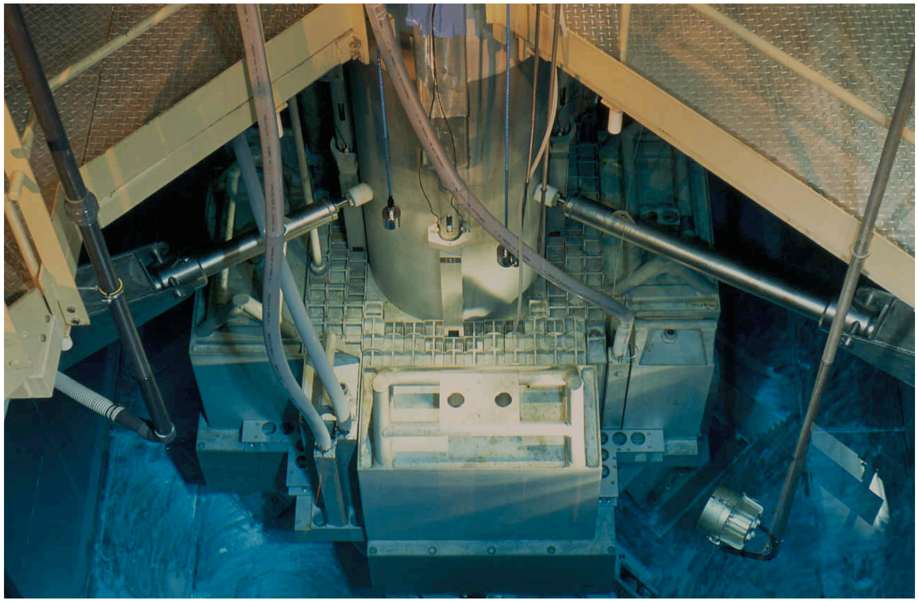
CARMEN: an experimental configuration in the MINERVE critical facility for the qualification of neutron cross sections in epithermal spectrum



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Outline

1. Introduction
2. The MINERVE facility
3. Oscillation technique of measurement
4. OSMOSE and OCEAN programs
5. Conception of the CARMEN lattice
    - Main characteristics of the CARMEN configuration
    - Estimation of experimental signals
    - Optimization of the design
    - Mechanical design
6. Conclusion and perspectives

Introduction

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To gain experimental data to under-moderated reactors, the cea made different studies :

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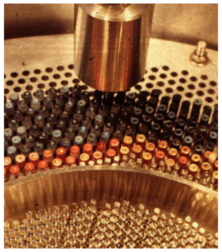
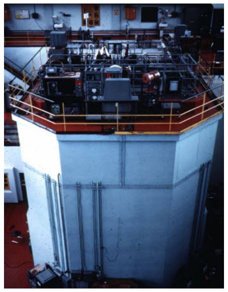
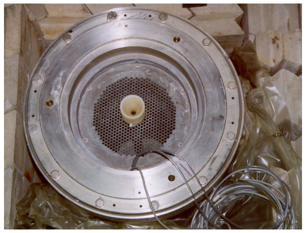




Qualification of neutronic parameters
(ERASME program in the EOLE facility (1985))

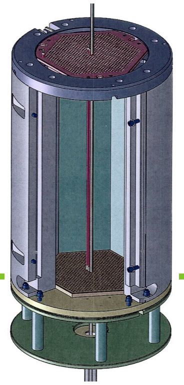
Determination of capture rates (heavy nuclides, fission products)
(ICARE irradiations in the MELUSINE facility (1986-1988))



Measurement of the global capture of fission products (oscillation of spent fuels)
(MORGANE program in the MINERVE facility (1986))

Complementary results were foreseen:

Improvement of cross sections for heavy nuclides and new neutron absorbers
(OSMOSE and OCEAN programs in the MINERVE facility)



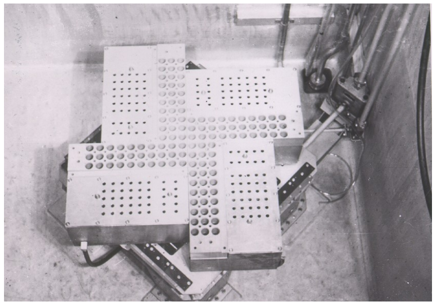
A new configuration has been designed:
CARMEN (Core with An epitheRMal nEutron moderatioN)

The MINERVE facility

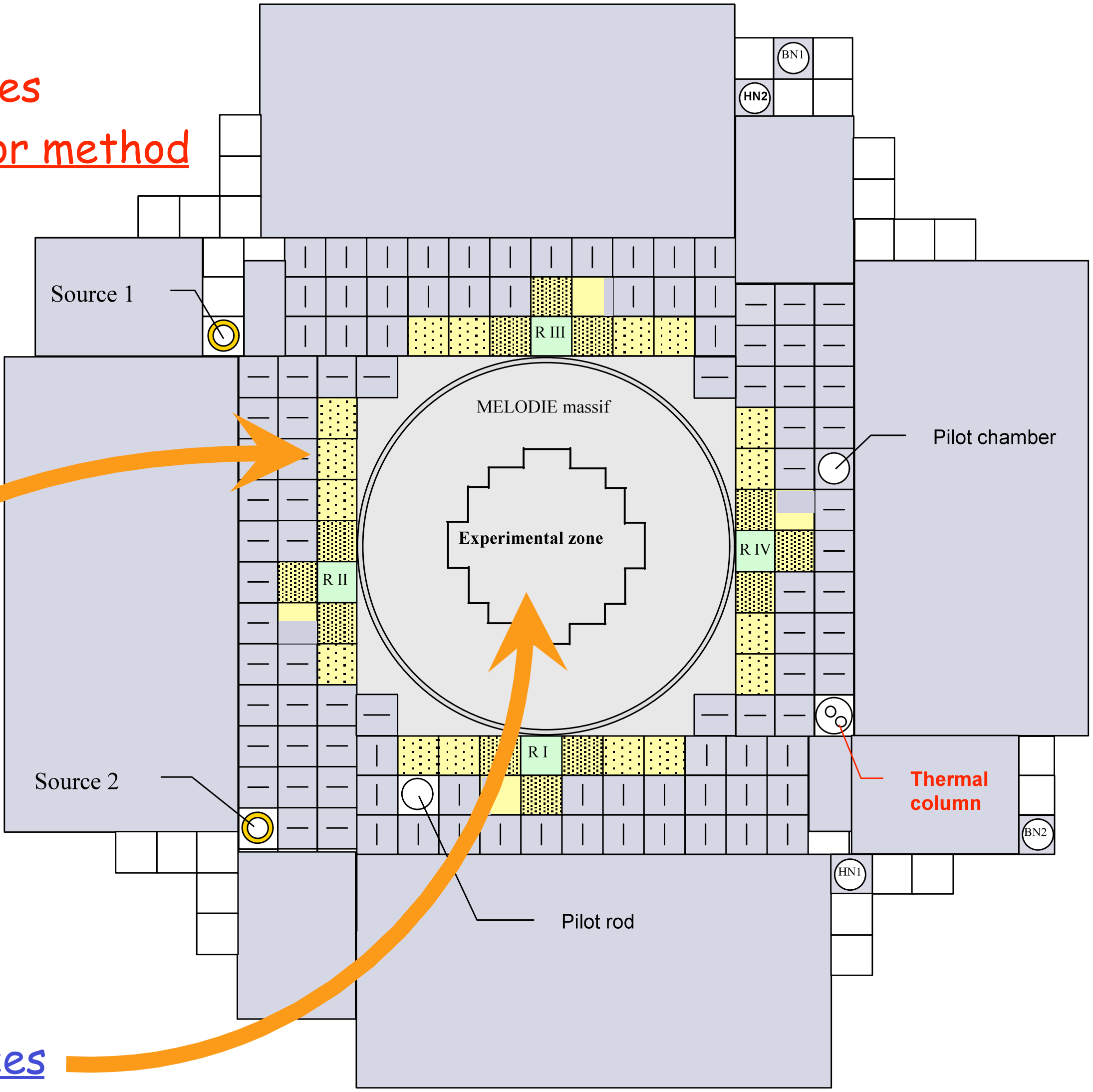
Devoted to neutronics studies
using the reactivity oscillator method

- Pool: 100 m^3 of water
- Zero power (< 100 W)
- Thermal flux: 10^7 n.cm^{-2}.s^{-1}.W^{-1}

- Driver zone on mobile grids

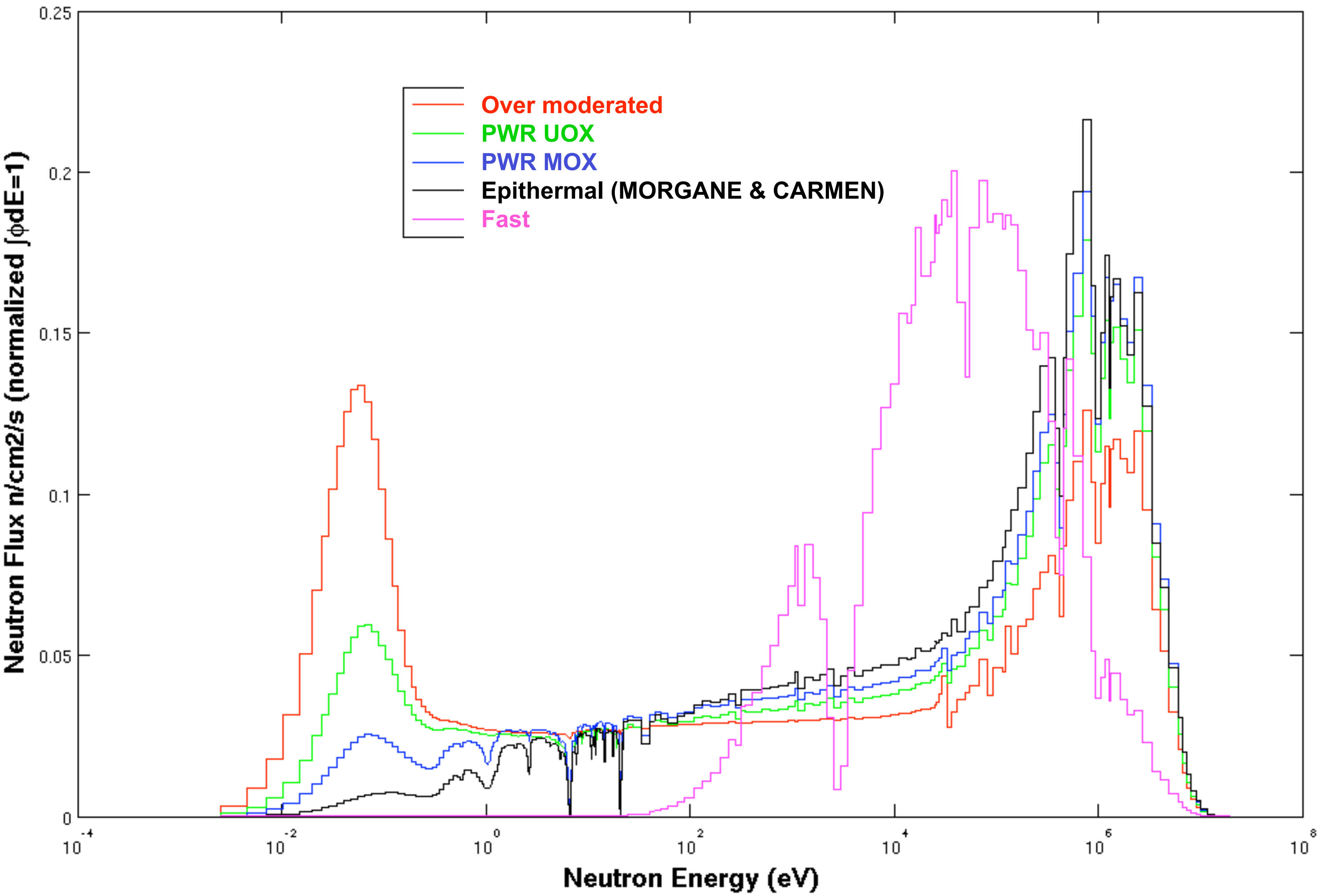


- Central cavity for experimental lattices

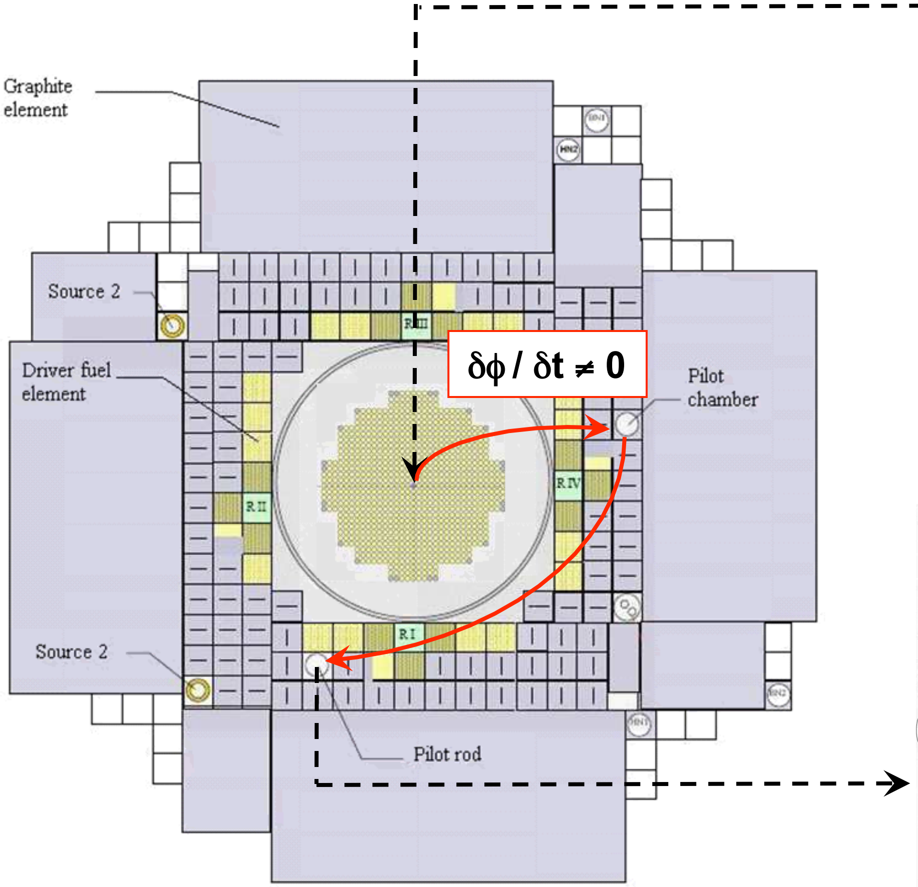


The MINERVE facility

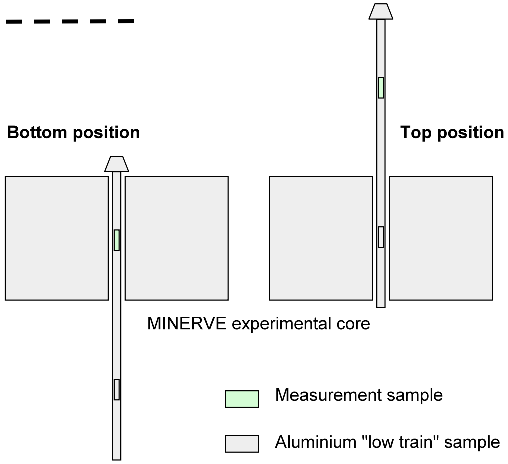
Neutronics spectra in the experimental zone :

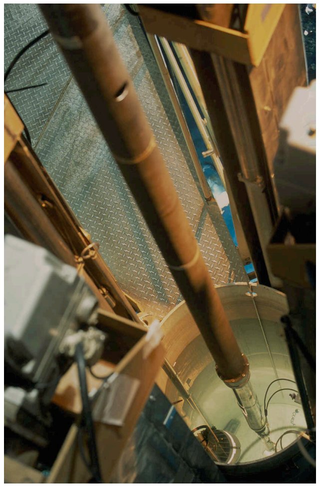


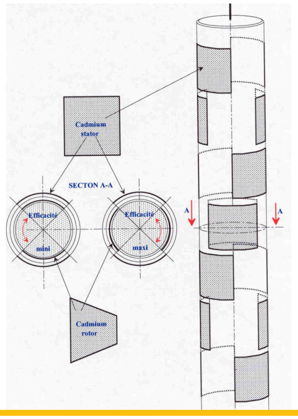
Oscillation technique of measurement

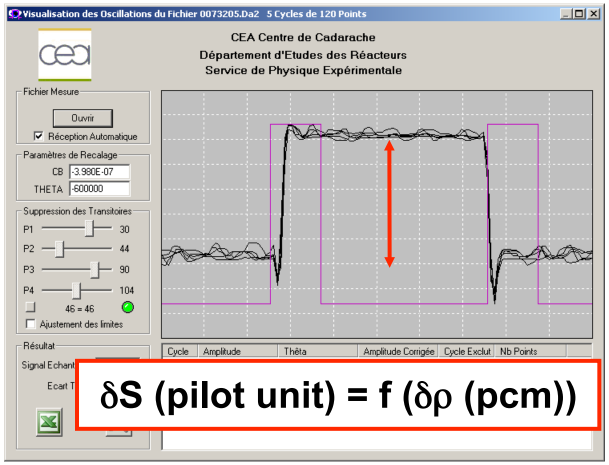


$\delta\phi / \delta t \neq 0$









CEA Centre de Cadarache
Département d'Etudes des Réacteurs
Service de Physique Expérimentale

Fichier Mesure
☑ Réception Automatique

Paramètres de Recalage
CB -3.980E-07
THETA -600000

Suppression des Transitoires
P1 30
P2 44
P3 90
P4 104
☐ 46 = 46
☐ Ajustement des limites

Résultat
Signal Echant
Ecart T

δS (pilot unit) = f ($\delta\rho$ (pcm))

Accuracy: about 3% for absolute reactivity worth (including the uncertainties on the material balance and on the calibration step)

Reactivity effects of less than 2 cents can be measured

1 measurement = 5 cycles of 120 s
1 sample = 5 measurements

The OSMOSE and OCEAN programs (2005 – 2012)

Partners:

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AREVA

eDF

ARGONNE NATIONAL LABORATORY

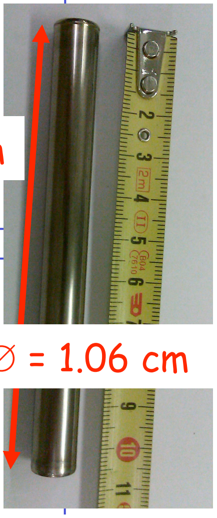
Office of Science
Department of Energy

To improve the knowledge on the absorption cross sections of:

OSMOSE : OScillation in Minerve of isOtopes in "Eupraxic" Spectra

Actinides:

Th-232	U-233 U-234 URE	Np-237	Pu-238 Pu-239 Pu-240 Pu-241 Pu-242	Am-241 Am-243	Cm-244 Cm-245



L = 10.35 cm

∅ = 1.06 cm

OCEAN : Oscillation in Core of SamplEs of Neutron Absorbers

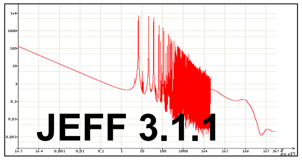
Absorbers:

Eu-151 Eu-153 Eu nat	Gd-155 Gd-157 Gd nat	Dy-160 Dy-161 Dy-162 Dy-163 Dy-164	Er-166 Er-167 Er-168 Er-170	Hf-177 Hf-178 Hf-179 Hf-180

To be integrated into the library JEFF3.1.1

Since 2006 PWR UOX *type spectrum (R1-UO2)*

Measure in different neutron spectra for having a better decomposition in energy domains for the qualification of nuclear data



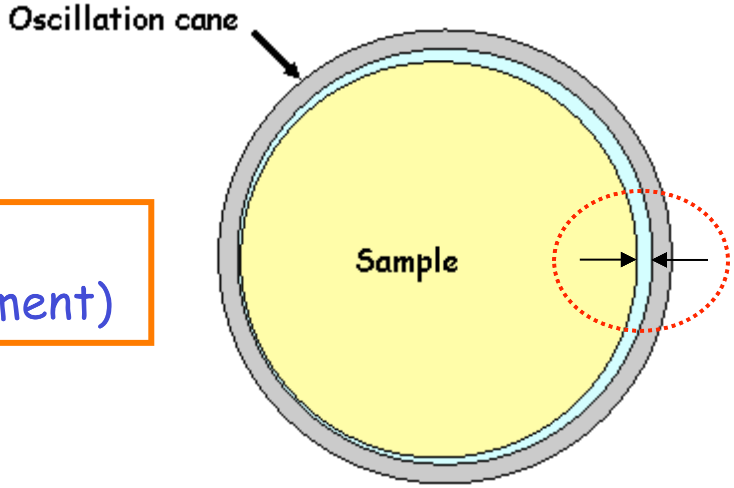
2012 Epithermal (High Conversion LWR) type spectrum *(CARMEN)*

Characteristics of the CARMEN configuration

Main parameters required for the design:

- Epithermal spectrum with a moderation ratio Vm/Vf = 0.9
- A high content in plutonium (representative of under-moderated concepts)
- Pins already available in the facility (7% in Pu and 3.7% in U-235)
- Several safety criteria to be respected (importance of the experimental zone compared to the driver zone)

Oscillation in a dry environment
(to improve the reproducibility of the measurement)



Estimation of experimental signals

Experimental signals in R1-MOX lower than in R1-UO2

	R1-UO2 configuration	R1-MOX configuration	CARMEN configuration
$\Delta S_{H8\text{-}H1}$ (pilot unit)	410 400 ± 1 000	119 600 ± 1 000	expected signal ~ 50 000 ± 1 000
Relative uncertainties	0.24%	0.84%	~ 2%

To optimize relative uncertainties for CARMEN lattice, experimental signals have to be <u>as high as possible</u>

Whatever the experimental lattice:

$$\Delta S = \boxed{\alpha^{calib}} \Delta\rho$$

Estimation of experimental signals

α^{calib}_{CARMEN} can be estimated by a combination of:

- 3D Monte-Carlo calculations (MCNP5 code)
- 2D deterministic calculation (APOLLO2.8 code)
- results of previous measurement (R1-UO2)

Checking of this method with the well known R1-MOX lattice

	Estimation	Measurement
α^{calib}_{R1-MOX} (pilot unit)	815 ± 98	790 ± 15

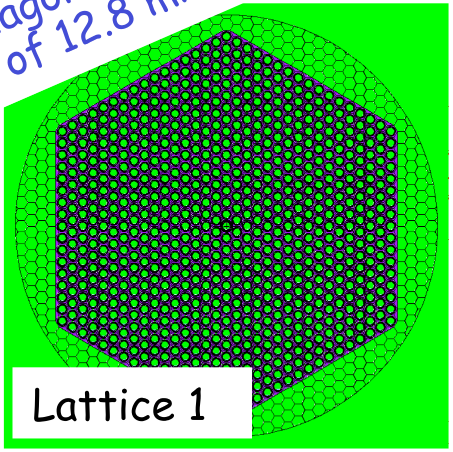
Good agreement

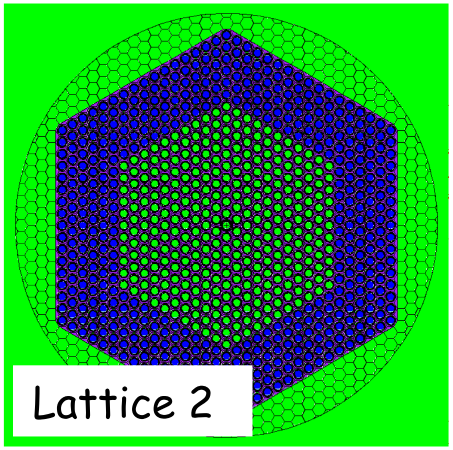
Optimization of the design

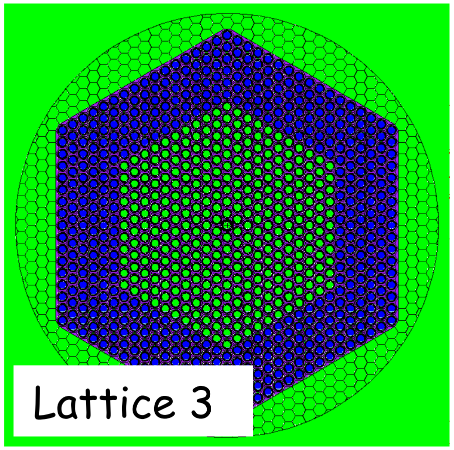
Lattice number	Calibration factor α^{calib}_{CARMEN}	ΔS_{CARMEN} (pilot unit)
1	835 ± 89	114 178 ± 12 170
2	1063 ± 90	145 355 ± 12 307
3	1475 ± 103	201 692 ± 14 084

ΔS_{R1-MOX}

Hexagonal lattice of 12.8 mm







Homogeneous
816 MOX 7% fuel pins

Overclad 11 mm of ∅ext

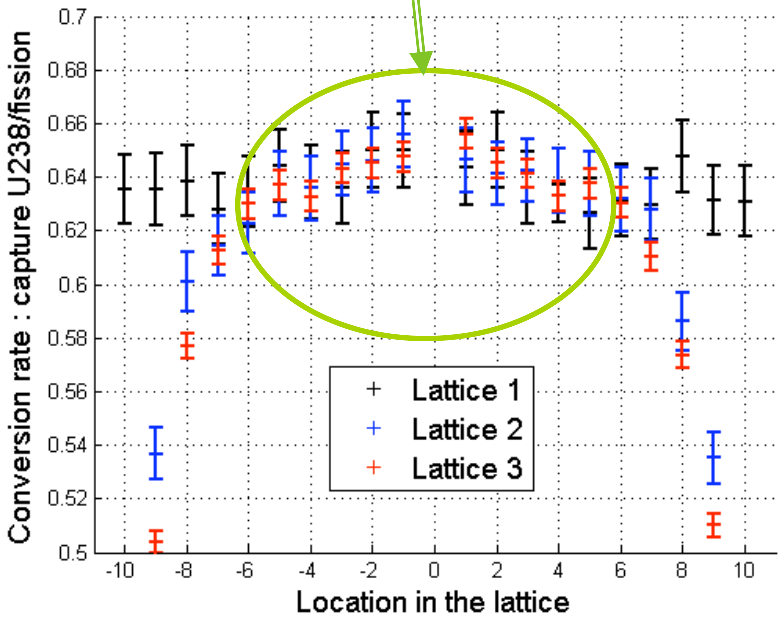
Heterogeneous
330 MOX 7% fuel pins
486 UO2 (3.7% U-235) fuel pins (buffer zone)

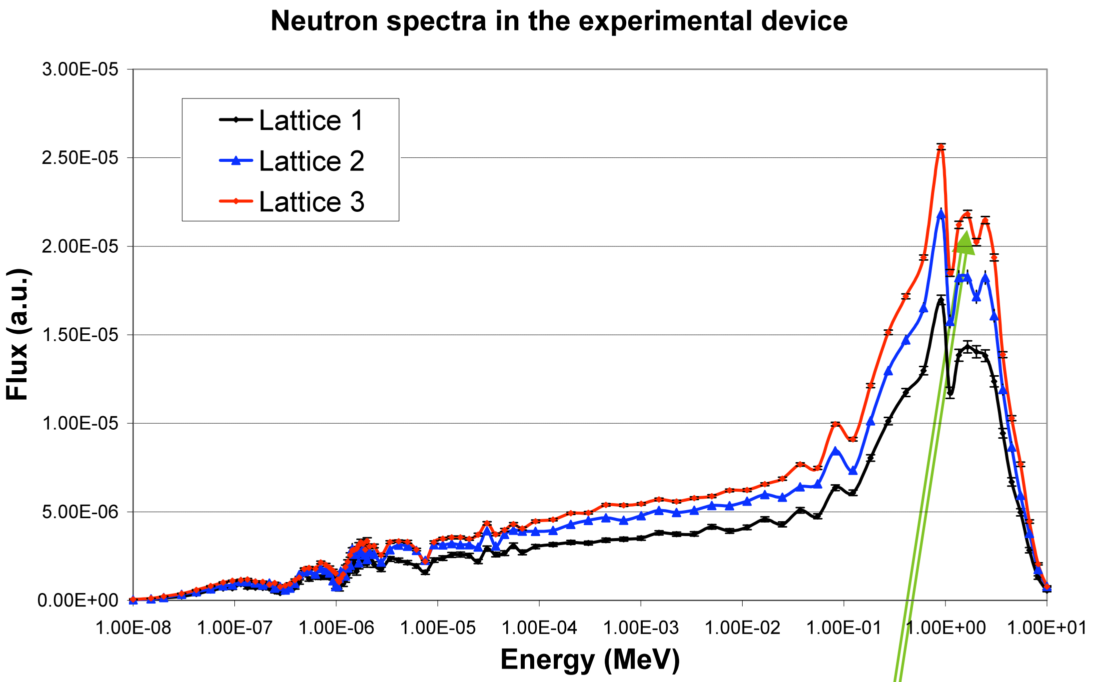
Overclad ∅ext=11 mm
∅ext=10.2 mm

UO2 drilled overclad

Optimization of the design

- Same conversion ratio ($\frac{C_{U-238}}{F_{total}}$) around the oscillation device

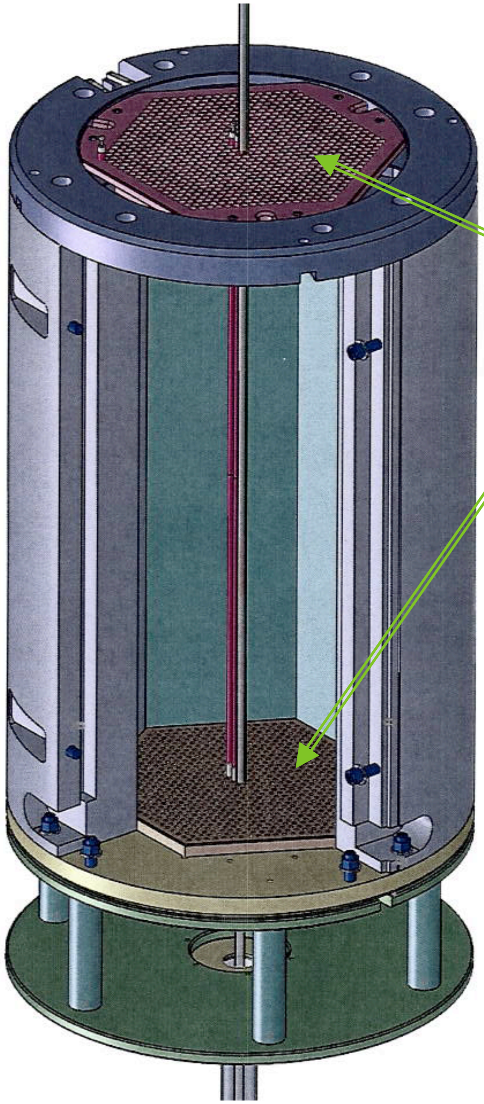




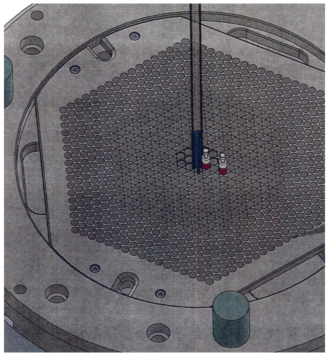
- Small increase of the flux level (lattice 3)

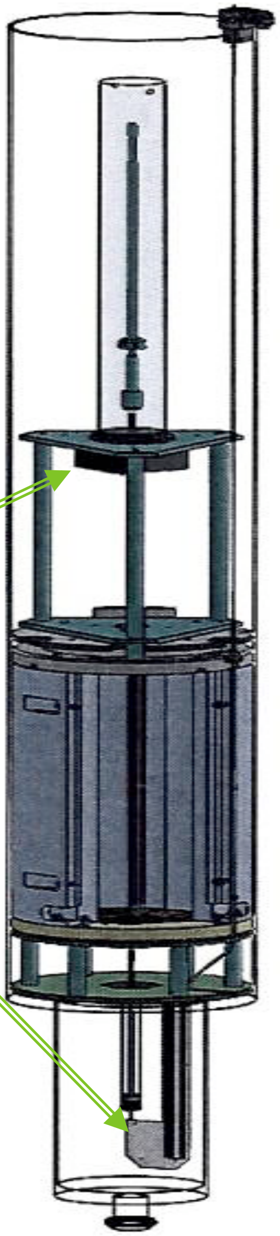
Third lattice will provide better results

Mechanical design



- 2 dedicated grid in an aluminum cask (versatility)
- Thick grid to drive the pins under 2 m of water
- Biological protection
- Dedicated device for extracting samples from the top of the pool





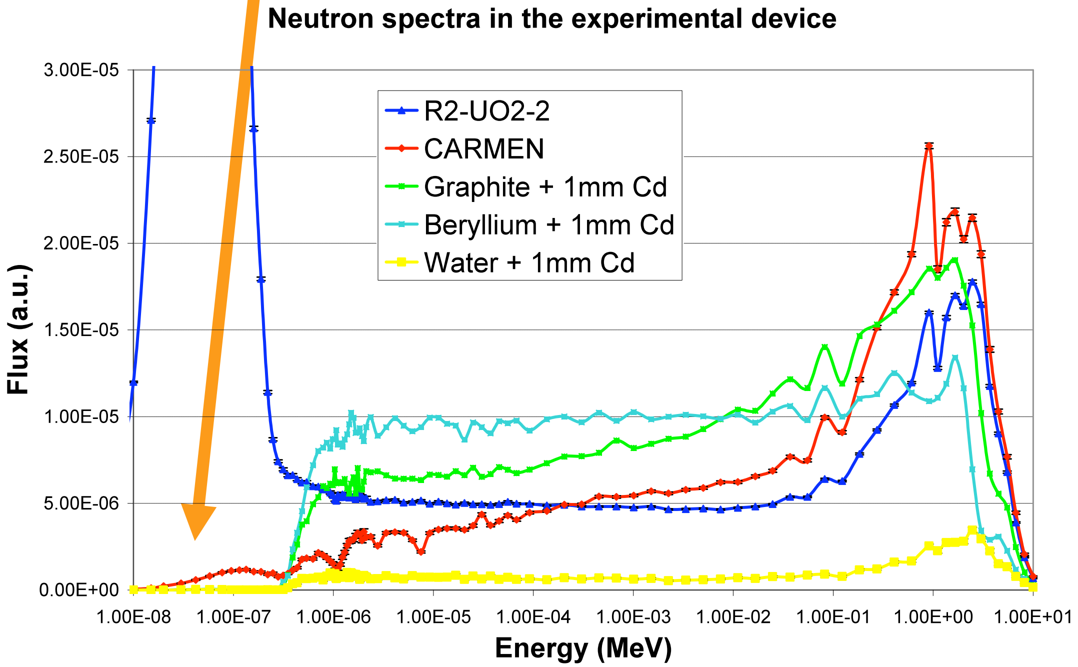
Conclusion and perspectives

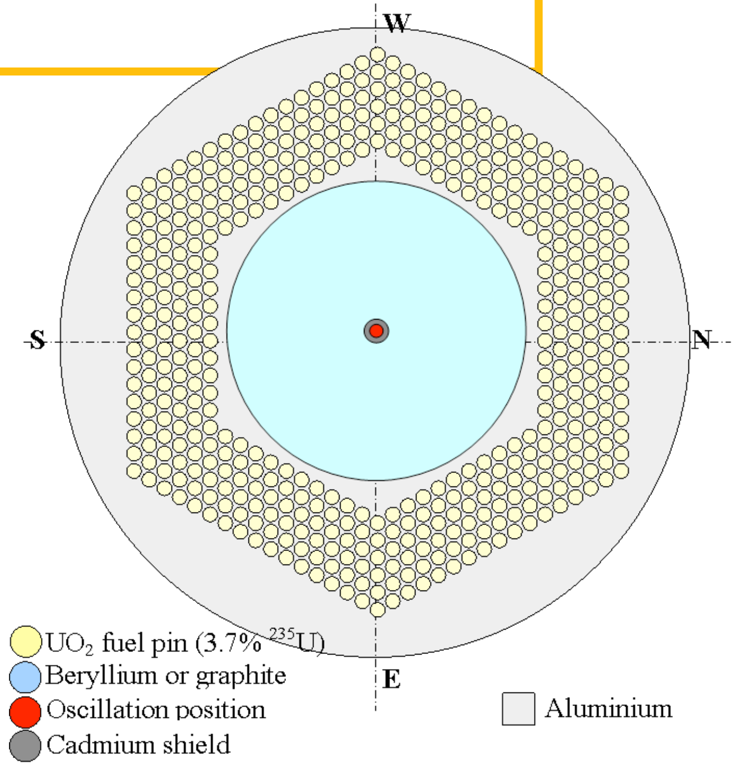
- Neutronic conception achieved
- Mechanical building in progress
- Reduction of experimental uncertainties
- New calibration samples
- Oscillations in CARMEN lattice should start in 2012

⇨ Improvements of nuclear data used for the JEFF3 library

Conclusion and perspectives

- Measurements under Cadmium shield to complete the decomposition in energy domains for the qualification of nuclear data
- MOX fuel pins can be replaced by Graphite or Beryllium cylinders





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Estimation of experimental signals

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A reactivity effect introduced by a sample is exactly compensated by an automatic pilot rod, made of overlapping cadmium sectors:

$$\left.\begin{array}{l}\Delta\rho = \dfrac{\Delta N_{Cd}\int\sigma_{Cd}(E)\Phi(E)\Phi^{*}(E)dE}{I_f} \\ \Delta N_{Cd} = c\Delta S\end{array}\right\} \Rightarrow \Delta S = \frac{1}{c}\frac{I_f}{\int\sigma_{Cd}(E)\Phi(E)\Phi^{*}(E)dE}\Delta\rho \qquad \text{Eq. 1}$$

As the proportionality factor c depends only of the acquisition system,

Eq 1 is rewritten for each core configuration:

$$\Delta S_C = \frac{\left(\int\sigma_{Cd}(E)\Phi(E)\Phi^{*}(E)dE\right)_R}{\left(\int\sigma_{Cd}(E)\Phi(E)\Phi^{*}(E)dE\right)_C}\frac{\Delta\rho_C}{\Delta\rho_R}\Delta S_R \qquad \text{Eq. 2}$$

The integrals can be simplified:

the capture cross section of cadmium is essentially thermal,

and by assuming the same spectral variations for both the adjoin and direct neutron fluxes:

$$\Delta S_C = \frac{\left(\Phi_{th}^2\right)_R}{\left(\Phi_{th}^2\right)_C}\frac{\Delta\rho_C}{\Delta\rho_R}\Delta S_R \qquad \text{Eq. 3}$$

The experimental signals in each configurations can be related to the reactivity effects calculated from 2D deterministic calculations though the same calibration process:

$$\Delta S = \alpha^{calib}\Delta\rho^{A2} \Rightarrow \alpha_C^{calib} = \frac{\Delta\rho_C}{\Delta\rho_R}\frac{\left(\Phi_{th}^2\right)_R}{\left(\Phi_{th}^2\right)_C}\frac{\Delta\rho_R^{A2}}{\Delta\rho_C^{A2}}\alpha_R^{calib}$$