< Technical Note >

THE JHR, A NEW MATERIAL TESTING REACTOR IN EUROPE

DANIEL IRACANE
CEA Nuclear Energy Division
Building 121, CEA Saclay, F - 91191 Gif Sur Yvette, France
E-mail : daniel.iracane@cea.fr

Received August 29, 2005

European Material Test Reactors (MTRs) have provided essential support for nuclear power programs over the last 40 years. MTRs are now ageing in Europe and they cannot ensure the securing of experimental capability for the next decades. In this context, a new Material Testing Reactor, named Jules Horowitz Reactor -JHR-, operated as an international user-facility, is under development in Europe.

The European MTRs context and the JHR objectives and status will be presented. Emphasis will be put on experiments in the field of nuclear fuels and materials irradiation which are developed in the framework of European and international collaboration.

KEYWORDS : JHR, Material Testing Reactor, Fuel and Material Experimental Irradiations

1. SITUATION OF MATERIAL TEST REACTORS IN EUROPE

European Material Test Reactors (MTRs) have provided essential support for nuclear power programs over the last 40 years. Associated with hot laboratories for the post irradiation examinations, they are structuring research facilities for the European Research Area in the fission domain. They address the development and the qualification of materials and fuels under irradiation with sizes and environment conditions relevant for nuclear power plants in order to optimise and demonstrate safe operations of existing and coming power reactors as well as to support future reactors design.

However, in Europe, MTRs will be more than 50 years old in the next decade and will face increasing probability of shut-down due to their obsolescence. Such a situation cannot be sustained on the long term since “nuclear energy is a competitive energy source meeting the dual requirements for energy security and the reduction of greenhouse gas emissions, and is also an essential component of the energy mix” [1].

Renewing the experimental irradiation capability meet not only technical needs but important stakes such as maintaining a high scientific expertise level by training of new generations of searchers, engineers and operators. This answers the European concern about the availability of competences and tools in the coming decades.

Then, a consensus has been drawn in Europe on the following statements [2], [3]:

- There is clearly a need of irradiation capability as long as nuclear power provides a significant part of the mix of energy production sources
- Given the age of current MTRs, there is a strategic need to renew MTRs in Europe; At least one new MTR shall be in operation in about a decade from now

Table 1. List of the main European Material Testing Reactors

Countries	Reactor	First criticality	Power (MWth)
Czech Re.	LVR15	1957	10
Norway	Halden	1960	19
Sweden	R2	1960	50
Netherland	HFR	1961	45
Belgium	BR2	1963	60
France	OSIRIS	1966	70

In the above list, R2 has been shut down in 2005 and OSIRIS will be shut down at the beginning of the next decade.

2. THE JULES HOROWITZ MATERIAL TEST REACTOR

To cope with this context, CEA with the support of EDF, has launched the Jules Horowitz Reactor Project (JHR) [4,5,6] as a new European MTR to be implemented in Cadarache (south of France); start of operation is foreseen in 2014.

The European Commission supports the development of research infrastructures of European interest, among which the JHR has a central role for the fission research.

A JHR International Advisory Group has been settled within the OECD/NEA framework to assess the project and to promote it as an international users-facility.

2.1 JHR Project Objectives

JHR will offer modern irradiation experimental capabilities for studying material & fuel behavior under irradiation. JHR will be a flexible experimental infrastructure to meet industrial and public needs related to generation 2, 3 and 4 power reactors and to different reactors technologies.

JHR is designed to provide high neutron flux (twice larger than the maximum available today in European MTRs), to run highly instrumented experiments in order to support advanced modeling giving prediction beyond experimental points, and to operate experimental devices giving environment conditions (pressure, temperature, flux, coolant chemistry, …) relevant for water reactors, for gas cooled thermal or fast reactors, for sodium fast reactors, etc

This irradiation experimental capability will address

- Power plant operation of existing and coming reactors (Gen 2 & 3) for material ageing and plant life management,
- Design evolutions for Gen 3 power reactors (in operation for all the century) such as performance improvement and evolution in the fuel cycle,
- Fuel performance and safety margins improvements with a strong continuous positive impact on Gen 2 & 3 reactor operating costs and on fuel cycle costs (burn-up and duty-cycle increase for UOX and MOX fuel)
- Fuel qualification in incidental or accidental situation
- Fuel optimization for High Temperature Reactors
- Innovative material & fuel development for Gen 4 systems in different environments (very high temperature, fast neutron gas cooled systems, various coolant such as supercritical water, lead, sodium, …) [7].

These objectives require representative tests of structural materials and fuel components as well as in-depth investigations with separated effects experiments coupled with advanced modeling.

For example, the JHR design accommodates improved on-line monitoring capabilities such as the fission product laboratory directly coupled to the experimental fuel sample under irradiation. This monitoring can be used to get key information on the fission gas source term during transients related to incidents. It can also provide time-dependant data on the fuel microstructure evolution during the irradiation, which is of course a valuable input for modeling developments.

The JHR design is optimized for the above technical objectives. As an important secondary objective, in connection with other producers, the JHR will contribute to secure the production of radioisotope for medical application in Europe, as a key public health stake.

2.2 JHR Planning and Funding

The JHR construction schedule is the following:

- Completion of definition studies in 2005 (typically 100 persons are working on definition studies since 2003)
- Decision for development & construction: second half 2005
- Development studies: 2006-2007
- Construction phase: 2008-2013
- Public consultation completed in spring 2005 without difficulty
- Preliminary safety analysis report submitted to the Safety Body in February 2006
- Construction permit delivery: 2007
- Start of operations: 2014

The JHR construction cost is 500 M€ (2005 economical conditions) for the period 2006-2014.

The JHR project, as a flexible research infrastructure, meets at the same time i) middle term needs for the industry (utilities, vendors) and ii) long term public issues related to sustainability and energy policy. For that reason, a balanced financing scheme is proposed between industry (EDF, AREVA, European and international industries) and public funding (CEA, European Commission, international laboratories).

2.3 Experimental Capability Characteristics

JHR is a 100MW tank pool reactor. [8,9,10]

The core area is inserted in a small pressured tank (section in the order of 740 mm diameter) with forced coolant convection (low pressure primary circuit at 1.5 Mpa, low temperature cooling, core inlet temperature in the order of 25°C). Reactor primary circuit is completely located inside the reactor building.

The reactor building is divided into two zones. The first zone contains the reactor hall and the reactor primary cooling system.

The second zone hosts the experimental areas in connection with in pile irradiation (eg., typically 10 loops support systems, gamma scanning, fission product analysis laboratory etc.). The Fission Product Laboratory will be settled in this area to be connected to several fuel loops ether for low activity gas measurements (HTR, …) or high activity gas measurements (LWR rod plenum, …) or water measurements (LWR coolant, …) with gaseous chromatography and mass spectrometry.

Bunkers and laboratories in the experimental area will use 300m^2 per level on 3 levels.

Pools in the reactor building are limited to the reactor pool (including neutronography for experiments) and an intermediary deactivation pool (for temporary storage of fuel elements, reflector elements or replaced core mechanical structures). During reactor shutdown, experimental devices can be temporarily stored in a dedicated rack in the reactor pool.

Hot cells, laboratories and storage pools are located in the nuclear auxiliaries building.

The experimental process will make use of two hot cells to manage experimental devices before and after the irradiation. Safety experiments are an important objective for JHR and require an "alpha cell" to manage devices with failed experimental fuel. A fourth hot cell will be dedicated to the transit of radioisotope for medical application and to the dry evacuation of used fuel. Three storage pools are dedicated respectively to spent fuel, experimental devices and mechanical components management.

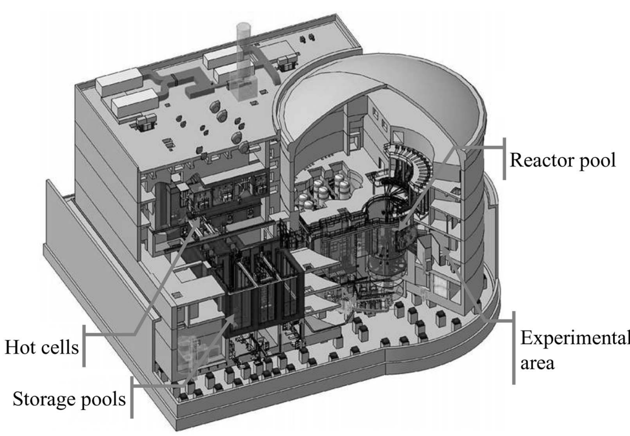

Fig. 1. JHR, a 100MW Tank Pool Reactor

Transfers, between reactor building and auxiliary building, of experimental devices are performed underwater with a monolithic water block linking reactor pool to experimental or storage areas in nuclear auxiliaries building.

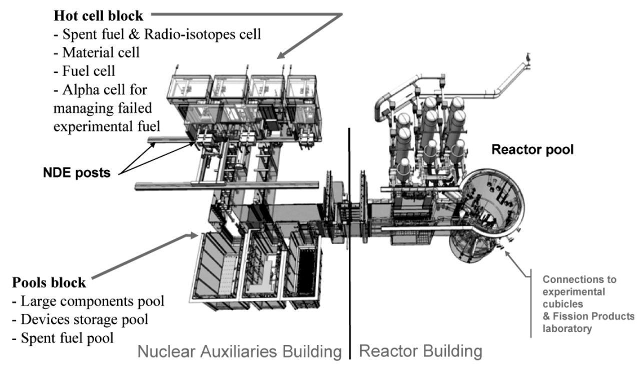

Fig. 2. Experimental Process from Reactor Building to Nuclear Auxiliaries Building

2.4 Core Features

The core (600 mm fuel active height) is cooled and moderated with water. It is operated with a high density low enriched fuel (5U enrichment lower than 20%), density 8 g/cm^3, requiring the development of UMo fuel. The fuel element is of circular shape (set of curved plates assembled with stiffeners) and comprises a central hole. The UMo fuel is under development within an international collaboration (UMo/Al dispersion solutions and monolithic UMo solution) [11]. As a back-up solution, the JHR may be started if necessary with an U3Si2 fuel with a larger enrichment (lower than 30%).

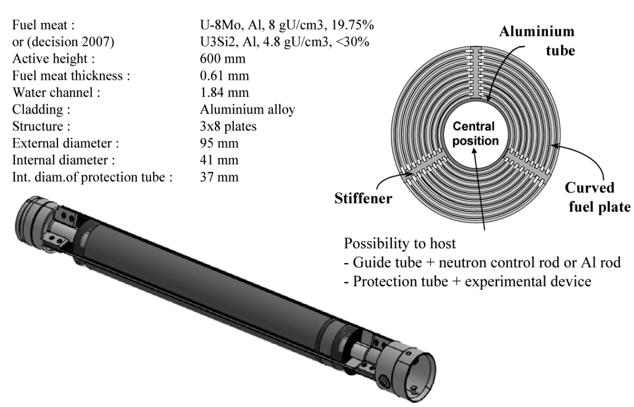

Fig. 3. JHR Fuel Element

The core area is surrounded by a reflector which optimizes the core cycle length and provides intense thermal fluxes in this area. The reflector area is made of water and beryllium elements. Irradiation devices can be placed either in the core area (in a fuel element central hole or in place of a fuel element) or in the reflector area.

A dedicated simulation codes package (HORUS3D) has been developed as a set of qualified tools which optimize neutronics and thermal-hydraulics margins in order to attain high performances [12].

In core experiment will address typically material experiments with high fast flux capability ranging from 2,5 10^{14} n/cm²/s up to 5 10^{14} n/cm²/s (perturbed fast neutron flux with energy larger than 1MeV) depending on the location.

In reflector experiments will address typically fuel experiment with perturbed thermal flux ranging from 5 10^{13} n/cm²/s up to 5 10^{14} n/cm²/s (perturbed thermal neutron flux). Experiments can be implemented in static locations, but also on displacement systems as an effective way to investigate transient regimes occurring in incidental or accidental situations.

These performances are to be understood as providing a flexible experimental capability able to create up to 16 dpa/year for in-core material experiments (with 260 full power operation days per year) and 850 W/cm (on 2% U5 enriched fuel) for in reflector simple fuel experiments.

The JHR facility will allow performing a significant number of simultaneous experiments in core (~ 10) and in reflector (~ 10).

3. EXPERIMENTAL DEVICES DEVELOPMENT

The development of JHR experimental devices offers a unique opportunity to develop a new generation of devices meeting up-to-date scientific and technological state of art as well as anticipated users' needs.

Development of experimental devices and related programmes requires international collaborations to benefit from the available large experience and to increase the critical mass of cross-disciplinary competences.

Several scientific topics are presently developed in the European framework [13,14,15,16] and are open to broader international collaborations as for example:

- Materials behaviour under high temperature conditions: the objective is the design of an experimental helium gas loop in the JHR core, at high temperature (700-1200°C) and high fast neutron flux (from 1 to 5 10^{14} n/cm²/). This loop is dedicated to separate effects experiments on selected materials, such as SiC/SiC, Oxide Dispersed Strengthened Steel (ODS) and ZrC.
- In-pile mechanical testing devices: The objective is the design of an in-pile mechanical testing device with on-line control of the stress and strain (axial and bi-axial load) and with a precise mechanical and temperature monitoring.
- Corrosion under irradiation: The objective is the design of the in-pile irradiation assisted cracking growth rate measurements, thanks to the local electric potential drop measurement.
- Current fuels experiments: This topic addresses end-

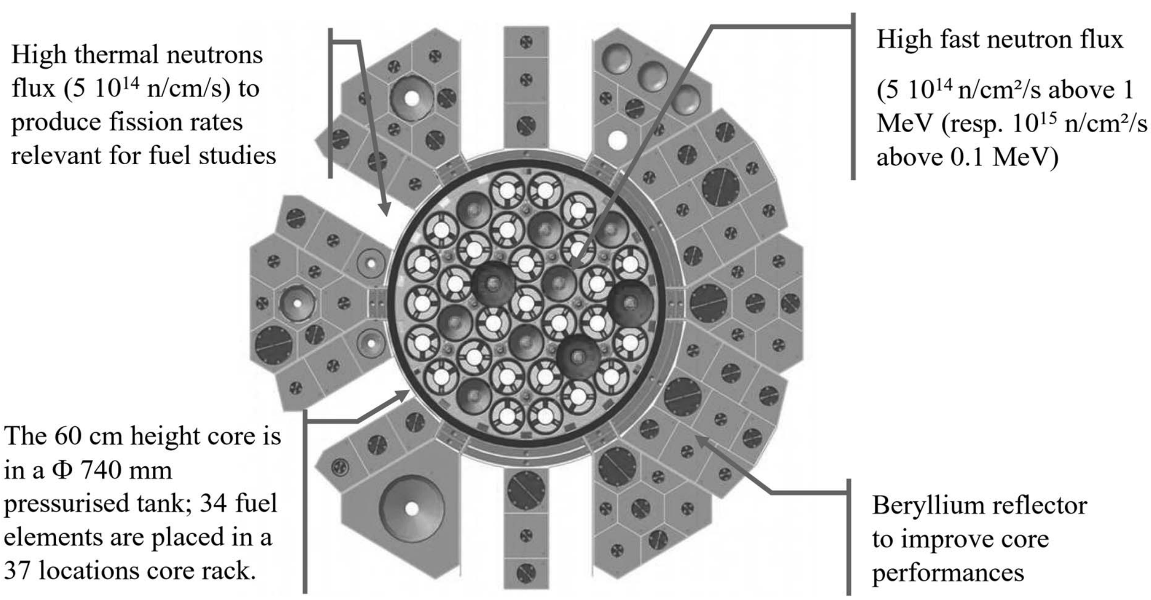

Fig. 4. 20 Experiments Can be Loaded in the Core and in the Reflector

of-life scenarios for LWR fuels, and notably the fuel thermal-mechanical behaviour and the fission gas release, thanks to a cluster of instrumented rodlets (central thermocouples, pressure gauges and fission gas sweeping lines) placed in a LWR loop.

- Gas system fuels: This topic addresses high pressure and high temperature gas rig designed for the irradiation of a 8 High/Very High Temperature Reactor compact stacks in the JHR reflector. The stack is swept by an inert gas at low flow rate to route the released fission gases to the fission product laboratory for quantitative measurements.
- Answering a growing demand, experiences for safety purposes are under discussion. The objective is the development of separated effect experiments bringing relevant information for LOCA or RIA scope. With online fission product measurement capability and a cell dedicated to failed experimental fuel management, JHR can accommodate this safety experiments.

Complementary to these items, several key technological components are under development (embarked NaK pump, online instrumentation, variable neutron screen …).

Even if these developments are driven to be implemented in JHR, they provide a strong added value for existing reactors and labs involved in material under irradiation studies by pushing the technological innovation and by disseminating the scientific state of art.

4. CONCLUSIONS

Nuclear electricity plays an important role and will stay for the long term a part of the energetic mix since it contributes to limit energy supply dependence and greenhouse gas production.

Nuclear plants will follow a long-term trend driven by the plant life extension and management, reinforcement of the safety, waste and resources management, flexibility and economics improvement.

In depth technical assessments will be required both for optimizing existing and coming plants and for the validation of new reactor concepts. Industry and safety bodies will need to have access to experimental capabilities and technical expertise since qualified knowledge will be needed for predicting structural component lifetime, for improving fuel management and reactor operation, for the development of new fuels and material.

Failure to meet such needs would lead to an economic and technical burden due to growing technical challenges for the future of nuclear energy: end of life of existing plants, construction of new reactors and development of new reactor concepts to meet sustainability issues.

Answering this need, the JHR will secure for a large part of the century the experimental irradiation capability in Europe for the benefit of international industries and public stakeholders through suited access rules:

- Members contributing to the financing of JHR construction will have guaranteed and secured access rights to experimental locations in the reactor in order to perform their Proprietary Experimental Programs.
- A Joint Program will be opened to international collaboration in order to address issues of common interest.
- Research laboratories will participate in Members' proprietary programs and/or through the Joint Program.

REFERENCES

[1] The Green Paper, "Towards a European Energy Security Strategy", published by the European Commission in November 2000

[2] FEUNMARR, Future European Union Needs in MAterial Research Reactors, 5th FP thematic network, Nov. 2001 – Oct 2002

[3] C. Vitanza, D. Iracane, D. Parrat, "Future needs for materials test reactors in Europe (FEUNMARR Findings)", 7th International Topical Meeting on Research Reactor Fuel Management, ENS, RRFM 2003.

[4] A. Ballagny, Y. Bouilloux, P. Chantoin, D. Iracane, "The Jules Horowitz Nuclear Complex. A Platform for R&D on Nuclear Fuel and Materials for the 21st Century", 8th Meeting of the International Group on Research Reactors (IGORR-2001)

[5] A. Ballagny "Main technical options of the JHR Project to achieve high flux performances and a high safety level" IGORR 9 – Sydney, March 2003

[6] A. Ballagny et al, "The JHR, a European MTR with extended experimental capabilities", IGORR 9 Sydney, March 2003

[7] F. Carre, "Fast Reactors R&D Strategy in France for a Sustainable Energy Supply and Reduction of Environmental Burdens", JAIF International Symposium – Tokyo, March 24, 2005

[8] JP. Dupuy, G. Ithurralde, G. Perotto, C. Leydier, X. Bravo "Jules Horowitz Reactor: General layout, main design options resulting from safety options, technical performances and operating constraints"; IGORR 10, Gaithersburg, Sept. 2005

[9] C. Pascal, Y. Demoisy, S. Gaillot, X. Bravo, F. Javier "Jules Horowitz Reactor: experimental capabilities"; IGORR 10, Gaithersburg, Sept. 2005

[10] M. Boyard, JM. Cherel, C. Pascal, B. Guigon; "The Jules Horowitz Reactor core and cooling system design"; IGORR 10, Gaithersburg, Sept. 2005

[11] J.L. Snelgrove, P. Lemoine, L. Alvarez, N. Arkhangelsky, "High density UMo fuels last results and reoriented qualification programs" 9th International Topical Meeting on Research Reactor Fuel Management, ENS, RRFM 2005

[12] G. Willermoz, A. Aggery, D. Blanchet, S. Cathalau, C. Chichoux, J. Di Salvo, C. Döderlein, D. Gallo, F. Gaudier, N. Huot, S. Loubière, B. Noël, H. Servière. "Horus3D code package development and validation for the JHR modelling" (PHYSOR 2004).

[13] D.Iracane, D. Parrat, "Irradiation of fuels and materials in the JHR, the 6th European JHR Co-ordination Action (JHR-CA)", 9th International Topical Meeting on Research

Reactor Fuel Management, ENS, RRFM 2005.
[14] G. Panichi, F. Julien, D. Parrat, D. Moulin, B. Pouchin, L. Buffe, N. Schmidt, L. Roux. "Developing irradiation devices for fuel experiments in the Jules Horowitz Reactor"; IGORR 10, Gaithersburg, Sept. 2005.
[15] S. Carassou, G. Panichi, F. Julien, P. Yvon, M. Auclair, S. Tahtinen, P. Moilanen, S. Maire, L. Roux. "Experimental material irradiation on the Jules Horowitz Reactor"; IGORR 10, Gaithersburg, Sept. 2005.
[16] J.F. Villard; Innovative in-pile instrumentation developments for irradiation experiments in MTRs; IGORR 10, Gaithersburg, Sept. 2005