THE JULES HOROWITZ REACTOR: A NEW EUROPEAN MTR (MATERIAL TESTING REACTOR) OPEN TO INTERNATIONAL COLLABORATION: UPDATE DESCRIPTION AND FOCUS ON THE MODERN SAFETY APPROACH

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Abstract

The Jules Horowitz Reactor (JHR) is a new Material Testing Reactor currently under construction at CEA Cadarache research centre in the south of France. It will represent a major Research Infrastructure for scientific studies dealing with material and fuel behaviour under irradiation (and is consequently identified for this purpose within various European road maps and forums; ESFRI, SNE-TP…). The reactor will also be devoted to medical isotopes production. The reactor will perform R&D programs for the optimization of the present generation of NPP, support the development of the next generation of NPP (mainly LWR) and also offer irradiation capacities for future reactors. JHR is designed, built and will be operated as an international user-facility open to international collaboration. In order to comply with the evolution of safety requirements and to guarantee long term operations, the construction safety standards of JHR have been significantly improved compared to MTRs built in the 60s. The paper gives an up-to-date status of the construction and of the developments performed to build the future experimental capacity and is particularly focusing on the modern Safety approach used and its consequences on the design of the reactor.

1. INTRODUCTION

European Material Testing Reactors (MTR) have provided an essential support for nuclear power programs over the last 40 years within the European Community. However, these Material Test Reactors (MTRs) will be more than 50 years old in this decade and will face increasing probability of shut-down due to the obsolescence of their safety standards and of their experimental capability. Such a situation cannot be sustained 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].

Associated with hot laboratories for the post irradiation examinations, MTRs are structuring research facilities for the European Research Area in the field of nuclear fission energy.

MTRs 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 power reactors as well as to support future reactor design:

- Nuclear plants will follow a long-term trend driven by the plant life extension and management, reinforcement of the safety, waste and resource management, flexibility and economic improvement;
- In parallel to extending performance and safety for existing and coming power plants, R&D programs are taking place in order to assess and develop new reactor concepts (Generation IV reactors) that meet sustainability purposes;
- In addition, for most European countries, keeping competences alive is a strategic cross-cutting issue; developing and operating a new and up-to-date research reactor appears to be an effective way to train a new generation of scientists and engineers.

This analysis was already made by a thematic network of Euratom 5th FP, involving experts and industry representatives, in order to answer the question from the European Commission on the need for a new Material Testing Reactor (MTR) in Europe [2].

This entire preparatory work leads to the fact that the JHR research infrastructure has been identified on the ESFRI Roadmap since 2008.

2. THE JHR PROJECT IN THIS CONTEXT

JHR will offer modern irradiation experimental capabilities to study material & fuel behaviour under irradiation. JHR will be a flexible experimental infrastructure to meet industrial and public needs within the European Union related to present and future Nuclear Power Reactors.

JHR is designed to provide high neutron flux (twice as large as the maximum available today in MTRs), to run highly instrumented experiments to support advanced modelling 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, …

These objectives require representative tests of structural materials and fuel components as well as in-depth investigations with “separate effects” experiments coupled with advanced modelling.

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.

As a modern research infrastructure, JHR will contribute to the development of expertise and know-how, and to the training of the next generation of scientists and operators with a positive impact on nuclear safety, competitiveness and social acceptance. The JHR is mainly designed to meet these technical objectives.

As another important objective, the JHR will contribute to secure the production of radioisotope for medical application. This is a key public health stake.

JHR, as a future international User Facility, is driven by an international consortium gathering industry (Utilities, Fuel vendors…) and public bodies (R&D centres, TSO, Regulator…).

The present members list of JHR consortium is the following: CEA (France), EDF (France), AREVA (France), Euratom, SCK·CEN (Belgium), UJV (Czech Republic), VTT (Finland), CIEMAT (Spain), Vattenfall (Sweden), DAE (India), JAEA (Japan).

The JHR facility description and the development of the first experimental capacity is described in detailed in previous RRFM and IGORR conferences [3], [4], [5], and after a short update status we will focus on a description of the modern Safety approach performed for this new MTR.

3. JHR UPDATE STATUS

1) Construction: The construction of JHR which was started in 2007 is going-on in a nominal way (foreseen first criticality second semester 2016):

Fig. 1. View of the building site mid-2011.

2) JHR as an International Scientific User Facility: In parallel to the construction, the preparation of an international community around JHR is continuing; this is an important topic because, as indicated in the introduction, building and gathering a strong international community in support to MTR experiments is a key-issue for the R&D in nuclear energy field. CEA is welcoming scientists –secondee- from various organisations who are integrated within the JHR team for the development of the experimental devices.

3) Building an international joint program: the JHIP (Jules Horowitz International Program): According to the consortium agreement, JHR is aimed to become a user reactor at international level on the model of the Halden Reactor Project with multinational project and proprietary experiments. Consequently, CEA is preparing, with the support of the OECD/NEA, a joint program called Jules Horowitz International Programme (JHIP) which has been thought with the strategic scope to address fuel and material issues of common interest that are key for operating plants and future NPP (mainly focused on LWR).

The CEA proposals mainly deal with fuel safety and reliability (LOCA and source Term experiments addressing fission products release in a variety of fuel failure conditions).

The target is to get a nearly completed JHIP OECD agreement by the end of 2011 in order to launch scientific programs up to 2012.

4. JHR SAFETY: AN INNOVATIVE APPROACH

The JHR differs from the previous generation of reactors by incorporating the safety analysis right from the design phase, based on a modern reference system and methodology; in particular those used in contemporary projects such as the EPR a GEN3 NPP under construction in Finland, China and France.

The methodological safety approach for the JHR is summarised, highlighting various innovative aspects and the specific design features of the new experimental reactor.

Then, some of the initial design choices and options are detailed, coming directly from this innovative approach and feedback from existing reactors.

4.1. General principles

The general nuclear safety approach for the JHR covers the design and construction phases and then the operation of the facility, including the experiments that will be performed there.

The principle of defence in depth, the basis of any safety approach for a modern nuclear facility, is summarised below:

Four levels of defence in depth are systematically analysed, for all facility conditions:

- Prevention by high-quality design, equipment fabrication and operation;
- Monitoring and detection: it is planned to equip the facility and the experiments with devices for monitoring capable of detecting faults during operation, as well as with operating regulation and control systems that keep the facility and experiments within their normal operating ranges;
- Back-up systems: plausible incident or accident events are postulated, and then the necessary back-up systems are studied and implemented to return the facility and the experiments to a safe state and maintain them in that state;
- Mitigation and management of severe accidents: very improbable accidents are envisaged and additional methods and/or procedures for managing such conditions are defined.

The 5^{th} level of defence in depth makes it possible to foresee the measures to be adopted offsite with regard to the population in the event of a severe accident. It does not have any concrete repercussions on the facility design process. This defence in depth process involves setting up of an approach using barriers between the radioactive products and the environment outside the facility.

With a view to enhancing safety in a technological irradiation reactor, the JHR project pays particular attention to confinement by aiming to improve the consistency of the safety approach between the facility and the experiments it hosts. By their very nature, these experiments change over time. This will be done by carrying out any necessary in-depth studies of the reactor, the experiments and/or their interfaces.

Apart from compliance with the basic principles (defence in depth, principle of barriers, ALARA principle), some additional specific aspects are taken into account from the design stage:

- Feedback from past experience;
- Definition of the specific features of an MTR – issues of availability/safety and the reactor/experiments pairing;
- Human factors;
- Methodologies and recommendations with regard to the common mode risks (geographical separation, diversification of equipment in terms of energy source or even of operation-maintenance);
- Requirements in terms of equipment qualification;
- In-service monitoring of Safety Important Component (SIC) equipment;
- Dismantling factors integrated as early as the design stage.

All this must be carried out in accordance with the regulations and standards relevant to nuclear facilities and equipment.

4.2. Method of incorporating safety from the design stage

Seven main types of risk are taken into account from the start of the design:

- Reactivity insertion accidents (RIA);
- Loss of primary flow;
- Loss of primary coolant (LOCA);
- Handling and storage accident;
- Accidents connected with the experimental devices and facilities;
- Internal hazards;
- External hazards.

Operating conditions that may be encountered by the JHR systems are characterised by an initial condition (IC) and an initiating event (IE) coming from the systems themselves, leading to a sequence of effects including the resulting cascading effects on the other systems.

The safety studies are conducted based on envelope conditions representing a type of conditions. These envelope conditions are called operating conditions (OC).

The safety demonstration is based on a deterministic approach and must be as exhaustive as possible, ranging from normal operating conditions through to mastered severe accidents, and including incidents and accidents. OC are classified according to their annual frequency of occurrence (AFO), by feedback and by expert opinion. The risk limitation conditions (RLC) are the subject of specific prevention criteria.

	Category	Name of category	Annual frequency of occurrence (AFO)
Design basis OC	OC1	Normal conditions (1st category of OC)	AFO (> 1/year)
	OC2	Incident conditions (2nd category of OC)	10^{-2}/year < AFO (≤ 1/year)
	OC3	Rare accident conditions (3rd category of OC)	10^{-4}/year < AFO ≤ 10^{-2}/year
	OC4	Hypothetical accident conditions (4th category of OC)	10^{-6}/year < AFO ≤ 10^{-4}/year
Risk limitation conditions (RLC)	CC	Complex conditions	Specific prevention criteria
	MSA	Mastered severe accidents	Specific prevention criteria
	ESA	Excluded severe accidents	Specific prevention criteria

The general safety objectives (GSO) in terms of staff and public dosimetry resulting from these operating conditions are thus defined.

The objective of the safety analysis is then to verify compliance with the general safety objectives in all OCs and RLCs after application of the single failure criterion in the case of OCs.

Two separate procedures are applied, one for design basis conditions, and the other for risk limitation conditions. To these are added:

- Application of the lines-of-defence method for mastered severe accidents (MSA). The identification of Safety Important Component (SIC) equipment and classification into 3 levels in relation to their importance for safety:

- Level 1: protection systems and the first barrier (example: fuel cladding);
- Level 2: back-up systems and the second and third confinement barriers;
- Level 3: other systems classified as safety systems.

This classification is necessary for defining the expected quality level in terms of design-manufacture and for its level of in-service monitoring (maintenance actions, inspection, etc.) Impact on the facility design

The above iterative process results in an overall architecture for the facility and associated systems that comply *de facto* with the basic safety principles and confirm the general safety objectives.

A few examples are given below, illustrating the impact of the safety analysis on the design choices for the facility. These choices are based on solutions that are frequently the result of feedback from facilities in the French Research Reactors fleet such as:

- Design of the ORPHEE, PHEBUS and CABRI reactors;
- Upgrades of ORPHEE, OSIRIS.

4.3. Reactor containment

The JHR Reactor Building is designed and operated in a very different way from a PWR: the absence of any pressurised primary and secondary systems results in a low design basis pressure (a few hundred millibar). Nevertheless, there may be staff present in the reactor building during power operation.

Several specific aspects lead to particularly rigorous treatment of the reactor containment:

- Need for a water block overlapping between the Nuclear Auxiliaries Building (NAB) and the Reactor Building (RB), enabling the fuel and experiments to be moved safely from the reactor block to the pools and cells;
- The Reactor Building must be constantly ventilated during normal operation;
- Reactor Building feed-troughs (equipment, etc.);
- Taking into account the BORAX-type mastered severe accidents that may lead to a rise in the containment pressure [6].

For these reasons, the following design choices were made:

- Containment partially prestressed using a specific concrete formulation and qualification process similar to that of the most recent containments in EDF plants, which broadly meet the leaktightness criteria in the event of a mastered severe accident;
- Leak recovery area into which all the Reactor Building feed-throughs lead so all leaks can be collected;
- Double insulation of every sensitive feed-through.

As with the EDF Cruas plant and the CEA STAR facility, taking account of the seismic risk associated with the choice of the site leads to the design of (figures 2 and 3):

- Approximately 200 studs with elastomeric anti-seismic pads;
- A containment structure made of concrete reinforced with suitable steel.

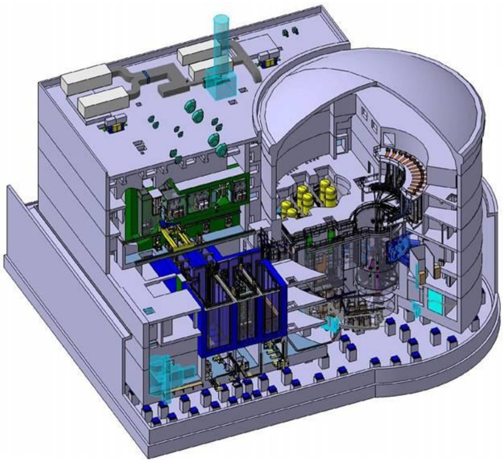

Fig. 2.Facility on aseismic pads.

Fig. 3.Columns bear and aseismic pads.

4.4. Water block

This consists of a leaktight, one-piece structure between the Reactor Building and the Nuclear Auxiliaries Building. The water block ensures the non-dewatering of the core in the event of an accident, while also permitting the irradiated fuel elements, devices and structures to be handled underwater. In comparison with previous reactors, the requirements have become more stringent, favouring access via the upper parts with leak tight doors. To ensure the leak tightness of the water block, the design of the metallic liners in the reactor pools enables any leaks to be recovered and all welds to be inspected.

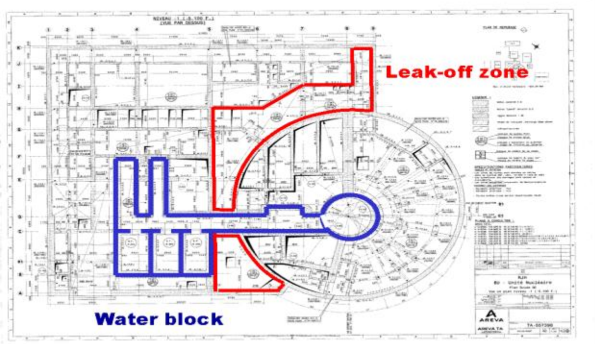

Fig. 4. Leak-off zone and water block.

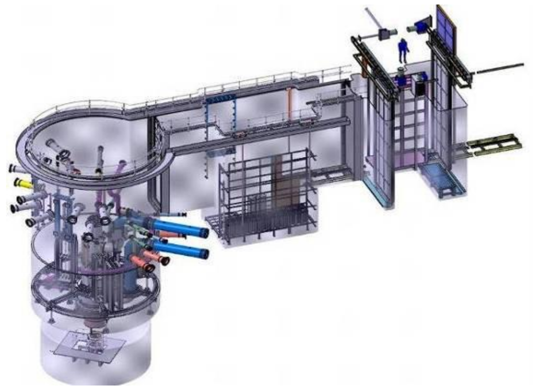

Fig. 5.Reactor pool and crossings.

5. CONCLUSION

As indicated, JHR building is going-on in a nominal way and its first criticality is scheduled for 2016. This facility –regarding the experimental capacity- is already open and will be more and more so to international collaboration. It is clear that within a context of nuclear renewal, the JHR will be a key infrastructure in the European Research Area for R&D in support to the use of nuclear energy.

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