

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

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The future Jules Horowitz Material Testing Reactor (JHR)

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

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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)

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CONTENTS

Réacteur Jules Horowitz Reactor

- 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 ava
- Conclusion

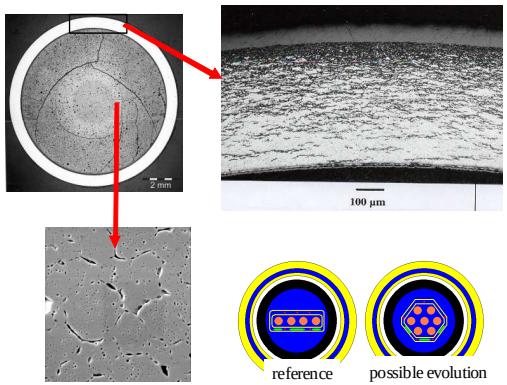
WWER Fuel Performance Meeting,
Burgas, Sept. 2011



JHR MAIN OBJECTIVES

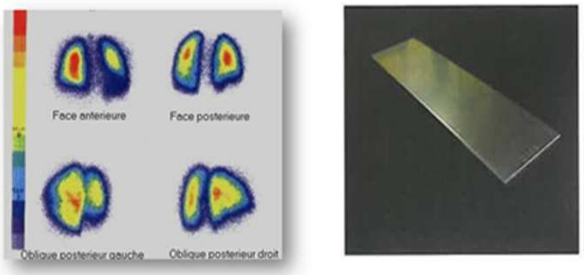
1. R&D in support to nuclear Industry

- 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**



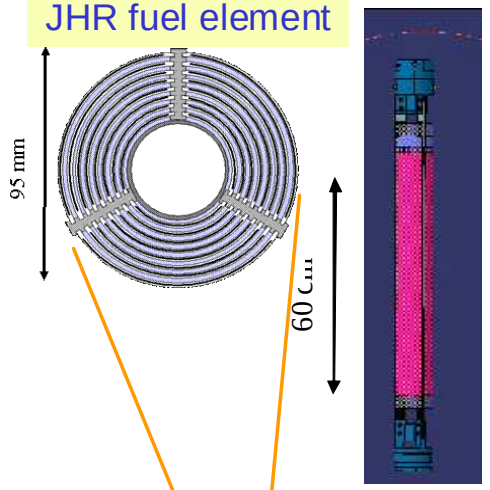
JHR: A 100 MWth POOL-TYPE LIGHT WATER MTR OPTIMIZED FOR FUEL AND MATERIAL TESTING

Hot cells (non destructive examinations)

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

Reactor block

JHR fuel element



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

Storage pools

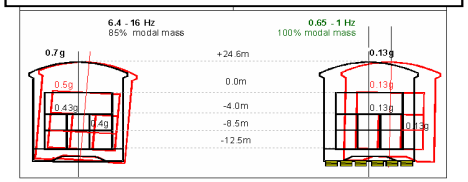
Experimental cubicles and analysis laboratories

Reactor pool with examination benches

Water channels in Be reflector

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

About 200 aseismic pads



Core Designed for UMo-Al fuel (70 MWth / 100 MWth)
Start-up with U_3Si_2-Al fuel

JHR: MAIN BUILDINGS ON SITE

BR (reactor building)

BAN (nuclear auxiliary building)

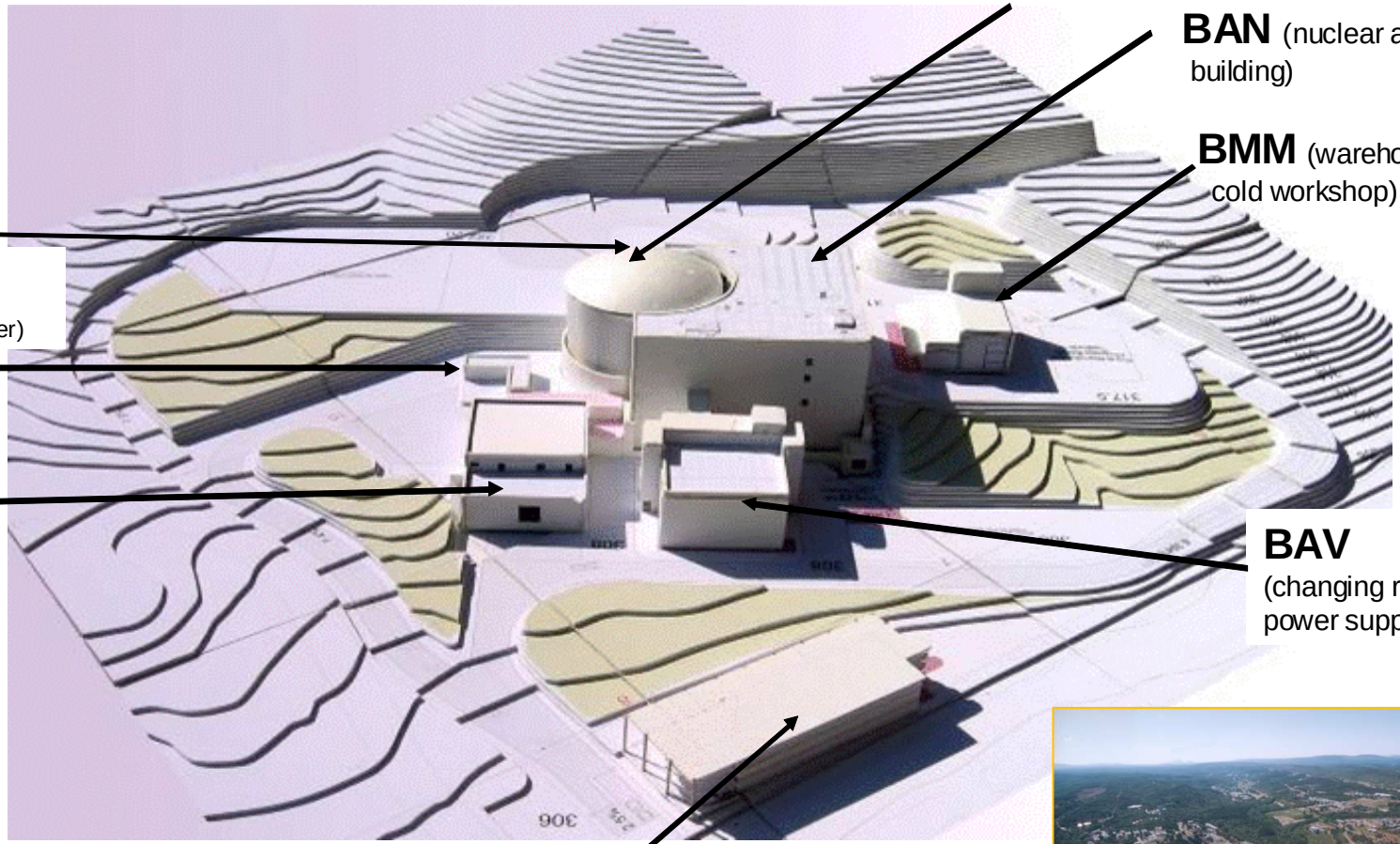
BMM (warehouse and cold workshop)

BAS B

Emergency systems (diesel generator sets and atm. heat exchanger)

BAS A

BMR
(cooling system)



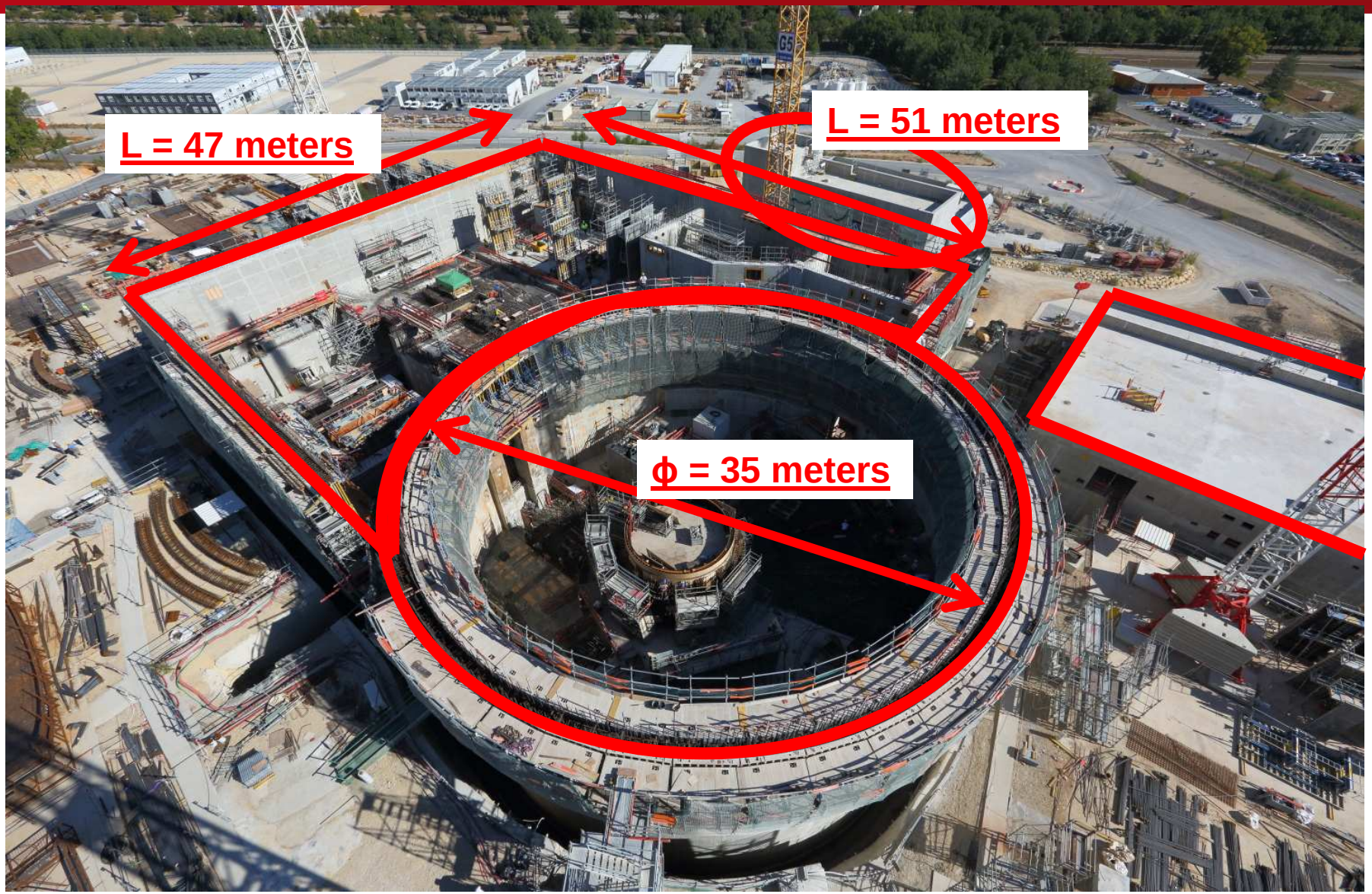
BAV
(changing rooms+ power supply)

BMX (offices)



CEA Cadarache

GENERAL VIEW OF JHR BUILDING SITE FEBRUARY 2013



POURING OF THE REACTOR BUILDING DOME (7-8 JANUARY 2015)

Duration: about 20 hours, with an average rate of 36 m^3 / 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









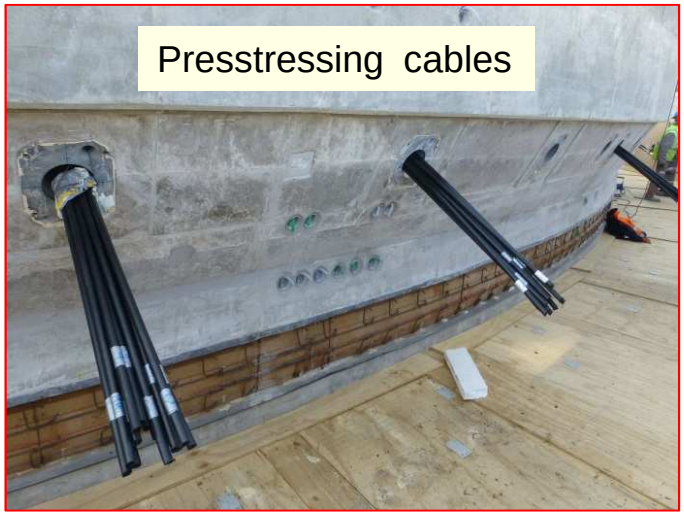
CIVIL WORKS: PREPARATORY WORK FOR THE REACTOR BUILDING PRE-STRESS (FEBRUARY 2015)



Implementation of presstressing cables

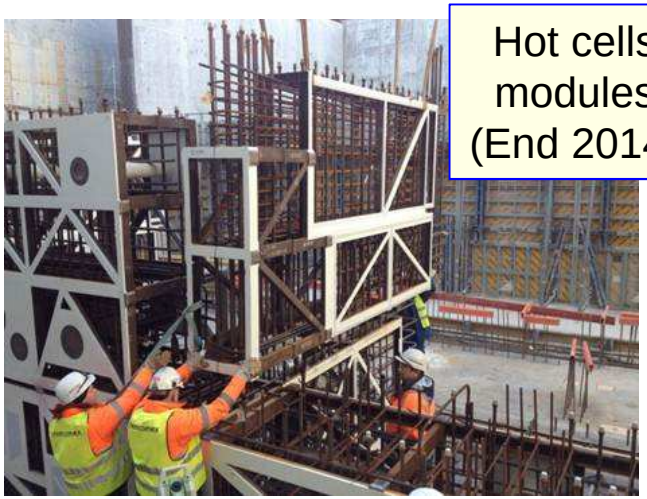


Presstressing cables





REACTOR BUILDING: MAIN EQUIPMENT MANUFACTURING AND INSTALLATION



Hot cells modules (End 2014)





Reactor block components (Spring 2015)



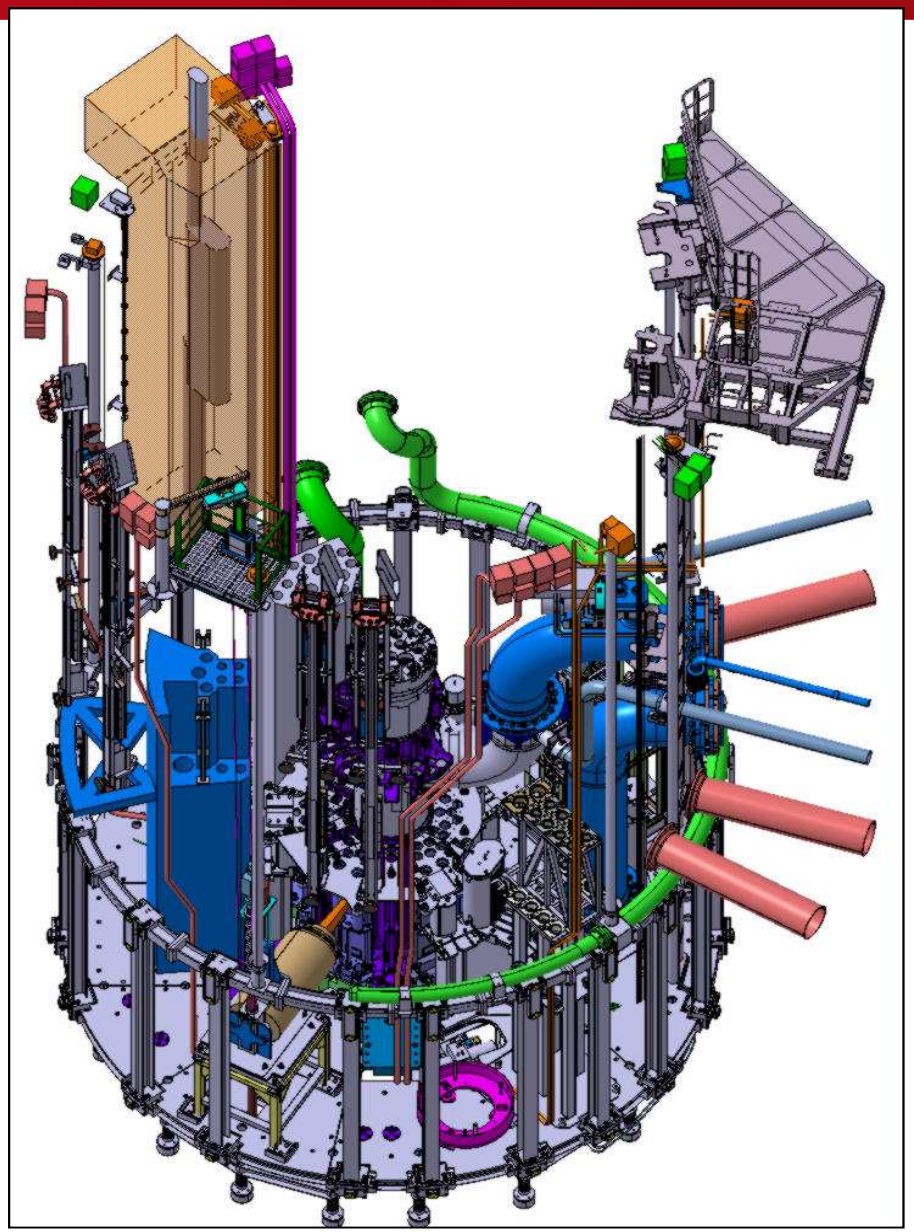
RER pool base welding (October - November 2014)





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

DECEMBER 18-19TH 2014: SUCCESS OF DETAILED DESIGN REVIEW FOR REACTOR BLOCK



REALIZATION

PHASE STARTING

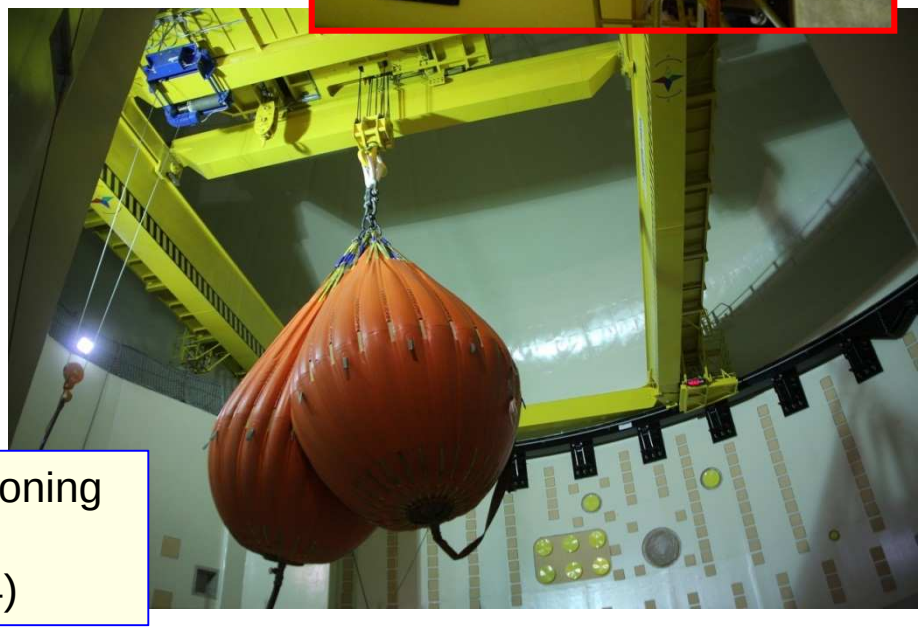
Important milestone !

COMMISSIONING TESTS FOR OTHER EQUIPMENT



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





Polar crane commissioning tests at full load (November 2014)

JHR REALIZATION PLANNING

- 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

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

VATTENFALL

AREVA

EDF

Ciemat
Centro de Investigaciones Energéticas, Medioambientales y Tecnológicas

SCK • CEN
STUDIECENTRUM VOOR KERNENERGIE
CENTRE D'ÉTUDE DE L'ÉNERGIE NUCLÉAIRE

cea

VTT

ÚJV

DAE

IAEC

Associated Partnership: JAEA

NATIONAL NUCLEAR LABORATORY

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

JHR CONSORTIUM : ECONOMICAL MODEL FOR INVESTMENT AND OPERATION

- 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

THE JHR AND ITS ANCILLARY FACILITIES TOWARDS AN "ICERR" (1/2)

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

ICERR (International CEnter based on Research Reactors)

IAEA International Atomic Energy Agency

- 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…)

THE JHR AND ITS ANCILLARY FACILITIES TOWARDS AN "ICERR" (2/2)

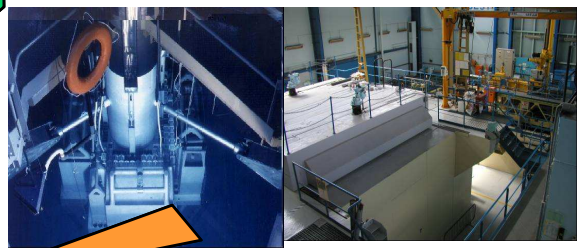
LECI : Hot Lab on Materials
- Hands-On Training (Equipments)
- R&D Projects





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

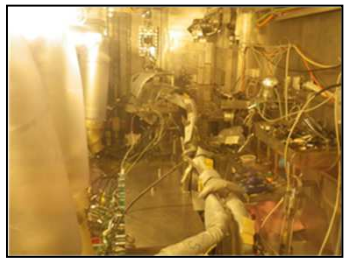
ZEPHYR : LPR





New Projects

LECA : Hot Lab on Fuel
- R&D Projects
- Hands-On Training (Equipments)

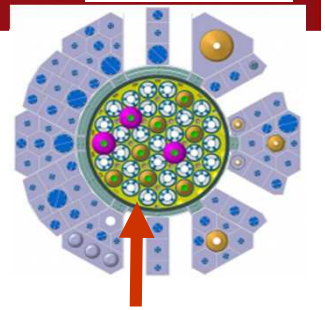


- Reminder of JHR general characteristics
- JHR building status
- JHR operation as an international User Facility
- **Irradiation hosting systems available at the JHR start-up**
- Irradiation hosting systems available after the JHR start-up
- Conclusion

FUEL TESTING: The MADISON HOSTING SYSTEM

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

=> No clad failure expected in normal operation

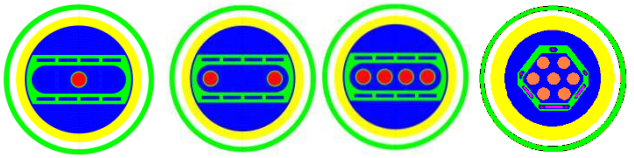


In JHR reflector on a displacement system

Designed with a large flexibilty 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, H_2, noble metals…)
  - Innovative chemistry upon request

Possible rod configurations



Temperature measurement

Clad thermocouple

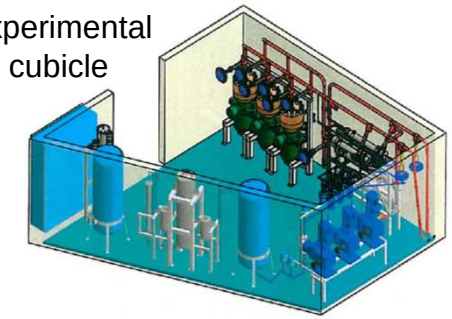
Clad Elongation

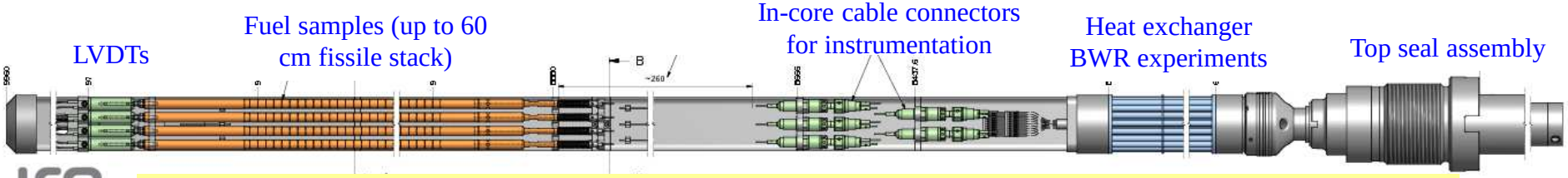
Fuel Stack Elongation

Fuel Plenum Pressure

Neutron flux

Experimental cubicle



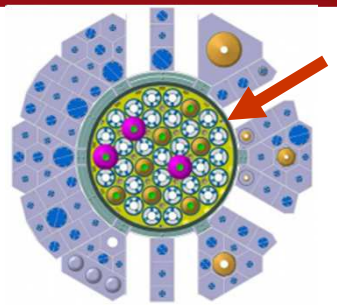


Project Status

- 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

FUEL TESTING: THE ADELINE HOSTING SYSTEM

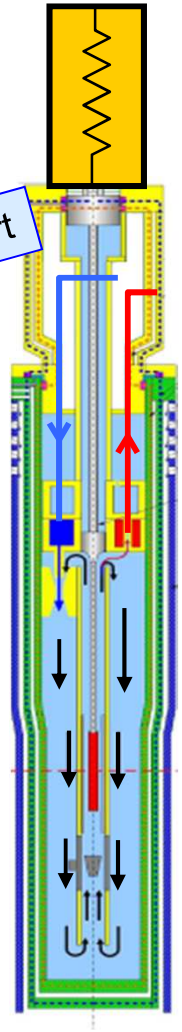
For characterization and qualification of a single LWR fuel rod under off-normal conditions (clad failure = target or a real risk)



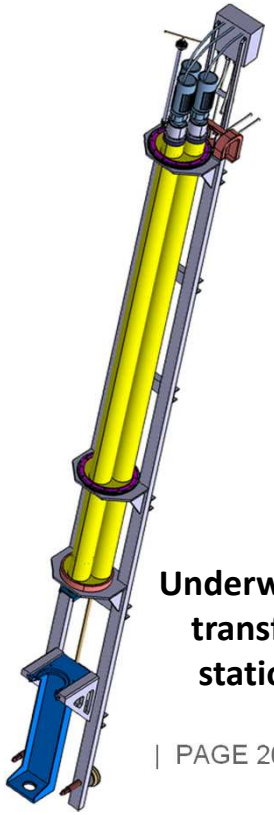
In JHR reflector on a displacement system

- 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

CIMAT DEMA Cegelec

MATERIALS TESTING: THE MICA HOSTING SYSTEM

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

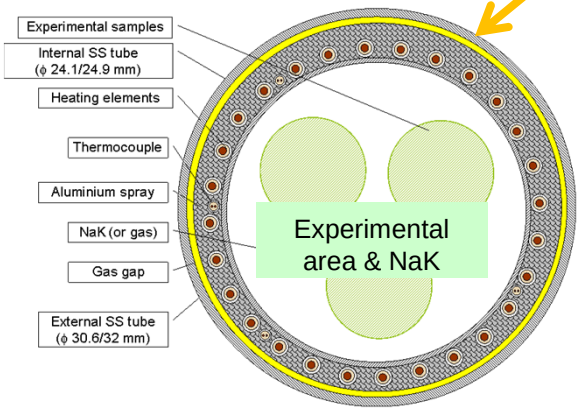
- Static NaK capsule
  - Based on the OSIRIS feedback (CHOUCA test device)
- In core location
  - Dose : up to 16 dpa/y (at 100 MWth)
- Sample temperature control (< 450°C):
  - Gamma heating
  - Gas gap dimension / nature of gas
  - Electric heating elements
- Sample holder (experimental area)
  - Outer 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









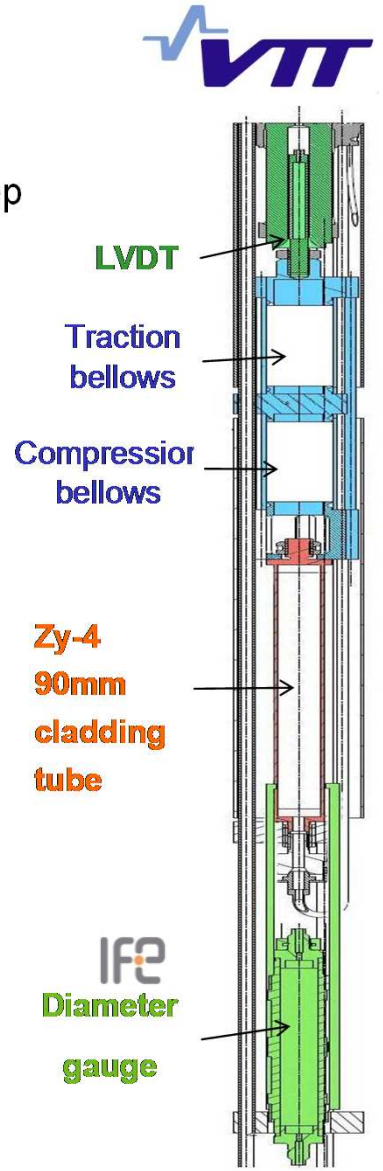


Project Status

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

MELODIE: A CHALLENGING EXPERIMENT TO PREPARE MICA INSTRUMENTED RIGS

- 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: 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 (DG)

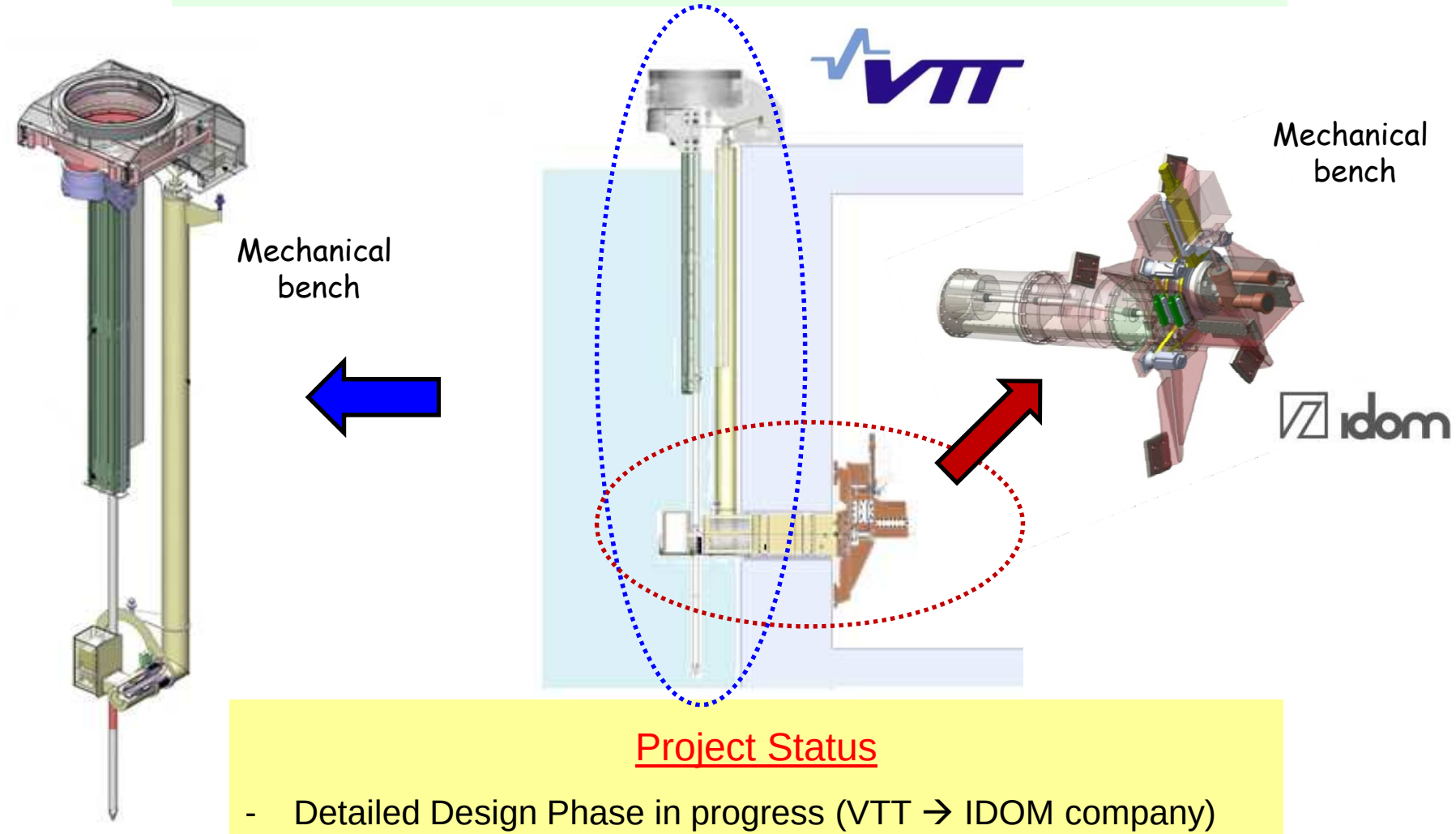


MELODIE Status

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

NON-DESTRUCTIVE EXAMINATION BENCHES IN SUPPORT TO THE EXPERIMENTAL PROCESS (1/2)

Underwater Gamma and X-Ray bench (UGXR)



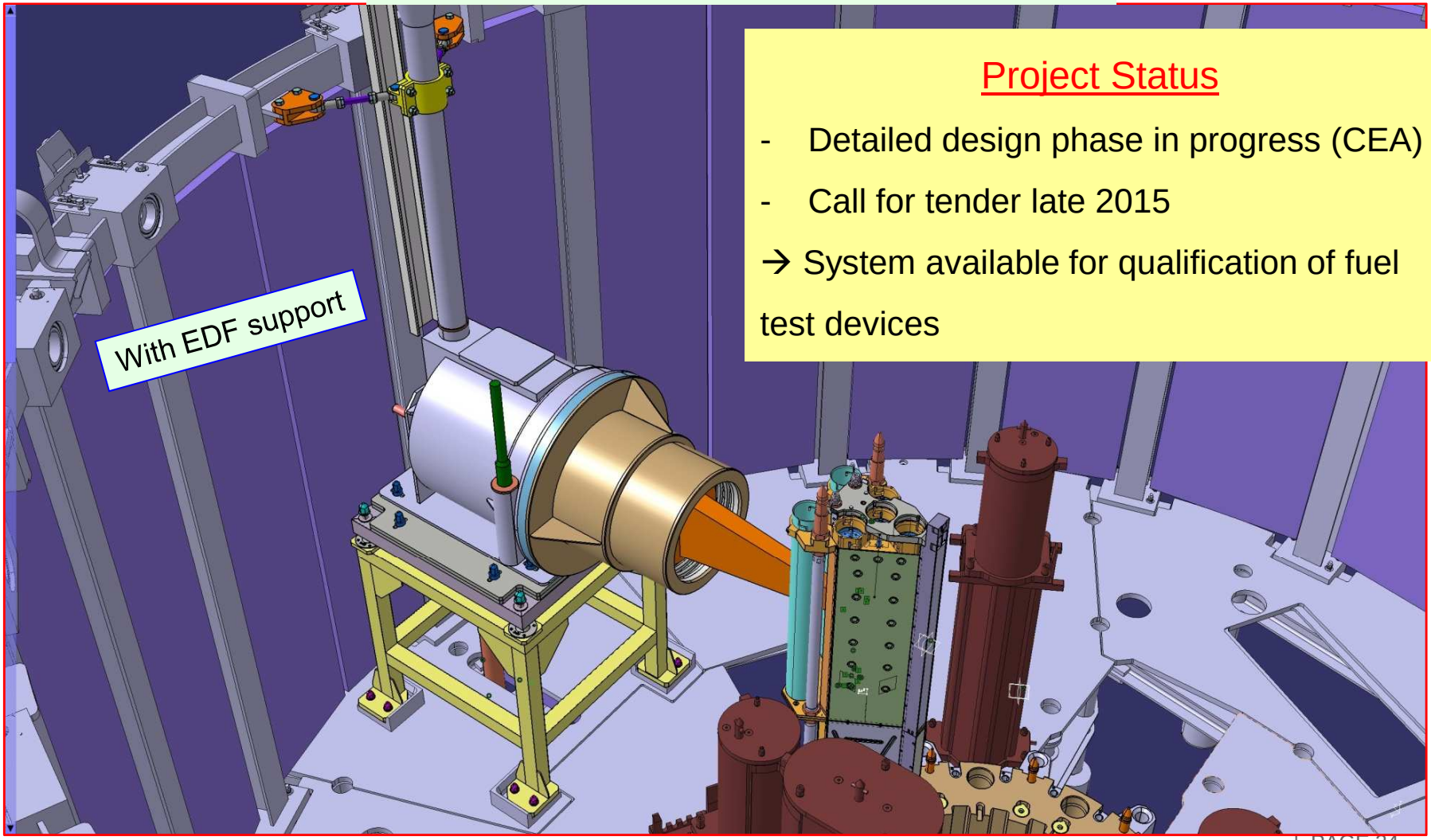
Project Status

- Detailed Design Phase in progress (VTT → IDOM company)

→ System available for qualification of fuel test devices

NON-DESTRUCTIVE EXAMINATION BENCHES IN SUPPORT TO THE EXPERIMENTAL PROCESS (2/2)

Neutron Imaging System (NIS)



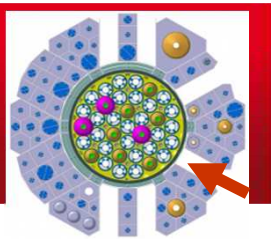
Project Status

- Detailed design phase in progress (CEA)
- Call for tender late 2015

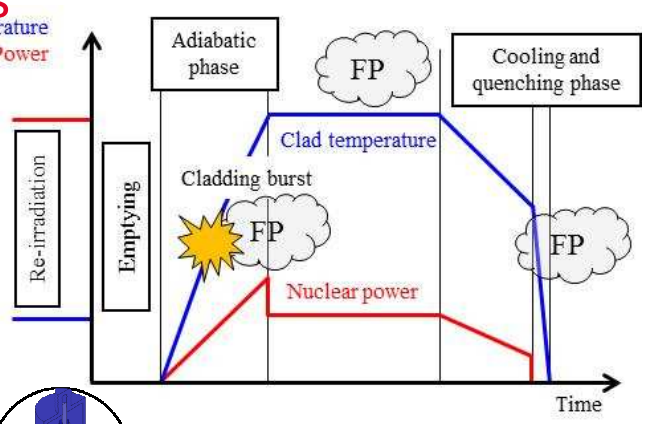
→ System available for qualification of fuel test devices

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

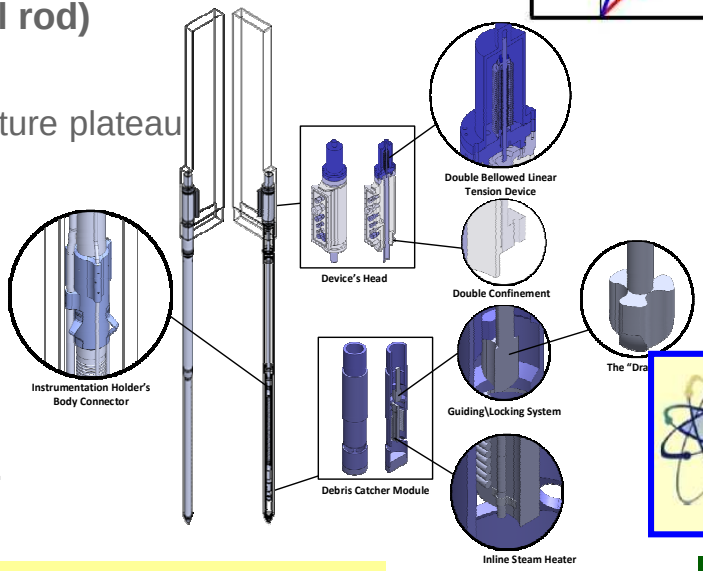
FUEL TESTING IN ACCIDENTAL CONDITIONS: THE LORELEI HOSTING SYSTEM

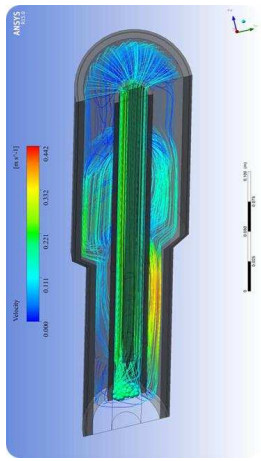


→ Dedicated to investigation of **LOCA** mechanisms



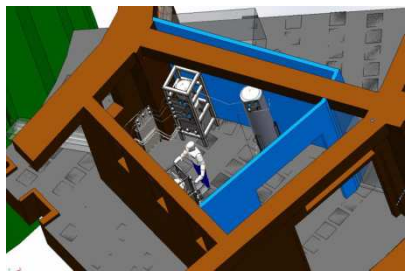
- **LOCA type sequence on LWR single rod (incl. WWER)**
  - Thermal-mechanical behaviour of fuel
  - Fissile stack evolution, fuel fragmentation and release
  - Radiological consequences
- **Integrated water loop capsule (single fuel rod)**
  - Re-irradiation phase
  - Dry out phase (He injection) + 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)**



MATERIALS TESTING UNDER HIGH DPA: THE CALIPSO HOSTING SYSTEM

- Thermodynamic loop integrated within the test device
  - Circulating NaK → NaK flow (2 m^3/h)
  - Heat Exchanger (HE) / Electrical Heater (EH)
  - Innovative electromagnetic pump (L 450 mm, D 80 mm)

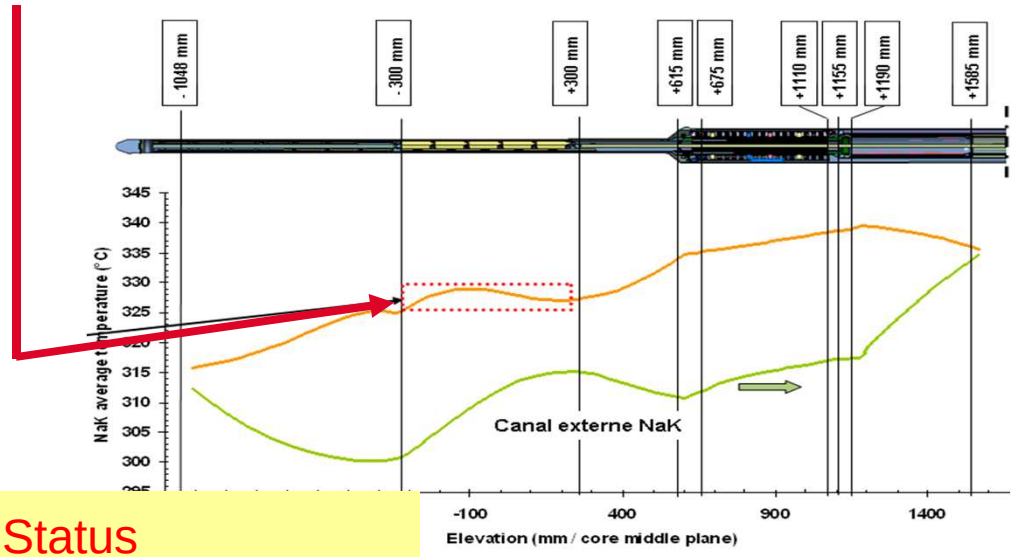


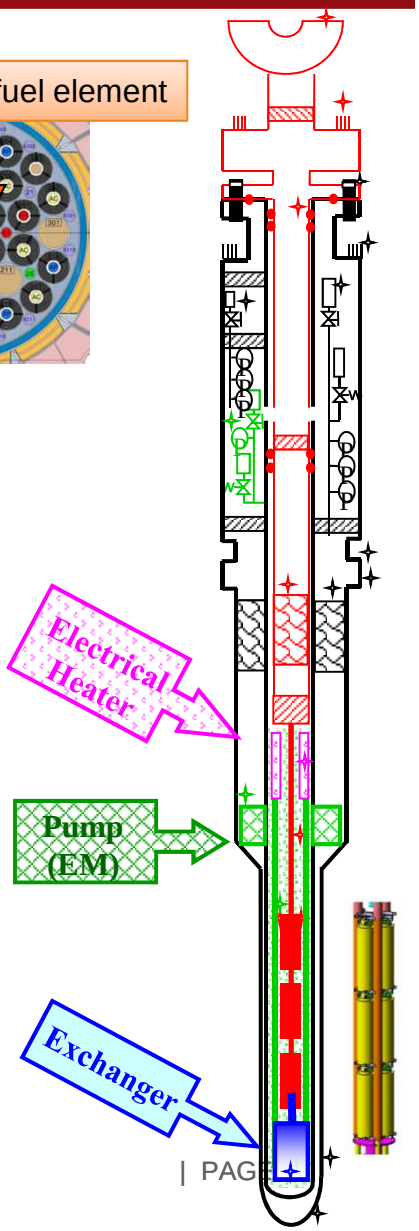
In the center of a fuel element



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
  - Δθ < 8°C (Tmax – Tmin all along the samples stack)

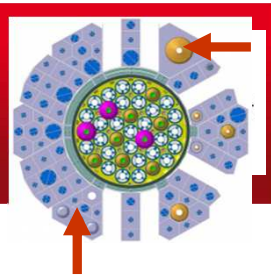




Project Status

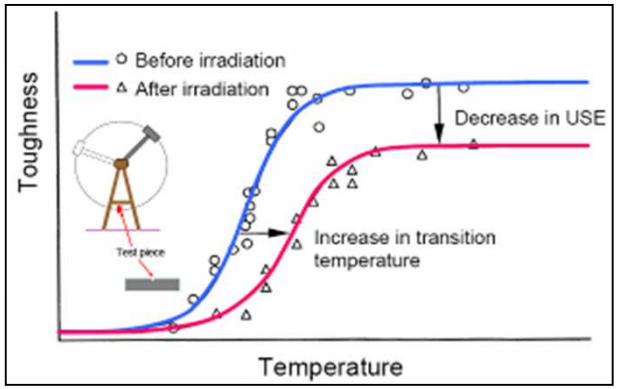
- Basic design phase in progress at CEA
- Feedback from MICA hosting system design

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

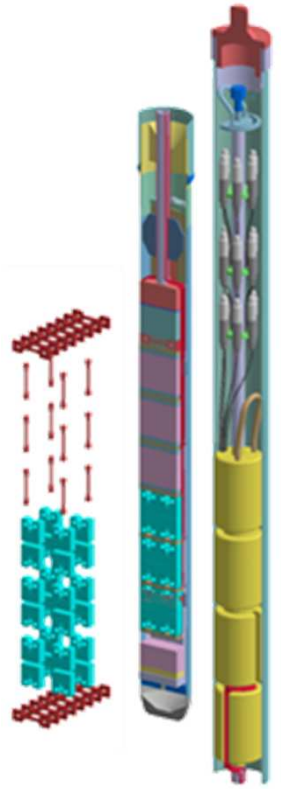


- Static Helium capsule
  - Based on the OSIRIS feedback (IRMA test device, 150 irradiation cycles)
- In-reflector fixed location
  - Dose : up to 100 mdpa/y (1 MeV)
- Samples temperature adjustment
  - Various materials (WWER…)
  - 230- 300°C
  - Gamma heating
  - Gas gap dimension
  - Electric heating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





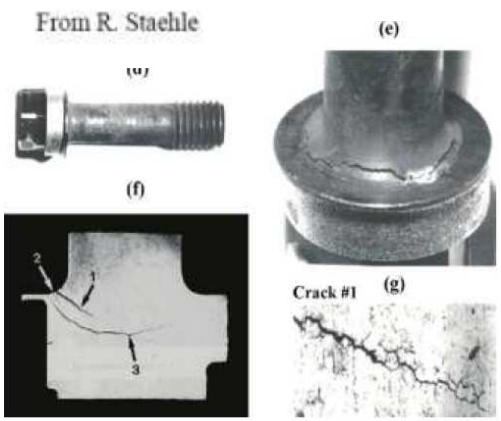
- ✓ Equivalent carrying volume: 30x62.5x500mm^3
- ✓ **Helium** gas
- ✓ **230 – 300°C** (furnace with 6 heating zones)
- ✓ **100 mdpa/year**



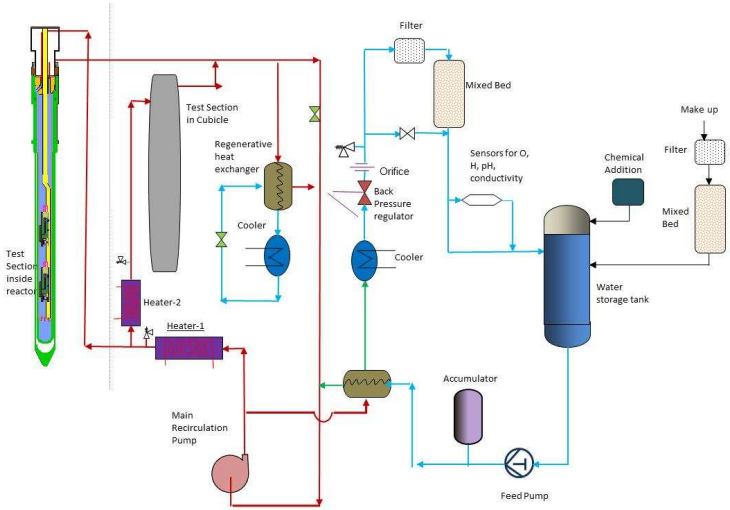
Project Status

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

CORROSION LOOP: THE CLOE HOSTING SYSTEM

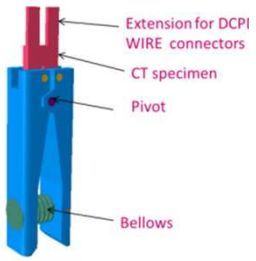


Localized corrosion phenomena can be a strong issue in some LWRs !!

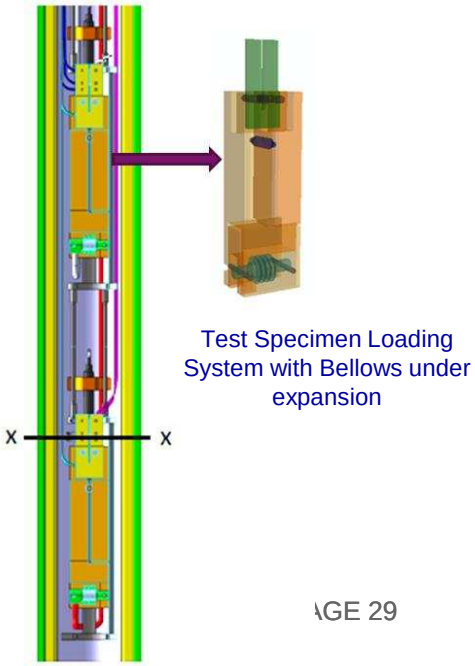


CLOE designed to perform integral experiments on crack initiation and crack propagation

- LWR conditions: well controlled and adjusted water chemistry, temperatures, …
- Fixed location (in reflector or in core)
- In-situ measurements: ECP, pH, H_2, load, LVDT, cracking propagation, DCPD



Loading System With Bellows Under Compression



Test Specimen Loading System with Bellows under expansion

Project Status

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

CONCLUSION

- 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
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Nuclear Energy Division (DEN)