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Actinide Fission and Capture Cross Section Measurements

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CEA – Saclay

in collaboration with

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Institut Laue-Langevin (ILL)
Berkeley National Laboratory (BNL)

Introduction

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The Mini-INCA project

Minor actinides transmutation study in high thermal neutron flux (at ILL)

- Development of innovative experimental techniques
  - Quasi on-line α- and γ-spectroscopy
  - Multi-deposit micro fission-chamber
- Accurate measurements of minor actinide nuclear data
  - Capture and fission cross sections
  - Branching ratio, half-lives

→ To check and improve nuclear data libraries

Experimental approach

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- Take advantage of high neutron fluxes (ILL)
- Precise characterization of the neutron flux
  - ✓ computer simulations
  - ✓ flux monitors

↓

- Characterize the transmutation chain
- Accurate measurements of σ_c and $T_{1/2}$
  - ✓ α- and γ-spectroscopy
  - ✓ mass spectrometry

↓

- On-line production of fissile isotopes
- Measurement of the fission cross section σ_f
  - ✓ μ fission-chambers

The ILL High Flux Reactor

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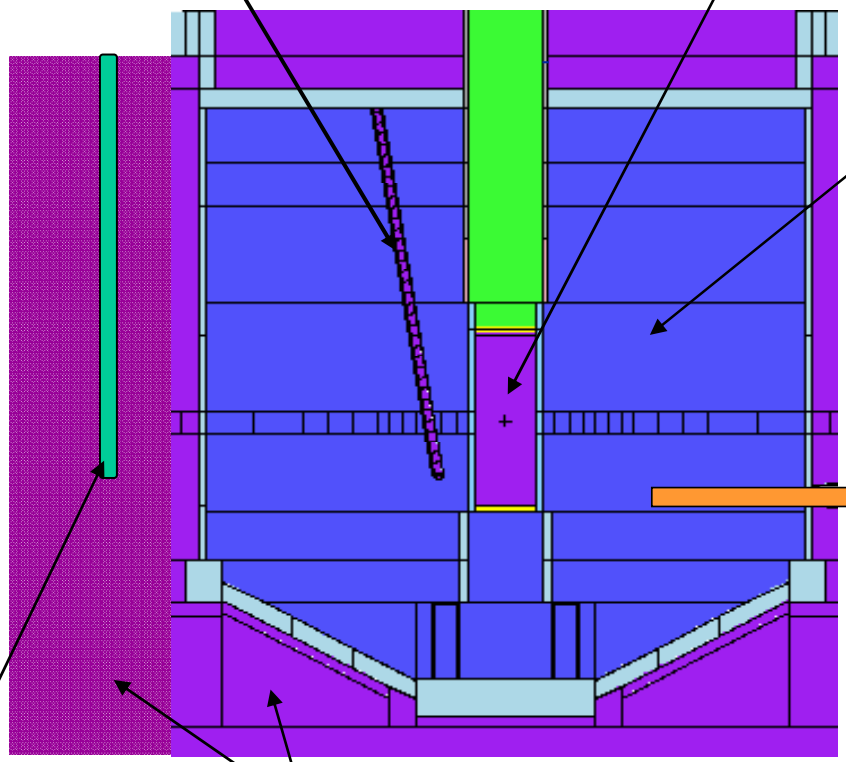

V4 channel
85–100% thermal neutrons
6×10^{13} – 1.5×10^{15} n/cm^2/s

Fuel element
^{235}U (93%)

D_2O tank

H9 channel
98% thermal neutrons
6×10^{14} n/cm^2/s

Mini-INCA chamber

α and γ spectroscopy

Automatic sample transport
Irradiation ⇔ Measurement

T4 channel
100% thermal
2.3×10^{13} n/cm^2/s

H_2O tank

ILL neutron flux

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Advantages of high fluxes

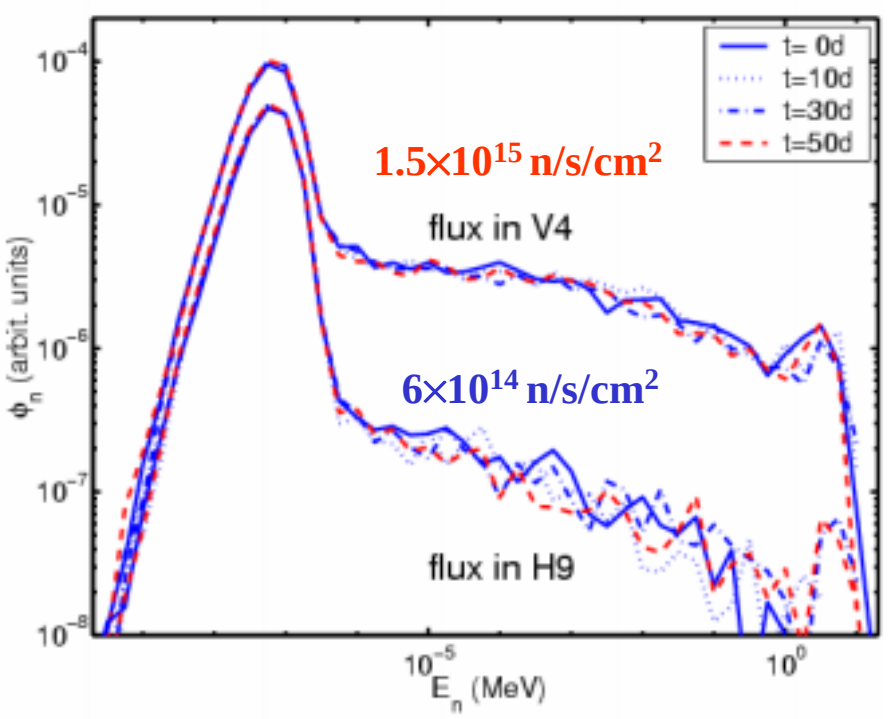
Low masses (~10 μg)

⇒ Access to rare or expensive isotopes
⇒ No local flux perturbation
⇒ No self-absorption of α and γ-rays

Short irradiation times

⇒ Access to short-lived isotopes

Small cross section measurements



α- and γ-spectroscopy station on H9

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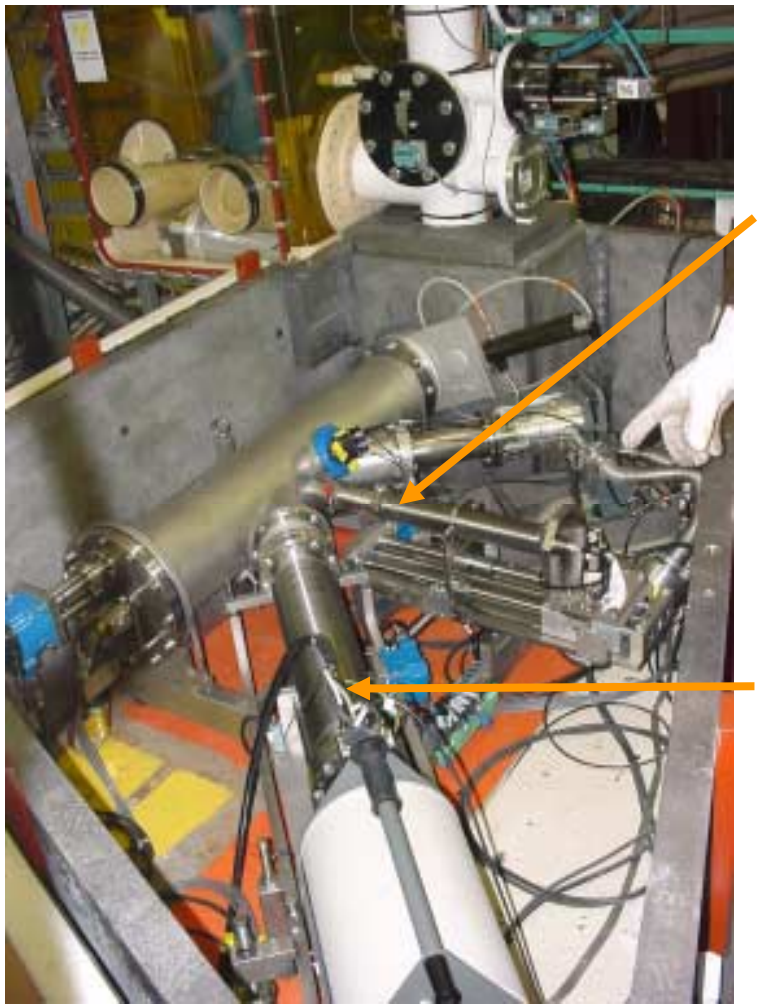
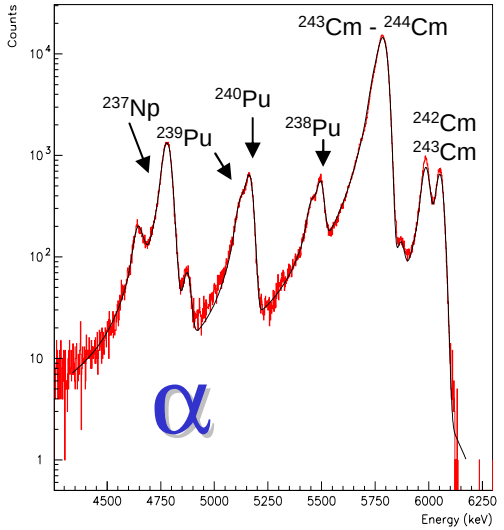
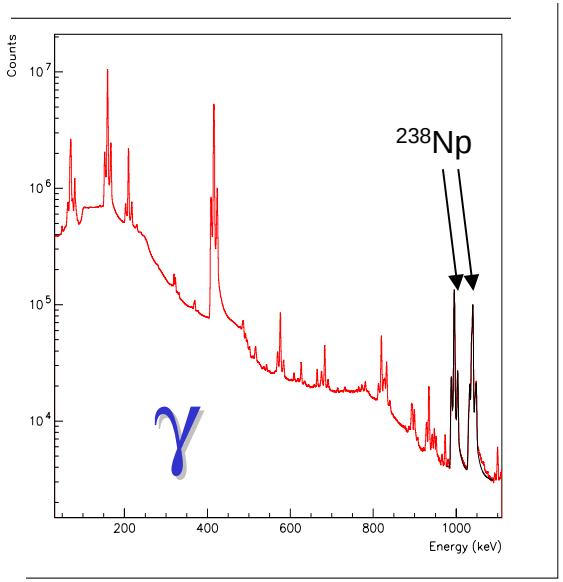


PIPS detector
up to 20 000 count/s

Ge detector
up to 80 000 count/s
or 10^6 count/s with
ADONIS DAQ
by CEA/DRT





Multi-deposit micro fission-chamber

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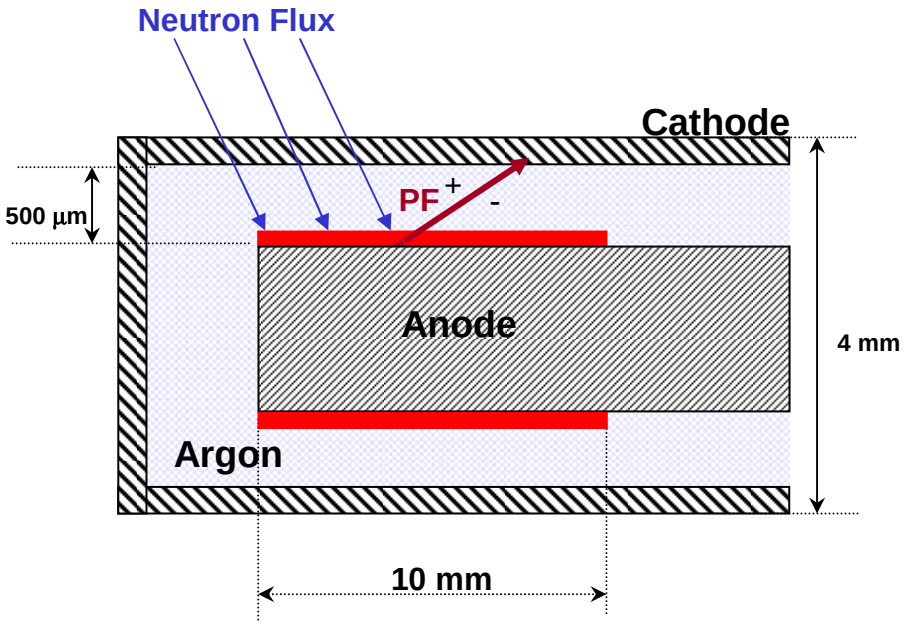

- ^{235}U for flux measurements

Multi-deposit micro fission-chamber

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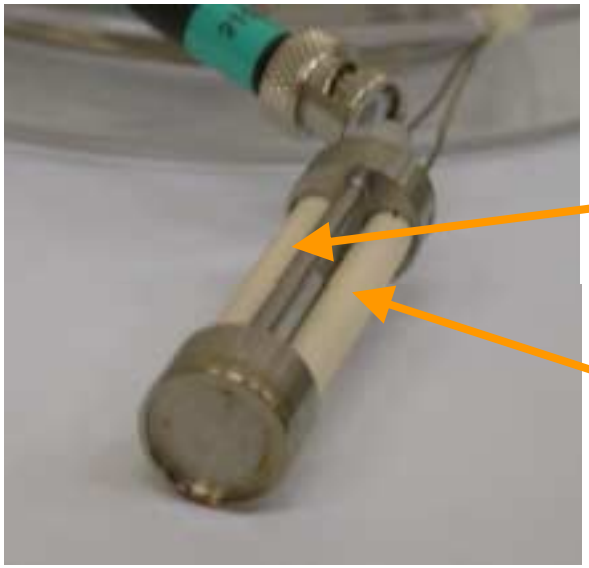

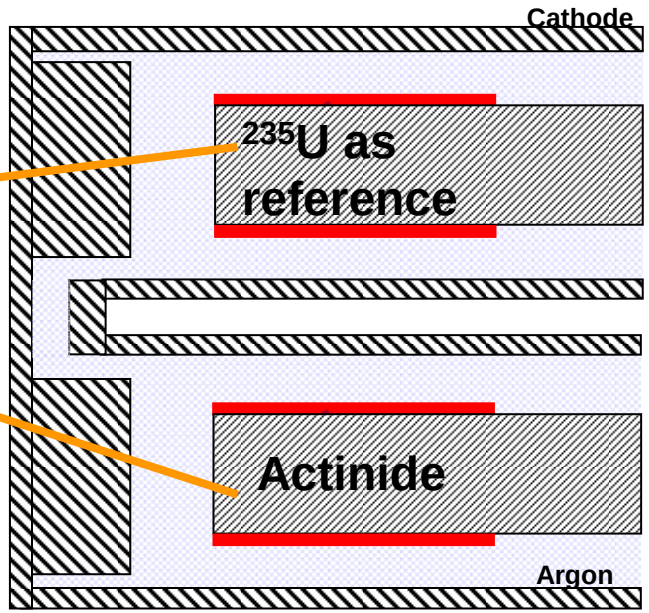

- ^{235}U for flux measurements
- Actinide for transmutation studies

Multi-deposit micro fission-chamber

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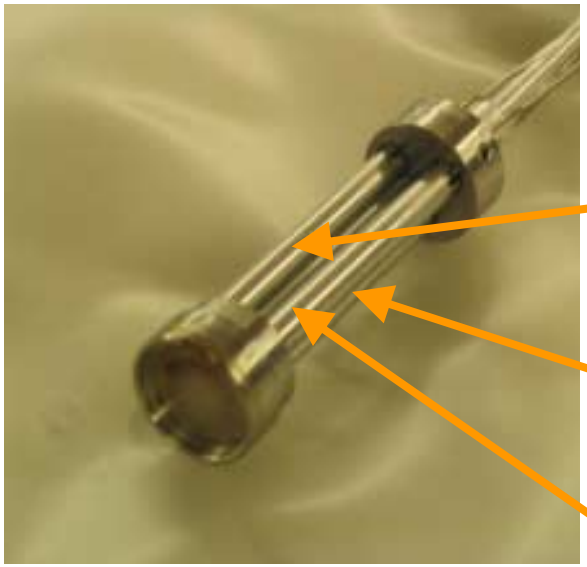

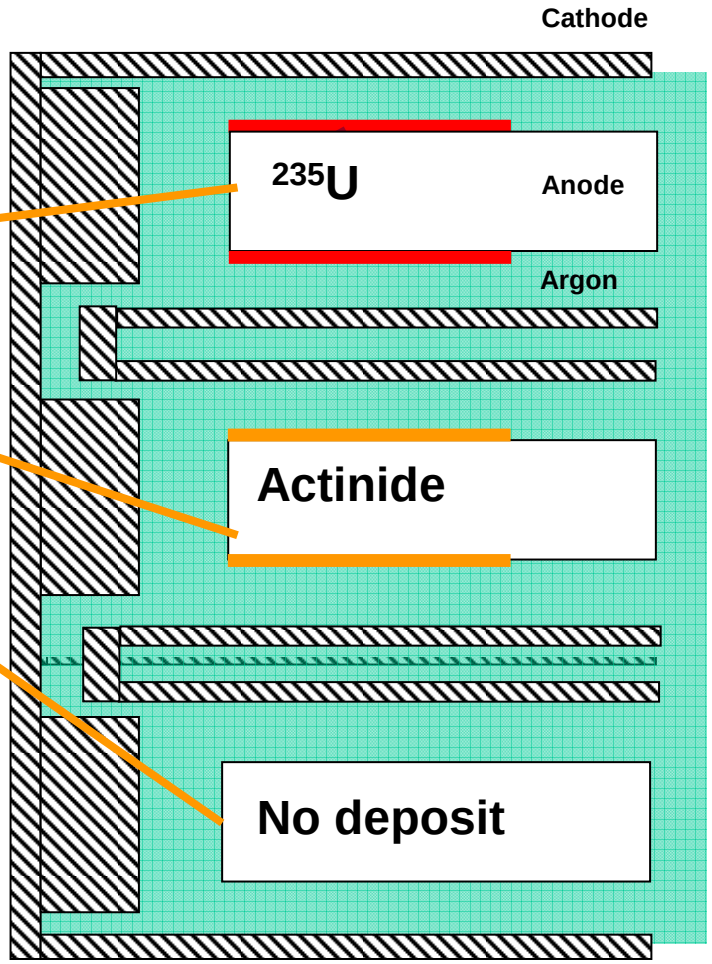

- ^{235}U for flux measurements
- Actinide for transmutation studies
- No deposit for bkgd measurements

^{241}Am chain – ^{241}Am & ^{242}Am capture

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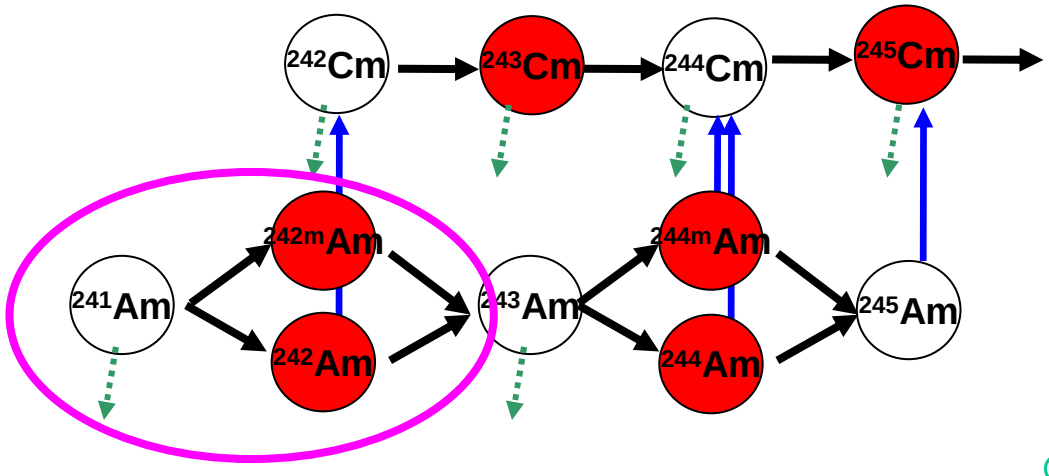

☺ ≤ 1 σ < 😐 ≤ 2 σ < ☹

Spectroscopy station on H9

^{241}Am (n, γ) ^{242}Am :	**696 ± 48 b**	JEFF-3.1 : 647 b 😐	JEFF-3.0/A : 615.5 b 😐
IR = $\sigma_{gs}/(\sigma_{gs}+\sigma_m)$:	**0.914 ± 0.007**	JEFF-3.1 : 0.91 ☺	JEFF-3.0/A : 0.92 ☺
^{242gs}Am (n, γ) ^{243}Am :	**330 ± 50 b**	JEFF-3.1 : 219 b ☹	JEFF-3.0/A : 332 b ☺

G. Fioni, et al., Nucl. Phys. A 693 (2001) 546

Sample irradiation in T4

^{241}Am (n, γ) ^{242}Am :	**712 ± 30 b**	
IR = $\sigma_{gs}/(\sigma_{gs}+\sigma_m)$:	**0.894 ± 0.004**	
^{242m}Am (n, γ) ^{243}Am :	**1173 ± 107 b**	JEFF-3.1 : 1231 b ☺ JEFF-3.0/A : 1809 b ☹

Preliminary

O. Bringer, Ph.D. Thesis (2007)
see also PHYSOR'06 conference

^{241}Am chain – ^{242}Am fission

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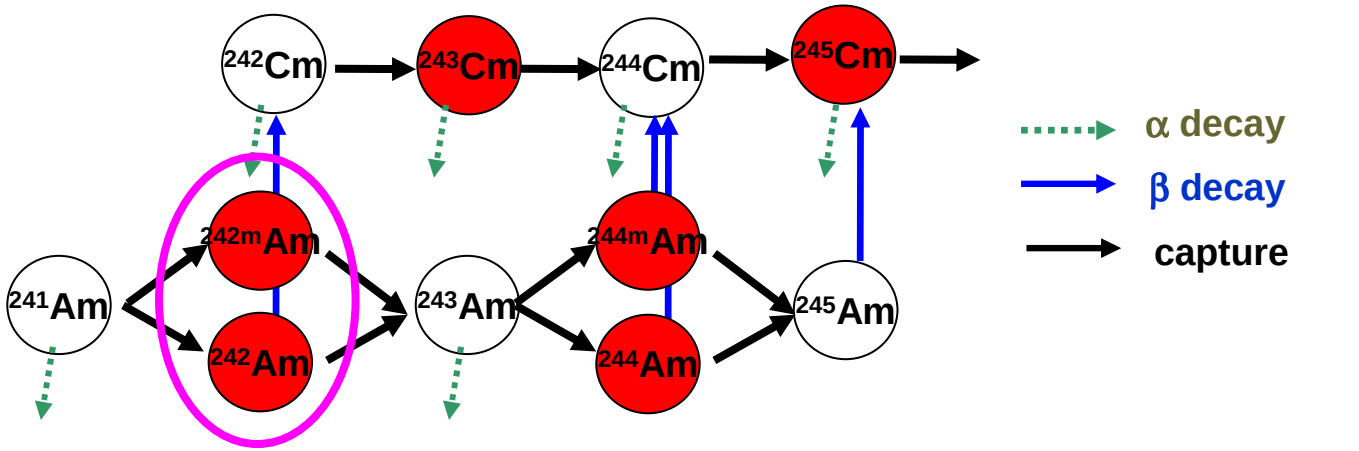

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Micro fission-chamber in V4

^{242gs}Am (n,f) :	**1735 ± 87 b**	JEFF-3.1 : 2094 b ☹	JEFF-3.0/A : 2158 b ☹
^{242m}Am (n,f) :	**6263 ± 313 b**	JEFF-3.1 : 6398 b ☺	JEFF-3.0/A : 6886 b 😐

Preliminary

O. Bringer, Ph.D. Thesis (2007)
See also PHYSOR'06 conference

^{241}Am chain – ^{243}Am capture

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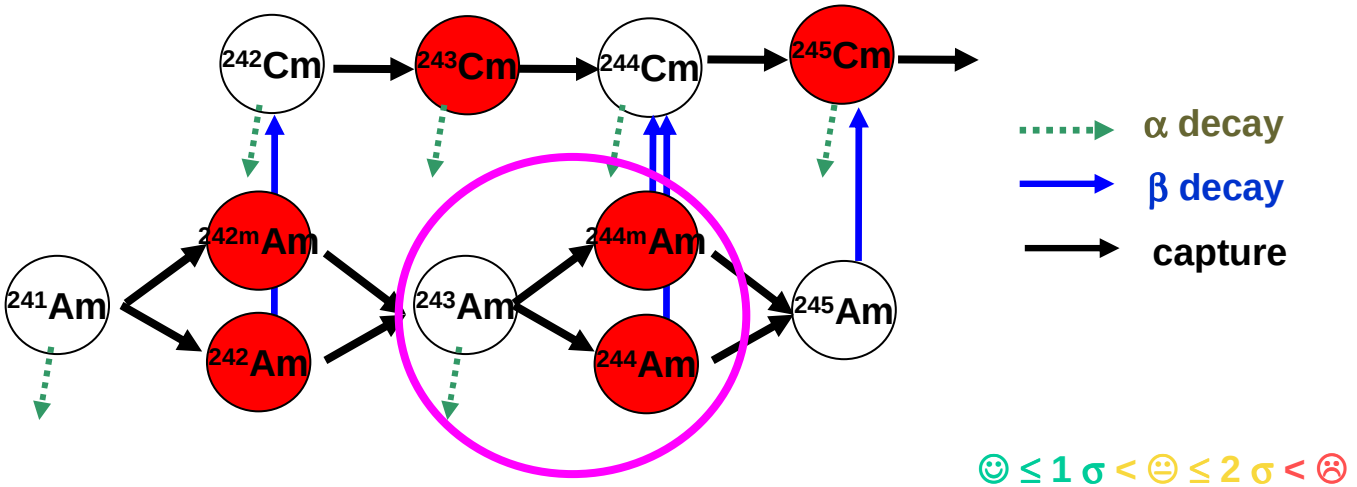

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Spectroscopy station on H9

^{243}Am (n, γ) ^{244}Am : 81.8 ± 3.6 b JEFF-3.1 : 76.7 b 😐 JEFF-3.0/A : 75.2 b 😐

^{243}Am (n, γ) ^{244gs}Am : 5.2 ± 1.6 b JEFF-3.1 : no data JEFF-3.0/A : 4.7 b ☺

O. Déruelle, Ph.D. Thesis (2002)

F. Marie, et al., Nucl. Instr. Meth. A 556 (2006) 547

^{244m}Am Half-life : 25.9 ± 0.9 min (Preliminary) JEFF-3.1/RDD : 26 ± 2 min ☺

Measured with very high count rate **ADONIS** DAQ (up to 10^6 count/s) developed by CEA/DRT

Not yet fully analyzed

^{241}Am chain – ^{242}Cm capture

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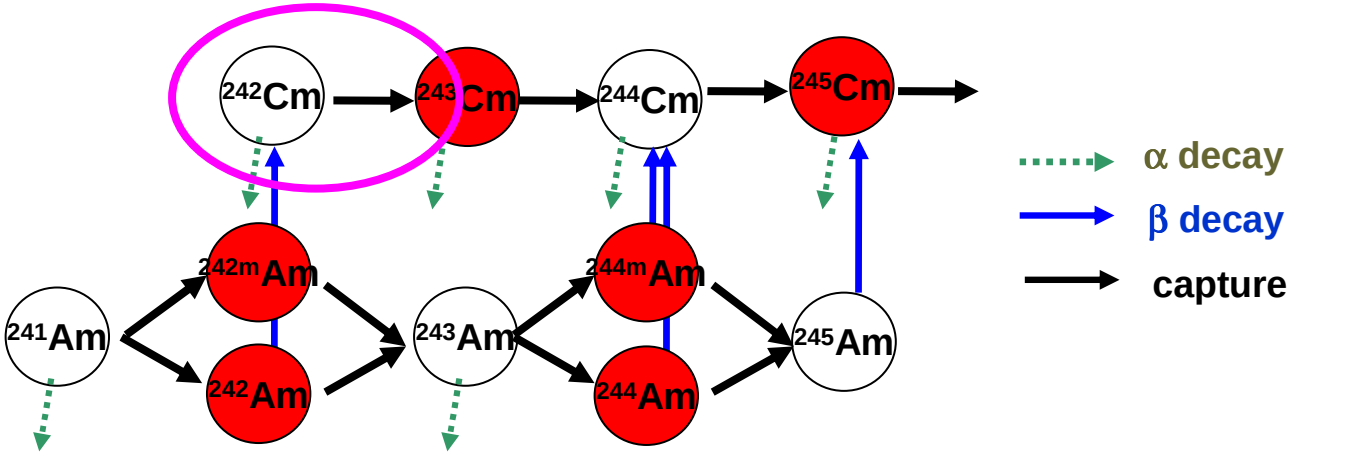

☺ ≤ 1 σ < 😐 ≤ 2 σ < ☹

Sample irradiation in T4

^{242}Cm (n, γ) ^{243}Cm : **22.6 ± 2 b**

Preliminary

JEFF-3.1 : 15.9 b ☹ JEFF-3.0/A : 16.5 b ☹

O. Bringer, Ph.D. Thesis (2007)
See also PHYSOR'06 conference

^{237}Np transmutation chain

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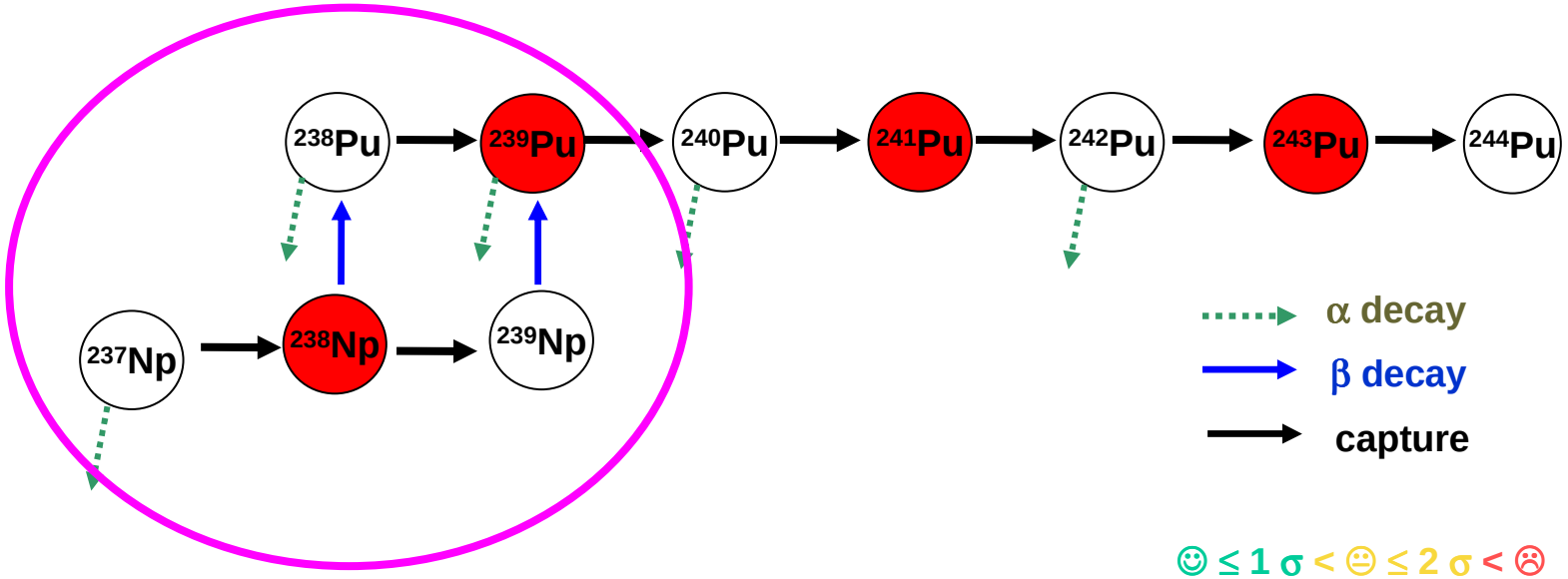

☺ ≤ 1 σ < 😐 ≤ 2 σ < ☹

Micro fission-chamber in V4

^{237}Np (n, γ) ^{238}Np	:	**180 ± 5 b**	JEFF-3.1 : 162 b ☹	JEFF-3.0/A : 181 b ☺
^{238}Np (n,f)	:	**2165 ± 70 b**	JEFF-3.1 : 2027 b 😐	JEFF-3.0/A : 2029 b 😐
^{238}Np (n, γ) ^{239}Np	:	**1035 ± 250 b**	JEFF-3.1 : 203 b ☹	JEFF-3.0/A : 203 b ☹
^{238}Pu (n, γ) ^{239}Pu	:	**476 ± 33 b**	JEFF-3.1 : 540 b 😐	JEFF-3.0/A : 547 b ☹

A. Letourneau, et al., to be published in Phys. Rev. C or Nucl. Phys. A

^{237}Np chain – ^{242}Pu capture

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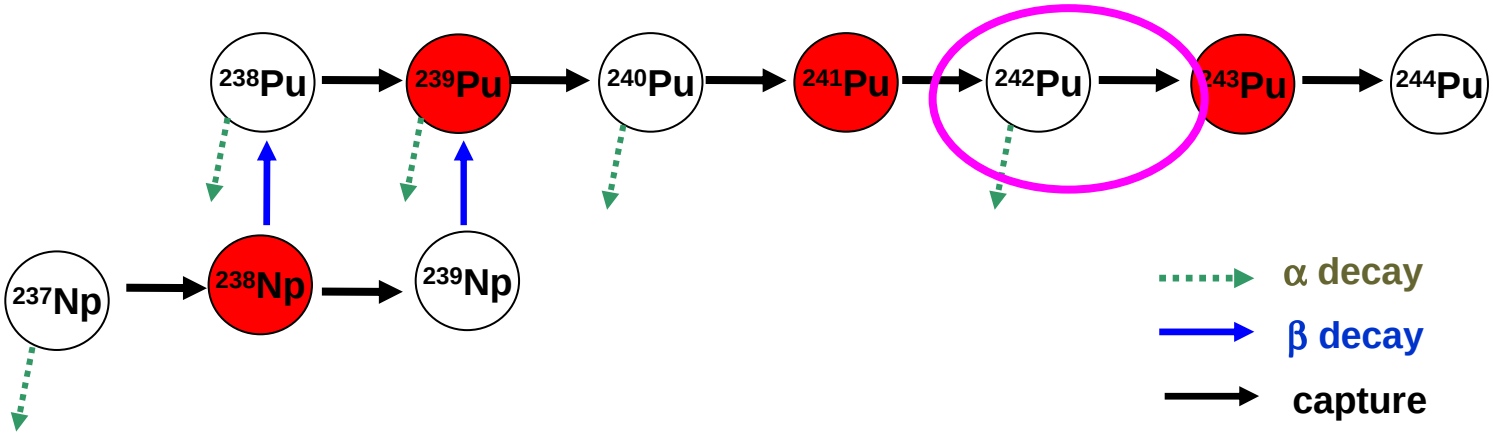

☺ ≤ 1 σ < 😐 ≤ 2 σ < ☹

Spectroscopy station on H9 { ^{242}Pu (n, γ) ^{243}Pu : **22.5 ± 1.1 b**

JEFF-3.1 : 18.8 b ☹ JEFF-3.0/A : 18.5 b ☹

O. Déruelle, Ph.D. Thesis (2002)

F. Marie, et al., Nucl. Instr. Meth. A 556 (2006) 547

^{232}Th / ^{233}U cycle

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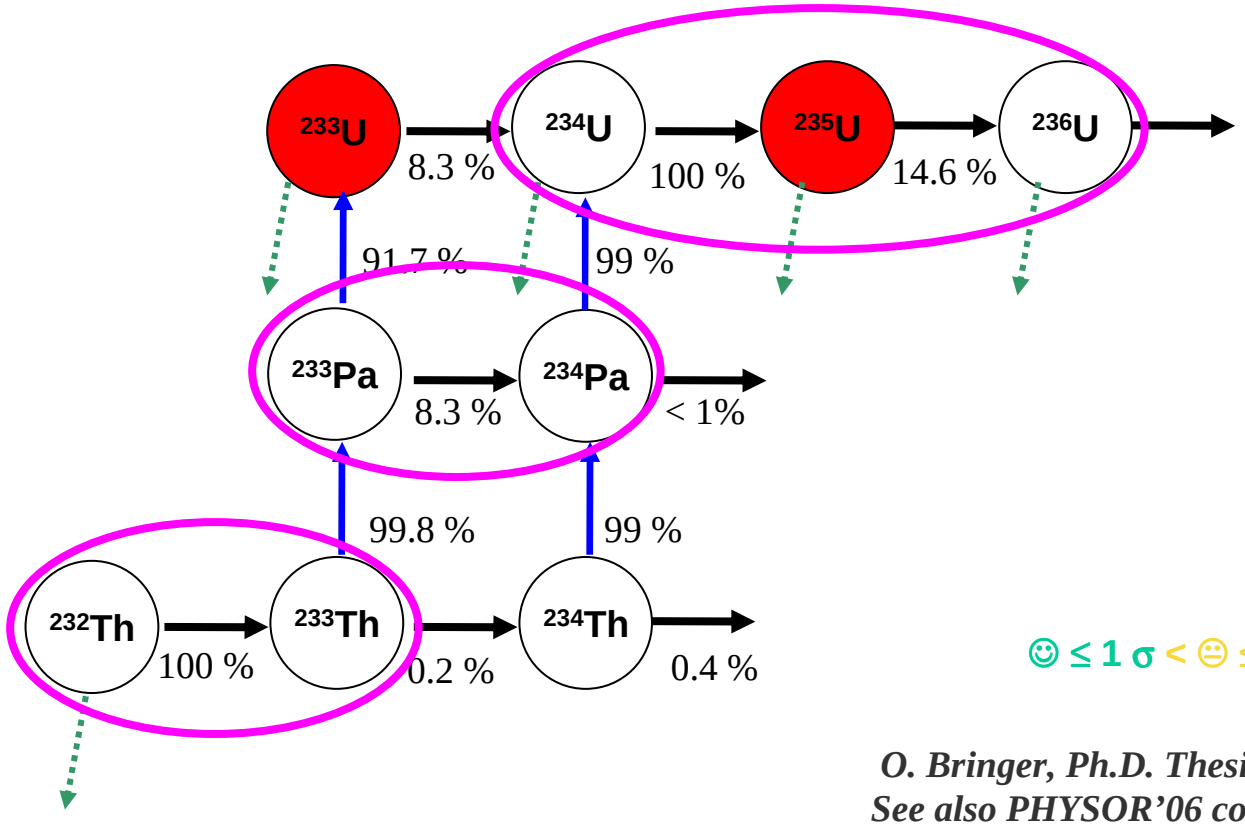

☺ ≤ 1 σ < 😐 ≤ 2 σ < ☹

O. Bringer, Ph.D. Thesis (2007)
See also PHYSOR'06 conference

Micro fission-chamber in V4

^{232}Th (n,γ) ^{233}Th	:	**7.4 ± 0.3 b**	JEFF-3.1 : 7.4 b ☺	JEFF-3.0/A : 7.4 b ☺
^{233}Pa (n,γ) ^{234}Pa	:	**40 ± 1 b**	JEFF-3.1 : 41 b ☺	JEFF-3.0/A : 41 b ☺
^{233}U (n,γ) ^{234}U	:	**39 ± 1.6 b**	JEFF-3.1 : 45 b ☹	JEFF-3.0/A : 46 b ☹
^{234}U (n,γ) ^{235}U	:	**104 ± 3.5 b**	JEFF-3.1 : 100 b 😐	JEFF-3.0/A : 103 b ☺
^{235}U (n,γ) ^{236}U	:	**98 ± 13 b**	JEFF-3.1 : 99 b ☺	JEFF-3.0/A : 99 b ☺

^{209}Bi activation (^{210}Po production)

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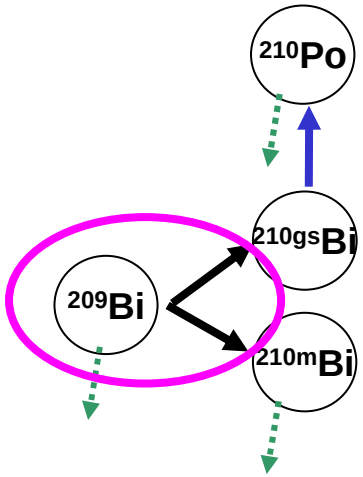

α decay
β decay
capture

☺ ≤ 1 σ < 😐 ≤ 2 σ < ☹

Spectroscopy station on H9

- ^{209}Bi (n, γ) ^{210gs}Bi : **17.9 ± 0.8 mb** — JEFF-3.1 : 28.5 mb ☹ — JEFF-3.0/A : 22.9 mb ☹
- ^{209}Bi (n, γ) ^{210m}Bi : **17.1 ± 2 mb** — JEFF-3.1 : 5.4 mb ☹ — JEFF-3.0/A : 11.0 mb ☹

A. Letourneau, et al., Ann. Nucl. Energy 33 (2006) 377

Conclusions and perspectives

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– Minor actinide transmutation study in thermal neutron flux (ILL)

- Development of specific detectors and fast electronics
- Accurate measurements of cross sections ($\Delta\sigma/\sigma$ ~ 3÷5 %)
- **New results have been published**

– Comparison with JEFF-3.1 library shows

- Minor actinide data are poorly known
- Discrepancies between JEFF-3.1/GP and JEFF-3.0/A
- **Some evaluations are not consistent with present measurements**

Differences larger than 2σ (☹) should be further investigated

Caution: consistent data (within 1σ (☺)) could differ by a few %

^{242m}Am(n,γ) : Δ~5%, ^{242m}Am(n,f) : Δ~2%, ^{243}Am(n,γ) : Δ~10%

Conclusions and perspectives

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This year (2006): Curium transmutation chain study

- *Capture cross sections*
  - ^{244}Cm (n,γ) in V4
  - ^{249}Cf (n,γ) in H9
- *Fission cross sections*
  - ^{245}Cm (n,f) in V4

Next years (≥ 2007)

- ^{243}Cm *capture & fission*
- ^{238}Pu *capture*
- *Major actinide capture* (Which ones? Which accuracy?)
- ^{248}Cm, ^{249}Bk *capture* (pure ^{248}Cm sample is needed !)

Main references

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- **"Incineration of ^{237}Np induced by thermal neutrons"**, A. Letourneau, *et al.*, to be submitted to *Phys. Rev. C* or *Nucl. Phys. A* (2006)
- **"Thermal neutron capture cross-section measurements of ^{243}Am and ^{242}Pu using the new mini-INCA α- and γ-spectroscopy station"**, F. Marie, *et al.*, *Nuclear Instruments and Methods in Physics Research A* ***556*** *(2006) 547-555*
- **"Actinide fission and capture cross section measurements at ILL: the Mini-INCA project"**, A. Letourneau, *et al.*, conference on *Nuclear fission and fission-product spectroscopy*, Cadarache, France, 11-14 May, 2005, p.11–18
- **"Measurement of the ^{210}Po production induced by thermal neutron capture on ^{209}Bi"**, A. Letourneau, *et al.*, *Annals of Nuclear Energy* ***33*** *(2006) 377-384*
- **"Thermal neutron capture branching ratio of ^{209}Bi using a gamma-ray technique"**, A. Letourneau, *et al.*, conference on *Capture Gamma-Ray Spectroscopy*, Prague, Czech Republic, 2-6 September, 2002, p.734–737
- **"Incineration of ^{241}Am induced by thermal neutrons"**, G. Fioni, *et al.*, *Nuclear Physics* ***A693*** *(2001) 546-564*