The STEREO experiment

Normalization of the ν-spectrum emitted by the ILL research reactor

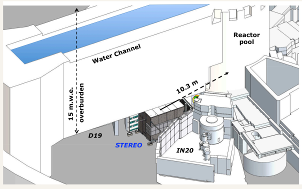
D. Lhuillier, on behalf of the STEREO collaboration

ILL Reactor Core &STEREO Site

ILL core
Compact: $\phi \times H \approx 40 \times 100$ cm.
HEU fuel, pure ^{235}U ν spectrum.
Thermal power
58.3 MW.

STEREO measurement
The multi-cell oscillation analysis (see P. del Amo Sanchez's poster) + reference ^{235}U spectrum requiring accurate control of:

- Normalization: P_{th}, fission β spectra
- Shape: neutrinos from n-capture & spent fuel, off-equilibrium effects



Thermal Power

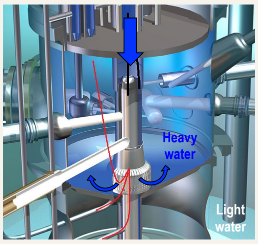
Accuracy determined from the instrumentation of the ILL core:

$$\delta P_{th} / P_{th} = 1.4\%$$

Relative contributions to the total thermal power:

P_{th} =
P_{D2O} 96.0 % (primary coolant)
+ P_{H2O} 1.4 % (heat leak to H20 pool)
+ P_{DRG} 0.9 %
+ P_{BP} 1.6 % (auxilary circuits)

$P_{th} = P_{fission} + P_{pumps}$ (constant 600 kW)



Enthalpy balance:

$$P_{th} = C_p(T) \times \rho(T) \times q \times \Delta T$$

Cp [J.kg^{-1}.°K^{-1}], ρ [kg.m^{-3}]: heat capacity at constant pressure and density of heavy water. Functions of temperature known at 0.1% level.

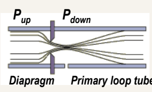
ΔT [°K]: *temperature increase of the D20 flow through the core, $T_{downstream} - T_{upstream} \approx 39 - 27 = 12$ K. 5 times redundant sensors and regular absolute calibrations provide a 0.85% relative uncertainty.*

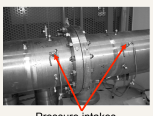
q [m^{-3}. h^{-1}] : heavy water flow, ~**2340 m^3.h^{-1}** to evacuate the very high power density in the core. Measured by the pressure drop downstream a diaphragm inserted in the coolant circuit

$$q = \alpha \times \sqrt{P_{up} - P_{down}}$$

Calibrated with 0.9% relative accuracy using a scale 1 mockup of the primary loop

0.5% relative accuracy achieved with redundant and calibrated sensors.





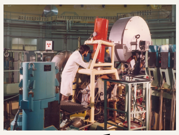
Pressure intakes

Effect of the aging of the diaphragm is neglected. Could be checked during the long reactor shutdown scheduled in 2020.

Neutrinos Per Fission

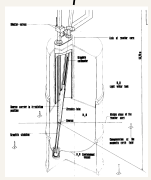
Reference fission β spectra measured at ILL and then converted to neutrino spectra.

The absolute normalization is provided by various e-conversion processes:



$$N_\beta = \frac{N_f^{Meas}}{N_{Calib}^{Meas}} \times \frac{n_{Calib}^{Atom}}{n_f^{Atom}} \times \frac{\sigma_{Calib}}{\sigma_f}$$

Reference spectra for ^{235}U and ^{239}Pu rely on ≠ calibration processes hence they have independent absolute normalization !



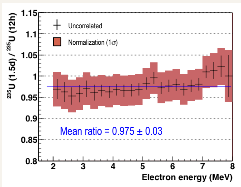
Nucl. Instr. and Meth. 154 (1978) 127-149

The ratio of reference spectra $^{235}U/^{239}Pu$ should be corrected by -5% w.r.t. Huber-Muller prediction.

History of measurements of reference spectra :

Isotope	$T_{irradiation}$	Calibration	Ref
^{235}U	1.5 day	$^{197}Au(n,e^-)^{198}Au$	[1] Phys. Lett. B 99 (1981) 251
^{239}Pu	1.5 day	$^{197}Au(n,e^-)^{198}Au$	[2] Phys. Lett. B 118 (1982) 162
^{235}U	12 h	$^{207}Pb(n,e^-)^{208}Pb$	[3] Phys. Lett. B 160 (1985) 325
^{241}Pu	1.8 day	$^{197}Au(n,e^-)^{198}Au$	[4] Phys. Lett. B 218 (1989) 365

Relative normalization of the two ^{235}U measurements (^{197}Au / ^{207}Pb)



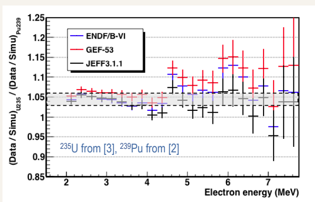
3% correction applied on data from [1] as recommended in [3].

Re-evaluation of fission cross sections:

Reaction	From articles	Updated JEFF3.1.1	Deviation
$^{235}U(n,f)$	[3] 566 ± 3 b	565.2 ± 1.2 b	-
$^{239}Pu(n,f)$	[2] 800 ± 8 b	785.8 ± 2.3 b	-1.8%
$^{241}Pu(n,f)$	[4] 1075 ± 9 b	1060.9 ± 8.9 b	-1.3%

Summation calculations serve as a coherent model for the study of RELATIVE variations between U and Pu spectra:

- Sum over all fission fragments using the cumulative yields from different nuclear data libraries
- ENSDF 2017 library used to build the β-branches



Double ratios show little sensitivity to the inputs from nuclear databases used for the summation calculations.

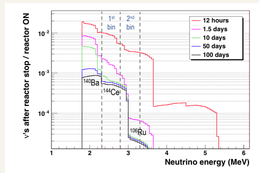
Global 4.5 ± 1.5 % deviation from unity, compatible with the sum of deviations 2.5 + 1.8 % mentioned above.

Correction to the **absolute normalization** of each isotope would need a **re-evaluation of the e-conversion cross-sections** σ_{calib}.

Corrections To Reference Spectra

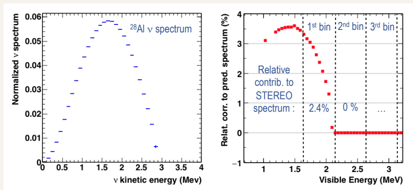
FISPACT simulations of the evolution of the ILL reactor with complete inventory of neutrino emitters for various irradiation times

Neutrinos from spent fuel:



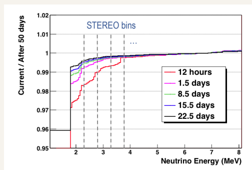
- Rejection of 1st day after reactor stop gets rid of most decays.
- Dominant component after few days is from the ^{144}Ce decay chain.
- Residual contribution to the first STEREO bin can reach few % depending on the position and number and stored fuel elements.

n-capture on reactor materials: $^{27}Al + n \rightarrow {}^{28}Al \rightarrow {}^{28}Si + \overline{\nu}_e + e^-$
Extra neutrinos emitted in the core area during reactor operation, to be included in the oscillation analysis.



Impact of n-capture on fission products is suppressed by the short irradiation time (P. Huber and P. Jaffke, Phys.Rev.Lett. 116 (2016)).

Off-equilibrium effects:



- STEREO threshold at $E_{visible}$ = 1.5 MeV reduces the sensitivity.
- ~ 1.5% correction in the first energy bin, in agreement with independent estimation from Phys. Rev. C83 (2011) 054615.

Conclusions

- $\delta P_{th}/P_{th}$=1.4%, STEREO is on track for an accurate check of the normalization of the ^{235}U spectrum. Final uncertainty to be driven by the uncertainty on ε_{det} and background – in progress.
- The **normalizations** of the reference fission spectra for **^{235}U and ^{239}Pu** should be treated as **independent** in the global fits (see for instance arXiv:1801.06467).
- **Established deviation of normalization** with respect to the Huber-Muller reference spectra:
  - **^{239}Pu : +1.8%, ^{241}Pu: +1.3%**
  - **^{235}U / ^{239}Pu : -5%.** Sharing of this correction between the two isotopes requires a re-evaluation of the cross-section of e-captures used for the calibration of the ILL β-spectra. This will have a direct impact on the discrepancy between the prediction and Daya Bay's results Phys.Rev.Lett. 118 (2017).
- The shape corrections from the ILL reference spectra are few % only for the low E bins with small associated systematics expected.

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