final conference

HIGHLY ENRICHED TARGET MATERIAL FOR THE PRODUCTION OF RADIOPHARMACEUTICAL ISOTOPES: THE USE OF ELECTROMAGNETIC SEPARATION

Presentation of SCALP: analysis facility for irradiation and isotopic separation
Development of an approach for isotope for medical applications
Proof of concept experiment
Conclusion

Synthesis & Characterization using ion AcceLerators for Pluridisciplinary research

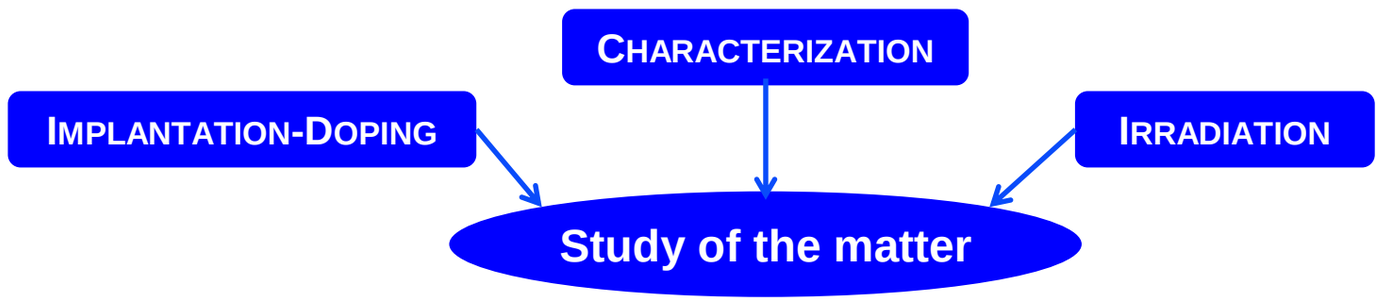
Concentration measurement

Ion beam analysis

Ion deposition

Implantation

Irradiation



SIDONIE
Isotopic separator

IRMA
Implanter 190 kV

ARAMIS
Tandem 2 MV

C.O. Bacri et al., Nucl. Instr. Meth. B 406 (2017) 48.

Synthesis & Characterization using ion AcceLerators for Pluridisciplinary research

Concentration measurement

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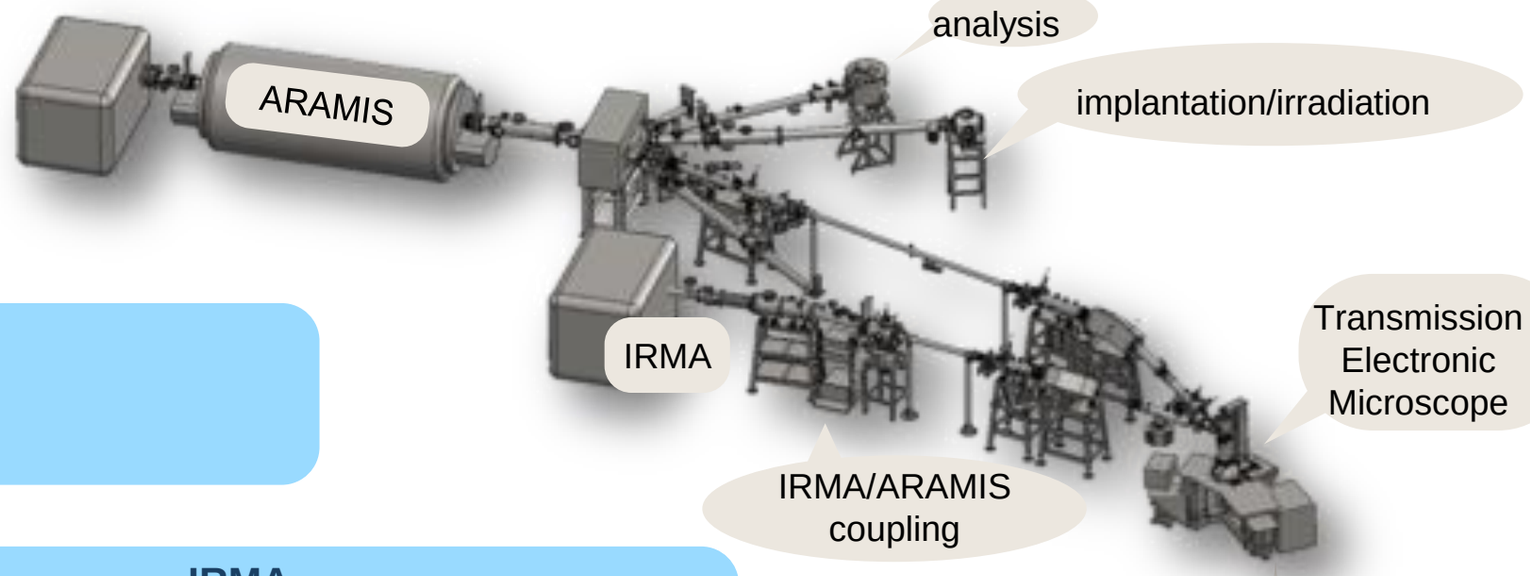
Ion deposition

Implantation

Irradiation

100 eV | 1 keV | 10 keV | 100 keV | 1 MeV | 10 MeV

Temperature sample
~ -170°C to 1100°C



analysis

implantation/irradiation

Transmission Electronic Microscope

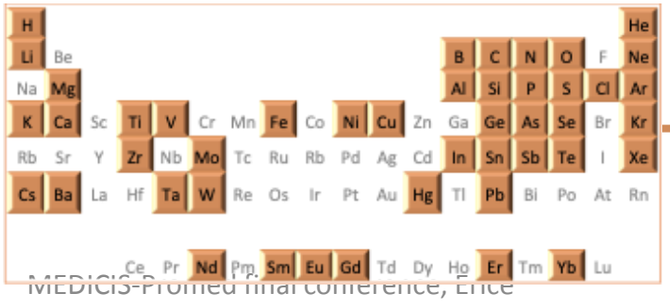
IRMA/ARAMIS coupling

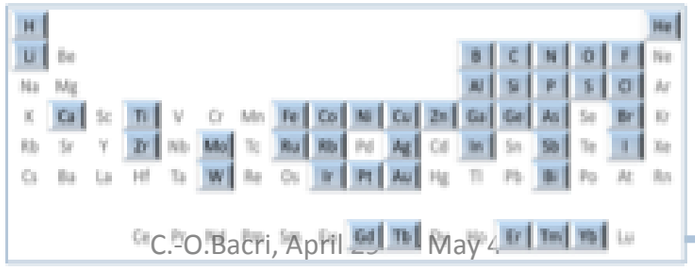
SIDONIE
Isotopic separator

IRMA
Implanter 190 kV

ARAMIS
Tandem 2 MV

IRMA/ARAMIS/TEM coupling





Synthesis & Characterization using ion AcceLerators for Pluridisciplinary research

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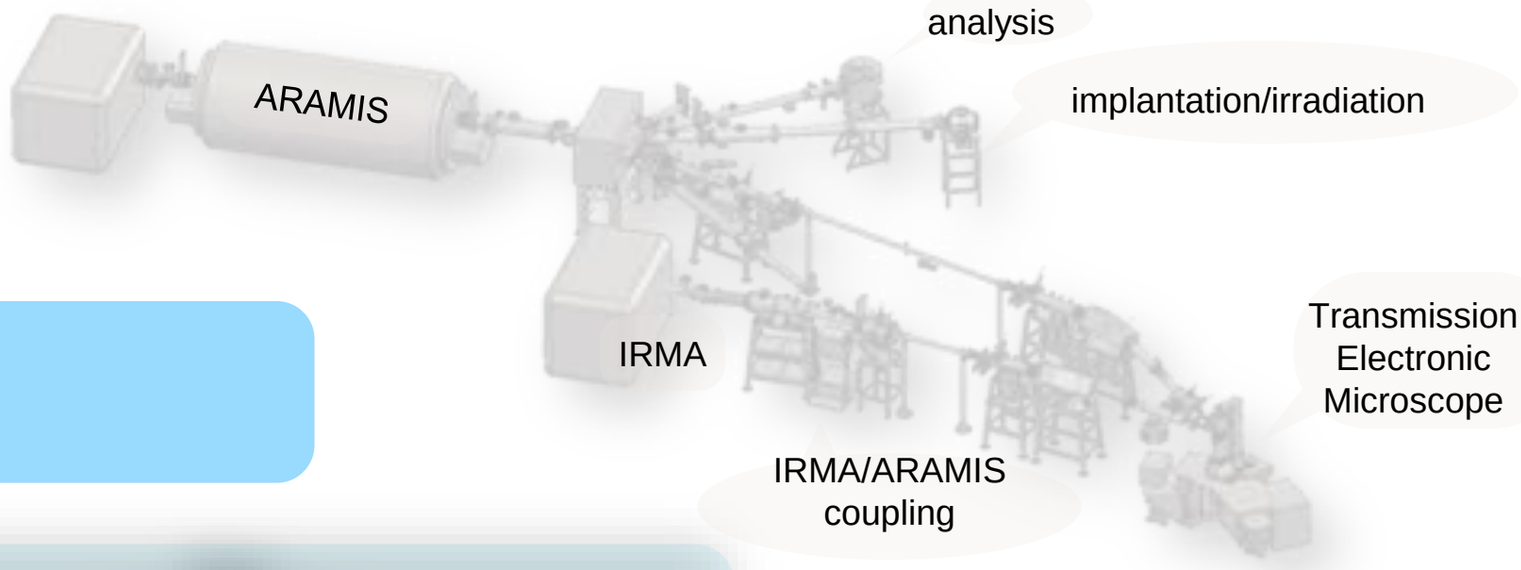

analysis

implantation/irradiation

Transmission Electronic Microscope

IRMA/ARAMIS coupling

IRMA
Implanter 190 kV

ARAMIS
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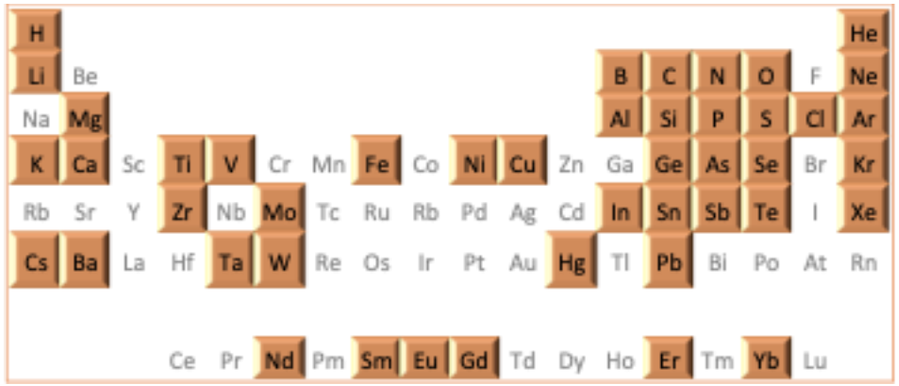
IRMA/ARAMIS/TEM coupling

THE SIDONIE SEPARATOR

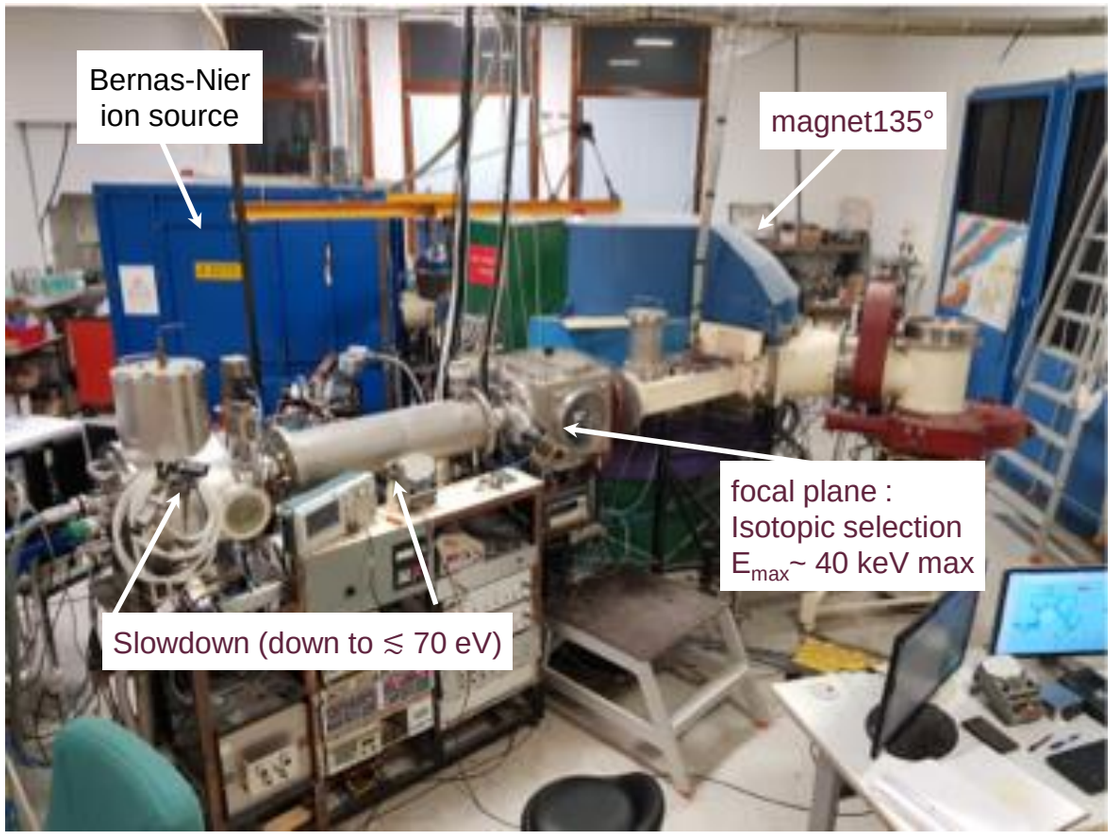
J.Camplan et al., NIM 84(1970)37
K.Alexandre et al., NIM84 (1970)45
N.Chauvin et al., NIM A521(2004) 149

(almost) all ions
can be accelerated
up to ≳10 mA extracted

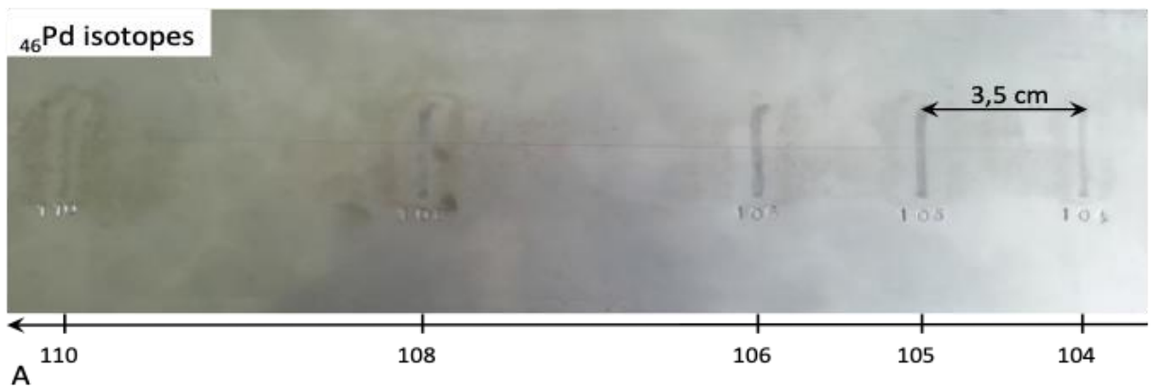


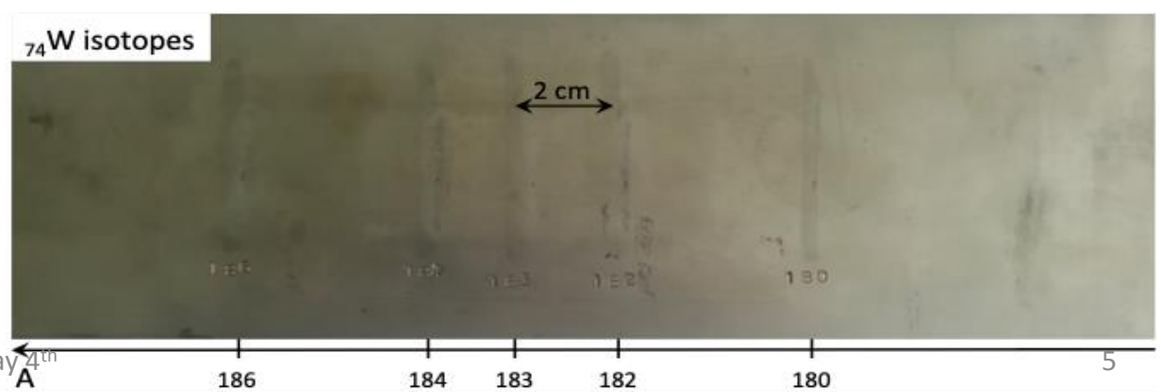
- ρ = 850 mm
- angle = 135°
- field index = 0,5

➛ horizontal and vertical focalisation



- B_{max} = 0,6 T
- Mass separation: 2000 mm x ΔM/M
- Isotopic enrichment: $\frac{N_f(^{235}U)/N_f(^{234}U)}{N_i(^{235}U)/N_i(^{234}U)}$ ³ 10000





Proof of concept experiment

Pure stable isotopes production → Production possible far from users (hospitals)

"small" accelerators
(medical cyclotron ?)

Transmutation
Production of short $T_{1/2}$ isotope

Chemical purification
Elimination of potential contaminant

Proof of concept experiment

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To do list

- **Choice of a test experiment**
- **Isotopic separation power measurement**
- **Production rate for stable isotope**
- **Cross section measurement**
  → Production rate (radioactive isotope)

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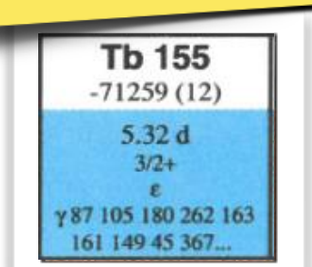
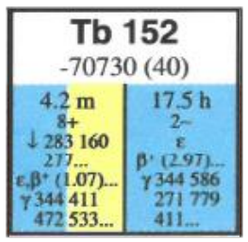
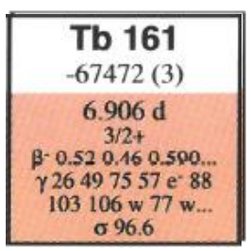
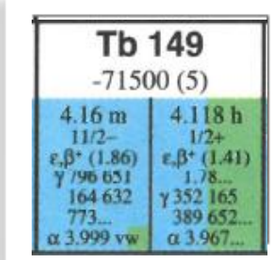






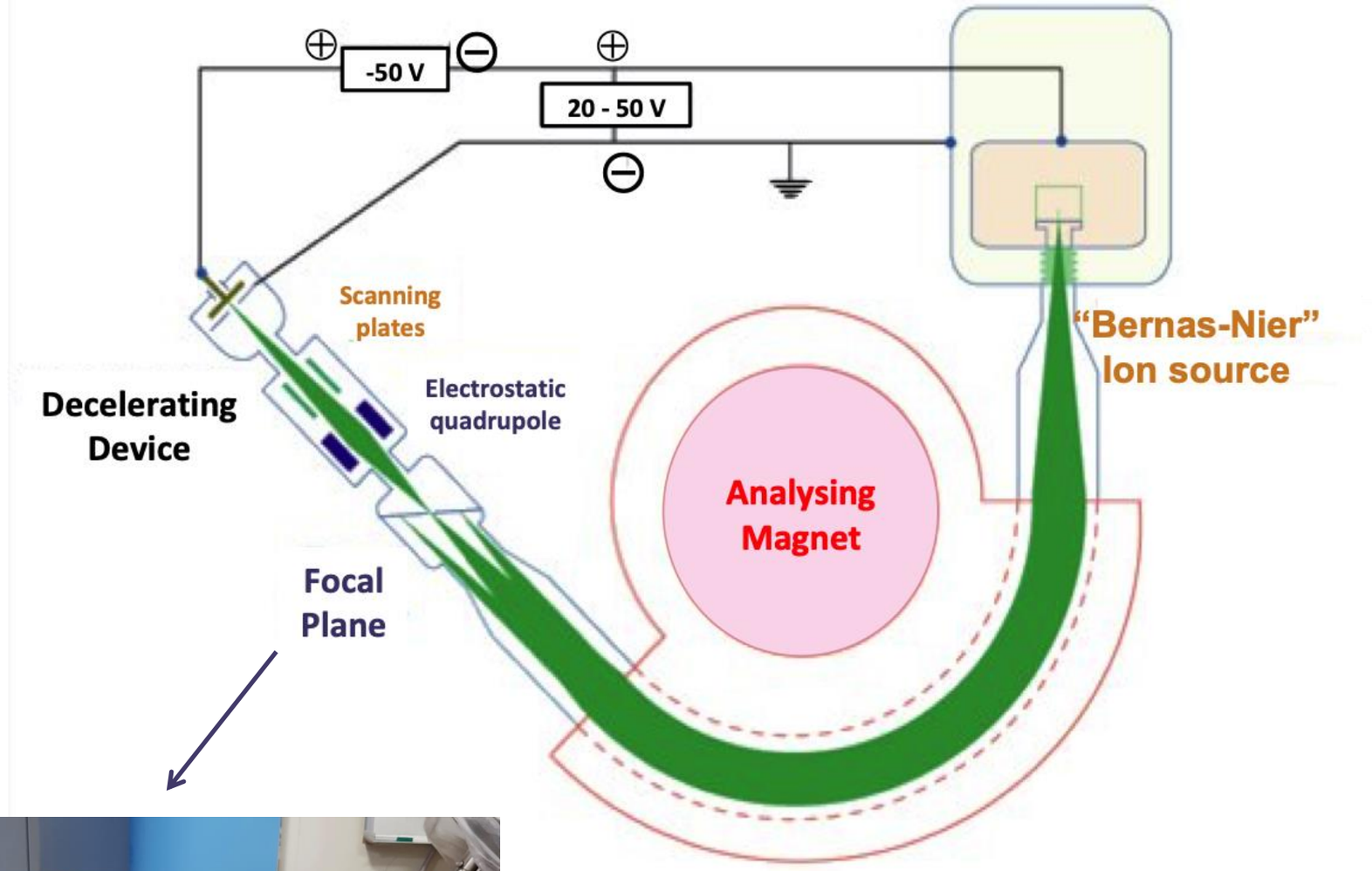


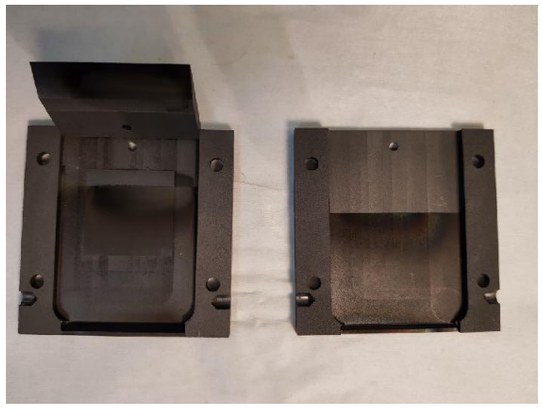
		$t_{1/2}$		Production mode
α therapy	^{149}Tb	4,18 h	E_α = 3,97 MeV	^{152}**Gd**(p,4n)^{149}Tb ≃ 40 MeV
TEP imaging	^{152}Tb	17,5 h	β^+	^{152}**Gd**(p,n)^{152}Tb ≃12 MeV
				^{155}**Gd**(p,4n)^{152}Tb ≃40 MeV
SPECT imaging Auger therapy	^{155}Tb	5,3 j	γ 87 keV and105 keV	^{155}**Gd**(p,n)^{155}Tb ≃10 MeV
β^- therapy	^{161}Tb	6,9 j	E_{β^-} = 0,15 keV e^-: 20-40 eV (most probable)	^{160}**Gd**(n,γ)^{161}Gd -> ^{161}Tb

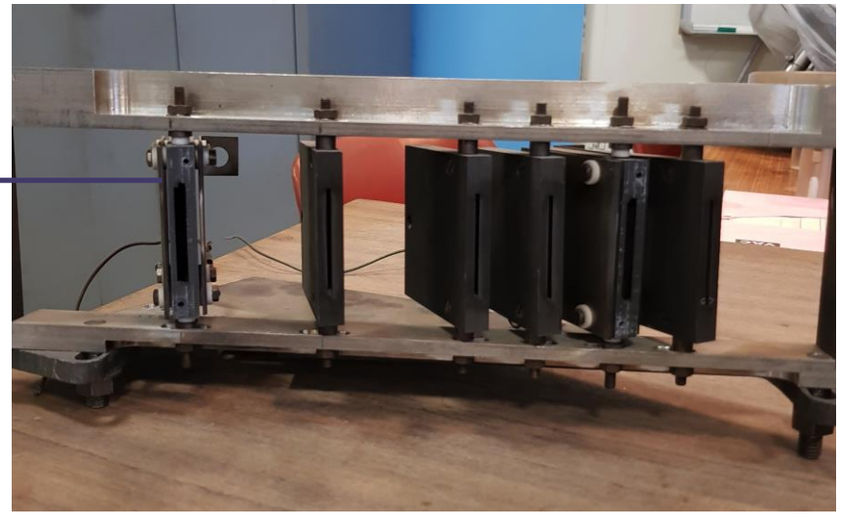
^{nat}Gd isotopes natural abundancies

152	153	154	155	156	157	158	159	160
0,2 %		2,15 %	14,73 %	20,47 %	15,68 %	24,87 %		21,90 %
1		10,75	73,65	102,35	78,4	124,35		109,5

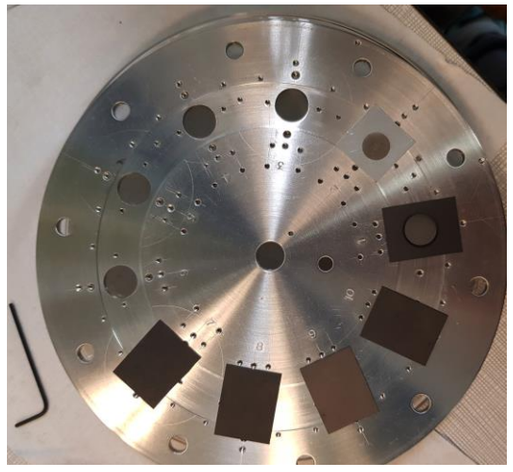
Pure isotope production

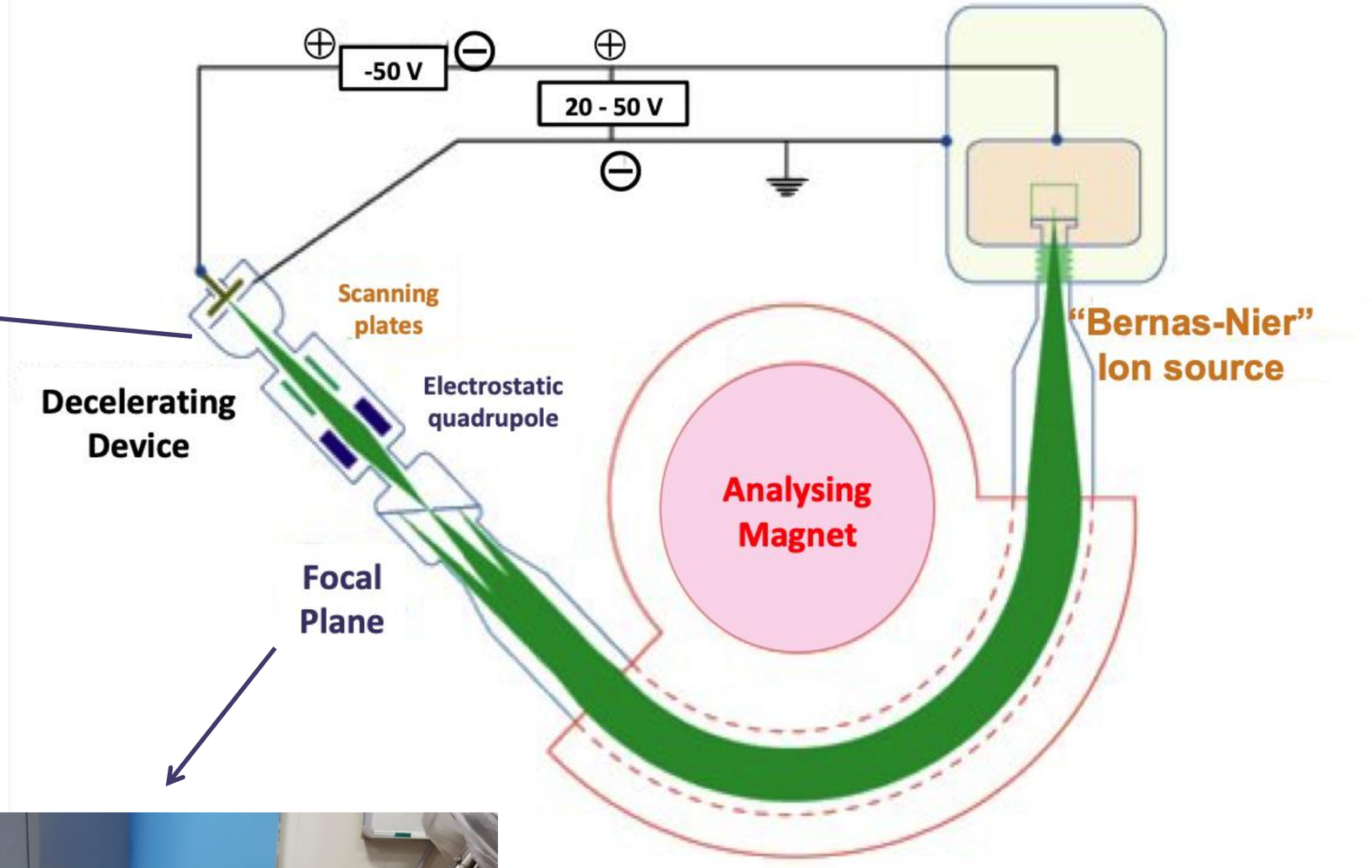


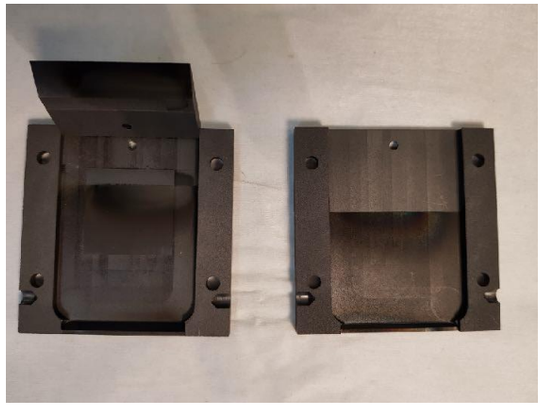


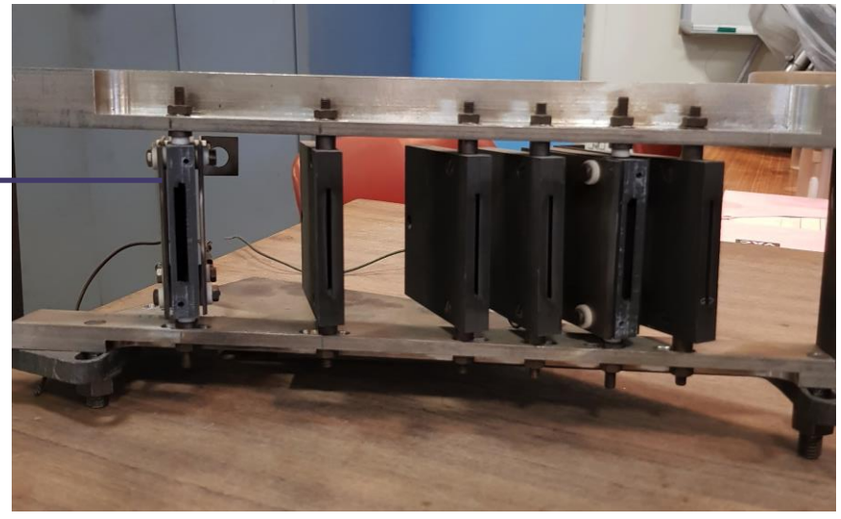


Pure isotope production

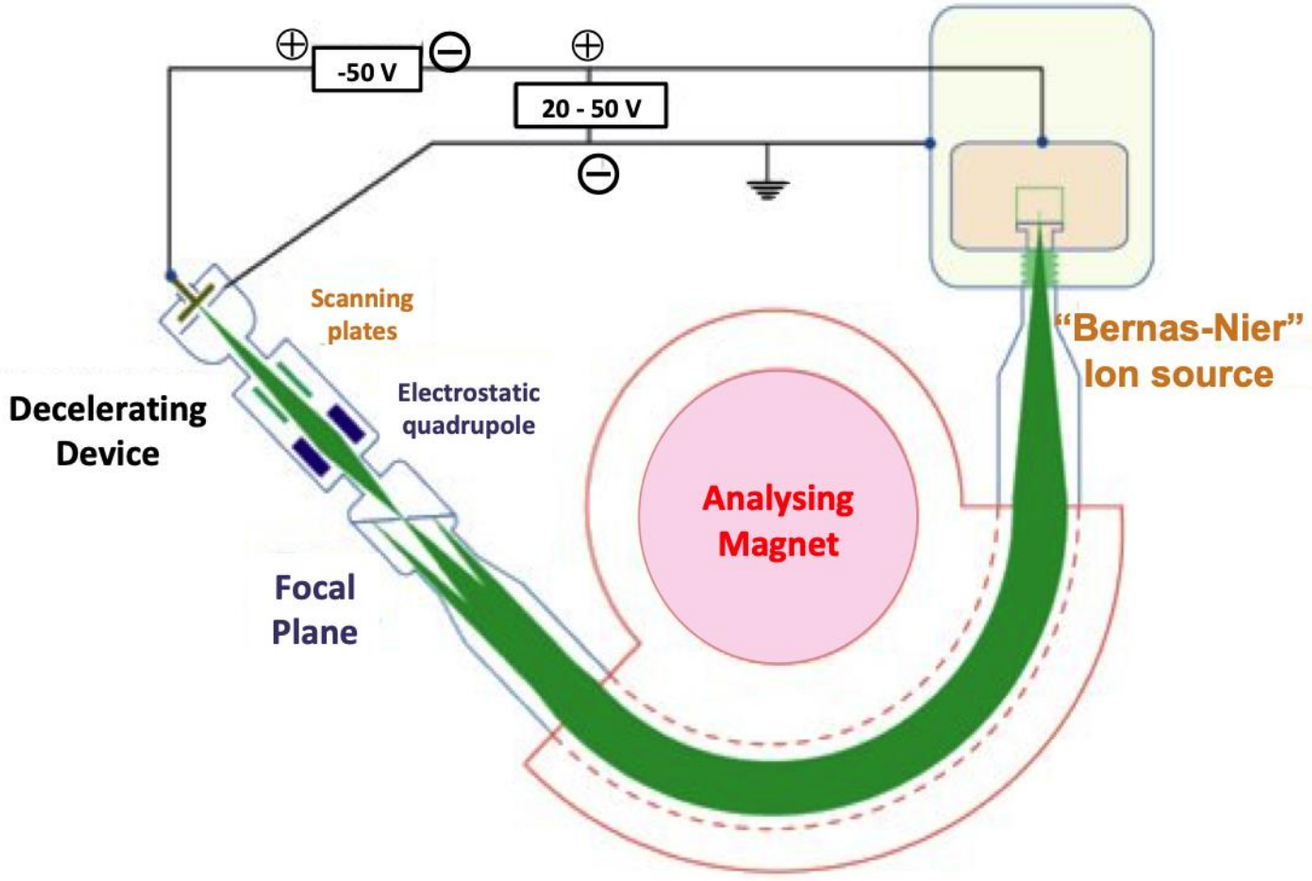


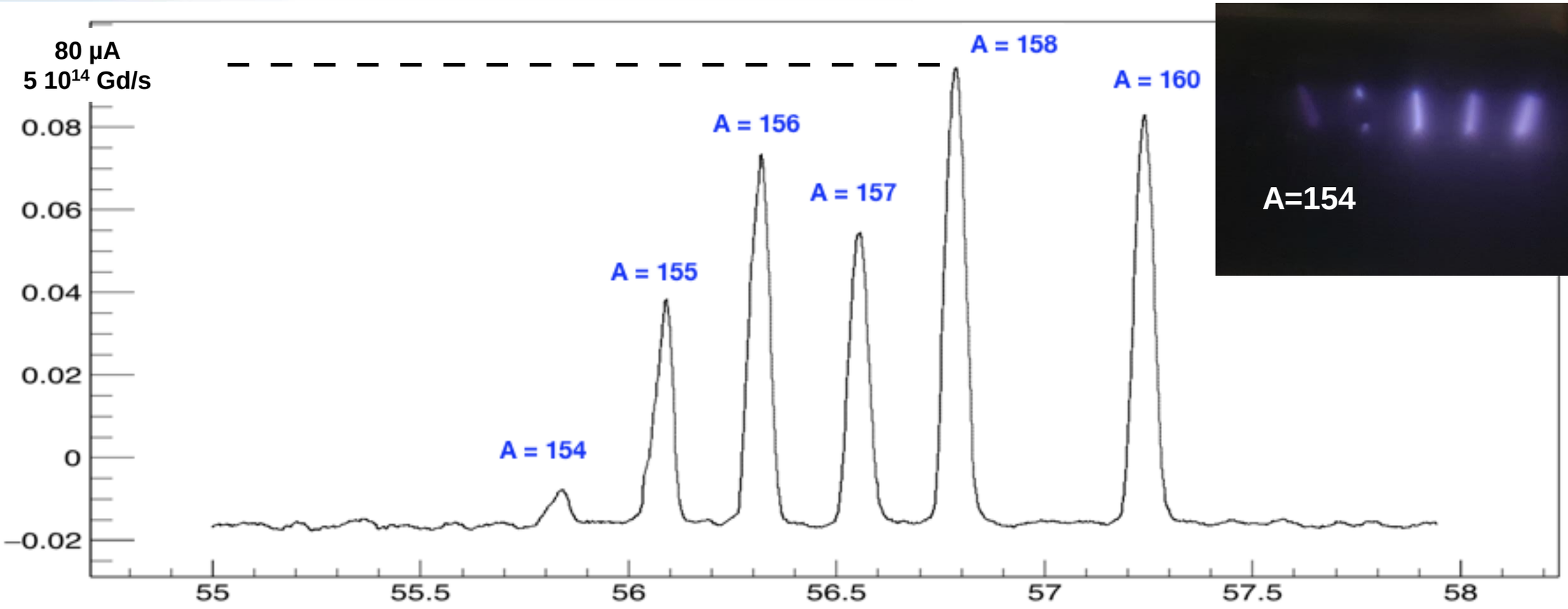


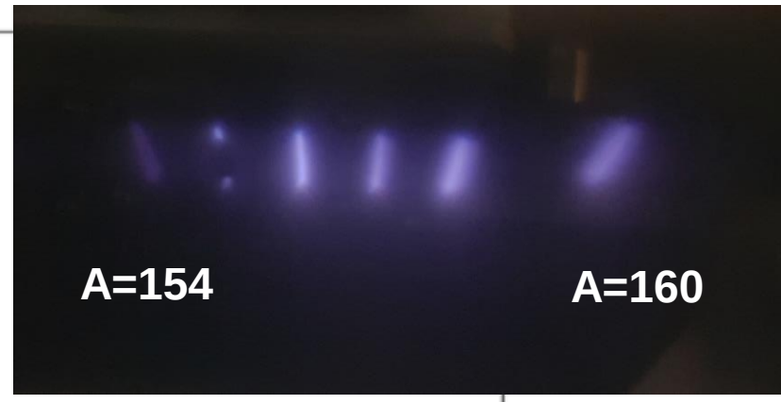




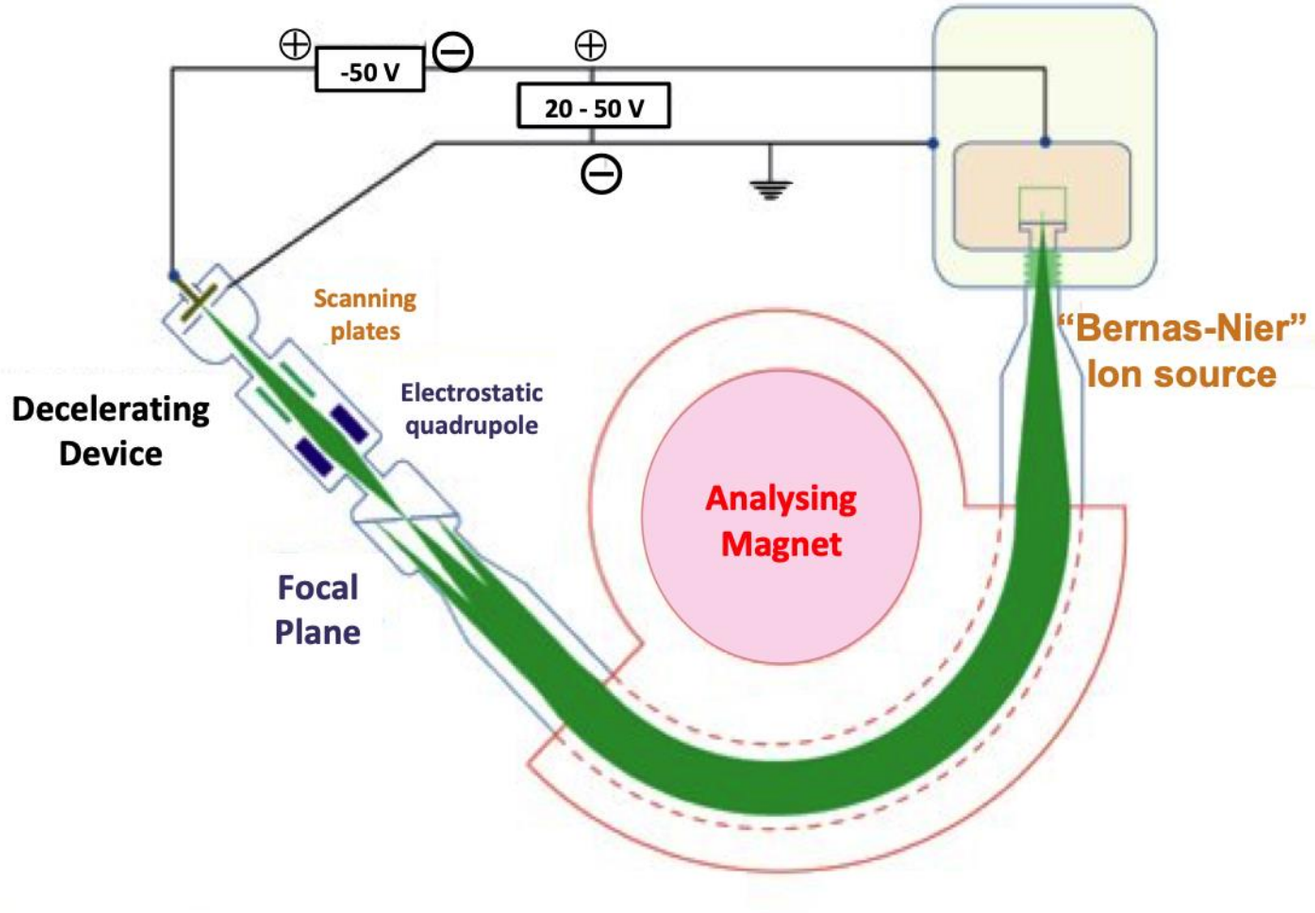
Pure isotope production







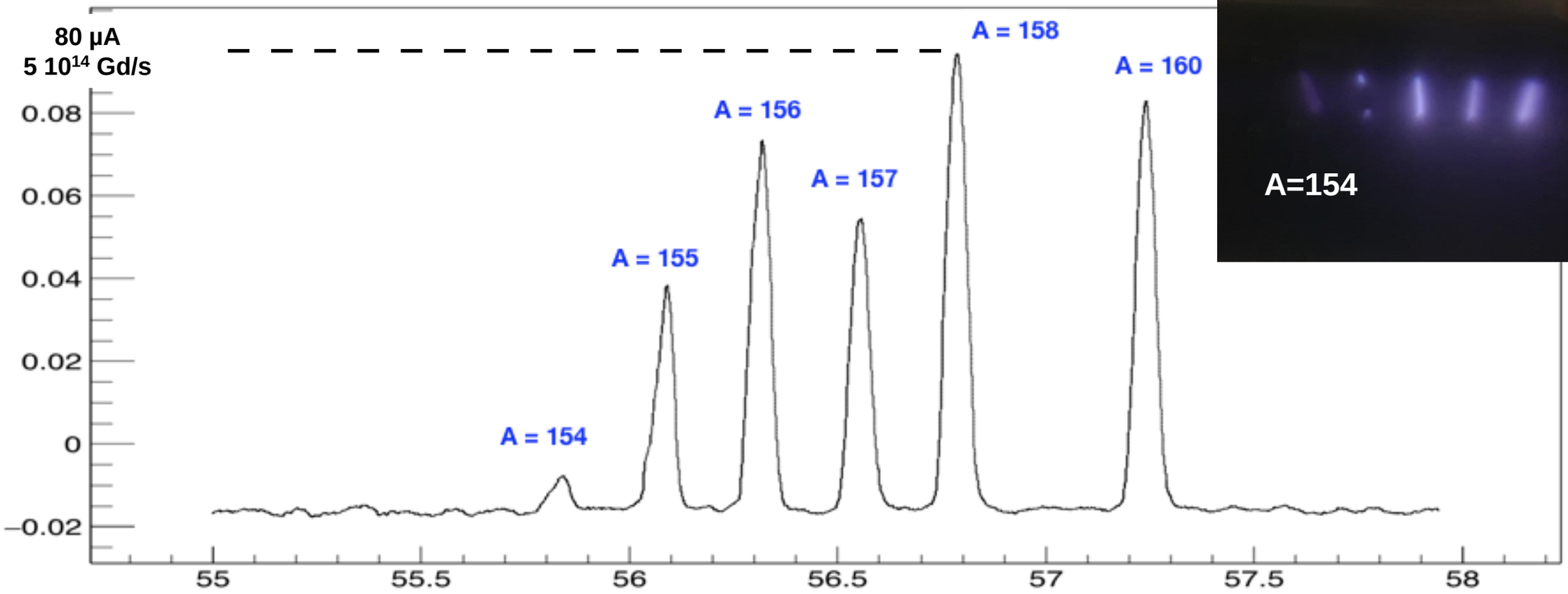
Pure isotope production

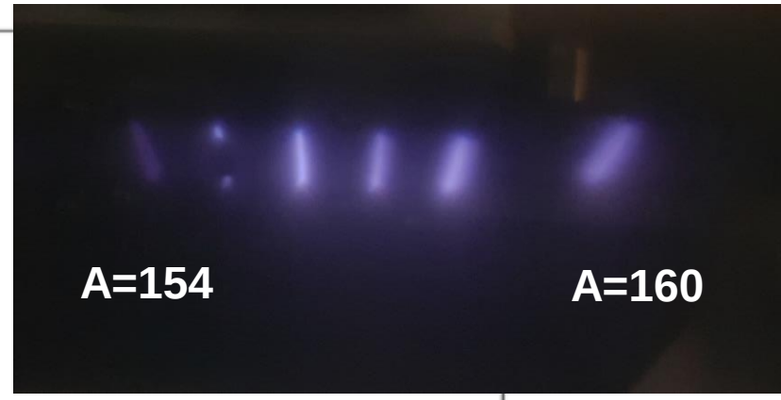


Pollution measurement

PGAA (Prompt Gamma Activation Analysis)
NAA (Neutron Activation Analysis)

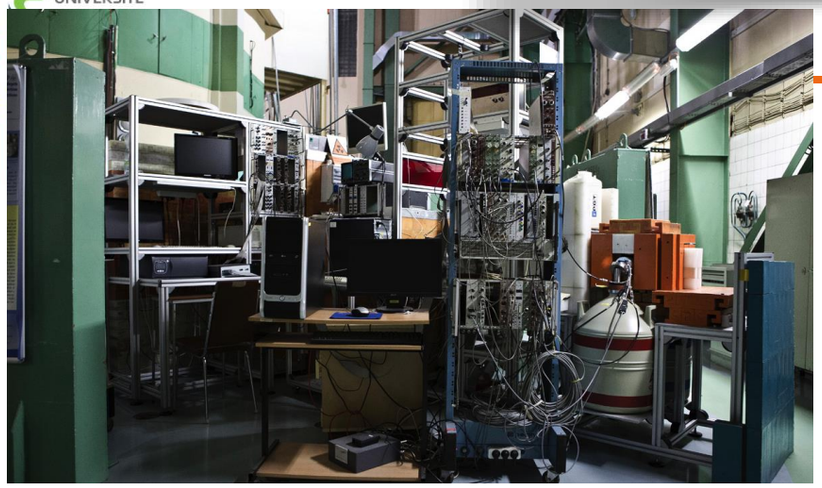
σ_{cap} (^{157}Gd) = 2.59 10^5 b
σ_{cap} (^{158}Gd) = 2.2 b



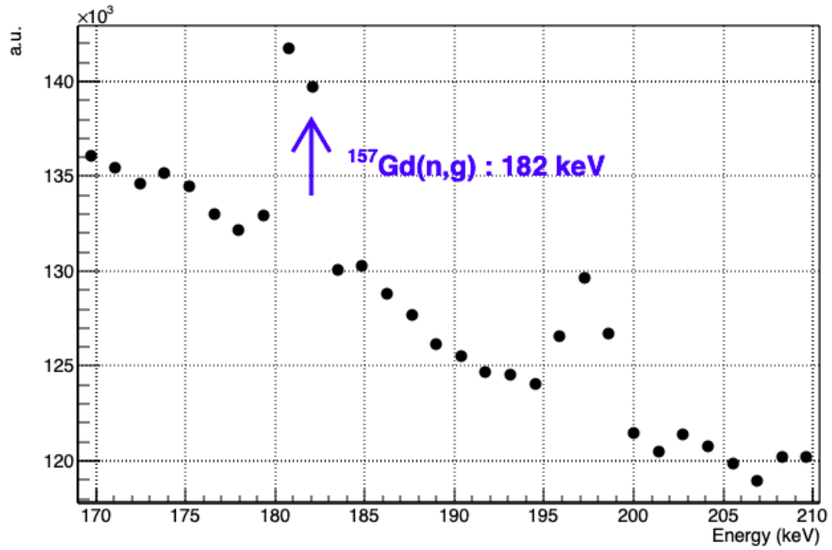


MEDICIS-Promed final conference, Erice
C.-O.Bacri, April 29th – May 4th
12

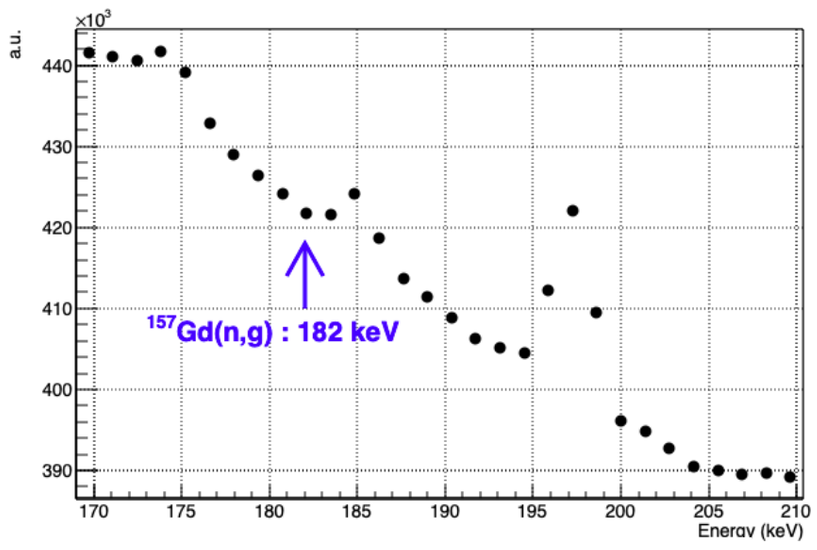
Purity measurement at LVR-15 reactor (NPI-Rěz)



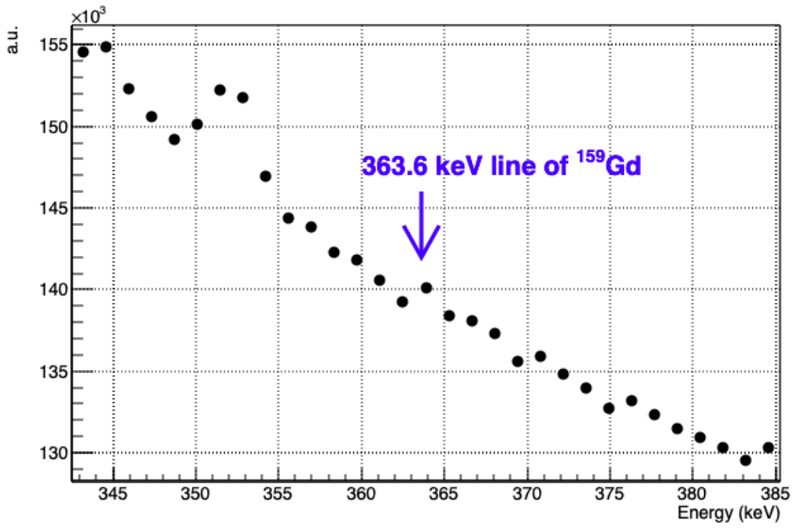
I. Tomandl
Realized under LM2015056 et LM2015074 contract financed by Ministry of Education, Youth and Sports of the Czech Republic.



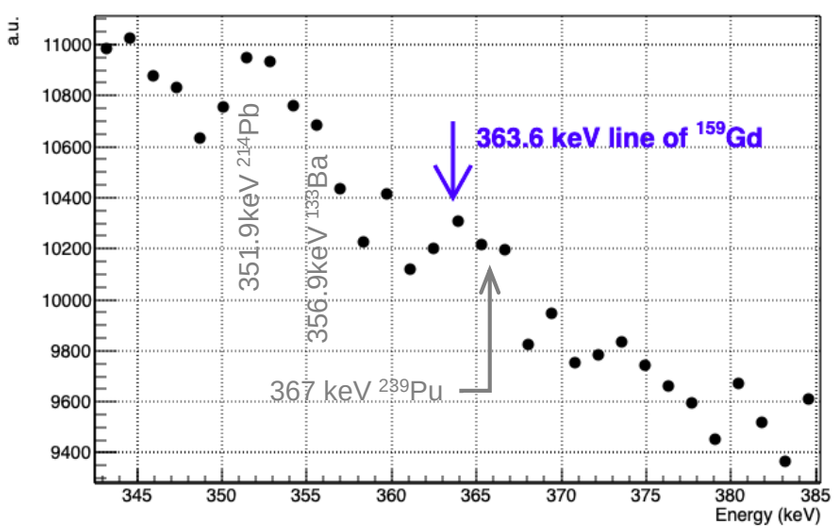
Reactor on
22 hours irradiation



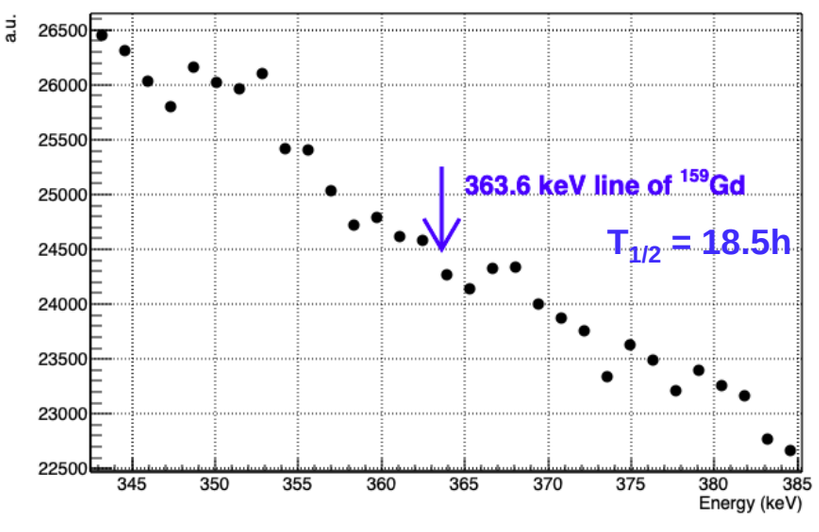
Reactor off – Background measurement
≲ 3 days counting



Reactor on
∼ 3 days neutron irradiation

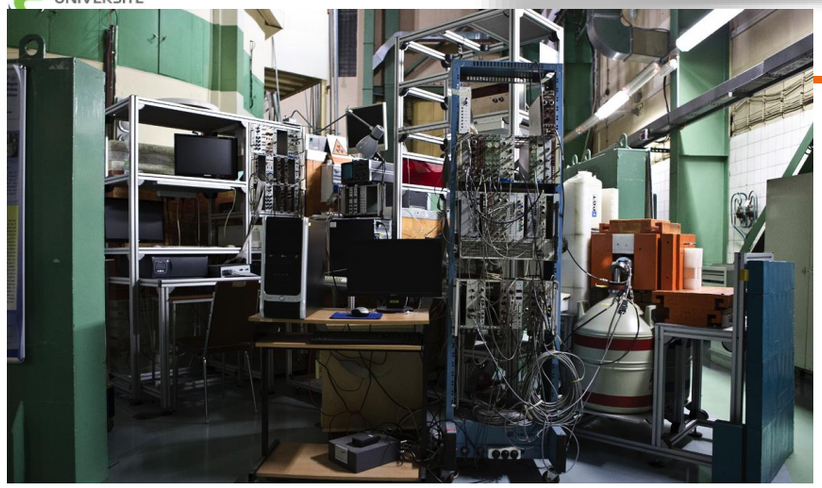


After neutron irradiation
∼ 11h counting just after reactor shutdown



After neutron irradiation :
31h counting, 35h after reactor shutdown

Purity measurement at LVR-15 reactor (NPI - Řež)



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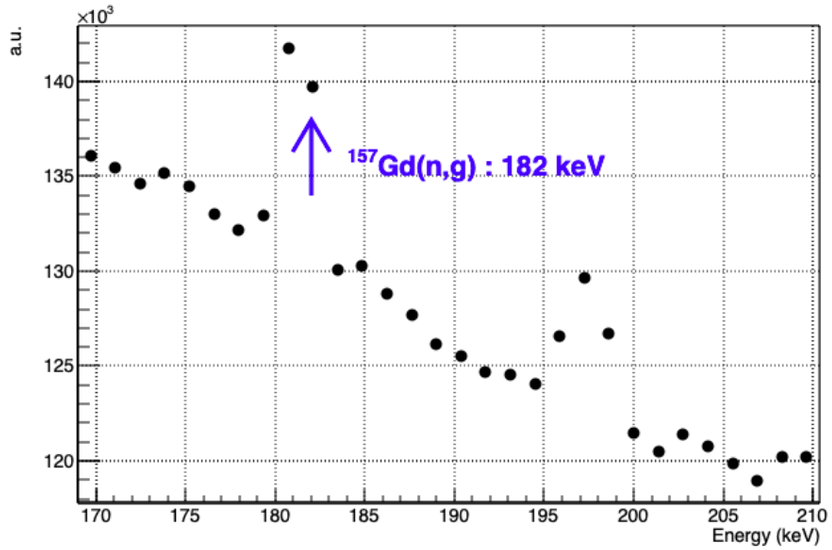
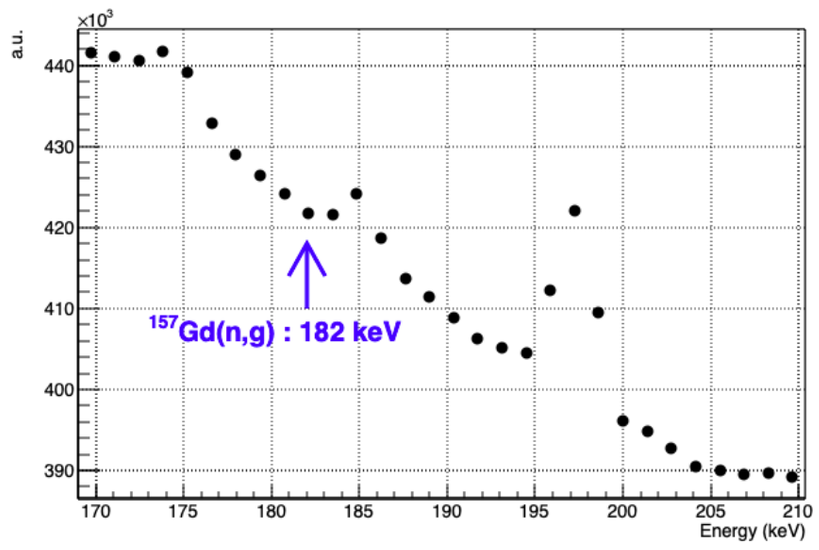
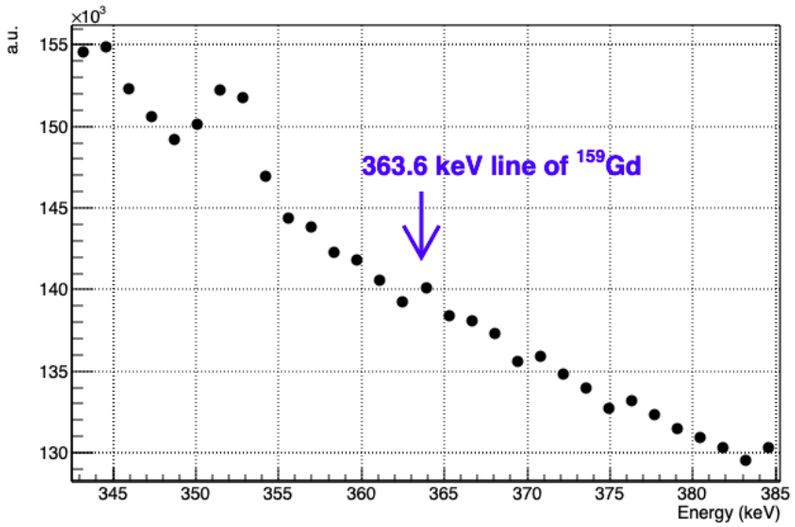


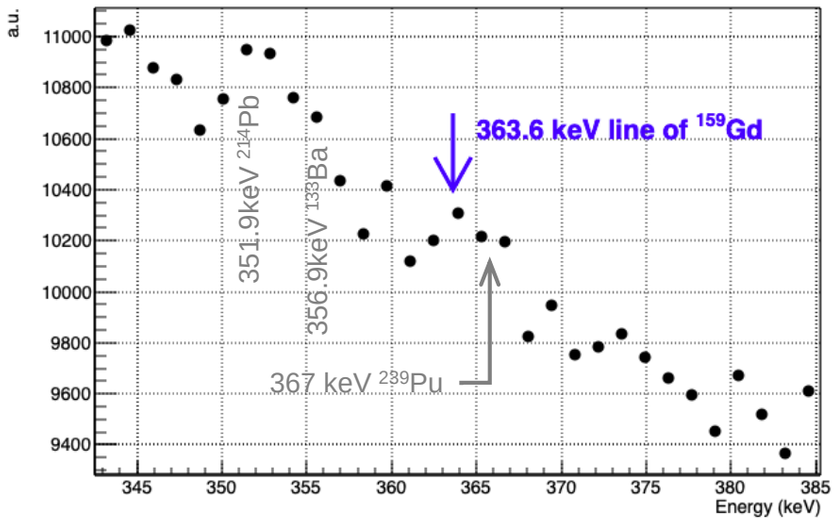
Reactor on
22 hours irradiation



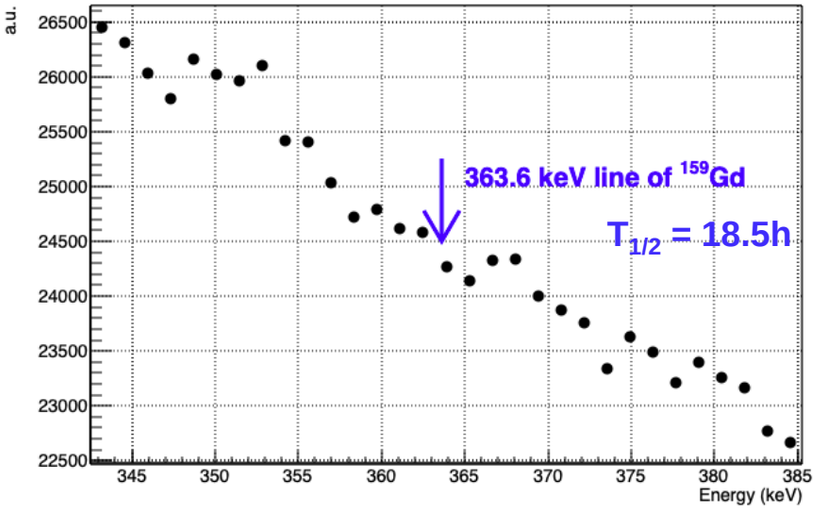
Reactor off
≲ 3 days counting



Reactor on
~ 3 days neutron irradiation



~ 11 h counting just after reactor shutdown



After neutron irradiation :
30/01 09:48 to 31/01 16:27

Very high purity !

$1.54 \pm 80\ 10^{-5} < {}^{157}Gd / {}^{158}Gd < 4.7 \pm 0.5\ \ 10^{-4}$

To conclude …

✓ Separation power of SIDONIE sufficient for medical needs

$1.54 \pm 80\ 10^{-5} < {}^{157}Gd / {}^{158}Gd < 4.7 \pm 0.5\ \ 10^{-4}$

- To achieve the “proof of concept” experiment

  → Make targets of ^{155}Gd at SIDONIE
  → Measure $^{155}Gd(p,\gamma)^{155}Tb$ at ARRONAX (stack foil technique)

Internship of Keerthana Kamalakannan

- To continue

  ➢ Study of pure isotope needs and related production rates

  ➢ Refurbish and upgrade SIDONIE
  → add some diagnostics, …
  → Improve ion source to increase reproducibility and delivered current

Have participated in this work …

Charles-Olivier Bacri, Dominique Ledu,

Florian Pallier, Franck Fortuna

Ulli Koester

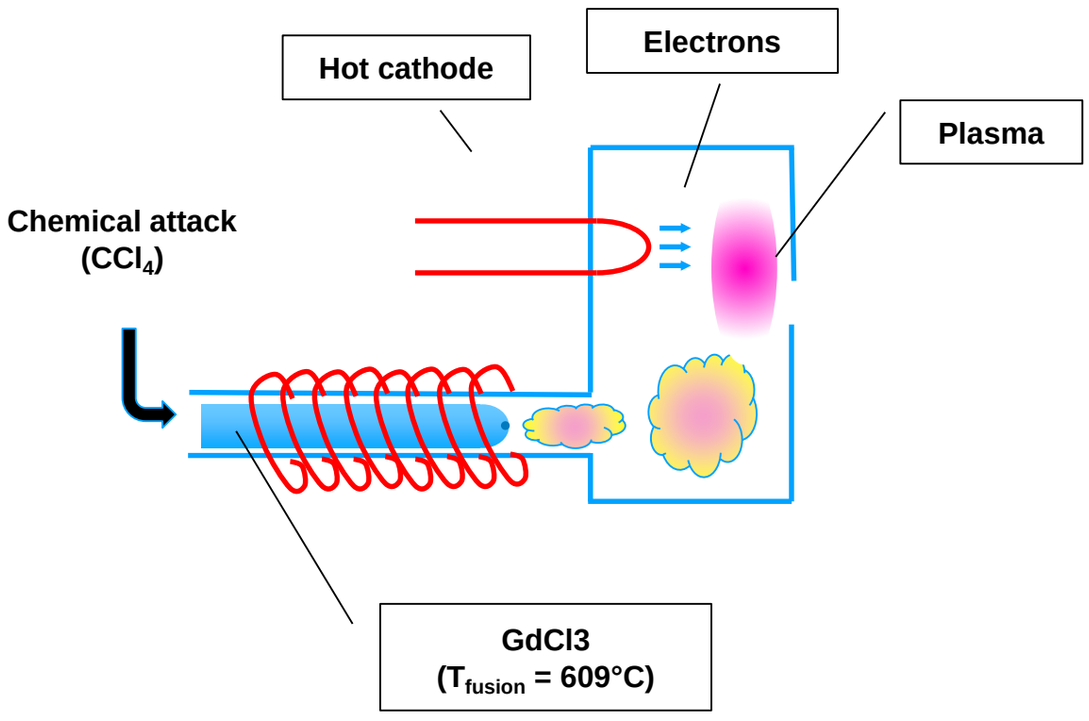
Ivo Tomandl

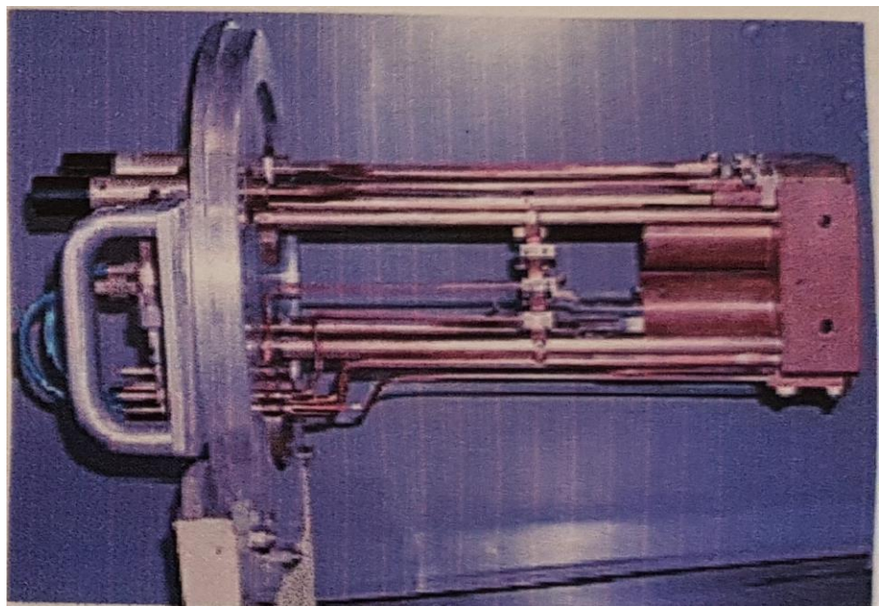
Nathalie Michel, Ferid Haddad

Keerthana Kamalakannan (internship)

Some more slides

Niers-Bernas ion source





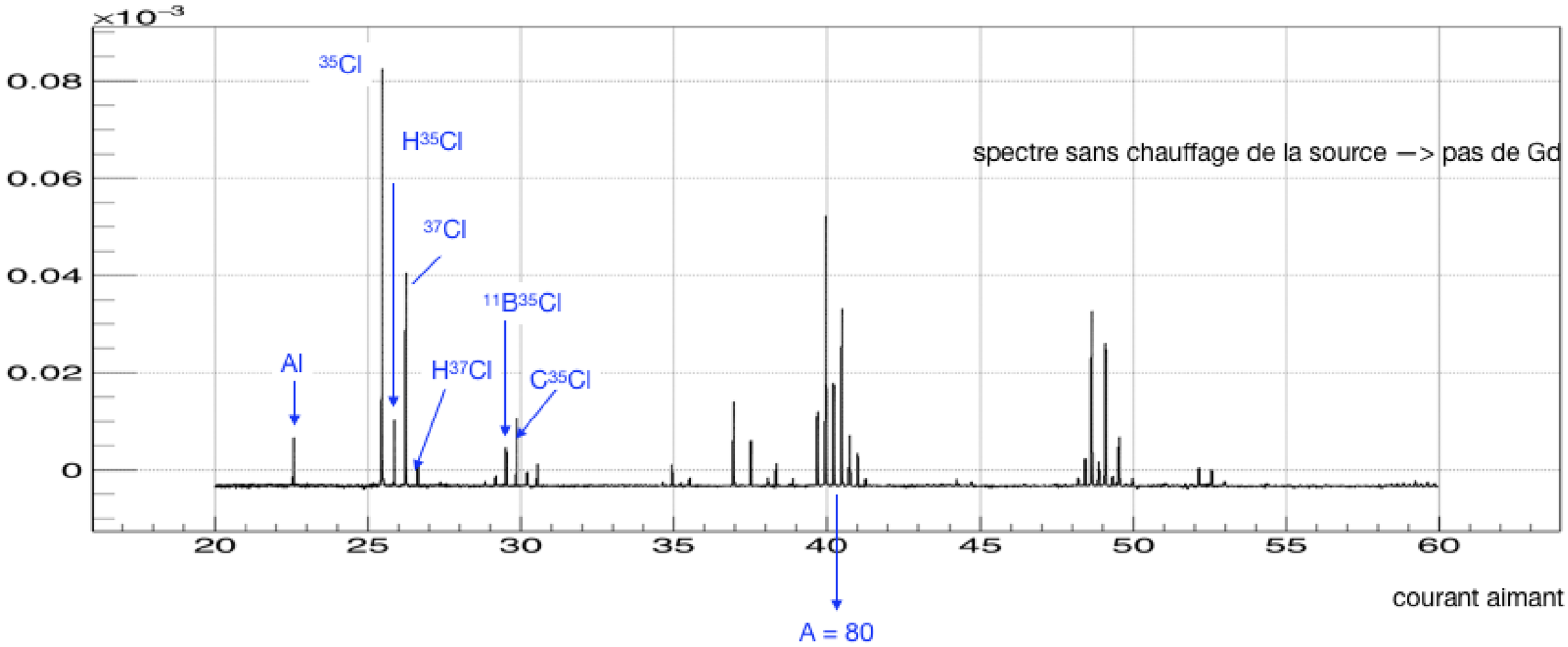
Production estimation

Natural abundancies of ^{nat}Gd isotopes								
152	153	154	155	156	157	158	159	160
0,2 %		2,15 %	14,73 %	20,47 %	15,68 %	24,87 %		21,90 %
1		10,75	73,65	102,35	78,4	124,35		109,5

estimation

For 80 µA de ^{155}Gd

		$t_{1/2}$		Production mode	Production time for **1 mg Gd**	mg of Gd for **1 GBq of Tb**
α therapy	^{149}Tb	4,18 h	E_α = 3,97 MeV	**^{152}Gd**(p,4n)^{149}Tb ≃ 40 MeV	≳ 12 days	161
TEP imaging	^{152}Tb	17,5 h	β^+	**^{152}Gd**(p,n)^{152}Tb ≃12 MeV	≳ 28 h	81
				^{155}Gd(p,4n)^{152}Tb ≃40 MeV	~ 4 h	45
SPECT imaging Auger therapy	^{155}Tb	5,3 j	γ 87 keV et 105 keV	**^{155}Gd**(p,n)^{155}Tb ≃10 MeV	~ 4 h	81
β^- therapy	^{161}Tb	6,9 j	E_{β^-} = 0,15 keV e^-: 20-40 eV (most probable)	**^{160}Gd**(n,γ)^{161}Gd -> ^{161}Tb	~ 3 h	42

Beam profile without Gd

source d'ions: GdO_2 (T_{fusion} = 2230°C) $\xrightarrow{CCl_4}$ $GdCl_3$ (T_{fusion} = 609°C)