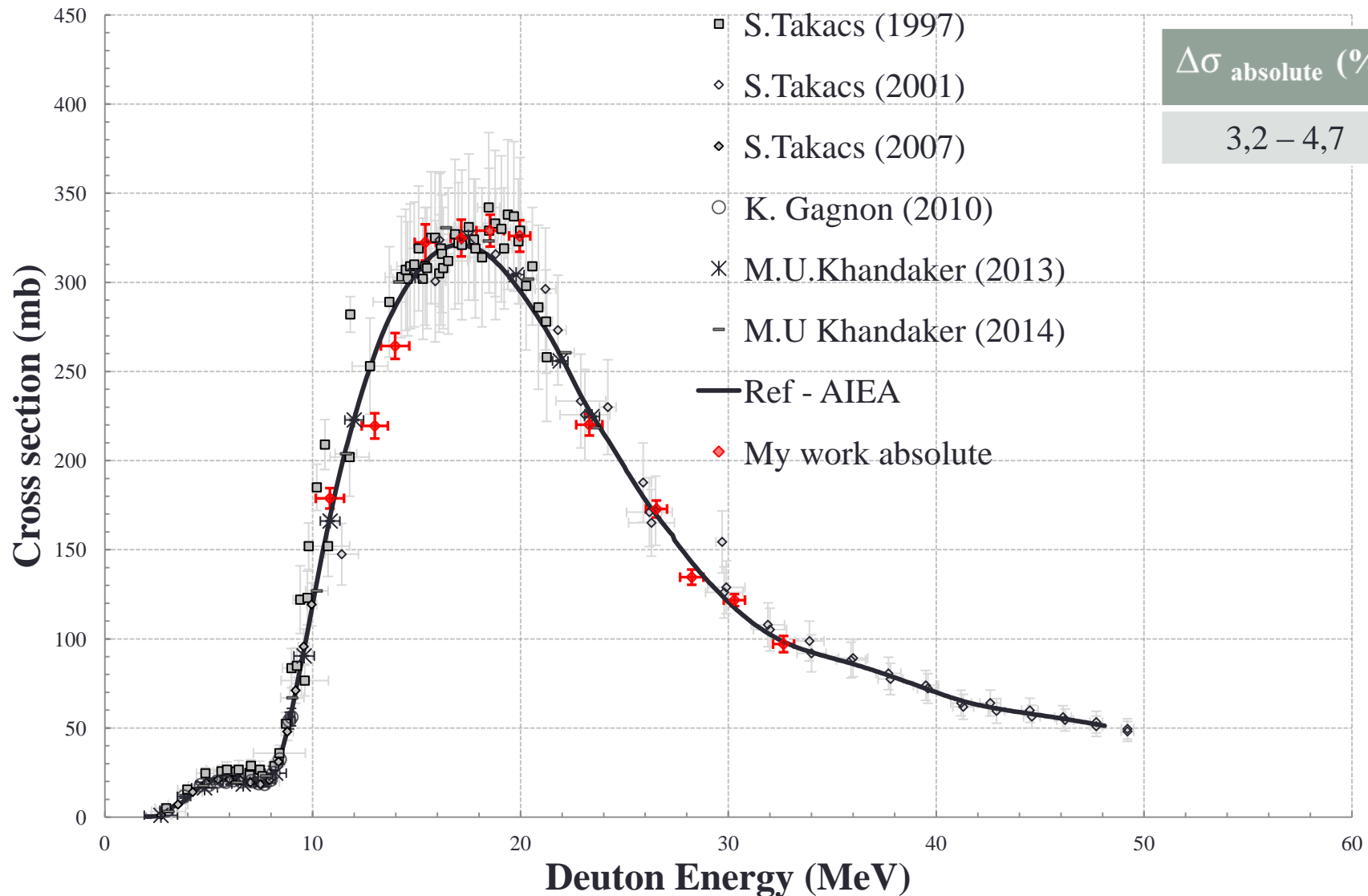
• Reaction of interest : $^{197}\text{Au}(d,2n)^{197\text{m}}\text{Hg}$



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



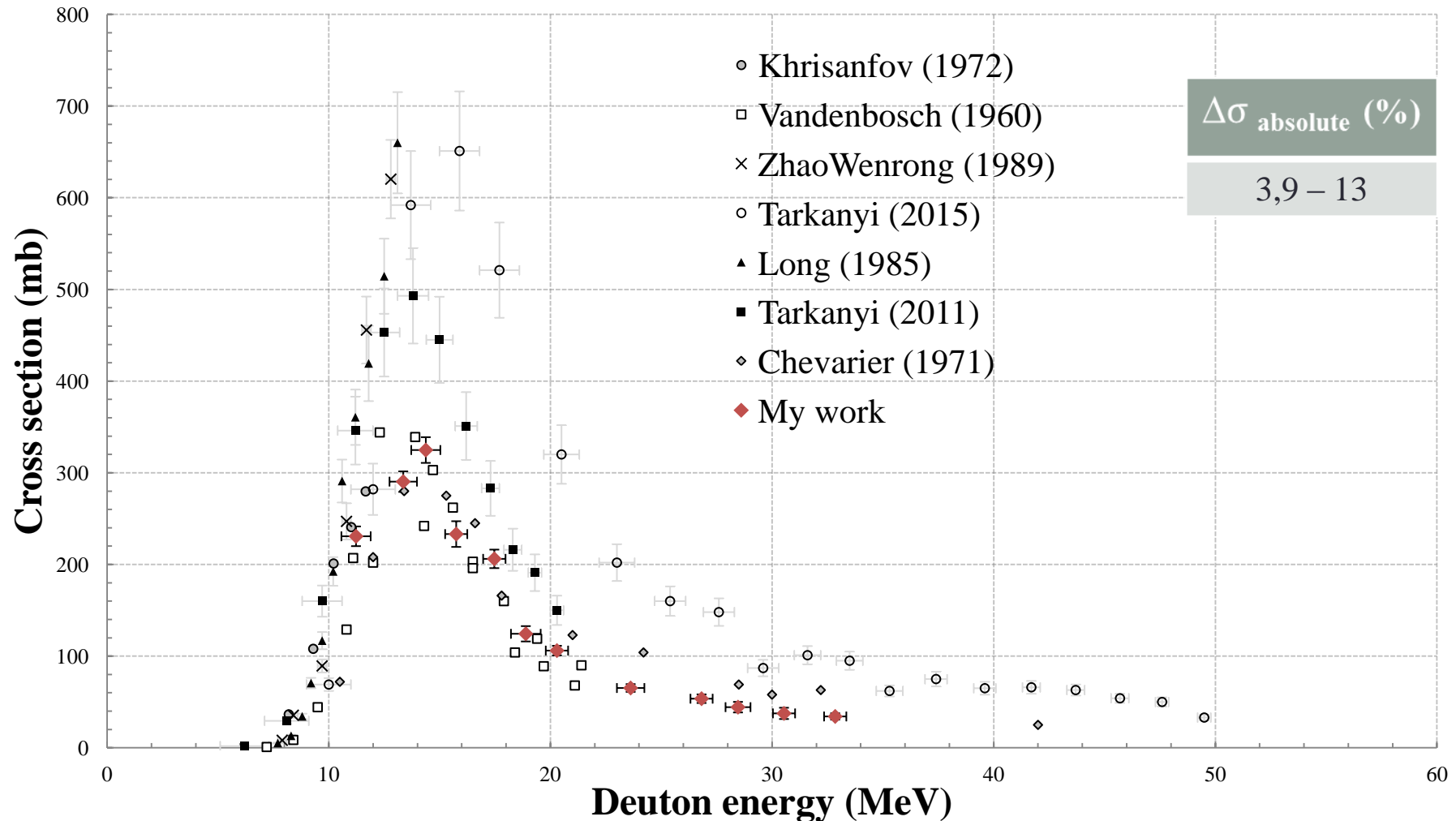
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- Reaction $^{197}\text{Au}(d,2n)^{197}\text{Hg}$

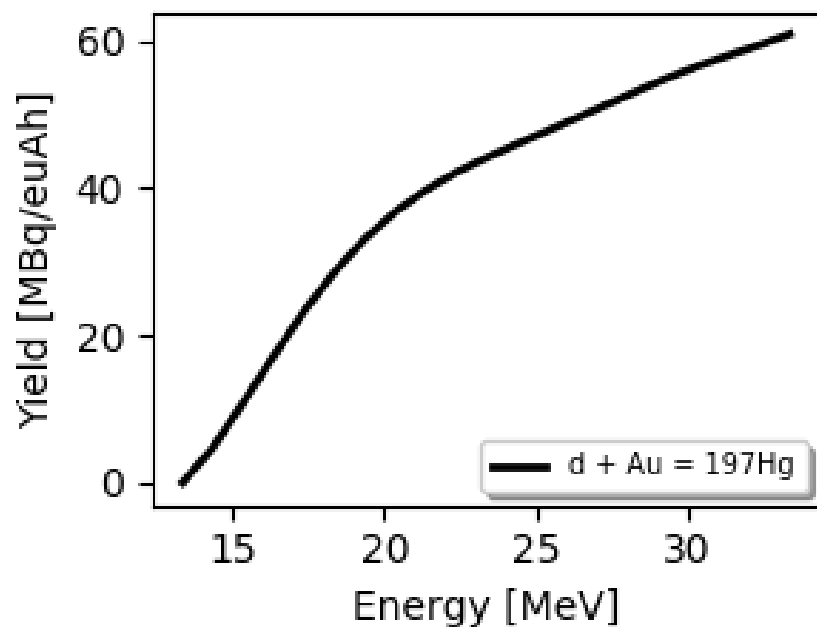
At the measure of activity: Contribution of

- The direct production
- The metastable decay
- Correction of the metastable decay



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

Estimate the production of $^{197\text{m}}\text{Hg}$



example 1

E [MeV]	σ [mb]
5	0
6	15
10	600
12	555
20	60

test

E [MeV]	σ [mb]
3.0	0
4.0	2E-1
8	4.5E2
10	625

example 2

E [MeV]	σ [mb]
4.5E0	18
5.5E0	215
12	440

TENDL-2015

E [MeV]	σ [mb]
28.0	32.7399
30.0	28.9305
35.0	21.6378
40.0	16.6622
45.0	13.2648

Projectile: p d α

Target nuclide:

Chemical form: gas

metal compound:

Ca	1
C	1
O	3

Density [g/cm³]:

Enrichment [%]:

Product nuclide:

State: all g m

Half-life: [h] [d]

Fit type: yield without σ fit

Radionuclide Yield Calculator a free GUI developed at ARRONAX by M.Sitarz

- Conclusion

- ^{197m}Hg is a good candidate to be use for **SPECT imaging**
- Data collected using the faraday as **more precise** than that collected with the monitor foil technique as expected. They are both in agreement.
- Our results are in **good agreement** with the IAEA recommended cross section values and other available data in the literature

- Outlook

- Our new set of data will also help extending the accuracy of databases and can be used to **constrain theoretical calculations**

• Collected data sets

Proton induced reactions:

Cu-67 → New data set from $^{68}\text{Zn}(p,2p)$

- NIMB 415 (2018) 41-47

Ac-225 → from Th-232(p,x)

- Phys. Med. Biol. **60** (2015) **931–946**

Ra-223 → from Th-232(p,x)

Fission fragment distribution → from Th-232(p,x)

- EPJ Web of Conferences 146, 08008 (2017)

Monitor reactions on **Ti, Ni and Cu** → from Th-232(p,x)

- E. Garrido et al., NIM. B 383 (2016) 191

Deuteron induced reactions:

Sc-44 → New data set for Ca-44(d,x)

- C. Duchemin et al, Phys. Med. Biol. **60** (2015) **6847**

Tb-155 → New data set for Gd-nat(d,x)

- Submitted to ARI

Re-186g → New data set for W-186(d,x)

- C. Duchemin et al, Appl. Rad. And Isot. **97** (2015) **52**

Th-226 → New data set for Th-232(d,x)

- C. Duchemin et al

Fission fragment distribution → from Th-232(d,x)

Nuclear Data Sheets **119** (2014) **267**

International Journal of Modern Physics **27** (2014)

Phys. Med. Biol. **60** (2015) **931**

Monitor reactions on **Ti**

- C. Duchemin et al, ARI **103** (2015)**160**

Hg-197m → New data set for Au-197(d,x)

Alpha induced reactions:

Sn-117m → Cd-116(α ,x)

- C.Duchemin et al, ARI 115 (2016) 113

Monitor reactions on **Cu, Ti, Ni**:

Thank you for your attention

^{197}Hg

Half life 64,14h

Decay 100% EC, no β^+

Main gamma emissions

77,3 keV (18,7%)

191,4 keV (0,6%)

^{195}Hg 10.53 H ϵ : 100.00%	^{196}Hg STABLE 0.15%	^{197}Hg 64.14 H ϵ : 100.00%	^{198}Hg STABLE 9.97%	^{199}Hg STABLE 16.87%	^{200}Hg STABLE 23.10%	^{201}Hg STABLE 13.18%
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^{195}Hg & $^{195\text{m}}\text{Hg}$

➤ **Half life** ^{195}Hg 10,5h

➤ **Half life** $^{195\text{m}}\text{Hg}$ 41,6h

➤ **Threshold** 19,3 MeV

^{195}Hg 10.53 H ϵ : 100.00%	^{196}Hg STABLE 0.15%	^{197}Hg 64.14 H ϵ : 100.00%	^{198}Hg STABLE 9.97%	^{199}Hg STABLE 16.87%	^{200}Hg STABLE 23.10%	^{201}Hg STABLE 13.18%
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