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Invited paper

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Title: Underwater NDE Systems in the Jules Horowitz Reactor (JHR) : Towards integration issues

1 Introduction:

Within the frame of JHR construction, Non Destructive Equipm*ents* (NDE) systems are required.

Examinations performs by these NDE will be based on gamma rays and high energy X rays and, also, on a neutron imaging equipment. The use of several types of rays provides powerful and complementary methods for assessment of irradiation nuclear fuel experiments.

This presentation is exclusively relevant to the interfaces between NDE equipments and the JHR facility during design, engineering and construction phases (constraints of development and integration on JHR site).

X-Ray transmission and Photon Emission Tomography are complementary examinations and therefore should be performed on the same objects without any repositioning on the test stand. The neutron imaging process measurement is performed on a specific and separate test stand in the reactor pool. Those test stands should be as identical as possible for swapping reasons.

All the objects scanned will be vertically installed on 3 possible benches:

- 2 mechanical benches in reactor pool (1 for γ and X-Ray and 1 for neutron imaging)
- 1 mechanical bench in a storage pool (γ and X-Ray).

Several constraints interfaces need to be solved because NDE systems architecture is complex – especially for γ and X-Ray (part in water pool, part behind the vessel structure, in air):

- Integration of mechanical benches in the pools need a deep design (high and large scale benches, need of a high positioning precision, heavy weight, behaviour and protection line during external aggression like an earth quake, high irradiation risk,),
- Definition of the detail safety referential to be applied,
- Radio protection evaluation (during measurement process and during maintenance),
- Design of the collimator plug penetration (feedthroughs and interface with vessel liner and the concrete frame, constraint of positioning, constraint of dose protection, …)
- Design of the collimators - especially for γ and X-Ray: mechanical slit conception and interfaces with detectors, high geometrical precision,
- Transfers and assemblies of these equipments on their JHR specific sites

Because there is a generic design between the 2 sites (reactor and storage pool) for mechanical benches dedicated for γ NDE, the illustrations given below concern the reactor pool (which leads to harder interfaces difficulties).

***Collaboration between CEA and VTT*:**

We should emphasize about the powerful collaboration between French CEA and Finland VTT organization to develop and supply the γ and X-Ray systems: VTT will ensure the detail design and supply following phases (while the feasibility and installation phases will be shared).

➯ ***Forward views of the general implantations of these NDE in the JHR reactor pool***

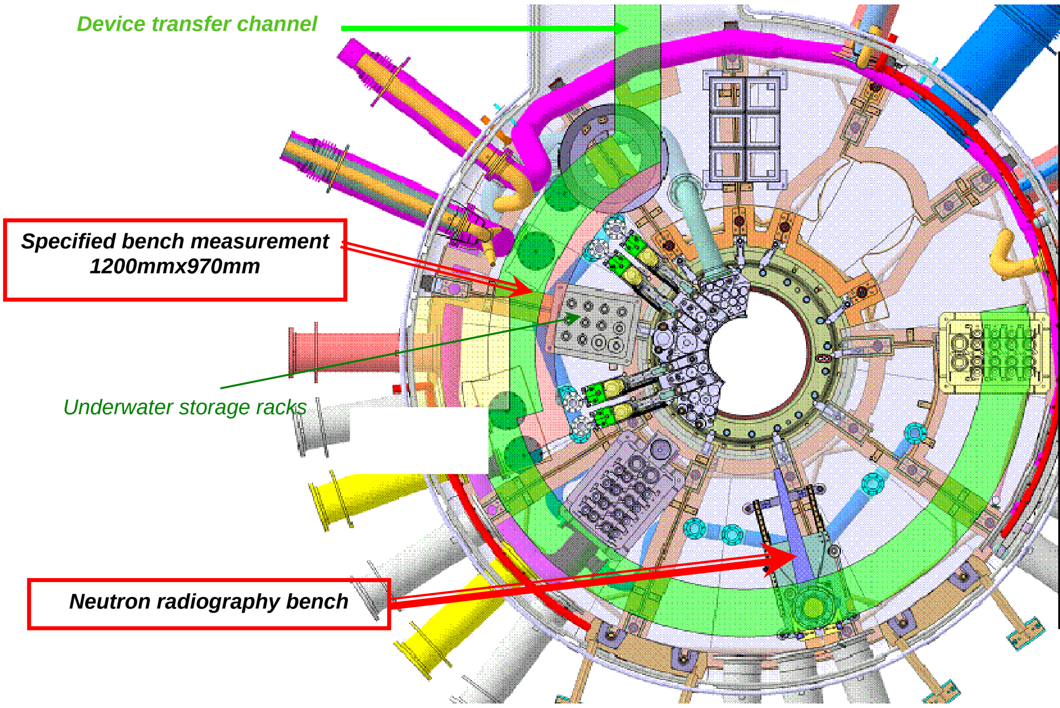


***Figure 1**: Reactor pool general Horizontal view with γ and neutron imaging benches position*

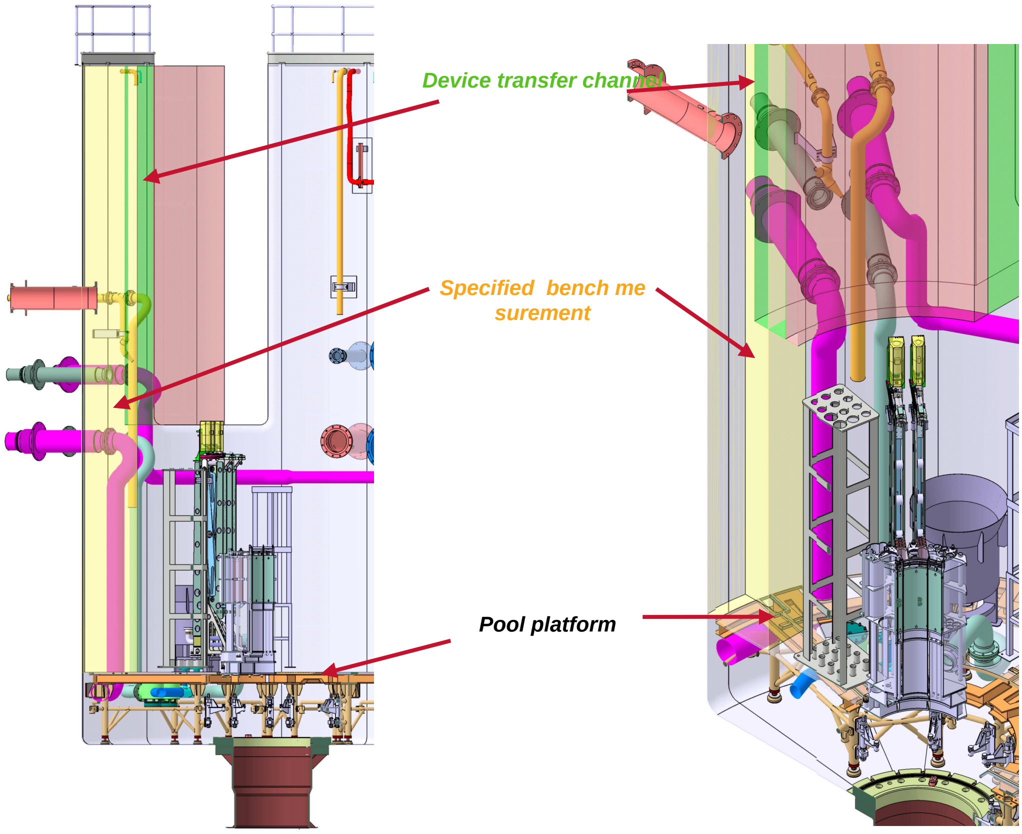
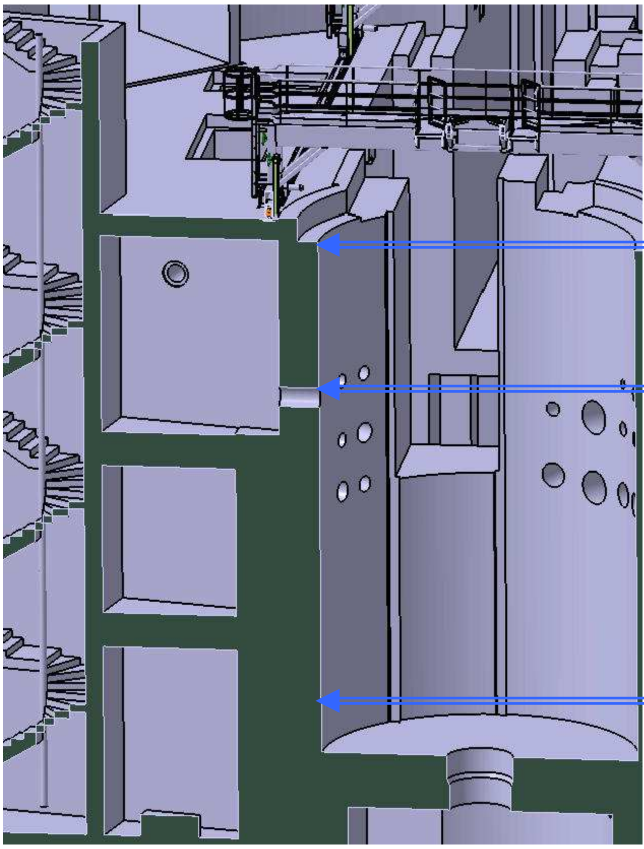


***Figure2**: Reactor pool general Vertical view with γ imaging bench "envelop position"*



<u>Figure 3</u>: JHR reactor pool current design and interfaces (γ imaging benches position)

2 <u>*Brief presentation of the JHR experimental devices and goals*</u>

2.1 Main function of JHR experimental device

The main function of JHR experimental devices is to reproduce thermal and neutron conditions on experimental sample during different irradiation scenarios (stable, power ramp, cladding rupture,). Also, the following subjects (interfaces and specific components) need to be deeply studied:

- Sample holder Experimental rod with instrumentation,
- Instrumentation Holder,
- Double containment,
- Head of the device,
- Under water connexions,
- Out of pile part.

2.2 NDE γ and neutron imaging systems: global goals

There are two main goals:

<u>1st</u>**:** Demand of a very ***high mechanical accuracy***: about 0, 1 mm (relative position benches, collimator axis):

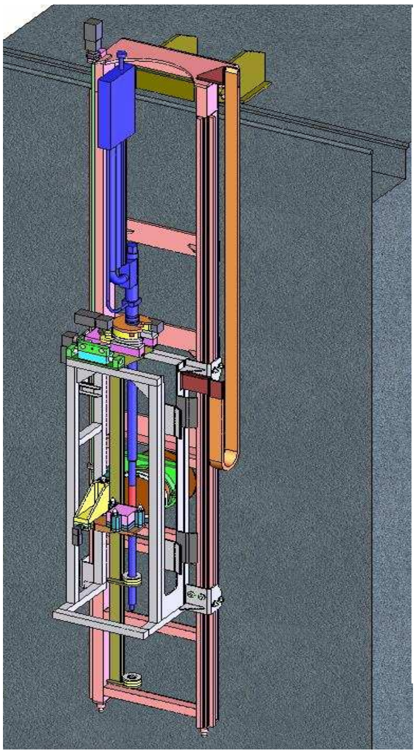
↳ *the need is a significant gain on the resolution of final fuel rod dimensional measurements in comparison of the to day equivalent installations (for example OSIRIS reactor) : the goal is an expected resolution of (100 µm)^3- (present resolution: ~500 µm)^3)*

<u>2nd</u>: ***Safety*** *(demonstration of "non aggression" in normal or accidental situations, no risk of primary water leak, etc…)*

3 *NDE γ and neutron imaging systems: description and interfaces main constraints*

3.1 - X rays and gamma scanning system

- **Mechanical bench "in pool interfaces"**



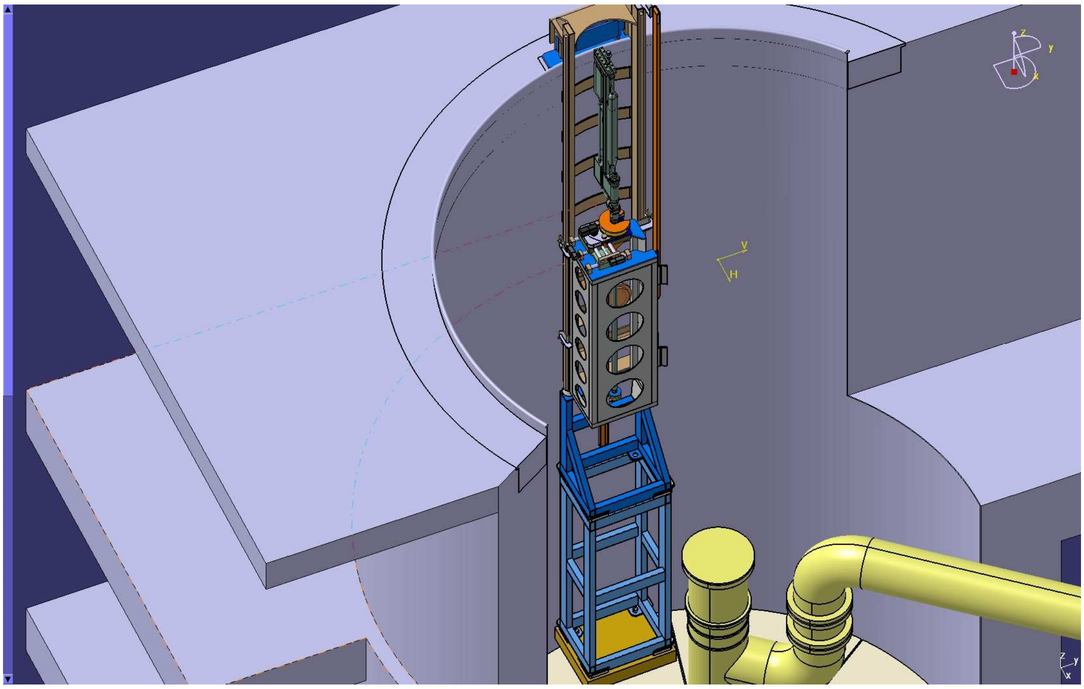
<u>Figure 4</u>: JHR reactor pool current γ bench design (Main principles: operation with an experimental rod on the bench carrier)

All the weigh *(bench and carrier, experimental device: total weight ~2500 to 3000 Kg)* is supported by the top: a specific interface is settled down on the pool bank - as shown in this figure4). The "nozzle" *(see the following figure 6) is* linked at the bench with a mechanical guide to insure the X, Y position with a high accuracy in front of the collimation axis – without any vertical transfer of weight.

The bench is composed by a fixed part (which is supported by the top) and a mobile part (or "carrier") which is supported by this fixed part: the "carrier" transmits 3 axes X, Y, Z movements (plus rotation) to the experimental device *(that permits more than full active length inspection and full rotation of the device for tomography purpose*).

Transfer and maintenance of the experimental device on the carrier are essential functions (need high level of safety and accuracy).

<u>Figure 5</u>: JHR reactor pool current γ bench design (Interfaces with reactor building and pool platform)



The bench needs to be guided (X, Y directions) at its bottom part: as shown on Figure 5.

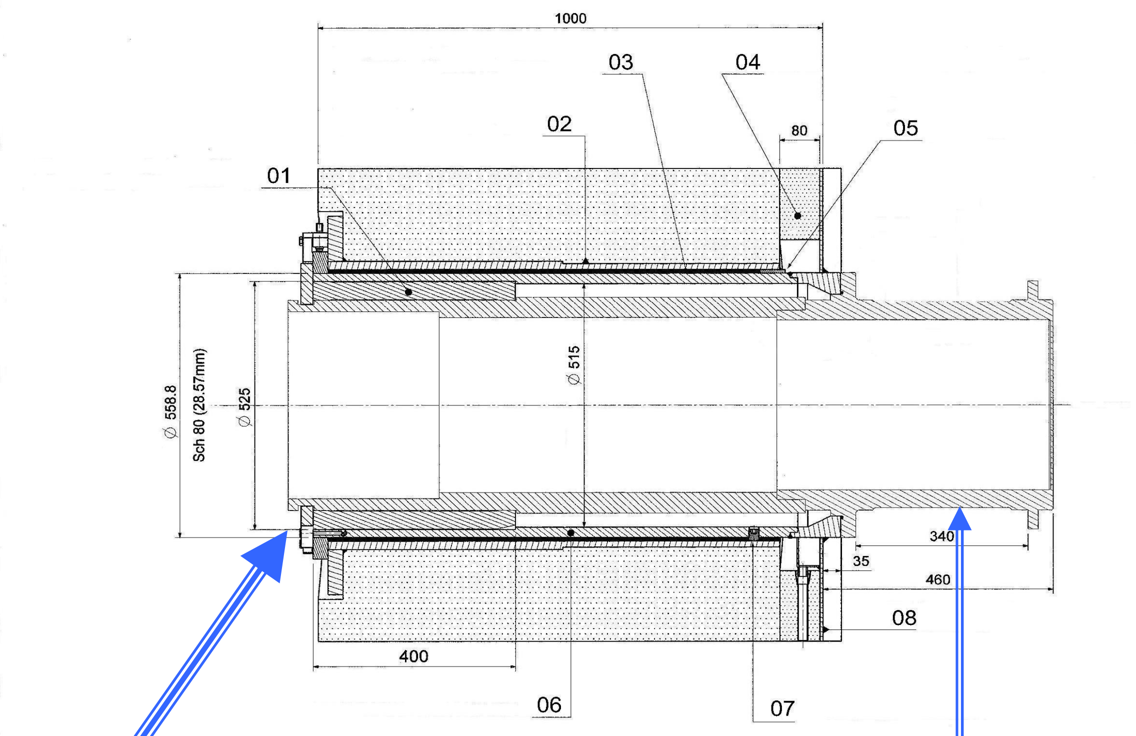
The important length *(more than 10 meters)* and the total weigh supported may cause statics deformations (significant bend) and –also- may create a risk in case of earthquakes: this interface with the pool platform is necessary.

- **Collimator plug penetration *(in pool and back in air interfaces –exploitation zone)***

***Figure 6*: Collimator plug penetration design**

(Principle: interfaces with pool liner and reactor building)

Mark: 01 and 03: *γ shielding;* 02:*1st sheath (interface with 1st phase concrete);* 04: 2st*phase concrete;* 05 and 07: *mechanical adjustment tools;* 06: *main sheath (interface with collimator system);* 08: *pool liner*



Back barrier: 2nd level of protection against primary water leak, interface with instrumentation system or X ray high energy generator; complementary biological protection (γ ray issued from the reactor pool and from the experimental rod …)

Immersed « nozzle »: basically it's a mechanical interface with the γ bench *(X, Y guide only, without static heavy weigh charge) which is essential for accuracy goal (guaranty of the position X, Y).* *Safety challenge: all external or internal aggression will be dismissed and the risk of water leak needs high welding control*

3.2 - Neutron imaging (NI) system[(1)]

[(1)]Reference: WCNR8 (2006) S Gaillot and all (CEA France) "In pool Neutron Radiograhy for JHR Reactor: a key Non Destructive Equipment Project within a modern Experimental Process"

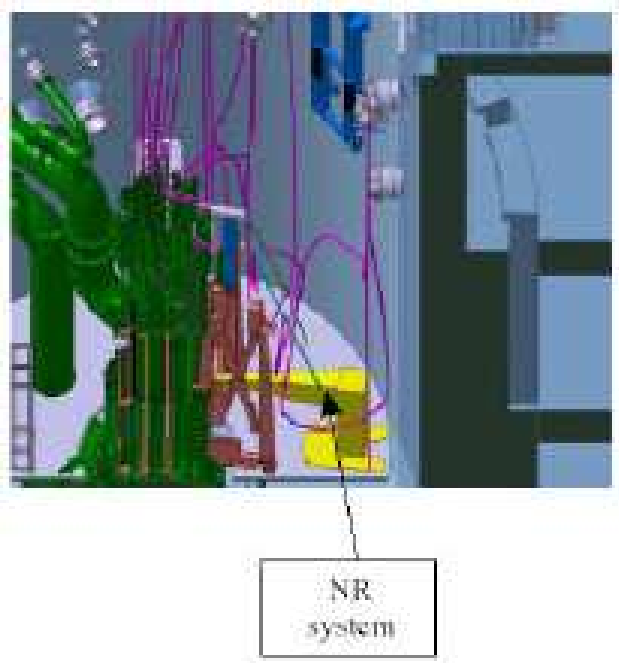


Figure 7: NI system implantation

This NI system located underwater is devoted to matter neutron probing on experimental samples to investigate the changes in properties and sizes of those objects due to in-core irradiation - or after interaction with the local environment.

The main targeted neutron bench performances are:

- Vertical full strokes with possibility of full component rotation for 3D tomography
- Possibility to tune the neutron flux coming from the core by playing on the distance to core.

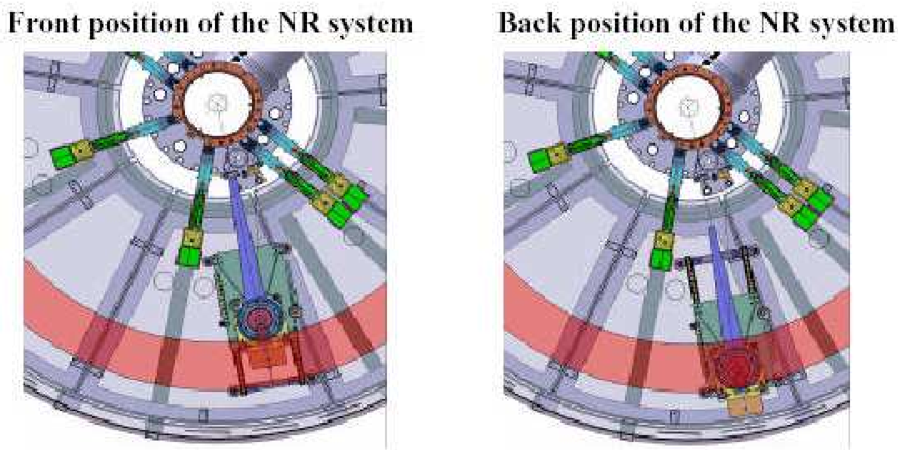


Figure 8: JHR NI system characteristics

Designed to accommodate objects installed vertically in a mechanical bench - like experimental rod with instrumentation *(similar to those used for γ and X ray NDE)*

The object to be screened will be placed in the carrier part of the bench, capable of 3 movements: radial stroke up to 100 mm (radial examinations), vertical stroke up to 800 mm (full active length inspection), and full rotation of the device for tomography purpose.

Following relatives accuracies are targeted: spatial resolution is about 100 microns (3 axis) and an angular accuracy of 100 microns at r = 100 mm on the rotation axis.

3. ***JHR NDE : main constraints interface and study needs& conclusions:***

NDE JHR systems installation is characterized by a ***high mechanical accuracy***:

- **About 0, 1 mm** *(relative position benches, collimator axis)*: this objective will permit to obtain a significant gain on the resolution of final fuel rod dimensional measurements in comparison of the to day equivalent installations.
- The goal is an expected resolution of $(100\ \mu m)^3$ on final fuel rod dimensional measurements (against ~$(500\ \mu m)^3$ to day)

The both mechanical design and supply challenges are equivalent for NI and γ benches. But, for NI bench, the safety process should be less complicated because all the NI system stays in the reactor pool (without any barrier penetration).

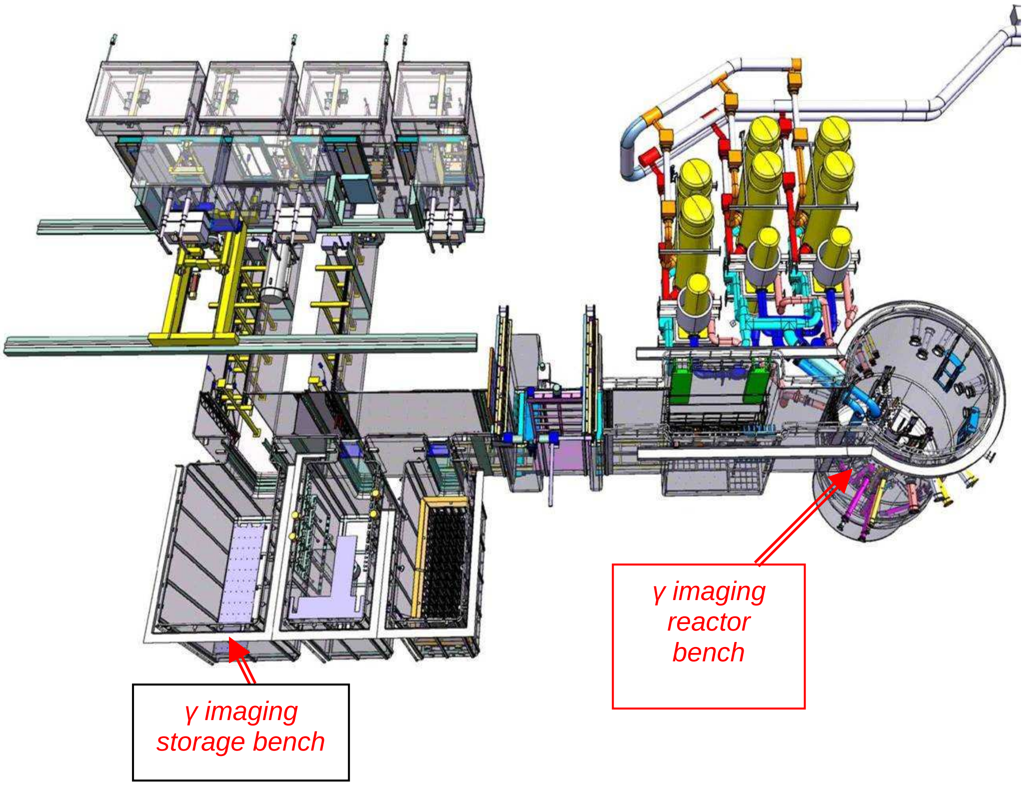
For γ benches (and their associated plug penetration), an important effort will be done in term of safety analysis and demonstration, but no more than for other primary systems. That needs to be deeply studies in the current phase of design.

Transfers and assemblies of these very long equipments on their JHR specific sites needs to be take in account during the current design: a concept of modular mechanical component – with on site assembly should be adopted.

Cross activities during exploitation of NDE system is an important parameter to be study early in the conception: it's essential for the success of the experimental process.

ANNEXED Figures

Figure 9 - General Horizontal view of reactor and pools block with γ imaging bench position



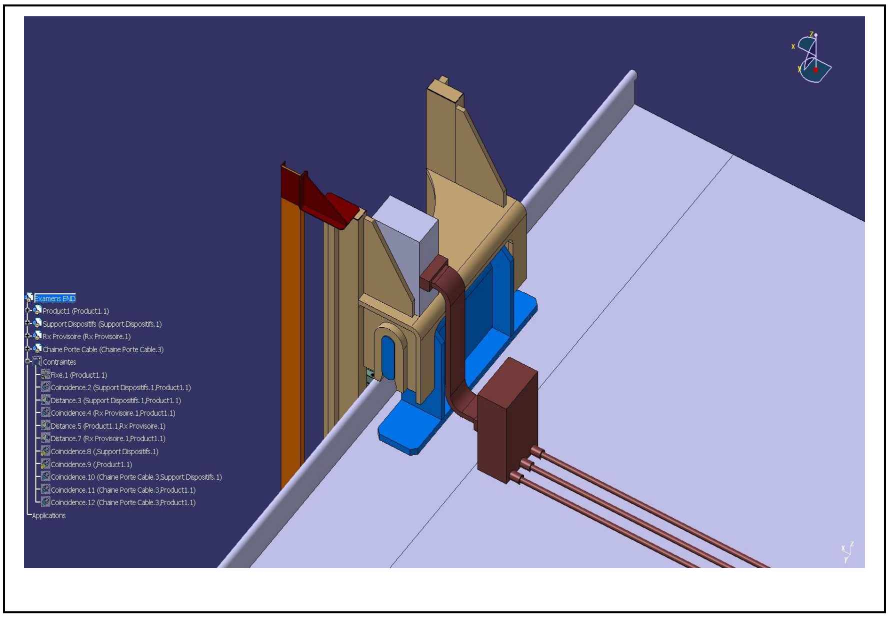


Figure 10 -

JHR reactor pool current γ bench design:

"Top support" (detail of the interface settled down on the pool bank)