MAIN TECHNICAL OPTIONS OF THE JULES HOROWITZ REACTOR PROJECT TO ACHIEVE HIGH FLUX PERFORMANCES AND HIGH SAFETY LEVEL

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Abstract

Since the shutdown of the SILOE reactor in 1997, the OSIRIS reactor has ensured the needs regarding technological irradiation at CEA including those of its industrial partners and customers. The Jules Horowitz Reactor will replace it and will offer a quite larger experimental field. It has the ambition to provide the necessary nuclear data and to maintain a fission research capability in Europe after 2010.

The Jules Horowitz Reactor will represent a significant step in terms of performances and experimental capabilities. This paper will present the main design option resulting from the preliminary studies. The choice of the specific power around 600 KW/l for the reference core configuration is a key decision to ensure the required flux level. Consequently many choices have to be made regarding the materials used in the core and the fuel element design. These involve many specific qualifications including codes validation.

The main safety options are based on :

- A safety approach based upon the defence-in-depth principle.
- A strategy of generic approaches to assess experimental risks in the facility.
- Internal events analysis taking into account risks linked to reactor and experiments (eg., radioactive source-term).
- Systematic consideration of external hazards (eg., earthquake, airplane crash) and internal hazards.
- Design of containment to manage and mitigate a severe reactor accident (consideration of "BORAX" accident, according to french safety practice for MTRs, beyond design basis reactivity insertion accident, involving core melting and core destruction phenomena).

1 – INTRODUCTION

The Material Testing Reactor (MTR) are, with the hot laboratories, essential tools for the knowledge of materials and nuclear fuels behaviour under irradiation.

Currently, in the world, only a small part of the experimental reactors has a power large enough (> 10 MW) to perform irradiations of materials and fuels. In Europe, these reactors which all were built at the beginning of the Sixties, will be more than 40 years old in 2010.

It's essential for Europe, which operates a fleet of 140 nuclear power plants to continue to rely on experimental reactor (MTR). It's also essential to rely on such a tool to carry out research associated to the development of a new generation of power plants. These needs were clearly confirmed by a group of experts, nominated in the framework of the European Community project FEUNMARR (Future European Needs in Material Research Reactors).

This context is at the origin of the Jules Horowitz reactor project (JHR) as an infrastructure of the European Research Area (ERA).[1]

This reactor will be located at Cadarache, within a large complex of nuclear facilities and laboratories in a very favourable scientific environment to implement the "fission platform". This location has to be considered as a major advantage to guarantee an optimal productivity of the facility and the scientific quality of research.

2 – MAIN OBJECTIVES

- Supporting existing power plant operation (material reliability, fuel performance and safety, …) by carrying out relevant separate effect and integral experiments on fuels and materials, in response to both industry and regulatory requirements.

- Supporting the development and the qualification of advanced materials and new fuels at conditions anticipated for new fission reactors and fusion by carrying out limited scale experiments prior to any larger scale technological demonstration.

- Development expertise and supporting the training of the staff to be employed in the nuclear industry which is a necessary condition for the restart of nuclear energy in the coming years.

- Supporting countries and the European Community future decisions related to new nuclear power plants construction or new concepts assessments.

To achieve all the expected performances, mainly the flux levels and to be able to offer an experimental capacity as large as possible for a long period (50 years), it was necessary to select specific design options.

3 – BASIC OPTIONS FOR THE DESIGN OF THE JHR

Main characteristics

Power	100 MW
Volume power	600 kW/l
Moderator	H_2O
Reflector	H_2O, Beryllium
Coolant	H_2O
Max non-disturbed fast neutrons flux (> 0.907 MeV)	$6.4\ 10^{14}$ n/cm^2/s
Max non disturbed thermal neutrons flux (< 0.625 eV)	$7.3\ 10^{14}$ n/cm^2/s
Inlet core temperature	25°C
Outlet core temperature	41°C
Coolant velocity in core	15 m/s
Direction of the flow in the core	Ascending
Maximum enrichment	20%
Average surface heat flux (on the fuel plates)	190 W/cm²
Maximum surface heat flux (on the fuel plates)	500 W/cm²
^{235}U core mass	21 kg

The structuring choices, retained at the end of the preliminary design studies result from three major objectives :

- The performances to reach to be able to meet durably a wide range of irradiation needs.
- The safety regulation and associated requirements.
- The minimization of the operation and capital costs.

3.1 – Provisions taken to meet durably a wide range of needs

3.1.1 - High thermal and fast flux levels

High thermal flux levels to :

- Enable better efficiency for increased burn up fuel qualification programs.
- Enlarge possibilities to reirradiate fuels up to very high burn up.

- Enlarge possibilities to perform power ramping in fuel safety related programs.

High fast flux levels to :

- Enlarge possibilities to build up significant damage on material samples.
- Increase possibilities to optimize irradiation programs on material samples.
- Carry out expertises and studies related to the power plant liftime extension.
- Investigate and to study materials for the future generation of power plants (quick selection of new materials under high fluxes and study of associated damaging mechanisms).

Key parameters to get high flux levels :

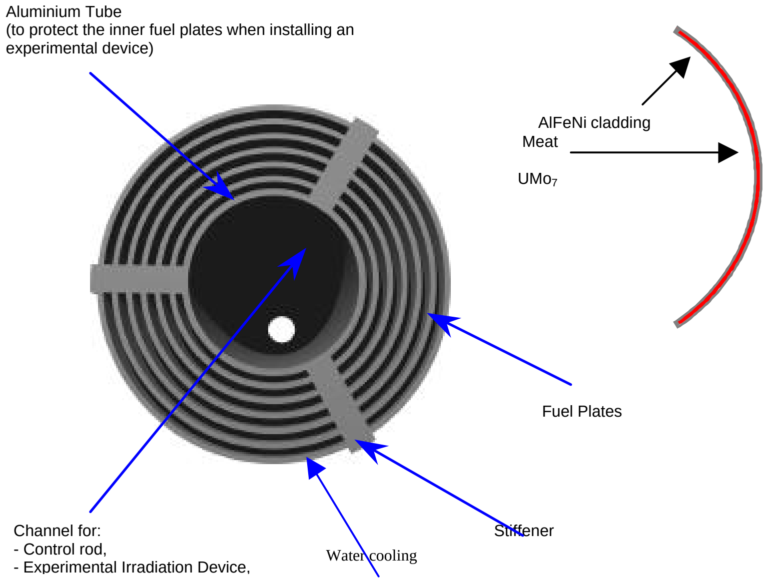
- ✓ *The power density of the reactor* (P. reactor/V. core) is basically the major parameter which determine the flux level. The choice of a high power density of 600 KW/liter makes it possible to reach the flux level required to achieve very high burn up and for the continuation of fuel irradiations already burnt in nuclear power plants. The core size is determined to offer a given number of experimental locations. The thermal power of the reactor (around 100 MW) which greatly affects the operation and capital costs will result from an optimisation during the detailed studies.

- ✓ *The water inlet temperature* in the core which has to be as low as possible results from a technico-economic compromise, it was fixed at 25°C. To get such a low temperature the reference option selected is to cool the reactor from the Canal de Provence's water (with 3 separate circuits) but the option to use, in addition, cooling towers is also considered in order to minimize the water consumption.

- ✓ *The fuel element design* is a determining parameter for the performances of the reactor. The choice of a cylindrical fuel element allows :
  - ▪ A good mechanical strength up to a water speed of 15 m/sec at least
  - ▪ To insert in the middle of each fuel element either a control rod or an experimental device within a symetrical flux distribution.

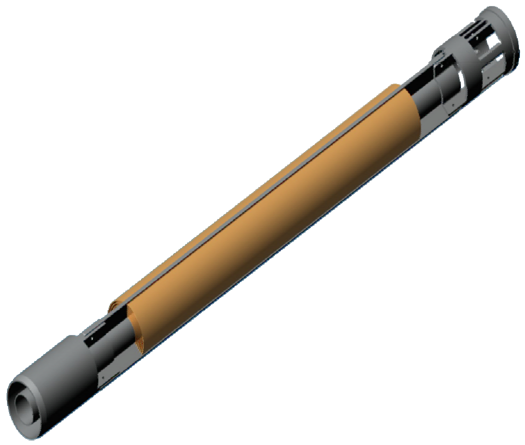
With the choice of fuel UMO_7 and the density of 8 gU/cm^3 [2] for the fuel meat it's possible to load an optimal amount of fissile material in the core. However the final density and the final thickness of the fuel meat in the plates will be decided only at the end of the fuel qualification programm in the JHR specific conditions of temperature and burn up.

High efficiency and low enrichment



ϕi 37 mm ϕe 80 mm

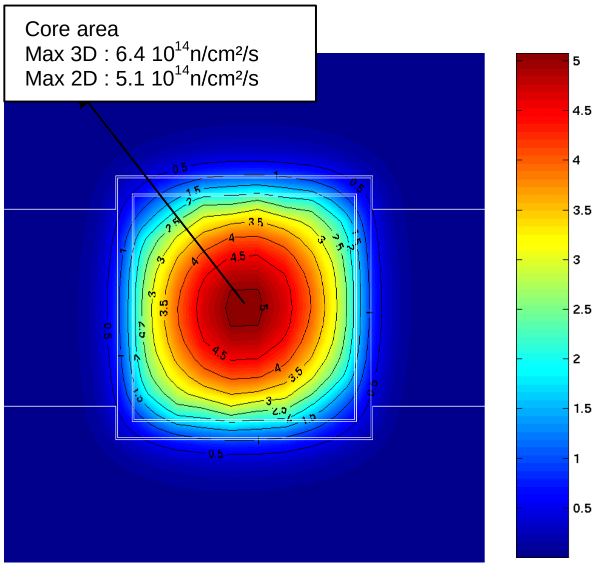
JHR fuel element cross section

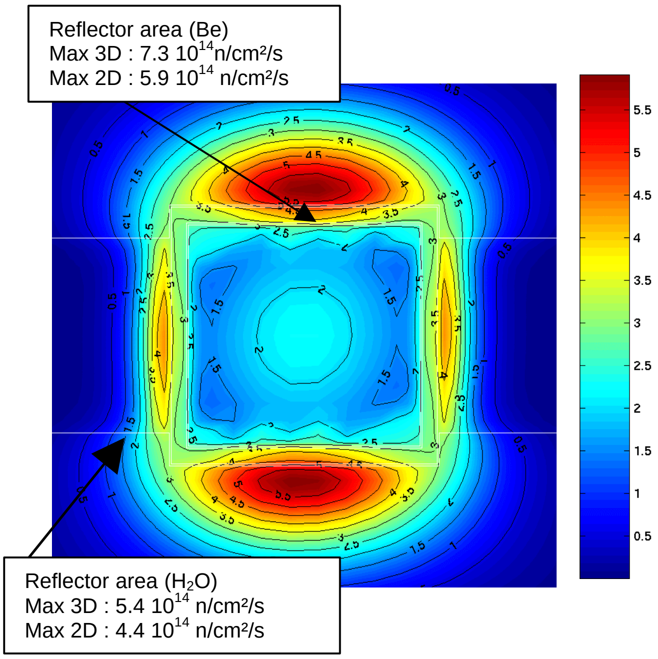


JHR fuel element

3.1.2 - A wide range of fluxes

The choice of a mixed reflector (beryllium and water) results from a compromise between the neutron performances of the core and the wish to offer fluxes characteristics as wide as possible. Thus it is possible to reach a fast flux range up to 6.4.10^{14}n/cm².s (E>0,907 MeV) in the core and a range of thermal flux up to 7.3.10^{14}n/cm².s in the beryllium part of the reflector.

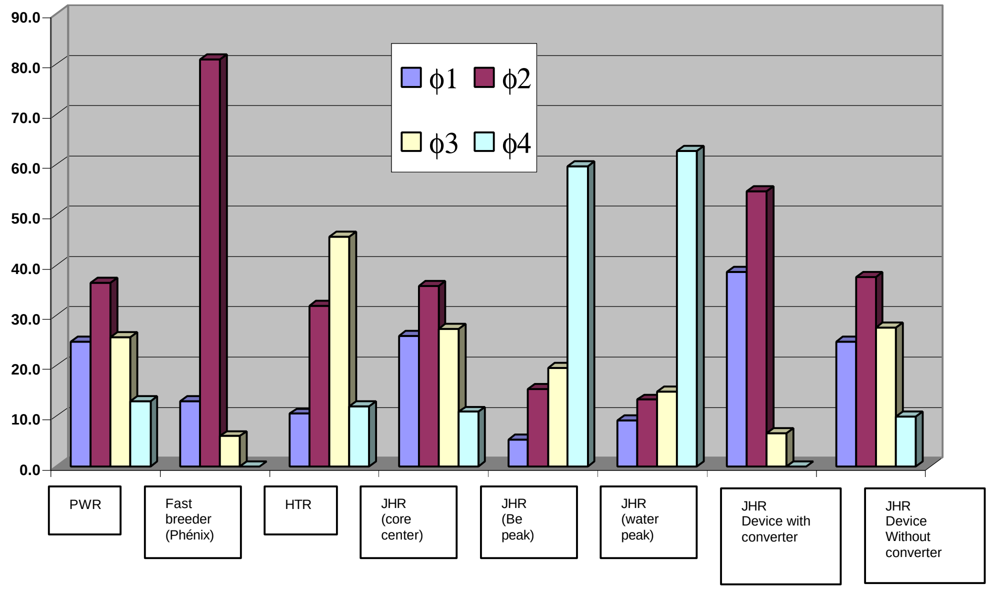

Core area
Max 3D : 6.4 10^{14}n/cm²/s
Max 2D : 5.1 10^{14}n/cm²/s


Reflector area (Be)
Max 3D : 7.3 10^{14}n/cm²/s
Max 2D : 5.9 10^{14} n/cm²/s

Reflector area (H_2O)
Max 3D : 5.4 10^{14} n/cm²/s
Max 2D : 4.4 10^{14} n/cm²/s

In order to widen the experimental field and to be able to carry out experiments in a fast spectrum or on the contrary more thermalized that in the JHR spectrum the possibility of replacing a fuel assembly by a specific device is considered.

To illustrate the flexibility resulting from the use of specific devices, the figure below shows a spectrum comparaison between PWR, fast breeder, HTR and JHR (core, water reflector, beryllium reflector and within a fast neutron converter device) (ϕ_1 neutrons > 0,907 Mev, ϕ_4 neutrons < 0,625 ev, ϕ_3 - ϕ_4 epithermal)



3.1.3 - <u>An evolutionary core configuration</u> (dismountable core rack)

The flexibility of the JHR facility to adjust its experimental capabilities to the future needs is a major option of the project :

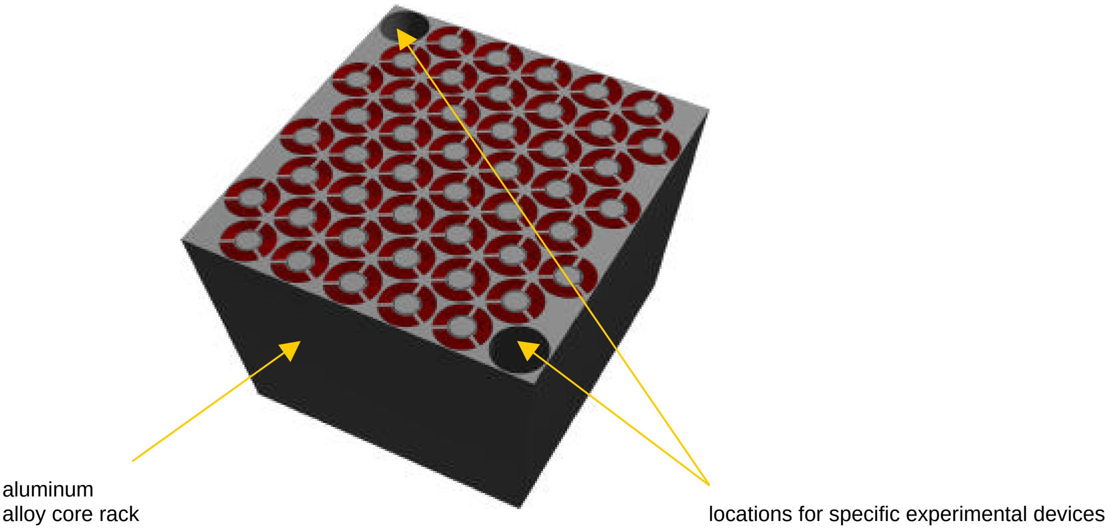
- the geometry of the fuel element enable the experiments to be carried out in the middle of the element or by substitution of a whole fuel element by an experimental device
- the displacement system in the surrounding reflector enable to move the device to adjust the flux level
- the reference core configuration can be easily changed for dedicated configurations to perform specific experiments such as safety related programs.

The ability to replace the reference aluminum core rack by a larger or a smaller component is an important option to :

- adjust the power density and consequently the flux level
- adjust the experimental capacity both inside the core and inside reflector.

For example, the reference high flux core configuration (600 KW/l) could be replaced by an alternative core configuration (300 KW/l) with an increased experimental load.

The replacement of the rack was examined particularly from the very beginning of the project with the objective switch of the configuration in less than 3 months.



JHR core

3.1.4 - <u>Specific provisions to perform oriented safety experiments</u>

The design of the JHR is based upon modern safety standards with special attention to experimental constraints mainly due to the safety oriented experiments.

All the experiments designed to study the mechanisms involved during accidental conditions have to be considered as “safety oriented experiments”.

In these experiments fuel failure and melting of a limited amount of fuel can occur. These events have to be considered as normal and taken into account in the safety analysis of the facility.

The aim of these irradiations experiments is not to test in the representative power reactor conditions a representative piece of fuel assembly (global test) but to understand the basic mechanisms. The experimental strategy is based on separate effect experiments.

3.2 – <u>To fulfil the safety regulations and associated requirements</u> [3]

3.2.1 - Main design principles

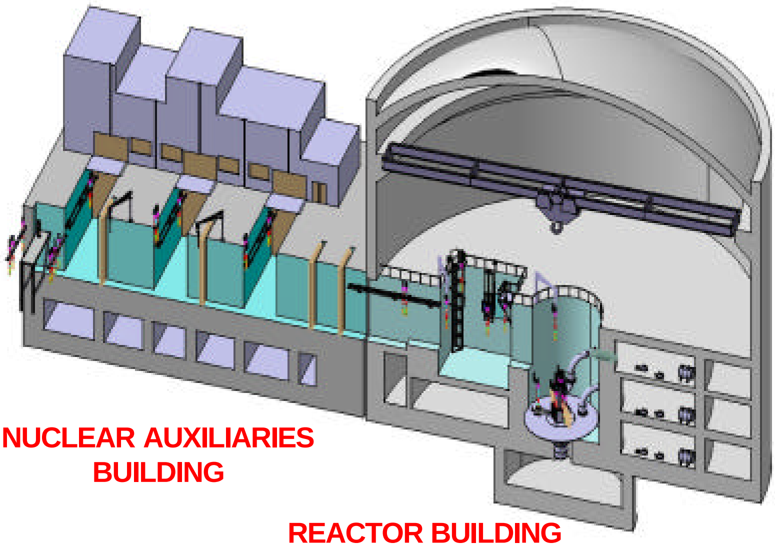
General architecture makes it possible to meet all the requirements by developing the functional segregation of the activities according to their type and the risks they generate and limiting the interactions between these various activities.

The first main principle resulted in separating the activities in two buildings, isolating :

- systems and activities specific to the reactor and the experiments within a reactor building. These two types of systems are also separated within this building in a reactor operation zone and an experiments operation zone,

- other systems relating to the nuclear activity and in particular means of pre-irradiation and post-irradiation treatment of the experiments in a Nuclear Auxiliaries Building (NAB).

The second principle is the concept of “water block”, i.e. a monolithic structure of civil engineering, inspectable from the outside, including the pools and the bunkers containing the primary circuit. This structure is continuous from the reactor building to the NAB. It includes an underwater lock ensuring the containment continuity of the two buildings. This water block guarantees that core is kept underwater in the event of primary circuit leakage.



3.2.2 – A safety approach based on the defence in depth principle (1)

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The design of the JHR relies on the defence in depth concept, based on the five following levels :

- 1st level : prevention (quality of design and realization, prevention of the anomalies),

- 2nd level : monitoring, detection, control and protection (quality of the operation, maintenance of the installation in the authorized operation range),

- 3rd level : safety actions,

- 4th level : accidents management and protection of the containment, limitation of the radiological consequences (prevention of the degradation of the accidental conditions and limitation of the consequences in case of severe accidents),

- 5th level : organization to answer any emergency (being able to manage the radioactive release).

The defence in depth principle leads to the implementation of several barriers between the radioactive products and the environment. For JHR, special attention is given to containment tightness and to the achievement of a homogenous safety base as regards internal events and/or hazards.

The reactor design takes into account :

- the experimental character of the installation that implies the segregation as much as possible between the operating systems of the reactor and the experimental devices,

- the risks related to internal hazards such are fire and internal flood and to external hazards such as earthquake, aircraft crash, extreme climatic conditions.

The safety of the experimental devices is designed taking into consideration the experimental constraints and the risks induced by the reactor.

The design takes into account experience feedback obtained in the field of experimental irradiation :

- to limit the normal operation releases, waste and worker doses with an ALARA approach,

- to integrate the human factor for the man/machine interface and for the working groups organization in charge of the reactor and of the experimental devices,

- to take into account the reactor maintenance constraints and the reactor dismantling.

To minimize the leakages all the penetrations in the reactor building are directed towards a zone known as “leakoff recovery zone” located between the two buildings (the reactor building and the NAB), which provides leak collection, and filtration. This global containment solution is supplemented in the lower part of the building (below the top level of the pools) by gathering on a single foundation slab the reactor building, the NAB and the leakoff recovery zone, within a single platform known as “nuclear unit”.

The reactor building will be made of concrete and will be circular in order to ensure its good behaviour in case of on accident leading to pressure increase.

The severe accident considered for the JHR is a beyond design reactivity insertion accident, involving instantaneous core melt and core destruction phenomena, the core remaining underwater. The third barrier is designed to manage and to mitigate this severe accident.

3.3 – To fulfil costs minimization requirements

Minimization of the capital and operation costs are strong requirements to ensure the success of the project. For example, the option to build two different buildings (reactor building and the auxiliary building) has been made to reduce as much as possible the size of the reactor building which cumulates the maximum of safety constraints, mainly due to the reactivity accident scenario taken for the reference severe accident.

The size of the various components of the primary circuit (pumps, heat exchangers …) and their location is optimised to limit the size of the reactor building and significant savings are expected from the use of parasismic neoprene posts under the buildings.

Concerning the operation costs :

- the option of a uranium density of 8gU/cm^3 in the fuel plates is taken to reduce the fuel cost cycle by increasing as much as possible the core lifetime and to reduce the spent fuel management cost

- the option to implement in service maintenance for specific systems or components is taken to improve the availability of the facility

- the option to use modern technologies to assist the operators is taken to minimize the number of operators in the shifts.

CONCLUSION

The JHR design results from the need to offer experimental possibilities as broad as possible for at least 50 years. It takes into account the foreseeable evolution of the programs related to the study of the new reactor types, in particular the gas cooled reactors. It also takes into account the analytical experiment needs for materials and fuels behaviour modelling under irradiation, including accidental situations.

The choice to build the JHR in CADARACHE expresses the will of CEA to guarantee to this research infrastructure a high level of excellence, offering a complete service.

It will be in the heart of a scientific platform. It will be broadly opened to the european and international co-operation. Il will gather all the functionalities and will offer the possibility of an effective knowledge production, with optimised costs.

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