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PART 1: EXECUTIVE SUMMARY
A. INTRODUCTION

Materials Testing Reactors (MTRs) are key infrastructures in Europe to sustain the nuclear industry and to prepare future reactor systems. Europe has a worldwide leadership in this field owing to several large power MTRs that were developed on a national basis. However, this situation is not sustainable because European MTRs will be more than 50 years old in the next decade and will face increasing probability of shut-down due to their obsolescence. This analysis was shared by experts and industry representatives in order to answer the European Commission question on the need for a new Materials Testing Reactor (MTR) in Europe (Future European Union Needs in Material Research Reactors – FEUNMARR – Fifth Framework Programme (FP5) Thematic Network). Conclusions clearly pointed out that at least one new MTR should be implemented in Europe to guarantee long-term experimental irradiation capability.

To meet needs assessed within the FEUNMARR network, it is also necessary to renew irradiation capabilities by designing a new generation of irradiation devices, since most of used irradiation devices have been developed several decades ago. Devices integrating new technological possibilities (e.g. materials operating at high temperature, miniaturised components, online instrumentation under high neutron flux, sample evolution) are now required to meet updated industrial needs and new scientific modelling capabilities. The most successful strategy in this field is clearly based on the European collaboration and a shared development of experimental devices, because it meets not only technical needs but also important stakes such as:

- increasing strongly the integration of the European MTRs community, which was fragmented due to its history. This stake appears as a drastic change compared to the past situation
- offering a high added value by gathering knowledge and experimental feedback. This presents a strong added value for existing MTRs by cross-fertilisation
- maintaining a high scientific expertise level by training of new generations of searchers, engineers and operators.

B. THE JULIUS HOROWITZ REACTOR COORDINATION ACTION (JHR-CA)

The JHR-CA has met these concerns by preparing the construction of a new MTR in Europe, the JHR project, and by consolidating the MTRs community on shared projects dedicated to experimental devices design. This two-year (2004-2005) programme had two main objectives:

- to structure a European collaboration on the definition of the irradiation devices, thanks to an Experts Group (EG). This group derived the definition of the JHR experimental devices design to meet current industrial demands (issues on existing or under development reactors such as fuel performance and safety, mechanical behaviour under irradiation, corrosion, ageing assessment) and to meet emerging needs (e.g. gas and high-temperature loop, fast-transient experiments). Contractors involved in this Group were the Commissariat à l’énergie atomique (France), Studiecentrum voor Kernenergie – Centre d’étude de l’énergie nucléaire (Belgium), Nuclear Research & Consultancy Group (the Netherlands), Karlsruhe University (Germany), Nuclear
Research Institute Řež plc (the Czech Republic), Nuclear Research Centre VTT (Finland), and Technicatome (France)

- to involve vendors, utilities and public stakeholders in the design of the experimental devices and next-generation MTRs. These end-users, gathered in a Users Group (UG), had to make sure that the JHR project provided a service-oriented irradiation platform fulfilling their needs. Contractors were Électricité de France, Kernkraftwerk Leibstadt KKL (Switzerland), FORTUM (Finland), IBERDROLA (Spain) and Framatome-ANP (France).

C. JHR-CA UNFOLDING

C.1 JHR-CA Experts Group meetings

Six Experts Group meetings were held during the programme:

- 2004: CEA HQ Paris (27/02), NRI Rez (21-22/06) and NRG Petten (25-26/11)
- 2005: CEA Cadarache (10-11/03), SCK-CEN Mol (13-14/06) and SCK-CEN HQ Brussels (16/12/05).

They were mainly devoted to presentation of the technical work (irradiation-device conceptual design build-up and optimisation, neutronic and thermal-hydraulic calculation results, etc.). They also allowed presenting some specific points of the JHR facility design in relation with the experimental capability (core design, displacement systems, hot cells, etc.). At the end of the study process, device integration assessment was presented by the engineering team. An important place has been reserved to recommendation release from the European MTR community, underlining critical points in the design or the implementation of the device or the experiment. Missing study points have also been highlighted, which will constitute specific topics of the development phase. These meetings were held with the presence of a Users Group representative.

C.2 Users Group meetings

After the first JHR-CA meeting that allowed defining key items to be followed by the Users Group, the users-group and the experts-group meetings were managed separately so that each group could mature its topics. A strong synergy existed between the JHR-CA Users Group and the International Advisory Group (IAG) established by OECD-NEA. Users Group representatives participated in JHR-IAG meetings. Their assessment remarks on the experts’ technical work have been included in the IAG Main Conclusions released by OECD/NEA in November 2005.
D. EXPERTS GROUP MAIN TECHNICAL FINDINGS

D.1 Overview of the documents production

Five scientific work packages (WPs) have been identified as proposing challenging exercises for the scientific community. The aim was to build up a conceptual design of an irradiation device capable of performing sophisticated in-situ measurements or controlling precisely the environment of the sample. The work performed in each scientific work package (WP1 to WP5) has been summarised in a final report, under the supervision of the WP leader, and gathering the following study topics:

- scientific and operational objectives and interest of the study
- input data by a common definition of an experimental scenario
- conceptual design of the device (main features and performance assessment)
- integration assessment
- global work assessment with identification of missing and critical points
- future work plan and continuation in a European programme (MTR+I3).

Specific technical documents have also been released in the frame of these work packages (materials operating at high temperature, specific irradiation needs for fusion materials, pressure vessels steels monitoring, etc.).

A work package dedicated to radioisotope production for medical applications (WP6) led to the release of a strategic document which constituted also the final report. Operation optimisation (WP7) led also to a final report proposing recommendations in the field of management and organisation, relations with the scientific community, and experimental and equipment processes.

A specific and important work has been performed on the integration process in the JHR environment (WP8). Besides the integration assessment work for each device design (included in each technical WP final report), several generic documents clarifying the interfaces with future end-users have been released:

- first version of the Users Handbook (JHR facility presentation and experimental capability description)
- safety general principles
- operating and control interfaces specifications.

D.2 WP1: Materials behaviour under high-temperature conditions (leader: NRI)

This work gathered NRI (WP leader), NRG, Uni-KA, and CEA. A large part of the work has been carried out at CEA, with the collaboration of a NRI fellowship and with the fruitful expertise support from Uni-KA.

The test device is an experimental helium gas loop at 7 MPa designed for material in-core irradiation at high-temperature and high-dose rate (the Helios loop). It is dedicated to separate effect experiments such as dose accumulation, temperature and time dependency tests, or environment dependency tests (helium with controlled impurities). Main specifications are:
• typical tested materials: SiC based ceramics and composites, ODS (Oxide Dispersion strengthened Steels) and ZrC, for high-temperature reactors
• fast neutron flux range: 1.5 \times 10^{14} to 5 \times 10^{14} n.cm^{-2}.s^{-1}
• nominal temperature: up to 1200 °C
• available space for sample holder: diameter 25 mm, length 600 mm
• fluid surrounding the samples: circulating helium.

A lot of thermal calculations have been carried out on a standard device design with consideration of both TZM/molybdenum and IG-110 graphite structural materials, and on a new design with a supplementary thermal shielding constituted by a tube offering a static gas gap between it and the pressure tube.

Based on the WP1 key study of the Helios conceptual design and feasibility study, some remarks for complementary studies have been pointed out, mainly:
• a better evaluation of the thermal shielding by calculations
• the development of a pre-heating component and of a pumping system
• the interest to have two geometries: a small one placed inside a JHR fuel element and a larger one which accepts instrumentation on the samples.

D.3 WP2 and 3: In-pile mechanical testing devices

The JHR-CA WP2 has produced the conceptual design of a specific sample holder for the JHR which allows material mechanical testing in controlled biaxial stress conditions (with simultaneously controlling the axial and hoop stress during the irradiation), with online measurements of the sample strain. The WP3 has produced a conceptual design of a JHR irradiation device with associated instrumentation to get information on material behaviour under irradiation and corrosion in LWR-representative conditions (pressure, temperature and water chemistry). To study irradiation-assisted stress corrosion cracking (IASCC), techniques for crack-growth rate measurements under flux have been proposed.

The in-pile test device is a stainless steel double-wall rig with a controlled gas gap. This generic rig could host different types of sample holders designed for each specific experiment. The sample-holder geometry depends on the type and number of samples to be irradiated and holds the experimental instrumentation. The irradiation rigs for material irradiation will cover a wide range of temperature and environments, but work was performed on a temperature range from about 280 to 500 °C with circulating liquid NaK as cooling medium.

An important requirement for these rigs is to control the temperature of the samples as well as to keep the temperature distribution homogeneous. The gamma heating induced by the high neutron flux induces a non-homogeneous heating of structures and samples. Therefore the device must have the capability to correct it. Thermal calculations have been performed with severe working hypotheses (gamma heating of 20 W/g, frame in stainless steel, sample in zirconium, and circulation of NaK at 0.5 kgs\(^{-1}\) and at a temperature of 400 °C). They identified very limited local “hot spots” at the contact between the sample and the transducers (+10 °C) with no significant additional strain (DUX < 1 micrometer).

Circumferential stress in the sample is controlled by internal pressure and axial stress by pneumatic internal bellows. The ratio between these stresses is the required biaxial ratio. The
best way to apply a controlled axial load is by using bellows. The strain measurements will be performed using a Linear Variable Differential Transformer (LVDT) system for the axial deformation. For the diametric deformation a strain gauge system is considered. This rig is being developed and will be tested in the coming years in an existing MTR to validate the technical options chosen.

In the frame of WP3, a post-doctoral researcher from CEA spent six months in the VTT laboratories to work on crack propagation monitoring. The aim of this stay was to validate the use of the direct current potential drop technique for stress corrosion crack growth monitoring on reduced-size compact tension specimens in simulated PWR primary water.

Several technological key components have been identified as common issues for these devices and can be developed for the benefit of existing MTRs as well as futures one. For example there is a need to establish a calibration procedure to pilot the biaxiality ratio in regard to the pressure ratio. Also the integrated NaK pump is a key element of the WP2 irradiation device, such as the in-pile instrumentation (electrochemical potential, electrochemical noise, Direct Current Potential Drop) for the IASCC studies.

**D.4 WP4: PWR loop for fuel-rod bundle irradiation**

This common work gathered SCK-CEN (WP leader), NRG, Technicatome and CEA. A large screening-calculation grid on thermo-mechanical and neutronic behaviour aspects has been carried out at CEA (Reactor Studies Dept.), with the fruitful operationnal expertise support from SCK-CEN. The integration work has been performed by Technicatome.

This test device is an experimental pressurised water loop designed for PWR fuel-rod cluster testing. Samples are 8 instrumented, fresh or segmented or re-fabricated pre-irradiated rods with a fissile length up to 600 mm and an external diameter of 9.5 mm. It is devoted to separate effect experiments on comparative characterisation of fuel rods irradiated in the same conditions, e.g. microstructure evolution, fission gas release and fission product distribution. It is designed for steady-state irradiation, medium power transients as well as first phase of loss of coolant experiments.

The in-pile part is a double-wall pressure tube with a controlled gas gap. This part is placed in the reactor’s beryllium reflector in one fixed position equipped with a variable thermal neutron screen that allows fuel-rod power adjustments and medium speed transients. The connection tubes are rigid and installed in the bottom of the pool. The cooling of the fuel rods is based on pressurised water forced convection. In the upper part of the loop, only a flow rate fraction goes back to the out-of-pile circuit. The other fraction is recycled by means of an injector set. Such a flow rate amplifier reduces the coolant flow rate circulating out-of-pile and consequently the size of components. It is worthwhile noticing that this design can slightly evolve, depending on the end-users’ needs.

Several designs have been considered to flatten the radial power gradient in the cluster, which is caused by the small size of the high-performance core. The best results are obtained with a ring-shaped arrangement of the 8 rods and with a crescent-shaped neutronic screen placed close to the front rods. With such a configuration, in zirconium alloy structures, calculations showed that the power gradient in the cluster could be reduced down to 2.0 kW/m (6 % of the mean value 35 kW/m).
During EG meetings or dedicated technical meetings, people agreed on the following main further studies:

- to finalise the rod bundle design (number and position of the fuel rods) in order to flatten the radial distribution of the power between rods, and to allow the best monitoring of the individual power seen by each rod
- to continue the studies on neutronic screens adapting locally the neutronic flux
- to design a sample holder supporting the rods and the instrumentation, and allowing the unloading and the handling of the bundle even in presence of a failed rod
- to conclude about the interest to have such a loop at a fixed position at the JHR core periphery.

D.5 WP5: Gas-cooled thermal reactor system fuels

This common work has gathered NRG (WP leader), SCK-CEN, Technicatome and CEA. Thermo-mechanical and neutronic calculations have been carried out at CEA (Reactor Studies Dept.), with expertise support from SCK and NRG. The integration work has been performed by Technicatome.

The test device designed in this WP is mainly dedicated to V/HTR fuel characterisation and qualification, such as thermo-mechanical behaviour, fission product release or particle failure rate determination. A typical sample could be a stack of up to 8 fresh or pre-irradiated compacts (50 mm long, outer diameter of 12.5 mm) placed in a graphite tube. The sample central temperature to be reproduced is in the range of 600-1400 °C in nominal operating conditions, but can reach 1600 °C in an incidental situation.

The in-pile test device is a double-wall rig with a controlled gas gap. The cooling is based on radial thermal conduction and radiation through the device structures, and on an external cooling imposed by the forced convection of the reactor pool water. A very low gas-flow rate of high-pressure helium (7 MPa) sweeps the samples contained in a special envelope to analyse fission product release under irradiation by routing them to the fission product analysis laboratory. The test rig will be placed in the reactor’s reflector in one of the experimental emplacements or on one of the standard displacement systems that allow fuel sample power variations. Two rigs could be simultaneously operating on the same displacement system, allowing 16 compacts to be irradiated at once.

Analytical thermal calculations were carried out for steady-state conditions. Results showed that the axial temperature discrepancy due to the non-flat power profile of the reactor could be avoided with a sample-holder tube machined with a non-uniform thickness in the axial direction. Moreover, for a given linear power, the control of the fuel sample temperature around the nominal operating point is possible by changing the mixture in the outer gas gap. For instance, replacing helium with nitrogen induces a fuel temperature increase of about 80 °C.

Neutronic calculations indicated that the target linear power of 200 W/cm is reachable in the JHR reflector, but with a fast to thermal neutron flux ratio too small compared to the target value of 0.5. Neutron spectrum hardening is possible by adding a nickel tube around the test
device. For instance, the target linear power with the specified spectrum can be obtained with a 5 mm thick screen.

Following main topics need complementary studies:

- the consequences of testing spherical elements instead of compacts
- the adaptation of the local neutronic spectrum in the experiment to fulfil the objectives (fast flux/thermal flux ratio) at different core distances and for different concepts of HTR power reactors
- the technological aspects of flattening the axial thermal distribution by manufacturing a variable gas gap between the pressure tubes
- the determination of the temperature distribution (and the mechanical consequences) in case of accident-condition simulations.

D.6 WP6: Medical applications

This WP was a more strategic one, where discussions between CEA, NRG and SCK took place to propose the future European landscape in this field. Since JHR is dedicated to the material and fuel science, it will provide only a back-up production capability (25-50 % of the European needs). To secure the European infrastructure policy, it proposed to support the NRG project of a new reactor dedicated to medical applications.

D.7 WP7: Operation optimisation

The WP7 was a support of the Users Group (WP9) and aimed at providing conditions for an optimum irradiation-device fleet operation and for good management of the experimental programmes. A first assessment of the Halden reactor project has been made and discussed.

E. USERS GROUP PRODUCTION

Four topics have been investigated by the Users Group, with release of recommendation documents for the three first ones:

- **Assessing the ongoing design versus needs**: This topic comprised the participation in the International Advisory Group (IAG) meetings, under the OECD/NEA framework, for assessing the overall JHR design, and the assessment of the experimental devices conceptual design proposed by the EG.
- **Relevance of JHR safety standards versus experimental needs**: This addresses the assessment of the JHR safety standards from the users’ point of view, with a possible release of requirements.
- **Testing capacity of JHR on safety tests**: The experimental capability of the JHR in safety tests follows a separate effect approach strategy. This important experimental field has to fulfil a need clearly expressed by end-users. The objective is to precise these needs and to formulate specifications for experiments dedicated to safety programmes.
- **Defining organisation and operation rules suitable for a new European MTR**: The recommendations released by the UG were supported by the WP7 conclusions.
F. CONCLUSION

The JHR-CA has provided a discontinuity in the European MTR community by allowing a fruitful and large co-operation with open exchanges and shared technical proposals. This trend is essential for building the ERA since it provides the necessary critical mass of means and competences. To strengthen and confirm this evolution, it is necessary to push the European cooperation toward an actual shared technological development of experimental devices together with person exchanges, opening access to facilities, etc. This is the goal of the MTR+I3 Integrated Infrastructure Initiative as proposed in the last Sixth Framework Programme (FP6) call.

The local public consultation on the JHR project was held from April to June 2005 and was a very positive success. The public meetings held in the framework of this consultation allowed presenting the European scale of the JHR project. This viewpoint had a very positive impact on the public debate level. An Internet site is available, gathering among other documents the public consultation-meeting reports:
http://www.cad.cea.fr/fr/actualite/RJH/RJH.asp

The JHR Internet site will also integrate the final JHR-CA technical deliverables in 2006.
PART 2: PROJECT DESCRIPTION
A. INTRODUCTION

European Materials Testing 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. Thanks to their irradiation capability constituted by a set of devoted irradiation devices, they address the development and the qualification of materials and fuels under irradiation with sizes and environment conditions relevant for nuclear power plants. Main objectives are to optimise and demonstrate safe operations for existing and coming power reactors as well as to support future reactor 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. This analysis was shared by experts and industry representatives in order to answer the European Commission question on the need for a new Materials Testing Reactor (MTR) in Europe (Future European Union Needs in Material Research Reactors – FEUNMARR – FP5 Thematic Network). The survey addressed the irradiation needs for material and fuel studies for commercial Generation II and III up to Generation IV reactors, for back-end cycle requirements with dedicated breeders or accelerator driven systems, and for fusion. The survey dealt also with nuclear medicine and fundamental research. Cross-cutting topics like education and training as well as operation best practices were addressed.

A consensus has been drawn on recommendations provided in the final report released in October 2002 [1] [2]:

- An initiative for a new MTR facility in Europe is to be launched to meet the continuous need of irradiation capabilities and to face the ageing of present OECD MTRs.
- This new facility has to be an international service-oriented user facility to meet demands from mature international industries and to address broadly shared issues (safety, sustainable development, etc.).
- The initiative to build the Jules Horowitz Reactor (JHR) and to organise an international programme around it is an important contribution to the joint development of a new European Materials Testing Reactor.
- A new MTR, such as the proposed JHR, should in due time establish robust technical links with existing MTRs, aiming at providing a broad and efficient network of facilities at the service of the international nuclear community. Programmes should be devised to reach a worldwide range of customers.

To meet needs assessed within the FEUNMARR network, it is also necessary to renew irradiation capabilities by designing a new generation of irradiation devices, since most of used irradiation devices have been developed several decades ago. Devices integrating new technological possibilities (e.g. materials operating at high temperature, miniaturised components, online instrumentation under high neutron flux, sample evolution) are now required to meet updated industrial needs and new scientific modelling capabilities.

The most successful strategy to renew the experimental irradiation capability is clearly based on European collaboration and a shared development of experimental devices, because it has to meet not only technical needs but also important stakes such as:

- increasing strongly the integration of the European MTRs community, which was
fragmented due to its history. Sharing this development will undoubtedly impel forthcoming collaborations on scientific programs. This stake appears as a drastic change compared to the past situation

• offering a high added value by gathering knowledge and experimental feedback. This presents a strong added value for existing MTRs by cross-fertilisation
• maintaining a high scientific expertise level in the training of new generations of searchers, engineers and operators. This meets the shared concern in Europe about the availability of competences and tools in the coming decades.

For these reasons, the European Union is the right level for implementing the innovation process required for developing new irradiation experimental devices. As a new MTR in Europe, the JHR project [3-9] offers a unique opportunity to trigger the innovation process in experimental-devices design. Of course, the associated implementation is driven by keeping in mind the added value for existing MTRs.

Shared European development of a new generation of irradiation experimental devices has started through a 2-year (2004-2005) EU programme called the Jules Horowitz Reactor Coordination Action (JHR-CA), gathering several European research institutes and MTR operators.

The JHR Coordination Action has issued a set of shared specification for these new devices. As a natural following step, the JHR-CA partners, within a larger panel of European labs, have launched a proposal for an Integrated Infrastructure Initiative (MTR+I3) with the purpose of starting the technological development of these devices for the benefit of existing and coming MTRs.

B. THE JULES HOROWITZ REACTOR COORDINATION ACTION (JHR-CA)

B.1 JHR-CA objectives and organisation

This programme has two main objectives:

B.1.1 To structure a European collaboration on the definition of the irradiation devices: the Experts Group (EG)

The JHR-CA gathers the European expertise for providing specifications and conceptual designs of a new generation of experimental devices with a careful consideration on the related overall processes and induced services. The integration of these conceptual designs in the JHR environment is assessed through several criteria such as:

• the performance of the devices versus the scientific and technological state of art,
• the flexibility and efficiency of the overall experimental process (not limited to the irradiation unfolding),
• the foreseen quality of the service for industry and research institutes (flexibility, short time-to-result, cost, quality of the data).

The Experts Group (EG) drives the definition of the JHR experimental devices design to meet current industrial demands (issues on existing or under development reactors such as fuel
performance and safety, mechanical behaviour under irradiation, corrosion, ageing assessment) and to meet emerging needs (e.g. gas and high-temperature loop, fast transient experiments, etc.).

The JHR-CA allows addressing through the European collaboration identified breakthrough for key technical stakes (hot temperature management, online instrumentations and control, variable neutron shield, etc). This provides an effective side-product for developing in the short term innovative programmes in existing research reactors for the benefit of MTRs users.

B.1.2 To involve end-users in the design process: the Users Group (UG)

The Coordination Action aims to involve vendors, utilities, public stakeholders in the design of the experimental devices and MTR next generation. These end-users will make sure that the JHR Project provides a service-oriented irradiation platform responding to their needs.

Through the Coordination Action, information on the detailed design and performances versus needs are broadly shared, which supports the convergence process toward the construction decision since:

- it is a decisive step for a renewing policy of research infrastructures for fission, covering the creation of new facility and the functioning of existing ones and access to them,
- it structures an European collaboration on the definition of the experimental devices with users involved from the beginning.

B.2 JHR-CA participants

The EG gathers representatives of the following institutes:

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The following companies are members of the UG:

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## C. JHR-CA WORK-PLAN SUMMARY

### C.1 Experts Group work packages

Five scientific work packages (WPs) have been identified as proposing challenging exercises for the scientific community. The aim is to build up a conceptual design of an irradiation device capable of performing sophisticated in-situ measurements or controlling precisely the environment of the sample. The first three ones concern the materials and the two others the nuclear fuel:

#### C.1.1 WP1: Materials behaviour under high-temperature conditions (leader: NRI)

The objective is the conceptual design of an experimental helium gas loop designed for irradiation of HTR materials in the JHR core, at high temperature (700-1200 °C) and high fast neutron flux (from 1,4 to 5,2 * 10^{14} n/cm².s). This loop is located inside a JHR fuel assembly, and is dedicated to separate effects experiments on selected materials, such as SiC/SiC, Oxide Dispersed Strengthened Steel (ODS) and ZrC.

#### C.1.2 WP2: In-pile mechanical testing devices (leader: VTT)

The work concerns the conceptual design of an in-pile mechanical testing device with online environment, stress and strain control. As a challenge, one aim to perform an online control (axial and bi-axial) load, with a precise mechanical and temperature monitoring on a single-axial device.

#### C.1.3 WP3: Corrosion under irradiation (leader: VTT)

The objective of this WP was (i) to develop in conjunction with WP2 a mechanical test device allowing in pile stress corrosion cracking growth rate measurements on reduced size compact tension specimens and (ii) also to validate the use of the direct current potential drop technique with reduced size compact tension specimens.
**C.1.4 WP4: PWR loop for fuel-rod bundle irradiation (leader: SCK-CEN)**

This WP addresses end-of-life scenarios for PWR fuels, and mainly the quantification of the fuel thermo-mechanical behaviour and fission gas release, thanks to a cluster of instrumented experimental rods (equipped with central thermocouples, and pressure gauges or fission gas sweeping lines) placed in a PWR loop. Irradiation concerns mainly steady-state power levels and moderate transients. The target range for the mean linear power was 20-40 kW/m and the maximum power gradient in the cluster should be smaller than 10 %.

**C.1.5 WP5: Thermal gas-cooled reactor system fuels (leader: NRG)**

This WP deals with a high-pressure and high-temperature gas rig designed for the irradiation of an 8 HTR/VHTR (High/Very High-temperature Reactor) compact stack 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. Three other work packages deal with subjects important for the sizing and the management of the JHR experimental capability:

**C.1.6 WP6: Medical applications (leader: NRG)**

This work package addresses the technical and strategic optimisation of the European isotopes production for medical applications, taking into account the increase of the demand and the securing of this production by networking two or three research reactors.

**C.1.7 WP7: Operation optimisation (leader: CEA)**

This cross-cutting topic provides conditions and internal rule recommendations for an optimum irradiation device fleet operation and for a good management of the experimental programmes. This optimisation will lead to shorten time-to-result and to provide a “quality attitude” towards the customer.

**C.1.8 WP8: Integration assessment (leader: TA)**

This essential cross-cutting topic is performed by the JHR team responsible for designing JHR core and facility. Using study results performed in WP1 to 6 and associated conceptual design build-up, this team identifies the interfaces between the experimental devices and the facility, and highlights the main constraints for the devices, in order to integrate them versus the reactor design. Moreover, it identifies the critical points to assess in the development phase. The interaction of WP8 with the other ones is summarised in Figure 1:
C.2 Users Group work packages

Four topics have been investigated by the Users Group:

C.2.1 Assessing the ongoing design versus needs

This topic comprises the participation to the International Advisory Group (IAG) meetings, in the frame of the OECD/NEA, for assessing the overall JHR design, and the assessment of the experimental devices conceptual design proposed by the EG.

C.2.2 Defining organisation and operation rules suitable for a new European MTR

The recommendations released by the UG are supported by the WP7 conclusions.

C.2.3 Relevance of JHR safety standards versus experimental needs

This addresses the assessment of the JHR safety standards from the users' point of view, with a possible release of requirements.

C.2.4 Testing capacity of JHR on safety tests

The experimental capability of the JHR in safety tests follows a separate effect approach strategy. This important experimental field has to fulfil a need clearly expressed by end-users. The objective is to precise these needs, and to formulate specifications for experiments dedicated to safety programmes.
D. JHR-CA DELIVERABLES

D.1. JHR-CA Experts Group meetings

Six Experts Group meetings (three per year) were held during the programme. They were mainly devoted to the presentation of the technical work (irradiation device conceptual design build-up and optimisation, neutronic and thermal-hydraulic calculation results, etc.). They also allowed presenting some specific points of the JHR facility design in relation with the experimental capability (core design, displacement systems, hot cells, etc.). At the end of the study process, device integration assessment was presented by the engineering team.

An important place has been reserved to recommendation release from the European MTR community, underlining critical points in the design, or in the implementation of the device or the experiment. Missing study points have also been highlighted, which will constitute specific topics of the development phase. These meetings were held with the presence of a Users Group representative.

D.2. Experts Group work packages

The work performed in each scientific work package (WP1 to WP5) has been summarised in a final report, under the supervision of the WP leader, gathering the following study topics:

- scientific and operational objectives and interest of the study
- input data by a common definition of an experimental scenario
- conceptual design of the device (main features and performance assessment)
- integration assessment
- global work assessment with identification of missing and critical points
- future work plan and continuation in an European programme (MTR+ I3).

Specific technical documents have also been released in the frame of these work packages (materials operating at high temperature, specific irradiation needs for fusion materials, pressure vessels steels monitoring, etc.).

The work package on medical applications (WP6) led to the release of a strategic document, which constituted also the final report. Operation optimisation (WP7) led also to a final report proposing recommendations in the field of management and organisation, relations with the scientific community, and experimental and equipment processes.

A specific and important work has been performed in the integration process (WP8). Besides the integration assessment work for each device design (included in each technical WP final report), several generic documents clarifying the interfaces with future end-users have been released:

- first version of the Users Handbook (JHR facility presentation and experimental capability description)
- safety general principles
- operating and control interfaces specifications.
D.3 WP9 – Users Group

After the first JHR-CA meeting that allowed defining key items to be followed by the Users Group, the users-group meeting and the experts-group meetings were managed separately so that each group can mature his topics. A strong synergy existed between the JHR-CA Users Group and the International Advisory Group (IAG) settled by the OECD-NEA. Users Group representatives assisted to the JHR IAG meetings, and their assessment remarks on the expert’s technical work have been included in the IAG Main Conclusions released by OECD/NEA in November 2005.

The Users Group also released two deliverables:

- A first assessment of the JHR safety standards and JHR operating rules from the point of view of the expected service
- As an important statement, the Users Group emphasised the importance of experiments for the fuel safety in JHR (LOCA type, RIA type and fuel-coolant interaction).

E. JHR-CA MAIN TECHNICAL FINDINGS (WP1 TO WP7)

E.1 WP1: Materials behaviour under high-temperature conditions

This common work has been done in the framework of work package 1, “High-temperature materials under irradiation”, of the JHR-CA programme, gathering NRI (WP leader), NRG, Uni-KA, and CEA. A large part of the work has been carried out at CEA, with the collaboration of a NRI fellowship, and with the fruitful expertise support from Uni-KA.

E.1.1 Irradiation device main features

The test device (see Figure 2) is an experimental helium gas loop at 7 MPa designed for material in-core irradiation at high temperature and high-dose rate (the Helios loop):

- typical materials: SiC based ceramics and composites, ODS (Oxide Dispersion strengthened Steels) and ZrC, for High-temperature Reactors,
- fast neutron flux range: $1.5 \times 10^{14}$ to $5 \times 10^{14}$ n.cm$^{-2}$.s$^{-1}$,
- nominal temperature: up to 1200 °C,
- available space for sample holder: diameter 25 mm, length 600 mm,
- fluid surrounding the samples: circulating helium.

It is dedicated to separate effect experiments such as:

- dose accumulation,
- temperature and time dependency tests,
- environment dependency test (helium with controlled impurities).

Different sample holders (see Figure 3) can be designed to reach specific experimental objectives, depending on the type of samples and instrumentation, taking into account the
operating range of the test loop, such as its internal diameter and thermal capabilities. The sample holder geometry depends on the type and number of samples to be irradiated.

The in-pile test device is a stainless steel double-wall pressure tube with a controlled gas gap. It is designed to ensure high-pressure high-temperature gas containment. This pressure tube could house different types of sample holders designed for each specific experiment. It also holds the experimental instrumentation such as thermocouples, neutron dosimeters, pressure sensors, etc. The test loop should be placed in one of the standard in-core experimental emplacements with the highest fast neutron flux.

The temperature control of the samples is possible by means of a small in-pile loop of circulating gas such as helium. Indeed, an integrated circulator situated at the head of the in-pile part and far above the active zone allows the fluid to flow down. After being pre-heated by means of electric heaters, the fluid travels through the active zone around the samples, and then it is cooled down by a heat exchanger situated at the bottom of the rig. Finally, the fluid returns up in the gap between the pressure tube’s inner wall and the sample holder shell.

For gas conditioning such as impurity monitoring and pressure control, inlet and outlet gas lines are connected to the out-of-pile equipments in bunker. Concerning the double-wall pressure tube, in-rig thermal gap pressure control system is designed to reduce the number of tubes between in-pile and out-of-pile equipment and thus to improve flexibility and handling of the test device.
E.1.2 Performance assessment summary

A lot of thermal calculations have been carried out on a standard device design with consideration of both TZM/molybdenum and IG-110 graphite structural materials, and on a new design with the supplementary thermal shielding constituted by a tube offering a static gas gap between it and the pressure tube (see Figure 4). Analysis of calculation results showed that:
• the new design can suppress the use of the additional heat exchanger
• the tubes around samples can be made of either IG-110 graphite or TZM/molybdenum
• the recommended sense of helium flow: helium down-flows in the central tube around samples and up-flows in the pressure tube
• the recommended helium flow rate is medium (between 10 and 15 g.s\(^{-1}\))
• supplementary thermal shielding will help to reach acceptable axial thermal gradient in Helios samples and to compensate thermal losses in the JHR pool
• optimal pre-heating system of helium: maximum temperature dependence of Helios samples.

**E.1.3 Work plan for complementary studies**

Based on the WP1 key study of the Helios conceptual design and feasibility study, the following remarks and work plan for complementary studies can be pointed out:

• a better evaluation of the thermal shielding by calculations
• the real detailed design, and notably studies on the effect of different thickness, of the Helios tubes, to optimize the axial temperature gradient in the samples
• the development of a pre-heating component and of a pumping system
• the development of the dosing and purification system
• the interest to have two geometries: a small one to be placed inside a JHR fuel element (diameter less than 32 mm), and a larger one which can accept instrumentation on the samples
• the effect of the thermal exchanges by radiation on the temperature distribution.

**E.2 WP2 and 3: In-pile mechanical testing devices**

WP2 gathered VTT (WP2 leader), and CEA. As this device should be dealing with various environments, including PWR and BWR water chemistry, it was decided to work jointly with WP3, “Corrosion under irradiation”, gathering VTT (WP3 leader), NRI and CEA.

**E.2.1 Irradiation device main features**

The JHR-CA WP2 has produced the conceptual design of a specific sample holder, to be implemented in the JHR, which allows a material mechanical testing in controlled biaxial stress conditions (with simultaneously controlling the axial and hoop stress during the irradiation), with online measurements of the sample strain. The WP3 has produced a conceptual design of a JHR irradiation device with associated instrumentation to get information on material behaviour under irradiation and corrosion in LWR representative conditions (pressure, temperature and water chemistry). To study irradiation assisted stress corrosion cracking (IASCC), techniques for crack growth rate measurements under flux have been proposed.

The in-pile test device is a stainless steel double-wall rig with a controlled gas gap. This generic rig could host different types of sample holders designed for each specific experiment. The sample holder geometry depends on the type and number of samples to be irradiated. It
holds also the experimental instrumentation such as thermocouples, neutron dosimeters, pressure sensors, strain gauges, displacement transducers, etc.

An important requirement for these rigs is to control the temperature of the samples as well as to keep the temperature distribution homogeneous. The gamma heating induced by the high neutron flux induces a non homogeneous heating of structures and samples, and therefore the device must have the capability to correct this inhomogeneous distribution of temperature.

The irradiation rigs for material irradiation will cover a wide range of temperatures and environments, but current work was performed on a temperature range from about 280 to 500 °C and liquid NaK as a cooling media. In this case, the accurate temperature control of the samples is possible by means of a small in-pile loop of circulating NaK, called “M3” (see Figure 5). Indeed, an annular electromagnetic pump (as shown in Figure 6) located above the active zone allows the fluid flowing down after being previously pre-heated by the mean of electric heater situated just above the pump. Then after travelling through the active zone around the samples, the fluid is cooled down by a heat exchanger located at the bottom of the rig. Finally, the fluid returns upwards in the gap between the rig inner wall and the sample holder shell. The dimensions of the electromagnetic pump are reduced to fit in the casing of the device.

**E.2.2 Description of the sample holder for the controlled biaxial stress device (WP2)**

Circumferential stress is controlled by internal pressure and axial stress by pneumatic internal bellows and the ratio between these stresses is the required biaxial ratio. In the case of in-pile tests, geometrical constraints demand for a “size optimized” solution. The best way to apply a controlled axial load is by using bellows, the sample being in tension or compression, whether the pressure inside the bellow is higher than that of the outside. In order to make this system more compact, the idea of placing the bellows inside the tubular samples emerged (Figure 7).

The strain measurements will be performed using a LVDT system for the axial deformation. For the diametric deformation, a strain-gauge system inspired from that of the Zircimog experiment is considered, but with a displacement system in order to measure the diameter in several axial locations. This rig is being developed and will be tested in the coming years in an existing MTR to validate the technical options chosen.

**E.2.3 Uniaxial device with crack propagation monitoring (WP3)**

In the frame of this project a post-doctoral researcher from CEA spent 6 months in the VTT laboratories to work on crack propagation monitoring. The aim of this stay was to validate the use of the direct current potential drop technique for stress corrosion crack growth monitoring on reduced size compact tension specimens in simulated PWR primary water. The samples used were cold-worked 316L stainless steel round compact tension specimens with a 5-mm thickness (5DCT).
M3 is the irradiation device located in the JHR core capable of performing irradiation of material samples under circulating NaK.
E.2.4 Thermo-mechanical performance assessment summary

Thermal calculations with finite element modelling have been performed in order to assess the sample temperature as well as the irradiation rig critical parts. The working hypotheses were: a gamma heating of 20 W/g, a frame in stainless steel, a sample in Zr and a circulation of NaK at 0.5 kgs⁻¹ and at a temperature of 400 °C. The main conclusions of these calculations were:

- The maximal temperature of the structures stays in a domain (454 °C) with no significant creep.
- The sample temperature is 406 °C, which is close to the NaK temperature (400 °C).
- There are local "hot spots" at the contact between the sample and the transducers (+ 10 °C) and no significant additional strain (DUX < 1 micrometer).
- There are local "hot spots" at the plug junctions (max. + 22 °C ) where no strain is expected due to very low stresses and axial heating gradient between the three samples (+ 7 °C ).

These calculations demonstrate the capacity of performing experiments with an acceptable spatial and temporal temperature gradient.

E.2.5 Work plan for complementary studies

Several technological key components have been identified as common issues for these devices and can be developed for the benefit of existing MTRs as well as futures one. For example there is a need to establish a calibration procedure to pilot the biaxiality ratio in regard to the pressure ratio. Also because placing the bellows inside the tubular specimens, the safety aspects as well as the temperature control have to be addressed. We also need to make sure that the components can perform adequately under neutron irradiation and/or in NaK environment. This means that the devices thought have to be build, qualified outside of a reactor and then implemented in an existing MTR to validate or guide our choices.

As strong evolutions occurred in the WP2 sample holder design since the first concept of the pneumatic testing device, there is a need to validate technical solutions. Therefore, a stepwise approach development is proposed, mainly in the frame of the FP6 MTR+I3 project. First, development of a sample holder for advanced types of samples with only axial-controlled stress and axial measurements is proposed. Then an internal-controlled pressure and diametric measurement will be added to performed test on tubular samples with biaxial stresses (with the bellow inside the specimen).

Regarding the issue of sample-temperature homogenisation, the integrated NaK pump is a key element of the WP2 irradiation device. In the MTR+I3 proposal, it is envisaged to design a compact NaK pump to evaluate its performances and to establish its technical specifications for procurement at a supplier. In parallel, a pump for Heavy Liquid Metal loop will be studied (JRA3 – WP3.4 ‘Miniaturised components’).

About the development of the irradiation device for IASCC studies, as the sample-holder design has been improved during the JHR-CA, it is necessary to continue the effort of development

- to manufacture and test the pneumatic loading system
• to develop the in-pile instrumentation (electrochemical potential, electrochemical noise, Direct Current Potential Drop)
• to demonstrate the validity of the methodology, firstly in autoclave.

E.3 WP4: PWR loop for fuel-rod bundle irradiation

This common work gathered SCK-CEN (WP leader), NRG, Technicatome, and CEA. A large screening-calculation grid on thermo-mechanical and neutron behaviour aspects has been carried out at CEA (Reactor Studies Dept.), with the fruitful operationnal expertise support from SCK-CEN. The integration work has been performed by Technicatome.

E.3.1 Irradiation device main features

This test device is an experimental pressurised water loop designed for PWR fuel-rod cluster testing. Typical samples are 8 segmented or re-fabricated fresh or pre-irradiated rods with a fissile length up to 600 mm and an external diameter of 9.5 mm. It is devoted to separate effect experiments on comparative characterisation of fuel rods irradiated in the same conditions, e.g. microstructure evolution, fission gas release and fission product distribution. It is designed for steady-state irradiation, medium power transients as well as first phase of loss of coolant experiments.

The in-pile part is a double-wall pressure tube with a controlled gas gap. It is designed to ensure high-pressure high-temperature water containment. This pressure tube houses the sample holder, which ensures the rod positioning in the test channel and holds the main experimental sensors. This in-pile part is placed in the reactor’s beryllium reflector in one fixed position equipped with a variable thermal neutron screen that allows fuel-rod power adjustments and medium speed transients. The connection tubes are rigid and installed in the bottom of the pool.

The cooling of the fuel rods is based on pressurised water forced convection. After being preheated by electrical means in the out-of-pile circuit, water reaches the in-pile containment, and flows down in the central tube of the sample holder (see Figure 8). Then, it rises into the annular test channel around the fuel rods and between the sample holder and the pressure tube. In the upper part of the loop, only a flow fraction goes back to the out-of-pile circuit, the other fraction is recycled by means of an injector set. Such a flow rate amplifier reduces the coolant flow rate circulating out-of-pile and consequently the size of components.

It is worthwhile noticing that this design can slightly evolve, depending on the end-users' needs.
E.3.2 Neutronic performance assessment summary

Neutronic calculations have been carried out at CEA with the TRIPOLI4 code (Monte-Carlo method) in a heterogeneous and three-dimensional modelling. The power variations were simulated by changing the pressure of a $^3$He shield around the test device. Another solution, not studied in the JHR-CA, could be to change the distance between the test device and the core vessel. Stainless steel and zirconium alloy structures were alternatively considered.

Several designs have been considered to flatten the radial power gradient in the cluster, which is caused by the small size of the high-performance core. The best results are obtained with a ring-shaped arrangement of the 8 rods, and with a crescent-shaped neutronic screen placed close to the front rods. With such a configuration, in zirconium alloy structures, calculations showed that the power gradient in the cluster could be reduced down to 2.0 kW/m (6 % of the mean value 35 kW/m), as shown on Figure 9.

Moreover, changing the pressure of a $^3$He shield around the fixed test device can adapt the power variations. A 5 bar pressure in a 5.8 mm thick tube around the test device induces a linear heat generation rate (LHGR) decrease of about 20 kW/m, and the power difference in the cluster is kept relatively low: 3.0 kW/m (22 % of the mean value 14 kW/m).
E.3.3 Work plan for complementary studies

During technical discussions among the JHR-CA participants, either during experts group meetings or during dedicated technical meetings, people agreed on the following further studies:

- finalising the rod bundle design (number and position of the fuel rods) in order to flatten the radial distribution of the LHGR between rods, and to allow the best monitoring of the individual LHGR seen by each rod. These choices have to take into account the cooling capability of the loop, and have to meet the scientific needs (e.g. reference rods and back-up rods)
- continuing the studies on a system of neutronic screens to adapt locally the neutronic flux
- designing a sample holder supporting the rods and the instrumentation (wires and mini tubes) and allowing the unloading and the handling of the bundle even in presence of a failed rod
- setting up the main safety requirements and the main safety options
- concluding on the interest in having such a loop at a fixed position in the JHR core periphery.

E.4 WP5: Gas-cooled thermal reactor system fuels

This common work has gathered NRG (WP leader), SCK-CEN, Technicatome and CEA. Thermo-mechanical and neutronic calculations have been carried out at CEA (Reactor Studies Dept.), with expertise support from SCK and NRG. The integration work has been performed by Technicatome.
**E.4.1 Irradiation device main features**

The test device designed in this WP is mainly dedicated to V/HTR fuel characterisation and qualification, such as thermo-mechanical behaviour, fission product release or particle failure rate determination. A typical sample could be a stack of up to 8 fresh or pre-irradiated compacts (50 mm long, outer diameter of 12.5 mm) placed in a graphite tube. The sample central temperature to be reproduced is in the range of 600-1400 °C in nominal operating conditions, but can reach 1600 °C in incidental situation.

The in-pile test device is a double-wall rig with a controlled gas gap (see Figure 10). The cooling is based on thermal conduction and radiation through the device different structures, and on an external cooling imposed by the forced convection of the reactor pool water (at 35 °C). A flow of high-pressure helium (7 MPa) sweeps the samples contained in a special envelope, to analyse fission-product release under irradiation, but the very low gas flow rate does not allow sample cooling by forced convection. Thus, given a specific nuclear power, the fuel sample temperature can be adjusted within a specific range by controlling the gas mixture in the rig thermal gap.

Coming from the out-of-pile part, helium flows downward in the annular gap between the sample-holder shell and the inner wall of the rig. Then it flows upward in the test channel before returning to the out-of-pile circuit. The test-device conditioning is possible from out-of-pile equipment situated in a bunker such as gases provider, compressor, circulator and links to the fission-product laboratory.

For all the nuclear safety data, independent wires are used between in-core sensors and out-of-core data acquisition system. For the other experimental data, analogue to digital converters and multiplexers are located in connection boxes situated at the top of the test device.

![Figure 10: Schematic view of the test rig](image)

The test rig should be placed in the reactor’s reflector in one of the experimental emplacements or on one of the standard displacement systems that allow fuel-sample power variations necessary for adjustment of power plateaus and cycling regimes. Two rigs could be...
simultaneously operating on the same displacement system, allowing 16 compacts to be irradiated at once.

**E.4.2 Thermal calculation assessment summary**

Analytical thermal calculations were carried out for steady-state conditions. For heat transfer evaluation, gamma heating in the different materials was taken into account and forced convection with the reactor pool water was considered to cool the test rig. Heat exchanges in gas gap are based on thermal conduction and radiation.

Figure 11 presents the axial temperature profile in the fuel compact. For different linear power values, three curves are given: (1) the dotted lines represent the linear power profile, (2) the solid marks represent the temperature with uniform gas gap thickness, and (3) the hollow marks represent the temperature with non-uniform gas gap thickness.

These results show that the axial temperature discrepancy due to the non-flat power profile of the reactor could be avoided with a sample holder tube machined with a non-uniform thickness in the axial direction.

For a given linear power, the control of the fuel sample temperature around the nominal operating point is possible by changing the mixture in the outer gas gap, for instance replacing helium by nitrogen induces a fuel temperature increase of about 80 °C. For larger temperature variations, a solution consists in changing the mixture of the sweeping gas, for instance a mixture of 15 % xenon and 85 % helium allows reaching the incidental operating target value of 1600 °C for a power density of 200 W/cm.

![Figure 11: Axial temperature profile of the compacts](image-url)
E.4.3 Neutronic calculation assessment summary

Neutronic calculations were carried out with the TRIPOLI4 code (Monte-Carlo method) in a heterogeneous and three-dimensional modelling. The test device was located in the beryllium reflector. Several cases were studied by changing the distance between the test device and the core vessel. Stainless Steel (SS) structures were tested. The simulation used 8 fresh-fuel compacts: 14.65 % enriched UO2 with 26 % particle filling ratio.

A first set of calculation indicated that the target linear power of 200 W/cm could be obtained at a core vessel distance of 28 cm. However, in such a location, the fast to thermal neutron flux ratio is too small compared to the target value of 0.5. Moreover, due to the axial flux profile of the JHR core, power discrepancies are rather large between compacts. Neutron spectrum hardening is possible by adding a Nickel tube around the test device. Figure 12 shows that the target linear power with the specified spectrum is obtained with a 5 mm thick screen.

![Neutronic simulation of an HTR test device placed in the JHR reflector](image)

**Figure 12:** Neutronic simulation of an HTR test device placed in the JHR reflector

E.4.4 Work plan for complementary studies

Conceptual design discussion among experts pointed out the following topics needing complementary studies:

- the consequences of testing spherical elements instead of compacts
• there should be a good interaction with the JHR-design team in order to ascertain that the JHR design aspects that are of importance to the current experiment (e.g. fission gas lines shielding or the displacement system) are designed in such a way that their design is acceptable to the present experiment
• the adaptation of the local neutronic spectrum in the experiment to fulfil the objectives (ratio fast flux/thermal flux) at different core distances and for different concepts of HTR power reactors
• the possibility of reusing parts of the irradiation device for several consecutive irradiations. Reusing parts will reduce the waste produced and the costs of the experiment. The item that might be most relevant for reuse is the double walled pressure tube
• the technological aspects of flattening the axial thermal distribution by manufacturing a variable gas gap between the pressure tubes
• the determination of the temperature distribution (and its mechanical/safety consequences) in case of the simulation of accident conditions (maximum central temperature for the compacts of 1600 °C) in transient conditions.

E.5 WP6: Medical applications

The WP6 was dedicated to radioisotope production for medical applications. This was a more strategic WP where discussions between CEA, NRG and SCK took place to propose the future European landscape in this field. Since JHR is dedicated to the material and fuel science, it will provide only a back-up production capability (25-50 % of the European needs). The question of securing the main European production capability is then open. To optimise the European infrastructure policy, it proposed to support the NRG project of a new reactor dedicated to medical applications.

E.6 WP7: Operation optimisation

The WP7 was a support of the Users Group (WP9) and aimed at providing conditions for an optimum irradiation-device fleet operation and for good management of the experimental programmes. A first assessment of the Halden reactor project has been made and discussed.

F. CONCLUSION

The JHR-CA has provided new forms of collaboration in the European MTR community by allowing a fruitful and large co-operation with open exchanges and shared technical proposals. This trend is essential for building the ERA since it provides the necessary critical mass of means and competences. To strengthen and confirm this evolution, it is necessary to push the European cooperation towards an actual shared technological development of experimental devices together with person exchanges, open access to facilities, etc. This is the goal of the MTR+I3 Integrated Infrastructure Initiative as proposed in the last FP6 call.
REFERENCES


