Le conseil scientifique de l'IN2P3

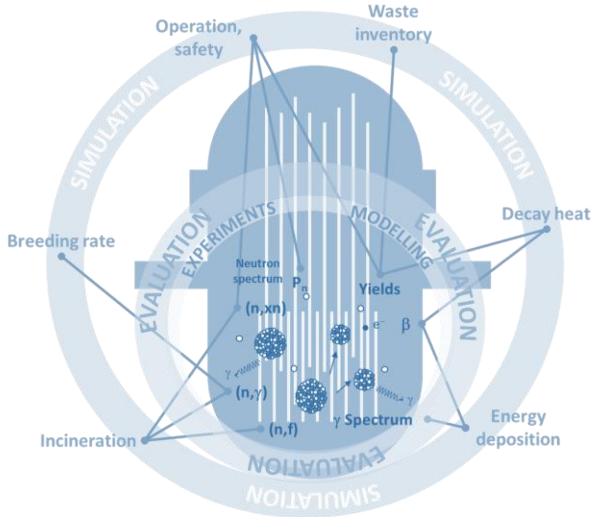
jeudi 3 février 2022,

« La physique nucléaire pour l'énergie »

Nuclear Data for Energy

M. Kerveno

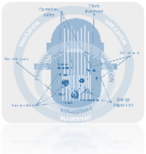
M. Kerveno *et al.* (IPHC),
M. Fallot *et al.* (SUBATECH),
L. Mathieu *et al.* (LP2i-Bordeaux),
F.R. Lecolley *et al.* (LPCC),
L. Audouin (IJCLab),
C. Sage *et al.* (LPSC)



SUMMARY

- CONTEXT
  - Nuclear Data for Energy
  - Evaluated Nuclear Data
- NUCLEAR DATA @ IN2P3
  - Organisation: MP OPALE
  - National & International Framework
- OPALE today & tomorrow
- CONCLUSIONS

SUMMARY



- CONTEXT

Nuclear Data for Energy

Evaluated Nuclear Data

- NUCLEAR DATA @ IN2P3

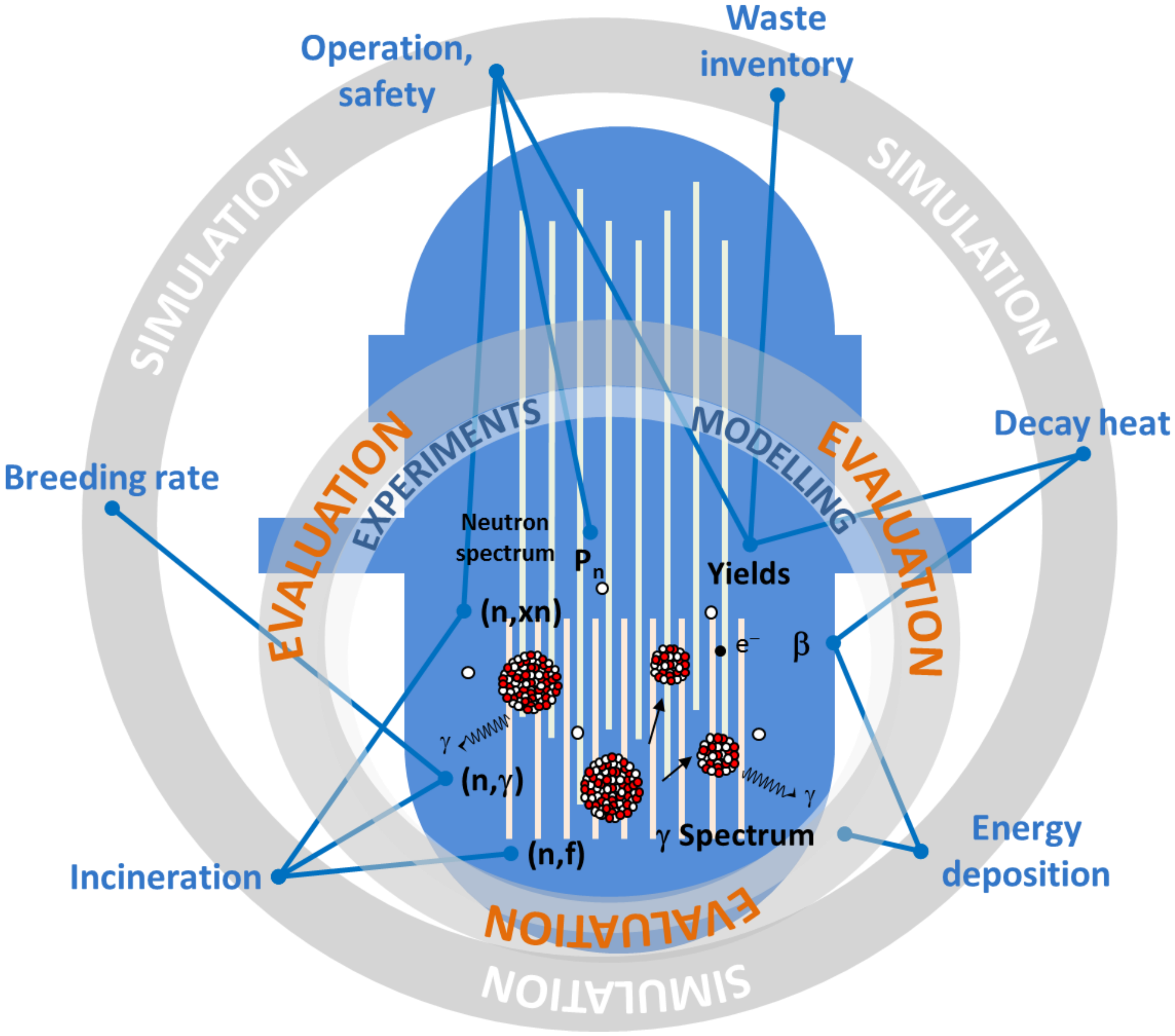
Organisation: MP OPALE

National & International Framework

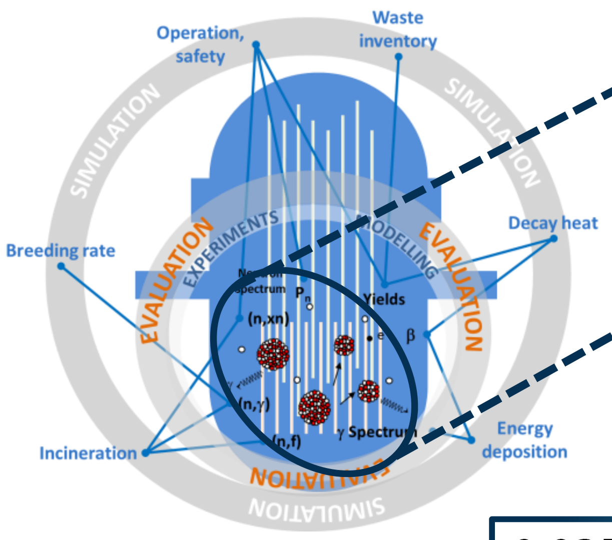
- OPALE today & tomorrow

- CONCLUSIONS

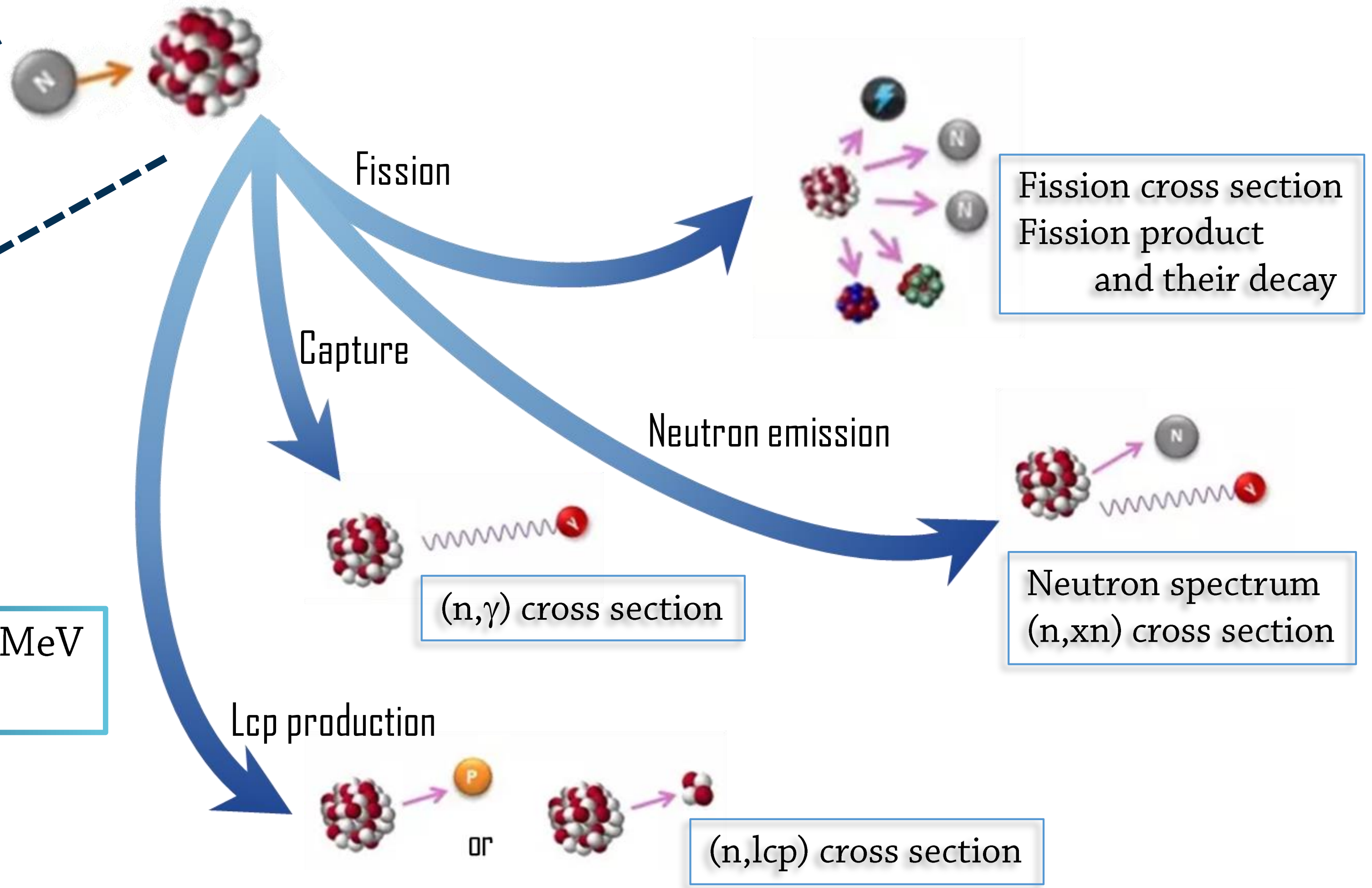
CONTEXT: Nuclear Data for Energy



CONTEXT: Nuclear Data for Energy

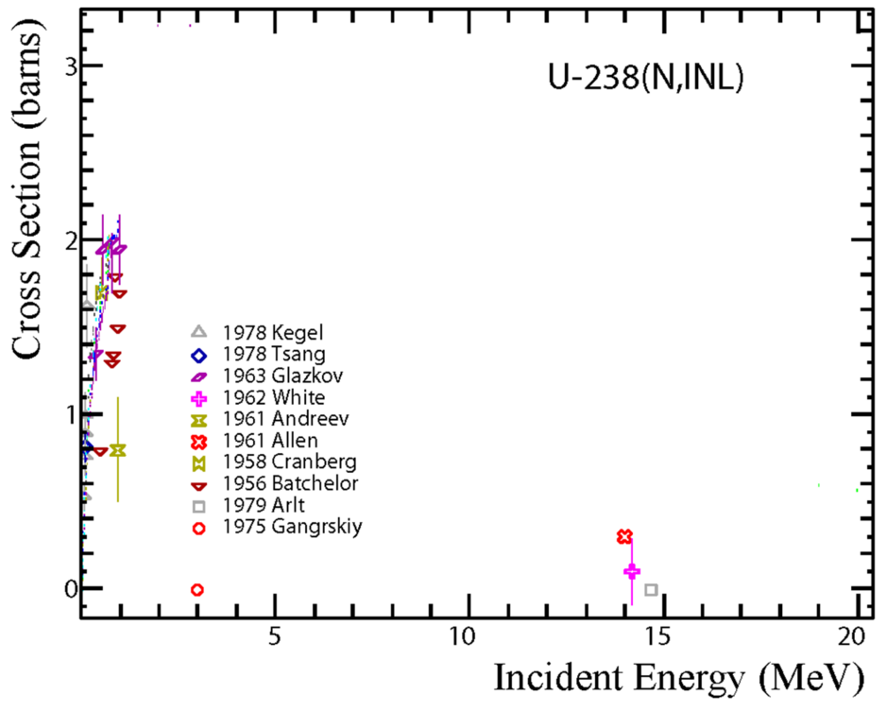


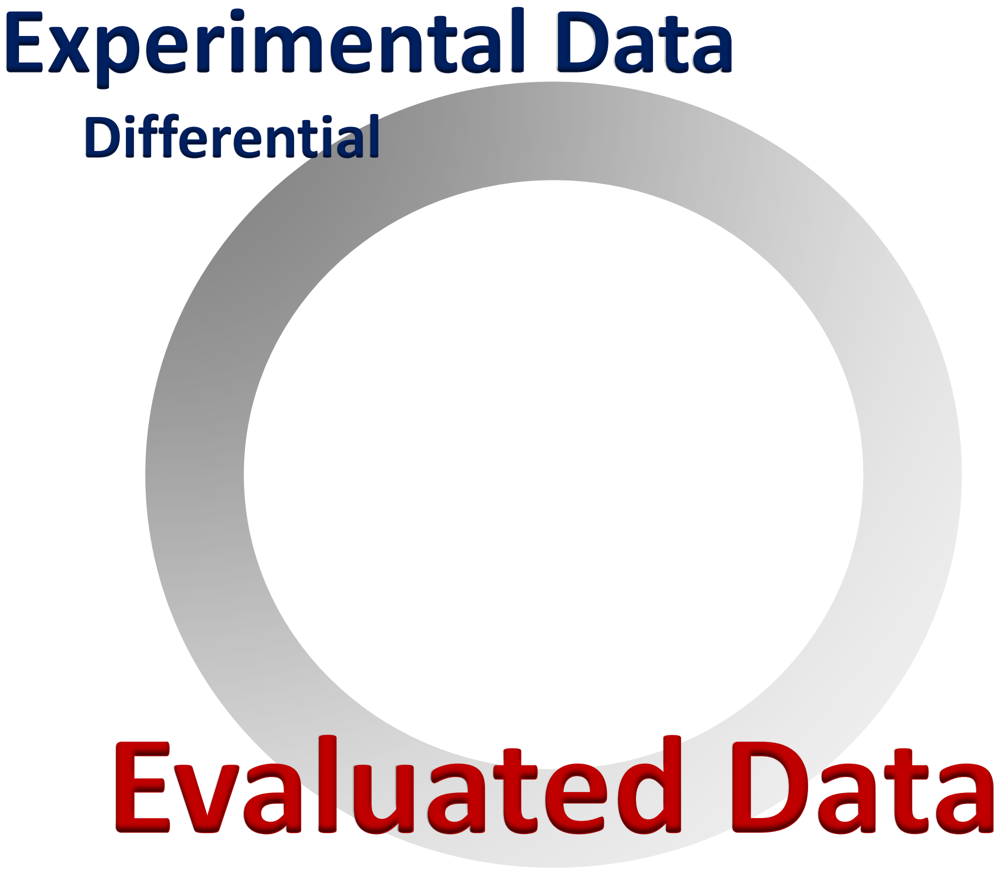
0.025 eV< **En**< a few 10 MeV
1<**Z**<98…

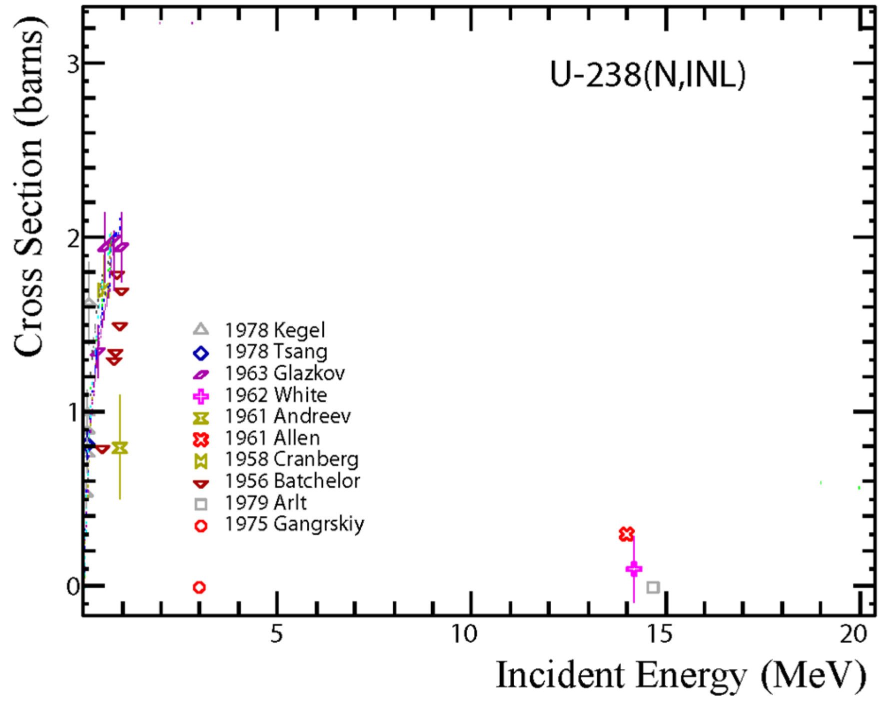


Evaluated nuclear data must provide **all required input data** (nuclear physics observables) to allow the **simulation of** such a **complex system.**

Evaluated Data

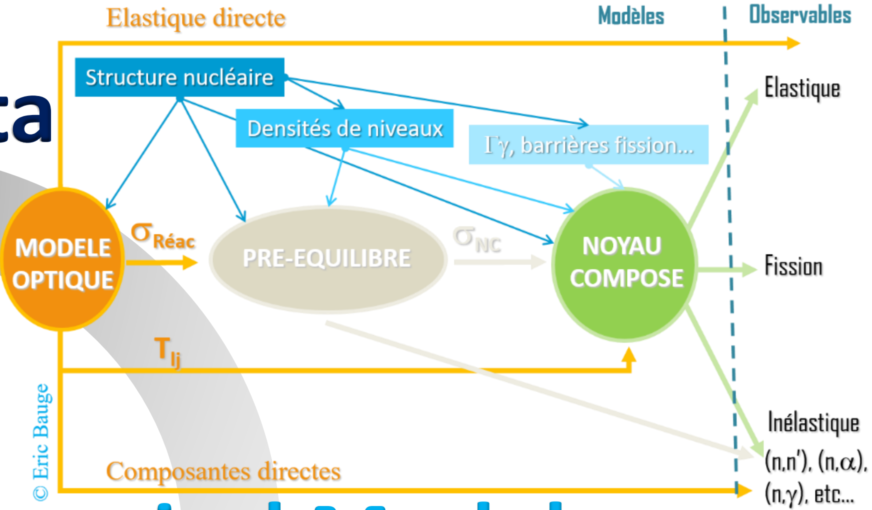

U-238(N,INL)
Cross Section (barns)
Incident Energy (MeV)
1978 Kegel
1978 Tsang
1963 Glazkov
1962 White
1961 Andreev
1961 Allen
1958 Cranberg
1956 Batchelor
1979 Arlt
1975 Gangrskiy


Experimental Data
Differential
Evaluated Data



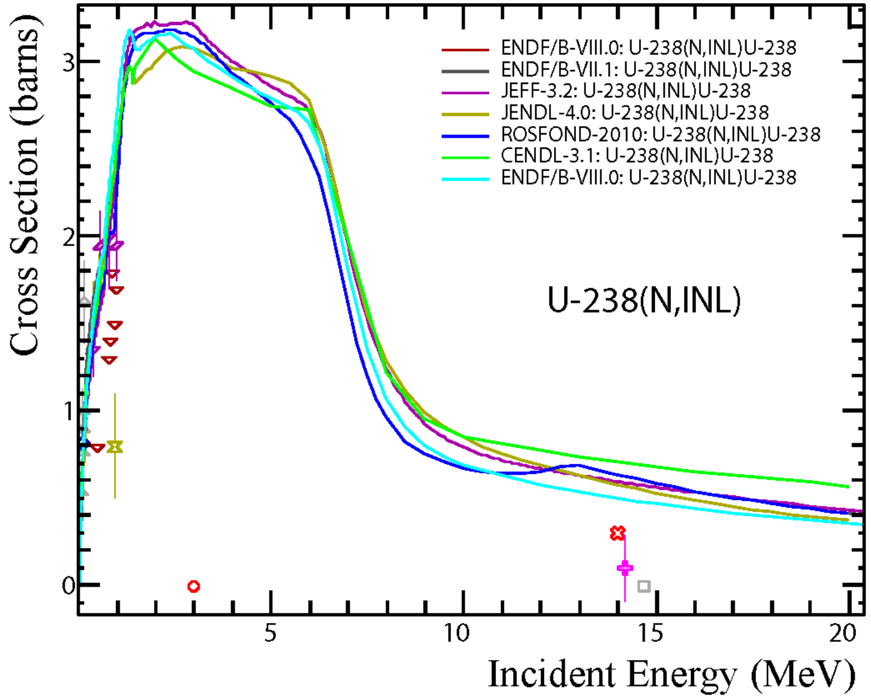
Experimental Data

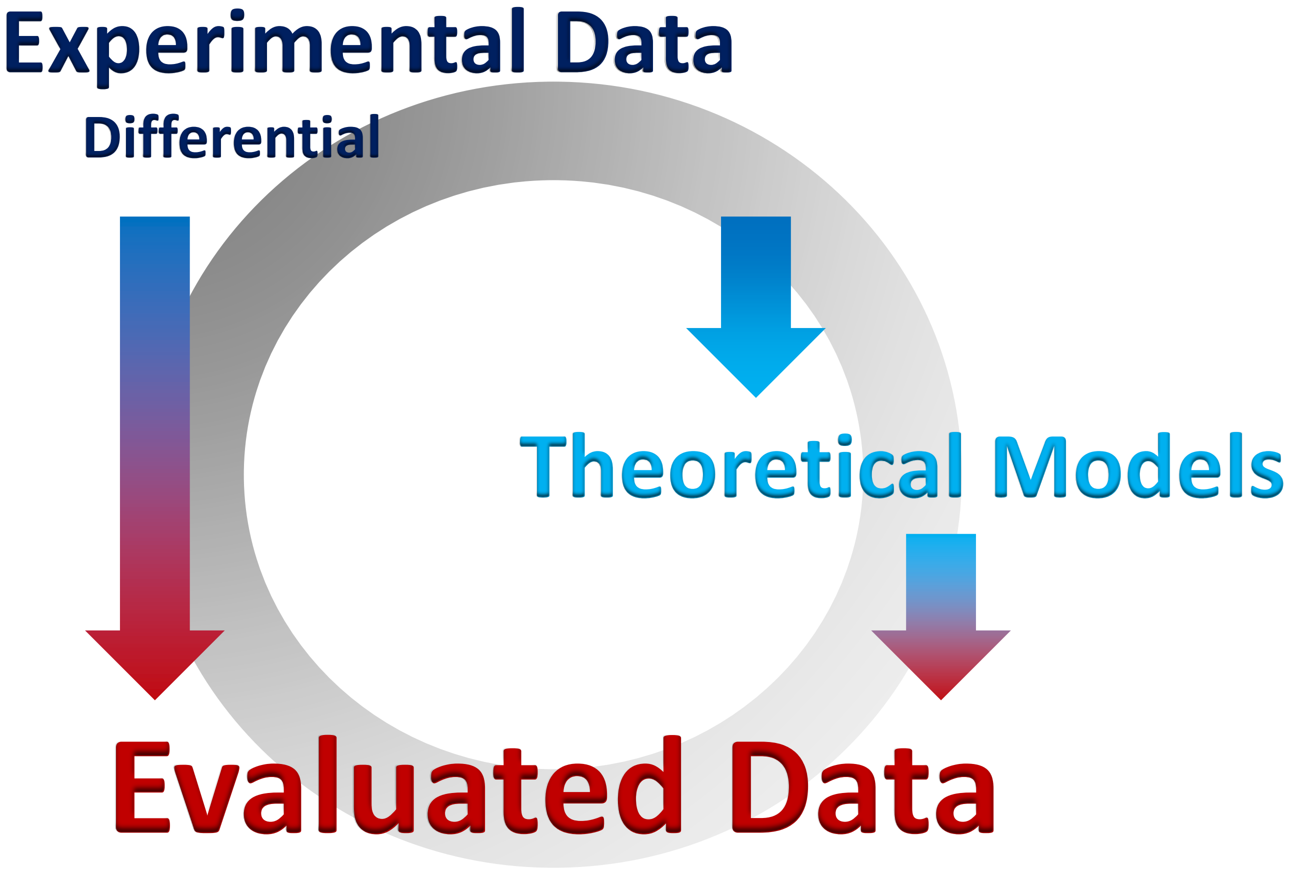
Differential



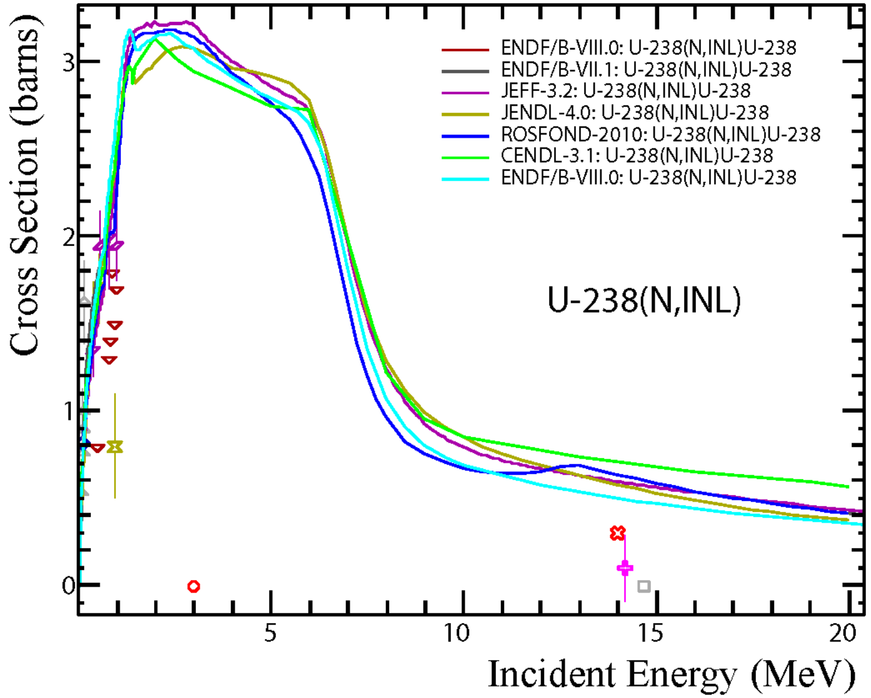
Theoretical Models

Evaluated Data


ENDF/B-VIII.0: U-238(N,INL)U-238
ENDF/B-VII.1: U-238(N,INL)U-238
JEFF-3.2: U-238(N,INL)U-238
JENDL-4.0: U-238(N,INL)U-238
ROSFOND-2010: U-238(N,INL)U-238
CENDL-3.1: U-238(N,INL)U-238
ENDF/B-VIII.0: U-238(N,INL)U-238
U-238(N,INL)
Cross Section (barns)
Incident Energy (MeV)
0
1
2
3
5
10
15
20


Experimental Data
Differential
Theoretical Models
Evaluated Data

CONTEXT: Evaluated Nuclear Data



Experimental Data

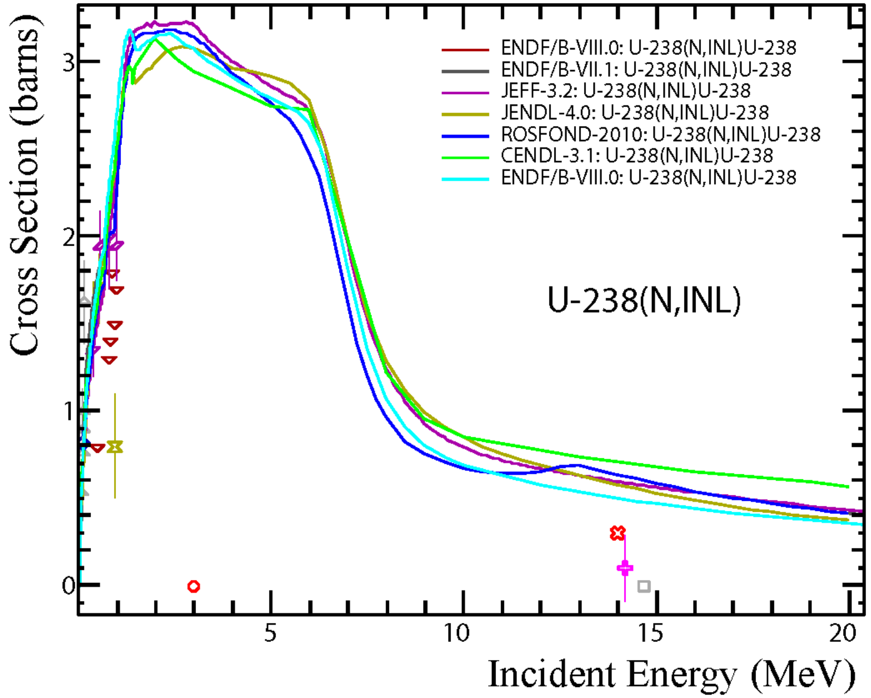
Differential & integral

J.L. Lecouey

Theoretical Models

Evaluated Data

Applications



Experimental Data

Differential & integral

J.L. Lecouey

Theoretical Models

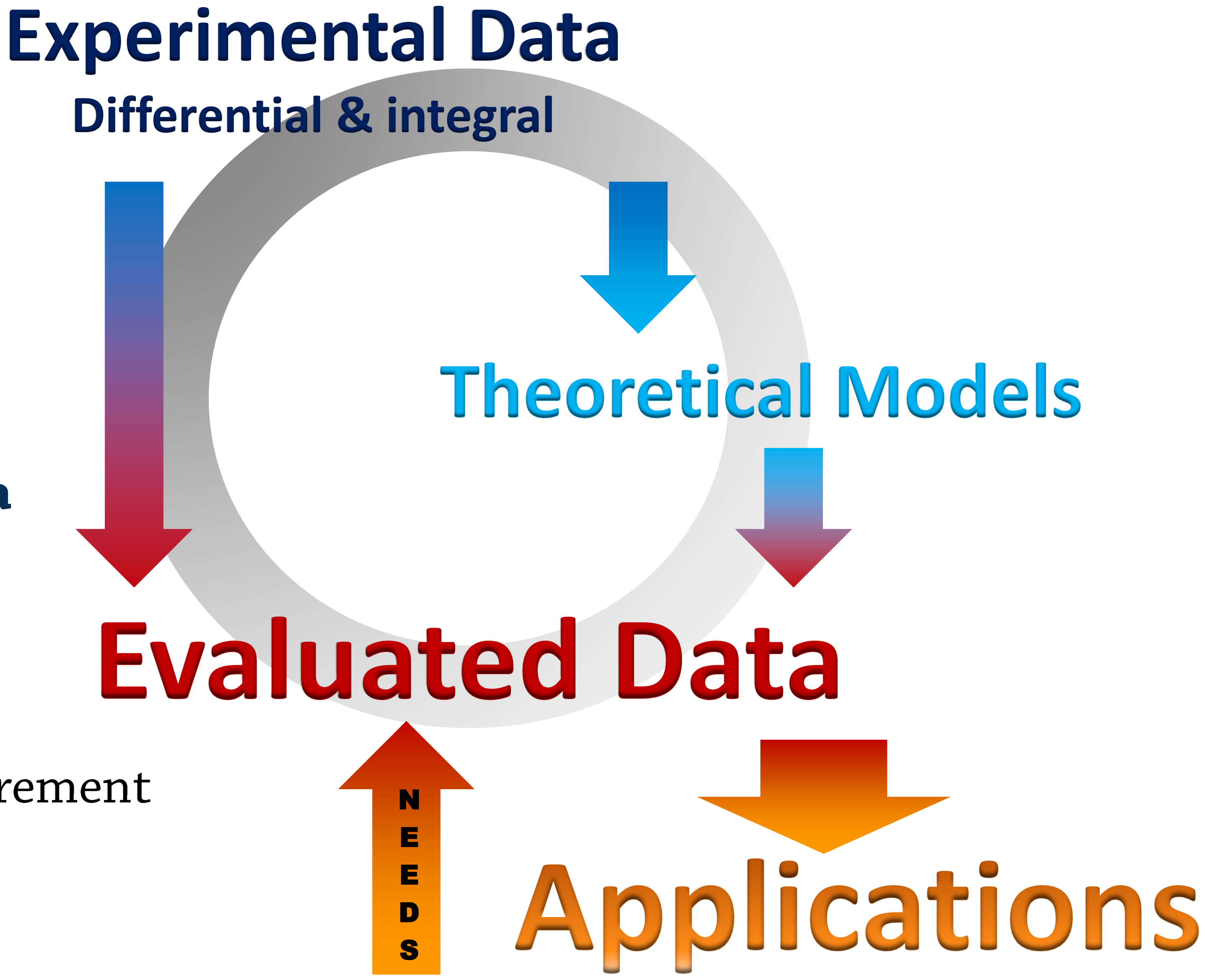
Evaluated Data

Applications

Evaluated data reflect
the **experimental** and **theoretical knowledge**
of **nuclear data**

Evaluated data reflect the **experimental** and **theoretical knowledge** of **nuclear data**

10 years can go by from the microscopic measurement to the new evaluated data.



TOOLS BOX

Experimental Data

Differential & integral

Experimental data base
EXFOR (IAEA)
microscopic data

critical benchmark data base
ICSBEP (NEA)
Integral data

Transport code
MC, deterministic

Theoretical Models

Nuclear reaction codes
TALYS, EMPIRE, …

Evaluated Data

Evaluated data base
ENDF, JEFF, JENDL, ….

NEEDS

Applications

TOOLS BOX

Experimental Data

Differential & integral

Experimental data base
EXFOR (IAEA)
microscopic data

critical benchmark data base
ICSBEP (NEA)
Integral data

Transport code
MC, deterministic

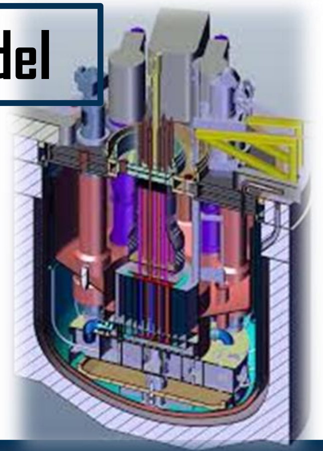
Theoretical Models

Nuclear reaction codes
TALYS, EMPIRE, …

Evaluated Data

Evaluated data base
ENDF, JEFF, JENDL, ….

System model



Which nucleus,
Which observable,
Which uncertainty?

Sensitivity studies
HPRL (NEA),
WPEC 26 (NEA)
Others …

X. Doligez

NEEDS

Applications

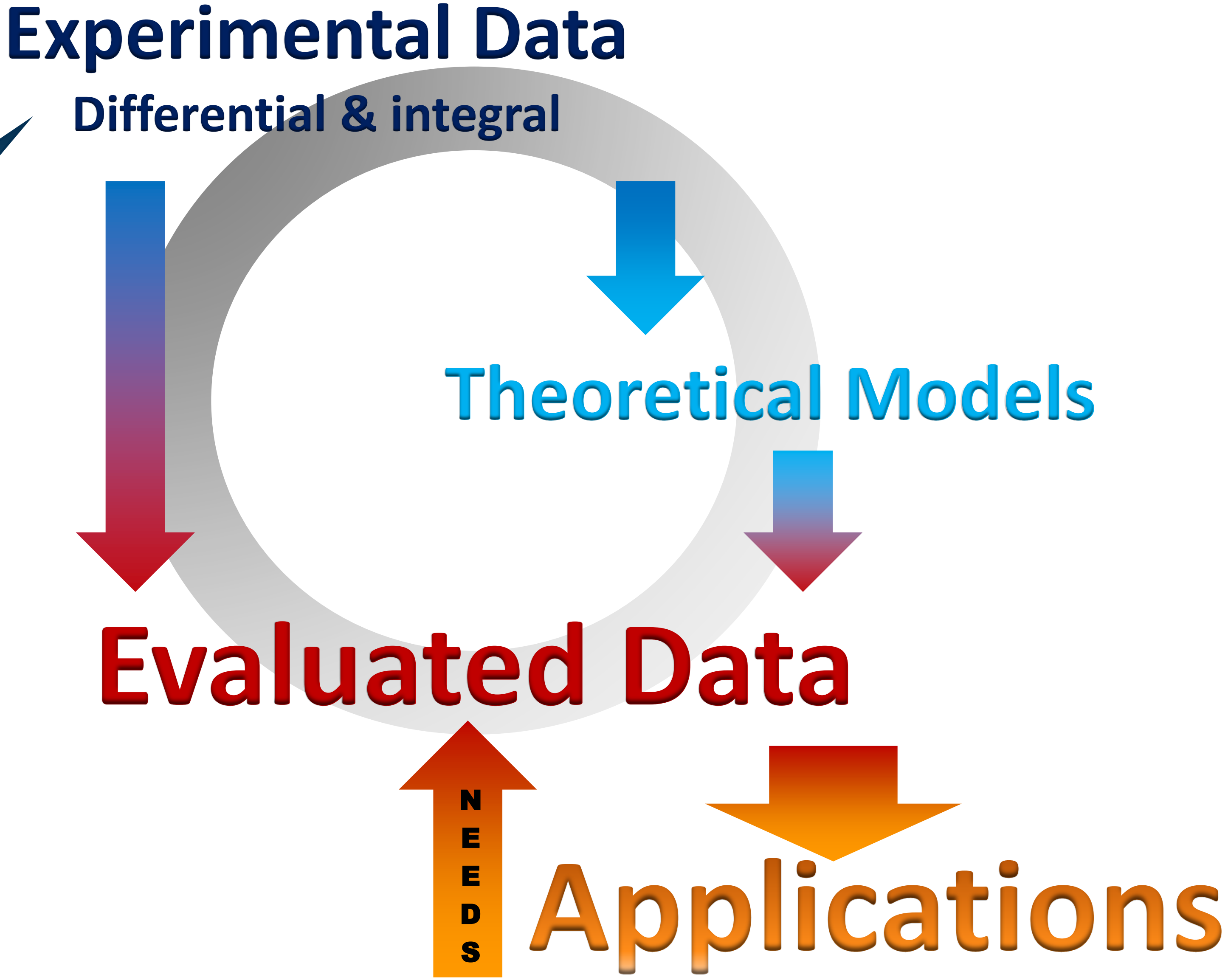
SUMMARY

- CONTEXT
  - Nuclear Data for Energy
  - Evaluated Nuclear Data
- NUCLEAR DATA @ IN2P3
  - Organisation: MP OPALE
  - National & International Framework
- OPALE today & tomorrow
- CONCLUSIONS

MASTER PROJECT

OPALE

des dOnnées exPérimentAles à l'évaLuation pour les réactEurs



Experimental programs are conducted to produce **new** and **accurate nuclear data**

OPALE

- 6 teams from 6 laboratories
- 18 senior research.
- 6 doc, 1 post doc

Fission Product

Universities
& Eng. schools

Fission Product Decay

Cross Sections

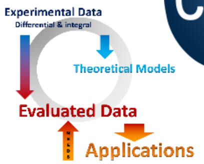
OPALE in its environment

NEEDS

NACRE

le Noyau Au Cœur du REacteur

cnrs cea IRSN INSTITUT DE RADIOPROTECTION ET DE SÛRETÉ NUCLÉAIRE



Fission Product

cnrs

Universities & Eng. schools

Fission Product Decay

Cross Sections

THE FRAMEWORK PROGRAMME FOR RESEARCH AND INNOVATION HORIZON 2020

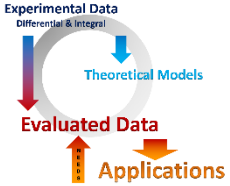
Union européenne

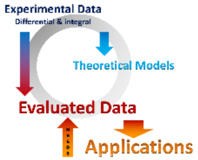
NFRP 2018 - SANDA WP1 leadership & WP6

SUPPLYING ACCURATE NUCLEAR DATA FOR ENERGY AND NON-ENERGY APPLICATIONS 2019-2023

NFRP 2018 - ARIEL

ACCELERATOR AND RESEARCH REACTOR INFRASTRUCTURES FOR EDUCATION AND LEARNING2019-2023





IAEA International Atomic Energy Agency

NDB JEFF project

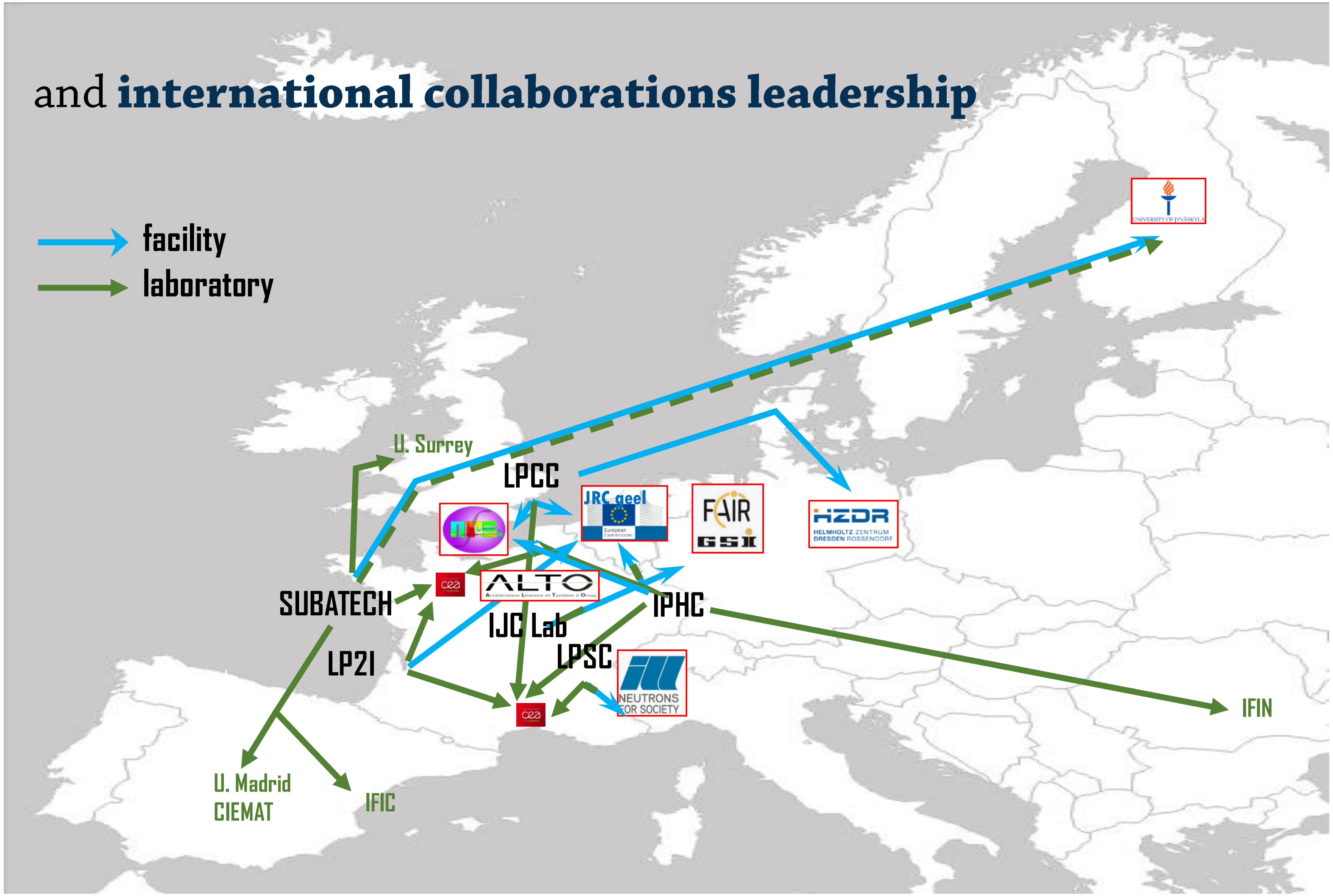
NEA NUCLEAR ENERGY AGENCY

OECD

International collaborations for all projects

OPALE

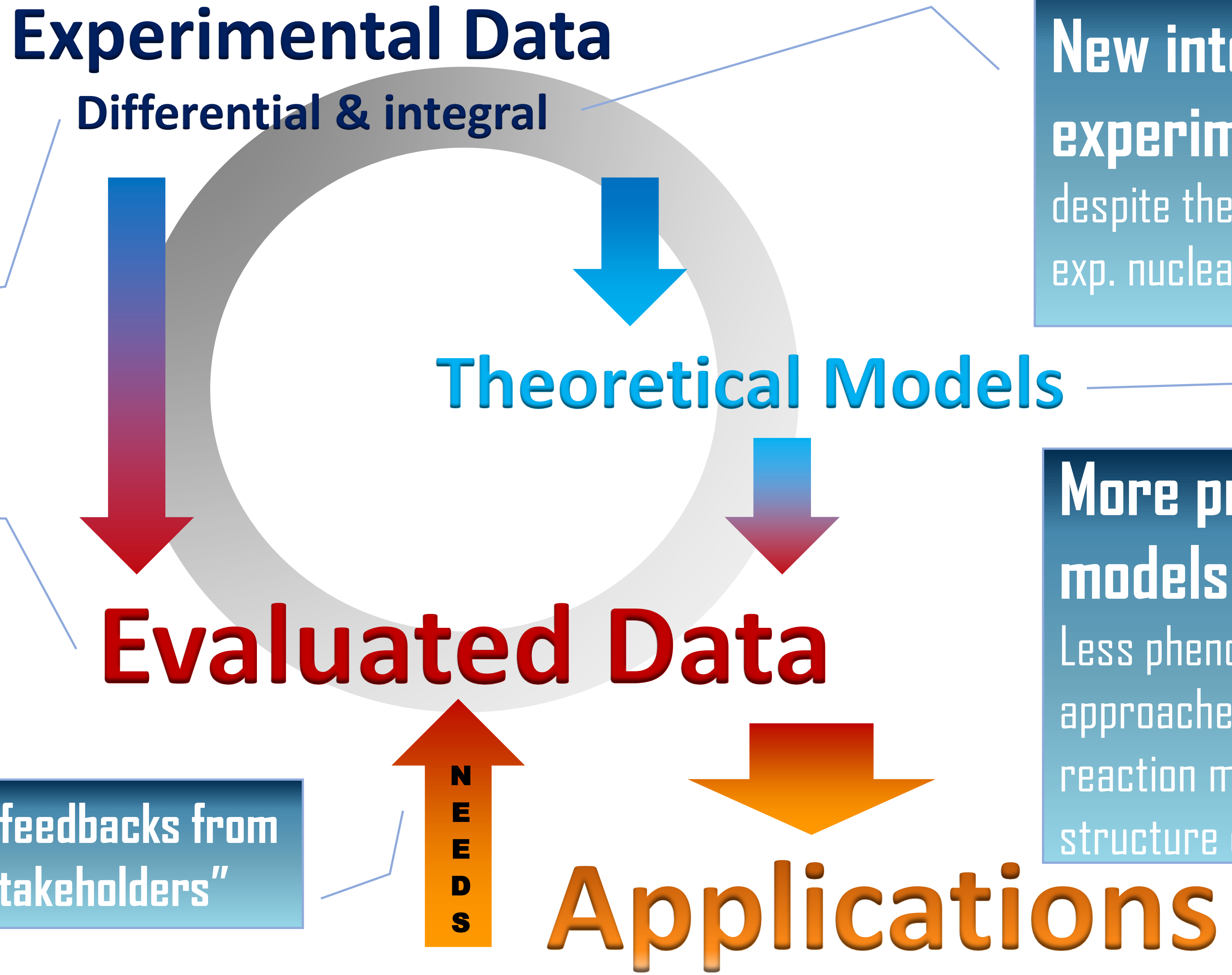
and international collaborations leadership



SUMMARY

New data :
Samples,
Accuracy,
Covariance infor.,
Availability of data,
...

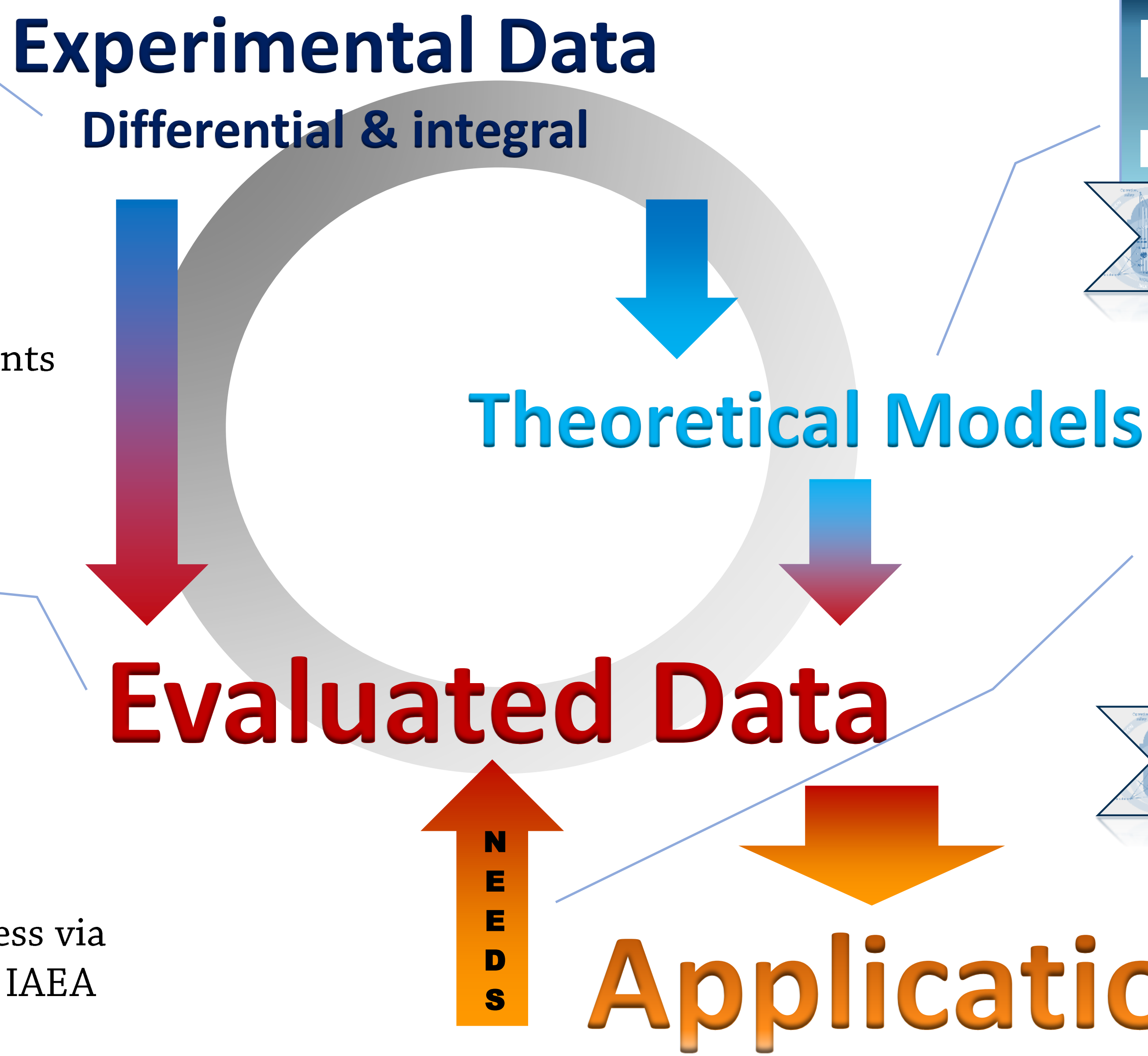
New integral experiments :
despite the lose of exp. nuclear reactor



New evaluation methods
Shorten the length of ND cycle, (despite the lack of manpower)

More predictive models
Less phenomenological approaches (nuclear reaction mod. & nucleus structure description)

More feedbacks from ND "stakeholders"



New data

OPALE

Innovative instruments
Innovative methods
High quality measurements
New facility

More predictive models

OPALE

Close collab. with theoreticians from CEA via NACRE and others

New evaluation methods

OPALE

Involvement in the evaluation process via NACRE, JEFF project, IAEA

More feedbacks from ND "stakeholders"

OPALE

Discussion with reactor physicists from IN2P3 via GDR SciNEE or in other frames

OPALE : answer to HPRL request

Development of innovative devices to perform accurate measurements

NEA NUCLEAR ENERGY AGENCY

NEA Nuclear Data High Priority Request List

ID	View	Target	Reaction	Quantity	Energy range	Sec.E/Angle	Accuracy	Cov	Field
2H		8-O-16	(n,a),(n,abs)	SIG	2 MeV-20 MeV		See details	Y	Fission
3H		94-PU-239	(n,f)	prompt g	Thermal-Fast	Eg=0-10MeV	7.5	Y	Fission
4H		92-U-235	(n,f)	prompt g	Thermal-Fast	Eg=0-10MeV	7.5	Y	Fission
8H		1-H-2	(n,el)	DA/DE	0.1 MeV-1 MeV	0-180 Deg	5	Y	Fission
15H		95-AM-241	(n,g),(n,tot)	SIG	Thermal-Fast		See details		Fission
18H		92-U-238	(n,inl)	SIG	65 keV-20 MeV	Emis spec.	See details	Y	Fission
19H		94-PU-238	(n,f)	SIG	9 keV-6 MeV		See details	Y	Fission
21H		95-AM-241	(n,f)	SIG	180 keV-20 MeV		See details	Y	Fission
22H		95-AM-242M	(n,f)	SIG	0.5 keV-6 MeV		See details	Y	Fission
25H		96-CM-244	(n,f)	SIG	65 keV-6 MeV		See details	Y	Fission
27H		96-CM-245	(n,f)	SIG	0.5 keV-6 MeV		See details	Y	Fission
32H		94-PU-239	(n,g)	SIG	0.1 eV-1.35 MeV		See details	Y	Fission
33H		94-PU-241	(n,g)	SIG	0.1 eV-1.35 MeV		See details	Y	Fission
34H		26-FE-56	(n,inl)	SIG	0.5 MeV-20 MeV	Emis spec.	See details	Y	Fission
35H		94-PU-241	(n,f)	SIG	0.5 eV-1.35 MeV		See details	Y	Fission
37H		94-PU-240	(n,f)	SIG	0.5 keV-5 MeV		See details	Y	Fission
38H		94-PU-240	(n,f)	nubar	200 keV-2 MeV		See details	Y	Fission
39H		94-PU-242	(n,f)	SIG	200 keV-20 MeV		See details	Y	Fission
41H		82-PB-206	(n,inl)	SIG	0.5 MeV-6 MeV		See details	Y	Fission
42H		82-PB-207	(n,inl)	SIG	0.5 MeV-6 MeV		See details	Y	Fission
45H		19-K-39	(n,p),(n,np)	SIG	10 MeV-20 MeV		10	Y	Fusion
97H		24-CR-50	(n,g)	SIG	1 keV-100 keV		8-10	Y	Fission
98H		24-CR-53	(n,g)	SIG	1 keV-100 keV		8-10	Y	Fission
99H		94-PU-239	(n,f)	nubar	Thermal-5 eV		1	Y	Fission
102H		64-GD-155	(n,g),(n,tot)	SIG	Thermal-100 eV		4	Y	Fission
103H		64-GD-157	(n,g),(n,tot)	SIG	Thermal-100 eV		4	Y	Fission
114H		83-BI-209	(n,g)Bi-210g,m	BR	500 eV-300 keV		10	Y	Fission,ADS
115H		94-PU-239	(n,tot)	SIG	Thermal-5 eV		1	Y	Fission
116H		3-LI-0	(d,x)Be-7	SIG	10 MeV-40 MeV		10	Y	Fusion
117H		3-LI-0	(d,x)H-3	SIG,TTY	5 MeV-40 MeV		10	Y	Fusion
118H		68-ER-167	(n,g)	SIG,RP	0.01 eV-100 eV		2	Y	Fission

$^{16}O(n,\alpha)$, 2 MeV – 20 MeV

- Above threshold (2.4 MeV), measurements and evaluations of $^{16}O(n,\alpha)$ are discrepant. The current uncertainty of $^{16}O(n,\alpha)$ is large (> 30%).
- These uncertainties have a significant impact on several applications:
  - $\approx$ 100 pcm in the k_{eff} of thermal and fast reactors.
  - $\approx$ 7% in the prediction of helium production in reactors.
  - $\approx$ 0.5% in the calibration of reference neutron-source strength.
- To improve the situation, new measurement and evaluation are requested in the range 2.5 - 10 MeV. The target accuracy for $^{16}O(n,\alpha)$ is 5% especially below 6 MeV.

LPC caen – Laboratoire de physique corpusculaire

$^{238}U(n,n')$, 65 keV – 20 MeV

Energy Range	Initial versus target uncertainties (%)					
	Initial	ABTR	SFR	EFR	GFR	LFR
6.07-19.6 MeV	29	12			7	
2.23-6.07 MeV	20	3	5	4	2	3
1.35-2.23 MeV	21	4	5	4	2	2
0.498-1.35 MeV	12	7	6	5	2	2
67.4-183 keV	11	7		9	7	4

IPHC – Institut Pluridisciplinaire Hubert CURIEN STRASBOURG

$^{242}Pu(n,f)$, 200 keV – 20 MeV

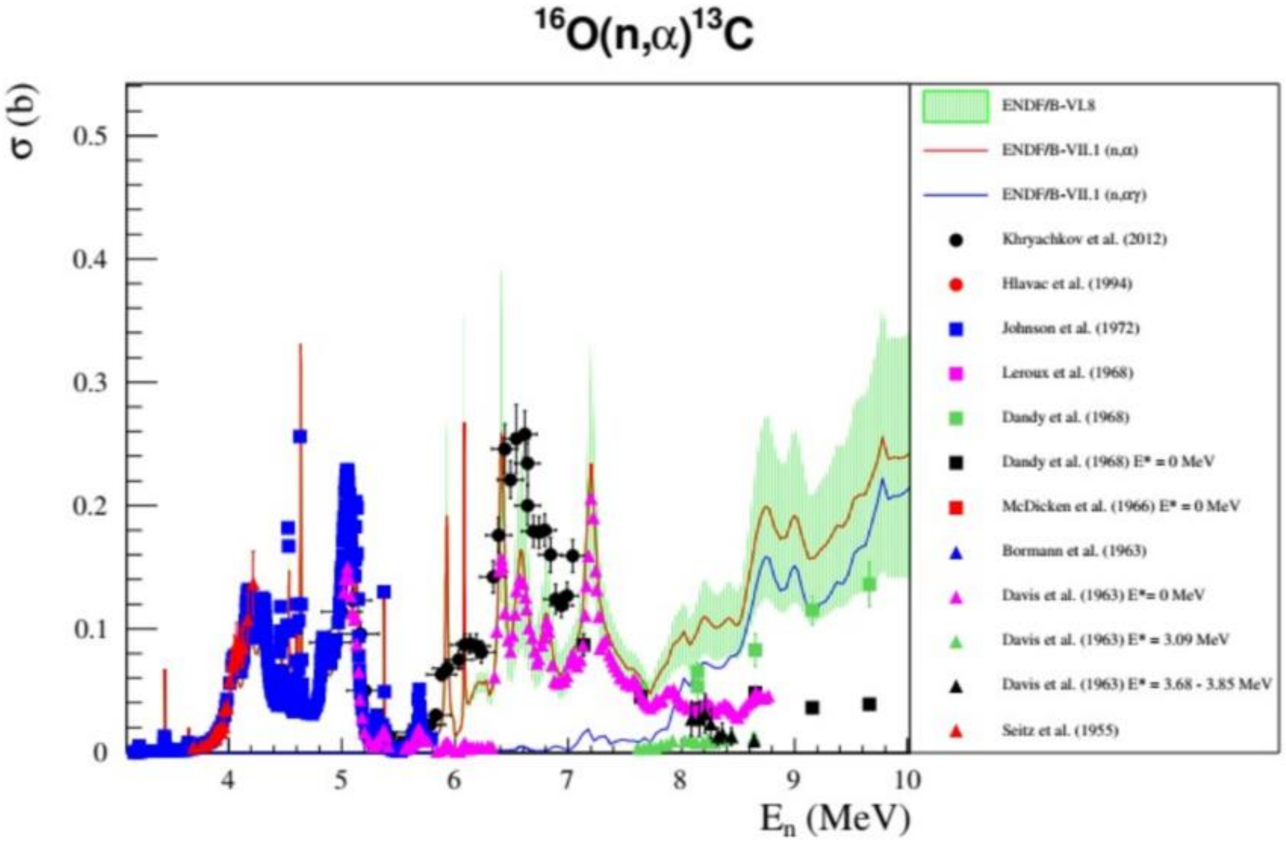
Energy Range	Initial versus target uncertainties (%)									
	Initial	SFR		EFR		GFR		LFR		ADMAB
		$\lambda=1$	$\lambda\neq1$,b	$\lambda=1$	$\lambda\neq1$,a	$\lambda=1$	$\lambda\neq1$,a	$\lambda=1$	$\lambda\neq1$,a	$\lambda=1$
6.07 - 19.6 MeV	37	15	14							
2.23 - 6.07 MeV	15	5	5			6	6	7	8	7
1.35 - 2.23 MeV	21	5	4			5	6	7	7	5
0.498 - 1.35 MeV	19	4	3	11	9	4	4	4	4	4
183 - 498 keV	19	9	8							

LP2i Bordeaux

OPALE : answer to HPRL request

$^{16}O(n,\alpha)$, 2 MeV – 20 MeV

Development of innovative devices to perform accurate measurements



G. Lehaut *et al.*, EPJ Web of Conferences **225**, 01001 (2020)

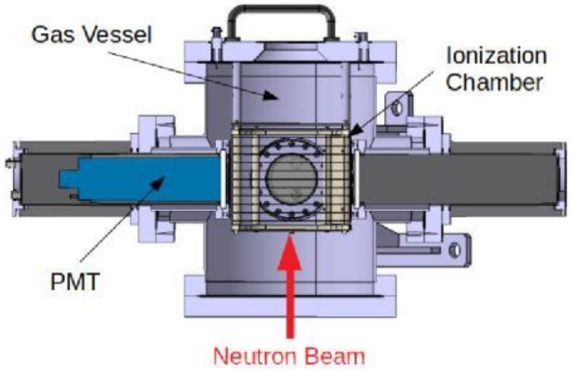
Strong requests to improve the knowledge of the $^{16}O(n,\alpha)$

- HPRL
- NEA WPEC SG 26
- NEA WPEC SG 40 CIELO project

=> Target accuracy 5% (especially below 6 MeV)

SCALP (Scintillating ionization Chamber for ALPha particle)

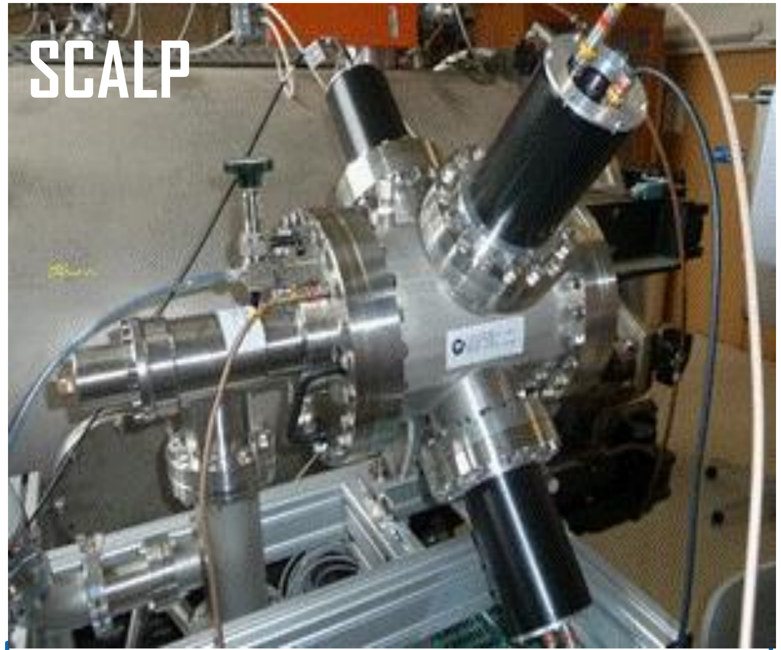
new scintillating ionization chamber used as an active target



-> cross section of (n, α) reactions on various gaseous targets such as ^{19}F or ^{16}O, from the reaction threshold up to 15 MeV.

OPALE : answer to HPRL request

$^{16}O(n,\alpha)$, 2 MeV – 20 MeV



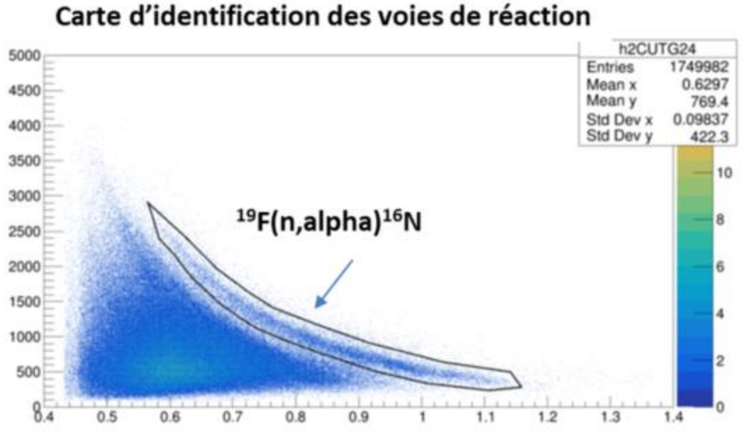
*Ionization chamber (pure CF_4 or mixture of CF_4 and a few % of CO_2),
* 4 photomultipliers
tubes collect the light emission associated with the neutron induced reactions in the gas.

Measurement campaigns

@ JRC/Geel, *(delayed due to COVID)*

@ n-ELBE Dresden, *(delayed due to COVID)*

@ SPIRAL2/NFS 2 tests in October 2021 with ^{19}F & ^{16}O



E_d vs tof_n (a.u.)

Very preliminary results for one run (~ 1 hour)

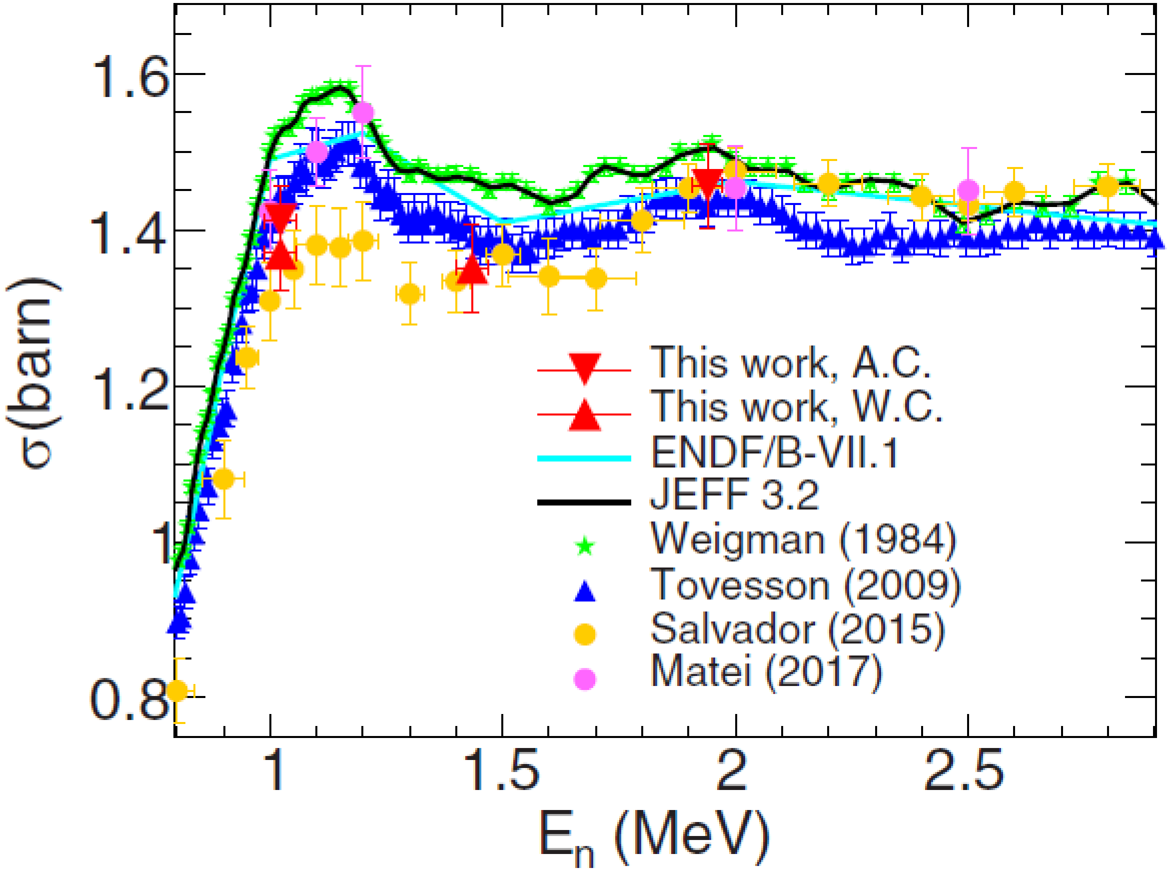
* A collaboration with CEA/DES/CAD has started for the evaluation part.

CEA/DES/CAD

OPALE : answer to HPRL request

$^{242}Pu(n,f)$, 200 keV – 20 MeV

Development of innovative devices to perform accurate measurements



P. Marini et al., Phys. Rev. C 96, 054604 (2017)

Requests to improve the knowledge of the $^{242}Pu(n,f)$

- HPRL
- NEA WPEC SG 26

=> Target accuracy 5-10%

Energy Range	Initial versus target uncertainties (%)										
	Initial	SFR		EFR		GFR		LFR		ADMAB
		λ=1	λ≠1,b	λ=1	λ≠1,a	λ=1	λ≠1,a	λ=1	λ≠1,a	λ=1
6.07 - 19.6 MeV	37	15	14							
2.23 - 6.07 MeV	15	5	5			6	6	7	8	7
1.35 - 2.23 MeV	21	5	4			5	6	7	7	5
0.498 - 1.35 MeV	19	4	3	11	9	4	4	4	4	4
183 - 498 keV	19	9	8							

New measurement with photovoltaic cells and H(n,n) normalization

H(n,n) normalization performed with two detection devices :

- Si detectors E_n>1 MeV
- new Gaseous Recoil Proton Telescope (GPRT) E_n < 1 MeV

OPALE : answer to HPRL request

^{242}Pu(n,f), 200 keV – 20 MeV

CEA/DES/CAD

LP2i Bordeaux

First results:

New measurement (1 MeV < E_n < 2 MeV) with H(n,n) normalization (precise standard) @ 4 MV Van de Graaff accelerator of CEA/DIF.

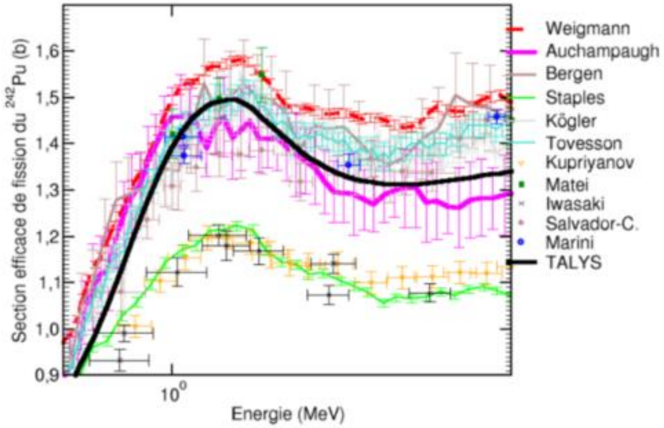
⇒ Confirmation of the low values of the cross section

⇒ No information on the structure around 1 MeV

New evaluation work made with CEA/DES/CAD

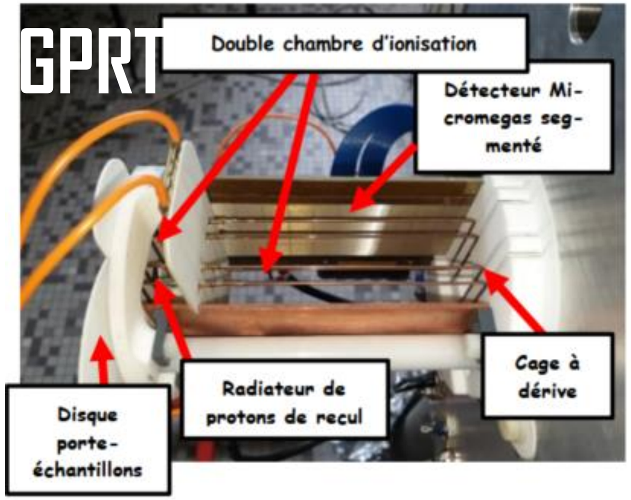
in a frame of a thesis

=> More realistic description of the cross section around 1 MeV obtained with TALYS



- **New accurate measurement** planned at JRC/Geel

- Finalization of **the GPRT development** for future accurate measurement at lower neutron energies

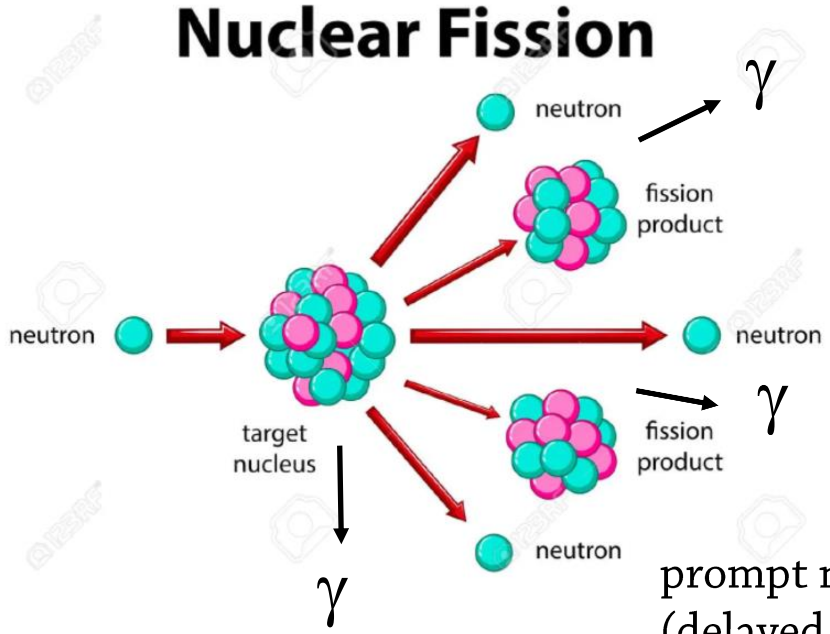


* hydrogen-rich "radiator" (conv. neutron to proton)
* mini Time Projection Chamber (segmented Micromegas detector based).

OPALE : Development of innovative devices and method for more comprehensive studies. systematic studies of Fragment Fission yields

LPSC GRENOBLE | MODANE

IJCLab Irène Joliot-Curie Laboratoire de Physique des 2 Infinis



kinetic energy
prompt γ-rays } **HEAT**

ternary α, t, d } **GAZ Prod.**

prompt neutrons
(delayed neutrons) } **CHAIN REACTION**

fission fragments } **DECAY HEAT, TOXICITY**

Fission Observables

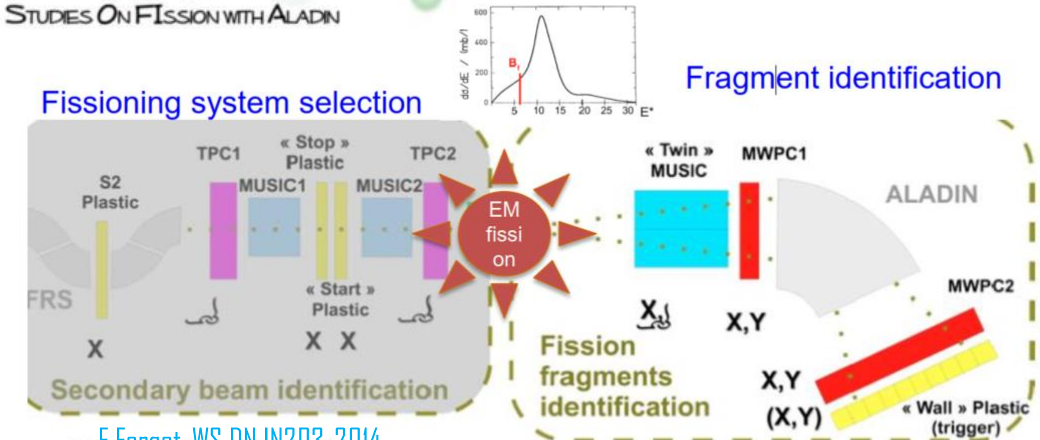
* Cross section
* **Fragment yields (A, Z, TKE)**
* Particle emission from the excited FF
  - Prompt neutrons
    (<ν>, <En>; ν(A), ν(TKE))
  - Prompt γ-rays
    (<Mγ>, <Eγ,tot>; Mγ(A), Mγ(TKE))
  - Neutron-γ correlations
  - Excitation-energy dependence
* Delayed neutron emission and decay heat
* neutrinos

OPALE : Development of innovative devices and method systematic studies of Fragment Fission yields

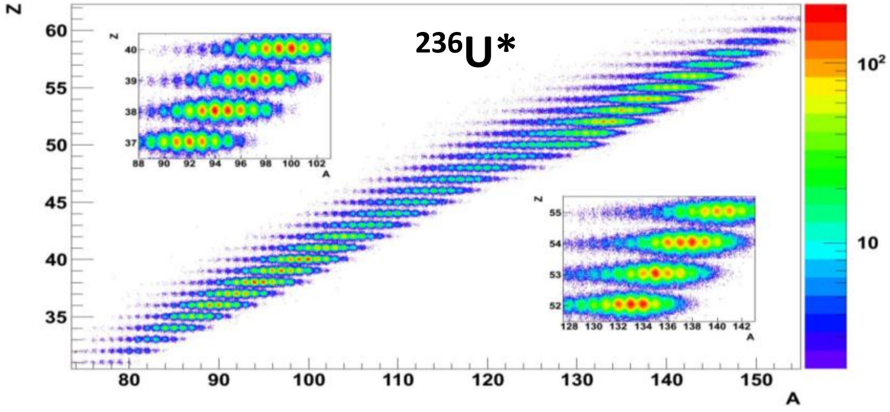
SOFIA
STUDIES ON FISSION WITH ALADIN

GSI

Electromagnetic fission of secondary relativistic beams



F.Farget, WS DN-IN2P3, 2014



Last results :

- Fission yield measured with unprecedented accuracy for $^{236}U^{*}$ and Th region A. Chatillon et al., Phys. Rev. Let. 124 (2020)
- More fundamental experiment for asymmetric fission in ^{180}Hg

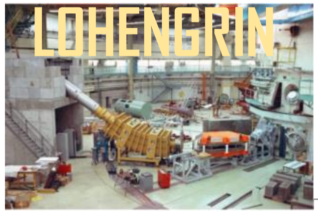
Measured observables
Fission yields,
Total kinetic energy,
Total prompt n multiplicity

- Fully and simultaneously identify both FF (0,55 u FWHM)
- For a wide variety of fissioning systems

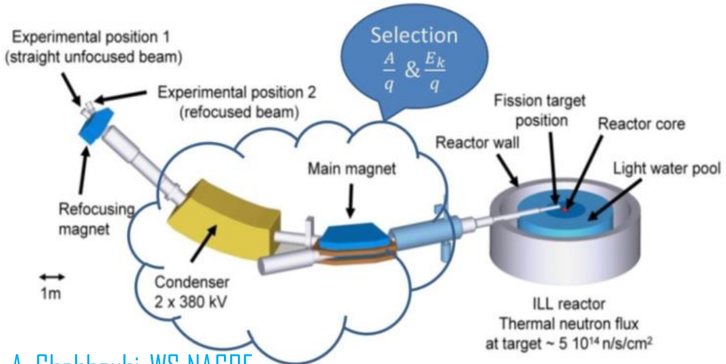
considering **^{242}Pu as primary beam**.
Access fission of heavier actinides : Am, Pu, Np…

CEA/DES/CAD, ILL

OPALE : Development of innovative devices and method systematic studies of Fragment Fission yields



NEUTRONS FOR SCIENCE



A. Chebboubi, WS NACRE

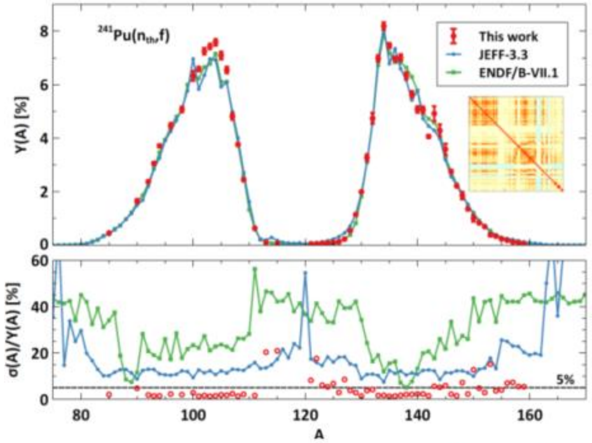
- absolute measurements of FF with an accuracy of 2 – 4 %,
- independent from any other data + exp. var-cov matrix.
- for a wide variety of fissioning systems
- Different techniques were developed in order to measure isomeric ratio (IR).

Measured observables

$\boldsymbol{Y(A,Z)}$ fission yields,
Symmetric and far asymmetric regions
$\boldsymbol{P(E^*,J^\pi)}$ excitation energy and spin distributions

A. Chebboubi et al., Eur. Phys. J. A 57 (2021) 335

Last results :

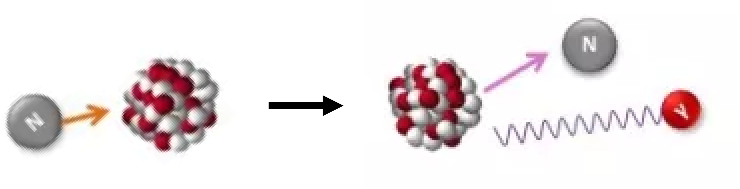


- ^{233}U, ^{235}U, ^{239}Pu, ^{241}Pu & ^{241}Am meas.
- Results on IR seem to disavow to the empirical model of Madland England, the use of FIFRELIN code (CEA) seems more relevant.

Deep **study of FF symmetric region** will give insights on low energy fission mode which could validate pheno/micro modelings used in evaluation.
=> Development of a **new TOF detector** to add a velocity filter (increased selectivity).
Meas. planed on ^{235}U, ^{239}Pu, ^{241}Pu

OPALE : Development of innovative devices and method for more comprehensive studies. The case of neutron inelastic scattering and (n, xn) reactions

EC-JRC-Geel, IFIN-HH, CEA/DAM/DIF, CEA/DES/CAD, LNL, AIEA



(n, n') & (n, xn) } NEUTRON SPECTRUM
NEUTRON POPULATION
NEW ELEMENT

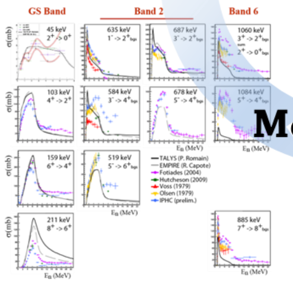
Prompt γ-ray spectroscopy method

XS (n,xn)
for En<Emax

Nuclear Structure Data

Constraints

EVALUATION



Measured (n,xn γ) XS

ACCURATE

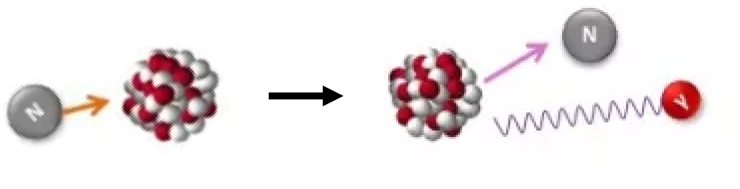
accuracy issues for (n,xn) reactions

- 1990's : strong demand for improvement of the inelastic scattering XS.
- Impact on core parameters in various future reactor designs (Vol. 26).
- Entries in HPRL (reduction of uncertainty from 20% to 5% or less).
- Several experimental efforts to address the challenges

but **improvements are still required.**

EC-JRC-Geel, IFIN-HH, CEA/DAM/DIF, CEA/DES/CAD, LNL, AIEA

OPALE : Development of innovative devices and method for more comprehensive studies. The case of neutron inelastic scattering and (n, xn) reactions



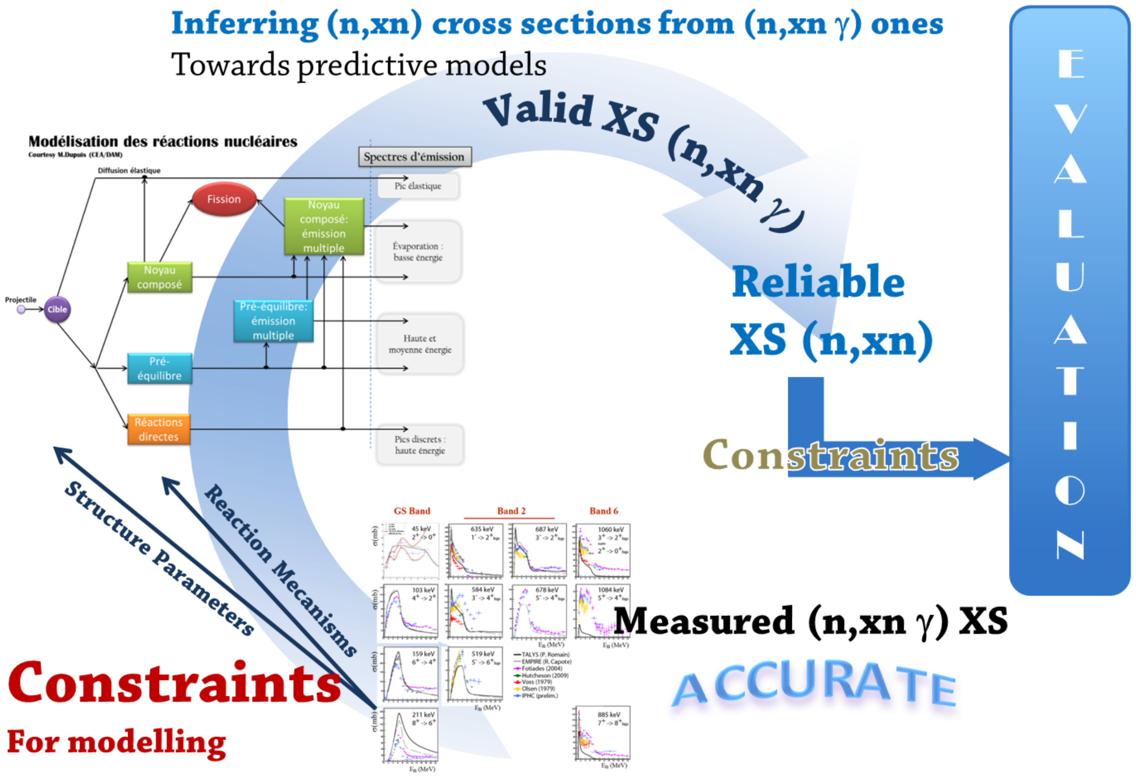
(n, n') & (n, xn) }
NEUTRON SPECTRUM
NEUTRON POPULATION
NEW ELEMENT

accuracy issues for (n,xn) reactions

- 1990's : strong demand for improvement of the inelastic scattering XS.
- Impact on core parameters in various future reactor designs (Vol. 26).
- Entries in HPRL (reduction of uncertainty from 20% to 5% or less).
- Several experimental efforts to address the challenges

but **improvements are still required.**

Prompt γ-ray spectroscopy method



OPALE : Development of innovative devices and method for more comprehensive studies. The case of neutron inelastic scattering and (n, xn) reactions

EC-JRC-Geel, IFIN-HH, CEA/DAM/DIF, CEA/DES/CAD, LNL, AIEA

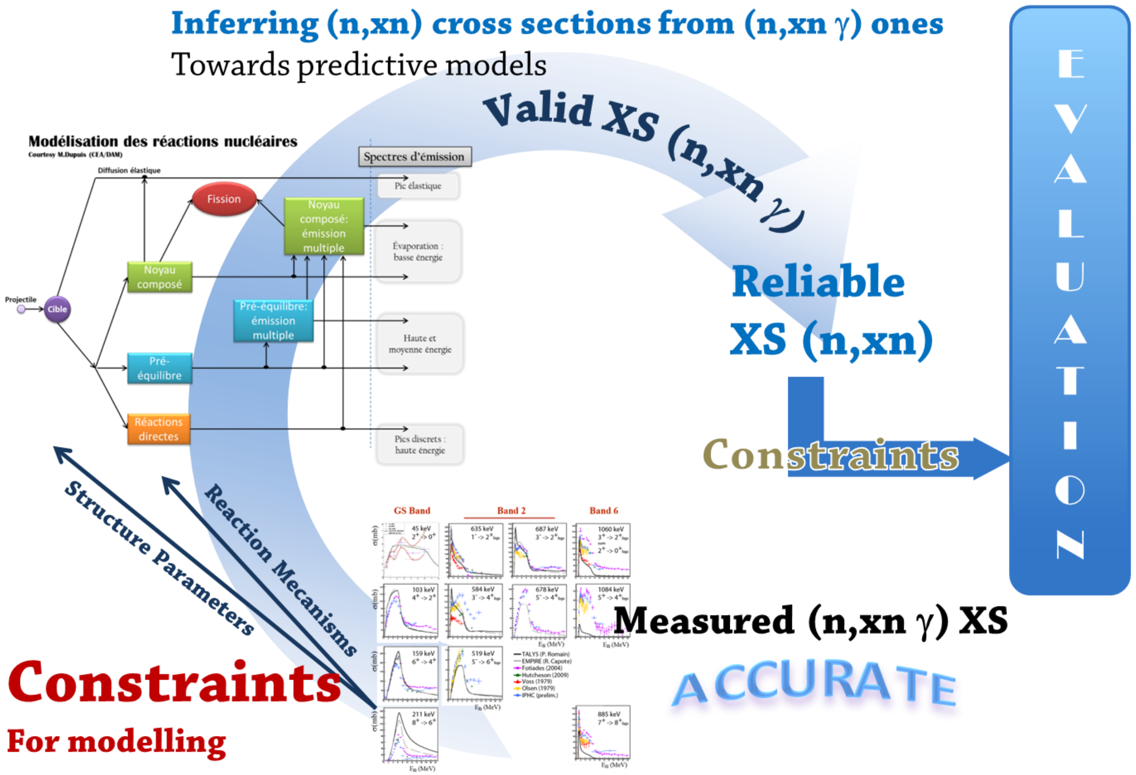
1 Fission Chamber,
5 HPGe Planar,1 HPGe seg.

Measured observables

(n, xnγ) XS with uncertainties
3 to 5% - En < 9 MeV
Up to 20% - En > 9 MeV
Corr. and cov. matrices

^{232}Th,
^{233,235}U,
^{238}U (HPRL)
^{nat}Zr,
^{nat,182,3,4,6}W,
^{57}Fe.

Prompt γ-ray spectroscopy method



OPALE : Development of innovative devices and method
Neutron inelastic scattering and (n, xn) reactions

EC-JRC-Geel, IFIN-HH, CEA/DAM/DIF, CEA/DES/CAD, LNL, AIEA

238U

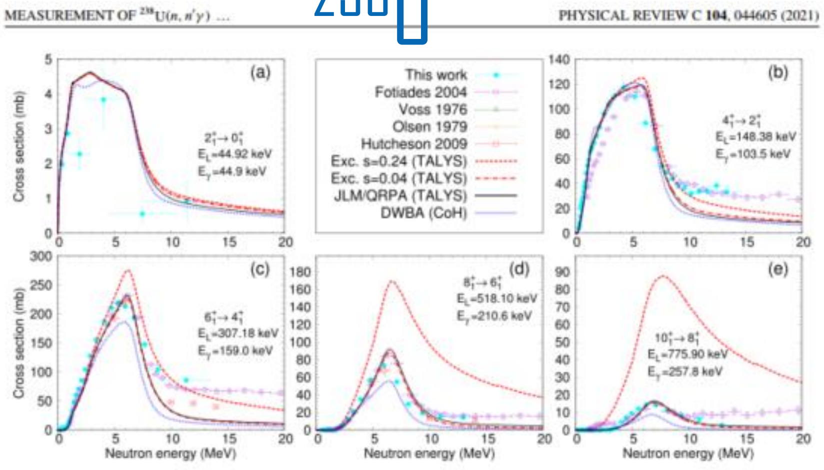
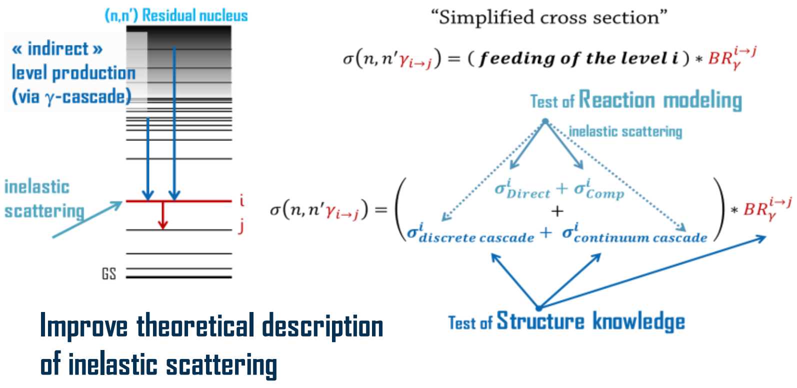


FIG. 11. Data for ^{238}U(n, n'γ) cross sections for transitions within the ground state rotational band. Spin and parity of the initial and final states, energy of the γ ray, experimental data (symbols) and calculations (curves) are defined in the plots. Calculations based on four different preequilibrium models are compared: excitons with s = 0.24 or s = 0.04, JLM/QRPA (TALYS code) and DWBA (CoH code).

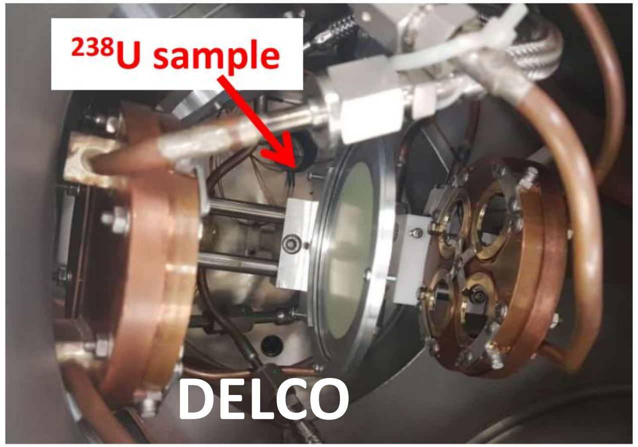
M. Kerveno, M. Dupuis, et al. PRC 104, 044605 (2021)

Last (main) results :

- Improvement of preequilibrium description with microscopic approach (QRPA nucl. struct. Meth.)
- Importance of nucl. struct. Knowledge
- New information about branching ratio
- E1 and M1 strength functions are of importance
- A new evaluation is coming, done in a frame of a thesis (IPHC-CEA)

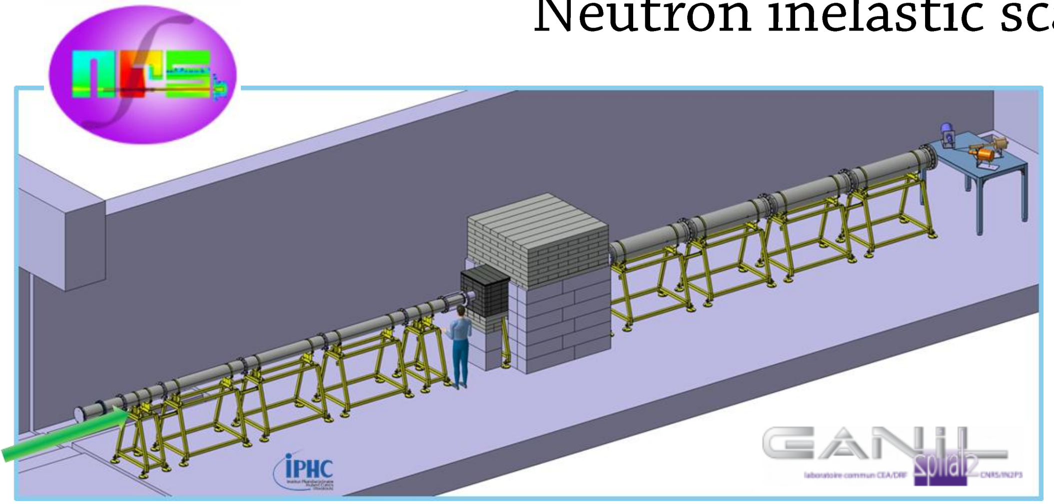


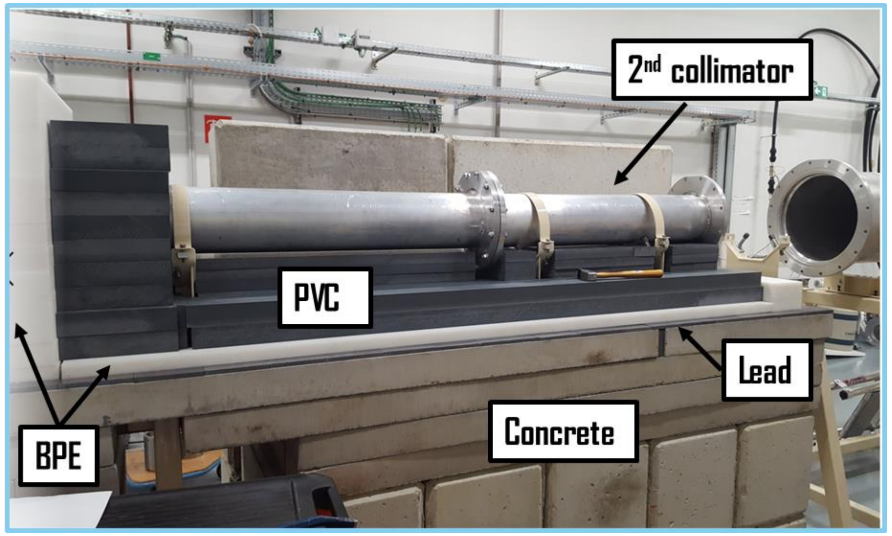
- New measurement on **^{239}Pu is foreseen in 2022**
- New **detector development** (conv. electron meas.): **DELCO**
- Sensitivity studies about Th cycle
- (n, 2n) & (n, 3n) campaigns **@ SPIRAL2/NFS**



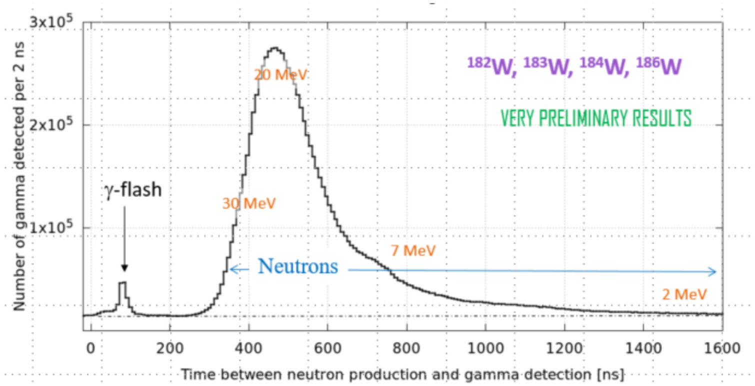
OPALE : Development of innovative devices and method

Neutron inelastic scattering and (n, xn) reactions

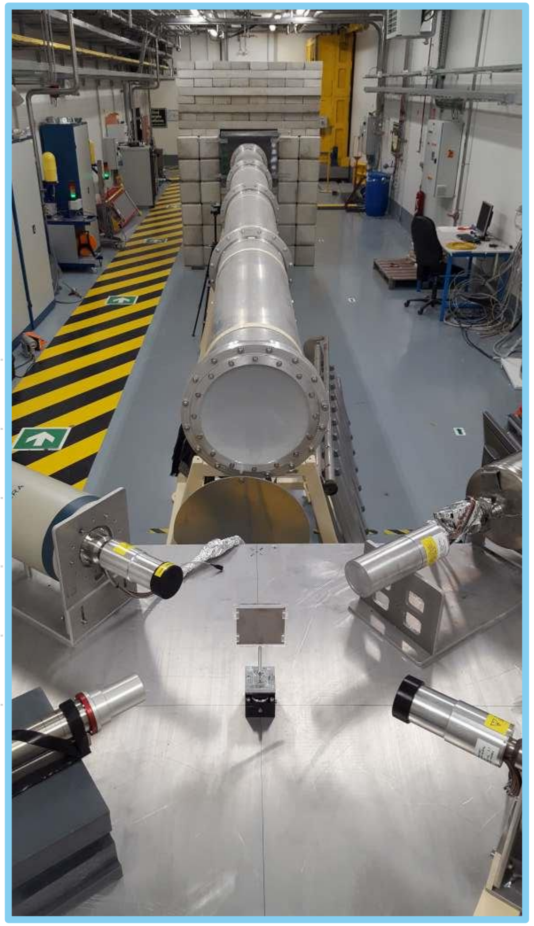




- Strong involvement in the building of ToF area
- LoI for test of the prompt γ-ray spectroscopy method @ NFS (done in 09/2021)



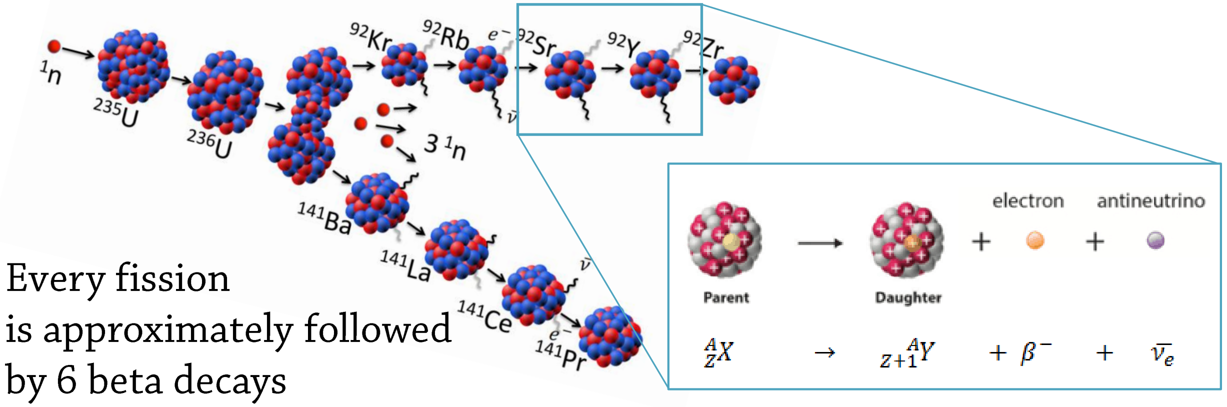
- Future measurement program for studies of (n, 2n) & (n, 3n) reactions on main actinides.



IFIC Valencia, U. Surrey, U. Madrid, CIEMAT IJClab, GANIL, LPC Caen, IP2I IAEA

OPALE : Development of innovative devices and method for more comprehensive studies

The case of fission process : β decay studies



Every fission is approximately followed by 6 beta decays (sizable amount of energy)

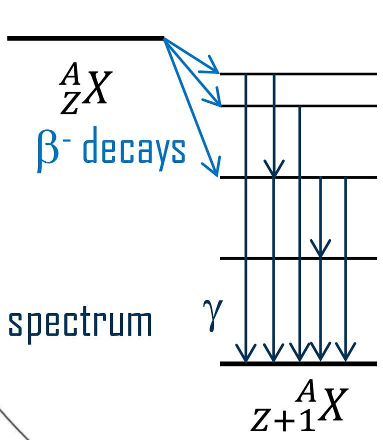
Decay heat and anti-neutrinos studies rely on the "**summation method**"

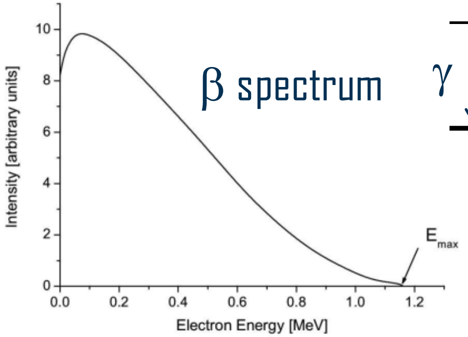
$$f(t) = \sum_i E_i \lambda_i N_i(t)$$

E_i Decay energy of the nucleus i (gamma, beta or both)

λ_i Decay constant of the nucleus i $\lambda = \frac{\ln(2)}{T_{1/2}}$

N_i Number of nuclei i at the cooling time t





Databases must contain:
half-lives,
mean γ- and β-energies released in the decay,
n-capture cross sections
& fission yields

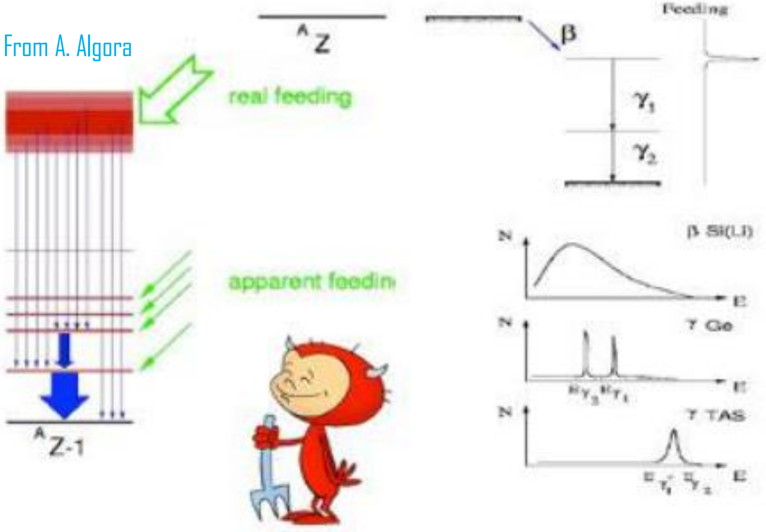
Released γ and β	DECAY HEAT
β-n emitters	DELAYED NEUTRON FRACTION
$\bar{\nu}$	REACTOR MONITORING NON-PROLIFERATION TOOL But also fund. Nucl. Physics

Decay heat & anti neutrinos calculations suffer from the **pandemonium effect** !!!

OPALE : Development of innovative devices and method for more comprehensive studies

IFIC Valencia, U. Surrey,
U. Madrid, CIEMAT
IJClab, GANIL, LPC Caen, IP2I
IAEA

THE PANDEMONIUM EFFECT

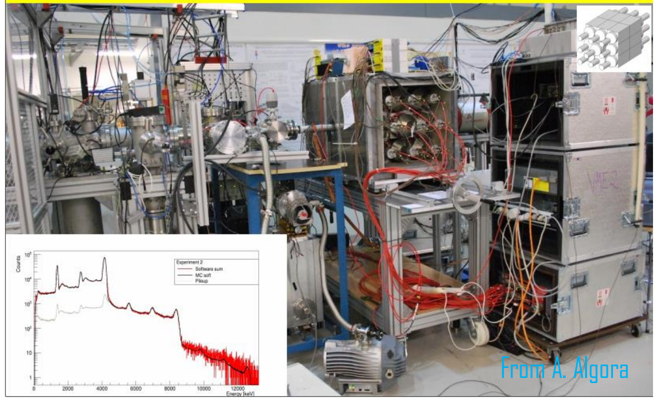


- Ge detectors are conventionally used to construct the level scheme populated in the decay
- From the γ intensity balance, the β-feeding is deduced

β-feeding distr. is distorted
due to pandemonium effect

TAGS measurements to solve the problem

DTAS at Jyväskylä (Feb. 2014)
(collaboration with Subatech, spokespersons: Fallot, Tain, Algora)



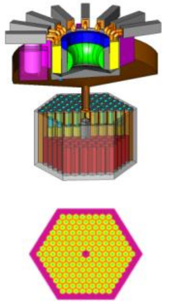
@ Jyväskylä

TAGS Experimental Campaigns in **2009**, in **2014**

A. Algora, …, M. Fallot, W. Gelletly, EPJ A 57, 85 (2021)

M. Estienne et al. PRL 123, (2019) 022502

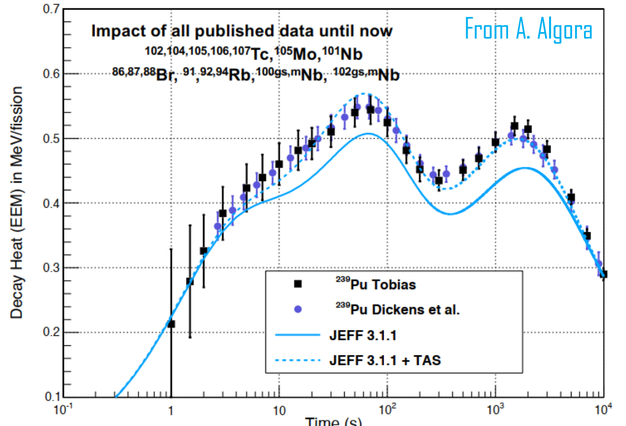
=> more than **25 measured important contributors** to the anti-neutrino spectra, to the decay heat and delayed neutron emitters



Section of Draining tank for a GenIV concept (MURE code, L. Giot)

Simulation code development, based on the summation method, for:

- Impact of new data
- Production of new priority lists of measurements.



Algora et al., Eur. Phys. J. A 57 (2021) 85
Courtesy of L. Giot

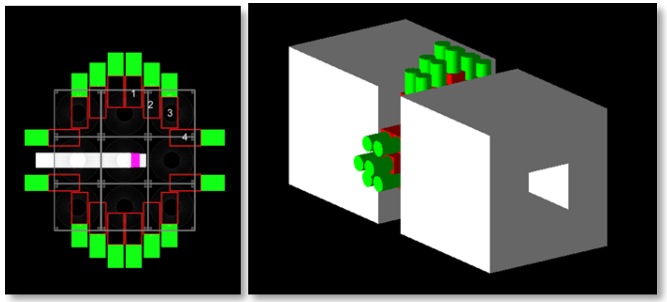
IFIC Valencia, U. Surrey,
U. Madrid, CIEMAT
IJClab, GANIL, LPC Caen, IP2I
IAEA

OPALE : Development of innovative devices and method for more comprehensive studies

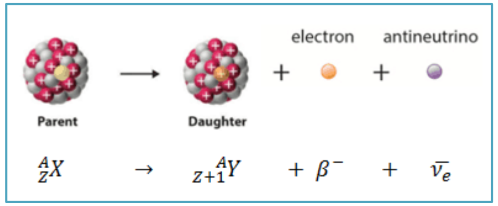
TAGS measurements

Need of TAGS meas. for more exotic nuclei

Dev. of **(NA)²STARS detector**
upgrade DTAS, Subatech, IFIC, Ciemat, IP2I
18 NaI & 16 LaBr3 (large efficiency combined with the very good energy resolution and timing of the LaBr3)



¤ Interest for **Nuclear Structure & astrophysics purposes**



Summation code

Codes development with SERPENT for decay heat calculation (strong link with sim. of Gen IV reactor) and SMURE for anti neutrinos

- Need to include uncertainties and error propagation.
- Antineutrino spectra can be used to help nuclear data evaluation (cf. GEF code, FY)

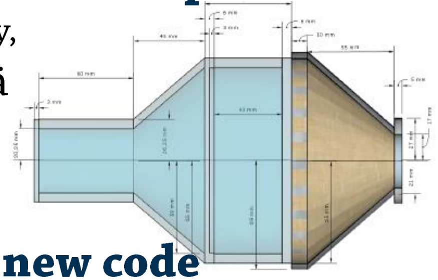
K.-H. Schmidt, M. Estienne, M. Fallot et al., NDS 173, (2021), 54-117

$\bar{\nu}$ spectra

Region above 4.5 MeV
- Shape anomaly
- Pandemonium effect is still dominant
- Lack of data for exotic nuclei

=> Study of the **shape of the β spectrum** for 1st order forbidden non-unique transition

Development of **the E-Shape det.**
Coll. Subatech – IFIC – Surrey,
first meas. @ Jyväskylä
(now!)



Development of a **new code**
Coll. With CEA/LNHB and theoreticians from CEA/DAM who works on the pn-QRPA model

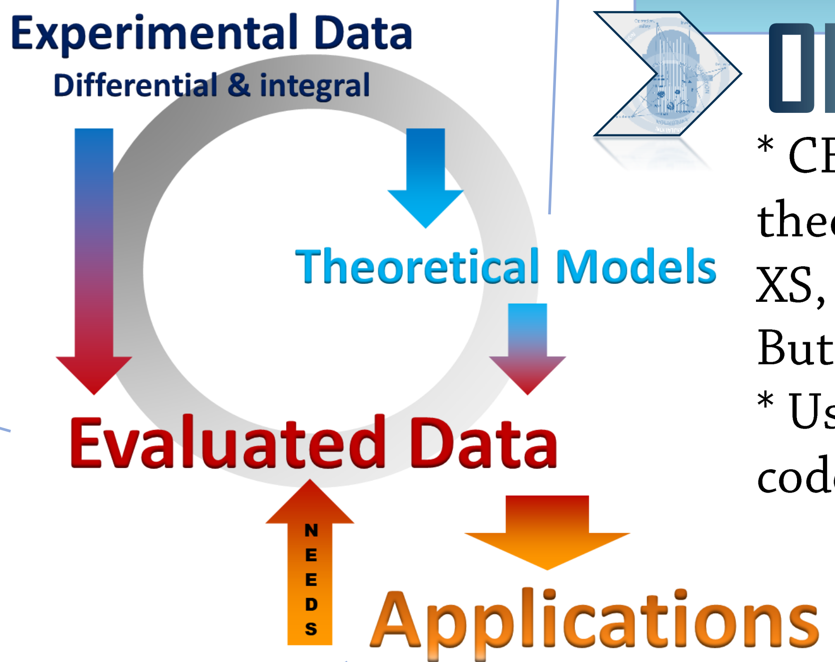
¤ **JUNO-TAO exp.** =>benchmark for ND

Decay data: **in the way of evaluation?**
DD evaluations suffer from a crucial lack of manpower, could exp. help?

New data

OPALE

* Innovative instruments & methods
SCALP, GPRT, GRAPhEME, TAGS, Lohengrin, SOFIA, …



More predictive models

OPALE

* CEA collaboration :
theoretical modeling of Fission yields and XS, inelastic scattering, β decay
But not only, IAEA, LANL, …
* Use and test of the GEF, TALYS, FIFRELIN codes used for evaluation purposes

New evaluation methods

OPALE

* CEA collaboration for evaluation:
Inelastic scattering, ^{242}Pu(n,f), ^{16}O(n,α), Fission yields
* IAEA CRP delayed neutrons, NEA WPEC, NEA-JEEF nuclear Data week

More feedbacks from ND “stakeholders”

OPALE

* GDR SciNEE : Sensitivity studies on DH for Gen IV systems, thorium cycle * NACRE: via CEA collab.

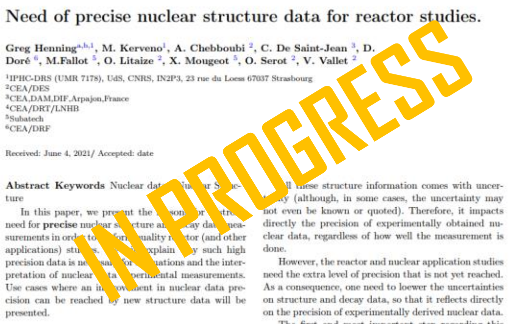
OPALE : fundamentally link to nuclear physics researches

IN2P3 provides the ideal environment to conduct research on nuclear data

¤ the proximity of all researches on **fission process @ IN2P3** is a real asset for our problematic

¤ It has recently been shown, in the frame on the NACRE project,
that **nuclear structure knowledge is a key element** for accurate nuclear data acquisition (experimental methods, simulation codes…).

- A **paper** is in **progress** to list our needs



Need of precise nuclear structure data for reactor studies.

Greg Henning[a,b,1], M. Kerveno[1], A. Chebbоubi [2], C. De Saint-Jean [3], D. Doré [6], M.Fallot [5], O. Litaize [2], X. Mougeot [5], O. Serot [2], V. Vallet [2]

[1]IPHC-DRS (UMR 7178), UdS, CNRS, IN2P3, 23 rue du Loess 67037 Strasbourg
[2]CEA/DES
[3]CEA,DAM,DIF,Arpajon,France
[4]CEA/DRT/LNHB
[5]Subatech
[6]CEA/DRF

Received: June 4, 2021/ Accepted: date

Abstract Keywords Nuclear dat[illegible] Nu[illegible]ar S[illegible]c-ture

In this paper, we pre[illegible]nt the [illegible]son[illegible] [illegible]str[illegible] need for **precise** nu[illegible]ear s[illegible]cture a[illegible] [illegible]cay da[illegible] mea-surements in ord[illegible] to [illegible]for[illegible] [illegible]uality r[illegible]tor (and other applications) stu[illegible]s. [illegible] [illegible]xplain [illegible]y such high precision data is ne[illegible]sa[illegible] for [illegible]uations and the inter-pretation of nuclear [illegible]ta [illegible]perimental measurements. Use cases where an i[illegible]ov[illegible]ent in nuclear data pre-cision can be reached [illegible] new structure data will be presented.

[illegible]ll these structure information comes with uncer-[illegible]y (although, in some cases, the uncertainty may not even be known or quoted). Therefore, it impacts directly the precision of experimentally obtained nu-clear data, regardless of how well the measurement is done.

However, the reactor and nuclear application studies need the extra level of precision that is not yet reached. As a consequence, one need to loewer the uncertainties on structure and decay data, so that it reflects directly on the precision of experimentally derived nuclear data.

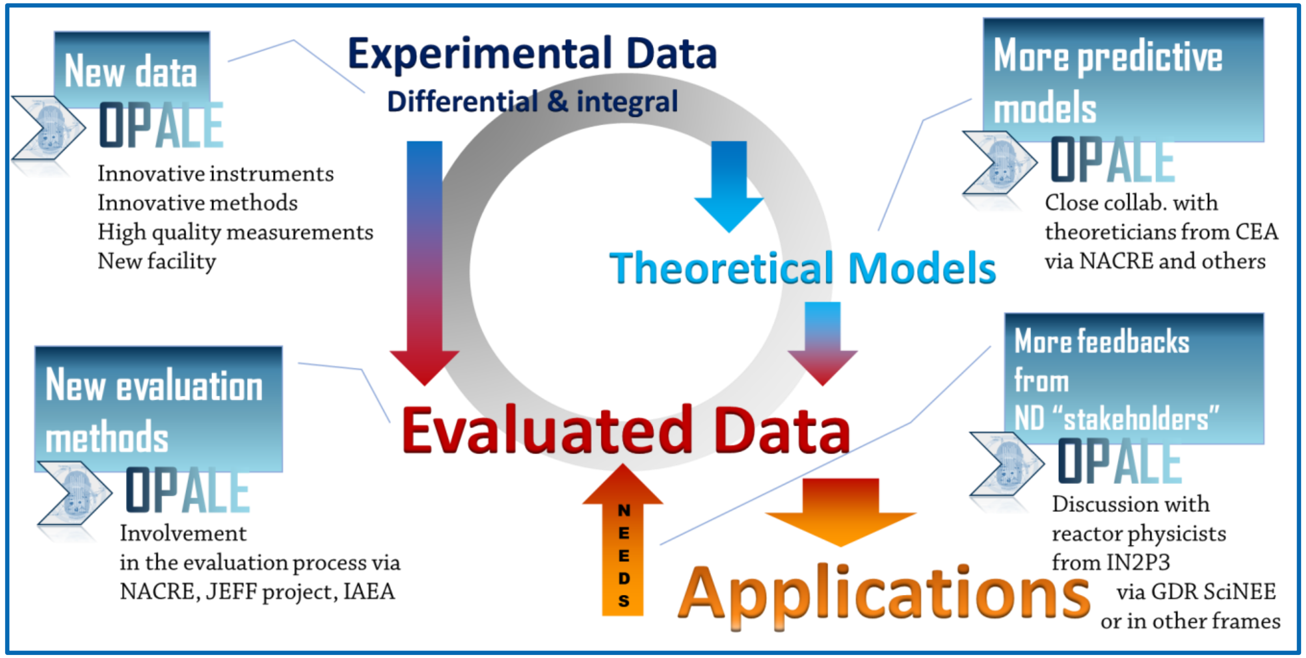
- A **workshop** will be organized (**06/2022**) to gather the ND com. with the « structure » com.
=> start discussion about possible collaboration in **nuclear structure measurements for nuclear energy application**

2 initiatives have already been **launched**

- Participation of IPHC in the **ν-ball2 @ALTO/LICORNE** experiment
-> new ^{238}U level scheme meas. up to 1.5 MeV
- Participation of IPHC in **nuclear structure experiment @ NFS**
-> to study the potential of (n,3n) reactions for nuclear structure meas. with EXOGAM.

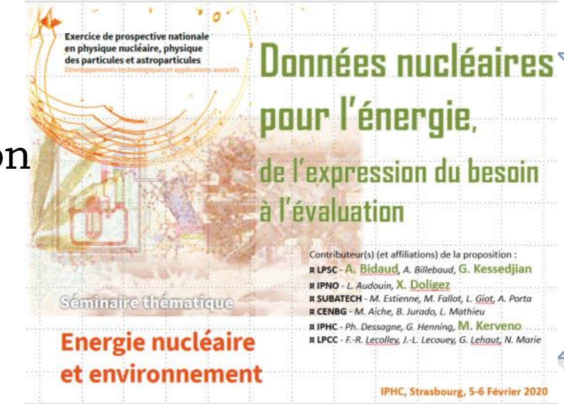
- CONTEXT
    - Nuclear Data for Energy
    - Evaluated Nuclear Data
- NUCLEAR DATA @ IN2P3
    - Organisation: MP OPALE
    - National & International Framework
- OPALE today & tomorrow
- CONCLUSIONS

CONCLUSIONS



- OPALE activities and researcher's have visibility at international level. We are leaders of our projects.
- Commitment in EU project preparation and management
- Continuous development of high quality instruments which could be used at new facilities e.g. SPIRAL2/NFS and DESIR
- An opening towards nuclear structure physics

- Scientific programs clearly identify for the 5-10 coming years with an increased involvement in evaluation and needs definition (cf. IN2P3 prospective exercise with a common Letter of intent)


Exercice de prospective nationale en physique nucléaire, physique des particules et astroparticules

Données nucléaires pour l'énergie, de l'expression du besoin à l'évaluation

Contributeur(s) (et affiliations) de la proposition :
- LPSC - A. Bidaud, A. Billebaud, G. Kessedjian
- IPNO - L. Audouin, X. Doligez
- SUBATECH - M. Estienne, M. Fallot, L. Giot, A. Porta
- CENBG - M. Aiche, B. Jurado, L. Mathieu
- IPHC - Ph. Dessagne, G. Henning, M. Kerveno
- LPCC - F.-R. Lecolley, J.-L. Lecouey, G. Lehaut, N. Marie

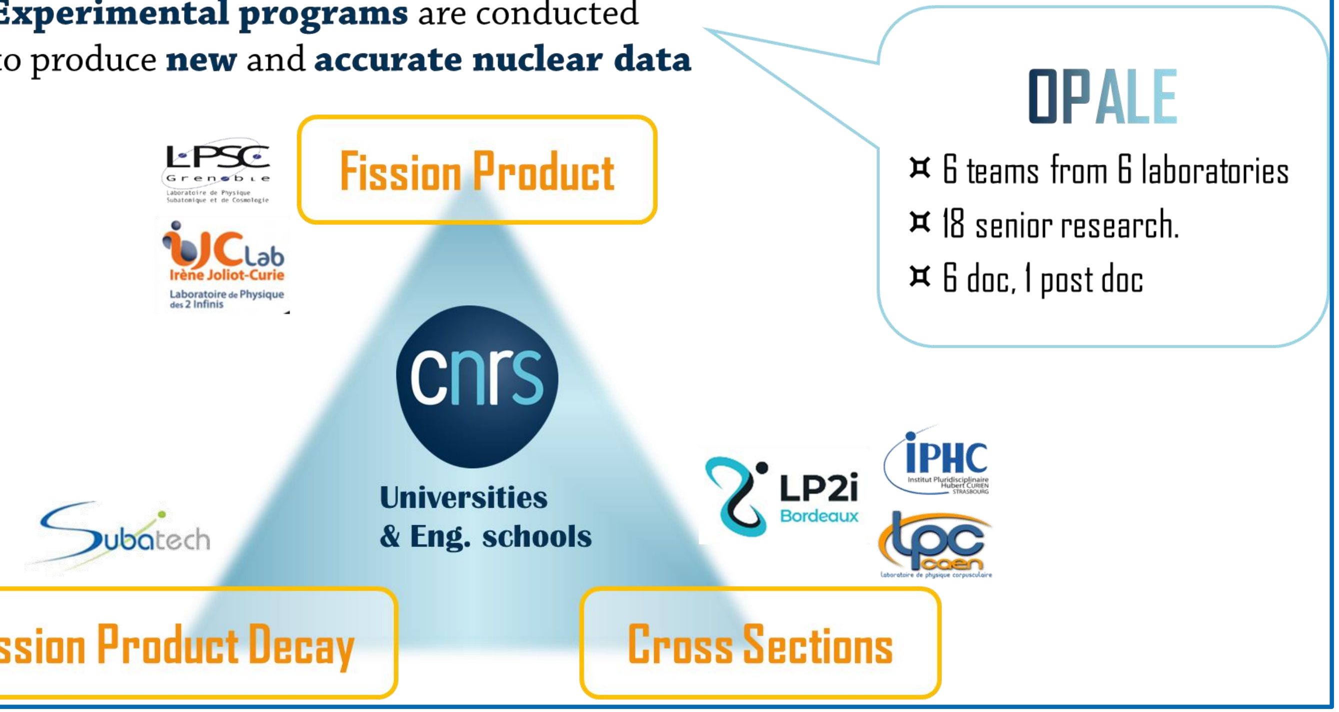
Séminaire thématique
Energie nucléaire et environnement

IPHC, Strasbourg, 5-6 Février 2020

In line with the science driver "**Exploring the potential of nuclear energy for the future and its impact on resources, wastes and costs**" by "**building nuclear databases as complete and accurate as possible**"

Resources are they in line with our ambitions?

Experimental programs are conducted to produce **new** and **accurate nuclear data**

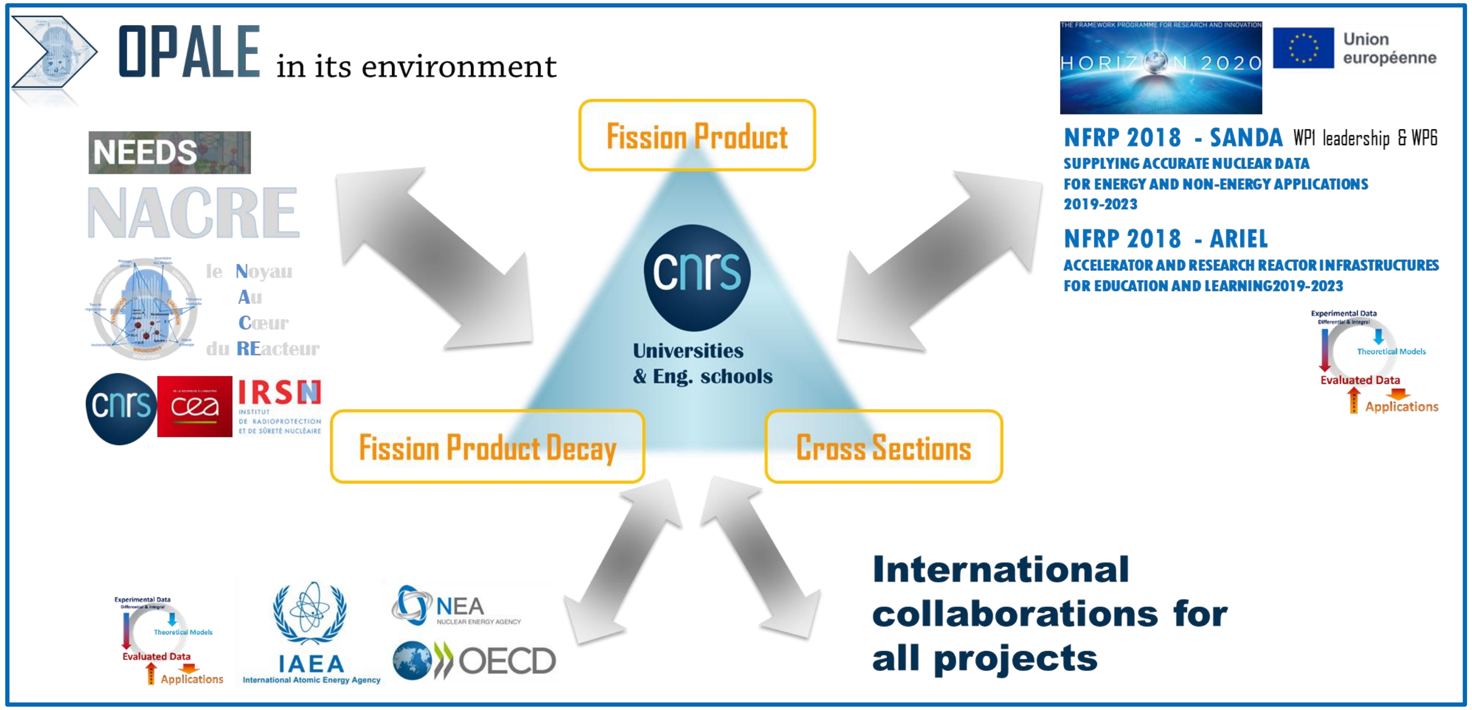


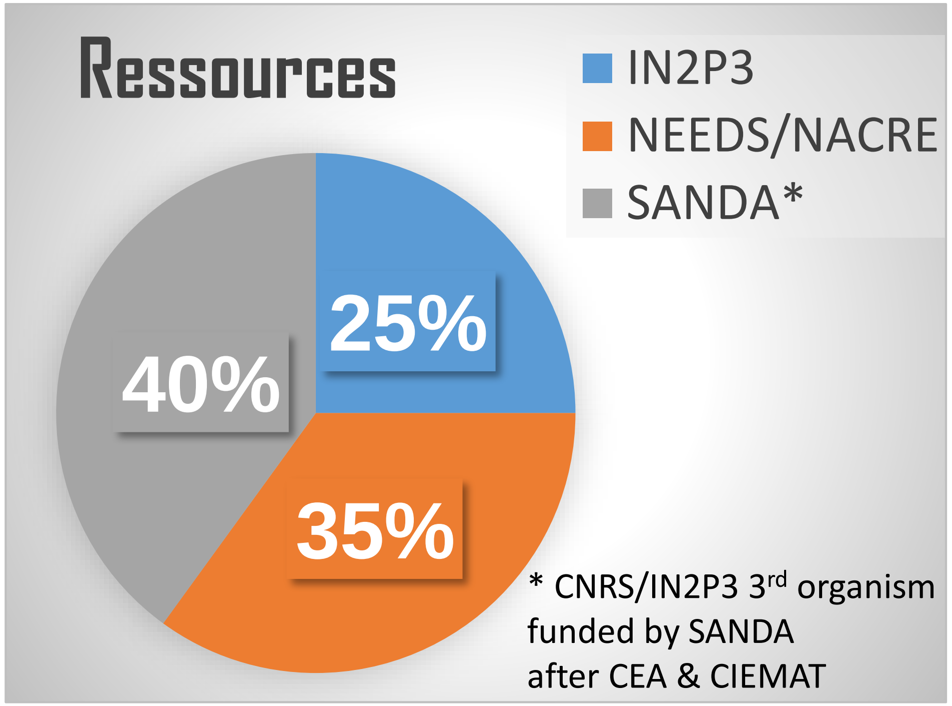
- **Small community** well structured thanks to the OPALE MP.
- The teams are rather young but **2 retirements** within 3 years without visibility on reinforcements.
- Most of the **teams are small (very small?)** and a departure can be critical (ex. n-TOF). The **limited human resources certainly slow down our productivity** (disadvantage in the face of competition.)
- Only **a few post-doctoral and thesis funding.**

- The activities evolve, we have a clear medium term visibility, but other projects can arise. We have developed **precious instruments** that can be use extensively and flexibly. There is not necessarily a known end date.
- The technical commitment is regular (maintenance/upgrade of instruments) and more consequent needs over a few years may emerge depending on the funding obtained for detector development.

CONCLUSIONS

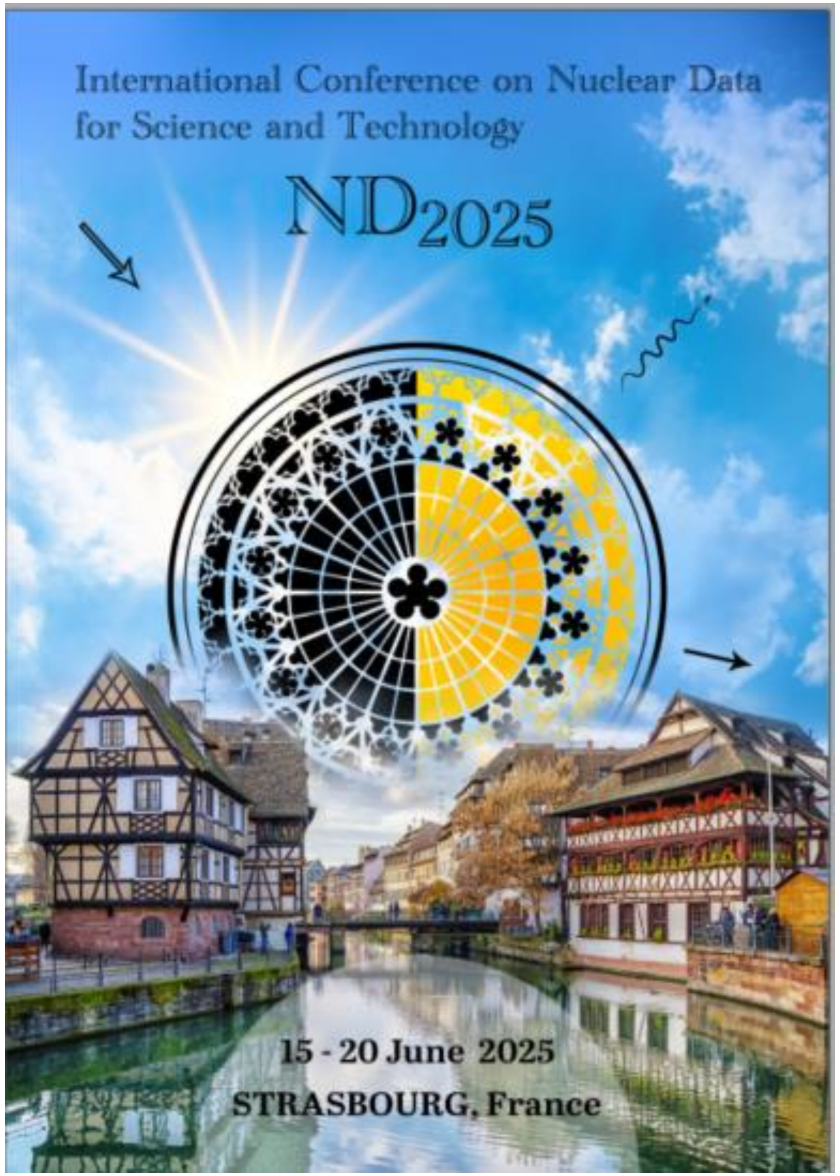
Resources are they in line with our ambitions?





In this scheme, multi-desk is essential <u>but risky</u>!! (only 25% from IN2P3)

- A lot of reporting works, need for sustainability of desks, fragility at the time of renewals, dependence on national and European policies
- Difficulty with IN2P3 financial inputs to start new detector developments. Total dependency to external funds.



Et si l'IN2P3 organisait « notre » conférence internationale,

« Internationale Conference on Nuclear Data
for Science and Technology 2025 »

à Strasbourg?

OPALE a relevé le défi de la candidature!

Thank you for your attention …