Influence des données de structure nucléaire sur la mesure des rendements de fission avec LOHENGRIN

FROM RESEARCH TO INDUSTRY

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Evaluated nuclear data

- **Evaluated Nuclear Data Files (ENDF)** : input parameters for nuclear reactor simulations !
- **How is build an evaluated file (ENDF) ?**

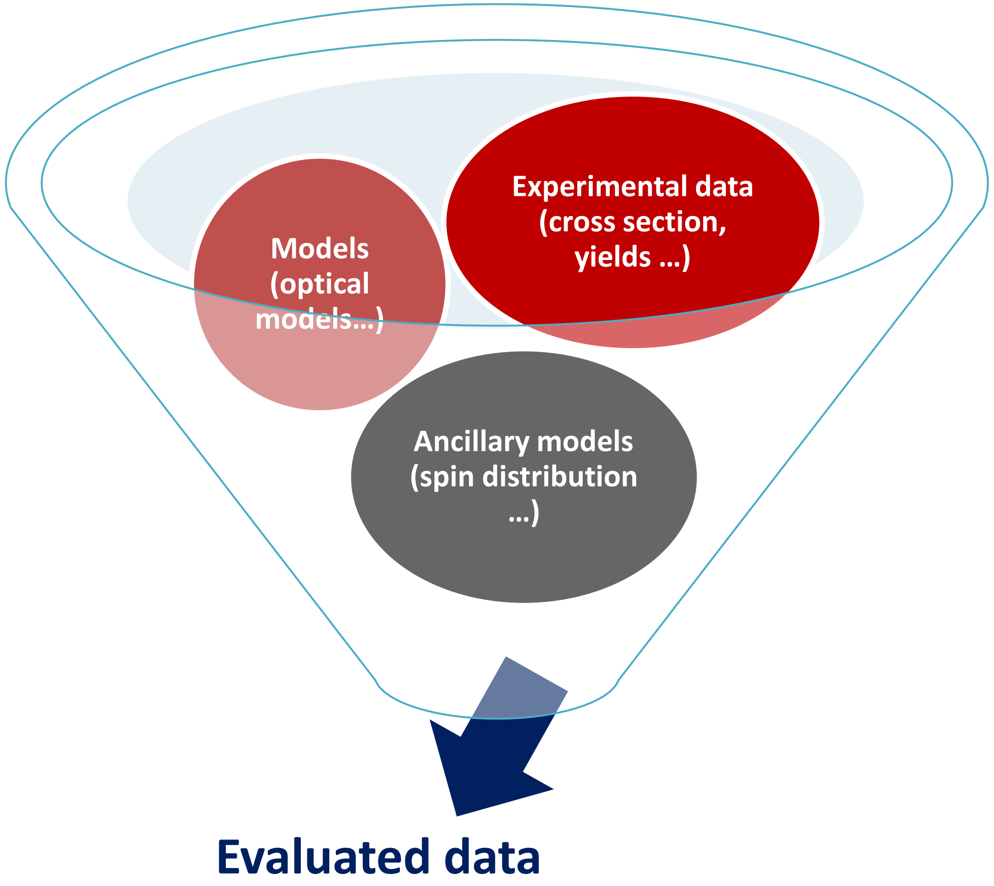
→ models

→ experimental data (Y(A), Y(A,Z), Y(TKE|A) …)

- **Why do we use models?**

→ get data which cannot be measured

→ reduce uncertainties



Evaluated nuclear data

Experimental data → Evaluated data → Nuclear reactors simulation → Cycle studies Scenario Safety…

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- **How to improve the evaluation process?**

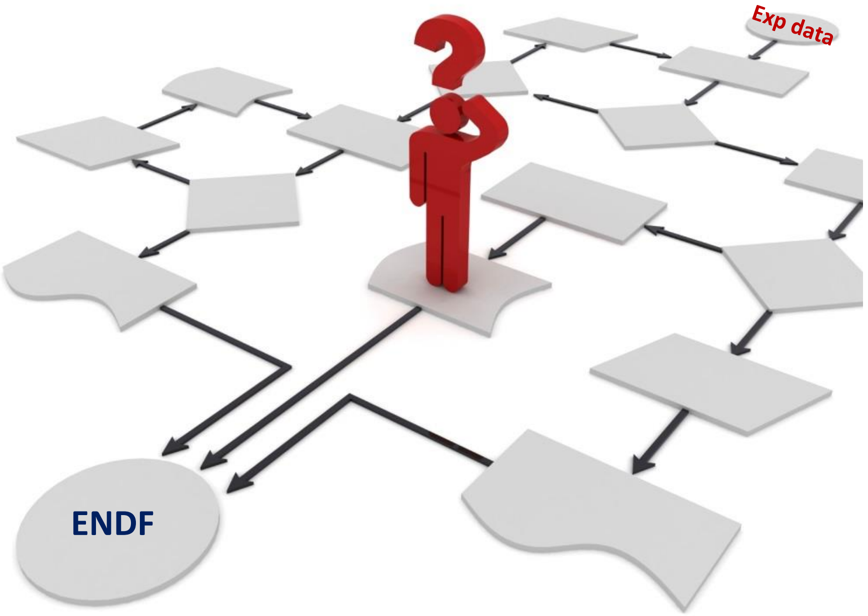
→ more “physical” models: improve knowledge of the fission process

→ new methods

  - Better control of systematic uncertainties
  - More accurate data
  - Evaluation process

→ complementary measurements

  - Substitution reaction
  - Isomeric ratio



Definition of fission yields

Fission yields = **production rate** of fission fragment for a given mass A, nuclear charge Z, excitation energy E^*, kinetic energy E_k, angular momentum J, parity π, and isomeric state m

$$\boldsymbol{Y(A, Z, E_k, E^*, J^\pi)} = Y(A) \times P(Z|A) \times P(E_k|A, Z) \times IR(m|A, Z, E^*, E_k)$$

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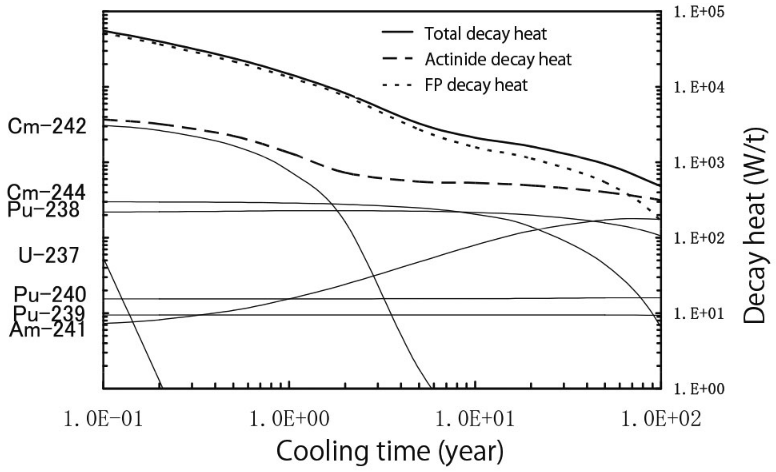
Independent fission yields $Y(A,Z,m)$ are used in nuclear reactor studies

Isotopic composition

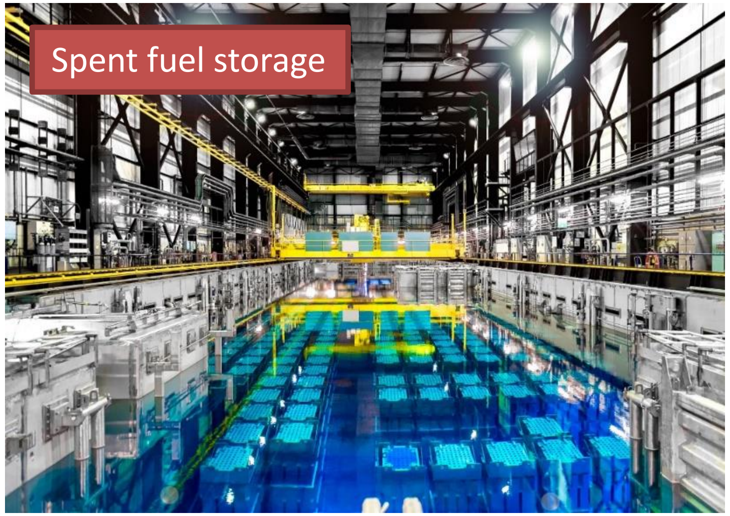
→ Residual power

→ Radiotoxicity of spent fuel



T. Yoshida, Atomic Energy Society of Japan, 10.15669/fukushimainsights.Vol.1.88, 2021

Decay Heat



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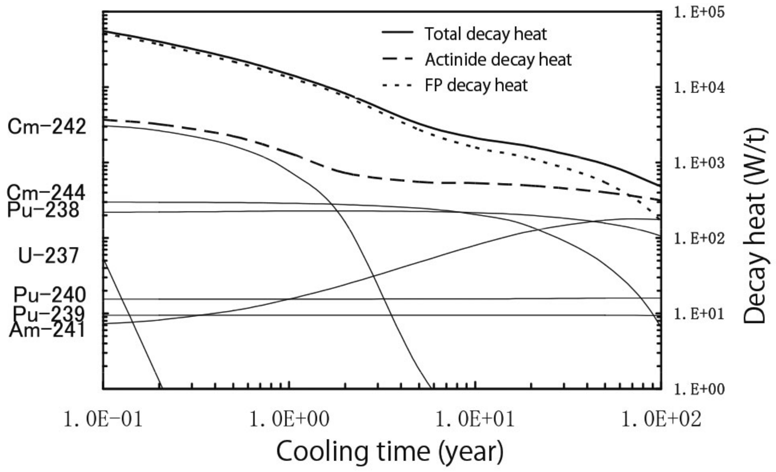
$\boldsymbol{IR(m|A,Z,E^*,E_k)}$: modeling prompt particle emission / foreseen material damage and heating in reactor studies



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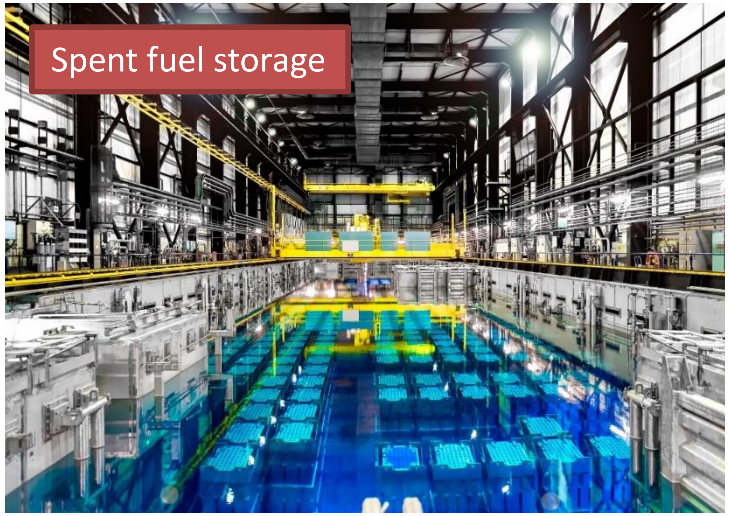

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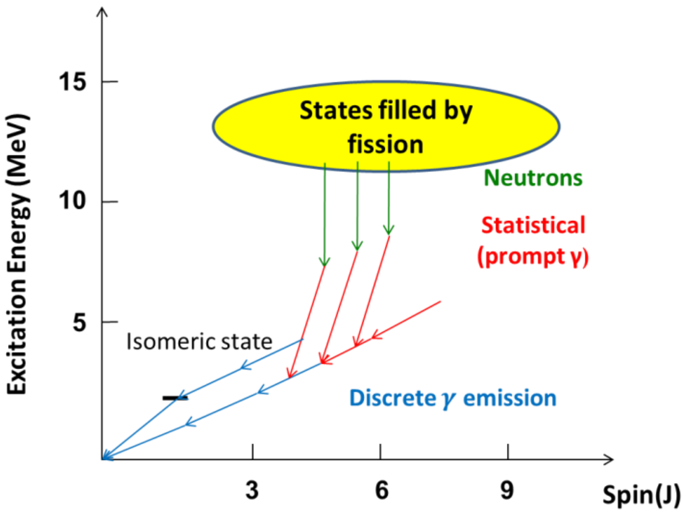
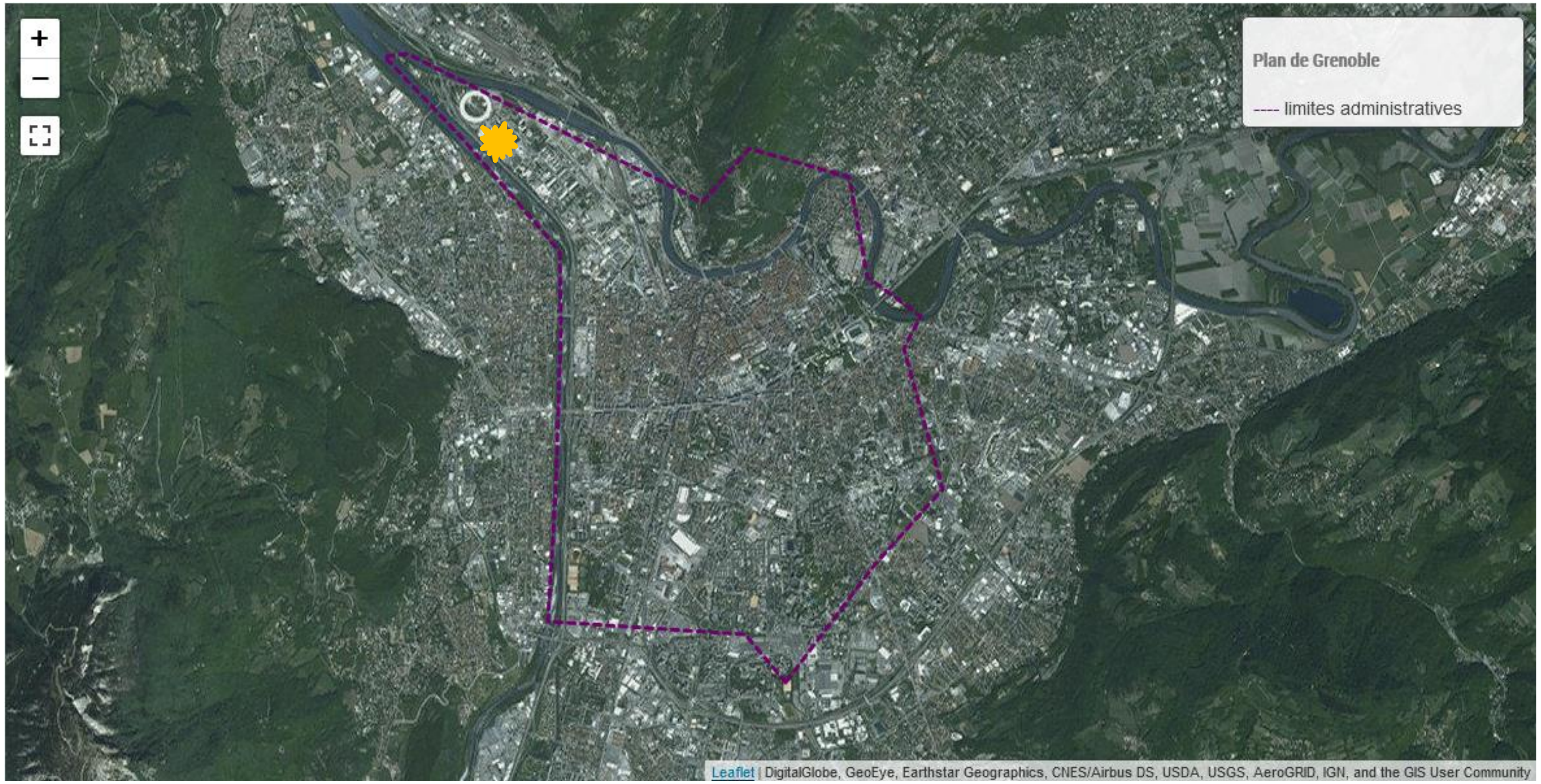
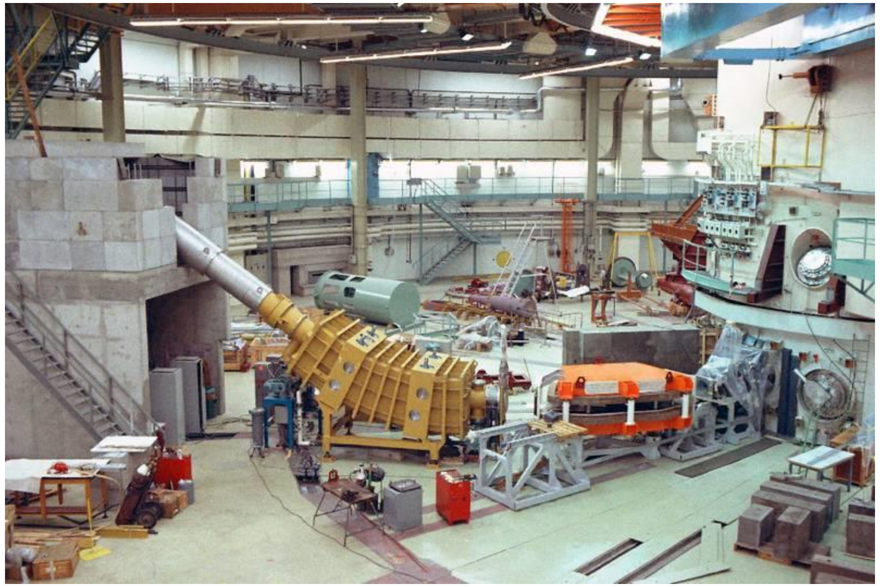


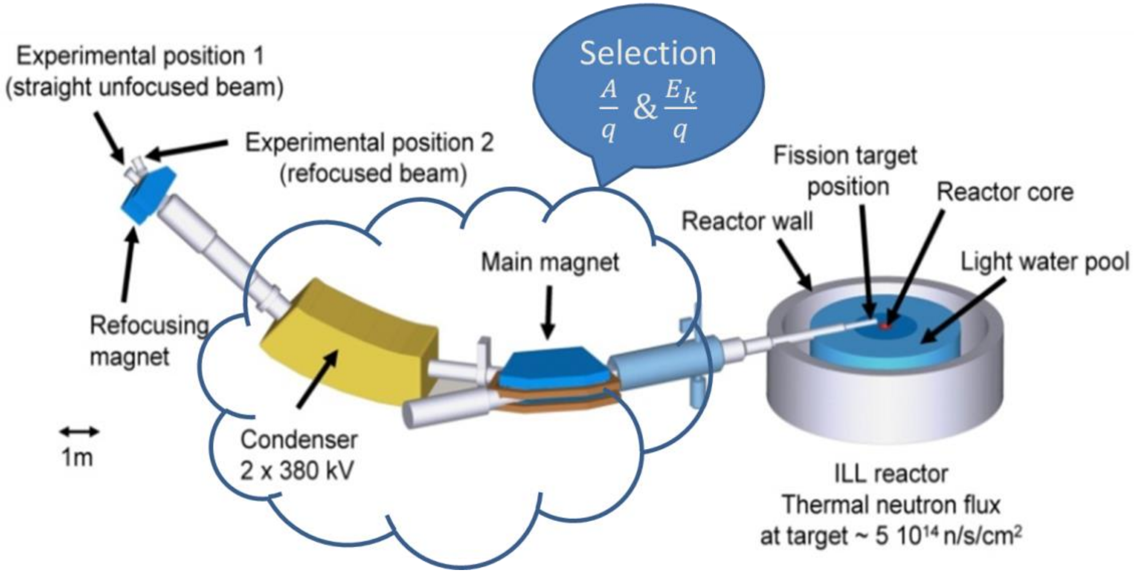
Institut Laue-Langevin

- ILL : founded and govern by France, Germany and United Kingdom
  - Build in 1967
  - 40 instruments (mainly neutron spectroscopy for biology, materials …)
  - 540 member staff + 1400 users per year
  - 105 M€ per year
  - High Flux Reactor : 58.3 MW thermal. New vessel in 1995.



LOHENGRIN working principle

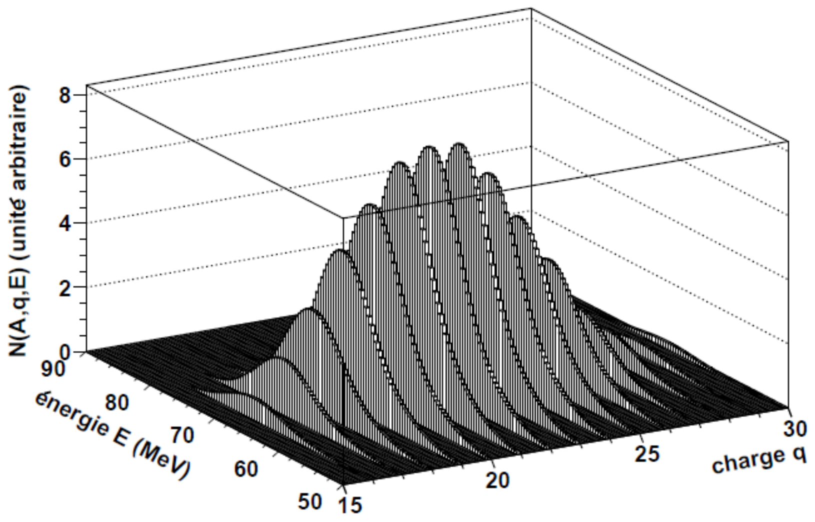




Lohengrin : selection with the mass over ionic charge $\frac{A}{q}$ and Kinetic energy over Ionic charge $\frac{E_k}{q}$ ratios

$$(A_1, E_1, q_1) \equiv (A_2, E_2, q_2) \equiv (A_3, E_3, q_3)$$

How to measure independent yields at LOHENGRIN



Relative measurements

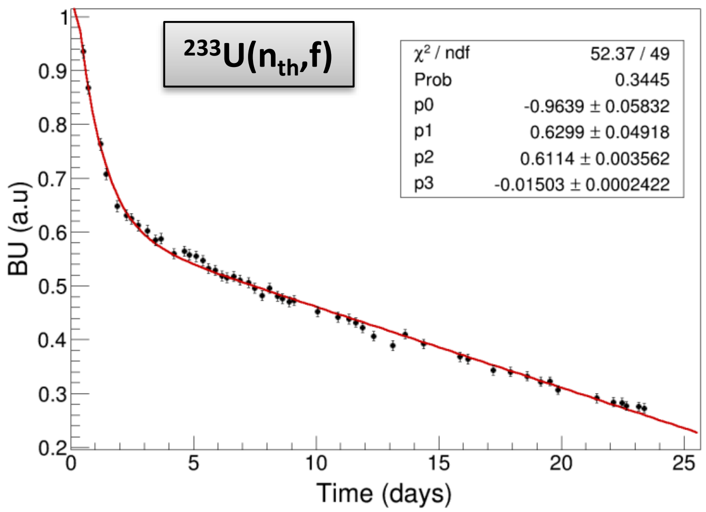
$$\mathcal{N}(A) = \sum_{q} \int_{E_k} \frac{\mathcal{N}(A,q,E_k)dE_k}{BU(t)}$$

Absolute assessment

$$Y(A) = \frac{\mathcal{N}(A)}{\sum_A \mathcal{N}(A)}$$

$$\sum_{Heavy\ A} Y(A) = 1$$

Time evolution of the target (Burn-Up)



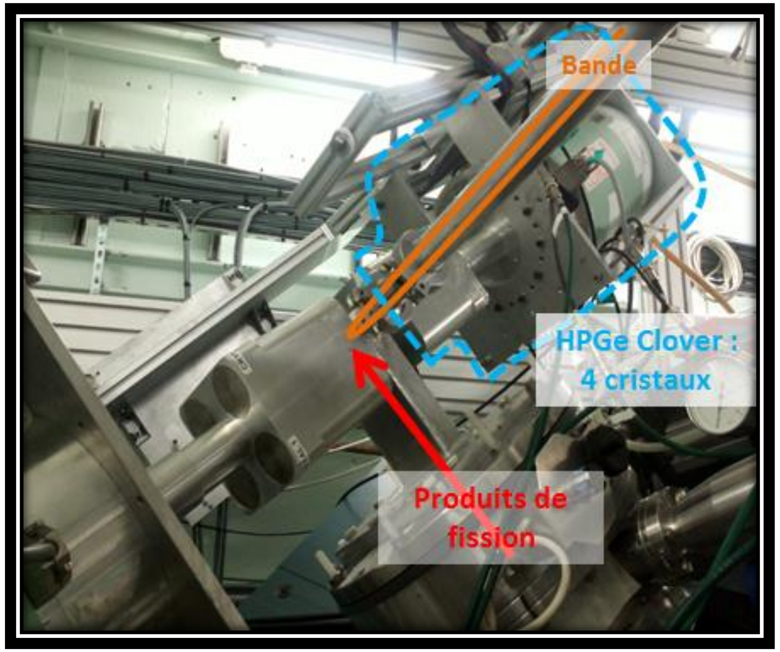
Main issue : burning of the target BU(t) and beam time

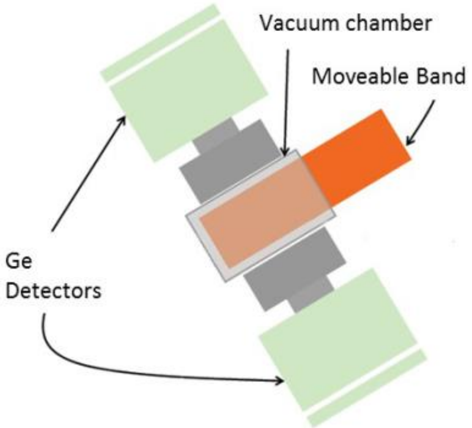
- Choices E_k, q distributions must be made
- Correlations between E_k and q make the analysis more complex
- Tremendous effort over 15 years to reduce the uncertainties and handle bias !

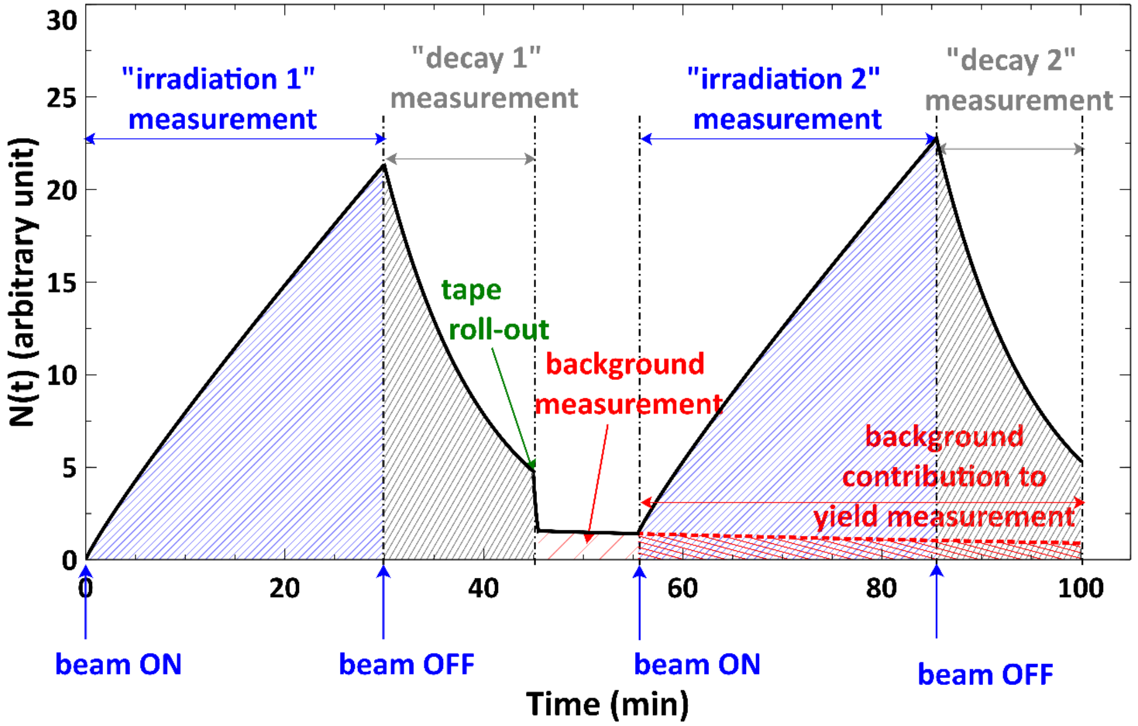
Current data taking :

- 3 E_k scan & 1 q scan to measure a mass yield (at least)
- 1 ionic charge with HPGe to measure independent yield
- For some masses (high electronic conversion) more scan are mandatory

Experimental setup







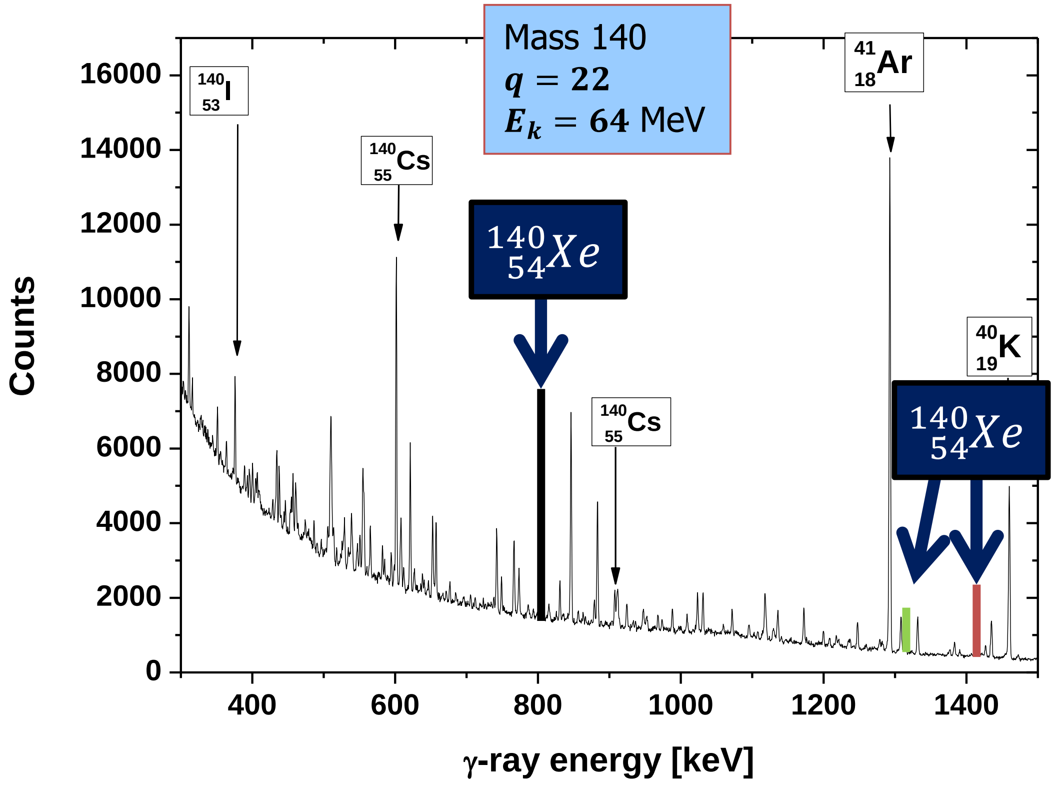
High Purity Germanium (HPGe)

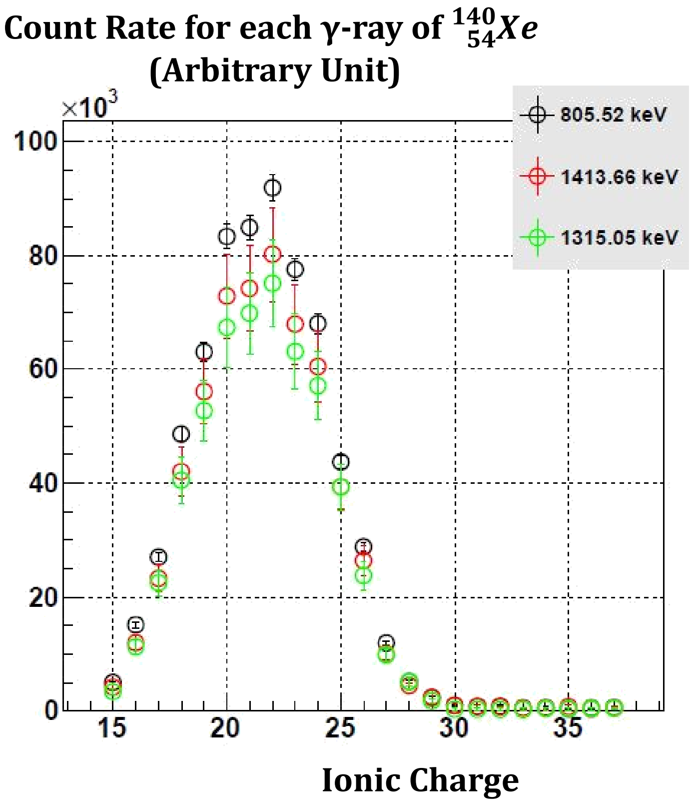
Assess fission fragment nuclear charge through γ measurements

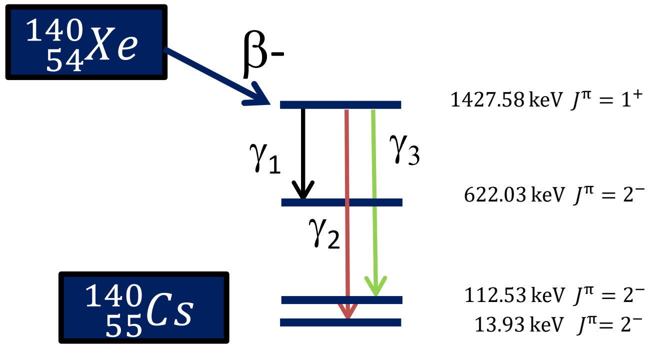
→ Current solution to study isotopic yields in the heavy mass region
→Results are dependent of the knowledge of fission fragment nuclear structure scheme

- Implantation of isotopes on the tape and the vacuum chamber
- Tape roll out : only the chamber frame “contains” isotopes
- Measurement of the “frame decay”

Gamma spectra: example for mass 140







$$^{140}_{53}I \overset{\beta-}{\Longrightarrow} {}^{140}_{54}Xe \Longrightarrow {}^{140}_{55}Cs \Longrightarrow {}^{140}_{56}Ba$$

$T_{1/2} = 0.86\ s$

$T_{1/2} = 13.6\ s$

$T_{1/2} = 63.7 s$

$T_{1/2} = 12.8\ d$

Analysis: example $^{241}Pu(n_{th},f)$ reaction

Julien-Lafferière et al., *Phys. Rev. C 102, 034602*

$$N_d = \frac{N_\gamma(Z,q|E_k)}{\epsilon_\gamma I_\gamma f_\gamma}$$

- The count rate N_γ is extracted using the Program Tv
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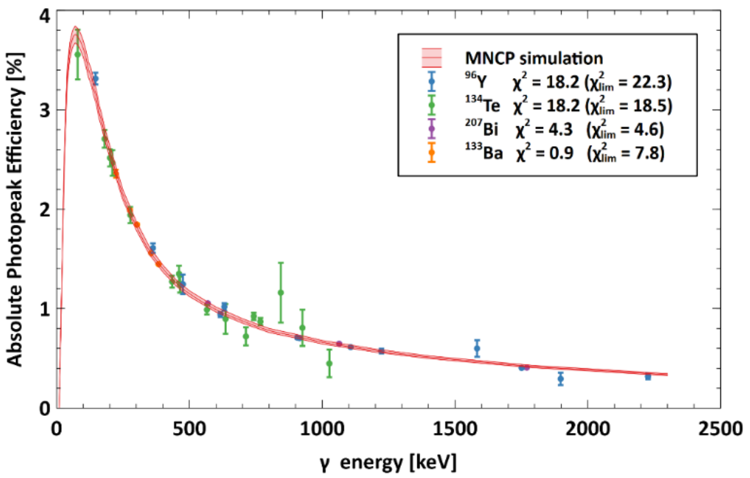

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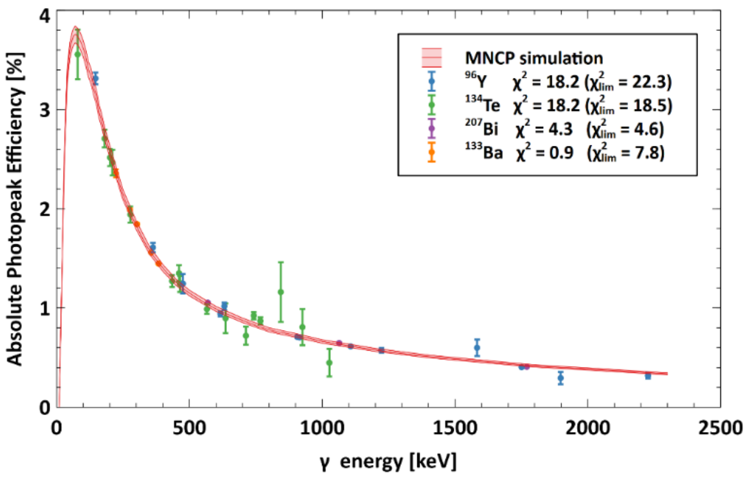
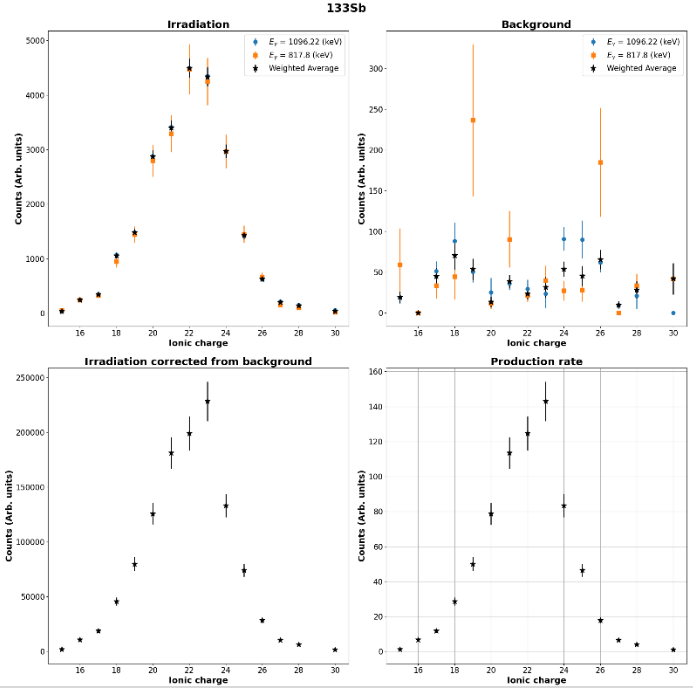
$$\tau(q|E_k) = Q\overline{N_{d_f}}(q|E_k)$$

- Averaging number of decay :
- The average number of decay N_d coming from fission f is corrected from the background bkg (from the frame):
$$\overline{N_{d_f}}(Z,q|E_k) = \overline{N_d}(Z,q|E_k) - \overline{N_{d_{bkg}}}(Z,q|E_k)$$
- Solving the Bateman equation $\boldsymbol{Q}$ to extract the production rate τ coming from fission





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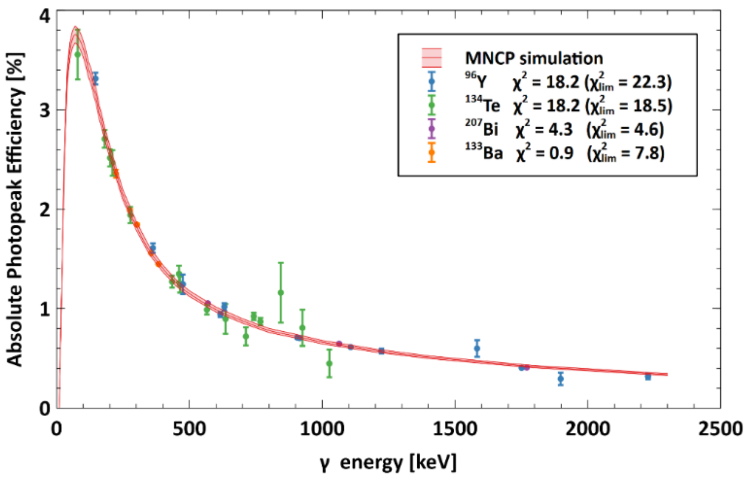
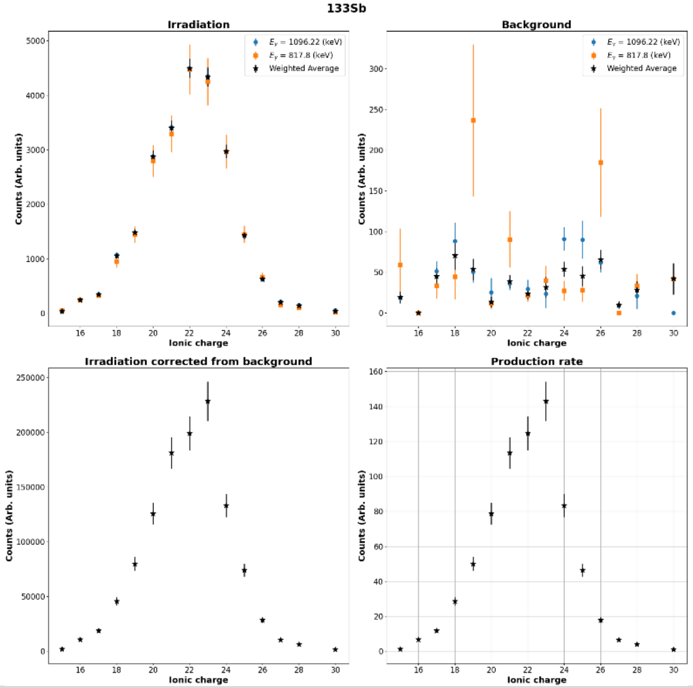
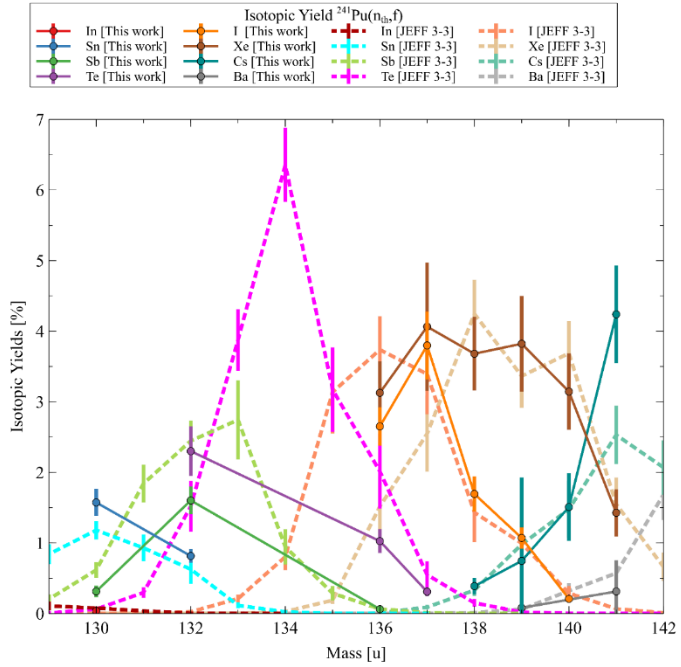
$$Y(A,Z) = N(Z|A) \times k_{139}$$

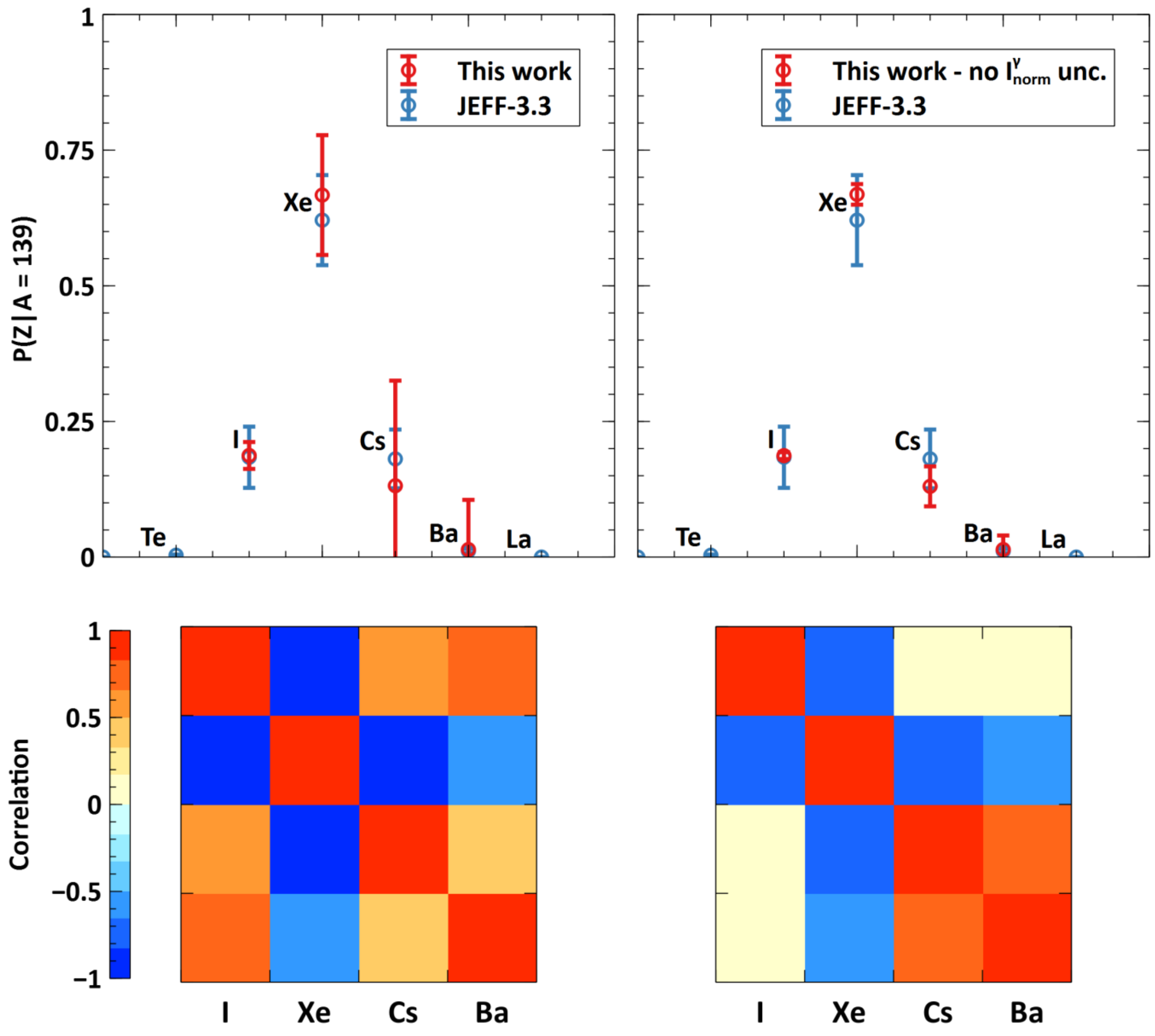
- Correction of kinetic energy dependency $P(E_k)$
- Correction from target evolution $BU(t)$
- Sum over all ionic charge:
  $$N(Z|A) = \sum_q \frac{\tau(Z,q,t|E_k,A)}{BU(t)P(E_k)}$$
- Normalisation with $A = 139$:
  $$k_{139} = Y(A=139)/\sum_Z N(Z|A=139)$$







Impact of nuclear structure uncertainties



$$I_{\gamma} = I_{\gamma}^{rel} \times I_{norm}^{\gamma}$$

Final uncertainty on isotopic yield is mainly driven by I_{norm}^{γ}

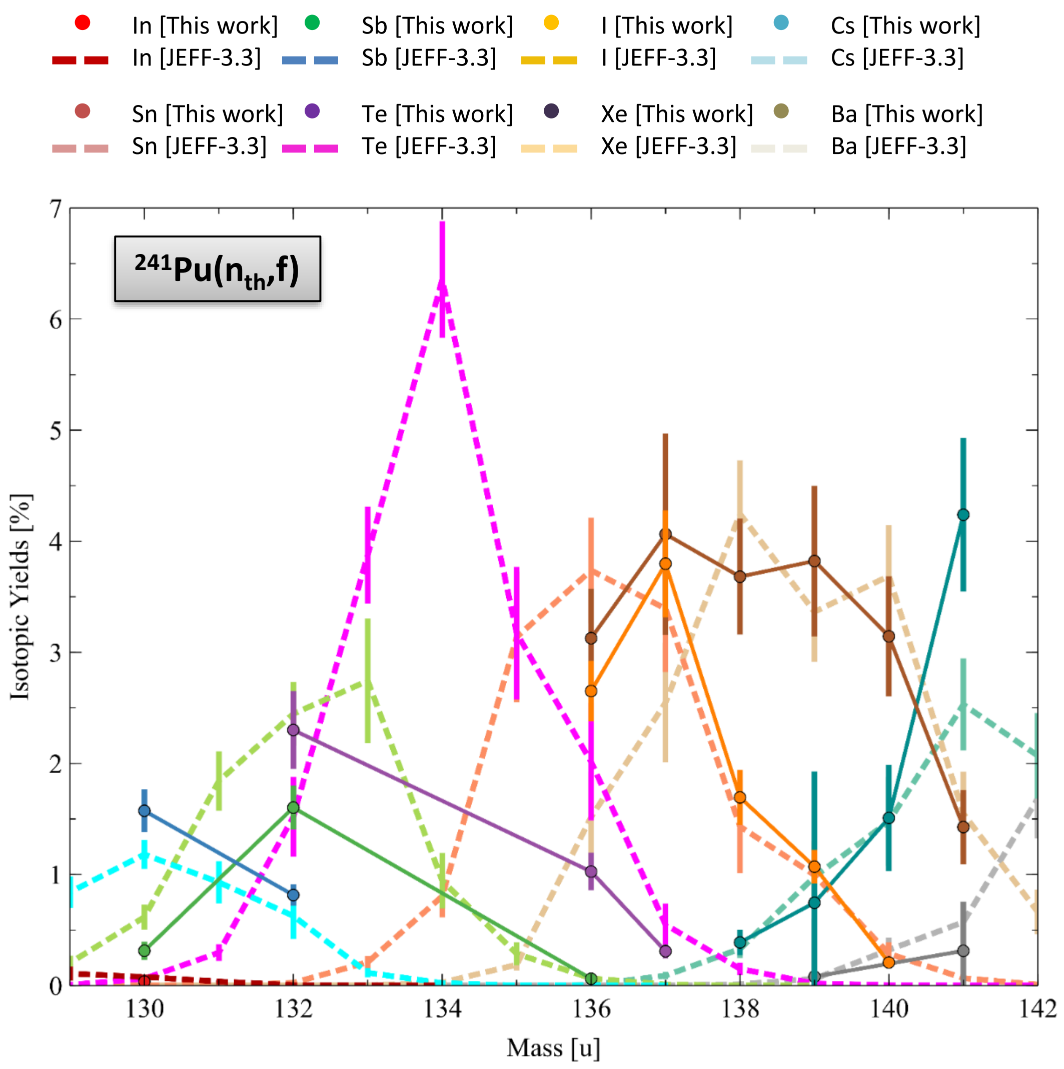
$$0.1\ \% \leq I_{rel} \leq 5\ \%$$

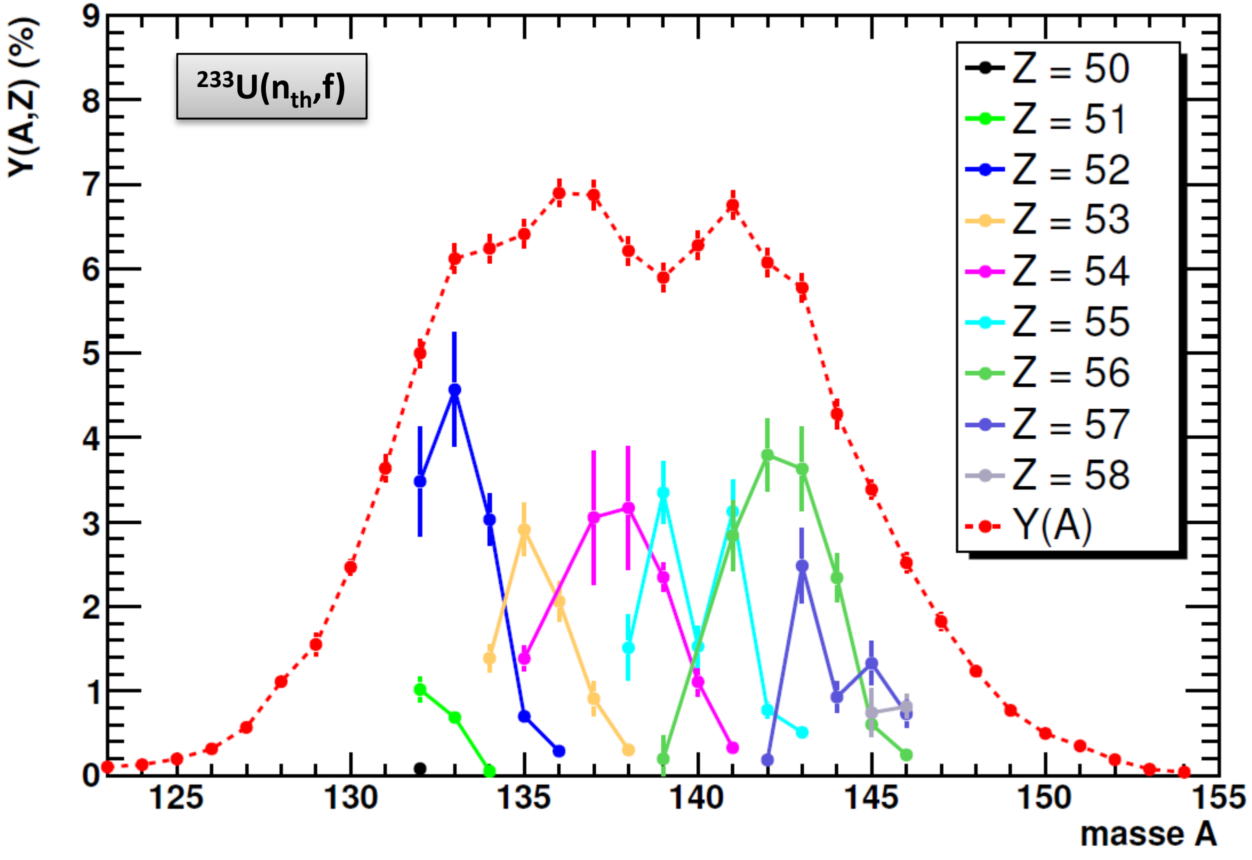
Example of uncertainties

Isotope	Total Uncertainty (on cumulative yields)	I^{γ}_{norm} uncertainty
^{141}Xe	23,29%	20,000%
^{141}Cs	13,12%	6,329%
^{141}Ba	11,56%	3,077%
^{140}I	11,06%	0,11%
^{140}Xe	16,38%	10,00%
^{140}Cs	11,72%	3,75%
^{139}I	14,04%	8,47%
^{139}Xe	15,20%	10,71%
^{139}Cs	21,95%	19,72%
^{139}Ba	15,08%	1,15%
^{138}I	92,05%	7,14%
^{138}Xe	32,02%	3,49%
^{138m}Cs	16,65%	15,79%
^{138}Cs	16,04%	1,57%

Isotope	Total Uncertainty (on cumulative yields)	I^{γ}_{norm} uncertainty
^{137}Te	20,71%	16,95%
^{137}I	12,13%	10,00%
^{137}Xe	14,38%	9,68%
^{136}Sb	39,36%	33,33%
^{136}Sn	15,66%	11,17%
^{136}I	9,60%	1,65%
^{136m}Xe	9,01%	8,00%
^{132}Sn	12,49%	2,46%
^{132}Sb	12,57%	10,00%
^{132}Te	13,25%	3,41%
^{130}In	13,65%	5,81%
^{130}Sn	12,24%	2,99%
^{130}Sb	11,50%	5,00%
^{130}Te	15,50%	5,00%

Some Highlights





Thank you for your attention

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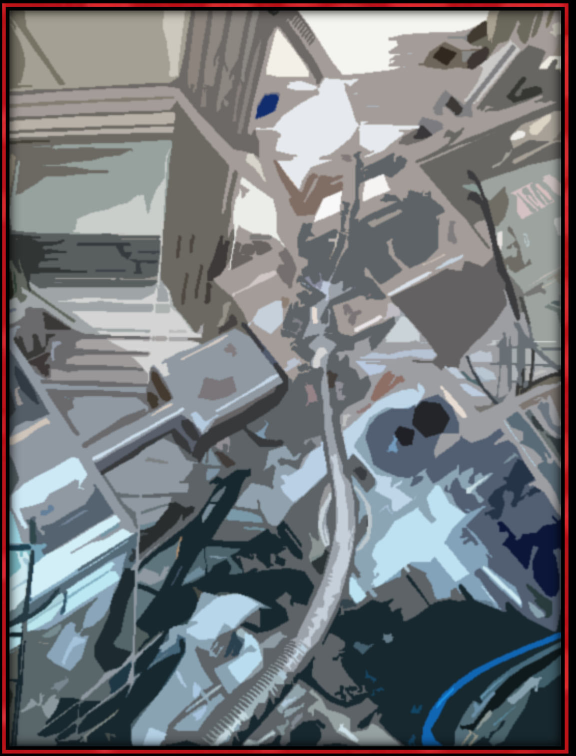

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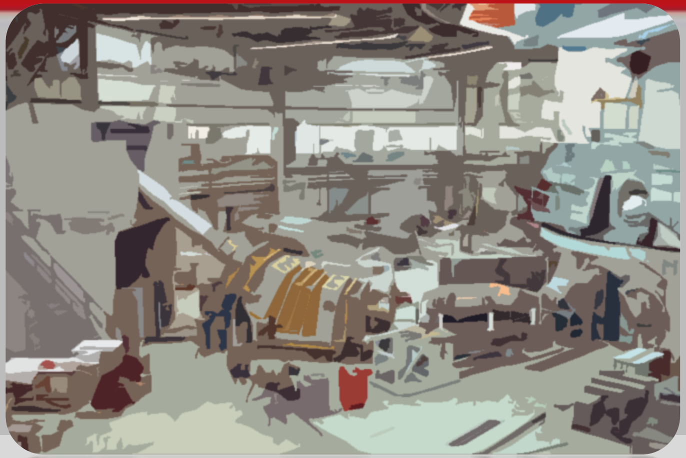

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