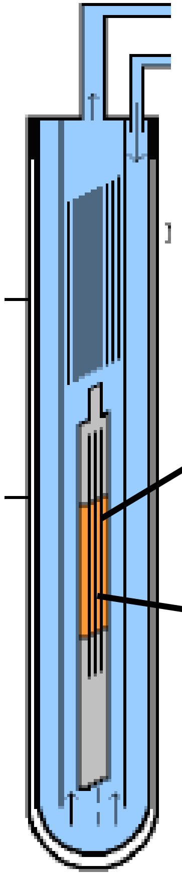
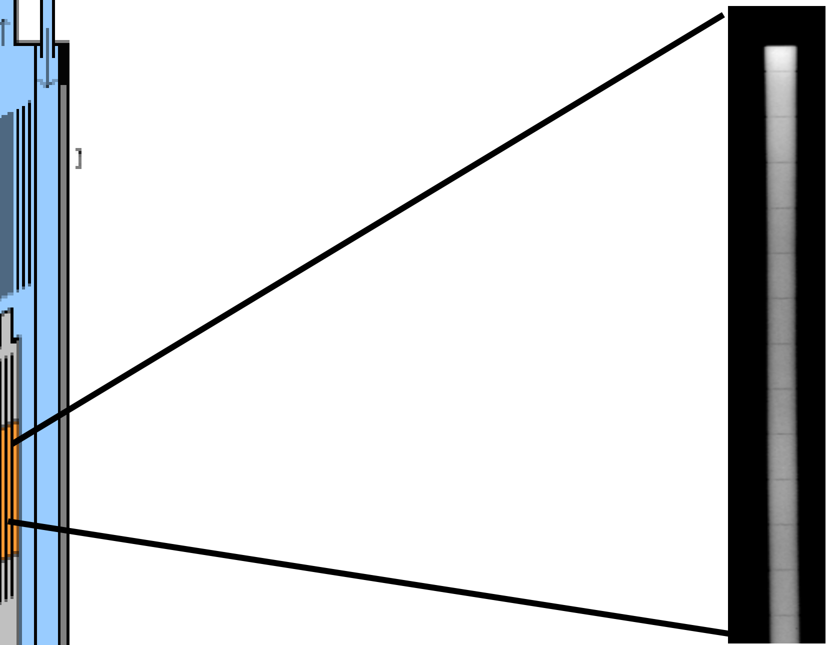
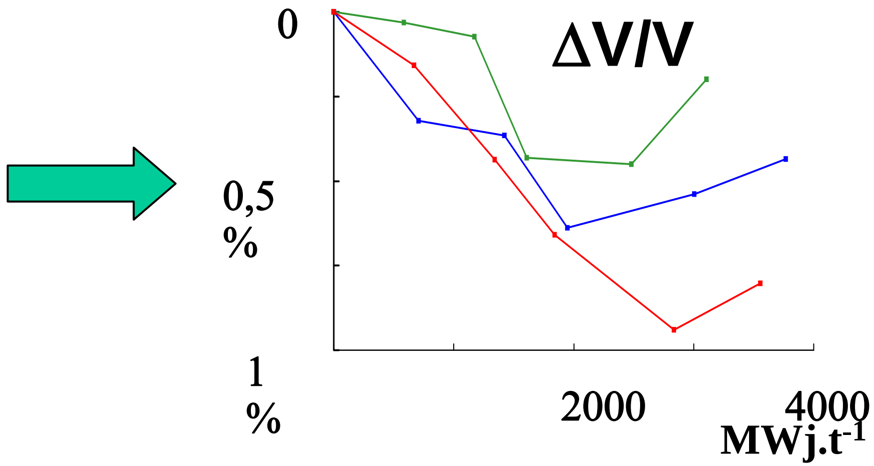
Irradiation Facilities and Examination Benches for Implementing Fuel Programs in the Future Jules Horowitz MTR







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Contents

- Introduction
- An experimental capacity driven by users needs
- From fuel development process to experimental requests
- Status on fuel hosting systems under development
- Non destructive examination benches
- Conclusions

The JHR: A new MTR in Europe

- **A new MTR is under construction in Europe since about 40 years**
- **Unique opportunity to design a whole irradiation device park**
  - ✓ In a modern safety frame
  - ✓ Targeted to offer maximum information during the experiment (on-line)
  - ✓ To fulfill end-user needs for several decades

  - ✓ To identify the future needs for a suitable design is mandatory… but not so easy!
    - ☞ Long term needs (> 2015) are generally not expressed
    - ☞ Identified short-term needs shall be solved in the coming years

Milestones of a fuel product development process

Identification and evaluation work

Nuclear fuel « landscape » after 2015

Expected R&D needs and associated time-frame

MTRs
Hot cells
etc.

Milestones of a fuel product development process in MTR

Sélection / Characterization **Qualification / Safety tests**

10-15 years

Fuel material knowledge
- Input data for modeling
- Microstructure selection

Behavior understanding
Laws and models set-up
- Separate effect experiments
- Instrumented samples
- On-line measurements
- Adapted LHGR time histories

Tests on industrial products
- Very high burn-ups
- Soliciting LHGR time histories
- Failed fuel rods
- Operation at the limits (ramps, lift-off, LOCA-type,…)
- Accidental situations (RIA, FCI...)

Material studies → **Test of industrial products**

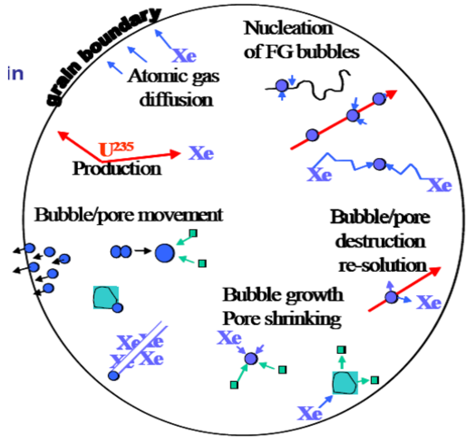
Numerous samples → **One single fuel rod**

Scientific stakes (Research, Fuel vendors) → **Operational stakes (Research, Utilities, Fuel vendors)**

Why are fuel irradiations in MTRs necessary for supporting the fuel development process?

Simulation tools are often not sufficiently validated when:

- ✓ Fuel product is improved, or is planned to be used beyond current operating conditions
- ✓ Fuel reliability shall be more proven
- ✓ Safety criteria have been changed



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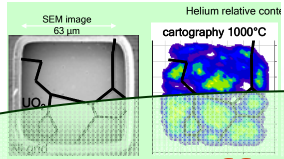
Fuel product is not allowed to be irradiated in a power plant (as a precursor)

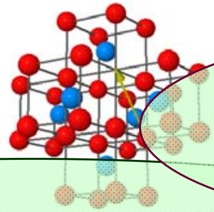
- ✓ Envelope use conditions
- ✓ Operating domain not reachable by a power reactor
- ✓ Reactor not existing

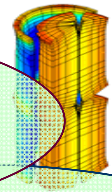
=> Need to support technical and safety assessment oriented **licensing file** **(industrial partner often leader)**

Knowledge valorization in simulation codes is a permanent driving force

Measuring fuel basic data:
Need for a science-based approach strategy coupling MTR, hot labs, large facilities and modeling





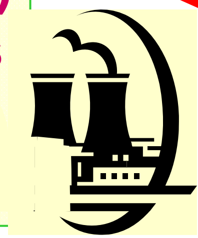


Multiscale modelling and simulation

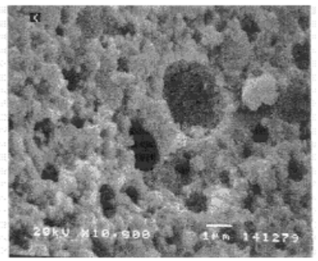
Separate effects experiments

In pile integral irradiation

Out of pile experiments	Ion Irradiations	Neutron (FP) Irradiations
Temp. effect Chem. effect	**Large Facilities** (Accelerator)	**MTR**



Hot Labs and Large Facilities

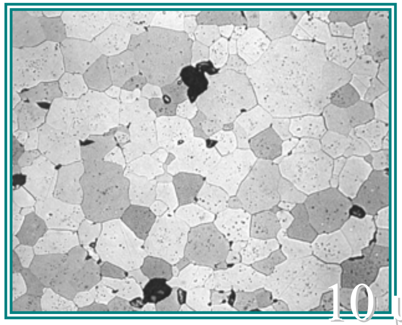


Fine characterization *before, after or under* irradiation

Multiscale characterization thanks to:
- Hot Lab Facilities : TEM, SIMS, EPMA, XRD…
- Large Facilities / Synchrotron XAS, XRD,
  ⇨Soleil: a specific beam line for irradiated fuel : Mars BL

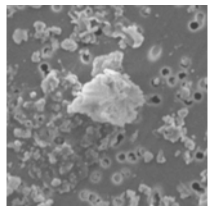
Expected fuel product evolutions (trends)

- ✓ Doped UO_2 or UO_2 with high content of neutronic absorbers (Gd, Er…)
- ✓ MOX with high Pu content or UO_2 with high ^{235}U enrichment (> 5%?)
- ✓ Innovative UO_2 or MOX fuel (geometry, microstructure)
- ✓ Triplet {fuel material, pellet geometry, clad material} optimization
- ✓ Etc… (specific needs)



Examples of expected issues for improving fuel reliability

Challenges	Operational stake
✓ Power ramps behavior ☞ Protocol, successive ramps…	Power plant maneuverability
✓ Internal EOL pressure ☞ FGs, He release	Fuel product life time
✓ Run beyond cladding breach ☞ FP release, U dissemination…	Plant operation and maintenance, wastes
✓ Iodine behavior ☞ Release, role for SCC ☞ Chemistry, link with other FP…	Power plant flexibility, source term



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From development process to experimental requests

Selection

Irradiation global but precise monitoring (T, fission rate)

Samples for PIE (microstructure analysis)

Characterization Understanding

Numerous and robust on-line instrumentation

Flexible LHGR time histories

Intermediate NDE checking

Homogeneity and representativeness on several fuel rods

Long term irradiations (creep, corrosion…)

Conditioning before other tests (ramps…)

Qualification

High LHGR

Failure risk and radionuclide release management

FP on-line measurements

Damaged sample management

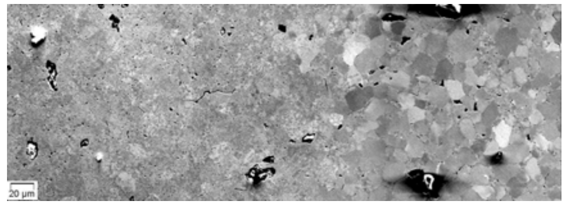
Safety tests

Highly instrumented and automated test
Devoted environment
Phenomenology

Experimental requests - Example 1: Power Ramps

Stakes

- ✓ PCI limits (plant maneuverability, flexibility…)
- ✓ Kinetics effects - Ultra-fast ramp (up to 1000 W/cm.min)
- ✓ FP influence on clad behavior (I…)
- ✓ Fuel microstructure evolution (cracks, swelling, FP distribution….)
- ✓ Specific fuel vendor/utility needs



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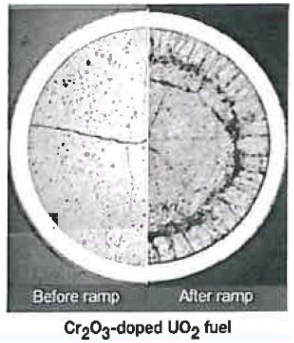
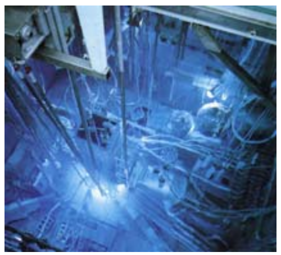


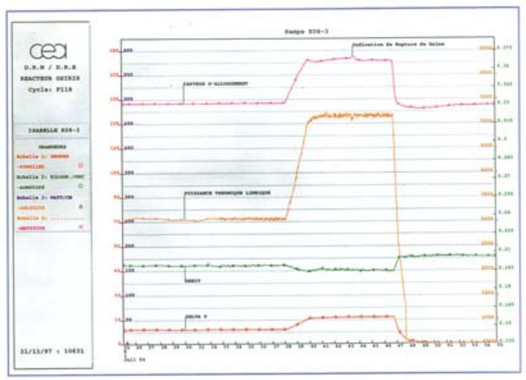
AREVA

Experimental requests from the scientific team

- ✓ Welcoming power ramp system (various protocols, successive tests…)
- ✓ Ramp campaign: rod conditioning in another irradiation device
- ✓ Qualified power increase linearity control (automated system coupled with SPND results…)
- ✓ On-line measurement (clad elongation, FGR, coolant activity…)

- ✓ Reliable system
  - ☞ High accuracy on LHGR target
  - ☞ Strong experimental feedback
  - ☞ Results feed PCI modeling
- ✓ PIE support

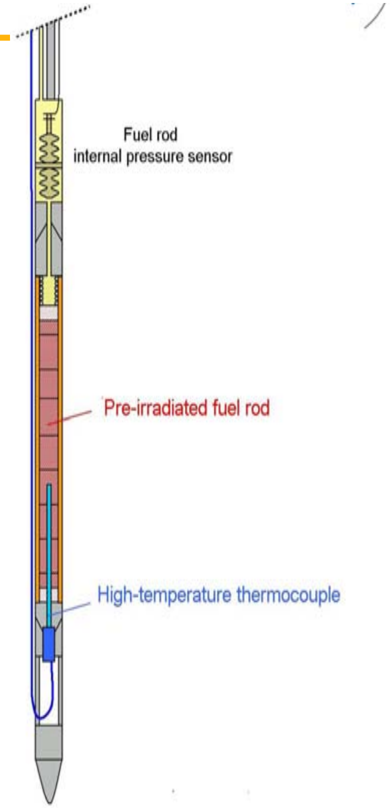




Experimental requests - Example 2: Fission Gas Release

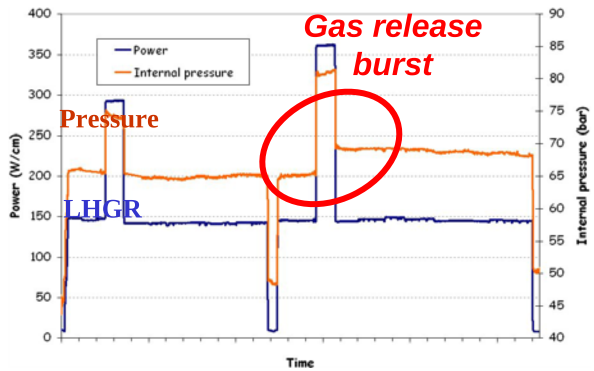
Stakes

- ✓ Quantification of FGR margins versus limits
  - ☞ Release values + kinetics (Envelope power time histories, cycling…)
  - ☞ He release specific issue
  - ☞ Radioactive source term
- ✓ Reduction of uncertainties and margins (Tc, λ, LHGR…)
  - ☞ Non linear system: Slight Plin/T increase ➔ Strong FGR increase
- ✓ Validation of advanced FG modeling



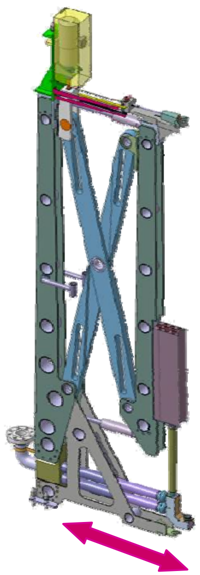
Experimental requests

- ✓ On-line FG measurement (gas sweeping) -> FP Laboratory
- ✓ Development of innovative in-pile instrumentation required
  - ☞ E.g. acoustic sensor (pressure + gas composition)
- ✓ Coupling with PIE thermal analyses



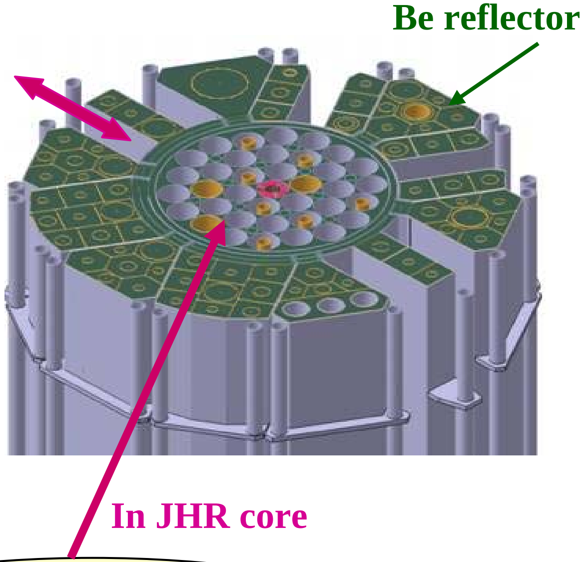
On-line measurement of the fuel rod pressure during power ramps in the REMORA-2 experiment

Hosting experimental systems for fuel samples under development



Moving box
to adjust
easily the distance
sample-JHR core

Δl=350 mm
V → ~5 mm/s
V back ~50 mm/s



For materials (Gen III, IV)

- CALIPSO (high performances)
- MICA

For LWR Fuels

MADISON

- Nominal conditions
- Long term experiments
- Comparative instrumented irradiation

ADELINE

- Beyond design criteria limits
- High power, transients (power ramps…)
- Post-failure behavior
- FG sweeping and recovering

LORELEI

- LOCA tests on a separate effect approach
- Thermal-mechanical behaviour of one LWR rod
- Includes the post blow-down phase

The MADISON fuel experimental hosting system

Description

A loop device for irradiation of LWR fuel samples in normal conditions of power reactors

- In reflector
- On displacement system
- Heavy components in cubicle

Type of fuel sample

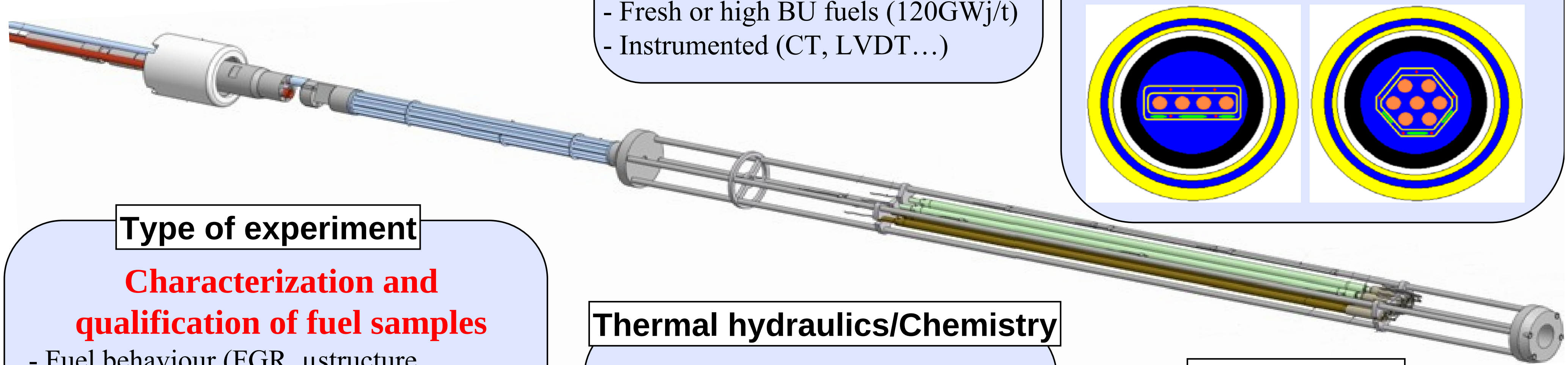
All type of LWR fuel samples

- PWR / BWR fuel samples
- UO2 fuels (up to 7% in U^{5})
- MOX fuels (up to 15% Pu/(U+Pu))
- Fresh or high BU fuels (120GWj/t)
- Instrumented (CT, LVDT…)

Carrying capacity

Flexible loop with a large carrying capacity

- 4 rods clad diameter ≤ 10 mm
- 3 rods clad diameter ≥ 10 mm
- Possible evolution 7 rods 200W/cm



Type of experiment

Characterization and qualification of fuel samples

- Fuel behaviour (FGR, µstructure evolution, corrosion…) vs BU and LHGR
- Long-term irradiations (fuel screening test or rod qualification)
- Re-irradiation before ramps

Thermal hydraulics/Chemistry

Representative of LWR power reactors

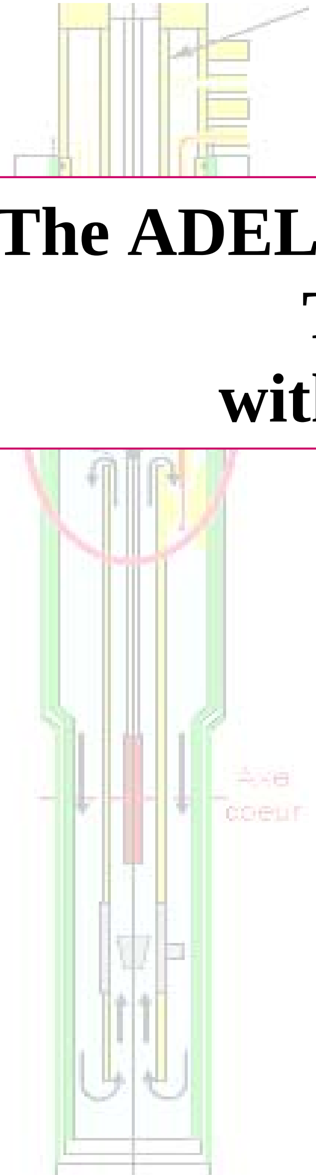
- PWR (155bars , 320 °C, 4 m/s)
- BWR (75 bars, T_{sat}, 1,8 m/s, low void fraction)
- Designed for 4 rods at 400 W/cm
- Standard chemistry (PWR /BWR)
- Specific chemistry (HWC,…)

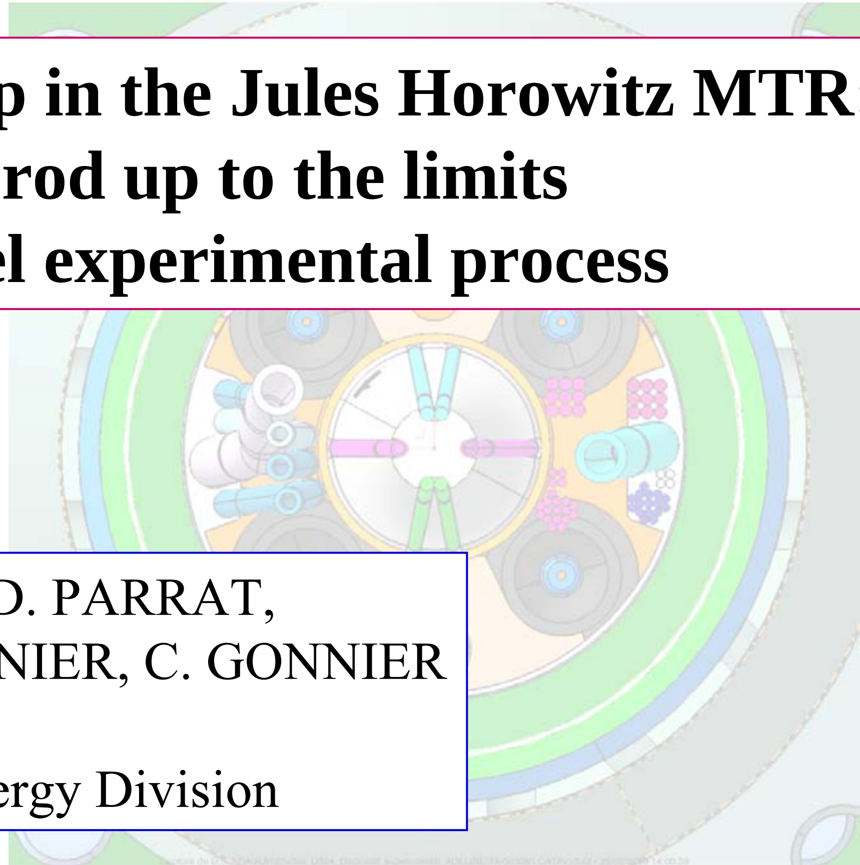
LHGR control

Good homogeneity between any 2 identical fuel rods

- 3-5% max. heterogeneity (four fuel rods sample holder) for all type of fuels / Burn up
- Use of thin neutron screens
- Precise thermal balance

Design and manufacturing in collaboration with IFE-Halden





The ADELINE irradiation loop in the Jules Horowitz MTR: Testing a LWR fuel rod up to the limits with a high quality level experimental process

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The LORELEI hosting system

Objectives

✓ Thermal-mechanical behaviour of one LWR rod

- ➢ Ballooning and clad burst (fuel relocation)
- ➢ Corrosion at high temperature
- ➢ Quenching and post-quench behaviour

✓ Radiological consequences : FP source term (with/without fuel re-irradiation)

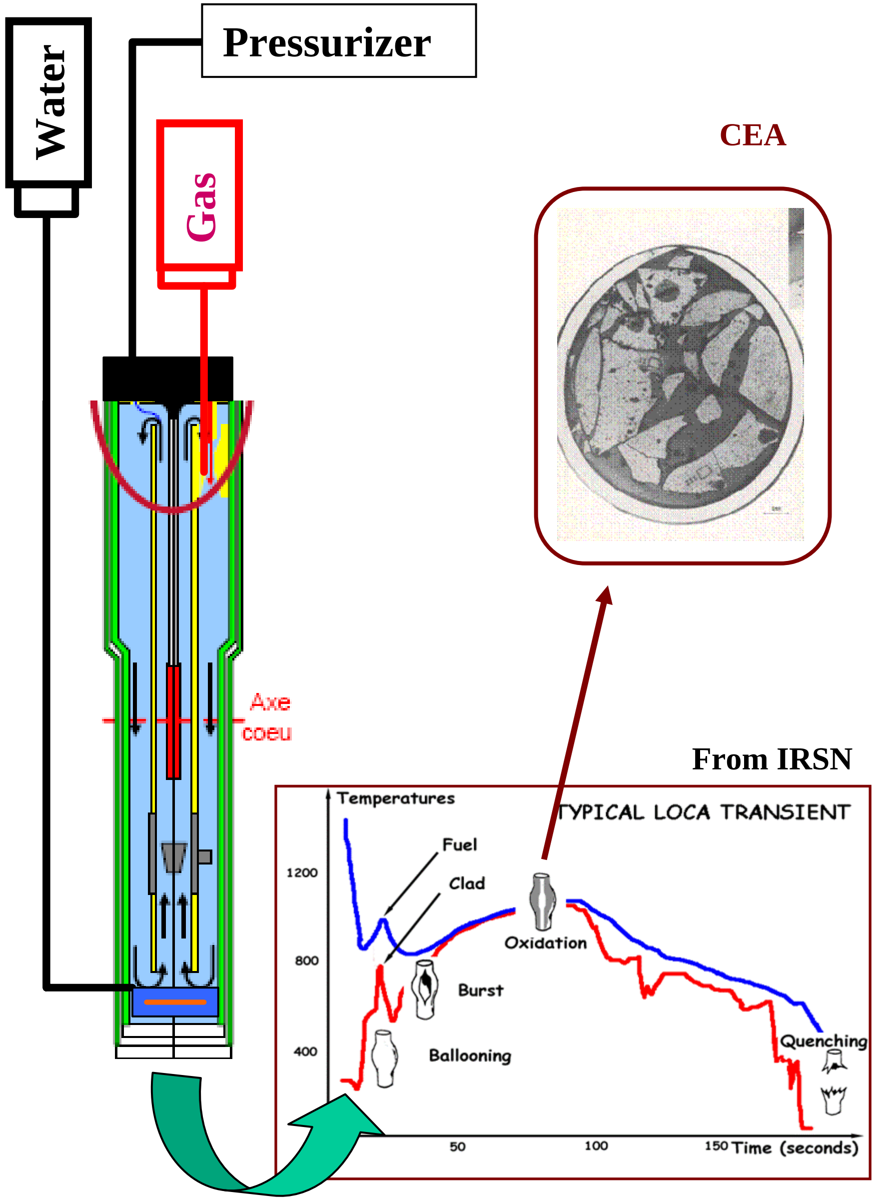
Technical design

✓ Device equipped with dewatering and quenching systems (gas and water tanks)

✓ Temperature controlled by displacement system

✓ Temperature distribution flattening : neutron screen (axial) and electrical heater (azimutal)

✓ Quick installation (for short lived FP measurement) on END benches (gamma scanning and X radiography)



A JHR hosting system development plan accorded to users needs

Madison (LWR fuel)	Available at the start of operation
Adeline (LWR fuel)	Available at the start of operation
Lorelei (LWR fuel)	Studied and Licensed
Instrumented capsule (fuel)	To be developed later on
Severe accident testing system (LWR fuel)	To be developed later on
Mica (material)	Available at the start of operation
Calipso (material)	Studied and licensed
Corrosion (material)	To be developed later on
SFR fuel testing systems	To be developed later on
GFR fuel testing systems	To be developed later on

Non Destructive Examinations in JHR: General objectives

- **Initial checks of the experimental loading** status just before the first irradiation
  - Handling possible effects (transportation, insertion in the device)
  - Precise positioning of instrumentation, sensors…

- **Adjustment of the experimental protocol** after a short irradiation run
  - Sample behavior
  - Power tuning…

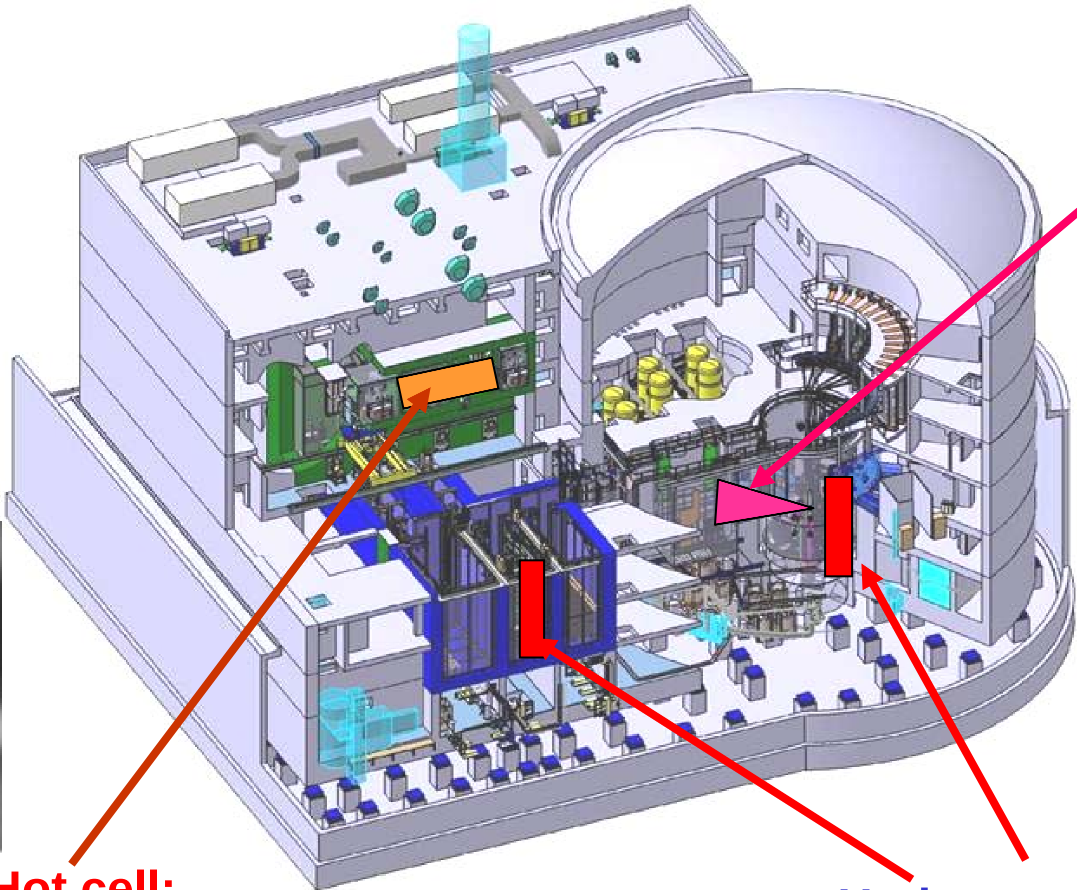
- **On the spot monitoring of the sample status after a test** on the close-by stand located in the reactor pool
  - Limited handlings to preserve the "as tested" sample geometry
  - Geometrical changes after an off-normal transient
  - Quantitative distribution of short half-life fission product…

- **Final NDE tests** after irradiation sequence
  - On unloaded sample

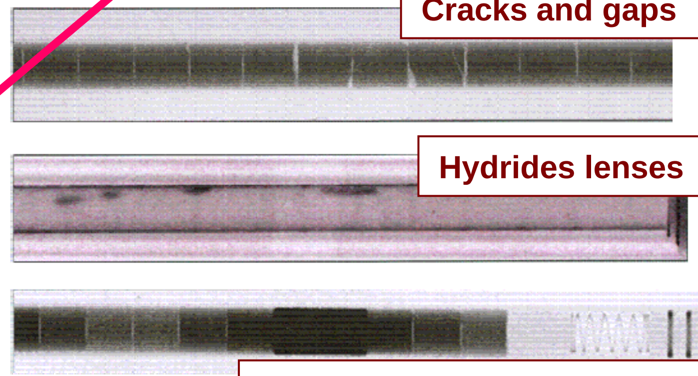
Non Destructive Examination Benches in JHR

Fuel Hot cell: Gamma and XR scanning system & multipurpose test benches

Sample examination



Underwater Neutron Imaging System



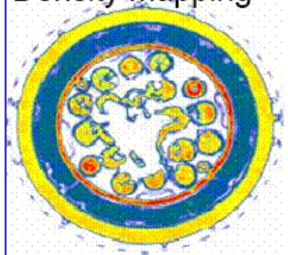
Hosting system examination (fuel sample inside)

Underwater photonic imaging systems (X-ray & γ) in reactor and storage pool

Feasiblity study in progress with VTT collaboration

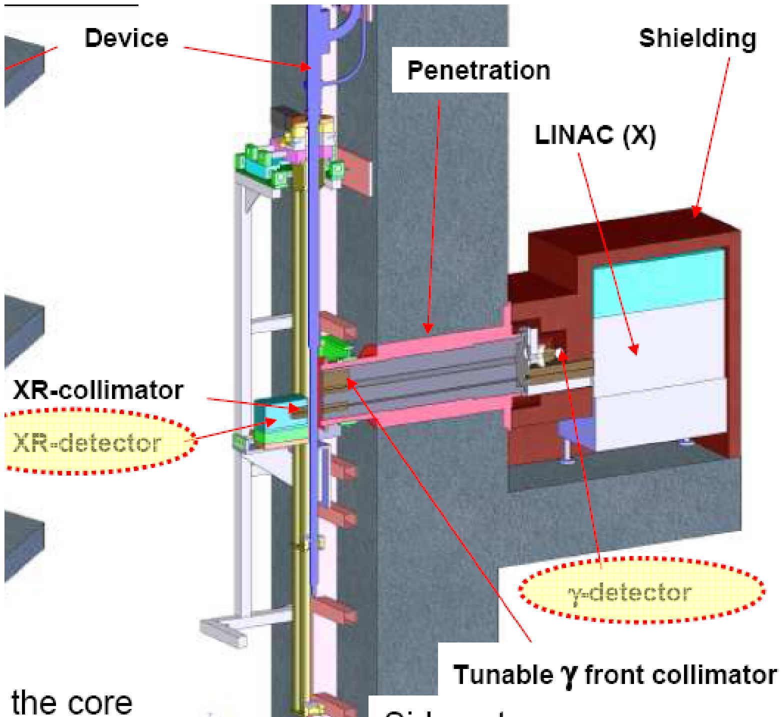
Phebus PF

Density mapping



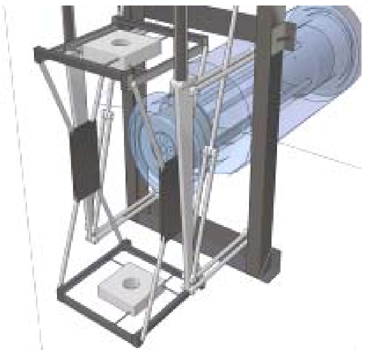
XR tomography (transmission)

Photonic and Neutron Imaging Systems



Side cutaway

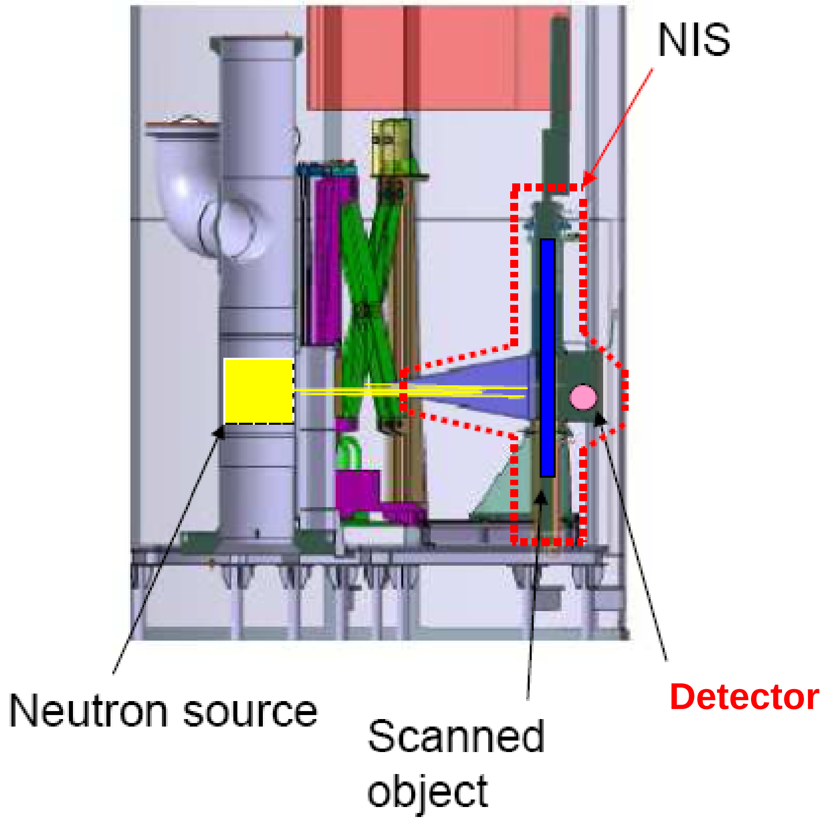
JHR underwater photonic imaging system



X,Y,Z RZ tables

Neutron Imaging System

Side view



Conclusions

- **Important work carried out on anticipation of users' needs**
  - ✓ As a key strategic input to steer priorities in hosting systems developments
  - ✓ As a key technical input for the development and the licensing
  - ✓ Necessary and beneficial for Users in order to get results as soon as possible

- **JHR offers a wide experimental domain**
  - ✓ A set of experimental hosting systems will be operational at the JHR operational starting
  - ✓ Development of some other systems closely linked to needs

- **The JHR experimental capacity definition is also dependent from the existing Users community (JHR consortium, JHIP)**

- **International scientists (young fellows and/or senior experts) are welcomed within the JHR team for building the future JHR community**