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The future Jules Horowitz Material Testing Reactor: an opportunity for developing international collaborations on a major European irradiation infrastructure

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DE LA RECHERCHE À L'INDUSTRIE

cea den



The future Jules Horowitz Material Testing Reactor (JHR)

An opportunity for developing
international collaborations on
a major European irradiation
infrastructure

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CEA Cadarache

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11th International Conference on
WWER Fuel Performance, Modelling and Experimental Support
26 September – 03 October, 2015, Golden Sands Resort, Varna (BG)

- ❖ Reminder of JHR main features
- ❖ JHR building status
- ❖ JHR operation as an international User Facility
- ❖ Irradiation hosting systems available at the JHR start-up
- ❖ Irradiation hosting systems available
- ❖ Conclusion

WWER Fuel Performance Meeting,
Burgas, Sept. 2011



The Future Jules Horowitz MTR
A Major European Research Infrastructure
for Sustaining
the International Irradiation Capacity

D. Parrat, G. Bignan, J.P. Chauvin, C. Gonnier

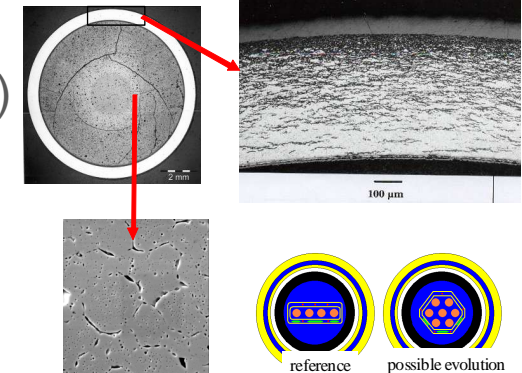
CEA, Nuclear Energy Division
CEA Cadarache

daniel.parrat@cea.fr

1 / 25 9th Int. Conference on WWER Fuel Performance, Modelling and Experimental Support, Helena Resort (BG), September 17-23, 2011

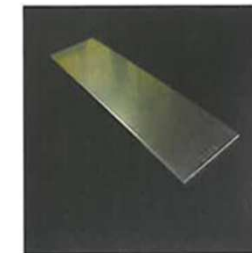
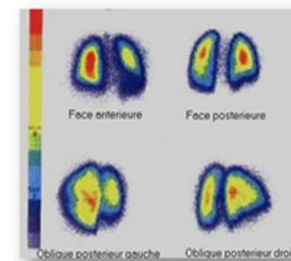
1. R&D in support to nuclear Industry

- 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

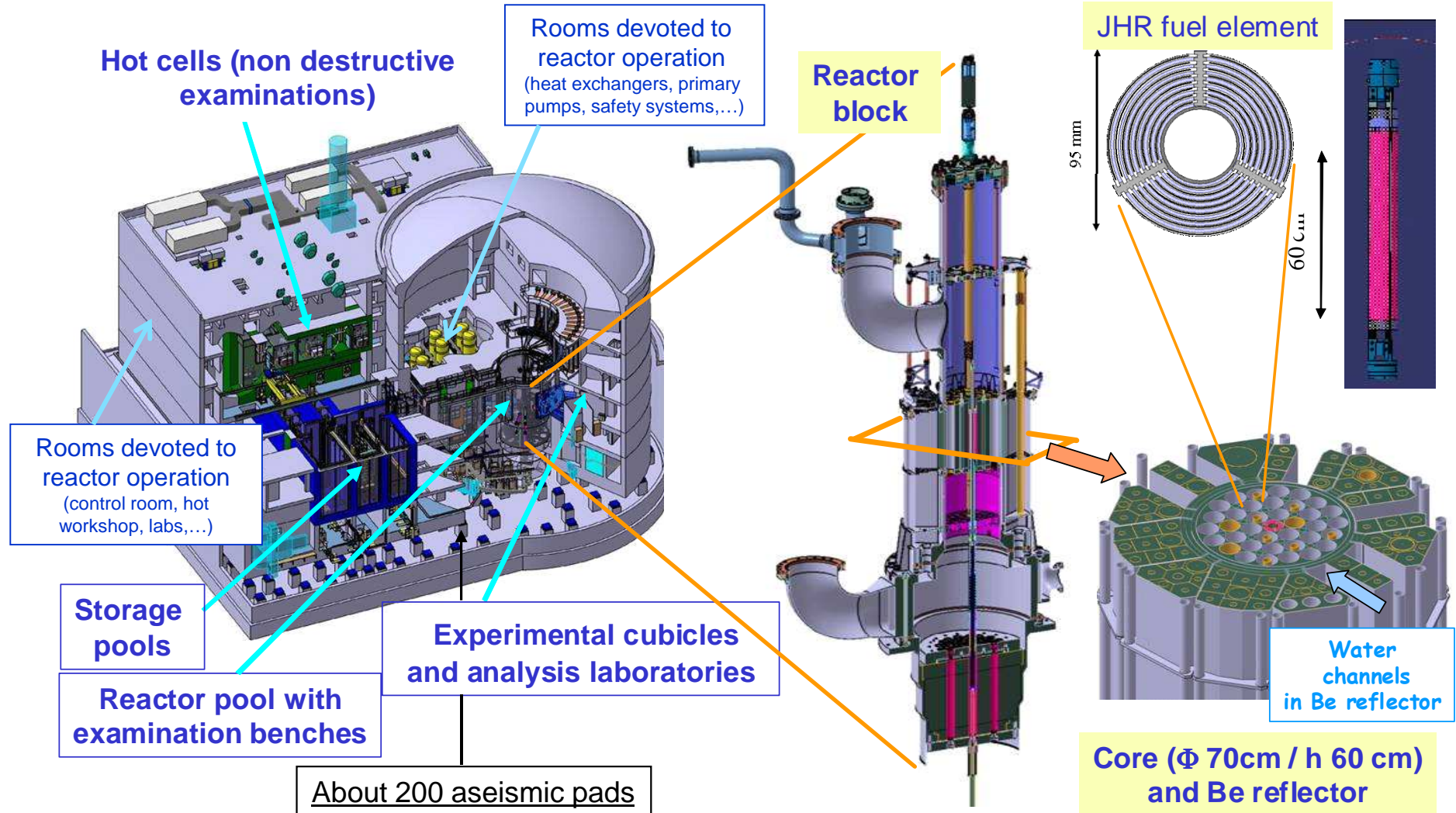
- ^{99}Mo production
 - JHR will supply 25% of the European demand (today about 8 millions protocols/year)
 - Up to 50% upon specific request



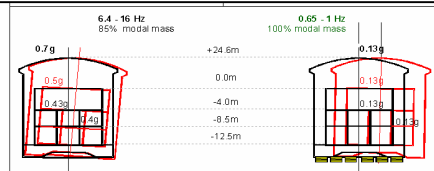
3. A key tool to support expertise

- 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**

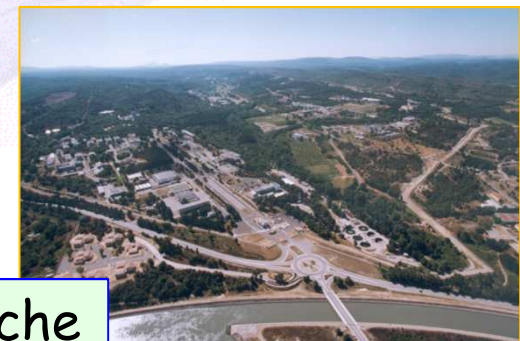
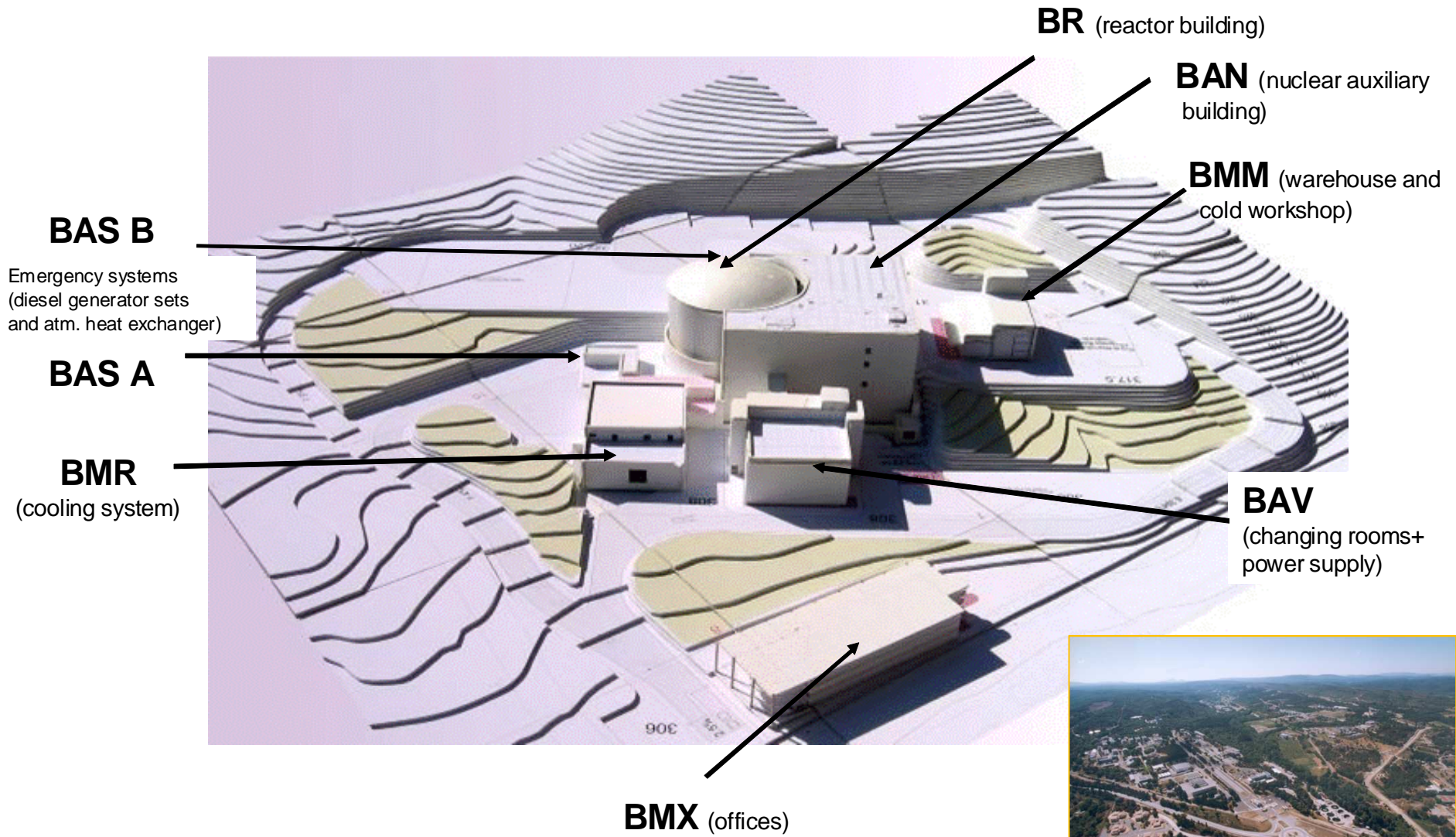


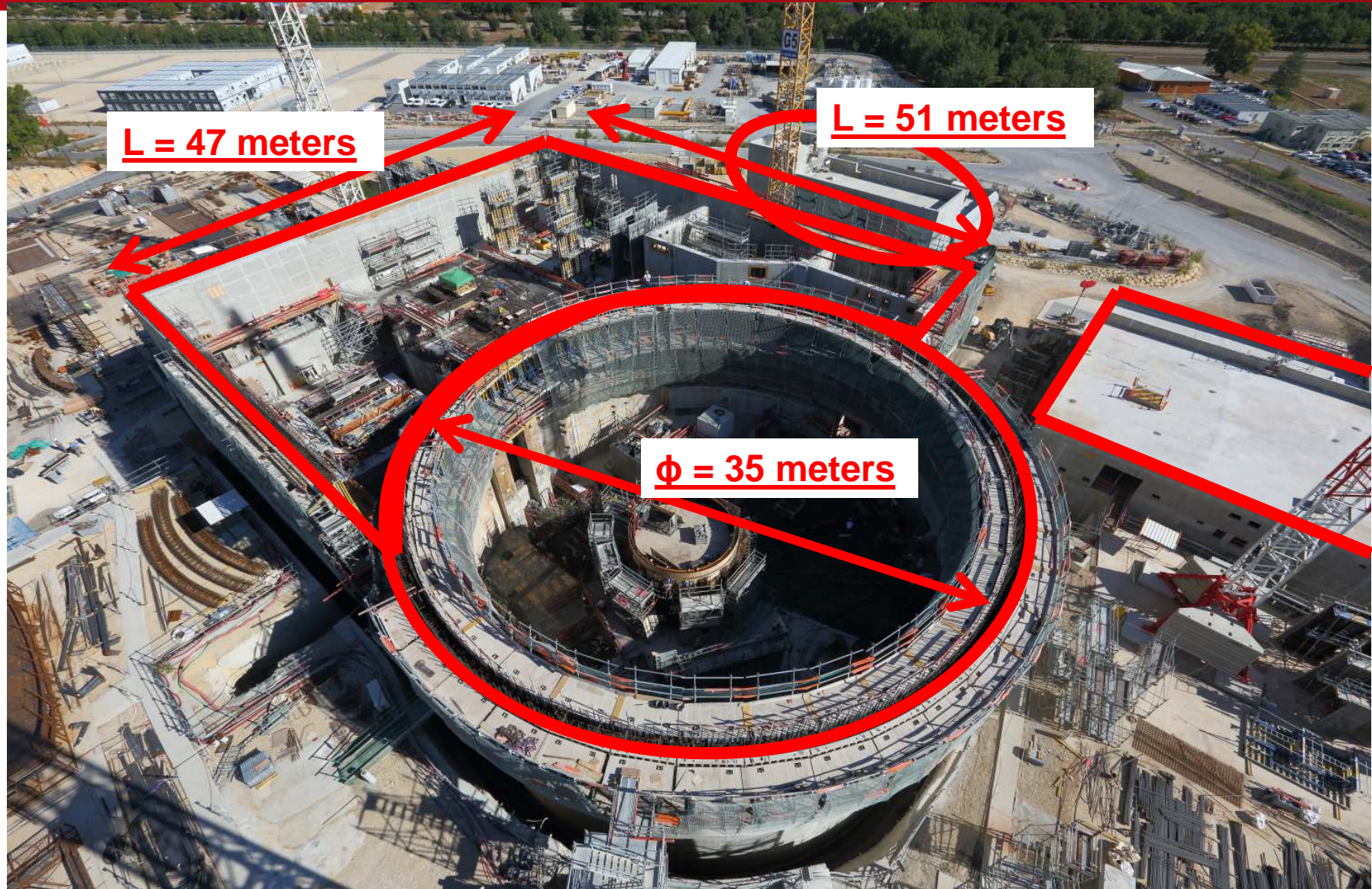


About 200 aseismic pads



**Core Designed for UMo-Al fuel (70 MWth / 100 MWth)
Start-up with U₃Si₂-Al fuel**





Duration: about 20 hours, with an average rate of $36 \text{ m}^3 / \text{h}$, up to 730 m^3 of self-compacting concrete

Pouring a dome of a nuclear reactor made in a single operation and using a self-compacting concrete : first time in Europe





Implementation of
prestressing cables



Prestressing cables

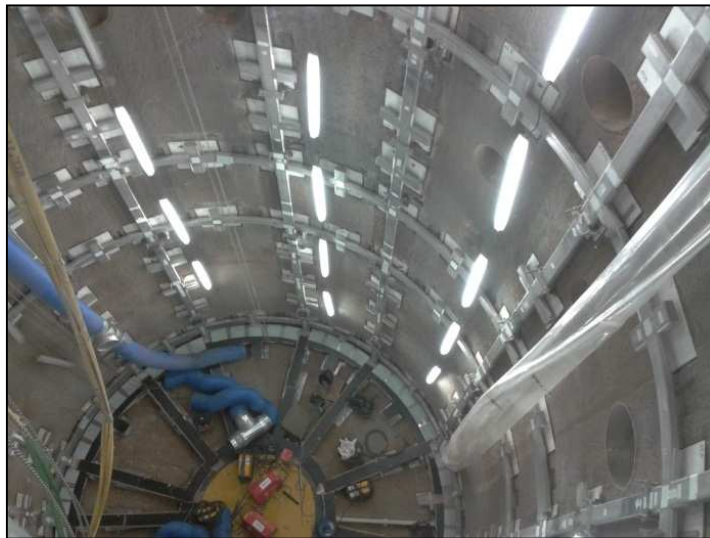




Hot cells
modules
(End 2014)



Reactor block
components
(Spring 2015)

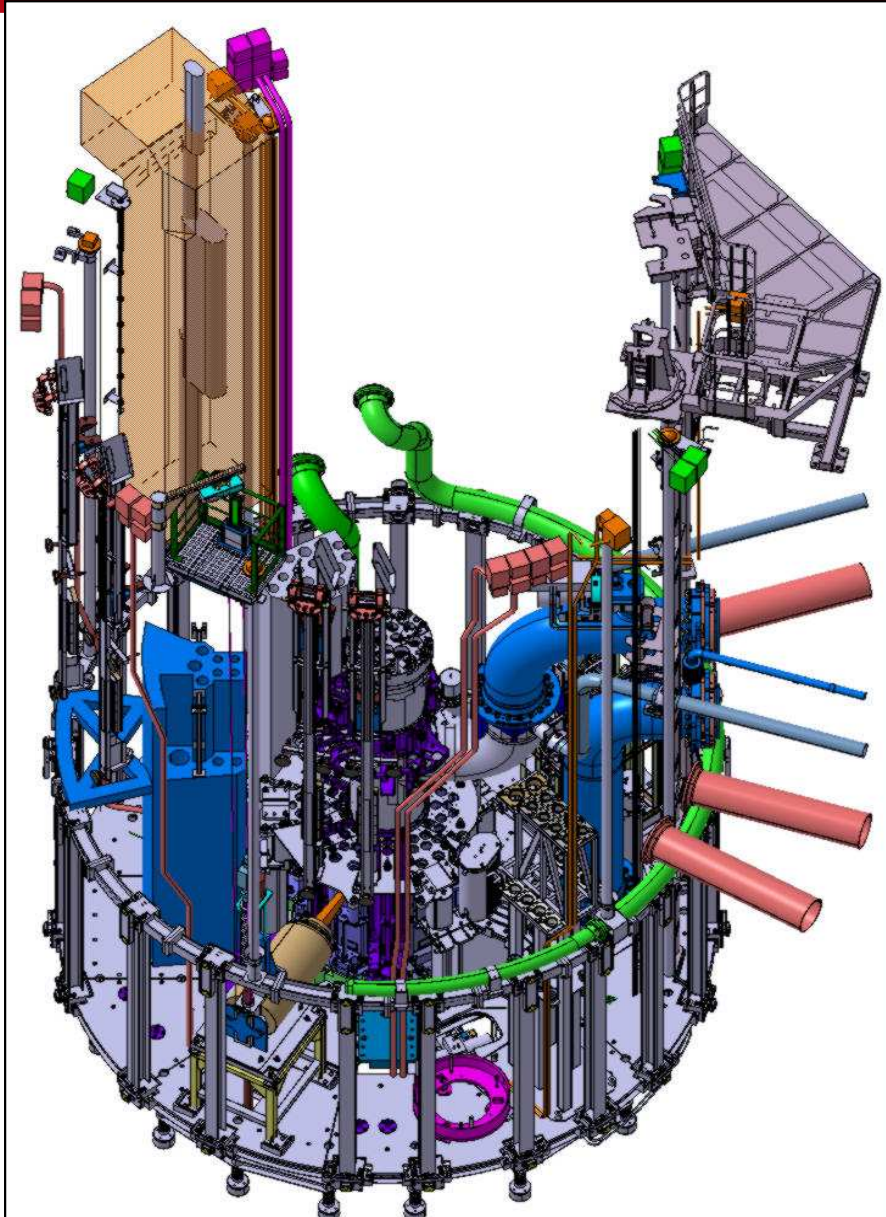


RER pool base welding
(October - November 2014)



Heat Exchanger in-factory forging:
Bottom part (November 2014)



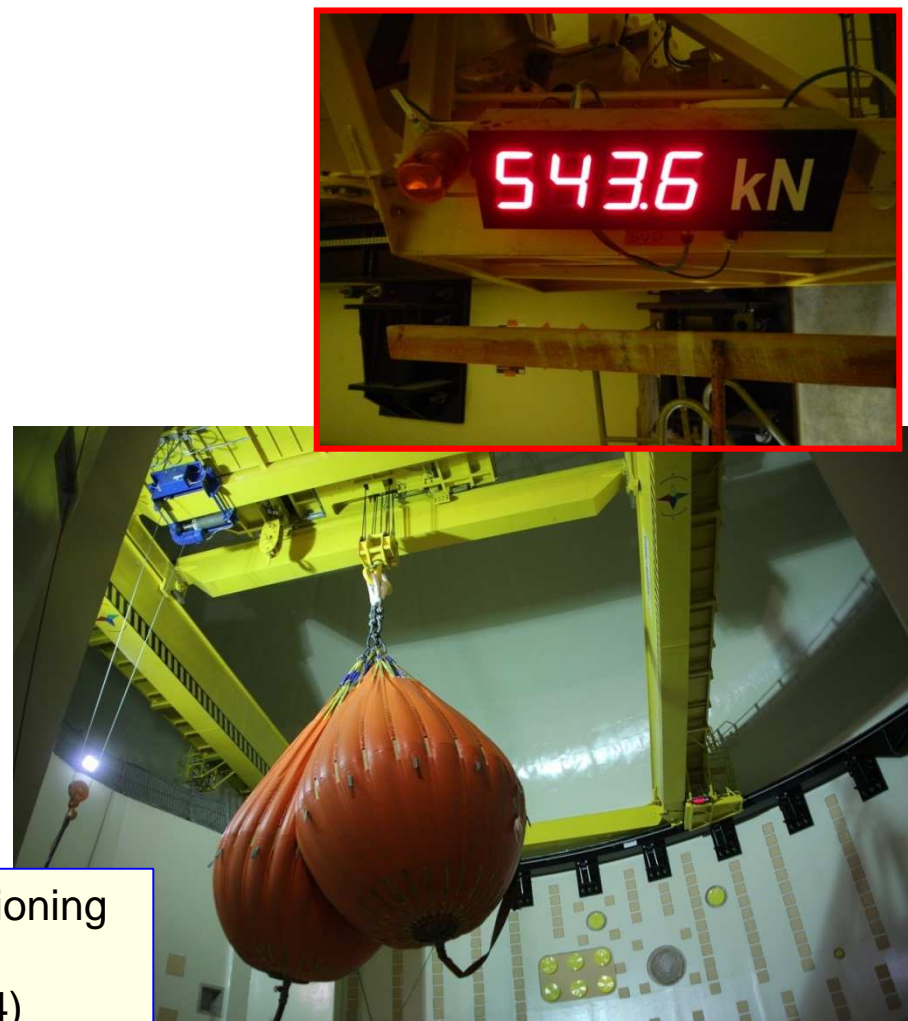


**REALIZATION
PHASE STARTING**

Important milestone !



In-factory tests for emergency diesel generators (End 2014)



Polar crane commissioning tests at full load (November 2014)

- Fuel qualification completed (in BR2)
- Civil work completed by mid-2016
- First criticality : second semester of 2019
- Full operation planned by the end of 2020

- ❖ Reminder of JHR general characteristics
- ❖ JHR building status
- ❖ JHR operation as an international User's Facility**
- ❖ Irradiation hosting systems available at the JHR start-up
- ❖ Irradiation hosting systems available after the JHR start-up
- ❖ Conclusion



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



Associated Partnership:



NNL is now 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 domestic consortium which gathers organizations among industry, R&D organizations, TSO, or Safety Authority

- CEA = Owner & nuclear operator with all liabilities
- JHR Member : Owner of guaranteed irradiation access rights
 - ⇒ In proportion of his financial commitment to the construction
 - ⇒ With a proportional voting right in the Consortium Board
- A Member can use totally or partly his access rights
 - ⇒ For implementing proprietary programs with full property of results
 - ⇒ And/or for participating to the Joint International Programs open to non-members
 - ⇒ And/or to address issues of common interest with a limited number of members (R&D, NPPs operation...)
- A lively structure !
 - ⇒ Yearly JHR Seminar on experimental capacity
 - ⇒ Working Groups : Fuels, Materials, Technology
 - To set up the first international programs*



Consortium is open to new member entrance until JHR completion

Invigorating international cooperation on Research Reactors : a French Contribution to the recent IAEA initiative "ICERR"

ICERR (International Center based on Research Reactors)



- ▶ Create international scientific networks
- ▶ Make available facilities and experience of mature R&D centres in the field of peaceful uses of Nuclear Energy to affiliates
- ▶ Lead innovative joint programs with shared results
- ▶ Host international scientists / engineers
- ▶ **Provide "hands on" nuclear education "in the field"**

Strong CEA intention to welcome Junior and/or Senior Scientists, Nuclear Engineers, Operators, Safety Managers... within JHR teams for various topics (R&D programs, Hands-on training on equipments...)

LECI : Hot Lab on Materials

- Hands-On Training (Equipments)
- R&D Projects



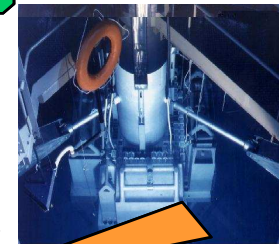
ISIS:

- Education & Training



ORPHEE : Neutron beams

- Hands-On Training (Equipments)
- R&D Projects



EOLE/MINERVE:

- Education & Training
- Hands-On Training R&D Projects

JHR : MTR

- Hands-On Training
- R&D Projects

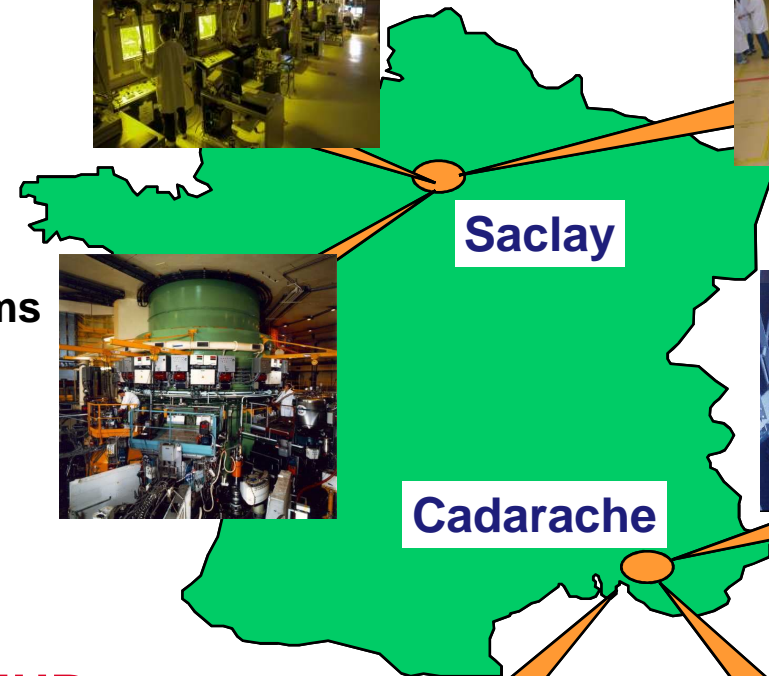
ZEPHYR : LPR



New Projects

LECA : Hot Lab on Fuel

- R&D Projects
- Hands-On Training (Equipments)



- ❖ Reminder of JHR general characteristics
- ❖ JHR building status
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- ❖ **Irradiation hosting systems available at the JHR start-up**
- ❖ Irradiation hosting systems available after the JHR start-up
- ❖ Conclusion

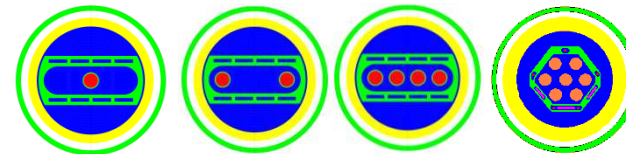
Dedicated to comparative instrumented irradiations (fuel evolution, clad corrosion...) in normal operation of NPPs

=> No clad failure expected in normal operation

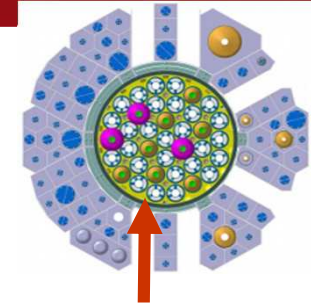
Designed with a large flexibility of use

- Adapted thermal-hydraulic conditions
 - ▶ PWR, BWR, **WWER** power systems
- Hosting capacity
 - ▶ High embarking capacity
 - ▶ Highly instrumented experiments
- Coolant chemistry specifications
 - ▶ Nominal chemistry (B, Li, H₂, noble metals...)
 - ▶ Innovative chemistry upon request

Possible rod configurations

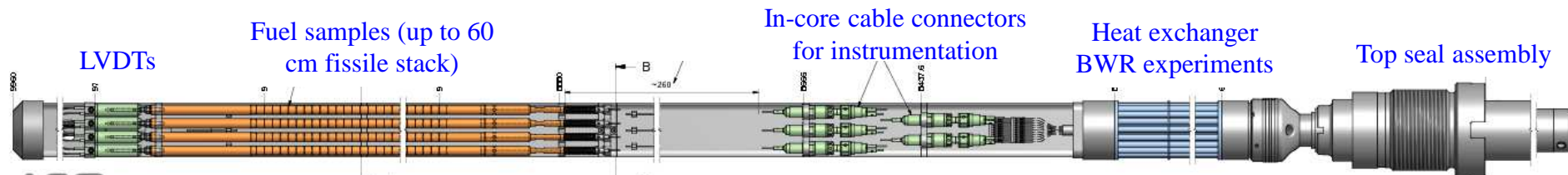
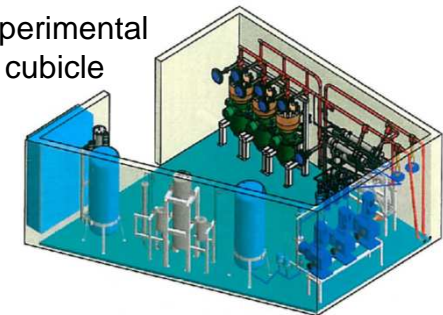


- Temperature measurement
- Clad thermocouple
- Clad Elongation
- Fuel Stack Elongation
- Fuel Plenum Pressure
- Neutron flux



In JHR reflector on a displacement system

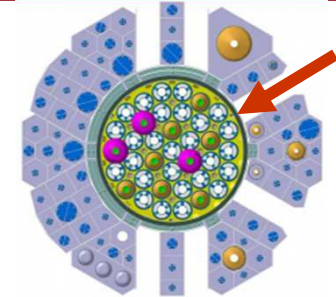
Experimental cubicle



Project Status

- Water loop / I&C systems/ Rig : Detailed Design Phase in progress (IFE, Halden, NO)
- Cubicle : Call for tender mid 2015 (detailed design, manufacturing, assembly on site)
- Pressure flask : Call for tender late 2015

For characterization and qualification of a single LWR fuel rod under off-normal conditions (clad failure = target or a real risk)

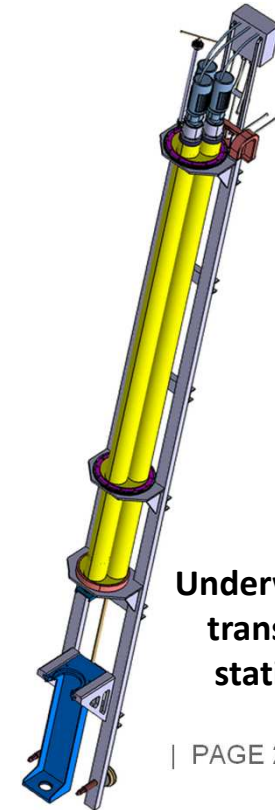
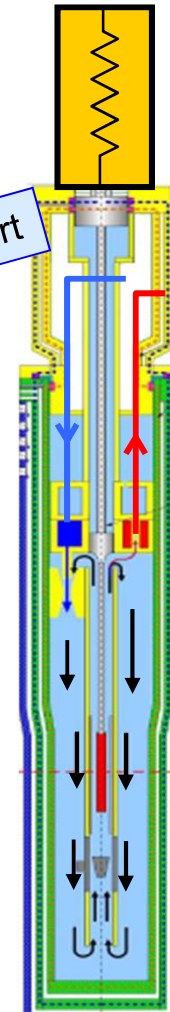


In JHR reflector on a displacement system

- Based on the OSIRIS feedback (ISABELLE 1 test device)
- **An In-pile part → 1st Rig designed for POWER RAMP TESTS**
 - ▶ Adapted to LWR geometries : PWR, BWR, **WWER**
 - ▶ Power ramp with high linear power up to 620 W/cm
 - ▶ High power ramp rate up to 700 W/cm.min
 - ▶ **Quantitative clad elongation measurement (2 LVDT)**
 - ▶ **Quantitative on-line gamma spectrometry system**
 - ▶ Up to 3 ramps / JHR cycle

With EDF support

In-pile part



Underwater transfer station

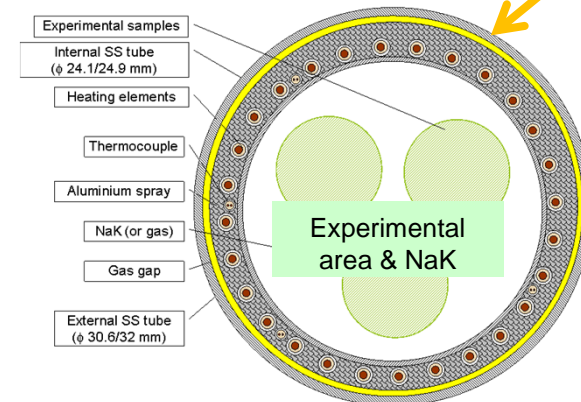
Project Status

- Nov. 2014 : Kick-off meeting with the contractor (detailed design, manufacturing, assembly & tests on site of the full test device)
- Dec. 2015 : End of the detailed design phase

Investigation of physical properties of materials (versus neutron flux, fluency and temperature)

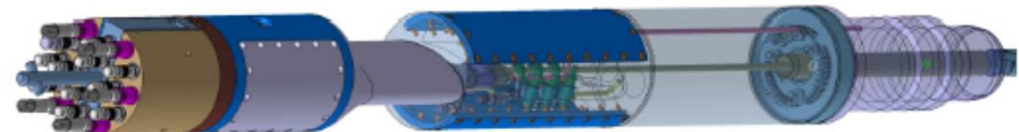
- Static NaK capsule
 - Based on the OSIRIS feedback (CHOUCA test device)
- In core location
 - Dose : up to 16 dpa/y (at 100 MWth)
- Sample temperature control (< 450°C):
 - Gamma heating
 - Gas gap dimension / nature of gas
 - Electric heating elements
- Sample holder (experimental area)
 - Outer diameter: 24 mm
 - Compromise between the number of samples and the quantity of instrumentation (TC, elongation sensor, diameter gauge, loading system...)

In core position
(central hole of a JHR fuel element)



Project Status

- Detailed design phase in progress (CEA)
- Call for tender late 2015 (manufacturing and tests on site)



■ Technical goals

- Study of LWR cladding irradiation creep
- Real time control of the biaxial stress + online measurement of the biaxial creep

■ OSIRIS environment

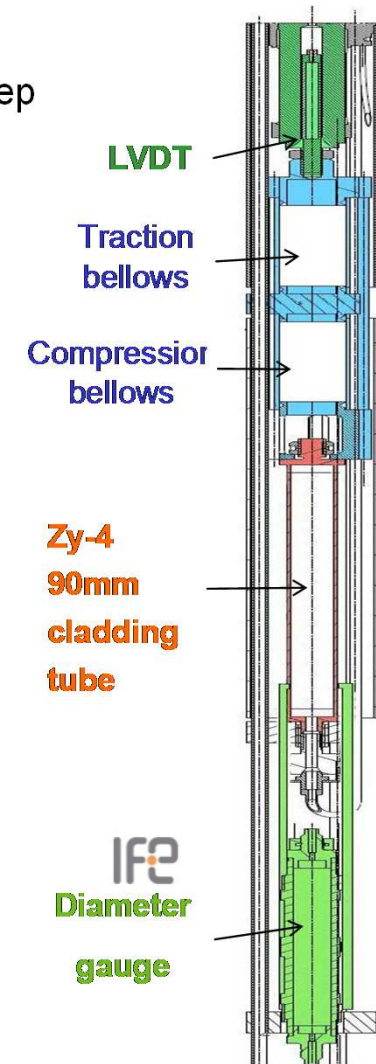
- Sample holder in a CHOUCA capsule → Similar to MICA capsule
- 350 °C, static NaK coolant → Similar to MICA capsule

■ Biaxial stress controlled in real time

- Specimen pressurization → Max pressure 160 bar
- Push-pull axial loading unit
- Hoop Stress limit: $\sigma_{\theta} = 120$ MPa, Axial stress limit: $\sigma_z = 180$ MPa

■ Online biaxial measurement of creep strain

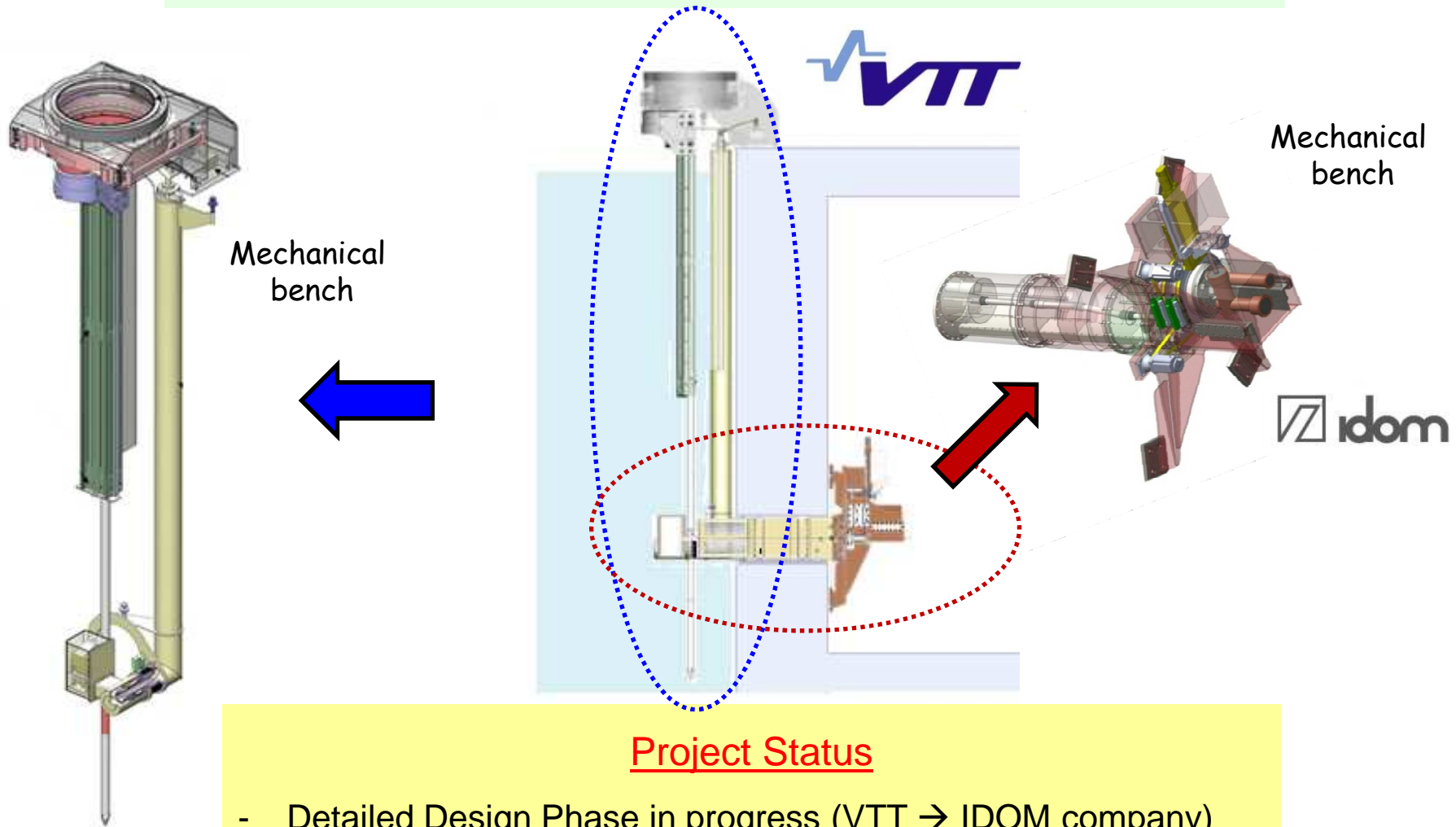
- Continuous measurement of axial strain with a 5-wire LVDT
- Periodical measurement of hoop strain with a diameter gauge (DG)



MELODIE Status

- Last tests of the device & sample holder in progress
- **First irradiation cycle in French MTR Osiris: Early May 2015**

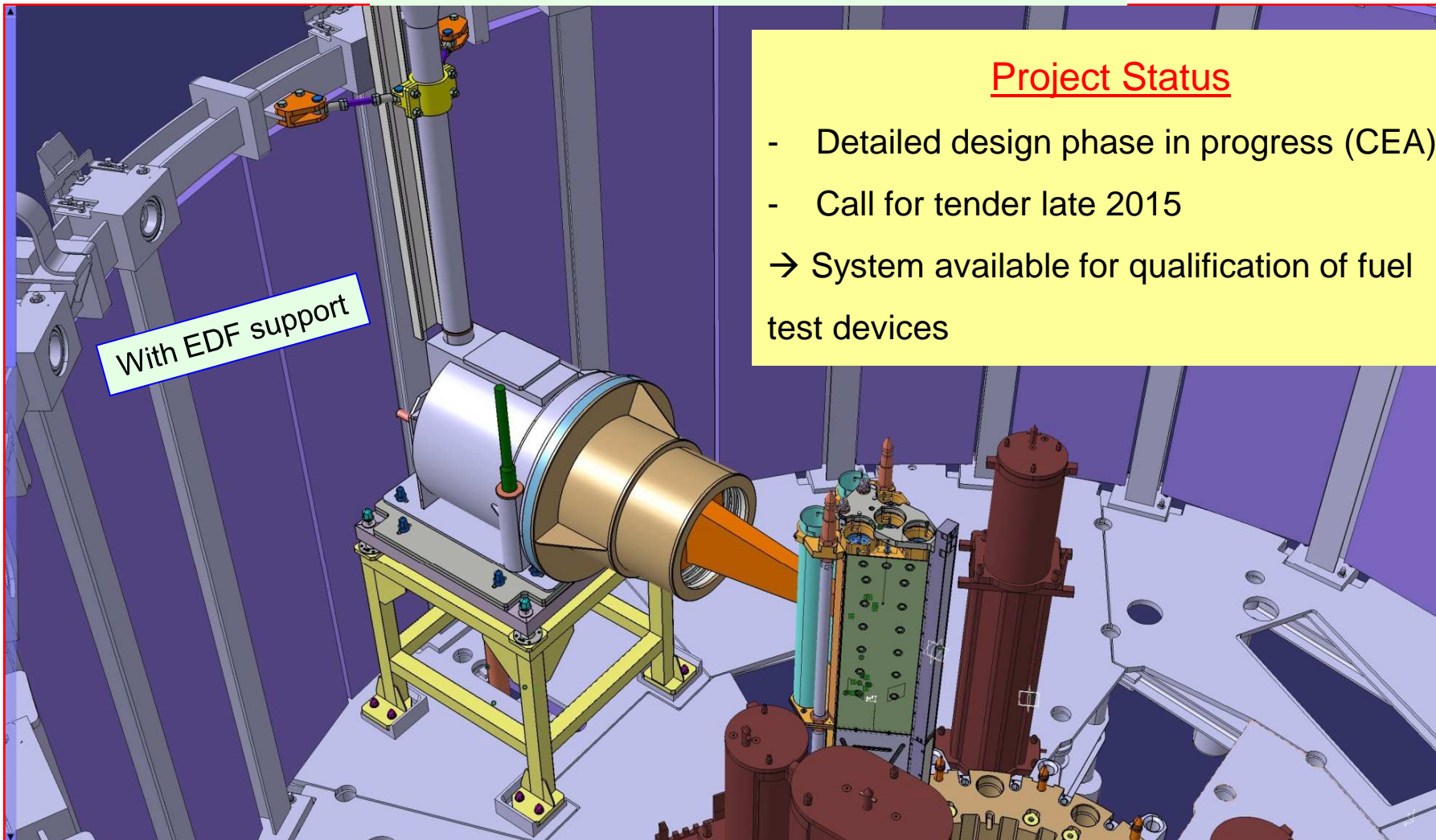
Underwater Gamma and X-Ray bench (UGXR)



Project Status

- Detailed Design Phase in progress (VTT → IDOM company)
- System available for qualification of fuel test devices

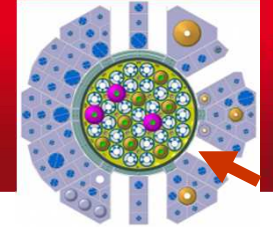
Neutron Imaging System (NIS)



Project Status

- Detailed design phase in progress (CEA)
- Call for tender late 2015
- System available for qualification of fuel test devices

- ❖ Reminder of JHR general characteristics
- ❖ JHR building status
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- ❖ Irradiation hosting systems available at the JHR start-up
- ❖ **Irradiation hosting systems available after the JHR start-up**
- ❖ Conclusion



→ Dedicated to investigation of **LOCA** mechanisms

LOCA type sequence on LWR single rod (incl. WWER)

- ▶ Thermal-mechanical behaviour of fuel
- ▶ Fissile stack evolution, fuel fragmentation and release
- ▶ Radiological consequences

Integrated water loop capsule (single fuel rod)

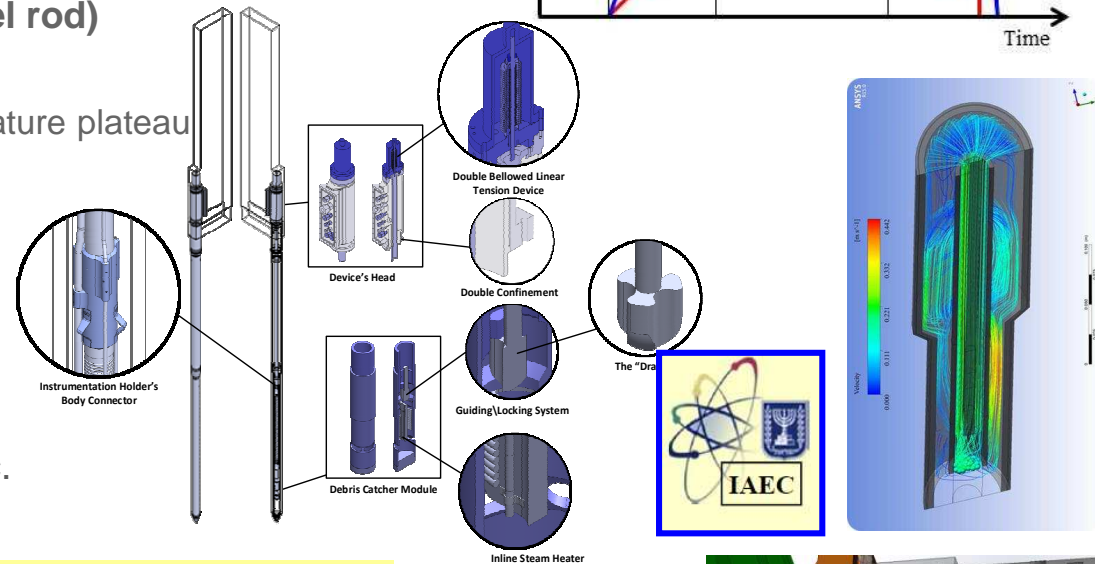
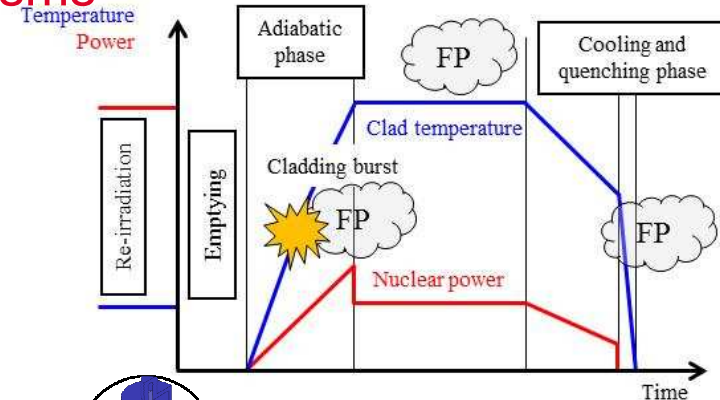
- ▶ Re-irradiation phase
- ▶ Dry out phase (He injection) + High temperature plateau
- ▶ Quenching phase (water injection)

Fission Product release analysis

- ▶ Connection to the JHR FP Laboratory

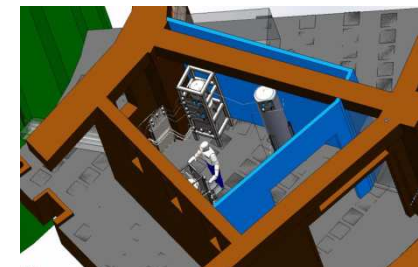
On-site examinations

- ▶ X-Ray tomography, Gamma scanning etc.
- ▶ Fuel "as tested" (minimum handling)



Project Status

- Preliminary Design Review in January 2014
- Detailed design in progress (review Early 2016)



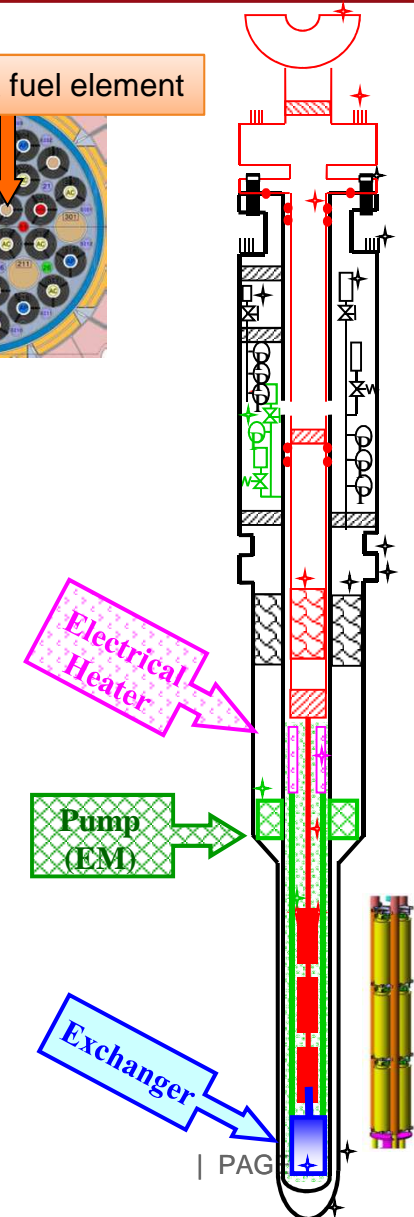
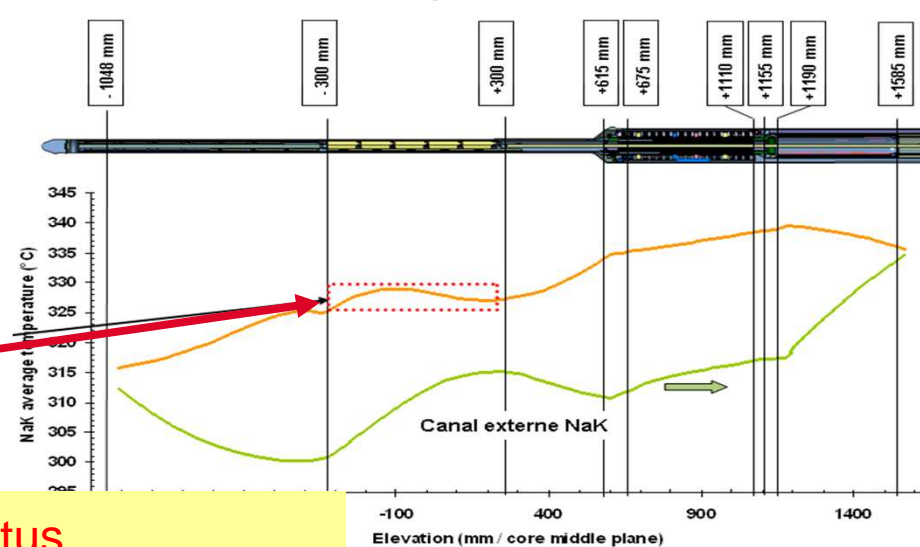
- Thermodynamic loop integrated within the test device
 - Circulating NaK → NaK flow (2 m³/h)
 - Heat Exchanger (HE) / Electrical Heater (EH)
 - Innovative electromagnetic pump (L 450 mm, D 80 mm)



Up to 16 dpa/year

- Improvement of the sample temperature control
 - From 250 up to 450°C (setting of HE & EH parameters)
 - Temperature homogeneity between samples
 - $\Delta\theta < 8^\circ\text{C}$ (Tmax – Tmin all along the samples stack)

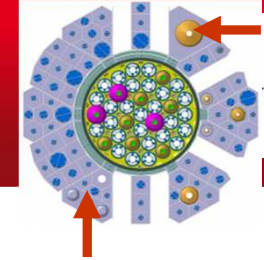
In the center of a fuel element



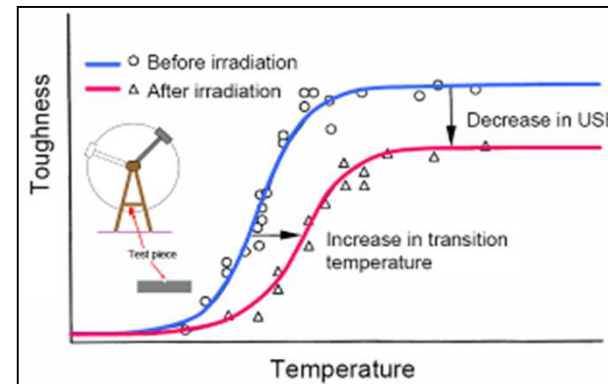
Project Status

- Basic design phase in progress at CEA
- Feedback from MICA hosting system design

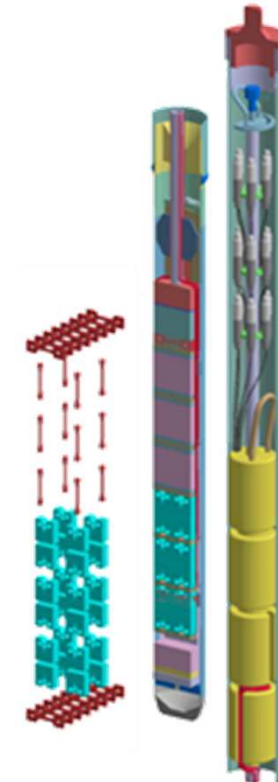
PHYSICAL PROPERTIES OF NPP PRESSURE VESSELS STEELS UNDER LOW DPA: THE OCCITANE HOSTING SYSTEM



- Static Helium capsule
 - Based on the OSIRIS feedback (IRMA test device, 150 irradiation cycles)
- In-reflector fixed location
 - Dose : up to 100 mdpa/y (1 MeV)
- Samples temperature adjustment
 - Various materials (WWER...)
 - 230- 300°C
 - Gamma heating
 - Gas gap dimension
 - Electric heating elements
- At least, 18 thermocouples, and 45 dosimeters



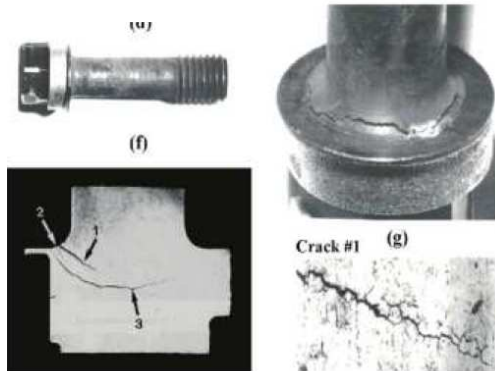
- ✓ Equivalent carrying volume: 30x62.5x500mm³
- ✓ Helium gas
- ✓ 230 – 300°C (furnace with 6 heating zones)
- ✓ 100 mdpa/year



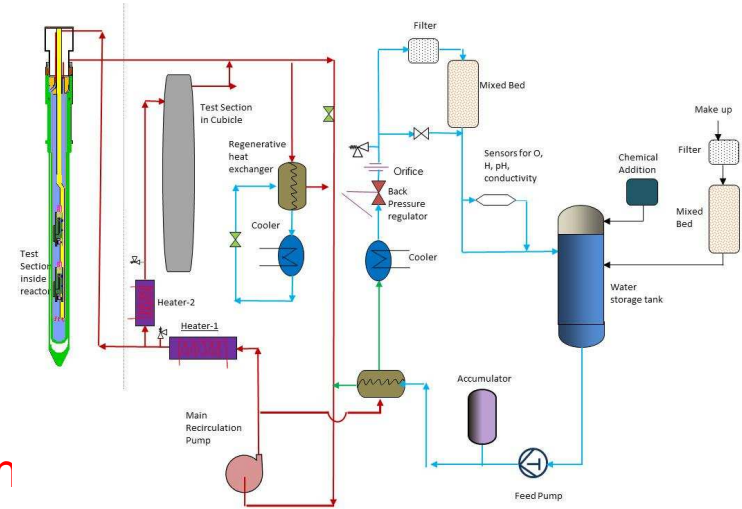
Project Status

- Feasibility study in 2013
- Next design phase adapted to customer requirements (temperature and gradients, neutron flux, sample holder section...)

From R. Staehle

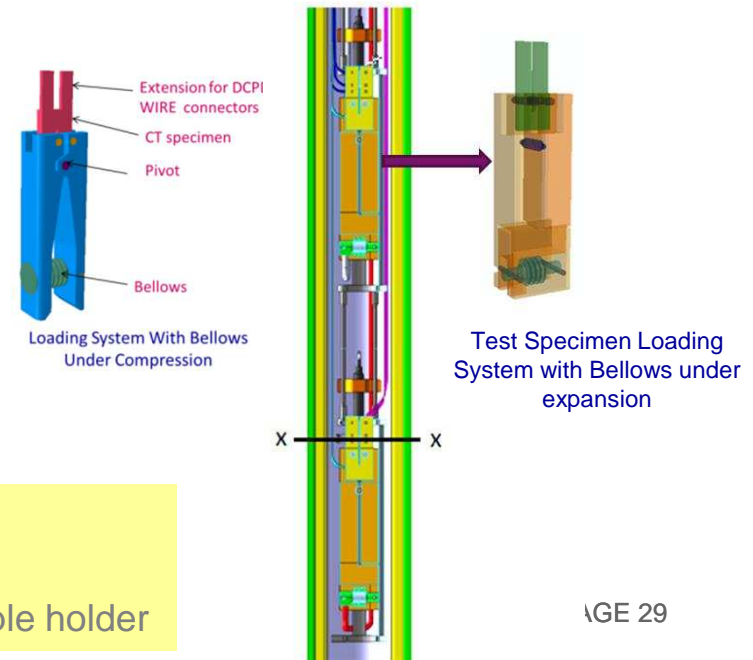


Localized corrosion phenomena can be a strong issue in some LWRs !!



CLOE designed to perform integral experiments on crack initiation and crack propagation

- **LWR conditions:** well controlled and adjusted water chemistry, temperatures, ...
- Fixed location (in reflector or in core)
- In-situ measurements: ECP, pH, H₂, load, LVDT, cracking propagation, DCPD



Project Status



- Preliminary design in progress at DAE/BARC: loop and sample holder

- ❖ JHR facility : a Material Testing Reactor designed
 - With the most recent technological developments (materials, instrumentation, I&C)
 - In a up-to-date safety frame (post-Fukushima)

- ❖ Operation as an international User's facility
 - JHR Consortium and international programs
 - Bilateral or multilateral programs
 - Key-stone for CEA candidacy as an "ICERR"
 - Welcome of scientists, engineers, operators, safety managers... in JHR teams

- ❖ Experimental capacity in support of fuel & materials irradiation pgs
 - Benefiting from OSIRIS and other facilities operational experience and knowhow
 - Integrating improvements from the JHR Consortium partners (on-line measurements, innovative technologies...)

- ❖ **Experimental capacity devoted in priority to LWR experiments**
 - **Fully compatible with WWER fuel rods and samples**
 - **Able to reproduce WWER irradiation parameters and environment**

*Thank you
for your attention !*



Commissariat à l'énergie atomique et aux énergies alternatives
Fuel Research Department (DEC)
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**Nuclear Energy Division
(DEN)**

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