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### ► To cite this version:

J. Estrade, X. Bravo, G. Bignan, Jl. Fabre, F. Pillot, et al.. Jules Horowitz Reactor: preparation of the commissioning phase and normal operation. RRFM, May 2017, Rotterdam, Netherlands. hal-02433902

**HAL Id: hal-02433902**

**<https://hal.science/hal-02433902>**

Submitted on 9 Jan 2020

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# **JULES HOROWITZ REACTOR: PREPARATION OF THE COMMISSIONING PHASE AND NORMAL OPERATION**

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## **ABSTRACT**

The Jules Horowitz Reactor (JHR) is a new modern Material Testing Reactor (MTR) currently under construction at CEA Cadarache research centre in the south of France. It will be a major research facility in support to the development and the qualification of material and fuel under irradiation with sizes and environment conditions relevant for nuclear power plants in order to optimise and demonstrate safe operations of existing power reactors as well as to support future reactors design. It will represent also an important research infrastructure for scientific studies dealing with material and fuel behaviour under irradiation. The JHR will as well contribute to secure the production of radioisotope for medical application. This is a key public health stake.

The construction of JHR is going-on. Once in operation beginning of next decade, the reactor will provide modern experimental capacity in support to R&D programs for the nuclear energy for the next 50 years.

In parallel to the facility construction, the preparation of the future staff and of the organisation to operate the reactor safely, reliably and efficiently is an important issue. CEA must also design and implement the first experimental devices for the start-up of the reactor. In this framework, many actions are in progress to elaborate:

- the staffing and the organisational structure for the commissioning test phases and also for normal operation,
- the documentation in support to the reactor operation (safety analysis report, general operating rules, procedures, instructions, ...),
- the maintenance, in service and periodic test programs,
- the staff training programs by using dedicated facilities (simulator,...),
- the commissioning test programs for ensuring that the layout of systems and subcomponents is completed in accordance with the design requirements, the specification performances and the safety criteria,
- the design and implementation of the first fleet of experimental devices in support to the commissioning test program and the future experimental programs.

These commissioning tests will also be helpful for transferring the knowledge on the installed systems to the operating team.

This paper will give an up-to-date status of the construction and schedule plan of the reactor and of the organisation for commissioning tests activities to prepare the future operation. A specific focus will be done on the utilisation, dealing on one hand, on the simulator for the elaboration/validation of the procedures and for the training programme and, on the second hand on the 3D simulator for training, preparing the operation (commissioning tests) and studying the implementation of the first fleet of experimental devices.

## 1. Introduction

This paper gives an up-to-date status of the construction and a description of the organizational structure, responsibilities and main actions for the Jules Horowitz (JHR) Material Testing Reactor (MTR) commissioning and routine operation.

Its construction is going-on and the reactor shall be operational by the beginning of the next decade. It will be operated by CEA, as an international user's facility on the CEA Cadarache site. The design of the reactor will provide modern experimental capacity in support to R&D programs for the nuclear energy for the next 50 years. It will also supply radio-isotopes used for medical applications.

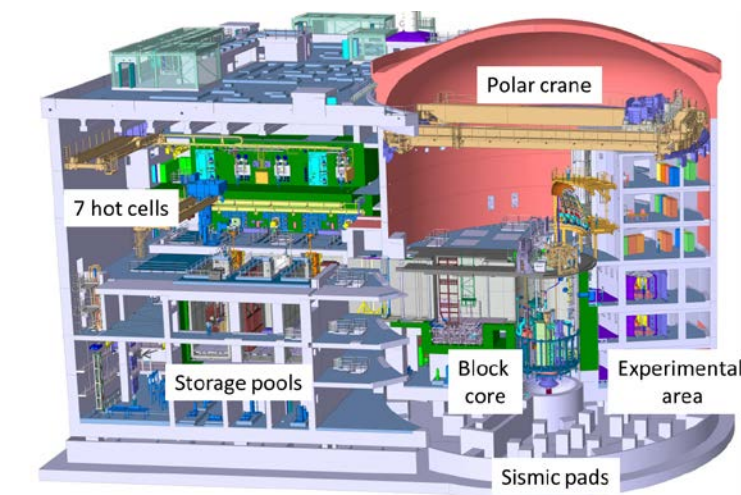
JHR will be a modern MTR. It is a pool-type reactor; the maximum power will be 100 MWth. Its design allows a large experimental capability inside and outside the reactor core. Due to the high power density, the core primary circuit is slightly pressurized. Several equipments will be implemented in the reactor building and be used in support to the experimental programs (3 small cells attached to the main 4 hot cells will allow the preparation and examination of test devices before and after irradiation, non-destructive examination benches (gamma spectrometry, X tomography, neutron imaging system) and specific laboratories (fission product lab, chemistry lab and dosimetry lab)).

In parallel to the construction of the reactor, the future staff training and the preparation of the organization, to operate the reactor safely, reliably and efficiently is a key item. In this framework, many actions are on-going to elaborate:

- the staffing and the organizational structure for the commissioning test phases and also for normal operation,
- the documentation in support to the reactor operation (safety analysis report, general operating rules, procedures, instructions, ...),
- the maintenance, in service and periodic test programs,
- the staff training programs by using dedicated facilities (simulator,...),
- the commissioning test programs for ensuring that the layout of systems and subcomponents is completed in accordance with the design requirements, the specification performances and the safety criteria,
- the design and implementation of the first fleet of experimental devices in support to the commissioning test program and the future experimental programs.

## 2. JHR general description

As a short description, the JHR layout is as follows:



*Fig. 1 JHR Facility*

The nuclear unit of JHR consists in a reactor building and a nuclear auxiliary building. The reactor building is made in pre-constraint concrete with a diameter of 37 m. The nuclear auxiliary building consists in 3 storage pools for spent fuels, irradiated experimental devices and 4 main hot cells for irradiated fuel and waste management but also preparation, conditioning of experiments and non-destructive examinations on irradiated samples. A transfer channel between the reactor building and the nuclear auxiliary building allows the underwater transfer of spent fuels and experimental devices between the two buildings.

### 3. JHR update status

Construction is currently under progress at CEA Cadarache Centre. Engineering studies were devoted to AREVA group subsidiary AREVA-TA, which now ensures the supervision of the construction site, and is also in charge of providing key reactor components. More than twenty other suppliers in the fields of civil works, mechanics, heating, ventilation, air-conditioning, electric components... contribute to the construction of the facility.



*General view of Reactor Building and Auxiliary unit building (Fall-2016)*

*Fig. 2: some views of the building site*

Regarding the construction work currently underway, apart from anticipated work (civil works, cranes, manufacturing of the main reactor pumps), the main electro-mechanical contracts were started from year 2011 on. Current status on construction site is more than 90% progress of civil works and increasing contribution of electro-mechanical tasks is going-on (recent highlights: implementation of the stack, cranes in the nuclear auxiliaries building).



*Fig. 3: some views of equipments*

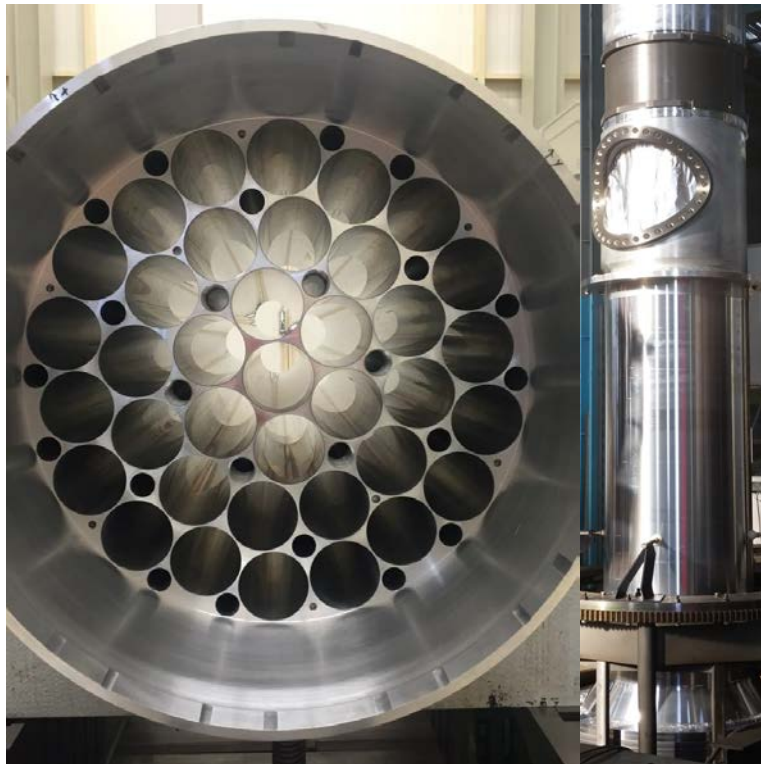


Next important milestones will be the installation of main circuits components (for the reactor building), and the completion of the hot cells complex structure (for the nuclear auxiliaries building).



*Fig. 4: hot cells complex structure*

In parallel, several components are in phase of realization or qualification (pumps, valves, diesel generator, equipments of the block core...).



*Fig. 5: realization of equipments of the Block core*

#### **4. Organization of the JHR project**

The organization of the JHR project, the complexity of the design and its associated challenges and the modern safety requirements lead to a specific organization to prepare the facility commissioning. Concerning the organization of JHR project:

- the primary contractor, AREVA [12], has to design and to construct the future unit except the different equipments or systems in support to the experimental programs,

- CEA has :
  - to install and commission the experimental devices and equipments,
  - to operate the reactor and the different systems during the commissioning test phases and after, during routine operation.

In 2010, a specific JHR section was set-up with 5 mains missions:

- Human Resources management to prepare the future operator,
- Setting-up of the operating referential (Safety Analysis Report, General Operating Rules...),
- Training and qualification of control room operator,
- Setting-up of the major contracts linked to the JHR operation (fuel assemblies, equipments, sub-contractors...),
- Design, manufacturing follow up, implementation and commissioning of the first fleet of experimental devices and associated equipments (non-destructive examination benches, laboratories...).

The future reactor operation and experimental systems operation staffs belong to this section to prepare the operation of the reactor and the nuclear auxiliaries as well as the integration of the test devices. These “mixed” staffs will contribute to enhance efficiency during this commissioning period but also for the future normal operation (existence of means shared between the operation and the experimental staffs to create a unique culture around the JHR).

## **5. Mains topics in preparation to start and operate JHR**

### **5.1. Proposal of staffing and organizational structure**

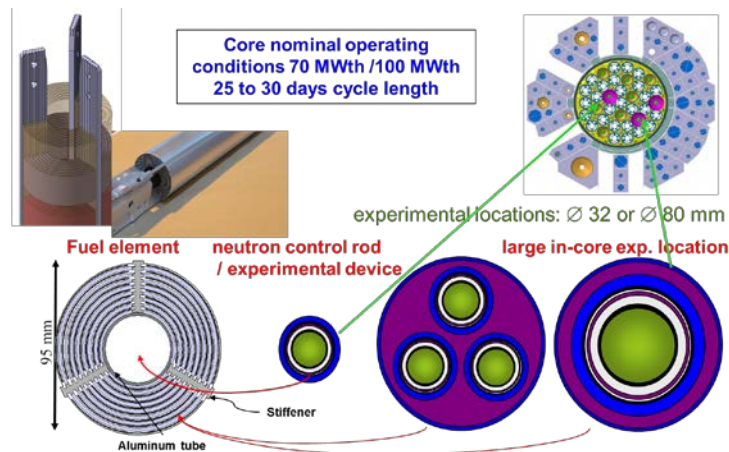
Based on the others research reactors feedback, the project of organization is also adapted to the reactor mission (neutrons for industry and medical application). This structure takes into account the future schedule of the reactor in operation and the maintenance and periodic test programs. The objective is to define clearly the responsibilities and the technical skills of each staff member (reactor manager, operation manager, shift manager and reactor operator) from the commissioning test phase to the normal operation.

JHR section and JHR project are also preparing the organization that will take place for the commissioning test program phase. The aim is to define the liability of each actor (main contractor, JHR project, future operator, contractors and sub-contractors).

## **5.2 Elaboration of the licensing and the operating documentation**

### **5.2.1 Elaboration of the licensing documentation**

Regarding the licensing documentation, CEA has to complete the project of Safety Analysis Report, provided by the primary contractor, with the test devices specifications (specific licensing document for each of them) and also with some complements on the core configurations (eg: first core and the associated safety studies).



\*Fig 6. JHR core

This Safety Analysis Report is completed by General Operating Rules (description of reactor operations, strategy in case of incidental or accidental situations, periodic tests and maintenance programs...).

### 5.2.2 Elaboration of the operating documentation

To elaborate the different documents in support to the commissioning test program and the future operation (routine operation), CEA has defined the operating documents structure based on the feedback of nuclear power plants, taking into account the specificities of experimental reactors. Three types of documents will be established:

- management and JHR safety and security referential documents (licensing),
- operating procedures (reactor and test devices),
- others activities (waste and nuclear materials management, transportation...).

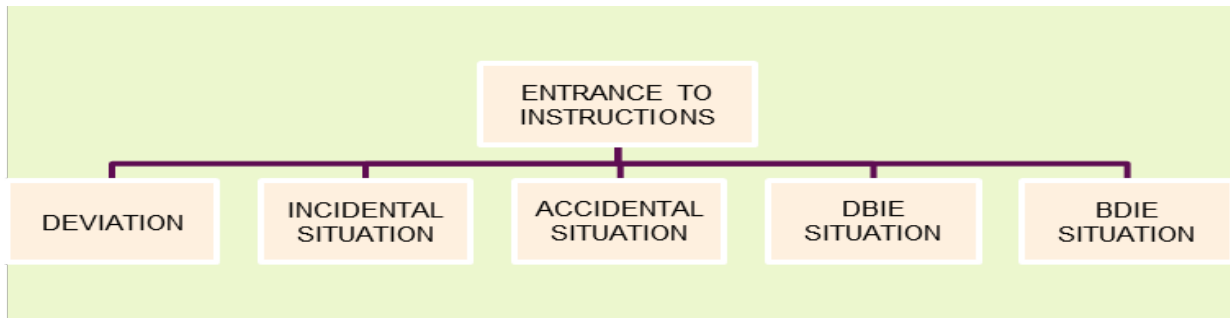
JHR section is in support to the JHR project to follow the construction studies or the tests of the main utility equipments (primary pumps, the fuel handling machine, the hot cells equipments...) mainly for the operation and maintenance items. Through the documentation and the studies on going, the JHR section analyses the systems and the equipments to establish the maintenance and periodic test program but also starts elaborating the reactor operating rules. Approximately, 6000 documents will be used to operate the reactor and the experimental hosting systems. Most of them will be validated during the commissioning test program, others by using the simulator (most of the incidental and accidental situations). Operational procedures must provide direction and guidance to the reactor staff in the performance of operational activities, including the conduct of test devices but also for the technical and administrative support activities (training, waste management, human resources, nuclear materials management...). They are in accordance with the safety requirements.

Concerning the operating procedures, we have rules and instructions:

- the rules: these documents identify the requirements, the conditions to operate close to the limits, the strategy to conduct the operation,
- the instructions: these documents are associated to the rules ; they provide step-by-step actions for accomplishing a specific task within that activity.

A specific item concerns the definition of the strategy of conduct in incidental and accidental situations. The conduct strategy proposal, in incidental and/or accidental situations, is based on the feedback of the strategies applied in nuclear power plants, taking into account the specificities of experimental reactors and the specific design of the command control of JHR. More than 200 Postulated Initiating Events (PIE), will be taken into account. The proposed strategy consists in separating the complex situations from the simple ones. For the complex situations, a document of «entrance to instruction » will allow:

- to confirm the expected automatic actions,
- to check the safety functions parameters,
- to realize a diagnosis with the aim of an orientation towards the adapted instruction.



*Fig 7. Strategy of conduct in incidental and accidental situations*

The orientation will be only a Deviation situation (D), or an Incidental (I) or an Accidental (A) situation or a Design and Beyond Design Basis Accident (H and U) situations.

The sequence of events includes the actuation of the Safety Category 1 systems that control the process initiated by the Design Basis Initiating Events (DBIE). Where prompt reliable action is required to deal with DBIE, the reactor design includes the means to automatically initiate the operation of the necessary safety systems. This ensures that the three main safety functions, namely: reactor shutdown, core cooling, and radionuclides confinement remain fulfilled with a high degree of reliability. The design reduces operator actions as far as feasible, particularly for the period during and following an accident condition with actuation of a protection/safeguard system (within 30 minutes). This period is devoted to use «entrance to instructions».

Considering this first action to define the conduct strategy in incidental and accidental situations, the next step will be to elaborate the first procedure and perform the study to identify the best strategy. The final step will consist in validation by using a simulator.



*Fig 8. First version of the Simulator*

### 5.3 Elaboration of the maintenance, in-service and periodic test programs

After identifying the main Systems, Structures and Components (SSC), important to safety, a first inventory of maintenance, surveillance, inspection and testing activities has been performed. Taking into account the project of organization of the operator staff (number of operator and competences), an optimization of the maintenance plan has been proposed in three categories:

- the maintenance program is done by the operator,
- the maintenance program is done by a specific sub-contractor,



- the maintenance program is done by general sub-contractors managed by the Cadarache research center.

The objective of this categorization is also to optimize the maintenance subcontracting of a limited number of SSCs.

This maintenance program should be reviewed since each contractor will send its own maintenance program strategy to confirm or modify the current project of maintenance plan. This part of activities can have a significant impact on the reactor operation cost.

The in-service inspection and periodic test program will be in compliance with the requirements associated to the SSCs and depends on the different categories of classification (safety category 1 to 3). This program is adapted and optimized also with the schedule of the reactor in operation.

#### 5.4 Elaboration of staff training program

As a basis of the future organizational structure, this training program for the future operators has been elaborated taking into account the feedback of similar worldwide nuclear facilities and the project of JHR organization structure. The strategy to establish this training plan was:

- to identify the different requirements for working in a nuclear unit (occupational health and safety, radiation protection, nuclear safety culture, waste management, nuclear materials management...),
- to identify the needs of competences for operating the reactor and the different circuits and establish the corresponding training program.

The training program preliminary inventory has identified approximately 130 different training courses. This program includes the JHR specificities. For the different phases of the project (commissioning test program, first start-up...) a schedule of the training sessions will be established in agreement with the actual annual recruitment of the reactor operation staff.



*Fig 9. JHR Control room and training program*

#### 5.5 Elaboration of commissioning test programs

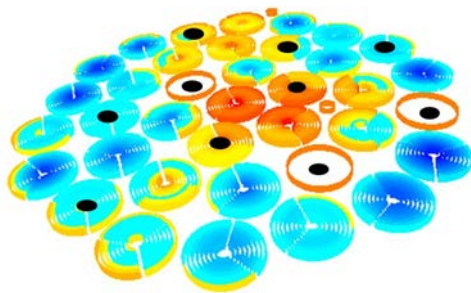
The elaboration of the Commissioning Test Program consists to identify the needs of tests, instrumentation and/or calculations to verify the safety criteria and the performance of each Systems, Structure and Component (SSC) during the commissioning phases. The approach is a “step by step” one:

- Step 1: test assembly for each SSC,
- Step 2: functional test,
- Step 3: individual integration test,

- Step 4: global integration test.

Some studies have been performed (neutronic and thermal hydraulic calculations) to define specific devices/instrumentation, in support to the first core loading and the first start-up. The objective of these studies is to check the JHR nominal performances and safety criteria (neutron and gamma detectors, temperature or flow sensors...). These specific instrumentations allows us:

- to enhance safety, by the characterization of the neutronic mapping of the core,
- to validate the contractual performances of the reactor (in particular to verify the performances of the experimental domain)
- to support the scientists being end-user of the reactor for the characterization of the experimental location (neutronics, gamma heating, thermalhydraulics...).



*Fig 10. Neutron fluxes in JHR core*

## 5.6 Design and implementation of the experimental device

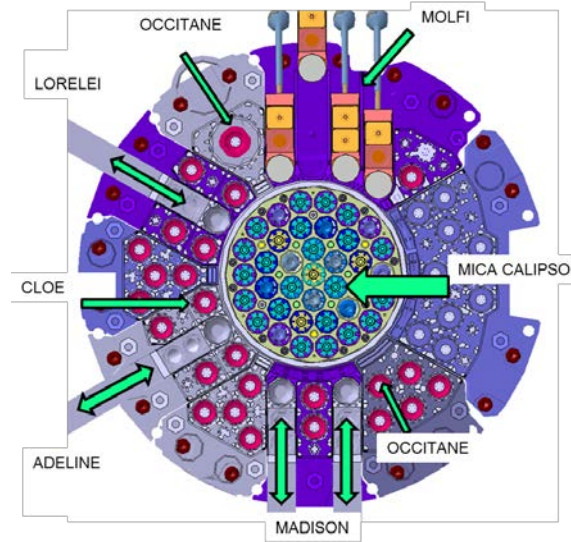
CEA is developing a set of test devices that will be operational for the startup of the reactor or few years later. These experimental hosting systems will have to fulfil experimental needs concerning current NPP technologies (GEN II-III) and possible support to future reactor concepts as well.

Experimental programs could be related to either fuel basis properties acquisition, mastering of margins or improvement of fuel products (clad and pellet), in term of performance, safety, maximum burn up, innovative materials or extension of validation domain of fuel performance codes.

The main experimental hosting systems currently under design are:

- MADISON test device which will be available at the JHR start up, and will allow testing the comparative behavior of several instrumented fuel rods (between 1 to 8 rods of up to 60 cm fissile stack height) under NPP normal operating conditions (no clad failure expected).
- ADELIN test device which will be available for the JHR start up, and will allow testing a single experimental rod up to its operating limits. The fuel rod will be tested under conditions that correspond to off-normal situations with possible occurrence of a clad failure. The first version so called ADELIN “power ramps” will focus on the clad failure occurrence during one of these abnormal situations.
- LORELEI test device which will be available right after the JHR start up and will allow testing a single rod under accidental situation that may lead to fuel damage. It will be able to reproduce all sequences of a LOCA-type transient,

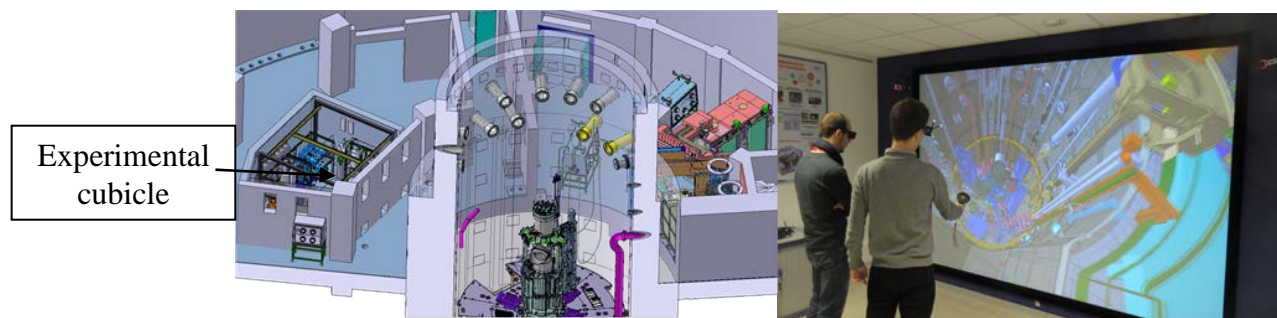
including the re-irradiation, the loss of coolant and the quenching phases, on a separate effect approach.



*Fig 11. Set of test devices that will be operational for the startup of the reactor or few years later*

These experimental devices dedicated to the fuel studies are completed by in-core and in reflector material test devices, corresponding to large ranges of irradiation conditions, in terms of temperature, neutron flux and neutron spectra. A special attention focuses on the improvement of the thermal stability and gradients in the interest zones of irradiated samples. Some specific devices will be described such as equipments designed to the qualification of reactor pressure vessel steels (OCCITANE test device), to the studies of creep-swelling of structural materials (MICA test device) or to the study of the stress corrosion cracking assisted by irradiation phenomena-IASCC (CLOE test device: a corrosion loop with an accurate water chemistry monitoring for PWR or BWR requirements).

CEA, in some cases with partners, is designing a first fleet of test devices expected at the reactor start-up or in the first operation years. JHR safety requirements are used also to design these experimental hosting systems. An important issue is the implementation of these test devices in the reactor: for each device, the implementation in the reactor building is studied to identify, for example, the power supply and instrumentation and control cabinet needs and also the impact on the venting and effluents facility networks. The equipments in each experimental cubicle and the implementation of electrical cabinets are defined. The studies include also the use of hot cells, handling systems and temporary storage area. The JHR section uses the same "integrated system" (the CATIA software) as the primary contractor.



*Fig 12. Layout of the experimental device in an experimental cubicle and 3D simulator*

## 6. Conclusion

The construction of JHR is going-on and the reactor shall be operational by the beginning of the next decade. In parallel to the construction of the reactor, the preparation of the future staff and of the organization to operate the reactor safely, reliably and efficiently but also the design and realization of the first set of hosting device are important issues. This paper gave an overview of these actions to prepare the commissioning phases, the routine operation and the future experimental programs.

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