NUCLEAR DATA FOR FISSION TECHNOLOGIES

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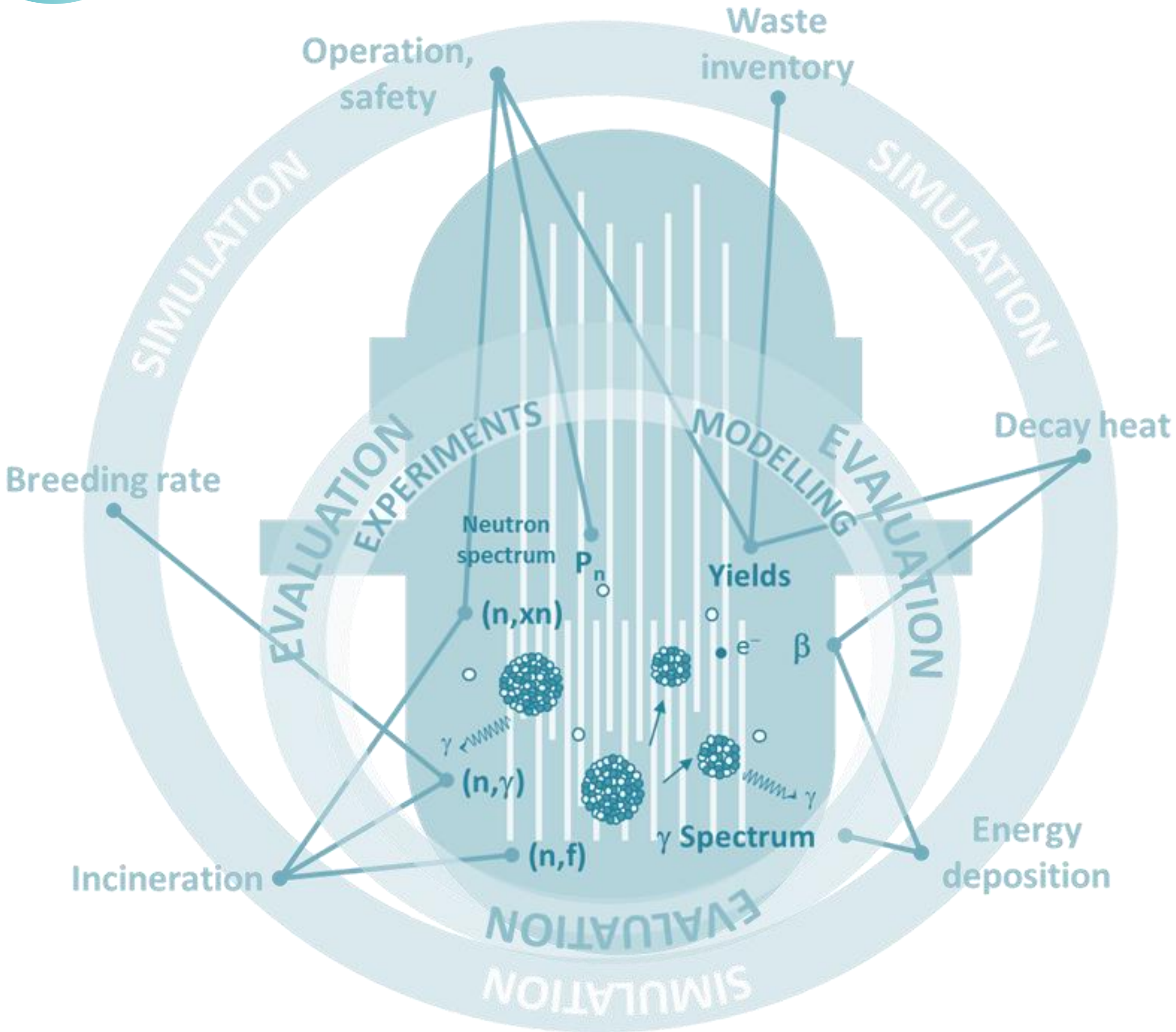
NUCLEAR DATA FOR FISSION TECHNOLOGIES



A broad subject!

Which I'm going to tackle
from my point of view as an experimentalist

OUTLINE

- **NUCLEAR DATA FOR FISSION TECHNOLOGIES**
  What are we talking about?
- **DEFINITION OF NEEDS**
- **EXPERIMENTAL CHALLENGES (A FEW)**
- **BUILDING BRIDGES!**

OUTLINE

NUCLEAR DATA FOR FISSION TECHNOLOGIES

What are we talking about?

DEFINITION OF NEEDS

EXPERIMENTAL CHALLENGES (A FEW)

BUILDING BRIDGES!

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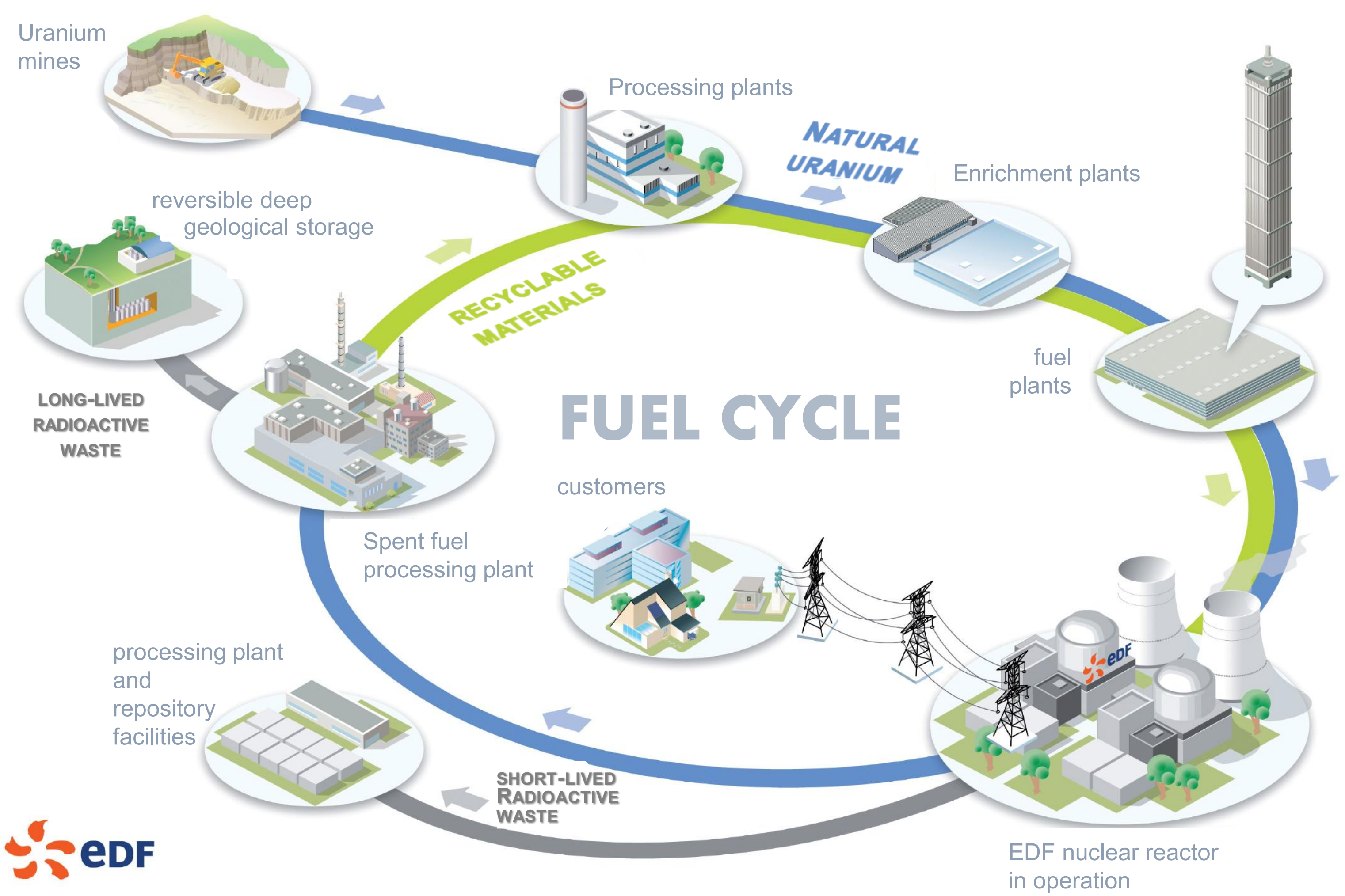
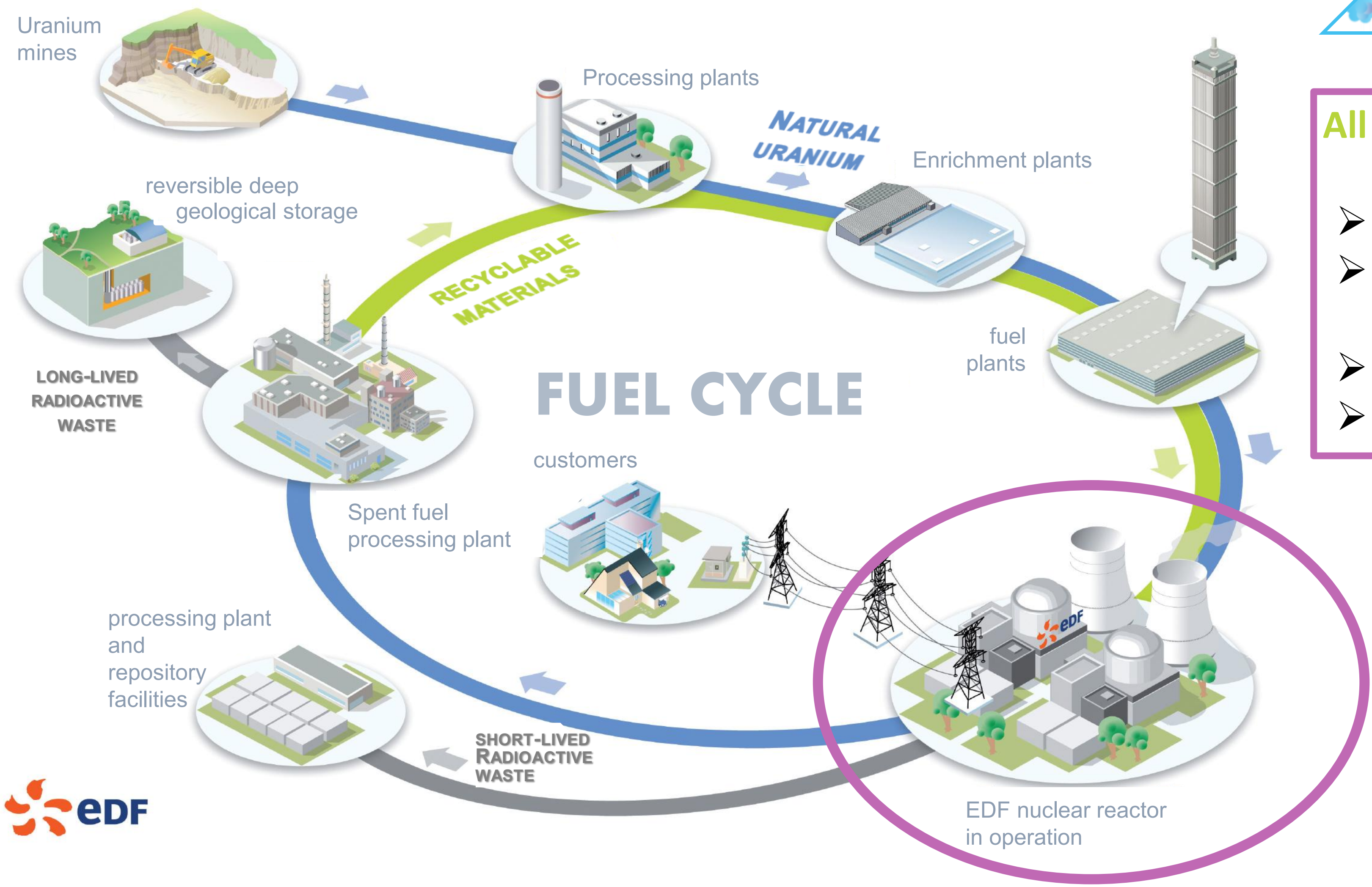


« fission technologies » cover

NUCLEAR DATA FOR FISSION TECHNOLOGIES

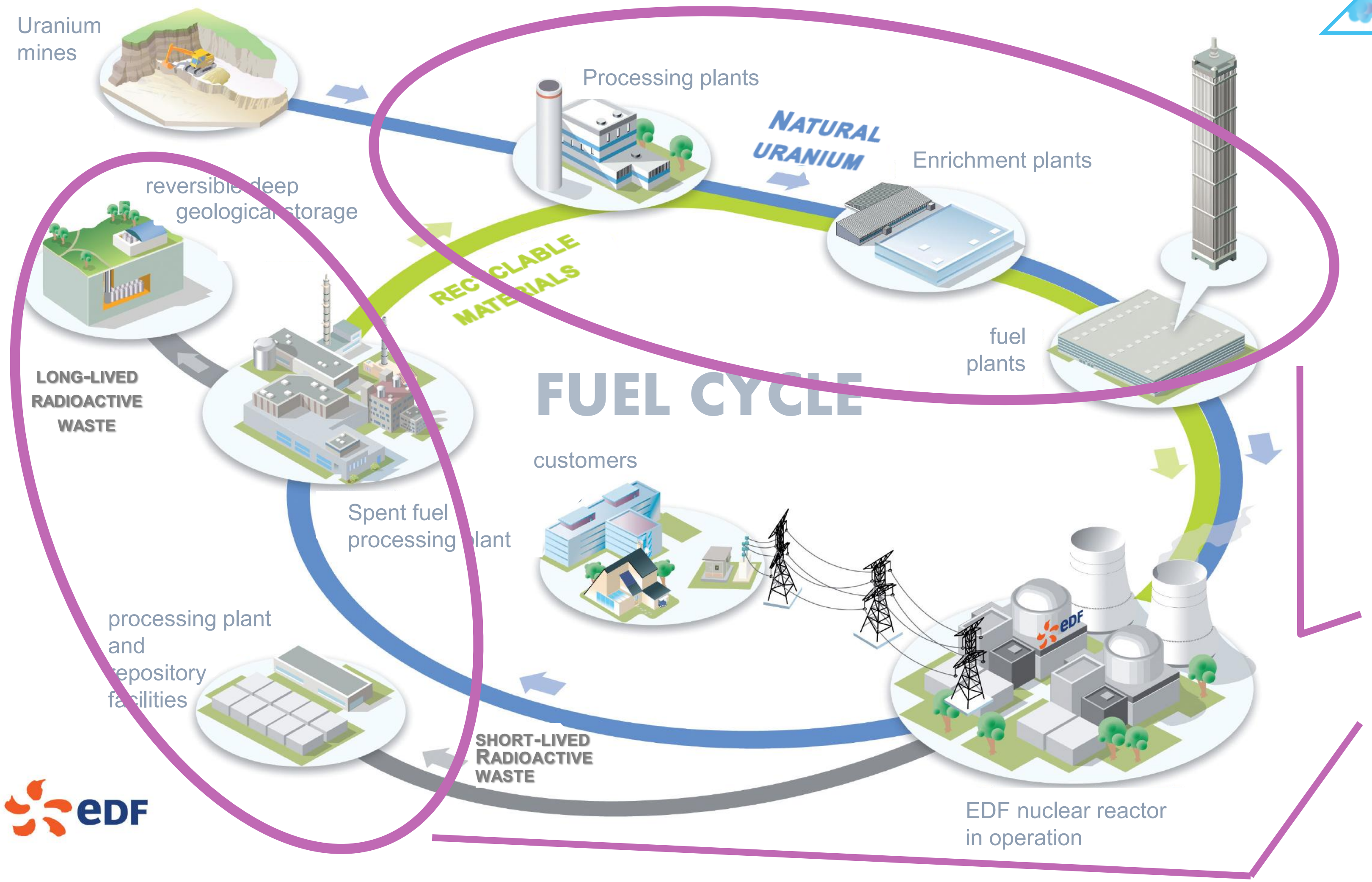


« fission technologies » cover

All reactor types :

- GEN III – LWR, BWR, HWR
- GEN IV – based on lead and sodium coolants, molten salts, ADS and SMR, AMR
- Research
- Propulsion systems

NUCLEAR DATA FOR FISSION TECHNOLOGIES



« fission technologies » cover

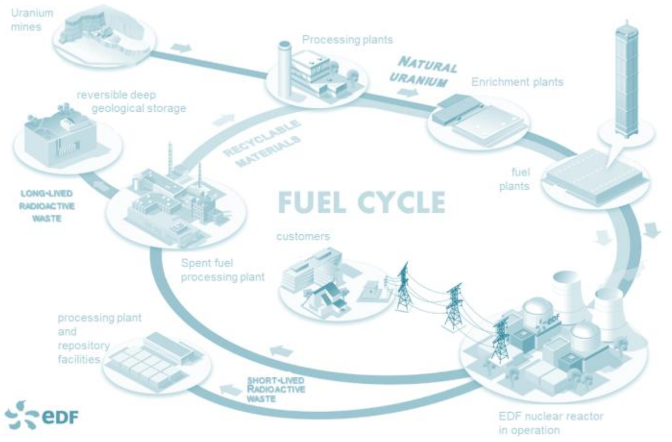
All reactor types :

- GEN III – LWR
- GEN IV – based on lead and sodium coolants, molten salts, ADS and SMR, AMR
- Research
- Propulsion systems

What ever reactor types :

- Fuel management
  [production, transport, storage, burnup, etc]
- Spent fuel management
  [transport, reprocessing, storage, disposal, etc]
- Radioprotection, safety, decommissioning etc

NUCLEAR DATA FOR FISSION TECHNOLOGIES



All the fuel cycle steps can/must be simulated

to answer to the safety authority requests & for economical issues

to study/design new reactor concepts & fuel cycles

Ex – reactors currently in operation :

for safety authorities, several quantities have to be calculated <u>with uncertainty</u>,

for various conditions (starting, stopping, during cycle and in accidental conditions)

- *K_{eff} (neutron multiplication factor)*
- *Power distribution in the reactor core*
- *Counter-reaction effects (doppler, temperature, void, moderator)*
- *Control rode efficiency*
- *Power/Activity factor*
- *Consumable poison*
- *Isotopic inventory*
- *Cycle length*
- *γ heating*
- *Reflector effect*
- *Radiotoxicity*
- *Residual power*
- *Radiation damages*

Ex – future reactors :

for the studies, design & licensing, these quantities have to be calculated too

NUCLEAR DATA FOR FISSION TECHNOLOGIES

The calculation/assessment of these quantities depends on **2 main parameters :** the neutron flux and the evolution of nuclides which are described **by 2 equations**

The story of a balance sheet : what is created, what disappears?

Neutron population is described by the **Boltzmann** equation

&

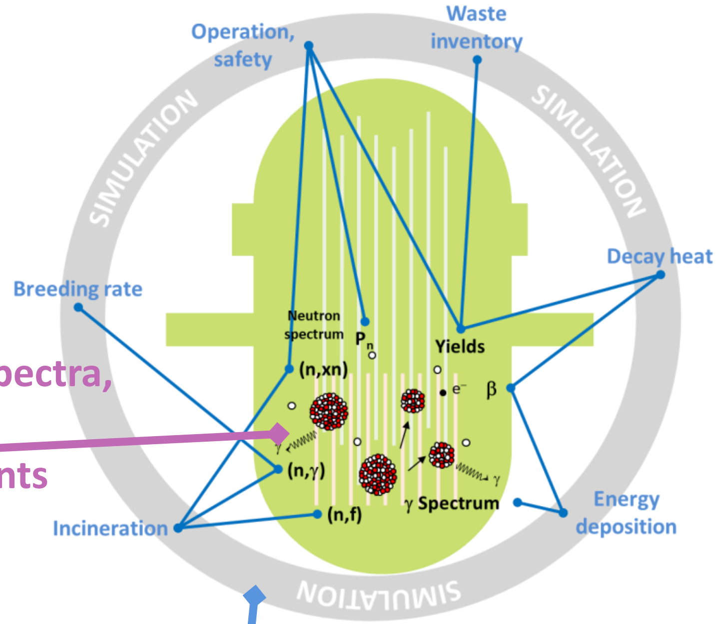
Nuclide evolution is described by the **Bateman** equations

$$\left[\frac{1}{v}\frac{\partial}{\partial t} + \hat{\Omega}\cdot\vec{\nabla} + \Sigma\right]\psi(\vec{r},E,\hat{\Omega},t)$$
$$= \int_0^\infty dE' \int d\hat{\Omega}' \Sigma_s(\vec{r},E'\to E,\hat{\Omega}'\to\hat{\Omega})\psi(\vec{r},E',\hat{\Omega},t)$$
$$+\sum_x \frac{1}{4\pi}\int_0^\infty dE' \chi_s(\vec{r},E'\to E)\nu_x(E',E)\Sigma_{f,x}(E',\vec{r})\phi(\vec{r},E')$$
$$+S_{ext}(\vec{r},E,\hat{\Omega},t)$$

&

$$\frac{dc}{dt} = ([\sigma]\psi + [\lambda])c(t)\,;\quad c(t_0) = c_0$$

Reaction cross section,
fission yields,
neutron and γ multiplicity & spectra,
decay data,
total radioactive decay constants

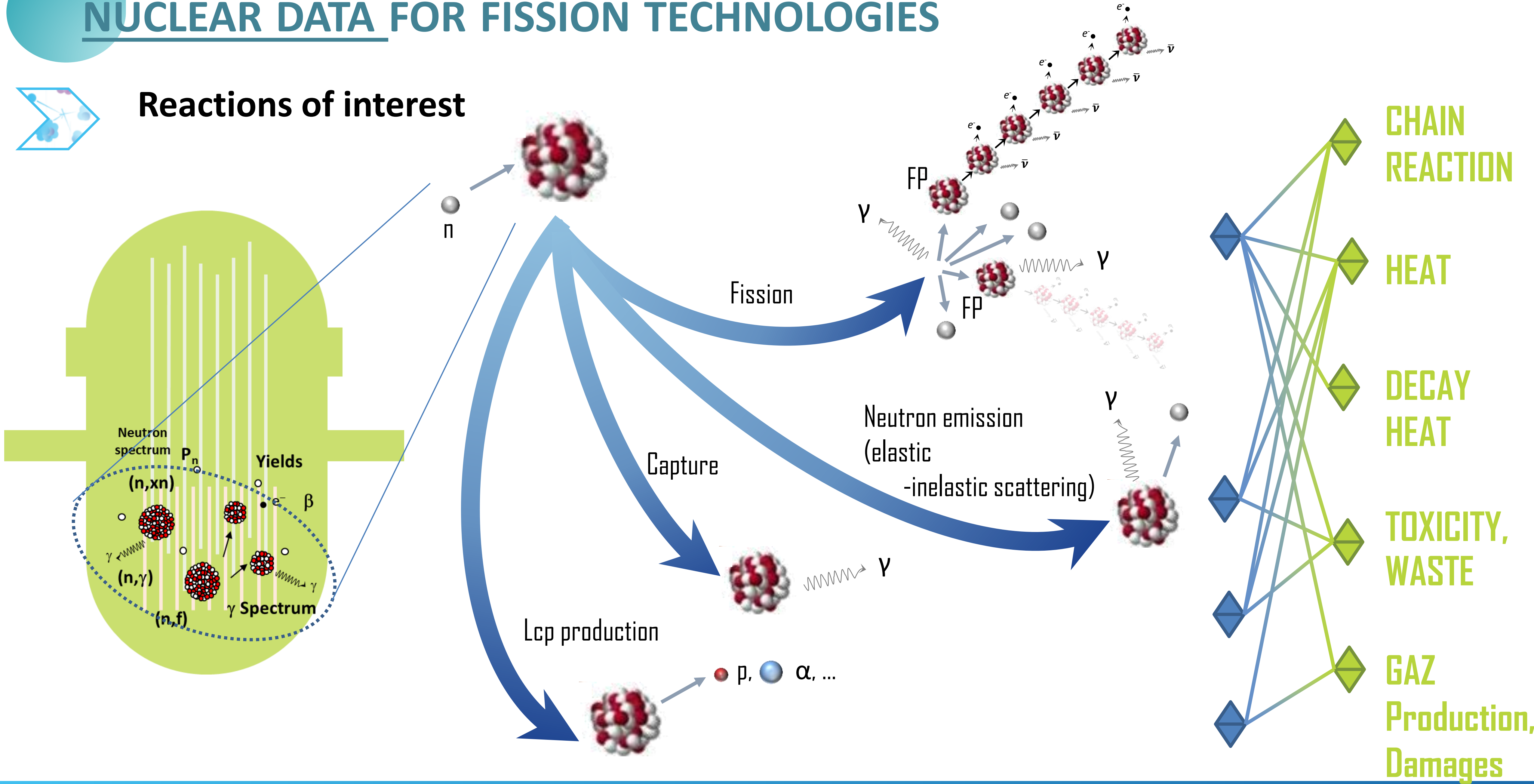


k_{eff}, power distribution, isotopic inventory, cycle length, γ heating, etc.

The coefficient are numbers called « **nuclear data** » related to nuclear physics process and constants.

NUCLEAR DATA FOR FISSION TECHNOLOGIES

Reactions of interest

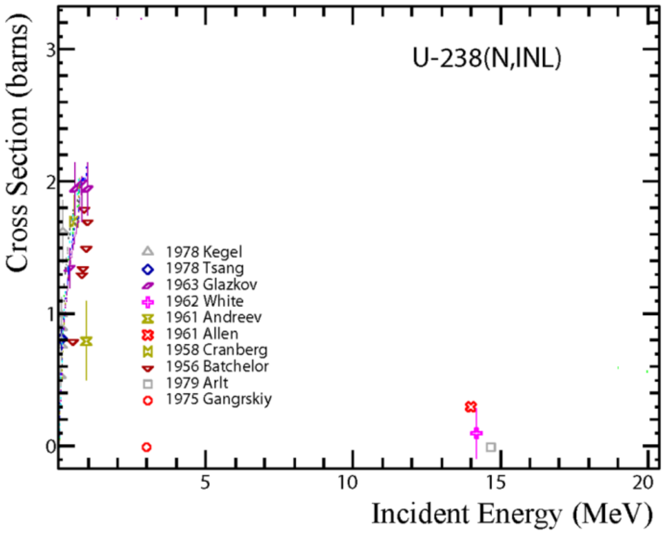


NUCLEAR DATA FOR FISSION TECHNOLOGIES

A short reminder :
evaluated nuclear data ("numbers")

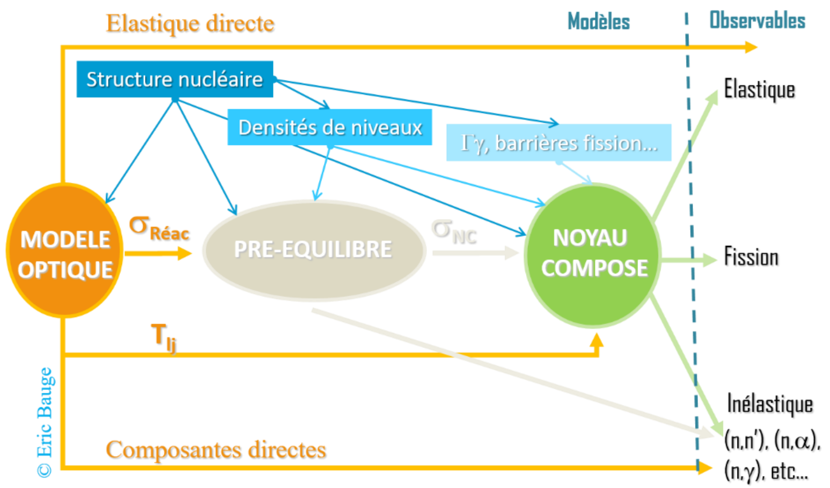
Experimental Data

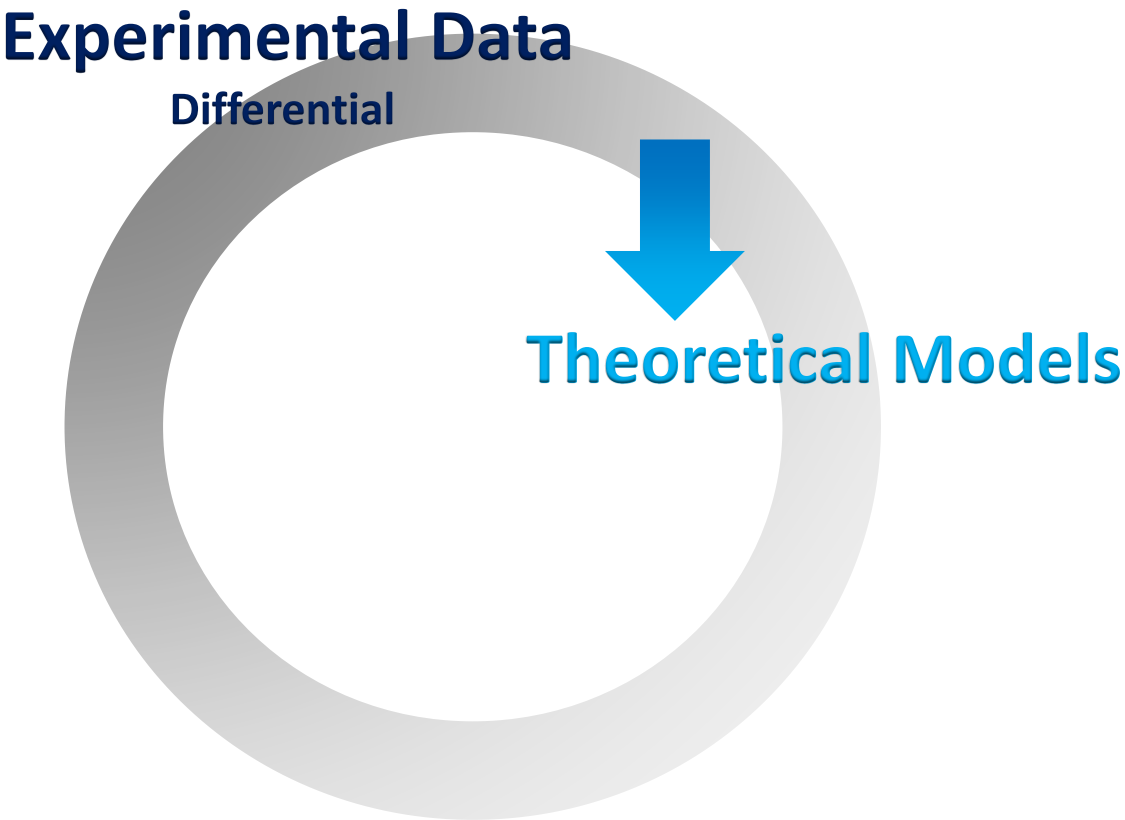
Differential



NUCLEAR DATA FOR FISSION TECHNOLOGIES

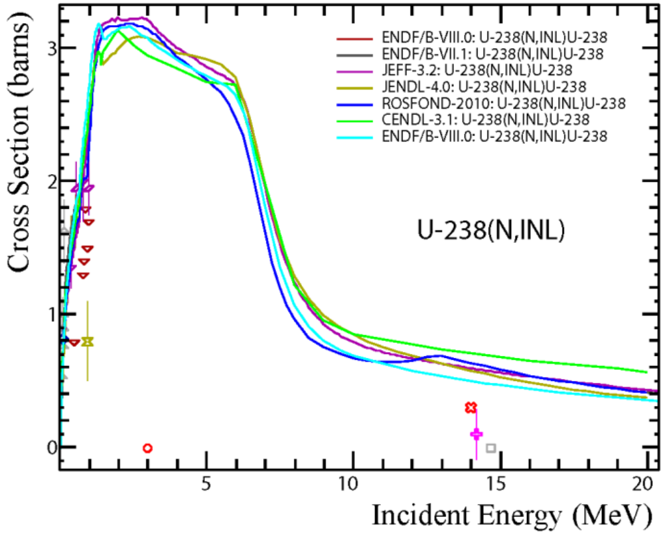
A short reminder : evaluated nuclear data ("numbers")

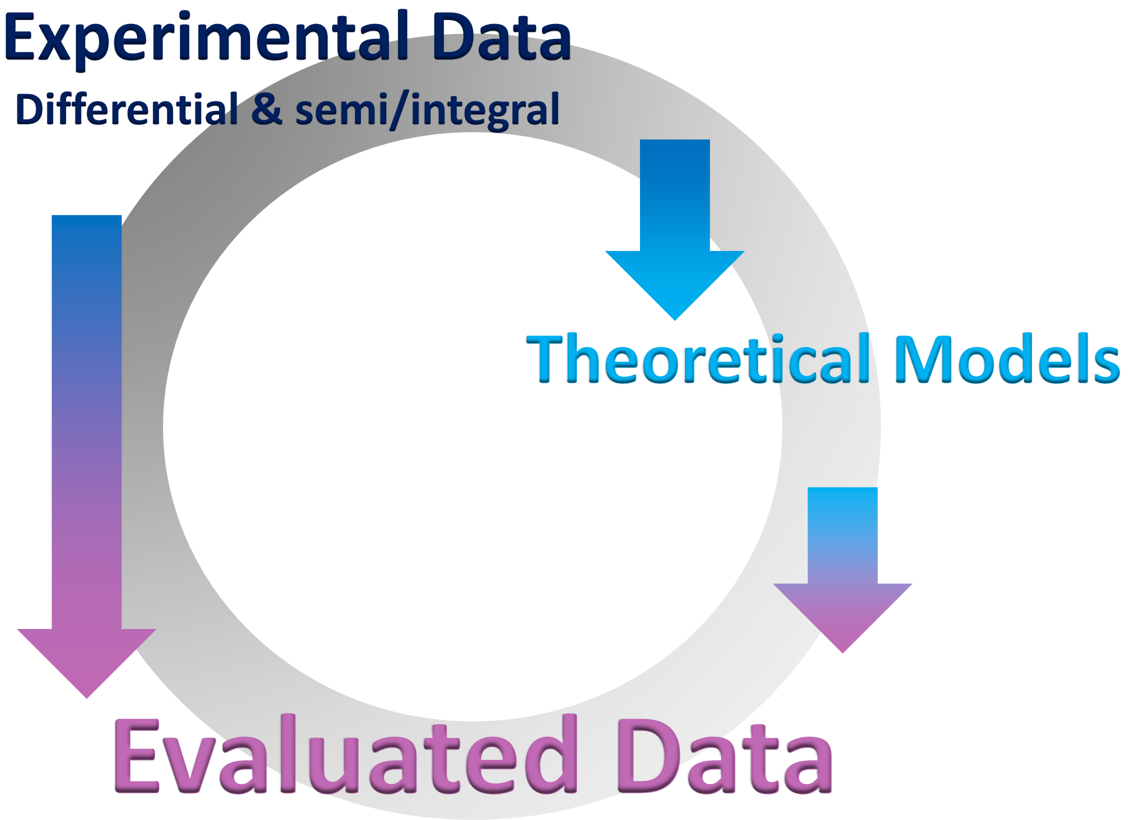




NUCLEAR DATA FOR FISSION TECHNOLOGIES

A short reminder : evaluated nuclear data ("numbers")






```
 6.215100+4 1.496234+2          0          0          0          06210 3 16  350
-5.596445+6-5.596445+6          0          0          1       1336210 3 16  351
        133          2                                             6210 3 16  352
 5.633849+6 0.000000+0 5.700000+6 1.580180-3 5.800000+6 6.073681-36210 3 16  353
 5.900000+6 1.347960-2 6.000000+6 2.690410-2 6.100000+6 4.687551-26210 3 16  354
 6.200000+6 7.598900-2 6.300000+6 1.119810-1 6.400000+6 1.518520-16210 3 16  355
 6.500000+6 2.016680-1 6.600000+6 2.528690-1 6.700000+6 3.144490-16210 3 16  356
 6.800000+6 3.780410-1 6.900000+6 4.433380-1 7.000000+6 5.136740-16210 3 16  357
 7.100000+6 5.833550-1 7.200000+6 6.576591-1 7.300000+6 7.306390-16210 3 16  358
 7.400000+6 8.033710-1 7.500000+6 8.746620-1 7.600000+6 9.434911-16210 3 16  359
 7.700000+6 1.010920+0 7.800000+6 1.078550+0 7.900000+6 1.140340+06210 3 16  360
 8.000000+6 1.202710+0 8.100000+6 1.257750+0 8.200000+6 1.313880+06210 3 16  361
 8.300000+6 1.367080+0 8.400000+6 1.416210+0 8.500000+6 1.463580+06210 3 16  362
 8.600000+6 1.506400+0 8.700000+6 1.546900+0 8.800000+6 1.586770+06210 3 16  363
 8.900000+6 1.623670+0 9.000000+6 1.656720+0 9.100000+6 1.687830+06210 3 16  364
 9.200000+6 1.717430+0 9.300000+6 1.745200+0 9.400000+6 1.771480+06210 3 16  365
 9.500000+6 1.796050+0 9.600000+6 1.817200+0 9.700000+6 1.837390+06210 3 16  366
 9.800000+6 1.858090+0 9.900000+6 1.876590+0 1.000000+7 1.893530+06210 3 16  367
```

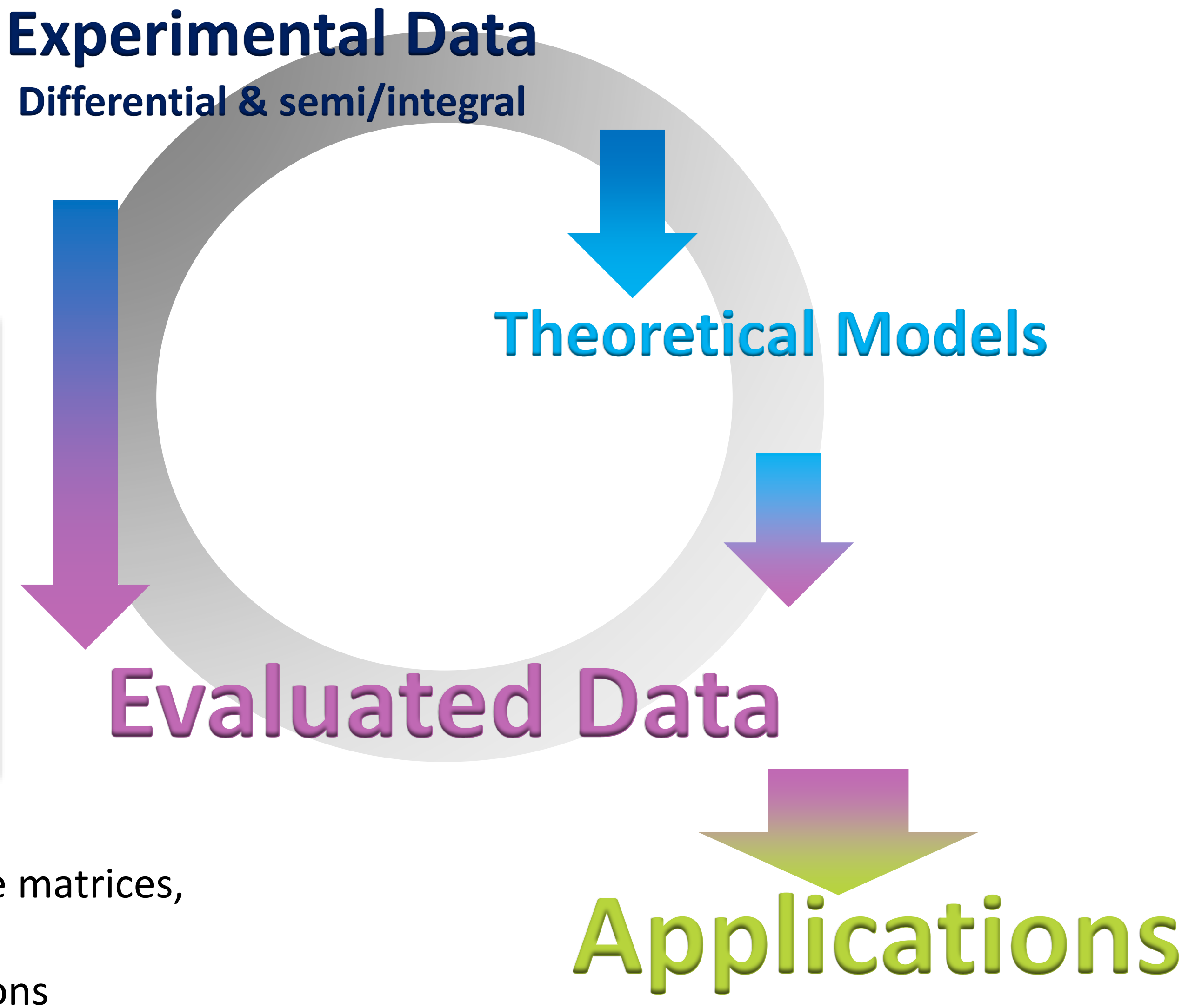

Evaluated data must be :

Robust – defined with uncertainties & covariance matrices, repeatable, traceability

NUCLEAR DATA FOR FISSION TECHNOLOGIES

A short reminder :
evaluated nuclear data ("numbers")

BENCHMARKING



Evaluated data must be :
Robust – defined with uncertainties & covariance matrices, repeatable, traceability
Validated – experimentally, useable for applications

OUTLINE

- NUCLEAR DATA FOR FISSION TECHNOLOGIES
  What are we talking about?

- **DEFINITION OF NEEDS**

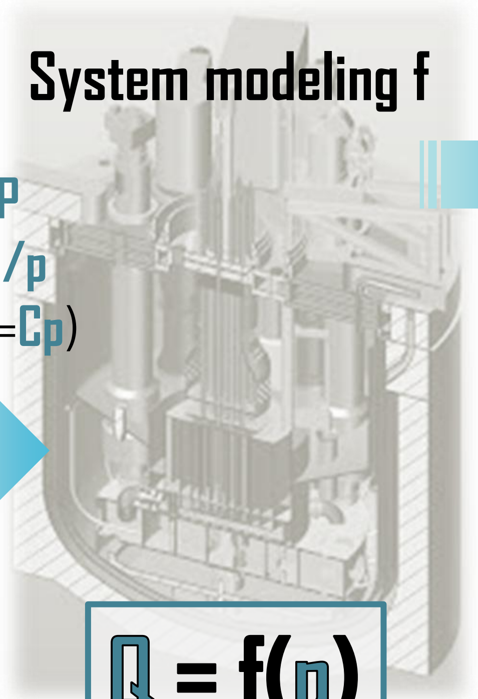
- EXPERIMENTAL CHALLENGES (A FEW)

- BUILDING BRIDGES!

DEFINITION OF NEEDS

Sensitivity studies

System modeling f



Input parameters p

Parameter uncertainty $\Delta p/p$ (=C_p)

For an operation domain,

Design & safety quantity Q,

With target uncertainty C_Q (margins)

Sensitivity coefficient :

$S = p/Q \times (\partial Q/\partial p)$

$Q = f(p)$

Sensitivity analysis (perturbation) :

Output requirement C_Q -> **quality requirement** on **nuclear data** input p

ND uncertainty + uncertainty propagation

-> **assessment of ND improvement needs**

Target accuracy requirements

- First reference work made by SG 26 (2008)

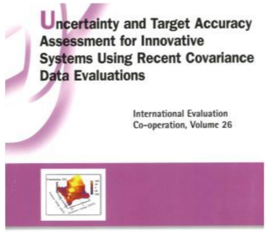
For 8 nuclear systems

- ABTR, EFR, SFR (Na)
- LFR, ADMAB (Pb)
- GFR (gas)

} Fast reactors

- PWR
- VHTR

} Thermal reactors



M. Salvatores and R. Jacqmin. Nuclear Science- NEA/WPEC-26, Vol. 26, NEA No 6410., 2008.

- Updated in 2023 by SG 46 – TAR exercise with other reactor types

- MACRE, Moltex, Alfred, Astrid, ESFR, JSFR, Nuscale, MYRRHA

Oscar Cabellos and Mathieu Hursin. NEA/WPEC-26, Vol. 46, NEA No xxx., 2023.

DEFINITION OF NEEDS

List of requirements

Cross section, nubar

SG26 & 46 : very tight target accuracy (%) requirements for several reactions & nuclides

HPRL : fed partially by the above mentioned work

NEA Nuclear Data High Priority Request List

HPRL Main | High Priority Requests (HPR) | General Requests (GR) | Special Purpose Quantities (SPQ): Standard, Dosimetry | New Request | EG-HPRL (SG-C)

Results of your search in the request list

Requests are shown from the following list(s):

High Priority (H)

Explanations of each column can be found in the table heads. To view the details of a request, please click on the **link symbol** after the request ID.
To send a comment on a particular entry, please view the request, and click on the **'letter'** symbol there.

ID	View	Target	Reaction	Quantity	Energy range	Sec.E/Angle	Accuracy	Cov	Field	Date
2H		8-O-16	(n,a),(n,abs)	SIG	2 MeV-20 MeV		See details	Y	Fission	12-SEP-08
8H		1-H-2	(n,el)	DA/DE	0.1 MeV-1 MeV	0-180 Deg	5	Y	Fission	16-APR-07
15H		95-AM-241	(n,g),(n,tot)	SIG	Thermal-Fast		See details		Fission	10-SEP-08
18H		92-U-238	(n,inl)	SIG	65 keV-20 MeV	Emis spec.	See details	Y	Fission	11-SEP-08
19H		94-PU-238	(n,f)	SIG	9 keV-6 MeV		See details	Y	Fission	11-SEP-08
21H		95-AM-241	(n,f)	SIG	180 keV-20 MeV		See details	Y	Fission	11-SEP-08
22H		95-AM-242M	(n,f)	SIG	0.5 keV-6 MeV		See details	Y	Fission	11-SEP-08
25H		96-CM-244	(n,f)	SIG	65 keV-6 MeV		See details	Y	Fission	12-SEP-08
27H		96-CM-245	(n,f)	SIG	0.5 keV-6 MeV		See details	Y	Fission	12-SEP-08
32H		94-PU-239	(n,g)	SIG	0.1 eV-1.35 MeV		See details	Y	Fission	12-SEP-08
33H		94-PU-241	(n,g)	SIG	0.1 eV-1.35 MeV		See details	Y	Fission	12-SEP-08
34H		26-FE-56	(n,inl)	SIG	0.5 MeV-20 MeV	Emis spec.	See details	Y	Fission	12-SEP-08
35H		94-PU-241	(n,f)	SIG	0.5 eV-1.35 MeV		See details	Y	Fission	12-SEP-08
37H		94-PU-240	(n,f)	SIG	0.5 keV-5 MeV		See details	Y	Fission	15-SEP-08
38H		94-PU-240	(n,f)	nubar	200 keV-2 MeV		See details	Y	Fission	15-SEP-08
39H		94-PU-242	(n,f)	SIG	200 keV-20 MeV		See details	Y	Fission	15-SEP-08
41H		82-PB-206	(n,inl)	SIG	0.5 MeV-6 MeV		See details	Y	Fission	15-SEP-08
42H		82-PB-207	(n,inl)	SIG	0.5 MeV-6 MeV		See details	Y	Fission	15-SEP-08
45H		19-K-39	(n,p),(n,np)	SIG	10 MeV-20 MeV		10	Y	Fusion	11-JUL-17
97H		24-CR-50	(n,g)	SIG	1 keV-100 keV		8-10	Y	Fission	05-FEB-18
98H		24-CR-53	(n,g)	SIG	1 keV-100 keV		8-10	Y	Fission	05-FEB-18
99H		94-PU-239	(n,f)	nubar	Thermal-5 eV		1	Y	Fission	12-APR-18
102H		64-GD-155	(n,g),(n,tot)	SIG	Thermal-100 eV		4	Y	Fission	09-MAY-18
103H		64-GD-157	(n,g),(n,tot)	SIG	Thermal-100 eV		4	Y	Fission	09-MAY-18
114H		83-BI-209	(n,g)Bi-210g,m	BR	500 eV-300 keV		10	Y	ADS,Fission	09-NOV-18
115H		94-PU-239	(n,tot)	SIG	Thermal-5 eV		1	Y	Fission	08-APR-19
116H		3-LI-0	(d,x)Be-7	SIG	10 MeV-40 MeV		10	Y	Fusion	31-MAY-21
117H		3-LI-0	(d,x)H-3	SIG,TTY	5 MeV-40 MeV		10	Y	Fusion	31-MAY-21
118H		68-ER-167	(n,g)	SIG,RP	0.01 eV-100 eV		2	Y	Fission	30-AUG-21
119H		17-CL-35	(n,p)	SIG	100 keV-5 MeV		5-8	Y	Fission	17-APR-22

Number of requests found: 30 (out of a total of 112 requests).

https://www.oecd-nea.org/dbdata/hprl/search.pl?vhp=on

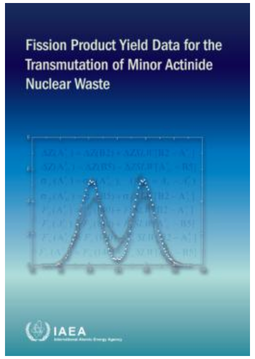
Decay heat, k_{eff} and reactivity vs burnup purposes

Fission yields

Work done in successive IAEA CRP's

"Fission product yield data for the transmutation of minor actinide nuclear waste" (2008)

https://www-nds.iaea.org/fycrp/



"Updating Fission Yield Data for Applications 2020-2025" INDC(NDS)-0817; https://doi.org/10.61092/iaea.qwbr-a6z9

decay data

Many IAEA CRP's works and documents

Essential tools & documentation to drive new measurements

Ex: 7 over the 11 (n,f) XS in HPRL have been measured at CERN n_TOF

DEFINITION OF NEEDS

Why do we still need new measurements? (summary)

- **New** experimental data
  where no or only rare data exists (e.g. GEN IV systems, SMR, AMR)
- **More accurate** experimental data (e.g. evaluation puzzle, HPRL, SG26 & 46)

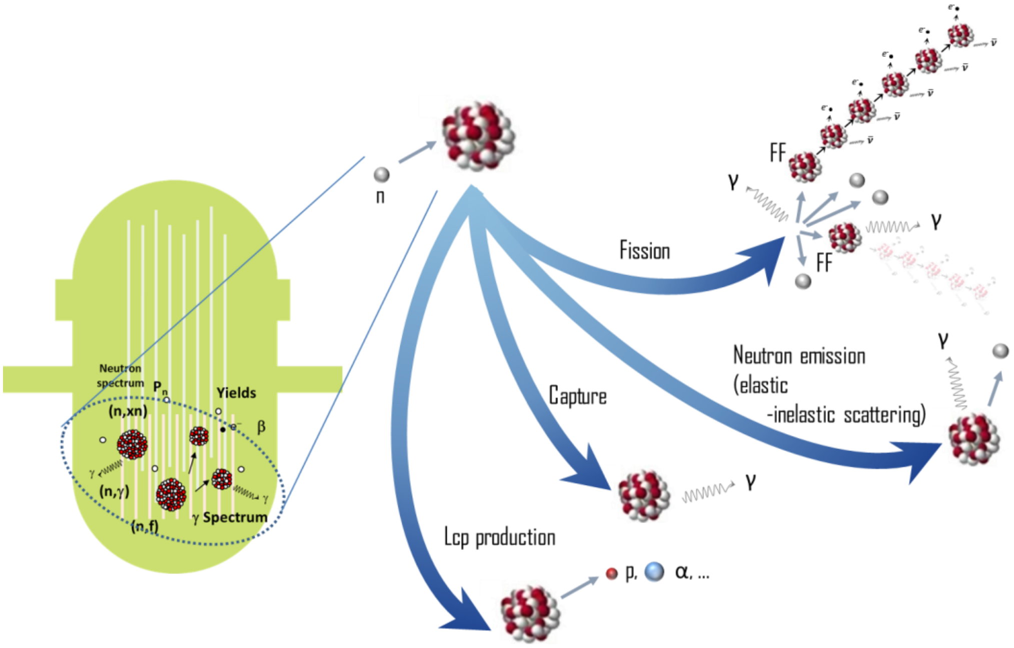
} Directly driven by technological needs

- Experimental data for **nuclear model improvement**
  Need to provide a systematic to calibrate the model especially for nuclei for which measurement is difficult (short lifetime, radioactive FP, Actinides)

OUTLINE

NUCLEAR DATA FOR FISSION TECHNOLOGIES

What are we talking about?



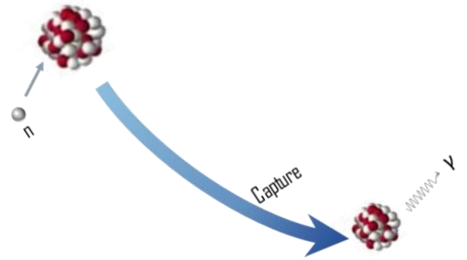
DEFINITION OF NEEDS

EXPERIMENTAL CHALLENGES (A FEW)

BUILDING BRIDGES!

EXPERIMENTAL CHALLENGES (A FEW)

NEUTRON CAPTURE



Impact on k_{eff}, production of long-lived actinides

Rather long list of requirements : **See in ND2025**

HPRL : ^{239,241}**Pu** *(2008)*; ^{53,50}**Cr** *(2008)*; ^{155,157}Gd *(2018)*; ^{209}**Bi** *(2018)*; ^{167}**Er** *(2021)*; ^{233}U *(2007)*; ^{242}Pu *(2007)*

SG26 & 46 : ^{235,238}U; ^{239,240,242}Pu; ^{241,242m,243}Am; ^{244}Cm

^{239}Pu

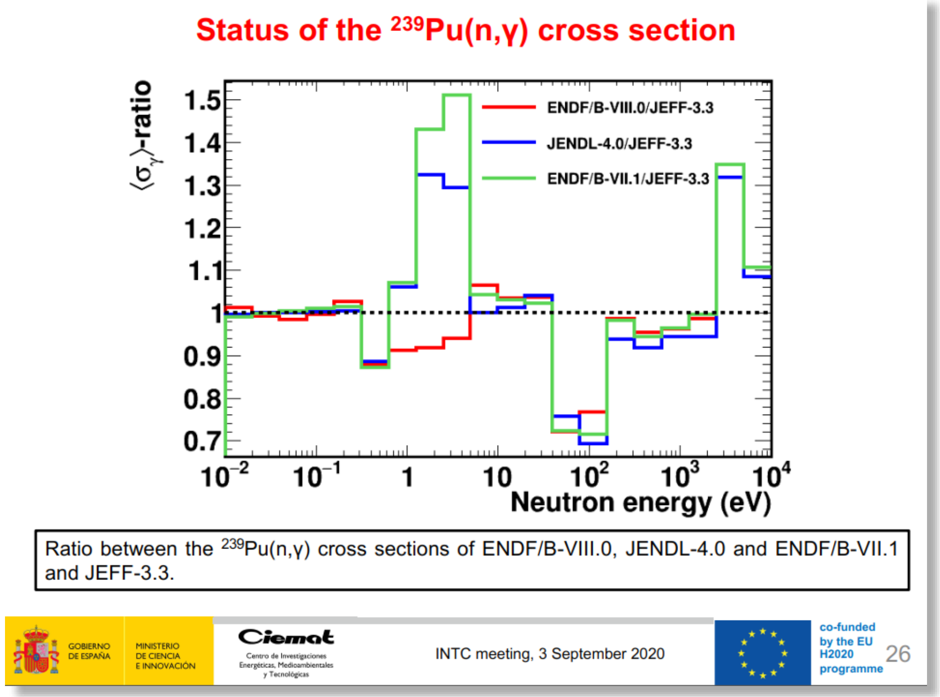
Important for next generation fast reactors (U/Pu cycle) or current reactors loaded with MOX fuel

a few measurements (only 2 allowing resonances analysis, *1971, 2014*)

Discrepancies between evaluations

Challenging measurement

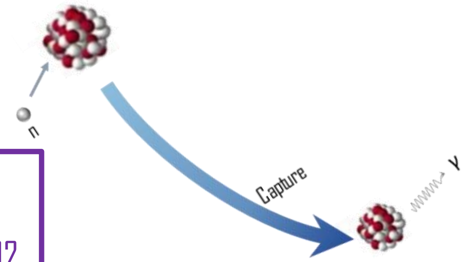
- Discrimination of γ's from fission
- Quality of the sample (reduce impurities)
- Robustness of detector (α from ^{239}Pu)
- Measurement on a broad energy range (th – 1 MeV)



V. Alcayne et al., « Proposal: measurement of 239Pu(n,γ) and α–ratio at EAR1 with TAC + fission detectors INTC 2020

EXPERIMENTAL CHALLENGES (A FEW)

NEUTRON CAPTURE



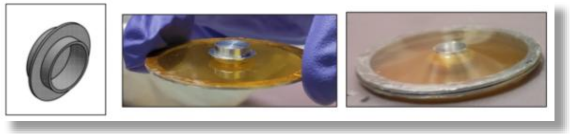
$^{239}Pu(n,\gamma)$ & α-ratio @ n_TOF

CIEMAT, University of Lodz, JRC-Geel, and the n_TOF collab

See in ND2025
Adrian Sanchez Caballero *et al.* #102
Aline Cahuzac #250 $^{241}Pu(n,\gamma)$

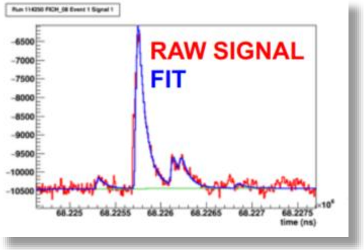
To meet the challenge :
Fission tagging configuration up to 1 keV & **Thick sample configuration**

- **NEW thick ^{239}Pu** (100 mg) encapsulated sample (*Prepared by JRC-Geel*).

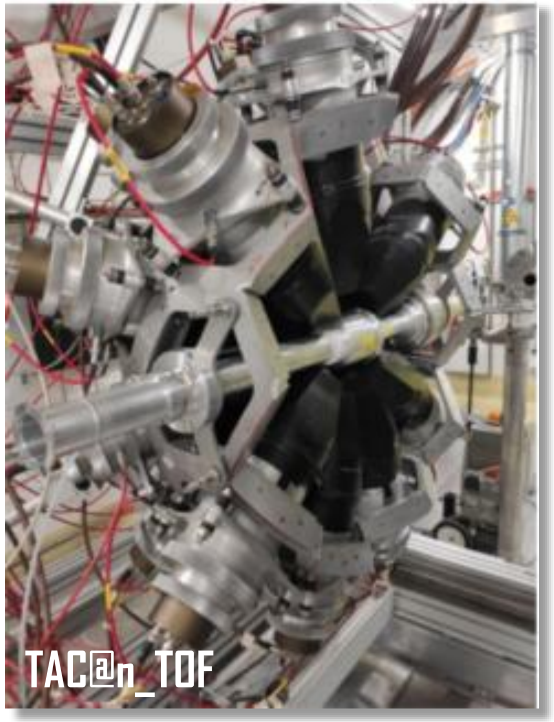


- **NEW fission chamber** (*University of Lodz*) with 10 x ~1mg ^{239}Pu targets (Mounted and tested with neutrons at *JRC-Geel/GELINA*).

- **NEW Li-doped neutron absorber** (designed by *CIEMAT* and fabricated by *CERN*).
- **NEW pipes** and **structure material** for the FC inside the TAC
- **NEW pulse shape analysis** routine for both FC and TAC



- **Expected uncertainties**
  FTC : 3% < 100 eV < 4-6% < 1 keV ;
  TSC : 100 eV < 3-4% < 10 keV.

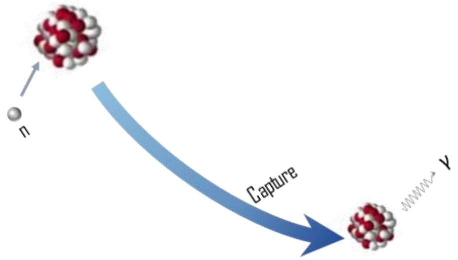


New & more accurate measurements

A. Sanchez Caballero *et al.* EPJ Web of Conferences **294**, 01003 (2024)
D. Cano Ott, JEFFDOC 2217

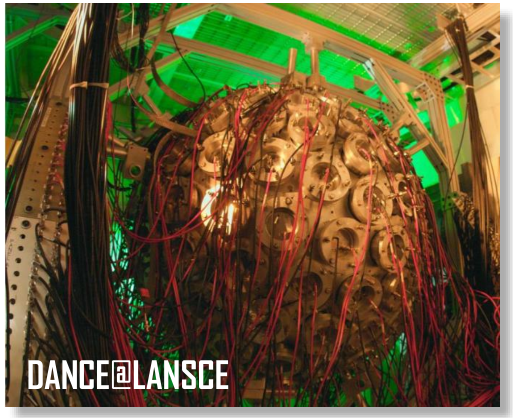
EXPERIMENTAL CHALLENGES (A FEW)

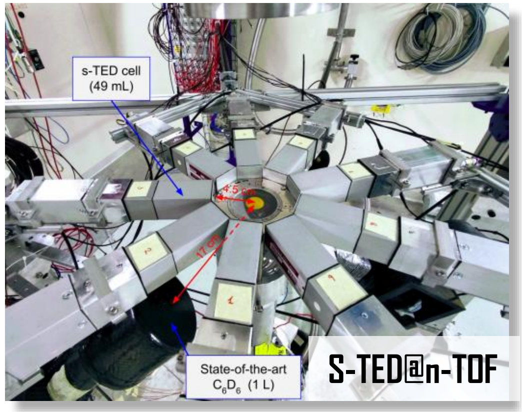
NEUTRON CAPTURE

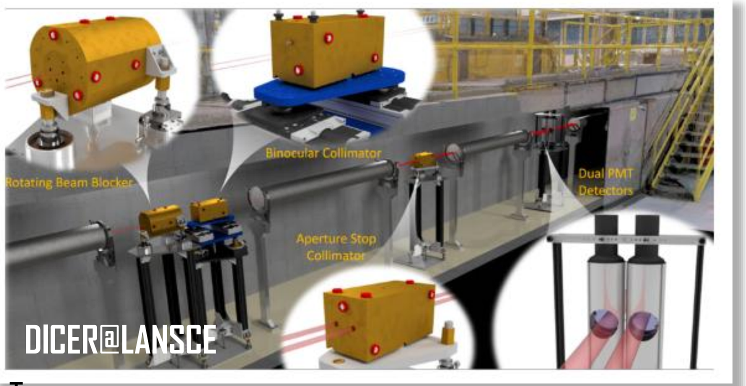


- Many experimental programs dedicated to (n, γ) measurement with important detectors development

  See the long list of **ND2025** presentations on (n,γ) experimental measurements







Transmission experiment

- Challenging measurement on short-lived nuclei

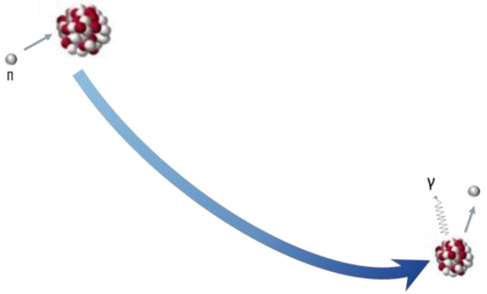
- Importance of encouraging exchanges with evaluators to better understand the needs then better constrain/design the exp. Project ; ex ^{238}U(n, γ)

APRENDE

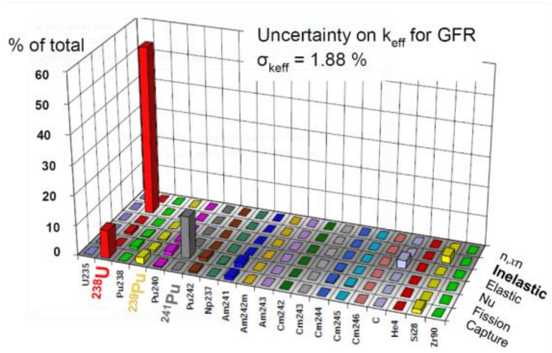
See in ND2025
Emilio Mendoza Cembranos *et al.* #602

EXPERIMENTAL CHALLENGES (A FEW)

NEUTRON SCATTERING



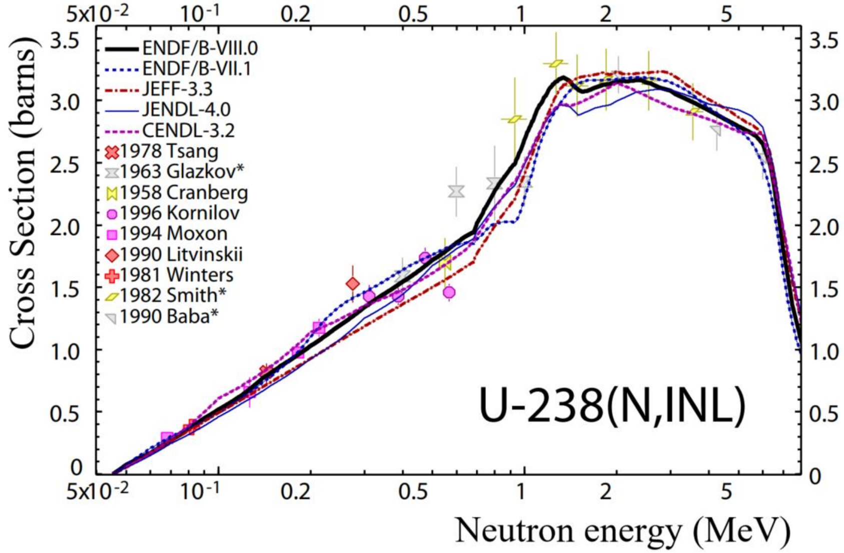
Impact on k_{eff}, peak power and doppler & void coefficient



Requirements : See in ND2025

HPRL : ^{238}U *(2008)*; ^{56}Fe *(2008)*; ^{206,208}Pb *(2008)*

SG26 & 46 : ^{207}Pb, ^{23}Na



^{238}U

Only few experimental data

Challenging measurement

- Complex neutron detection
- In actinides, γ measurement penalized by the high IC coefficient In high Z nuclei (first level de-excitation)
- Tight target accuracy

New & more accurate measurements & Nuclear model improvements

EXPERIMENTAL CHALLENGES (A FEW)

NEUTRON SCATTERING

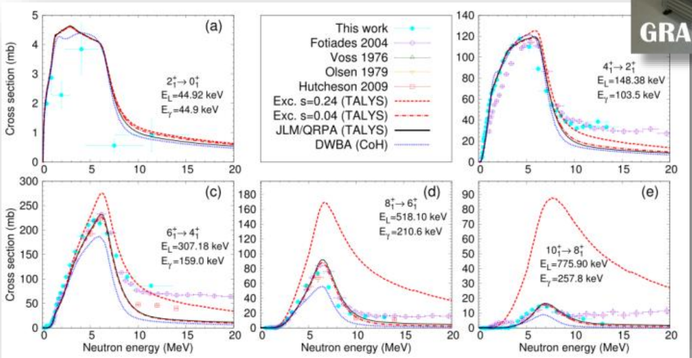
^{238}U(n, n'γ) & ^{238}U integral meas. & theory

CNRS/IPHC, CEA/DES & DAM, IAEA, LANL

A whole efficient package :

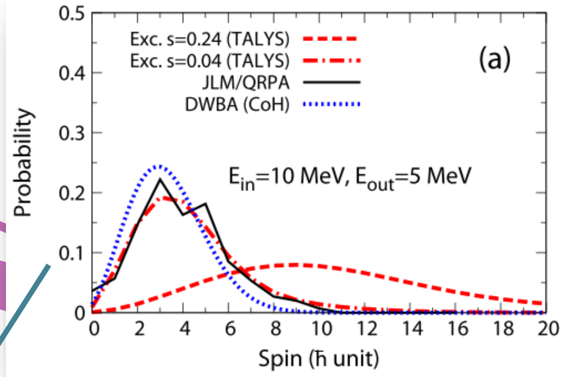
Differential ^{238}U(n, n'γ) XS measurement

2 new integral experiments for ^{238}U(n, n') XS validation: overestimation of the XS (~10%)



M. Kerveno, M. Dupuis et al., Phys. Rev. C **104**, 044605 (2021)

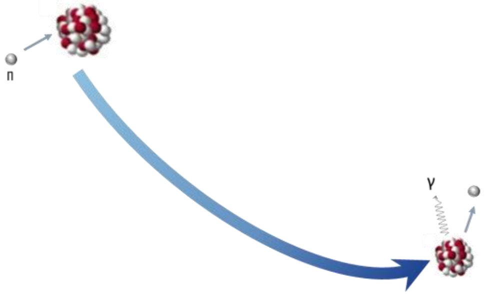
Constraint on modeling : Calibration of the pre-equilibrium spin cutoff



New spin cutoff used in the last JEFF upgrade

EXPERIMENTAL CHALLENGES (A FEW)

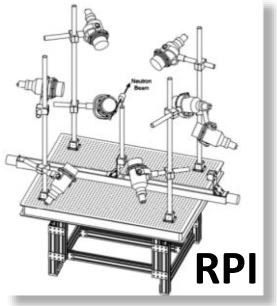
NEUTRON SCATTERING



Inelastic scattering

➢ **Importance to use all the experimental techniques and facilities available**

Prompt γ-ray spectroscopy, neutron detection, n-γ coincidences, quasi-differential measurements…



See in ND2025

GRAPhEME ; Greg Henning *et al.* #41
GAINS ; Andreea Oprea *et al.* #178,
MArian Boromiza *et al.* #136,
Jisk Knijpstra *et al.* #114,
Alexandru Negret *et al.* #48,
Adina Coman, *et al.* #95
MAELS : Maëlle Kerveno *et al.*, # 134
@nELBE: Roland Beyer *et al.*, #346
@TUNL : Anthony Ramirez *et al.*, #246
n_TOF ; matthew Birch *et al.*, #328

APRENDE

See in ND2025

ELISA ; Georgios Gkatis *et al.* #215
Maria Diakaki *et al.* #524,

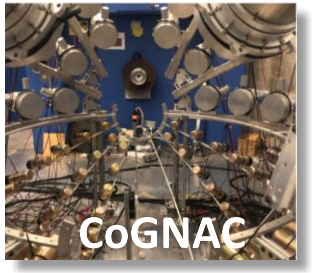
APRENDE

See in ND2025

GENESIS ; Thibault Laplace *et al.*, #518
CoGNAC : Keegan Kelly *et al.*, #117,118

See in ND2025

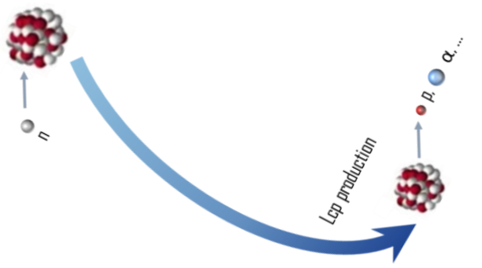
RPI ; Yaron Danon *et al.*, #79



- ❑ Still important measurements to come on actinides (ex ^{239}Pu with GRAPhEME)
- ❑ High resolution measurements on structural materials are mandatory to describe the region of high energy resonances (new initiative @ CERN/n_TOF)
- ❑ Measurement campaigns for (n, xn) reactions have started at the new GANIL-NFS facility

EXPERIMENTAL CHALLENGES (A FEW)

LCP PRODUCTION



Impact on reactivity in fast chloride molten salt reactor design

A few entries but new interest for MSFR reactor type: **See in ND2025**

HPRL : ^{16}O(n,α) *(2008)*, ^{39}K(n,p) *(2017)*, **^{35}Cl(n, p)** *0.1-5 MeV (2022)*

SG 46 : **^{35}Cl(n, p)** *0.5 -10 MeV (2023)*

K. Hanselman *et al.*, Phys. Rev. C **110**, 024609 (2024)

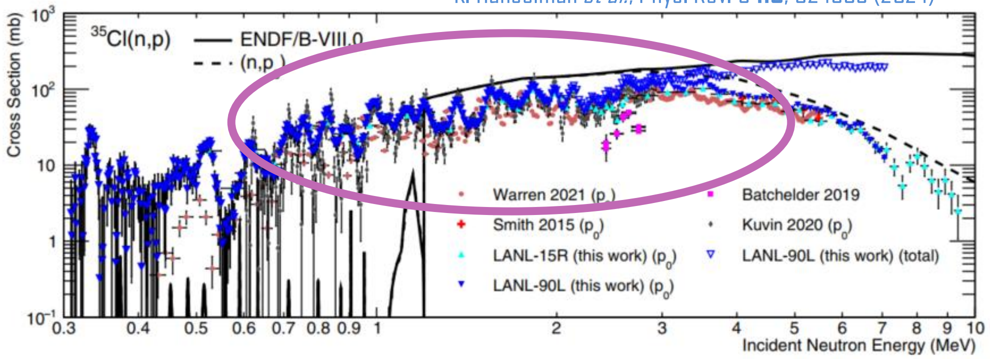


FIG. 4. Summary of newest data from WNR for ^{35}Cl(n, p) compared to available literature [1,20,21,23].

New
& more accurate measurements
& Nuclear model improvements

^{35}Cl A request from stakeholders

Needs of new and more accurate measurements above 100 keV

Experimental and theoretical efforts

- Several new measurements (LANL, CERN, NPL, …) with different techniques at different facilities
- Solve the discontinuous jump between R-matrix and HF approaches

See in ND2025
Daniel Smith et al. #619
Antonio Matinez et al. #421,

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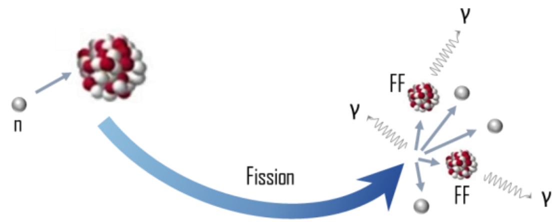
EXPERIMENTAL CHALLENGES (A FEW)

NEUTRON INDUCED FISSION



Still many entries in HPRL:

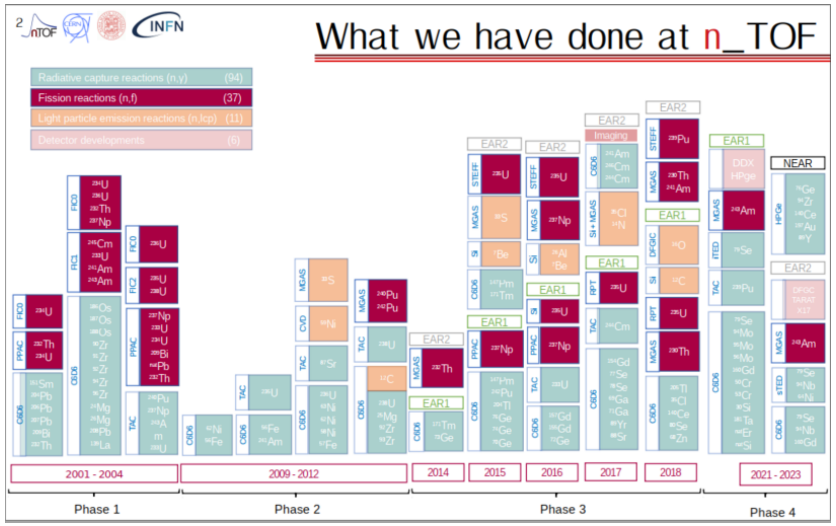
HPRL : ^{235}U, ^{237}Np, ^{238,239,240,241,242}Pu, ^{241,242m}Am, ^{244,245}Cm *(2008)*

SG 46 : ^{239,240}Pu, ^{238}U *(2023)*

A lot of (n,f) fission XS measurements exist but :

- "old" measurements lack the level of detail regarding uncertainty quantification (ex. ^{239}Pu)
- To avoid "renormalization" issues, new measurement on wide neutron energy ranges are required
- "non-fissile" actinides (n,f) XS are still experimentally poorly known (ex. ^{240,242}Pu, ^{243}Am)
- Investigations of (n,f) XS standard over a wide range of energy (extension to high energy > 100 MeV) HPRL SPQ-Standards

A. Manna *et al.*, CNR*24



See in ND2025
Lucas Snyder *et al.* #15

See in ND2025
Nikolaos Kyritsis *et al.* #422
Ludovic Mathieu *et al.* #225

See in ND2025
Maria Anastasiou *et al.* #64
Yonghao Chen *et al.* #264
Veatriki Michalopoulou *et al.* #394

New & more accurate measurements

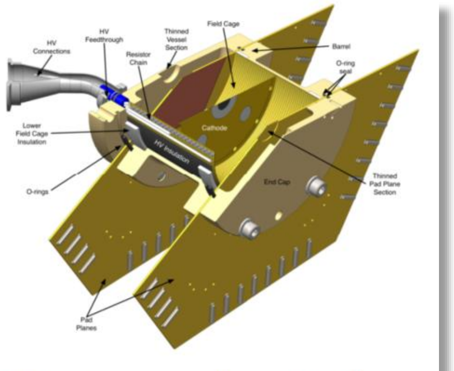


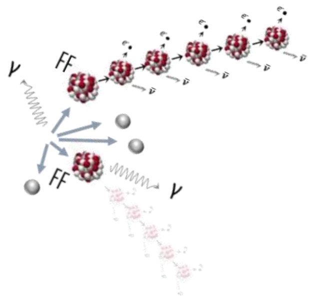
FIG. 3. A cutaway image of the fissionTPC. The neutron beam passes through the thinned sections of the vessel and pad plane. The actinide target is mounted in the center of the cathode. Taken from Fig. 2 of Ref. [19].

NIFFTE Fission TPC@WNR

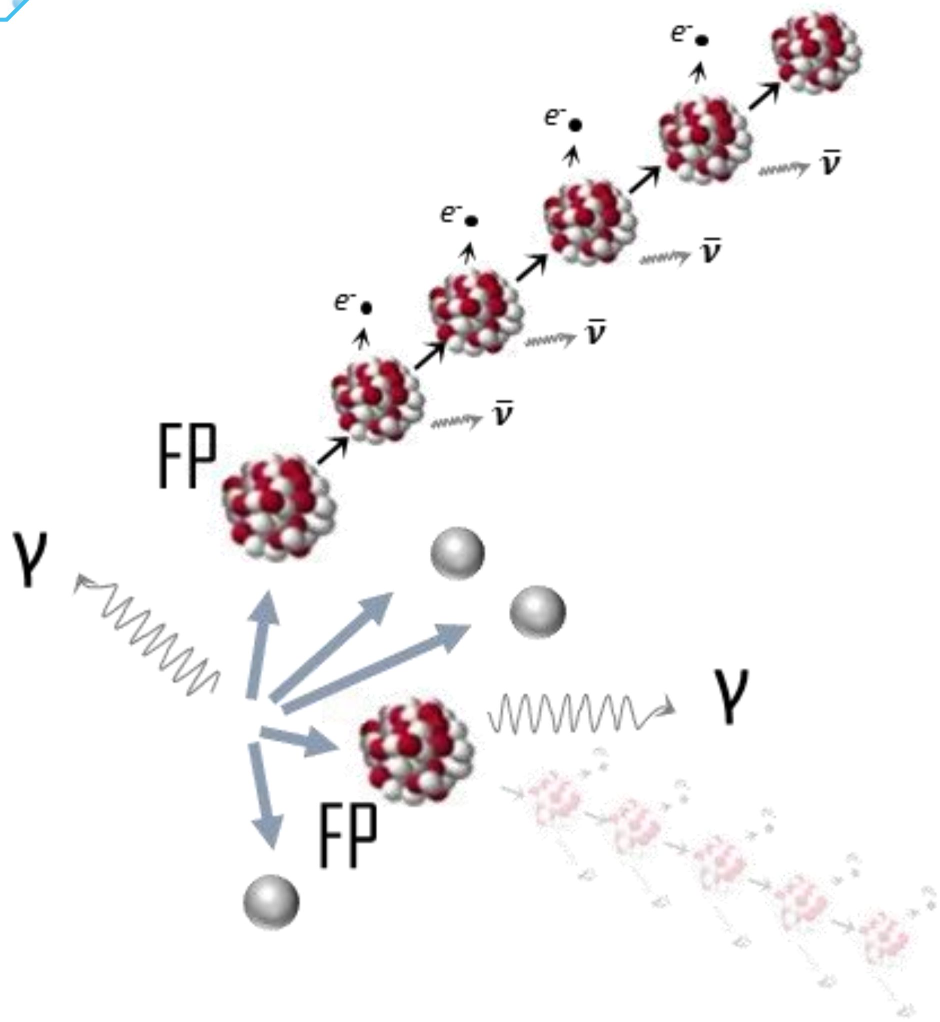
L. Snyder,et al., Nucl. Data Sheet **178** (2021) 1–40

EXPERIMENTAL CHALLENGES (A FEW)

POST-FISSION OBSERVABLES



Fission : a complex process



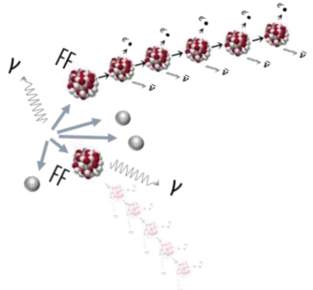
β^- emission Delayed γ	Decay heat (reactor safety),
$\bar{\nu}$ emission	Reactor monitoring, non-proliferation tool
Delayed neutron	Chain reaction control

Decay data

A. Algora

Fission Products	Heat, toxicity
Prompt neutrons	Chain reaction
Prompt γ	Heat

EXPERIMENTAL CHALLENGES (A FEW)



Fission Product Yields

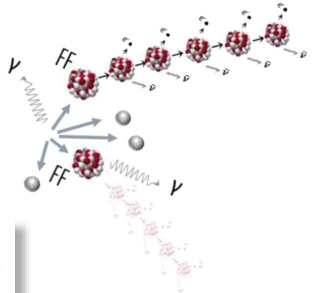
Impact :
- $Y(A, Z)$ **fission yields**
  - Inventory and radiotoxicity of spent fuel
  - Isotopic composition → Residual power
- **(Z, I) Kinetic energy dependence : excitation energy and spin distributions**
  - modeling prompt particle emission (n/γ) for material damage/heating in the reactor

A double challenge : accurate measurements & modeling
Novel interest in FY with emerging of fast reactor concepts and waste transmutation.
In the 2000s, data exist only for E_{th}, 500 keV and 14 MeV.

Challenges :
- Need to extend the systematic to new FPY **in the fast energy range** and **for minor actinides**
- Multi-observables measurements -FF(A,Z, **E***,J^{π})- before and after neutron evaporation, emitted neutrons & γ's
- Needs to produce accurate data with **covariance information** (E_{th} and above) for evaluation and codes validation
- For neutron induced fission experiments, keep the **accessibility of spectroscopic targets**

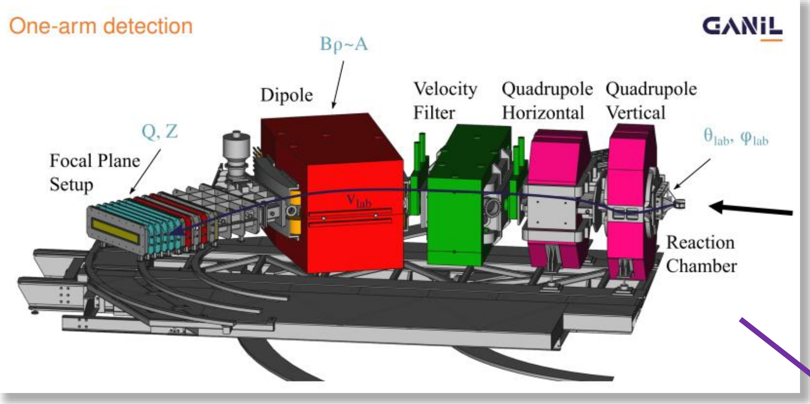
EXPERIMENTAL CHALLENGES (A FEW)

POST-FISSION OBSERVABLES



Fission Product Yields

Several initiatives to measure FPY
with more and more complete experimental setups
that give access to several quantities



Ex : The VAMOS (magnetic spectrometer) experiment @GANIL
using transfer/fusion induced reaction

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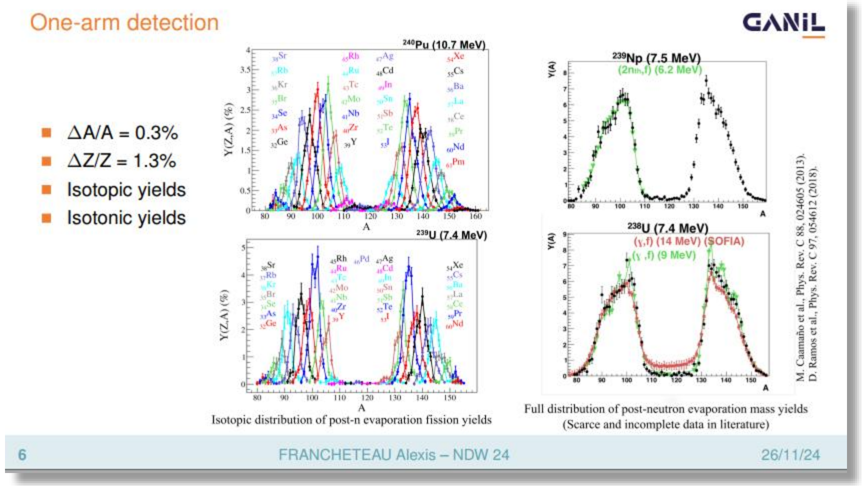


A. Francheteau, JEFFDOC 2368

- Access to a Large range of actinides
- Identification of the fissioning system:

Access to **excitation energy ΔE^* ~700 keV** (FWHM)

- Measurement of **isotopic yield Y(A,Z)**

$\Delta A/A = 0.3\%$ $\Delta Z/Z = 1.3\%$

- Two arms setup (FALSTAFF) : meas. of the 2nd fragment

2v method -> **pre-neutron isotopic yield and TKE**

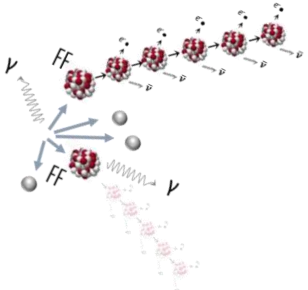
- Neutron detector

Neutron multiplicity & energy

See in ND2025
Indu Jangid *et al.* #85
Alexis Francheteau *et al.* #305
Alex Cobo Zarzuelo *et al.* #281

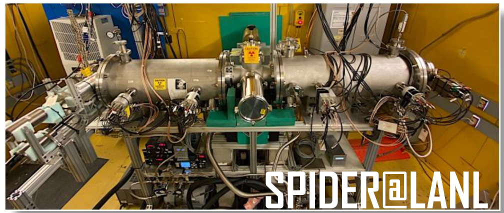
EXPERIMENTAL CHALLENGES (A FEW)

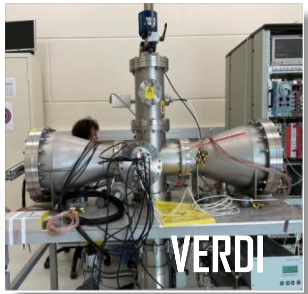
POST-FISSION OBSERVABLES



Fission Product Yields : A session dedicated at ND2025!
Which shows the dynamics of the topic!

2E-2v measurements at neutron beams
Challenge of the mass resolution
and isotopic identification!





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See in ND2025
Jean Eric Ducret *et al.* #116
A. M. Gomez Londono *et al.* #91

Measurements of isomeric ratio
to better understand the angular momentum in fission fragment, constrain models and enhance the predictive power of simulation tools (γ-heating in reactors)
LOHENGRIN@ILL, JYFLTRAP@IGISOL, ν-ball@ALTO

See in ND2025
Stephan Pomp *et al.* #99
Andreas Solders *et al.* #92
Henrik Haug *et al.* #595
Abdelhazize Chebboubi *et al.* #92

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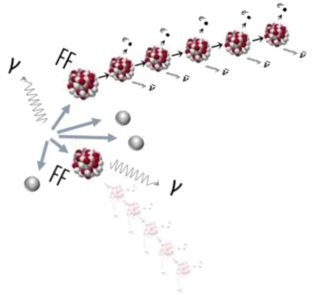
New
& more accurate measurements
& Nuclear model improvements

EXPERIMENTAL CHALLENGES (A FEW)

POST-FISSION OBSERVABLES



Prompt Fission Neutron / Gamma Spectra & multiplicity

Impact :

- **Core reactivity** (PFNS, nubar) ex: ^{239}Pu solution thermal-critical assemblies with high neutron leakage,
  $\Delta\overline{E}\ \sim 30\ keV\ (1-2\%)$-> Δk_{eff}~1000 pcm (1%) R. Capote *et al.*, Nucl. Data Sheets **131** (2016) 1–106
- **Vessel fluence :** reactor life time (PFNS)
- **Nuclear heating** (PFNS & PFGS) ex: Under-prediction of γ-heating by 10 - 28 % for ^{235}U and ^{239}Pu

Requirements :

- **IAEA CRP** in 2009 on PFNS to produce new PFNS evaluations with uncertainties for actinides.
- **HPRL** request in 2006 for ^{235}U and ^{239}Pu PFGS ; request for ^{244}Cm and ^{243}Am PFNS

Challenges :

- PFNS : solve discrepancies in measurements & improve measurements at low & high energies
  (En <100 keV , En> 10 MeV)
- PFGS : γ-discrimination between prompt-fission γ and neutron induced γ,
  wide-spread time distribution (from ps to μs)
- Neutrons and γ spectra are difficult to model

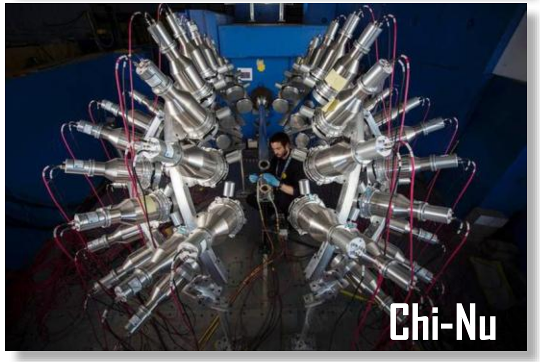
EXPERIMENTAL CHALLENGES (A FEW)

POST-FISSION OBSERVABLES

Prompt Fission Neutron Spectra & multiplicity

Huge measurement program @WNR (CEA-NNSA collaboration) **:**

➢ 20 years of instrumental developments to increase the quality of PFNS measurements!



Comparison of Results from … NUCLEAR DATA SHEETS K.J. Kelly, P. Marini *et al.*

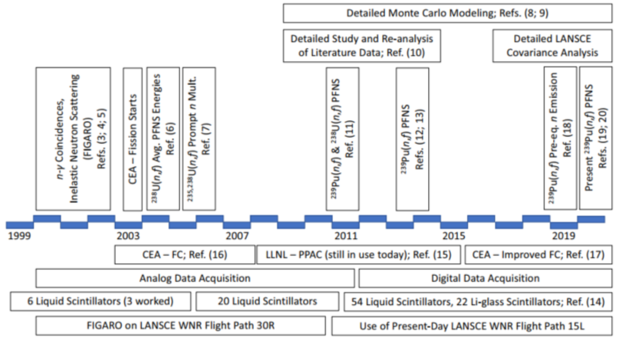


FIG. 1. Timeline of development and collaboration between the NNSA and CEA starting from analog electronics and limited particle detection capabilities to modern, state-of-the-art experimental environments, leading to the efforts to measure the ^{239}Pu(n,f) PFNS compared in this work. See the text for a description.

K.J. Kelly *et al.*, Nucl. Data Sheets **173** (2021) 42–53

See in ND2025
Matthew Devlin *et al.* #317

- ❑ Better neutron angular coverage, increase of the measured outgoing neutron energy range, more « transparent » FC, better statistics, …
- ❑ Important experimental data for evaluation but also for discrimination between the different theoretical approaches.

New
& more accurate measurements
& Nuclear model improvements

OUTLINE

- NUCLEAR DATA FOR FISSION TECHNOLOGIES
  What are we talking about?
- DEFINITION OF NEEDS
- EXPERIMENTAL CHALLENGES (A FEW)
- **BUILDING BRIDGES!**

BUILDING BRIDGES !

A take away message for experimentalists

Substantial experimental effort to provide new and high-quality nuclear data, over the last 30 years !
The "easy" measurements have been already done, some challenges still remain.

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UNDERSTAND THE NEEDS

- take advantage of the IAEA's and NEA **extraordinary documentary database** (CRP, WPEC,…)
- **Exchanges with evaluators** before and after the experiment to enhance the chance to meet the experimental needs and improve the evaluation process (action in progress in EU-APRENDE project https://indico.psi.ch/event/16894/)

APRENDE

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UNDERSTAND THE NEEDS

PROVIDE CONSOLIDATED DATA

- Apply the **FAIR principle**
- **Detailed document on the uncertainty quantification, potential bias** to improve the evaluation process
  (some templates exist ! Ex: D. Neudecker, A.M. Lewis, J.R. Vanhoy, et al., EPJ N 9 (2023) 31-32,33,35)
- Provide experimental **correlations and covariances**

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UNDERSTAND THE NEEDS

PROVIDE CONSOLIDATED DATA

Evaluators Community
& Users/Stakeholders

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NUCLEAR STRUCTURE DATA

- Many experimental techniques are based on **nuclear structure information**.

Lack of precise information.

Need for precise nuclear structure data for reactor studies, G.Henning et al. EPJ N 10, 6 (2024)

UNDERSTAND THE NEEDS
PROVIDE CONSOLIDATED DATA

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NUCLEAR STRUCTURE DATA

INNOVATIVE EXPERIMENTS

- Still challenge for nuclei with short half life (Xe-135, U-237, Np-239)

IAEA Technical Meeting on Neutron-induced Reactions on Short-lived Nuclei- 2025/08/25-29

- Take advantage of new development in fundamental nuclear physics research.

Ex : NECTAR (Nuclear rEaCTions At storage Rings) project

See in ND2025

Camille Berthelot *et al.* #253

UNDERSTAND THE NEEDS
PROVIDE CONSOLIDATED DATA

Evaluators Community
& Users/Stakeholders

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NUCLEAR STRUCTURE DATA

INNOVATIVE EXPERIMENTS

USE OF IA/DEEP LEARNING

- A real potential for complex data analysis or signal treatment

Ex : VAMOS++

M. Rejmund, A. Lemasson, Seven-dimensional trajectory reconstruction for VAMOS++, NIM A **1076**, (2025), 170445

UNDERSTAND THE NEEDS

PROVIDE CONSOLIDATED DATA

Evaluators Community & Users/Stakeholders

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- NUCLEAR STRUCTURE DATA
- INNOVATIVE EXPERIMENTS
- USE OF IA/DEEP LEARNING

Fondamental
Nuclear Physics Community

- UNDERSTAND THE NEEDS
- PROVIDE CONSOLIDATED DATA

Evaluators Community
& Users/Stakeholders

Building bridges !

A take away message for experimentalists

Substantial experimental effort to provide new and high-quality nuclear data, over the last 30 years !
The “easy” measurements have been already done, some challenges still remain.

Nuclear structure data
Innovative experiments
Use of IA/deep learning

Understand the needs
Provide consolidated data

Fondamental
Nuclear Physics Community

Evaluators Community
& Users/Stakeholders

Maintain :
- the capability to provide high quality samples
- the access to facilities
- attractivity to the next physicist generation

BUILDING BRIDGES !

A take away message for experimentalists

Substantial experimental effort to provide new and high-quality nuclear data, over the last 30 years !
The “easy” measurements have been already done, some challenges still remain.

- NUCLEAR STRUCTURE DATA
- INNOVATIVE EXPERIMENTS
- USE OF IA/DEEP LEARNING

- UNDERSTAND THE NEEDS
- PROVIDE CONSOLIDATED DATA

Fondamental
Nuclear Physics Community

National and International Bodies

Evaluators Community
& Users/Stakeholders

MAINTAIN :
- THE CAPABILITY TO PROVIDE HIGH QUALITY SAMPLES
- THE ACCESS TO FACILITIES
- ATTRACTIVITY TO THE NEXT PHYSICIST GENERATION

THANK YOU

David Bernard,
Emmeric Dupont,
Olivier Sérot,
Arjan Plompen,
Dimitri Rochman,
Gilles Noguere,
Stephan Oberstedt
et al.

In memory of Sylvain David