More than 40 Years of Neutronics Experiments in Critical Facilities of Cadarache: from EOLE and MINERVE to the Future ZEPHYR Reactor


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OUTLINE

- The EOLE, MINERVE Zero Power Reactors

- Overview of the Experiments performed for validation of French codes and Nuclear Data Library

- What about the future of ZPR? The ZEPHIR Project.
Main features

- Light Water Facility (1\textsuperscript{st} criticality: 1965)
- Max. Power 1 kW (usually 30W)
- Outer vessel $\phi=2.3\text{m}$ in a concrete tank
- Inner vessel built for each program ($\phi\approx1\text{m}$)
- Core height $\sim80\text{cm}$ (fissile)
- 4 B\textsubscript{4}C safety rods + 1 pilot rod
- Criticality: water flooding + pilot rod adjustment
- Thermal regulation at $\pm0.1^\circ\text{C}$ from 5 to 90°C

A wide range of core configurations

- Fuels:
  - UO\textsubscript{2} (3.7\% $^{235}\text{U}$) fuel pins
  - MOX (4\% to 8.7\% Pu) fuel pins
  - MTR assemblies ($U_3Si_2$ plates with 20\% $^{235}\text{U}$)
  - Fuels with burnable poisons (UO\textsubscript{2}-Gd\textsubscript{2}O\textsubscript{3})
- Absorbers: B\textsubscript{4}C, Hf, Ag-In-Cd, Pyrex rods
- Stainless Steel or Light Water Reflectors
- Moderation by Light Water with the possibility to add boron (0 – 3000 ppm)
Main features

- 140m³ Light Water Pool Facility (1ˢᵗ crit. 1959)
- Max. Power 100W, room T°C
- **Driver Zone** (Outer): standard MTR 93% UAl assemblies reflected by graphite
- **Test Zone** (Inner): any kind of core configuration thermal, epithermal, fast neutron spectra
- 4 Hf control rods + 1 fine pilot rod
- Criticality: control rod adjustment

Main applications

- Reactivity measurements of samples
  - Fresh and burnt fuels from LWR or FBR
  - Isotopic Reactivity Worth: $^{109}\text{Ag}$, $^{103}\text{Rh}$, $^{133}\text{Cs}$, $^{239}\text{Pu}$, $^{241}\text{Am}$, $^{244}\text{Cm}$...
- Neutron Activation Analysis
- Development and validation of experimental techniques related to neutron (Fission Chambers) and photon (TLD, OSLD)
- Education and training
- Open to international collaboration
EOLE and MINERVE Measurement capabilities

**EOLE**
- Single or cluster rod efficiency.
- Temperature coefficient.
- Void effects.
- Measurements in Subcritical conditions by MSM
- Fission rates by integral or individual peak $\gamma$-spectrometry
- Power peak in the core
- Spectral Indices
- Kinetics parameters
- Simple lattices to mock-up exp.

**MINERVE**
- Fission rates by integral or individual peak $\gamma$-spectrometry
- Spectral Indices
- Oscillation technique of sample for which we determine the reactivity.
- Calibration versus reference absorbers ($^{10}$B, $^{6}$Li, Au) or fissile ($^{235}$U)
- Activation of samples then individual peak $\gamma$-spectrometry

- Two reactors,
- Two control rooms but
- Same building,
- Same measurement room.
Homogeneous lattices: ±190 pcm for UO$_2$, ±290 pcm for MOX ($1\sigma$)
EXPERIMENTS IN EOLE: 1/3 MOXed PWR

MOCK-UP Cores
100% MOX-BWR

EPICURE UMZONE core

BASALA-H Core
PERLE for Heavy Reflector
GEN-3 reactor

FLUOLE for PWR Reflector
& Vessel fluence
GEN-2 reactor

<table>
<thead>
<tr>
<th>Uncertainty on Reflector saving (1σ)</th>
<th>H₂O</th>
<th>± 1.9 %</th>
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<tbody>
<tr>
<td>PWR</td>
<td>± 2.0 %</td>
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<tr>
<td>SS</td>
<td>± 2.7 %</td>
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</tbody>
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MINERVE: Integral Capture cross-section measurements – Status on Mendeleïev table

### Structural Materials

#### Moderators

#### Absorbers and poisons

### Instrumentation

### References

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<th>Reference 3</th>
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### Heavy nuclides

### BUC nuclides
Near future of EOLE and MINERVE facilities

**EOLE:**
- GEN3-PWR
- Massive use of Gd
- Heavy Reflector

**MINERVE:**
- GEN3-PWR
- Measurement of $\alpha$ factor (local/global signal)
- Calibration of instrumentation
- Experimental techniques benchmarking for future ZPRs
WHAT ABOUT THE FUTURE? Future of ZPR in France

- EOLE and MINERVE Facilities will stop their activities by the end of 2019

- A working group was settled in 2006-2009 to evaluate the opportunity to keep experimental capacities for Core physics studies
  ➔ Conclusion: France should keep experimental facilities for GEN-II / GEN-III (and GEN-IV)

- Industrial challenges for the next years
  - NPP « Life Extension » : 40y → 60y
  - Increase of cycle length: 12months → 18/24months
  - Increase of fuel burn-up: 40GWD/t → >60GWD/t
  - Criticality/Safety assessment related to Burn-Up Credit
  - Improvement in Nuclear Data knowledge
  - Innovative LWR designs (High conversion, SMR,...)
  - Innovative calculation schemes, physics coupling

  ➔ The CEA is investigating a new experimental Zero Power Facility ZEPHYR

ZEPHYR = Zero power Experimental Physics Reactor
ZEPHYR ambition is to keep all the functionalities and potentialities of EOLE and MINERVE, while extending them to:

- Doppler measurement of samples between $-200^\circ C < T < 2000^\circ C$
- Criticality/Safety assessment related to BUC
- Extension of irradiated fuel measurements to SFR (burnt fuel from PHENIX or from the future ASTRID industrial demonstrator)
- Modelling of core degradation on neutronics
- Dynamical measurements (vs quasi-statics in « traditional » ZPR)
- Coupled cores for Nuclear Data improvement (complementarity with MASURCA)
- Specific JHR device qualification if required

ZEPHYR would be a more international facility
- Extension of industrial partnerships with other countries

Preliminary studies of the building and core design have started in 2014
CONCLUSIONS

3 Keys Points to remind

- Zero Power Facilities: a key-role in the development / improvement of GEN-II, GEN-III and associated activities (storage, transportation, reprocessing)

- « Open » access to the EOLE and MINERVE still available up to 2019

- CEA would like to keep an experimental facility and is currently designing a new critical facility ZEPHYR
THANK YOU FOR YOUR ATTENTION
ANY QUESTIONS?