This project has received funding from the Euratom research and training programme 2014-2018 under grant agreement No 847552.

Deliverable D2.4: Report on the ^{239}Pu, ^{233}U, ^{14}N and ^{35,37}Cl inelastic cross section measurements at GELINA (M48)

Task 2.3: Neutron elastic and inelastic scattering and neutron multiplication cross sections

Responsible: IFIN-HH
Speaker: Adina Coman
Partners: CNRS/IPHC, JRC-Geel

This project has received funding from the Euratom research and training programme 2014-2018 under grant agreement No 847552.

Main results expected in the deliverable

- γ production cross sections following the (n,xnγ) reaction on: ^{239}Pu, ^{233}U, ^{14}N and ^{35,37}Cl

The experiments were planned at the GELINA neutron source of the EC-JRC, Geel, Belgium

GAINS:

Cross section measurements of structural materials: **^{14}N, ^{35,37}Cl.**

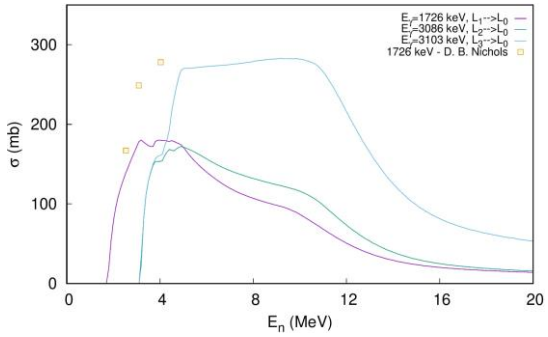
GRAPhEME:

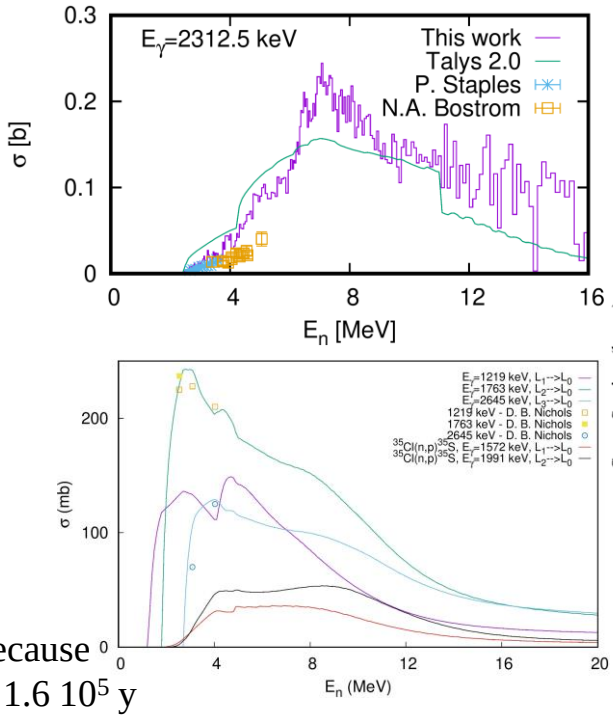
Cross section measurements of actinides: **^{233}U, ^{239}Pu**

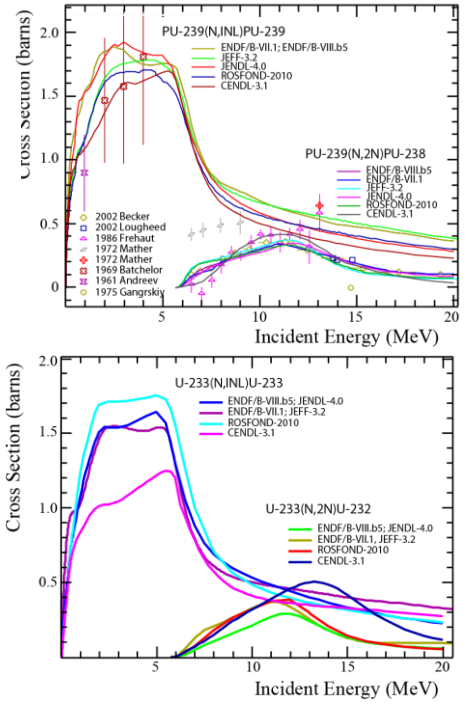
This project has received funding from the Euratom research and training programme 2014-2018 under grant agreement No 847552.

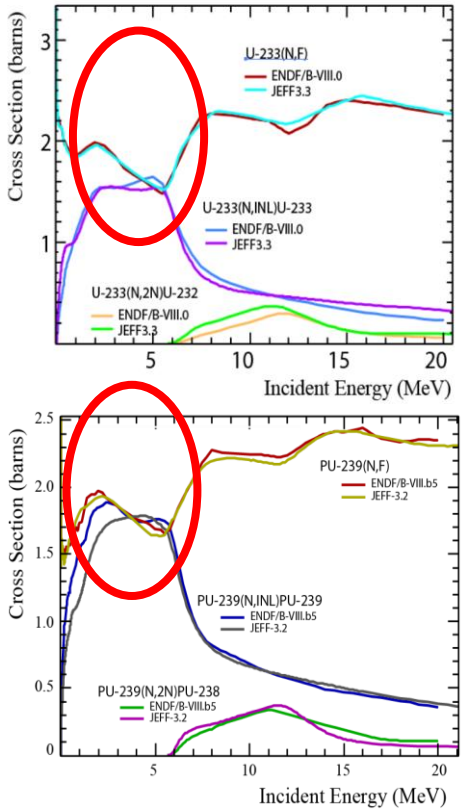
Context

- Study of the UN, U2N3 and UN2 fuels considered for the Gen IV reactors
- Design and study of the Fast Spectrum-Molted Salt Reactors based on chloride salts
- Study of breeding Th/U and U/Pu fuel cycles and k_{eff} coefficient
- ^{238}U(n, inl) is a HPRL entry
- Scarce data









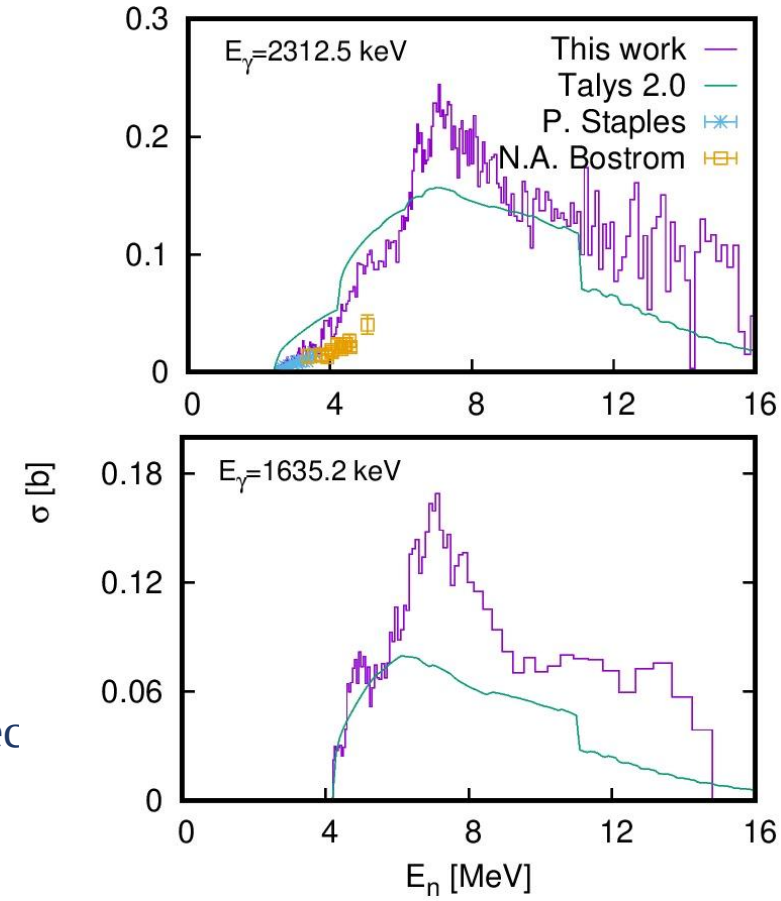
Actinides very difficult to measure because
- High rate of radioactivity ^{233}U $T_{1/2}$= 1.6 10^5 y
  ^{239}Pu $T_{1/2}$= 24110 y,
- Fission cross section is high.

This project has received funding from the Euratom research and training programme 2014-2018 under grant agreement No 847552.

^{14}N(n, inl) cross sections at GELINA (IFIN-HH, EC-JRC, CNRC/IPHC)

Measurements performed using the GAINS spectrometer

- delayed due to COVID pandemic + GELINA maintenance
- 12 HPGe detectors (110º, 150º and 125º) - ^{235}U fission chamber
- ACQIRIS and STRUCK digitizers in parallel
- 10x10 cm plate of Si_3N_4 (0.411 g/cm^2 of ^{14}N)
- the production cross sections of the first 2 transitions were produced



✅ Data taking and data analysis completed.
Final checks/corrections ongoing

✅ Comparison with theoretical calculation

SOON Article in preparation.

SOON The data will be submitted to EXFOR

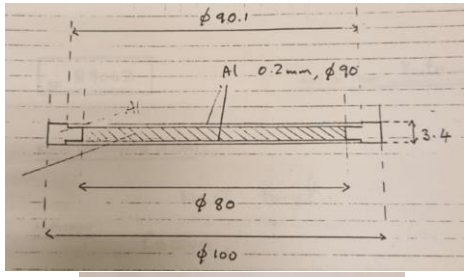
The first energy-extended measurement of the ^{14}N(n, n'γ) cross sec

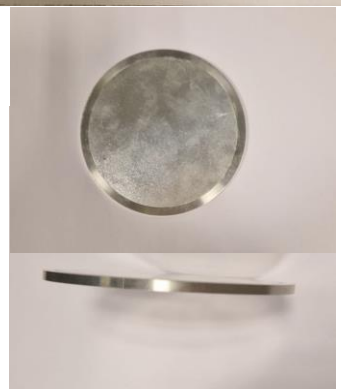
Publications/workshops/Conferences :
A. Olacel, et al., PRC 106, 024609 (2022)
A. Olacel, et al., EPJ Web of Conferences 284, 01007 (2023)
M. Boromiza, et al., EPJ Web of Conferences 284, 01010 (2023)
ND2022, WINS2023

Experimental results included in the report

This project has received funding from the Euratom research and training programme 2014-2018 under grant agreement No 847552.

^{35,37}Cl(n, inl) cross sections at GELINA (IFIN-HH, EC-JRC, CNRC/IPHC)





Measurement planned 2023-2024

- GAINS - 12 HPGe detectors (110º, 150º and 125º)
- ^{235}U fission chamber
- ACQIRIS and STRUCK digitizers in parallel
- 8 cm diam. disk of NaCl encapsulate in 0.02 cm Al (0.247 g/cm^2 of ^{35}Cl and 0.079 g/cm^2 of ^{37}Cl)
- expected the production cross sections of the first transitions in ^{35}Cl and ^{37}Cl
- needed ≅ 1500 h of beam time (≅3 months)

GELINA is stopped since September 2023.

When GELINA starts, NaCl - high priority
Data taking will be extended in 2025

When available, the data will be analyzed and the results will be submitted in EXFOR and discussed in an open-access publication.
The SANDA project will be properly acknowledged.
No other funds will be used for this work.

The first energy-extended measurement of the ^{35,37}Cl(n, n'γ) cross sections

No experimental results included in the report

This project has received funding from the Euratom research and training programme 2014-2018 under grant agreement No 847552.

^{233}U(n, inel) cross sections at GELINA (CNRS/IPHC, JRC-Geel, IFIN-HH)

✅ Measurement performed with the GRAPhEME setup

- 5 planar HPGe + 1 segmented – 6 x 6 pixels
- ^{235}U fission chamber
- ^{233}U sample (8.3 g of metallic ^{233}U, thickness of 0.64 mm, A= 3 GBq)
- TNT digitizers
- ≅ 4500 h of beam time collected.

✅ New data analysis procedure : semi Monte Carlo

Publications/workshops/Conferences :
F. Claeys, EPJ Web of Conferences **284**, 01014 (2023)
ND2022

¤ Dedicated tool developed in Python3 : N random draw from Gaussian distribution of every parameters x of $\sigma(E_n)$

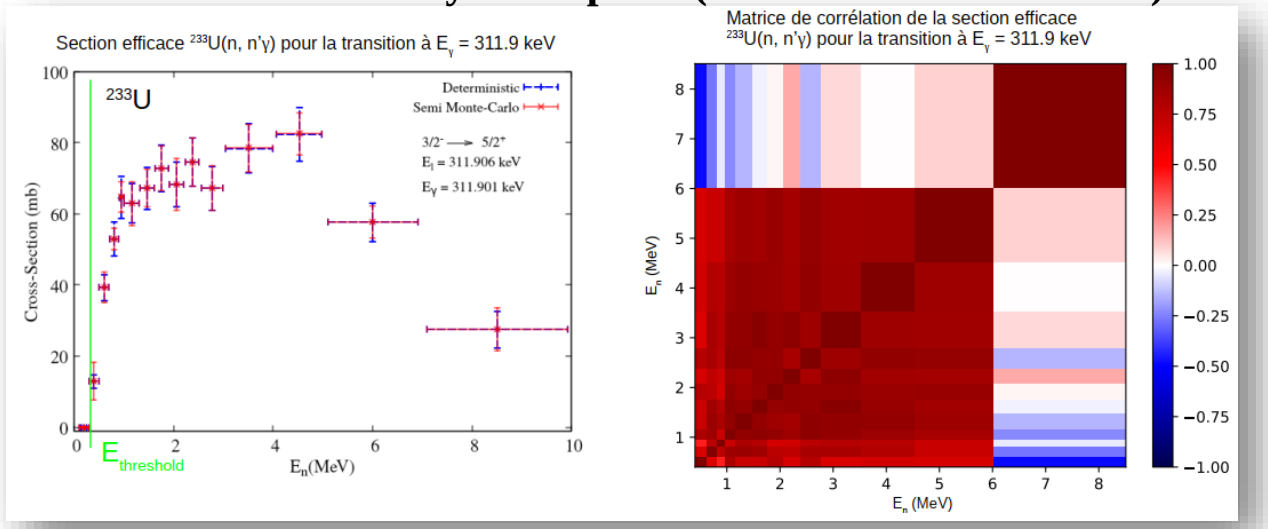
- $x = \{n_\gamma^{DET}(E_n);\ N_{233U};\ N_n(E_n);\ \tau_{pile-up}^{DET};\ \varepsilon^{FC};\ \varepsilon^{DET};\ \alpha_{air}\}$
- central value of the distribution = $\sigma(E_n)$
- Standard deviation of the distribution = $\Delta\sigma(E_n)$

¤ Validation of the method :
Comparison with deterministic analysis

$$\frac{\langle \sigma_{MC} - \sigma_{det.} \rangle}{\sigma_{det.}} = 0.14\%$$

$$\frac{\langle \Delta\sigma_{MC} - \Delta\sigma_{det.} \rangle}{\sigma_{det.}} = [0.11 - 26.96]\%$$

Full uncertainty description (correlation + covariance)

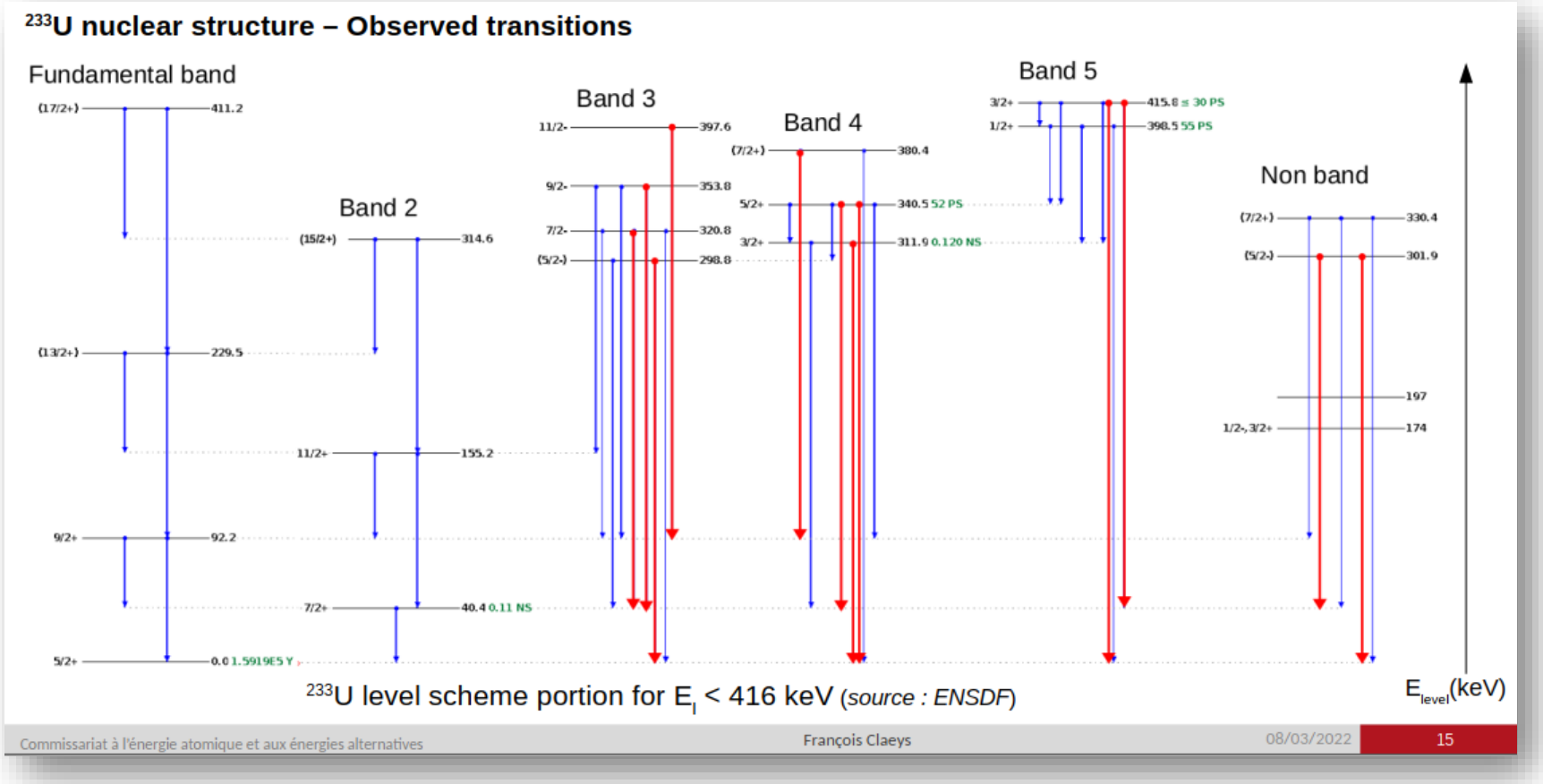


This project has received funding from the Euratom research and training programme 2014-2018 under grant agreement No 847552.

^{233}U(n, inel) cross sections at GELINA (CNRS/IPHC, JRC-Geel, IFIN-HH)

Results

- 12 γ transitions have been observed (ever measured)

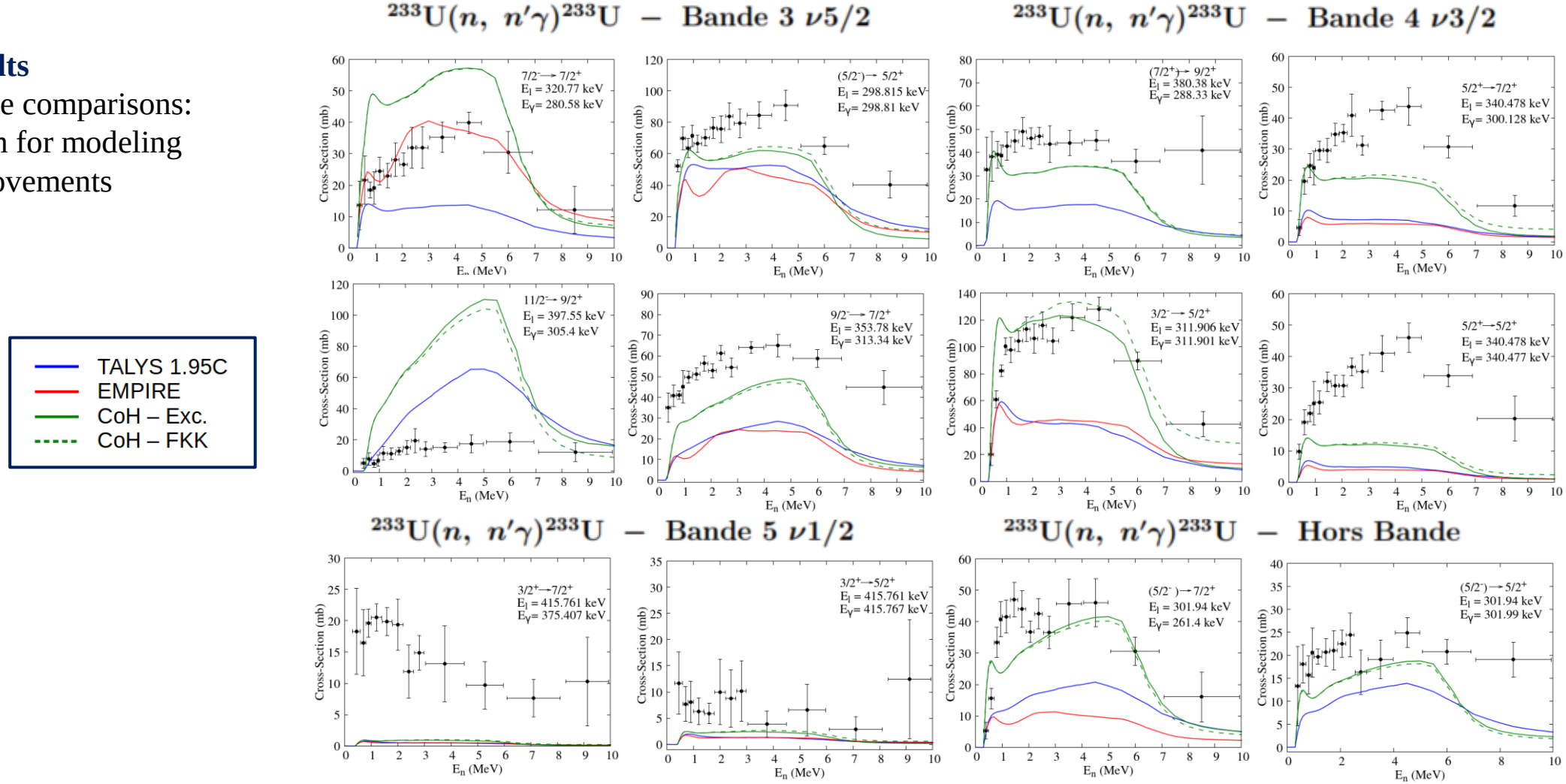


This project has received funding from the Euratom research and training programme 2014-2018 under grant agreement No 847552.

^{233}U(n, inel) cross sections at GELINA (CNRS/IPHC, JRC-Geel, IFIN-HH)

Results

- code comparisons: Room for modeling improvements



Experimental results included in the report

This project has received funding from the Euratom research and training programme 2014-2018 under grant agreement No 847552.

^{239}Pu(n, inel) cross sections at GELINA (CNRS/IPHC, JRC-Geel, IFIN-HH)

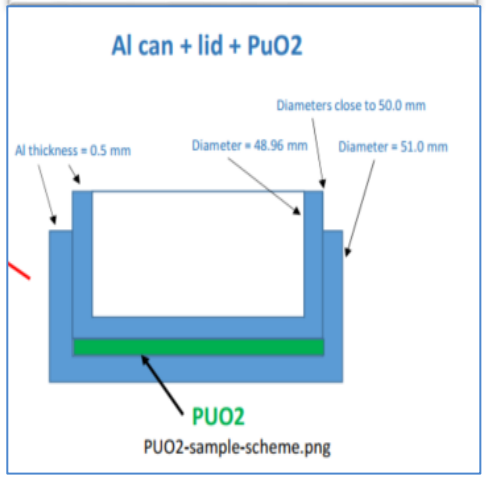
The challenge of the sample making (WP3 SANDA)

¤ The **first challenge** was to obtain a **Pu sample as free as possible from ^{241}Am**.
Work done by SCK-CEN (Mol Belgium) from PuO_2 powder provided by EC-JRC-Geel.
Separation and purification of Am and Pu by peroxide precipitation
In γ spectrum of the sample, one sees
- mainly γ-lines from the decay of ^{239}Pu -> ^{235}U
- main lines from the decay of ^{241}Am -> ^{237}Np

¤ **^{239}Pu sample - 2.3 g of PuO2 compressed powder, activity of 5.2 GBq,**

¤ **determination of accurate mass of ^{239}Pu :** γ counting
(as done for ^{233}U)

☣delay for the making of the sample (COVID crisis)
– received spring 2022



m = 2,3 g
Ø= 49,95 mm, A = 5,2 GBq

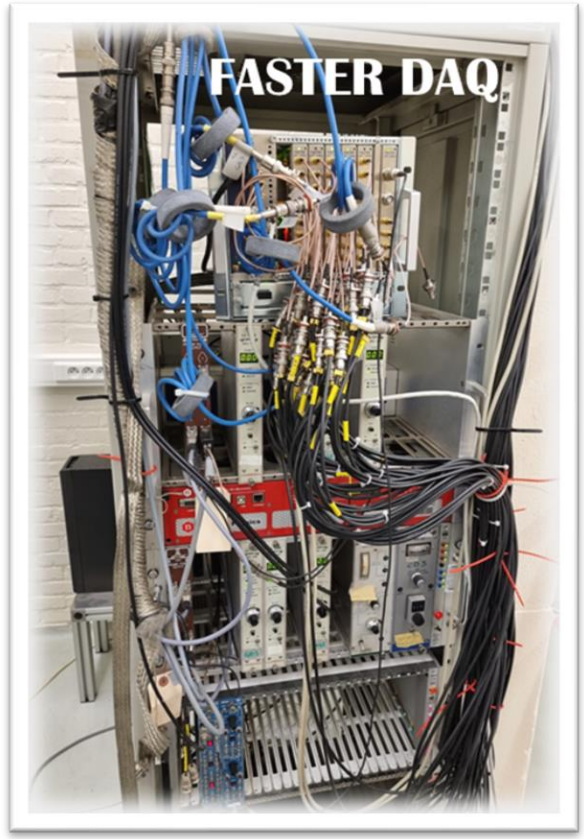
A. Moens et al. EPJ Web of Conf. ***285****, 04002 (2023)*

This project has received funding from the Euratom research and training programme 2014-2018 under grant agreement No 847552.

^{239}Pu(n, inel) cross sections at GELINA (CNRS/IPHC, JRC-Geel, IFIN-HH)

Measurement in progress with the GRAPhEME setup,
- 6 planar HPGe + 1 segmented – 6 x 6 pixels
- ^{235}U fission chamber
- FASTER digitizers

▶beam start in June 2022 (low beam intensity) for setting up



Reduction of GELINA operation time (electricity costs…) in 2023
GELINA is stopped since September 2023.

Only ~1300 h of beam time (with different DAQ setting) collected up to now.

Experiment is pending, we are waiting for the restart of GELINA
- planned to start on September 2024 (after the end of the project)

The results will be submitted to EXFOR and discussed in an open-access publication with proper acknowledgement to SANDA.

✍ **no data will be available for the report**

This project has received funding from the Euratom research and training programme 2014-2018 under grant agreement No 847552.

^{238}U(n, inel) cross sections at GELINA (CNRS/IPHC, JRC-Geel, IFIN-HH)

Not in the Deliverable but in the TASK

¤ Part of Deliverable D.2.5

¤ Measurement performed with the GRAPhEME setup, 4 planar HPGe, 1 ^{235}U FC, ^{nat}U sample, TNT DAQ.

3000 h of beam time collected, up to 2139 h for useable data.

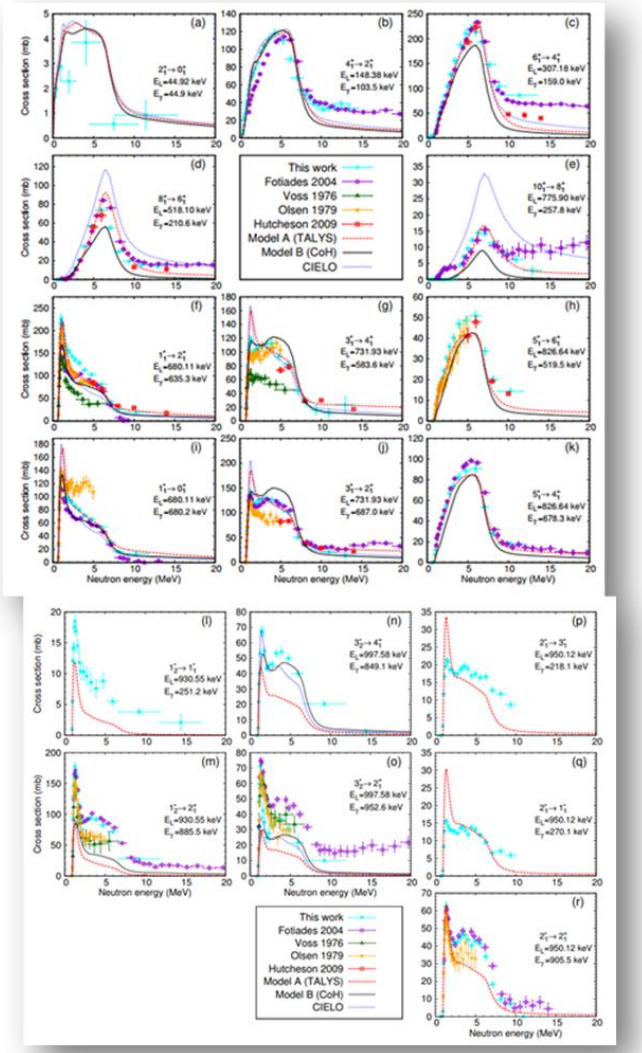
¤ The data taking, the analysis and the comparison with theoretical predictions have been done. Progress in the pre equilibrium modeling has been achieved.

¤ An article on this work has been published

¤ M. Kerveno, M. Dupuis et al., Phys. Rev. C 104, 044605, 2021.

¤ 18 ^{238}U(n,n'γ) cross sections have been transmitted to EXFOR

- entry number 22795



This project has received funding from the Euratom research and training programme 2014-2018 under grant agreement No 847552.

^{209}Bi and ^{206}Pb branching ratio measurements (JRC-Geel)

Not in the Deliverable but in the TASK

See the talk of P. Romojaro on D2.5

HORIZON 2020

HORIZON 2020 RESEARCH AND INNOVATION FRAMEWORK PROGRAMME OF THE EUROPEAN ATOMIC ENERGY COMMUNITY

Nuclear Fission and Radiation Protection 2018 (NFRP-2018-4)

Project acronym:	**SANDA**
Project full title:	**Solving Challenges in Nuclear Data for the Safety of European Nuclear facilities**
Grant Agreement no.:	**H2020 Grant Agreement number: 847552**
Workpackage N°:	***WP2***
Identification N°:	***D2.5***
Type of document:	***Deliverable***
Title:	Report on the measurements of the branching ratio for ^{209}Bi, ^{208}Pb(n,tot) and ^{238}U(n,inel) cross sections at GELINA

This project has received funding from the Euratom research and training programme 2014-2018 under grant agreement No 847552.

Summary of Deliverable 2.4

^{14}N

✅ Article and EXFOR files in preparation.

^{35,37}Cl

⛔ impossible to have data before the end of the project

^{233}U

✅ Thesis defended 03/2023 (François Claeys), article and EXFOR files in preparation

¤ **F. Claeys et al. EPJ Web of Conferences 284, 01014 (2023) [ND2022]**

👉 12 ^{233}U(n,n'γ) cross sections, ever measured, will be transmitted to EXFOR –

^{239}Pu

⛔ impossible to obtain the request statistic before the end of the SANDA project.

⚠ ^{239}Pu and ^{35,37}Cl will be completed when GELINA restarts

Results will be published and included in EXFOR properly acknowledging SANDA

Publications/workshops/Conferences :
M. Kerveno, et al. EPJ Web of Conferences 284, 01005 (2023)
M. Kerveno, M. Dupuis, et al. Physical Review C 104, 044605 (2021)
M. Kerveno, M. Dupuis, et al. Eur. Phys. J Web of Conferences 239, 01023 (2020).
F. Claeys, et al. EPJ Web of Conferences 284, 01014 (2023)
A. Olacel, et al., PRC 106, 024609 (2022)
A. Olacel, et al., EPJ Web of Conferences 284, 01007 (2023)
M. Boromiza, et al., EPJ Web of Conferences 284, 01010 (2023)
- ND2019, ND2022, WINS2023, JEFF NDW (11/2020), SANDA meeting (03/2022)