DE LA RECHERCHE À L'INDUSTRIE

The Jules Horowitz Research Reactor

Experimental devices and first orientations for the experimental programs

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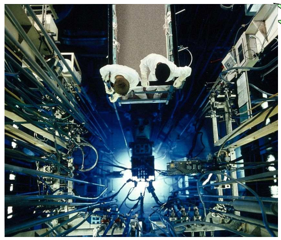
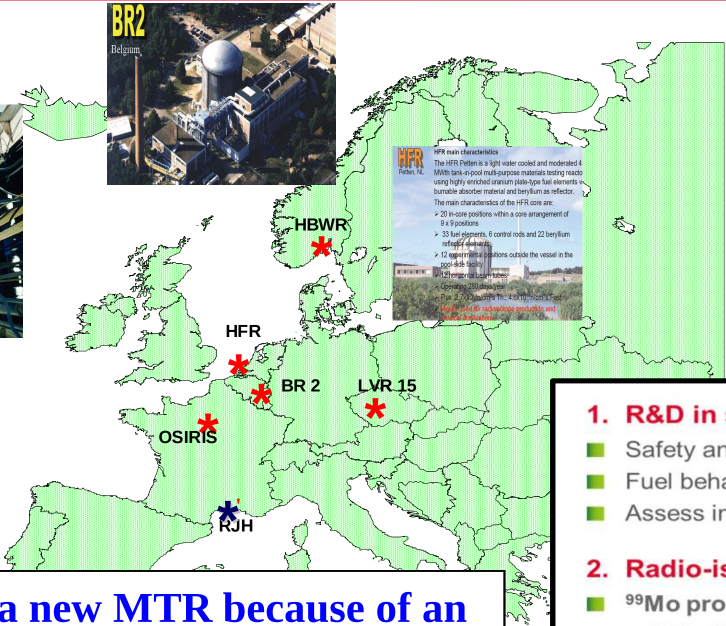
Jules Horowitz
1921-1995
Pioneer and leading expert in nuclear physic

www.cea.fr

Jules Horwitz Reactor: The CONTEXT



OSIRIS

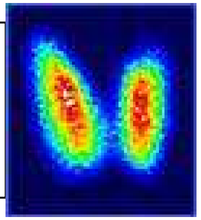


* under construction

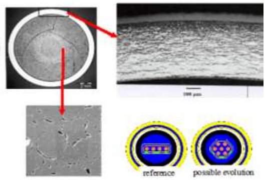
The needs of a new brand MTR for R&D in support to industry and regulators linked to the evolution of nuclear energy:
Plant life time extension of GII reactors
Surge of GIII reactors
Preparation of GIV technology

The need of a new MTR because of an ageing fleet of MTR in Europe (with old safety standards)

The complementary needs: Medical applications (99Mo-99Tc / scintigraphy)



1. **R&D in support to nuclear Industry**
   - Safety and Plant life time management (ageing & new plants)
   - Fuel behavior validation in incidental and accidental situation
   - Assess innovations and related safety for future NPPs



2. **Radio-isotopes supply for medical application**
   - **^{99}Mo production**

     - JHR will supply 25% of the European demand (today about 8 millions protocols/year)

     -Up to 50% upon specific request

See the presentation dedicated to the Moly production in JHR

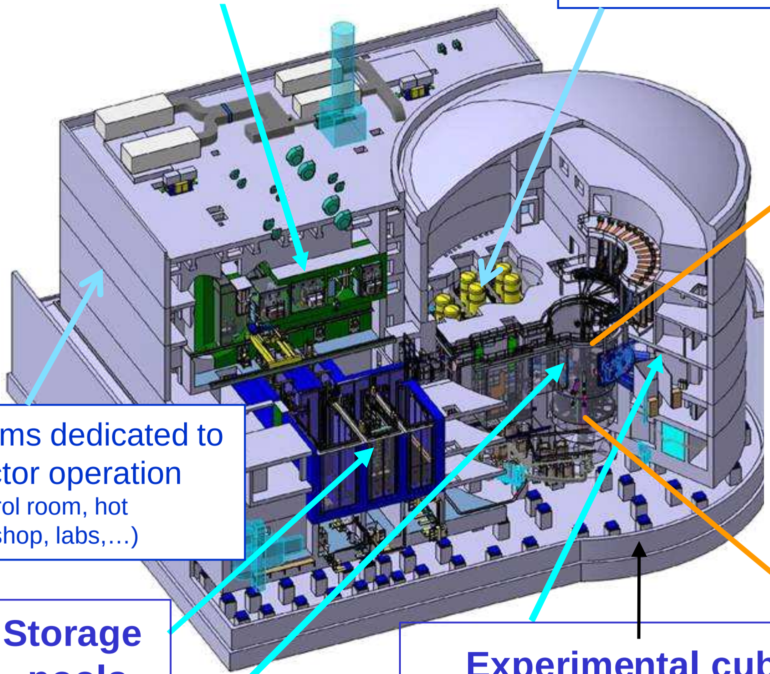
3. **A key tool to support expertise**
   - Training new generations (JHR simulator, secondees program)
   - Maintaining a national expertise staff and credibility for public acceptance
   - **Assessing safety requirements evolution and international regulation harmonization**

Context (needs and safety standards) => specific technical choices for the JHR

JHR general design : a 100MWth pool type light water MTR optimized for fuel and material testing

Hot cells (non destructive examinations)

Rooms dedicated to reactor operation
(heat exchangers, primary pumps, safety systems,…)



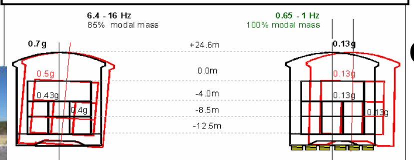
Rooms dedicated to reactor operation
(control room, hot workshop, labs,…)

Storage pools

Reactor pool with examination benches

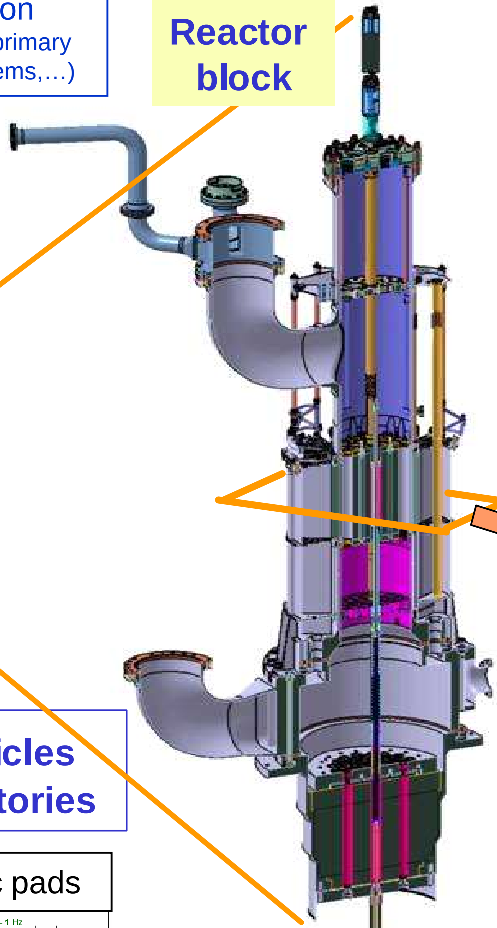
Experimental cubicles and analysis laboratories

About 200 aseismic pads

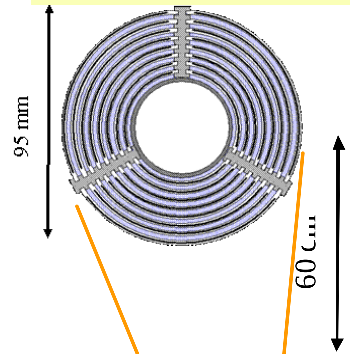


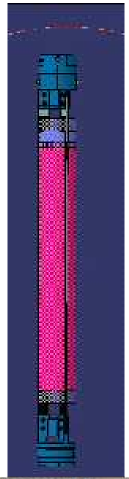
BR : Φ 37m H 45m
BAN : 51x47m H 35m
Pool : Φ 7m H 12m

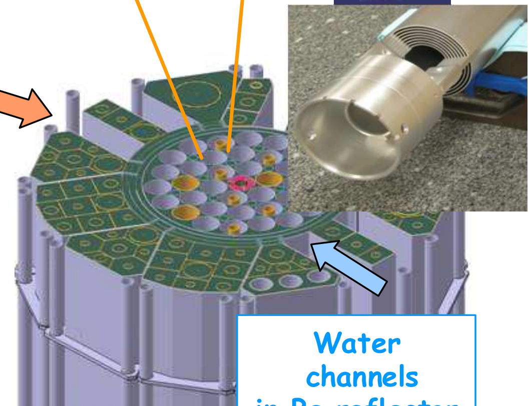
Reactor block



JHR fuel element







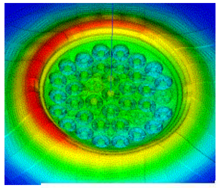
Water channels in Be reflector

Core (Φ 70cm / h 60 cm) and Be reflector

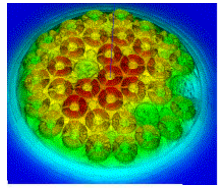
Core Designed for UMo-Al fuel
Start-up with U_3Si_2-Al fuel
70 MWth / 100 MWth
25 to 30 days cycle length
6-7 days shutdown

JHR experimental capacity
general characteristics of the core

Thermal neutron flux



Fast neutron flux



The core is under moderated =>
high fast neutron flux in the core
and high thermal neutron flux in the reflector

~20 simultaneous experiments

In reflector

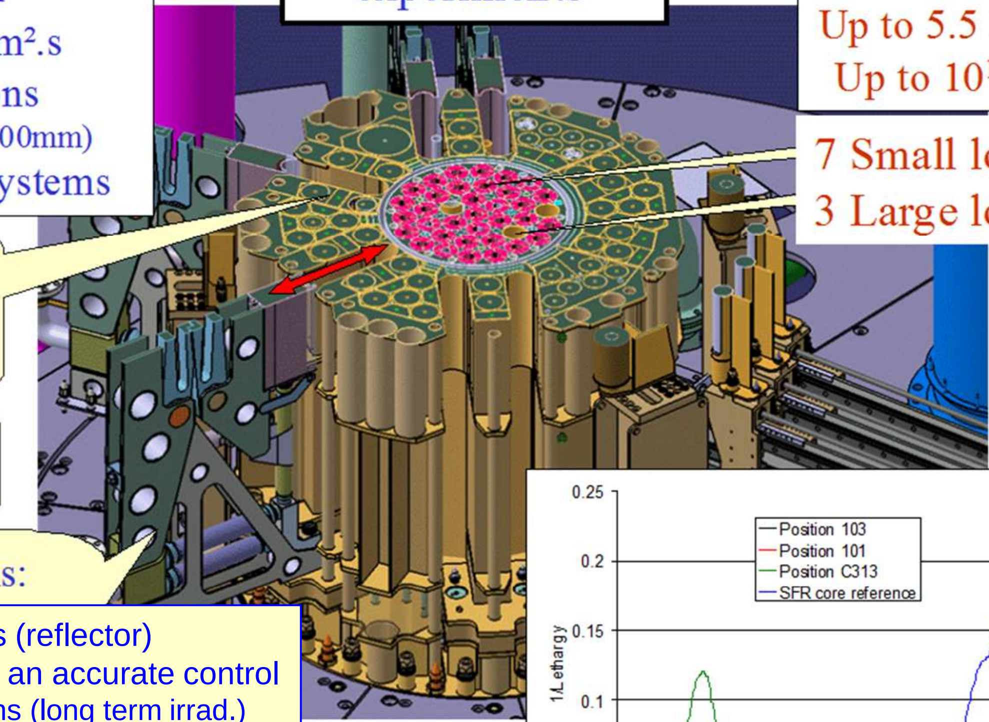
Up to 5.5 10^{14} n/cm².s
~20 fixed positions
(F 100mm ; 1 position F 200mm)
and 6 displacement systems

Fuel studies: up to 600 W/cm with a 1% ^{235}U PWR rod

Material ageing
(low ageing rate)

Displacement systems:

- Located in the water channels (reflector)
- Flexible power variations with an accurate control
  - Steady state conditions (long term irrad.)
  - Power cycling (load follow)
  - Power ramps (up to 700W/cm/s)
- Experiment decoupled from the core



In core

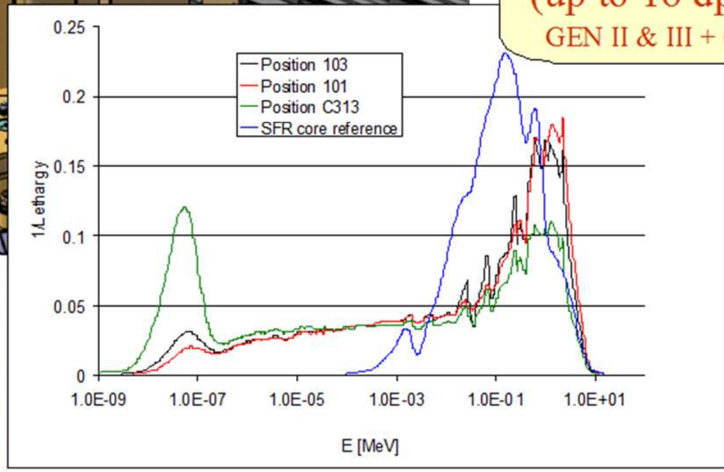
Up to 5.5 10^{14} n/cm².s > 1 MeV
Up to 10^{15} n/cm².s > 0.1 MeV

7 Small locations (F ~ 32 mm)
3 Large locations (F ~ 80 mm)

Fuel experiment
(fast neutron flux – GEN IV)

Material ageing
(up to 16 dpa/y)
GEN II & III + GEN IV

Core Designed for UMo-Al fuel
Start-up with U_3Si_2-Al fuel
70 MWth / 100 MWth
25 to 30 days cycle length
6-7 days shutdown

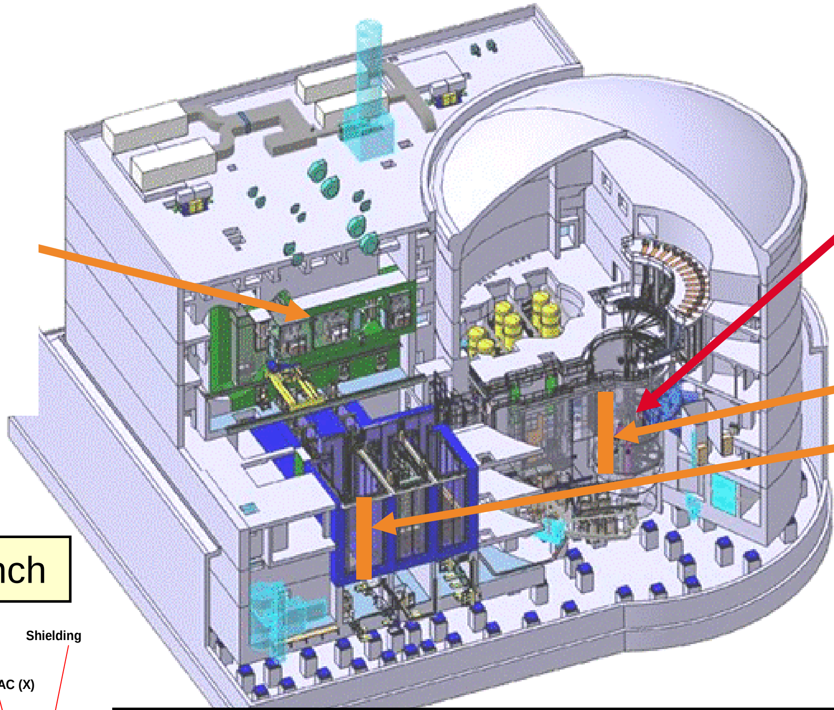


JHR facility & experimental capacity: the Non Destructive Examination Benches

Sample examination in hot cells

Gamma and X-Ray tomography systems

Multipurpose test benches



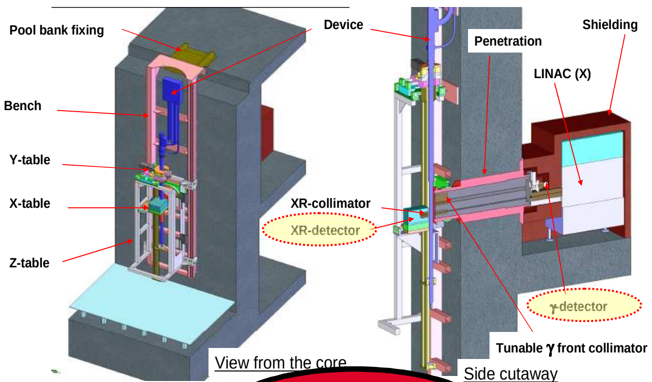
Test device examination in pools

Neutron imaging system in reactor pool

Coupled X-ray & γ bench in reactor pool

Coupled X-ray & γ bench in storage pool

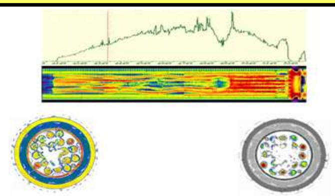
Coupled Gamma &X-ray bench

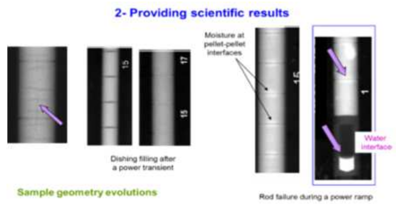


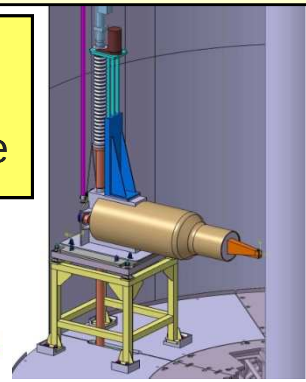
VTT
In-Kind

Neutron Imaging System

- Initial checks of the experimental loading
- Adjustment of the experimental protocol
- On-site NDE tests after the irradiation phase

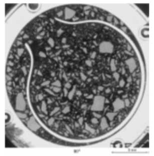


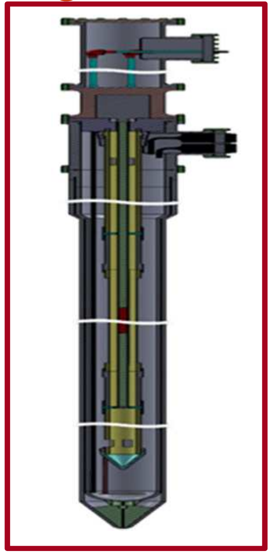




Hosting experimental systems (dedicated to LWR fuel testing)

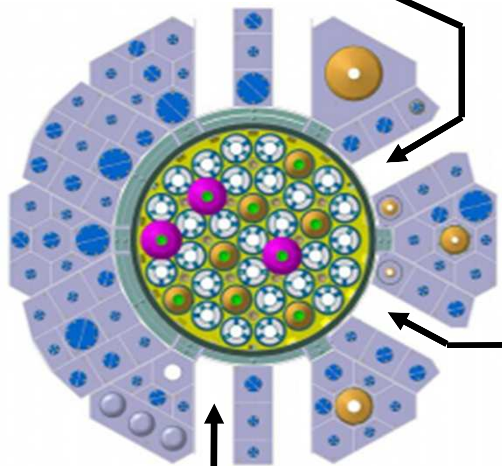
LORELEI fuel testing under accidental conditions (LOCA)





- Source Term (FP releases)
- Rod thermal-mechanical behaviour
  - ➢ Ballooning and clad burst (fuel relocation)
  - ➢ Corrosion at high temperature
  - ➢ Quenching and post-quench behaviour

IAEC In-Kind

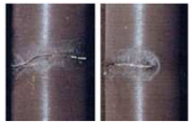


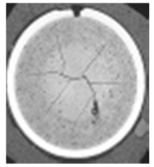
ADELINE

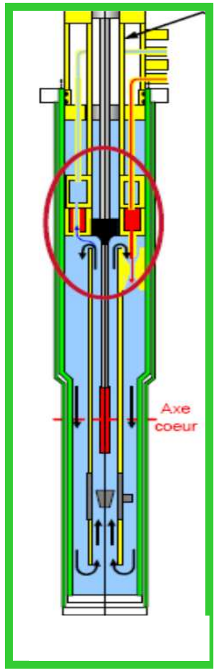
EDF Support

For fuel testing under off-normal conditions

Power transient (up to 620W/cm), post clad failure fuel behavior, Lift-off experiment…



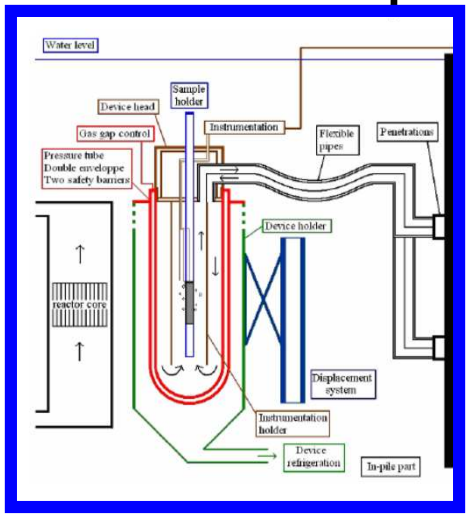


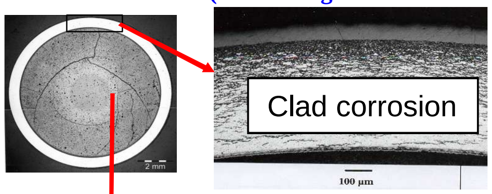


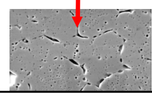
MADISON

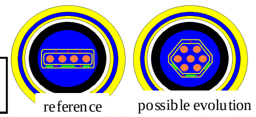
For fuel testing under nominal conditions (short / long term irradiations)

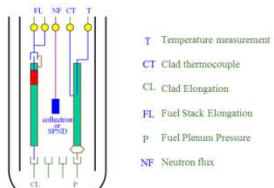
CEA Support

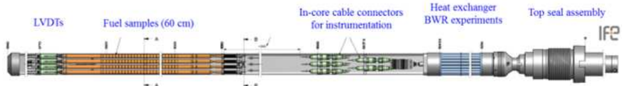








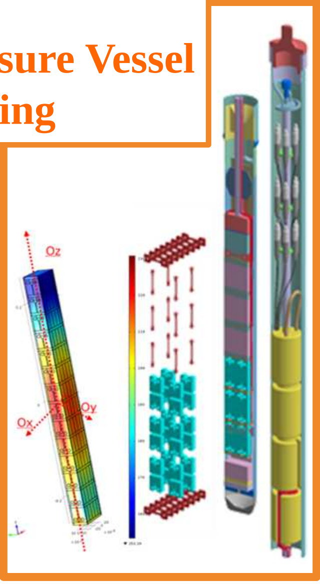


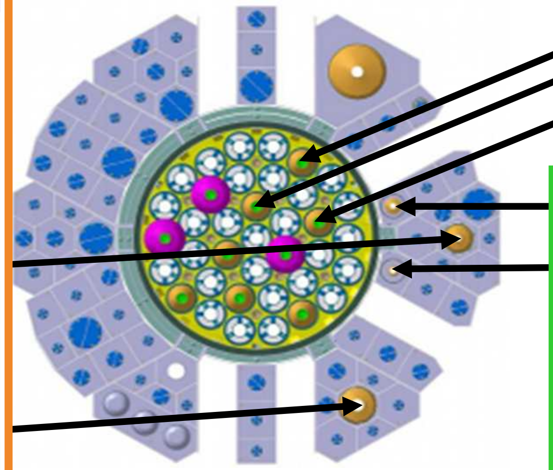


Hosting experimental systems (dedicated to LWR material testing)

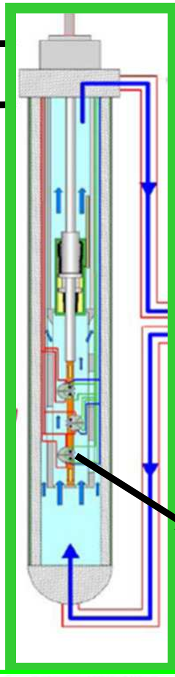
OCCITANE

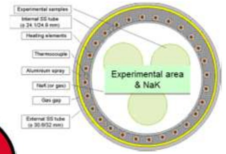
For pressure Vessel steel testing





CEA Support





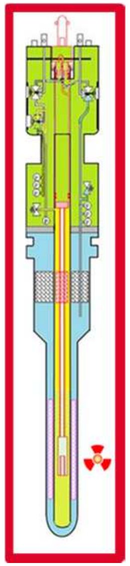
CALIPSO, MICA

For material testing

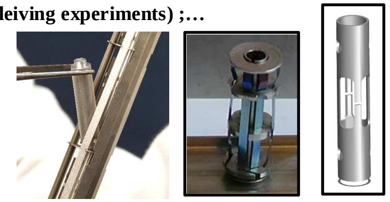
under high dpa (up to 16dpa/y)

and accurate temperature control

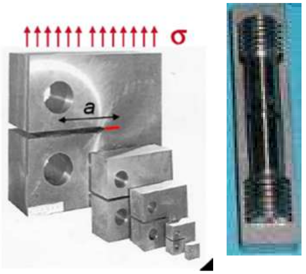
(+ mechanical loading)



specimen for µ structure evolution, tensile test ; for 1 or 2 D creep tests ; for bending tests (stress releiving experiments) ;…

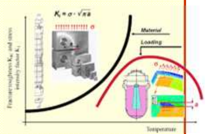


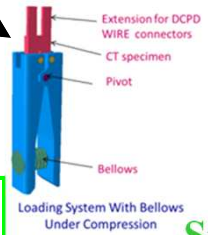
- Irradiated material behaviour
  - ✓ **tensile tests, resilience test (Charpy), crack propagation tests …..**
- -Behaviour of Thermal affected zones



CEA Support

- ✓ Equivalent carrying volume 30x62.5x500mm^3
- ✓ **Helium**
- ✓ **230 – 300°C**
- ✓ **100 mdpa/year**





CLOE Corrosion loop

for "Zr alloy Corrosion"

and "Irradiation Assisted Stress Corrosion Cracking"

(Water loop, 190 bar, 360°C, radiolysis, representative chemical conditions, samples under stress …)

DAE In-Kind

Réacteur Jules Horowitz Reactor

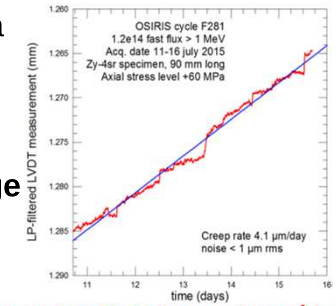
An example of sample holder designed for MICA test device
Melodie sample holder

MELODIE (MEchanical LOading Device for Irradiation Experiments) experiment performed in OSIRIS – 2015

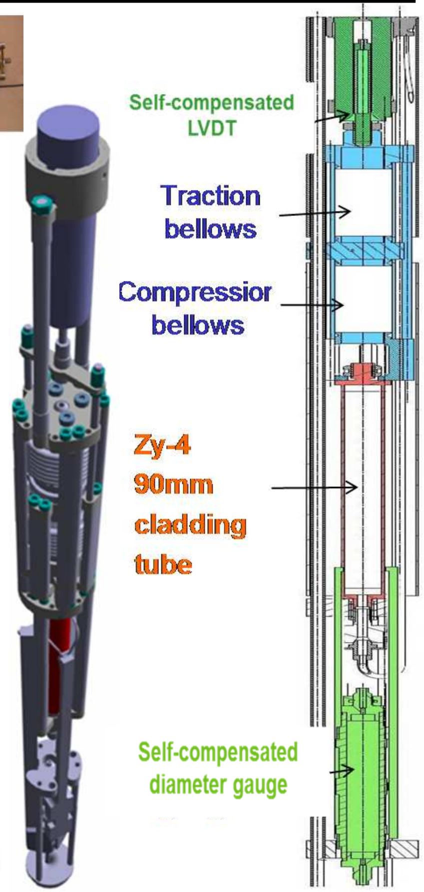
a challenging experiment … to prepare MICA instrumented rigs

Creep test with a bi-axial loading experimental device (controlled bi-axial load)
and an on-line bi-axial deformation measurement device (sample diameter and length)

- Technical goals
  - Study of LWR cladding 2D irradiation creep
  - 2D : anisotropic material, multiaxial stresses because of gas pressure and PCMI
- OSIRIS environment
  - Sample holder in a CHOUCA capsule similar to MICA
  - 350 °C, static NaK coolant
- Biaxial stress controlled in real time
  - Specimen pressurization →Max pressure 160 bar
  - Push-pull axial loading unit (biaxiality ratio : 0 to 1)
  - Hoop Stress limit: σ_Θ = 120 MPa, Axial stress limit: σ_z = 180 MPa
- Online biaxial measurement of creep strain
  - **Continuous measurement of axial strain with a 5-wire LVDT**
  - **Periodical measurement of hoop strain with a diameter gauge**
- Partnerships
  - Design and manufacturing of MELODIE : VTT
  - Self-compensated LVDT (axial + DG) : IFE



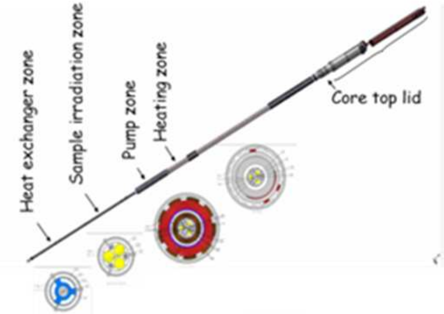
Creep rate @ 60 Mpa ≈ 4 µm/day
Creep rate @ 110 Mpa ≈ 8 µm/day

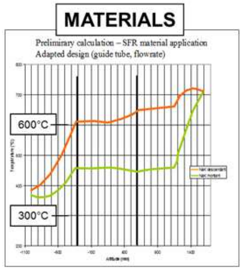


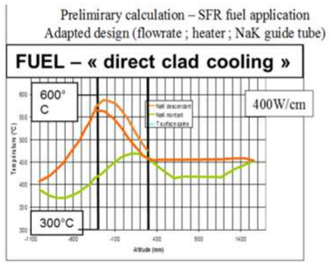
Towards GEN IV and the "FUSION technologies" (test devices under conceptual design)

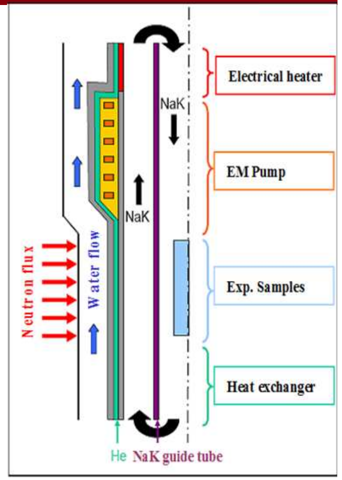
GEN IV (mainly SFR): adaptation of the Calipso test device

- → Material irradiation : adaptation for high temperature, up to 650°C
- → Fuel irradiation : In-core : long term irradiations (NaK- neutron filters)
  In-reflector : off-normal situations, power and flowrate transients (Na)



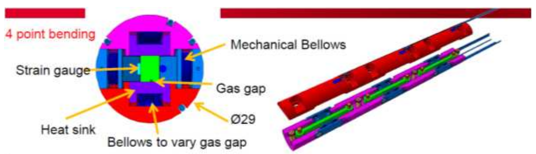


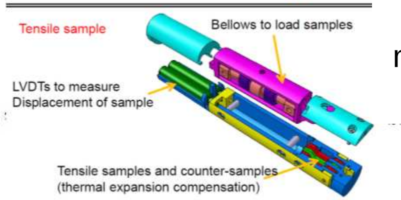




Fusion technologies : Inquiry about the needs => three conceptual designs (FUSERO test devices):

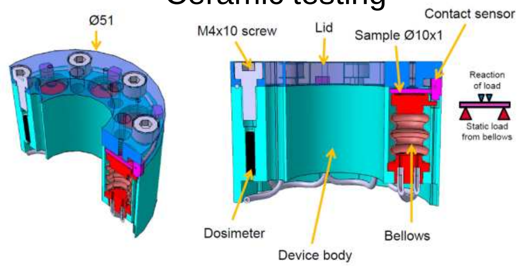
- → Thermo-Mechanical Fatigue testing: study of components submitted to both mechanical strain and thermal strain (from the breeding blanket to divertor tiles).
- → Ceramic testing (for diagnostic windows); samples bi-axially loaded, analysis of optical properties and sub-critical crack growth.
- → Cryogenic testing for the study of electrical and structural properties of superconducting magnet materials.





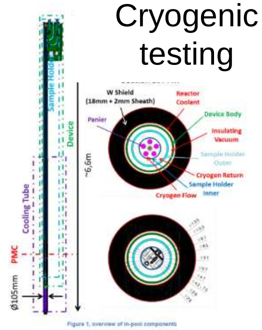
Thermo-mechanical fatigue

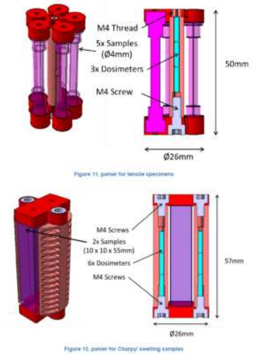
Ceramic testing



*current design with room in middle for shaft for optical stages, no longer needed

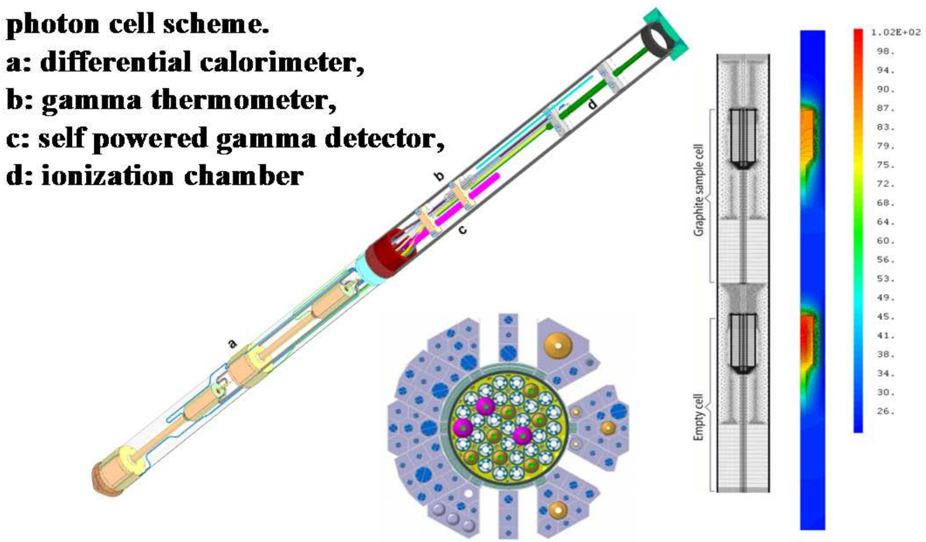
Cryogenic testing





Test Devices for « Start Up Tests »

Nuclear Heating Measurements in Material Testing Reactor



General objectives

-Verification of the performances of the facility

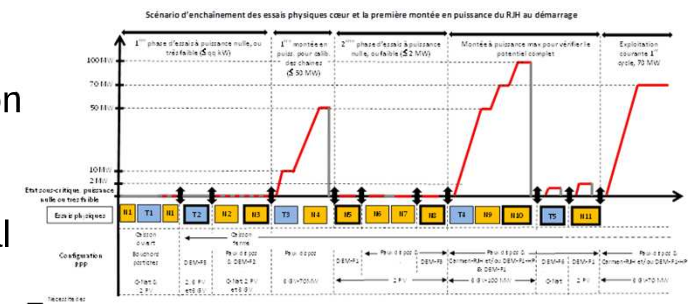
-Verification of the safety parameters

-Accurate determination of the experimental parameters
(a challenge: to be as accurate as the present MTRs which started to operate at least 40 years ago…)

Optimization of the strategy for the start-up tests (timing of the tests, accuracy, power level, reactor configuration,….)

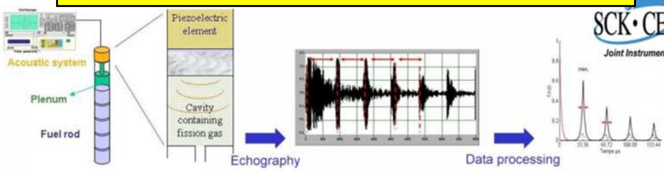
Analysis of the needs in terms of instrumentation

- Neutron flux and gamma heating mapping, neutron spectra
- fissile power, reactivity measurement, in core void effect evaluation
- THy (flowrate in experimental cavities, in core, in reflector ; core under free convection, ...)
- Devices dedicated to the thermal mapping of the reactor structural materials

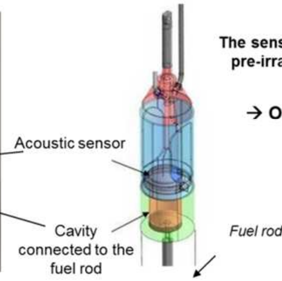


Examples of instrumentation developments

Measurement of Fission Gas Release By using an acoustic sensor

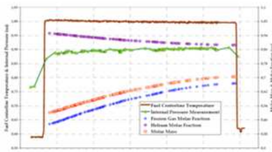


Online measurement of the **molar mass** of the gas inside the fuel rod (→ **fraction of released fission gas**)



The sensor is implemented on pre-irradiated PWR fuel rods

→ Operational in OSIRIS reactor since 2011 (REMORA-3 experiment)

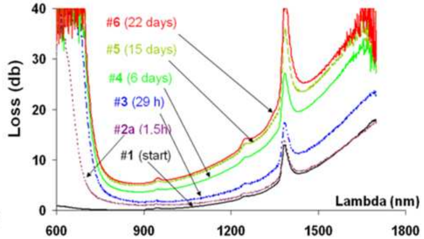


Measurement technics using optical fibers

Results of COSI experiment (2006-OSIRIS) : some optical fiber can endure intense neutron flux irradiation

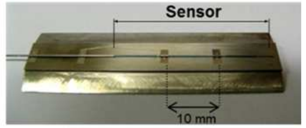
- *Favorable spectral region in the 800-1200 nm range*
- *Measured radio-induced losses < 10 dB*

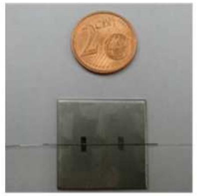
→ suitable multimode and single mode fibers exist for in-pile applications

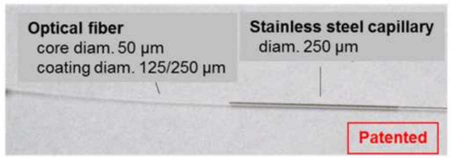


→ **Fiber-based extensometer** developed to measure the elongation of material samples (tested in BR2 reactor in 2009)

Major interests :
- Very compact sensor
- Low instrusivity
- High accuracy (< µm)



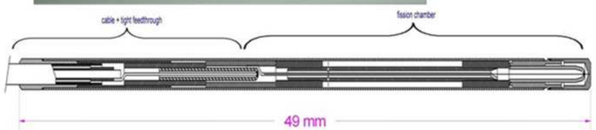




Sub-miniature fission chambers

Ionisation chambers with fissile deposit, external diameter down to 1,5mm, with integrated cable

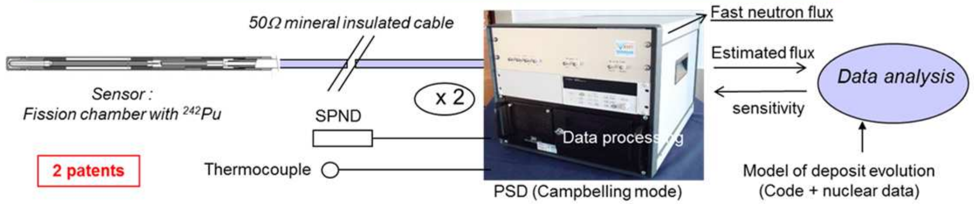
Developed and manufactured by CEA in Cadarache (U, Pu, Np, Am, Cm, Th deposits…)



→ Operational in MTR, ZPR, etc.

On-line Measurement of Fast neutron flux in MTRs

- Patented miniature fission chamber sensitive to fast neutrons (>1MeV - 242Pu deposit)
- Dual channel dedicated electronics and signal processing software
- Data analysis software for on-line extraction of the fast neutron flux even with a high thermal part

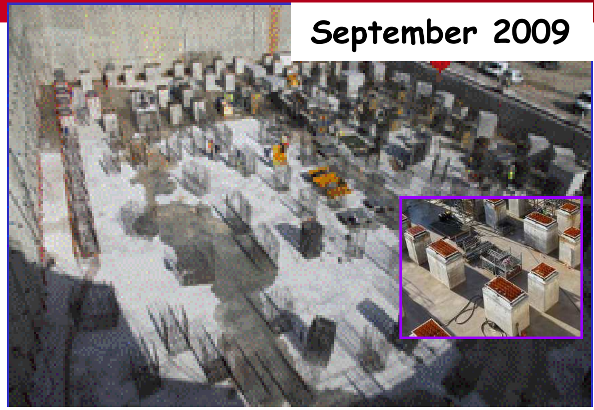


→Qualified in BR2 reactor in 2009, now operational

DE LA RECHERCHE À L'INDUSTRIE

Some milestones of the project – civil work


July 2007


September 2009


December 2010



Mid 2017

19/03/2007 Signature of the JHR consortium


July 2011 containment wall first pouring


January 2015


2015

Réacteur Jules Horowitz Reactor

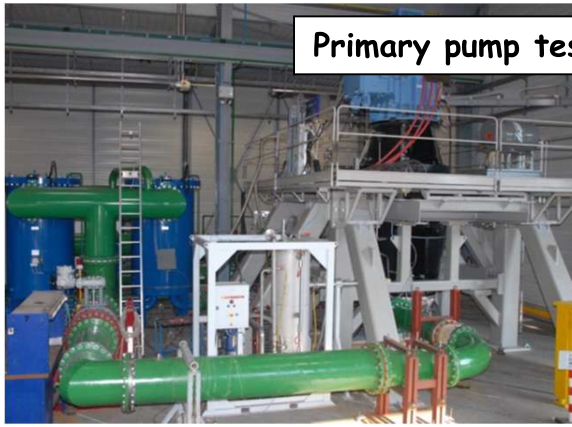

December 2013

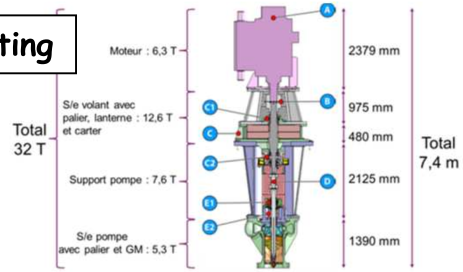

November 2012

Examples of some components manufacturing and testing

Polar crane testing nov 2014

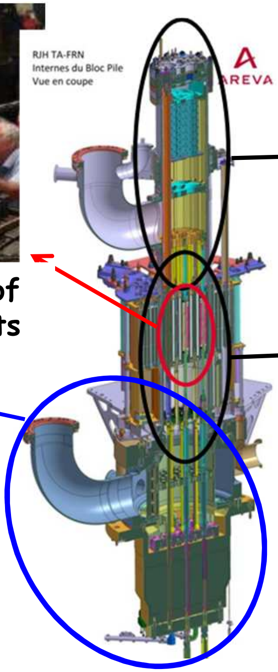
Primary pump testing



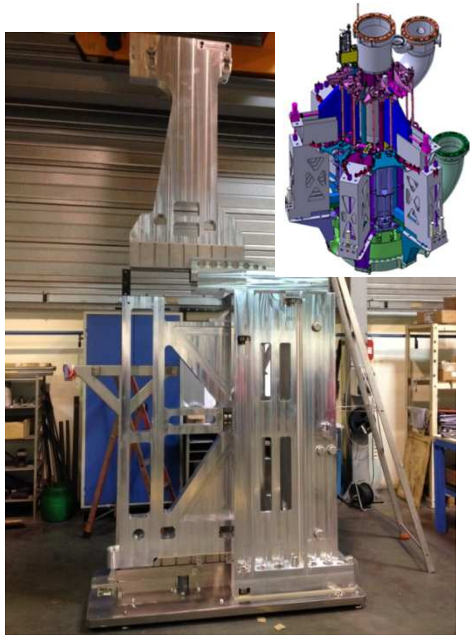


- Pression eau refoulement : 16,8 bar
- Débit nominal unitaire 2470 m³/h, total 7400 m³/h
- Temps de ralentissement : de 30 à 35 s à sur inertie propre pour obtenir le demi-débit
- Puissance moteur ~1,4 MW

Manufacturing of core components



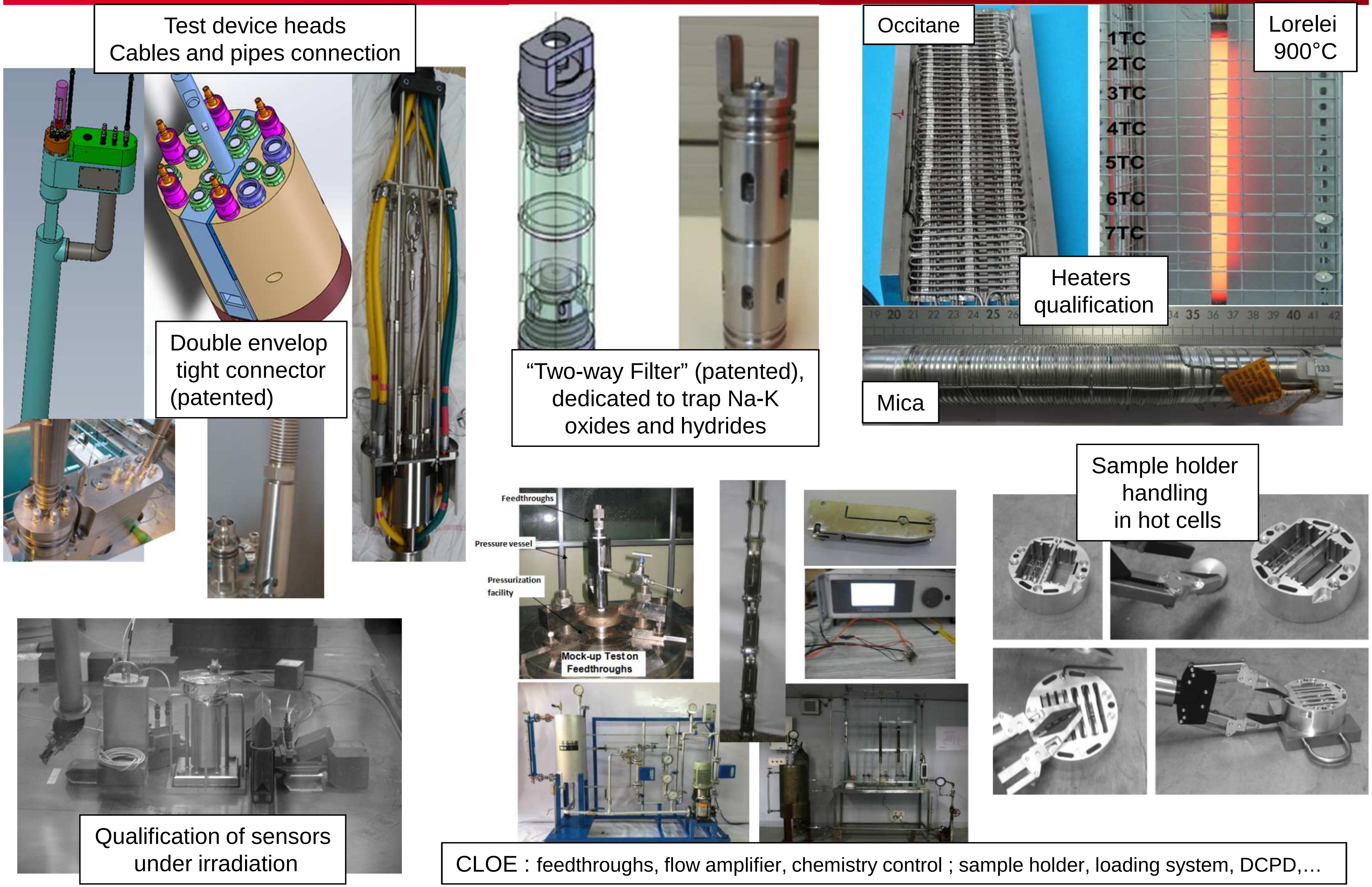
Heat exchangers (primary/secondary system)



Mock up of displacement system
Currently under testing

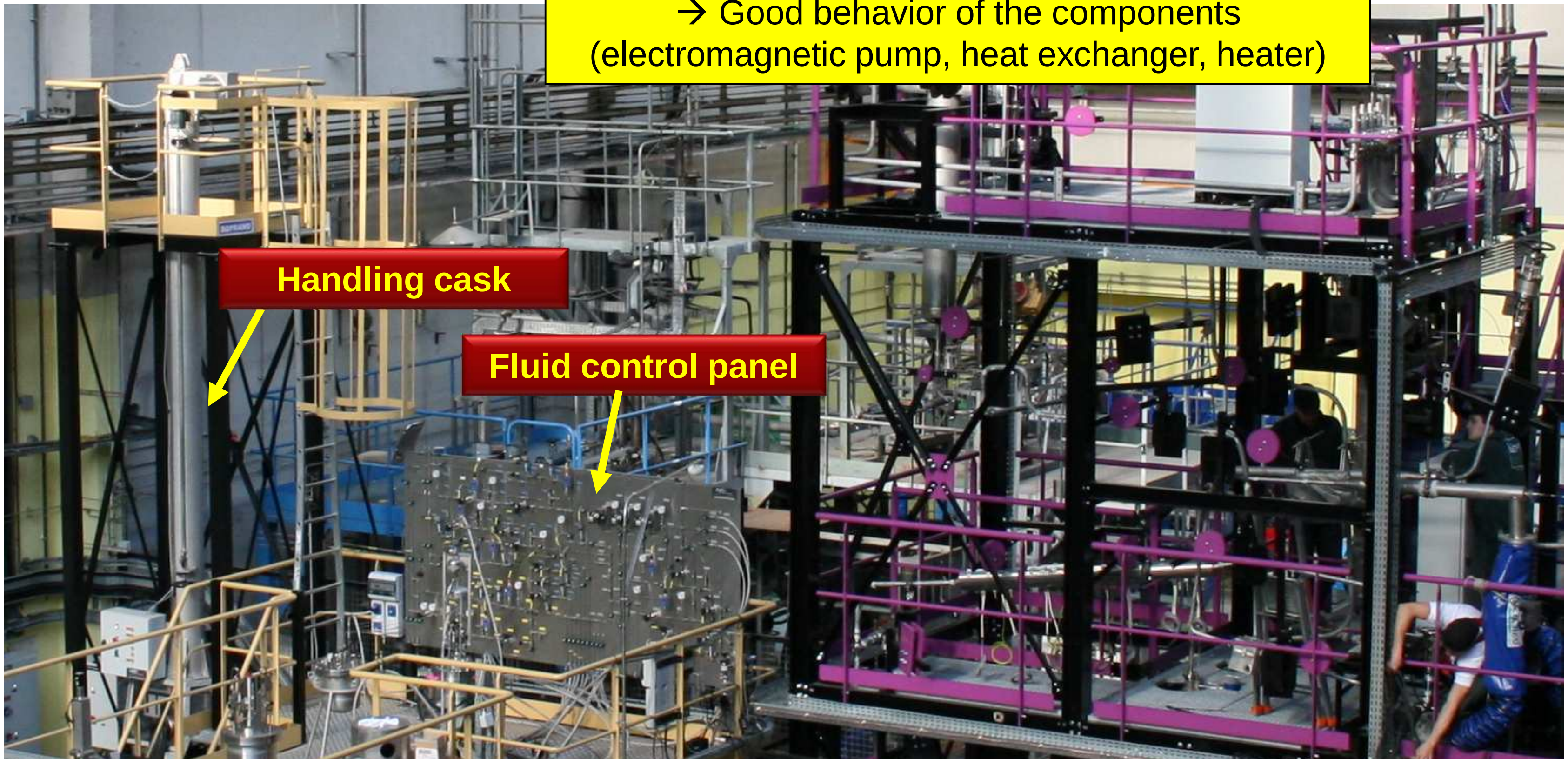
Emergency diesel generator (tested on a shacking table)

Exemples of some experimental component manufacturing and testing

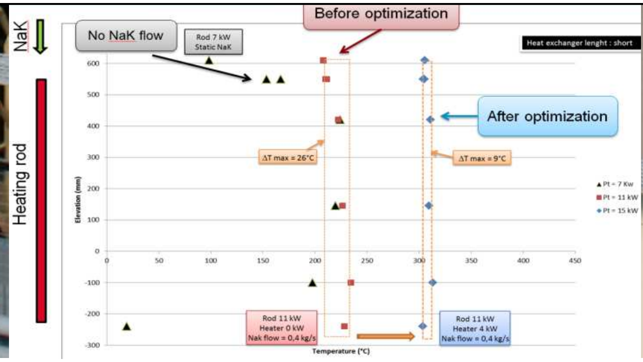


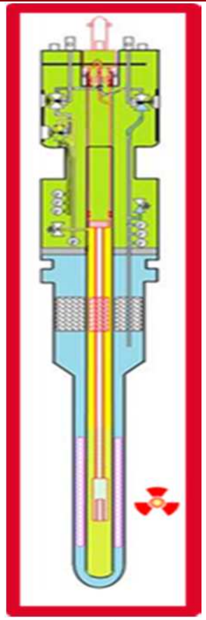
Qualification of CALIPSO prototype + NaK process (in SOPRANO facility)

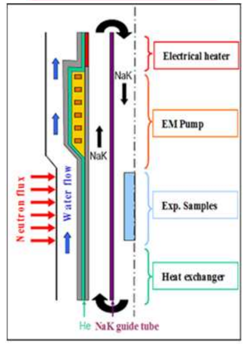
→ Good behavior of the components (electromagnetic pump, heat exchanger, heater)

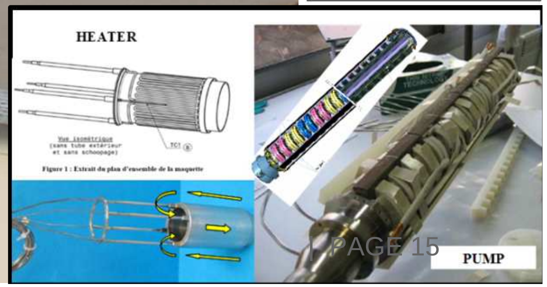


Temperature distribution in the test section









JHR CONSORTIUM & GOVERNING BOARD

19/03/2007 Signature of the JHR consortium

JHR consortium gathers organizations which take part financially in the construction of JHR (1 representative / organization)

JHR Consortium current partnership: Research centers & Industrial companies

Studsvik

AREVA

EDF

Ciemat – Centro de Investigaciones Energéticas, Medioambientales y Tecnológicas

SCK•CEN – Studiecentrum voor Kernenergie – Centre d'étude de l'énergie nucléaire

cea – De la recherche à l'industrie

VTT

ÚJV

DAE

IAEC

Associated Partnership: JAEA

National Nuclear Laboratory

NNL is the UK representative to JHR
UK/CEA agreement – March 2013

In some cases, the organization (member of the JHR consortium) is itself the representative of a national consortium which gathers organizations among industry, R&D organizations, TSO, or safety authority

Réacteur / Jules / Horowitz / Reactor

PREPARATION of EXPERIMENTAL PROGRAMS

Governing Board decision (2012) : creation of **3 Working Groups on fuel, material and technology issues**

- **To provide recommendations and guidance** regarding the reactor experimental capacity including hints on the facilities to be developed versus potential R&D needs and taking into account cost/benefit analysis
- **To gather an international scientific Community** for exchange of information and knowledge including scientific and technical seminars to identify and prioritize the topics of interest,

The preparation of the future JHR program:

- The identification of **open issues** in the field of nuclear fuel and nuclear materials development and qualification,
- The definition of criteria to elaborate **"ranking grids"** about fuels / materials types, reactor systems

In order to define the experimental objectives and main irradiation conditions, taking into account the availability and constraints of JHR experimental devices.

- And finally the set up of a **priority list**

The initiation of a first R&D program in a **short term future** (before the start of JHR) that will be performed in **operating MTRs** and/or in **hot cell laboratories** (to gather the International scientific community and set-up a group which will be operational at the JHR start-up). This first R&D program will have a continuation in the JHR

See the presentation dedicated to the FIJHOP R&D program proposal

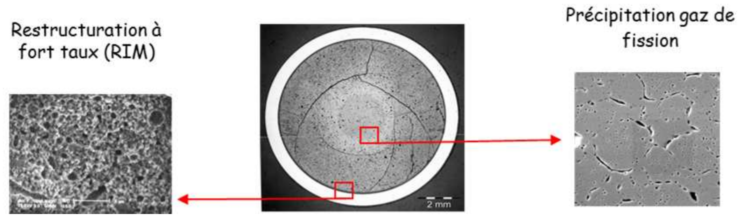
FUEL RANKING GRID ASSESSMENT : FIRST RESULTS and HIGHLIGHTS

Essential / Strong interest on:

- ✓ LWR fuel material basis properties (thermal-mechanical, FP effects. Less interest for new fuel concepts)
- ✓ Fuel element performance : power up-rates
- ✓ LWR fuel in incidental situations : power ramps, failed fuel behavior (also in normal operation)
- ✓ LWR accidental situations : LOCA (less interest for other off-normal situations)
- ✓ Gen IV : Integral fuel performance : SFR type-concept

Lower interest on:

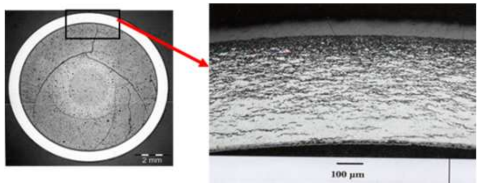
- ✓ Selection/Characterization of Th-based LWR fuels
- ✓ High conversion LWRs
- ✓ Minor actinides transmutation
- ✓ Particle fuel concept (e.g. HTR)
- ✓ Driver fuels for research reactors



MATERIAL RANKING GRID ASSESSMENT : FIRST RESULTS - HIGHLIGHTS

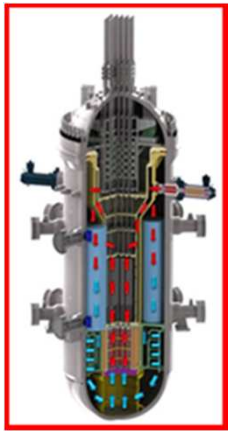
Cladding

- ✓ Cladding behavior : creep test (2D), effect of environment, effect of irradiation on µstructure (embrittlement, creep, hardening (GII&III), swelling (GIV))
- ✓ High demanding conditions (both material and fuel issues)



Reactor pressure vessel

- ✓ effect of irradiation on µstructure and mechanical properties



Internals

- ✓ effect of irradiation and environment (LWR)

Absobers (both material and fuel issues)

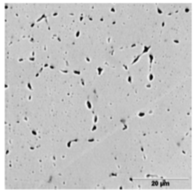
- ✓ effect of irradiation and overall behavior (degradation, swelling,…)

gathering an international scientific community by initiating of a new R&D program (proposal)

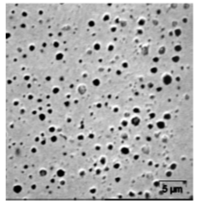
See the presentation dedicated to the FIJHOP R&D program proposal

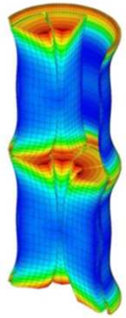
Fuel program

Identification and quantification of the phenomena involved in power transient and having an impact on the clad loading.



Quantification of fission gas release effect
and impact on pellet-clad interaction
during a power transient
(successive power steps)

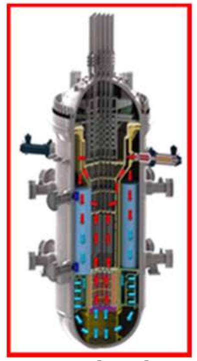




First experiment : in ~ 2019 in an existing European MTR ; similar experiment will be carried out on a similar fuel rod in the ADELINE LWR irradiation loop in JHR (>2020)

Material program

Neutron spectrum effect on Stainless Steel behavior
Dose-damage relationship quantified by tensile testing
and microstructure characterizations.
Effect of ratio "epithermal + fast" neutron flux / "fast" neutron flux (Rs 2 - 5)
on mechanical properties and on µstructure of SS



Irradiation test in MTR in mid 2019-2020 - PIE analysis in 2020-2022 (benchmark of PIE technics in various hot labs) - Additional / complementary tests will be performed later-on in JHR (> 2020)

Réacteur / Jules / Horowitz / Reactor

THANKS FOR YOUR ATTENTION

Any Questions?

Participants at the annual experimental seminar