Developing Irradiation Devices for Fuel Experiments in the Jules HOROWITZ Reactor

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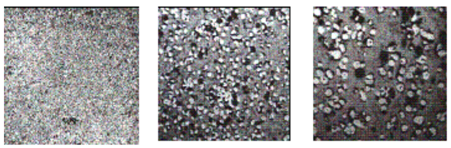
Outline

- Introduction
- Steps required to qualify nuclear fuels in a MTR
- JHR fuel irradiation device studies
  - Examples of fuel irradiation device studies
    - ✓ *A major possibility: the displacement system*
    - ✓ *PWR loop for fuel rod cluster*
    - ✓ *V/HTR capsule*
    - ✓ *GCFR capsule*
- Conclusion

Introduction

Development and Qualification
of a power reactor nuclear fuel

Basis concept → **Licensing**

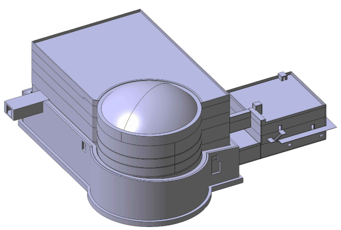


Manufacturing ↔ **Irradiations in MTRs**

R and D

Mechanistic modeling

Operational challenges + Scientific approach



JHR fuel experimental capability designed within international collaboration

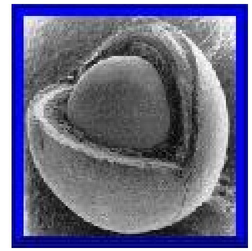
✓ Joint development of new innovative experimental devices : E.U. 6th FP JHR-CA

✓ International Advisory Group (OECD)

✓ Bilateral contacts with industry

Main steps required to qualify nuclear fuels in MTR

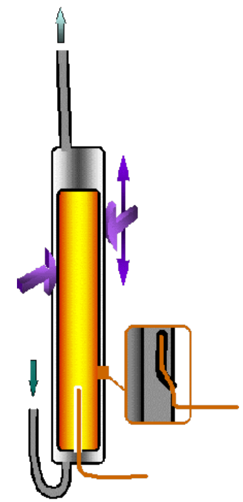
1. Selection irradiations



- Choose a few number of materials fulfilling given needs among a lot of candidates

Normal operation

2. Characterization and understanding irradiations



- Gain data on material properties controlling fuel behavior
- Build-up fuel behavior models

Operational limits

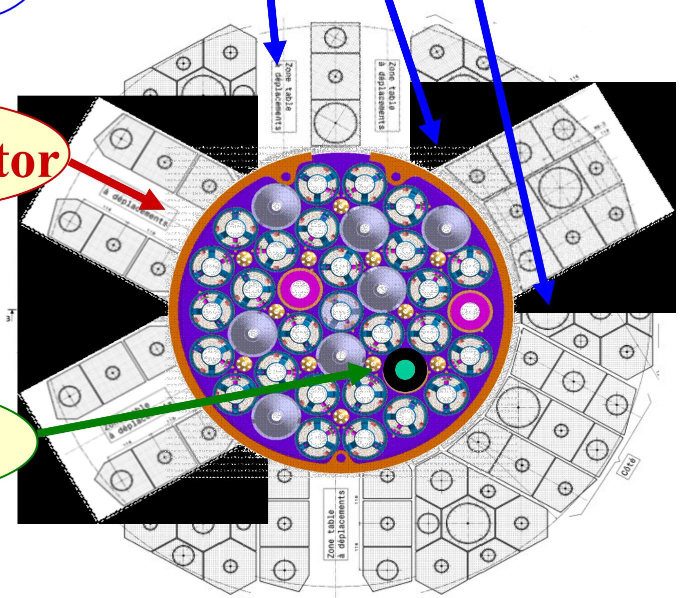
3. Irradiations in support to the in-power reactor qualification program

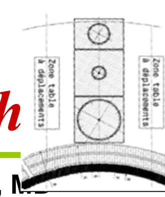
- Check fuel behavior in all potential situations
- Verify that the final product (rod,…) behavior is satisfactory

Off-normal conditions

JHR fuel irradiation device studies

- Light Water Reactors
  - ✓ Rig for accelerated cooking of a batch of samples
  - ✓ PWR/BWR boiling capsules for single rod
  - ✓ PWR loop for single rod
  - ✓ PWR loop for rod cluster
  - ✓ Rigs for RIA, LOCA separate effect tests
- (Very) High Temperature Reactors
  - ✓ Loop (up to 800-900°C)
  - ✓ Capsule for compact-type stack (> 800°C)
- Gas Cooled Fast Reactors
  - ✓ Gas rig or loop for plate-type fuel
- Sodium Fast Reactors, Naval Propulsion,…

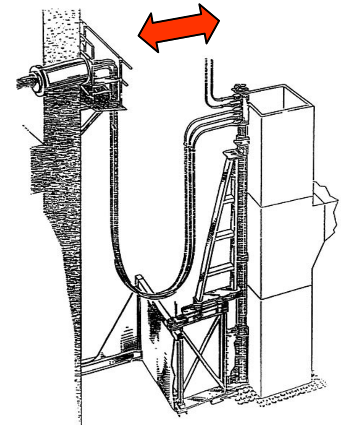




List and associated development level can evolve depending on th s

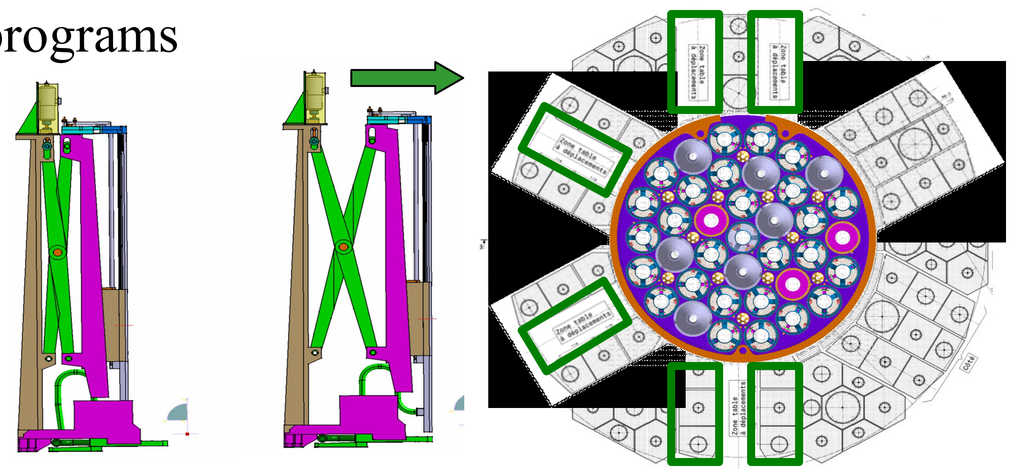
A JHR key feature: The displacement system

- Possibility to
  - ✓ Vary the fuel linear power (LHGR) by adjustment of the device-core distance
  - ✓ Control easily the power variation rate
  - ✓ Have a rear position at very low LHGR



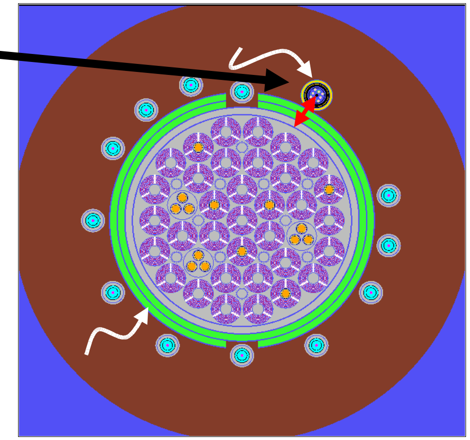
- Takes profit from the huge experience feedback in Osiris
  - ✓ Isabelle 1…. → **Ramp tests**, Power cycling…
  - ✓ Acknowledged by a panel of experts *(CEA-EDF-FRAMATOME ANP)* as a reference facility for ramp programs

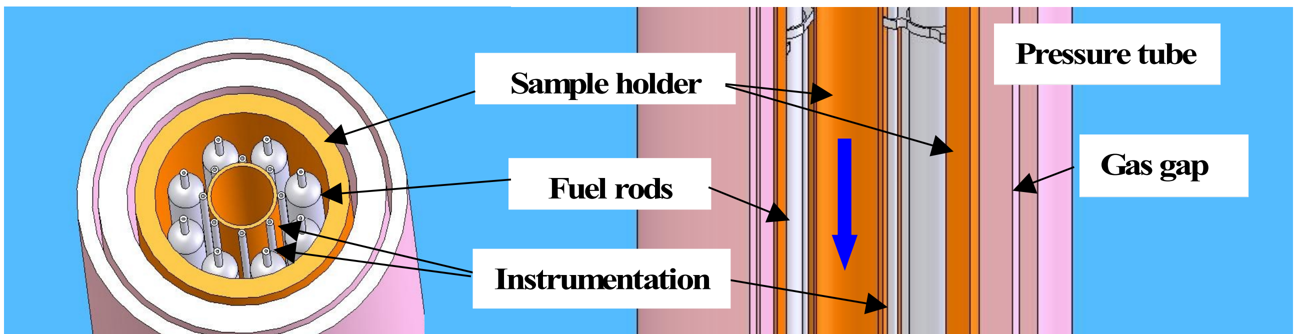
Will be the reference system for fuel experiment conducting in JHR



C4m: A loop for PWR rod cluster (1/2)

- Irradiation of 6 to 8 rods in the same PWR conditions
  - ✓ Comparative characterization of fuel microstructures (e.g. end-of-life behavior)
  - ✓ Fissile length up to 60 cm
  - ✓ Instrumented rods (central temperature, internal pressure, gas sweeping minitubes)





Mean linear power per rod	400 W/cm
Gamma heating (Zirconium alloy)	3.75 W/g
Fissile length	60 cm
Axial shape factor (max./mean)	1.25
Inlet coolant mass flow rate	2.5 kg/s
Inlet/outlet coolant temperature	300 / 320 °C
Cladding temperature	344 °C

Loop design can evolve depending on the needs

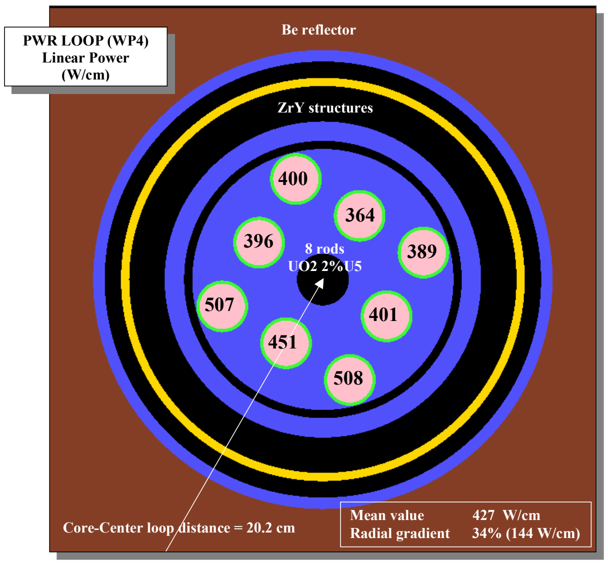
C4m: A loop for PWR rod cluster (2/2)

C4m challenging specifications

- ✓ Mean LHGR range: 200 – 400 W/cm
- ✓ Maximum LHGR gradient in the cluster < 10 %

Compatible with a fixed position ?

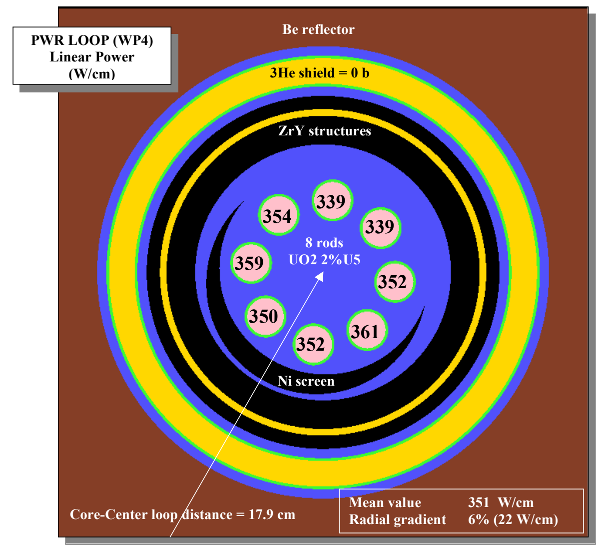
Examples of neutronic calculations results (TRIPOLI 4 code)



2% ^{235}U UO_2 rods

Zy alloy pressure tubes

Power variations reproduced by ^{3}He screen



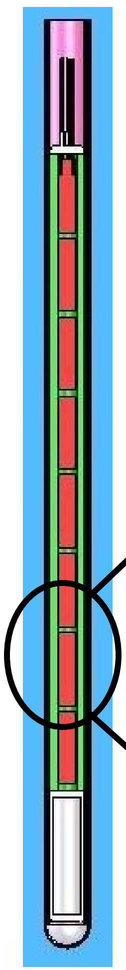
Square lattice
Mean LHGR: 430 W/cm
Power gradient not satisfying: **34%**

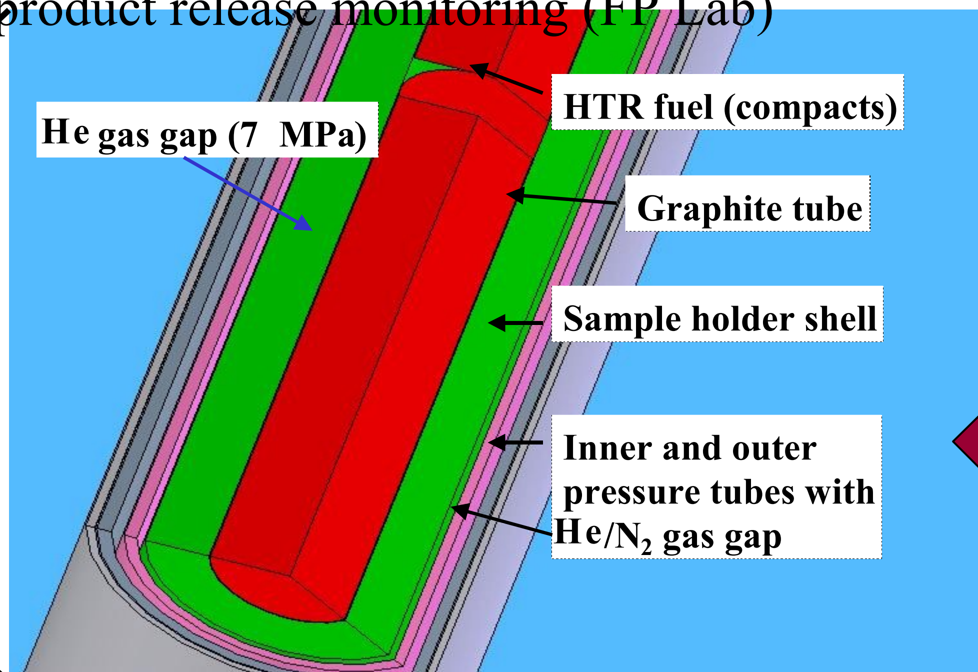
Ring shaped cluster
+ crescent-shape neutronic screen
Mean LHGR: 350 W/cm
Power gradient meets specifications: **6%**

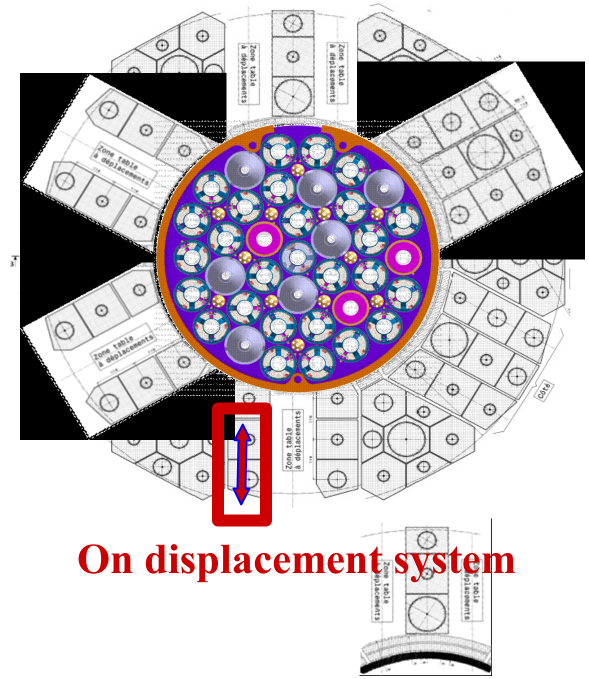
C4g: A gas rig for V/HTR conditions (1/2)

Irradiation of a compact stack (V/HTR)

- ✓ Characterization and qualification experiments
- ✓ 8 compacts stack (40 cm) in a capsule
- ✓ Statistical approach (2 devices/displacement system)
- ✓ Central temperature : 900-1400°C (nominal)
- ✓ Fission product release monitoring (FP Lab)







Temperature decrease controlled by gas gaps

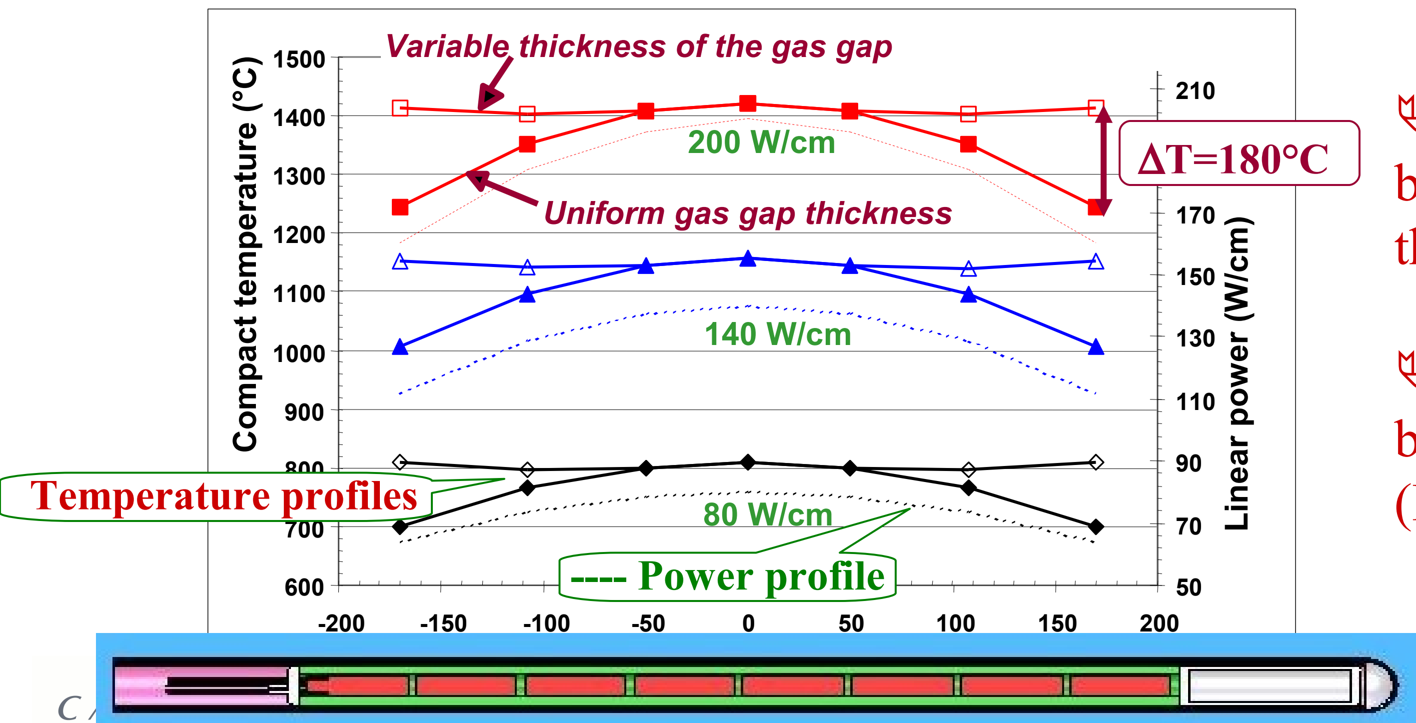
C4g: A gas rig for V/HTR conditions (2/2)

C4g challenging specifications

- ✓ Flat axial temperature distribution
- ✓ Large range of LHGR: 60-200 W/cm
- ✓ Power discrepancy between compacts : 5 %
- ✓ Very soft neutronic spectrum (fast/thermal # 0,5)

Necessity to adapt locally the irradiation conditions

Thermal calculations results



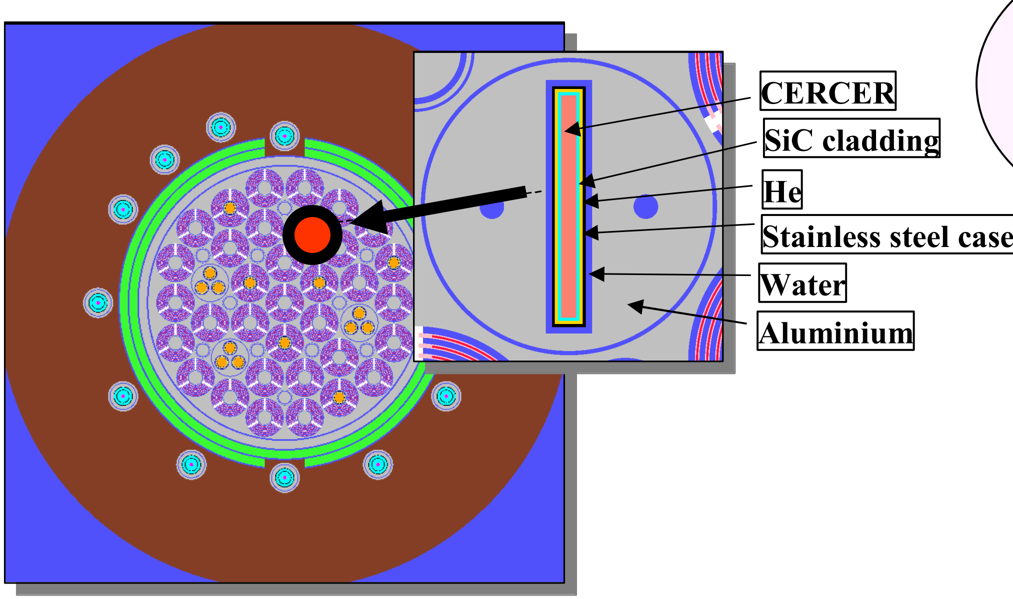
Axial temperature flattened by a variable outer gas gap thickness

Sample temperature adjusted by gas outer gap composition (He -> N_2 => ΔT = + 80°C)

A gas rig for Gen IV/GFR fuel plate test

Preliminary neutronic performance assessment

CERCER: (UPu)C in a SiC matrix



In place of a JHR fuel element

GFR objectives:
250 W/cm³
0,04 dpa/EFPD

Best design:
5% Pu +
1 mm Cd + 3 mm Hf screens
~ 400 W/cm³
0,03 dpa/EFPD

Preliminary results show that:

- Local irradiation conditions are close to GFR objectives
- SiC damages can be enhanced by irradiation location optimization
- Design will be optimized after thermal-hydraulical assessment

JHR may be a useful facility for GFR material science

Conclusions

- **Design of a new generation of fuel devices answering sustainable energy needs based on**
  - ✓ **Anticipated end-users and scientific people needs**
  - ✓ **Identified irradiation scenarios offering challenging specifications and demanding inter-cycle operations**

- **Synthesis of the design studies**
  - ✓ **Presented results are a first exploratory work (JHR definition phase)**
  - ✓ **Fulfilling a large range of irradiation specifications by local adaptation of environmental conditions (LHGR, neutronic spectrum, temperature,…)**

- **Technological development of devices or components from 2006**
  - ✓ **Importance of the European Union collaboration (6th FP "MTR+")**
  - ✓ **Work is wide open to the international collaboration**