AREVA

The Jules Horowitz Reactor (JHR) Project

»The Jules Horowitz Reactor core and cooling system design

»(2005)

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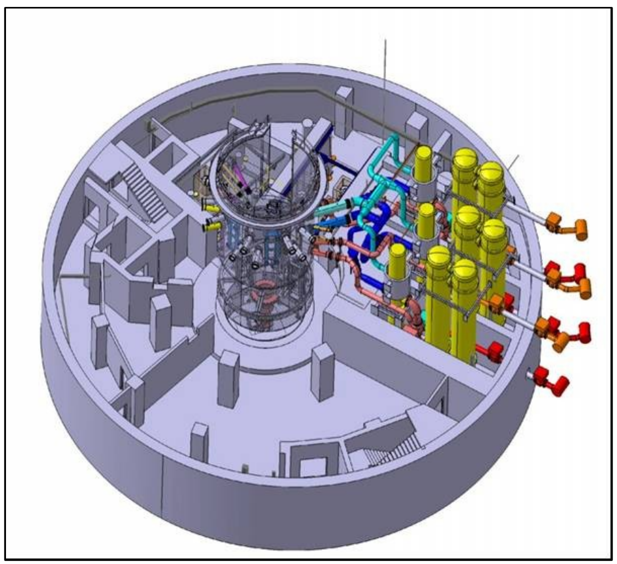
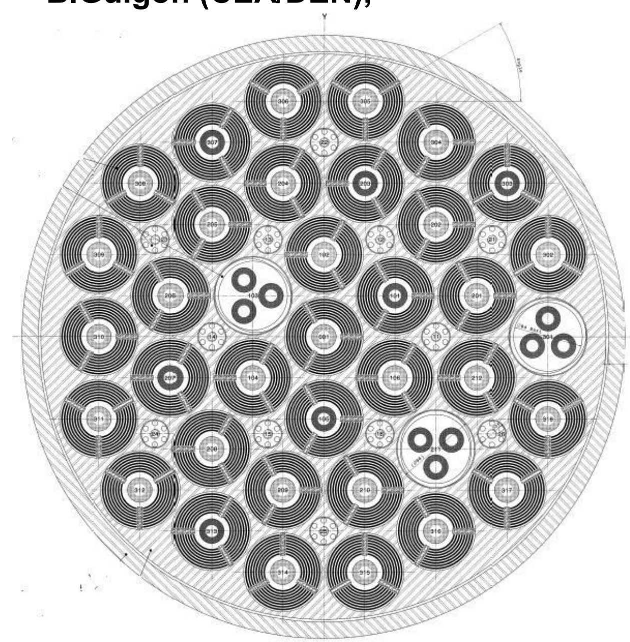
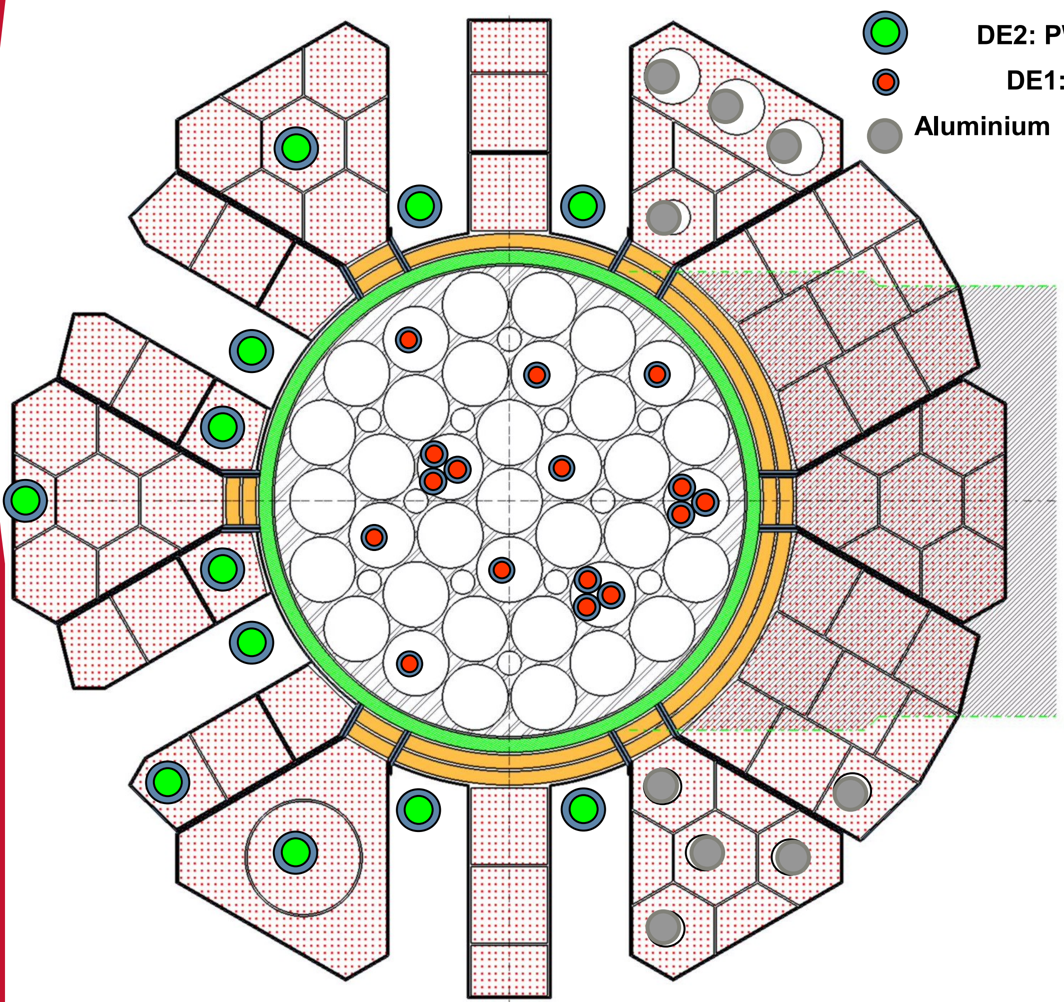




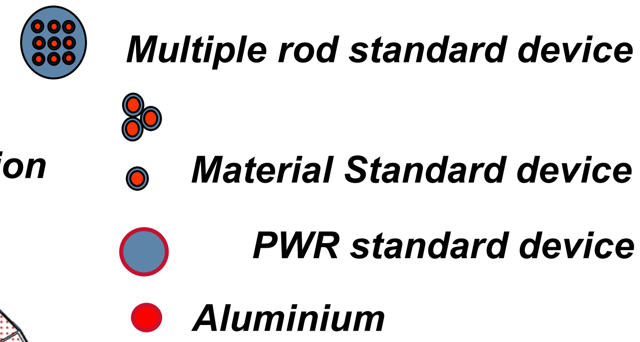
Reference Configuration

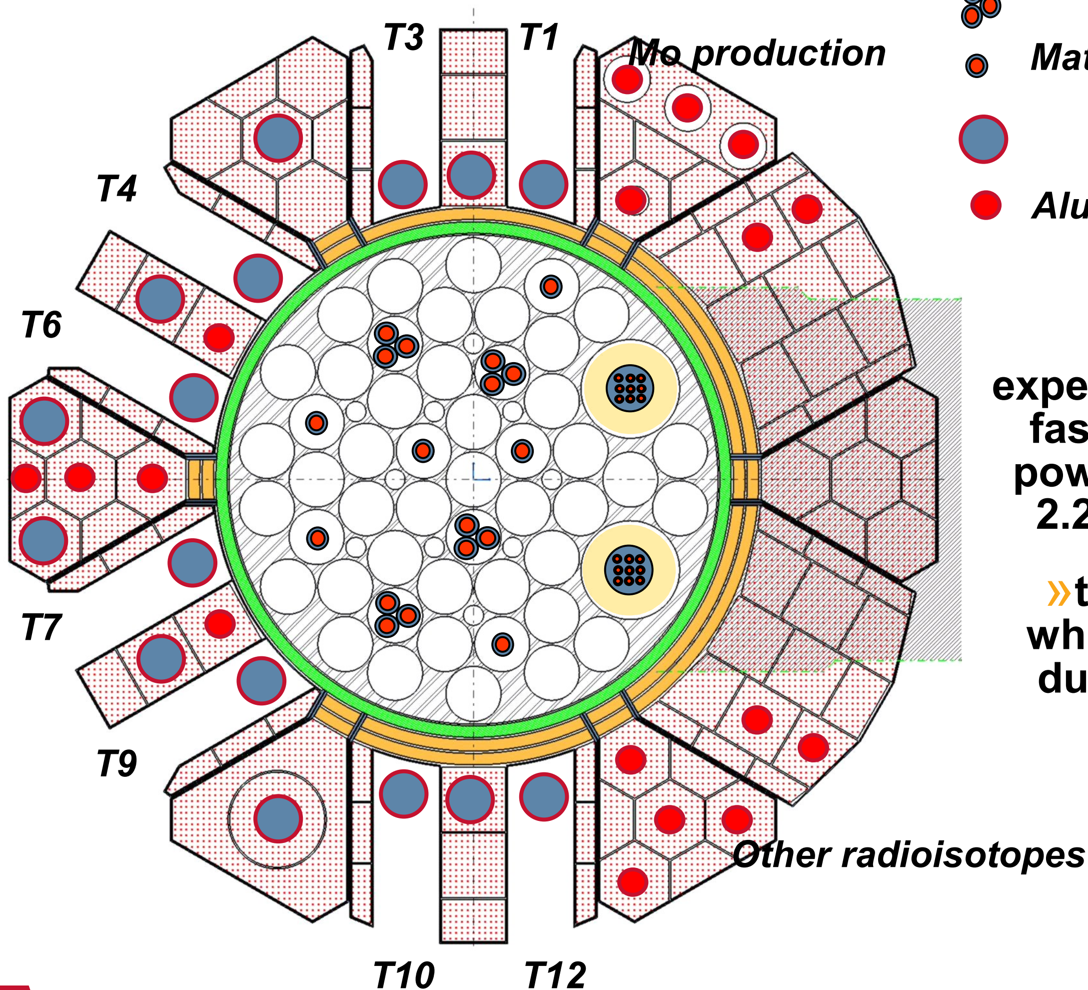


» **capable of :**

- » **High Dpa damages in the core : 5.5 x 10^{14} n./cm2/s effective fast flux (E > 0.907 MeV) integrated in a steel test sample**
- » **Power ramp maximal power 600 W/cm in PWR type rod with 1% U_{235} enrichment in the reflector**

Large configuration





» Standard irradiation experiment objectives: effective fast flux 4.10^{14} n/cm²/s and a power ramp of 600 W/cm on a 2.25% U_{235} enriched fuel pin

» two large in-core devices which may remain in reactor during refueling operations

Design requirements

Reactor nuclear power limited to 100 MW

U_{235} enrichment ≤ 20% with a new meat technology

Core coolant velocity limitation: 18 m/s

High level of safety,

Enclosed primary circuit

Operability of 275 days per year, but using only a few fresh fuel elements per year (about 100),

Configuration change time interval : 2 months allowed

Computer Programs

Neutronics:

- Regular shape: HORUS3D/N deterministic scheme based on CRONOS and APPOLO programs
- Irregular shape:
  - Firstly, stochastic calculations (MCNP, TRIPOLI) propagation (step 0)
  - Secondly, a whole core variation calculation using transport theory (plate by plate modeling but in 2D) for:
    - neutronic data determination for safety study purposes
    - material inventory determination
  - The whole being fed into stochastic codes (MCNP, TRIPOLI)

Thermohydraulics:

- HORUS3D/Th and Sys: based on FLICA and CATHARE and the CEDRIC programs. Hydraulic flow calculations TRIO code,

Mechanical:

- CAD mockup integrated with the CATIA software,

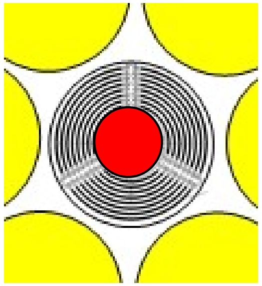
Fuel element thermomechanics:

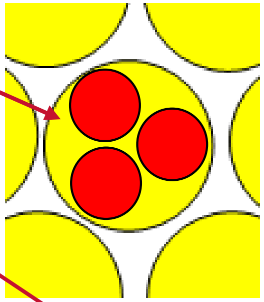
- use of the IDEAS software based on results obtained with the MAIA code for the plate (CEA code developed for the U-Mo fuel study).

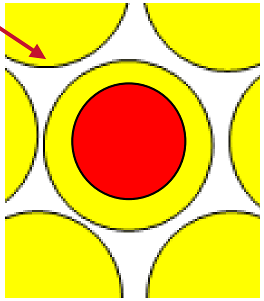
Slot size definition for both configurations

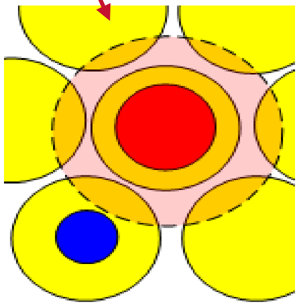
Slot size

- Accommodation of a fuel element
- Accommodation of a threefold irradiation device
- Accommodation of an irradiation device
- Interaction between irradiation device and control rod mechanism









Irradiation device size:

- In place of a fuel element

Minimal diameter:

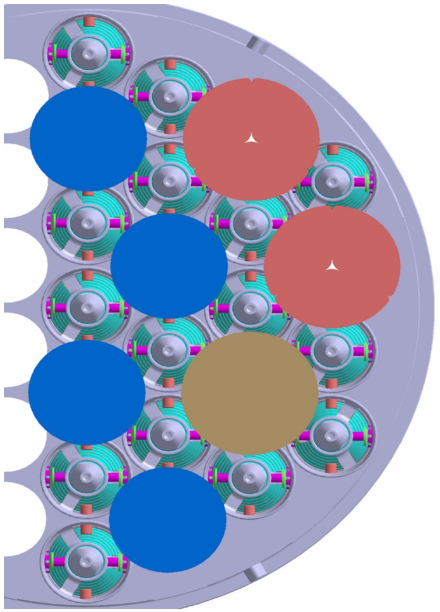
  - 70 mm in the core
  - 80 mm from 300 mm above the fissile material
  - 120 mm at the reactor vessel lid level

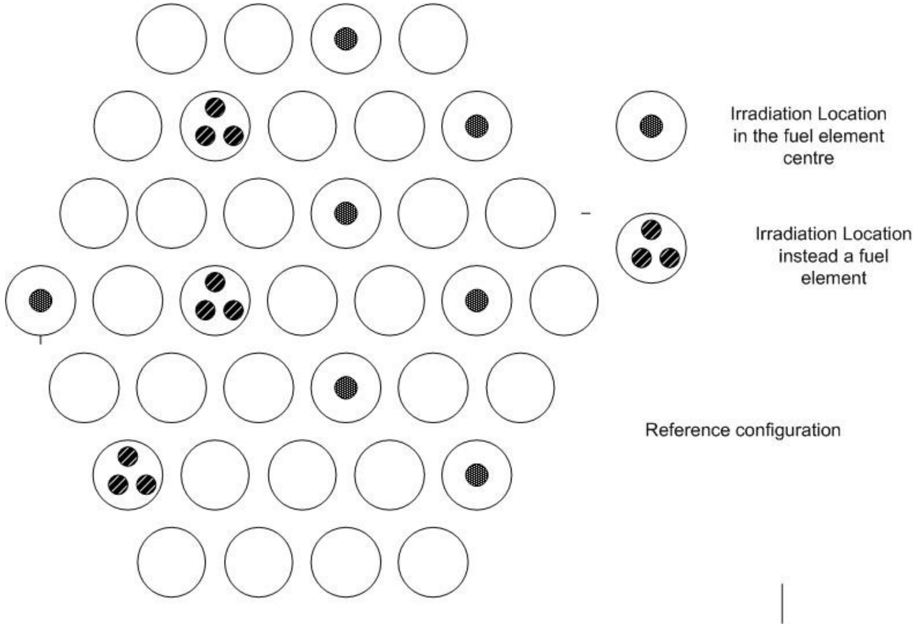
- At fuel element centre:
  - minimal diameter 32 mm in the core
  - 37 mm from 300 mm above the fissile material
  - 120 mm at the reactor vessel lid level
- 3 locations can accommodate 140 mm diameter device from 300 mm above the fissile material

Minimal slot size 90 mm (dia.) to meet irradiation device accommodation requirements

Reference Core volume definition

- **Core volume / number of slots**
  - **Interaction between irradiation devices**
  - **Number of devices to accommodate**



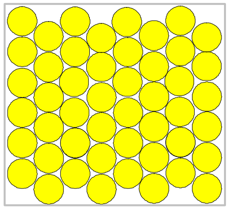


Accommodation requirements lead to 37 slots for the reference core configuration

Core shape

Core shape

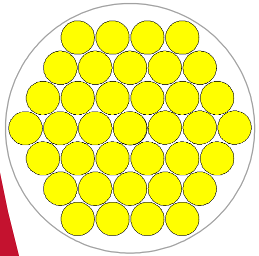
Rectangular



- 20 kg U_{235}
- 29 EFPD
- Max fast flux 6.3 10^{14} $n/cm^2/s$

hexagonal

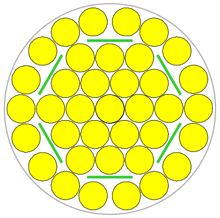
Regular shape



- 27 kg U_{235}
- 66 EFPD
- Max fast flux 5.3 10^{14} n/cm2/s

Irregular shape

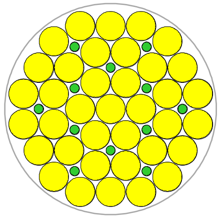
Version 1



- 27 kg U_{235}
- 52 EFPD
- Max. fast flux 5.5 10^{14} n/cm2/s

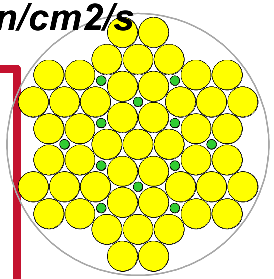
Version 2 : Daisy shape

37slots

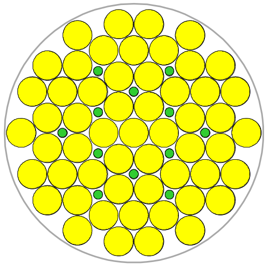


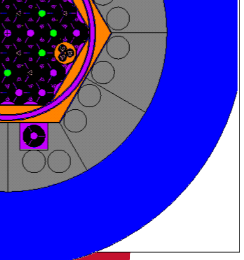
- 27 kg U_{235}
- 59 EFPD
- Max fast flux 5.2 10^{14} n/cm2/s

49 slots

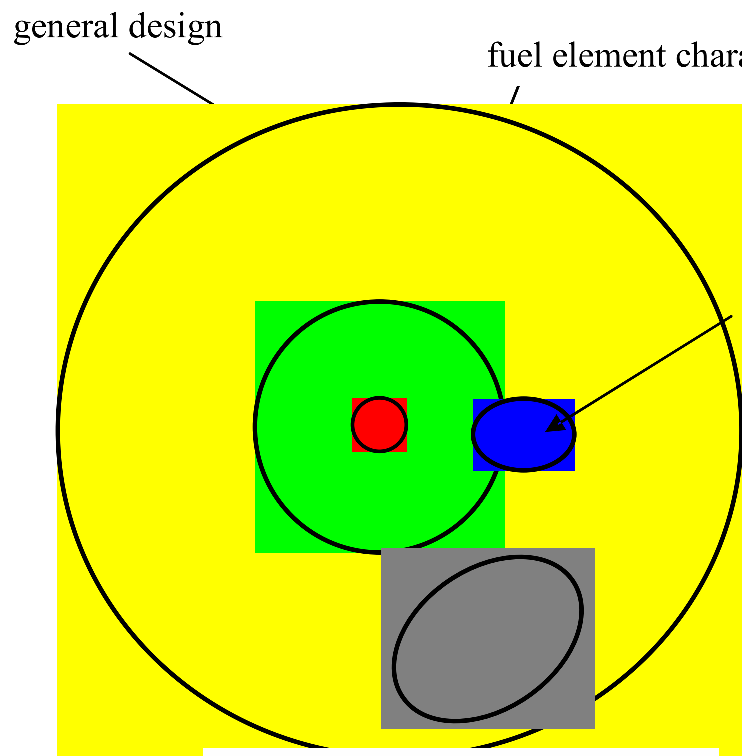


55 slots

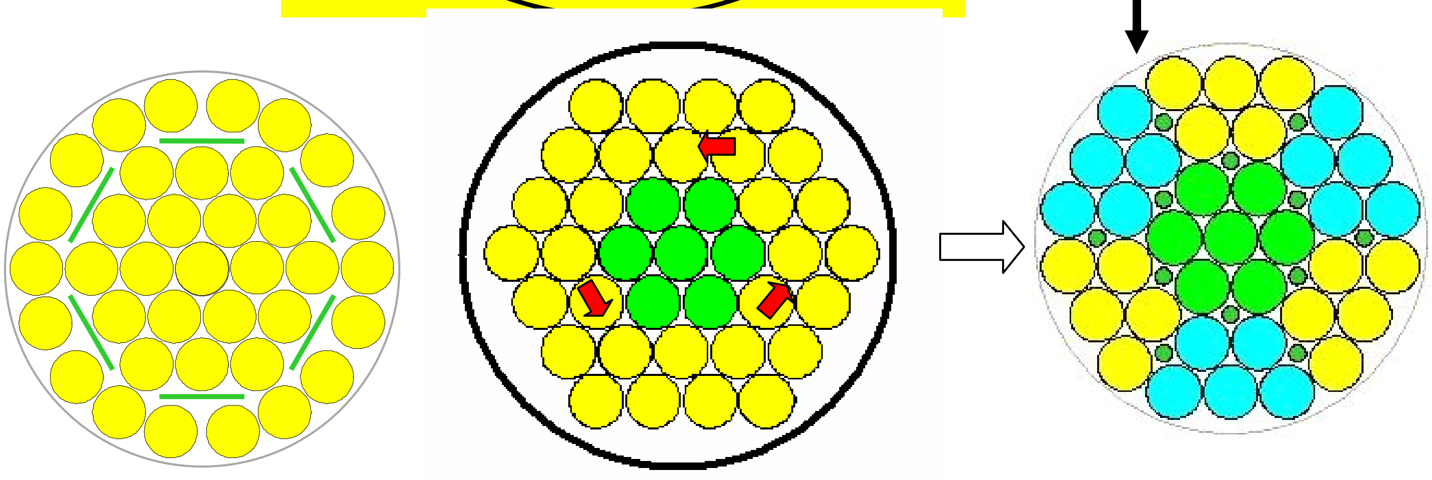




Core shape & power ramp performance

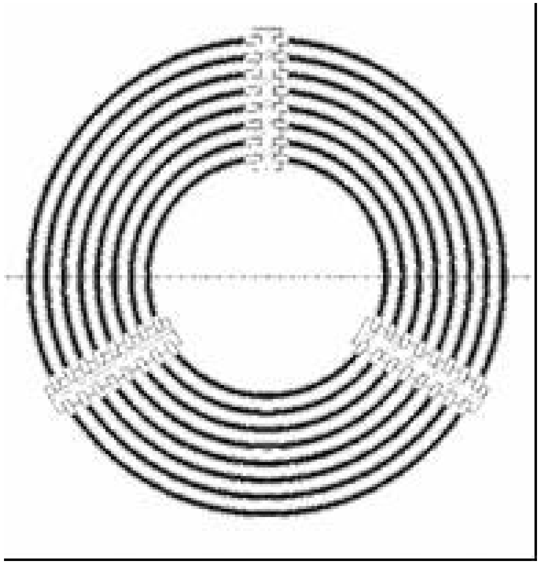


- Selected shape:
- 2 Fuel elements as close as possible to the core vessel



Design selection for the fuel element and the core pitch

- In core fast flux performance and cycle duration requirement lead to a minimal fuel pitch
- 8 plate elements and a 1.84 mm fuel pitch were retained
- High density LEU fuel is required



Hot channel thermal hydraulic studies: input data

- **Uncertainties for Programs and Modeling Methods :**
  - Maximum 3D power factor: 2.9
  - Maximum 2D power factor for a track (including local fuel mass heterogeneity): 2.52
  - Modeling uncertainties: (Heat transfer coefficient uncertainty, wall superheat, wall friction under flux)
- **Manufacturing tolerances:**
  - local fuel mass heterogeneity along a track, local fuel mass heterogeneity,
  - fuel channel geometry
- **Operating tolerances:**
  - water inlet temperature,
  - Core power 100 MW taking account of uncertainties and variation range during operation
  - Hot channel underfeeding
  - Uncertainties on the primary flow and variation range during operation:
- **Characteristic evolution under irradiation:**
  - Channel Reduction (oxide layer, swelling)

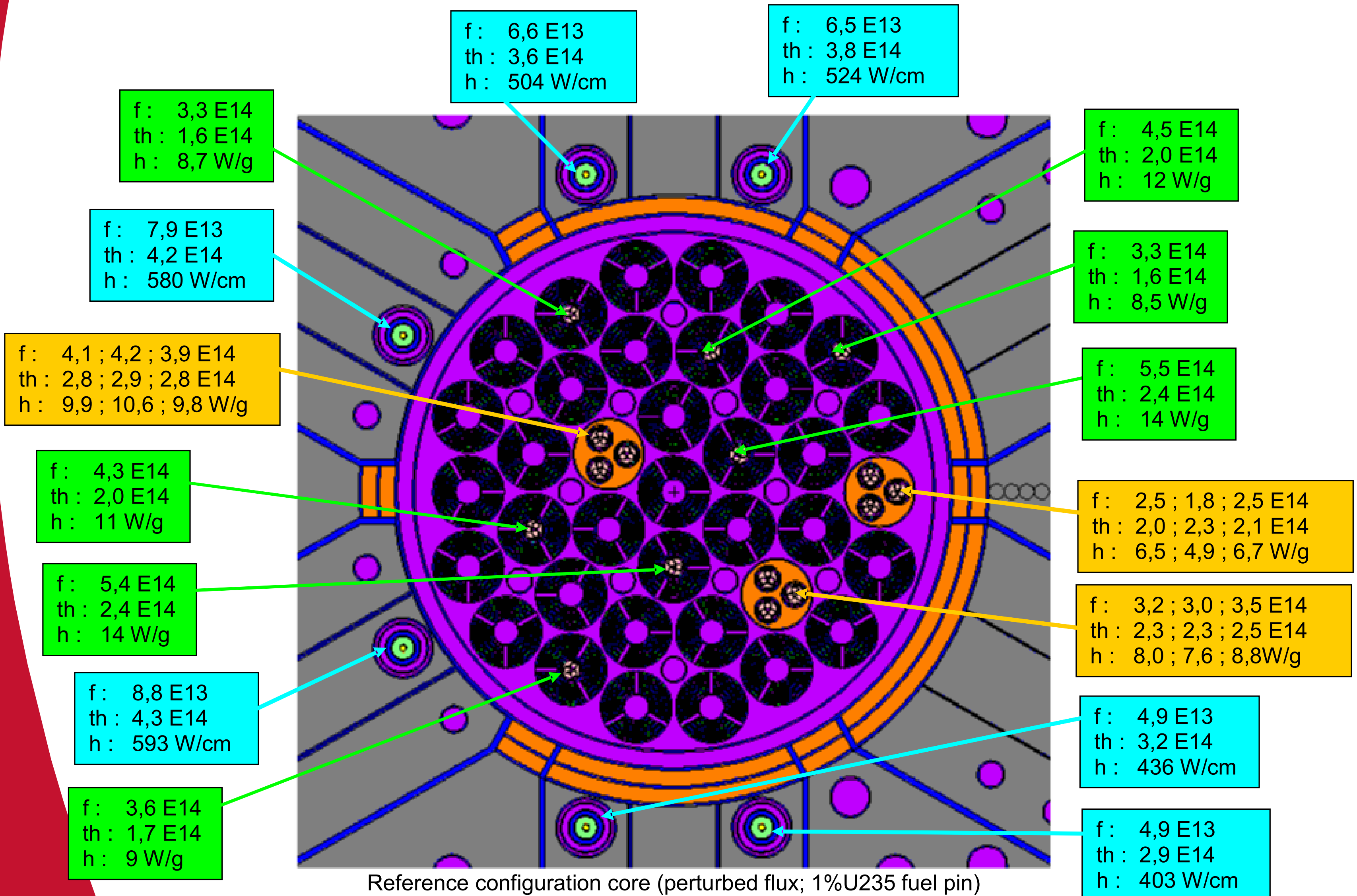
- **Maximum 3D power factor: namely 3.37 (about 550 W/cm2)**
- **Minimal hot channel gap: 1.55 mm**

Hot channel thermal hydraulic studies

- **Criteria:**
  - **SF1 (normal operating conditions)**
    - **T cladding ≤ 140°C , No nucleated boiling**
  - **SF2 (incidental conditions)**
    - **Tmax fuel < 515°C , No nucleated boiling**
  - **SF3 (rare accidental conditions)**
    - **T max fuel < 515°C , T max cladding < 400°C , No flow redistribution**
  - **SF4 (hypothetical accidental conditions)**
    - **T max cladding < 645°C , No flow redistribution**
- **Selected postulated initiating events :**
  - **Loss of primary flow accident, loss of power supply, black-out and transition to natural convection,**
  - **Partial or total loss of secondary flow,**
  - **Break diameter of 200 mm in the core coolant system in pool, break diameter of 100 mm in shielded compartment, break diameter of 600 mm**
  - **Reactivity injections (prompt jumps and ramps).**

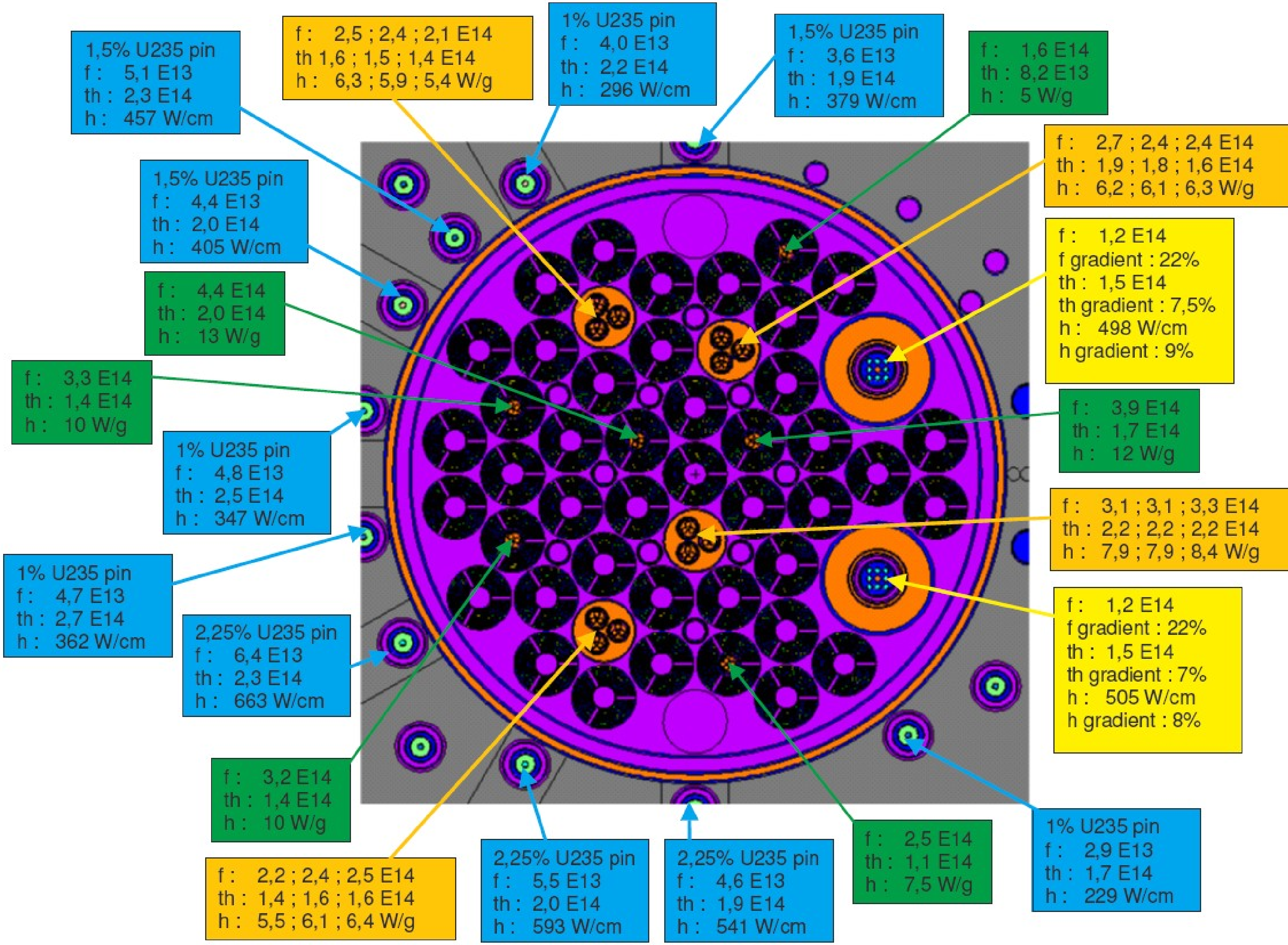
The retained primary flow rate is 8500 m3/h

Characteristics and performances achieved
Reference configuration



Reference configuration core (perturbed flux; 1%U235 fuel pin)
f : fast flux (>0,907 MeV)
t: thermal flux (<0,625 eV)

Characteristics and performances achieved
Large configuration



Conclusion

- In conclusion, the existing definition of the RJH reactor results in:
  - Cores and associated systems achieving high performances for devices (fluxes and irradiation location characteristics)
  - A large and versatile reflector
  - A versatile general design allowing a reactor configuration change,
- Safety studies associated with this reactor cover the U-Mo fuel with a U235 20% enrichment and the back up option for JHR start-up: U3Si2 fuel with a U235 27% enrichment.
- This has been possible thanks to:
  - Many technical exchanges between the prime contractor (AREVA, EDF) and the client (CEA),
  - An integrated team organization within the prime contractor, suitable for the context of the RJH design studies,
  - an important volume of work (50 man - year),
  - Pragmatic use of computer programs combining stochastic programs and deterministic programs for neutronics,
  - Involvement of a manufacturer for the future fuel for relevant purposes.