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Fission Yield Activities @ CEA-Cadarache

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Content

Fission Yield Measurements on Lohengrin @ Institut Laue Langevin (Grenoble)

- *Experimental Procedure*
- *Experimental covariance matrix*

Covariance Matrix Generation for JEFF/Fission Yield

- *Semi-empirical model used*
- *Some preliminary results on 235U(n,f) and 239Pu(n,f)*

Fission Yield calculation using FIFRELIN Monte Carlo code

- *Brief description of the code*
- *Example on 239Pu(n,f)*

Fission Yield Measurements at Institut Laue Langevin (Grenoble)

Objectives:

O. Serot et al., Nucl. Data Sheets,119 (2014) 320-323

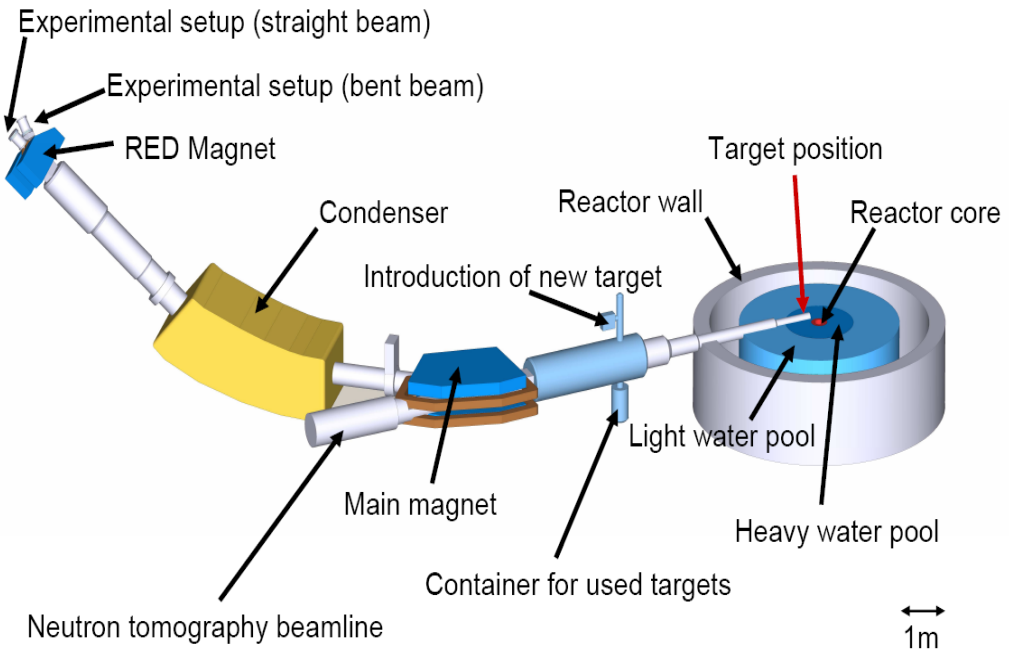
For reactor applications

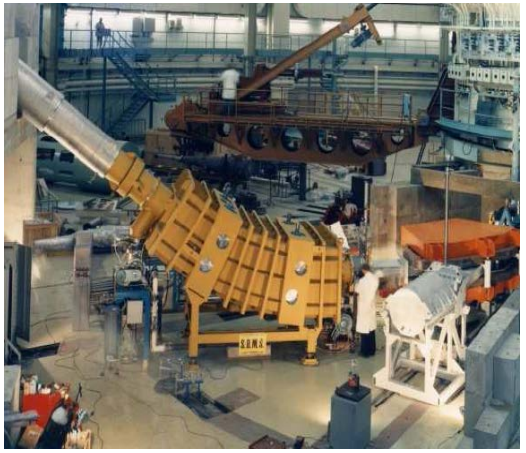
- Experimental campaign mainly in the heavy mass region
- Try to reduce uncertainties compared to JEFF
- Recently: to give the experimental covariance matrix, useful for the future evaluation (JEFF-3.2)

For more fundamental physics:

- Investigate the isomeric ratio as a function of the Kinetic Energy of the FF (thesis A. Cheboubbi)
- Investigate the ns-isomeric state (thesis A. Cheboubbi)
- Investigate the odd-even effects as a function of the Kinetic Energy of the FF (new thesis, will start in Oct, 2015)

The fission fragment separator 'Lohengrin' @ the high-flux reactor of the Institute Laue Langevin in Grenoble (France)



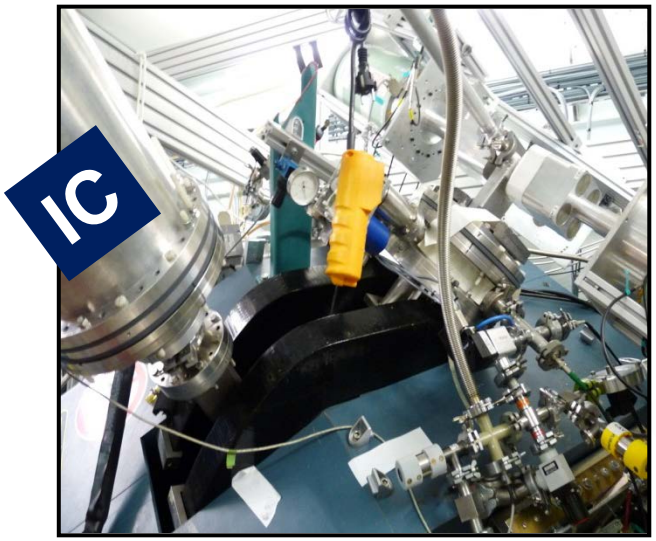


Target placed close to the core of the reactor: thermal neutron flux of about **5.3×10^{14} n/cm^2/s**

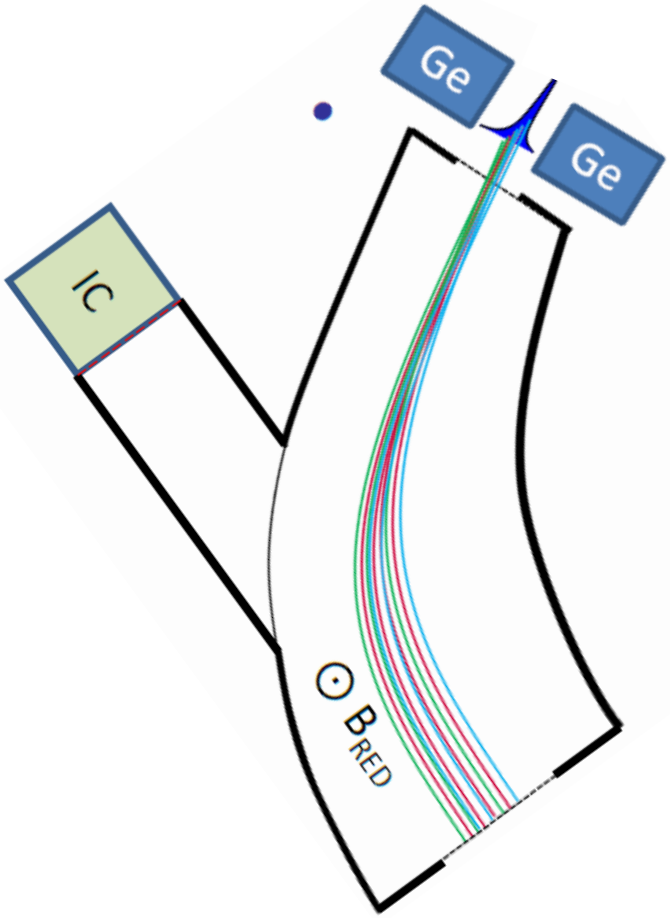
Combination of a magnetic and electric fields allows a selection of the FP according to their **A/q** and **E/q** ratios

A: mass of the FP
E: Kinetic energy of the FP
q: ionic charge of the FP

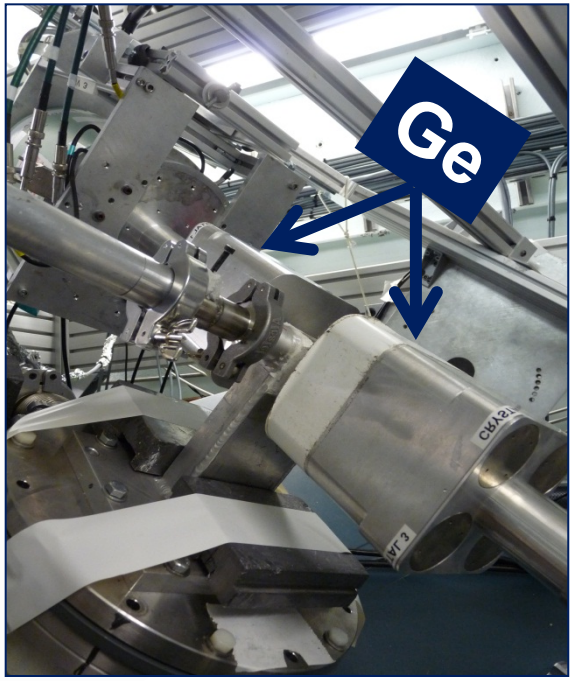
Fission Yield Measurements at Institut Laue Langevin / Experimental Setup



Ionisation Chamber (IC) used for the mass Yield measurement: Y(A)



(From G. Kessedjian)

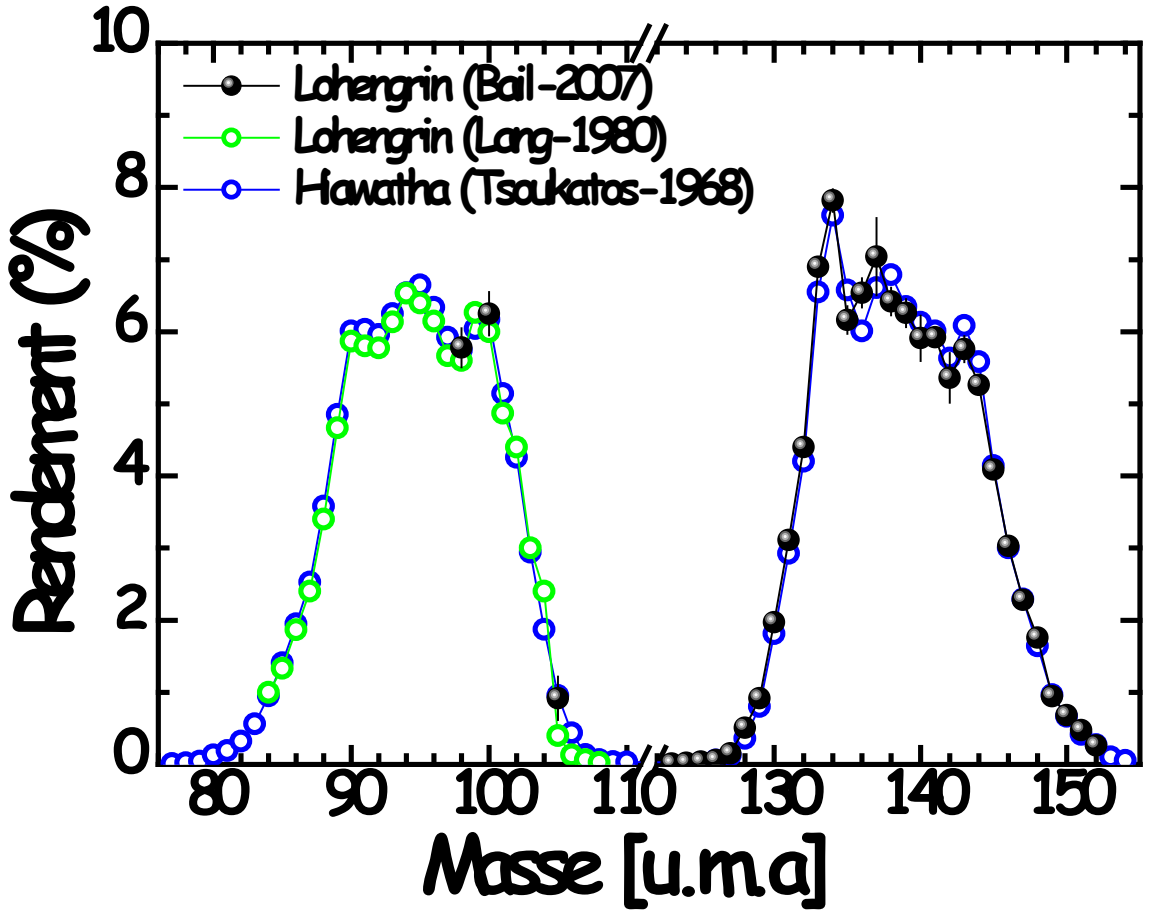


Spectrometry gamma (clover Ge) used for the Isotopic Yield measurement: Y(A,Z)

Fission Yield Measurements at Institut Laue Langevin / Mass Yield Results

$^{235}U(n_{th},f)$

PhD thesis, A. Bail (2009):

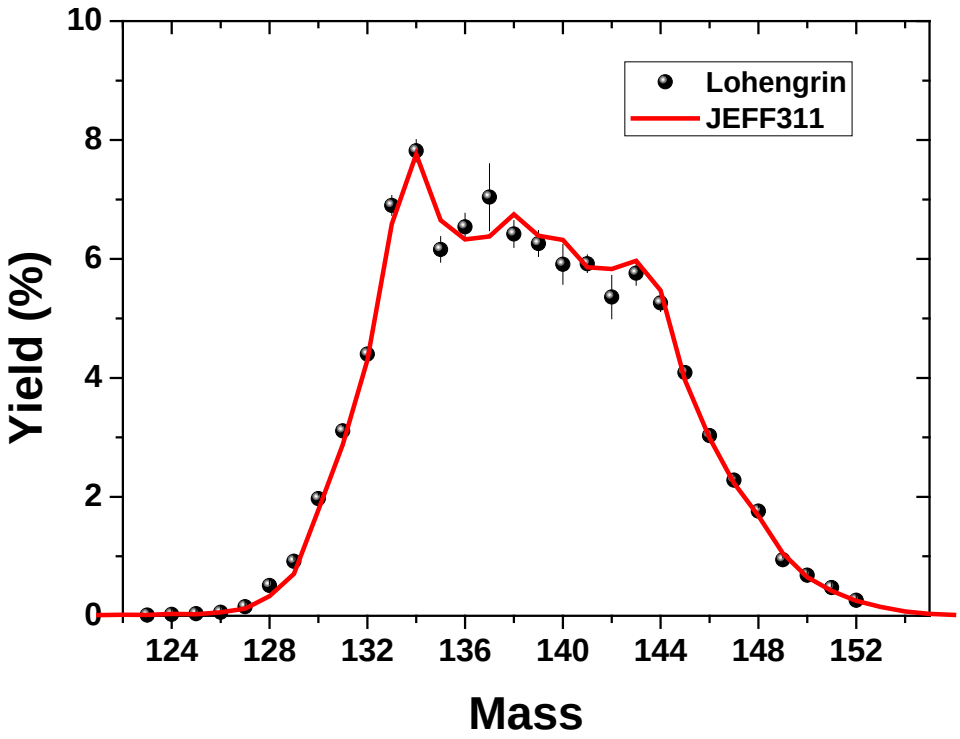


Comparison with experimental data:

- Lang= Lohengrin in the Light region
- Bail = Lohengrin in the heavy region

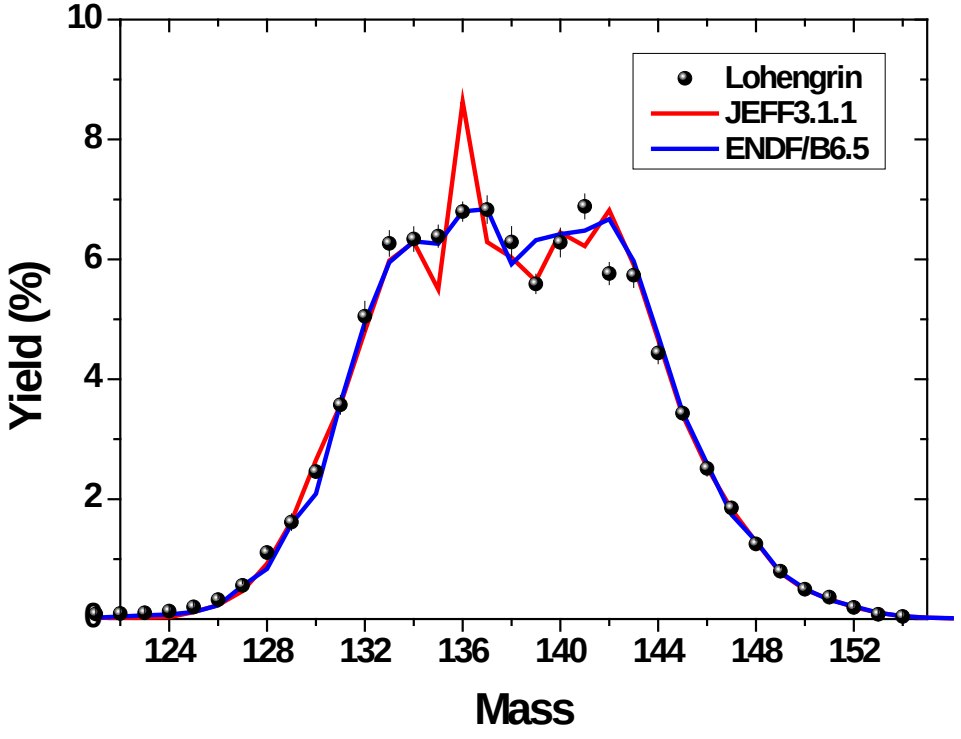
Fission Yield Measurements at Institut Laue Langevin / Mass Yield Results

$^{235}U(n_{th},f)$



Adeline BAIL, PhD thesis (Oct. 2009)

$^{233}U(n_{th},f)$

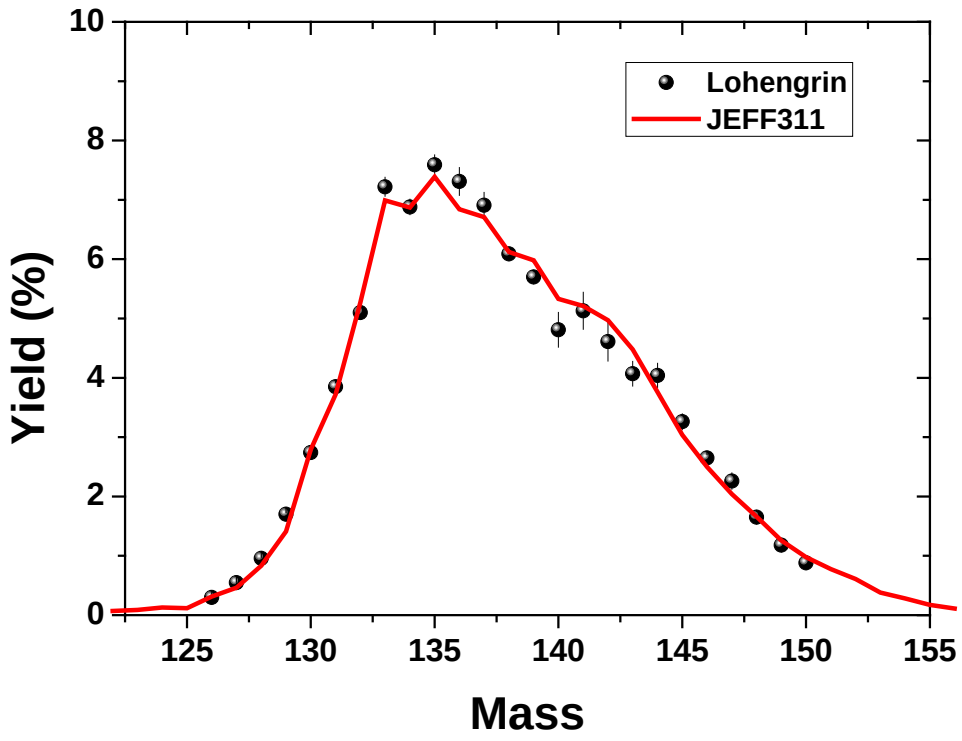


Florence MARTIN, PhD thesis, (Dec. 2013)

F. Martin et al., *IEEE Conf. Proc.* of ANIMMA, Ghent, Belgium, 2011.

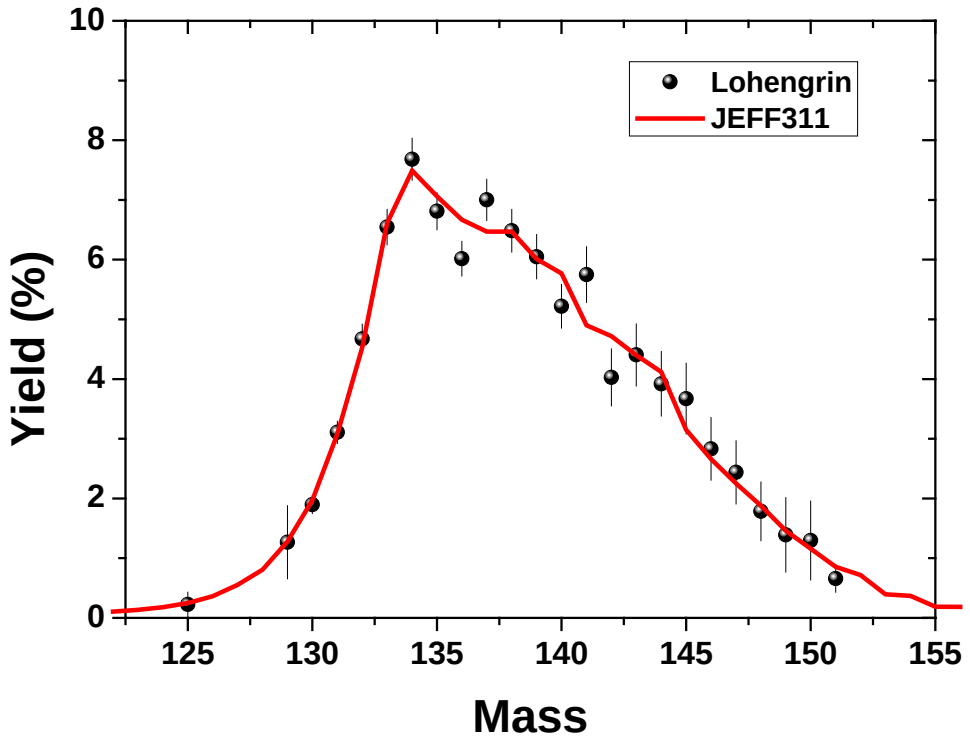
Fission Yield Measurements at Institut Laue Langevin / Mass Yield Results

$^{239}Pu(n_{th},f)$



Adeline BAIL, PhD thesis (Oct. 2009)

$^{241}Pu(n_{th},f)$



Florence MARTIN, PhD thesis, (Dec. 2013)

Fission Yield Measurements at Institut Laue Langevin / Mass Yield Results

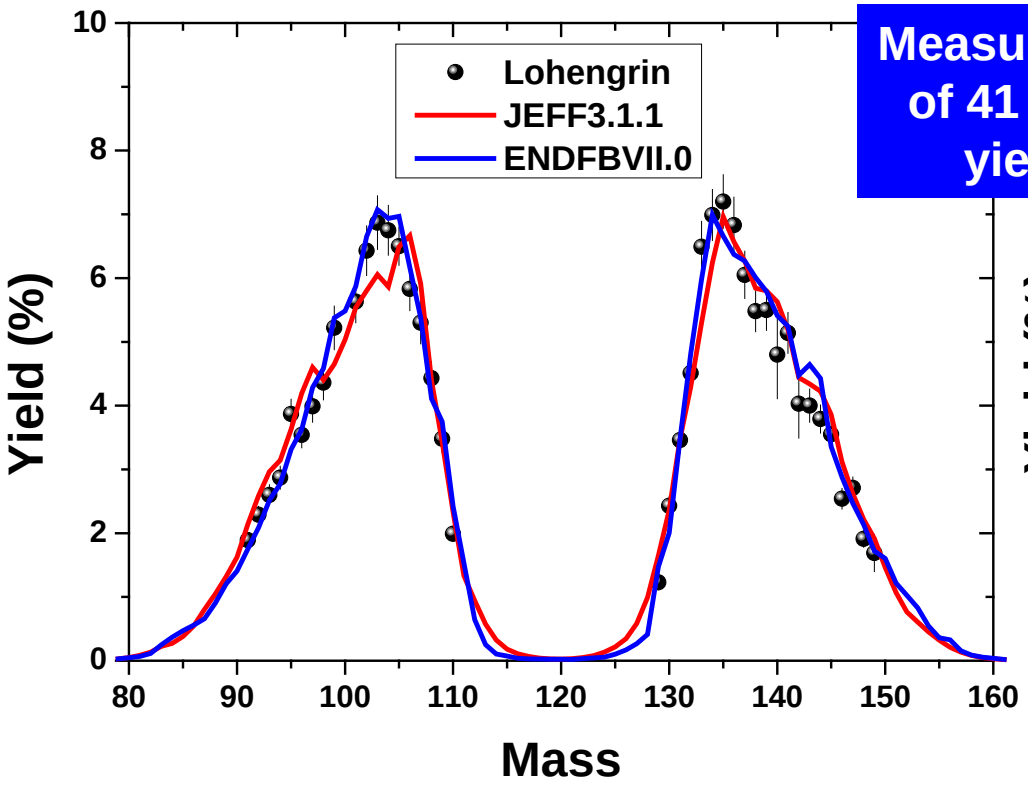
$^{241}Am(2n_{th},f)$

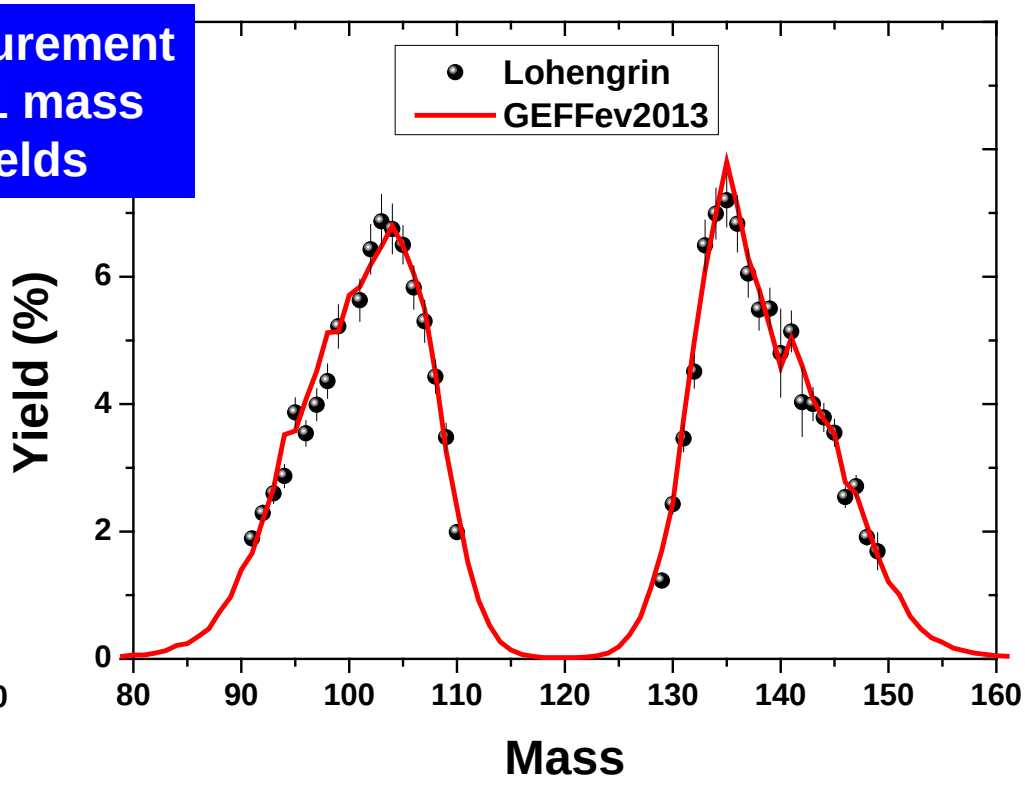
PhD thesis, Ch. Amouroux (oct. 2014): $^{241}Am(2n_{th},f)$

Ch. Amouroux, WONDER-2012, EPJ Web of Conferences, Vol. 42 (2013)

Ch. Amouroux, Fission- 2013, Caen (France) May 2013

Measurement of 41 mass yields





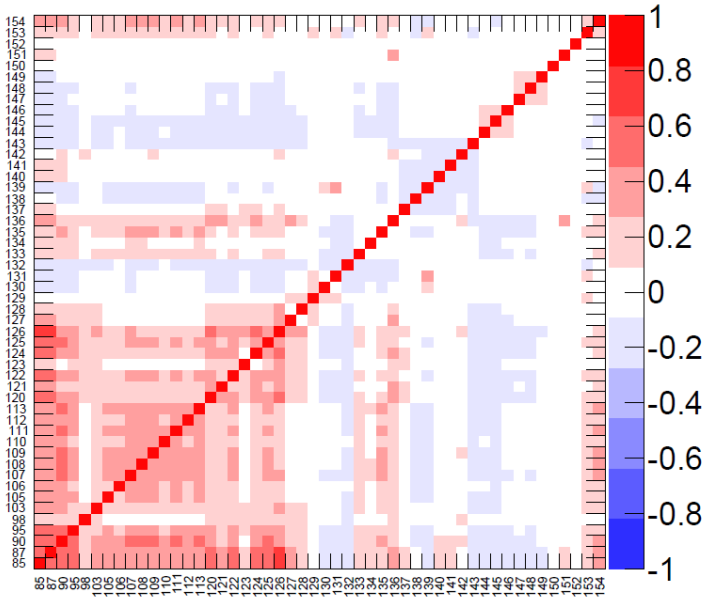
- Good agreement with ENDF/B.7 and JEFF-3.1.1 in the heavy mass region
- Better agreement with ENDF/B.7 in the light mass region

Fission Yield Measurements at Institut Laue Langevin / Mass Yield Results

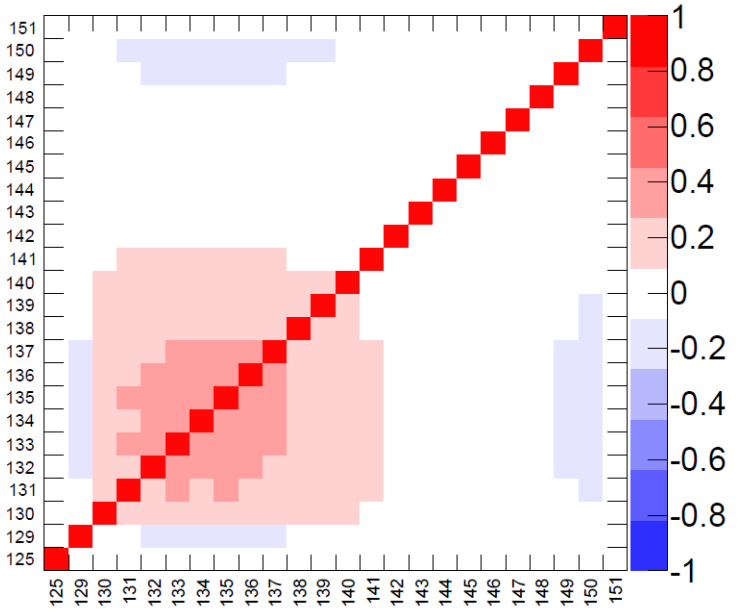
Experimental Variance – Covariance Matrix determined during the analysis procedure

- Correction of the Burn-up
- Use of several samples
- Normalization…

Example 233U



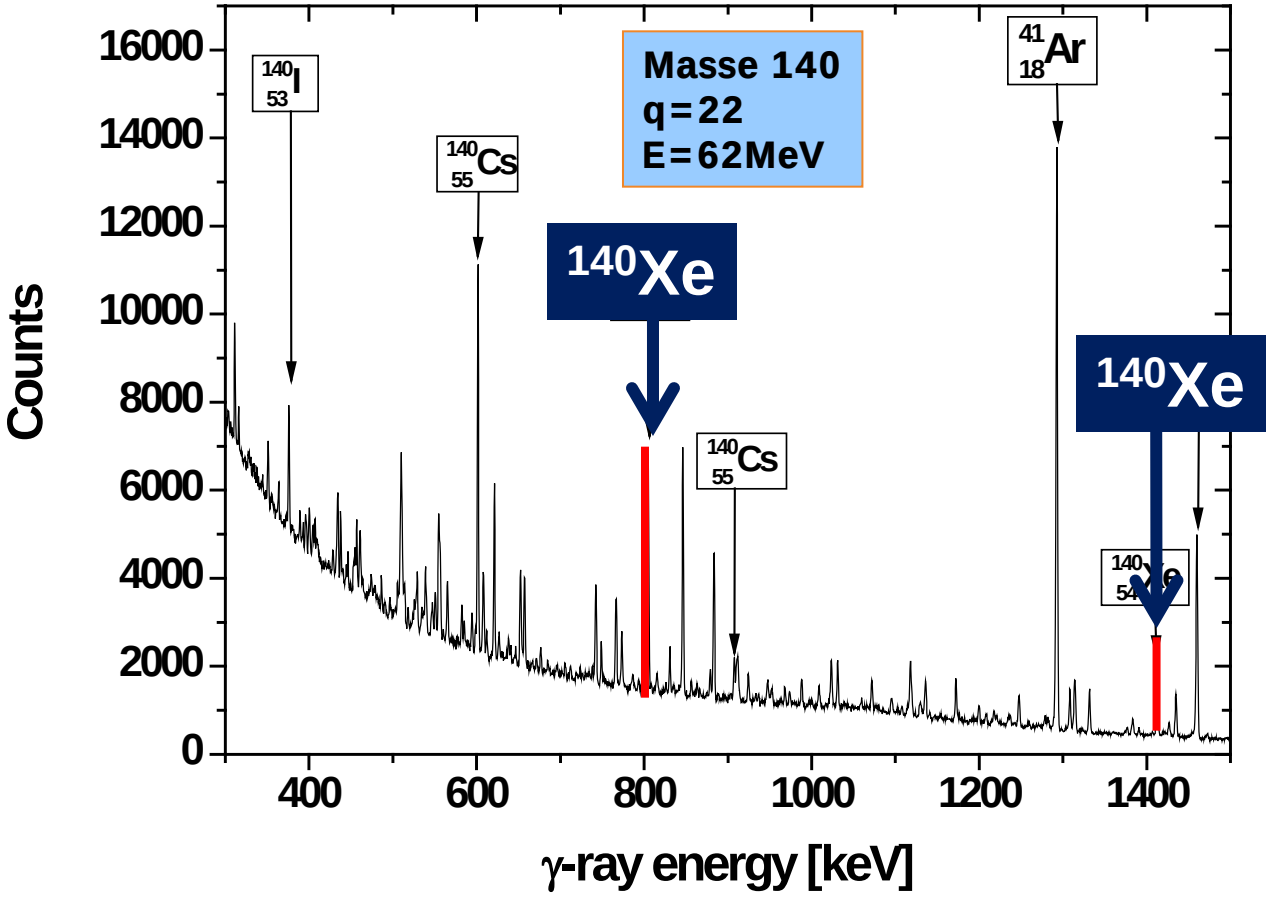
Example 241Pu



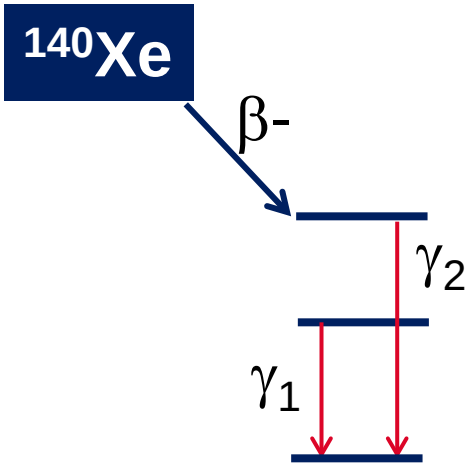
PhD thesis, F. Martin (dec. 2013): $^{233}U(n_{th},f)$

F. Martin et al., *IEEE Conf. Proc.* of ANIMMA, Ghent, Belgium, 2011.

Selection of a γ-ray which is emitted after the β- decay of a fission product : $N_{\gamma 1}(q, E, A, Z)$



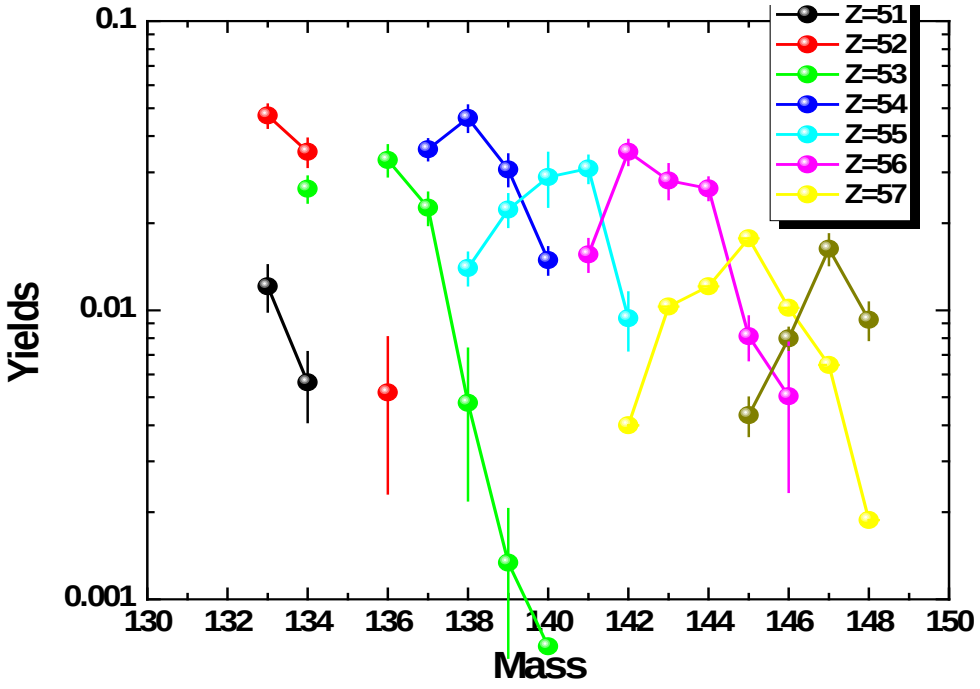
isotopic identification by gamma spectrometry



Fission Yield Measurements at Institut Laue Langevin / Isotopic Yield Results

$^{239}Pu(n_{th},f)$

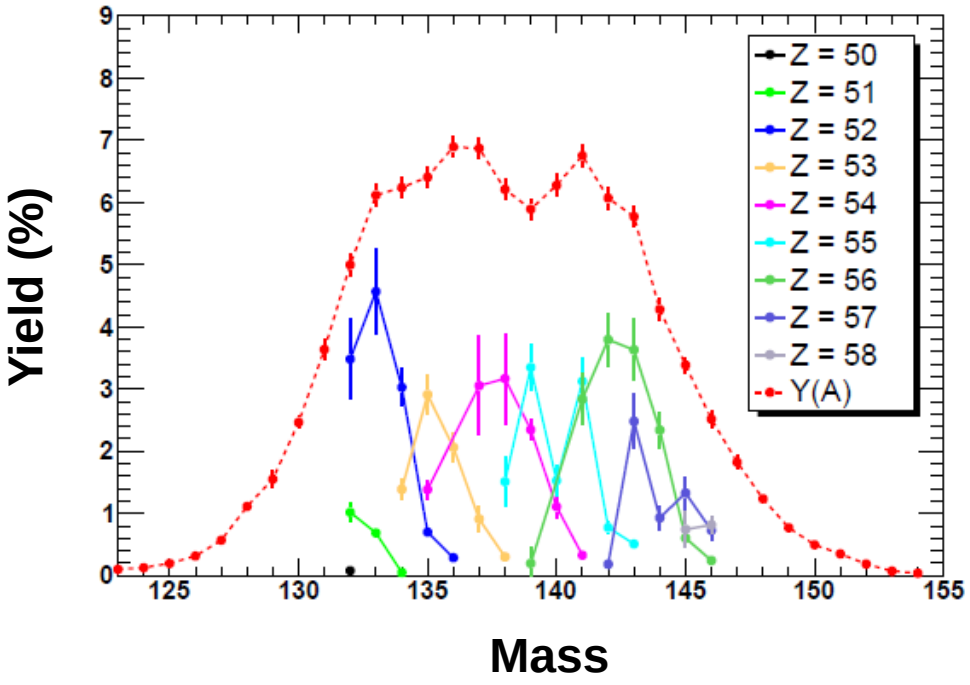
A Bail et al., PRC 84, 034605 (2011)



- 65 FP were measured (Light + Heavy)
- Reduction of the uncertainties compared to JEFF.3.1.1
- Rather good agreement with JEFF3.1.1

$^{233}U(n_{th},f)$

F. Martin et al., Nucl. Data. Sheets, 119, (2014) 328-330



- 52 FP were measured (Light + Heavy)

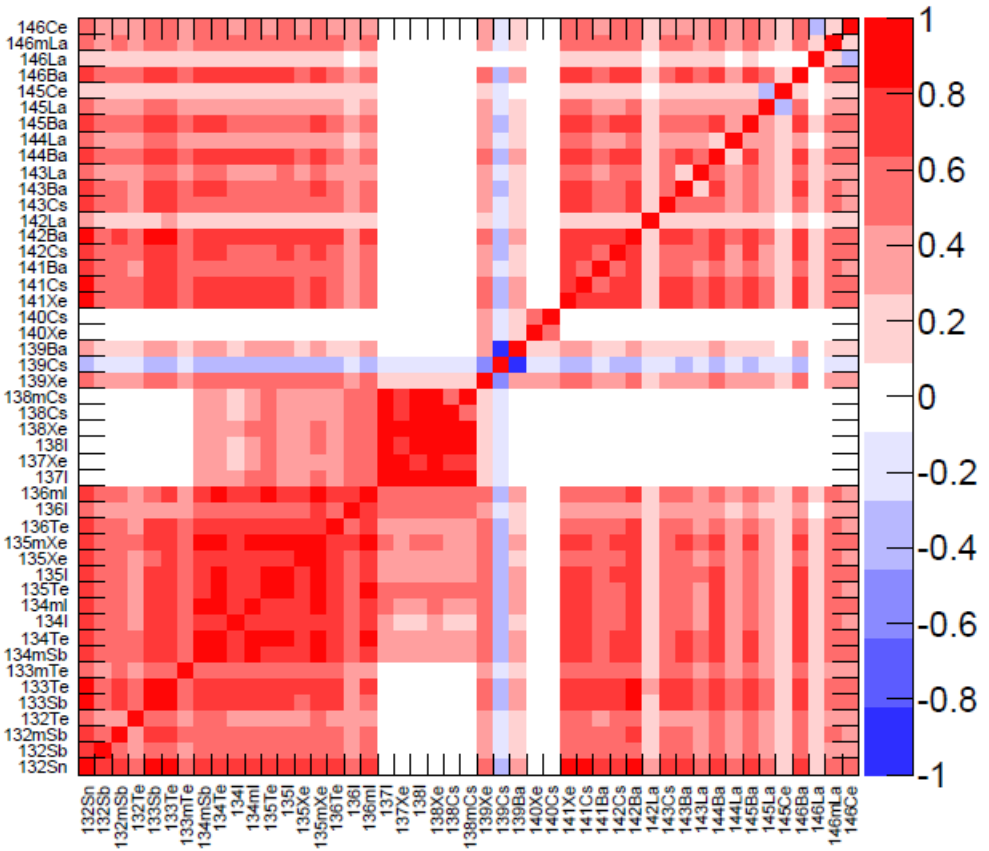
Fission Yield Measurements at Institut Laue Langevin / Isotopic Yield Results

$^{233}U(n_{th},f)$

F. Martin et al., Nucl. Data. Sheets, 119, (2014) 328-330

Experimental variance-covariance matrix determined for the first time

- Correction of the Burn-up
- Use of several samples
- Normalization,
- Efficiency of the γ–detection
- Correction for the production and disappearance of nuclei by solving Bateman's equations



(F. Martin, thesis, dec. 2013)

Covariance Matrix Generation for JEFF/Fission Yield

- *Semi-empirical model used*
- *Some preliminary results on 235U(n,f) and 239Pu(n,f)*

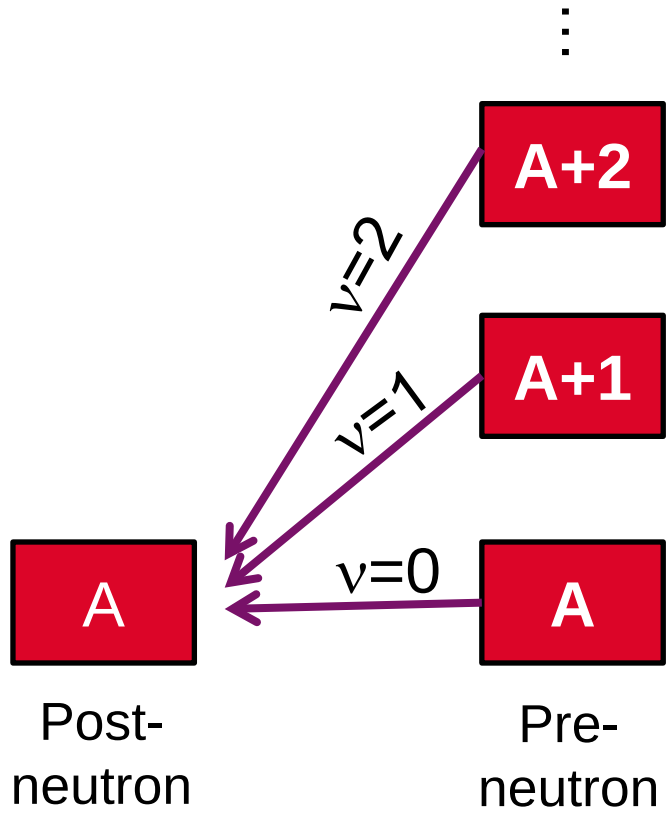
PhD work of Nicholas TERRANOVA

Our aim: Evaluation of the variance-covariance matrix for the JEFF-3.1.1 Fission Yield

The model used for mass yield:

$$Y_{post}(A) = \sum_{\nu=0}^{\infty} Y_{pre}(A+\nu) \times P_{A+\nu}(\nu)$$

- $Y_{post}(A)$: Yield of mass A after prompt neutron emission
- $Y_{pre}(A+\nu)$: Yield of mass A +ν before prompt neutron emission
- $P_{A+\nu}(\nu)$: Probability of a primary fission fragment of mass A +ν to emit ν prompt neutron



Covariance Matrix Generation for JEFF/Fission Yield

Example on $^{235}U(n_{th},f)$

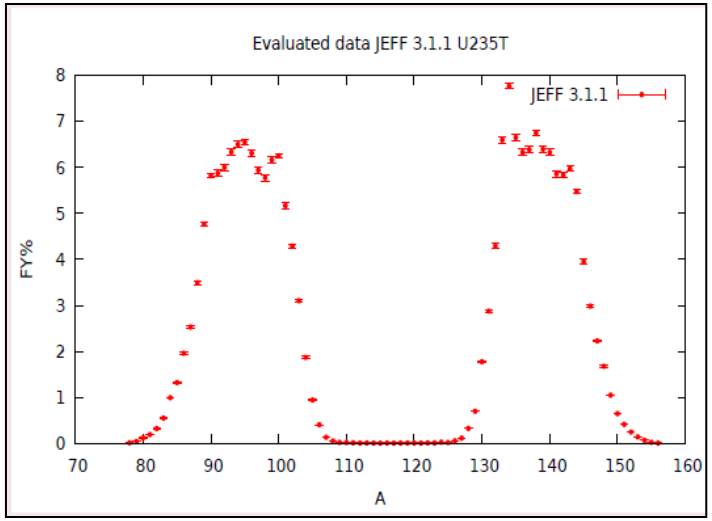
$$Y_{post}(A) = \sum_{\nu=0}^{\infty} Y_{pre}(A+\nu) \times P_{A+\nu}(\nu)$$

Ypre: from fission modes (measurements performed by Zeynalov et al., Proc. ISINN13 (2005))

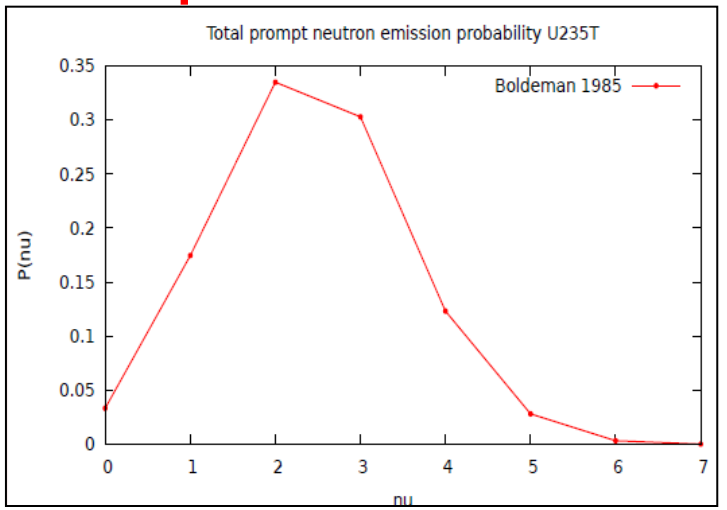
$P_{A+\nu}(\nu)$: Gaussian distribution

- Average value taken from the saw-tooth (Vorobyev (2010)
- Width assumed constant for each mass: 0.5

Adjsustement of the free parameters: Generalized Least Squared Method (Bayesian Approach)



Ypost from JEFF-3.1



Total prompt n-distribution

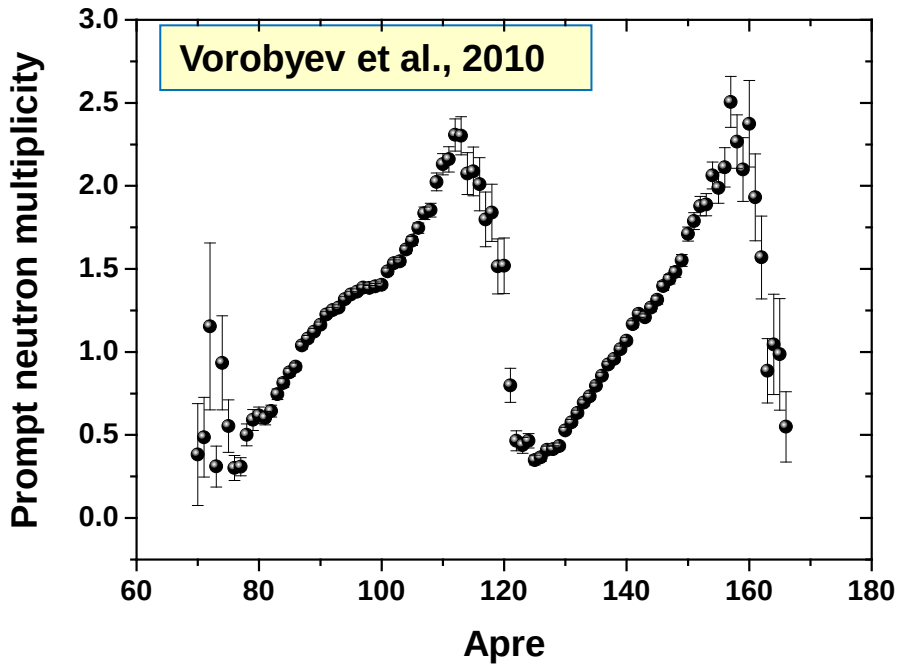
Initial parameters for $^{235}U(n_{th},f)$

- Fission modes for the pre-neutron yield: Ypre

	<A_heavy>	Width_ Heavy	Weight %
St. I	133.8 ± 0.2	2.60 ± 0.05	16.2 ± 0.5
St. II	141.1 ± 0.2	4.95 ± 0.05	83.7 ± 0.5
SL	118	5.05 ± 0.05	0.12 ± 0.01

Zeynalov, Furman and Hambsch, Proc. ISINN13 (2005)

- Average value of the P_{Apre} (ν)



- Width of the P_{Apre} (ν): σ=0.5

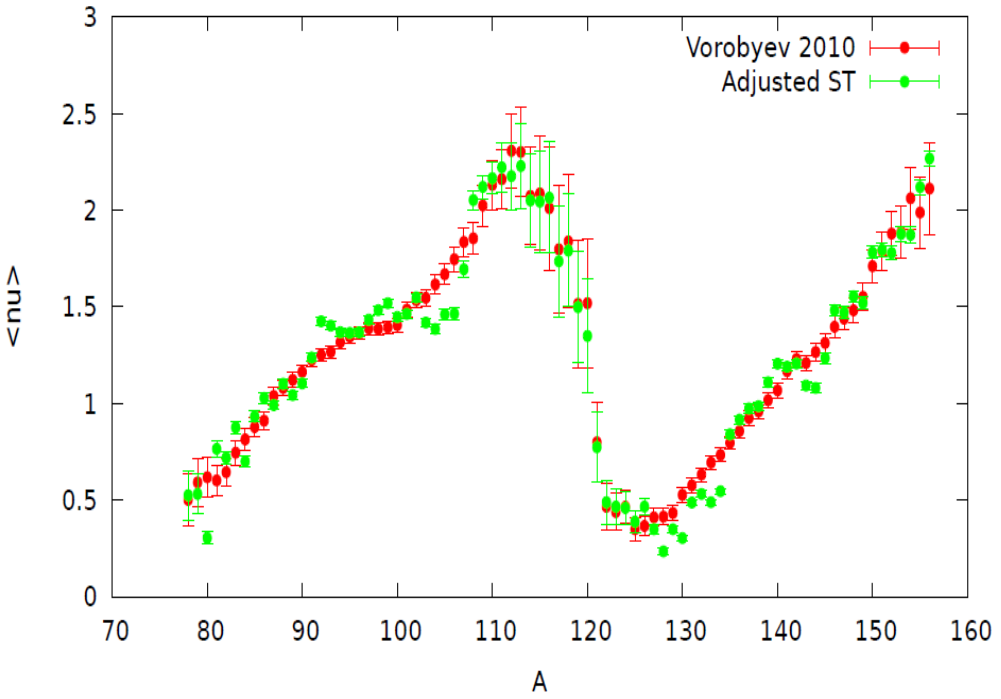
Covariance Matrix Generation for JEFF/Fission Yield

Adjusted parameters for $^{235}U(n_{th},f)$

- Fission modes for the pre-neutron mass yield: Ypre

	<A_heavy>	Width Heavy	Weight (%)
St. I	134.0	2.1	21.11
St. II	141.3	4.8	78.74
SL	118	5.1	0.15

- Average value of the P_{Apre} (ν)

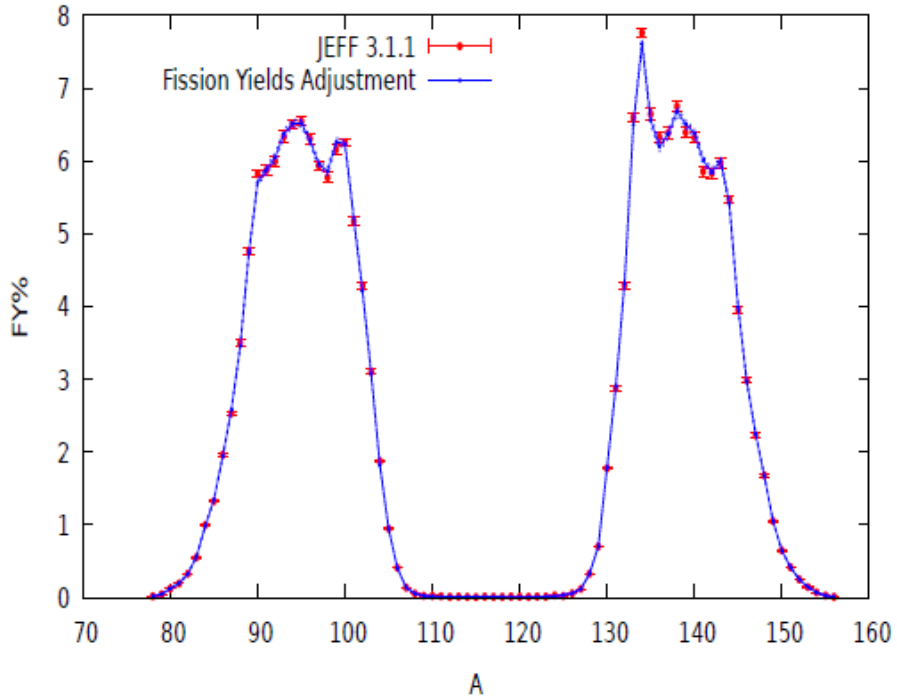


- Width of the P_{Apre} (ν): σ=0.8

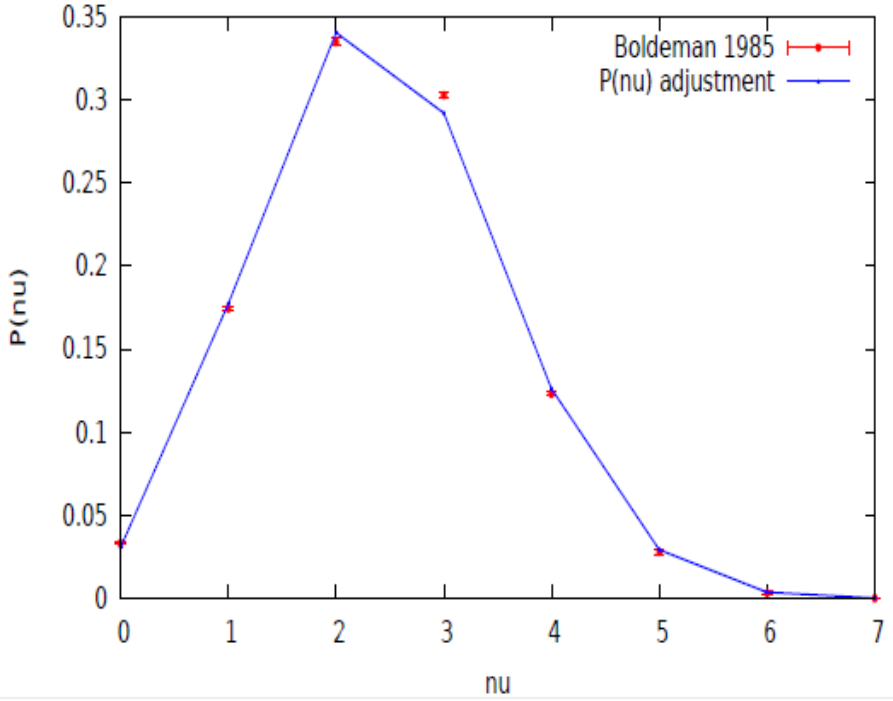
N. Terranova, O. Serot, P. Archier et al.
Nuclear Data Sheets, 123 (2015) 225-230

Covariance Matrix Generation for JEFF/Fission Yield

Independant Fission Yields (JEFF-3.1.1)



Total P(ν) (From Boldeman (1985)

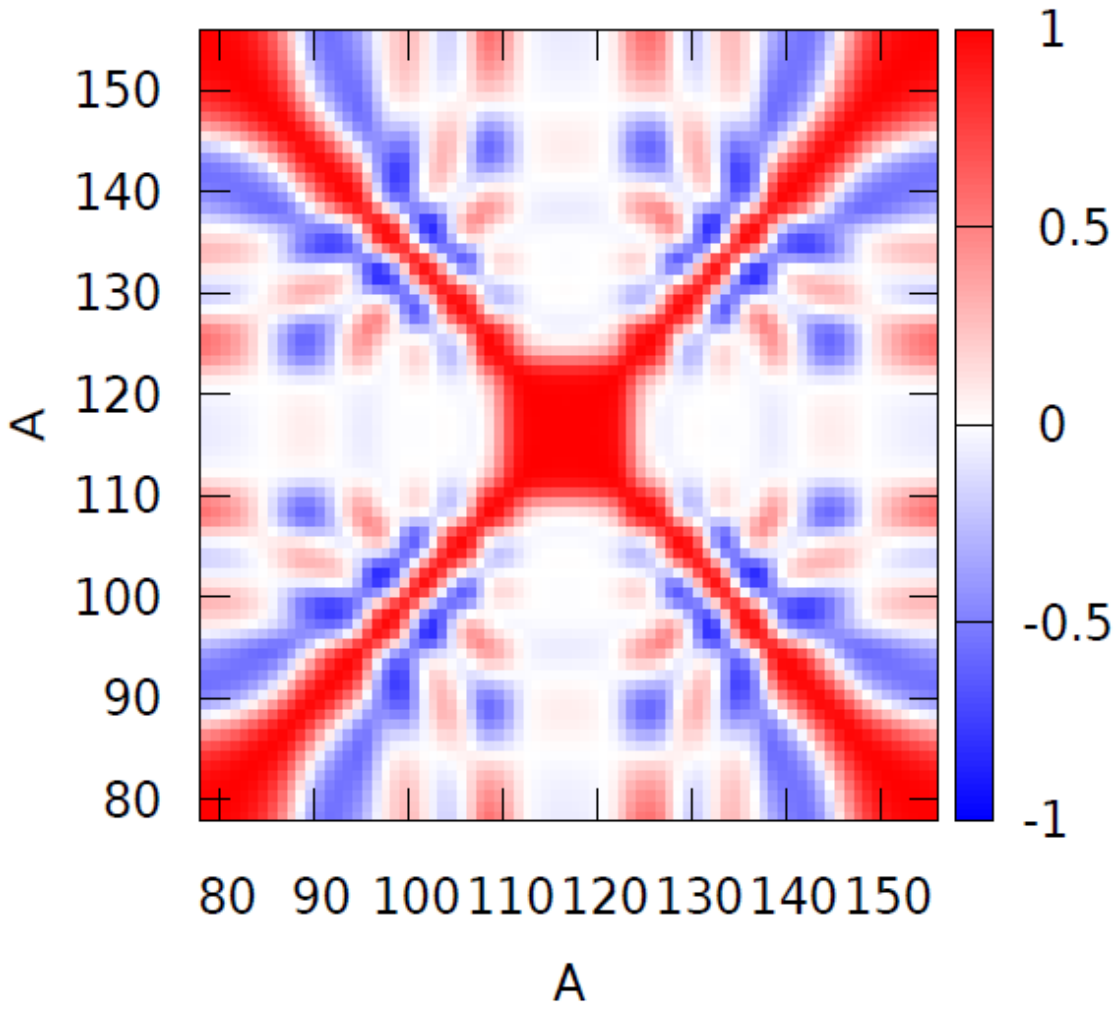


Our model can reproduce both fission yields and the total prompt neutron distribution

N. Terranova, O. Serot, P. Archier et al.
Nuclear Data Sheets, 123 (2015) 225-230

Covariance Matrix Generation for JEFF/Fission Yield

Correlation matrix estimated from the Bayesian approach (Generalized Least Squared Method) available in the CONRAD code (CEA-Cadarache)

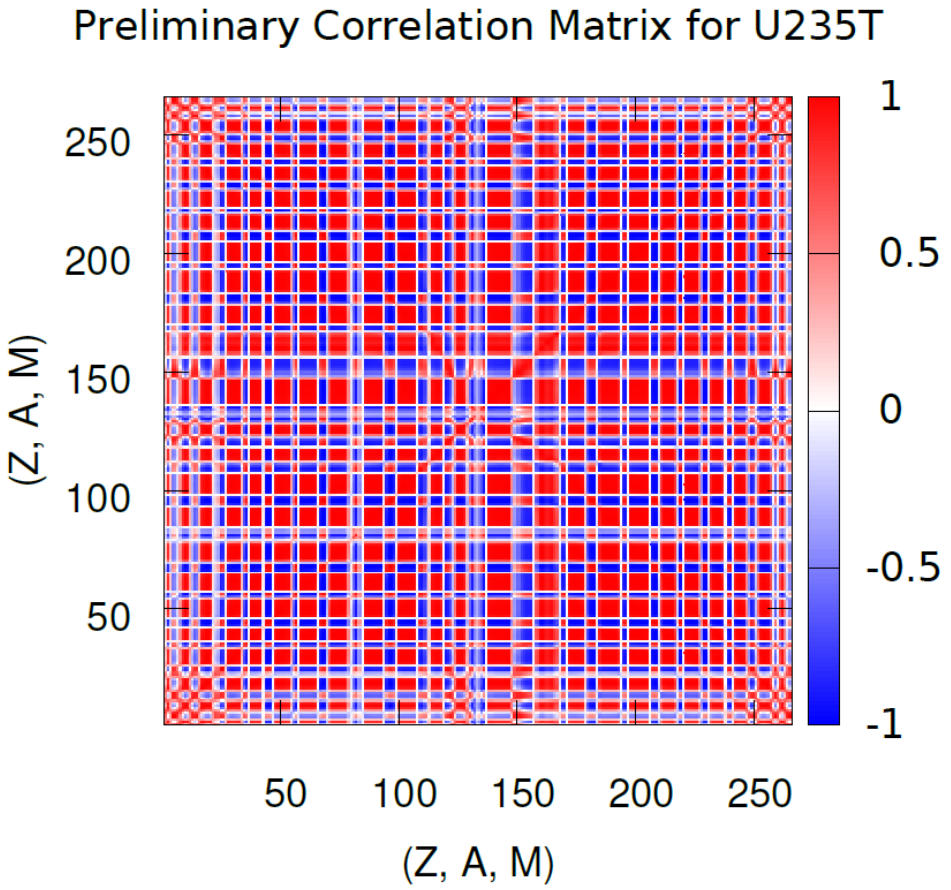


$^{235}U(n_{th},f)$

N. Terranova, O. Serot, P. Archier et al.
Nuclear Data Sheets, 123 (2015) 225-230

Covariance Matrix Generation for JEFF/Fission Yield

$$Y_{post}(A,\ Z,\ M) = \left[\sum_{\nu_i=0}^{\infty} Y_{pre}(A+\nu_i)\cdot p_{A+\nu_i}(\nu_i)\cdot f(A+\nu_i,\ Z)\right]\cdot R(A,\ Z,\ M)$$



Charge distribution: Wahl model

Isomeric Ratio: Madland and England model

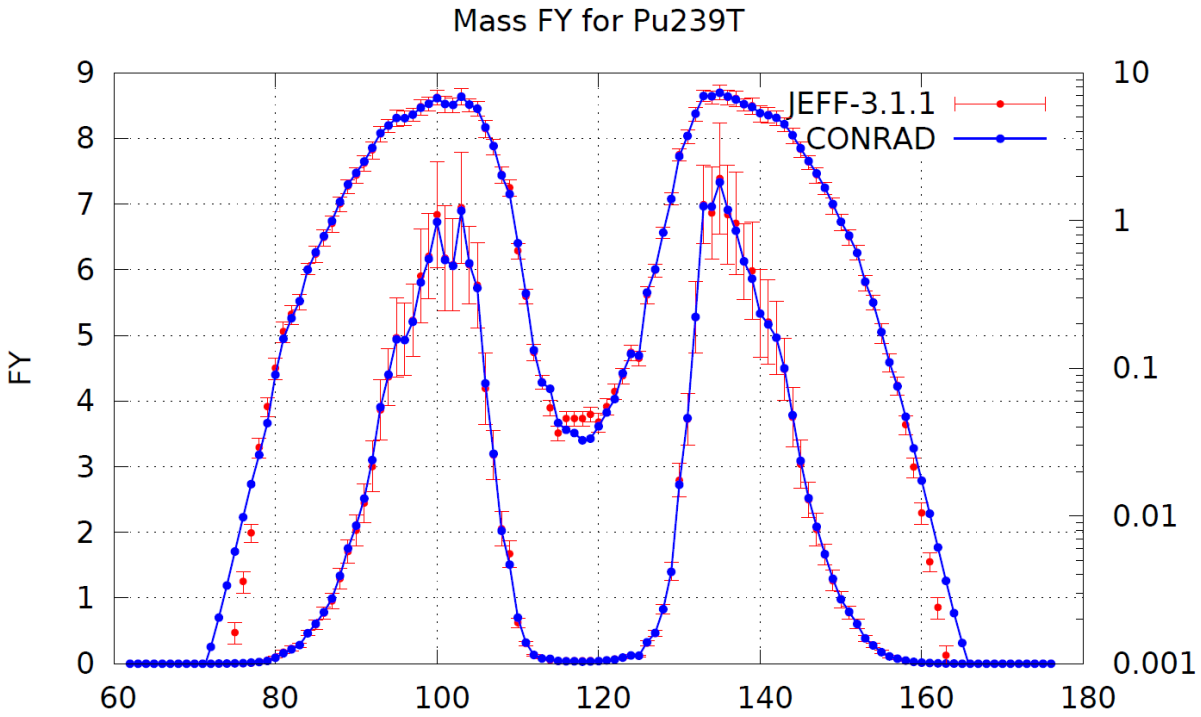
$^{235}U(n_{th},f)$

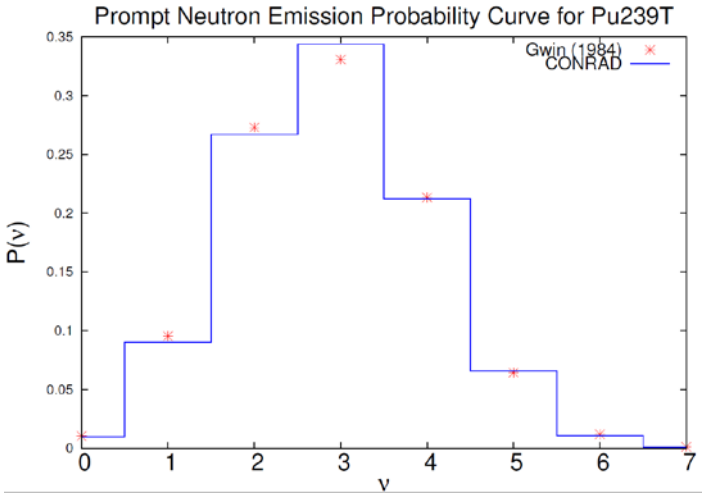
N. Terranova, P. Archier, O. Serot, et al. , JEFF-doc 1649, April, 2015

Covariance Matrix Generation for JEFF/Fission Yield

$^{239}Pu(n_{th},f)$

After adjustment of the fission mode characteristics and of the saw-tooth



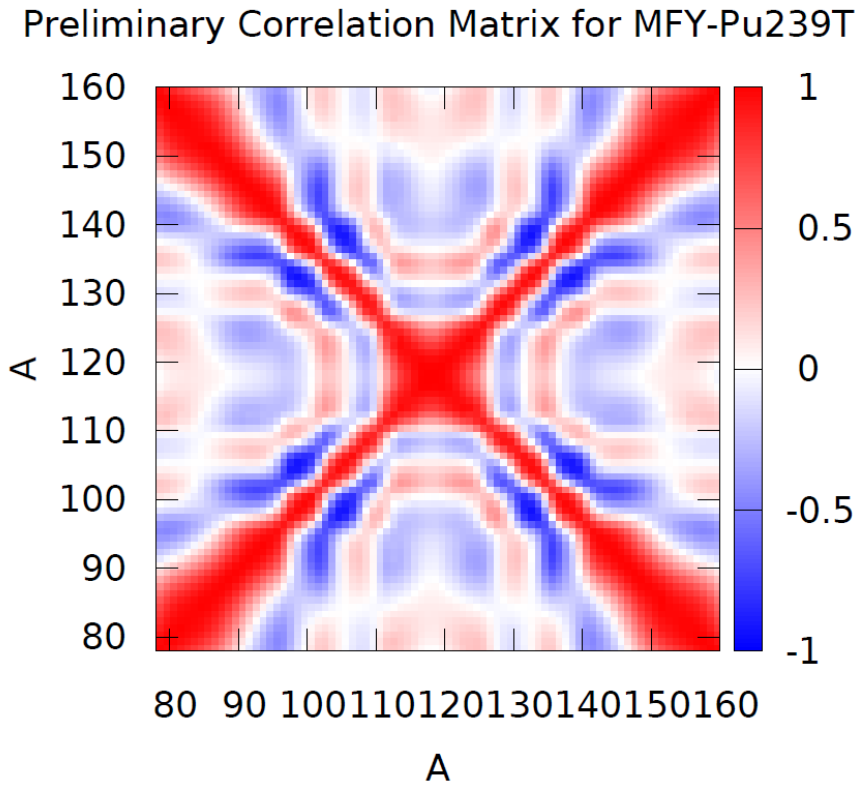


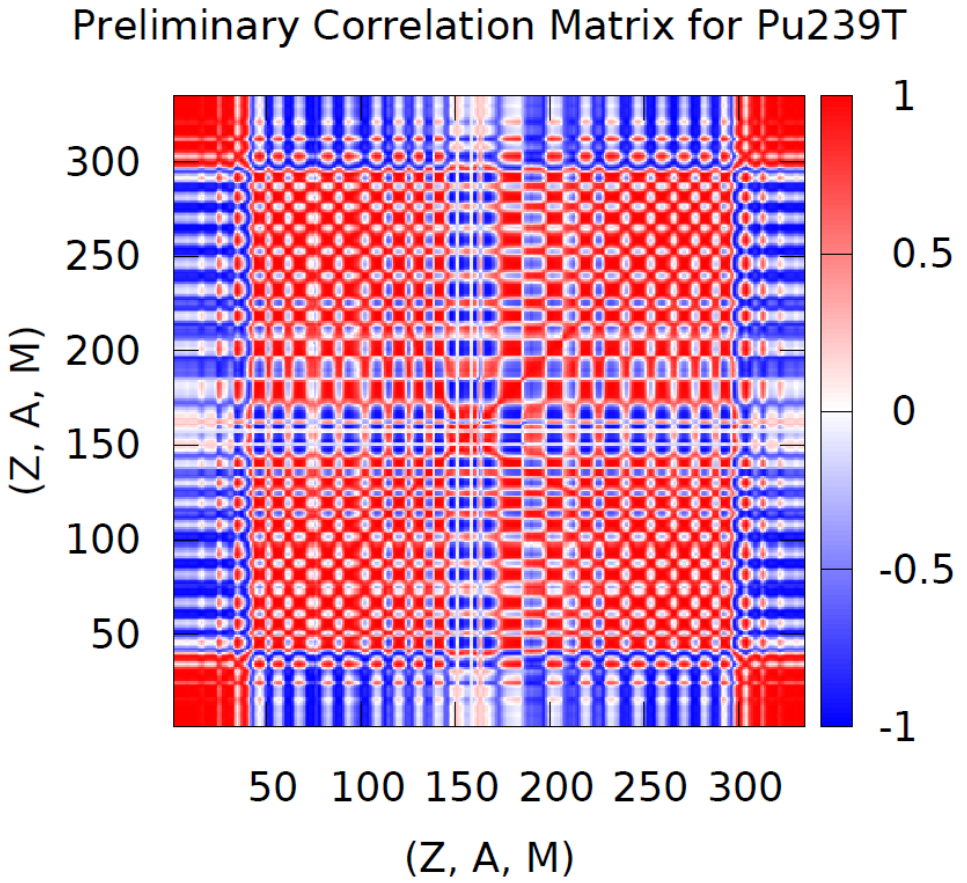
Fision Yield from JEFF-3.1.1 can be perfectly reproduced, as well as the total prompt neutron emission probability measured by Gwin (1984)

Covariance Matrix Generation for JEFF/Fission Yield

$^{239}Pu(n_{th},f)$

And the correlation matrix can be determined



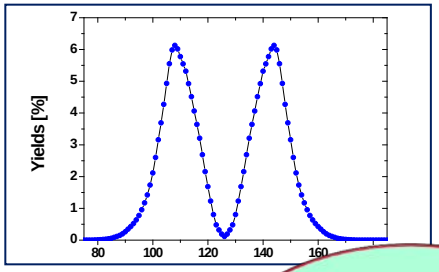


Fission Yield calculation using FIFRELIN Monte Carlo code

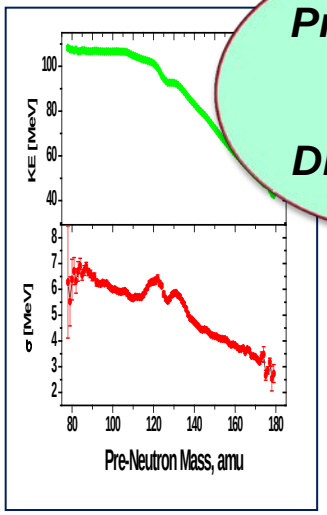
- *Brief description of the code*
- *Example on 239Pu(n,f)*

Fission Yield calculation using FIFRELIN code / Brief description

Input Data



Pre-neutron mass distribution



Pre-neutron Kinetic Energy Distribution

Code FIFRELIN:

- ***Fission Models*** *(Nuclear Charges, Sharing of the excitation energy, Spin distribution of the FF,…)*
- ***Nuclear Structure models*** *(Level densities, Strength functions, Neutron transmission,…)*
- ***Deexcitation Models*** *(Weisskopf, Hauser-Feshbach…)*
- ***Data Base (RIPL,…)***

Output Data

- ***Prompts Neutrons: N(E), P(nu), Nu(A), Nu(TKE), …***
- ***Prompt Gamma Spectra, Mult., …***
- ***Post-neutron Yields***
- ***Energy Released …***

O. Litaize, O. Serot, PRC 82, 054616 52010)
D. Regnier, PhD thesis, (Oct. 2013)

Fission Yield calculation using FIFRELIN code / Brief description

1 **Light Fragment:**
Sampling from the pre-neutron mass distribution and from the KE distribution (nuclear charge from: UCD + polarisation + odd-even effect

A_L , Z_L , KE_L

2 **Heavy Fragment:**
$A_H = A_{fission} - A_L$ et $Z_H = Z_{fission} - Z_L$
KE from the conservation laws

A_H , Z_H , KE_H

3 Determination of the Total Excitation Energy at scission (TXE)

TXE

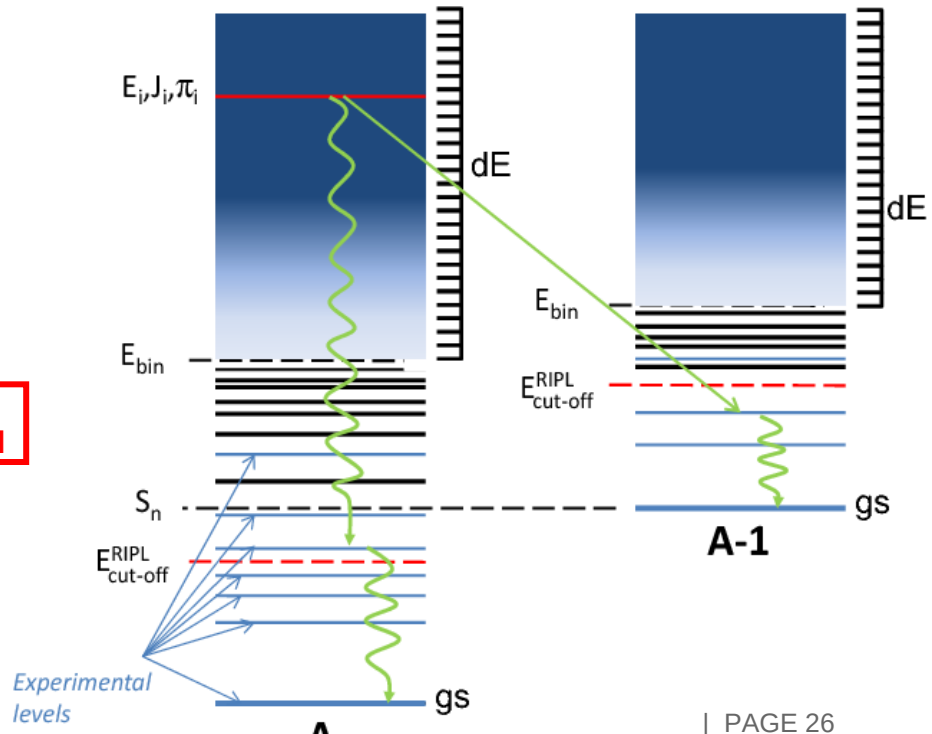
4 Sampling of the spin parity for each fragment

J_L J_H

5 Sharing of TXE between both Fission Fragments

E^*_L E^*_H

6 Desexcitation of each Fission Fragment which are fully characterized:
A, Z, J, pi, E*, Erot

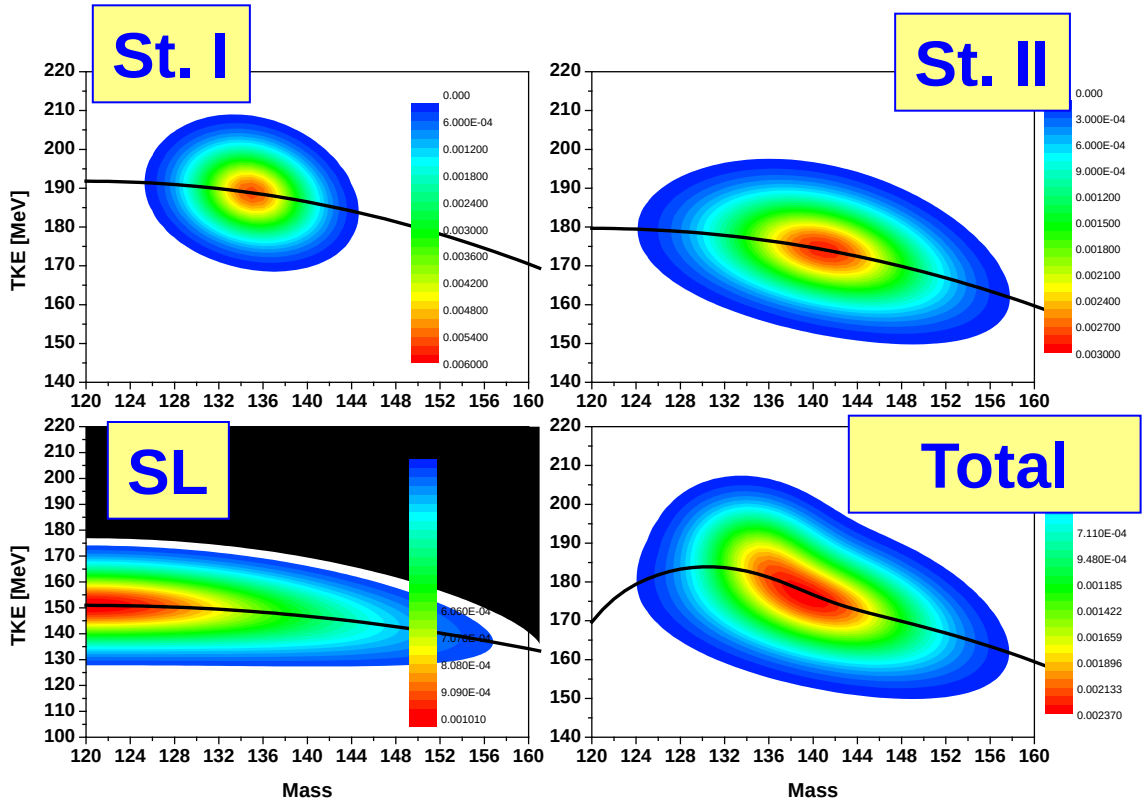


Fission Yield calculation using FIFRELIN code / Example on 239Pu(n,f)

Calculations were performed in 3 steps:
1st Step, for the Standard I fission mode
2nd step, for the Standard 2
3rd step, for the Super Long

Example: $^{239}Pu(n_{th},f)$

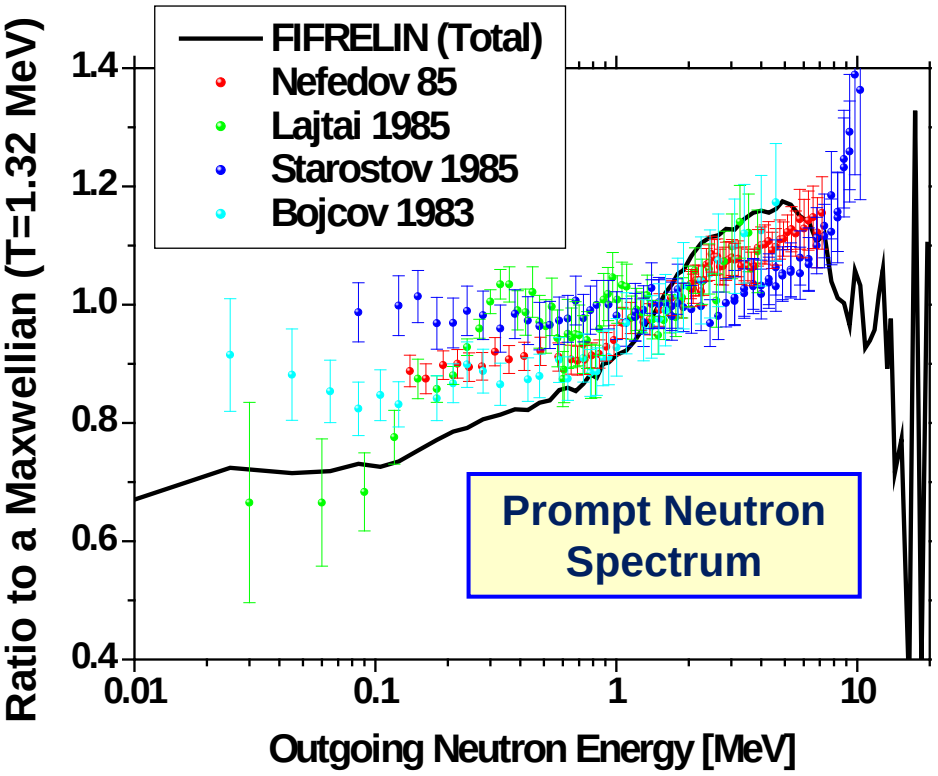
	St. I	St. II	SL
<AH>	134.97	140.96	120.0
σ_M	3.73	6.48	15.8
<TKE>	188.63	173.65	148.35
σ_{TKE}	7.71	8.51	9.93
W (%)	22.83	76.60	0.57

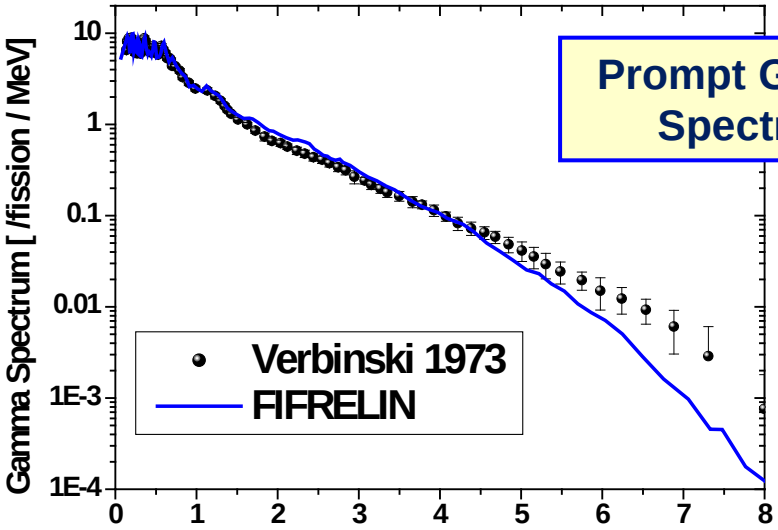


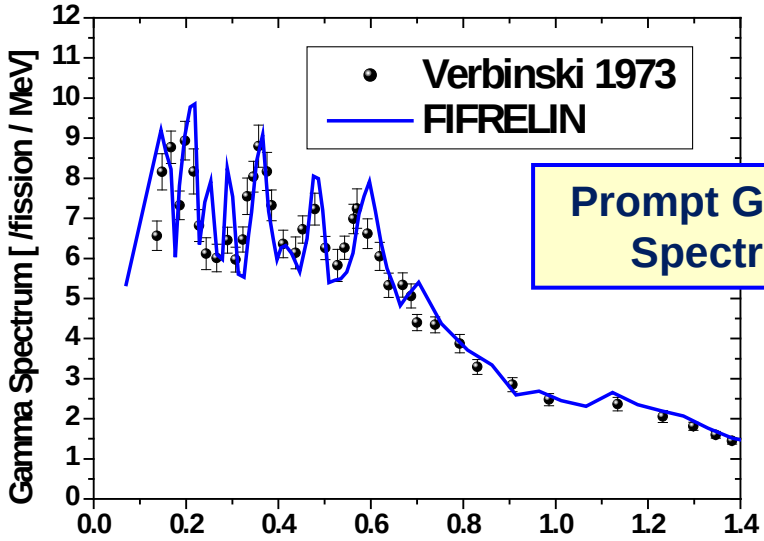
Fission modes determined experimentally by Demattè (PhD thesis, Gent (Belgium), 1997

Fission Yield calculation using FIFRELIN code / Example on 239Pu(n,f)

Calculated prompt neutron and gamma Spectra



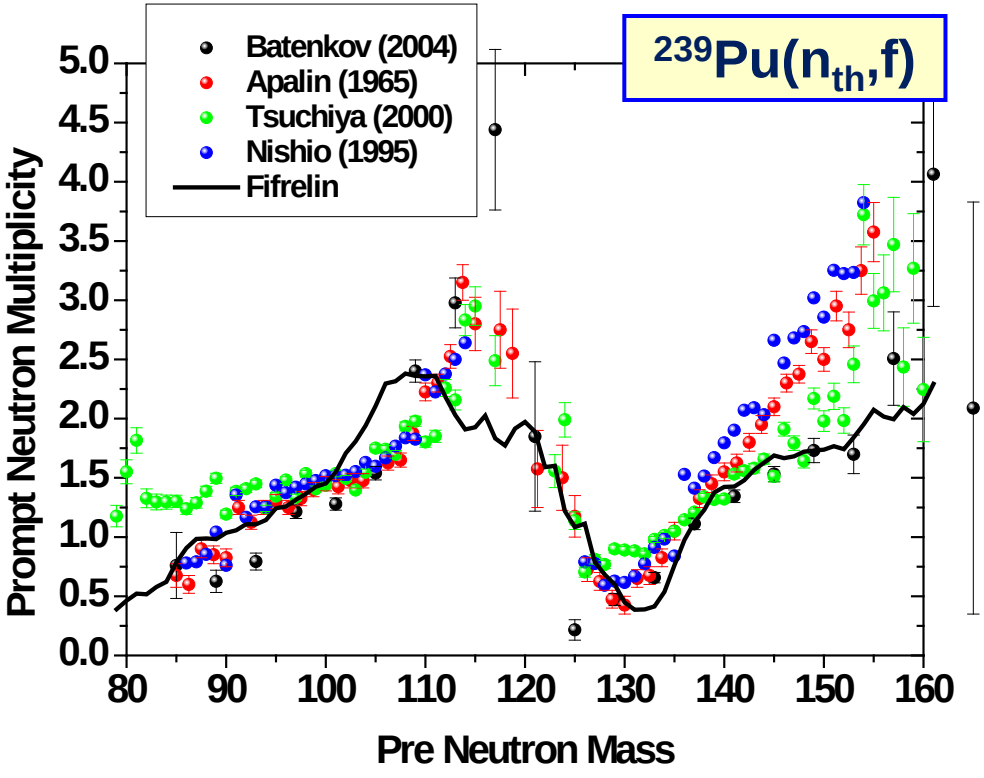




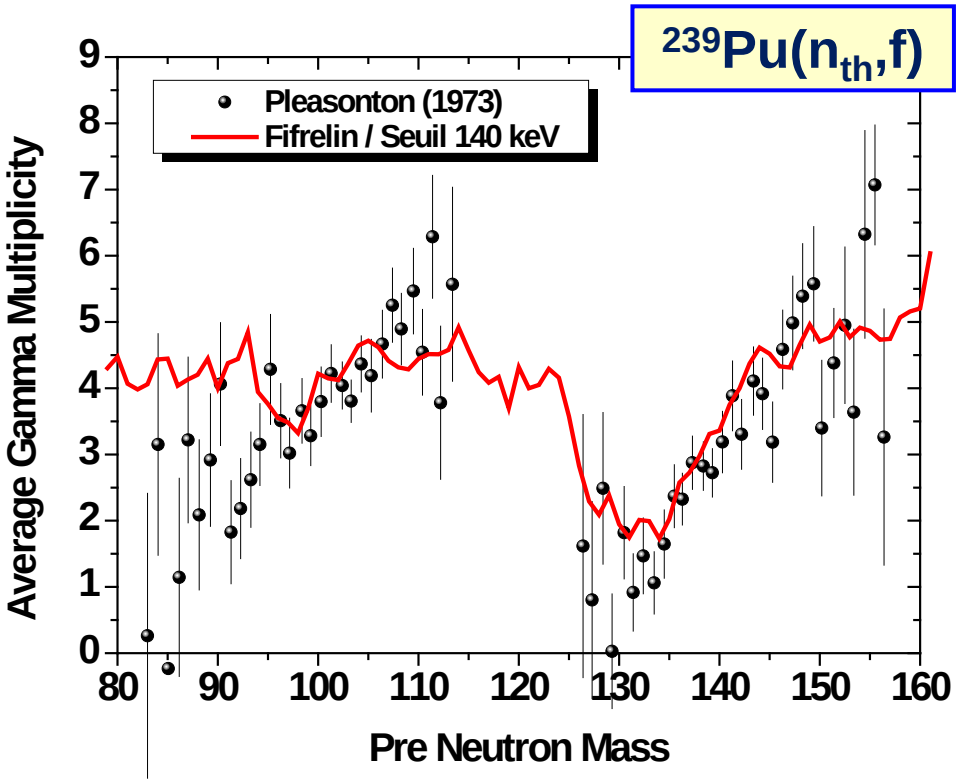
O. Serot, O. Litaize, D. Regnier, Physics Procedia (2013)

Fission Yield calculation using FIFRELIN code / Example on 239Pu(n,f)

Prompt Neutron Multiplicity



Prompt Gamma Multiplicity



O. Serot, O. Litaize, D. Regnier, Physics Procedia (2013)

Fission Yield calculation using FIFRELIN code / Example on 239Pu(n,f)

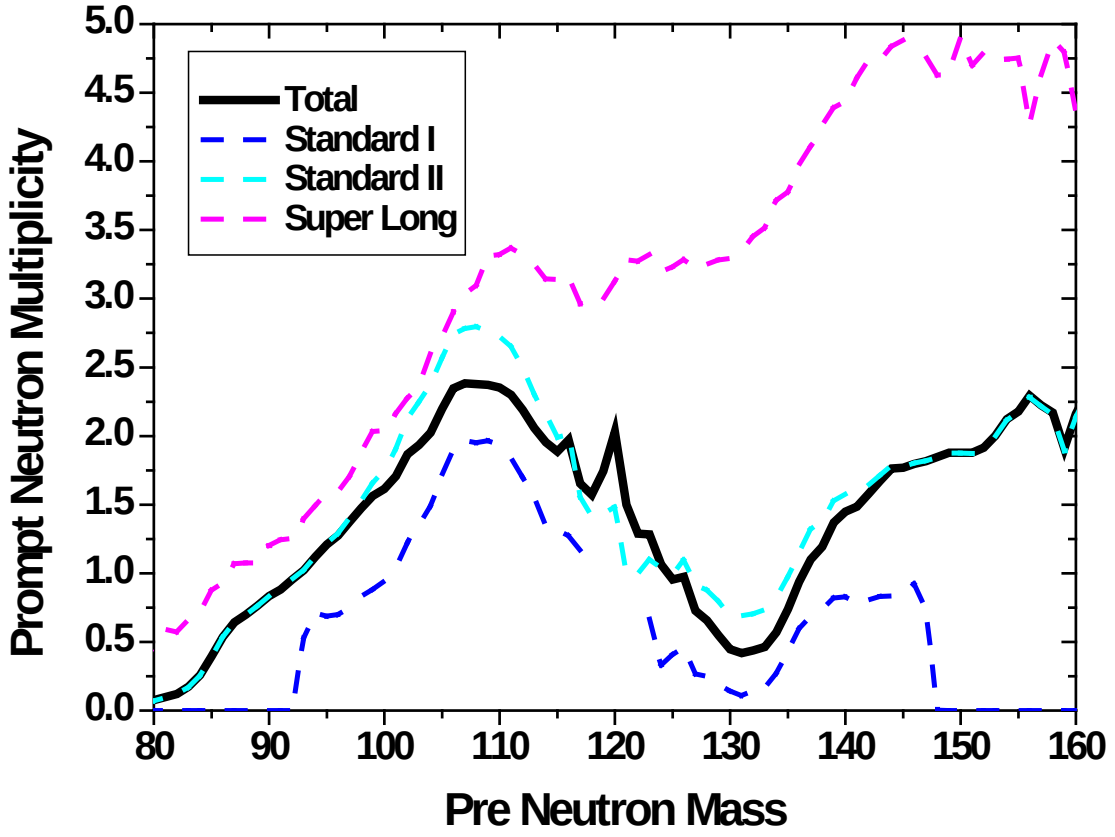
FIFRELIN Results

	ν_L	ν_H	ν_{Tot}
St. I	1.56	0.43	1.99
St. II	1.71	1.48	3.19
SL	2.67	3.72	6.39
Total	1.68	1.25	2.93

Experimental and evaluated data

	ν_{Tot}
Boldeman	2.879 ± 0.060
Holden	2.881 ± 0.009
JEFF- 3.1.1	2.87

Prompt Neutron Multiplicity for each mode



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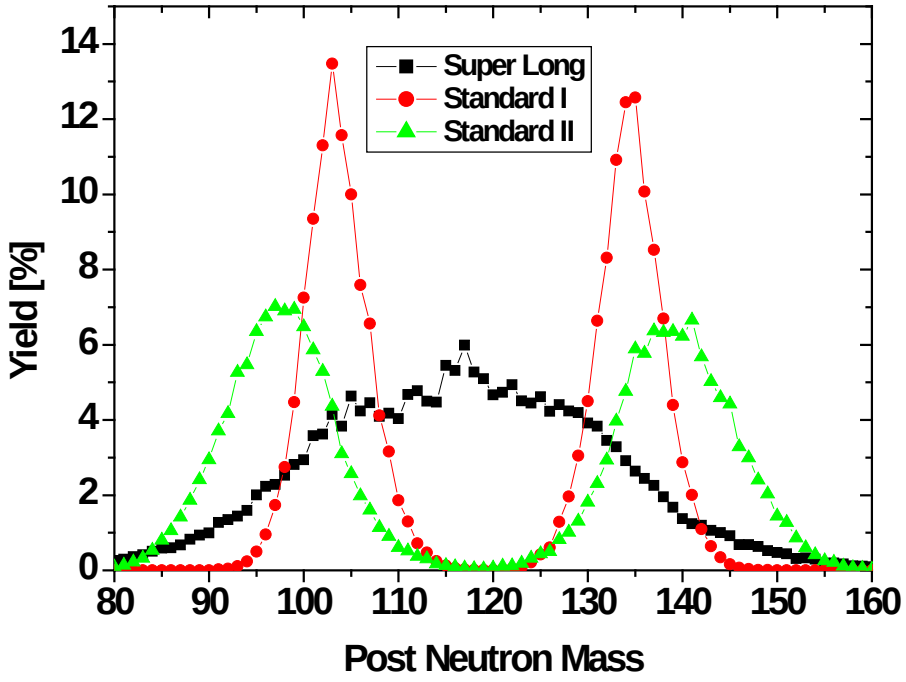
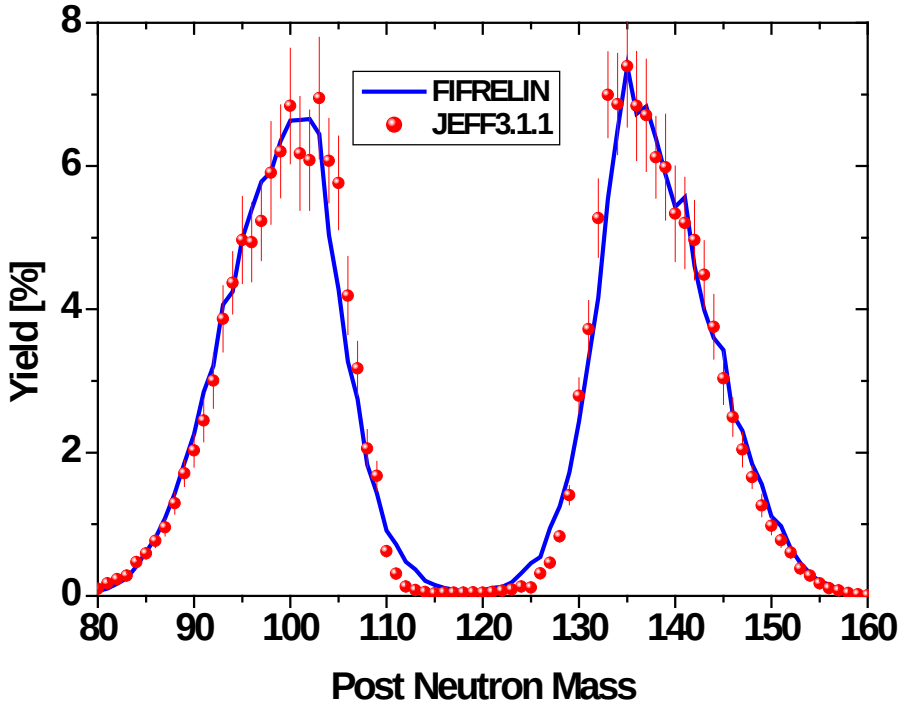
Fission Yield calculation using FIFRELIN code / Example on 239Pu(n,f)

Post-neutron Fission yield for each mode



Total Post-Neutron Fission Yield (comparison with JEFF-3.1.1)



O. Serot, O. Litaize, D. Regnier, Physics Procedia (2013)

Conclusion

Experimental activities at ILL

- Measurements performed at ILL on Lohengrin mass spectrometer: mainly in the heavy mass region for several fissioning systems
- For the first time, the experimental covariance matrix could be determined: will be useful for the future JEFF3.2 / FY evaluation

Covariance Matrix Generation for JEFF/Fission Yield

From semi-empirical models, the covariance matrix associated to the JEFF-3.1.1 evaluations were generated (work still in progress): useful for neutronic calculations

Fission Yield Calculations with FIFRELIN code

From our Monte Carlo code FIFRELIN which simulates the deexcitation of Fission Frgaments, Fission Yields can be calculated as well as several other fission obervables

Collaboration

Experimental activities at ILL

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