THE HOT CELLS OF THE JULES HOROWITZ REACTOR: A MODERN HOT CELLS COMPLEX DESIGNED FOR CONVENIENT MANAGEMENT OF IRRADIATED SAMPLES AND COMPONENTS

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1 Introduction

This paper presents the Hot Cells complex implemented in the new CEA Material Testing Reactor: the Jules Horowitz Reactor (JHR).

After a general presentation of the JHR, the main safety requirements implemented into the hot cells and experimental requirements are presented. Layout of JHR Hot Cells and associated equipment are then developed to present the future JHR Hot Cell complex.

2 General purpose of JHR

The Jules Horowitz Reactor (JHR) is a new Material Testing Reactor (MTR) currently under construction at the CEA Cadarache center, in the south of France. It will be a major Research facility in support to the development and the qualification of materials and fuels under irradiation with scales and experimental conditions relevant for nuclear power plants, in order to optimize and demonstrate safe operations of existing power reactors, as well as to support future reactor design. It will also represent an important Research Infrastructure for scientific studies dealing with material and fuel behavior under irradiation.

Also, the JHR will also contribute to secure the production of radioisotope for medical application. This is a key public health issue.

The first operation of JHR is planned before the end of this decade. The design of the reactor will provide an essential facility for supporting nuclear energy programs for the next 50 years.

3 Safety requirement

JHR is designed for a lifetime of 50 years. In order to operate satisfactorily during this period, the design of the facility has integrated, from upstream phases of design, the most recent safety requirements. In this respect, the CEA aim to build a modern nuclear reactor that is exemplary in terms of safety.

Regarding more specifically the hot cells, the main risks considered in the safety analysis are as follows:

- dissemination of radioactive dust,
- seismic event,
- radiation hazards,
- load fall,
- fire,
- criticality hazard.

The main safety requirements for each of the above risks are as follows:

3.1 *Dissemination*

The prevention of the risk of dissemination is based on a high-level static containment, completed with a dynamic containment associated with a multistage filtration system.

JHR Hot cells are designed to ensure a maximum leakage rate of 10^{-2} Volume/h. To do this, the cells are fully covered with an inner stainless steel liner and each opening (door, trapdoor) has its own leakage rate (5 l/h under a pressure differential of 32 daPa for doors, for example).

Nuclear ventilation system (Figure 1) maintains a permanent depression in cells (32 daPa at nominal operating). Ventilation tubes are entirely made of stainless steel and are equipped with a set of High Efficiency Particulate Air (HEPA) filters (filtration rate of 10^{-3} minimum): two stages + one pre-filter located inside the cell for 3 cells out of 4 (IIIB family according to norm ISO 17873). The last cell is an Alpha cell, dedicated for receiving experiments at high risk of dissemination (cladding failure). This cell has an extra filter (family IV). All cells also have iodine traps.

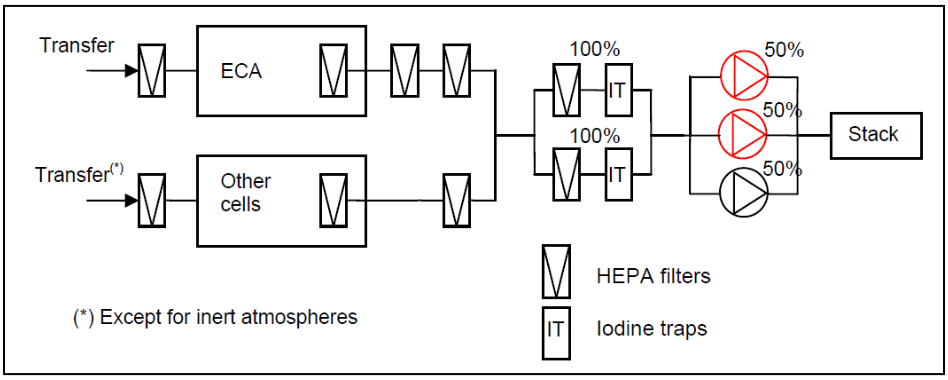

Figure 1. Ventilation scheme of the JHR hot cells.

All cells are also equipped with a fire safety valve, to allow by-passing the pre-filter in case of clogging in a fire situation. This permits maintaining the cell ventilation operating longer in case of fire.

3.2 *Seismic event*

Safety requirements regarding seismic event are:

- preservation of the biological protections,
- preservation of the static and dynamic containments,
- mastery of sub-criticality.

The main structures of the cell are designed to stay in place during an earthquake: the heavy concrete walls are dimensioned accordingly, as well as wall crossings (shielded windows, manipulators, plugs, electrical crossings, ...) which are dimensioned to stay in place in their housing. Radiation protection is then preserved during and after an earthquake.

The liner is designed to keep its tightness under earthquake. The ventilation of cells is designed to continue operating during and after the earthquake. Static and dynamic containment is maintained under earthquake.

Regarding sub-criticality, equipment inside the cells using the control mode geometry must keep their shape during an earthquake.

3.3 Radiation hazards

The cell walls (including all singularities) are designed according to the following source term:

- gamma radiation: 100 kCi ($3,7.10^{15}$ Bq) of ^{60}Co)
- neutron radiation: $2,7.10^{8}$ n/s,

Note that the MCNP radiation calculations were made directly from the 3D CATIA model, to have a very accurate representation of the design.

A word about the cell walls constitution: they are made of 1.20 m thick heavy concrete (density 3.5). In the case of an empty crossings (for example embedded ventilation tubes-Figure 2), these are staggered and additional biological protection (embedded lead bricks : Ⓐ, Ⓑ) are placed in the wall to reproduce a concrete thickness equivalence.

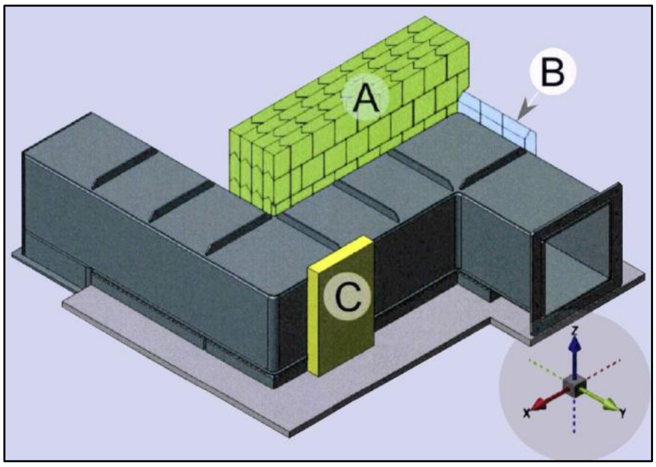

Figure 2. Biological calculation of a ventilation tube.

The maximum target dose for operators is 10 µSv/h, but can vary depending on the presence of the source (fixed or moving) and room occupancy (temporary or permanent).

3.4 Load fall

The risk of load fall inside the cell is taken into account along two axes: the reliability of lifting equipment (crane units are safety classified and their probability of failure against falling load must remain below 10^{-5}/year) and the dimensioning of floors to sustain the heaviest load (2.5T at 7 m). Note that the cell inner liner is not designed for the worst case drop (only the concreted floor is), the safety demonstration is based on a dynamic confinement preservation in this case.

Any equipment present in the cell and heavier than 100 kg has to be also anchored and designed to withstand earthquakes.

3.5 Fire Protection

Fire protection is a major objective for nuclear buildings and hot cells in particular. Given the state of industrial technical solutions available to date, there is no solution for setting a fire compartment compatible with hot cells boundaries. Essential elements for hot cells (shielded windows, manipulators in particular) do not have sufficient fire qualification.

This leads to extending the limits of the fire compartment to the surrounding rooms (Figure 3). This has major consequences on the surrounding rooms and ventilation systems: the fire doors and fire dampers are not placed at the hot cells boundaries, but at the limits of the surrounding rooms : the cells are thus fully inserted into a large fire compartment, including its upper and lower faces.

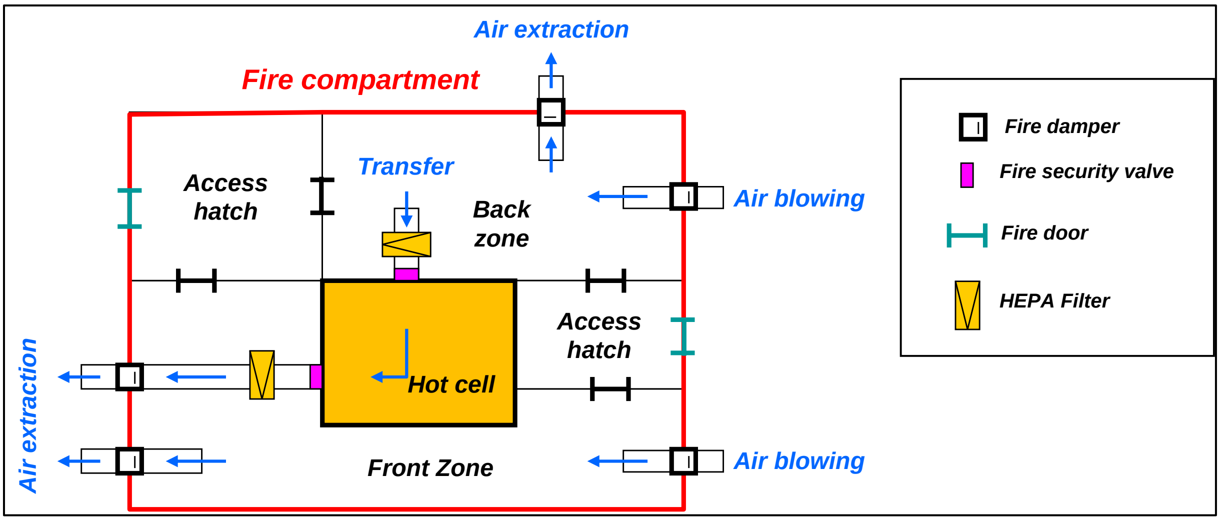

Figure 3. Hot cell fire protection concept.

4 Experimental needs

On top of the irradiation experimentation, which is the primary purpose of JHR, hot cells have the mission to host experimental equipment to perform non-destructive tests on irradiated samples (material and fuel).

Equipment dedicated to the experimental characterization in JHR is presented in the paragraph dealing with experimental cells.

5 Overview of JHR hot cells

5.1 Main functions

JHR hot cells are intended to manage all irradiated materials coming out from the experimental reactor. We thus find:

- the JHR irradiated fuel after pool decay for evacuation and reprocessing,

- the experimental samples of irradiated fuel and/or materials for characterization in the facility or externally,
- the medical radionuclides after irradiation, for evacuation and extraction of radioactive tracers,
- the irradiated structures of the reactor,
- the radiating and / or contaminant waste generated by the reactor.

There are 7 JHR hot cells, divided into two categories: four operating cells for operation and maintenance of the reactor and three cells dedicated to experimental programs. These three cells also provide entry through hatches to the four operating cells.

5.2 The operating and maintenance cells

The 4 operating cells have an approximate area of 10 m^2 and a height of 13 m, and are located above the channel leading to the storage pools of the reactor's spent components (Figure 4).

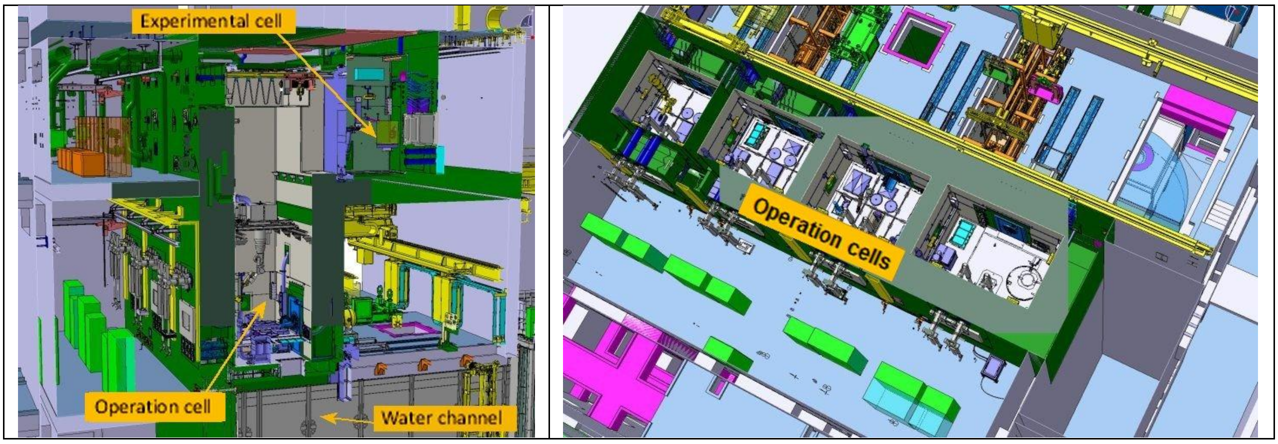

Figure 4. Overview of the JHR operating cells.

These cells include:

- Two polyvalent cells to treat fuels and experimental samples. These cells can be inerted and one of them has a well wash and a pneumatic transfer for dosimeters. Well washing is intended to neutralize the solid metal alloy (NaK) coolant used in some experimental devices. Due to its interaction with air and water, the cell is inerted and NaK residues are neutralized in the well. The samples can then be retrieved for examination,
- A dedicated cell for fuel, medical radionuclides evacuation and characterization of waste before disposal,
- A dedicated Alpha cell for processing experiments with substantial risk of dissemination (experience with cladding failure).

Each cell has the following facilities:

- a lifting unit designed for earthquake (at 2.5T load). This lifting unit is designed to be extracted from cell by remote operation in case of failure,
- heavy and lightweight means for tele-operations (master-slave and heavy manipulators) to provide the bulk handling operations in cell,
- means of vision (large shielded window, hardened camera) and listening system to cell,

- storage locations (garbage bins, experimental devices),
- a mobile work place for experimental devices, allowing vertical movement of the devices in front of the window,
- a tight irreversible hatch for small equipment entry,
- horizontal transfer means between cells (side of operating cells) and vertical (to the experimental cells)
- an entry motorized trapdoor in cells from water channels,
- Cask connections interface in back zone, including:
    - a tight double door (DPTE) for the alpha cell,
    - an additional vertical cask connection in the fuel cell.

5.3 Experimental cells

There are 3 experimental cells dedicated to experimental programs, located in the upper part offset from operating cells (Figure 5). They have a dual purpose:

- receiving the experimental devices to perform characterization in cells (non-destructive examination of materials and fuels),
- Serving as a response to heavy maintenance in large cells. Generally, this type of shielded hatch is located directly above the main cell. In the case of the JHR, forced development of the installation led to an offset solution. Innovative solutions have therefore been developed to overcome this difficulty (for instance, extraction lifting units laterally and not vertically).

These cells are equipped with the same facilities as the operating cells. However master-slave manipulators are of a higher accuracy for handling small objects.

These cells are designed to allow relatively easy access to operators. Contamination is thus kept as low as possible and shielded doors permit isolating the operators from the atmosphere of operating cells.

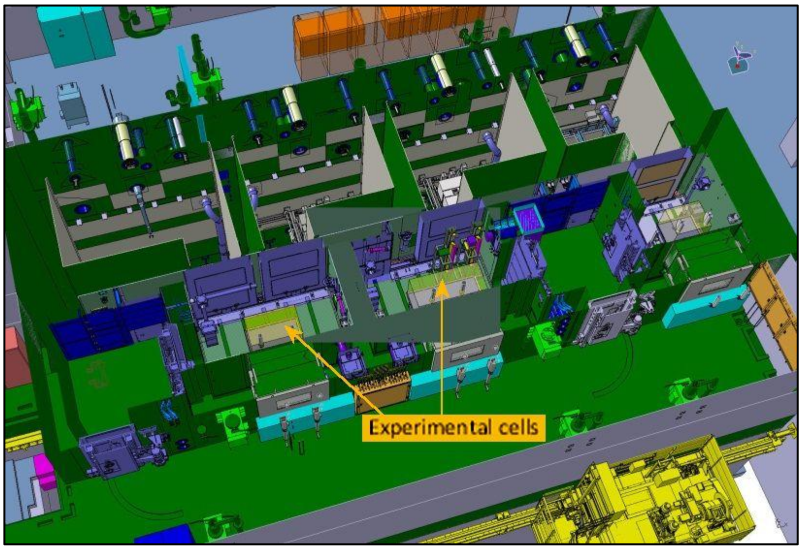

Figure 5. View from above of the JHR experimental cells.

The experimental equipment allow Non Destructive Test (NDT) of materials and fuel samples.

For materials, NDT bench (under development) will perform dimensional measurements of high precision, for example to evaluate the behavior of samples under neutron flow (swelling).

For fuels, NDT bench is in advanced stage of design studies. This equipment is dedicated to gamma measurements and X-ray imaging of fuel samples, previously extracted from JHR experimental devices. It permits the examination of a great diversity of sizes and shapes of fuel objects (rods, plates, JHR fuel element, innovative fuels, …) inside the overall limits of a cylinder 150 mm in diameter, up to 1200 mm in height.

The gamma station Figure 6, ①) is located inside the airlock (access hatch). It measures the radial and/or axial activity profile of each detectable radionuclide located inside the volume defined by an adaptable pre-collimator ②.

The X-Ray imaging bench allows generating X-ray radiograms and X-ray transmission tomograms by emitting X-rays from the accelerator ⑤. Associated with a prototype X-ray camera ⑥ placed to the opposite side, the image resolution will allow a very detailed characterization of the fuel sample.

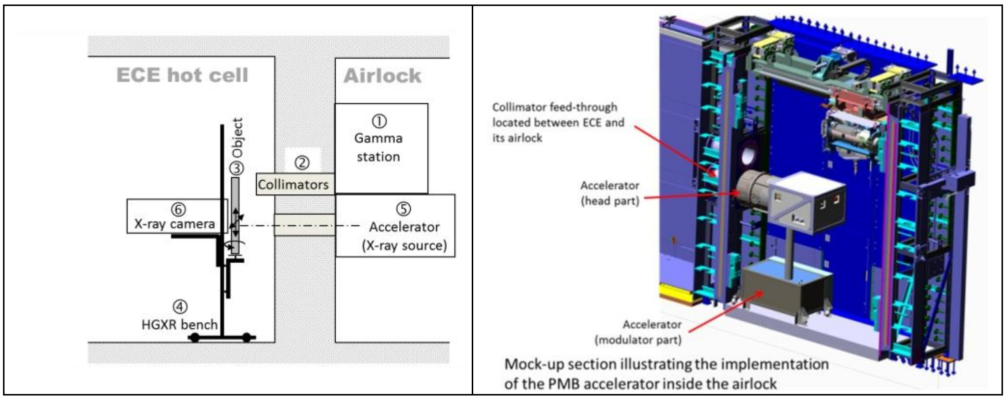

Figure 6. Overview of the gamma-X-ray device.