Conceptual design of a pressurized water loop for the irradiation of 6 fuel rods in the Jules Horowitz Reactor

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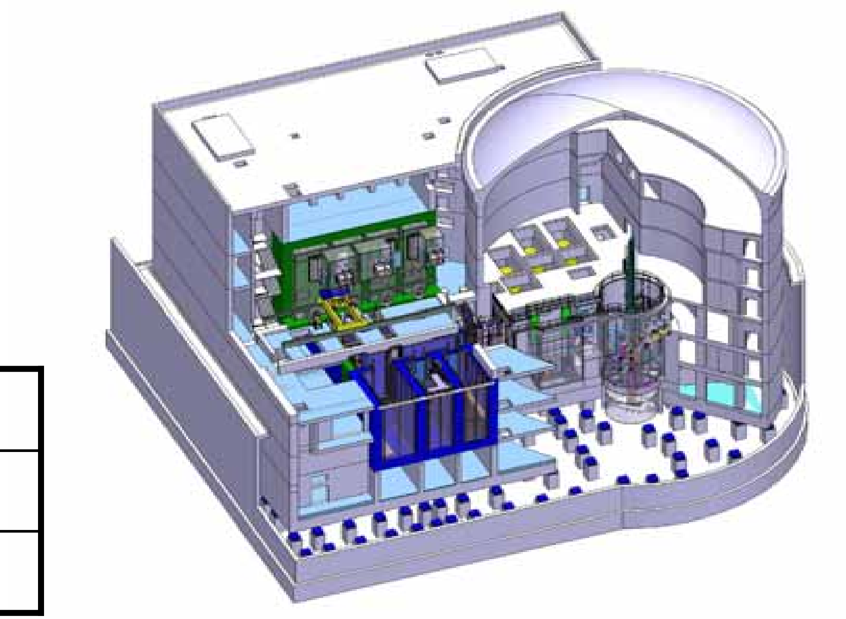
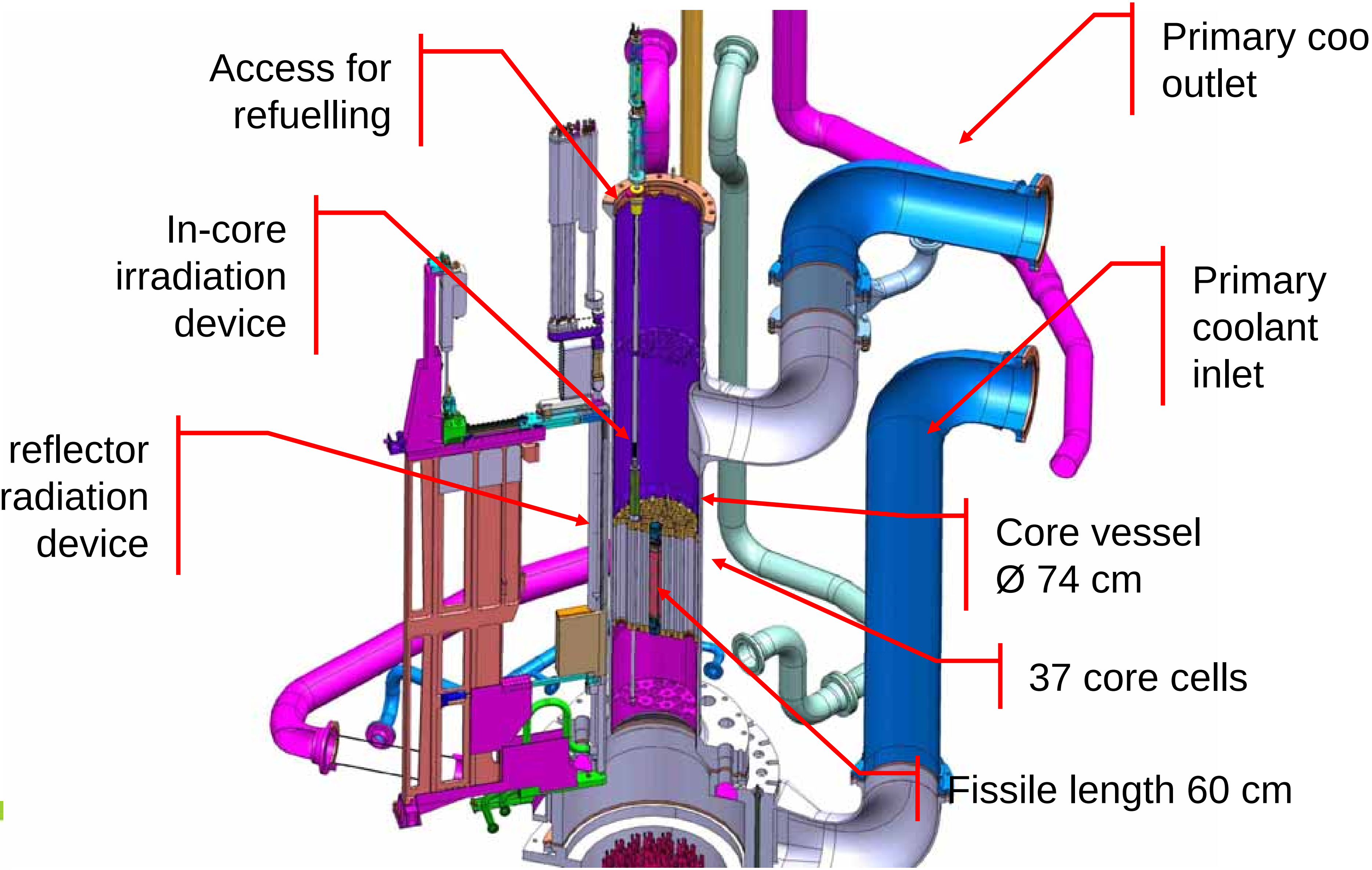
The Jules Horowitz Reactor (JHR)

- Mainly dedicated
  - to studies of material and fuel behaviour under irradiation
  - to radioisotope production
- A major role
  - for innovation and characterizations required by GEN IV reactor fuels and materials
  - for supporting safety and performance improvements of generation 2 and 3 Light Water Reactors (LWR)



Development studies	2006-2007
Construction & tests	2008-2013
First criticality	2014

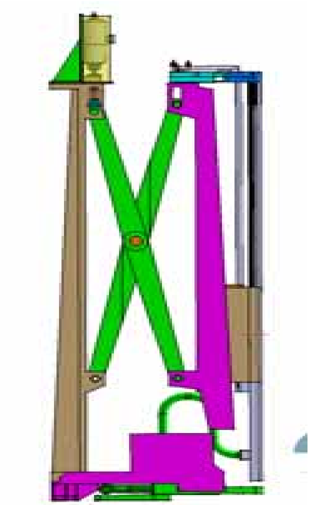
Reactor pile block inside reactor pool



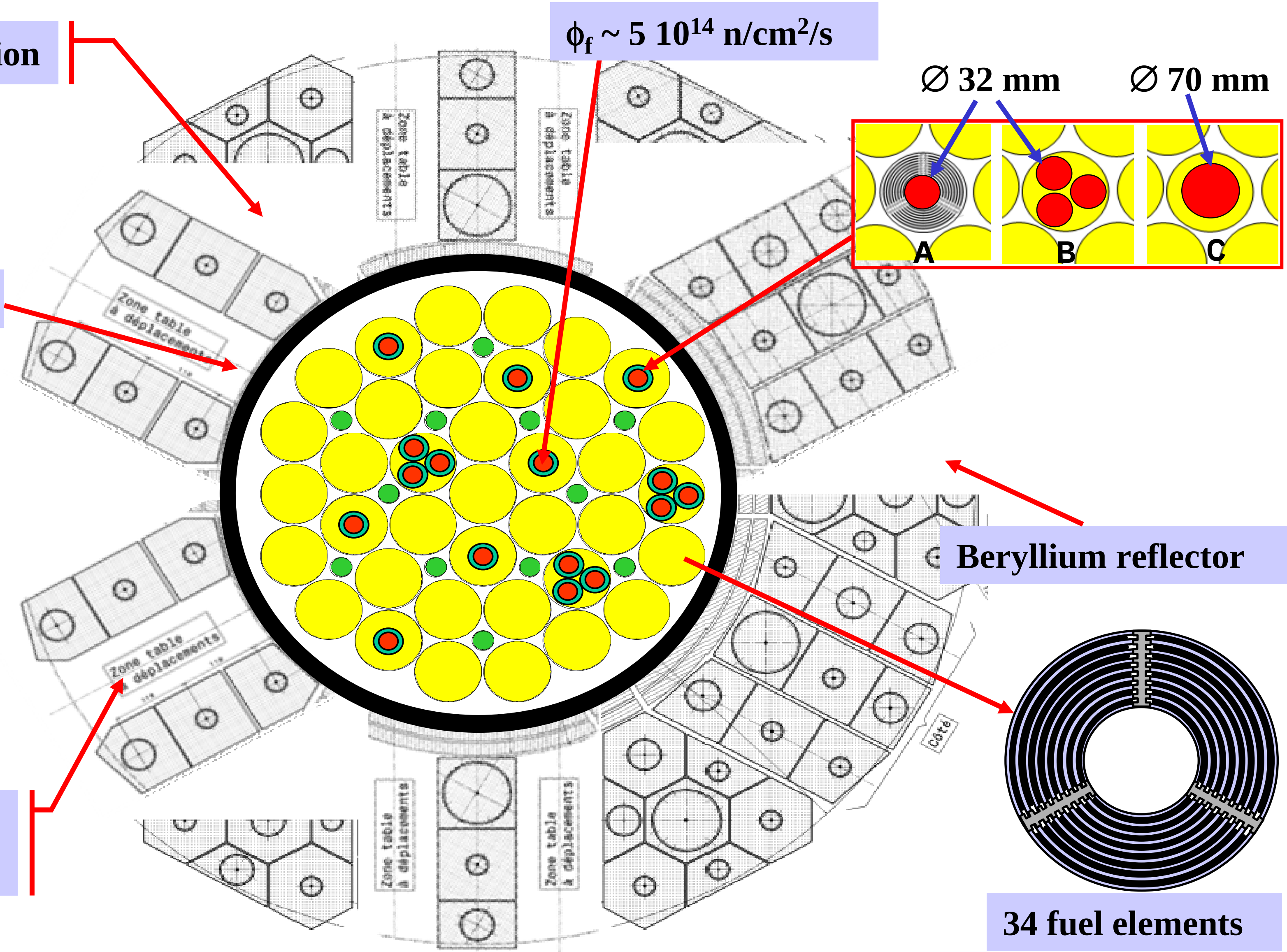
Experimental locations

Fixed position

$\phi_{th} \sim 5\ 10^{14}$ n/cm²/s



Displacement system
to adjust position

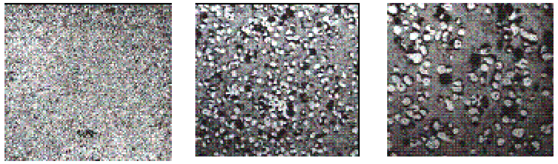


Qualification of a power reactor nuclear fuel

Basis concept → **Licensing**

Manufacturing R&D ↔ **Irradiations in MTRs**

Mechanistic modeling



- Screening and comparison irradiation tests are necessary
  - to choose one or a few fuel materials among a batch of candidates,
  - offering a good potential behaviour with respect to technical specifications
- First exploratory tests can be performed
  - in a simple test device
  - not representative of the reactor conditions
  - with limited on-line instrumentation
- However in a comparison phase of new products,
  - it is relevant to irradiate, in the same flux, several rods in conditions similar to the power reactor

Functional requirement for a device to select LWR fuel

- Several rods (~ 6) irradiated in the same flux
- Perfect knowledge and monitoring of the local conditions
  - especially for Linear Heat Generation Rate (LHGR)
- The best homogeneity of LHGR with regards to Fission Gas Release (FGR)
  - 5 % LHGR increase may induce 40 % FGR increase
- To improve the understanding of fuel behaviour under irradiation,
  - in-situ measurement of the main parameters
  - e.g. fuel temperature and rod pressure
- Time history of irradiation
  - generally stable power levels
  - with periodical power adjustments
- Irradiation duration
  - short if beginning-of-life phenomena are to be quantified e.g. 3 to 6 months
  - generally a long experiment (several years) to reach very high burnups
- Irradiation device and instrumentation
  - robust and reliable

Main characteristics of the test device

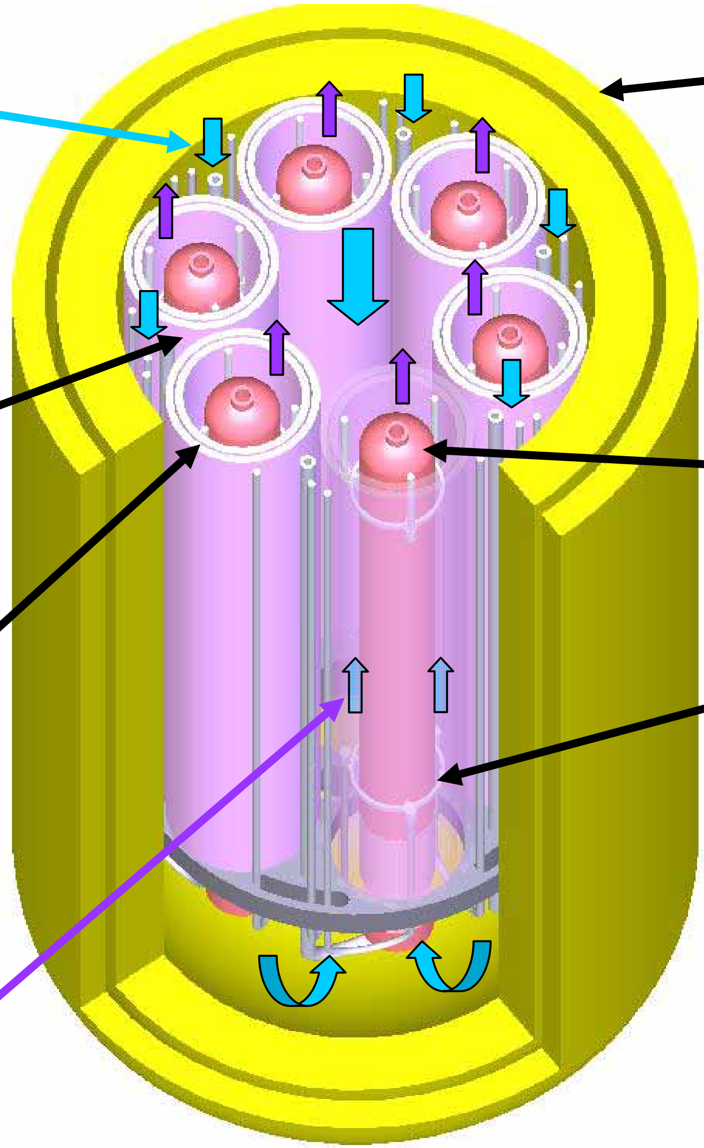
- Experimental pressurized water loop
  - Inlet temperature : 300 °C
  - Pressure : 15.5 MPa
- Designed to LWR fuel rod testing
  - Rod diameter : 9.5 mm
  - 6 samples
  - Fresh or pre-irradiated fuel
  - Fissile length ~ 450 mm
- In the JHR's reflector
  - In one specific experimental location equipped with a variable thermal neutron screen
  - Or on one of the JHR's displacement systems
- Steady stage irradiation but allowing fuel rod power changes

Operating principle of the in-pile part

Down-comer
(water down flow)

Zircaloy double-wall pressure tube
- High temperature, high pressure water Containment
- Controlled gas gap

Sample holder with
6 independent test channels
- positioning of the rods
- holding the sensors



6 fuel rods

Test channel tubes
-2 stainless steel tubes
-Inert gas gap

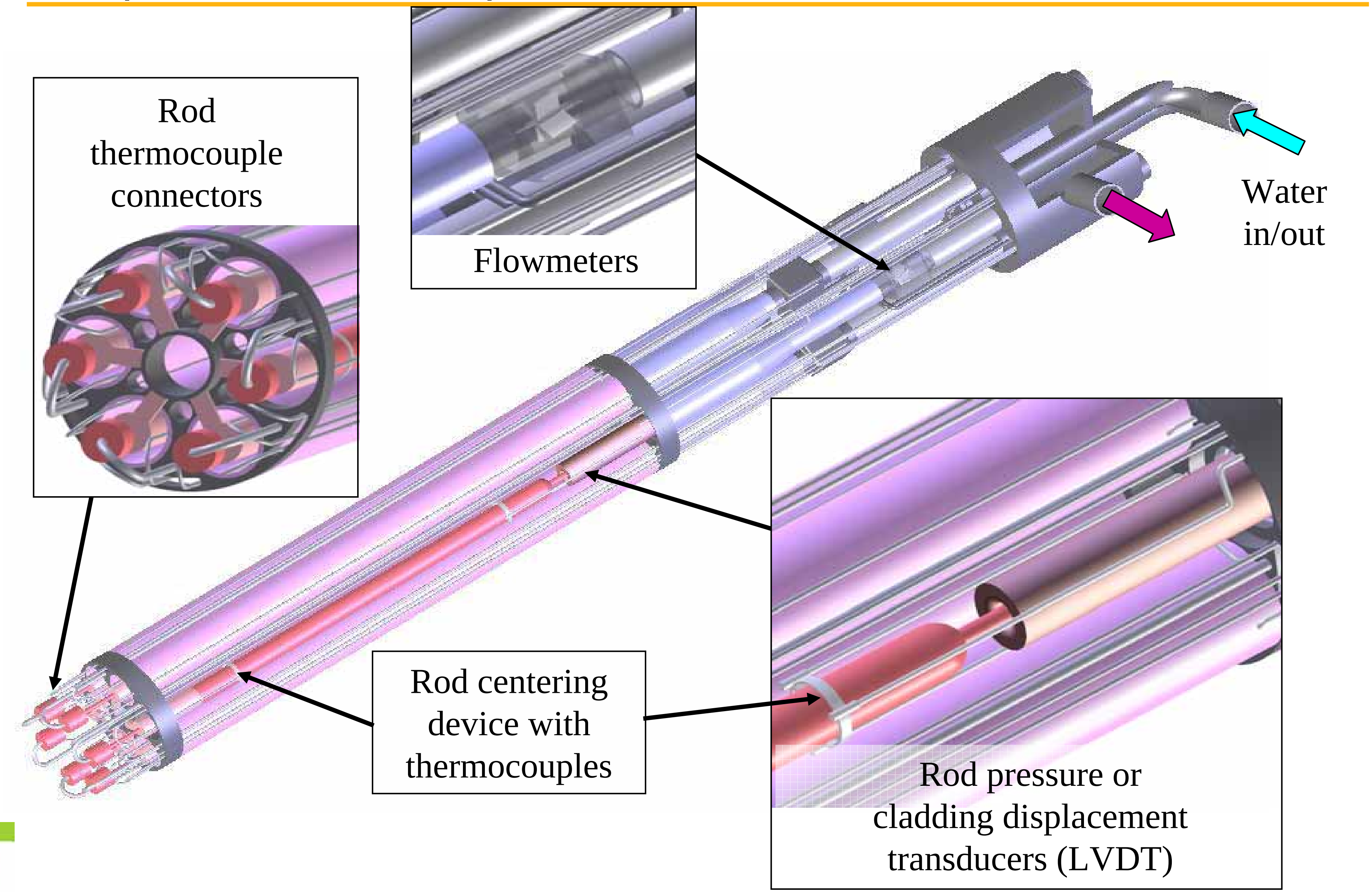
Rod centering device + water temperature measurement

6 test channels
(water up flow)

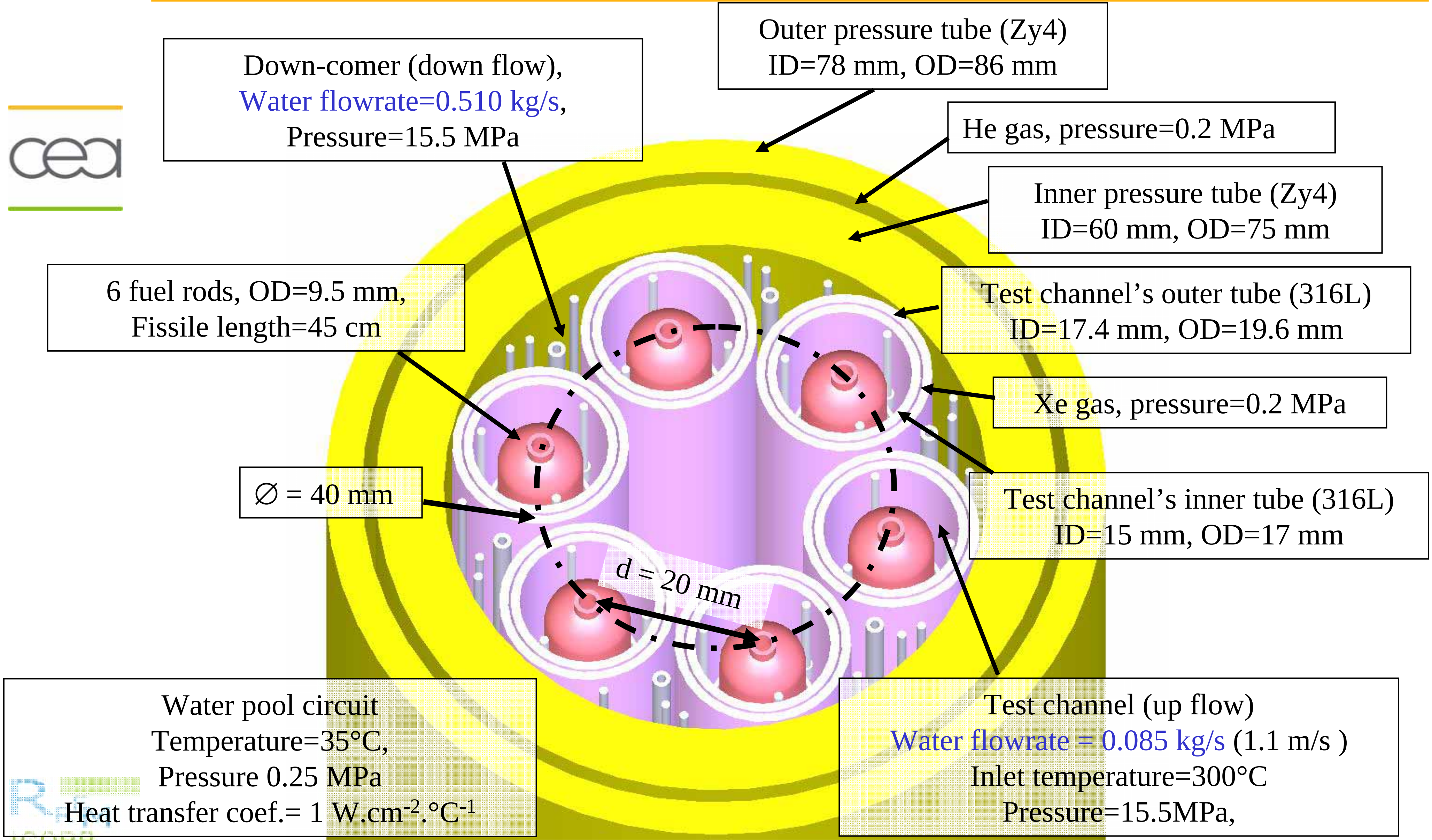
Main in-pile instrumentation

- Accurate monitoring of LHGR of each fuel rod, with independent thermal balance for each test channel
  - Inlet and outlet temperatures measured by thermocouples placed respectively below and above fissile column
  - Flowrates measured by small turbines placed in each test channel above the fuel rods
- To improve the understanding of fuel behaviour under irradiation, each fuel rod could be instrumented at both ends, e.g. :
  - Fuel central thermocouple with tight path in the bottom of the rod + watertight connector
  - Cable free detector based on Linear Voltage Differential Transformer (LVDT) at the top end of the rod to measure
    - Either rod internal pressure
    - Or cladding length variation
    - Or fuel column displacement

Sample holder and in-pile instrumentation

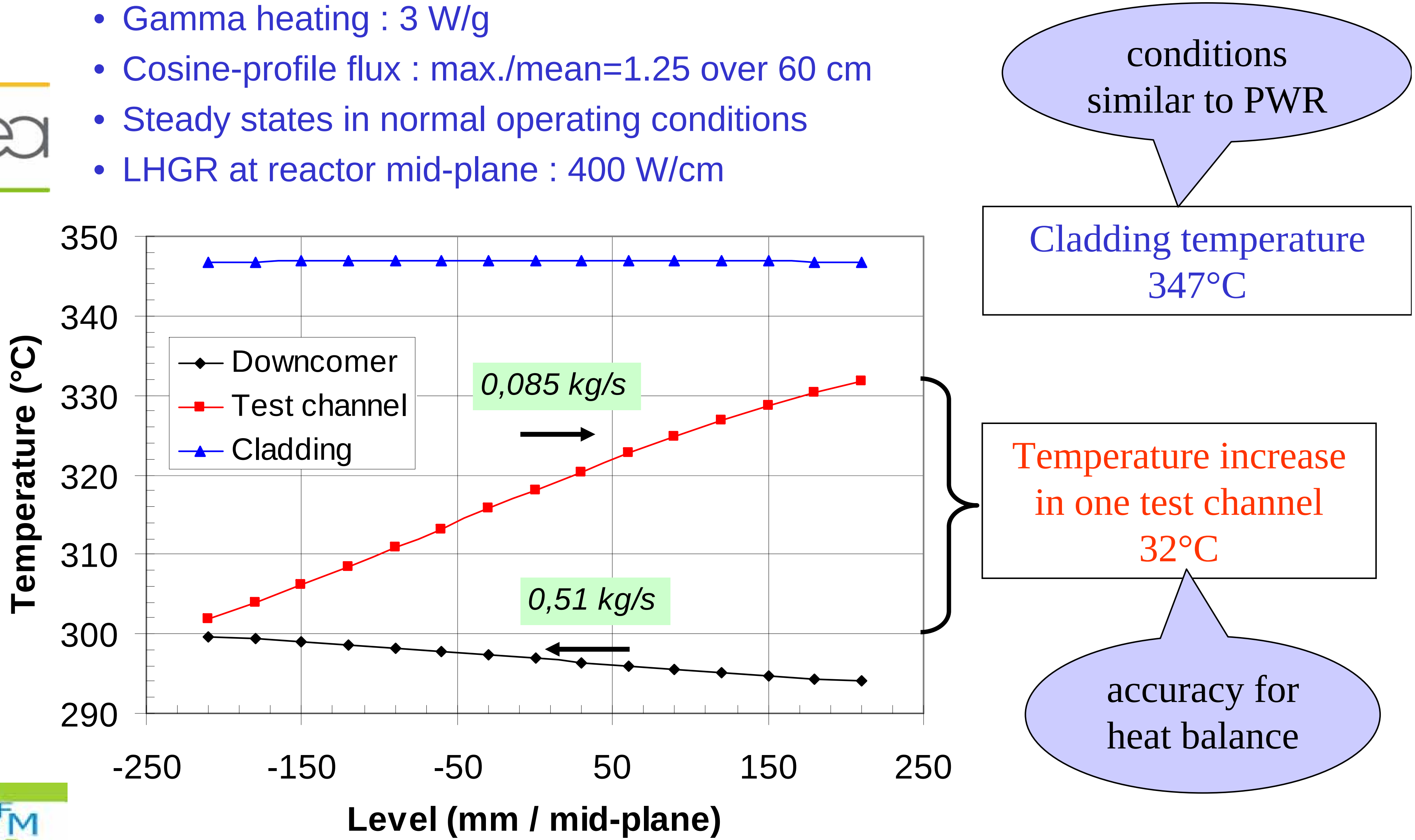


Dimensions and hypothesis for calculations



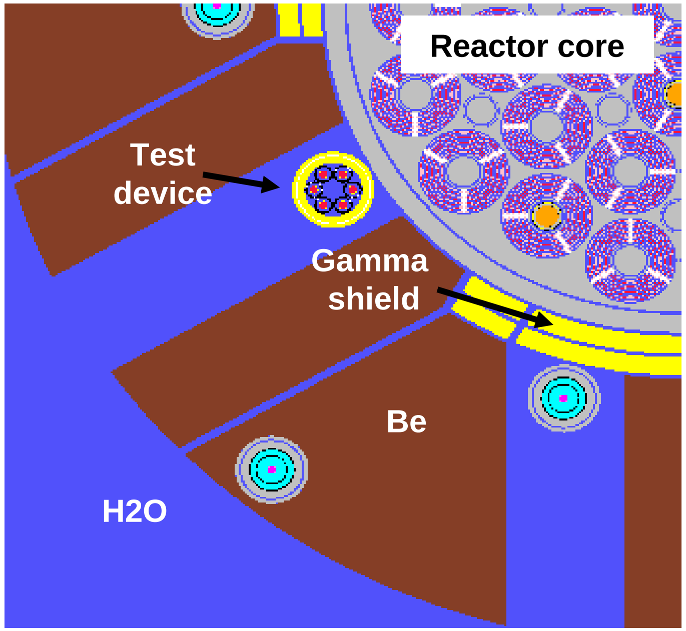
Thermal-hydraulic results

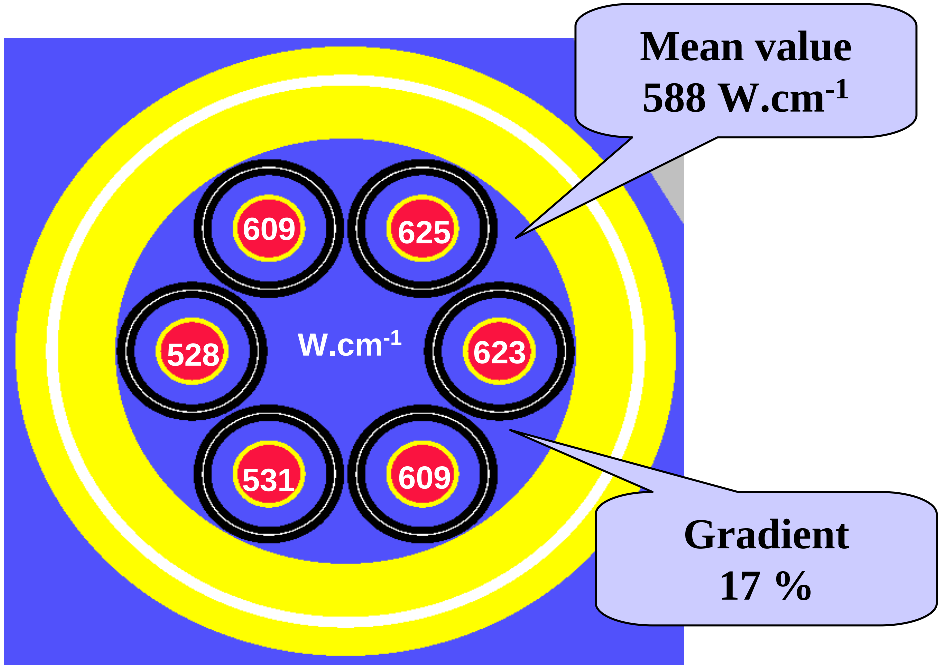
- Gamma heating : 3 W/g
- Cosine-profile flux : max./mean=1.25 over 60 cm
- Steady states in normal operating conditions
- LHGR at reactor mid-plane : 400 W/cm



Neutronic calculations

- Simulations carried out with the 3D TRIPOLI4 Monte Carlo code
- Experimental fuel samples : 2% enriched fresh UO2 fuel rods
- LHGR of experimental rods given at reactor mid-plane

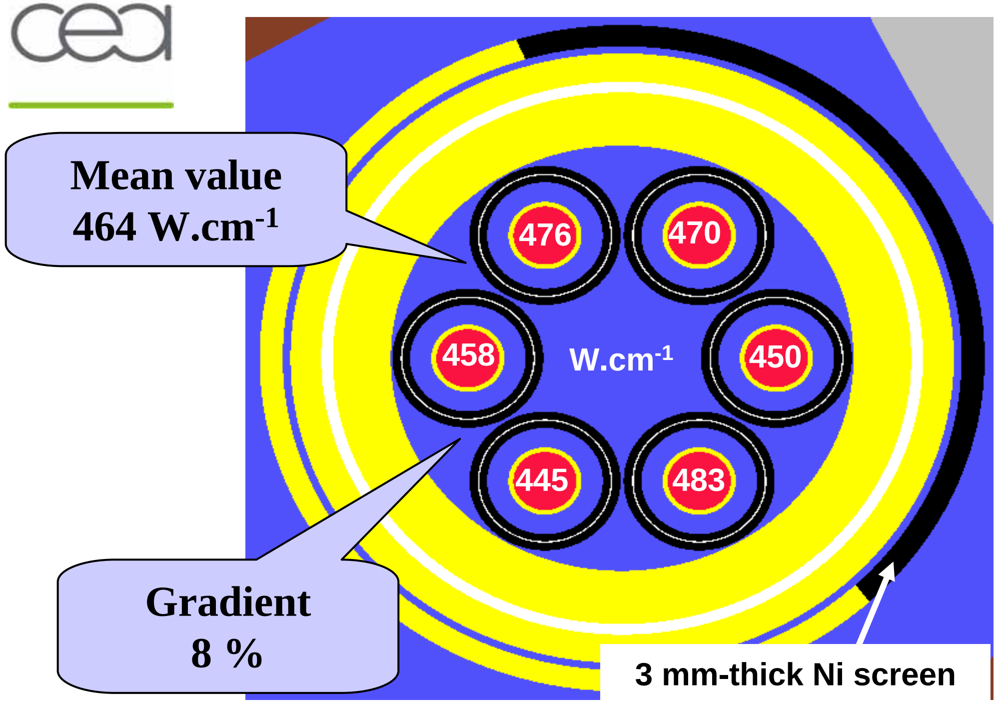


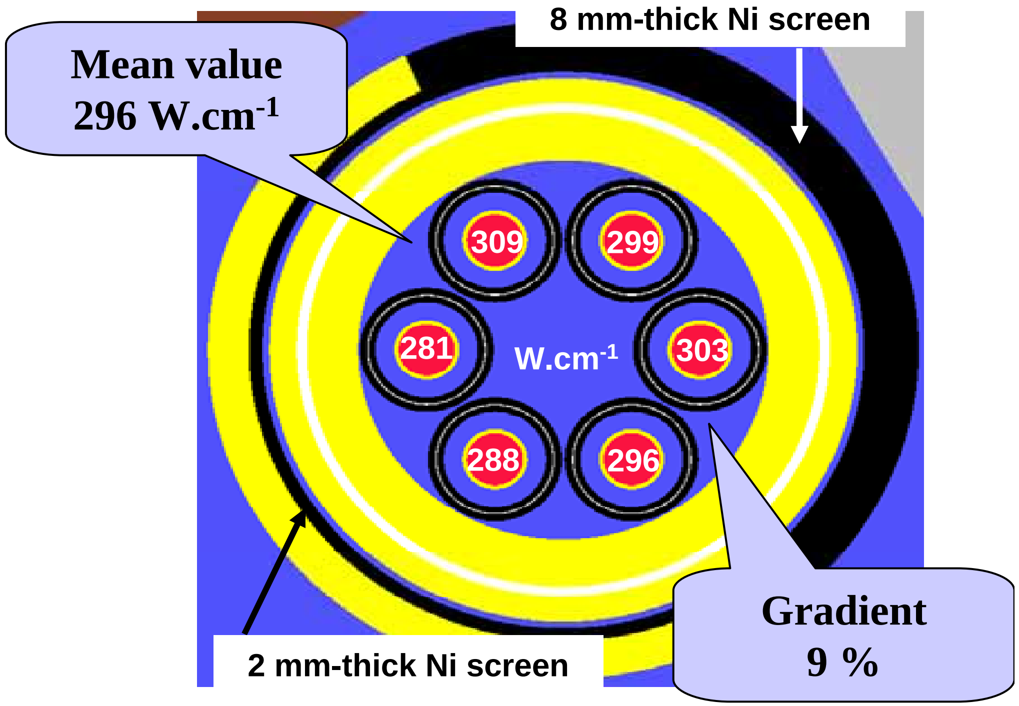


- Different studies performed by varying the distance of the loop's axis from the core rack
- The best homogeneity of LHGR obtained near the core in the peak of thermal neutron flux (7 cm from the core)

Reducing the LHGR values and the gradient

- A solution consists in keeping the test device near the core rack and adding a Nickel screen of varying thickness





- Possible configuration :
  - a specific Nickel screen for a given operating point
  - and the displacement system kept to make small changes around this operating point

Conclusion

- The important features of the concept lie in
  - its specific sample-holder providing 6 test channels to improve on-line monitoring of LHGR thanks to independent heat balances
  - the possibility to load fuel rods equipped with two sensors at both ends
- Solutions with Nickel screens have been proposed
  - to minimize the LHGR differences between rods
- In a next stage, definition of the main components of the loop taking into account its out-of-pile circuit
  - in steady state operating conditions
  - in transient and incidental operating conditions
- Proposal to discuss with fuel R&D teams and end-users
  - to confirm the interest in multi-rod irradiation experiments
  - to carry on the study and the development of such a test device