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Session VI

New Research Reactor Projects

THE JULES HOROWITZ REACTOR PROJECT, A DRIVER FOR REVIVAL OF THE RESEARCH REACTOR COMMUNITY

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ABSTRACT

The first concrete of the nuclear island for the Jules Horowitz Reactor (JHR) was poured at the end of July 2009 and construction is ongoing. The JHR is the largest new platform for irradiation experiments supporting Generation II and III reactors, Generation IV technologies, and radioisotope production. This facility, composed of a unique grouping of workshops, hot cells and hot laboratories together with a first -rate MTR research reactor, will ensure that the process, from preparations for irradiation experiments through post-irradiation non-destructive examination, is completed expediently, efficiently and, of course, safely.

In addition to the performance requirements to be met in terms of neutron fluxes on the samples ($5x10^{14}$ $n.cm^{-2}/sec^{-1}$ E> 1 MeV in core and $3,6x10^{14}$ $n.cm^{-2}/sec^{-1}$ E<0.625 eV in the reflector) and the JHR's considerable irradiation capabilities (more than 20 experiments and one-tenth of irradiation area for simultaneous radioisotope production), the JHR is the first MTR to be built since the end of the 1960s, making this an especially challenging project.

The presentation will provide an overview of the reactor, hot cells and laboratories and an outline of the key milestones in the project schedule, including initial criticality in early 2014 and radioisotope production in 2015. This will be followed by a description of the project organization set up by the CEA as owner and future operator and AREVA TA as prime contractor and supplier of critical systems, and a discussion of project challenges, especially those dealing with the following items:

- accommodation of a broad experimental domain,
- involvement by international partners making in-kind contributions to the project,
- development of components critical to safety and performance,
- the revival of engineering of research reactors and experimental devices involving France's historical players in the field of research reactors, and
- tools to carry out the project, including computer codes for core physics and design and construction codes for the reactor's mechanical components, auxiliaries and irradiation devices.

1. Overview of the JHR facility

1.1 Purpose

The Jules Horowitz Reactor (JHR) is the largest new experimental platform dedicated to irradiation experiments in support of Generation II and III reactors, Generation IV technologies, and radioisotope production.

3D view of JHR plant – CEA, AREVA TA

1.2 Main features

The high fluxes required are driving the design of the reactor for the JHR experimental platform.
To meet the present and future needs of power reactors requires significantly higher neutron fluxes than the Osiris reactor. The performance targets are shown in the table below:

Perturbed Fast flux on a material sample in the core (E > 0.907 MeV)	5×10^{14} n/cm^2 /sec
Perturbed Thermal flux on fuel sample in the reflector (E < 0.625 eV)	3.6×10^{14} n/cm^2 /sec
Irradiation damage on a material sample in the core	15 dpa/yr
Linear power on a fuel sample in the reflector (high burn-up fuel simulated with a U-235 enrichment of 1%)	500 W/cm

The facility is designed to accommodate more than 20 irradiation devices during a reactor cycle. At the reactor level, this irradiation capacity requires 10 irradiation locations in the core and 12 irradiation locations in the reflector, 6 of which are on displacement systems. Some additional locations in the reflector are dedicated to radioisotope production.

The high flux, fast flux and thermal flux performance together with power ramp-up capability in the reflector require a new core concept, while the number and diversity of irradiation experiments require easy access to the core. After studying several alternative designs, an in-pool tank design was selected; the primary coolant pumps provide dynamic pressurization of the contained primary cooling system. The reflector surrounding the core tank is accessible even when the reactor is at full power.

In addition to the integrated laboratories and several pools dedicated to different uses, the facility includes a hot cell block comprising a set of four major cells, including two beta-gamma multi-purpose hot cells for irradiation experiments, a true alpha hot cell, and a hot cell for dry packaging of radioisotopes or irradiated fuel elements, and several measurement cells.

1.3 Project schedule


JHR AREVA TA teams at design stage

The project milestones are as follows:

- The conceptual design, including development of facility specifications, was completed in 2002.
- The preliminary design was prepared from 2002 to 2005. During this phase, the main design options to achieve the required performance were defined, the main systems were designed, and the construction license application was prepared.
- The construction license (Regulated Nuclear Facility license decree) was granted in 2009. after the Preliminary Safety Report elaborated by Areva TA had been instructed by the French Safety Authority (ASN),
- In parallel, detailed design work was carried out, with 90% of the requests for bids for the industrial procurement packages issued before the end of 2009. The CEA, as the project owner, is in the process of awarding contracts for those packages. Procurement contracts for the main aluminum and stainless steel supplies are also being placed.
- Site leveling and excavation are completed. The civil works contact was awarded in early 2009, and the first concrete was poured in August 2009.
- The construction and installation phase will be completed by mid 2013.
- Then the commissioning phase will lead to the first criticality, scheduled for the beginning of 2014.

2. Organization

2.1 International partnership

The JHR is designed, built and will be operated as a facility for international users. There are several reasons for this:

- Given the maturity and globalization of the industry, domestic tools no longer have the required level of economic and technical efficiency. Meanwhile, countries with nuclear power programs need access to high-performance experimental capabilities for irradiation to support technical skills and ensure the competitiveness and safety of nuclear power.
- International cooperation is needed to share the costs and benefits of experimental results in support of research topics related to safety and public policy, such as waste management.
- The pooling of research results is even more useful in the health field, especially when it comes to nuclear medicine, as has already been demonstrated in Europe.

This project is steered and funded by an international consortium of reactor vendors, utilities and public stakeholders set up in March 2007 when construction began. The current members of the consortium are:

- Research laboratories: CIEMAT of Spain, the CEA of France, NRJ/UJV of the Czech Republic, the European Commission, SCK/CEN of Belgium, VTT of Finland, and The Department of Atomic Energy of India,
- Industrial organizations: AREVA, EDF and VATTENFALL.

Two associated partners are also involved in the JHR: DAE of India and JAEA of Japan.
Discussions with research institutes and utilities are ongoing to broaden the JHR consortium.

2.2 Project organization

As the owner and operator of the nuclear facility, the CEA is providing project leadership, integrating user requirements, and developing the irradiation device fleet in close collaboration with the international partners.

First concrete poured at summer 2009

AREVA TA is the lead entity in the prime contracting organization, consisting of AREVA NP, EDF and AREVA TA. Previously located in Aix en Provence, the prime contractor team moved to the construction site last October; it is an integrated engineering team composed in average of 100 people (peak value 170) assigned by the partners and some subcontractors. The prime contactor is responsible for facility design, construction and commissioning and for cost and schedule performance.

A unique feature of the construction phase of the project involves in-kind contributions from some of the project's foreign partners:
- NRI/UJV of the Czech Republic is providing the hot cells,
- CIEMAT of Spain is providing the primary heat exchangers, and
- some laboratory equipment is coming from Finland.

These contributions are subject to the same procurement procedures by the prime contractor as for other services and supplies: the procurement is prepared by the prime contractor, the contracts are placed by the CEA, and follow-up, inspection and acceptance of the work is carried out by the prime contractor. Key procurement packages include:
- civil work, performed by Razel;
- primary cooling pumps, supplied by Union pump;
- the reactor unit, including the control rod drive mechanisms, safety-related components, primary cooling system, and instrumentation and control system, manufactured and commissioned by AREVA TA; and
- the fuel, fabricated by AREVA Cerca.

3. Examples of project challenges

3.1 Experimental domain

The JHR is fully optimized for irradiation testing of materials and fuel under both normal and off-normal operating conditions:
- with irradiation loops simulating operation of various power reactor technologies, and
- with high flux capacity to address existing and future nuclear power plant requirements.

The design of the JHR experimental device fleet is driven by identified and expected future experimental needs. Development of some devices is ongoing, as presented in ref <4.>. These first devices are important because they meet end-user expectations and allow us to define most of the JHR experimental standards and performance requirements for the future. The simultaneous rollout of the facility project and the irradiation devices is a key factor for successful allocation of the relevant engineering interfaces.

3.2 Component development

To ensure construction quality, safety and performance, plans call for the following qualifications to be performed:

- fuel plate and fuel assembly;
- manufacturing (forging, welding) of the core rack and core tank;
- primary pumps, flap valves of the reflector cooling circuit, sensors and associated devices, ball valve for the irradiation device thimble;
- seismic-resistant bearing pads;
- reactor pool capability to maintain the core underwater after a hypothetical severe accident;
- reactor block behavior subjected to primary flow; and
- displacement systems for irradiation devices.

These activities were identified and planned at the end of the conceptual design phase. The development and qualification program is led by the prime contractor and involves contributions from different CEA research laboratories and industrial companies. Most of these activities have been completed and significant improvements have been made, for example:

- The JHR fuel project to develop a long-term high-density fuel solution and a solution to secure the start of operations using U3Si2 fuel is split between the CEA, which is responsible for the fuel plate, and the prime contractor, responsible for the fuel assembly. Qualification is ongoing. Last year, a major milestone was achieved with the successful irradiation of a fuel assembly prototype at BR2. The fuel qualification aspects are described in several publications (see <2.> <6.><8.>).
- Welding and manufacturing processes have been improved via a far-reaching technical development program for reactor block components. Gains have been made in better welding control and improved material characteristics of thick parts. Some of these topics are described in ref <9.>. These activities are an excellent opportunity to strengthen skills in this field for the owner, the prime contractor and the suppliers.

The qualification program is still ongoing and some formal qualifications will be completed before commissioning.

3.3 Tools

Computer codes and calculations for safety and performance

Precise, accurate computer codes are required to address performance and safety issues. The development and qualification of a set of codes began at the end of the conceptual design phase. The HORUS3D (Horowitz Reactor Simulation Unified System) is a comprehensive neutronics and thermal-hydraulics package dedicated to JHR studies.

It is based on the APOLLO2 and CRONOS2 codes for neutronics, the APOLLO2, TRIPOLI4 and PEPIN2 of DARWIN package for nuclear and photonic heating calculations, and the FLICA 4 and CATHARE code for core thermal-hydraulics and system modeling. Development and qualification of this package is a major undertaking of the CEA involving several specific experimental programs.

Substantial experience has been acquired with this set of tools, which is now being used to support facility and irradiation device design for the JHR project. It has also been applied successfully to other projects, some aspects of which are detailed in ref <7.>. In addition, a new set of codes and calculations resulting directly from this program is being implemented for core calculations and experiments at the OSIRIS reactor. The benefits are presented in ref <10.>.

Design and construction code for mechanical components

The CEA and AREVA, in its role as support contractor to the owner, launched the development of a new design and construction code called RCC-MX in 1998 to address the specific features of the research reactor. The objective was to have a code available for design and procurement of new JHR components, auxiliaries and irradiation devices. This code incorporates lessons learned from 60 years of French research reactor design and operation, complies with the most recent European standards, and is specific to several features of research reactors:

- use of low neutron capture material such as aluminum or zirconium alloys for reactor block components operating at low pressure and temperature;
- use of slender structures for the experimental device for operation under extremely severe pressure and temperature conditions;
- the presence of highly aggressive irradiation conditions, causing nuclear heating and neutron embrittlement of mechanical structures.

Existing nuclear design and construction codes could not be used because they do not address these specific features. A first draft of the code was issued in 2002, followed by two releases, one in 2005 for JHR component design and the other in 2008 for JHR component procurement.

Development of the code was a major undertaking:

- collection of irradiated material data and their updating via a materials characterization program focused primarily on irradiated material properties and aluminum and zirconium alloys;
- integration of lessons learned from design and construction of components for various research reactors, including valuable feedback from the refurbishment of the Cabri reactor;
- compliance with international standards to facilitate its use by foreign partners; and
- compliance with French regulations pertaining to nuclear pressure equipment.

4. Revival of the research reactor community

For the prime contractor, the biggest challenge was to rebuild the skills required to design and engineer a high-performance MTR more than 20 years after ORPHEE and 40 years after the OSIRIS project. Fortunately, AREVA TA continued to carry out a large number of major nuclear projects during this time, including more than 10 nuclear propulsion and test reactors in the last 12 years and other nuclear facilities, and has also been involved in major experimental facilities projects.

La Maâmora Centre, Morocco

Modern engineering tools and methods were developed, used and tailored to specific project requirements during this period. The performance of these tools and methods and the skills gained as a result were deciding factors in the company’s successful diversification beyond its historical base into the field of fusion (ITER and LMJ), the final assembly line of some

Airbuses, and a new metro line for Paris, the MF2000. TA was also involved in major refurbishment of French research reactors such as SILOE and RHF. For the CABRI new loop project currently undergoing commissioning, TA supplied the new test loop and the new reactor block. At the same time, AREVA TA teams worked as the leader of an international consortium on the Maâmora research centre in Morocco, housing a TRIGA II reactor. In addition, for its own needs as operator of the nuclear propulsion test reactors, TA refurbished the low-power AZUR reactor used for core qualifications and training.

To meet milestones for the JHR project, the strategy was to:

- build an integrated team to meet the challenges of high performance, new design, and new research reactor project;
- select experienced, skilled partners to supplement TA's skills;
- use methods and tools successfully demonstrated on other projects, to the extent possible;
- build the team around a core group of some 20 TA people skilled in research reactor engineering.

AREVA TA teams

Today, the team provides a wide range of skills – project management, design, procurement, construction and commissioning involving disciplines such as civil engineering, fluid systems, instrumentation and control, mechanical engineering, electrical engineering, materials behavior, and nuclear design and engineering (neutronics, thermal hydraulics, radiation protection, radiological consequences, safety analysis, operations, human factors, installation, ILS and configuration management) – and is fully operational at the Cadarache site. Key success factors are:

- a consortium that shares losses as well as gains;
- project management;
- synergistic skills within the team, including civil engineering skills from EDF, small reactor design and engineering skills from TA, and the construction skills of AREVA NP;
- the use of tools and a virtual mock-up to support engineering activities such as TA's PDM, based on the commercial Matrix program and the CAD system CATIA;
- synergies and cross-fertilization harvested from the design and engineering of nuclear propulsion reactors and research reactors;
- a substantial training program for both the owner and the prime contractor, with more than 350 people trained in features specific to research reactors provided by INSTN at TA's training center;
- early development by the CEA of computer codes, design and construction codes, and some key components.

5. Conclusion

The JHR project is on track, with major project milestones achieved and the groundwork laid for successful first criticality in early 2014 followed by the start of experimental irradiation. In addition to these achievements, the project is driving the revival of the research reactor community.

6. References

<1.> Sustaining Material Testing Capacity in France: From OSIRIS to JHR G. Bignan, D. Iracane, S. Loubière, C. Blandin CEA (France) IGORR 12 Conference - Beijing - October 2009.

<2.> Jules Horowitz Reactor Project: status and fuel licensing process" M.C. ANSELMET ET AL " RRFM 2009 Vienna (AUSTRIA)

<3.> "AMMON: an experimental program in the EOLE critical facility for the validation of the JHR neutron and photon HORUS3D calculation scheme" JC. KLEIN et al IGORR 12 Beijing (PRC)

<4.> Irradiation Facilities and examination Benches for implementing fuels programs in the future JHR Material Testing Reactor" D. PARRAT et al "IGORR 12 Beijing (PRC)

<5.> "Underwater NDE Systems in the JHR: Towards integration issues" G. LE GUILLOU et al IGORR 12 Beijing (PRC)

<6.> QUALIFICATION PROGRAM FOR THE RJH FUEL ELEMENTS M.-C. Anselmet (CEA, DEN, Cadarache) – P.-M. Lemoine (CEA, DEN, Saclay) – S. Brisson, G. Miras, (AREVA-TA) – France, E. Koonen, P. Benoit, P. Gouat, (SCK-CEN) – this conference

<7.> NEUTRONIC DESIGN OF SMALL REACTORS T. Bonaccorsi, M. Boyard, E. Lefevre, J. Piela, L. Chabert (AREVA TA) – France – This conference

<8.> VALIDATION OF STRUCTURAL DESIGN OF JHR FUEL ELEMENT L. Le Bourdonnec (AREVA NP), P. Lemoine, V. Marelle, M.-C. Anselmet (CEA), G. Miras, S. Brisson (AREVA TA) – France- This conference

<9.> Irradiation effects on 6061-T6 Aluminium alloy used for JHR Internal Structures B. Kapusta, J. Garnier, B. Maugard, L. Allais, P. Lemoine-CEA (France)

<10.> Validation and qualification of the ANUBIS scheme, Used for safety assessment and operation management of the OSIRIS reactor - O.Gueton,P.Sireta,C.Doderlein,C.D'Aletto,J.Di Salvo-CEA (France)

A SUSTAINABILITY ANALYSIS OF THE BRAZILIAN MULTIPURPOSE REACTOR PROJECT

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ABSTRACT

The project of a new research reactor in Brazil for radioisotope production, support of the nuclear energy program and scientific research has received a positive sign of the government and is starting to be developed by the Brazilian Commission of Nuclear Energy. International Atomic Energy Agency points out that the implementation of a new research reactor is a major undertaking for a country, requiring an analysis to identify to which extent the conditions of the national nuclear program are proper and adequate to lead to a sustainable research reactor life cycle. This paper introduces the Brazilian Multipurpose Reactor Project (RMB) and describes the sustainability analysis performed, which has shown that the national nuclear infrastructure presents a very favourable condition to the implementation of the RMB project as well as to provide a sustainable life cycle for this new research reactor.

1. Introduction

Brazil has four research reactors (RR) in operation: the IEA-R1, a 5 MW pool type RR; the IPR-R1, a 100 kW TRIGA Mark I type RR; the ARGONAUTA, a 500 W Argonaut type RR – all constructed during the 50´s and 60´s and utilized for training, teaching and nuclear research – and a 100W nationally developed critical facility constructed in the 80´s, mainly for the development and qualification of reactor physics. All these RRs are operated by the Brazilian Commission of Nuclear Energy (CNEN) and have been fulfilling their mission along the last 50 years. However, IEA-R1 is the only one that has been used for radioisotope production, although with limited capacity. The international molybdenum 99 supply crisis is affecting significantly the Brazilian nuclear medicine services, since 100% of this radioisotope used to be imported from Canada. The recently revisited Brazilian Nuclear Program has decided for the conclusion of the third nuclear power plant (NPP), the construction of at least four more NPPs until 2030, as well as the establishment of a national capacity to supply all the fuel needed to operate the Brazilian NPPs. This new scenario of the nuclear activities in Brazil gave rise to the Brazilian Multipurpose Reactor Project (RMB), which is being developed by CNEN. According to the International Atomic Energy Agency (IAEA) many countries have built RRs without a clear understanding of their intended uses or needs. To countries intending to build new RRs, IAEA stresses the importance to perform an analysis, as a supporting tool to this strategic decision, to identify to which extent the national infrastructure provides the conditions to lead to a safe, secure, peaceful, efficient and sustainable RR life cycle. This paper introduces the RMB Project and describes a sustainability analysis based on nineteen infrastructure issues pointed out by IAEA.

2. The RMB Project

The RMB will be an open pool multipurpose research reactor, using low enriched uranium fuel, with a neutron flux higher than $2x10^{14}$ n/cm^2/s. Its power is still to be defined within the range of 20 to 50 MW. The RMB is designed to perform three main functions: radioisotope production (mainly molybdenum); fuel and material irradiation testing to support the Brazilian nuclear energy program; and provide neutron beams for scientific and applied research. Its site has already been selected, and the conceptual design is under development. The estimated cost is around USD 500,000,000 and its operation is scheduled to start in 2016. Figure 1 shows an overview of the RMB project scope.

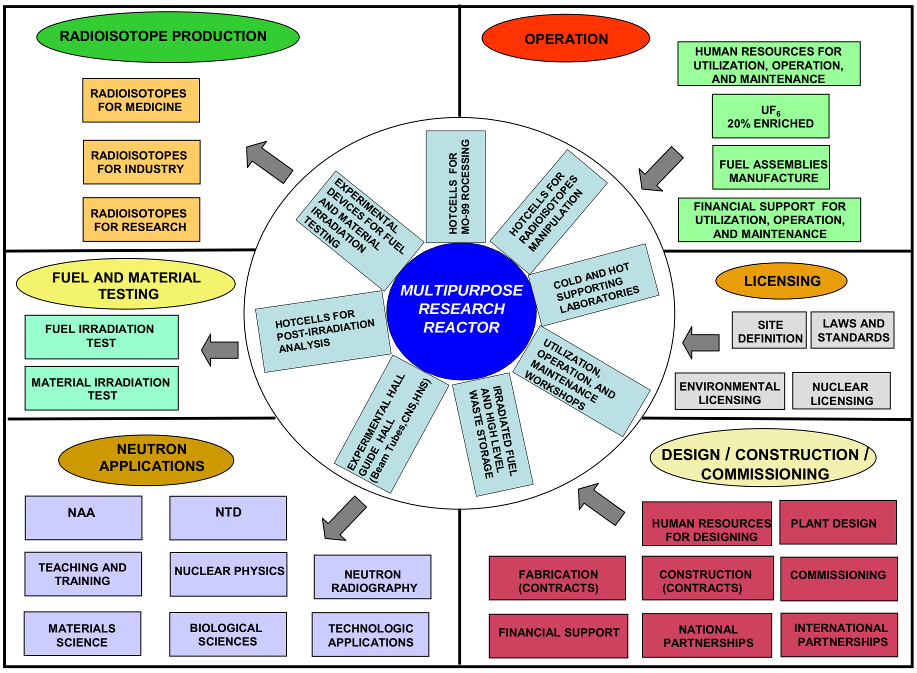

Fig 1. RMB project scope overview.

3. RMB Sustainability Analysis

The IAEA Nuclear Series NG-G3.1 [1] provides relevant information on the development of a national infrastructure for Nuclear Power. IAEA is now developing a similar document, which intends to provide a framework of milestones in the development of a national infrastructure for supporting a research reactor programme [2]. The sustainability analysis presented in this paper has been performed based on the 19 infrastructure issues suggested by IAEA considering the requirements related to reach Milestone 1 – Ready to Make a Knowledgeable Commitment to a RR Program [2]. Each requirement has been analysed based on the related existing national condition and has been considered as fulfilled ("OK"), under development ("UD") or to be developed ("TBD").

Issue 1: National Position

- *Nuclear research reactor program implementing organization (NRRPIO) established and staffed.* – The Brazilian Nuclear Energy Commission (CNEN) is the NRRPIO. A specific organizational structure has been defined for the RMB Project with a High Level Committee subordinated to the President of CNEN and an Executive Committee for implementing the Project. (**OK**)
- *Safety, security and non-proliferation needs recognized.* - These needs are completely recognized and are established by the Federal Constitution. (**OK**)
- *Appropriate international legal instruments identified*. - Brazil is an IAEA Member State and participates actively in the development of legal instruments. (**OK**)
- *Establishment of effectively independent regulatory body recognized.* - Brazil has an effectively independent regulatory body established. (**OK**)
- *Nuclear power inserted in nation's development strategy*. – Brazil has already two NPPs and four RRs in operation, and the nuclear programme is part of the 2030 National Energy Plan [3] and the 2007-2010 Science, Technology and Innovation Plan [4]. (**OK**)
- *Financial resources evaluated* - RMB will cost around USD 500,000,000, to be financed by the Brazilian government. (**OK**)

- *Supply of national and international components and services assessed.* - This supply still has to be assessed. It is expected around 70% of national supply. (**TBD**)
- *Transparent communication and interaction regarding the RR program established*. - A transparent communication regarding the RMB project is being implemented in all levels in the country and also to the international community. (**OK**)

Issue 2: Nuclear Safety

- *Recognized the need for relevance of nuclear safety.* - The relevance of nuclear safety is recognized for all nuclear activities performed in the country. (**OK**)
- *Recognized the need for cooperation in international partnerships*. - Brazil is an active member of IAEA, participating in many safety related cooperative projects. (**OK**)
- *Recognized the need for intergovernmental instruments on safety.* - Brazil is an IAEA Member State and adopts internally most of its safety principles and guides. (**OK**)
- *Recognized the need for support through international co-operation*. – Most of International co-operation support for the RMB Project has already been identified. (**OK**)

Issue 3: Management

- *Available nuclear technologies identified.* - Nuclear technology available internationally has been identified through similar RR projects. (**OK**)
- *Availability of long term financial resources analysed*. - The availability of the possible main sources for the long-term financial resources is under discussion. (**UD**)
- *Ownership options and operational responsibilities considered*. - CNEN is the responsible for the project implementation and for the future operation of the RMB. However, due to the radioisotope production activities there is a discussion on the possibility that a public company be created to be in charge of the RMB. (**TBD**)
- *Unique Member State conditions evaluated*. - The unique conditions of Brazil have been evaluated. (**OK**)

Issue 4: Funding and Financing Strategies Established

- *Initial infrastructure* - Brazil already has a comprehensive nuclear infrastructure with two NPPs in operation, one NPP under construction, four RRs in operation, eight nuclear research centres, and a supporting nuclear industry organization in the country. (**OK**)
- *Socio-political acceptance* - The RMB project has received good socio-political acceptance, especially for the fact that it consists on the strategic national long-term solution for the Mo-99 supply for medical application. (**OK**)
- *Creation or hiring expertise*. - RMB project is supposed to be developed through several partnerships with nuclear R&D institutes and universities. It is also seen as a main stream for renewing the aged experts still working in the nuclear field in country. (**UD**)
- *Creation of expertise for competent project management*. - CNEN has just implemented Project Management Offices and provided training on Project Management Institute good practices and on the application of specific project management software. (**UD**)
- *Creation of competent operating staff.* – Brazil has long experience in RR operation. The RMB operating staff is already under definition. However there is the need to hire personnel. (**TBD**)

Issue 5: Legal Framework

- *All the basic elements for the legal framework identified by NRRPIO and discussed with the other involved organizations.* - Brazil has a legal nuclear framework implemented since the 60’s. (**OK**)
- *Determination to develop and promulgate required laws indicated by Government*. - Brazil has a legal nuclear framework implemented since the 60’s. (**OK**)

Issue 6: Safeguards

- *Obligations under NPT and non-proliferation treaties, including SSAC establishment, recognized.* - Brazil has signed NPT, Tlatelolco, and is part of ABACC, having all nuclear installations and nuclear material under international safeguard control. (**OK**)
- *Implementation and enforcement of safeguards legislation planned.* - Brazil has signed NPT, Tlatelolco, and is part of ABACC. Additional safeguard protocol is under government discussion. (**OK**)

Issue 7: Regulatory Framework

- *Clear recognition of the need for a regulatory framework identified*. - Brazil has a regulatory framework implemented since the 60's. (**OK**)

Issue 8: Radiation Protection

- *Recognition of hazards presented by RR operation, and the need to enhance national laws and expand their safety infrastructures.* - Brazil develops nuclear fuel cycle activities, has two NPPs in operation and utilizes nuclear technology in medicine and industry. The importance of operational safety is completely recognized in the country, and there are laws and nuclear standards already established. (**OK**)
- *Radiation protection requirements and practices equivalent to those provided by the IAEA BSS and SS considered*. - Brazil develops nuclear fuel cycle activities, has two NPPs in operation and utilizes nuclear technology in medicine and industry. The importance of radiation protection is completely recognized, and there are laws and nuclear standards already established. (**OK**)

Issue 9: Application

- *Study by NRRPIO to determine the uses of the research reactor that will benefit the country*. - RMB will be used for radioisotope production (health program), for materials and fuel irradiation tests (nuclear energy and nuclear propulsion programs), and for neutron beams research (S&T program). Its social, technical and scientific benefits for the country are clear. Just as an example, about 1.3 million medical examinations use annually the Mo-99 imported and processed in Brazil. (**OK**)

Issue 10: Human Resources Development

- *Knowledge and skills needed to support a RR program identified by NRRPIO*. - Human resources profiles and quantities for RMB project and operation have been identified. The RMB project is seen as a major opportunity for renewing the aged experts still working in the nuclear field in country. (**OK)**
- *Plan to develop and maintain the human resource base developed*. - A specific group has been created to manage the RMB operation issues, mainly the needed operational staff. There is good expertise from the four RRs in operation in the country. (**UD**)

Issue 11: Stakeholder Involvement

- *Open and timely interaction and communication regarding the RR program addressed from the beginning*. - RMB project has been presented to its main stakeholders [CNEN, CTMSP (Navy), Eletronuclear (NPPs operator), INB (nuclear fuel cycle), SBBMN (nuclear medicine), Nuclear R&D Institutes] from the beginning. (**UD**)
- *Strong public information and education program initiated by Government and NRRPIO.* - CNEN and other institutions have been providing public information on RMB project. (**UD**)

Issue 12: Site and Supporting Facilities

- *General survey of potential sites, conducted by NRRPIO*. - Aramar Nuclear Experimental Centre, in Ipero, state of São Paulo, has been selected to be the RMB site. (**OK**)

Issue 13: Environmental Protection

- *Unique environmental issues analysed by NRRPIO.* - Environmental issues are part of the environmental licensing process imposed by federal laws. (**UD**)
- *Environmental impacts and improvements communicated*. - Environmental impacts and improvements are part of the environmental licensing process, which includes a public audience. (**UD**)

Issue 14: Emergency Planning

- *Need for emergency planning*. - Emergency planning is part of the nuclear licensing process in Brazil. (**UD**)
- *Communication with and involvement of local and national government taken into account*. - The São Paulo State Government is given full support to the Project, including funding. There is also an integrated national nuclear emergency plan due to the existing NPPs. (**OK**)

Issue 15: Security and Physical Protection

- *Requirements for security and physical protection acknowledged*. - Security and physical protection requirements are part of the nuclear licensing process, as well as of the project integrated management system. (**OK**)
- *Necessary legislation identified*. - Legislation already exists. (**OK**)

Issue 16: Nuclear Fuel Cycle

- *Knowledge of nuclear fuel cycle steps and approaches.* - Brazil has the domain of all nuclear fuel cycle steps. The establishment of a dedicated route for national fuel supply to the RMB is part of the project. (**OK**)
- *Need for site spent fuel storage recognized.* - RMB project includes site spent fuel storage installation. (**OK**)
- *Interim spent fuel storage considered*. - Brazil is discussing the design of an interim spent fuel storage that will consider RMB project. (**OK**)

Issue 17: Radioactive waste

- *The burdens of radioactive waste from RR recognized by NRRPIO*. - The burdens of radioactive waste are completely recognized by CNEN. (**OK**)
- *Current capabilities for waste disposal reviewed*. - RMB project includes installations for radioactive waste disposal. The country is planning to start construction of its low and intermediate level radioactive waste repository not later than 2013. (**OK**)
- *Options for ultimate disposal of high-level radioactive waste recognized*. – At present Brazilian policy do not consider spent fuel as high-level waste. A specific group has been created to manage the RMB decommissioning issues. (**TBD**)

Issue 18: Industrial Involvement

- *National policy with respect national and local industrial involvement considered*. - The national policy is to maximize the participation of national and local industries in the RMB project. (**OK**)
- *Strict application of quality programs for nuclear equipment and services recognized*. - Quality program for nuclear equipments and services is a requirement of the RMB project integrated management system. (**OK**)

Issue 19: Procurement

- *Unique requirements associated with purchasing nuclear equipment and services recognized by NRRPIO*. - The unique requirements of nuclear equipment and services are completely recognized by CNEN. (**OK**)
- *Consistent policies for nuclear procurement taken*. - Brazil has experience on the procurement of nuclear components and services. (**OK**)

4. Conclusion

The RMB sustainability analysis has demonstrated that from the 50 requirements analysed, the present Brazilian infrastructure fulfils 74%, is developing some actions on 18% and needs to start to develop actions on 8%. This leads to the conclusion that the present national context and the established nuclear infrastructure favour the implementation of the RMB project and provide conditions for a sustainable life cycle for this new research reactor.

5. References

[1] IAEA Nuclear Energy Series NG-G-3.1, Milestones in the Development of a National Infrastructure for Nuclear Power

[2] Milestones in the Development of a National Infrastructure for a Research Reactor Programme. International Atomic Energy Agency, Draft version, Vienna 2009.

[3] Plano Nacional de Energia 2030 (2030 Brazilian Energy Plan - in Portuguese). Empresa de Pesquisa Energética, 2007, in www.epe.gov.br/PNE.

[4] Science, Technology and Innovation for National Development. Action Plan 2007-2010. Summary Document. Ministry of Science and Technology, 2007, in www.mct.gov.br

VALIDATION OF STRUCTURAL DESIGN OF JHR FUEL ELEMENT

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ABSTRACT

The validation of the structural design of the Jules Horowitz Reactor fuel element was made by the Finite Element Method, starting from the Computer Aided Design. The JHR fuel element is a cylindrical assembly of three sectors composed of eight rolled fuel plates. A roll-swaging process is used to join the fuel plates to three aluminium stiffeners. The hydraulic gap between each plate is 1.95 mm. The JHR fuel assembly is fastened at both ends to the upper and lower endfittings by riveting.

The main stresses are essentially thermal loads, imposed on the fuel zone of the plates. These thermal loads result from the nuclear heat flux (W/cm^2). The mechanical loads are mainly hydraulic thrust forces. The average coolant velocity is 15 m/s. Seismic effects are also studied.

The fuel assembly is entirely modelled by thin shells. The model takes into account asymmetric thermal loads which often appear in Research Reactors. The mechanics of the fuel plates vary in function of the burn up. These mechanical properties are derived from the data sets used in the MAIA code, and the validity of the structure is demonstrable at throughout the life of the fuel.

Results concerning displacement are compared to functional criteria, while results concerning stress are compared to RCC-MX criteria. The results of this analysis show that the mechanical and geometrical integrity of the JHR fuel elements is respected for Operating Categories 1 and 2.

This paper presents the methodology of this demonstration for the results obtained.

1. Introduction

1.1 Qualification program for JHR elements

The fuel element is one of the major parts of the JHR project because it has to ensure the performances required for reactor operation and to guarantee the functional requirements. The aims of the qualification program are [1] [2] [3]:

- The validation of the fuel element design option to prove the required performances,
- The qualification of the manufacturing routes for plate fabrication and assembly,
- The qualification of the hydraulic behaviour,
- The qualification of the behaviour under irradiation [4] [5].

This paper focuses on the validation of the design option, i.e. the demonstration of the JHR fuel element's mechanical and geometrical integrity under Operating Categories 1 and 2.

1.2 Succinct geometrical description of JHR Fuel Element

The JHR Fuel Element is a cylindrical element, composed of a fuel section fitted with an endfitting at each extremity. The fuel section is constituted of an assembly of three sectors of 8 sizes of concentric plate (see figure 1). The plates are roll-swaged to three stiffeners which ensure the connection with the endfittings [6].

Fig. 1: JHR Fuel Element

Each plate consists of a fuel core in high density U_3Si_2 (4.8 g/cm^3) and of a boron insert in an AG3 frame, cladded by an AlFeNi cover-sheet.

The nominal thickness of the plates is 1.37 mm, i.e. 0.61 mm core fuel and 0.38 mm cladding. The plates are separated by a watergap of 1.95 mm (see figure 2).

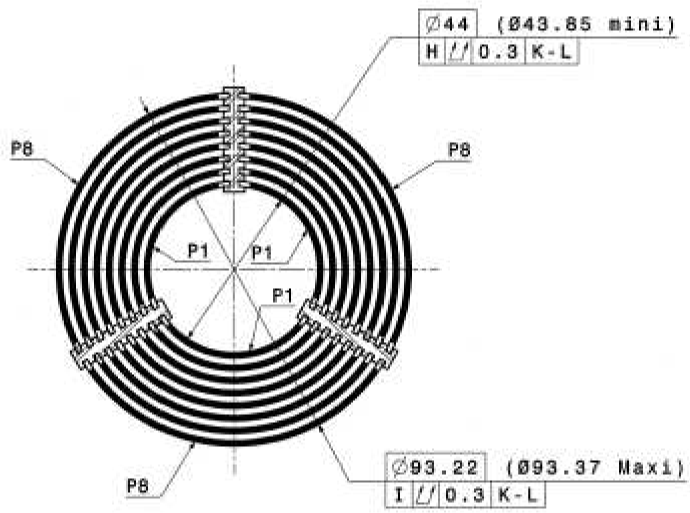

Fig 2: JHR fuel section

Endfittings are riveted to the fuel assembly. These endfittings provide interfaces permitting the positioning and locking of the Fuel Element to the reactor's internal structures.

2. Validation of the fuel element design

The purpose of this study is to perform the dimensioning of the RJH fuel element based on the results of the study of the fuel plates but without replacing it. This means that plate size is not addressed in this document. Instead the influence of the plates on the behaviour of the entire fuel element is studied by means of equivalent models.

- It can be considered that at the end of the Fuel Element's life cycle, the oxide layer on the core zone has a uniform thickness of 50 µm.
- The thermal conductivity of the "meat" at the end of the Fuel Element's life cycle is considered to be 10 W/m/K.
- The effects of the boron poison insert, colaminated at the end of the fuel plate, are ignored. The insert is considered to have the same mechanical characteristics as the AlFeNi.
- In the thin shell modelling, the fuel plate is considered to have the mechanical behaviour of the AlFeNi, i.e. the equivalent Young's modulus and Poisson's ratio are those of the AlFeNi. Thus, the fuel plate as a whole is considered to have the thermal mechanical behaviour of the AlFeNi, apart from thermal conductivity, which varies with the burn up and which is calculated by MAIA.

2.1 Operating categories

The fuel plates and elements are designed to guarantee three fundamental reactor safety functions:

- Confinement of radio-elements,
- Removal of decay heat,
- Control over reactivity

The functional requirements for the fuel element are as follows [7]:

Operating Categories	Fuel functional requirements
OC1 – Normal conditions	Cladding integrity
OC2 – Incidental conditions	Cladding integrity
OC3 – Emergency conditions	Several fusion possible though no fusion
OC4 – Faulty conditions	Fusion possible though limited

Table 1: Operating categories and associated functional requirement for the fuel

2.2 Ambient conditions

- The maximum burn up for a Fuel Element is 140 Equivalent Full Power Days and 169,900 MWd/tU, or 73% (2.21×10^{21} f/cm^3) for the maximum value of one plate.
- The average heat flow, without uncertainties, changes during operation or technological factors is 152 W/cm^2.
- The average wet temperature, considering uncertainties, operational changes in operations and technological factors, is 65°C.
- The maximum heat flux at the operating limit, all uncertainties and technological factors included, is 516 W/cm^2.

- The maximum wet temperature at the operating limit, all uncertainties included, is 165℃.
- The maximum coolant velocity is 16 m/s.

3. Meshing

3.1 2D meshing of the fuel assembly

First, a model of a one-third fuel assembly with symmetric conditions at the stiffeners is built with the finite element software I-DEAS, as presented in figure 3.

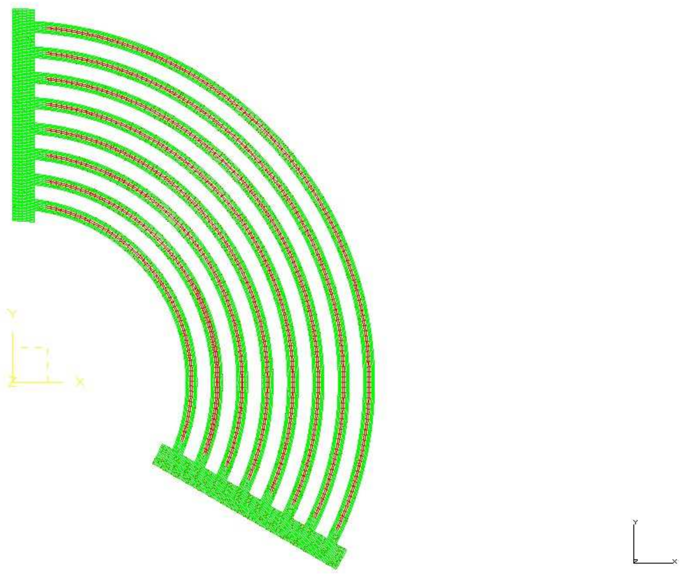

Fig. 3: 2D type meshing of a one-third fuel assembly

The elements are solid tetrahedral. The thickness of the elements is sufficiently reduced to consider this model as a representation of 2D-type phenomena. The introduction of this thickness is however necessary in the I-DEAS code, to set up the heat generation load in the fuel core.

3.2 3D meshing of the fuel assembly

To limit the size of the model (see figure 4), we choose shell elements which means:

- Using average thermal loads in the thickness of the fuel plates,
- Evaluating the equivalent mechanical characteristics of the fuel plates.

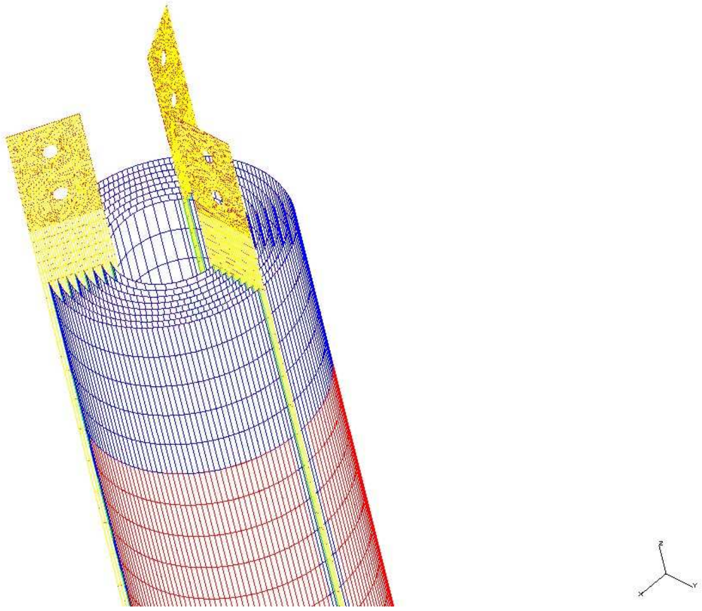

Fig. 4: 3D meshing of JHR fuel assembly

To model the links between the stiffeners and the tips, we need to represent the binding of the Fuel Element to its endfittings. The model of the fuel assembly is completed by three types of beam:

- Rigid beams installed in the holes of the stiffeners like bicycle spokes – the beams converge radially at the centre of the holes – to represent the transmission of forces to the neutral axis of the rivets,
- Solid round beams modelling the rivets,
- Very rigid beams representing the upper and lower endfittings.

3.3 3D meshing of the endfittings

The 3D model elements of:

- The upper endfitting (see figure 5)
- The lower endfitting (see figure 6)
- The upper endfitting lock (see figure 5)

are tetrahedral solid elements. Meshes are made directly from the geometry of the CAD drawing. This avoids input errors.

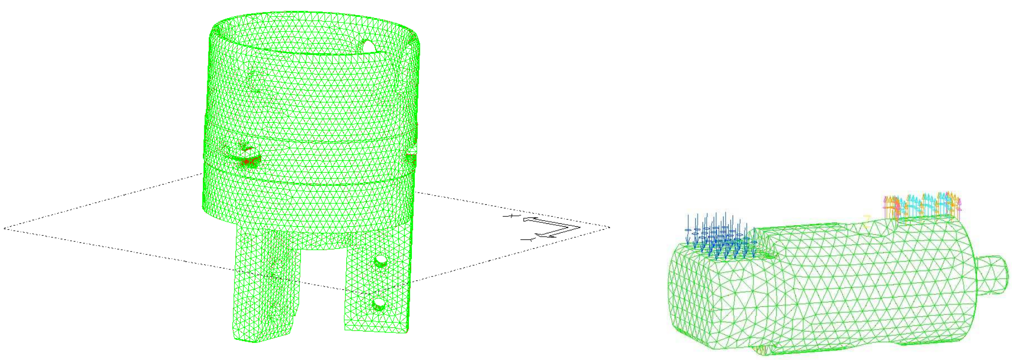

Figure 5: Tetrahedral meshing of the upper endfitting and its lock

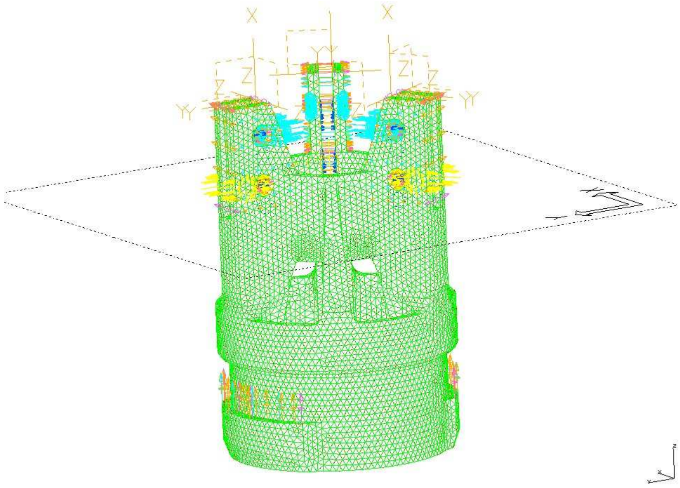

Figure 6: Tetrahedral meshing of the lower endfitting

4. MAIA / I-DEAS exchanges

MAIA calculations contribute to the validation of the structural design of the JHR fuel element. This contribution includes:

- Changes in the characteristics of the materials (thermal conductivity, mechanical properties of the fuel plates and exchange coefficients)
- The oxide layer kinetic law
- Displacement of the fuel plates due to swelling
- Consideration of the distribution of swelling in the fuel plates, which helps overcome the impact of this on the load of the stiffeners.

5. Loads

5.1 Thermal loads

The thermal loads of 2D-type calculations are as follows:

- Power density expressed in W/cm^3 in the core zone
- Coolant temperature
- Exchange coefficient.

We obtain a temperature gradient within the thickness of the fuel plate, which is used to calculate an average temperature, in order to apply a temperature loading imposed on the 3D shell model of the fuel assembly.

The results of the 2D-type calculation for the temperature of the stiffeners and the non-core zone of the fuel plate are also imposed on the 3D model of the full assembly.

These sets of imposed temperature are the thermal loads of the 3D model of the fuel assembly.

5.2 Mechanical loads

5.2.1 Mechanical loads on the rivets

The 6 rivets of the lower endfitting are solicited by the force of hydraulic pressure in Operating Categories 1 and 2. The 6 rivets of the upper tip are solicited in the event of failure of the first fuel element lock.

The force of the hydraulic pressure is evaluated at 4,400 N.

The stress applied to the rivets results from the combination of stress due to thermal expansion with the forces resulting from 3D assembly loads.

5.2.2 Mechanical loads on the endfittings

The most important primary mechanical force applied on the upper tip is the force of hydraulic pressure, i.e. 4400 N, applied to the mass of the endfitting receiving the lock. The resulting forces due to thermal expansion of the fuel plates are also applied to the holes for the rivets.

Similarly, for Operating Categories 1 and 2, a value of 4,400 N due to the force of hydraulic pressure is applied to the holes for the rivets of the lower endfitting, and added to the secondary forces resulting from thermal expansion of the fuel plates.

5.3 Seismic effects

5.3.1 In the horizontal direction

The fuel element is secured to the rack by the upper and lower grids. The rack is secured to the caisson (see figures 7, 8, 9).

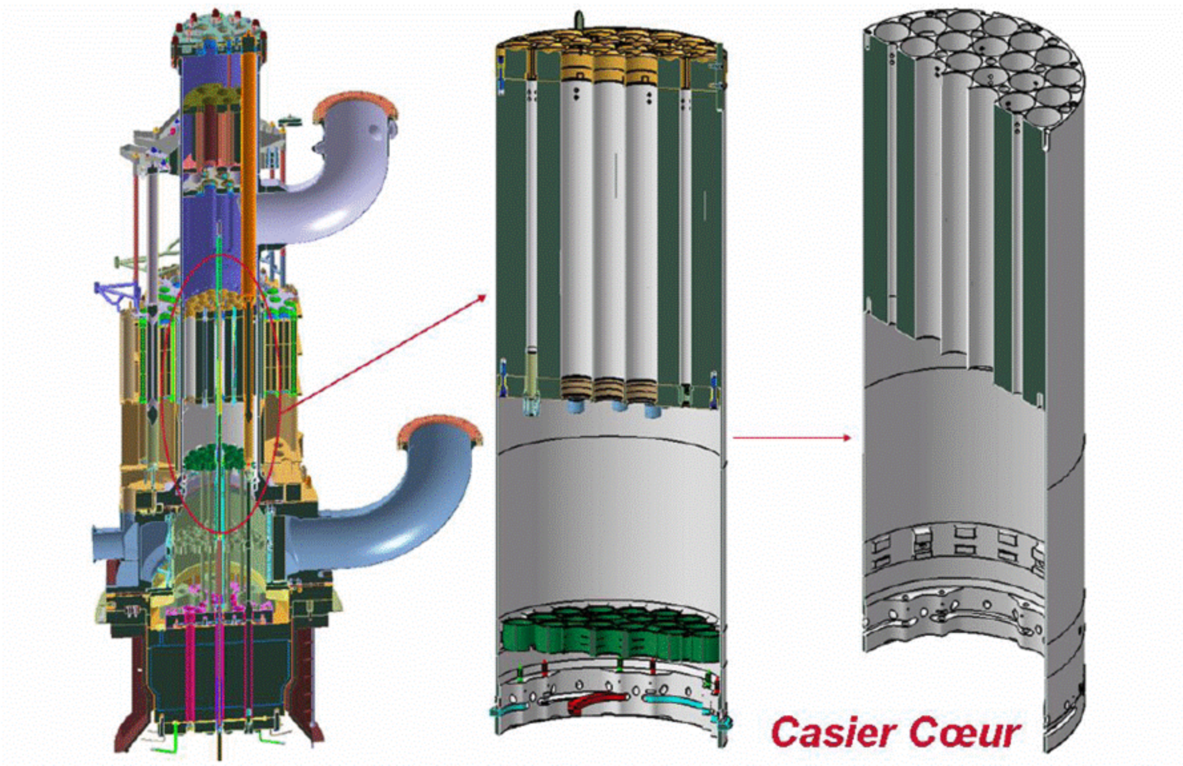

Figure 7: Design of the core-rack

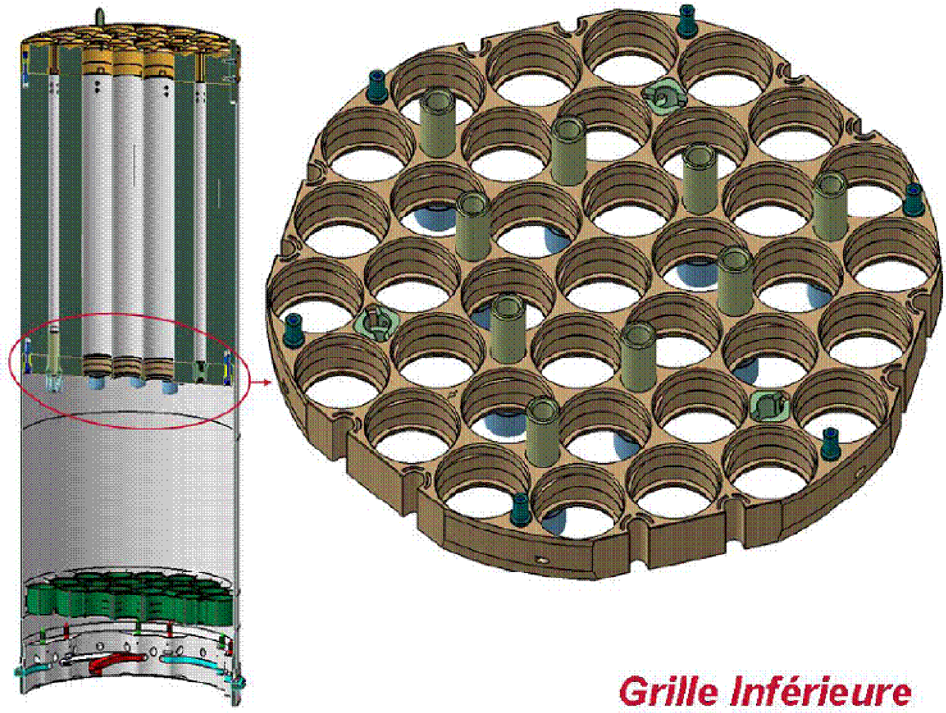

Figure 8: Design of the Lower Grid

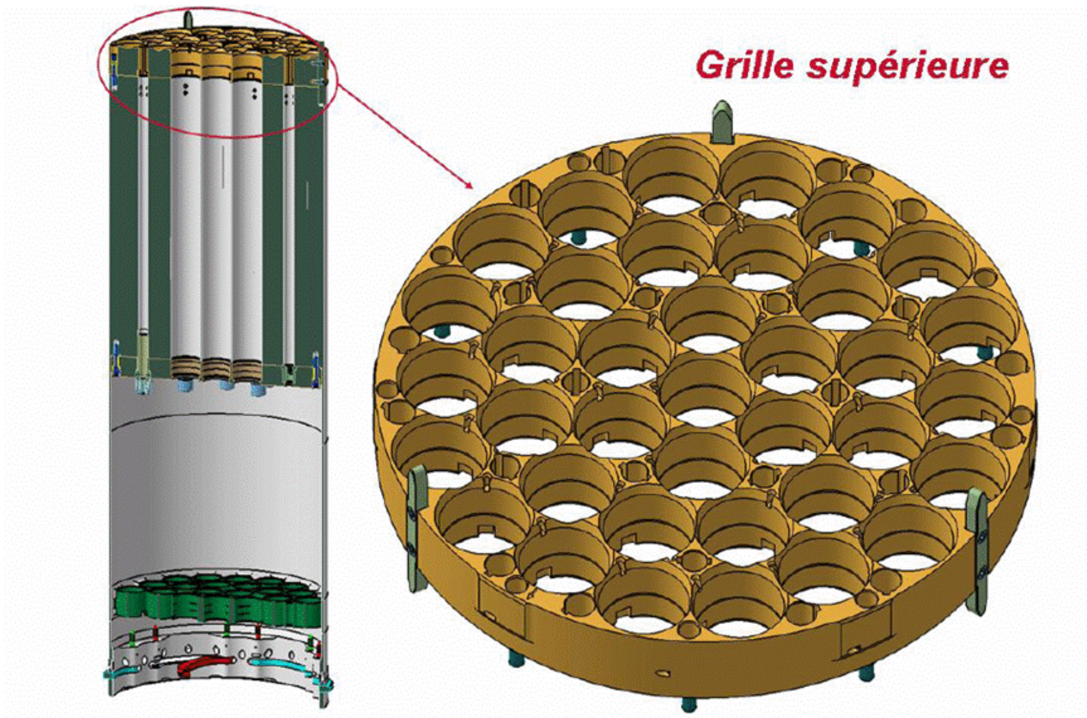

Figure 9: Design of the Upper Grid

The reactor building is placed on aseismic bearing pads. The horizontal and vertical spectra encountered by the Fuel Element are those of the floor's response to the earthquake.

The rack-caisson set with the 34 fuel elements has a rigid dynamic behaviour in the horizontal direction because of the effect of the seismic restraints. In the horizontal direction, the fuel element may be treated as a supported-supported beam. The first bending frequency is beyond the horizontal floor peak spectrum of 0.7 Hz (see figure 10).

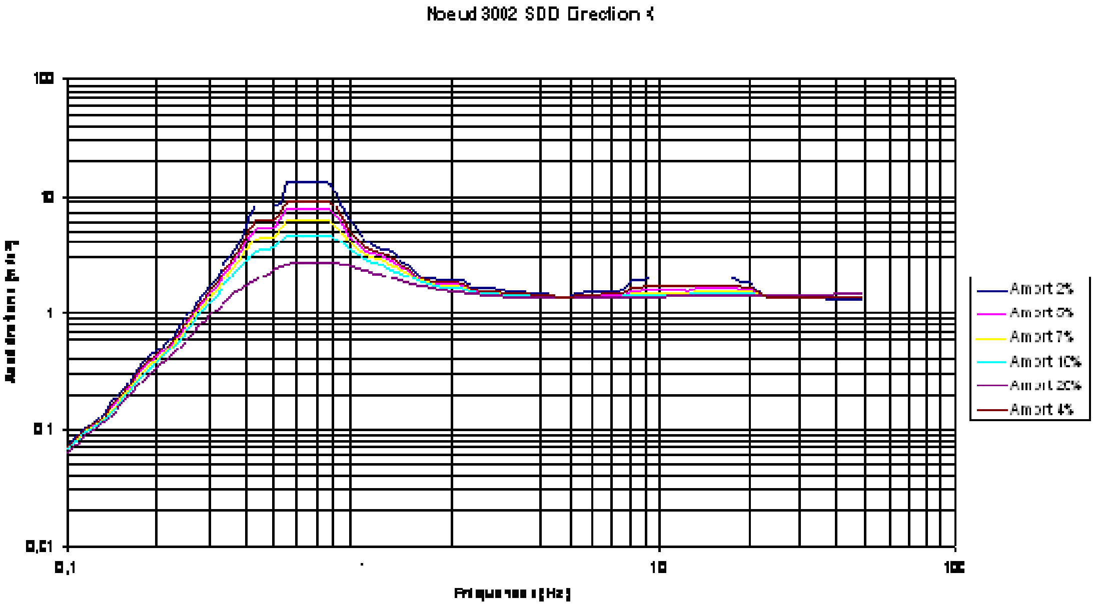

Figure 10: Floor response spectra (horizontal direction)

A horizontal acceleration of about 0.2 g is applied. So in operation, the horizontal seismic effect is negligible.

5.3.2 In the vertical direction

The fuel element is rigidly secured to the lower grid. This grid is linked to the rack. The fuel element – grid – rack set is considered to have a frequency above the vertical spectrum cutoff frequency (see figure 11).

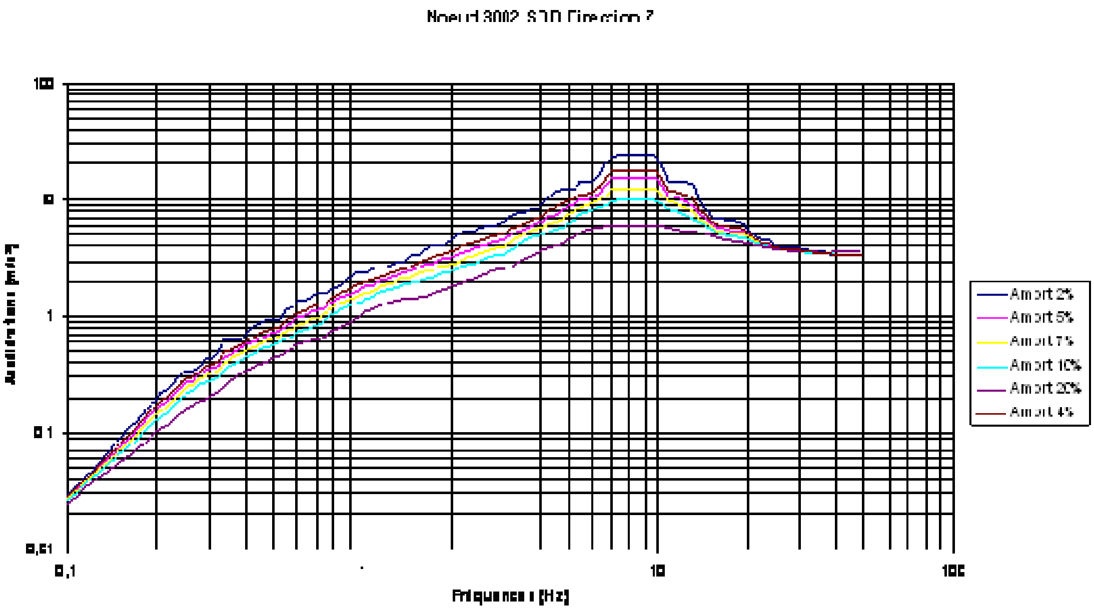

Figure 11: Floor response spectra (vertical direction)

A vertical acceleration of about 0.5 g is applied. So in operation, the vertical seismic effect and the weight effect are negligible with regard to the hydraulic thrust force.

5.3.3 Conclusion

The stresses induced by seismic effects are negligible with regard to the hydraulic thrust forces. They are not taken into account in the calculations for the validation of structural design in the JHR fuel element.

6. Results and criteria

6.1 Results of the 2D-type calculations

Thermal loads and results are summarized in Table 2.

Load set	Description	Stiffener temperature	Fuel zone temperature
OC1 set n°1	Maximal local power density at the start of the first cycle – symmetrical load	58°C	102°C
OC1 set n°2	Maximal local power density at the start of the first cycle – asymmetrical load	58°C	102°C on 2 fuel sectors 71°C on one fuel sector
OC1 set n°3	Maximal local power density at the end of the last cycle – symmetrical load	46°C	139°C
OC1 set n°4	Maximal local power density at the end of the last cycle – asymmetrical load	46°C	139°C on 2 fuel sectors 97°C on one fuel sector
OC2 set n°5	Overshoot at the start of the first cycle – symmetrical load	62°C	113°C
OC2 set n°6	Overshoot at the start of the first cycle – asymmetrical load	62°C	113°C on 2 fuel sectors 79°C on one fuel sector
OC2 set n°7	Overshoot at the end of the last cycle – symmetrical load	47°C	156°C
OC2 set n°8	Overshoot at the end of the last cycle – asymmetrical load	47°C	156°C on 2 fuel sectors 109°C on one fuel sector

Table 2: Results of 2D-type calculations

The asymmetrical loads on the three sectors of the fuel element are due to the neutron flux asymmetries existing in the core of the reactor (orientation of each Fuel Element relative to the others, presence of devices in the alveoli of the rack, partial reloading of used Fuel Elements).

6.2 Results of 3D calculations of the fuel assembly and associated criteria

The results of the calculations of overall Fuel Element distortion are analyzed to take this result into account in the geometric functional analysis of the reactor. Then the results concerning stress in the stiffeners are compared to the RCC-MX criteria.

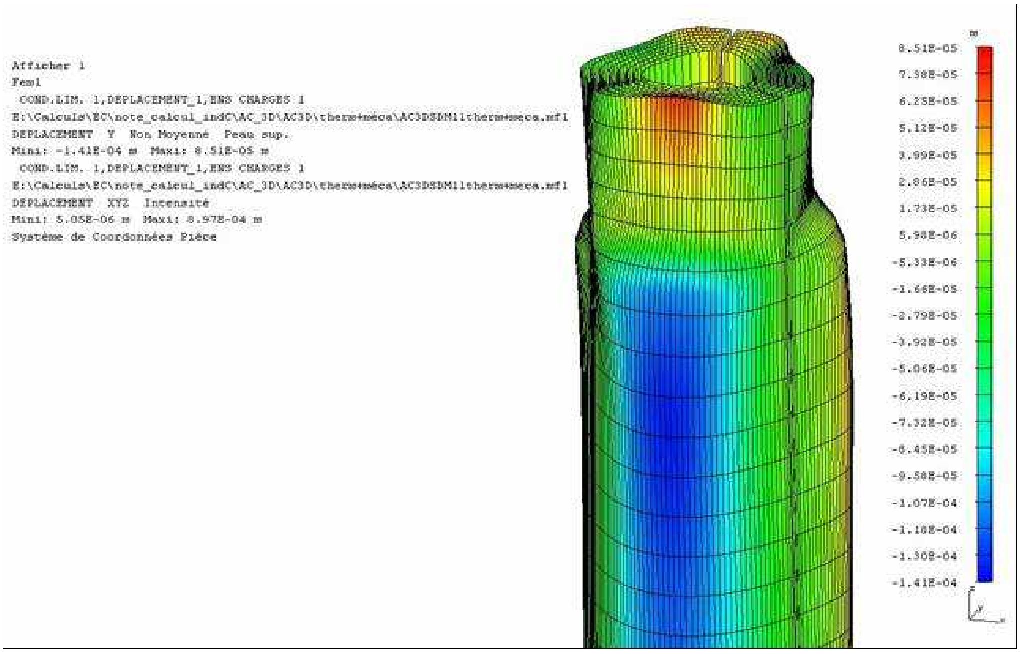

Figure 12: Example of the results of 3D symmetrical calculations

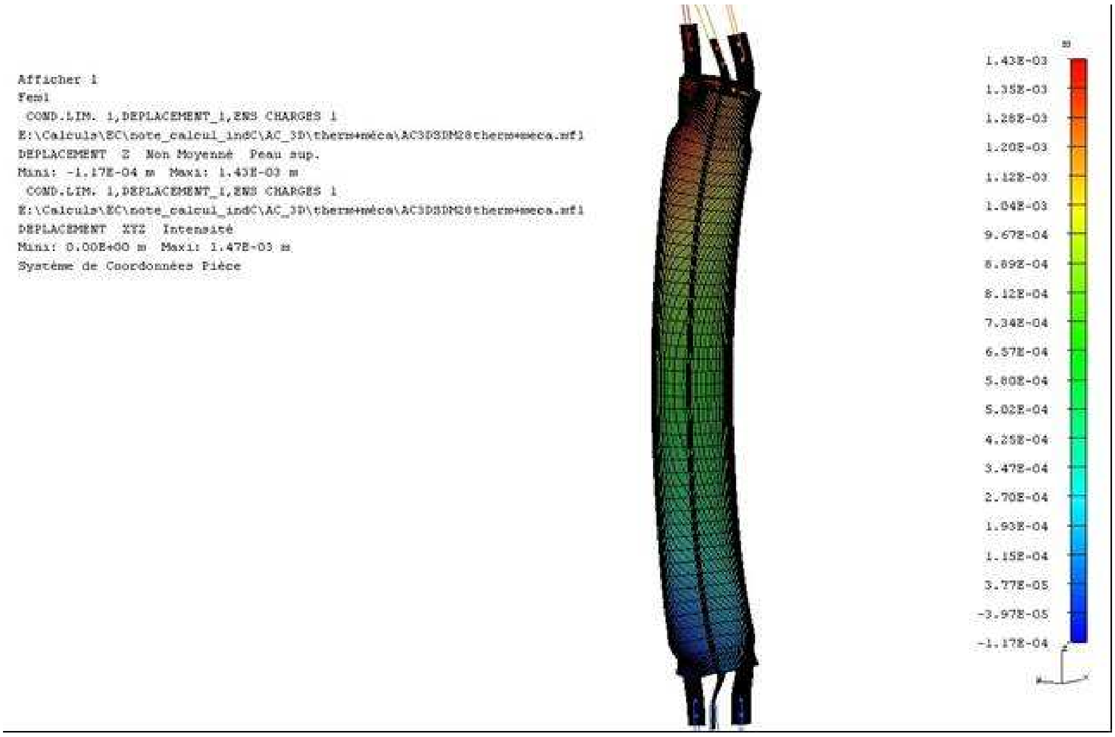

Figure 13: Example of results of 3D asymmetrical calculations

The selected results of fuel assembly 3D calculations are as follows:

- Radial deformation of plate 8 with regard to the functional condition of the cooling gap between plate 8 and rack
- Radial deformation of the stiffeners
- Maximum vertical deformation of the stiffeners.

These results are presented:

- As a graph for symmetrical loads between the sectors of the fuel plates
- As a table for asymmetrical loads between the sectors of the fuel plates. As the 3D geometry is distorted along the three axes, the significant result selected is that of maximum radial deformation.

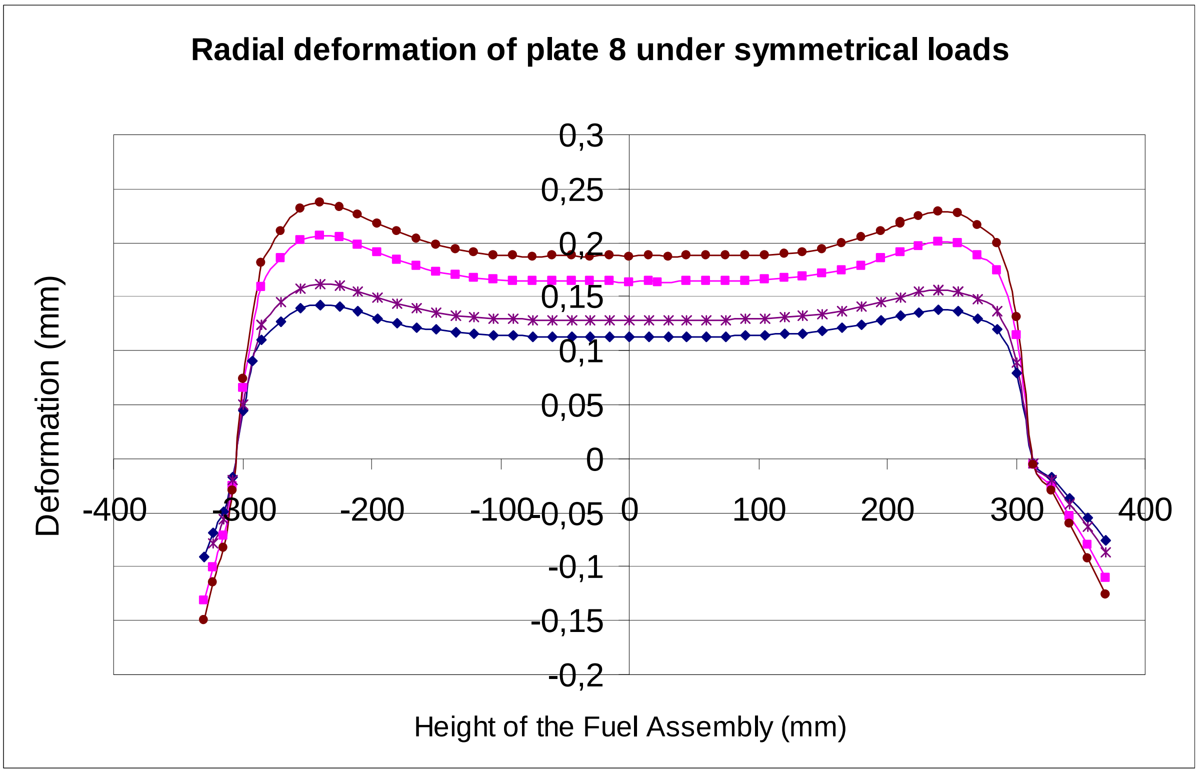

Figure 14: Radial deformation of plate 8 under symmetrical loads

Load sets	Maximum radial deformation of the most deformed plate 8 (mm)
OC1 set n°1	0,339 mm
OC1 set n°2	0,466 mm
OC2 set n°1	0,375 mm
OC2 set n°2	0,524 mm

Table 3: Maximum radial deformation of the most deformed plate

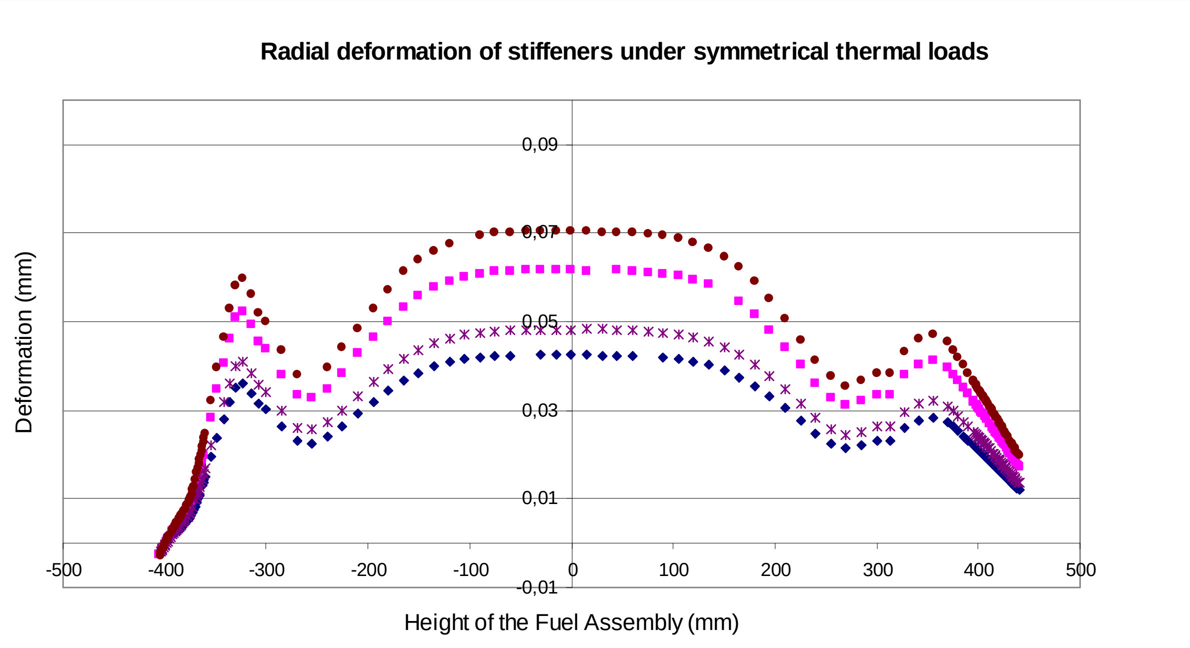

Figure 15: Radial deformation of stiffeners under symmetrical thermal loads

Load sets	Maximum radial deformation of the most deformed stiffener (mm)
OC1 set n°1	0,328 mm
OC1 set n°2	0,340 mm
OC2 set n°1	0,362 mm
OC2 set n°2	0,506 mm

Table 4: Maximum radial deformation of the most deformed stiffener

6.3 Results for stiffener stress

The field of analysis of the stiffeners is that of negligible irradiation. Although the fuel element is at the heart of neutron production, its life expectancy is short enough to fall short of the significant irradiation curve.

This is also true for the other substructures studied.

The maximum thermal flux encountered by the stiffeners is $2.36\text{x}10^{14}$ n_{th}/cm^2.

The maximum fluency encountered by the stiffeners is thus:

$$2.36\text{x}10^{14} \text{ x } 3{,}600 \text{ x } 24 \text{ x } 35 \text{ x } 4 = 2.85\text{x}10^{21}\ n_{th}/cm^2 < 28\text{x}10^{21}\ n_{th}/cm^2 \text{ at } 50°C$$

which is the limit for analysis as negligible irradiation.

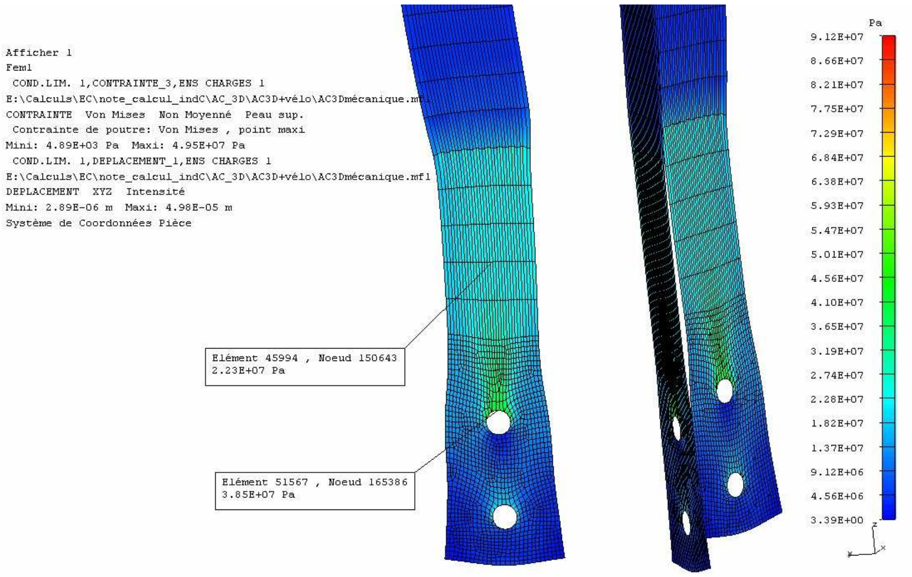

Figure 16: Results of Von Mises Stress calculation in the rivet holes of the stiffeners

Load set	Maximum Von Mises Stress in a stiffeners : at the rivet holes
OC1 set n°1 – symmetrical thermal load	31 MPa
OC1 set n°2 – asymmetrical thermal load	172 MPa
OC1 set n°3 – symmetrical thermal load	31 MPa
OC1 set n°4 – asymmetrical thermal load	235 MPa
OC2 set n°1 – symmetrical thermal load	37 MPa
OC2 set n°2 – asymmetrical thermal load	190 MPa
OC2 set n°3 – symmetrical thermal load	52 MPa
OC2 set n°4 – asymmetrical thermal load	264 MPa

Table 5: Results of Von Mises stress calculation in the rivet holes of the stiffeners

<u>Study of type P damage</u>

There is a maximum Von Mises stress of 23 MPa in the body of the stiffeners.
There is a maximum Von Mises stress of 49.5 MPa at the rivet holes.

The following criteria must be respected:

- P_m<S_m in the body of the stiffeners
- P_l<1.5 S_m at the rivet holes

The value of the S_m is 87 Pa from 20℃ to 75℃ for the type of alumini um used.

In the body of the stiffeners we find 23 MPa < 87 MPa.
At the rivet holes we find 49.5 MPa < 130 MPa.

The RCC-MX dimensioning criteria are respected for type P damage.

<u>Study of type S damage</u>

In the body of the stiffeners, secondary thermal stresses reach a maximum of 200 MPa.

The maximum primary stress in the body of the stiffeners is 49.5 MPa. Consequently:

Max (Pl+Pb) + ΔQ < 3 Sm
49.5 + 200 < 261 MPa

The only stresses over 200 MPa are very localised around the rivet holes, and can be considered as peak stress: the fatigue analysis appear below.

Fatigue analysis

The point of maximum load around the rivet holes displays a localised thermal stress of 264 MPa and a primary stress of 49.5 MPa. This gives a total of 313.5 MPa, to be considered as a peak stress.

$$\overline{\Delta\sigma_{tot}} = 313.5\, MPa$$

$$\overline{\Delta\varepsilon_1} = \frac{2}{3}\cdot(1+\nu)\cdot\frac{\overline{\Delta\sigma_{tot}}}{E}$$

according to the RCC-MX.

As the primary stresses are low (49.5 MPa) $\overline{\Delta\varepsilon_2} = 0$ is selected.

For the calculation of $\overline{\Delta\varepsilon_3}$ the RCC-MX indicates:

If $\overline{\Delta\varepsilon_i}$ is not known, an increase factor of $\overline{\Delta\varepsilon_1} + \overline{\Delta\varepsilon_2} + \overline{\Delta\varepsilon_3}$ is obtained by supposing that $\overline{\Delta\varepsilon_i}$ =0.

Thus

$$\overline{\Delta\varepsilon_{fic}} = \sqrt{\frac{2}{3}\cdot\frac{1+\nu}{E}\cdot\overline{\Delta\sigma_{tot}}\cdot\overline{\Delta\varepsilon_1}} = \overline{\Delta\varepsilon_1}$$

So

$$\overline{\Delta\varepsilon_1} + \overline{\Delta\varepsilon_2} + \overline{\Delta\varepsilon_3} = K_\varepsilon \cdot \overline{\Delta\varepsilon_1}$$

$$\overline{\Delta\varepsilon_4} = (K_\nu - 1)\cdot\overline{\Delta\varepsilon_1}$$

And therefore

$$\overline{\Delta\varepsilon_1} + \overline{\Delta\varepsilon_2} + \overline{\Delta\varepsilon_3} + \overline{\Delta\varepsilon_4} = (K_\varepsilon + K_\nu - 1)\cdot\overline{\Delta\varepsilon_1}$$

$$\overline{\Delta\varepsilon} = \overline{\Delta\varepsilon_1} + \overline{\Delta\varepsilon_2} + \overline{\Delta\varepsilon_3} + \overline{\Delta\varepsilon_4} = \frac{2}{3}\cdot(1+\nu)\cdot\frac{\overline{\Delta\sigma_{tot}}}{E}\cdot(K_\varepsilon + K_\nu - 1)$$

For the type of aluminium used, at 94℃:

$\nu = 0,33$

E=72500 Mpa

$K\varepsilon = 1,002$

$K\nu = 1,001$

$\overline{\Delta\varepsilon}$ =0,386%

The corresponding number of admissible cycles is about 2,225.

As the actual number of cycles is 100, fatigue damage is calculated thus:

$$V_A(\Delta_\varepsilon) = \frac{100}{2225} = 0{,}045$$

Conclusion: The stiffeners do not suffer fatigue damage.

6.4 Stress on rivets

The combined effects of hydraulic force and stiffener expansion on the most heavily loaded rivet are:

- Vertical shear force at the two stiffener / endfitting interfaces
- The hydraulic force of 4,400 N distributed over the 6 rivets

The results of the 3D dimensioning calculation are added, i.e. about 8,000 N.

The equivalent Von Mises stress is:

$$VM = \sqrt{\sigma^2 + 3 \cdot \tau^2} = \sqrt{68^2 + 3 \cdot 153^2} = 274\ MPa$$

For a titanium rivet where :

R_m=897 Mpa

S_m=R_m/3=299 Mpa

the following inequation must be respected:

$$VM = 274 MPa \leq S_m = 299 MPa\ .$$

This is the case.

6.5 Stress results in the other substructures of the Fuel Element

The field of analysis of these substructures is that of negligible irradiation. Only the stress results are compared to the RCC-MX criteria.

6.5.1 Upper endfitting

Operating Categories 1 and 2

The upper endfitting is only subject to a thermal load due to its own expansion and the force applied via the rivets by stiffener expansion. As the upper endfitting is not weaker than the stiffener and has no supporting function, this load can be considered as secondary.

For symmetrical loads the maximum stress, around 33 MPa, is much less than the RCC-MX criteria of $3S_m$ (6061-T6 at 50℃) = 261 MPa.

For asymmetrical loads stress within the structure remain less than, or equal to, $3S_m$ = 261 MPa, with the exception of one tiny red point which can be considered as insignificant because the secondary stress will naturally be distributed around this point.

SLR Operating Category

The operating category known as SLR (Situation de Limitation du Risque: risk limitation situation) is analyzed as a level 4 Operating Category, since the load is constituted only by the forces due to hydraulic pressure. In this category, only the primary stresses are analyzed, since there is no risk of buckling for this structure which is not at all slender and the thermal load can thus be ignored.

The structure attains a very localised maximum of 395 MPa which falls very rapidly away from this point. In manufacturing, the sharp edges will be attenuated.

A supporting line segment sketched on the structure and passing through the point gives the following stress:

$$\overline{P_m} = 112 MPa \leq Inf\left(2{,}4 \cdot S_m ; 0{,}7 \cdot R_m ; 2 A à 50°C\right) = 182 MPa$$

$$\overline{P_m + P_b} = 191 MPa \leq 1{,}5 \cdot Inf\left(2{,}4 \cdot S_m ; 0{,}7 \cdot R_m ; 2 A à 50°C\right) = 273 MPa .$$

Conclusion:

The inequations are respected. The upper endfitting is sufficiently well-dimensioned for all reactor Operating Categories.

6.5.2 Upper endfitting lock

The lock is only under load in the SLR Category, in the event of flange rupture on the lower endfitting. On this totally primary load the maximum stress within the lock reaches 902 MPa.

One RCC-MX material capable of resisting this load is the stainless steel of type X6NiCrTiMoVB-25-15-2 used for fastenings.

As this material is very hard, the membrane breaking limit must not be exceeded and the Category 4 fastenings criteria for membrane plus bending stresses must be applied. In the event of rupture of one of the flanges we obtain:

$$\overline{\sigma_m + \sigma_b} = 902 MPa \approx \left(R_m\right)_{\min} = 886 MPa \text{ (10S at 50°C)}$$

Although the limit is exceeded by 1.5 %, this is not significant considering the precision of the calculations and the loads, and the following must be considered:

- Flange rupture without lock rupture is already hypothetical, since the dimensions of the flange are calculated. Rupture of the flange is thus a Category 4 event and, as the system is not sealed, level 4 criteria are appropriate. As the effort is distributed over the two locks, it is reduced by half, and the above inequation is thus satisfied with a margin close to 50%. The event of simultaneous rupture of flange and one lock is thus beyond level 4, and so it is admissible that the level of stress be at the extreme limit.
- According to the RCC-MX, it is possible to use for the lock steel of group 10S with a higher R_m, of up to 1150 MPa.

6.5.3 Lower endfitting

Study of type P damage

The structure as a whole encounters only weak stress. Neither membrane stress nor membrane plus bending stresses need be considered. The structure attains a maximum of 68 MPa localized at the flange, which can be considered as a local primary membrane stress.

The following inequation is respected:

$$\overline{P_l} = 68MPa \leq 1{,}5 \cdot S_m\left(2A\ at\ 50°C\right) = 1{,}5 \cdot 87 = 130MPa\,.$$

Study of type S damage

Two types of thermal load must be considered in addition to the loads due to hydraulic pressure.

- Symmetrical loads :

The sum of primary and secondary stress attains a maximum of 109 MPa, and the following inequation is respected:

$$\overline{P_l + P_b + \Delta Q} = 109MPa \leq 3 \cdot S_m(2Aà50°C) = 261MPa$$

Conclusion: There is no risk of progressive deformation.

- Asymmetrical loads :

Over almost all the structure the sum of primary and secondary stress is less than $3S_m$ = 261 MPa, except for one very localised point where the stress can be considered as a peak, analyzed only as fatigue.

There is thus no risk of progressive deformation. The peak stress is analyzed below as fatigue.

Fatigue analysis:

At the point of maximum load, the flange, peak stress reaches $\overline{\Delta\sigma_{tot}} = 440$ MPa and analysis at 50℃ gives the following:

$$\overline{\Delta\varepsilon} = \frac{2}{3} \cdot \left(1+\nu\right) \cdot \frac{\overline{\Delta\sigma_{tot}}}{E} \cdot \left(K_\varepsilon + K_\nu - 1\right)$$

where:
$\nu = 0.33$
$\overline{\Delta\sigma_{tot}} = 440MPa$
E=74000 Mpa

According to RCC-MX:
$K_\varepsilon = 1{,}026$

$K_v = 1{,}012$

Thus:

$$\overline{\Delta\varepsilon} = 0{,}55\%$$

According to RCC-MX, the corresponding number of admissible cycles is 706.

This is a conservative analysis, since the most severe thermal loads are applied to each cycle.

As the real life of the Fuel Element is of 100 cycles, fatigue damage V respects the following inequation:

$$V_A\left(\overline{\Delta\varepsilon}\right) = \frac{n}{N_{adm}} = \frac{100}{706} = 0{,}14 \leq 1$$

In conformity with RCC-MX, fatigue resistance is thus satisfactory.

7. Conclusion

MAIA, with its more mechanistic modelling, proved to be the ideal support for the simplified modelling of I-DEAS.

RCC-MX criteria are respected for stress in the upper endfitting, the upper endfitting lock, the lower endfitting, the rivets and the stiffeners.

The deformation results are taken into account for geometrical functional analysis of the reactor, in particular:

- The maximum radial displacement of plate 8 (0.6 mm)
- The maximal vertical displacement of the fuel element in operation (1.5 mm)

so as to respect the minimum coolant gap, and the assembly clearances necessary for assembly and operation.

8. References

[1] – MC. Anselmet, P. Lemoine, D. Iracane, E. Koonen, P. Benoit, I. Cailliere, P. Colomb, T. Pin, S. Brisson, S. Guillot, Qualification program for JHR fuel elements
RRFM 2009, Vienna, Austria, 22-25 March 2009

[2] – MC. Anselmet, P. Lemoine, E. Koonen, Ph. Benoit, Ph. Gouat, G. Miras, S. Brisson, Qualification program for the RJH fuel elements, this meeting

[3] – P. Lemoine, MC. Anselmet, E. Koonen, Ph. Benoit, Ph. Gouat, G. Miras, S. Brisson, Qualification of the BR2-EVITA loop and irradiation of the first JHR lead test assembly, RERTR 2009, Beijing, China, 1-5 November 2009

[4] – MC. Anselmet, P. Lemoine, E. Koonen, P. Benoit, P. Gouat, W. Claes, F. Geens, G. Miras, S. Brisson, Qualification program for JHR fuel elements: Irradiation of the firste JHR test assembly in the BR2-EVITA loop, this meeting

[5] – E. Koonen, Ph. Gouat, Ph. Benoit, V. Kuzminov, P. Lemoine, MC. Anselmet, S. Brisson, S. Guillot, EVITA : a semi-open loop in BR2 for RJH fuel qualification
RRFM 2009, Vienna, Austria, 22-25 March 2009

[6] – I. Cailliere, P. Colomb, MC. Anselmet, P. Lemoine, F. Joppen, P. Benoit, E. Koonen, S. Brisson, S. Guillot, LTA's Manufacturing for JHR fuel qualification program in BR2 reactor, RRFM 2009, Vienna, Austria, 22-25 March 2009

[7] – MC. Anselmet, G. Bignan, D. Iracane, P. Lemoine, B. Maugard, P. Tremodeux
Jules Horowitz Reactor Project: Status and fuel licensing project
RRFM 2009, Vienna, Austria, 22-25 March 2009

SAFETY INFRASTRUCTURE FOR COUNTRIES ESTABLISHING THEIR FIRST RESEARCH REACTOR

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ABSTRACT

Establishment of a research reactor is a major project requiring careful planning, preparation, implementation, and investment in time and human resources. The implementation of such a project requires establishment of sustainable infrastructures, including legal and regulatory, safety, technical, and economic. An analysis of the needs for a new research reactor facility should be performed including the development of a utilization plan and evaluation of site availability and suitability. All these elements should be covered by a feasibility study of the project. This paper discusses the elements of such a study with the main focus on the specific activities and steps for developing the necessary safety infrastructure. Progressive involvement of the main organizations in the project, and application of the IAEA Code of Conduct on the Safety of Research Reactors and IAEA Safety Standards in different phases of the project are presented and discussed.

1. Introduction

For more than 60 years, research reactors (RRs) have been a corner stone in the development and application of nuclear science and technology. The multi-disciplinary research that RRs can support has led to the development of numerous capacities in a wide variety of areas including nuclear power, radioisotope production for medical and industrial applications, neutron beam research, material development, and personnel training. In addition, some countries considered RRs an important step for the development of nuclear power reactors. Recently a number of countries have started planning to build their first RR as a tool to develop the necessary national infrastructure in the view of embarking on a nuclear power programme.

The introduction of the first RR in a country requires establishment of national sustainable infrastructures which cover a wide range of areas. These include legal and regulatory framework, siting, transport of equipment and supplies to the site, facilities for fuel handling and radioactive waste management, emergency preparedness, and facilities associated with the reactor applications as well as the human and financial resources necessary to implement the project and to ensure sustainable safe, secure, and efficient operation. In order to ensure establishment of the infrastructure elements, several activities should be completed during different phases of a RR project. The main characteristics of these phases are discussed in the following sections together with the elements of the nuclear safety infrastructure, and major safety activities that should be completed in different phases of the first RR project in a country.

2. Research Reactor Project Phases

The INSAG-22 report [1] establishes five phases for the development of a national safety infrastructure for a nuclear power programme. In line with the IAEA publication NG-G-3.1 [2], the first three phases cover the period from the point of initial consideration of embarking on a nuclear power programme to the point at which a country is ready to commission and operate the first nuclear power plant. Phases 4 and 5 are concerned with the operation and decommissioning stages, respectively. The same approach is adopted for the establishment of the first RR and necessary safety infrastructure. Figure 1 presents the initial three phases of the first RR project and the associated milestones. Phases 4 and 5 are not discussed in the present work.

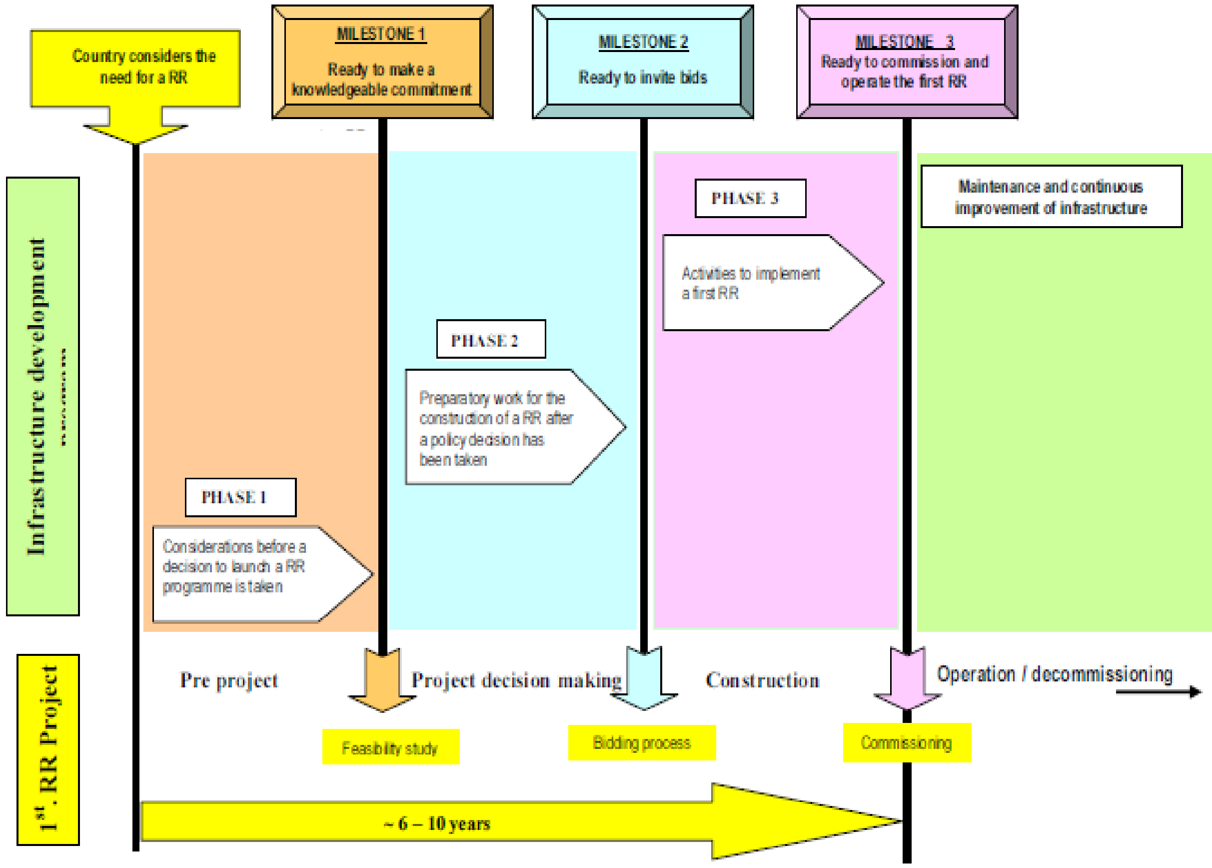

Figure 1: Phases of implementation of the first RR project

Phase 1 is related to the pre-project activities which cover all considerations before a decision to lunch a RR programme is taken. These considerations are consolidated in a form of a feasibility study showing the needs (or not) for a RR. Such a study is the main deliverable of this phase and based on its results, a country should be ready to make a knowledgeable commitment to proceed (or not) with the introduction of the first RR (Milestone 1). The activities of Phase 2 cover the preparatory work for the reactor construction, including the establishment of the legal framework, regulatory body, and operating organization which should be able to select the preferred site for the reactor, develop the bid technical specifications, and be ready at the end of this phase to invite bids (Milestone 2). During Phase 3 the activities for implementing the RR project should be completed, including finalization of the design and construction stages with the relevant licensing activities. By the end of Phase 3 the RR should be ready for commissioning (Milestone 3).

Experience has shown that the duration of implementing the activities corresponding to these three phases may be up to approximately ten years, depending upon the existing infrastructure at the beginning of the project and resources available for the project. The duration also depends on the reactor type, size, intended utilization programme, and contract methodology (i.e. turn-key or contracts with different levels of national participation), and may be reduced significantly in the case of low power RRs dedicated to education and training. Similarly, a graded approach may be used in the implementation of the activities of different phases. While all the safety requirements associated with these activities should be considered, their application may be graded based on the potential hazard of the reactor.

3- Elements of nuclear safety infrastructure

The nuclear safety infrastructure is defined as the set of institutional, organizational and technical elements and conditions established to provide a sound foundation for ensuring a sustainable high level of nuclear safety [1]. The establishment of this infrastructure should start early in the process of developing the RR through effective application of the provisions of the IAEA Code of Conduct on the Safety of Research Reactors [3], and by making use of the IAEA Safety Standards. This is to ensure that relevant activities are conducted in a safe manner during different stages of the reactor lifetime, which cover siting, design, procurement and construction, commissioning, operation, utilization and decommissioning. According to the structure of the IAEA Safety Standards, the elements of the nuclear safety infrastructure can be defined as presented in Table 1, which also indicates references to the IAEA main Safety Standards which support the establishment of the infrastructure elements.

Table 1: Elements of the safety infrastructure with the corresponding

IAEA main supporting Safety Standards

Elements of the safety infrastructure	
National policy and strategy [4]	Radiation protection [4,7]
Global nuclear safety regime [4,5]	Safety assessment [4,8]
Legal framework [4,5]	Safety of radioactive waste, spent fuel management and decommissioning [4,9]
Regulatory framework [4,5]	Emergency preparedness and response [10]
Transparency and openness [4]	Operating organization [4]
Funding and financing [4]	Site survey, selection and evaluation [4,11]
External support organization and contractors [4]	Design safety [4]
Leadership and management of safety [4, 6]	Preparation for commissioning [4]
Human resources development [4, 6]	Transport safety [12]
Research on safety for regulatory process [6]	Interfaces with nuclear security

The level of application of the IAEA Safety Standards and involvement of the government and other organizations will normally increase progressively during the different phases of developing a RR programme. While all the activities of Phase 1 are performed by the government, the operating organization and regulatory body (being established at the beginning of Phase 2) are responsible to implement the activities corresponding to this phase. The involvement of these organizations will increase gradually along Phase 2. However, the level of involvement of the regulatory body will be relatively higher due to its responsibility for establishing the safety requirements for different activities beforehand. The involvement of the operating organization, which has the prime responsibility on safety, will increase along Phase 3. The involvement of the government will be reduced significantly during Phases 2 and 3, and will include mainly support of maintenance and improvement of some infrastructure elements such as national policy and strategy, global nuclear safety regime, legal and regulatory framework, funding and financing, safety management, emergency preparedness and radioactive waste management including decommissioning.

4- Major safety activities in the different phases of building the first RR

The major safety activities in the different phases of building the first RR in a country are presented in Figure 2. The IAEA Safety Standards establish the safety requirements for the implementation of these activities and should be applied progressively during the different phases of building a RR. Figure 2 also indicates the required level of application of the IAEA Safety Standards (i.e. awareness of the requirements, requirements under implementation, and requirements fully implemented). Detailed discussions of these activities are presented in the following sections.

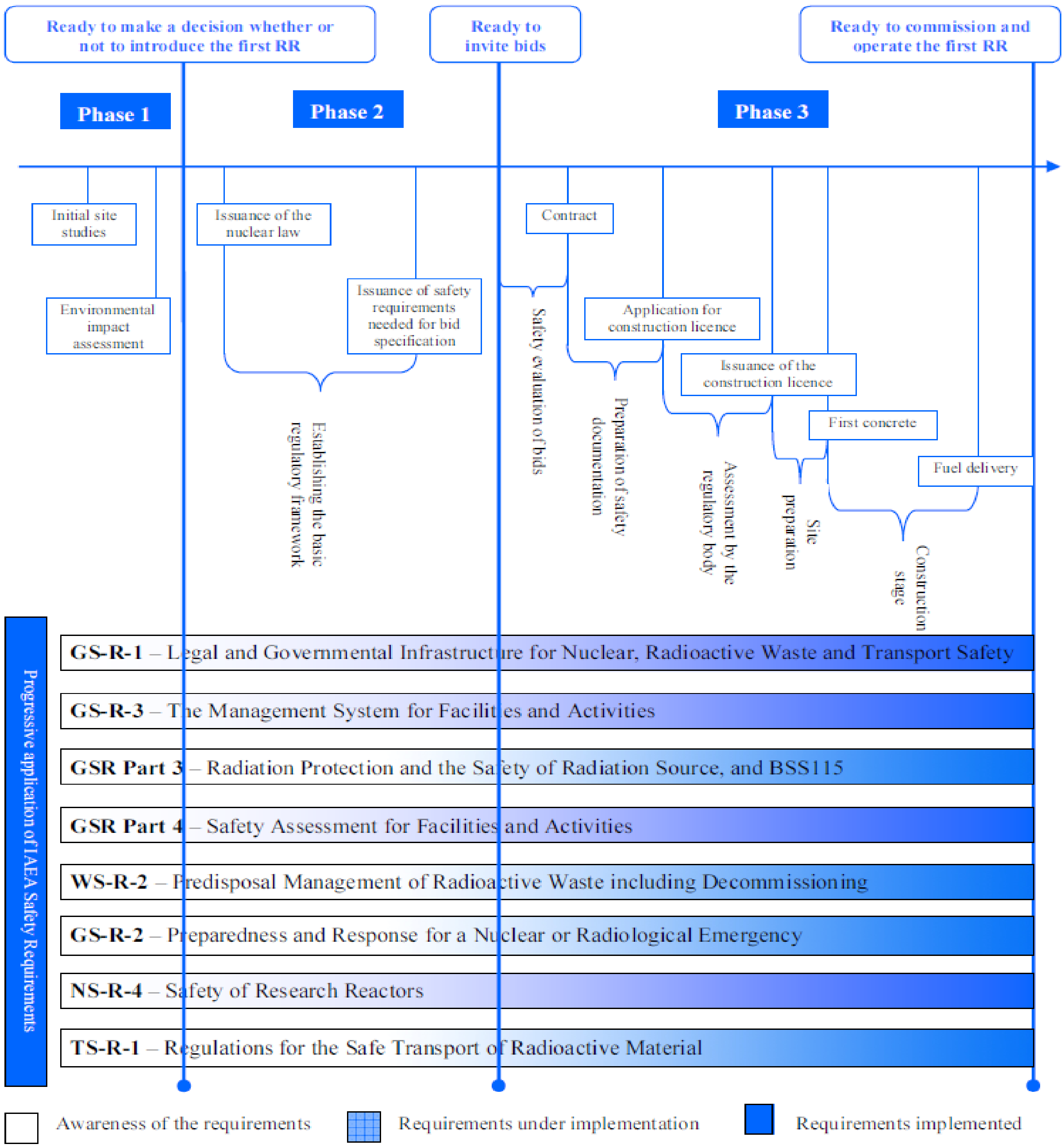

Figure 2: Major safety related activities in different phases of building the first RR and illustration of progressive application of the IAEA Safety Standards

4.1. Major safety activities in Phase 1

Experience has shown that a robust utilization plan was not always a part of the decision making process for determining whether a RR should be built, or should continue to operate, in a long term run. It is therefore essential at the initial stage to perform a feasibility study justifying the need for a RR in accordance with Principle 4 (Justification of Facilities and Activities) of the Fundamental Safety Principles [13]. It is also necessary to have a clear definition of the reactor purpose, utilization, and users as well as pre-selection of the reactor type and size including experimental facilities. The feasibility study should consider the advantages and disadvantages of utilizing alternative technologies (e.g. spallation neutron source and cyclotrons), and possible use of the RRs existing in the region.

The feasibility study should also address the government commitment to adhere to the international obligations and to apply the provisions of the IAEA Code of Conduct on the Safety of Research Reactors, including the need to:

- Consider various safety principles that are applied to the development of the RR;
- Establish an effective legal and regulatory framework for safety, including an independent regulatory body, and an operating organization with prime responsibility on safety;
- Establish a sustainable financing system for all activities related to safety, both from an operational and regulatory point of view;
- Establish an effective management system and provide for a strong leadership capabilities and foster safety culture within the involved organizations;
- Provide for adequate arrangements for building the technical competence of the involved organizations;
- Develop and implement a national strategy for long-term radioactive waste and spent fuel management and decommissioning of the facility;
- Provide for adequate arrangements for emergency preparedness and response.

In addition, an initial site survey should be an essential part of the feasibility study. The initial site survey includes identification of potential and preferred candidate site(s) according to established criteria and on the basis of the existing data. Identification of the preferred candidate site(s) should be supported by a radiological impact assessment, which should also be a part of the feasibility study.

4.2. Major safety activities in Phase 2

Once the decision to build the RR has been made, based on the results of the feasibility study, the activities to establish the necessary safety infrastructure should proceed during Phases 2 and 3. The highest priority is given to enacting the essential elements of the legal framework including establishment of an effective and independent regulatory body and the operating organization. During this phase the regulatory body should establish a licensing process for the RR, specifying the documentation and procedures in the various steps. Establishment of a suitable working relationship between the regulatory body and operating organization, and early involvement of the regulatory body in the process, including specification of the safety requirements needed for the bidding process, are essential for successful implementation of the project.

During this phase, the decisions that need to be made by the operating organization typically include the type, size, and safety features of the RR to be built as well as the associated experimental facilities. The operating organization should also proceed with the reactor site evaluation and selection. The site parameters which are needed for the reactor design and operation should be identified and included in the technical specifications of the bid. Attention should be given to the availability of expertise in site selection, bidding, and evaluation of the technical offers from different vendors.

Development of human resources and competences is a high priority task in this phase. The regulatory body should start developing the necessary competences in establishing regulations and performing regulatory review, licensing and inspection. It is also essential that the operating organization start developing the knowledge and skills through specialized training (and even fundamental education to some extent). The needed competences include performance of safety assessment, reactor commissioning, operation, maintenance, and utilization in compliance with the safety requirements. In addition to these topics, specialized training is also needed in reactor physics, thermal-hydraulics, radiation protection, core management and fuel handling, quality assurance, and safety culture. Such training requirements could be obtained from the reactor vendor in accordance with the technical specifications of the bid.

4.3- Major safety activities in Phase 3

This phase consists of intensive activities to build the RR. One of the first activities in this phase is the technical evaluation of the bids. In this regard, the operating organization should ensure adequate safety review of the design proposed by the vendors in the submitted bids. Adherence of the design to the IAEA Safety Standards should be one of the criteria established for the selection of the winning bid. The project execution schedule should include hold points for regulatory review and verification that the activities of safety significance are properly implemented.

This phase requires significant development and training for all levels of staff. Recruitment of the operation and maintenance personnel should begin early in this phase. The participation of reactor staff in different activities of this phase including design review, construction activities, and development of operating documents will have a positive impact on safety and effective utilization of the reactor. It will also help development of a safety culture and acceptance of the responsibilities for the transferred systems at the end of Phase 3. It is beneficial to include in the project organization chart a group (or individual) responsible for human resources development, whose duties will include establishing links with the vendor to ensure knowledge transfer to the operating organization and adequate training of the reactor staff.

Preparation of the Safety Analysis Report (SAR) should start as early as possible in the design stage. The operating organization should ensure proper interaction with the reactor designer in the preparation of the safety documents. The SAR, including a comprehensive safety assessment, Operational Limits and Conditions (OLCs) and specification of the codes and standards which provide acceptable reference for design and construction, is the main safety document for the licensing process. The regulatory body, prior to issuing the construction license, should assess the SAR and verify that the relevant safety requirements can be met.

During the construction stage, the operating organization should ensure adequate involvement in the construction process to ensure that the safety systems and components are constructed according to the approved design. A process should be in place, in accordance with the management system, to address changes in the design during the construction, and maintain the knowledge on the design and construction during the lifetime of the reactor. These items should also be verified by the regulatory body.

In addition to the commissioning programme, all the management programmes for operation should be developed during this phase. These include the operating procedures, maintenance, periodic testing, and inspection programmes. The operational radiation protection programme and the emergency plan should be fully implemented at the time fuel is received at the reactor building. The corresponding chapters of the SAR should be prepared by the operating organziation and assessed by the regulatory body during preparation for commissioning.

5. Conclusion

The decision to build a RR should be based on a study showing the feasibility of the reactor. The study should evaluate the real needs, utilization programme, and availability of a suitable site. It should also show the commitment to establish the necessary safety and technical infrastructures. Establishment of such infrastructures should start early in the process and should be achieved progressively during the different phases of the project through effective application of the IAEA Code of Conduct on the Safety of Research Reactors and by making use of the IAEA Safety Standards.

Through the lifetime of the RR, periodic safety reviews aiming at ensuring high level of safety should be performed to deal with cumulative effects of reactor ageing, modifications, changes in utilization programme or installation of new experimental devices, operating experience feedback, and changes in safety requirements, as well as site-related aspects.

6. References

[1] IAEA, Nuclear Safety Infrastructure for a National Nuclear Power Programme Supported by the IAEA Fundamental Safety Principles, INSAG-22 Report, IAEA, Vienna, 2008
[2] IAEA, Milestones in the Development of a National Infrastructure for Nuclear Power, Nuclear Energy Series No. NG-G-3.1, IAEA, Vienna, 2007
[3] IAEA, Code of Conduct on the Safety of Research Reactors, IAEA, Vienna, 2004
[4] IAEA, Legal and Governmental Infrastructure for Nuclear, Radiation, Radioactive Waste and Transport Safety Requirements, IAEA Safety Standards Series No. GS-R-1, IAEA, Vienna, 2000
[5] IAEA, Safety of Research Reactors, Safety Standards Series No. NS-R-4, IAEA, Vienna, 2005
[6] IAEA, The Management System for Facilities and Activities, IAEA Safety Standards Series No. GS-R-3, IAEA, Vienna, 2006
[7] FAO, IAEA, ILO, IMO, OECD/NEA, and WHO, International Basic Safety Standards for Protection against Ionizing Radiation and for the Safety of Radiation Sources. Safety Series 115, IAEA, 1996
[8] IAEA, Safety Assessment for Nuclear Facilities, Safety Standards Series No. GSR 4, IAEA, Vienna 2009
[9] IAEA, Preparedness and Response for a Nuclear or Radiological Emergency, Safety Requirements, Safety Standards Series No. GS-R-2, IAEA, Vienna, 2002
[10] IAEA, Predisposal Management of Radioactive Waste including Decommissioning, Safety Standards Series No. WS-R-2, IAEA, 2000
[11] IAEA, Site Evaluation for Nuclear Installations, Safety Requirement, IAEA Safety Standard Series No. NS-R-3, IAEA, Vienna, 2003
[12] IAEA, Regulation for the Safe Transport of Radioactive material (2005 Edition), IAEA Safety Standards Series No. TS-R-1, IAEA, Vienna, 2005
[13] Euroatom, FAO, IAEA, ILO, IMO, OECD/NEQ, UNEP, and WHO, Fundamental Safety Principles, Safety Standards Series No. SF-1, IAEA, Vienna, 2006

THE PALLAS RESEARCH AND ISOTOPE REACTOR PROJECT STATUS

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ABSTRACT

In the European Union the first generation research reactors is nearing their end of life condition. Several committees recommend a comprehensive set of reactors in the EU, amongst them the replacement for the HFR research and isotope reactor in Petten: PALLAS. The business case for PALLAS supports a future for a research and isotope reactor in Petten as a perfect fit for the future EU set of test reactors.
The tender for PALLAS started in 2007, following the EU rules for tendering complex objects with the competitive dialogue. This procedure involved an extensive consultation phase between individual tendering companies and NRG, resulting in definitive specifications in summer 2008. The evaluation of offers, including conceptual designs, took place in summer 2009. At present NRG is still active in the acquisition of the funding for the project.
The licensing path has been started in autumn 2009 with a initiation note on the environmental impact assessment, EIA. The public hearings held in the lead to the advice from the national EIA committee for the approach of the assessment. The PALLAS project team in Petten will guide the design and build processes. It is also responsible for the licensing of the building and operation of PALLAS. The team also manages the design and construction for the infrastructure, such as cooling devices, including remnant heat utilization, and utility provisions. A particular responsibility for the team is the design and construction of experimental and isotope capsules, based on launch customer requirements.

1. Introduction

The fifties of the 20th century saw the start of the design and building of a large fleet of research reactors in the range from “zero” to over 100 MW thermal power. In the EU the first generation of the larger types of research reactors is being phased out after operational lives of 40 years and more. The maintenance costs are increasing and the continuity of operation is compromised by the aging of materials and components. The High Flux Reactor in Petten, The Netherlands, is amongst them. It was built in the fifties and started full operation in 1961. It received a substantial upgrade in 1984 when the first reactor vessel was replaced by a new one. At the same time the vessel design was adapted to the developing application fields of the HFR. Aluminium vessels embrittle from the transmutation product silicon formed from thermal neutron interaction. The choice for the Petten site is to envisage another vessel replacement or to build a new reactor. Besides the vessel other components age as well and the changeing utilization, and ecomnomic considerations also have an effect on the decision for upgradeing or building a successor to the HFR.
Four parties, the Joint Research Centre – Institute for Energy, Petten, COVIDIEN Mallinckrodt Medical, Petten, the Technical University Delft, and NRG, Petten took the initiative to innovate for the continuity of a safe and reliable neutron irradiation capacity on Petten site. At the same time the successor to the HFR, named PALLAS, should remain an integral part of the EU nuclear research infrastructure. The target year given in 2004 for

starting the reactor operation was 2016. The project for the realization of PALLAS is presently in the phase of tendering the design and building of the reactor and peripheral installations and equipment. The present paper provides the progress and status of the realization of PALLAS.

2. Role of PALLAS in the EU

The thematic network "Future European Union Needs in Materials Research Reactors", FEUNMARR, stated in 2001 that "given the age of current Materials Test Reactors (MTR) there is a strategic need to renew Materials Test Reactors in Europe". Continuity in irradiation capacity for research and development for fission and fusion power plants is essential for securing energy production in the EU and the world as a whole [1]
The European Strategy Forum on Research Infrastructures (ESFRI) noted in 2006 that the next prominent nuclear facilities such as the International Fusion Materials Irradiation Facility (IFMIF) and the Réacteur Jules Horowitz (JRH) in France. PALLAS will be an MTR devoted to Research & Development with dedicated isotope production [2].
In 2008, the Committee for Netherlands' Roadmap for Large-Scale Research Facilities (Commissie van Velzen) of the Ministry of Education, Culture and Science carried out an international peer review of PALLAS resulting in very positive advice for the go-ahead of the PALLAS project. Early 2009 PALLAS was added to the list for the Netherlands' National Roadmap Large Scale Research Facilities in particular for the development of fourth generation nuclear power plants. In December 2009 the Netherland's ESFRI delegation have submitted PALLAS to the Executive Board for consideration for inclusion in the new / upgraded Research Infrastructure (RI) of pan-European relevance.
The Sustainable Nuclear Energy Platform, SNETP, vision report and Strategic Research Agenda for the development of nuclear energy, makes the need for PALLAS clear with statements as " To hold on to its leadership in reactor technology, Europe must maintain its efforts towards the realisation of a European Research Infrastructure Area" and the PALLAS project will provide an innovative irradiation facility and reinforce the supply of radio-nuclides for medical application in Europe" [3].
CEA (French Atomic Energy Commission), SCK-CEN (Belgium Nuclear Research Centre) and NRG work together to provide a network between their respective installations, provide back-up for medical isotope production and share specialist testing expertise. Réacteur Jules Horowitz (RJH/France) is primarily designed for research projects that serve scientific, industrial and public needs. PALLAS and RJH will be complementary. Within the EU the fission related pre-commercial research is organized under the EURATOM treaty within the European frame work programs. The HFR holds a crucial position in these nuclear research networks and later PALLAS will continue this position.
In the letter for the Parliament issued 16 October 2009 the Netherlands government expressed clearly their positive vision on the building of Pallas [4]. The letter stipulates that the replacement of the HFR by a state-of-the-art reactor will satisfy both the need for nuclear research, and the security of radio-pharmaca supply. The letter expresses the vision that the multipurpose reactor provides sufficient flexibility for fulfilling these tasks, building on the existing Netherlands knowledge infrastructure in the fields of nuclear technology, and the radio isotopes.

3. Reactor Requirements

The requirements for PALLAS are derived from the vision on three strategic areas:

- Safety and Environment in relation to nuclear energy generation with existing nuclear power reactors and the partitioning and transmutation research to reduce remnant waste.
- Energy and security of supply to satisfy rising energy demand with even more effective power plants and fuel cycles, such as the thorium fission cycle and the trtium generation technology for fusion.

- Health care for the world population increasing both in age and wealth stimulating increasing demand for existing isotope diagnostics and therapies and development of new isotope based treatments.

In addition to the future vision the experience of the past 50 years HFR utilization formed input for the technical requirements. The similar longterm investment in PALLAS cries out for the same basis: flexibility, keeping room for adjustments for the unforeseeable trends. Major requirements thus are: a power range of 30 to 80 MW in a tank in pool reactor that can use uraniumsilicide for a start, but can use UMo fuel elements without major core changes, as soon as they have been qualified. Neutron beams will be omitted, because of the excellent EU high intensity facilities provided by ILL, Grenoble and the FRM-2, Munich, up to the middle of the 21st century. In The Netherlands the Technical University Delft will provide specialized beam facilities in the next decades. More requirement details are given in [5].

4. The tendering process

The tender procedure is in line with the EU rules for complicated one of a kind design and construction projects. The procedure starts with a qualification of the tenderers followed by dialogue and consultation between the employer and the qualified tenderers with the aim to make the final requirements clear and remove all disambiguity before the decisive tender phase. The three qualified tenderers included the consoria of AREVA Ballast Nedam, KAERI-KOPEC-DOOSAN, and INVAP–ISOLUX. The dialogue phase with sessions of several days devoted to the dialogue with each party independently in Petten, resulted in the answering in writing about 400 questions of the tenderers. Only one major requirement had to be adjusted. The fast neutron flux specification had to be reduced with about 30 % in order to allow for sufficient flexibility in the operation. The fuel burn-up and skewness of the neutron distribution were much more attractive for the average operation after the reduction in fast flux level.

The procedure allowed NRG to produce the final employers requirements in summer 2008. The accompanying award criteria for the tender concentrated on: licensibility of the design, treatment of safety and health physics aspects, production capacity and quality, investment costs, and cost of operation. After the draft contract was completed in agreement with all parties, NRG received the tenders in May 2009. Before NRG teams had visited all three vendors in Korea, Germany and Argentina respectively.

In summer 2009 NRG analysed the valid tenders. It became evident that the technical requirements could be met, though the solutions followed different paths. NRG selected the most economically advantageous tender. The contract could though not be awarded, because in the meantime the requirements for the financing of the reactor design and building had changed, affecting the timetable to such a degree that a new tender became inevitable.

The definite fundraising for the total project is still ongoing. At present it is expected that full public funding will be needed for the project phase leading to the building and operation license for PALLAS, based on the detailed design, and the safety analyses produced in parallel. The building will rely on:

- public funding for the precompetitive research and science development carried out in PALLAS.
- Private funding for the investment needed for the commercial prodcution of isotopes.

This approach is in line with the EU policy for public money spending for commercial production.

5. Licensing

In The Netherlands 6 Ministeries form the Competent Authority for the KEW [Nuclear Energy Law]. Early 2008 the first project information exchange of NRG with the coordinating Competent Authority for the KEW, the Ministry of Housing, Spatial Planning and the

Environment, VROM, was held. VROM takes the IAEA framework as the basis for its policy extended with rules pertinent for Netherlands particular circumstances. For research reactors with a thermal power over 30 MW several rules will be similar to those established for power reactors in our kingdom. An amendment NRG anticipates is a supplementary shut down/observation room. Other preconditions anticipated are:

- withstand high internal pressure and aircraft crash
  - long ‘grace period’ in the event of an accident
  - CDF $\leq 10^{-6}$

In 2009 NRG has published the Initial Memorandum [6], informing the public about its’ plans with PALLAS and how to analyse, and control its’ environmental impact. The formal submisson of the Initial Memorandum to VROM triggers in The Netherlands the Environmental Impact Assessment procedure. The public hearings, organised by VROM, were held in the two candidate locations: the communities of Petten and Zijpe. The viewpoints of the Netherlands’ public, gathered during and after the meetings are used by the IEA committee to set the themes for the IEA analyses and report. The committee has given its guidelines in February 2010. NRG has started working on the IEA and expects to complete the work by the end of next year.

As soon as possible the definite reference license basis and the definite operational limits and controls should be agreed with the regulator in order to complete the design and license application. NRG will be responsible for obtaining the license, but relies of course on the vendor design and safety analyses quality. Transparant and strict communication lines between regulator, license applicant and vendor is essential for the speed and quality of the work needed. As soon as the detailed design and safety analyses are completed the building and operation license application will be submitted. The building can start after the license has been issued, now expected in 2012. After the building has been completed a complete check on the installed equipment and procedures will be conducted in order to verify the boundaries layed out in the license application. Therefore it is most important to settle early in the project for the reference license basis in order to speed up the design and safety analyses, and subsequently limit the project risks.

6. Project organisation

The PALLAS project team in Petten will review and asses the design and build processes provided by the vendor. It will have primary responsibility for the licensing of the building and operation of PALLAS, with the supporting design and safety supplied by the vendor. The major projects the team has to manage are:

- Control and supervision tasks for the design & license phase for PALLAS
- Evaluation and verification of nuclear design codes of vendor.
- Netherlands Environmental Impact Assessment: Milieu Effect Rapportage
- Netherlands Nuclear Law: KernenergieWet, KeW, build and operation license
- Operation and Commissioning preparation
- Experimental irradiation devices design and embedding in the reactor core
- Isotope irradiation devices design and embedding in the reactor core
- Site lay out
- Infrastructure: adapt power, gas, water, sewer, data supply, and etc. to PALLAS.
- Cooling water supply including licenses.
- Remnant heat processing and disposal

The project organisation has a director and chief project leader manageing the lead engineers of the major projects. The core team will consist of less than 15 members. They will be supported by experts from NRG and third parties supplying consultancy NRG cannot provide. Subcontractors will supply the design and hardware needed to accomplish the goals of the projects. The PALLAS team details the scope and planning for the design and construction for the infrastructure needed and controls the contract management.

The listed projects have strong relations with respect to the specifications for the resulting hardware and the inter-related time schedules. Interface management will thus have high priority on a day to day basis. An example is the cooling infrastructure for PALLAS, including

utilization of remnant heat, and utility provisions that show strong interlinks, amd dependence on the main project the research reactor PALLAS.
Another responsibility for the team is the design and construction of experimental and isotope capsules. The interplay with the core design is essential, but there is also a strong link needed with the users and customers for experimental and isotope irradiation devices. Special efforts will be devoted to select launch customers for particualr irradiation capsules and loops. The operating license for PALLAS will provide an envelope for the type of rigs that can be used in the PALLAS core. The devices selected from the launch customers and users will also serve as reference test capsules for the commissioning phase.
The Milieu Effect Rapport delivery and the application for the build and operation license will require deep insight in the whole project integrated results and devices. This effort will be the responsibility of the project team as a whole with the close and well defined co-operation with the industry. With the formal framework in place and the continuation of the proffessionalism, enthousiams and dedication already shown in the tender phase by all involved the PALLAS project will become a great research and isotope reactor.

7. Conclusion

1. The role of PALLAS in the EU future reasearch and isotope utilization is well established.
2. The tender process has lead to offers that technically seem feasible. The compettition and dialogue procedure for the tender was most effective in arriving in stable requirements and clear offers.
3. The financial arrangements for the project continuation have not yet been concluded.
4. The licensing path has been started with the Environmental Impact Assessment, based on the results of publc hearings following the Netherlands practices.
5. The project organisation for the PALLAS project is ready for the next phase: the design and license preparation, followed by construction and commissoning as soon as the building and operating license has been awarded.

8. References

[1] D.P. PARAT, FEUNMARR Final Synthesis Report, contract nr. FIR1-CT-2001-20122, Brussels, October 2001.
[2] European Roadmap for Research Infrastructures 2006, page 68, European Communities, Luxemburg, ISBN-92-79-2694-1, (2006).
[3] The sustainable Nuclear Energy Technology platform, A vision report, Special report EUR 22842, p. 30, Directorate-General for Research Euratom, Brussels (2007).
[4] WEBADDRESS: http://ikregeer.nl/document/KST135944
[5] B. van der Schaaf, F.J. Blom, K.O. Broekhaus, R. Jansma, PALLAS the new Petten research and isotope reactor, Proceedings of RRFM2008 from 2 to 5th March 2008, Hamburg
[6] PALLAS – building tomorrow's healthcare and energy supply today, Initial Memorandum PALLAS from NRG, 17 November 2009. WEBADDRESS: http://www.vrom.nl/pagina.html?id=45072}

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REVISITING HOMOGENEOUS SUSPENSION REACTORS FOR PRODUCTION OF RADIOISOTOPES.

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ABSTRACT

Some 50 years ago in Geneva Conferences I, II and III (1955. 1958 and 1964) on the Peaceful Uses of Atomic Energy, and also in Vienna Symposium on Reactor Experiments (1961), several papers where presented by different countries referring to advances in homogeneous suspension reactors.

In particular the Dutch KEMA Suspension Test Reactor (KSTR) was developed, built and successfully operated in the sixties and seventies. It was a 1MWth reactor in which a suspension (6 microns spheres) of mixed UO_2 / ThO_2 in light water was circulated in a closed loop through a sphere-shaped vessel.

One of the basic ideas on these suspension reactors was to apply the fission recoil separation effect as a means of purification of the fuel: the non-volatile fission products can be adsorbed in dispersed active charcoal and removed from the liquid.

Undoubtedly, this method can present some advantages and better yields for the production of Mo-99 and other short lived radioisotopes, since they have to be extracted from a liquid in which practically no uranium is present.

Details are mentioned of the different aspects that have been taken into account and which ones could be added in the corresponding actualization of suspension reactors for radioisotope production. In recent years great advances have been made in nanotechnology that can be used in the tailoring of fuel particles and adsorbent media.

Recently, in CNEA Buenos Aires, a new facility has been inaugurated and is being equipped and licensed for laboratory experiments and preparative synthesis of nuclear nanoparticles. RA-6 and RA-3 experimental reactors in Argentina can be used for in-pile testing.

1. Introduction

Radioisotopes obtained from the fission of ^{235}U are usually produced from a target material in a heterogeneous reactor [1]. In fluid fuel reactors, fission products can be recovered by separating them from the moderating liquid without using any additional target. This alternative, and the possibility of using low enriched uranium (LEU), makes homogeneous reactors attractive to be studied from the point of view of producing commercial radioisotopes and withstanding non proliferation objectives [2].

2. Homogeneous Suspension Reactors

Laboratory experiments performed by H. Halban and I. Kowarski at Cambridge University in England at the end of 1940 indicated hat a successful self-sustaining chain reaction could be achieved with a slurry of uranium oxide (U_30_8) in heavy water. These initial developments of aqueous homogeneous reactors were delayed because of heavy water shortage in the early forties. Next experiments were performed when enriched uranium could be available. Simultaneously with the development of aqueous homogeneous reactors [3] several prototypes of suspended particles or semi-homogeneous [4] fluid fuel reactors were thought up. By the end of the decade there was increased interest to determine the potentialities of suspensions of solid uranium compounds as reactor fuels as a result, for example, of high temperature instabilities of uranium sulphate solutions. Fuel- and fertile-material suspensions with uranium oxides slurries and thorium oxide slurries were studied for power production and breeder reactors.

Attention was specially focused to homogeneous reactors since large energy outputs could be achieved per unit volume with negative temperature coefficient, no structural metallic fuel elements, possibility of continuous purification and, hitherto, high burn-up of fuel could be achieved. These advantages are also common for suspension reactors. Some prototype was thought to work with slightly enriched UO_2 suspension using light water as moderator [5]. The idea of this prototype was to investigate the stability of the reactor with fluctuations of suspension concentration, the performance of the suspended particles, reactor materials and liquid moderator under corrosion, erosion, particle attrition and radiation damage and decomposition. Also it was of interest to investigate continuous and batch type purification methods knowing, for example, that for safety reasons, the delayed neutrons must be liberated inside the reactor and this is related with controlling conditions in the circulating velocity of suspended particles.

Although the purpose of this prototype was for power production, it is interesting to notice that the size of the particles between 5 and 12 microns is such that fission products will finally finish in the liquid having low probability of reentering another particle. The purpose is to automatically separate poisoning fission products; any other radioisotopes of interest could also be separated. The decomposition of the suspension liquid caused by the fission products, on an average, is a factor of two smaller than in a homogeneous solution reactor since the stopping path is half through the particle and the other half in the liquid. Also a smaller decomposition is expected from the point of view that practically no electrolytes that promote the formation of hydrogen and oxygen need to be present, as in the case of a homogeneous solution.

Homogeneous reactors are classified as circulating fuel or boiling, depending upon the method of removing heat. A circulating fuel reactor is one in which the fluid fuel is circulated through the reactor and external exchange equipment removes heat by natural or forced convection. In a boiling reactor heat is removed by vaporizing coolant in the reactor and condensing the separate vapor in external heat exchangers [6]. A boiling reactor may operate either with an unorganized or an organized circulation of the active mixture [7].Also aqueous homogeneous reactors were classified as “one-region” or “two-region” according to the distribution of fissile and fertile materials in the reactor [6]. These classifications can also be extrapolated for the cases of homogeneous suspension reactors.

An important issue to take into account when looking backwards homogeneous or semi-homogeneous (suspension) reactors is that they were intended for power production. When thinking nowadays on homogeneous reactors for radioisotopes production, new designs can be sustained on behalf of smaller powers involved per production unit.

3. Suspension Developments Review

It is illustrative the starting and finishing comments of the Oak Ridge National Laboratory work untitled “Aqueous Uranium and Thorium Slurries” [8] about fisil and fertile fuels in suspension. Several advantages were early recognized when preliminary chemical and engineering studies were conducted at Columbia University and at the University of Chicago, with special emphasis in stating that uranium slurries as homogeneous reactor fuels have the significant advantage over solutions of being less corrosive; and concluding that both slurry fuel and slurry fertile systems can be developed for nuclear purposes after analyzing chemical stability, preparation methods, abrasion-corrosion, caking, sedimentation characteristics and pumping methods.

The Pennsylvania Advanced Reactor (PAR) Project, that began in 1955, had as objective to determine the feasibility of building a 150 MW (electric) aqueous homogeneous pressurized reactor for central station use with a mixture of uranium oxide fuel and thorium oxide fertile material of a single-region slurry type [9, 10]. France [11], Netherlands [12, 13] and Czechoslovakia [14] also showed interest in suspensions containing dispersed uranium in a boiling reactor (PHOEBUS), pressurized aqueous suspension type small reactor with a slurry containing 4% by volume of UO_2 (20% ^{235}U) particles of 4-13 microns size [15] (KSTR, KEMA Suspension Test Reactor) [16, 17] and a homogeneous pressurized reactor with fuel suspension of enriched U_3O_8 of 10 MW (thermal), respectively. United Kingdom performed chemical investigation in the preparation and properties of slurries of thorium, uranium and plutonium oxides [18] while Australia carried out research on the dynamic properties of suspensions in pumped loops to provide information for a liquid metal fuel suspension type of reactor [19].

4. General and Particle characteristics

It seems that there are no significant differences between using a solution or a suspension in the analysis of the type of homogeneous reactor (circulating fuel or boiling) to be used for radioisotopes production. Specific powers of 20 KW per liter of suspension, and even much higher, and average thermal neutron fluxes in the reactor core higher than 2.10^{13} n/cm^2sec can be obtained. From past experiences in homogeneous suspension reactors a series of considerations can be outlined from the point of view of the implicitness referring to suspended particles.

The size of the particles should be smaller than the penetration distance of fission products that is of the order of 10 microns. If the volume concentration of the particles is low (a few volume percent) as will be the case for a 20% enriched uranium it is to be expected that the greater part of the fission products will be stopped in the water and not re-enter the particles.

The lower limit is determined by the possibility of simple and efficient mechanical separation of fuel particles and water, the latter containing fission and corrosion products, in solution or as small precipitates. This dimension can be taken such that particles should be bigger than 1 micron. In the minimum size criteria it can also be considered that nuclear recoils produced by non fission neutron captures should be smaller than the minimum size of the particles so as to retain transformed nuclei in the solid media. The settling velocity of 10 microns particles containing uranium in water is approximately 0.5 mm/seg. This velocity means that stirring should be present to avoid particles deposition.

The rate of water decomposition in suspensions is lower than in the case of solutions since fission products loose part of their energy in the generating particles and the recombination back reaction under catalytic action of the particles is promoted. If the generating rate and recombination is not enough, as in the case of high power designs, an additional catalytic recombining system of hydrogen and oxygen will probably have to be incorporated in some kind of plenum chamber.

It is desirable that the particles have small specific surface in order to reduce adsorption of liberated fission products. To diminish adsorption effects, particles could additionally be covered with a convenient cladding, as for example an amorphous, crystalline or mixed oxide, or even graphite. Coverage can also help in controlling erosion, attrition and hydrodynamic properties. The fact that fission products can be controlled to be mainly in the water without presence of uranium is an interesting system for obtaining important yields in radioisotopes production. This item, or verification of this hypothesis, is important to perform in present first experiments. From another point of view, addition of adsorbent substances such as big particles of activated carbon, could help in the recollection of fission products from the liquid. Particles, precipitates and solution can be handled and separated for further processing by hydrocyclones specially designed.

In the case of suspension systems attention should also be directed to the possibility of particle attrition, ought to the moving suspension and radiation damage, and instabilities due to settling if the circulation of the compound fluid failed .

Since suspension of particles is conceived basically as a physical system in contrast with solutions that have chemical characteristics, other fluids can be considered to be used as moderators and coolants, as in the case of organic compounds such as dyphenil and terphenyls [20].

5. Conclusions

In solution reactors, uranium concentration is limited by solubility or corrosion effects, and in slurries, by the effective viscosity and settling characteristics . Concentrations up to 4000 g/liter may he considered for fluidized beds, four times higher than for solutions.

Important control of the chemistry of the fluid can be performed in the case of suspended particles since the presence of uranium and plutonium is extremely reduced outside the particles. Size of suspended particles and their concentration should be such that fission products are liberated towards the liquid without reentering another particle. It is expected that these characteristics of suspended particles homogeneous reactors be directly related with important yields of extraction of radioisotopes of interest. It is being planed to perform experiments in which this capability can be evaluated.

Compound particles containing the fissile elements and particles that adsorb fission products can be designed on behalf of increasing the performance of radioisotopes production.

6. References

1. H. Bonet. Security of Supply for Fission Medical Radio-Isotopes Based on Optimal Use of the Test Reactor Network. RRFM, 22 -25 March 2009, Vienna, Austria.
2. E. Bradley, P. Adelfang and N. Ramamoorthy. IAEA Publication: Tecdoc-1601 – Homogeneous Aqueous Solution Nuclear Reactors for the Production of ^{99}Mo and Other Short Lived Radioistotopes. RRFM, 22 -25 March 2009, Vienna, Austria.
3. Nuclear Reactor Engineering. S. Glasstone and A. Sesonske. Ed. D. Van Nostrand Company, Inc. Princeton, New Jersey, USA.1963.
4. Aqueous Homogeneous Reactors. Chapter 4, Technology of Aqueous Suspensions. Ed. J. A. Lane. Oak Ridge National Laboratory, Tennessee, USA.
June 1958. http://www.energyfromthorium.com/FluidFuelReactors.html
5. H. de Bruyn et al. The Design of a Small Scale Prototype of a Homogeneous Power Reactor Fueled with a Uranium Oxide Suspension. Proc. Int. Conf. Peaceful Uses of Atomic Energy, Vol. 3. Geneva, 1955. p. 116-120.
6. R. B. Briggs and J. A. Swartout. Aqueous Homogeneous Power Reactors. Proc. Int. Conf. Peaceful Uses of Atomic Energy, Vol. 3. Geneva, 1955. p. 175-187.
7. A. I. Alichanow et al. A Boiling Homogeneous Nuclear Reactor for Power. Proc. Int. Conf. Peaceful Uses of Atomic Energy, Vol. 3. Geneva, 1955. p. 156-174.
8. A. S. Kitzes and R. N. Lyon. Aqueous Uranium and Thorium Slurries. Proc. Int. Conf. Peaceful Uses of Atomic Energy, Vol. 9. Geneva, 1955. p. 414-422.
9. W. E. Johnson et al. Design Considerations for the Pennsylvania Advanced Reactor Plant. Proc. Second Int. Conf. Peaceful Uses of Atomic Energy, Vol. 9. Geneva, 1958. p. 202-210.
10. W. E. Johnson et al. Technology of Aqueous Thoria Slurries for Single-region Homogeneous Reactors. Proc. Second Int. Conf. Peaceful Uses of Atomic Energy, Vol. 7. Geneva, 1958. p. 34-38.
11. J. Beneviste et al. Ideas Concerning a Homogeneous Reactor Project. Proc. Second Int. Conf. Peaceful Uses of Atomic Energy, Vol. 9. Geneva, 1958. p. 415-426.
12. P. J. Kreyger ey al. Development of a 250 KW Aqueous Homogeneous Single Region Suspension Reactor. Proc. Second Int. Conf. Peaceful Uses of Atomic Energy, Vol. 9. Geneva, 1958. p. 427-440.
13. J. J. Went. The Aqueous Homogeneous Suspension reactor Project. Proc. Third Int. Conf. Peaceful Uses of Atomic Energy, Vol. 11. Geneva, 1964. p. 266-273.
14. V. Zajic, J. Pfann and J. Gregor. Design of an Experimental 10 MW Homogeneous Reactor Fueled with Circulating Uranium Oxide Suspension in Light Water. Proc. Second Int. Conf. Peaceful Uses of Atomic Energy, Vol. 9. Geneva, 1958. p. 441-446.
15. A. Hermans. The Preparation of Uranium Dioxide Fuel for a Suspension Reactor. Proc. Second Int. Conf. Peaceful Uses of Atomic Energy, Vol. 7. Geneva, 1958. p. 39-44.
16. J. A. H. Kersten, J. J. Went and J. J. van Zolingen. Physical Aspects of an Aqueous Homogeneous Suspension Reactor. Proc. Series. Symposium on Power Reactor Experiments I. Vienna, 1961. p. 197-223.
17. M. E. A. Hermans et al. Chemical Aspects of an Aqueous Homogeneous Suspension Reactor. Proc. Series. Symposium on Power Reactor Experiments I. Vienna, 1961. p. 225-245.
18. J. K. Dawson et al. Some Chemical Problems of Homogeneous Aqueous Reactors. Proc. Second Int. Conf. Peaceful Uses of Atomic Energy, Vol. 7. Geneva, 1958. p. 22-33.
19. R. C. Cairns. Fluid Flow Studies of Simulated Suspensions for a Liquid Metal Fuel Suspension Reactor. Proceedings of the Second International Conference on the Peaceful Uses of Atomic Energy, Vol. 7. Geneva, 1958. p. 45-53.
20. C. A. Trilling. The OMRE-a Test of the Organic Moderator-Coolant Concept. Proceedings of the Second International Conference on the Peaceful Uses of Atomic Energy, Vol. 9. Geneva, 1958. p. 468-489.

CREATION OF NUCLEAR RESEARCH CENTRES IN NEW ENTRANT COUNTRIES

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ABSTRACT

A number of prerequisites must be fulfilled before setting up a nuclear program in a new entrant country. This includes the training of future operating teams in the safety culture and the acquisition of the necessary technological knowledge. A NRC brings together the facilities and structures to meet this need. Similarly, prerequisites for the construction of an NRC in Maâmora (Morocco) have been completed by AREVA. These include establishing the contract, constructing the nuclear research centre and above all, commissioning the facilities. This paper gives the feedback from the team formed by AREVA and CNESTEN on the adventure the construction of the NRC Maâmora has been.

1. Introduction

The purpose of this paper is to give a feedback on the construction of the Maâmora Nuclear Research Centre (NRC) in Morocco for new entrant countries entering the field of nuclear energy used for peaceful purposes. The Maâmora NRC, whose construction was completed in 2007, was built on behalf of the Moroccan CNESTEN (National Centre for Nuclear Energy, Sciences and Technologies) by AREVA TA, the reactor module was build by the U.S. General Atomics. The Maâmora NRC occupies an area of 25 hectares approximately twenty kilometres north of Rabat. It comprises a dozen modules, half of them nuclear. The completed area covers 14 000 sq m.

In 2008, 'CNESTEN' commissioned its 2 MW nuclear research reactor 'TRIGA MARKII'.

This NRC includes several laboratories specialized in various nuclear applications (health, biology, water, environment and industry).

In this paper, we will discuss the Moroccan strategy to setting up a NRC and the important installation phases of the main facilities in terms of identified needs (nuclear applications, research, human resources, training, education and so on), preparation of legal framework, integration of international nuclear laws and treaties, implication of local industry, skills etc.

Furthermore, we will underline the importance of the technical bilateral and multilateral cooperation at each step of the project's development.

2. Moroccan strategy for the realisation of NRC

Since the first oil crisis in 1973, Morocco has considered the nuclear option as a long term energy solution. It is in this perspective that Morocco then ushered the nuclear era a within a legalist framework in conformity with international treaties & conventions (NPT, Safeguards, safety, security…).

Having said that, Morocco launched, during the eighties, two important projects:

- Carrying out of technical, economic and site feasibility studies of the first nuclear power plant during the eighties. Such studies have since then been gradually updated.
- The setting up of National Centre for Nuclear energy, Sciences and Technology (CNESTEN) Nuclear Research Centre equipped with 2MW power research reactor as a technological platform to prepare the introduction of nuclear power programme and to provide radiation and waste safety services.

The process adopted by Morocco to implement its Nuclear Research Centre was based on IAEA safety standards and concern five areas:

- Definition of the national nuclear applications' needs and NRC functions,
- Institutional and Regulatory framework,
- Selection of the firm in charge of construction works and contract establishment,
- Design, construction and realisation of the project,
- Bilateral and multilateral cooperation,
- Education and training.

2.1 Identifying the needs phase

The CNESTEN carried out a feasibility study on the Nuclear Research Centre based on the definition of the national needs in terms of nuclear techniques usage (radioisotopes, analysis, training, radioactive wastes).

This study covered the sectors susceptible to use nuclear techniques:

- University research activities,
- Health (nuclear medicine, cancerology, radiology),
- Industry (radiography)
- Agriculture (soil, plants),
- Environment (ground water, sea, rivers)

2.2 Definition of functions and activities of the Centre

From the three missions assigned to the Centre by its law of creation (research, service and technical support for the State) and the results of the national needs, the CNESTEN defined the main scientific, technical and support functions.

These functions are linked to the following activities:

- Facilities operation (reactor, waste management facilities and technical facilities)
- The production of radioisotopes and radiopharmaceuticals
- Analysis by radiation or other analytical techniques
- Liquid and solid waste treatment generated by external and internal users
- Metrology and electronic measurements instrumentation
- Radioprotection control and environment monitoring functions
- Technical and maintenance functions

3. Basic design of the NRC

Based on the definition of the work program adopted by the CNESTEN, AREVA TA proposed a basic design of the entire NRC integrated on a greenfield proposed by the CNESTEN located in the Maâmora forest.
This basic design was developed in close consultation with CNESTEN scientists taking into account:
- The feedback from operators of equivalent facilities in the world, particularly those of the French CEA
- The location and the situation
- The safety constraints of the country
- The economic optimization of the operation

Moreover, the architectural constraints induced by the architect commissioned by the CNESTEN were taken into account.
This basic design was the basis of the future technical contract and helped set a price.

4. Elaboration of the contract

4.1 Contents of the contract
The contract included 2 main parts:
- A turnkey contract package for design, equipment supply, construction and inactive commissioning of the whole facility,
- A budget for the purchase of the last minute and up to date laboratory equipment, this being difficult to specify when the contract was first signed.

4.2 Financing aspects
To finance the transaction, AREVA TA proposed to make its offer using French funds covering the 2 major contracts. This funding, originating from an intergovernmental protocol, allowed loans to be offered at very attractive interest rates.

4.3 Insurance, custom clearance, VAT
All the paperwork have required two side rather cumbersome and time before starting the project to be taken into account in planning the construction of such facilities.

5. Obtaining the necessary authorizations and licences

5.1 Legal and regulatory framework

The Moroccan national legal and regulatory framework for the protection against ionizing radiation and the safety of radioactive sources initially based on the law has been reviewed and completed in agreement with international standards.

This legislation establishes two regulatory authorities:

- The Ministry of Energy, Mines, Water and the Environment is the regulatory body in charge of the control and licensing of nuclear installation. The process adopted by the RB to assess the authorization request, submitted by the CNESTEN to launch the construction of NRC, was carried out by local expertise from different institutions (the university, technical departments, and research institutes).
  This expertise is organized within a national framework called “National Commission of Nuclear Safety” (NCNS) responsible to the Ministry as RB. This group supervised for more ten years (1996-2009) the process of licensing the NRC project: site approval, construction, fuel loading, commissioning and reactor operation.

- Concurrently, the Ministry of Health delegates the responsibility to National Center of Radioprotection (CNRP) for the main regulatory functions of all the other radiation practices and sources.

5.2 Licensing process of the NRC steps

Morocco paid particular attention that the design of the Centre was carried out accordingly to the safety standards of the suppliers country of origin concerning pieces of equipment and materials and if necessary in accordance with IAEA standards. The authorization process as described in national regulations and applicable to the project plans for 5 phases:

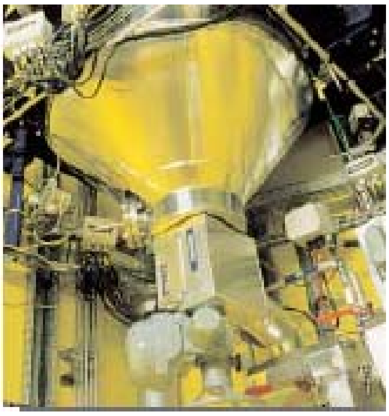
1. Construction authorization: delivery on the basis of the preliminary safety report (including site approbation)
2. Authorization to commission trial runs delivered after reactor fuelling: delivery supported by a provisional safety report
3. Authorization to rejects effluents after treatment process and radioactive decay
4. Operating licence delivered on the basis of the definitive safety report

All these authorizations are delivered by the Energy and Mines, Water and Environment Ministry supported by the National Nuclear Safety Commission which comprises national experts. Some Public agencies are also consulted for advice before delivering an authorization.

6. Purchasing management

Generally the developed financial protocol required a significant amount of purchasing in France. On this basis, the principle of purchasing and subcontracting for the successful completion of the NRC was the following:

6.1 Safety equipments



The pieces of equipment were purchased in France using the usual suppliers who provided all the guarantees in terms of quality achievement and quality assurance.

6.2 Standard components

These components were purchased in Morocco to avoid the costs associated with transport and customs clearance. Also this allowed for greater responsiveness in terms of time.

7. Civil works

All the work was subcontracted to local companies under the supervision of AREVA in order to improve the technical skills of the local operators. This is very important for creating a local network of expertise that will accompany the CNESTEN during the operation of the NRC, from maintenance to the expansion of facilities.
The detailed design drawings and calculation notes involved were subcontracted to local engineering firms under the close supervision of AREVA for economic purposes and for better responsiveness in terms of documents availability for civil works.

8. Commissioning, training and operation beginning

8.1 Commissioning

During the test phases of equipment, systems and units for a particular module, test teams consisted of people from AREVA associated with future operators to train them and ease the commissioning of the facilities.

8.2 Training

AREVA has trained future CNESTEN operators and maintenance personnel in its own facilities in France or directly on the Maâmora site. Similarly, Moroccan firms which participated in the construction of the NRC and obtained maintenance contracts from the CNESTEN have also expressed the wish to be trained by AREVA.

8.3 Operation beginning

Concerning facility operations, AREVA, thanks to its own experience as an operator of nuclear facilities, has provided assistance for establishing and organizing a monitoring committee for the operating of CNESTEN. The benefit was to follow the commissioning of the documentation and verify its proper use during the operating phase.

For the module reactor, operational documentation includes:
-the Safety Report,
-the General operation rules
- the running instructions,
-the maintenance procedures,
-the procedures, documents and methods for testing materials.

9. Multilateral and bi-lateral cooperation (France – USA…)

The IAEA has provided permanent and precious support for planning the project, choosing the reactor, selecting the scientific and technical activities as well as training personnel.

Establishing bi-lateral cooperation agreements with French Public Agencies (CEA, IRSN, ANDRA …) and American also (National Livermoore Laboratory) allowed engaging in many acts of cooperation (expertise and training) covering different domains.

10. Personnel training

The training approach adopted by the Centre for building the scientific and technical teams follows two lines of principle:

- Training session in similar nuclear research centres (France, USA)

Based on the needs and the project phase, the CNESTEN has established annual cooperation programs with French and American public agencies. An important number of training sessions have also been organized with the assistance of the IAEA in research centres similar to the one located in Morocco.

- On the job training

- By implicating engineers and researchers in the technical definition phase with AREVA (definition of the functional specifications for the activities, technical specifications for the equipment, choice of process…)
- By participating to the monitoring and control phases (engineering study, equipment purchase, assembly, trials, commissioning of the equipment and installations, construction works, …)
- By assisting, during the commissioning trial runs of the reactor, to the preparation phase consisting in the fire-up of the Centre's modules

- Bringing expertise to the teams (AIEA, CEA, IRSN, NLL…)

The objective of these punctual assignments was to assist the teams in choosing the pieces of equipment and experimentation processes.

The IAEA has especially been solicited to organize assessments and project reviews during critical phases of the project (INSAR).

PARTIAL DISMANTLING ACTIVITIES PRIOR TO THE REFURBISHMENT OF THE IRT RESEARCH REACTOR IN SOFIA, BULGARIA

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ABSTRACT

In 2001 the Bulgarian Government took a decision for refurbishment and conversion of the research reactor in Sofia in low power reactor. By reason of this decision it has been performed a partial dismantling of the IRT-Sofia old systems and equipment, with an intention to re-use the concrete bio shield for the new low power research reactor.

For most efficient use of resources there was a need for implementation of the engineering project, “Plan for partial dismantling of equipment of the IRT-Sofia as a part of the refurbishment into low power research reactor” which has been already accomplished.

Introduction

The IRT-Sofia research reactor was designed and constructed from 1958 to 1961. First criticality was reached in September 1961. The reactor has been started up 4189 times to run 24623 hours altogether at different power levels /by 2 MW/ agreed upon with the users at regular weekly meetings. The reactor was shut down in 1999 for refurbishment and conversion.

The reactor is pool type, cooled and moderated with light water. The core contains up to 48 fuel and graphite assemblies. There are 14, 15, or 16 fuel rods per assembly. Fuel rods are EK-10 type, /10 % enrichment/ and C-36 /36 % enrichment/. The reflector includes 13 graphite blocks. Safety and control system includes 7 in core rods - 2 safety rods, 4 regulating rods, and 1 automatic regulating rod. The cooling system includes 3 pumps, special ejector pipe, max flow rate 540 m^3, 2 heat exchangers, 4 ion exchange, and 2 mechanical filters. The maximum capacity of the storage pool is 108 fuel assemblies. It has connections to reactor pool and hot cell laboratories. Experimental channels are 11 horizontal and 12 vertical, the maximum neutron flux on 2 MW thermal powers is 2E13 n/cm^2.sec.

In order to realize the reconstruction project of the IRT - Sofia, it is necessary to develop and fulfill a Plan for Partial Dismantling /PPD/ of the research reactor IRT-Sofia according to national legislation [1] and IAEA Safety Guide [2].

The PPD is intended to describe in detail the succession of procedures related to the dismantling of the equipment of the research reactor IRT-2000 which is not to be used for the purposes of its reconstruction into a low-power reactor and the following operations for reduction of the radioactive waste volume, decontamination, sorting, packaging, temporary storage, and transportation for delivery to the state company “Radioactive waste”. The main purpose of the partial dismantling planning is to ensure the safety of personnel and population as well as protection of the environment.

Expose

The partial dismantling activities are part of the overall process of IRT-Sofia research reactor refurbishment. The final stage of the IRT-Sofia after the partial dismantling will be the initial stage of mounting the IRT-Sofia new systems and equipment. The criteria that should be taken into account are the following:

- Ensuring full technological possibility for mounting of the new systems and equipment;

- Removal of the dismantled equipment from the mounting sites;
- Ensuring surface contamination levels and effective dose rate below the admissible values according to the Bulgarian normative requirements.

The PPD of the IRT-Sofia equipment has been implemented in the following sequence:

- Removal of reactor internal systems;
- Removal of bottom rack from spent fuel storage;
- Removal of peripheral systems;
- Preservation of bio shield and aluminum cover of the reactor pool to prepare them to accommodate to the new low power reactor;
- The new stainless steel reactor vessel is going to be mounted into the old aluminum vessel with an appropriate material between them;
- Preservation of the reactor building for further use.

Advantages of this implementation of partial dismantling are:

- Alternative usage of the facility /the reconstructed reactor site/;
- Re-utilization of personnel experience gained during the IRT-Sofia operation.

Prior to the dismantling activities it was necessary to have organization structure for their management with clearly defined activities and responsibilities for everyone participating in them /Fig 1/.

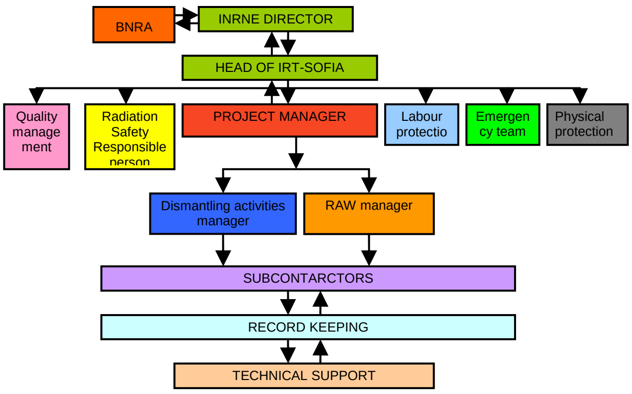

Fig 1. Organization structure

The main activities that have been carried out prior to the dismantling are the following:

- Characterization of the IRT-2000 materials has been carried out through the methods of measuring, taking samples /Fig 2/, and smears from the materials of the facilities, which are liable to dismantling and through calculation method;
- Restrictive walls and portal arch RADOS-RTM-860TS type installation and verification of its operation capability;
- Building of temporary barriers /tent/ and temporary ventilation for environmental protection from radioactive discharges during the dismantling activities;
- Temporary power supply is installed necessary for the dismantling activities;
- The condition of the 12.5 tons bridge crane and telpher was checked;
- The operability of the following technological systems was checked:
    - special ventilation in the reactor main hall /technological systems B1 and B2/;
    - special sewage;
    - power supply;
    - radiation control systems – portable and fixed;
- The site for secondary processing and decontamination of the dismantled equipment was constructed with local ventilation /Fig 3/;
- Special transport containers for radioactive waste were provided;

- The reactor main hall was cleaned of redundant equipment, protections, experimental devices, and others which will obstruct the implementation of the partial dismantling activities;
- The necessary quantity of water was drained from the reactor tank after preliminary pre-dismantling decontamination of the internal reactor equipment;
- The equipment intended for dismantling were disconnected from the power supply;
- Draining of the first circuit tubes, heat exchangers, and pumps were performed;
- The radiation conditions were checked prior to the commencement of the dismantling activities.

Fig 2. Smears and samples taking

Fig 3. Temporary tent and ventilation

During the implementation of the PPD the following working zones are defined:

- Zone 1 - dismantling of reactor pool equipment /Fig 4, Fig 5/

Fig 4. Reactor pool prior the dismantling

Fig 5. Reactor pool after the dismantling

- Zone 2 - dismantling of first cooling loop equipment /Fig 6, Fig 7/

Fig 6. First cooling loop prior the dismantling

Fig 7. First cooling loop after the dismantling

- Zone 3 - dismantling at the reactor site
- Zone 4 - dismantling of the thermal column /Fig 8, Fig 9, Fig. 10, and Fig 11/

Fig 8. The Thermal Column /TC/ prior the dismantling

Fig 9. TC after the dismantling

Fig 10. Graphite from the TC removal

Fig 11. The TC after the dismantling

- Zone 5 - secondary processing and deactivation of the dismantled equipment

The dosimetry person on duty determines the allowed time for working at each one of the zones, depending on equivalent dose rate and the accepted limits of permissible irradiation.

Obtained collective doses during the partial dismantling activities are the following:
- In the reactor pool - 2.47 man mSv;
- In the dismantling of the TC externally /in the reactor hall/ - 2.41 man mSv;
- On the reactor site - 80 man µSv;
- On the site for secondary treatment and decontamination of the dismantled equipment - 271 man µSv;
- On the premises of the first circuit loop - 123 man µSv.

RAW management involves all activities, including also the decommissioning ones, which are connected with manipulation, preliminary treatment, processing, conditioning, storage, and disposal of RAW, excluding their transportation outside the reactor site.

The quantities of RAW as a result of the partial dismantling of IRT-Sofia equipment, determined according to [3], article 5 are the following:

▪ Solid RAW, metal 2a and 2b category	1686 kg	/1680 kg planned/
▪ Solid RAW, non-metals 2a and 2b category	70 kg	/70 kg planned/
▪ Solid RAW, metal 2a and 2b category	5040 kg	/5040 kg planned/
▪ Solid RAW, non-metal 2a and 2b category	11035 kg	/10000 kg/
▪ Solid RAW, metal 1 and 2a category	2736 kg	/5800 kg planned/
▪ Liquid RAW, reactor pool	60000 l	/60000 l planned/
▪ Liquid RAW, decontamination solutions	1000 l	/6000 l planned/
▪ Liquid RAW, ion-exchange resins	160 l	/320 l planned/

The RAW obtained from partial dismantling of IRT-Sofia facilities are collected, decontaminated, packed and stored temporarily on reactor site. After RAW is packed and placed in licensed transport containers /Fig 12/ it is going to be delivered to state enterprise “RAW” for storage.

Liquid RAW from IRT were delivered to the state enterprise “RAW” for recycling and storage.

Fig 13. Transport containers for RAW

Conclusions

Final radiological survey of the reactor pool and the premises after completion of dismantling activities has been performed to ensure that the realize criteria have been met. The prepared Final report will give opportunity for the new equipment and systems mounting.

Acknowledgments

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References

[1] Act on safe use of nuclear energy, State Gazette, No. 63, 28.06.2002
[2] IAEA, Standard Format and Content for Safety Related Decommissioning Documents, Safety Report Series No. 45, 2005
[3] Regulation for safety in management of radioactive wastes, SG, no. 72, 2004

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