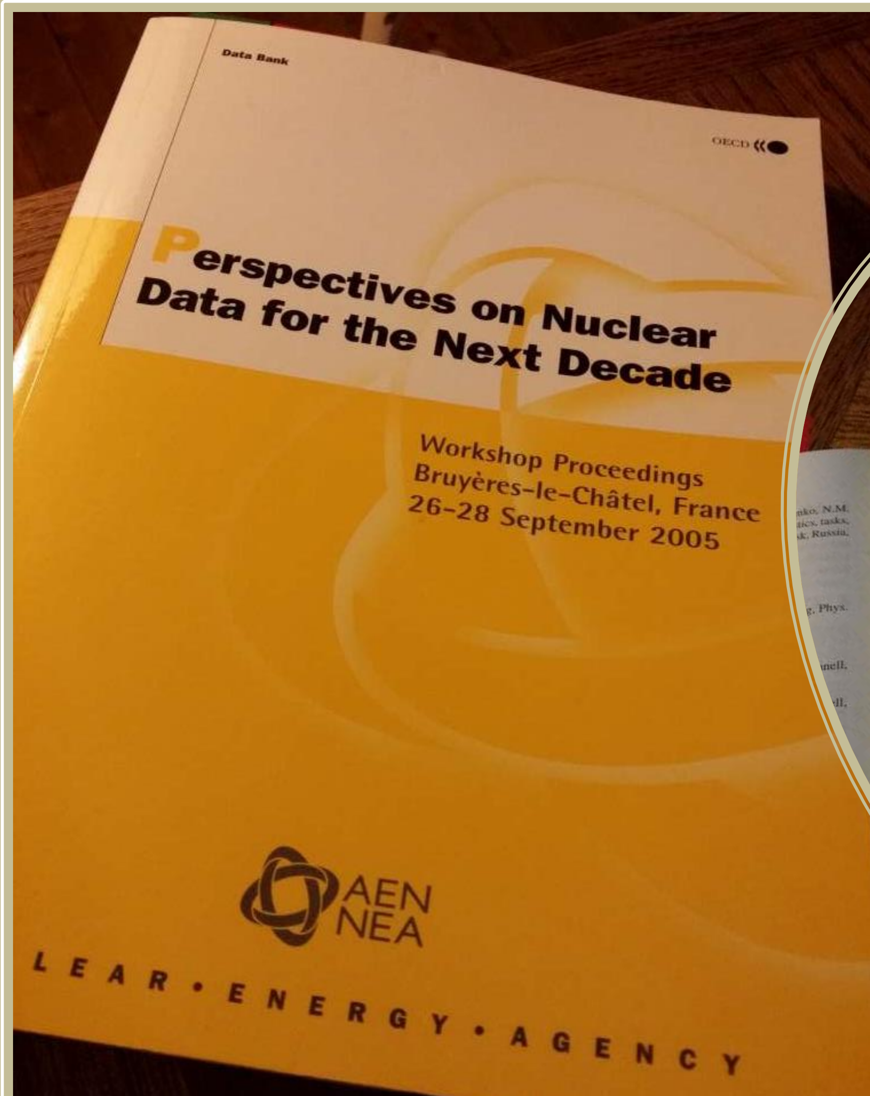
P(ND)²-2

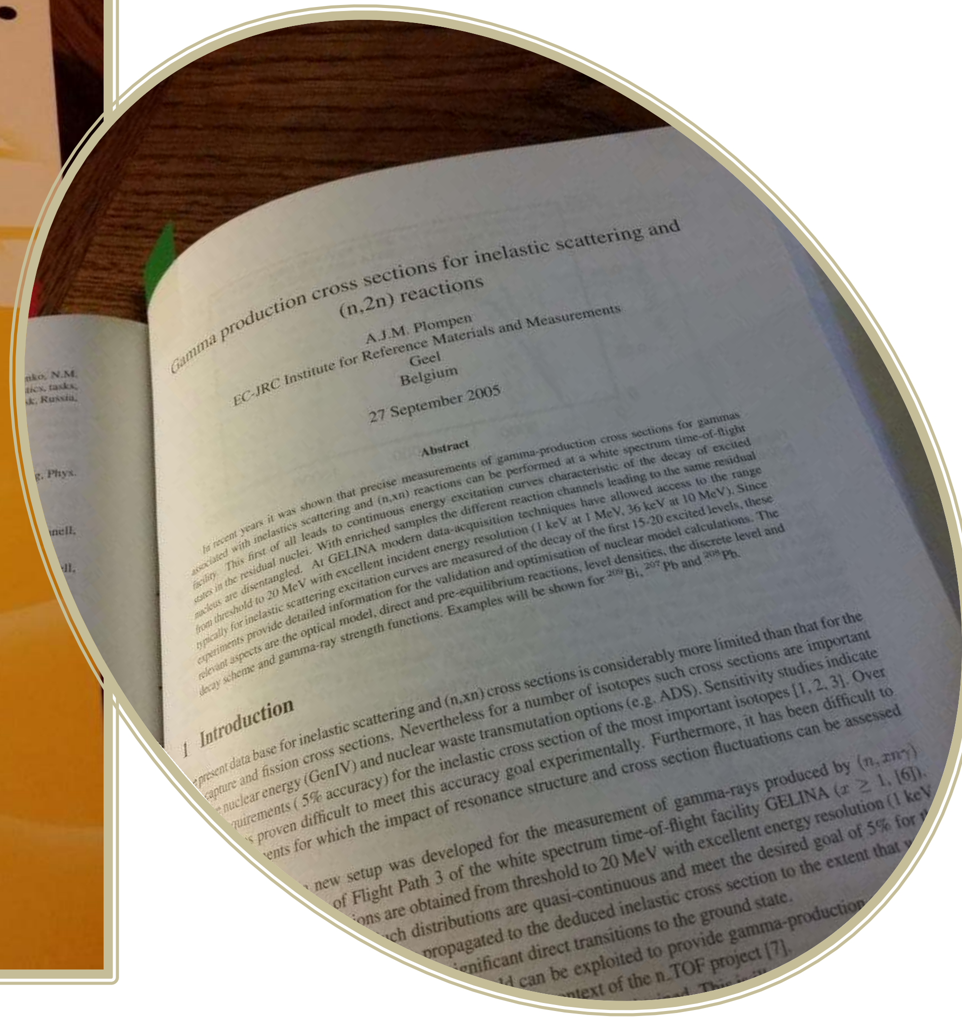
Perspectives on Nuclear Data for the Next Decade

(n,xn γ) cross sections : relevant tests for nuclear reaction codes?

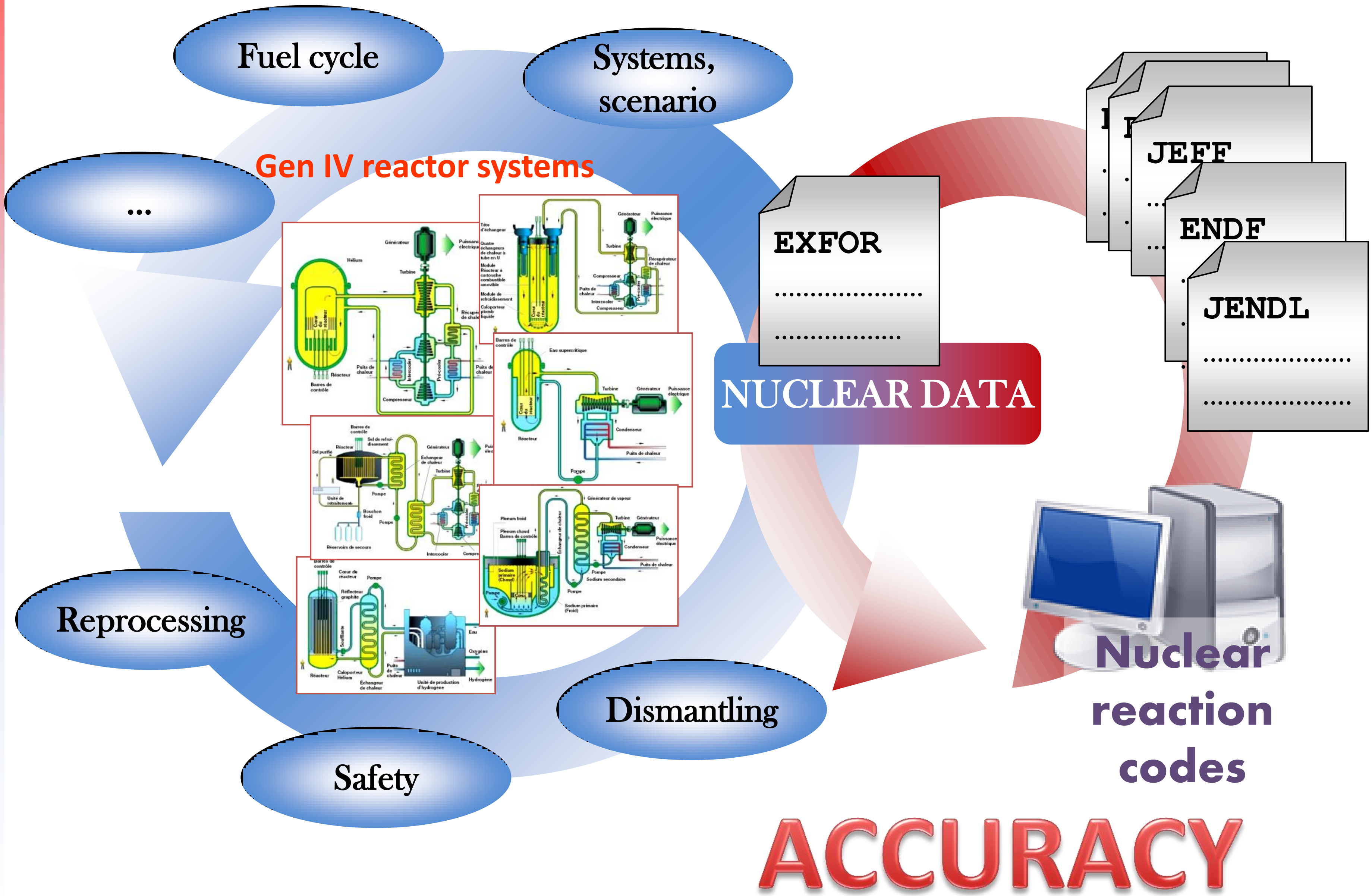
M. Kerveno, A. Bacquias, Ph. Dessagne, G. Henning, G. Rudolf - *CNRS/IPHC*
M. Nyman, A. J. M. Plompen - *JRC/IRMM*
C. Borcea, A. Negret - *IFIN-HH*

From P(ND)²-1 to P(ND)²-2

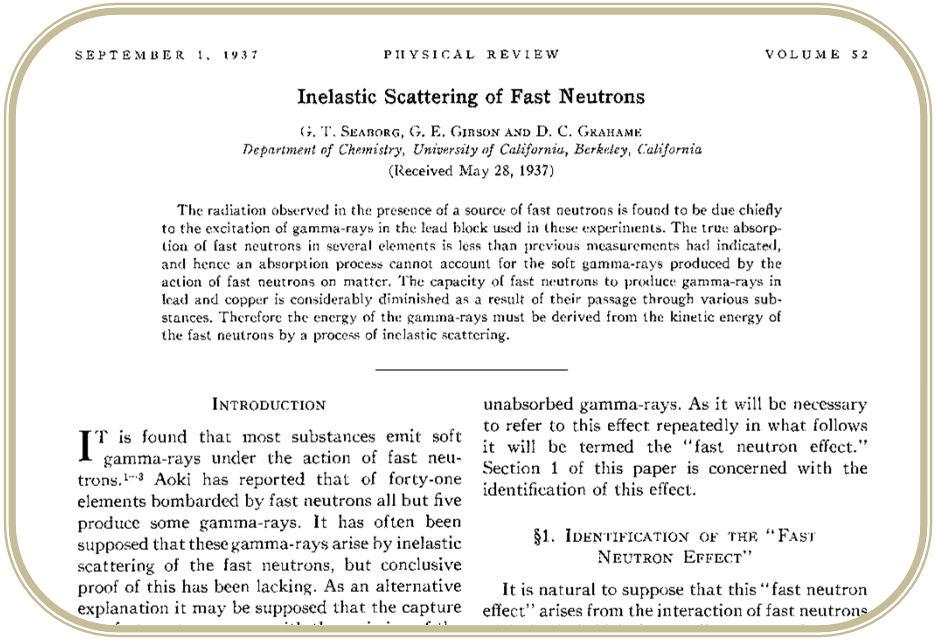




General context



General context : inelastic scattering, (n,xn) reactions



SEPTEMBER 1, 1937 PHYSICAL REVIEW VOLUME 52

Inelastic Scattering of Fast Neutrons

G. T. Seaborg, G. E. Gibson and D. C. Grahame
Department of Chemistry, University of California, Berkeley, California
(Received May 28, 1937)

The radiation observed in the presence of a source of fast neutrons is found to be due chiefly to the excitation of gamma-rays in the lead block used in these experiments. The true absorption of fast neutrons in several elements is less than previous measurements had indicated, and hence an absorption process cannot account for the soft gamma-rays produced by the action of fast neutrons on matter. The capacity of fast neutrons to produce gamma-rays in lead and copper is considerably diminished as a result of their passage through various substances. Therefore the energy of the gamma-rays must be derived from the kinetic energy of the fast neutrons by a process of inelastic scattering.

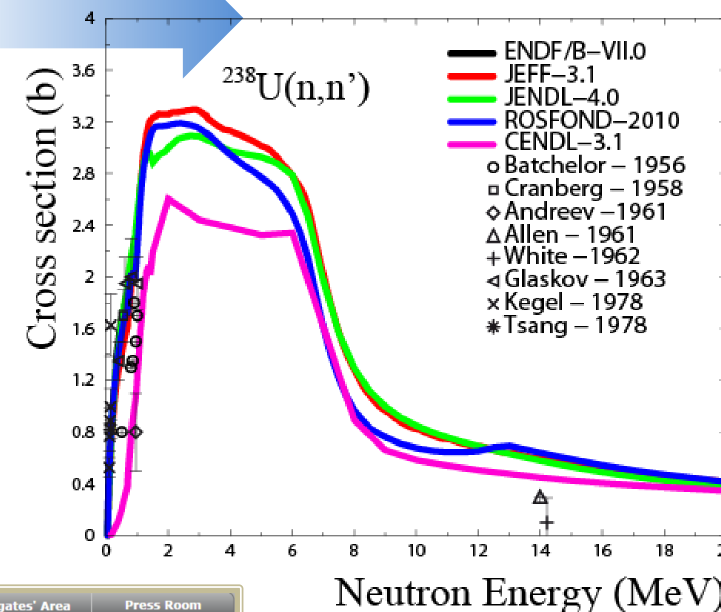
Introduction

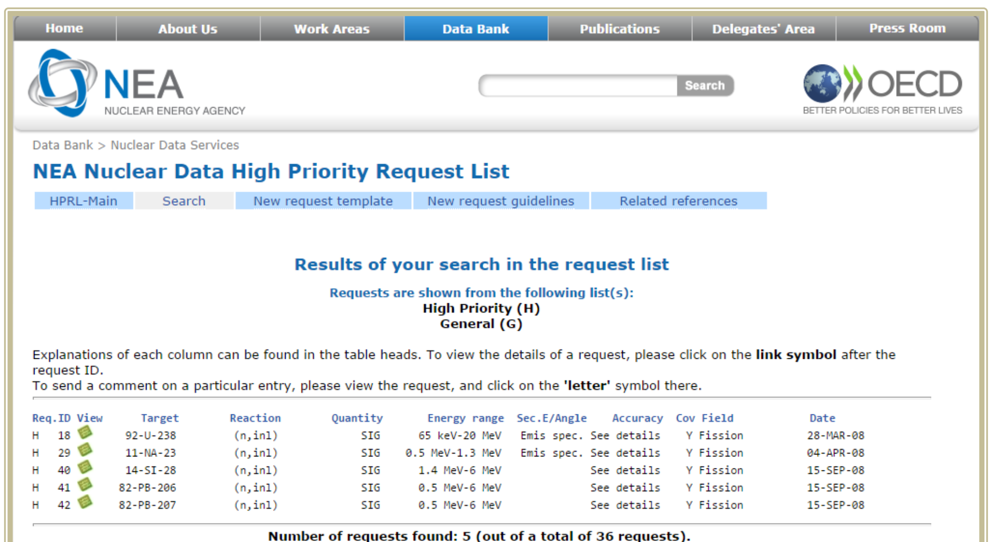
It is found that most substances emit soft gamma-rays under the action of fast neutrons.[1–3] Aoki has reported that of forty-one elements bombarded by fast neutrons all but five produce some gamma-rays. It has often been supposed that these gamma-rays arise by inelastic scattering of the fast neutrons, but conclusive proof of this has been lacking. As an alternative explanation it may be supposed that the capture unabsorbed gamma-rays. As it will be necessary to refer to this effect repeatedly in what follows it will be termed the "fast neutron effect." Section 1 of this paper is concerned with the identification of this effect.

§1. Identification of the "Fast Neutron Effect"

It is natural to suppose that this "fast neutron effect" arises from the interaction of fast neutrons

70 years later …





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Results of your search in the request list

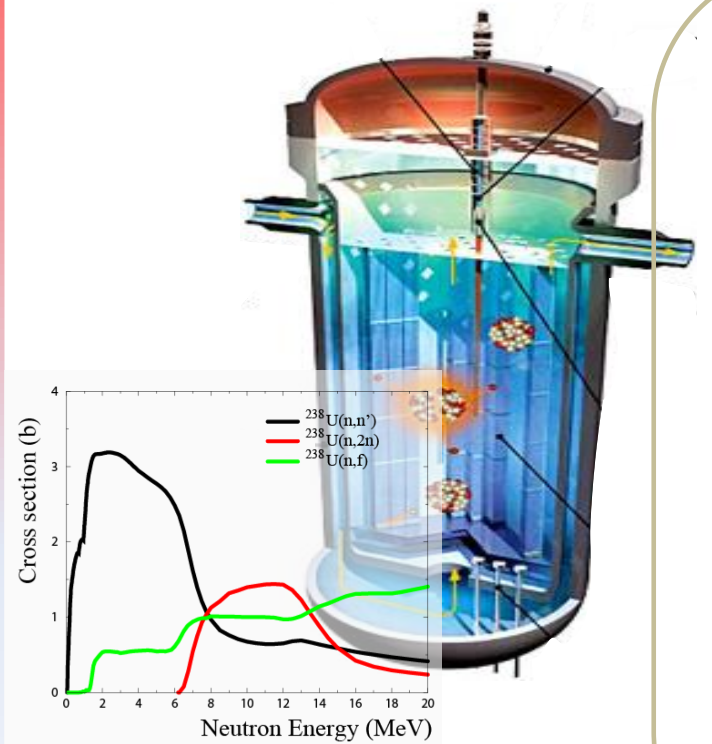
Requests are shown from the following list(s):
High Priority (H)
General (G)

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.

Req.ID		View	Target	Reaction	Quantity	Energy range	Sec.E/Angle	Accuracy	Cov	Field	Date
H	18		92-U-238	(n,inl)	SIG	65 keV-20 MeV	Emis spec.	See details	Y	Fission	28-MAR-08
H	29		11-NA-23	(n,inl)	SIG	0.5 MeV-1.3 MeV	Emis spec.	See details	Y	Fission	04-APR-08
H	40		14-SI-28	(n,inl)	SIG	1.4 MeV-6 MeV		See details	Y	Fission	15-SEP-08
H	41		82-PB-206	(n,inl)	SIG	0.5 MeV-6 MeV		See details	Y	Fission	15-SEP-08
H	42		82-PB-207	(n,inl)	SIG	0.5 MeV-6 MeV		See details	Y	Fission	15-SEP-08

Number of requests found: 5 (out of a total of 36 requests).

General context : example of inelastic scattering on ^{238}U



^{238}U(n,n') problematic (A.Santamarina et al.)

GEN-3 commercial reactors :
large sizes => radial power very sensitive to ND
GEN-4 reactors :
fast neutron spectrum => k_{eff} sensitive to ND

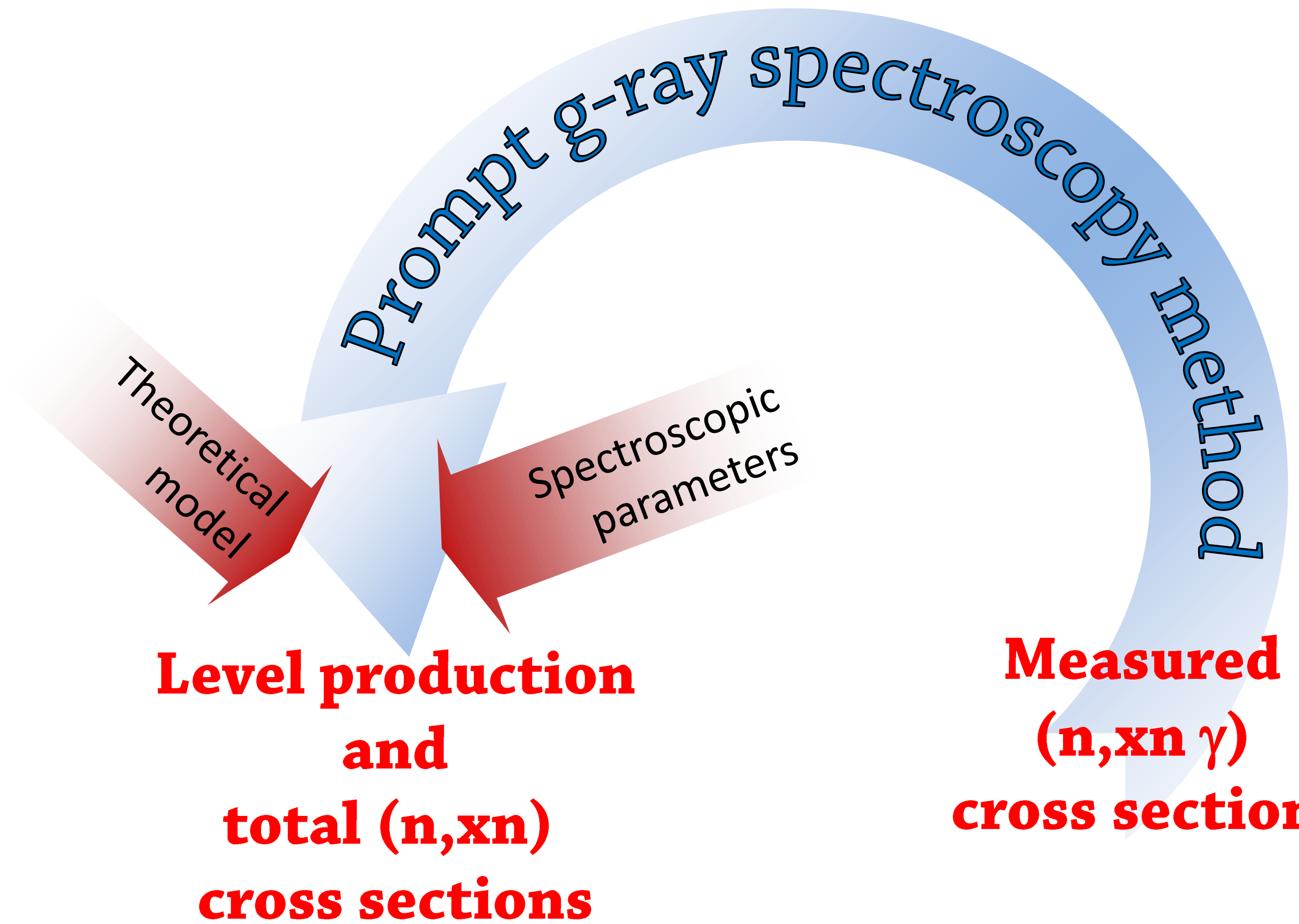
State of the art for ^{238}U(n,n') :
40 meas. in EXFOR from 1956 to 2009
8 total cross section measurements
=> large discrepancies between experimental data and between evaluated cross sections
=> **^{238}U(n,n') XS uncertainty = from 5% to 20 %**

Target accuracy on ^{238}U(n,n') :
-> PWR : **± 10 %**
-> SFR : **± 5 %**

Request ID	18			
Target	Reaction and process	Incident Energ		nce
92-U-238	(n,inl) SIG	65 keV-20 Me		
Field	Subfield	Date Request		
Fission	Fast Reactors EFR,SFR,ABTR...	28-MAR-08	11-SEP-08	

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

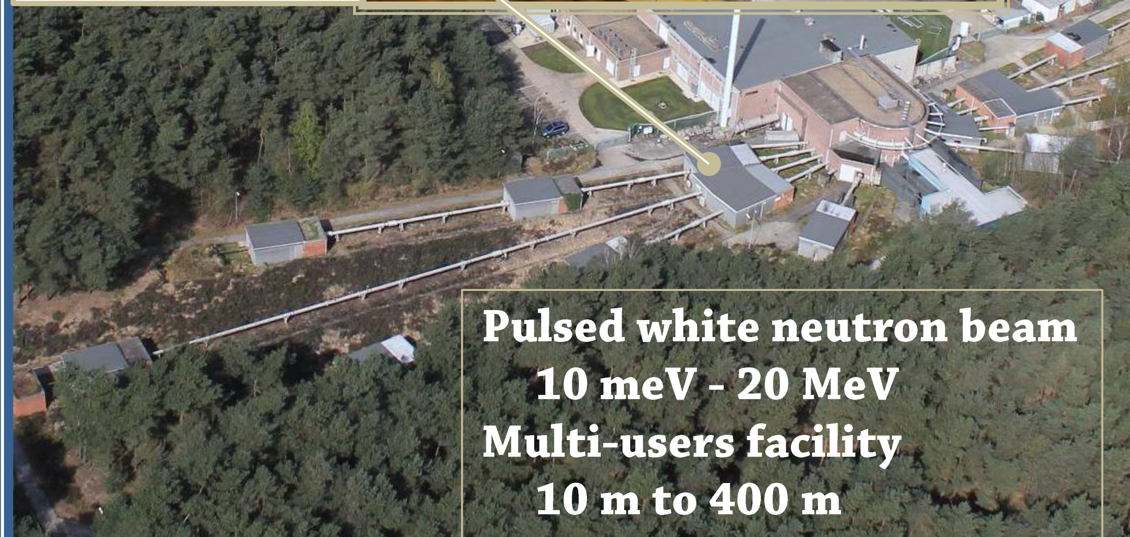
Inelastic scattering and (n,xn) experimental studies



Inelastic scattering and (n,xn) experimental studies

4 HPGe Planar
(110°,150°)
Actinides samples
ΔEn = 10 keV @ En = 1 MeV

Neutron Time of flight facility
GELINA@IRMM(Geel)

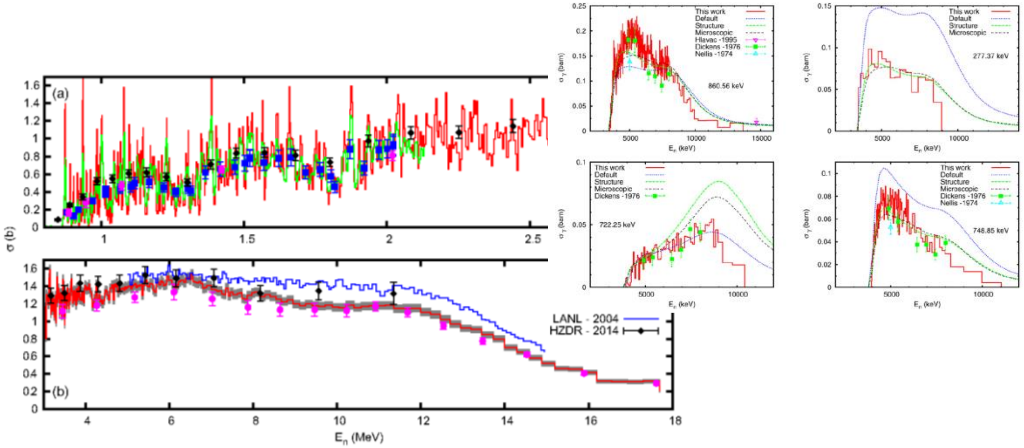


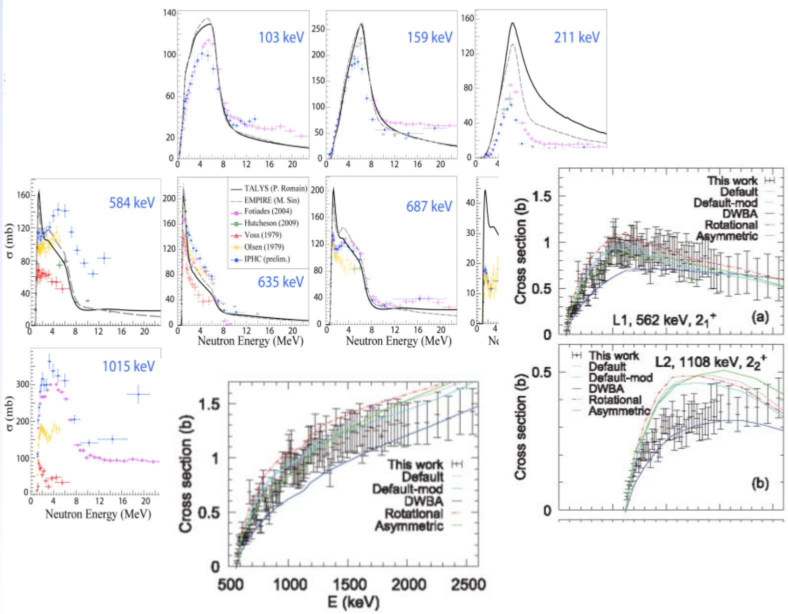
12 HPGe Ø 80 mm x L 80 mm
(110°,150°)
ΔEn = 1 keV @ En = 1 MeV

^{12}C, ^{23}Na, ^{24}Mg, ^{28}Si, ^{52}Cr, ^{56}Fe, ^{58}Ni, ^{76}Ge, ^{nat}Zr, ^{nat,182,183,184,186}W, ^{206,207,208}Pb, ^{209}Bi, ^{232}Th, ^{235,238}U

(n,xn γ) technique : experience feedback

Powerful method which provides a lot of cross sections :
- (n,xn γ)
- Level production
- total





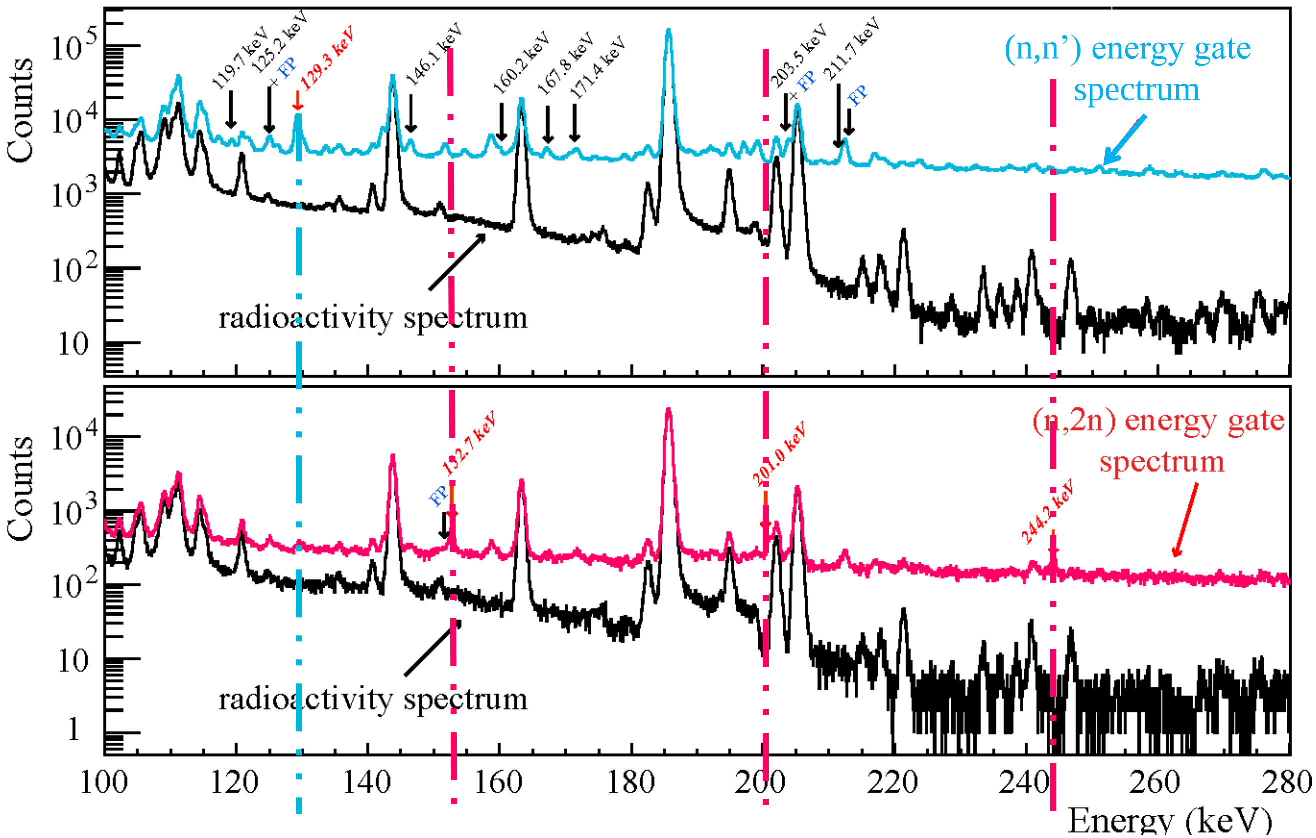
^{52}Cr : L.C. Mihailescu *et al.* **NPA786(2007)1**
^{209}Bi : L.C. Mihailescu *et al.* **NPA799(2008)1**
^{208}Pb : L.C. Mihailescu *et al.* **NPA811(2008)1**
^{23}Na : C. Rouki *et al.* **NIMA672(2012)82**
^{235}U : M. Kerveno *et al.* **PRC87(2013)024609**
0ν2β : A. Negret *et al.* **PRC88(2013)027601**
^{28}Si : A. Negret et al. **PRC88(2013)034604**
^{76}Ge : C.Rouki *et al.* **PRC88(2013)054613**
^{56}Fe : A. Negret *et al.* **PRC90(2014)034602**
^{24}Mg : A.Olacel *et al.* **PRC90(2014)034603**
^{232}Th : M.Kerveno *et al.* **EPJA(2014) accepted**
^{7}Li, ^{12}C, ^{58}Ni, ^{nat,184,186}W, ^{206,207}Pb, ^{232}Th, ^{238}U: conf.

(n,xn γ) technique : experience feedback

γ spectra very selective for the reaction identification
but

- **mixing reaction channels possible if sample not pure**
- **complex decay scheme for actinide + radioactivity**
- **fission products contamination may occur with fissionable sample**

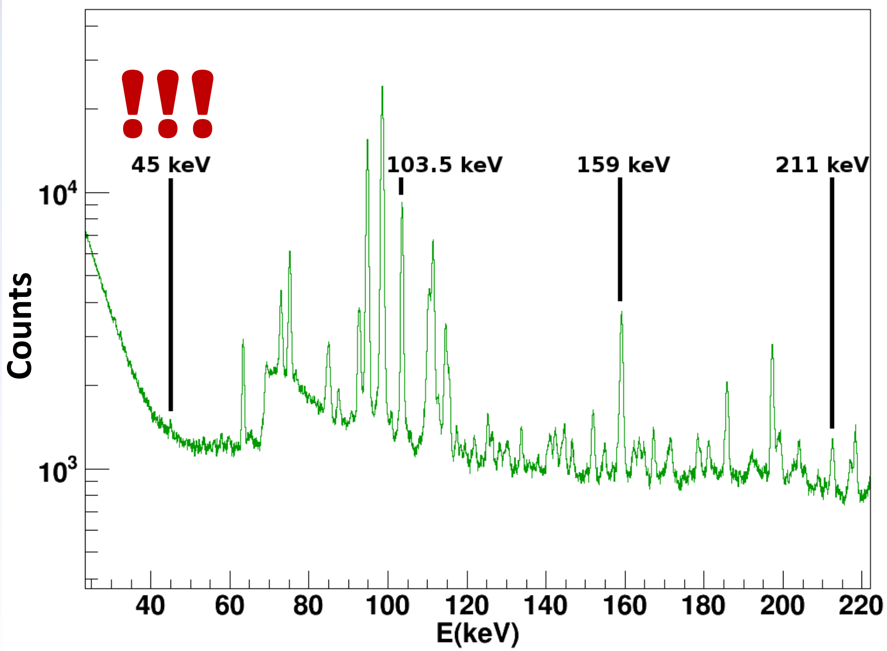
^{235}U example

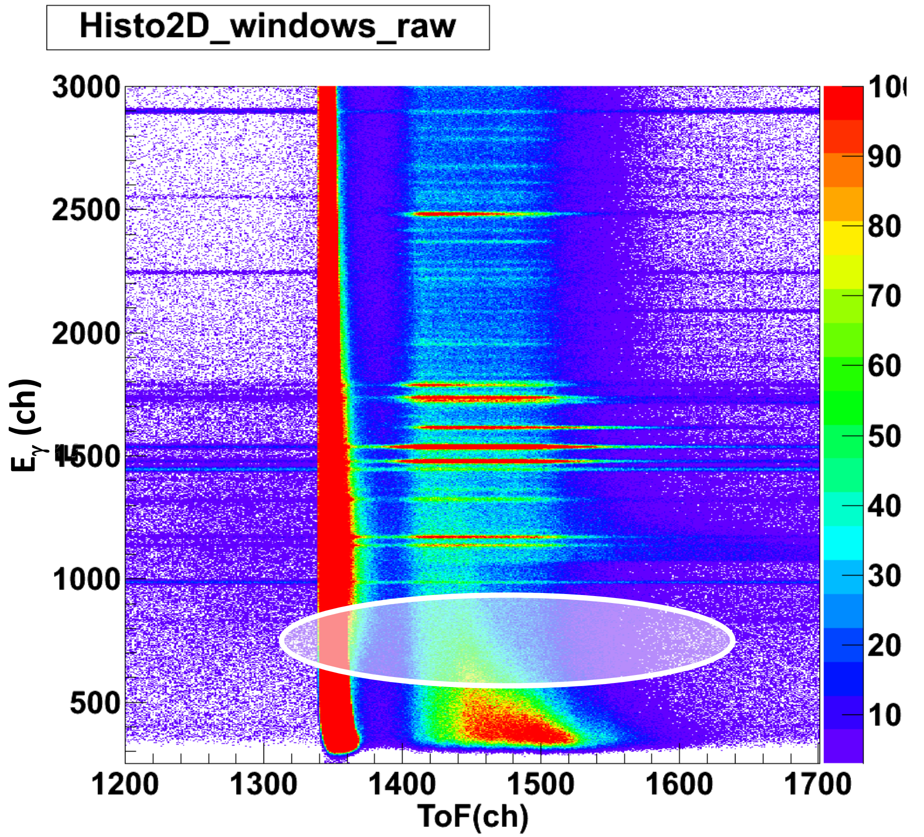


(n,xn γ) technique : experience feedback

γ spectra very selective for the reaction identification
but
poor efficiency for low energy γ due to IC in actinides + electronic effects

^{238}U
example

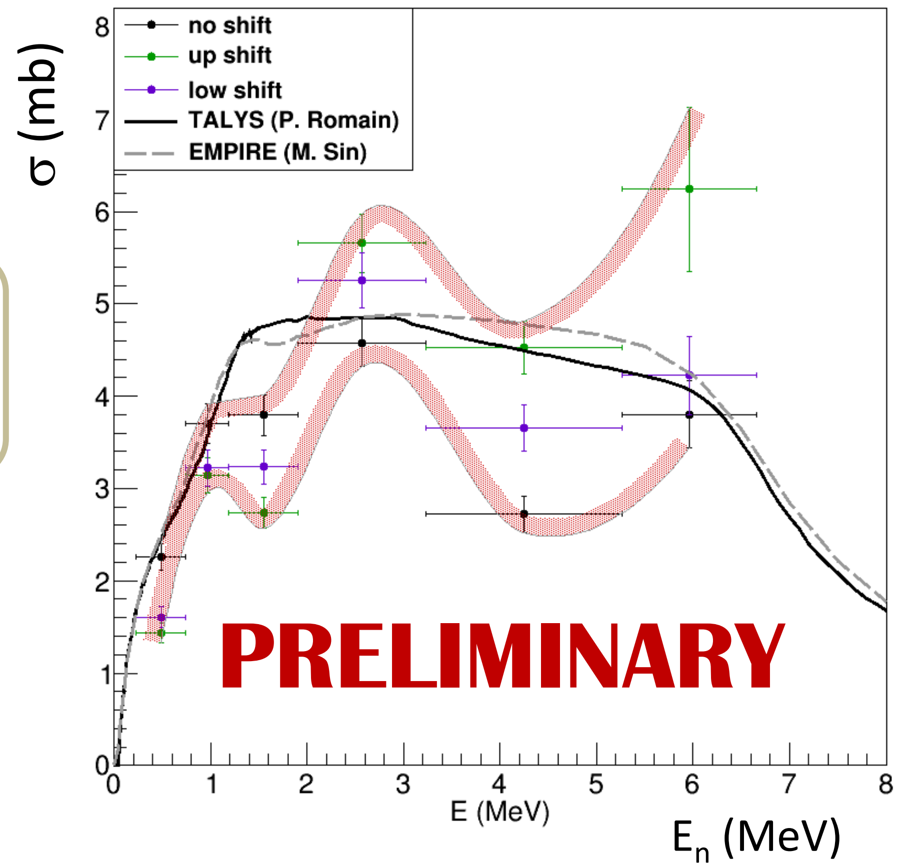




(n,xn γ) technique : experience feedback

γ spectra very selective for the reaction identification
but
poor efficiency for low energy γ due to IC in actinides + electronic effects

^{238}U example :
L1 (2^+) -> L0 (0^+) E_γ = 45 keV



(n,xn γ) technique : experience feedback

Uncertainties budget

$\Delta\sigma/\sigma$: from **3% to 20%**

Detected hits in a given ray:
- **peak identification** (possible contamination)
- **Good statistics**
- **Low background**

Cross section of a given γ ray transition [b]

$$\frac{d\sigma^{(n,xn\gamma)}}{d\Omega}(\theta) = \frac{n_{\det}}{N_{at} \cdot \phi_n \cdot \varepsilon_\gamma \cdot t}$$

Acquisition time [s]
- **Long time measurements** (stability)

Number of atoms in target
- **Sample composition**
- **Precise** measurements (**size, weight**)

γ detection efficiency
- **Measurements**
- **Simulations** (attenuation, oxidation)

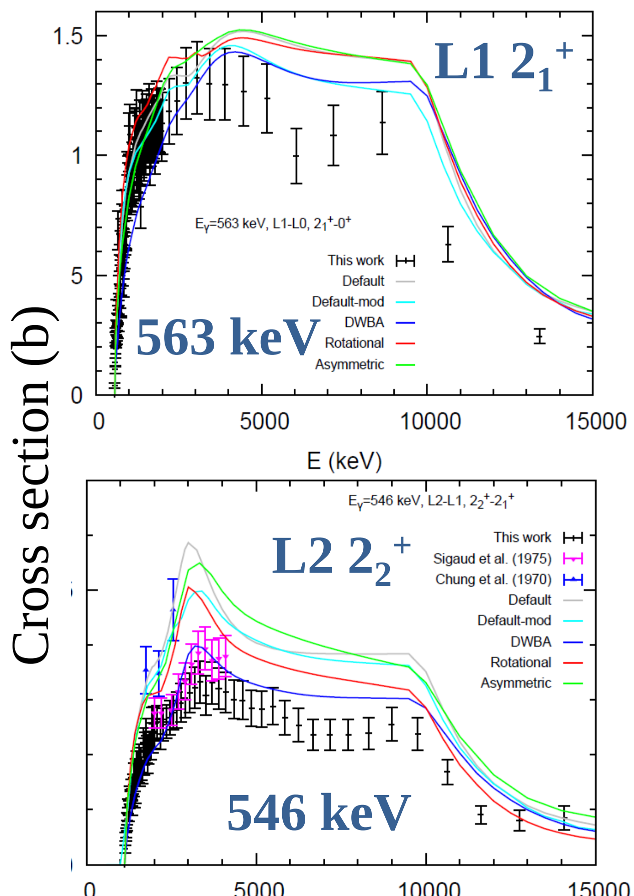
Incident neutron flux [$s^{-1} \cdot cm^{-2}$]
Fission chamber characteristics

(n,xn γ) cross sections and models...

^{76}Ge
GAINS

C.Rouki *et al.* **PRC88(2013)054613**

Motivations: Background in 0νββ-experiment
-> Neutron induced production of the 2040 keV γ-transition



Experiment
Default
Mod. OMP
DWBA
Rotational
Asymmetric

5 (n,n' γ) XS, 5 level prod. XS, ^{76}Ge(n,n') XS

Extensive TALYS model calc.:
-default phys. model
-modified OMP
-effect of the deformation (DWBA, rot., asym.)

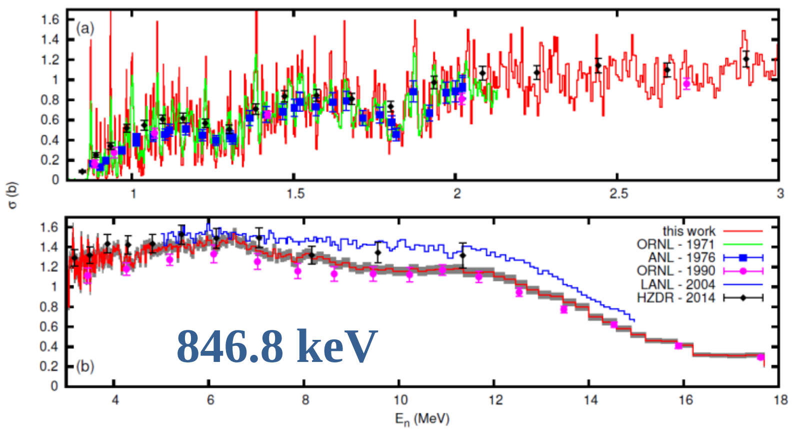
⇒ Improvement with coupled channel calc.
⇒ Not enough exp. total and elastic angular XS to optimize OM

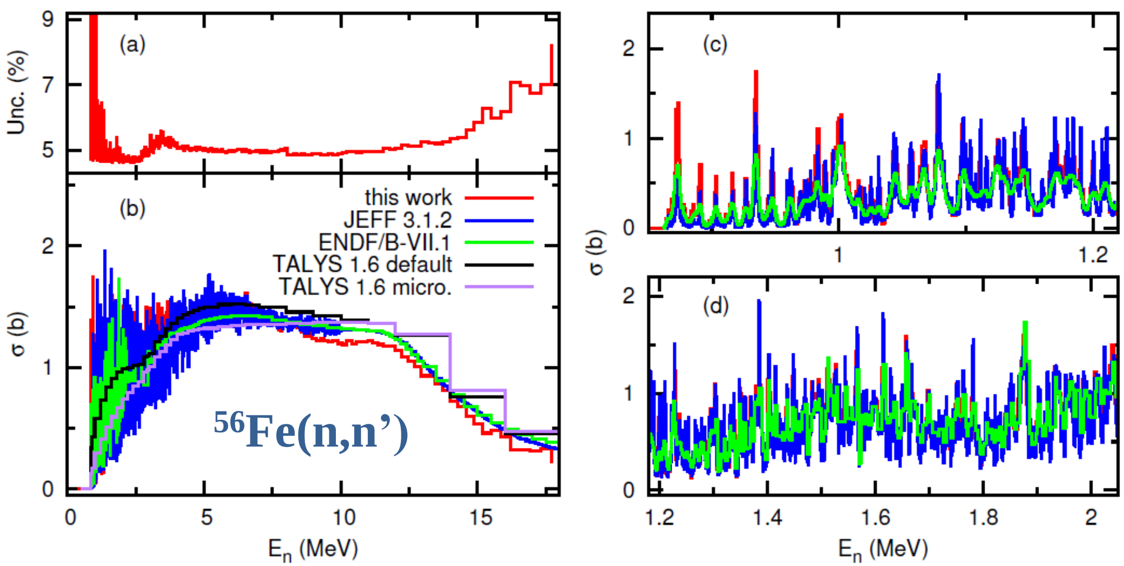
(n,xn γ) cross sections and models…

GAINS ^{56}Fe

A. Negret *et al.* **PRC90(2014)034602**

Motivations: structural materials in reactor
-> requirement of accuracies <5% and even ~2% for ADS!!





20 (n,n' γ) XS,
10 level prod. XS, 6 (n,2n γ) XS, ^{56}Fe(n,n') XS

- Special care to accuracy and systematic effects
- High energy resolution
- TALYS calculations default versus microscopic

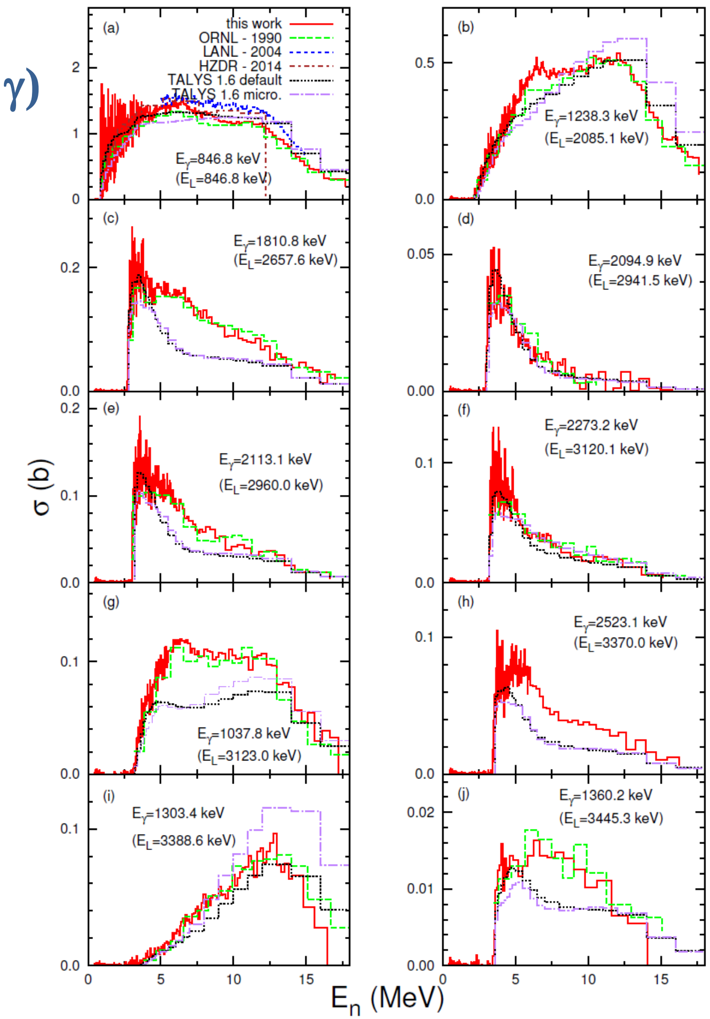
(n,xn γ) cross sections and models…

GAINS ^{56}**Fe**

A. Negret *et al.* **PRC90(2014)034602**

Motivations: structural materials in reactor
-> requirement of accuracies <5% and even ~2% for ADS!!

^{56}Fe(n,n' γ)



20 (n,n' γ) XS,
10 level prod. XS, 6 (n,2n γ) XS, ^{56}Fe(n,n') XS

- Special care to accuracy and systematic effects
- TALYS calc. default versus microscopic

⇒ Default param. Better than microscopic ones: pb with ^{56}Fe theo. description?

(n,xn γ) cross sections and models…

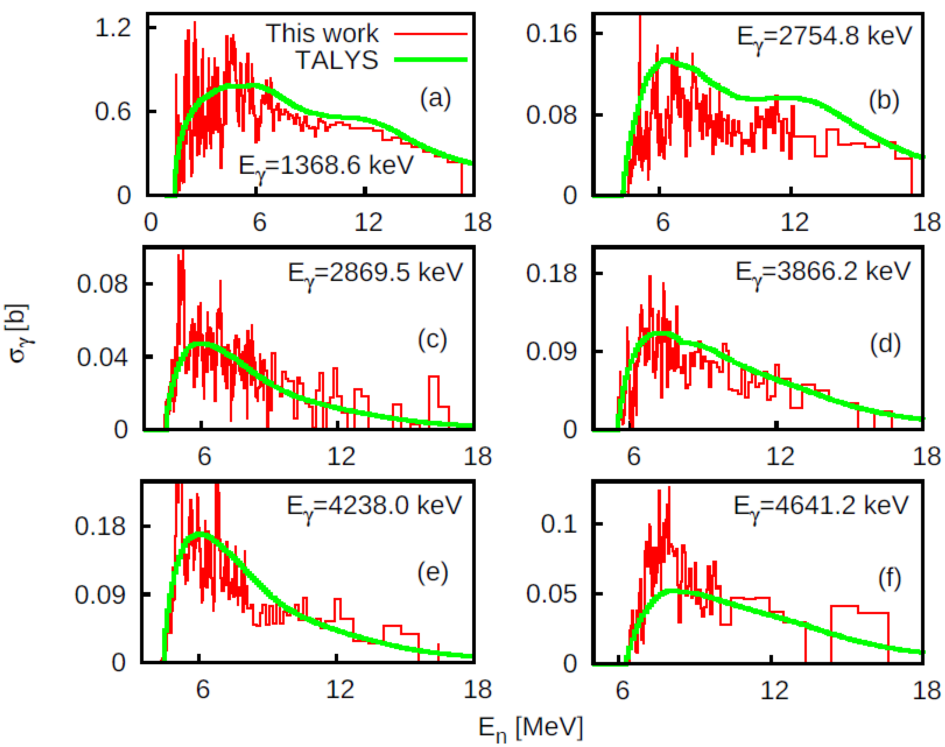
GAINS ^{24}Mg

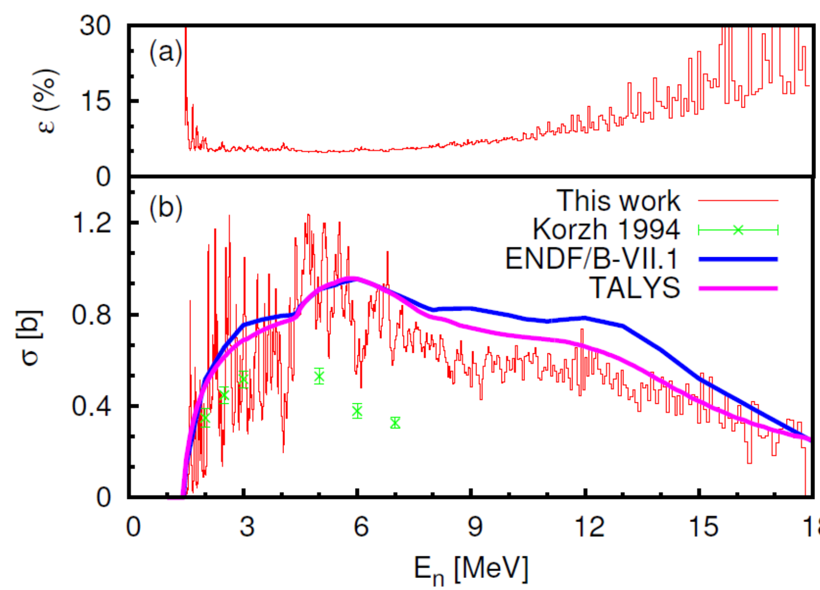
A.Olacel *et al.* **PRC90(2014)034603**

Motivations: structural materials in reactor, ^{24}Mg production in SFR

6 (n,n' γ) XS, 5 level prod. XS, ^{24}Mg(n,n') XS

TALYS calculations :
default versus microscopic
⇒ No difference observed
⇒ TALYS produces XS in relative good agreement



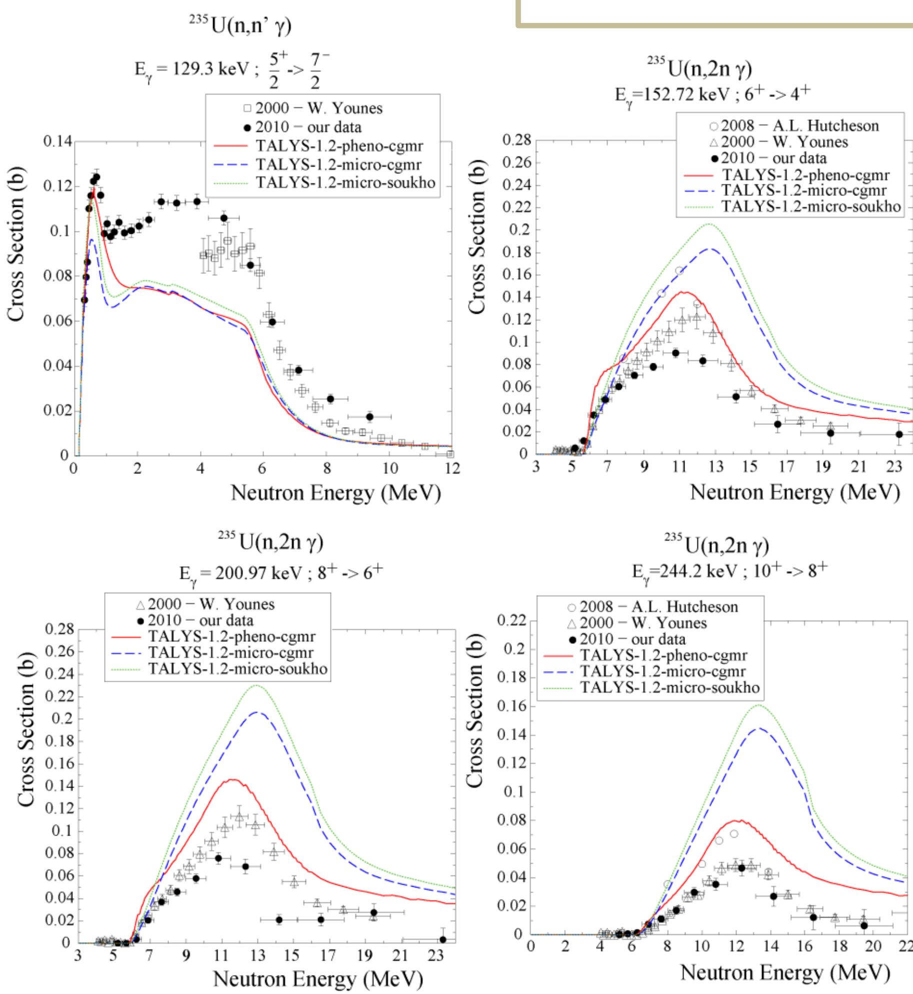


(n,xn γ) cross sections and models…

^{235}U
GRAPhEME

M. Kerveno *et al.* **PRC87(2013)024609**

Motivations: Actinides studies with a "well known" nucleus



1 (n,n' γ) XS, 3 (n,2n γ) XS

- Difficulty to analyse (n,n') channel
- TALYS calculations :

Combination of ≠ OM and phenomelogical or microscopic parameters inputs.

⇒ Pheno-cgmr is better

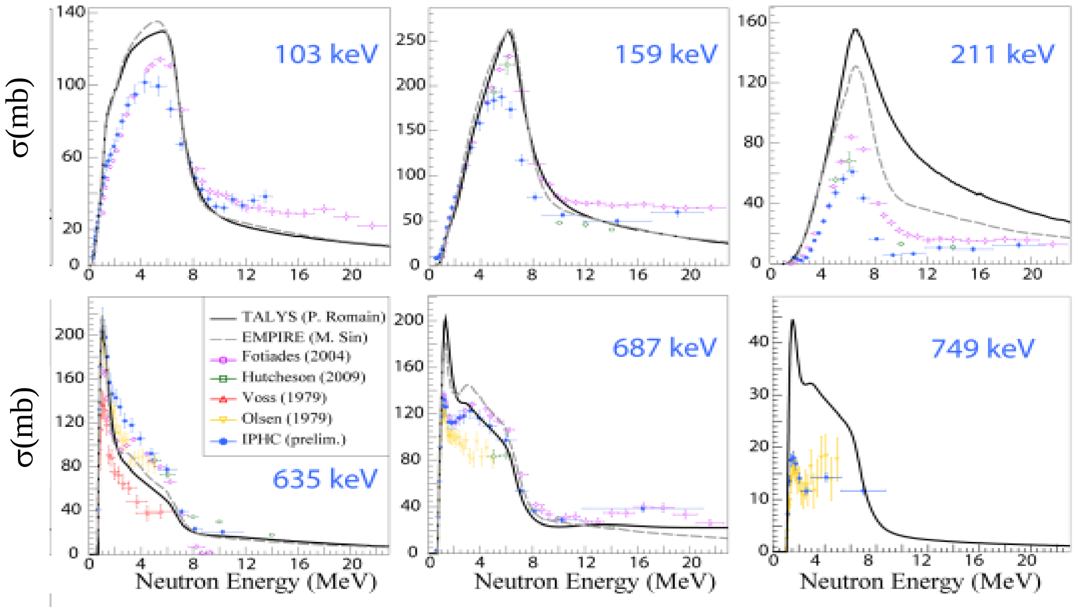
⇒ Still discrepancies

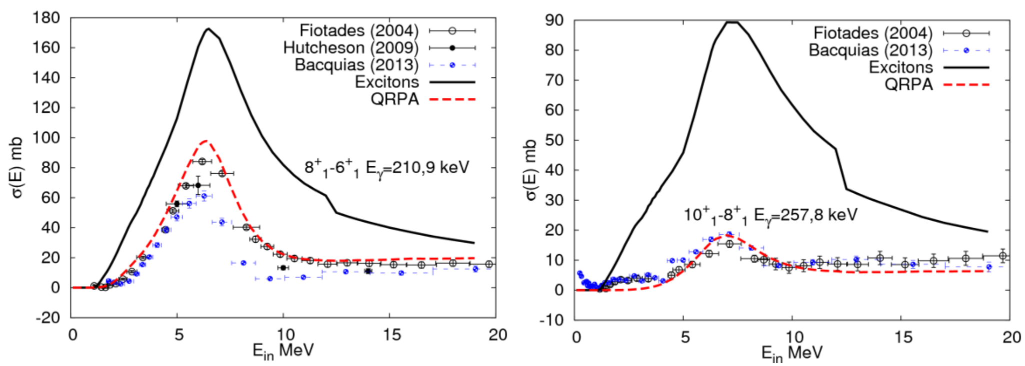
(n,xn γ) cross sections and models…

^{238}U
GRAPhEME

A.Bacquias *et al.*
In progress …

Motivations: see general context





36 (n,n' γ), 3 (n,2n γ), 4(n,3n γ) XS

- Large set of data
- TALYS and EMPIRE calculations :

⇒ No general agreement

⇒ Better description with QRPA modelisation (M.Dupuis presentation)

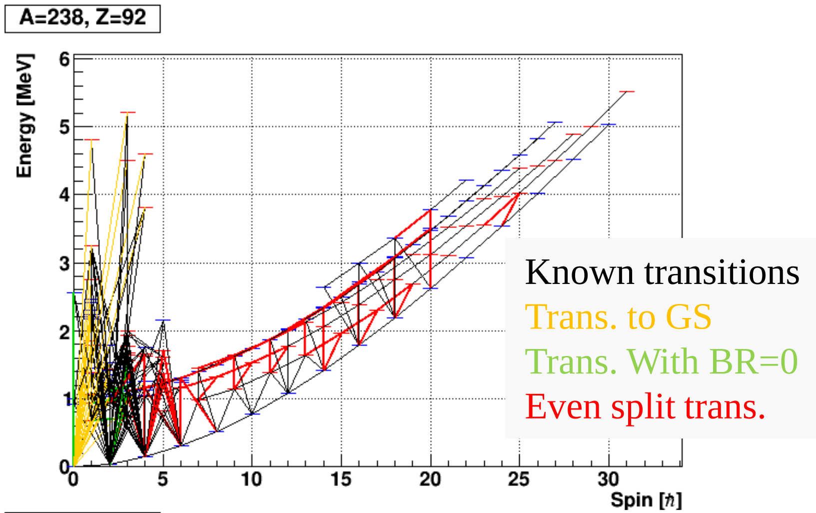
⇒ Better knowledge of level scheme

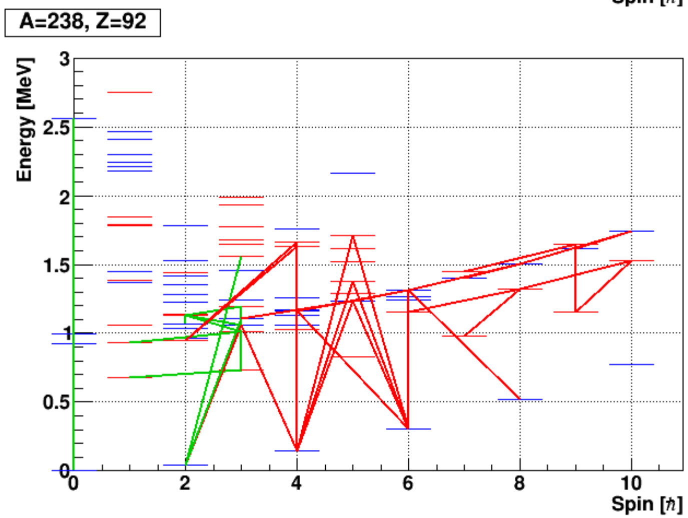
(n,xn γ) cross sections and models…

^{238}U
GRAPhEME

A.Bacquias *et al.*
In progress …

Effect of unknown branching ratios





Effect of unknown BR

- Impact of low lying states (even split redistribute flux to first and second level of GSB)
- Sensitivity test, MC simul. with several BR scheme possibilities (TALYS db, Weisskopf trans. Proba., all even splits)

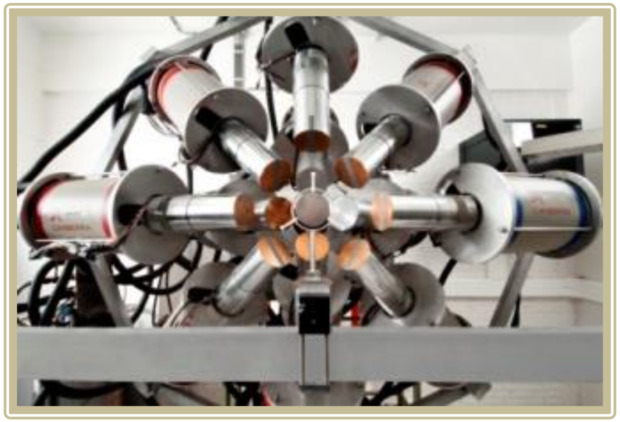
⇒ Effect of 10% for the decay paths connected to first levels in the GSB
⇒ Need to improve bibliography study, more simulations of the effects, exp. determination on BR

Summary

GAINS and **GRAPhEME** provide **comprehensive data sets** :
($n,x_{=1,2,3}n\ \gamma$), level production and (n,n') cross sections for 0<En<20 MeV with high resolution and for 3<Z<92.
Uncertainty target of few % -> difficult to reach (range 3%-20%).

-> Exclusive cross sections are a **real challenge** for the theoretical codes as many processes are involved and thus could be tested.
-> Model calculations with **relative good agreement** for **non-actinide** nuclei
but still **not enough precise** for industrial application.
-> For actinides, situation is worse but **improvements are foreseen**.
-> Improvements of the nuclear structure data seem required.

Perspectives



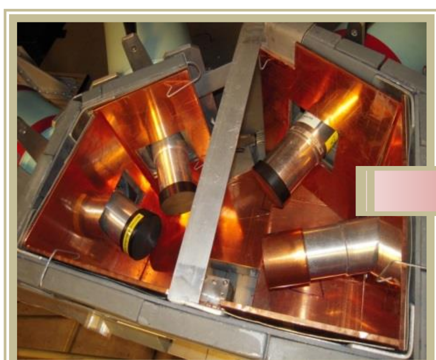
GAINS

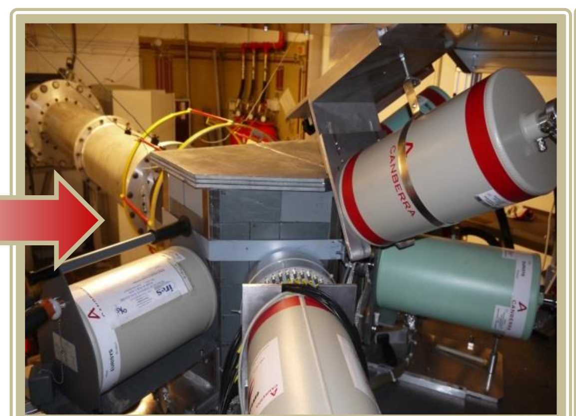
Ongoing:

^{7}Li (standard?), ^{48}Ti, ^{57}Fe, ^{63}Cu, ^{65}Cu, Mo, Zr

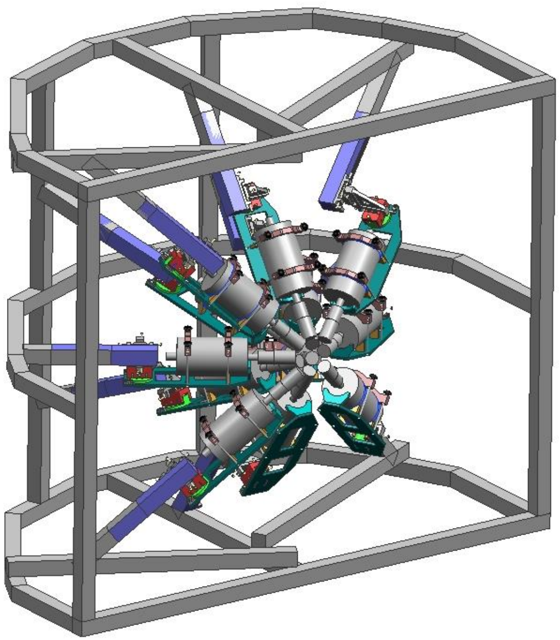
GRAPhEME

- Ongoing:
  ^{233}U -> upgrade of the set-up with a pixelised HPGe detector
- Long measurement for low energy gamma transitions in actinides or electron conversion measurements?



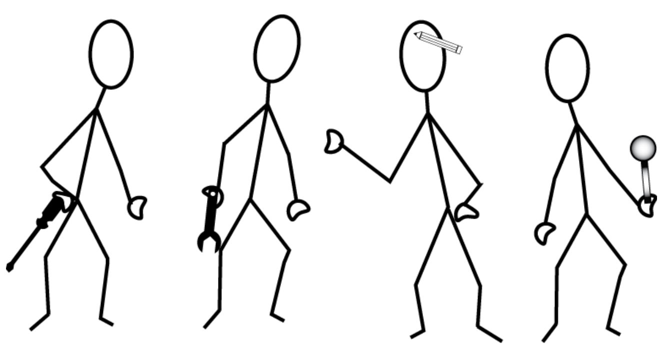


Perspectives



Coupling of GAINS and GRAPhEME

γ-γ coincidence measurements
for nuclear structure studies
(n,xn γ) measurements @NFS - GANIL



Maintain strong links with evaluators and theoreticians
(WINS, ESNT, JEFF/NEEDS … workshops)

Thank you for your attention …