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Session I

International Topics and Overview on New Projects and Fuel Developments

Session I - International Topics and Overview on New Projects and Fuel

JHR PROJECT STATUS

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ABSTRACT

In Europe, nuclear electricity plays an important role and will stay for the long term a part of the energy mix since it contributes to the energy security of supply and to the reduction of greenhouse gas production.

The Jules Horowitz Reactor (JHR) is a new high performance material testing reactor under construction in Cadarache (France); start of operation is foreseen in 2014.

The JHR is a strategic infrastructure in the European Research Area, open to the international collaboration, to support safety, lifetime management and operation optimisation of current nuclear power plants, development of new types of reactors with improved resources and fuel cycle management, medical applications, material development for fusion reactor…

The design has been completed in 2005 and the preliminary safety report has been issued and is under assessment by the safety body.

A JHR Consortium gathering several industries and research institutes has been settled to finance the construction in order to have a secured and guaranteed access to the JHR experimental capacity.

1. Background

Continuous improvements in the nuclear fission industry require, on the long term, testing the behaviour of the materials and fuels used in nuclear power plants:

1 - Extending the lifespan of Generation II reactors and demonstrating the lifespan of such reactors as EPR (Generation III) is essential for countries having nuclear power plants, whatever their nuclear policy may be in the long-run.

2 - Fuel technology in nuclear power plants is continuously upgraded to achieve better performances and to optimise the fuel cycle, still keeping the best level of safety. As a key part of these performances improvement, it is necessary to experimentally explore the full range of fuel behaviour to determine fuel stability limits and determine safety margins. Fuel is and will stay a strategic topic in the long term (Generations II, III, IV) for nuclear industry.

3 - Besides the industrial goals set for the short and medium term, nuclear energy is also the subject of public policies set for the medium and long term to explore technical solutions towards sustainable development (Generation IV). Innovative materials and fuels are required to resist to high temperatures or fast neutron flux.

Up-to-date and sustainable research infrastructures, such as the Jules Horowitz Reactor (JHR), are necessary to support power reactors developments such as driven in Generation IV forum and to meet the continuous needs from light water reactors that will be in operation all along the XXIst century.

2. JHR technical scope

2.1. *For current and coming power reactor technologies*

Public and industrial needs for experimental irradiations in support of existing nuclear plants are continuous and well known. Taking benefit of the large available experience from existing MTRs, the JHR has been optimised to perform high quality experiments for existing nuclear reactors.

This encompasses for illustration

- Several capsules and loops, for PWR and BWR fuel or corrosion studies, settled on displacement systems in the reflector. This will provides high quality ramp systems to study transients or power regulated experiments.

- High neutron flux experiments for LWR experiments in the core. As a major stake, dedicated experimental devices are developed to perform low thermal gradients irradiation despite the high gamma heating.

- Improved capacity to perform safety experiments (dedicated alpha cell, displacement systems to manage safe positions after the test).

- On line fission products and helium measurement (at low as well as high level, in gas as well as in water conditions) during the fuel irradiation to optimise fuel microstructures (grain size, homogeneity, additives …) for the economy (high burn up fuel), the safety (fission products retention for severe accident impact) and the minor actinide management capacity.

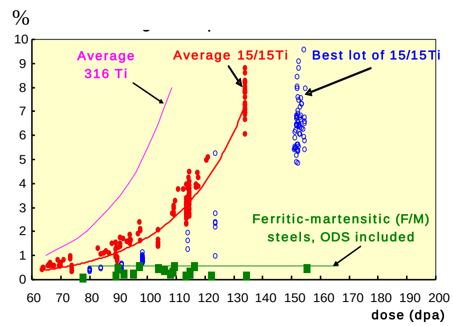
2.2. *For future reactors*

With high flux performances and the flexibility required for in depth experimental investigation, JHR is also optimised to meet future reactors needs.

Innovative materials and fuels which resist to high temperatures and/or fast neutron flux in different environments are necessary: structural materials such as graphite (VHTR and MSR), austenitic and ferritic steels (VHTR, SFR, GFR, LFR), Ni based alloys (SCWR), ceramics (GFR)… Experimental irradiations have to be carried out in order to study microstructural and dimensional evolution, but also the behaviour under stress. New fuels for the different Gen IV systems need also to be qualified in research reactors

The foreseen innovative structural materials are common to fission and fusion application.

Hoop deformation of different grades of austenitic Phénix claddings and ferrito-martensitic materials versus dose



For instance, the swelling of austenitic steel claddings limit the burn-up of SFR fuels. More important, implementing low swelling materials may allow reducing coolant channels thickness, which is one of the paths to cope with coolant void reactivity coefficient. Advanced austenitic steels of the type 15Cr/20-25Ni may allow reaching doses of the order of 150 dpa, limited by swelling and the associated loss of mechanical strength. Switching to ferritic/martensitic steels may allow reaching 200dpa. Oxide Dispersion Strengthened (ODS) ferritic steels with ~14% Cr and more could be utilised up to temperature of the order of 900°C, thanks to their improved creep resistance resulting from a dispersion of nanoscale precipitates of Yttrium oxide. Although irradiation data are scarce, the bcc crystalline structure should result in an excellent resistance to swelling.

Going to even higher temperature will require switching from metals to ceramics. Interesting candidate materials for GFR and fusion are Silicon Carbide composites. The SiCf/SiC composites with cubic stoichiometric fibres and matrix are attractive for high temperature application: up to 1000-1200°C in nominal conditions and up to ~1600°C in incidental or accidental conditions. The main issues are (i) the long term stability of dimension and physical properties, (ii) the irradiation detrimental effect on the inter-phase and its capability of deviating cracks and thus providing reasonable fracture toughness, (iii) the required higher creep strength of the fibre to bear the thermal-mechanical loading in long term service under high temperature and neutron flux, (iv) the type of mechanical damage under irradiation and creep. The behaviour of these materials under coupled irradiation and mechanical stress is a major challenge.

The development and implementation of these advanced metallic alloys and ceramic composites will need breakthroughs in material science, from process development (material fabrication, assembling…) to performance assessment (behaviour under coupled temperature, mechanical stress and irradiation). These challenges require comprehensive tests and in-depth investigations of structural materials and fuel components to be addressed by a high performance experimental irradiation infrastructure such as Jules Horowitz Reactor (JHR) and ultimately in an experimental fast neutron reactors.

3. Situation of Material Test Reactors in Europe

European Material Test Reactors (MTRs) have provided essential support for nuclear power programs over the last 40 years. Associated with hot laboratories for the post irradiation examinations, they are structuring research facilities for the European Research Area in the fission domain.

Countries	Reactor	Operation	Power (MWth)
Czech Re.	LVR15	1957	10
Norway	Halden	1960	19
Sweden	R2	1960-2005	50
Netherland	HFR	1961	45
Belgium	BR2	1961	100
France	OSIRIS	1966	70

However, in Europe, MTRs will be more than 50 years old in the next decade and will face increasing probability of shut-down due to their obsolescence. The reactor R2 has been shut down in 2005 and OSIRIS will be shut down at the beginning of the next decade. Renewing the experimental irradiation capability meet not only technical needs but important stakes such as maintaining a high scientific expertise level by training of new generations of searchers, engineers and operators.

4. The Jules Horowitz material test Reactor

To cope with this context, the Jules Horowitz Reactor Project (JHR) has been launched as a new MTR in Europe to be implemented in Cadarache (south of France); start of operation is foreseen in 2014 [1].

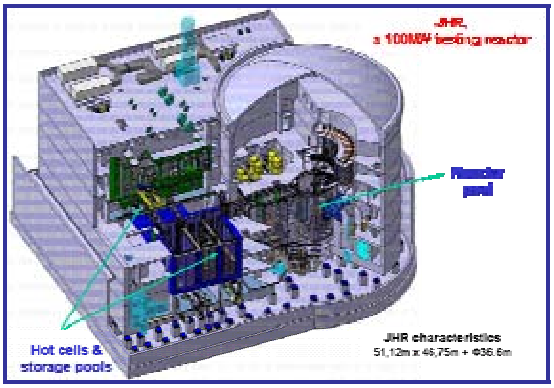
The JHR start of operation is foreseen in 2014. The definition studies are completed (2003-2005). The present development studies (2006-2007) is dedicated to the supply of components, to the qualification of key components, to a major licensing step (the preliminary safety analysis report was submitted to the Safety Body in February 2006), to the preparation of the site in Cadarache. The public consultation and public enquiry were completed respectively in spring 2005 and February 2007 without difficulty.

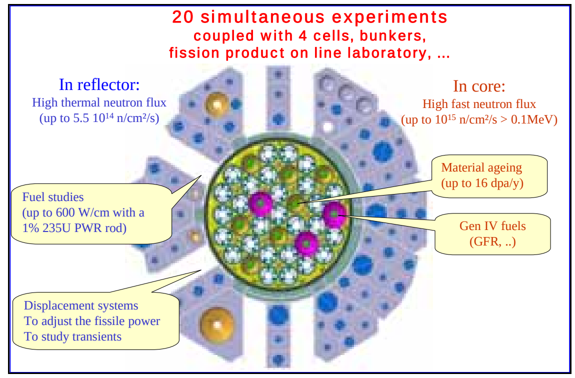
The JHR is a 100MW tank pool reactor.

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

The reactor building is divided into two zones. The first zone contains the reactor hall and the reactor primary cooling system. The second zone hosts the experimental areas in connection with in pile irradiation (eg., typically 10 loops support systems, gamma scanning, fission product analysis laboratory etc.). The Fission Product Laboratory will be settled in this area to be connected to several fuel loops ether for low activity gas measurements (HTR, …) or high activity gas measurements (LWR rod plenum, …) or water measurements (LWR coolant, …) with gaseous chromatography and mass spectrometry. Bunkers and laboratories in the experimental area will use 300m² per level on 3 levels.

Hot cells, laboratories and storage pools are located in the nuclear auxiliaries building. The experimental process will make use of two hot cells to manage experimental devices before and after the irradiation. Safety experiments are an important objective for JHR and require an "alpha cell" for an effective management of devices with failed experimental fuel. A fourth hot cell will be dedicated to the transit of radioisotope for medical application and to the dry evacuation of used fuel.





The core (600 mm fuel active height) is cooled and moderated with water. The core area is surrounded by a reflector (water and beryllium elements) which optimizes the core cycle length and provides intense thermal fluxes in this area.

The fuel element is of circular shape. The JHR is designed to be operated with a reprocessable high density low enriched fuel (5U enrichment lower than 20%, density 8 g/cm3). CEA is deeply committed in the development of the UMo fuel within an international collaboration. In case the UMo is not available at the industrial level, the JHR may be started for a limited period with an U3Si2 fuel at typically 27% U5.

Irradiation devices can be placed either in the core area (in a fuel element central hole or in place of a fuel element) or in the reflector area. In core experiment will address typically material experiments with high fast flux capability up to 5 10^{14} n/cm²/s (resp. 10^{15} n/cm²/s) perturbed fast neutron flux with energy larger than 1MeV (resp. 0,1MeV), that is up to 16 dpa/year with 260 full power operation days per year.

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

5. European and international collaboration

5.1. The JHR Consortium

A JHR Consortium has been set up to finance the JHR construction and to provide to funding Members a secured and guaranteed access rights to the JHR experimental capability.

In early 2007, this Consortium gathers industries and research institutes from several European Member States such as France (CEA, EDF, AREVA), Belgium (SCK), Czech Republic (NRI), Finland (VTT), Spain (CIEMAT as a representative of a pool of industries and public bodies).

JHR is a mature project of European interest and is identified as a research infrastructure of pan-European interest by the European Strategic Forum for Research Infrastructure (ESFRI[1]). Following the ESFRI

[1] ESFRI established a European roadmap for the construction of the next generation of large-scale Research Infrastructures in close collaboration with the European Commission and based on an international peer-review.

process and through successive steps in the 7th FP and 8th FP, the European Commission, represented by the Joint Research Centre, will become a full Member of the JHR Consortium in order to have access to JHR experimental capacity for implementing the European Community policy.

Discussions are ongoing with other European and non-European countries to enlarge the JHR Consortium.

The JHR funding process was driven by two principles: i) a balance contribution between private and public funding, a strong commitment from the hosting country with the participation of the European and international fission community. This funding scheme appeared as an effective way to renew research infrastructures managed as user-facilities for the benefit of a broad community.

The JHR Consortium Agreement binds Members contributing to the financing of the JHR construction. CEA is the owner and nuclear operator of the JHR.

Members contributing to the financing of JHR construction will have guaranteed and secured access rights to experimental locations in the reactor in order to perform their Proprietary Experimental Programs. In parallel, a Joint Program will be opened to international collaboration in order to address issues of common interest.

Operation costs are paid only for utilised rights; access rights can be utilised partly or in totality each year. Non utilised access rights can be cumulated from one year to the following.

Non-Member will have access to the JHR facility, under decision of the JHR Consortium Board, and within conditions defined by the strategic and commercial policy of the JHR Consortium.

5.2. Experimental devices

The development of JHR experimental devices offers a unique opportunity to develop a new generation of experimental devices meeting up-to-date scientific and technological state of art as well as anticipated users' needs. Development of experimental devices and related programmes requires international collaborations to benefit from the available large experience and to increase the critical mass of cross-disciplinary competences.

Several scientific topics have been assessed in the European 6th framework program JHR coordination action (2004-2005) [2]. In parallel, a new impetus has been put on instrumentation technologies by the creation of a joint lab between CEA and SCK•CEN [3]. Several devices have been investigated within the JHR project to optimise the interfaces with the JHR facility [4, 5].

A new FP6 project (MTR+I3, "MTR plus" integrated infrastructure initiative) has been launch with 18 European partners for the period 2006-2009 with the purpose of building up the European material testing reactor community, of supporting state of the art design of innovative irradiation devices:

Mechanical Testing Device	Mechanical testing devices under mechanical loads
	Corrosion under irradiation
Fuel Testing devices	Neutron screen development for fuel and transmutation studies
	Transmutation
	Power transient systems and neutron screen development for LWRs
	Water Chemistry
	Fission Product measurement
Non LWR Loop design	Gas loop
	Heavy liquid metal loop
	Supercritical water loop
	Miniaturised components
Safety tests instrumentation	

6. Conclusion

The JHR will provide for a large part of the century the experimental irradiation capability in Europe for the benefit of international industries and public stakeholders.

The year 2007 is a major milestone for the JHR project with the launch of the JHR Consortium gathering a first set of funding partners.

The establishment of the JHR Consortium together with the networking of relevant research laboratories is a most important step in the building of the coming generation of R&D competences and infrastructure. This is required to cope with R&D needs to support present and future power reactors.

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IAEA's SUBPROGRAMME ON RESEARCH REACTORS: TECHNOLOGY AND NON-PROLIFERATION

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ABSTRACT

For nuclear research and technology development to continue to advance, research reactors (RRs) must be safely and reliably operated, adequately utilized, refurbished when necessary, provided with adequate proliferation-resistant fuel cycle services and safely decommissioned at the end of life.
The IAEA has established its competence in the area of RRs with a long history of assistance to Member States in improving their utilization, by taking the lead in the development of norms and codes of good practice for all aspects of the nuclear fuel cycle and in the planning and implementation of decommissioning. The IAEA Subprogramme on RRs is formulated to cover a broad range of RR issues and to promote the continued development of scientific research and technological development using RRs. Member States look to the IAEA for coordination of the worldwide effort in this area and for help in solving specific problems.
In this paper a description of the ongoing and planned activities under the IAEA's Subprogramme on RRs for the years 2007-2009 is presented. Special emphasis is put on new international collaborative undertakings, like the new IAEA's Technical Working Group on RRs.

1. Introduction

The IAEA coordinates and implements an array of activities that together provide broad support for RRs. As with other aspects of nuclear technology, RR activities within the IAEA are spread through diverse groups in different Departments. To ensure a common approach a Cross-Cutting Coordination Group on Research Reactors (CCCGRR) has been established, with representatives from all departments actively supporting RR activities.

Utilization and application activities are generally lead from within the Department of Nuclear Applications (NA). With respect to RRs, NA is primarily carrying out IAEA activities to assist and advise Member States in assessing their needs for research and development in the nuclear sciences, as well in supporting their activities in specific fields.

Safety and Security aspects of RRs operation and decommissioning are handled by the Department of Nuclear Safety and Security (NS).

The technological, fuel cycle and operational aspects of RR management are supported by the Department of Nuclear Energy (NE). NE is primarily working to support RR organizations in their pursuit of often diverse strategic objectives within the context of modern RR operational constraints. Today RR operating organizations must overcome challenges such as the ongoing management of ageing facilities, pressures for increase vigilance with respect to non proliferation, and shrinking resources (financial as well as human) while fulfilling an expanding role in support of nuclear technology development within an evolving “nuclear renaissance”.

In addition, the Department of Nuclear Safeguards is responsible for the control of the fissile material for RR and the Department of Technical Cooperation (TC) supports RR activities for the principal benefit of RRs in developing countries. TC is subsequently supported by NA, NS, and NE who assist in the development and implementation of relevant TC projects within their specific fields of expertise.

The Subprogramme on RRs is under IAEA’s Programme D on Nuclear Science. Implementation of the IAEA Subprogramme on RRs (IAEA code D.2) is shared between NE and NA while separate subprogrammes, managed by NS, deal with RR safety and security. In this paper, only the activities managed by NE and NA under the subprogramme on RRs are presented, including a complete description of the ongoing and planned activities for the years 2007-2009. Special emphasis is put on new international collaborative undertakings, like the IAEA’s Technical Working Group on RRs. The IAEA organization chart is presented in Fig. 1, the Subprogramme on RRs is implemented by the RRs Unit in the Division of Nuclear Fuel Cycle and Waste Technology and the Physics Section in the Division of Physical and Chemical Sciences.

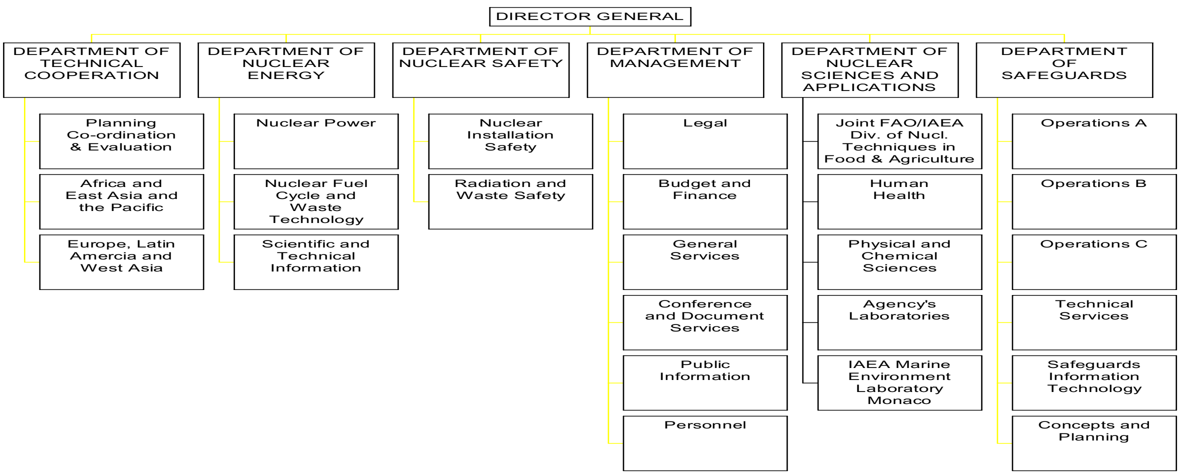

Fig. 1. IAEA organization chart

2. Subprogramme on RRs

For nuclear research and technology development to continue to advance, RRs must be safely and reliably operated, adequately utilized, refurbished when necessary, provided with adequate proliferation resistant fuel cycle services and safely decommissioned at the end of life. Moreover, since about 60% of the operating RRs in the world are over 30 years old, ageing core materials and the technology of ageing management are priority issues in the majority of Member States with aged RRs.

The IAEA has established its competence in the area of RRs with a long history of assistance to Member States in improving their utilization, by taking the lead in the development of norms and codes of good practice for all aspects of the nuclear fuel cycle and in the planning and implementation of decommissioning. This Subprogramme is formulated to cover a broad range of RR issues and to promote the continued development of scientific research and technological development using RRs. Member States look to the IAEA for coordination of the worldwide effort in this area and for help in solving specific problems.

From the traditional support of fundamental research and training, the focus of the Subprogramme has recently moved to helping facilities with strategic planning to increase use in more sustainable areas such as isotope production and materials modification, in refurbishment and replacement of ageing equipment, in the management of increasing spent fuel inventories and in planning decommissioning. The Subprogramme supports regional and interregional thematic collaborations, networking and centres of excellence for enhanced utilization of RRs.

To contribute to non-proliferation efforts worldwide, support of RERTR and the programmes of returning of RR fuel to the country of origin has been strengthened. To address RR support needed for the evolutionary and innovative nuclear power reactors and fuel cycles, the subprogramme promotes international collaboration to assess projected needs, with a long term time horizon, for RRs on a global and regional basis.

Funding reductions and limited succession planning have strained available resources of a number of RRs, pressurising many facilities to pursue commercial activities to remain in operation. It is in this context that modern RRs are to be used to conduct advanced research in support of innovative nuclear development (in most cases to very aggressive schedules) and training. To support the scientific, educational and commercial demands being placed in present times on RRs, a new project addressing RR Operation, Maintenance, Availability and Reliability has been initiated in 2007.

The main objectives of the RRs Subprogramme are:

- To increase the capabilities of interested Member States to safely and reliably carry out scientific research and technology development at RRs, conduct ageing management, decommissioning, refurbishment and modernization; and
- To enhance the potential of interested Member States to plan new facilities when needed, to cope with RR fuel cycle issues and reduce proliferation risks by conversion from Highly Enriched Uranium (HEU) to Low Enriched Uranium (LEU) of RRs cores and targets used for radioisotope production, and to repatriate fuel to the country of origin.

3. Projects under the Subprogramme on RRs

Organization of the Subprogramme on RRs in projects is shown in Fig. 2.

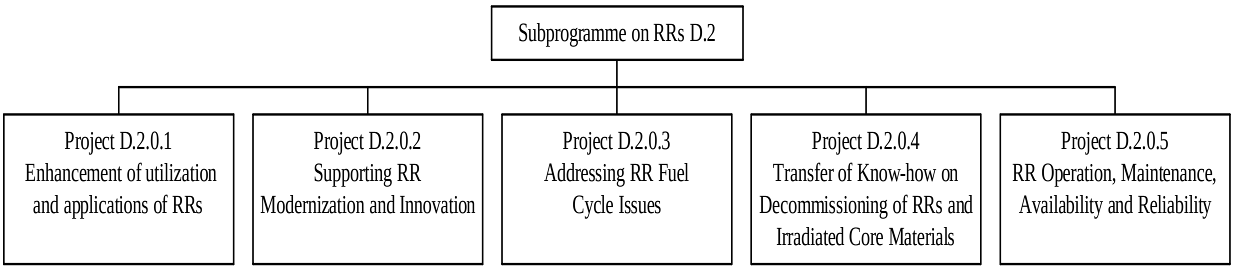

Fig. 2 Projects under the Subprogramme on RRs

A brief description of each one of the projects is given in the following paragraphs.

3.1. Project D.2.0.1: Enhancement of utilization and applications of RRs

RRs have played and continue to play a key role in the development of the peaceful uses of atomic energy. Their contribution to the education and training of scientists and engineers for the whole nuclear community is well documented. In addition they have played an important role in development of science and technology, in the production of isotopes for medicine and industry, in non-destructive testing of materials, in analytical studies, in the modification of materials, in research in various areas of science and in support of nuclear power programmes.

Existing RRs, especially in developing countries, should be supported on an individual level for example in radioisotope production, beam line applications, and analytical services as well as in regional or collaborative efforts in education and training. The sharing of resources will increase the utilization on the one hand and on the other hand pave the way for the decommissioning of under-utilized ageing reactors, without depleting knowledge base and human resources.

We give here an overview of this project formulated to cover the broad range of possible applications and to promote the continued development of scientific research and technological development using RRs.

The main objectives of this project are:

- To enhance RR utilization in Member States for many practical applications, such as isotope production, neutron radiography, neutron beam research and material characterization and testing consistent with RR features; and
- To increase cooperation between different RR centres.

Some of the activities proposed to be carried out under this project are:

- Develop a RR assessment methodology on strategic networking;
- Update RR Database (RRDB). Incorporate user need modification/changes;
- Organize a Technical Meeting (TM) on RR application for materials under high neutron fluence and particle flux in energy sector;
- Coordinate a Coordinated Research Project (CRP) on “Development, characterization and testing of materials using neutrons and complementary techniques” and “Development and application of the techniques of residual stress measurements in materials”;
- Organize a technical meeting on strategic planning and regional networking for sustainability;
- Provide technical support for the IAEA-TC projects involving utilization and applications of RRs;
- Support and participate in meetings pertinent to RRs and neutron based techniques;
- Prepare report on data acquisition and analysis for neutron beam line experiments; and
- Prepare a report on specific application of RRs.

In addition, publication of technical documents based on the output of CRPs and TMs will help in disseminating knowledge and capacity building for RR operators and users.

3.2. Project D.2.0.2: Supporting RR Modernization and Innovation

Member States, especially developing Member States, involved in planning or carrying out refurbishment and modernization of RRs often look to the IAEA for advice and assistance and to exchange information and ideas. Similarly, IAEA assistance is requested when new RRs or major innovative systems, such as in-core loops or cold sources, are being planned or constructed. Regional and interregional thematic collaborations, networking and centres of excellence are being increasingly considered worldwide as an appropriate way to enhance utilization of RRs. This project is designed to fulfil these needs by collecting and sharing relevant information, including best practices and lessons learned.

The main objective of this project is:

- To increase the competence of interested Member States to plan and implement large scale refurbishment and modernization of RRs, and to plan and implement construction of new RRs or major RR systems.

Some of the activities proposed to be carried out under this project are:

- Develop regional RR networks and centres of excellence;

- Provide advice and assistance as requested to RR planning, modernization or refurbishment;
- Hold international workshops on modernization and refurbishment of RRs;
- Coordinate a CRP on innovative methods in RR analysis (2008–2011); and
- Support TC projects on modernization and innovation.

3.3. Project D.2.0.3: Addressing RR Fuel Cycle Issues

The IAEA has been involved for more than twenty years in supporting international nuclear non-proliferation efforts associated with reducing the amount of HEU in international commerce. IAEA projects and activities have directly supported the RERTR programme, as well as directly associated efforts to return RR fuel to the country where it was originally enriched. IAEA efforts have included the development and maintenance of several data bases with information related to RRs and RR spent fuel inventories that have been essential in planning and managing both RERTR and spent fuel return programmes. After the announcement of the Global Threat Reduction Initiative (GTRI) by United States Secretary of Energy Spencer Abraham on May 2004 at the IAEA headquarters in Vienna and following recommendations of the 2004 RERTR meeting, held in Vienna in November 2004, IAEA support of RERTR and the programmes of repatriation of RR fuel to the country of origin have been strengthened and a comprehensive number of new activities have been initiated in 2005 and 2006.

At the back end of the fuel cycle, hundreds of RRs worldwide, both operational and shut down but not yet decommissioned, are storing spent fuel on site. In many cases, this RR spent nuclear fuel (RRSNF) is old (more than 30 years) and physically degraded. Therefore the continued safe, reliable and economic handling, management and storage of RRSNF of all types, standard, failed and experimental, is a serious issue for almost all Member States with RRs. In particular, most RRSNF is aluminium clad which is particularly vulnerable to corrosion. Many Member States, especially those having RRs but no power reactors, are expressing concerns about final disposition of RR spent nuclear fuel. Non-proliferation and environmental concerns associated with RRSNF have become just as important, if not more so, as the above mentioned technical concerns. This project is designed to address these issues.

The main objective of this project is:

- To strengthen the capability of interested Member States having RRs to deal with all fuel cycle issues including fuel development, fabrication and qualification, mitigation of identified health, and environmental vulnerabilities associated with spent fuel management; and to promote conversion from HEU to LEU, repatriation of spent fuel to its country of origin, and regional solutions to the back end of the fuel cycle.

Some of the activities proposed to be carried out under this project are:

- Maintain a database on spent fuel from research and test reactors, publish summary statistics periodically;
- Provide advice and assistance as requested to RRs with corroded or otherwise degraded spent fuel;
- Support spent fuel assessment teams for the preparation for shipment of RR spent fuel;
- Update the RR core conversion guidebook to include conversion to high density U-Mo fuels;
- Prepare a technical document on good practices for the management and storage of RR spent fuel;
- Update the guidelines documents on the technical and administrative procedures required for the shipment of spent fuel;
- Support national projects on RR fuel and fuel cladding;
- Prepare a technical document on the economic aspects of the RR nuclear fuel cycle;
- Support activities related to RR conversion and return of RR spent fuel to the country of origin;

- Prepare a technical document on the use of LEU in accelerator driven subcritical assemblies;
- Coordinate an International Technical Working Group on RRs;
- Coordinate a CRP on small-scale, indigenous production of Mo-99 using LEU or neutron activation;
- Coordinate a CRP on conversion of miniature neutron source RRs (MNSR) to low enriched uranium (LEU);
- Evaluate RR support needed for the innovative nuclear power reactors and fuel cycles; and
- Prepare a technical document on good practices for water quality management at RRs.

3.4. Project D.2.0.4: Facilitating Transfer of Know-How on Decommissioning of Research Reactors and Irradiated Core Materials

A large number of RRs are approaching the end of their useful lifetime and become likely candidates for decommissioning. Within the broader range of nuclear facilities, the decommissioning of RRs presents some unique features including experimental devices, unusual materials, and often proximity to populated areas. A lot of RRs are situated in Member States not having adequate resources for the decommissioning of their reactors. Decommissioning is the inevitable legacy of operation of RRs and needs timely and effective management. This includes management of the materials that result from the decommissioning project. To this end, accurate assessments of the material arising from all sources are required and methods/technologies should be available for Member States to minimize arisings and any environmental impact from the wastes. In many instances the radiation damage mechanisms of core materials, especially after high fluences are poorly understood. With many RRs now beginning to decommission or undergoing extensive refurbishment, it has been pointed out that an opportunity to take samples from the core materials and to study their microstructures is being squandered. Besides providing valuable information for decommissioning waste management, the life extension of RRs and input for improved materials for new reactors, the promotion of information exchange and effective coordinated research effort in this area has the potential to increase the understanding of fundamental ageing mechanisms of reactor structural materials.

The main objectives of this project are:

- To increase the capability in interested Member States with RRs to plan and implement decommissioning; and
- To improve understanding of the ageing of irradiated materials and advanced materials for reactor core applications.

Some of the activities proposed to be carried out under this project are:

- Prepare a technical report on decommissioning of RRs and other small nuclear facilities under constrained resources;
- Prepare a technical document on how to make use of samples from the cores of decommissioning or refurbishing reactors to improve understanding of ageing irradiated core materials;
- Prepare a technical document on cost estimates for decommissioning of RRs;
- Prepare a technical report on pool side inspection of RR fuel; and
- Coordinate a CRP on ageing of irradiated reactor core materials.

3.5. Project D.2.0.5: Research reactor operation, maintenance, availability and reliability

Since the mid 1980’s, investment in nuclear RR facilities and infrastructure has decreased significantly compared with earlier decades. Many older facilities have been decommissioned, permanently shutdown, or are faced with probable shutdown in the very near future. Funding reductions and limited succession planning have strained available resources, pressuring many facilities to pursue commercial activities to remain in operation. It is in this context that modern RRs are being tasked to conduct advanced research in support of innovative nuclear development (in most cases to very aggressive schedules) and training. To support the scientific, educational and commercial demands being placed in present times on RRs, many are looking to optimize operations and maintenance activities to ensure the most cost effective completion of their assigned missions. Many Member States look to the IAEA for advice, ideas and information exchange on these topics. This project aims to fulfil these requests by documenting good practices and lessons learnt as an element for strengthening the operational management.

The main objective of this project is:

- To increase the competence of interested Member States to develop operations and/or maintenance plans and implement these plans to optimize facility availability and reliability.

Some of the activities proposed to be carried out under this project are:

- Prepare a technical document on RR availability and reliability;
- Prepare a technical report on RR quality management system development;
- Coordinate a CRP on on-line monitoring systems for RRs; and
- Support TC projects involving operation, maintenance, availability and reliability improvements.

4. Technical Working Group on Research Reactors (TWGRR)

The TWGRR, a new international collaborative undertaking under IAEA’s Subprogramme D.2, will consist in a group of experts to provide advice and support programme implementation, reflecting a global network of excellence and expertise in the area of RRs.

4.1. Scope

The TWGRR will focus its work on activities related to all types of RRs, including critical assemblies, subcritical assemblies and pulsed reactors. Also included in the scope are facilities for: RR fuel fabrication, RR fuel development, RR fuel post irradiation and RR spent fuel storage. All managerial areas involved in the operation of the above listed types of facilities are included in the scope of the TWGRR. The TWGRR will give the necessary attention to all of its relevant aspects, including operation, utilization, nuclear fuel cycle, maintenance, refurbishment, modernization, quality assurance, new designs and decommissioning. The TWGRR will especially address the projected needs for RRs on a global and regional basis with a long-term time horizon. The scope of the TWGRR cuts across all IAEA organizational structures dealing with RRs.

4.2. Functions

The functions of the TWGRR are:

- To provide advice and guidance, and to marshal support in their countries for implementation of the IAEA's programmatic activities in the areas of RR operation, utilization, nuclear fuel cycle, maintenance, refurbishment, modernization, quality assurance, new designs and decommissioning;
- To provide a forum for information and knowledge sharing on national and international programmes development in the area of RR operation, utilization, nuclear fuel cycle, maintenance, refurbishment, modernization, quality assurance, new designs and decommissioning;
- To act as a link between the IAEA’s activities in specific area and national scientific communities, delivering information from and to national communities;
- To provide advice on preparatory actions in Member States and the IAEA’s activities in planning and implementing coordinated research projects, collaborative assessments and other activities as well as the review of the results on RR activities within their scope;
- To develop and/or review selected documents from the Nuclear Energy Series, assess existing gaps and advise on preparation of new ones, in the scope of their field of activity;

- To identify important topics for discussion at the Standing Advisory Group for Nuclear Energy (SAGNE) and contribute to status reports, technical meetings and topical conferences in the field of RRs;
- To provide guidance to member states in order to improve and optimize the utilization of RRs, in national, regional and extra regional contexts. When considered appropriated, to provide guidance in order to define actions for reactors that have been placed in shutdown condition;
- To identify relevant issues and topics which might increase cooperation among different RR centres, particularly in various regions of the world;
- To encourage and facilitate regional and international collaborative programmes in the construction and utilization of RRs, and to be a forum for discussion of issues related to impediments and challenges that can be faced by the concept of a regional RR park;
- To propose the realization of events that will work as a forum for the exchange of information among the participants in all areas indicated in **4.1**. Such events include, technical meetings, workshops, international symposiums and conferences;
- To address the projected needs for RRs on a global and regional basis with a long-term time horizon; and
- To encourage participation of young professionals, as appropriate, in IAEA activities.

4.3. Membership

Members of the TWG on RRs shall be appointed by the Deputy Director General, for Nuclear Energy, following consultation with the respective national authorities or organizations.

Members of the TWG on RRs:

- Shall be recognized experts that worked with RRs having extensive links with national technical communities. There shall be appropriate representation on the Group from RR operators, fuel cycle, materials specialists, designers of RRs, researchers and users of RRs;
- Are to serve for a standard length of four years;
- Shall participate in the Group in their personal capacity and shall provide as appropriate views on national policies and strategies in the technical field; and
- May as appropriate bring experts to provide additional information and share experience in the meetings of the TWG.

The Deputy Director General of the Department of Nuclear Energy may from time to time also co-opt additional members and/or invite observers from other Member States and international or regional organizations on an ad-hoc or continuing basis.

4.4. Methods of Work and Deliverables

The TWG on RRs will determine its own methods of work, including preparation of its Agenda, establishment of special groups, keeping of records and other procedures, and report on its findings to SAGNE. The activity of the TWG on RRs between periodic meetings shall be coordinated by a Scientific Secretary taking into due consideration the relevant recommendations of the TWG and SAGNE. Following each meeting the TWG on RRs shall provide the Deputy Director General with a report on its achievements and recommendations. The report shall be also published on the WEB in a format and content agreeable to all members. The Chairman of the TWG shall communicate to SAGNE recommendations for strategic development or other important topics to be discussed at SAGNE meetings.

4.5. Meetings

The TWG on RRs will meet at regular intervals but no more than once in a year with each meeting lasting up to five workings days. Extraordinary meetings may be called when required.

5. Conclusions

The IAEA subprogramme on RRs maintains the focus on the different facets of RRs for their effective utilization and management. In order to address increasingly important non-proliferation concerns, emphasis is put on the support of Member States' work in the framework of the GTRI on RR core conversion from HEU to LEU, conversion from HEU to LEU of targets used for radioisotope production, the repatriation of RR fuels to the country of origin, and the global clean out of RR fissile material, including experimental or exotic fuels and sources. To help achieving an enhanced utilization of RRs, the subprogramme supports the establishment of regional and interregional thematic collaborations, networking and centres of excellence. To address the issue of RR support for evolutionary and innovative nuclear power reactors and fuel cycles, the subprogramme promotes international collaboration to assess projected needs over the long term for RRs on a global and regional basis. To support the scientific, educational and commercial demands being placed at present on RRs, a new project on RR operation, maintenance, availability and reliability has been initiated in 2007.

The new TWGRR will provide a unique forum for information and knowledge sharing on national and international programmes in all technical areas of RR and will provide advice and guidance for implementation of the IAEA's programmatic activities in those areas.

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REFURBISHMENT AND PERSPECTIVE FOR ILL

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ABSTRACT

The ILL has been pursuing three major upgrade operations, involving its reactor, its scientific instruments, and the support facilities offered by the site as a whole. The last ten-year safety reviews of the high-flux reactor were held in 1994 and 2002. The first review followed the replacement of the reactor block. The second focused on the installations' compliance with new Safe Shutdown Earthquake standards (0,6g at 6 Hz), with a major refit programme from 2003 to 2006. During this period reactor operations could nevertheless be maintained for 150 days per year, and the new Key Reactor Components programme was launched. In addition, neutronic studies were performed with a view to reducing the consumption of uranium and being able to explore conversion. In parallel to, and beyond, the refit, the performance of ILL's experimental facilities is being enhanced through the long-term on-going Millennium Programme. Finally, in order to attract more and more scientists to the ILL, ESRF and EMBL, the three institutes are together pushing for a development of their joint site, as well as promoting partnerships for science and technology. ILL is thus ensuring both its users and funders that its reactor remains in state-of-the-art condition; we are now ready for 20 more years of operation, ensuring a reliable flux of quality neutrons for investigative purposes.

Introduction

This presentation develops the following items:

- Previous refurbishment of the reactor (replacement of the Reactor Block …)
- Refit programme
- Four parallel 10-year investment programmes:
    - The renewal of key reactor components;
    - The provision of new moderators, instruments and techniques;
    - The creation of Partnerships for Science and Technology;
    - The partnership to develop the overall site.

These programmes assume that the lifetime of the Institute will extend at least to 2024 and probably beyond.

The very high flux delivered by the HFR makes possible specific high performance experiments, such as:

- Magnetic structure determination under hydrostatic pressure conditions (above 7 GPa),
- Diffraction studies for minute sample volumes (less than 0,001 mm),
- Physical measurements on atoms which present a large nucleon excess,
- Actinide transmutation in compliance with French regulations on nuclear waste management.

Neutrons provide a powerful tool for investigating nature at all levels, from testing theories about the evolution of the universe to elucidating the complex processes of life. The ILL offers experimental facilities and expertise covering all these areas:

- Chemistry and materials (catalysts, pharmaceuticals, hydrogen-storage materials, environmentally-friendly fuels, earth science …),
- Engineering (operation of engines and efficient combustion, composite materials, welding and surface treatments ...),

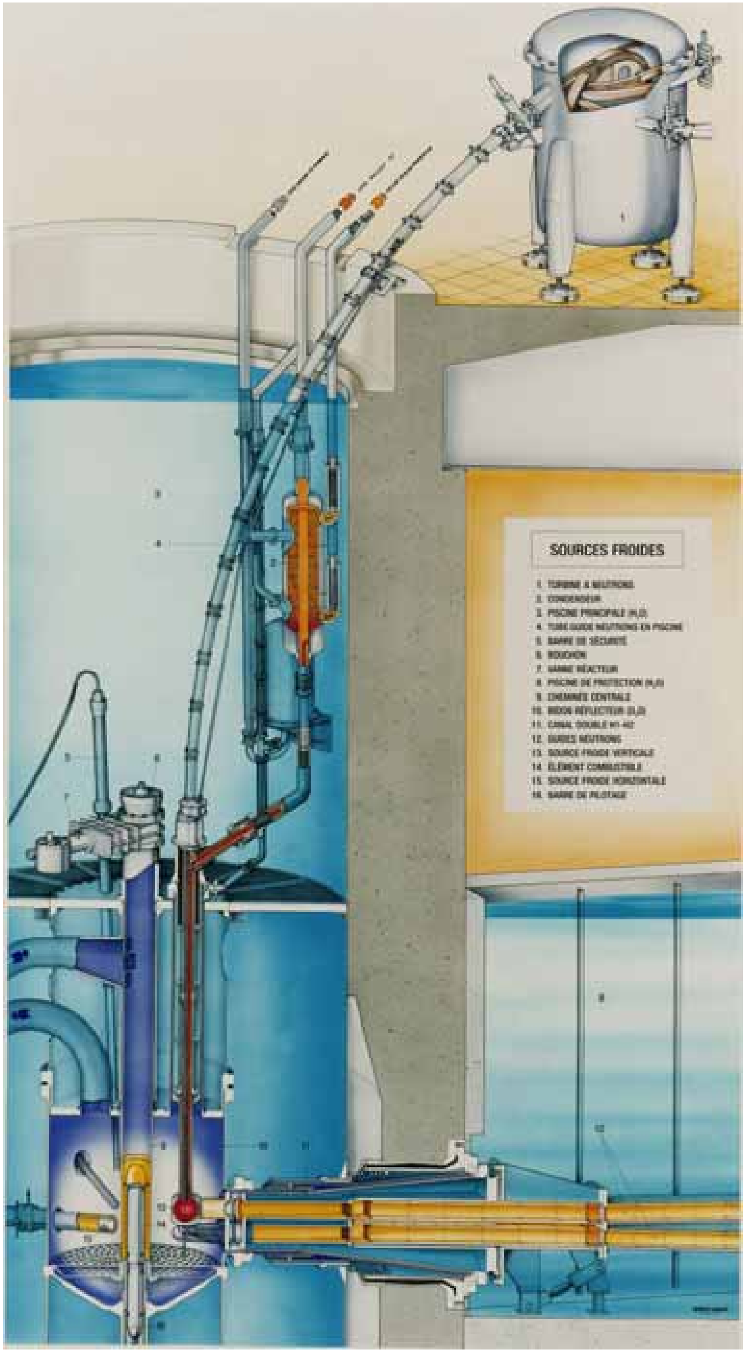
- Magnetism and electronics (exotic magnetic behaviour, molecular magnets, high-temperature superconductors, planetary magnetism …),
- Liquids and soft matter (plastics, cosmetics, viscosity, multi-component lubricants …),
- Fundamental physics (basis of quantum mechanics, fundamentals of the gravitational force, refining theories of particles and force, cosmological evolution …),
- And biology (enzymatic mechanisms, cell membranes, digestive processes, drug delivery and action, gene therapy …).

Previous refurbishment of the reactor

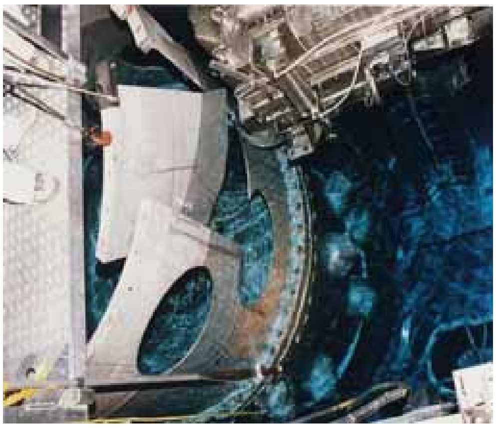
The main steps have been:

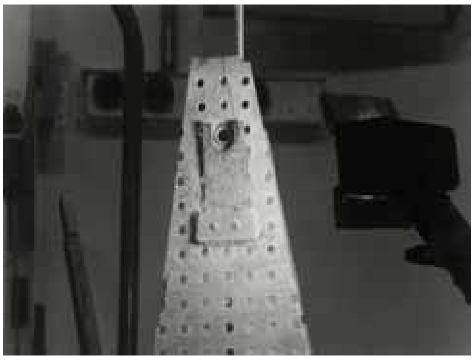
- 1985: A new vertical cold source equipped with a vertical and curved guide tube connected with a turbine. This device feeds ultra-cold neutrons to the experimental instruments.

- 1987: a second (horizontal) cold source. It has been positioned in the front part of a horizontal beam tube. It feeds the second guide hall ILL 22.

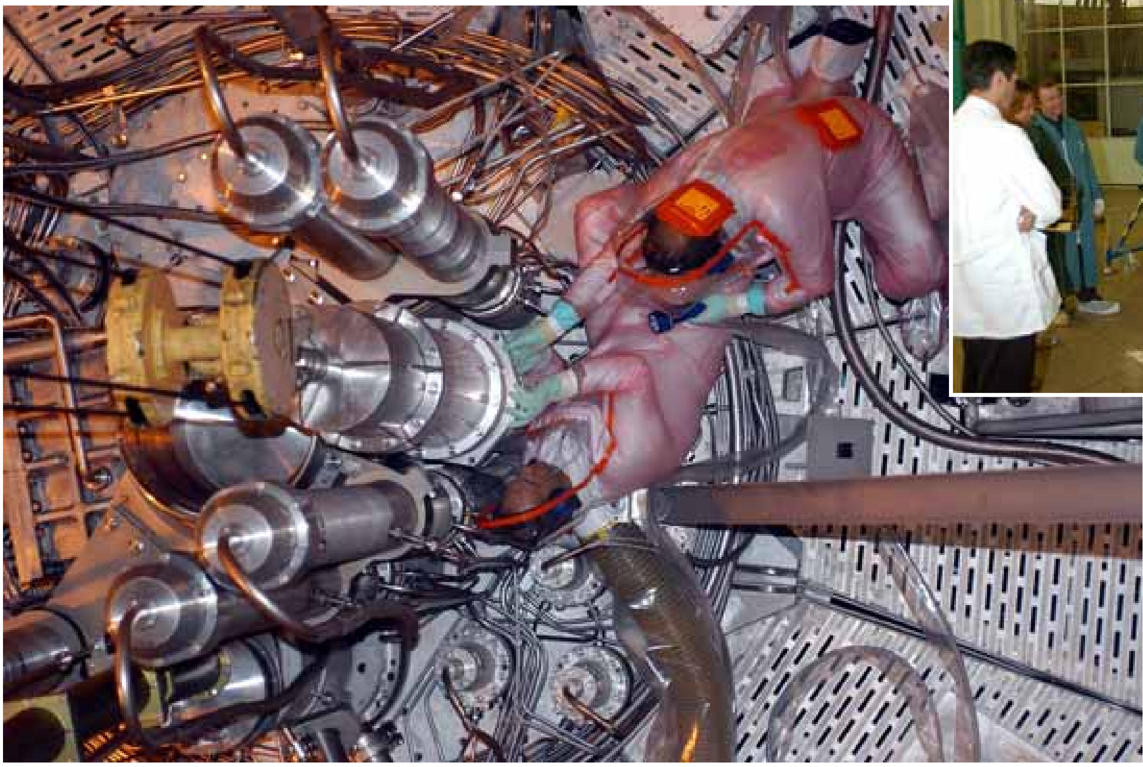


- From 1991 to 1994: replacement of the reactor block consequently the observation of an uncommon trace on the upper antiturbulence grid.





- 2002: replacement of the hot source after 30 years of operation. Some minor modifications were introduced in the light of experience: the thermocouples were secured in position; the central thermocouple now has improved heat resistance; the design has been simplified by eliminating a redundant thermocouple. The source works perfectly at 2000°C, and its three beam lines are highly appreciated by the researchers.



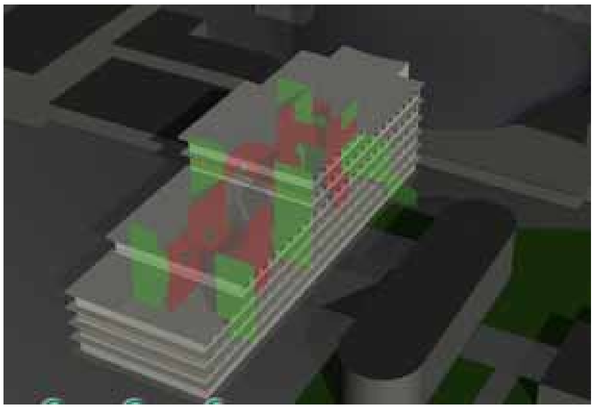
- 2004: replacement of the aluminium beam tube H9 by a zircaloy tube. This has extended its service life, allowing extended reactor operations and reduced radiation exposure for workers.

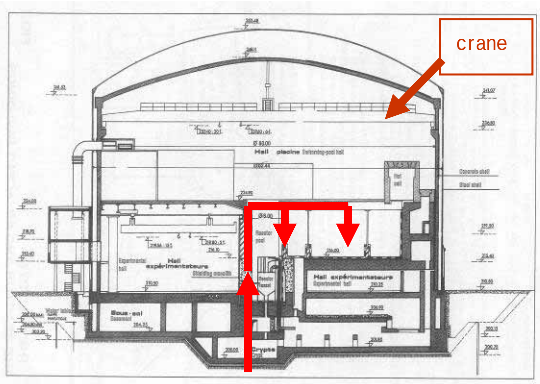
Refit Programme

Following the last safety review in 2002, and in the perspective of 20 more years of operation, a huge amount of work was performed between 2003-2006 to reinforce the reactor and ensure its compliance with Safe Shutdown Earthquake requirements. Throughout the period of this major refit the ILL was able to maintain user service with three 50-day reactor cycles per year. The work included:

- Reinforcement of the transfer canal
- Deconstruction of the concrete structures on the upper floor of the reactor, including the nuclear ventilation system
- 3 new ventilation units to replace the old one
- Comb connexion between the slab (upper floor) and the concrete containment, securing the slab to the containment wall rather than to the wall of the reactor pool, thus reducing stresses
- New seismically qualified circuits: new seismic trip channels, safety valves, leak-tight containment penetrations…
- Modification of the buildings surrounding the reactor: the office building has been reinforced and the front part of the guide halls has been sectioned to avoid contact with the reactor …
- Doubling of the protection circuits
- Significant reinforcement of security measures (malevolence and theft).

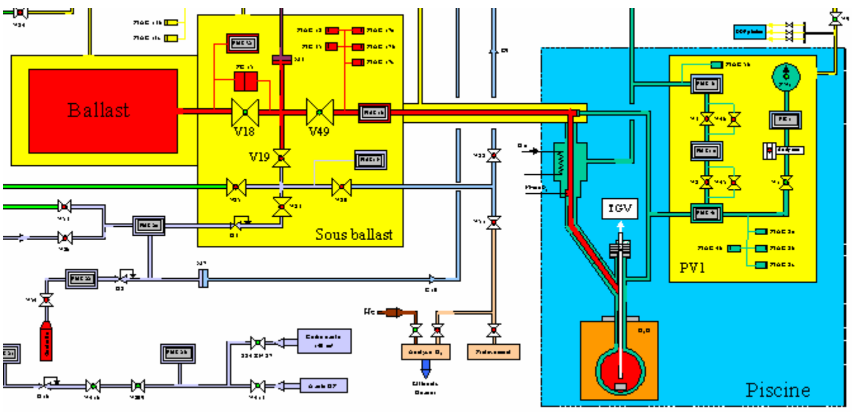
We still need to finalise the EIS-S list ("Elements Important for Safety – Seismic") and reinforce measures against acts of EIS-S-related aggression.

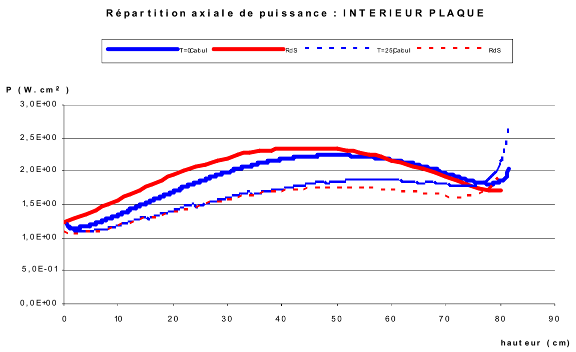
Four parallel 10-year investment programmes

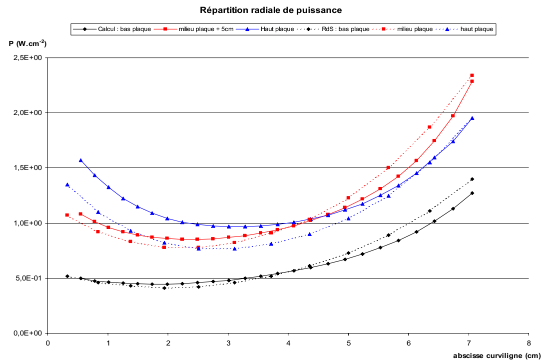
- The aim of the Key Reactor Components programme is to guarantee reliability until 2024. Indeed several important systems have been operating for 35 years. The main focus of this programme is on:
  - Safety rods, 12 new safety rods, project for a new design **(on-going)**
  - **Vertical cold source: renewal of the instrumentation and (digital) control system and of the pressure-resistant housings; addition of a new mimic panel in the control room (accomplished during the Refit Programme, taking advantage of the long 2005-2006 shutdown)**

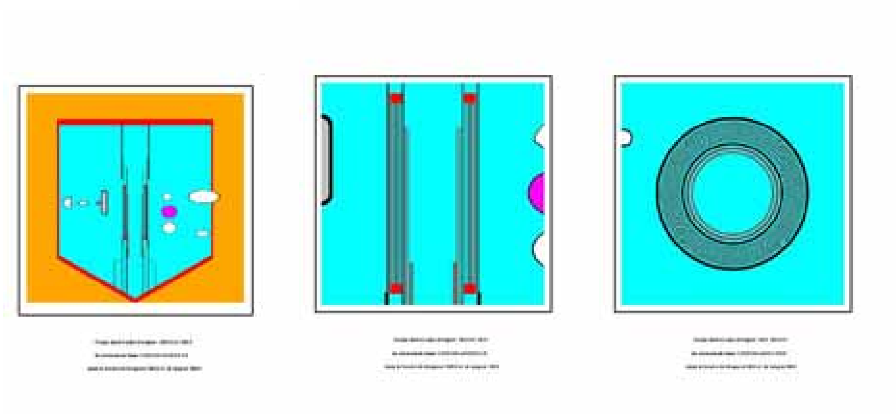


- **Fuel handling devices: Renewal of the instrumentation and control system with a digital one (done during the Refit Programme, taking advantage of the long 2005-2006 shutdown)**

- Upgrade of the electricity supply (from 15KV to 20 KV) - planned for 2007
- Fuel element: improvements in the use of uranium. This would allow us to take advantage of the package of design tools "Coeur", in collaboration with the CEA. We could then explore and assess the possibilities of using lowly-enriched uranium when it becomes available (on-going)







- o Beam tubes: many will have to be replaced in the near future, and some of them will be manufactured in zircaloy instead of aluminium (on-going)

- o A spare vertical cold source cell (in-pile part - the present one is 12 years old)
- o Reinforcement of fire, physical, and radiation protection measures, and of the primary circuit components
- o Gaseous effluent extraction system: redundancy and seismic qualification (on-going)
- o Overhead crane: aseismic bearing pads on the bracket (on-going)
- o Nuclear measuring channels
- o Renewal of the beam tubes' experimental equipment
- o 3rd cold source
- o Ultra-cold neutron source

Development of new instruments and techniques:
On the strength of the ten-fold gains in experimental performance achieved by the Millennium Programme's phase M0 (2000–2007), phases M1 and M2 have been launched:

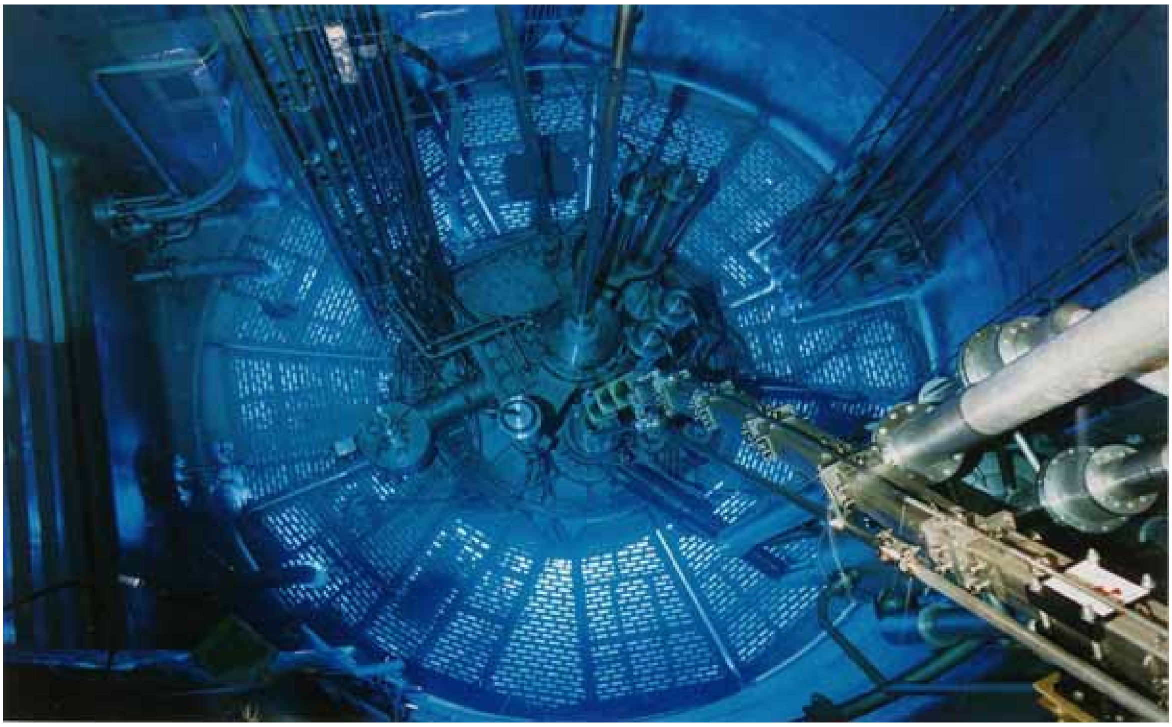
- New high-intensity thermal guides
- Development of a high-density ultra-cold neutron source
- Reconfiguration of the instruments in two 5-year phases
- Increase in public instruments from 25 to 30 by 2011
- Increase in CRG instruments from 10 to a maximum of 15, according to demand.

- Creation of partnerships for science and technology by capitalising upon the experience of the Partnership for Structural Biology (PSB) laboratory:
  - Partnerships for soft condensed matter, for materials science and engineering
  - An Advanced Neutron Technology Centre surrounded by private engineering companies
  - Partnership for high magnetic fields (ILL and ESRF).

- Joint development of the site:
  - New entrance (visitor centre, conference and training complex, delivery)
  - Fourth Guest House
  - Common building (library, restaurant)
  - Crèche.

Conclusion

Pushing safety, technological quality and experimental performance, ILL is thus guaranteeing that its reactor, its instruments and its environment remain in state-of-the-art condition; ILL is now ready for 20 more years of operation, ensuring a reliable flux of neutrons for the scientific community.



THE OPAL REACTOR

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ABSTRACT

The OPAL reactor went critical for the first time on 12 August 2006 and achieved full power for the first time on 3 November 2006. This has been a successful project characterised by extensive interaction with the project's stakeholders during project definition and the use of a performance-based turnkey contract which gave the contractor the maximum opportunity to optimise the design to achieve performance and cost effectiveness.

The contactor, INVAP SE, provided significant in-house resources as well as project managing an international team of suppliers and sub-contractor deliver the project's objectives. A key contributor to the project's successful outcomes has been the development and maintenance of an excellent working relationship between the ANSTO and INVAP project teams.

Commissioning was undertaken in accordance with the IAEA recommended stages. The main results of hot commissioning are reviewed and the problems encountered examined. Operational experience since hot commissioning is also reviewed.

1. Introduction

The project to provide a replacement for Australia's HIFAR reactor commenced with Government approval in September 1997 and reached its latest major milestone with the achievement of first full power operation in November 2006. The project has been a successful project for both ANSTO and INVAP. This paper presents, and reflects on with the benefit of hindsight, the approaches used to define the project requirements, choose the supplier and deliver the project, emphasising those good practices that contributed to the project success.

2. Project Planning, Organisation and Implementation

2.1 Assignment of responsibility

Very early in the project the decision was made by ANSTO to procure the facility through the use of a single turnkey contract and to employ a performance-based specification which would necessarily assign to the contractor complete design responsibility. That is, the contractor would not only be responsible for the performance of systems such as process and electrical, but would be responsible for ensuring the delivery of neutrons of the required spectra at the required flux to the required size and number of beam and irradiation facilities.

It took a while for some of ANSTO's stakeholders to embrace this performance-based approach and the general feedback that we had from the then potential contractors was that this was a novel approach. Other than the type of the reactor (pool type), the power (20 MW), the fuel enrichment (maximum 20%)

and the end-users requirements, no other features of the reactor were specified to the Tenderers. The effect was that ANSTO gave significant flexibility to the contractor to produce a cost-effective design for the reactor that could achieve a high performance.

Whilst the contract performance demonstration tests are yet to be completed, the results to date do not suggest that any of performance requirements will not be achieved. If the project were to be restarted now with the benefit of hindsight, neither ANSTO nor INVAP would change this approach

2.2 Stakeholders

In the early stages of the project ANSTO identified a very wide range of organisations and individuals that had an interest in the project. Some of these were obvious, for example government (federal, state and local), users, operators and the local community, but others were less obvious, for example what did ANSTO's public relations group want to be able to achieve? We identified all their expectations, worked towards meeting them, and communicated with them regularly throughout the project. An example of this was that members of the project team met regularly with members of the local community in an open forum which allowed concerns to be addressed.

While we had some early opposition from committed anti-nuclear groups, the local government organisation, and a few individuals of the local community, we have maintained strong broad stakeholder support throughout the project.

2.3 Contractor selection

A two stage process was utilised; a prequalification round followed by the main tender round. In the main round tenderers were required to submit sufficient information by way of conceptual design and calculation to demonstrate that they had a design which was capable of delivering the required performance. As it was recognised that this requirement would cause a significant cost to tenderers, the purpose of the prequalification round was to eliminate all tenderers who failed to convince ANSTO that they had a chance of being successful in the main tender round. While the tenderers were not universally happy with the amount of information ANSTO sought in the main tender round, with the benefit of hindsight, the process served ANSTO very well.

From the tenderers' point of view, this two stage approach was useful in the sense that before committing significant resources to the tender, the tenderers were assured by succeeding in the prequalification process that there was a level playing field, in which all prequalified tenderers had a priori equal chances of being selected.

Tender preparation was one of the most intensive parts of the project for the tenderers, whilst tender evaluation was a very intense part of the project for ANSTO. The tender process, from prequalification to contract signature took almost two years, with the first informative meeting for potential tenderers taking place in September 1998, the prequalification being decided in December 1998, the Request for Tender being issued in August 1999, the tenders being lodged in December 1999, the preferred tenderer being selected in June 2000 and the Contract being signed in July 2000.

Key to the success of the project was that the Tender process assured that the principal's and contractor's goals were aligned: the main goal for the project for both ANSTO and INVAP was for OPAL to be a world class reactor in both radioisotope production and neutron research.

2.4 ANSTO's role post-contract

The contract assigned full design responsibility to INVAP, i.e., INVAP was responsible for the preparation, checking and approval of all design documents. However ANSTO maintained a team of engineers and scientists who reviewed designs for compliance with the contract requirements and issued acceptances of them prior to manufacture.

During manufacture, installation and pre-commissioning testing INVAP were responsible for the planning and conduct of all inspections and tests. However, the same ANSTO team of engineers and scientists who were responsible for the review and acceptance of designs provided independent witnessing of significant inspections and tests. With components being manufactured in Europe, North and South America, Asia and across a number of Australian states this required a significant commitment of ANSTO's resources, but this high level of independent QA has given significant confidence to ANSTO of the quality of the facility and has been essential in the management of regulatory expectations.

2.5 INVAP's Management Strategy

INVAP decided to carry out all the preparatory work for the project during the tender preparation. All the management plans, the detailed project program, based on a detailed Work Breakdown Structure, the assignment of responsibilities and the organisation chart were defined during the Tender process and submitted to ANSTO with the Tender. This allowed INVAP to very efficiently launch the project once the Contract was signed.

The project management plan imposed several formal and written communication processes between ANSTO and INVAP, whilst several informal communications processes were put in place by ANSTO and INVAP management, including a communication protocol which determined the counterparts in each organisation. Efficient and frequent communications between the two organisations proved to be key to the project success.

INVAP use an integrated team approach for projects: the team responsible for preparing a tender stays with the project for its duration. As ANSTO used a similar approach, most participants in the project have had the opportunity to interact for several years. The building of these long-term partnerships between ANSTO's and INVAP's officers ensured that the goals of both organisations remained aligned.

INVAP used an Earned Value methodology for the project control. The Work Breakdown Structure was used for both project planning and progress control. Formal risk management procedures proved to be valuable.

2.6 Relationship with the regulatory body

In every nuclear project, the management of the interface between the project and the Regulatory Body is fundamental. Key to the success of the project was the cooperation of ANSTO and INVAP in submitting well prepared (mostly by INVAP) and reviewed (by ANSTO) documents to ARPANSA, and frequent and periodic (weekly) meetings between ARPANSA, ANSTO and INVAP helped to obtain the required licences (licence to construct and licence to operate) and authorisations (more than one hundred and thirty authorisations for manufacturing and/or installing safety related components).

3. Hot Commissioning and Operational Experience

The Construction Licence issued by ARPANSA, the Australian nuclear regulator, allowed cold commissioning up to but not including fuel loading. From the issuing of the Licence to Operate, ANSTO took responsibility for operating the facility under INVAP supervision. The commissioning of the reactor was carried out by joint INVAP/ANSTO commissioning teams, while the activities were planned and the daily operations decided by the Commissioning Group, formed by the Reactor Manager, ANSTO's Engineering Manager and INVAP's Design and Commissioning Manager. Key to the success of the commissioning was the ability of ANSTO, to train, with assistance from INVAP, a full operation crew in time for taking control of the facility.

Stage A cold commissioning tests (74 days), including full system tests with dummy fuel assemblies in the reactor core, were completed in May 2006.

Stage B1 Commissioning
ARPANSA issued the Operating Licence in July 2006 allowing Stage B1 hot commissioning to commence. Three types of fuel assembly were loaded in the first core:

- 212 g U^{235} without burnable poison (BP)
- 383 g U^{235} with BP
- 484 g U^{235} with BP (OPAL standard fuel)

Nine of the full core sixteen fuel assemblies were loaded initially and for each subsequent fuel assembly loaded the control rods were withdrawn and the sub-critical multiplication factor determined. The reactor was taken critical on 12 August 2006 with fourteen fuel assemblies loaded as predicted. The shutdown value of the First Shutdown System with single control rod failure was measured for this first critical core.
The main issue during this testing stage was spurious trips from the nucleonics instrumentation due to electronic noise. This was resolved by close attention to earthing, connections and cable screening.
Stage B1 was completed (5 days), the report issued and ARPANSA approval was received to commence Stage B2.

Stage B2 Commissioning
The full core was loaded and 22 low power tests (up to 400kW) were carried out over 25 days to measure key nuclear and reactivity parameters of the core. The calculated power peaking factor (2.42) was checked by gold wire irradiations and good agreement obtained.

Stage B2 Design verification results

Variable	Value	Design Criteria
Isothermal Feedback Coefficient	-15.74 [pcm/ºC]	< 0
Void Feedback Coefficient	-222.89 [pcm/% Void]	< 0
Power Feedback Coefficient	-0.74 [pcm/kW]	< 0
Power Peaking Factor	2.48 [-]	< 3
Shutdown Margin of the First Shutdown System	10067 [pcm]	> 3000
Shutdown Margin (Single Failure) First Shutdown System	6276 [pcm]	> 1000
Shutdown Margin of the Second Shutdown System	10461 [pcm]	> 1000
Safety Factor of Reactivity	2.01 [-]	> 1.5
Shutdown Margin of the First Shutdown System at 0.5 sec	9966 [pcm]	> 2000
Second Shutdown System Reactivity worth in 15 sec	8488 [pcm]	> 3000
Control Rod Plate Reactivity Insertion Rate	19.6 [pcm/sec]	< 20

Issues during Stage B2 commissioning:

- Wide range nucleonics detectors discontinuity as detector changed from pulse to Campbell mode – offsets adjusted and okay.
- Wide range set point for rate enable occurred with detector in pulse mode where the signal is noisy. The rate enable setpoint was raised as this was still within the safety case.
- Failure of a diesel starter motor during a test run. Main cause was identified to be a faulty battery.

Stage C commissioning

Approval was received on 13 October 2006 to commence Stage C commissioning. During this stage the reactor power was increased in steps up to full load (20 MW) which was first achieved on 3 November 2006. Twenty four test procedures were used and more than seventy test records completed.

Issues during Stage C commissioning:

- The CNS turbine was removed so only testing with the CNS in standby (warm) mode was completed.
- The core outlet temperature sensors did not give a true indication of the core outlet temperature. The primary coolant flow path around these detectors was modified and the problem solved.
- Cooling tower performance allowed the operation of the reactor at full power, but extrapolation to the design basis ambient conditions indicated that four of the five fans would not be sufficient for this heat load. The manufacturer has improved the fan performance and further tests are scheduled for March 2007

In addition to the CNS, Stage C testing of some of the irradiation facilities is still outstanding.

Reactor Schedule

The reactor successfully finished its first operating cycle on the 30th of December 2006, after 26 full power days.

Towards the end of the end of the first operating cycle, it was found that the isotopic purity of the heavy water in the reflector vessel is slowly reducing due to a light water leak. The source of the leak has been determined to be a non-structural seal weld associated with the neutron beam tube connection to the vessel. Different repair strategies are being investigated, but the reactor can continue to be operated at full power.

The first reactor refuelling was completed in February. This core is calculated to have the highest PPF and the calculated value (2.49) was confirmed by gold wire measurements (2.48). The reactor is operating at full load 20 MW for testing of neutron beam instruments, commissioning of irradiation facilities and continuing carrying out the contract performance demonstration tests.

CNS commissioning is scheduled to restart mid March.

Commissioning has proceeded to schedule without major problems. ANSTO is now looking forward to completing commissioning and moving into routine operation this year.

4. Conclusion

The OPAL project has been a successful project for both ANSTO and INVAP. Key to the success of the project were:

- Ongoing stakeholder commitment
- A very carefully designed and conducted tendering process
- Effective assignment of responsibilities through the contract
- Goal alignment between the principal and the supplier
- Strong cooperation, enhanced by frequent communications between the parties
- Integrated management teams, both within ANSTO and INVAP.
- Formal management procedures, known, accepted and reviewed by the parties.
- Detailed program, used for both project programming and project control.
- Joint management between ANSTO and INVAP of regulatory issues, including frequent and periodic meetings with the Regulatory Body.
- The timely availability of a complete and fully trained operation crew.

Last, but most important, ANSTO, INVAP and ARPANSA succeeded in assigning excellent people to the project. At the end of the day, any project is as good as the people participating in it.

Reducing the Risk of Nuclear Terrorism through the Creation of a New Forum for Collecting and Sharing Nuclear Material Security Best Practices: The Case for the World Institute for Nuclear Security (WINS)

Corey Hinderstein
March 1, 2007

One of the greatest security challenges of the 21st century is preventing the spread and use of nuclear weapons. The rise of global terrorism has created a new demand for nuclear weapons and a new willingness to use them. There is little doubt that if terrorists acquire nuclear weapons they will use them.

Supplies of highly enriched uranium and plutonium, the necessary materials to make a nuclear weapon, are widely dispersed around the world. Obtaining these essential ingredients is one of the hardest parts of making a nuclear weapon. Since these materials are difficult to make, the most likely way a terrorist organization will get them is through illicit purchase or theft. Terrorists will try to acquire nuclear material from wherever it is easiest to steal or from anyone willing to sell. Terrorists won't necessarily look where there is the most material; they may go to the place where the material is the most vulnerable or accessible.

Vulnerable nuclear material anywhere is a threat to everyone, everywhere. Like most global problems, the defense against nuclear terrorism is dependent upon cooperative and collective global action.

Mission and Need for Nuclear Material Security Best Practices Organization

The world community is aware of the danger of nuclear terrorism. Among other things, the concern of the international community has been translated since 9/11 into several new international instruments to help strengthen our global capacity to keep nuclear materials and weapons out of the hands of terrorists. Key among these initiatives are UN Security Council Resolution 1540; the Amendment to the Convention on the Physical Protection of Nuclear Materials; the International Convention for the Suppression of Acts of Nuclear Terrorism and the creation of the Nuclear Security Fund at the International Atomic Energy Agency (IAEA) with its associated plan for assisting states with implementation of their security obligations, including through the creation of more detailed nuclear security guidelines. While these initiatives form an important legal and institutional architecture, they still fall short.

There are several key reasons that our existing global nuclear security architecture is not yet sufficient. These reasons include inadequate implementing mechanisms for existing nuclear security initiatives, and the institutional and budgetary constraints of the IAEA, the international organization charged with supporting most of these efforts.

While the various legal and voluntary initiatives described above are important for beginning to create necessary norms and legal frameworks, in very few cases have they been translated into actions. UNSCR 1540 established a Committee to help review the reports required to be submitted by states, but the Committee is not equipped (by either budget or staff) to help states implement the requirements of the resolution. The Convention on the Physical Protection of Nuclear Materials (CPPNM) has no implementing or oversight mechanism, and the Amendment to the Convention has not entered into force (only seven of the 80 states required for its entry into force have ratified it).

The International Atomic Energy Agency does provide assistance to states requesting help with nuclear security issues, but its capacity for action is limited by its budget (with an annual total of about $15 million per year for all of its nuclear security programs) and its personnel. The IAEA is also limited by its charter to working with states (as opposed to industry for example), and its activities are generally limited to non-weapons materials and facilities.

In addition, despite various bi- and multi-lateral mechanisms for nuclear security cooperation, a comprehensive, global approach to nuclear material security is still missing. Physical protection and MC&A practices vary from country to country and facility to facility, and this is particularly true because establishing the standards for the physical protection of nuclear materials is the sovereign responsibility of the state.

A global best practices organization could be the mechanism for raising the level of global best practices of nuclear materials security in a time urgent way, and serve as a tool for industry and operators who want to stay ahead of the threat. Such an organization could provide a forum for the exchange of experience, lessons learned, and new ideas at the "grass roots" facility-operations level: a forum for practitioners rather than policy makers. In this way, the nuclear materials management community, and all of the partners involved in the organization can reduce the risk of a terrorist event that would threaten the viability of peaceful nuclear activities internationally.

Potential Activities

The primary role of a global best practices organization would be to provide a forum for the exchange of information between operators, industry, governments, and government entities regarding on-the-ground experiences and lessons learned in providing for the security of nuclear materials. Through consultation with the international nuclear materials management community we have concluded that this core mission is not being done by any existing mechanism, and would be valuable to facility operators and managers. We are exploring the creation of such an organization, nominally called the World Institute for Nuclear Security (WINS).

WINS could conduct and facilitate a range of activities, in which entities can choose to participate voluntarily and on a case-by-case basis. For reasons of staffing and financing, it is likely that WINS activities will start from a narrow focus and then broaden with time. It also may be difficult initially to directly involve some military materials or facilities, but nuclear weapons states' and non-NPT states' facility operators and authorities could still participate broadly in the activities of the organization. The process of expanding WINS activities will likely be driven by the confidence of the participants.

An initial activity of WINS should be to collect “best practices” for nuclear material security. WINS will serve as a forum for operators and practitioners to share security strategies that go beyond internationally accepted standards to improve material security. These approaches would contribute to efforts to help facilities implement obligations under UN Security Council resolution 1540 and IAEA INFCIRC/225 Rev. 4.

The IAEA has developed a 2006-2009 Nuclear Security Plan to “achieve improved worldwide security of nuclear and other radiological material.” This is a significant and important achievement. In support of this effort, activities that would complement and supplement the Plan and assist the IAEA in realizing its nuclear security goals should be a major focus of WINS. It will be vital for WINS, in particular in the start-up phase, to work closely with the IAEA to avoid duplication of effort and therefore wasting of resources. There are some areas that the IAEA cannot address and where WINS may be better able to contribute. Some of these areas could include working directly with facilities in the nuclear weapon states, working with non-civilian entities, conducting activities in non-NPT states, and engaging directly with the nuclear industry, including with facilities and operators.

WINS has an important role to play in raising the international awareness of the need for increased attention to nuclear materials security. WINS can also contribute to establishing and building the resource base of experts and services for nuclear material security. These kinds of activities can benefit all groups and individuals working in the field.

We believe WINS could also contemplate the conduct of peer reviews to be carried out on a voluntary basis, and designed to assist facilities in identifying ways that they can improve security implementation. On the one hand, peer review might be one of the most sensitive and difficult activities for a new organization to undertake, and therefore might not be easily incorporated into the initial activities of WINS. However, the experience of the World Association of Nuclear Operators (WANO), which focuses on nuclear safety, demonstrated that the conduct of peer reviews was important in shaping the activities of and support for the organization.

Scope of Materials to be Addressed

Defining the materials to be addressed by WINS activities will impact organizational priorities and shape activities and participation in the organization. The global universe of nuclear materials and facility types is diverse. WINS could address all nuclear and radioactive materials, be limited to nuclear weapons direct use materials in significant quantities, or cover another subset of materials.

We recommend that the decision on which materials to address should be based on a risk-based assessment that returns to the core rationale for establishing the organization. Under these terms, for example, WINS could define its initial goal as ensuring security of unirradiated direct use materials. This would include highly enriched uranium (HEU), separated plutonium, and fresh MOX. WINS's ability to address the most sensitive materials in the category (e.g., military stockpiles) would depend on the active participation of facility operators and governments responsible for such materials.

Nothing in the definition of this scope should be interpreted as limiting the range of membership and future activities of the organization. Activities geared toward best practices in the management of material as defined above will naturally have potential application for less attractive material. Therefore, participation and information sharing with facilities responsible for other related nuclear and radiological materials should be supported and encouraged.

Potential Participants

Potential participants in the WINS effort could include:

(1) ***Private Industry***
(2) ***Government Agencies and Government Entities***
(3) ***International Organizations***
(4) ***Non-Government Organizations***
(5) ***Professional Associations***
(6) ***Universities***

There are many ways to organize or categorize participation. WANO, for example, is organized primarily based on geographic location of the members. For a diverse participation, such as envisioned for WINS, it may prove valuable to organize participants around technology and facility type. For information sharing purposes, there are likely to be areas that are most valuable for operators of similar facilities, although many security issues can be discussed broadly.

Costs and Financing

Start-up funding could be acquired through voluntary donations from industry, related government entities, NGOs, individuals, associations, professional organizations, and international organizations. WINS will generate sustained funding if it proves to contribute to the interests and values of the nuclear community.

In order for the entity to remain viable over time, we believe it will be important to create a sustainable funding stream. Contributions could be made through in-kind donations, up front commitments, sustaining commitments, and ad-hoc donations.

Challenges

There are many challenges to the creation of an institution to collect and disseminate best practices on nuclear material security. These include, in particular, sensitivities about the sharing of security information between countries and organizations. This should not be an insurmountable barrier as the nature of WINS is not designed to be a public forum, nor is information about specific security measures in place at specific sites necessary.

It is also important to emphasize that participation in WINS will not mean the acceptance of new obligations on the part of facilities or organizations. The goal is information sharing and exchange, not imposing new security obligations.

Finally, some potential participants have noted that there is no generally accepted economic rationale for participation, as there was in the case of safety concerns following the Chernobyl accident for establishment of WANO. To this argument, we respond that the potential global economic costs of a nuclear terrorism event are likely to be substantial and the impact on the nuclear industry may be disproportionate to that experienced by industries in general. The international nuclear community should not wait for a "security Chernobyl" to take steps from preventing a terrorist from accessing nuclear material.

Next Steps

In November 2006, NTI organized and co-sponsored an international "Experts Group" meeting to explore the WINS concept. Twenty-five participants attended from 17 different countries and the International Atomic Energy Agency (IAEA), including government regulators, ministries, and private industry. At the conclusion of the meeting, there was general consensus on the need for WINS and the importance of continuing to advance the concept with support from NTI and other international partners.

As a result of the Experts' discussion, NTI, in partnership with INMM and the IAEA, is working to carry out three "pilot projects" to demonstrate the value of WINS-type activities to nuclear material managers and facility operators. These activities will be developed through consultation with a number of international partners, including the facility operator communities. We hope to define and carry out a demonstration project in two areas in 2007: plutonium security and highly enriched uranium. Concurrently, NTI is working to cultivate high-level international political support for WINS.

The Renaissance of Fast Sodium Reactors
2007 assessment: situation and contributions from the PHENIX experimental reactor

RRFM/IGORR meeting
12 to 14 march 2007 –Lyon -France.

J Guidez: Director of PHENIX plant.

The first nuclear reactor to produce electrical current was the fast sodium/ potassium reactor EBR1, on 20 December 1951 in Idaho (USA) . Following this pioneering experience, France, Germany, Great Britain, USA, Japan, Russia and India launched construction of fast sodium reactors. In the “post –Chernobyl” years, waves of protest against nuclear power grew and swelled, leading to a strong overall slowdown for this reactor type. The SNR300 project in Germany never started up, and was shut down. In Great Britain, PFR was definitely shut down, operation of MONJU in Japan and BN800 project in Russia were frozen, FFTF in the United States shut down, and finally the SPX1 project in France was also stopped. When PHENIX started back up in 2003, there were only three other research reactors operating worldwide: FBTR in India, BOR 60 in Russia and JOYO in Japan, and one power reactor BN600 in Russia.

The Generation IV initiative was the opportunity for global thinking about reactors for the future, referred to as fourth generation reactors. Six reactor designs were selected, including the fast sodium reactor. However, after several years, most of the countries (in or out of GENIV group) have officially announced or confirmed that the fast sodium reactor is their priority reference design. These countries include Japan, China, Korea, Russia (simultaneously with lead reactors), and India. With the GNEP, the United States has announced a project for a fast sodium-cooled, waste-burning reactor. In France, within the scope of the law of 28 June 2006, the country has announced and confirmed the decision to build a prototype scheduled for operation in 2020.

These and other plans are all sustained in a very practical manner by the ongoing production in the field. PHENIX has been operating since 2003, demonstrating the fast reactors’ ability to burn waste. Following the excellent results obtained by the BN600, Russia has re-launched the BN 800 project. China is currently in the process of building a 65-MWT research reactor, scheduled for divergence in 2009. In Japan, work is underway on MONJU for divergence in 2008. In India, a 1200-MWT power reactor is under construction, scheduled for divergence in September 2010, the first of a three-reactor unit.

The stakes behind this renaissance in nuclear power are important indeed. These fast reactors promise to produce world energy for thousands of years through breeding. No production of greenhouse gases. And long-life waste is burned. Moreover, significant progress has been made in terms of safety, reliability, availability and inspectability for this reactor type.
A presentation is made on the experience gained at PHENIX since 1974, and on the industrial validation during his operation, of the points described above.

1. THE PAST UNTIL 2003

The first nuclear reactor to produce electricity was a sodium-cooled fast reactor (NAK), in 1951, the EBR 1 in the United States.
Since that time, 18 fast sodium reactors have operated in many different countries and in 2003, when Phénix started back up, there remained three experimental reactors in the world: BOR60 in Russia, FBTR in India, JOYO in Japan, and one power-producing reactor: BN600 (600 MWe) in Russia.

The enclosed table shows the number of years of operation for these 18 reactors, as of 2007, and shows that accumulated operating experience comes to approximately 379 years. This has led to extremely significant feedback benefiting the fast sodium reactor type.

FAST REACTORS OPERATIONAL DATA 2007

Reactor (country)	Thermal Power (MW)	First criticality	Final shut-down	Operational period (years)
EBR-I (USA)	1.4	1951	1957	6
BR-5/BR-10 (Russia)	8	1958	2002	44
DFR (UK)	60	1959	1977	18
EBR-II (USA)	62.5	1961	1991	30
EFFBR (USA)	200	1963	1972	9
Rapsodie (France)	40	1967	1983	16
BOR-60 (Russia)	55	1968		39
SEFOR (USA)	20	1969	1972	3
BN-350 (Kazakhstan)	750	1972	1999	27
Phenix (France)	563	1973		34
PFR (UK)	650	1974	1994	20
JOYO (Japan)	50-75/100	1977		30
KNK-II (Germany)	58	1977	1991	14
FFTF (USA)	400	1980	1993	13
BN-600 (Russia)	1470	1980		24
SuperPhenix (France)	3000	1985	1997	12
FBTR (India)	40	1985		22
MONJU (Japan)	714	1994		13
BN-800 (Russia)	2000	Under construction		
CEFR (China)	65	Under construction		
PFBR (India)	1250	Under construction		
Total All Fast Reactors				379

Total per country (years)	
Russia	110
USA	61
France	62
UK	38
Japan	43
Kazakhstan	27
India	22
Germany	14

2. GENERATION IV

The Generation IV initiative has enabled a comprehensive overview for the future, of the possibilities of the reactor types, leading to a list of 6 reactor types, including 3 fast reactors:

– VHTR,
– Gas-cooled fast reactor
– Sodium-cooled fast reactor
– Lead-cooled fast reactor
– Molten salt reactor,
– Supercritical water-cooled reactor

After several years of research and reflection, the actual situation in 2007 with respect to the six possibilities is as follows:

Korea: Korea has announced the choice of the sodium reactor as the GEN IV reactor. However, no actual construction projects are underway (simply the Kalimer research project).

China: China continues its efforts in several fields, particularly in the HTR.
However, a 75-MWth sodium-cooled fast reactor is under construction, scheduled for divergence in 2010.

CEFR (China)

This prototype reactor has been described as the start of a series of this type of reactor.

India: India has long seen the fast reactor type as a long-term energy solution for the future.
The FBTR reactor has been operational since 19__ and has applied for a 20-year lifetime extension. This experimental reactor is used to qualify materials and fuel.

FBTR (India)

However, construction of a 1200-MWth reactor was launched in late 2004.

PBFR/India/2007

This reactor should diverge in 2010, and is the first in a series of 3 identical reactors.

Russia: Here too, the choice of sodium reactors has long been made. The recent successful operations of the BN600 has led Russia to request an extension in the life of the reactor.

BN 600 (Russia)

The BN800 reactor was budgeted in 2006. Work has been resumed, and foundations have been poured.
Reactor divergence is scheduled for approximately 2012.
However, Russia continues to work on the lead-cooled fast reactor option, which is the reactor type which equips the nuclear submarines. Russia has strong expertise in this field.

Japan: Within the scope of GenIV, Japan is the leader for the sodium-cooled fast reactors. With Joyo serving as an irradiation reactor, and Monju as a power-producing reactor, Japan has the tools at hand to start such a reactor type up. The Monju reactor had been shut down since the 1992 sodium leak. It was authorized to undertake repairs in 2006 and should gradually start back up, achieving full power between 2008 and 2010.

JOYO (Japan)

MONJU (Japan)

USA: The last American fast reactor (FFTF) has been shut down.

The GNEP project introduced in 2006 calls for an actinide-burning fast reactor. If this reactor is built, it will most likely be a sodium-cooled fast reactor.

France

In France, 2006 was a very active and positive year:

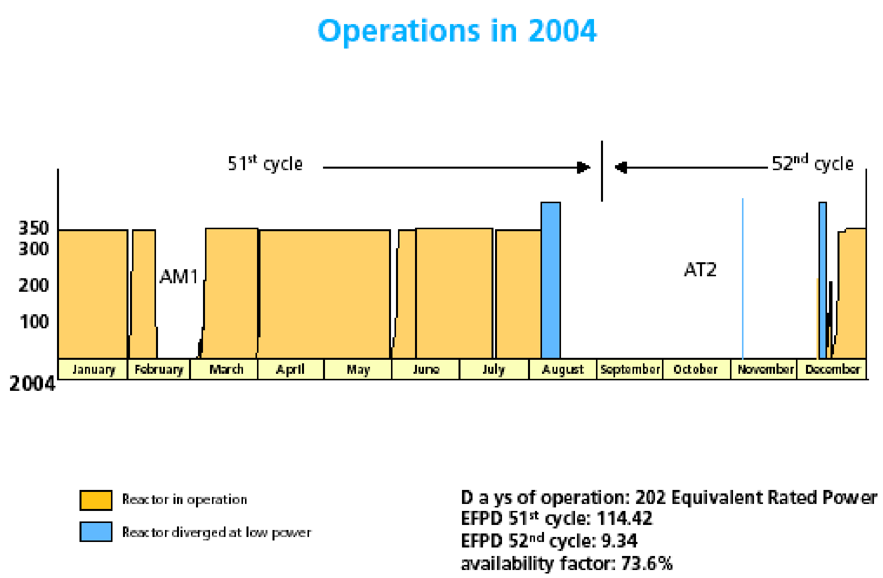
- January 2006: the President of France announced that a GenIV prototype reactor should be operation by 2020.
- June 2006: the law on nuclear waste processing and future was voted. This law also confirms the prototype by 2020.
- December 2006: The Nuclear Energy Council (CEN) confirmed France's nuclear policy for the years to come. The statement is made that the 2002 prototype will be a sodium-cooled fast reactor, and that the gas reactor remains a long-term development option.

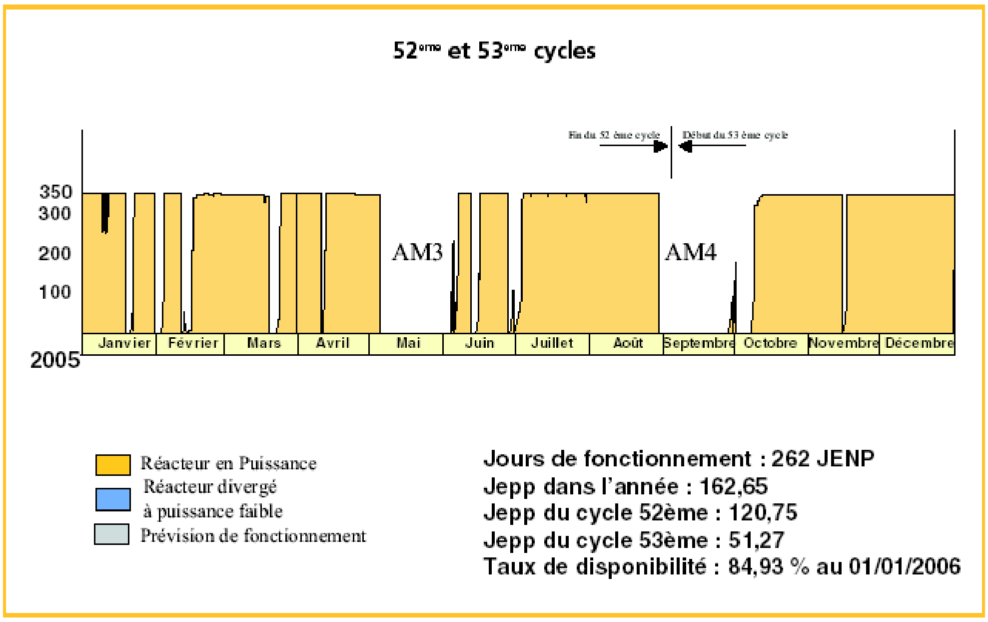
Conclusion: Options remain open on various levels for the potentially promising reactors, in particular the lead-cooled fast reactor (Russia,….), the gas-cooled fast reactor (France), the HTR reactors (China, USA,…).

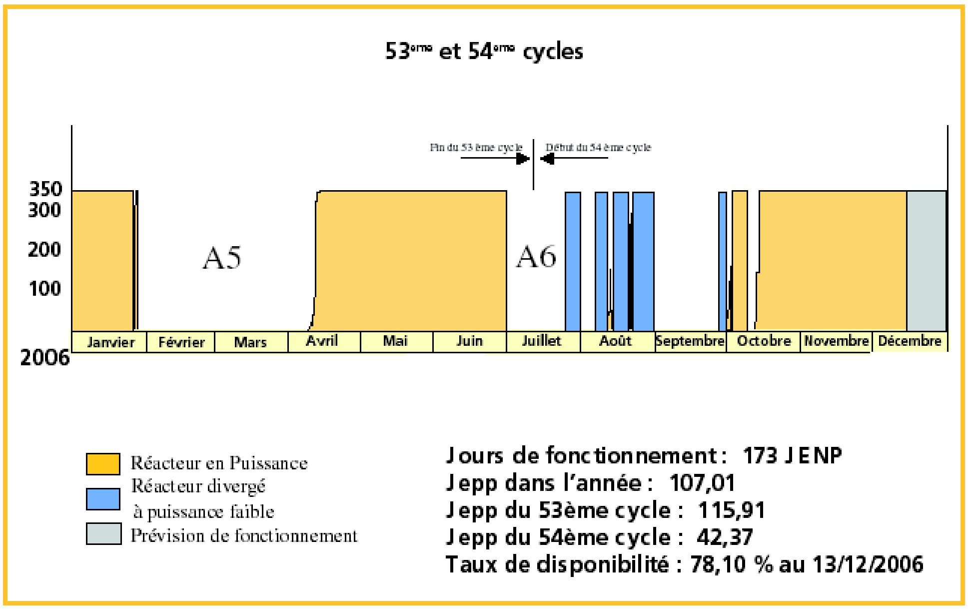
However, significant feedback on sodium-cooled reactors has emphasized the sodium-cooled solution, and convergence is taking place, at least in the short term, towards the construction of sodium-cooled fast reactors.

3. PHÉNIX OPERATIONS SINCE STARTING BACK UP

During these positive times, the successful operations at the Phénix reactors continues on, since starting back up in 2003.







The 3 diagrams below correspond to the availability at interest rates of 74 %, 85 % and 78 %.

In early 2007, the record for operation without spurious shutdown was beaten on 21 January. The record was established in 1990, with 99 days of operations.

In addition to producing electricity, reactor operations can also include a research and test program, for the purpose of materials development and future fuels, and transmutation experiments.

4. EXPERIMENTS FOCUSED ON DEVELOPMENT OF FUTURE SYSTEMS

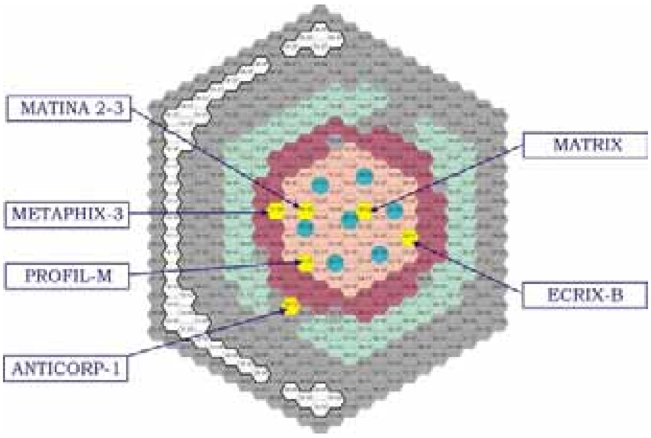
An experimental program is being conducted in the PHENIX reactor within the scope of developing future energy systems (FNR-G, FNR-Na, ADS, ITER ...). The purpose is to acquire knowledge on the inert materials under consideration as structural materials for these systems (MATRIX, FUTURIX-MI, and ELIXIR) and on innovative fuel concepts (FUTURIX-Concepts).
The MATRIX program, led jointly with the US-DOE, consists in irradiating, with a target dose of 65 dpa, inert materials such as ceramics (SiC, TiN, ZrN...) and metallic alloys (T91, T92, ODS...) considered as structural materials for the future systems (ADS, FNR-G, ITER) . The entire experiment includes over 1000 specimens. Eighteen months after program launch, the experimental rig was placed in the reactor in early 2006.
The FUTURIX-MI experiment, also a collaboration with ITU and USDOE, consists in studying the behavior of refractory materials (Mo- or Nb-based carbide and nitride ceramics) under irradiation and high temperature (approx. 1000°C). These materials are being studied for the FNR-G structures. Work in 2006 focused on producing the internal components (sample holders, DAF ...) for the rig, scheduled to enter the reactor in early 2007.
On the subject of inert materials, the irradiation objectives for the ELIXIR experiment were reached in 2006. The ELIXIR program called for irradiation up to 45 dpa of austenitic steels used for PWR reactor internals, and martensitic steels for fusion reactors such as ITER. The irradiated specimens will be sent to Saclay and Kalrsruhe in early 2007.
Research on innovative fuels for future systems (FNR-G) is the objective of the FUTURIX-Concept experiment. This programs researches, produces and irradiates, in PHENIX, special nitride and carbide type fuel concepts: pellets and micro-pellets of fuels inserted in honeycomb-shaped inert structures, beads of fissile and inert particles in TiN or SiC type matrices. The experimental pins were completed in 2006.
In addition, within the scope of increased plutonium consumption in FNR-Na fuels, the CAPRIX experiment, which contained two $UPuO_2$ pins with 45 % plutonium content, reached the objective of an average fission rate of 10 at% in 2006.

5. EXPERIMENTS FOCUSED ON TRANSMUTATION RESEARCH

The goal of the experiments conducted at PHENIX is to demonstrate the technical feasibility of transmutation of minor actinides and long-life fission products in a fast neutron reactor. The experimental objectives include:

- acquisition of basic neutronic data (PROFIL experiments),
- development of concepts for transmutation targets (ECRIX, CAMIX-COCHIX, MATINA) for minor actinides and fission products (ANTICORP),
- development of fuel for transmutation reactors (METAPHIX, FUTURIX-FTA).

The PROFIL-R and PROFIL-M experiments, conducted to acquire knowledge on nuclear reactions, comprise pins containing several dozen isotope specimens (actinides and fission products). During irradiation, these pins are placed in rapid spectrum (PROFIL-R) or slightly moderated spectrum (PROFIL-M). The PROFIL-R experiment reached its irradiation objective in August 2005, after 252 EFPD. The experimental pins were sent to Cadarache in late 2006. The PROFIL-M experiment was placed in the reactor in July 2006.

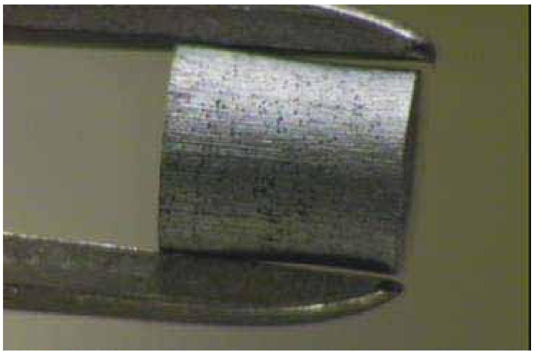


Experiments placed in the reactor core at the start of the 54th irradiation cycle

The MATINA 1A and MATINA 2-3 experiments were dedicated to studying the behavior of the inert matrices used as transmutation target support materials. Several materials were tested (ceramics, refractory metals). The minor actinides to be transmuted were able to be simulated by fissile phases.
The first part of these experiments (MATINA 1A) came out of the reactor in 2004. The non-destructive testing conducted at PHENIX, and the first results from the destructive testing at Cadarache confirm the good behavior of the MgO matrix, currently considered the reference material. The second experimental part, MATINA 2-3, studies new ceramic materials and optimized concepts of actinide dispersion in the matrices. The experiment was placed in the reactor during the A6 outage in July 2006.
The ECRIX and CAMIX-COCHIX experiments test various concepts of transmutation targets (inert matrices containing particles of Americium) in slightly moderated neutronic spectra, either in the core (ECRIX-B), or in the fertile blankets (ECRIX-H, CAMIX-COCHIX). The ECRIX-B is still in the reactor after 410 EFPD. However, irradiation of ECRIX-H terminated in early 2006 after having attained a fission rate of approximately 35at%. Pins are currently still being examined in the Irradiated Elements Cell (IEC). For the CAMIX and COCHIX experiments, 2006 was primarily spent assembling the rigs at PHENIX and preparing the application for irradiation authorization with the Safety Authority.

On the subject of transmutation of long-life fission products, the ANTICORP-1 ^{99}Tc ingots under irradiation, has been in the reactor since 2003, with the irradiation objective of 720 EFPD. In late 2006, the transmutation rate had reached approximately 18at%.
The METAPHIX and FUTURIX-FTA experiments involve research on fuels used for the incineration of minor actinides (homogenous mode). These are international programs involving foreign partners such as ITU and CRIEPI, for METAPHIX and US-DOE, ITU and JAEA for FUTURIX-FTA. The three METAPHIX 1-2-3 rigs, each containing three experimental pins of UpuZr alloy with various levels of minor actinides and rare earths (up to 5%) entered the reactor in late 2003. The METAPHIX 1 and 2 rigs came out in August 2004 and July 2006 respectively, after 120 EFPD and 360 EFPD of irradiation, which corresponds to fission rates of 2.5 and 7 at%. Non-destructive testing of METAPHIX-2 will take place in the IEC during 2007. The experimental pins from the METAPHIX 3 rig, scheduled for unloading in 2008, had reached fission rates of approximately 7 at% at the end of 2006.

The FUTURIX-FTA experiment, whose objective is to study the different fuels containing high actinide contents (between 1.3 and 5.8 g/cm^3), consists of three rigs holding 8 experimental pins in all. The fuel types under study are the metallic alloys (UPuNpAmZr, PuAmZr), the nitrides (PuAmZrN, UPuNpAmN), the CERCER ($PuAmO_2$+MgO) and the CERMET ($PuAmO_2$+Mo, $PuAmZrO_2$+Mo). Work in 2006 primarily concentrated on making the pellets and the pins, which were received at PHENIX in early September. The application for irradiation authorization is currently being processed. The objective is to place the experiments in the reactor during the first quarter of 2007.



FUTURIX-FTA – Experimental CERMET pellet

6. CONCLUSION

In conclusion, with its transmutation experiments, in conjunction with the research on separation, Phénix is currently in the process of providing the successful demonstration of the possibility of sodium-cooled fast reactors for optimized management of future nuclear waste.

In the 1980's, Phénix successfully reprocessed, first at APM, then at the Hague, the equivalent of four and one-half cores (which is approximately 25 tons of fuel). It then re-made, then re-used this fuel to demonstrate on the industrial scale, the technological feasibility of breeding. Breeding multiplies by a factor of approximately 100 the possibilities of using uranium, thus avoiding any possibility of shortage in the future.

These two demonstrations show that the sodium-cooled fast reactor is a tool for producing electricity which also entails sustainable development criteria in terms of overcoming shortages and waste optimization.

When the Phénix reactor shuts down in 2009, a series of new reactors will just be getting underway: CEFR in China, PBFR in India, BN800 in Russia and MONJU in Japan.
The sodium-cooled fast reactor increasingly appears to be the number one candidate in the category of Fourth Generation reactors.

DEVELOPING RESEARCH REACTOR COALITIONS AND CENTRES OF EXCELLENCE

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ABSTRACT

The IAEA, in line with its statute and mandatory responsibilities to support its member states in the promotion of peaceful uses of nuclear energy in concert with global nuclear non-proliferation, nuclear material security, and threat reduction objectives is well positioned to provide support for regional and international cooperation involving the research reactor community.

The IAEA is pleased to announce an initiative to form one or more coalitions of research reactor operators and stakeholders to improve the sustainability of research reactors through improved market analysis and strategic/business planning, joint marketing of services, increased contacts with prospective customers and enhanced public information. Such coalition(s) will also be designed to promulgate high standards of nuclear material security, safety, quality control/assurance and to conform with global non-proliferation trends.

1. Introduction

Research reactors continue to play a key role in the development of peaceful uses of atomic energy. They are used for a variety of purposes such as education and training, production of medical and industrial isotopes, non-destructive testing, analytical studies, modification of materials, for research in physics, biology and materials science, and in support of nuclear power programmes. The IAEA Research Reactor Data Base lists about 250 operational research reactors worldwide, many of which have been operating for more than 40 years.

Through both statistical and anecdotal evidence, it is clear that many of these reactors are underutilized, face critical issues related to sustainability, and must make important decisions concerning future operation. These challenges are occurring in the context of increased concerns over global non-proliferation and nuclear material security, due to which research reactor operators are coming under increased pressure to substantially improve physical security and convert to the use of low enriched uranium (LEU) fuel. Thus, there is a complex environment for research reactors, and one in which underutilized and therefore likely poorly funded facilities invoke particular concern.

Many research reactors are challenged to generate sufficient income to offset operational costs, often in a context of declining political and/or public support. Many research reactor operators have limited access to potential customers for their services and are not familiar with the business planning concepts needed to secure additional commercial revenues or governmental or international programme funding. This not only results in reduced income for the facilities involved, but sometimes also in research reactor services priced below full cost, preventing recovery of back-end costs and creating unsustainable market norms.

Parochial attitudes and competitive behaviour restrict information sharing, dissemination of best practices, and mutual support that could otherwise result in a coordinated approach to market development, building upon strengths of various facilities. Moreover, belief that the markets for research reactor products and services are a "zero-sum" game, with market gains by one research reactor coming at the expense of another facility, result in a general lack of openness within the research reactor community.

Yet there is evidence to suggest that the market for research reactor services is supply limited, rather than demand limited. A number of factors limit the ability of research reactors to expand their user base and to generate new sources of revenue:

- Many potential customers do not know how, or where, to contact the research reactor community, and have only limited knowledge or awareness of the range of research reactor services, equipment and locations available.
- The standards of quality control and quality assurance between research reactors are not uniform, impede business development, and may result in a lack of confidence in service reliability. As a consequence, customers need to conduct due diligence for each facility to be used, reducing the enthusiasm and financial rationale for developing additional sources of supply.
- Transport of radionuclides is becoming increasingly difficult, with examples of shipments held in customs, prevented from leaving the country of origin or from entering the customer destination, and requires specific expertise and experience to manage this issue.

In order to address the complex of issues related to sustainability, security, and non-proliferation aspects of research reactors, and to promote international and regional cooperation, the IAEA is initiating the Research Reactor Coalitions and Centres of Excellence initiative. This activity is supported by a two-year grant from the Nuclear Threat Initiative, Inc. (NTI), and by a 2007-2008 IAEA Technical Cooperation Project, "Enhancement of the Sustainability of Research Reactors and their Safe Operation Through Regional Cooperation, Networking, and Coalitions" (RER/4/029). These two activities will work in an integrated manner, along with other relevant national and regional IAEA Technical Cooperation projects and complementary IAEA regular and extra-budgetary funded programme activities in research reactor utilization, safety, security, and the fuel cycle. These activities were endorsed by the IAEA Board of Governors in its March 2007 meeting which encouraged regional cooperation and networking among research reactors.

The aim of this initiative will be to establish a pilot project involving the formation of at least one voluntary, subscription-based, self-financed coalition of research reactor operators (possibly including other participants, sponsors, etc.), which may serve as a model for the establishment of additional coalitions.

2. Concept Operations and Benefits

The principle objectives of the IAEA in initiating the Research Reactor Coalitions initiative are to promote enhanced utilization of individual facilities and at the same time support the implementation of high standards of nuclear material security and physical protection, safety, and quality assurance.

While different types of coalitions are envisaged, many potential coalitions will coordinate the marketing and sales of services from participating research reactors in order to increase the availability of such services to potential customers, and will encourage/facilitate formation of joint ventures between highly utilized facilities requiring new, lower cost, or regionally sited irradiation capacity with capable but underutilized reactors. In achieving this, it is expected that the partners will:

- Develop and peer review strategic plans of the research reactors involved, both individually and collectively,
- Share market analysis and marketing expertise to support the participating research reactors that currently do not have access to such skills, both for commercial and scientific/research activities,

- Catalogue and publicize the scientific and technical capabilities of the research reactors in the coalition,
- Develop realistic cost estimates and pricing strategies, and carry out collective procurements or negotiations with suppliers to receive cheaper prices, and
- Create economies of scale to give groups of reactors more powerful voices commercially and politically and facilitate both fuel supply and "back-end" solutions.

A coalition of this type may thus resemble joint marketing by small-scale suppliers or one of the airline alliances or similar cooperative marketing arrangements that are formed to grow the market through coordinated services, in the context of meeting high standards of quality and safety. In other ways, this type of coalition will provide some functions similar to a trade association in regard to interacting with national governments and other relevant organizations to represent the collective interests of the coalition.

Coalitions would benefit the participating research reactors, their customers, and the wider community as summarized in Table 1 and described below. They would:

- Optimize the services offered (education and training, production of isotopes, industrial irradiation services such as transmutation doping, neutron activation analysis and other analytical services for industry and government) on a geographical basis, reducing the need for international transport of radioactive materials,
- Make maximum use of expertise or equipment at a particular facilities, and perhaps enable particular facilities to specialize in services in which they a "comparative advantage", and customers would be able to receive advice regarding the range of facilities, and locations, available from a single point of contact rather than through multiple agreements with different reactors, and
- Use the combined expertise of the participant facilities to best advise and serve their customers. This would help increase customer knowledge of, and access to, the radiation services, and support the customer with a more reliable and comprehensive customer service.

Research reactors that form a coalition would gain from the improved planning and marketing capabilities of the coalition, and sharing of best practices in operations and security. Their customers would benefit from a more homogeneous and sympathetic standard of service. Coalition participants may gain from payments made by countries or institutes that subscribe to the coalition as an alternative to operating their own reactors. Better-utilized facilities that join a coalition could gain from payments to cover professional expertise made available to the coalition.

In cases where existing, well-utilized reactors are experiencing capacity issues, contractual arrangements or joint ventures may be initiated with under-utilized reactors for irradiation services, directly benefiting the under-utilized reactor with commercial revenues and access to expertise, and the well-utilized facility with a resolution to its capacity problems.

As noted, one of the objectives of the IAEA is to contribute to the improvement of research reactor safety and nuclear material security and the physical protection of facilities. As participation in a coalition will be beneficial to the participants and therefore desirable, it provides an opportunity to define minimum standards for participation, and to make access to the coalition conditional upon those standards being maintained. It is thus expected that each coalition will:

- Encourage/incentivise best-practices on research reactor nuclear material security, safety (including application of the Code of Conduct on the Safety of Research Reactors),
- Encourage/reward/provide incentives to and provide assistance for conversion to low enriched uranium (LEU),
- Encourage adoption of a common Quality Assurance/Quality Control standards and implement a system of accreditation (e.g. through inter-comparison exercises),

- Assist with acquisition of external funding for such items as irradiation services, human resource development, including succession planning, and operational experience.

Improving utilization will result in additional commercial revenues and may help to reinforce domestic governmental support, thereby improving sustainability and assisting individual reactors to pay for operational, safety, and security improvements.

Because each coalition will be able to communicate and share best practice in all areas of reactor operation, this will reduce risks from research reactor operation, and help ensure that all appropriate international standards are fully observed. A regular technical and professional interchange would help build confidence and trust in the availability of equipment, facilities and expertise at partner reactors. In certain cases, it could be expected that smaller research facilities would find it more beneficial to have access to superior equipment and expertise at another site, via the coalition, than to maintain independent capabilities possibly not meeting the same standards.

Coalitions would therefore help promote regional and international cooperation by developing the cooperative environment prerequisite to establish centers of excellence and to rationalize research reactor activities. Other coalitions maybe formed specifically to provide shared access to scientific and experimental research, training, and irradiation services to countries without research reactors. Developing countries without a national-based research reactor could thereby access the benefits of peaceful uses of nuclear technology by participating in, and supporting, a research reactor coalition. The shared user facility would benefit by payments made for access or for shared equipment by countries or institutes that subscribe to the coalition as an alternative to operating their own reactors.

Due to the large capital costs, it is expected that future research reactors will more often be constructed as regional or international facilities instead of on a national basis. Further, any technically required research reactor operations involving HEU would eventually be concentrated at a very limited number of highly secure facilities that would also serve as shared-user centers.

The wider community would gain from overall improvements to operational safety practices and the reduced risk of nuclear accidents or incidents.

3. Project Development and Plans

Initial discussions concerning the possibility of formulating a project on Research Reactor Coalitions began on the margins of the RRFM meeting in Sofia in May 2006. A concept paper was drafted, and the IAEA requested NTI in June 2006 to provide seed funding for an initial meeting to further scope the concept.

Subsequently, the IAEA convened a Consultancy Meeting on Developing Proposals for Research Reactor Coalitions and Centres of Excellence" in Vienna from 31 August – 5 September 2006. This meeting reviewed a number of existing international arrangements involving groups of research reactors, discussed the general concept of research reactor coalitions as well as a number of potential subject areas for such work, and reviewed and revised a draft concept paper. This concept paper formed the basis of a grant request submitted by the IAEA to NTI. In October 2006, NTI's Board approved a grant to the IAEA for a two-year project.

The IAEA views this activity as a continuation and deepening of efforts to further integrate its research reactor activities, particularly through the Cross-Cutting Coordinator for Research Reactors. As such, the NTI grant will be coordinated with other IAEA regular, Technical Cooperation, and extrabudgetary funded activities related to research reactor utilization, safety, security, spent fuel management and the fuel cycle, and non-proliferation. The IAEA aims to assist in generating and coordinating ideas, promoting concepts, providing support for meetings and expert missions. Thus, the IAEA's role is that of a facilitator and to a smaller degree, business incubator.

Community Benefit	**Reactor Operator Benefit**	**Customer Benefit**
Disseminate and Encourage Best Practices • Control and Accounting • Non-proliferation • Nuclear Security/Physical Protection (including conversion to LEU) • Operational Safety • Radiation Safety	*Improve Sustainability* • Strategic Planning • Business Planning • Facilitate acquisition of new business and/or funding	*Better Awareness of Available Capabilities* • Customer less reliant on own expertise
Reduce Nuclear Terrorism Risk • Rationalize **radioisotope** supply geography • Reduce Activities Shipped • Reduce Distances Shipped • Improve nuclear material security • Improve spent fuel management	*Increase Market Access for Individual Reactors* • Some products/services via the Network • Improve utilization factors	*Reduced Costs and Complexity* • Rational matching of needs and capabilities/locations • One-stop shop
Build Trust and Confidence in mutual support networks • Promote Regional/International Cooperations • Improve access to the peaceful uses of nuclear technology. Precursor to Centers of Excellence • Additional resources/capabilities • Establish peer group leaders	*Increase Professional Opportunities* • Closer peer group interaction • Access to equipment and expertise at other facilities • Access to different types of irradiation facility	*Improve Service Level* • Standardized Quality Assurance • More available facilities • Improved Reliability • Back-up options

Table 1: Summary of Coalition Benefits

Between October and December 2006, the IAEA conducted informal consultations with a number of research reactor operators, commercial entities, research reactor irradiation services users, and other stakeholders. These informal discussions resulted in the development of approximately fifteen “notional proposals” covering a range of subjects for possible coalitions. A weekly conference call was held to execute an action item list designed to advance further development of the notional proposals. Several of the notional proposals were further elaborated in specific papers.

In January 2007, the IAEA held a Consultancy on Project Planning for Research Reactor Coalitions, under Technical Cooperation Project RER/4/029, which reviewed existing research reactor networking arrangements and examined the need for market studies and analyses to support specific coalitions. The meeting also reviewed and prioritized the “notional proposals” and developed a work plan. Preliminary discussions (which will continue on the margins of RRFM/Lyon) have resulted in progress on notional proposals related to:

Africa
East Asia
Europe Radiotracers
Latin America (2), and involving the following topical areas:

Research reactor planning
Production of medical and industrial radioisotopes
Fuel irradiation and testing
Neutron sciences and experimentation

The IAEA plans to issue a circular note to representatives of IAEA Member States inviting research reactor institutions and other related organizations to express interest in participating in a coalition and to provide concrete proposals to the IAEA.

Future meetings will be held in Vienna and at the sites of coalition participants in order to promote detailed discussions between potential coalition members to define specific coalition arrangements and activities. The IAEA will also provide support for administrative and other arrangements for coalition activities, and will provide expertise and assistance in the development of strategic and business plans for the coalition and the participating research reactors and also to develop public information and marketing materials.

4. Conclusion

The international research reactor community needs to be poised to meet arising societal needs, especially to support the anticipated “nuclear renaissance” to satisfy rapidly expanding global energy requirements with carbon-free electricity production and for emerging nuclear medicine technologies, but also for many other applications. This requires the operators of research reactors to be financially secure, operating under the best practices of safety, security and physical protection, consistent with non-proliferation goals, and on the basis of strengthened regional and international cooperation.

It is expected that at least one specific coalition will be announced later this year at the RERTR 2007 international meeting in Prague, Czech Republic and/or the 2007 IAEA research reactor conference in Sydney, Australia in November 2007.

REFURBISHMENT AND ACTIVITIES AT TAJOURA REACTOR

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ABSTRACT

The Tajoura Research Reactor was built in the late seventies by the former Soviet Union for Libya. Its maximum power rating is 10 MW. Its design facilitates the production of radioisotopes and the performance of material testing experiments. The reactor is provided with a critical assembly that is an exact mockup of the reactor core to test and neutronically study the different core configurations. Both of the Critical Assembly and the reactor were recently converted from the HEU fuel (Type IRT-2M) to the LEU fuel (Type IRT-4M).

1. Introduction

Tajoura Renewable Energies and Water Desalination Research Centre (REWDRC) is a national research centre, which provides a program of scientific activities in nuclear science and technology. It is located outside the city of Tajoura, 35 km east of Tripoli. The Tajoura nuclear facility is part of this center and it consists of two installations, the Tajoura Research Reactor and the Critical Facility.
The Tajoura Research Reactor is a 10 MW light water cooled and moderated beryllium reflected, pool type reactor. The reactor was designed and constructed by the former Soviet Union, as a turn key project. The construction of the reactor started in 1977; the power start-up of the reactor took place in 1983.
The reactor is intended to be used in:
1-Carrying out fundamental investigations in

- Nuclear physics
- Solid state physics
- Neutron physics
- Radiation biology
- Radiation chemistry

2- Carrying out the activation analysis of element composition of substances
3- The production of radioactive isotopes.
4- Study the behavior of structural materials directly in the process of irradiation.

The Critical Facility is a complete mockup of the Tajoura Reactor. It was commissioned at the end of 1980. It is used in reactor modeling, testing, training operators, and student education.

This paper concentrates on capabilities of the reactor, Tajoura staff practices related to maintenance and operation of the facilities, and organizational improvements to enhance the safety of the reactor.

2. Reactor irradiation positions and beam tubes

The reactor is equipped with eleven horizontal channels for neutron beams, two of them being the two ends of a through channel with a diameter of 150 mm. The largest channel is a radial channel with a diameter of 230 mm and is intended for radiation biology studies, while the rest are 100 mm diameter radial and tangential channels. During the eighties these beam tubes were utilized by physicists to study the nuclear structure of some elements, and to study the use of local materials in shielding. |In the reactor core there are more than 50 vertical irradiation positions in the stationary and removable reflector. With different core configurations it is possible to introduce neutron traps at the center or in the corners of the core with very high thermal neutron flux. For sample transfer from core side to the hot cell the reactor is provided with under water taxi. The reactor is also equipped with a pneumatic rabbit system for short and intermediate half life isotopes for activation analysis measurements.

3. Organization:

REWDRC is under the Bureau of Research and Development. The general organization of the center in relation to the Reactor Section is given in Figure (1)

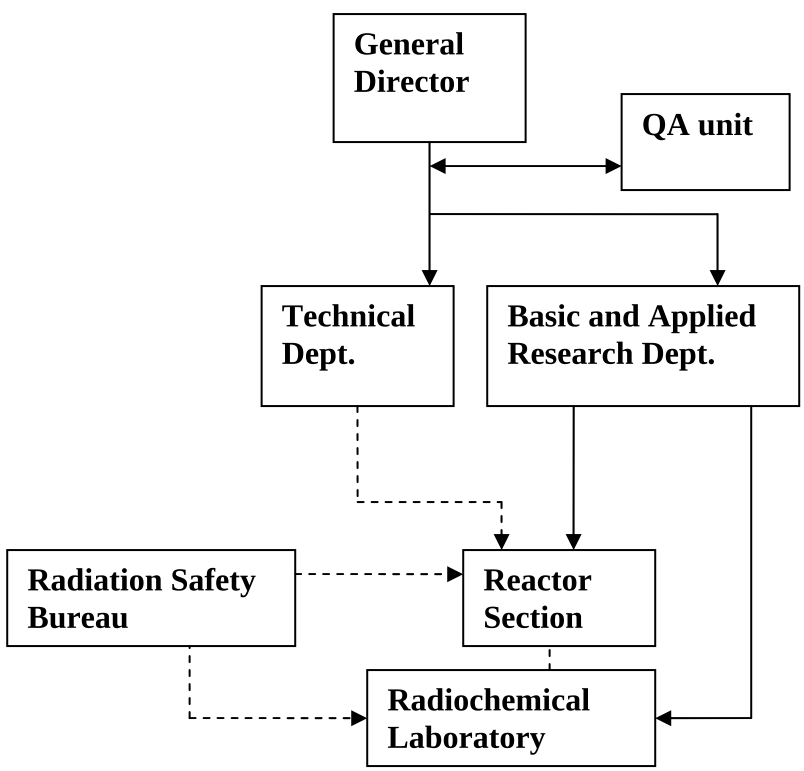

Figure 1: General outline of REWDRC Organization in relation to Reactor Section.

The Reactor Section is part of the Basic and Applied Research Department. The Technical Department provides services to the Reactor Section such as the operation and maintenance of the secondary and third circuit, air conditioning, hot water supply, and air ventilation. The Radiation Safety Office controls all radiation protection matters at the reactor section.
When the reactor was commissioned the law number 2 of the year 1982 concerning the protection against ionizing radiation was already in force. However, a dedicated law for reactor operation and utilization did not exist, and the reactor was operated under the permission of the authority of the Ministry of Atomic Energy. According to this permission the staff of the reactor had to strictly follow the rules and operation procedures set by the reactor provider (these were the rules applicable at the former Soviet Union). When the reactor was commissioned no separate safety analysis report document as it is commonly known today was provided, even though all the essential elements of a safety analysis report were included in various know how and operation manuals of the system. In the year 1997 the IAEA and in accordance to agency standards indicated to the management of the center the need to establish the safety of the reactor by preparing a safety analysis report. Since that time reactor staff started to prepare the most important part of the safety analysis report mainly the accident analysis chapter. In the year 2004 the Regulatory Body (RB) started effectively doing its work related to the Tajoura Reactor and the Critical Facility. The RB adapted the recommendations of IAEA concerning the safety and operation of reactors since conversion of the Tajoura Reactor and the Critical Facility was foreseen at that time. During the years 2005 and 2006 the accident analysis chapter for the Tajoura Reactor and the Critical Facility using the two types of fuel (HEU, LEU) was completed.

4. Reactor utilization

The utilization of the reactor suffered the most due to the hard ship which had confronted the country during the years 1985-2000. Economic hardship, sanctions and trade embargo all have contributed to the low utilization program for the reactor. The utilization was limited to the use of the reactor as an educational tool for university students, for training and retraining of reactor operators and for capacity building in the field of radiation safety, radiation chemistry, isotope production and neutron activation analysis.

In the years 1984-1986 nine different isotopes were produced in the reactor. The radiochemical laboratory at the REWDRC did the work of separating these isotopes. These isotopes were produced to gain experience and for training the personnel. However, Na^{24} was supplied to a local industry, for purposes of evaluating the homogeneity of the production process, while I^{131} [(1)]was ordered by local hospitals for the diagnosis and treatment of thyroids. Tc^{99m} (2,3,4)was produced as a part of capacity building but its use in hospitals was not possible due to the lack of a clean room, which is necessary for producing Tc^{99m} suitable for medical applications.
In the years 1987-1999 the production of I^{131} was continued to supply the local hospitals
Br^{82} [(5)] was also produced as part of an IAEA project to improve reactor utilization in industrial applications.

Number	Isotope	Half life	Target
1	P^{32}	14.2 d	P_2O_5
2	Na^{24}	15 hrs	
3	Au^{198}	2.7 d	Pure gold 99.99%
4	K^{42}	12.36 hrs	K_2CO_3
5	Cr^{51}	27.7 d	Enriched chromium metal with Cr^{50}
6	Fe^{59}	44.6 d	Enriched ferric oxide
7	I^{131}	8.1 d	TeO_2
8	Tc^{99m}	6 hrs	MoO_3
9	Br^{82}	35 hrs	KBr

Table 1: Radioactive isotopes produced in Tajoura Reactor

5. Reactor refurbishment

Due to corrosion problems, both fans of cooling tower were out of order. This fact and the lack of spare parts have contributed to the deterioration of the cooling tower which was replaced in the 1998 together with parts of the third circuit pipes.
The reactor control system included computer monitoring system which provided the monitoring of around 100 reactor parameters. The computer was also used to detect failures and provide for the operator an event log. Many of the parameters which were not measured were calculated by the computer using suitable formula. After three years the computer started to have problems due to difficulties in securing spare for the maintenance and due the rapidly changing computer technologies. It was decided to introduce a new system based on desktop computers to replace the old monitoring system. The work was done by the reactor staff. The new monitoring system is capable of monitoring more than 8o reactor parameters and can calculate some parameters which are important for safety.
The instrumentation and control system, which was provided by the supplier of the reactor, was designed and constructed in the seventies. The circuits of I& C system are of low scale integration. Its maintenance is very costly and time consuming because of the size of the system, which is huge and over dimensioned. Also no longer are spare parts available for the maintenance. It was decided to replace the system by a new system incorporating new technologies, which will reduce its size and thus the burden of its maintenance. The work expected to start on refurbishment of the control and safety systems for the reactor and for the critical facility in the near future.

6. Maintenance strategies at the facility:

Since the year 1984 when the facility was completely handed over to the Libyan side, the management has been investing all its efforts to keep both the reactor and the critical facility in an excellent technical state. This was accomplished with low inventory of spare parts and decreasing resources during the time economic hardship in late eighties and the sanctions during the nineties. Thanks are due to the maintenance program which concentrated on:

- ✓ Appling a strict control of water quality in all closed circuits to keep the conductivity in the primary circuit of the reactor below the recommended limits (<1 μs/cm) and the pH between 5.5 and 6.0.

- ✓ The conductivity in the secondary circuit was kept below 10 µs/cm and pH between 6.0 and 8.0. In the critical facility potassium bichromate was added to its pool water as a corrosion inhibitor
- ✓ The continues maintenance of the mechanical filters responsible for air quality Control to insure the removal of fine sand particles which are a characteristic of the area.
- ✓ The operation of the primary circuit, the secondary circuit and the purification system at least twice a week when the reactor is not operated to reduce corrosion risk, and keep the circuits in working condition.
- ✓ The adoption of predictive maintenance instead of periodical maintenance without jeopardizing the safety to reduce the need for spare parts proved its effectiveness in situations through which our reactor was subjected to.

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IRRADIATION FACILITIES AT THE ADVANCED TEST REACTOR

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ABSTRACT

The Advanced Test Reactor (ATR) is one of the world's premiere test reactors for performing long term, high flux, and/or large volume irradiation test programs. The ATR is a very versatile facility with a wide variety of experimental test capabilities for providing the environment needed in an irradiation experiment. These different capabilities include passive sealed capsule experiments, instrumented and/or temperature-controlled experiments, and pressurized water loop experiment facilities. Monitoring systems have also been utilized on the exhaust gas lines from instrumented temperature-controlled experiments to monitor different parameters, such as fission gases for fuel experiments, during irradiation. The ATR irradiation positions vary in diameter from 1.6 cm (0.625 inches) to 12.7 cm (5.0 inches) over an active core length of 122 cm (48.0 inches). This paper discusses the different irradiation capabilities available and the cost/benefit issues related to each capability.

1. Introduction

The Advanced Test Reactor (ATR), a light water moderated, beryllium-reflected pressurized water reactor, located at the Idaho National Laboratory (INL) is a valuable resource available for use in developing the materials and fuels necessary to support the next generation reactors and advanced fuel cycles. The ATR has a long history of irradiation testing in support of reactor development and the INL has been designated as the United States Department of Energy's lead laboratory for nuclear energy development. The ATR reactor vessel is constructed of solid stainless steel and is located far enough away from the active core that neutron embrittlement of the vessel is not a concern core. In addition, the ATR core is completely replaced every 7 to 10 years, with the last change having been completed in January 2005. These two major factors, combined with a very proactive maintenance and plant equipment replacement program, have resulted in the ATR operational life being essentially unlimited. The ATR has a maximum power of 250 MW and can provide maximum thermal neutron fluxes of 1E15 neutrons/cm^2-second and maximum fast (E>1.0 MeV) neutron fluxes of 5E14 neutrons/cm^2-second. This allows considerable acceleration of accumulated neutron fluence to materials and fuels over what would be seen in a typical power reactor. These fluences combined with the 77 irradiation positions varying in diameter from 16 mm (0.625 inches) to 127 mm (5.0 inches) over an active core height of 1.2 m (48.0 inches) make ATR a very versatile and unique facility.

The ATR core cross section, shown in Figure 1, consists of 40 curved fuel elements configured in a serpentine arrangement around a 3 by 3 array of prime irradiation locations in the core termed flux traps. The flux traps derive their name from the high-intensity neutron flux that is concentrated in them due to the close proximity of the fuel and the materials used in these "traps". The ATR's unique horizontal rotating control drum system (termed outer shim control cylinders) provides stable axial/vertical flux profiles for experiments throughout each reactor operating cycle unperturbed by the typical vertically positioned control components. This stable axial flux profile, with the peak flux at the centre of the core, allows experimenters to have specimens positioned in the core to receive different known neutron fluences during the same irradiation periods over the duration of test programs requiring several years of irradiation. This system also allows the reactor to operate different sections of the core at different power levels. The ATR core is divided into five different operating lobes: the four corner lobes and the centre lobe. Each lobe of the reactor may be operated at a different power level (within specific limitations) during each reactor cycle.

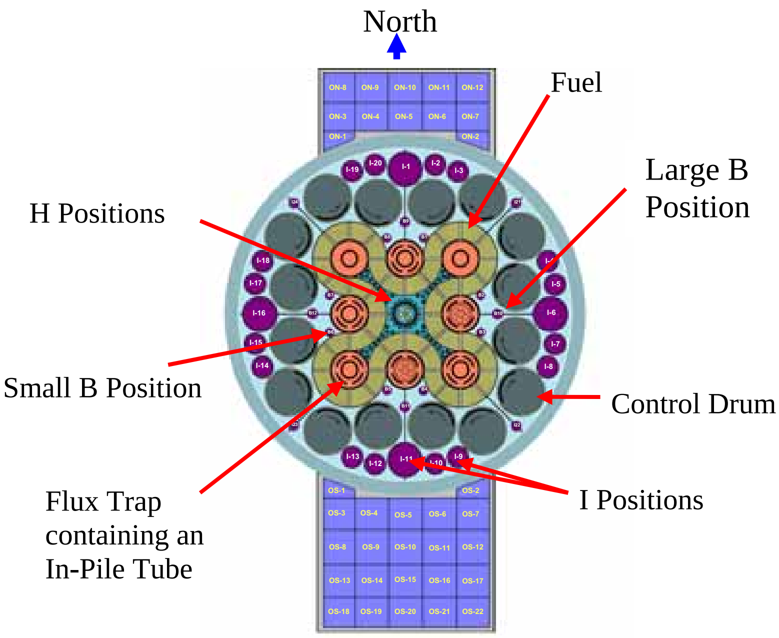

Figure 1 - ATR Core Cross Section

2. Experiment Types

Three major types of irradiation testing are employed in the ATR. The simplest and least expensive type is a static sealed capsule with only passive instrumentation. The next level of complexity in testing includes active instrumentation for measurement and/or control of specific testing parameters, typically temperature and/or pressure. The last and most complex method is the pressurized water loops that are connected to in-pile tubes located in the flux traps. Each of these irradiation types and their relative cost, schedule and operation differences are discussed in detail in the following sections.

2.1. Static Capsule Experiments

Static capsules experiments are self-contained (typically) sealed experiment encapsulations surrounding the irradiation specimens with an inert gas environment. However, occasionally the capsules are not sealed but allow the experiment specimens to be in contact with the reactor primary coolant to prevent excessive temperatures during irradiation. These capsules typically include passive instrumentation such as flux wires for neutron fluence monitoring and/or melt wires for temperature monitoring during irradiation. In addition, the temperature of a static capsule may also be controlled, within limits, by incorporating a small insulating gas jacket (filled with an inert gas) between the specimens and the outside capsule wall or pressure boundary. A suitable gas jacket width can usually be selected to provide the irradiation temperature desired by the experiment customer based upon the gamma and reaction heating characteristics of the specimens and capsule materials and proper selection of the insulating gas.

The static capsules may vary in length from several centimetres to full core height of 1.2 meters. They also may vary in diameter from 12-mm or possibly less for the small irradiation positions (or a portion of an irradiation position) to more than 120-mm for the larger irradiation positions. The capsules are typically constructed of aluminium or stainless steel, but zircaloy has also been utilized. Depending upon the contents and pressure of the capsule, a secondary containment may be included to meet the ATR safety requirements. The capsules are usually contained in an irradiation basket, which radially locates the capsules in the irradiation position and vertically positions them within the ATR core. Occasionally due to space limitations, a static capsule has been used to also serve the function of the basket, but in these cases, the capsules must fill the entire irradiation height and have a similar handling feature at the top of the capsule for installation and removal from the core.

The benefits of utilizing static capsules for irradiation testing include the ease of removal from and replacement into the reactor vessel to support specimen or capsule replacements or to avoid one of ATR’s short high power cycles. This ease of removal and replacement can also be utilized to relocate fueled capsule experiments to a higher power location to compensate for fuel burn-up. This type of testing is also less expensive than the other types of irradiation testing and due to its simplicity; it requires the least amount of time to get specimens into the reactor. However, static capsule testing has less flexibility and control of operating parameters (such as specimen temperatures) during the irradiation and greater reliance is made on the design analyses since passive instrumentation can only provide snap shot values of the operating parameters during irradiation (i.e. a melt wire can provide the maximum temperature attained during an irradiation but not the amount of time or when the maximum temperature was achieved).

2.2. Instrumented Lead Experiments

The next level of complexity in testing incorporates active instrumentation for continuous monitoring and control of certain experiment parameters during irradiation. These actively monitored and controlled experiments are commonly referred to as instrumented lead experiments, deriving their name from the active instrument leads (such as thermocouples or pressure taps) that they contain. An instrumented lead experiment containment is very similar to a static capsule, with the major difference being an umbilical tube connecting the experiment to a control system outside of the reactor vessel. The umbilical tube is used to house the instrument leads (thermocouples, pressure taps, etc.) and temperature control gas lines from the irradiation position within the reactor core to the reactor vessel wall. The instrument leads and gas lines are then routed outside the reactor vessel to the control and data collection/monitoring equipment. An instrumented lead experiment may contain several vertically stacked capsules, and is specifically designed to meet the experimenter’s needs. This is accomplished by selecting a suitable irradiation position, which will provide the necessary gamma and/or reaction heating as well as the total neutron fluence within the available schedule, and then designing the umbilical tube routing necessary to connect the experiment to the reactor vessel wall.

The most common parameter to be monitored and controlled in an instrumented lead experiment during irradiation is the specimen temperature. The temperature of each experiment capsule is independently controlled by varying the thermal conductivity of a gas mixture in a very small insulating gas jacket between the specimens and the experiment containment. This is accomplished by blending a conductor gas with an insulator gas. Helium is used as the conductor gas and neon is typically used as the insulator gas. However argon has also been used as an insulator gas (with helium as the conductor) when a larger temperature control band is needed and the activity from the by-product Ar-41 does not affect the experiment data collection (i.e. monitoring of the experiment temperature control exhaust gas for fission gases, etc.). During normal operation, the gases are blended automatically to control the specimen capsule temperature based upon feedback from the thermocouples. The computer controlled gas blending system permits a blend range of 98% of one gas to 2% of the other to maximize the temperature control range for the experiments.

Temperature measurements are typically taken with at least two thermocouples per capsule to provide assurance against an errant thermocouple and to also provide redundancy in the event of a thermocouple failure. The control system also provides automatic gas verification to assure the correct gas is connected to the supply ports in the system to prevent an uncontrollable temperature excursion resulting from a gas supply mix-up (i.e. insulator gas connected to a conductor gas port or vice versa). Monitoring of the temperature control exhaust gas is quite common to sense for different materials as a measure of the experiment performance or conditions. There are several options available for monitoring that have been employed on previous experiments conducted in the ATR. The most common monitoring has been for fission gases in fueled experiments to monitor fuel performance during irradiation. However, other monitors have also been utilized such as a gas chromatograph to monitor for chemical changes in an experiment cover gas due to oxidation of the specimens, and monitoring for supplemental gases to detect leakage through a test barrier during irradiation. Alarm functions are provided to call attention to circumstances such as temperature excursions or valve position errors. Helium purges to each individual specimen capsules are automatically actuated in the unlikely event of the ability to measure or control the temperature is lost. In order to minimize response time between a gas mixture change and a change in temperature in the experiment specimens, the gas system maintains a continuous flow to the experiment through very small internal diameter tubing. Manual control capability is provided at the gas blending panels to provide a helium purge of the experiment capsules in the event of a computer failure. Data acquisition and archive are also included as part of the control system function. Real time displays of all temperatures, gas mixtures, and alarm conditions are provided at the operator control station. All data are archived to removable media, with the data being time stamped and recorded once every ten minutes to as often as once every ten seconds. The control processor will record these values in a circular first-in, first-out format for at least six months.

The benefits of performing an instrumented lead experiment are more precise monitoring and control of the experiment parameters during irradiation as well as monitoring the temperature control exhaust gas to establish specimen performance during the irradiation. However, this type of experiment has the detriments of higher total experiment costs and a longer lead time to get an experiment into the reactor than a static capsule. There are also higher costs and risks associated with removal and re-installation of an instrumented lead experiment in the reactor for specimen replacements or to avoid a short high power ATR operating cycle.

2.3. Pressurized Water Loops

Five of the ATR flux traps contain In-Pile Tubes (IPT), which are connected to pressurized water loops. The other four flux trap positions currently contain capsule irradiation facilities, and have also contained the ITV as mentioned above. An IPT is the reactor in-vessel component of a pressurized water loop, and it provides a barrier between the reactor coolant system water and the pressurized water loop coolant. Although the experiment is isolated from the reactor coolant system by the IPT, the test specimens within the IPT are still subjected to the high intensity neutron and gamma flux environment of the reactor. The IPT extends completely through the reactor vessel with closure plugs and seals at the reactor’s top and bottom heads. This allows the top seals to be opened and each experiment to be independently inserted or removed. The experiments are suspended from the top closure plugs using a hanger rod. The hanger rod vertically positions the experiment within the reactor core and provides a pathway for test instrumentation. Anything from scaled-down reactor fuel rod bundles to core structural materials can be irradiated in these pressurized water loops. Each IPT is connected to a separate pressurized water loop, which allows material or fuel testing at different pressures, temperatures, flow rates, water chemistry, and neutron flux (dependent of the location within the ATR core) with only one reactor.

The loops are connected to a state-of-the-art computer control system. This system controls, monitors, and provides emergency functions and alarms for each loop. The experiment designers, though constrained by ATR’s unique operating and safety requirements, are free to develop a test with specific operating conditions within the space and operating envelope created by the IPT and loop. A loop experiment can contain a variety of instrumentation including flow, temperature, fluence, pressure, differential pressure, fission product monitoring, and water chemistry. All of these parameters can be monitored by the Loop Operating Control System (LOCS) and controlled by the LOCS reactor control system, or by operator intervention. The LOCS is a state-of-the-art computer system designed specifically for the ATR loops. The system controls all aspects of loop operations (flow, pressure, and temperature) for all five loops simultaneously. This information is displayed on the Loop Operating Console and interfaces with the reactor control system. Loop Operators are stationed at the controls to operate and monitor the systems to meet the experiment sponsors requirements. Typical operations include setting, monitoring and maintaining flow rates, temperatures, pressure, and water chemistry.

There are two Powered Axial Locator Mechanism (PALM) drive units that can be connected to specially configured tests in the loop facilities so that complex transient testing can be performed. The PALM drive units move a small test section from above the reactor core region into the core region and back out again either very quickly, approximately 2 seconds, or slowly depending on test requirements. This process simulates multiple start-up and shutdown cycles of test fuels and materials.

Thousands of cycles can be simulated during a normal ATR operating cycle. The PALM drive units are also used to precisely position a test within the neutron flux of the reactor and change this position slightly as the reactor fuel burns.

The benefits of performing a pressurized water loop experiment are (as with the instrumented lead experiments) more precise monitoring and control of the experiment parameters during irradiation as well as monitoring the loop water chemistry to establish specimen performance during the irradiation. However, this type of experiment has the detriments of the highest total experiment costs and the longest lead time to get an experiment into the reactor.

2.4. New Gas Test Loop

A new Gas Test Loop (GTL) for ATR is in the conceptual design phase, and therefore concepts to be developed in later design phases of the system are being identified. The current configuration is planned for installation in one of the large flux trap positions (e.g. NE or NW) to maximize the flux rates available to experimenters. In order to achieve the high fast flux rate goals of the GTL (by minimizing the moderation effects of the coolant system on the neutron spectrum within the GTL facility), a large forced convection gas heat transfer system is needed for cooling of the GTL facility. Helium is the coolant under consideration for the large forced convection system. The existing gas testing facilities at ATR utilize either no (static capsule) or very low (lead experiments – 50 cc/min) temperature control gas flows, and therefore rely mainly on conduction but may also include radiation heat transfer mechanisms. Several irradiation positions (or MIPTs) are planned within the new GTL flux trap, and the current gas conduction/radiation heat transfer system is planned for use within the MIPTs for final temperature adjustment of the irradiation specimens. In addition to use of a flux trap position, the concept also includes fast flux boosting by including additional fuel around the outside of the test positions. A configuration has been proposed for the additional booster fuel and development and testing of the booster fuel is currently being pursued. Since the booster fuel is the main driver in the design of the GTL, the final design of the loop is dependent upon successful completion of the booster fuel testing.

3. Conclusion

The ATR has a long history in fuel and material irradiations, and will be fulfilling a critical role in the future fuel and material testing necessary to develop the next generation reactor systems and advanced fuel cycles. The capabilities and experience at the ATR, as well as the other test reactors throughout the world, will be vitally important for the development of these new systems to provide the world with clean safe energy supplies in the future.

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Current and prospective fuel test programmes in the MIR reactor

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ABSTRACT

The MIR reactor is mainly designed for testing fragments of fuel elements and fuel assemblies (FA) of different nuclear power reactor types under normal (stationary and transient) operating conditions as well as emergency ones in a certain project. At present six test loop facilities are being operated (2 PWR loops, 2 BWR loops and 2 steam coolant loops). The majority of current fuel tests is conducted for improving and upgrading the Russian PWR fuel, such as: long term tests of short-size rods with different modifications of cladding materials and fuel pellets; further irradiation of NPP refabricated and full-size fuel rods up to achieving 80 MW·d/kg U; experiments with leaking fuel rods at different burn-up and under transient conditions; continuation of the RAMP type experiments at high burn-up of fuel; in-pile tests with simulation of LOCA and RIA type accidents. Testing of the LEU research reactor fuel is conducted within the framework of the RERTR programme. Upgrading of gas cooled and steam cooled loop facilities is scheduled for testing the HTGR fuel and sub-critical water-cooled reactor, correspondingly. The present paper describes the major programs of the WWER high burn-up fuel behavior study in the MIR reactor, capabilities of the applied techniques and some results of the performed irradiation tests.

1. Introduction

The MIR reactor is a heterogeneous thermal reactor with a moderator and a reflector made of metal beryllium [1]. It has a channel-type design and is placed in the water pool. The frame of the core is made up of hexagonal beryllium blocks with width across flats of 148,5. In the central axis holes of the blocks channel bodies are installed for operating FAs (37 pcs); combined operating FA with absorber (12 pcs); experimental loop channels (11 pcs). The maximum diameter of experimental channels is up to 148 mm, height of core 1000 mm.

At present 6 loop facilities (PV-1, PVK-1, PV-2, PVK-2, PVP-1, PVP-2) are being in operation and 2 facilities (PG, PM) have not been used for the last 15 years (table 1).

No	Parameters, unit	Loop facilities							
		PV-1	**PVK-1**	**PV -2**	**PVK -2**	**PVP-1**	**PVP-2**	**PG**	**PM**
1.	Coolant	water	boiling water	water	boiling water	water, steam	water, steam	nitrogen, helium	heavy metal
2.	Number of test channels	2	2	2	2	1	1	1	1
3.	Maximum channel power, kW	1500	1500	1500	1500	100	2000	160	500
4.	Maximum coolant temperature, C°: -in outlet of channel, -in outlet of device	 350 350	 350 350	 350 350	 365 365	 500 500	 550 1100	 500 1000	 550 550
5.	Maximum pressure, MPa	17,0	17,0	18,0	18,0	8,5	15,0	20,0	1,7
6.	Maximum coolant flow rate through the channel, m^3/h	16,0	16,0	13,0	13,0	0,6	10,0		5,0

Table 1. Key parameters of loop facilities

Water and boiling water high-temperature loop facilities provide necessary coolant parameters for WWER fuel testing. Lay-out of control rods of the reactor and loop facilities in the core makes it possible to perform several testing programs simultaneously at different values of neutron flux density in the loop channel (they differ by a factor of 5 to 10). A high neutron flux density (up to ~ 5·1018 m^{-2}·s^{-1}) allows repeated irradiation of standard or experimental fuel rods from the WWER fuel assemblies up to a burnup of ~ 80 MWd/kgU and higher. The main purpose of loop testing is experimental examinations of fuel rod new modifications serviceability and reliability at different normal and accidental operating conditions. These operating conditions include in particular the following: long-term operation under nominal parameters with allowance for tolerance; daily power cycling with a fast power change (power ramping); design-basis accidents followed by heat-transfer drop (coolant loss, burn-out), positive reactivity insertion and operation with leaking fuel rods.

The presented in this paper programs and techniques for in-pile examination of the WWER fuel are aimed at obtaining experimental data that are necessary to provide conformity of the WWER fuel with licensing requirements such as: total pressure of helium and fission gas under the cladding; plastic strain of the cladding as a result of its interaction with fuel; temperature, strain and integrity of claddings in case of design-basis accident with loss of coolant (LOCA); local depth of cladding oxidation; value of fuel enthalpy under design-basis reactivity increase accident (RIA); permissible number of leaking fuel rods in the core and others.

2. Experimental techniques for WWER fuel testing in the MIR reactor

Comparison of the WWER fuel operating conditions with characteristics of the MIR water-coolant loop facilities (table 2) testify their conformity.

Parameter	WWER	MIR
Maximum LP, kW/m	≤ 44.7	Higher values are possible
Pressure, MPa	≤ 17.7	≤ 18.0
Maximum coolant temperature inlet / outlet, °C	290 / 340	325 / 350
Coolant-chemical conditions Boric acid concentration, g/kg	Ammonia-boric-potassium Up to 10	Provided Up to 10*
Coolant velocity, m/s	5.7	Provided
Burn-up, MWd/kgU	~ 55	Up to 100
Start time of fuel rod leaking	Impossible	Possible
Increase of liner power	Impossible	Possible
Intermediate control of fuel rod status	NA	Possible in the pool and shielded hot cell
Control and change of water chemistry	NA	Possible

Table 2. The WWER fuel operating conditions and characteristics of the MIR loop facilities

Several types of irradiation devices have been designed for testing of the WWER-type fuel rods [2]:
- the module type, dismountable device for testing short-size (≤ 250 mm) fuel rods, up to 4 such rigs can be installed one over another in the loop channel;
- dismountable and instrumented device for testing fuel rods ~ 1000 mm, containing up to 19 fuel rods;
- device for combined irradiation of non-instrumented refabricated (≤ 1000 mm) and full-size fuel rods (≤ 3500 mm) taken from spent NPP with WWER fuel assemblies;
- device for tests of instrumented refabricated fuel rods (≤ 1000 mm) and full-size fuel rods (≤ 3500 mm);
- dismountable devices for power cycling and RAMP experiments of instrumented fuel rods by displacement or rotation of the absorbing screens in the experimental channel;

- instrumented devices for simulation of RIA and LOCA conditions (fuel rod drying and overheating);
- devices and equipment for leaking fuel rods testing.

Types and characteristics of instrumentation for in-pile measurements of coolant, cladding and fuel pellet temperatures; fuel rods elongation, change of cladding diameter; gas pressure inside fuel rods, neutron flux and stem content in coolant are given in table 3.

Parameter	Transducer	Measurement range	Measuring error	Sensor dimensions, mm	
				Diameter	Length
Coolant (T_c)and cladding temperature (T_{cl})	Chromel-alumel thermocouple	up to 1100 ^oC	0.75%	0.5	
Fuel pellet temperature (T_f)	Chromel-alumel thermoprobe	up to 1100 ^oC	0.75%	1…1.5	
	W-Re thermoprobe	up to 2300 ^oC	~ 1.5%	1.2…2	
Cladding elongation (δL)	Liner differential inductosyn transducer (LDIT)	(0…5) mm	± 30μm	16	80
Diameter change (δD)	LDIT	(0…200)·μm	± 2μm	16	80
Gas pressure inside of fuel rod (P_f)	Bellows rolling diaphragm + LDDT	(0…20) MPa	~ 1.5 %	16	80
Neutron flux (F)	Rh-, V-, Hf - direct-charge detector	$10^{15}…10^{19}$ $m^{-2}s^{-1}$	~ 1%	2…4	50…100
Volume steam content in coolant (β)	Cable-type resistivity sensor	20…100%	10%	1.5	

Table 3. Characteristics of instrumentation for in-pile measurements

3. The program and main results of WWER fuel testing in the MIR reactor

3.1. Irradiation of refabricated and full-size WWER fuel rods

The test objective is to investigate the behavior of fuel under higher burn-up and to achieve higher burn-up for preparation of RAMP, LOCA and RIA tests (table 4).

Type of fuel rod	Number of fuel rods	Length of fuel rods, m	Initial burnup, MWd/kgU	Final burnup, MWd/kgU	Liner power, kW/m
WWER-1000	2	3.53	49…50	62…63	18…30
WWER-1000	1	0.95	49	63	19…31
WWER-440	2	2.42	61	72	17…28
WWER-440	1	0.94	60	72	19…31
WWER-1000	5	3.53	53…55	74…75	18…24
WWER-1000	3	0.4	53…58	74…78	18…24

Table 4. General data on irradiation of the WWER refabricated and full-size fuel rods

3.2. Testing under power ramping conditions

By now 14 RAMP tests with the WWER fuel rods have been performed in the MIR reactor. Experimental fuel rods of different modifications, as well as full-size and refabricated fuel rods were tested at burn-up values from ~ 10 MWd/kgU up to ~ 70 MWd/kgU. In figure 1 are illustrated the main results of experiments - range of liner power (LP) changing and state of cladding after power ramp.

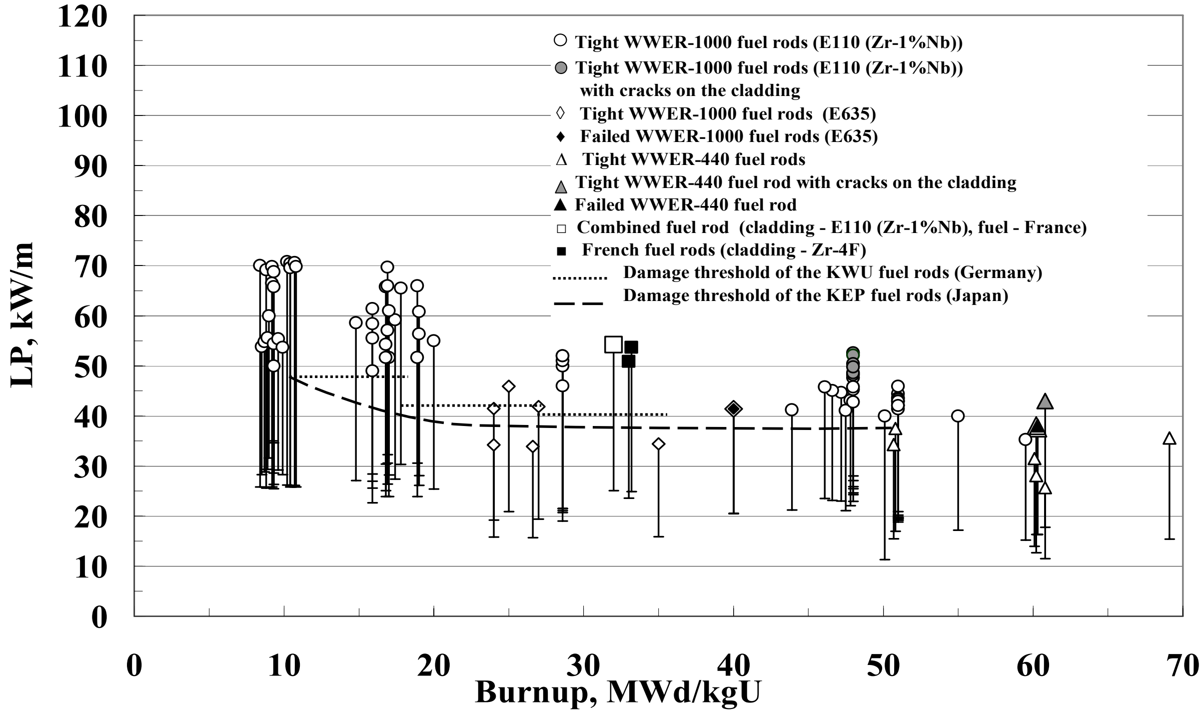

Figure 1. RAMP tests liner power amplitudes versus WWER fuel rods burn-up

In 2008 it is planned to finish RAMP experimental program for WWER-1000 fuel with high burn-up ~ 80 MWd/kgU.

3.3. Testing under power cycling conditions

The objective of testing is to obtain experimental data that characterize a change in the cladding strain, gas pressure in the free volume of a fuel rod, fuel temperature in course of daily power cycling. The fuel rod power changed within (20…30) minutes, exposure at the stable power level makes up ~ 6 hours. Data on tests are presented in table 5.

Type of fuel rod	Number of fuel rods	Instrumentation	Burnup, MWd/kgU	Initial LP, kW/m	LP increase step, kW/m	LP increase rate, kW/m/min
WWER-440	1	P_f, δL, δD	51	19	10	0.3
WWER-440	5	T_f	51…60	15…19	8…10	~ 0.3
WWER-440	4	T_f	52...61	18	11	~ 0.9
WWER-1000	2	T_f, L	49…50	21; 21*	9; 21*	0.6; 0.9*
WWER-1000	2	P_f, δL	49...50	21	9	0.6

Table 5. The main data of power cycling tests

Power cycling tests will be continued for WWER-1000 fuel rods with burn-up ~ 60 MWd/kgU and higher in 2007-2008.

3.4. Testing under fuel rod drying, overheating and reflooding conditions (LOCA)

A series of tests was performed with the WWER-440 and WWER-1000 multi-element fuel assembly fragments under different phases of design-basis LOCA conditions [3]. The objective of the tests is to verify or refine serviceability criteria of fuel rods and fuel assemblies, determine ultimate parameters, which allow disassembling of the core after operation under deteriorated heat transfer conditions, and to obtain data for code verification and improvement. The main parameters of experiments are given in

Experiment	Number of fresh fuel rods	Number/ burn-up, of irradiated fuel rods, MWd/kgU	Pressure in loop, MPa	Implemented temperature range, °C	Instrumentation	Fuel rod status	
						Non-failed	Failed
SL-1	18	-	12	530…950	Tc, T_{cl}, T_f, F, β	+	
SL-2	19	-	12	Up to 1200	-//-		+
SL-5	6	1/52	4.9	750…1250	-//-		+
SL-5P	6	1/49	6	700…930	-//-	+	
SL-3	19	-	4	650…730	Tc, T_{cl}, T_f, F, P_f	+	
LL-1	19	3/50	4	550...850	-//-	+	

Table 8. The main parameters of LOCA experiments

LOCA experiments will be continued for WWER-1000 fuel rods with burn-up ~ 60 MWd/kgU and higher in 2007-2008.

3.4. Testing of the WWER-1000 high burn-up fuel rods under design-basis RIA conditions

Calculation data show that the WWER-1000 reactor parameters of the design-basis RIA conditions are as follows: power ratio in impulse ~ 2, half-width of impulse – (2…2.5)s, power rise duration ~ 1s. The program and techniques were developed for tests performed in the MIR loop facilities to obtain experimental data on behavior of high burn-up fuel rods under the above-mentioned conditions [4]. In the MIR loop channel it is possible for high burn-up fuel to provide a rising of liner power in impulse up to ~ 4.0 times and to control power rise duration from ~ 0.5s and more. In 2006 was started experimental program and were provided 2 experiments for WWER-1000 fuel rods with burn-up ~ 50 MWd/kgU, in 2007-2008 the program will be continued.

3.5. Leaking high burn-up fuel rods testing

Taking into account the state of the WWER fuel rods with a burn-up of above ~ (45…50) MWd/kgU, new experimental data are necessary for the development and verification of computer codes, validation of safe operation criteria for WWER reactors in case of leaking fuel rods appearance, as well as for prediction of a change in their state and radiation situation. For this purpose, a testing program was developed and a series of tests is being prepared now to be performed in the MIR loop facilities with refabricated fuel rods claddings some of which have artificial defects. In 2006 first experiment was conducted, in 2007-2008 the program will be continued.

4. Conclusion

Several types of irradiation devices have been designed for testing WWER-type fuel rods under steady state parameters; daily power cycling with a fast power change (power ramping); design-basis accidents have been developed. The current fuel tests program aimed at improving the Russian operating WWER-440 and WWER-1000 fuel should be finished in the MIR reactor in 2008.

At present prospective program of fuel testing for evolutionary design of WWER with improved economics and safety (project AES-2006) is being created. The testing program of upgrading fuel AES-2006 reactors will start in 2008.

In the MIR reactor will be continued testing of the LEU research reactor fuel within the framework of the RERTR program, and in March 2007 will be started testing of 4 full-scale IRT-4 type fuel assemblies.

Upgrading of gas cooled PG-1 loop with increasing coolant outlet temperature up to 1100 ^{o}C for in-pile investigations HTGR fuel and steam cooled PVP-2 loop with increasing the pressure up to 22.5 MPa for testing fuel and constructive materials sub-critical water-cooled reactor are scheduled.

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