Reactor Antineutrinos & Non Proliferation :

- Experimental needs for a better knowledge of the antineutrino spectra from ^{235}U, $^{239,241}Pu$, ^{238}U

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AAP Workshop – 26 sept. 06

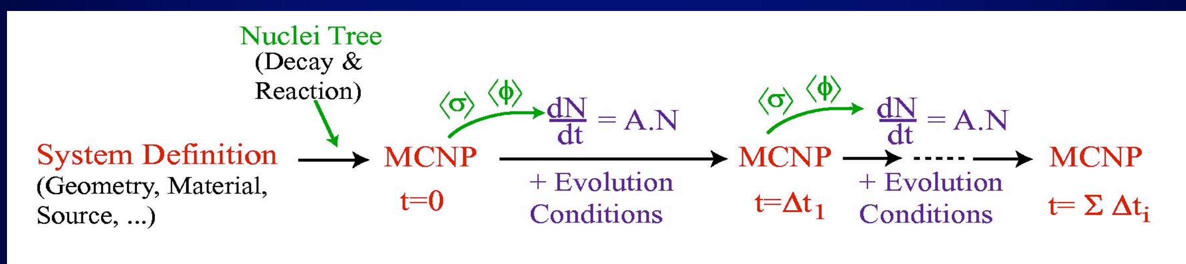
Outline

- Development of MURE simulation tool for scenario studies…
- Previous measurements of antineutrino energy spectra
- « Dissection » of antineutrino energy spectrum of ^{235}U : FP contributions
- Interfacing MURE with nuclear databases and using an interface on the Beta-S code
- Conclusions and outlooks

Simulation effort

Fission product proportions vary with the fuel burn-up and with time because of the wide range of half-lives involved.

- Aim = Simulation of the anti-neutrino spectrum built from the fission product spectra
- For proper translation from beta to antineutrinos: individual end-points and shapes
- Need for « dynamical » calculation to simulate the evolution of fuel composition and the decay chains of the fission products

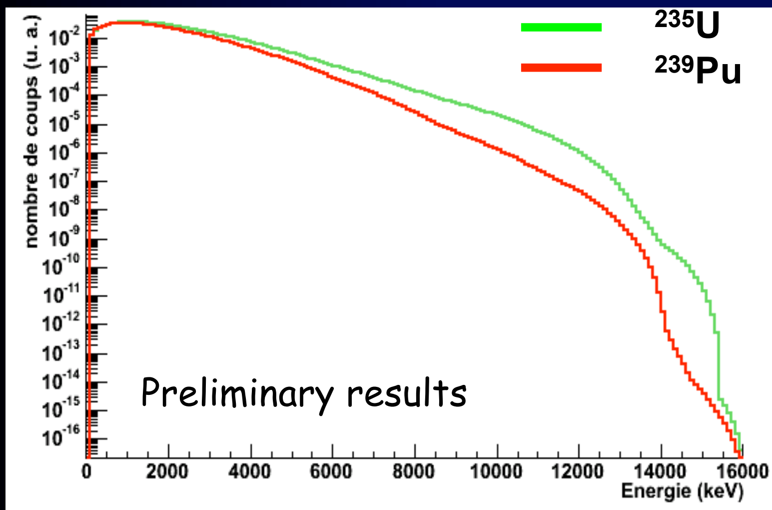


MURE **MCNP Utility for Reactor Evolution**

MURE : O. Méplan et al. ENC Proceedings (2005)

Simulation effort

Developments to obtain a precise calculation of the evolution with time of the antineutrino spectrum in order to have a generic tool for proliferation scenario studies (even for rapid changes)



1 – Simulated spectra of emitted antineutrinos from the fission of ^{239}Pu and ^{235}U using MURE :

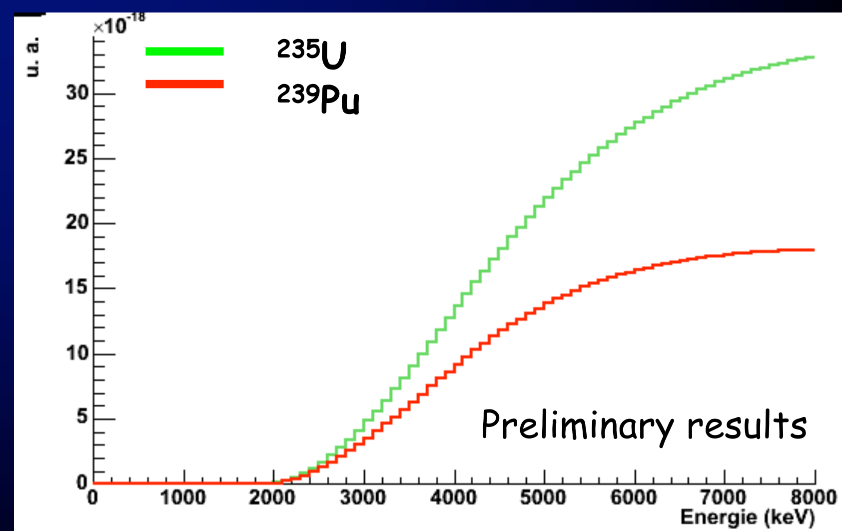
MURE

Relevant observables ?

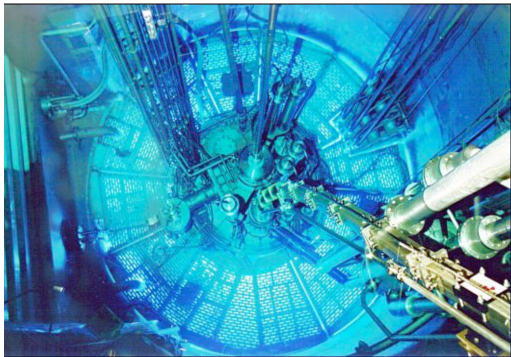
2 – Folding with the detection cross-section

Threshold : 1.804 MeV

3 – Cumulative spectrum in energy of antineutrinos folded by the detection cross-section



Thèse de S. Cormon



Starting an experimental program…

- **Theoretical approach :** Klapdor & Metzinger microscopic calc. of trans. matrix elements (PLB82 + PRL82), Vogel et al. for ^{238}U
- **Integral β–spectra** measured by Schreckenbach et al. (at better than 2% until 8 MeV) & Hahn et al. @ILL ^{235}U, $^{239,241}Pu$ targets, but conversion : global fit including 30 arbitrary contributions: global shape uncertainty from 1.3%@3MeV to 9%@8MeV
- **FP contributions :** measurements of Tengblad et al. 111 nuclei @ISOLDE and OSIRIS don't agree with the experimental integral spectra (important errors : 5% at 4MeV, 11% at 5MeV and 20% at 8MeV)
- **Chooz and Bugey :** energy spectrum and flux in agreement with Scheckenbach et al. + Vogel et al., 1.9 % error on reactor ν_e flux

According to Bemporad et al. unknown decays contribute as much as 25% of the antineutrinos at energies > 4MeV !!?
(Bemporad et al., Rev. of Mod. Phys.74 2002)

⇓

First list of n-rich nuclei : ^{86}Ge, $^{90-92}Se$, ^{94}Br, $^{94-98}Kr$, ^{100}Rb, $^{100-102}Sr$, $^{108-112}Mo$, $^{106-113}Tc$, $^{113-115}Ru$, $^{130-131}Cd$…

Examining the FP contributions

➢ Tengblad et al. included 370 nuclides in his spectrum including 111 exp. spectra from short half-lives, but also 177 BR and end-points (spin/parity ?), 25 known β-strengths and 67 extrapolated β-strength !!!

➢First step = build back the spectrum obtained that time

✓ **Need to read nuclear databases :**

ENSDF : BR and endpoints, spin/parities when known !
JEFF3.1 : BR and endpoints, spin/parities when known
ENDF-B-VI : BR, endpoints, spin/parities + continuous spectra by Gross theory
JEF2.2 : contains some of the spectra measured by Tengblad et al.

✓ **Beta Decay Theory to have the spectrum shape :**

Fermi Theory of Beta Decay:

-Assumes a Weak interaction at a point.

$\lambda = 2\pi \mid V_{fi} \mid^2 \rho(E_f)$ where $V_{fi} = \int \psi_f^* V \psi_I \, dv$

and $\rho(E_f) = dn/dE_f$ - no.of states in interval dE_f

Beta Decay Theory

The shape of the spectrum goes like:

$$N(Z,W)dW = g^2/2\pi^3 \times F(Z,W) \times \rho W(W_0 - W)^2 \times S_n(W)\, dW$$

End point

Weak interaction coupling constant

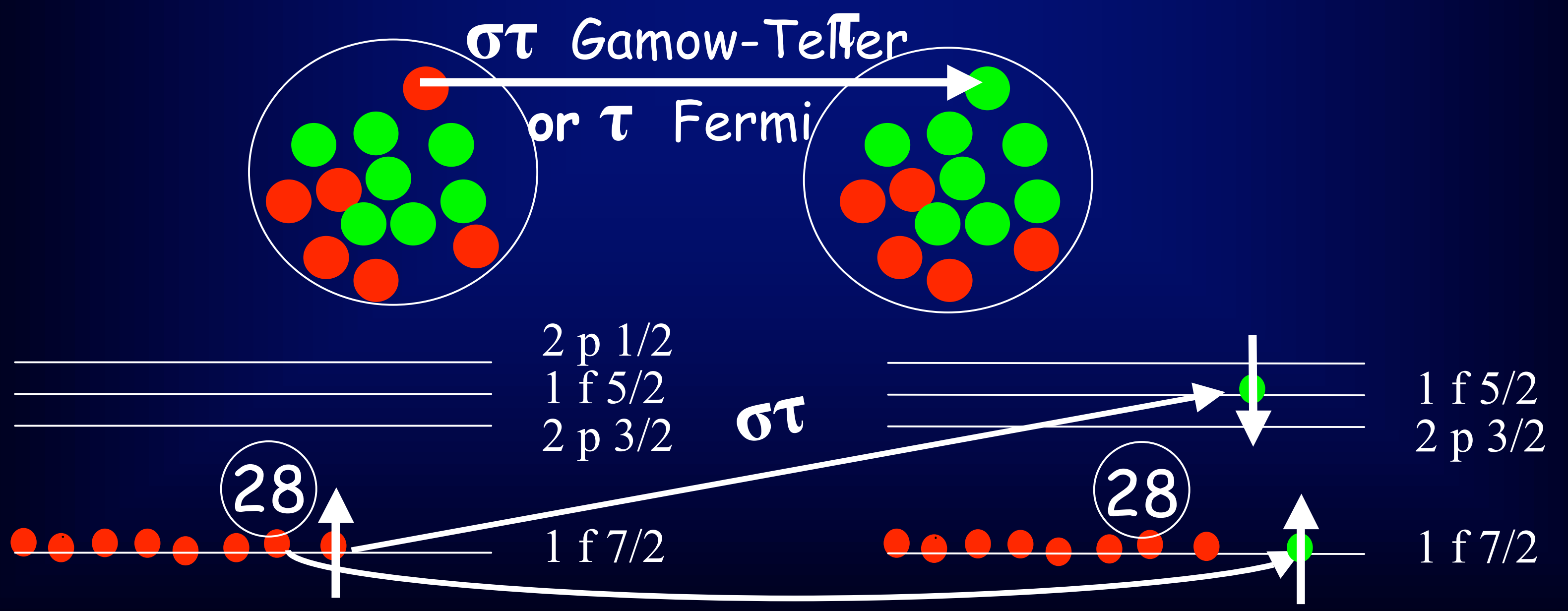
Fermi Function

Momentum in $m_e c^2$ units

Total electron energy in $m_e c^2$ units

Nuclear Matrix element

Shape factor for allowed and nth forbidden transition



β-decay and Classification of β-spectra :

Classification	ΔJ	Δπ	logft
Allowed	0,±1 (0+ $\not\to$ 0+)	No	4-6
1st forbidden non-unique	0, ± 1	Yes	6-10
1st forbidden unique	± 2	Yes	7-10
2nd forbidden non-unique	± 2	No	11-14
2nd forbidden unique	± 3	No	14
3rd forbidden non-unique	± 3	Yes	17-19
3rd forbidden unique	± 4	Yes	18

- Transition rate $\lambda = \frac{0.693}{t_{1/2}}$. We introduce $ft_{1/2} \propto Const./\ |M_{fi}|^2$
- The vast majority of β-transition are classified as allowed type
  - « Shape factors » : emphasize the high energy region of the spectra compared with allowed spectra

« BESTIOLE » package : interface by D. Lhuillier (CEA/SPhN) on BETA-S code from Oak Ridge*

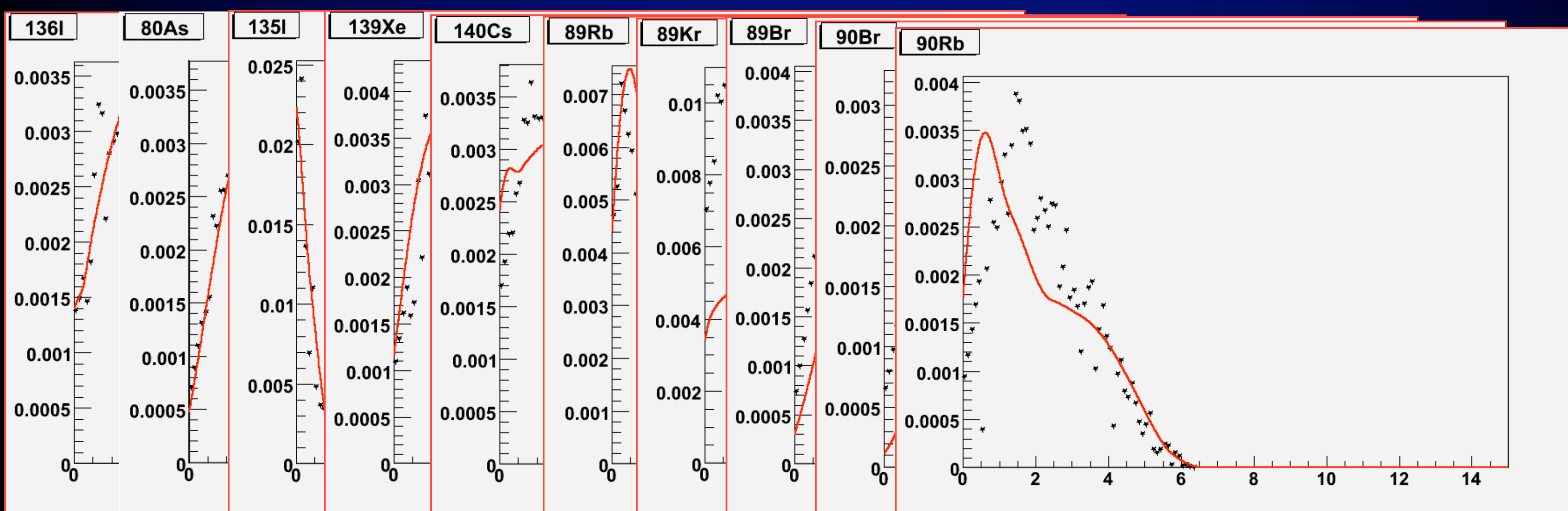
✓ Reads ENSDF Branching ratios, End-points and spin/parities

✓ Allowed, 1st, 2nd and 3rd forbidden unique transitions are explicitly represented

✓ 1st forbidden non-unique : shape factor S1(W) independent of energy = idem as allowed transitions

✓ 2nd and 3rd forbidden non-unique : original approximation = assumed to have an allowed shape

→ Modified to take the 1st and 2nd forbidden unique shape instead

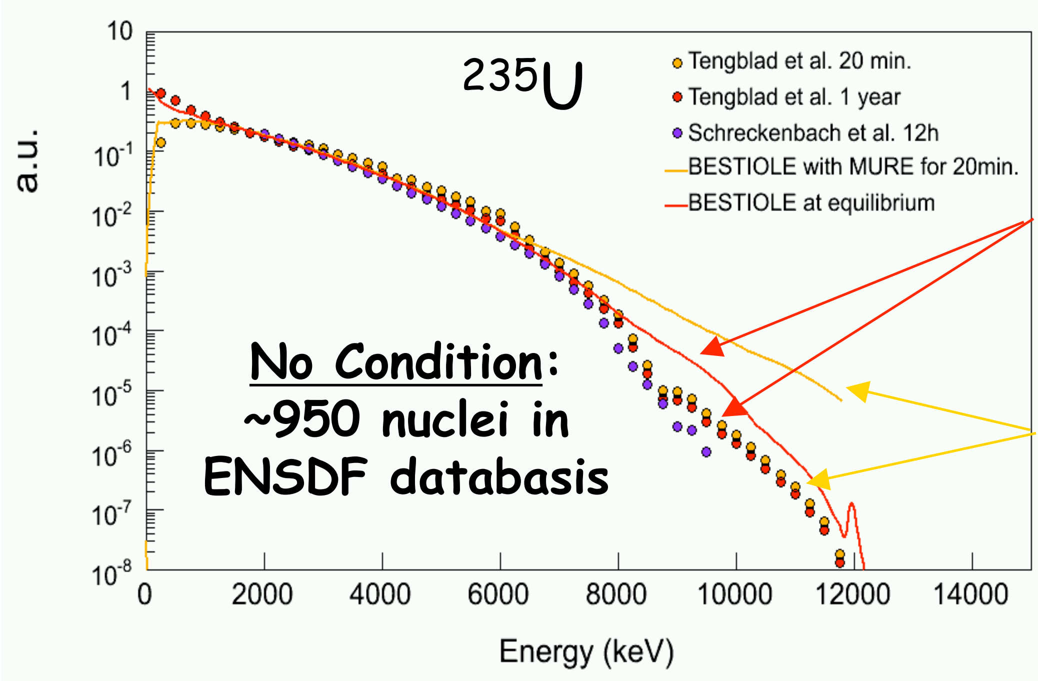


*Report COG-96-33-I RC-1564

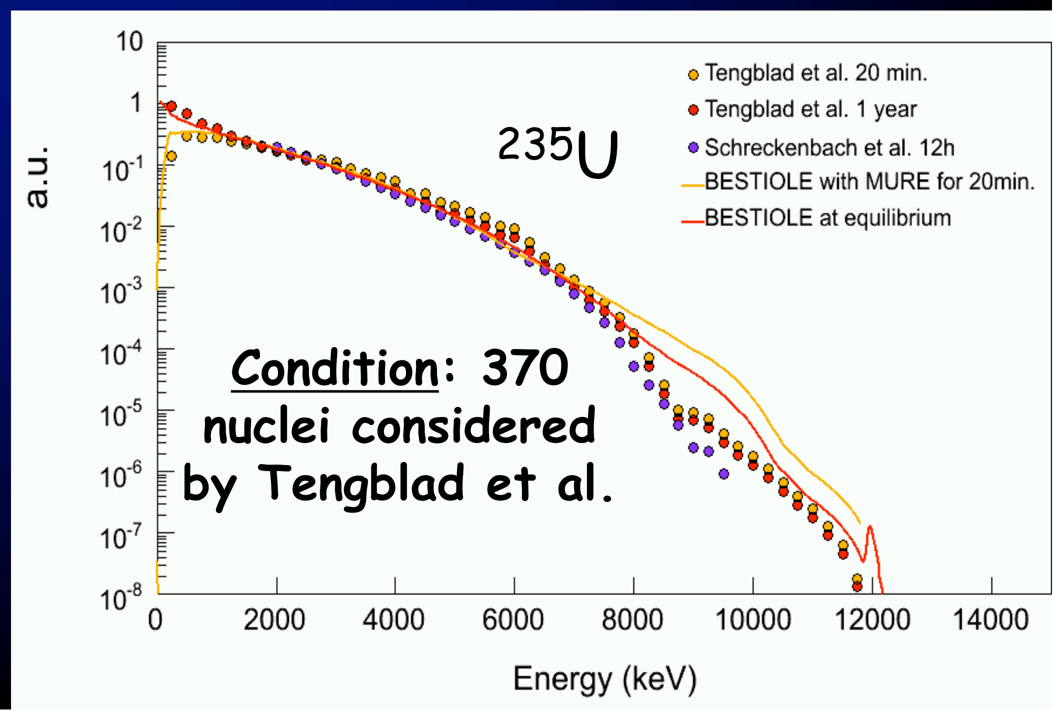
Results

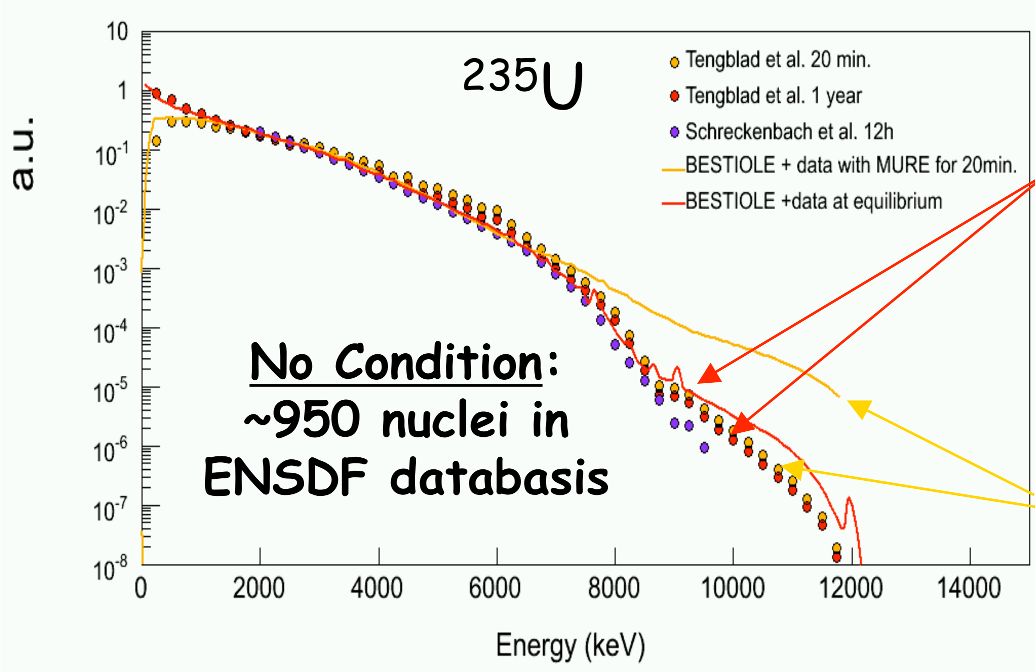
Tengblad et al. 1 year of irradiation Compared with BESTIOLE for ~950 nuclei with cumulative yields

Tengblad et al. 20min. of irradiation Compared with MURE 20min. evolution using the spectra from BESTIOLE



Including more nuclei: among them exotic nuclei, with short half-lives, high end-points, and more numerous forbidden transitions





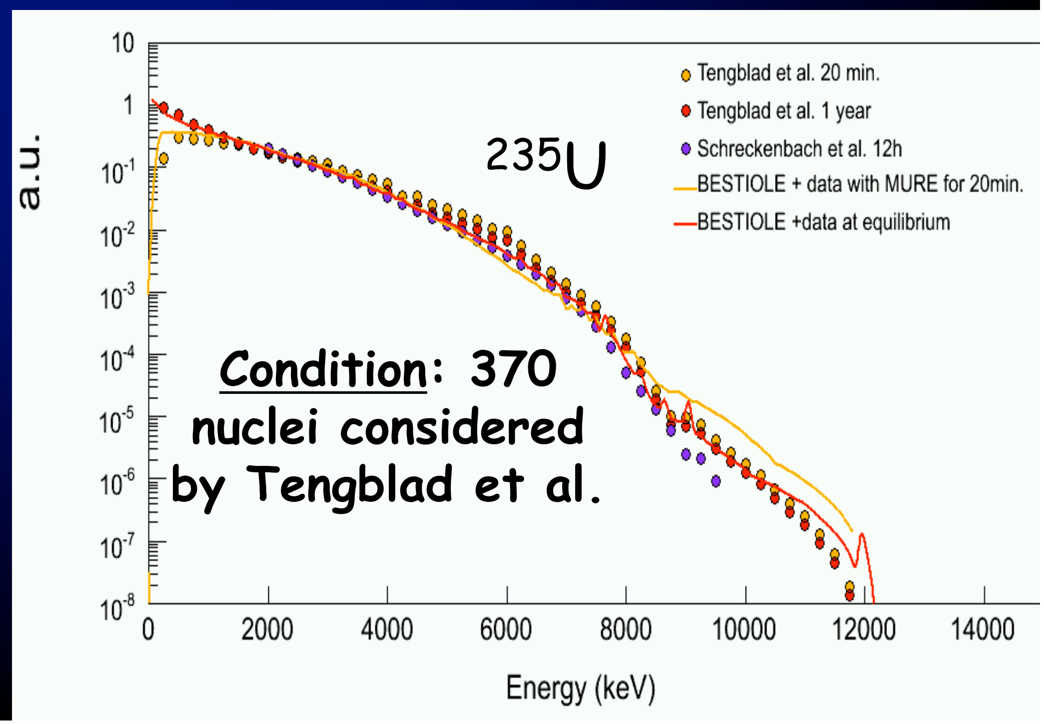
Results

Tengblad et al. 1 year of irradiation Compared with BESTIOLE and 75 exp. spectra among the 111 mesured by Tengblad et al. for ~950 nuclei with cumulative yields

Tengblad et al. 20min. of irradiation Compared with MURE 20min. evolution for BESTIOLE and 75 exp. spectra

Including exp. spectra :
- Nearly reconstitutes Tengblad spectrum
- We clearly see some more nuclei should be taken into account at high energy + more exp. spectra when forbidden non-unique transition !!!

→ **Solving the shape discrepancy** with Schreckenbach et al. ?



Towards a better understanding of antineutrino spectra: n-rich fission products beta decay

- **Double-Chooz phase 1**: when only far detector,
  => better precision on the reactor ν_e spectrum very useful

- **Double-Chooz phase 2**: best measurement of reactor ν_e spectrum and flux ~ >10^5 evts/y

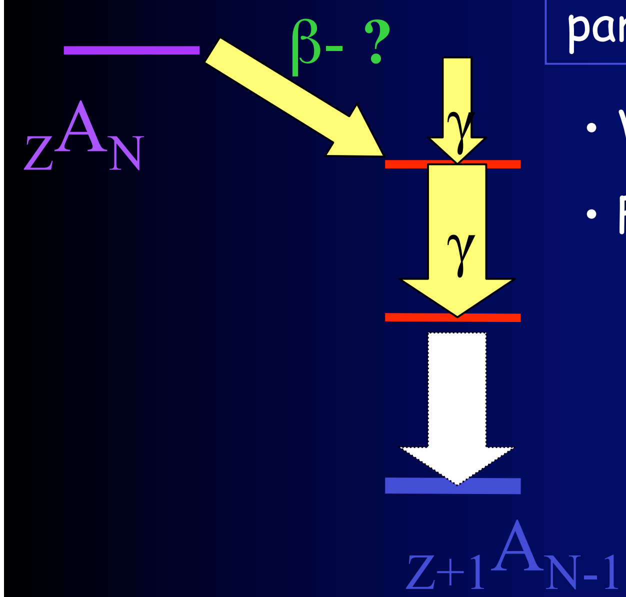
- Nuclear reactor physics and safety (decay heat calc.) /future (Gen. IV) reactors (decay heat + β-delayed n)

- Nuclear structure (exotic nuclei), nuclear astrophysics for the most exotic ones…

- Astroparticle physics : future neutrino experiments (relic Supernovae…) ν spectrum never measured beyond 8 MeV

Strong common points with measurements for reactor decay heat calculation in nuclear reactors

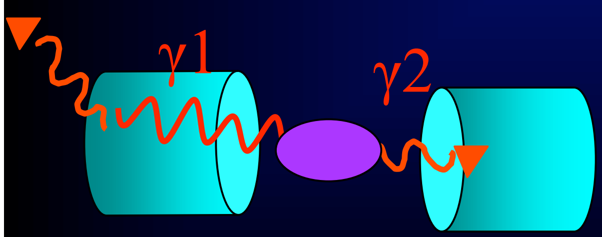
- Data required-cross-sections, fission yields, decay half-lives, mean beta and gamma energies, neutron capture cross-sections and uncertainties in these data.



The problem of measuring the β - feeding (if no delayed part.emission)

- We use our Ge detectors to construct the decay scheme
- From the γ-balance we extract the β -feeding

Low efficiency of Ge detectors at high energy => Pandemonium effect = displacement of the β- strength (overestimation of high energies)



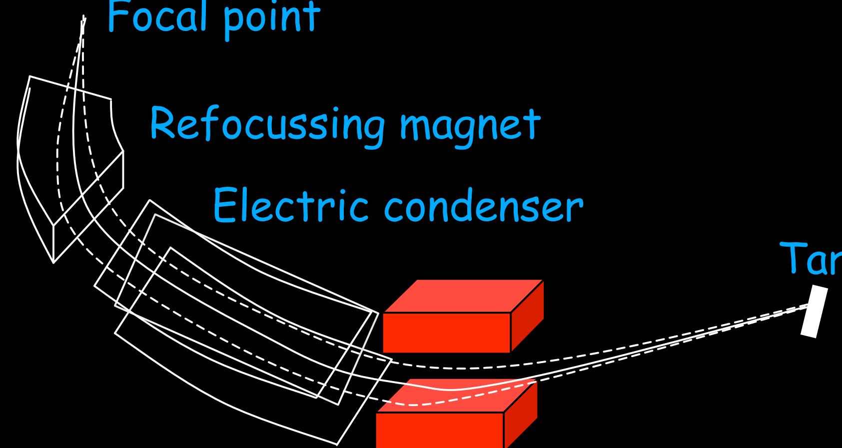
« Pandemonium effect » = indication to explain the discrepancy between Tengblad and Schreckenbach ?

From W. Gelletly et al.

✘ Test experiment @ Institut Laue-Langevin High Flux Reactor (Grenoble) last summer :

β–spectra measurements for A=90, 94 :
beta singles + β–γ coincidences

- LOHENGRIN Spectrometer : A/q
- Target ^{235}U(6mg)
- 1 HPGe clover
- 25.8mm Silicon detector



⇨ Test of the simulation of the evolution of beta spectra from isobaric chains A=90,94

⇨ Analysis on going…, PhD thesis of S. Cormon

✘ Propose experiments on the ALTO facility for the next PAC: ex: intensities of Br-Kr-Rb 100 times bigger than ILL.

Good point: discussions started with collaboration for decay heat related measurements (J.L.Tain, W. gelletly et al.) on ALTO: some nuclei in common

✘ Measure integral β spectrum from fast ^{238}U fission : theoretical calculation from Vogel et al. (89), error ≤ 10%, gives ≤ 8% of PWR reactor antineutrinos

Conclusions and outlooks

- Possible origins of discrepancies between previous measurements :
  - lack of short half-life nuclei
  - highly forbidden transitions more important at high energy
  - Pandemonium effect in nuclear data basis ?

- Comparison between ENSDF and ENDF, JEFF…

- Theoretical point of view : *Gross Theory for β- decay*, Microscopic models ?

- Isolate the most pertinent nuclei to be measured (forbidden non-unique transitions) that influence the spectrum shape (especially high energy part)

- Proposal to use the *ALTO facility, GANIL*… ^{238}U beta spectrum ?
+ *Moscow-Kurchatov initiative*…