DE LA RECHERCHE À L'INDUSTRIE

^{237}Np absolute delayed neutron yield measurements

D. Doré[1)], X. Ledoux[2)], R. Nolte[3)], F. Gagnon-Moisan[3,4)],
L. Thulliez[1,5)], O. Litaize[5)], S. Roettger[3)], O. Serot[5)]

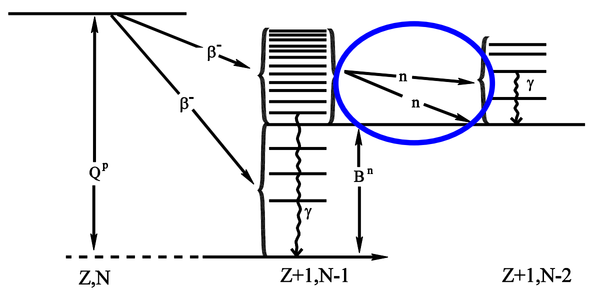
1) Irfu/SPhN, CEA/Saclay, France
2) GANIL, Caen, France
3) PTB, Braunschweig, Germany
4) PSI, Villigen, Switzerland
5) DEN/SPRC, CEA/Cadarache, France

Content

- ✓ Reminder & Motivations
- ✓ Facility and Experimental setup
- ✓ Experimental scenario
- ✓ Analysis
- ✓ Results and Interpretation
- ✓ Conclusion

Delayed Neutrons (DN)

Reminder :



(fissioning nucleus , E*)→ fission fragments

Precursors

DN characteristics

Very « useful » neutrons:

DN are used to « tag » nuclear content

DN play an important role in reactor control

→for ADS, DN yield of minor actinides have to be known

Fundamental study :

DNY vs E_{neut} : dependence not well understood

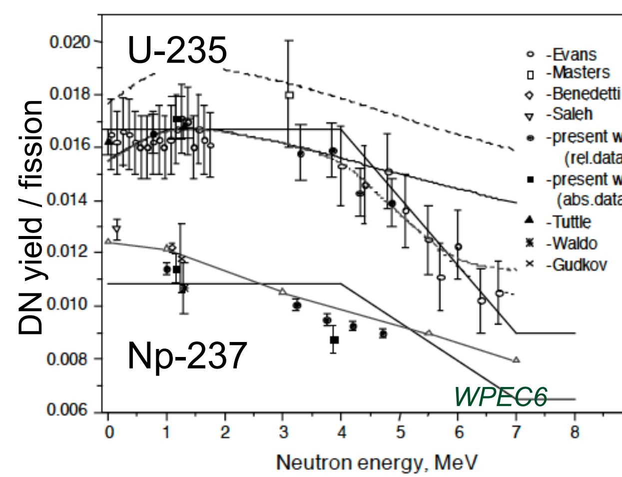
Special trend:

Opening of the second chance channel?

Excitation energy sharing ?

Even-odd effects ?

(T. Ohsawa et al.)



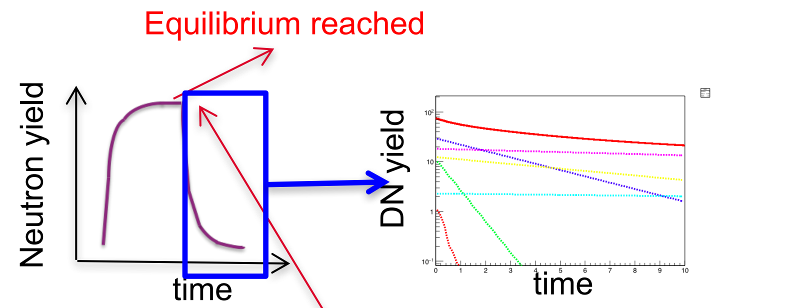
DELAYED NEUTRONS

Each fissioning nucleus → DN characteristics:

- absolute yield : ν_d
- group parameters : a_i, λ_i

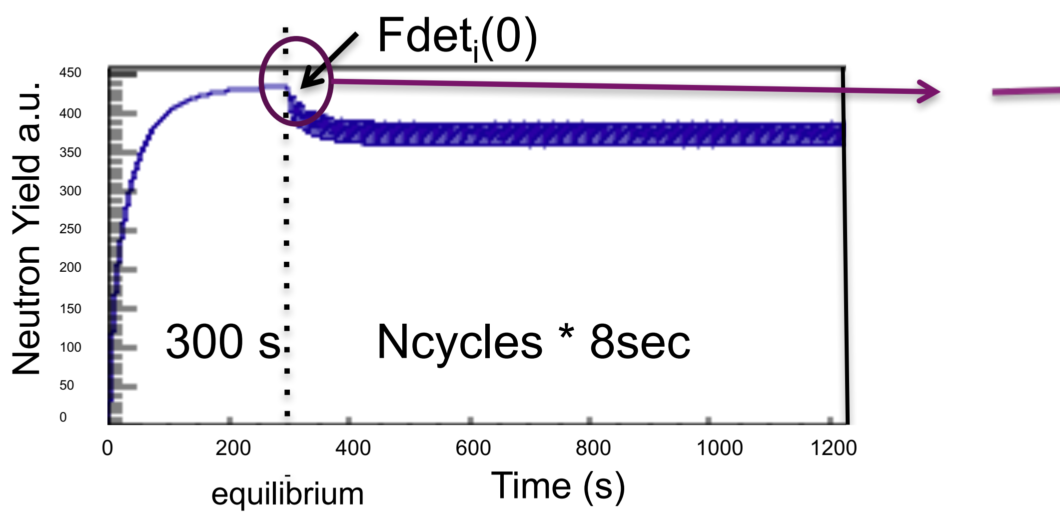
$$Y_d(t) = \upsilon_d \sum_{i=1,6} a_i \exp(-\lambda_i t)\left(1-\exp(-\lambda_i t_{irr})\right)$$

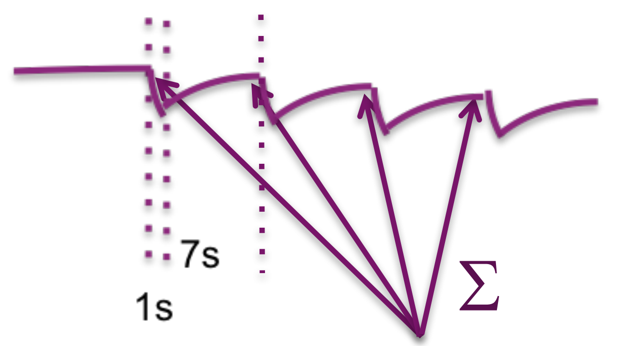
$$\sum_i a_i = 1$$



Absolute DN yield ν_d: yield at t=0 after reaching the equilibrium

Experimental scenario: neutron-induced fission





(Flux, simu)

$$\nu_d = Fdet(0) / (\varepsilon N_{fiss})$$

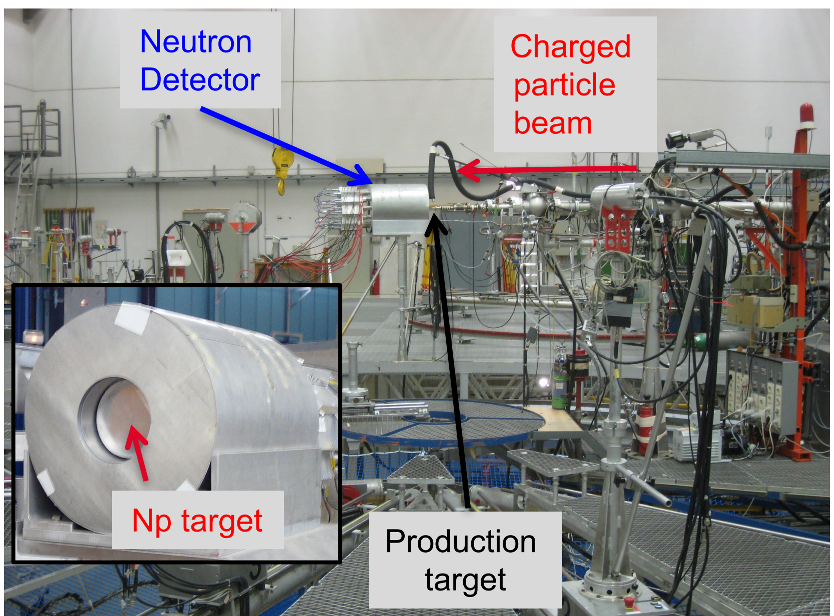
FACILITY AND EXPERIMENTAL SETUP

Monokinetics $n_{(1 \text{ to } 16 \text{ MeV})}$ + ^{237}Np -> Fission …. DN
≠reactor measurements

p + t, d + d, d + t reactions

PTB facility (Physikalisch Technische Bundesanstalt)
- Van de Graff or Cyclotron
- Precise time structure of the beam
- Neutron flux measurement
- Low background (neutron pit)

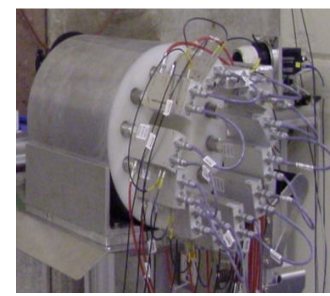
PTB Low Scatter Hall



D. Doré

Neutron detector

12 ^{3}He tubes (4 bar)
CH_2 matrix
Cd wrap
Efficiency determined with ^{252}Cf & simu



^{237}Np target
Φ = 80 mm
Δx = 0.5 mm
M = 49.47g (0,27)
50 µSv/h (100 cm)

MEASUREMENTS

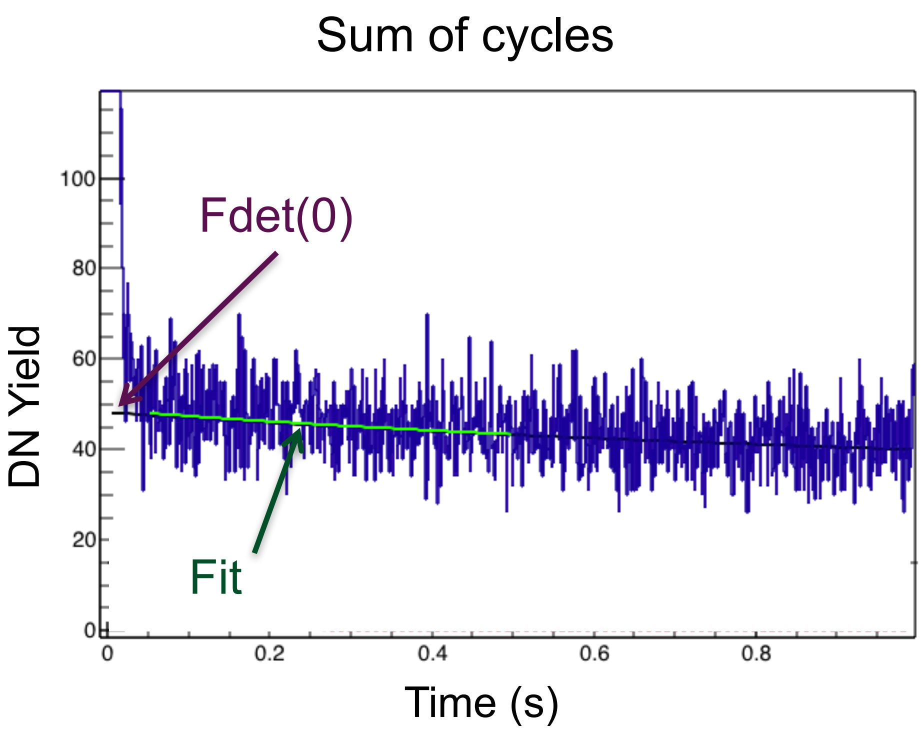
Measurements :

- Background of Np sample (10 counts/s)
- DN det. efficiency meas. (^{252}Cf source, different positions, simulations) → ε~12-15 %

- For each beam energy

- ❖ Incident neutron energy and flux meas.: proton recoil telescope, long counter
- ❖ Background measurements:
  - - DN with beam without Np
  - - DN with beam & Np target & empty gas production target (deuterium)
- ❖ DN measurement with Np and beam

ANALYSIS



Analysis:

- Identify the beginning of the cycle
- Sum of the cycles
- Corrections for dead time
- Fit to extract the value at T=0
  - 6 exponentials *with a_i λ_i parameters and corrections (equilibrium)*

Different a_i & λ_i values (literature)

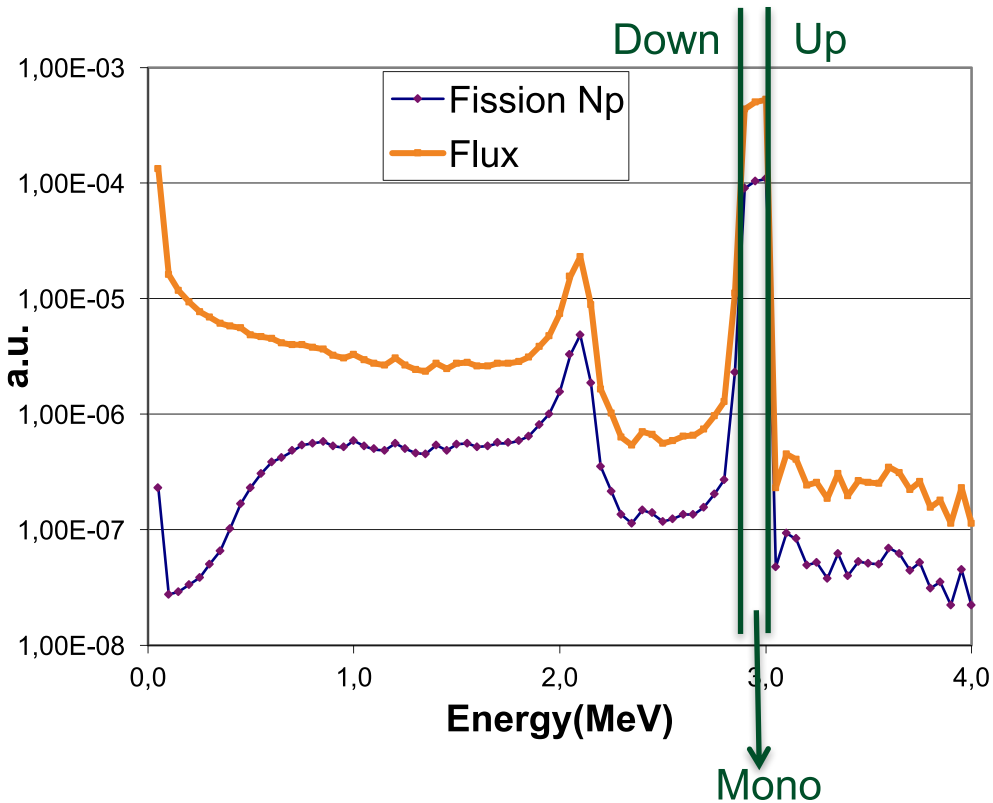
Measured background taken into account

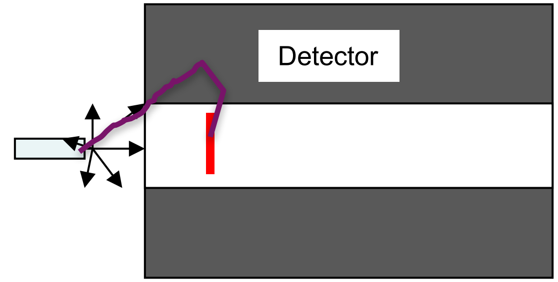
$$\nu_d = \text{Fdet}(0) / (\varepsilon N_{fiss})$$

Simu & Flux

Fission number calculations

MCNPX Simulations : full geometry





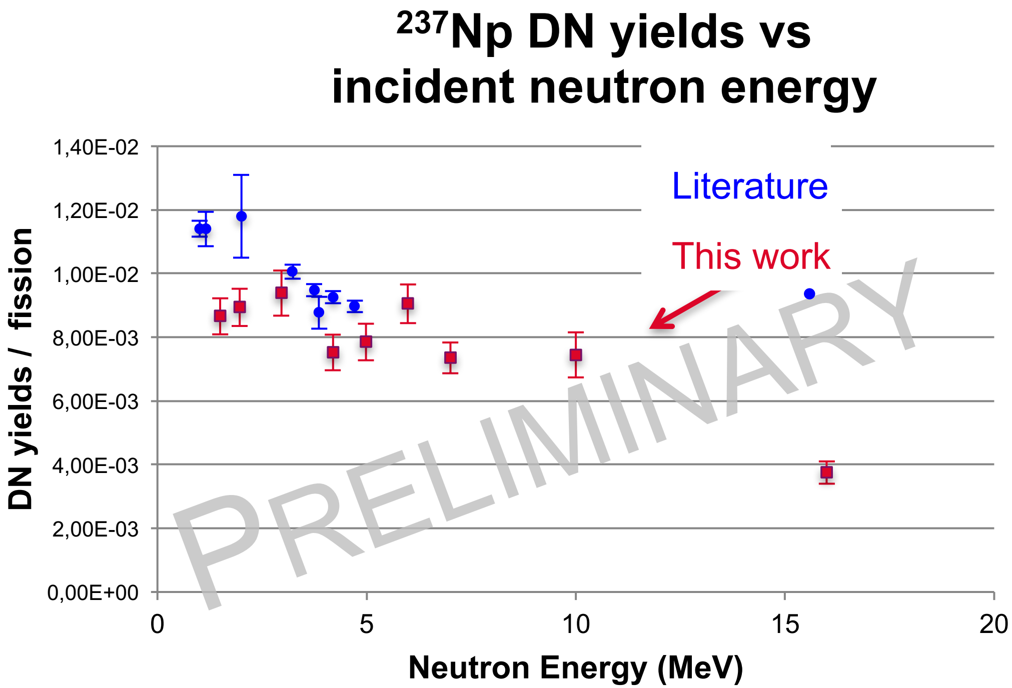
Diffusion, Energy spreading :
reaction at E ≠ Ebeam

$$F\det(0) = (\upsilon^{mono}\ N^{mono}_{fission} + \upsilon^{u}\ N^{u}_{fission} + \upsilon^{d}\ N^{d}_{fission})/\varepsilon$$

N_{fiss} Mono, Up & Down normalized using the flux measurements.

DN Up and Down:
- calculated with estimated ν_d (iterative process)

$$\boxed{\upsilon_d^{mono} = \frac{F_{\det}(0)/\varepsilon - \upsilon^{u}\ N^{u}_{fission} - \upsilon^{d}\ N^{d}_{fission}}{N^{mono}_{fission}}}$$



Absolute measurements

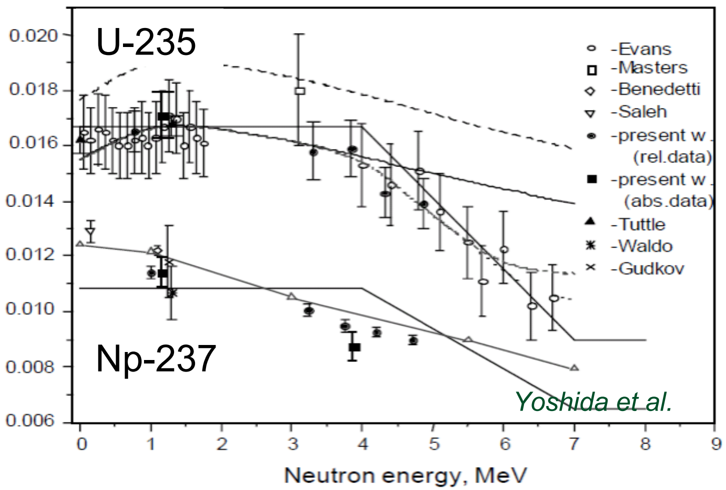
(flux normalization)

- ✓ Propagation of uncertainties
- ✓ Corrections :
  - Dead time
  - Quasi-Equilibrium
  - Impurities in the target
  - Neutron diffusion
  - …

✧ DN yields & uncertainties are preliminary

✧ Covariance matrix calculations are in progress

INTERPRETATION / MODELS

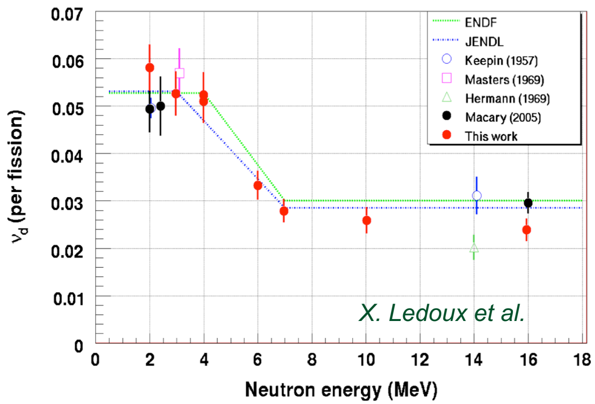


^{235}U and ^{237}Np show different trends !

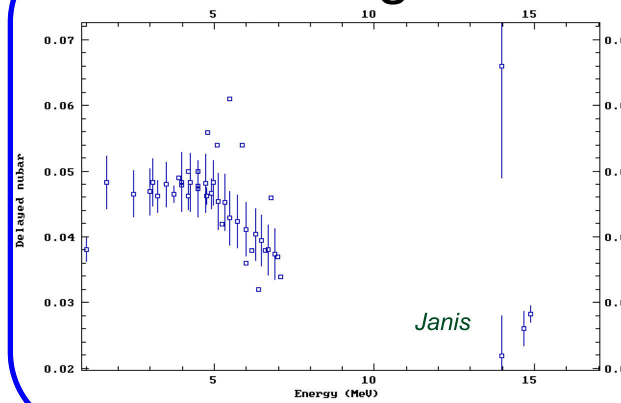
U, Th, Pu → same behaviour : even Z
Np : odd Z

DN neutrons yields vs Energy

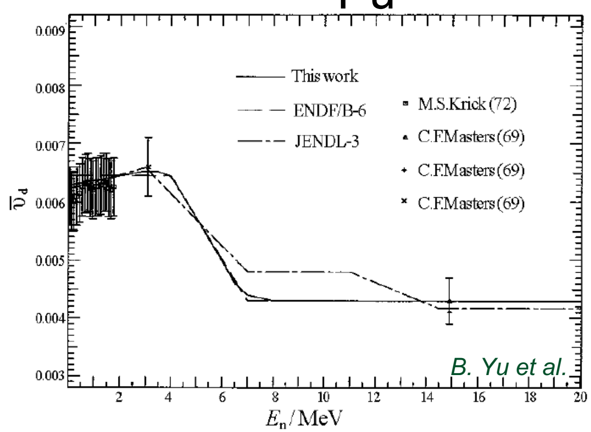
^{232}Th



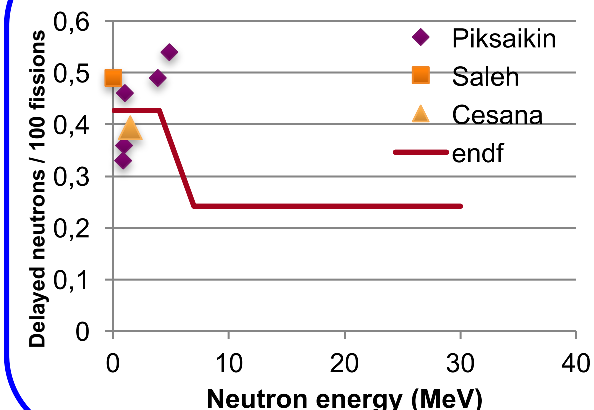
^{238}U



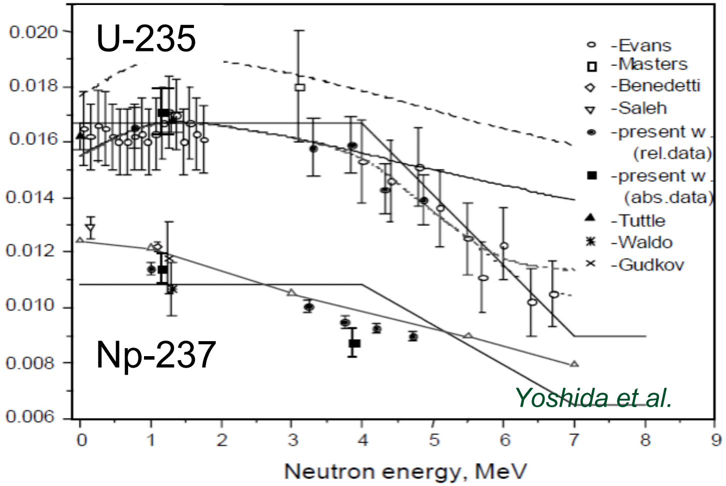
^{239}Pu



^{241}Am



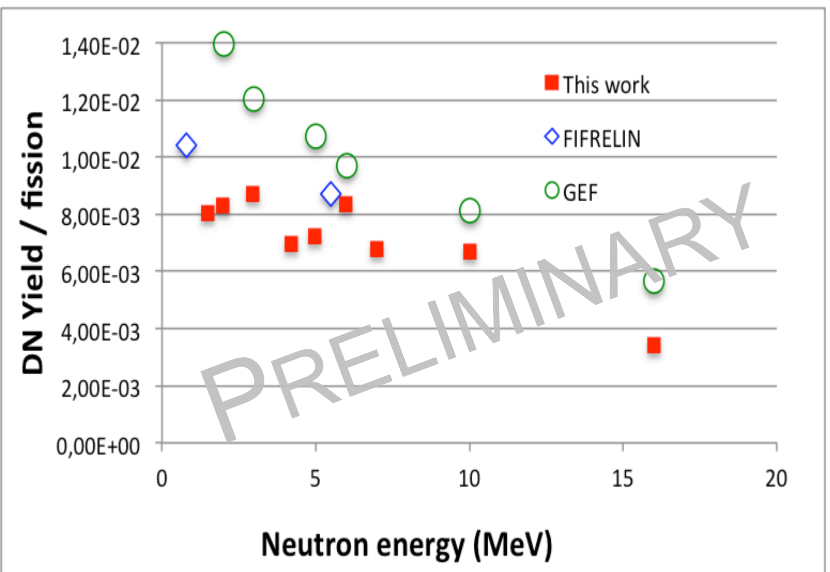
INTERPRETATION / MODELS



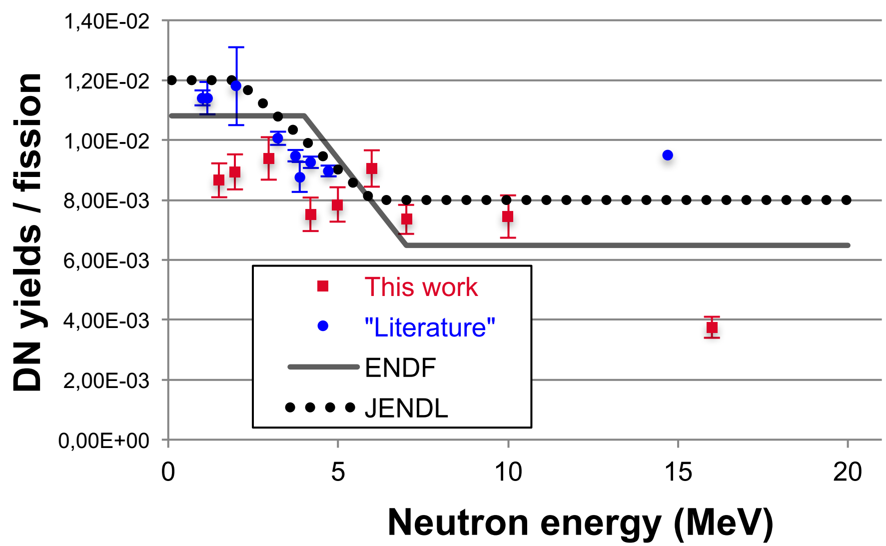
^{235}U and ^{237}Np show different trends !

U, Th, Pu → same behaviour : even Z
Np : odd Z

Comparison Data – Fifrelin - GEF



Comparison Data – ENDF_BVII- JENDL4.0



CONCLUSION

^{237}Np absolute DN yields from 1 to 16 MeV incident neutron energy was measured at PTB

- monitoring of neutron flux
- precise time structure of the beam
- detector efficiency measured
- corrections applied for non-equilibrium, diffused neutrons, …

- Uncertainties are propagated
- Correlation matrix will be finalized soon

Interpretation/models/libraries

- Standard libraries do not reproduce experimental DN energy trend
- Fifrelin calc. closer than GEF calc. for ^{237}Np
- Energy dependence to investigate…

D. Doré[1)], X. Ledoux[2)], R. Nolte[3)], F. Gagnon-Moisan[3,4)], L. Thulliez[1,5)], O. Litaize[5)], S. Roettger[3)], O. Serot[5)]

1) Irfu/SPhN, CEA/Saclay, France
2) GANIL, Caen, France
3) PTB, Braunschweig, Germany
4) PSI, Villigen, Switzerland
5) DEN/SPRC, CEA/Cadarache, France

Special thanks to the technical staff of PTB