R&D for the production of innovative radioelements at GANIL

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Agenda

- Motivations and opportunities
- Current projects
  - At-211
  - Other α emitters
  - Dosimetry
  - Liquid target

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Motivations

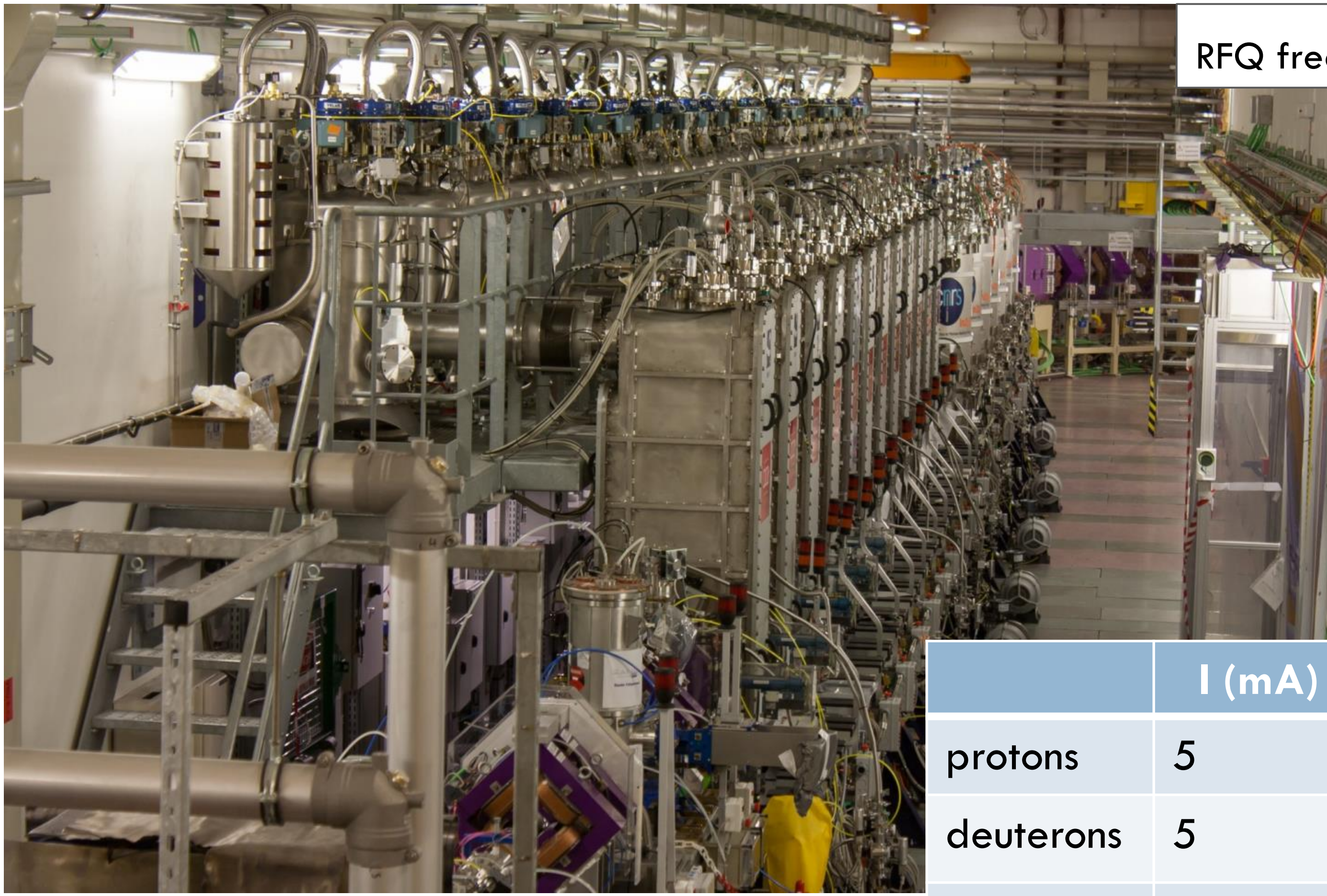
- A strong request from society which research labs like GANIL can partly address
- An R&D on the production of innovative radioelements for nuclear medicine
- A new field to exploit at best the potentialities of the new LINAC
- Endorsed by the GANIL Scientific Council
- In the SPIRAL2 blue paper
- Outcome might serve fundamental research

Opportunities at SPIRAL2

- Limited current (cyclotrons):
  - Dedicated machines, not optimized for R&D production of new isotopes (fixed energy) => cross-section, contamination,…
  - Only proton, deuteron and/or alpha
  - Target not designed for high beam intensities

- New possibilities at SPIRAL2:
  - Very intense beams at optimal energy
  - New beams compared to existing production facility machines

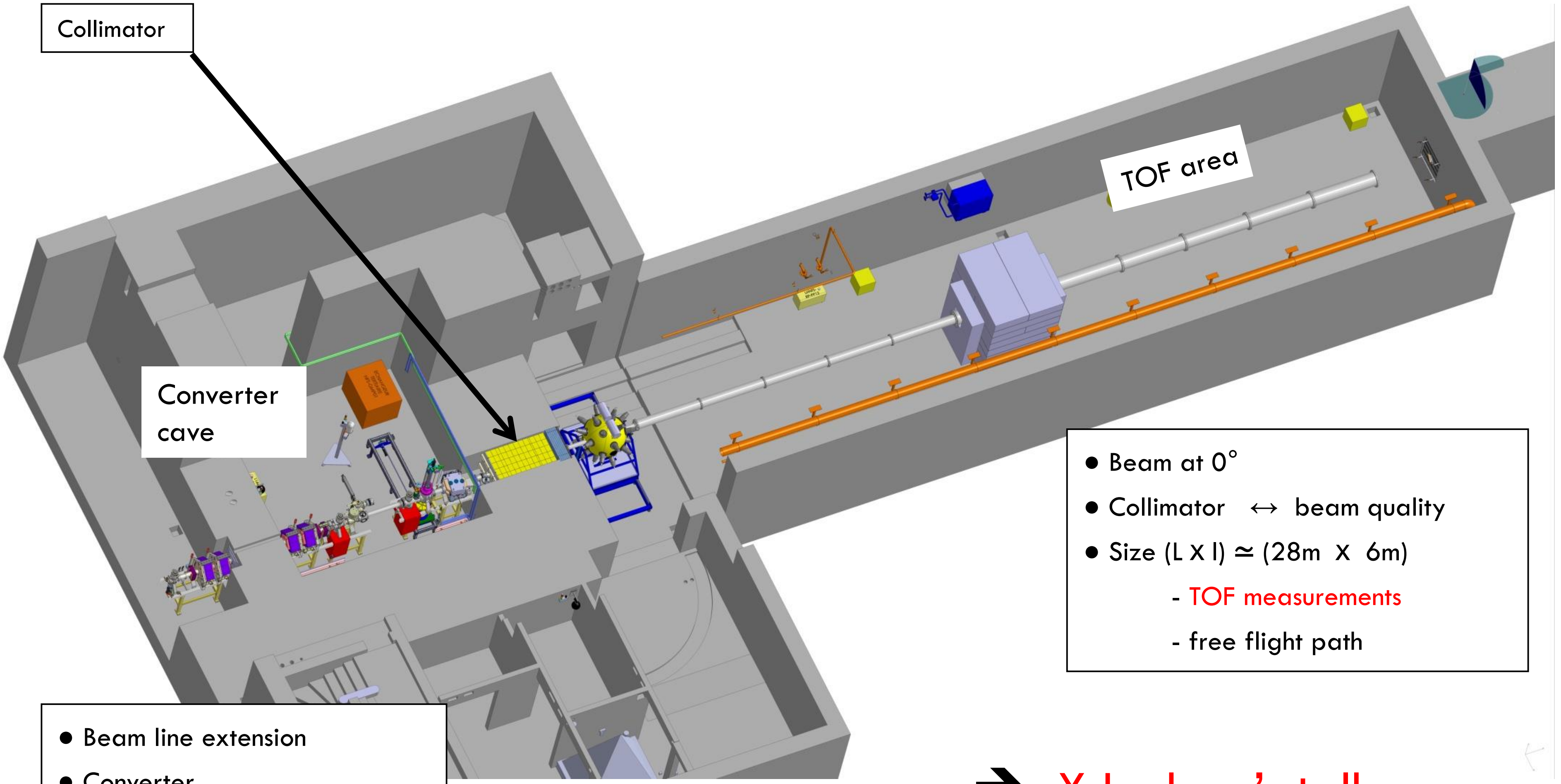
The SPIRAL2 LINAC



RFQ frequency F = 88MHz

	I (mA)	Energy (MeV/u)
protons	5	2-33
deuterons	5	2-20
alpha	3	2-20
Ions (1/3)	1	2-14.5

NFS



- Beam at 0°
- Collimator ↔ beam quality
- Size (L X l) ≃ (28m X 6m)
  - TOF measurements
  - free flight path

- Beam line extension
- Converter
- Magnet and beam dump
- Irradiation station (n, p, d)

➔ X Ledoux's talk

Strategy for radio-isotopes

- Strategy:
  - Only R&D
  - Collaboration
  - Targeted goals
  - Focus on alpha emitters

- Current isotopes of interest:
  - ^{211}At (ARRONAX et al)
  - α+Th reaction products

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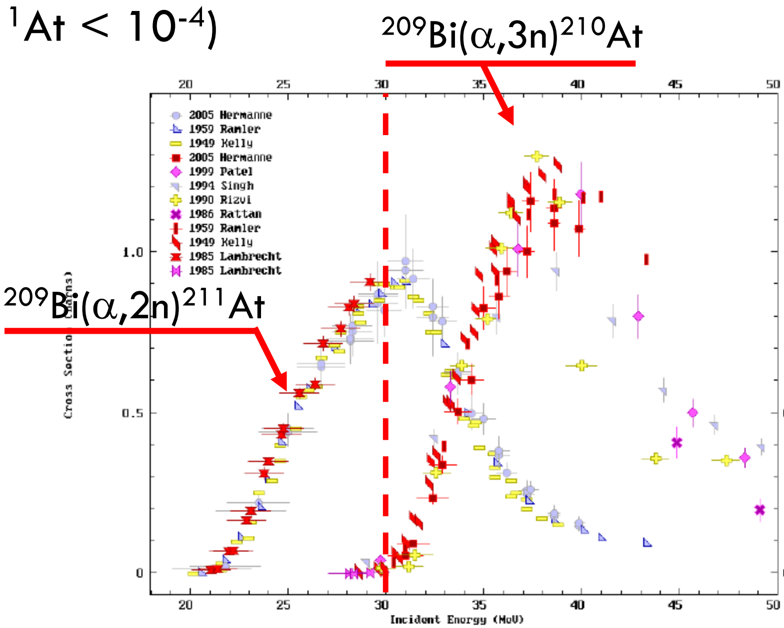
^{211}At at NFS (1)

Production using ^{209}Bi(α,2n)^{211}At

- Réaction
  - Reaction threshold 20.72 MeV
  - Cross section max 900 mb at 30 MeV
  - Production of contaminant ^{210}Po ^{209}Bi(α,3n)^{210}At → ^{210}Po, $t_{1/2}$ = 138 d, Et=28.61 MeV
  - Optimal energy ≈30 MeV (ratio N^{210}At/N^{211}At < 10^{-4})



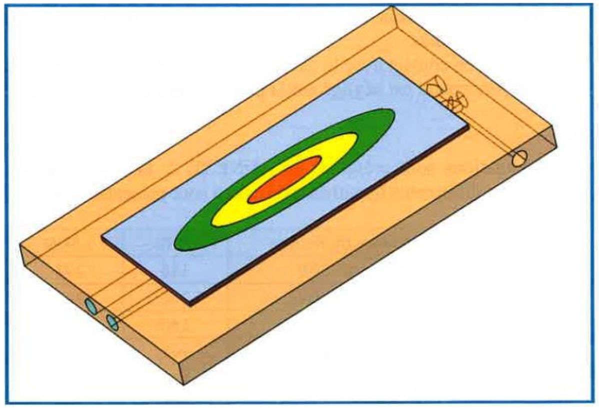
- Production estimate:
  - Alpha 28 MeV, 1 kW
  - Target : Bi on AlN backing
  - At-211 production : 9.6 GBq in 8h

Scenario

- Target from ARRONAX
- Irradiation at SPIRAL2
  - Irradiation station in the converter room
  - Beam: 28 MeV α, 70 μA ($3.15^{e}14$ α/s)
  - Tirr: 4 to 8h
  - Production of ~10GBq of At-211
  - Dose Rate after 30 min cooling: 0.25 mSv/h at 30 cm
- Irradiated targets sent to ARRONAX
- Extraction, labelling, QC at ARRONAX

Thermal study

- 1kW deposited
- Two designs:
  - Target on cold copper
  - Direct backing water cooling
- Parameters:
  - Thermal resistance target-copper
  - Cooling liquid temperature



	résistance thermique	1KW	1,5KW	2KW
solution plaquée (eau 15°C)	100 mm².C/W	188	292	
	200 mm².C/W	252	387	
solution plaquée (éthanol -30°C)	100 mm².C/W	140	243	
	200 mm².C/W	202	340	
solution contact eau (eau 15°C)		156	228	309
solution contact eau (éthanol -30°C)		105	180	260

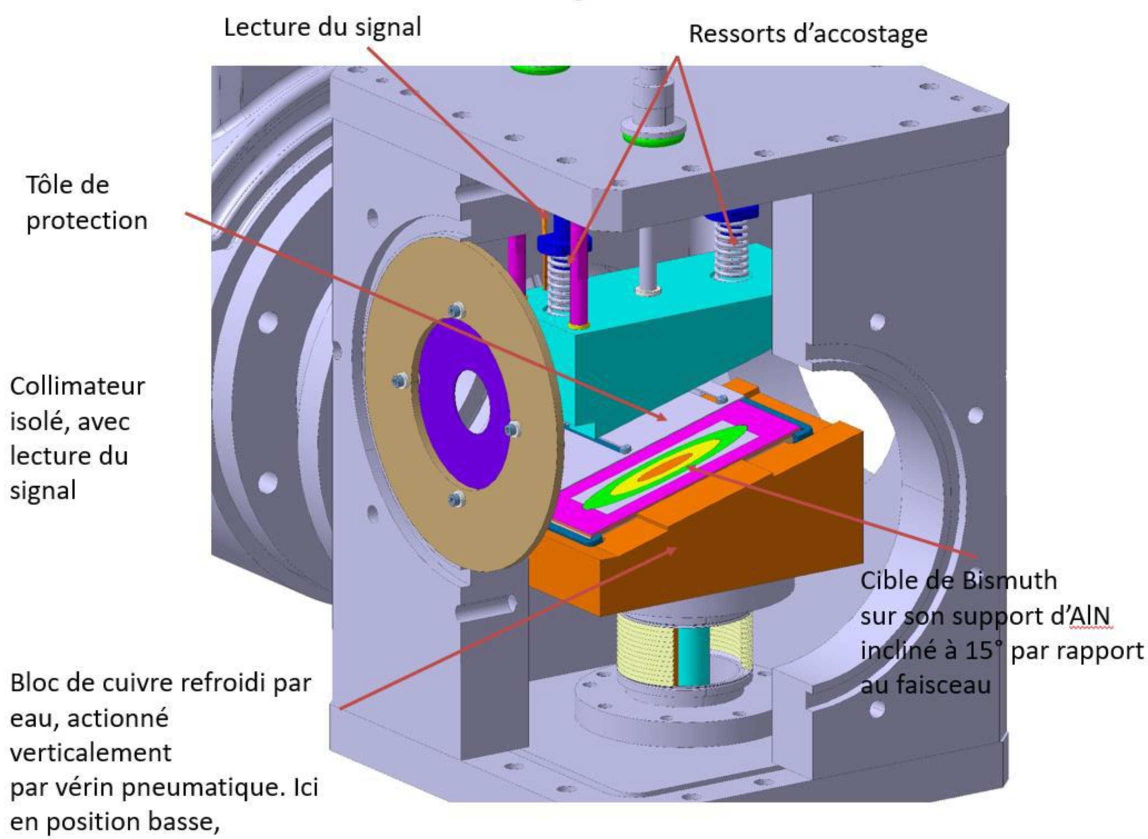
Tableau 4 : températures maximum de la cible calculées en °C

1 kW OK. Measurement of thermal resistance

T_{fusion} Bi= 271°C

The irradiation station

- Manual load/unload
- Target on actuator (beam focusing before irradiation)
- Unload using vinyl confinement
- Dosimetry measurements
  - extremity : 480µSv
  - Full body : 20µSv
- Shipment : A type parcel



Collaboration NPI
Under assembly

Higher power dissipation

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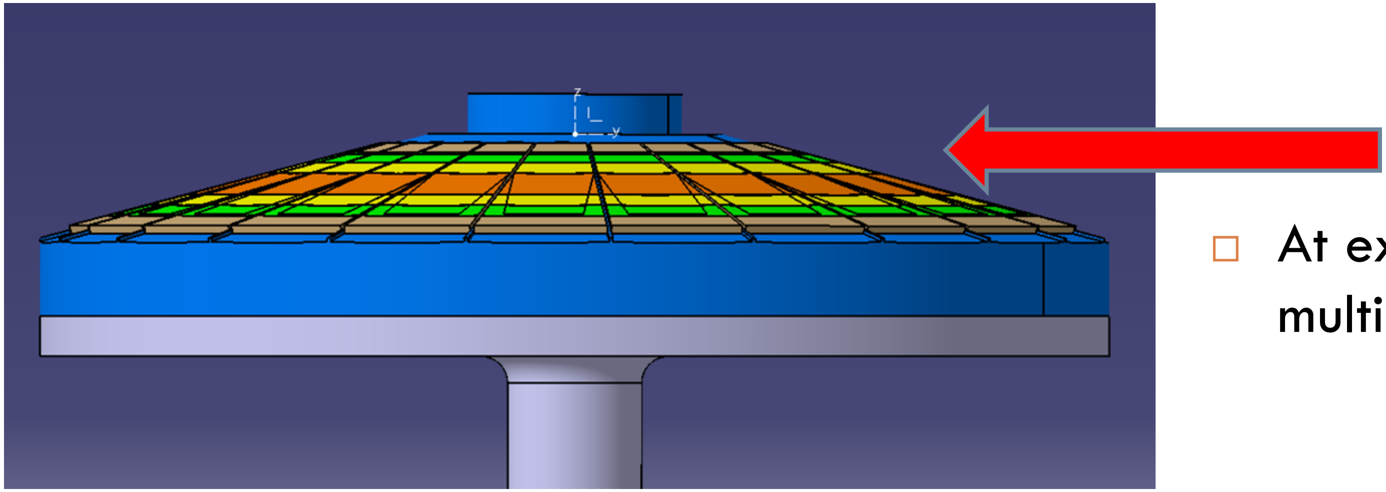
Feasibility study

- Production via α + Bi
- Collaboration NPI Rez
- Goal: ~10 kW
- Rotating target+water cooling

Ø beam (+/-3 σ) =24mm
we kept the angle of the target of 15°

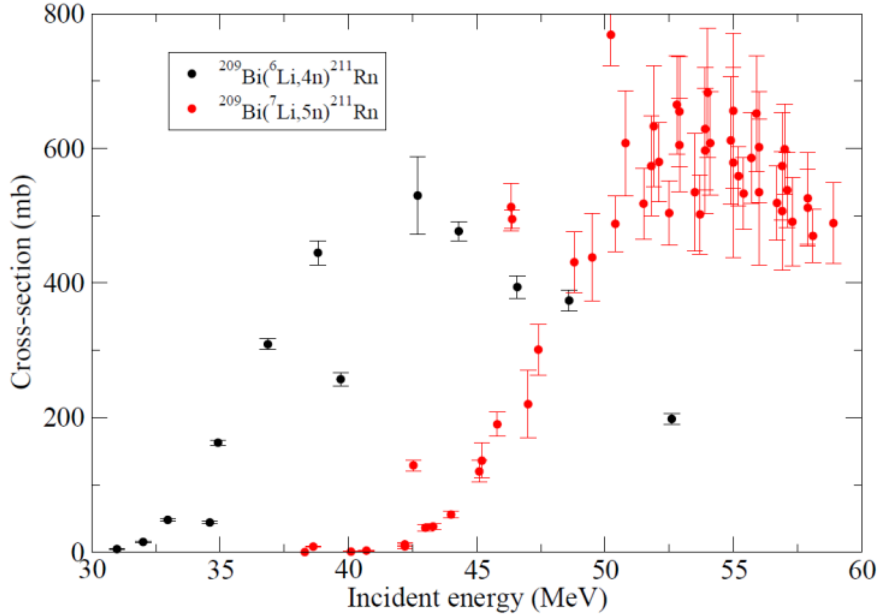


- At extraction with multiple targets?

^{211}At at NFS: generator

Design of a generator using ^{209}Bi(^{6}Li,4n)^{211}Rn or ^{209}Bi(^{7}Li,5n)^{211}Rn

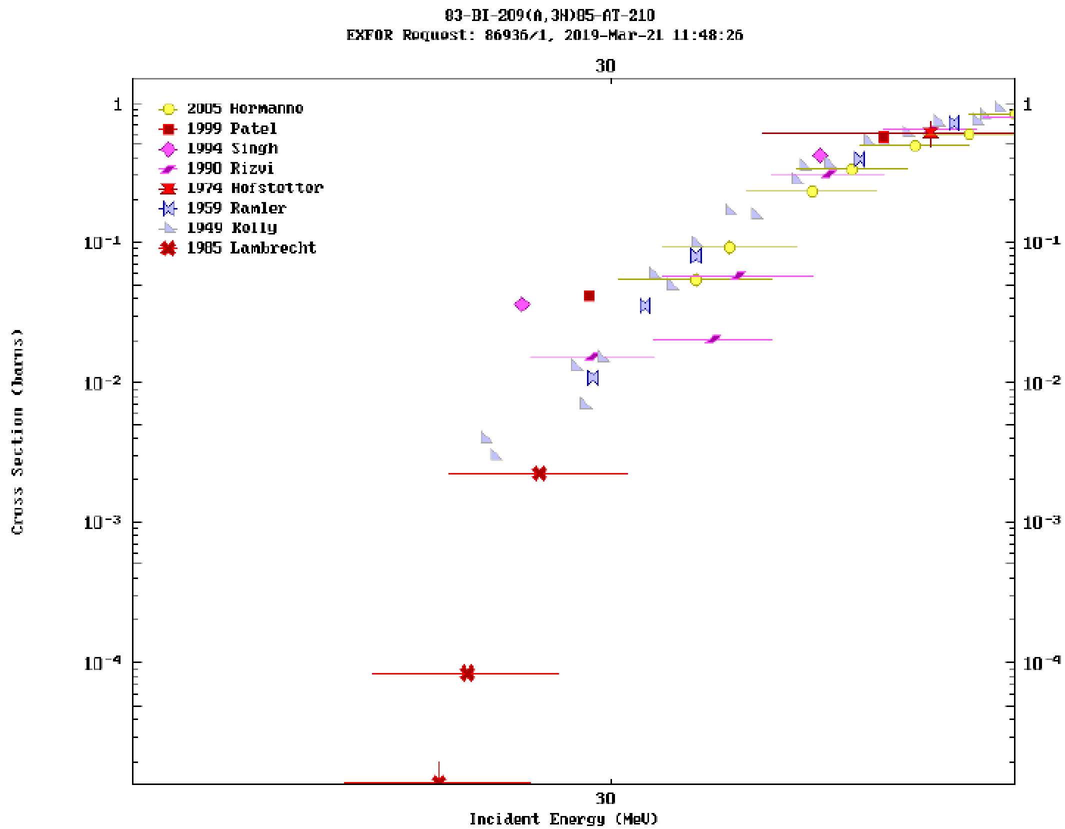
- Reaction
  - Reaction threshold
    - 28.5 MeV for ^{209}Bi(^{6}Li,4n)
    - 36.13 MeV for ^{209}Bi(^{7}Li,5n)
  - ^{210}Po contamination
    - E(^{6}Li)< 36 MeV for ^{209}Bi(^{6}Li,4n)
    - E(^{7}Li)< 48 MeV for ^{209}Bi(^{7}Li,5n)
  - Energy domain of SPIRAL2
- Production estimate:
  - LISE code
  - Lithium beam stopped in target
  - Optimal irradiation time : 14h
  - Best reaction **^{209}Bi(^{7}Li,5n)^{211}Rn**



48 MeV	36 MeV	Rapport activité
Act-utile (Bq/µA)	Act-utile (Bq/µA)	
^{7}Li	^{6}Li	^{7}Li/^{6}Li
4,84E+05	1,83E+05	2,65

^{211}At at NFS: contaminants

- ^{210}At:
  - ^{210}At → ^{210}Po
  - One single cross-section measurements in the alpha induced reaction
  - Nothing beyond 48 MeV with Li beam (max cross section at 55 MeV for ^{7}Li)
- ^{209,210}Po:
  - Direct production in (α,t) or (α,dn) or (α,2np)
  - Incomplete fusion using ^{7}Li (t transfer followed by n evaporation) (10% of the yield involves α emission in Yb+^{7}Li)
- α+Pb:
  - PbBi eutectic liquid target. No EXFOR data



→ Cross section measurements at NFS

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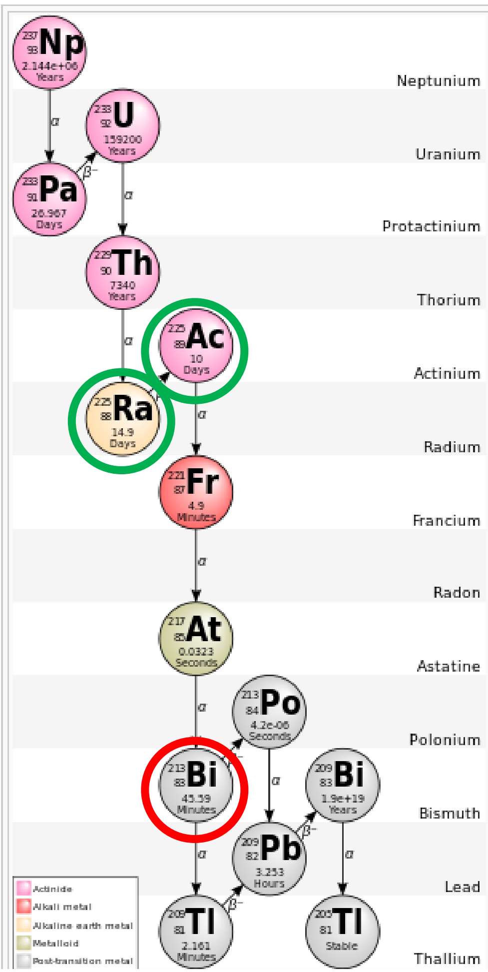
Other α emitters

Bi-213 from Ra-225 or l'Ac-225

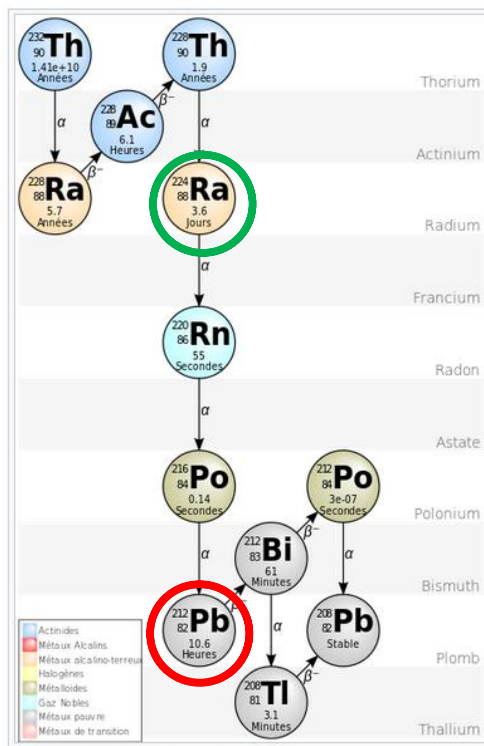


Neptunium 237 decay chain

Generators

Radio-isotopes of interest

Pb-212 from Ra-224

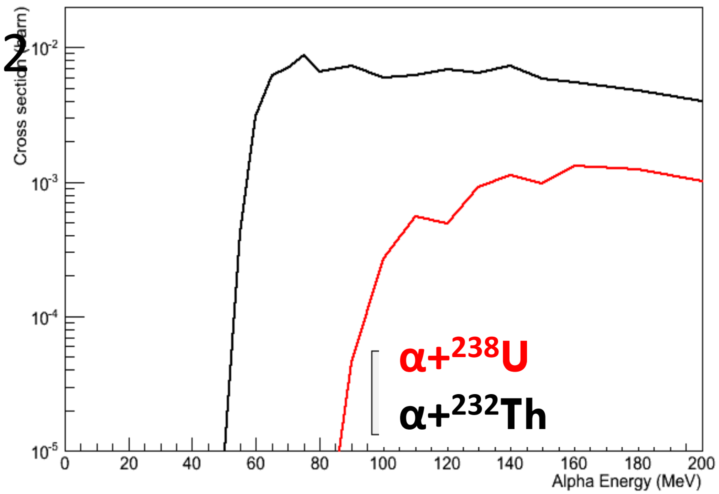


Thorium 232 decay chain

Generators from the α + Th-232 reaction

Ra-224

- Database TENDL-2014: Reaction α + Th-232
- Reaction threshold
  - ≈ 50 MeV for α + Th-232
  - ≈ 100 MeV for α + U-238



- Production rate calculations :
  - Natural thorium target 0.05 cm so that $E_{out} \approx$ 50 MeV
  - FISPACT-II vs PHITS : huge differences
  - I=200μA (6.2e14 α/s)
  - T_{irr}=1d

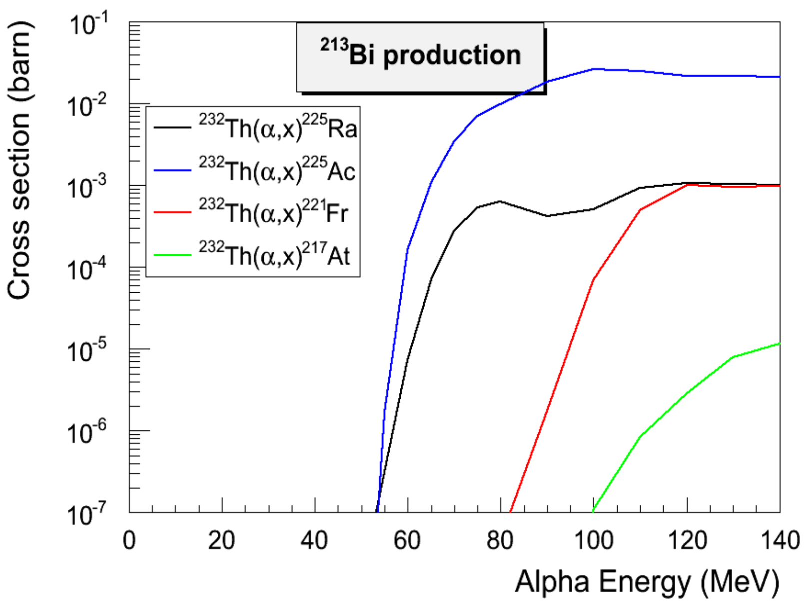
	MCNPX+FISPACT II	PHITS
^{224}Ra	3.56×10^{8} Bq/g	5.34×10^{6} Bq/g

⇨ First cross-section measurements to constrain models

⇨ Approved experiment

Ac-225

- Database TENDL-2014: Reaction α + Th-232
- Reaction threshold
  - ≈ 50 MeV for Ac-225 and Ra-225
  - ≈ 100 MeV for Bi-213
- FISPACT-II calculations:
  - Natural thorium target 0.05 cm so that E_{out}≈ 50 MeV
  - I=200μA (6.2e14 α/s)
  - T_{irr}=1 and 10 d



	80 MeV	
	A(Bq/g)	% Atot
Irradiation 1j	1.24E+08	0.39%
Irradiation 10 j	9.30E+08	0.495%

⇨ First cross-section measurements to constrain models

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Radioisotope evaluation

Dosimetry

Development of a new radiopharmaceutical ➡ Studies /Evaluations clinic /**preclinic**

BIOLOGICAL observable **vs. PHYSICAL dose**

➔ AM Frelin's talk

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Liquid target

- Liquid Bi target
  - Design an «as simple as possible» liquid Bi target; not a loop
  - Cooled Bi container; confinement issues
  - Online and continuous extraction of At or Rn; how to concile with the previous point?...
  - Design study in the next years (JRA ERINS; collaboration Czech Rep, ARRONAX, SUBATECH, INFN, HIL; ANR?)

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Conclusions (1)

- SPIRAL-2 beams offer opportunities for R&D on production of innovative radioisotopes
- GANIL concentrate on target irradiations → collaborations
- Astate (with ARRONAX, SUBATECH, NPI Rez):
  - Measurements of α +^{209}Bi et +^{6,7}Li+^{209}Bi at NFS; impurities
  - Irradiation station for Bi under construction
  - Design study for high power (10 kW; solid Bi)
  - Long-term: liquid bismuth target with continuous online extraction of At-211 or Rn-211
  - Safety, transport, autorisation, manpower,…

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Conclusions (2)

- Other alpha emitters : Bi-213, Pb-212:
  - Production study using $\alpha + {}^{232}Th$. Approved experiment.
  - Cross-section measurements ↔ nuclear data interest

- Development of dosimetry studies to evaluate new radioisotopes:
  - Focus on alpha dosimetry (detection methods; in-vitro distribution; effects;…). Very little done
  - Connection physics-radiobiology; interdisciplinary studies; CYCERON

Conclusions (3)

- Implementation:
  - Various possibilities evaluated (from optimal to simple)
  - Requires developement (chopper) and safety aspects
- Extremely fruitfull Czech Rep. – France collaboration
- **Many very interesting opportunities. New in-lab culture…**

THANK YOU