



# **Future MTR capabilities Jules Horowitz ReactoretIn-core instrumentation for MTR experiments**

J.-F. Villard, G. Bignan

## **► To cite this version:**

J.-F. Villard, G. Bignan. Future MTR capabilities Jules Horowitz ReactoretIn-core instrumentation for MTR experiments. ICTP/IAEA Workshop “Research Reactors for Development of Materials and Fuels for Innovative Nuclear Energy Systems”, Nov 2017, Trieste, Italy. hal-02416242

**HAL Id: hal-02416242**

**<https://hal.science/hal-02416242>**

Submitted on 17 Dec 2019

**HAL** is a multi-disciplinary open access archive for the deposit and dissemination of scientific research documents, whether they are published or not. The documents may come from teaching and research institutions in France or abroad, or from public or private research centers.

L'archive ouverte pluridisciplinaire **HAL**, est destinée au dépôt et à la diffusion de documents scientifiques de niveau recherche, publiés ou non, émanant des établissements d'enseignement et de recherche français ou étrangers, des laboratoires publics ou privés.

# Future MTR capabilities : Jules Horowitz Reactor

**Jean-François VILLARD, Gilles BIGNAN**

French alternative energies and atomic energy commission  
Nuclear Energy Division – Reactor Studies Department  
Cadarache – F-13108 St Paul Lez Durance, France

Joint ICTP/IAEA Workshop “Research Reactors for Development of  
Materials and Fuels for Innovative Nuclear Energy Systems”

6-10 November 2017, ICTP - Trieste, Italy

## Summary

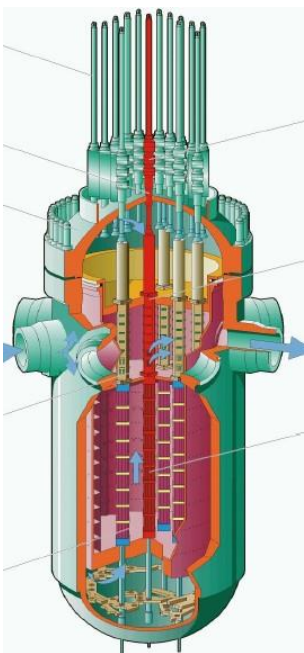
1. Context and objectives of the JHR
2. General figures of the JHR
3. Experimental capabilities of the JHR
4. JHR consortium and collaborations
5. Status of the reactor construction

# **1. Context and objectives of the JHR**

# 1. Context and objectives of the JHR

## In-pile testing in support of the nuclear Industry

Just for France, 58 NPPs means more than 10 000 fuel assemblies under irradiation at a time...



The fuel has to be carefully designed, with enough **Safety Analysis Design Margins**

+ **new fuel managements**

+ **new LWR standards...**

→ need to generate additional margins



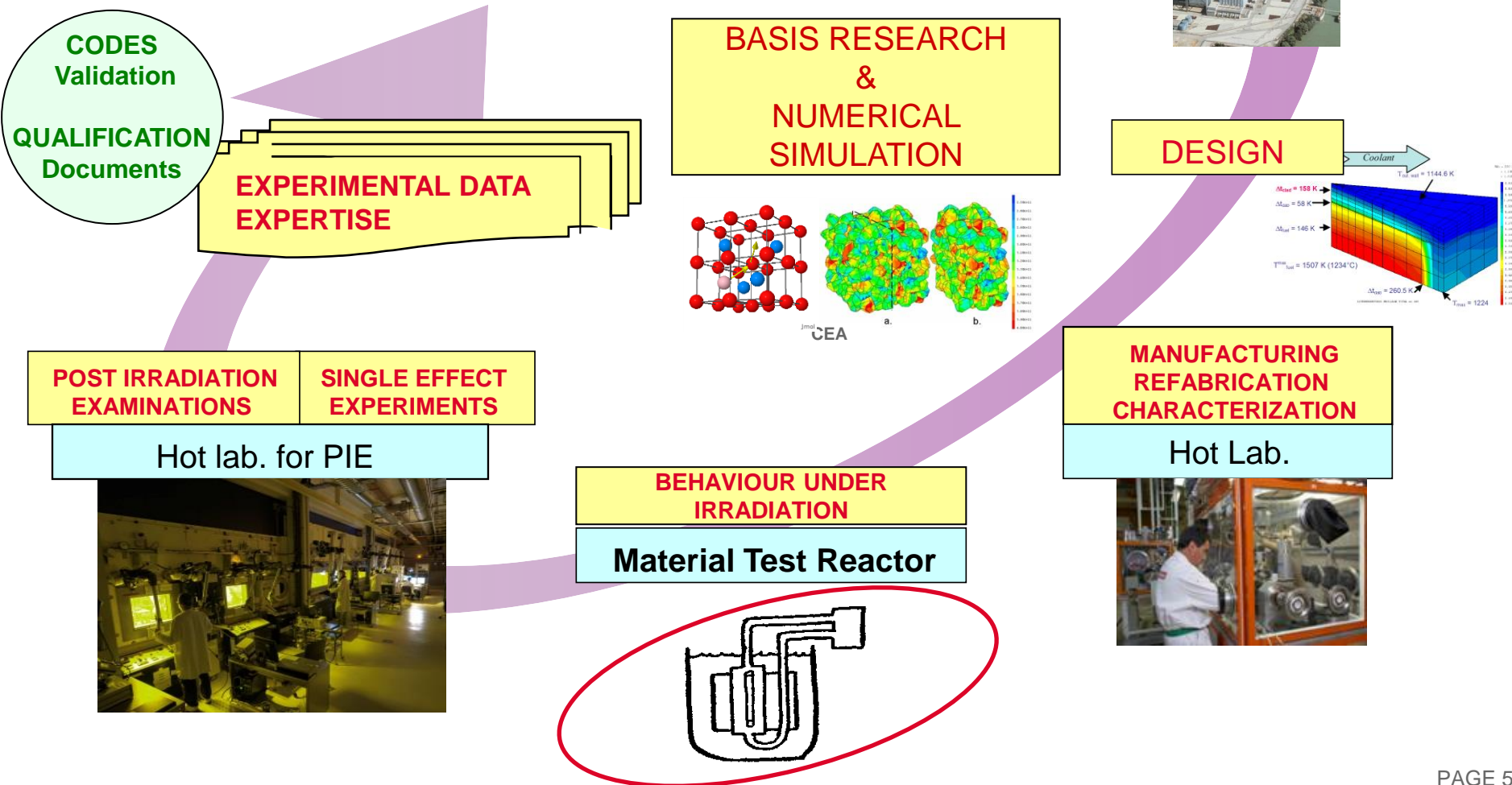
1. **Improve Modeling, Calculation tools and Testing**
2. **Improve Safety Analysis design Methods**
3. **Improve Fuel Product**



**In-pile data required !**

# 1. Context and objectives of the JHR

## The Key-Role of Material Testing Reactors for Fuel and Material qualification under irradiation

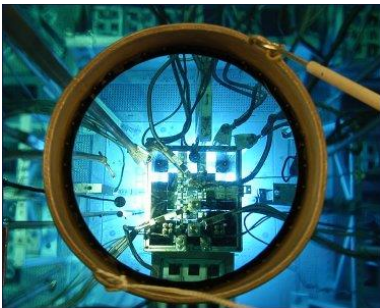


# 1. Context and objectives of the JHR

## MTRs in France



**SILOE**  
*Shutdown 1997*



**OSIRIS**  
*Shutdown 2015*



**PHENIX**  
*Shutdown 2010*



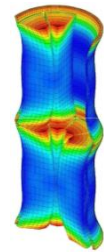
# 1. Context and objectives of the JHR



## Jules Horowitz Reactor Main objectives

### 1. R&D in support to nuclear Industry

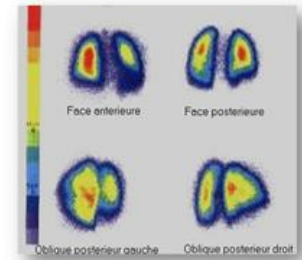
- Safety and Plant life time management (ageing & new plants)
- Fuel behavior validation in incidental and accidental situation
- Assess innovations and related safety for future NPPs



### 2. Radio-isotopes supply for medical application

#### ■ $^{99}\text{Mo}$ 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

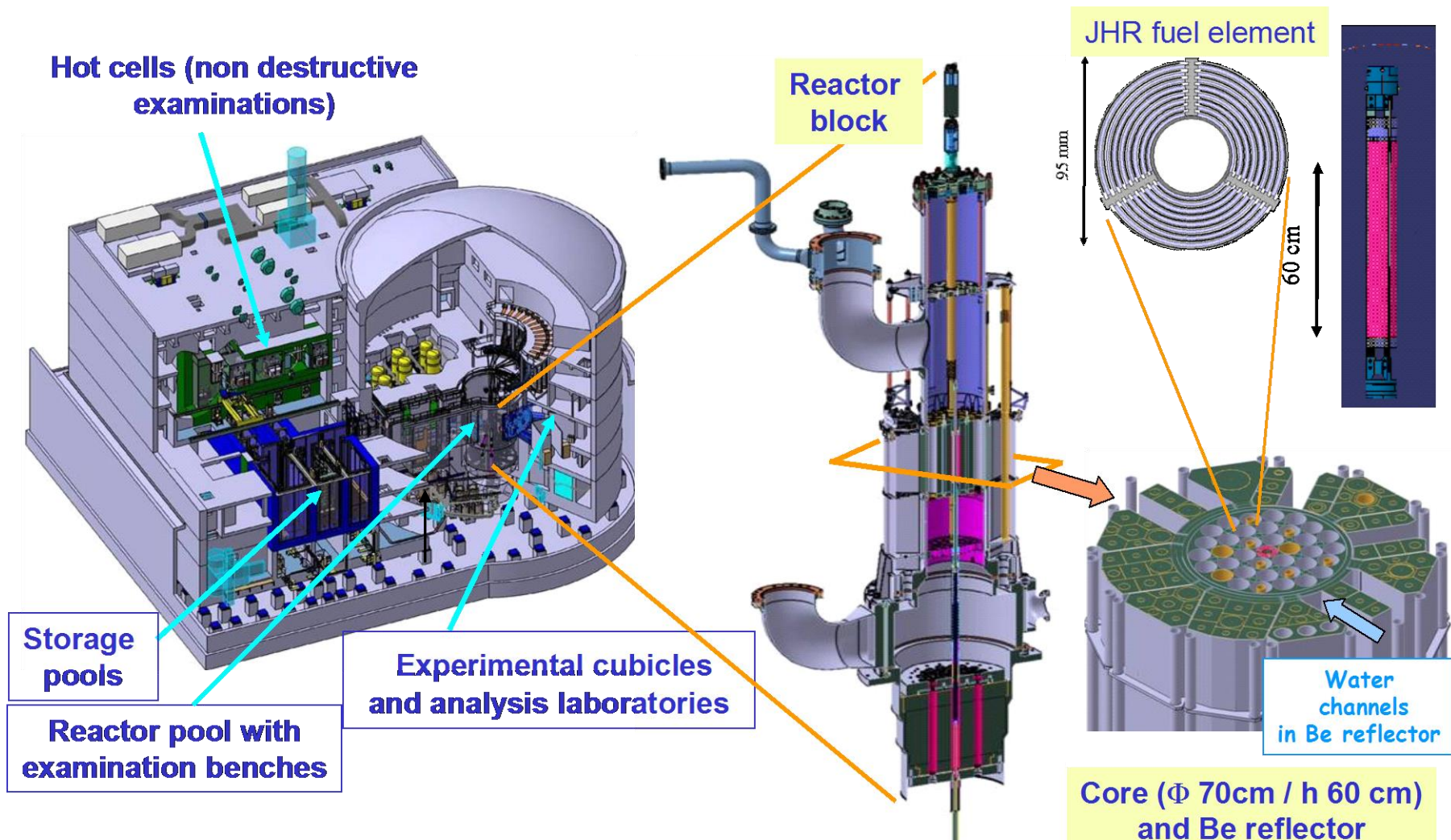




## **2. General figures of the JHR**

## 2. General figures of the JHR

**JHR: a modern 100 MWth pool-type light water MTR optimized for fuel and material testing**



## 2. General figures of the JHR

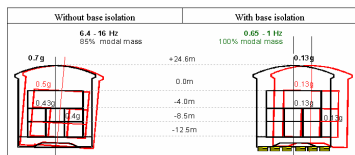
### General layout of the JHR site

#### Reactor Building

Reactor pool  
(DD, NDE)

Experimental  
rooms

About 200  
aseismic pads



Cooling systems

#### Nuclear Auxiliary Building

Laboratories

Control room

Hot cells  
(NDE + handling)

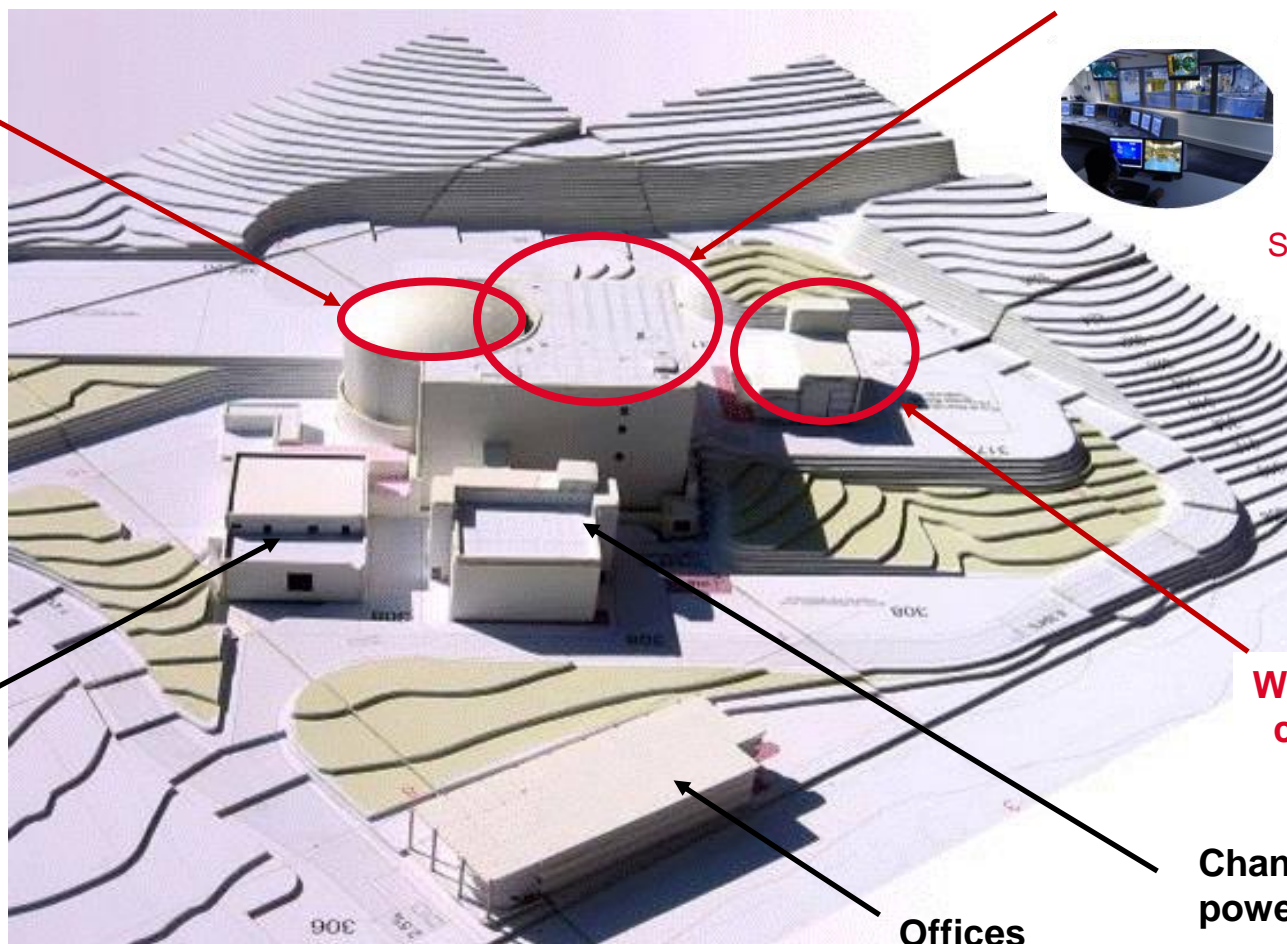
Storage pools (NDE)



Warehouse and  
cold workshop

Changing rooms +  
power supply

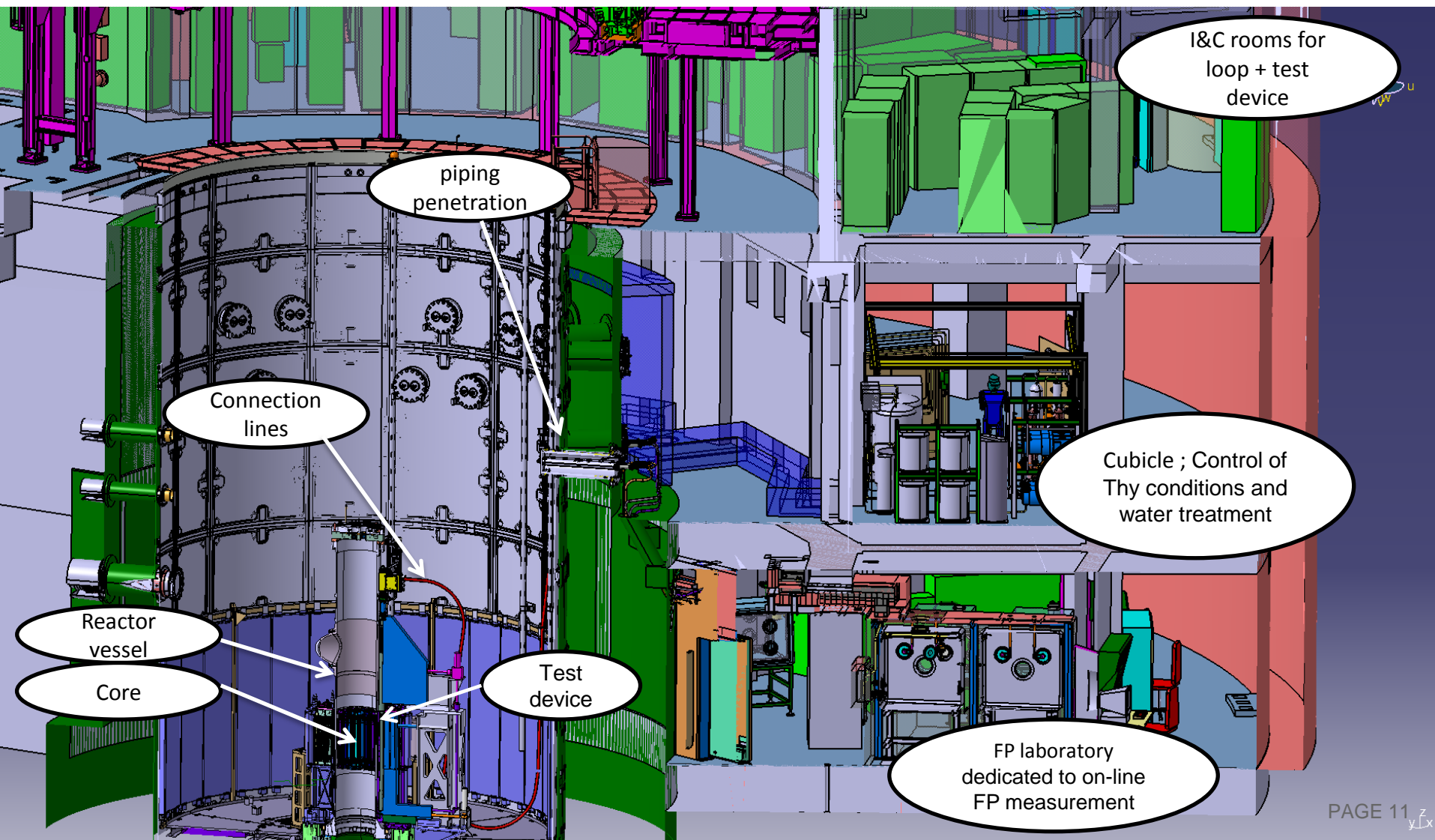
Offices





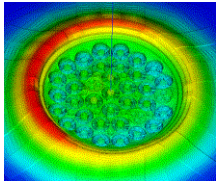
## 2. General figures of the JHR

### Reactor building

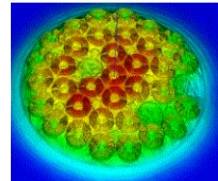


## 2. General figures of the JHR

Thermal neutron flux



Fast neutron flux



The core is under moderated:  
 → High fast neutron flux in the core  
 → High thermal neutron flux in the reflector

### In reflector

Up to  $5.5 \cdot 10^{14}$  n/cm<sup>2</sup>.s  
 ~20 fixed positions  
 (100mm ; 1 position 200mm)  
 and 6 displacement systems

~20 simultaneous  
experiments

### In core

Up to  $5.5 \cdot 10^{14}$  n/cm<sup>2</sup>.s > 1 MeV  
 Up to  $10^{15}$  n/cm<sup>2</sup>.s > 0.1 MeV

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

Fuel studies: up to  
 600 W/cm with a  
 1% <sup>235</sup>U PWR rod

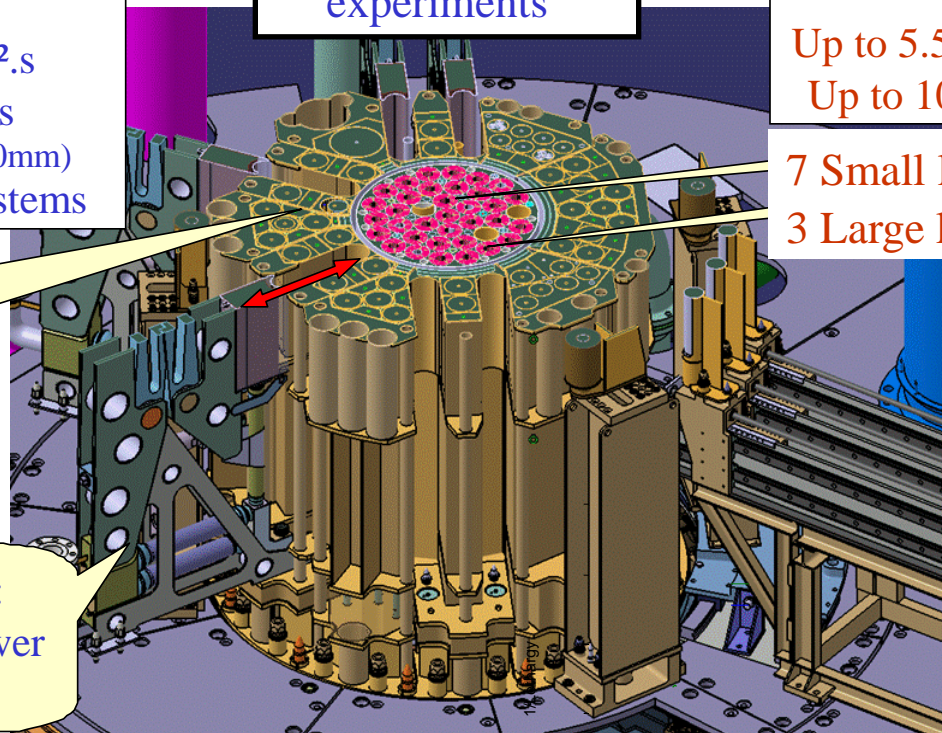
Material ageing  
 (low ageing rate)

Displacement systems:

- Adjust the fissile power
- Study transients

Fuel experiment  
 (fast neutron flux – GEN IV)

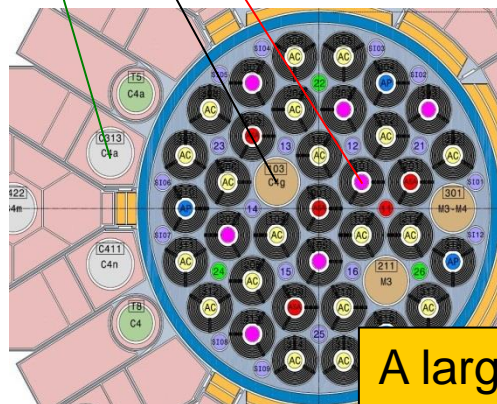
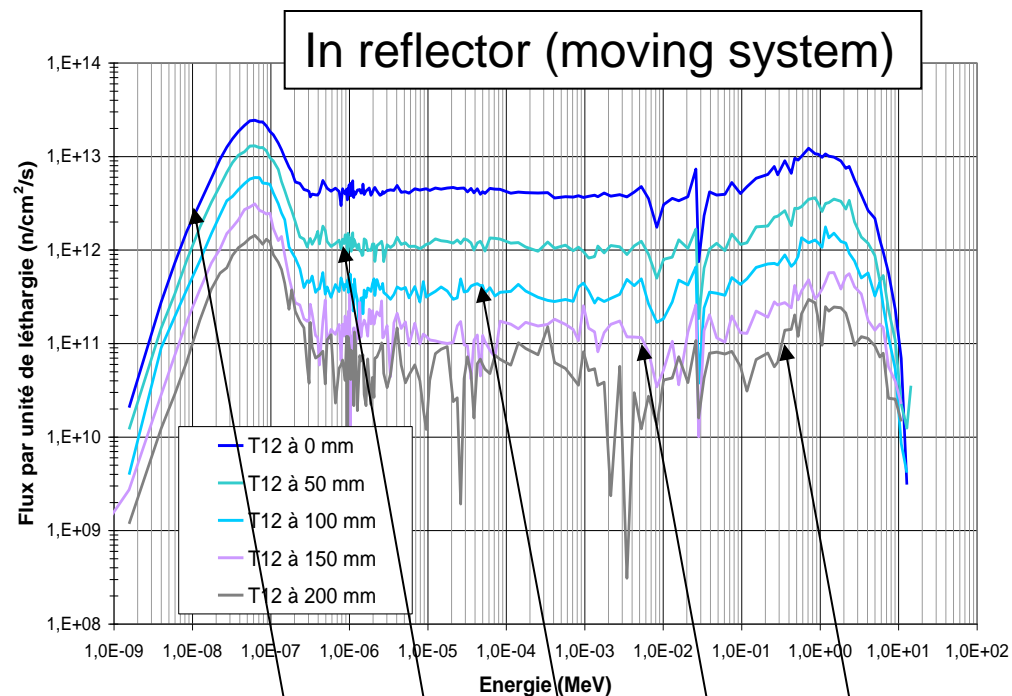
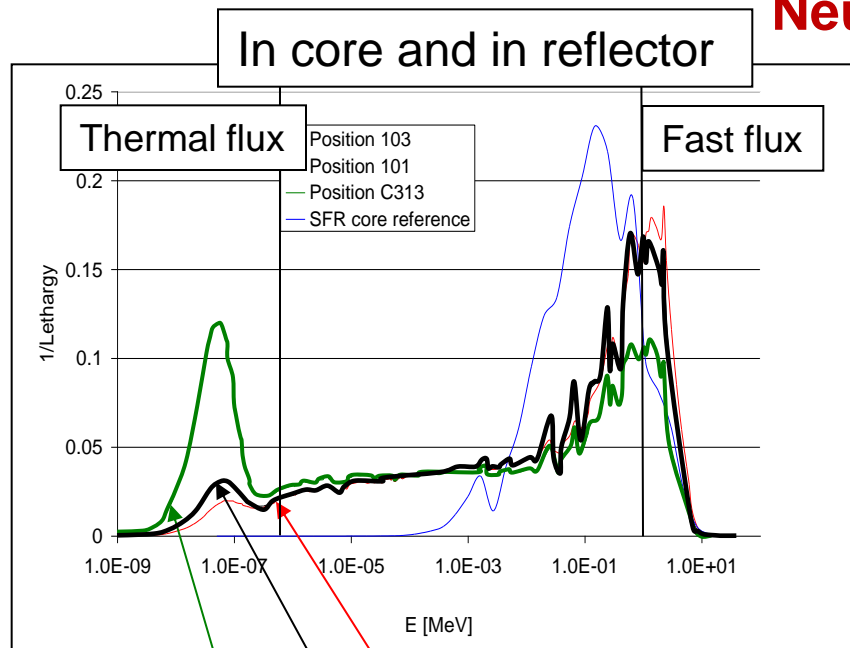
Material ageing  
 (up to 16 dpa/y)  
 GEN II & III + GEN IV



Core Designed for UMoAl fuel  
 Start-up with U<sub>3</sub>Si<sub>2</sub>-Al fuel  
 70 MWth / 100 MWth  
 25 to 30 days cycle length  
 6-7 days shutdown

## 2. General figures of the JHR

### Neutron spectra



A large range of neutron fluxes and spectra  
(and possible adaptation with « neutron filters »)

### **3. Experimental capabilities of the JHR**

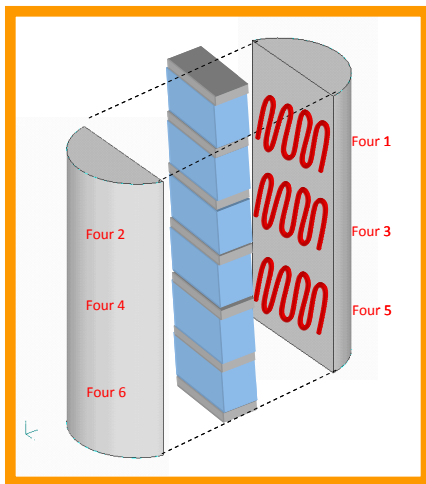


### 3. Experimental capabilities of the JHR

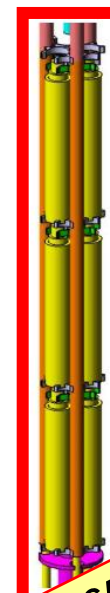
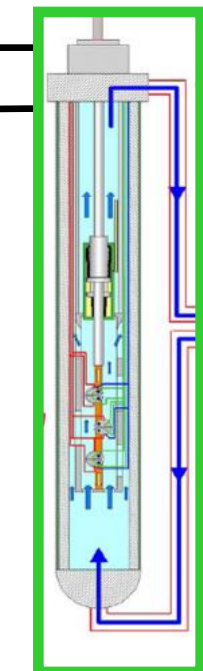
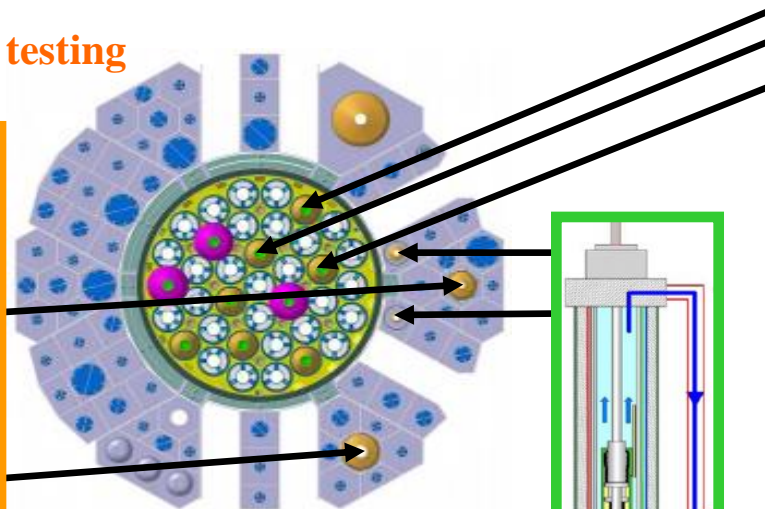
## Hosting experimental systems (dedicated to LWR material testing)

#### OCCITANE

For pressure vessel steel testing



- Irradiated material behaviour  
Tensile tests, resilience test (Charpy),  
crack propagation tests .....
- Behaviour of Thermal  
affected zones



**CALIPSO, MICA**  
For material testing  
under high dpa  
and accurate  
temperature control  
(+ mechanical loading)

specimen for  $\mu$  structure evolution, tensile test ;  
for 1 or 2 D creep tests ; for bending tests (stress  
relieving experiments) ;...



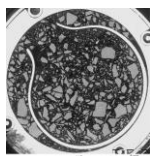
MICA  
Available  
at JHR  
start-up

**CLOE Corrosion loop**  
for “Zr alloy Corrosion” and  
“Irradiation Assisted Stress  
Corrosion Cracking”

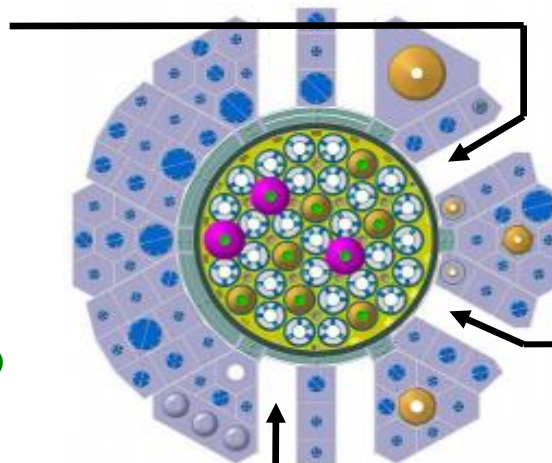
# 3. Experimental capabilities of the JHR

## Hosting experimental systems (dedicated to LWR fuel testing)

### LORELEI fuel testing under accidental conditions (LOCA)

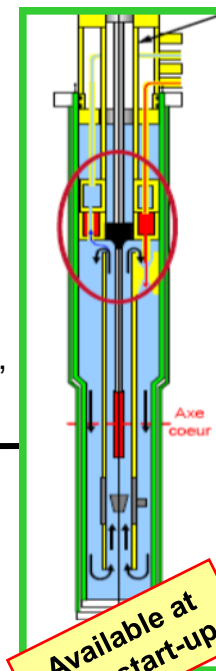
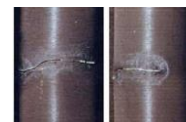


- Source Term (FP releases)
- Rod thermal-mechanical behaviour
  - Ballooning and clad burst (fuel relocation)
  - Corrosion at high temperature
  - Quenching and post-quench behaviour

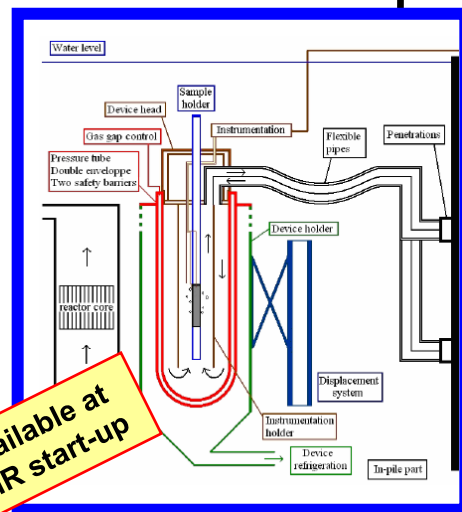
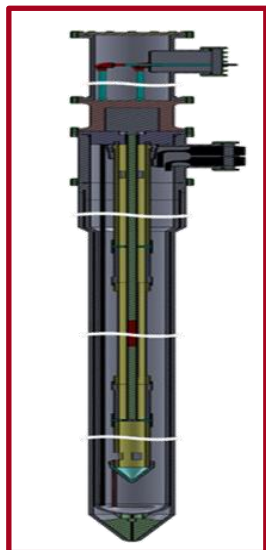


### ADELINÉ For fuel testing under off-normal conditions

Power transient,  
post clad failure fuel behavior,  
Lift-off experiment...

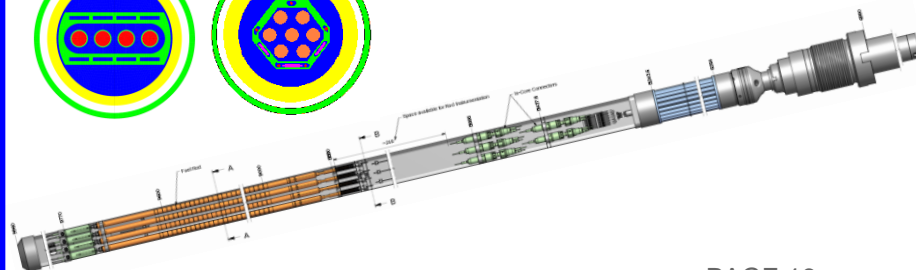
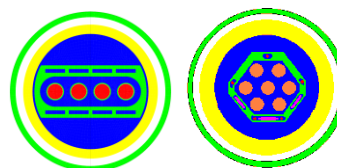


Available at  
JHR start-up



Available at  
JHR start-up

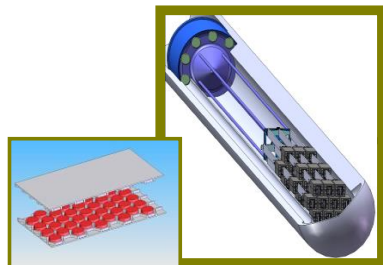
### MADISON For fuel testing under nominal conditions



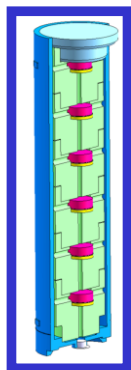
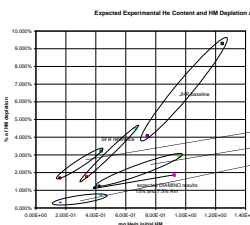
# 3. Experimental capabilities of the JHR

## Other possible hosting experimental systems (conceptual studies)

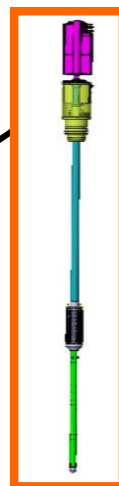
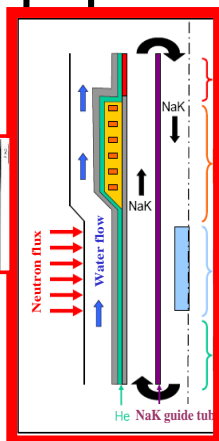
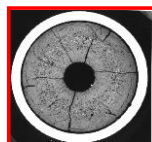
High temp. material irradiation (600-1000°C)  
Large capacity



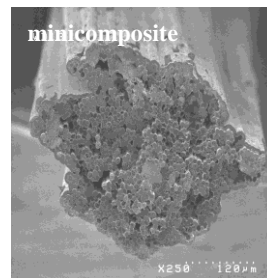
Transmutation  
studies



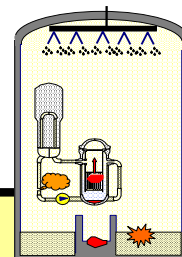
**CALIPSO adapted to  
SFR fuel and material**  
Normal=> in core  
Off normal => in reflector



MICA (material irradiation) adapted to 1000°C gas conditions (Phaeton type – Osiris technology)



Other topics



LWR : Adeline « FP » ; Adeline “power to melt”

**LWR severe accident studies**

GFR : fuel irradiation (normal and off-normal conditions)

Fuel characterization : basic properties under irradiation  
(thermal diffusivity, thermal creep,...)



# 3. Experimental capabilities of the JHR

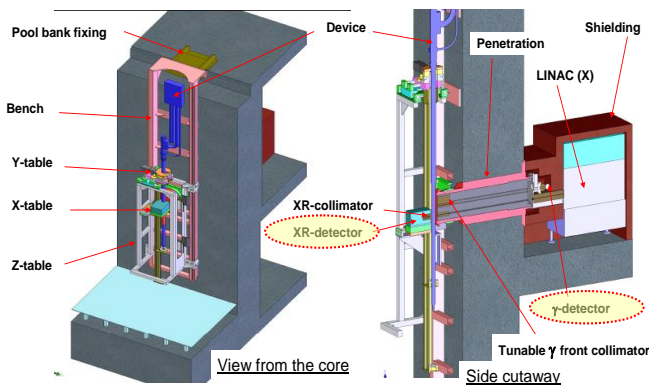
## Non Destructive Examination (NDE) Benches

Sample examination  
in hot cells

Gamma and X-Ray  
tomography systems

Multipurpose test benches

Coupled Gamma & X-ray bench



Test device  
examination in pools

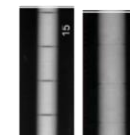
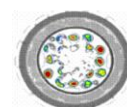
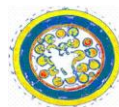
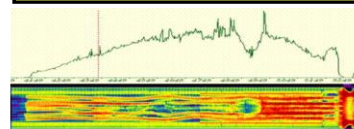
Neutron imaging system  
in reactor pool

Coupled X-ray & γ  
bench in reactor pool

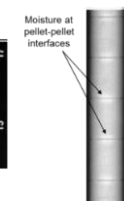
Coupled X-ray & γ  
bench in storage pool

Neutron Imaging System

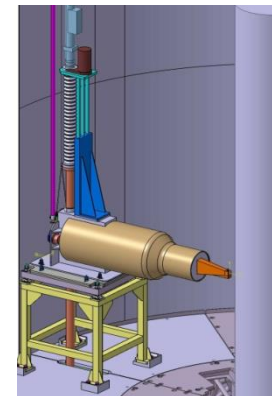
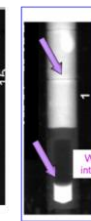
Initial checks of the experimental loading  
Adjustment of the experimental protocol  
On-site NDE tests after the irradiation phase



Dishing filling after  
a power transient



Rod failure during a power ramp



## **4. JHR consortium and collaborations**

## 4. JHR consortium and collaborations

### JHR Consortium : economical model for investment & operation

- CEA = Owner & nuclear operator with all liabilities
- JHR Consortium Members own **Guaranteed Access Rights** (in proportion of their financial commitment to the construction)
- 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
- *Open to new member entrance until JHR completion*

### JHR Consortium current partnership: Research centers & Industrial companies

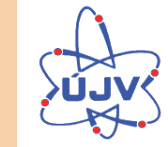














Associated Partnership: JAEA



## 4. JHR consortium and collaborations

### THE JHR AND ANCILLARY FACILITIES AS AN “ICERR”

Objectives of the CEA-ICERR (IAEA Terms of Ref):

- 🚩 **Create international scientific networks**
- 🚩 **Make available CEA facilities and experience to affiliates**
- 🚩 **Lead innovative joint programs with shared results**
- 🚩 **Enhance utilization of Research Reactors**
- 🚩 **Host international scientists / engineers (visiting scientists, operators...)**
- 🚩 **Provide “hands on” nuclear education “in the field”**



Since CEA designation in September 2015, 6 Member States from the IAEA have signed an Agreement with CEA

**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 equipment...)**



## **5. Status of the reactor construction**

## 5. Status of the reactor construction



Civil work of Reactor Building  
and Auxiliary Unit Building  
nearly completed



Preparation for pool  
liner setting-up



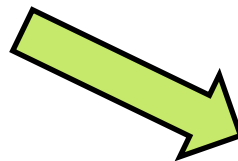
Delivery of Hot Cells  
end of 2016  
(Czech partners)

## 5. Status of the reactor construction



December 2016

**March 2017 : NUCLEAR UNIT  
CLOSURE**



March 2017





## 5. Status of the reactor construction

### Core components



Horse saddle flange

Main water box with primary system connection



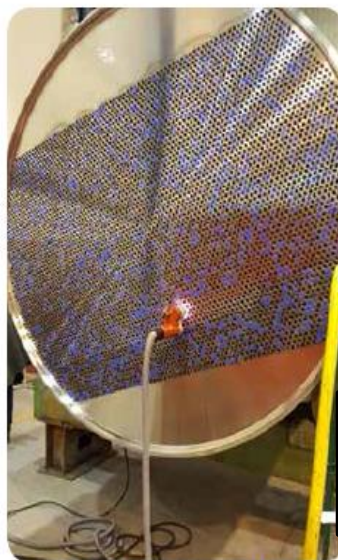
Last welding on the vessel  
Electron beam welding



Rack for fuel elements

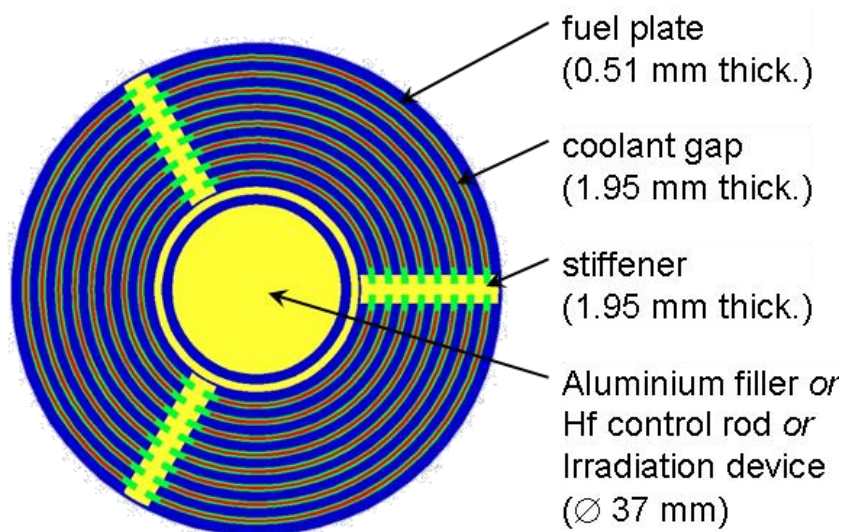
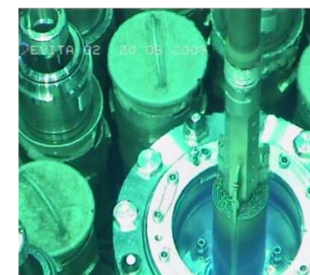
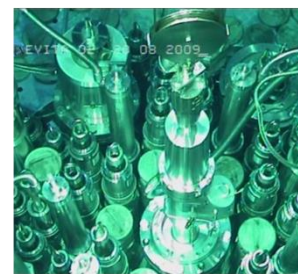


Heat Exchangers  
(Spanish partner)



## 5. Status of the reactor construction

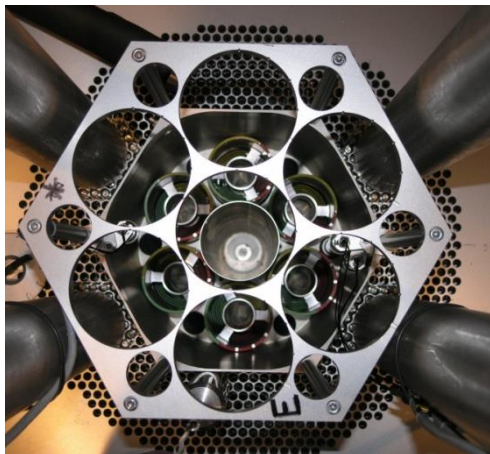
### JHR Fuel qualification (EVITA Program performed in BR2 reactor)



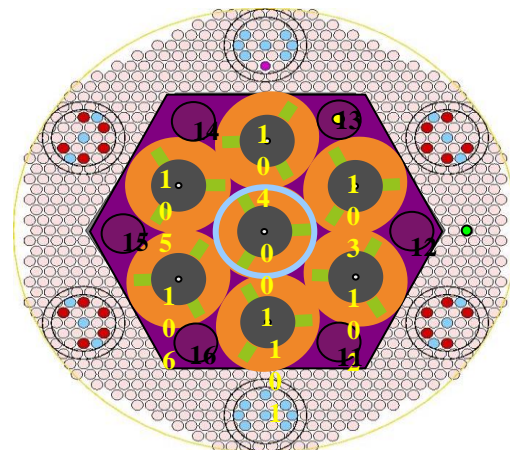


## 5. Status of the reactor construction

### Development and experimental validation of a new calculation scheme for JHR



**AMMON program performed in EOLE reactor (2010-2013) :**  
provided relevant experimental data  
for the qualification of the main JHR  
safety and design parameters




AMMON « reference »  
configuration

Neutron/photon parameter	Experimental uncertainty ( $1\sigma$ )
Core excess reactivity	$\pm 12$ pcm
Hafnium reactivity worth	$< \pm 0.5\%$ (critical state technique) $\pm 5\%$ (MSM technique)
Assembly power	$\pm 1\%$
Plate power density	$\pm 1\%$
Axial plate power profile	$\pm 1$ to $1.5\%$
Azimuthal plate power profile	$\pm 1$ to $1.5\%$
Fuel plate modified conversion ratio	$\pm 2\%$
Spectrum indexes	$\pm 1.8$ to $3\%$
Effective delayed neutron fraction	$\pm 19$ pcm
Effective prompt neutron generation time	$\pm 0.8$ \$
Photon heating (TLDs/OSLDs)	$\pm 4$ to $4.5\%$

## General conclusion

1. **Material Testing Reactors remains key-tools in R&D support for nuclear power industry**
2. **Research Reactors are now more “costly machines” than in the past...**
3. **Considering the increasing complexity of the experiments (due to enhanced requirements from simulation) the use of international platform (as will be JHR) is recommended**
4. **Innovative in-core instrumentation is a key for the quality and attractiveness of future MTR experimental programs, together with Post-Irradiation Analysis capabilities**





French alternative energies and atomic energy commission  
Cadarache | F-13108 Saint-Paul-lez-Durance | France  
T. +33 (0)4 42 25 79 62 | F. +33 (0)4 42 25 78 76  
Etablissement public à caractère industriel et commercial  
RCS Paris B 775 685 019

Nuclear Energy Division  
Reactor Studies Department  
Experimental Physics Section  
Instrumentation Sensors and Dosimetry Laboratory