PROJECT FINAL REPORT

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Introduction

The **Jules Horowitz Reactor Collaborative Project (JHR-CP)** addresses the support for the implementation of the Jules Horowitz Material Testing Reactor, a new research infrastructure of pan-European interest.

This reactor, planned to start in 2014 in the CEA Cadarache research center, will be, for several decades, a high performance major research facility in the European Research Area for nuclear energy and for radio-isotopes production.

JHR is a mature project of European interest and consequently is identified as a research infrastructure of pan-European interest by the **European Strategic Forum on Research Infrastructures** (**ESFRI**).

Because JHR is a key research infrastructure of pan-European interest and is opened to international cooperation, 20% of the JHR Project costs are supported by european and international partners.

Several european research institutes and utilities have decided to join the JHR Project for having a long term access to an up-to-date high performance research infrastructure. In the same way, as a contribution to the JHR construction, the JHR-CP gathered well known **European research institutes**:

- **CEA** (France),
- **CIEMAT** (Spain),
- **UJV-NRI** (Czech Republic),
- **SCK-CEN** (Belgium),
- **VTT** (Finland).

Some of them have gathered a pool of several national public and private partners, like CIEMAT, which asked two Spanish private partners (**Empresarios Agrupados** and **ENSA**) to participate in JHR-CP for their competences in materials manufacturing within the nuclear field.

I. Project's objectives

The present JHR-CP addresses a preparatory phase for the JHR project. This preparatory phase aims at improving the project maturity required to enable the construction work. In consequence, the JHR-CP actions will cover relevant outstanding issues in the following areas:

- **Strategic plan for qualification program of critical components:** this qualification program is a structuring item to enable the licensing process, facing today's state-of-art safety requirements for MTRs (Material Testing Reactor).

- **Technical works:** topics have been selected for their impact within the MTR's community as partial qualification tests for material and fuel used in the JHR construction and definition of the methodology for studying the JHR mastered severe accident (BORAX type).

- **Project logistics:** two activities are required to prepare the future utilisation of JHR by the European community. The first one addresses the training of JHR experimental physicists. The second one addresses the production of a users-handbook for operation and experimentation. The proposed JHR-CP actions are at the front-edge of the JHR Project. These actions will provide high added value steps toward the implementation of a new European Material Testing Reactor.

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II. Main results

The JHR-CP project started in January 2009, for 12 months initially and has been extended on 3 months mainly for the work-package TA3 related to the support to the reactor design and construction through heat exchangers definition in order to face with an increase in the duration of the procurement procedure of the heat exchanger tubes.

For this 15 months programme, the main results achieved are mainly dealing with two kinds of actions:

- The first one firstly concerns the knowledge of the reactor itself for any people which will be involved in the realisation of experimental program on the JHR and secondly deals with the training of new experimental physicists which will be involved in MTR irradiation experiments and more particularly in JHR experiments. (**Net working Activities**).

- The second one concerns the qualification and improvement of the materials involved in the JHR construction, and the improvement of the calculation tools used for the JHR conception with the production of European Standards.(**Technical Activities**).

II.1 Net working Activities

II.1.1 Training

In the framework of the implementation of experiments in the JHR, which will start in 2014, needs in education/training have emerged. Some of these needs are directly concerning the experimental physicists coming from different European teams. For performing experiments the experimental physicists need professional experience in the fields of Engineering, Measurements and Physics (materials, neutron Physics, thermo-hydraulic…). Several courses already exist in different European countries, but they are mostly focusing on the physics (neutron physic) of the reactor itself and less on the experimental devices. Therefore, we propose **a new academic course on designing and using experimental devices.** This course mainly concerns the design and the use of experimental devices in research reactors and the definition of experimental programs. The course addresses the following items:

1. Experimental reactors and devices
2. Thermo-hydraulics for MTRs (Metal Test Reactors)
3. Neutron Physic
4. Mechanical behaviour (fuel and materials)
5. Instrumentation and measurement techniques
6. Safety of experimental devices
7. Conducting an experiment

This course could be represented by its learning Ladder presented in Fig. 1. Moreover this course initially dedicated to the JHR training will be extended and used for all the European MTRs, in order to respond to a real interest expressed by the members of the JHR-CP.

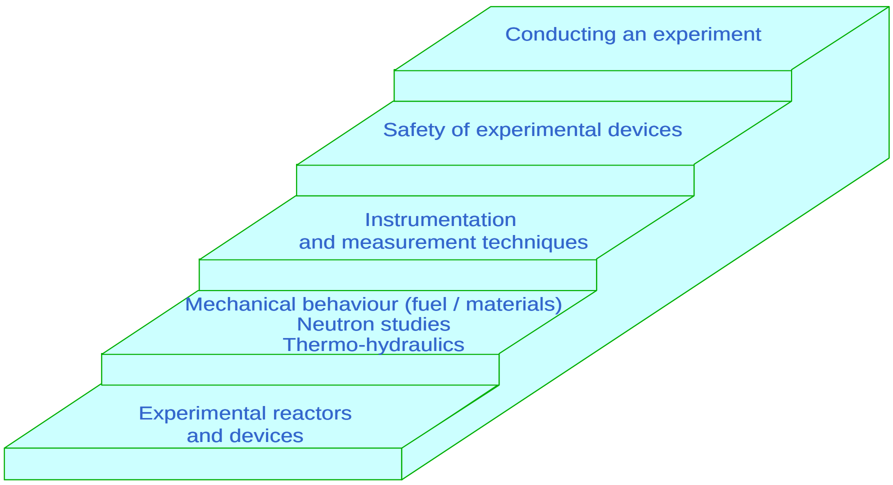

Fig.1: JHR-CP Learning Ladder

This course will take place in a set of already existing other courses (Fig. 2). This course should also lead to create other extra courses when the needs will emerge.

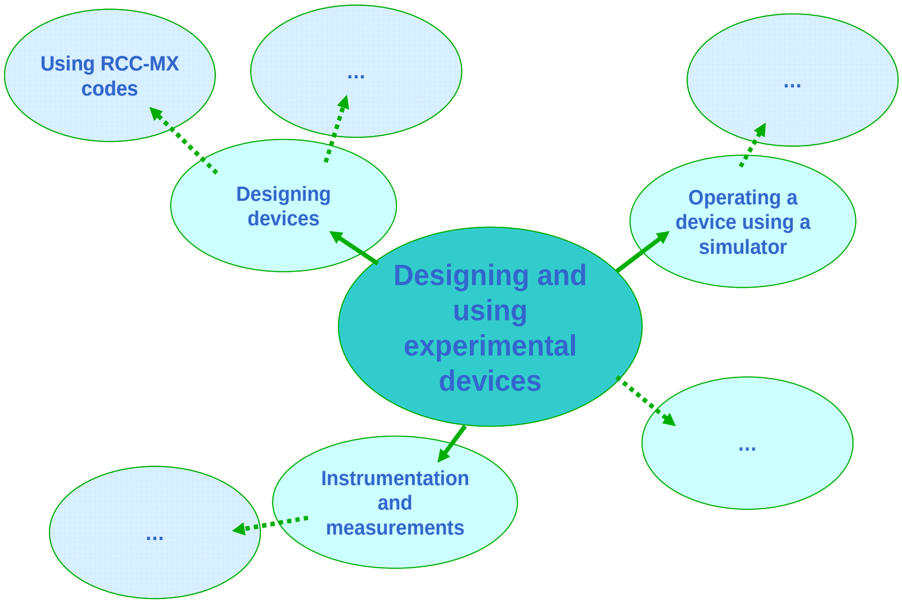

Fig.2: JHR-CP training course in the environment

II.1.2 JHR Handbook

As an international user-facility, the Jules Horowitz Reactor (JHR) will provide a modern experimental capability for studying materials and fuel behaviour under irradiation for applications such as,

- Support to nuclear power plants of Generations II and III;
- Development for reactors of future generations;
- Radio-isotope production for medical applications.

The facility is designed to meet the most modern requirements of safety regulations ensuring quality and safety when conducting the experiments. The JHR integrates in the nuclear unit all the experimental equipment that will enable experimental irradiations, intermediate controls and associated examinations to be carried out.

In order to allow the right utilisation of the JHR by any people, which will be involved in the realisation of experimental program, it was decided to produce **the reference handbook** (2009 version) describing main data related to reactor, experimental devices, non destructive examination, fission product lab, etc…

The user handbook has been written in order to allow any JHR incomers (scientist, experimental physicist, operators …) to quickly have a right vision of the JHR facility, of its experimental capacity and of its general mode of operation. With this objective the JHR user handbook has been divided in three different parts:
Part one: facility presentation of the Jules Horowitz Reactor (Fig.3)
Part two: presentation of the experimental capability (Fig.4)
Part three: presentation of the general operation of the overall JHR facility (Fig.5)

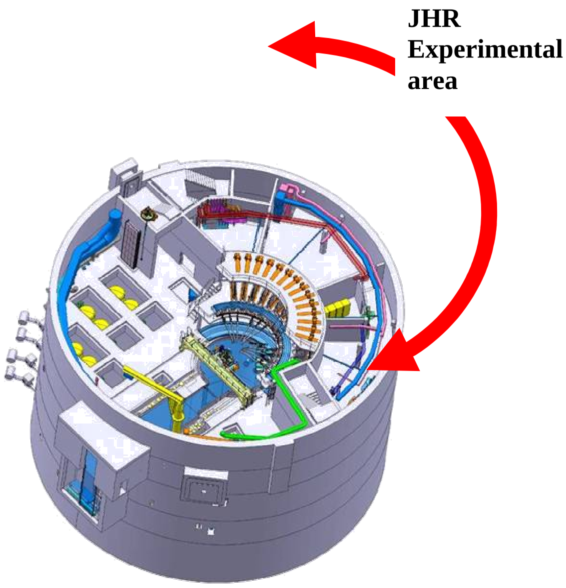

Fig.3: JHR Control Room **Fig.4: experimental Area in reactor Building**

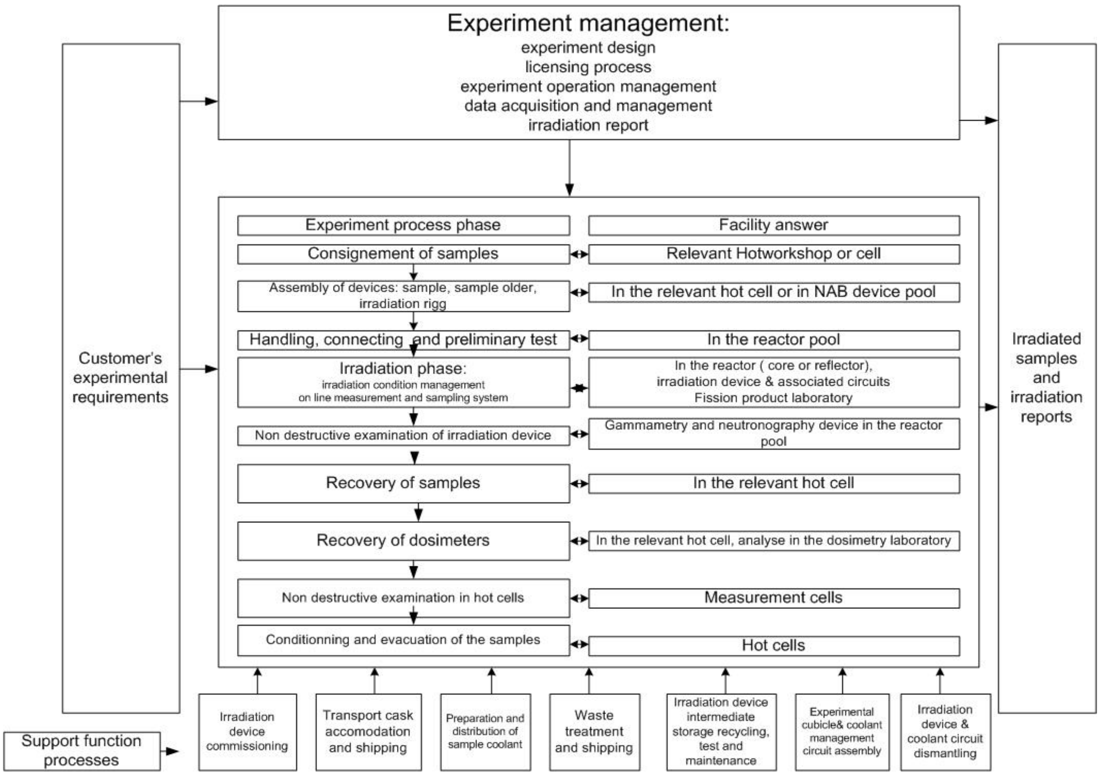

Fig.5: Experimental process of an irradiation sequence in the JHR

II.2 Technical activities

The different activities performed during the JHR-CP have been led by the necessity of:

- The definition of the qualification of critical components which are critical due to technological uncertainties related to innovations necessary to get the JHR performances
- the qualification and improvement of the materials involved in the JHR construction,
- the improvement of the neutron physic tools used in the JHR core design
- the improvement of the methodology for the JHR mastered severe accident taken into account as safety reference in the JHR construction
- the improvement of the calculation tools used for the JHR conception with the production of European standards of the JHR construction applied to JHR key component such as the heat exchangers of the reactor.

II.2.1 JHR strategic plan for qualification programme

The objective of these activities was to work out the strategic planning for the qualification actions, consistently with the overall JHR construction and safety process schedule.

The **Qualification programme** has been established for the JHR components which are critical due to technological uncertainties related to innovations necessary to get the JHR performances. The set up and the implementation of the strategic plan for qualification is a cornerstone of the JHR licensing process.

This plan covers:

- Components for which early qualification is attributed to the Prime Contractor and paid under the development contract;
- Components for which the management of development and early qualification actions is attributed to the Prime Contractor;
- Components for which the responsibility of qualification is transferred to the supplier because they do not represent any major criticality issues.

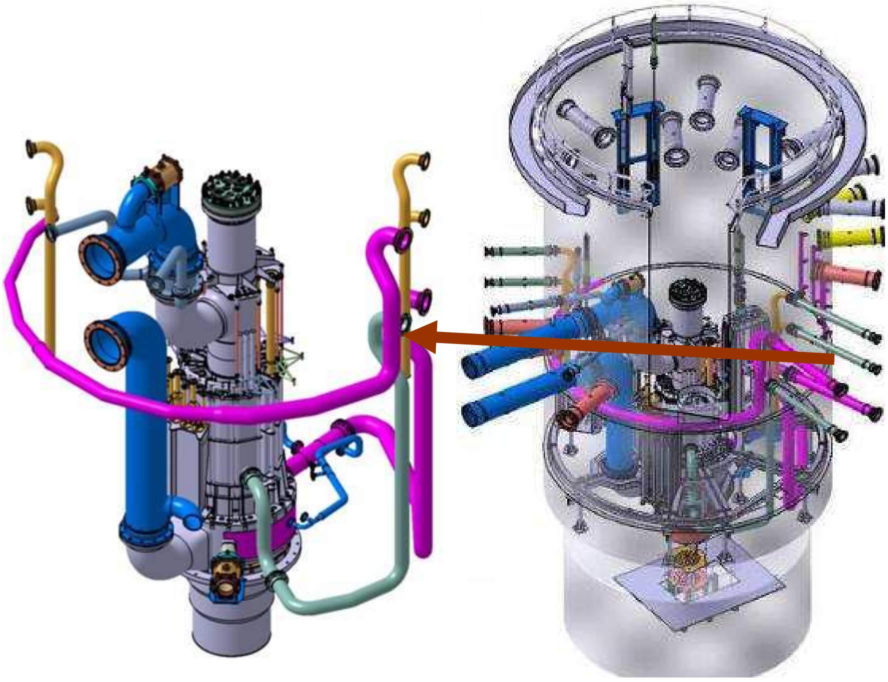

Fig.6: View of the core with a partial view of the primary circuit of JHR

In order to establish such a programme several phases of work were necessary, the main phases are the following:

- First phase to identify the critical JHR components with regard to safety demonstration and programme risks;
- Second phase to recommend or require a series of early qualification actions to be conducted on these components;
- Third phase to describe the qualification actions on a number of other components, not qualified or unavailable in the usual products from suppliers.

Of course all these phases were conducted with the main goal of the possibility of qualifying some of these components in advance allowing to remove as many risks as possible from the construction schedule according to the deadlines identified at this stage of the JHR construction process.

The main goal of this activity have been to establish the qualification programme of the JHR components which are critical due to technological uncertainties related to innovations necessary to get the JHR performances. Qualification tasks are mandatory for the JHR fuel, the JHR core tank (Fig.6 and Fig.8), the cooling primary circuit with the primary pumps, the mechanisms of the control rods of the core, the pool vessel of the reactor building, the anti-seismic plots of the nuclear building (Fig.7).

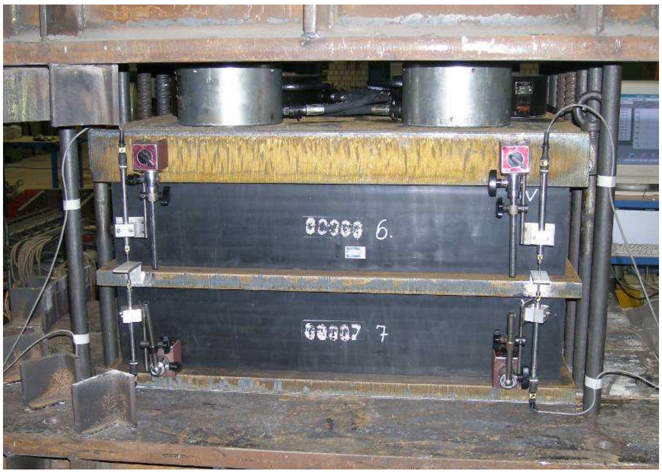

Fig.7: JHR anti-seismic plots

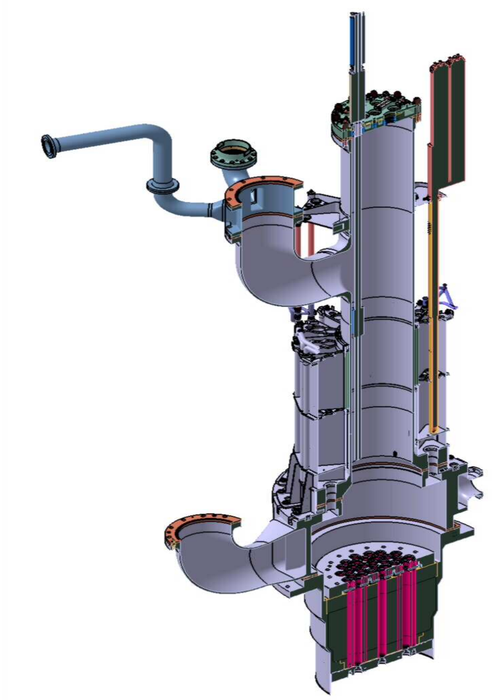

Fig.8: view of the JHR reactor tank

II.2.2 JHR technical work on Qualification Tests and Safety Studies

Due to sensitive constraints related to its responsibility as nuclear operator related to the JHR construction, CEA has to demonstrate to the safety regulatory body that the JHR design is complying with the update safety standards. In order to be able to perform such a demonstration some of experiments are required (**Qualification tests**) and some new methodology of safety analysis had to be developed (**Safety studies**)

II.2.2.1 Qualification test

In the framework of the licensing process of the JHR, two types of experiments are underway at the moment:

- A validation of core vessel structural material (specific aluminium alloy) under irradiation in order to confirm the good ageing behaviour of this material,

- A validation of the neutron core physic calculation for the specific geometry of the JHR fuel elements and for the specific geometry of the core.

Specific Aluminium Alloy Qualification tests

JHR is intended to irradiate samples at levels up to twice those of OSIRIS. The reactor will be slightly pressurized, and its internal structures will be made from specific neutron-transparent materials to achieve these high levels of irradiation. Many of these structural materials will be subjected to high fluence, such as the reactor vessel, which serves as the core-reflector interface and must therefore resist major mechanical and thermal loads.

Precipitation-hardened 6061-T6 aluminium alloy was chosen for these internal structures (core vessel, rack, etc.) in order to provide safe, reliable operation with an economically feasible lifespan. This alloy is considered to have better post-irradiation properties than AG3-NET-O. The main risks associated with this material and its components are:

- Reduced ductility, resulting in a lower total tensile strain,
- Reduced fracture toughness, resulting in a material more likely to undergo sudden failure,
- Irradiation creep and swelling, resulting in a change of the component dimensions.

As part of the first two levels of containment, the mechanical properties of the critical components that are subject to irradiation must be guaranteed during the design phase, and they must be able to be monitored during operation.

An irradiation programme focusing on these materials have been implemented with the goal of reducing these risks.

The RAJAH program involves the irradiation of Al 6061-T6 and AG3NET-O samples in OSIRIS in the core reflector position. This program studies their tensile strain, fracture toughness (Fig.9), and impact strength under a high thermal neutron flux. This irradiation programme which is foreseen to finish with the shutdown of OSIRIS, will provide a lot of data on the Al 6061-T6 alloy.

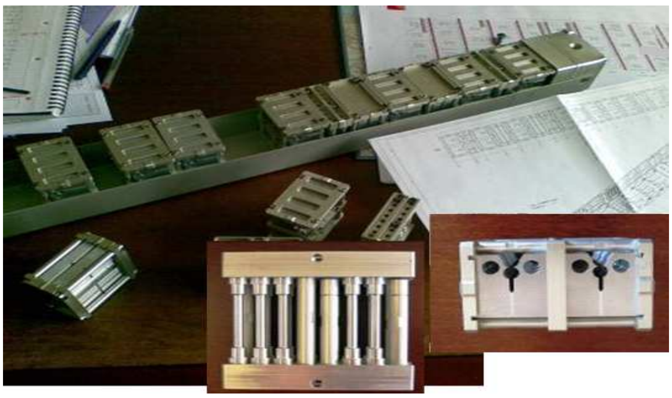

Fig.9: upper part : Tray containing baskets;
Lower part : tensile and fracture toughness baskets before irradiation

Validation of the neutron core physic calculation:

Considering the lack of neutron physics core calculation qualification, an experimental programme called AMMON has been defined in the EOLE reactor. This one will use seven full scale JHR fuel elements which will be loaded at the central part of the EOLE zero power reactor (Fig.10) in order to reach better knowledge on neutron physics data (3D power distribution, absorber anti-reactivity, critical mass, reflector effect, delayed neutron fraction, void effect, isothermal temperature coefficient…).

Six main core configurations have been defined (Fig.11):

- AMMON-Ref: reference configuration for the validation of basic design parameters: critical state (integral effect), axial and radial power distributions (local effects), temperature coefficient, reactivity effects of each heterogeneity by subcritical counting, gamma measurement in the Al cask using recent improvement of the thermo-luminescent technique in the ADAPh program,
- AMMON-Hf: integral and local effect of an Hafnium rod inserted in the central assembly,
- AMMON-Void: integral and local effect of a voiding of the central fuel element,
- AMMON-GC: integral and local effect of a group of experimental devices,
- AMMON-WH: integral and local effect of a water hole effect,
- AMMON-Be: integral and local effect of a beryllium block inserted in place of a fuel assembly.

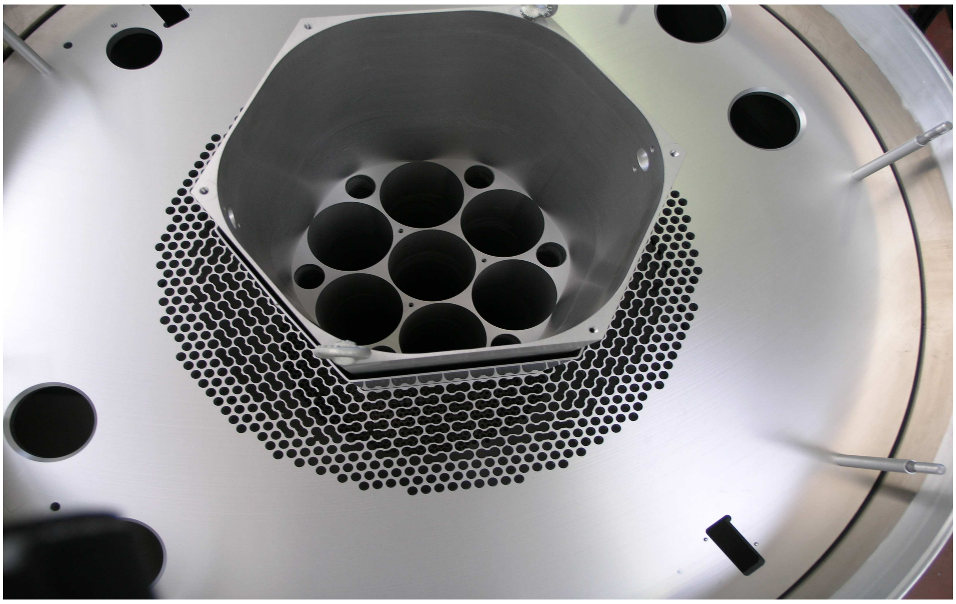

Fig. 10: AMMON Lattice in EOLE

The following experimental data are measured using different techniques:

- The reactivity change between core configurations measured by the Modified Source Method (MSM technique based on fission chamber counting), and by critical size determination,

- The fine radial and axial power distribution in the fuel plates measured by gamma spectrometry on particular peaks with a very narrow collimation and by activation foils,

- The spectral indices measured using miniature fission chambers and activation foils,

- The modified conversion ratio derived from the measurement of particular peak activities by gamma- spectrometry,

- The gamma-heating in specific materials (Be, Hf) derived from the measurement of thermo-luminescent detectors.

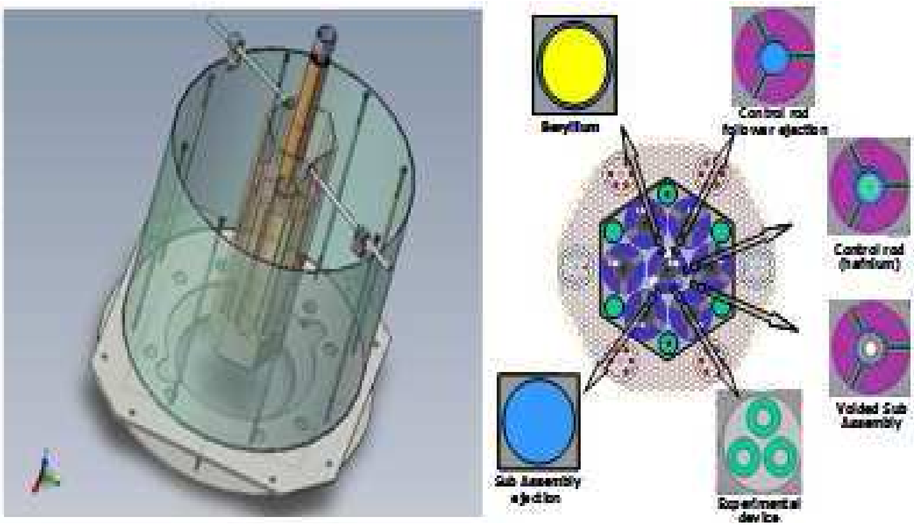

Fig. 11: AMMON various configurations

II.2.2.2 JHR safety studies

Beyond the four classical safety categories, the French safety methodology defines several conditions integrating the Mastered Severe Accident (MSA) for which it is necessary to demonstrate that the consequences are controlled.
The BORAX accident (Boiling Water Reactor Experiment) is the MSA reference to be taken into account for the JHR containment design.
This conventional accident consists in a fast ejection of a control rod, leading to a nuclear power excursion and the fusion of part of the nuclear fuel. This is supposed to lead to a steam explosion generated by the violent interaction between liquid aluminium and the cooling water. This phenomenon consists of a complex and fast sequence of physical-chemical processes with different time and space scales.
Two major issues are considered (Fig.12):

- The mechanical consequences with evaluation of the impact on the containment and verification of the acceptable behaviour for the pool system.
- The radiological consequences with respect to released activities, with two relevant aspects which are the path of migration of the radionuclides to the pool surface, and the pressure increase kinetics into the containment hall.

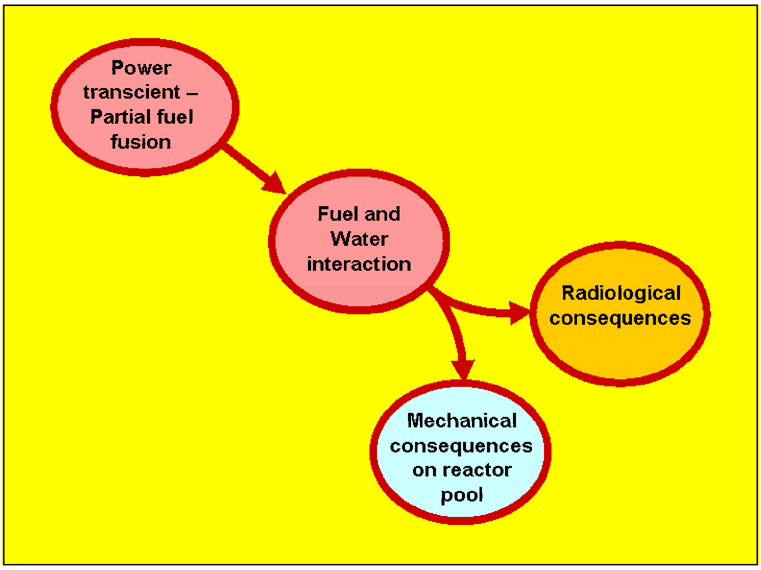

Fig.12: BORAX accident synoptic – Safety issues

Pursuing a preliminary qualitative approach based on a detailed assessment of accidents and experiments performed on research reactors worldwide since the beginning of the nuclear area, the understanding of the complete accident progression was improved. Faced with the present inability to model such an accident comprehensively, the scenario was divided into different elementary steps, and the associated physical mechanisms and the available computation tools were identified
Identifying and modelling the different phenomena involved in the Borax sequence we established the setting-up of a BORAX calculation scheme, making it possible to quantify the different stages of the accident.

Finally the calculation scheme of the BORAX accident (Fig.13) has enabled to better understand complex physical phenomena involved in very short time frames, obtaining a reasonably conservative quantification of the different parameters at all stages of the accident and support safety assessment.

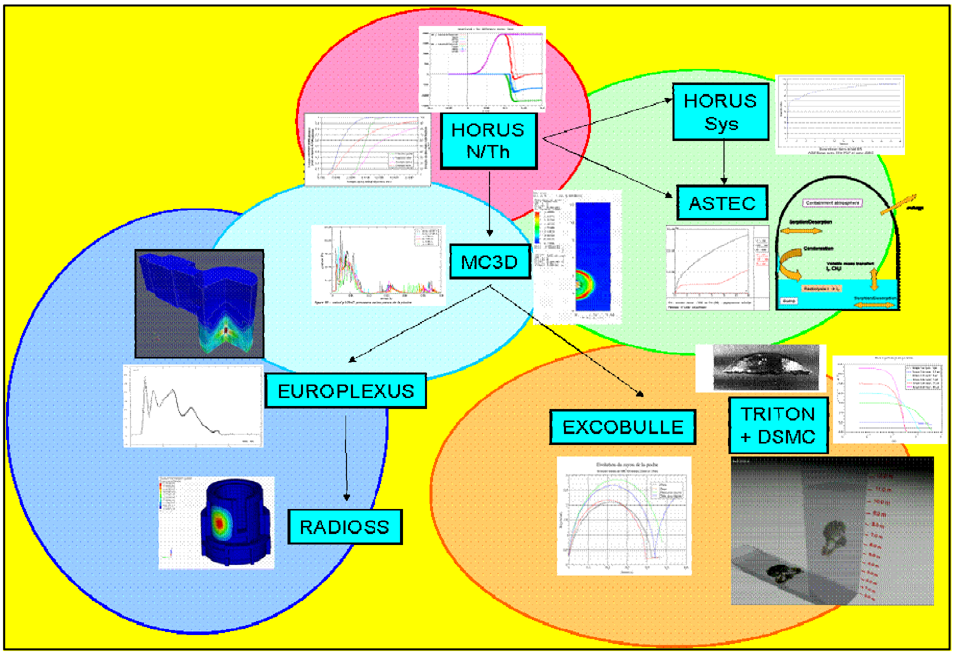

Fig.13: BORAX calculation scheme

II.3 JHR technical activities to support reactor design and construction

The JHR, as a new European MTR, has been designed with a high level of performance. This led to a core design with a high power density in order to provide high level fast and thermal neutron flux.

This core design requires a high performance cooling system. Consequently the primary cooling circuit is the most important component of JHR. The JHR cooling system has been studied in order:

- To achieve the cooling performance assigned to the reactor with respect of maximum hot spot on fuel elements, taking into account the experimental loading;
- To insure, in all situations, the cooling of the core and experimental devices even in case of severe accident postulated in the safety demonstration.

In the light of the above consideration the design and the construction of the JHR heat exchangers (Fig.14) has to take into account the best existing state-of-the-art technology and the conception and manufacturing rules (**European standards**) provided for the new generation of Experimental Plant through the RCCMX 'Règles de Calcul de Conception Mécanique réacteurs eXpérimentaux' (mechanical calculation and design rules for experimental reactors) presented to the French Safety Authority.

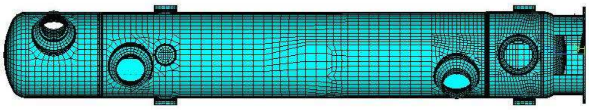

Fig.14: JHR Heat Exchanger; computation mesh

In particularl the definition and the construction of the heat exchanger involve the following phases:
1. The pre-design and design studies;
2. The material procurement under the RCCMX rules;
3. The verification of the material characteristic conformity of the procurement with the RCCMX rules.

The expected objective of such a task was mainly to achieve a first full-scale test of the application of the new RCCMX rules for designing and manufacturing critical components by European industries.

Design studies

The main primary system of the Jules Horowitz Reactor is provided with three piping systems, each equipped with a vertical-axis heat exchanger. The three heat exchangers have an identical configuration and their main functions are as follows:

- To guarantee the specified cooling power (110 MW),
- To act as a second safety barrier for the JHR in operation

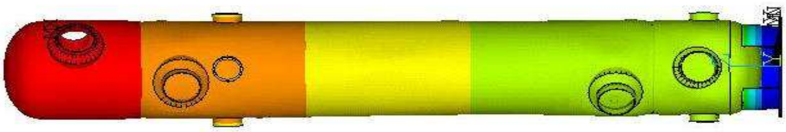

Fig.15: JHR Heat Exchanger; Temperature distribution in operation

The studies have covered the design of the heat exchanger components for the JHR main primary system, i.e. the components of the heat exchanger for the reactor's primary and secondary systems, including the heat exchanger support required to withstand all the thermo-mechanical loads (Fig.15) acting on each heat exchanger during their operation life. The studies have also included a preliminary assessment of the stresses applied to the various heat exchanger components.

The design conditions have been also analysed to justify the preliminary design of the heat exchanger components and its support.

Finally these studies have concluded in agreement with the thermo-mechanical design and the brief check performed, that the configuration recommended in the drawings appears to be satisfactory in order to withstand the forces corresponding to the various operating cases, without compromising the structural integrity of the main primary system heat exchangers for the Jules Horowitz Reactor (JHR). Moreover the results have also concluded that the drawing complies with the RCCMX design code applicable to this project.

On this basis the procurement of the heat exchanger tubes could be done.

Material procurement

The work associated to this phase was mainly the achievement of the specification of the procurement of the heat exchanger tubes of the JHR.

It is gathering all requirements necessary to supply correctly the tubes in compliance with the RCCMX codes and with the ESPN law. These requirements are mainly dealing with:

- The scope of the procurement;
- The referenced document to be applied (for instance the RCCMX code in its last version);
- The basis of the purchase;
- The marking procedure of the procurement;
- The packaging for the shipment;
- The quality insurance.

The requirements and the specified fabrication process have been verified by the representative control organism notified by the French regulatory body which has recommended to upgrade the specification in order to take into account directly without any equivalence, the last version of the RCCMX code. This recommendation has led to an increase in the duration of this phase, leading to the 3 months extension of the duration of the contract.

On the basis of the final version of the specification a large call for tender has been organised to choice the supplier of the tubes which has led to choice the **Ukrainian society CENTRAVIS** as supplier under the control of the organism notified by the French regulatory body.

Conformity with the RCCMX

During the realisation of this task a non predictable delay in implementing the work package TA3, called « Support to the reactor design and construction: heat exchanger definition » has been dolt with, due to an increase in the duration of the procurement procedure of the heat exchanger tubes.
This was due to the innovative and challenging character of such a technical action, for which the first European reference in the application of the new standards in designing and fabricating nuclear equipment under gas or liquid pressure was created. More precisely, the representative control organism notified by the French regulatory body, asked to correct the procurement specification of the heat exchanger tubes in order to take into account a new upgraded version of the normalised code used for the conception. This new version of the code requested by the organism of control had to gather the rules defined for the conception of the large experimental equipment and the ESPN law requirement. This request of the authority has been implemented to avoid any possible conflict, between the conception rules and the law, which could lead to a lack in the definition of the responsibility in case of mismatch of any nuclear equipment under gas or liquid pressure.

Finally once the specification of the heat exchanger tubes was corrected, the representative control organism notified by the French regulatory body has issued a positive verification of the material characteristic conformity of the heat exchanger tubes. It has concluded that in agreement with the thermo-mechanical design and the check performed, the configuration recommended (applying the RCCM-X new version) appears to be satisfactory in order to withstand the forces corresponding to the various operating cases, without necessarily compromising the structural integrity of the main primary system heat exchangers for the Jules Horowitz Reactor (JHR).

III. Impact and Use

The JHR-CP has to be considered as the preparatory phase of the JHR construction and equipment.
This preparatory phase has aimed at improving the project maturity required to enable the construction work.
The JHR-CP actions are at the front-edge of the JHR Project. These actions have provided high added value steps toward the implementation of a new European Material Testing Reactor from the technology and operation organization point of view.

It is acknowledged that the JHR will have a key-role in the coming decades, as a major research reactor within Europe for nuclear energy. The scientific results obtained with the JHR experimental capacity will contribute to the European leadership in this field.
The JHR-CP has addressed key issues toward the implementation of a new high performance material testing reactor in Europe: qualification of critical components, safety assessment, and training of a new generation of operators, contribution to standards…

Moreover the project has paid attention to dissemination activities, except for industrial process requiring a severe confidentiality to guarantee commercial competitiveness and industrial property.
The dissemination has been performed through various means like scientific conference, publication, handbook, public web portal and website.

This could be illustrated by the following actions:

- Meetings and conferences

In addition to the direct use of the technical results for the JHR construction and licensing, three publications in international conferences (IGORR and ANIMA conferences), in order to disseminate the knowledge generated by the JHR-CP in the world nuclear community, have been made:

-Mastered severe accident used for MTR safety demonstration,

-Behaviour of the aluminium structure under irradiation (the aluminium is one of the most used structural material in MTR), using the RAJA results,

-Improvement of the calculation scheme for the MTR, using the AMMON neutron physics experiments.

- Contribution to standards

The design and construction of any new research infrastructure such as the JHR have to be compliant with standards. In the case of the JHR these standards are given by the French RCCMX codes. The objective of the JHR-CP in this field was to achieve a first full-scale test of the application of the new RCCMX rules for designing and manufacturing critical components by European industries through the studies on the JHR heat exchanger.

This test has given experience feedback. This feedback has shown that in such application of new rules the interpretation of the text could present some deviation between the designer and the control organism, leading an increase of the instruction duration and leading to a modification of the design. It is strongly recommended to involve the control organisation as soon as possible in order to avoid any misunderstanding between the different bodies.
This work provided a valuable experience and contributed to the plan for using and disseminating knowledge in the European industries.

-Training and Handbook

The Users Handbook has been conceived to describe the JHR facility, the integration conditions for an experiment proposed by an end-user, the experimental capacity of the JHR, and the general operation of the overall JHR facility. It represents an important work carried out and reviewed in common by the partners
The User Handbook has been written in order to allow any JHR incomers (scientist, experimental physicist, operator …) to quickly have an overview of the JHR facility, of its experimental capacity and of its general mode of operation.
The Users Handbook will be widely disseminated since it describes the JHR facility for any JHR user.

After a detailed review of the existing training courses which are offered in the different institutions and European countries, the JHR-CP members decided to propose a new set of academic training courses which allow to complete the present offers and which are more focused on the JHR at the beginning.
Therefore this course mainly concerns the design and the use of experimental devices in research reactors and the definition of experimental programmes. And it should give strong basic information on all important aspects of MTR experiment design and operation.
This course was initially dedicated to the JHR, but taking into account in detail the concern raised by the JHR-CP members, finally the JHR-CP partners expressed a real interest in such a course and decided to extend and use it for the whole European MTRs community.

IV. Website

The JHR-CP website will be maintained for the next phase of the JHR construction project.
The website provides the following information:

1. General information in the project
2. The project presentation
3. The official documents of the project when they are public
4. The work done for each activity of the project through description pages
5. The public data and documents generated by the JHR-CP work

Website address:
www.cad.cea.fr/rjh/JHR-CP/index.html

V. Conclusion

Taking into account the important work performed within the European and international community with the support of the European Commission, the JHR-CP actions have covered relevant outstanding issues in the following areas:

- Strategic plan for qualification program of critical components; this qualification program is a structuring item to enable the licensing process, facing today's state-of-art safety requirements for MTRs.
- Technical works which have led to the qualification and improvement of the materials involved in the JHR construction, and to the improvement of the calculation tools used for the JHR design aiming to the production of European Standards.
- Project logistics which has contributed to prepare the future utilisation of JHR by the European community firstly by establishing a training course for the future JHR scientist end-users, and secondly by providing a users-handbook for operation and experimentation.

These actions have given high added value steps toward the implementation of a new European Material Testing Reactor from technology and operation organization point of view.

Addressing a preparatory phase for the JHR project, phase which has allowed the improvement of the project maturity, the JHR-CP finally achieved its goal and allows stepping forward in the construction and equipment phase of the Jules Horowitz Reactor, which is a key research infrastructure in Europe to support public bodies and nuclear industry for both present and future reactor systems, leading Europe to conserve its worldwide leadership in this field.

List of all beneficiaries with the corresponding contact name and associated coordinates

Code	Beneficiary name	Contact name	Short name	Country
CO01	COMMISSARIAT A L'ENERGIE ATOMIQUE	CHAUVIN Jean-Pierre	CEA	FRANCE
P02	CENTRO DE INVESTIGACIONES ENERGETICAS MEDIOAMBIENTALES Y TECNOLOGICAS	GONZALEZ Enrique	CIEMAT	SPAIN
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P05	STUDIE CENTRUM VOOR KERNENERGIE CENTRE D'ETUDE DE L'ENERGIE NUCLEAIRE	VERMEEREN Ludo	SCK-CEN	BELGIUM
P06	EMPRESARIOS AGRUPADOS INTERNACIONAL	CASTRO LOPEZ Fernando	EA	SPAIN
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