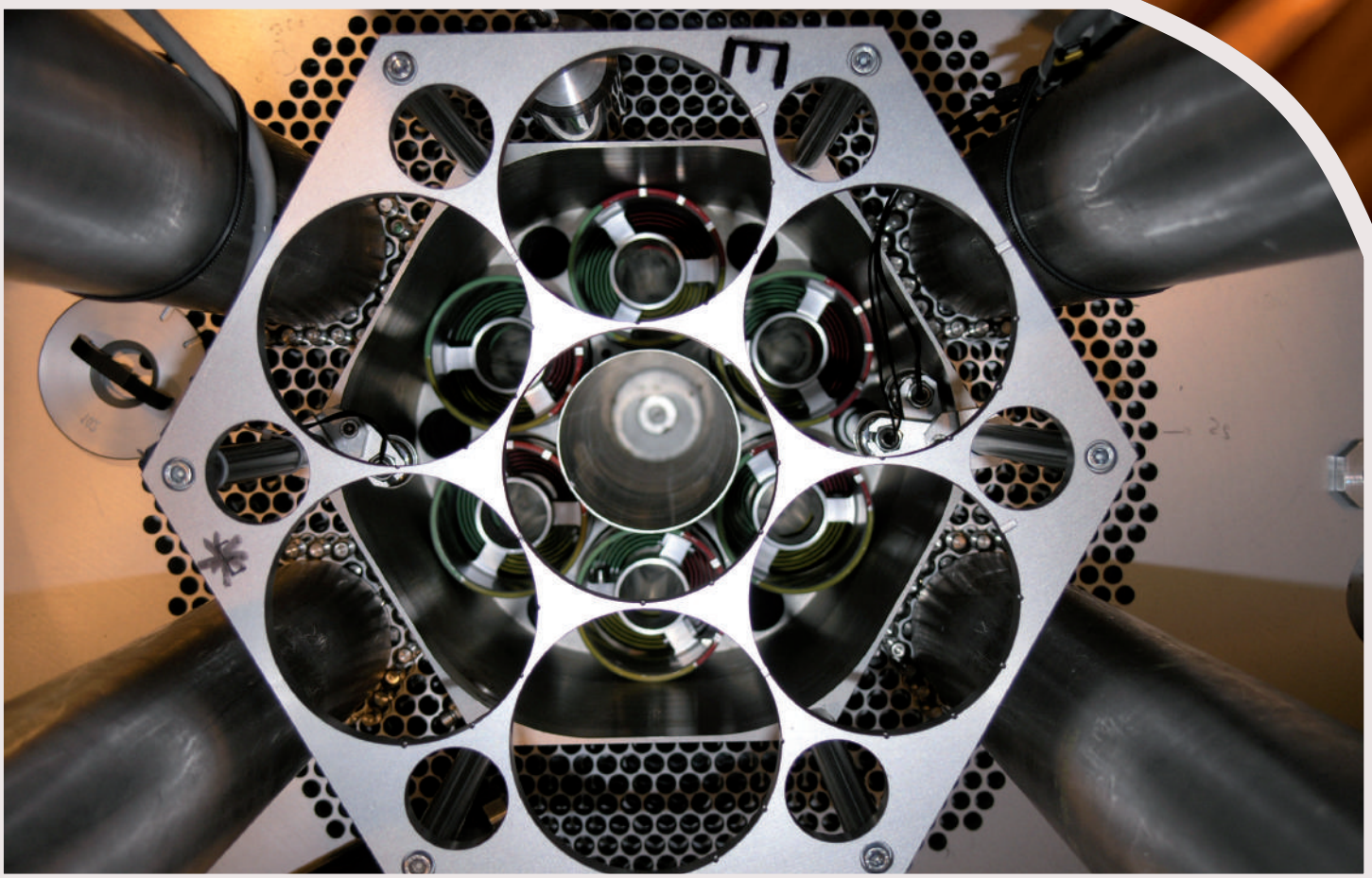

2013 Review

French Research Reactors

DE LA RECHERCHE À L'INDUSTRIE

cea

The Reactor Operators' Club (Club d'Exploitants des Réacteurs de Recherche - CER) is the meeting and discussion forum for operators of French research reactors.
All the material presented in this publication is only provided for information and is not contractual.

In 2013, The IAEA listed approximately 240 research reactors in activity in more or less 50 countries.

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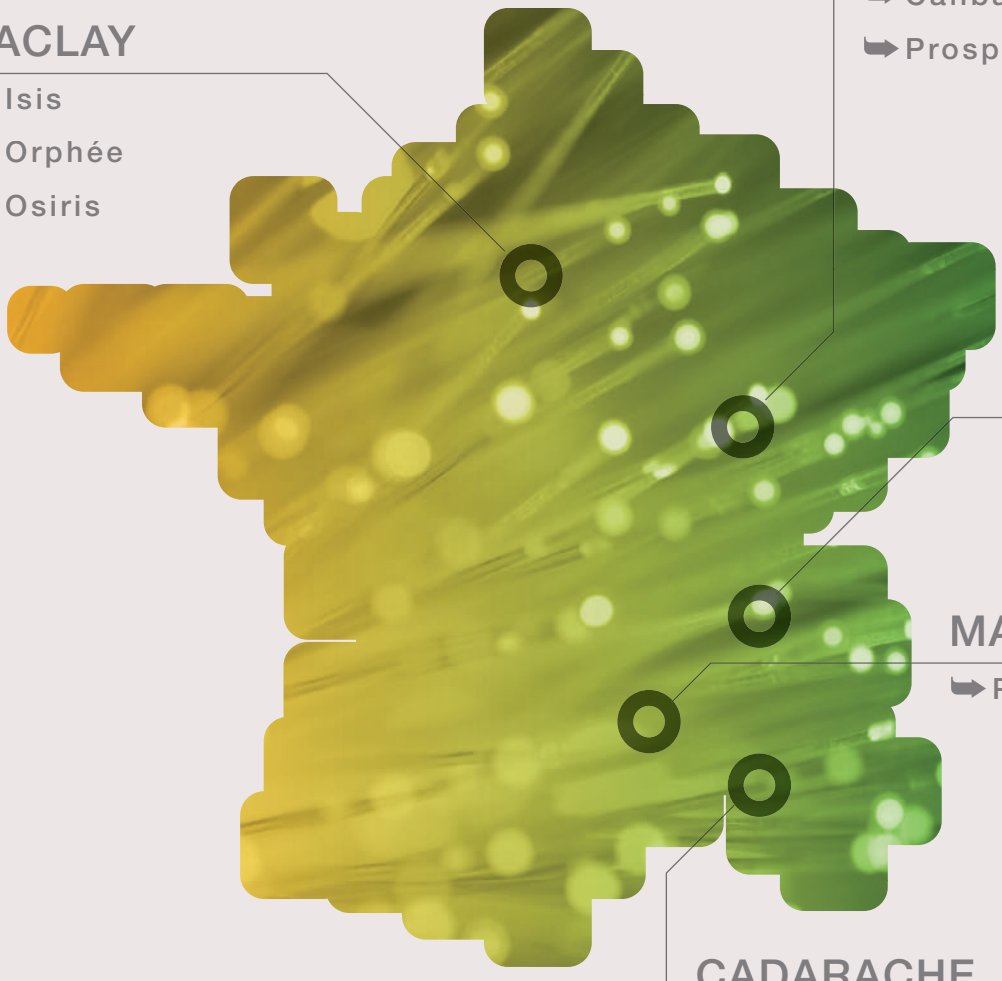


SACLAY

- Isis
- Orphée
- Osiris

VALDUC

- Caliban
- Prospéro

GRENOBLE

- HFR-ILL

MARCOULE

- Phénix

CADARACHE

- Azur
- Éole
- Minerve
- Masurca
- Cabri
- Phébus
- JHR
- RES

Editorial

2013: Refurbishment and improvements to prepare the future of our research reactors

While 2012 was marked by the renewed interest of experts in using critical mock-ups to support not only the validation of computer codes but also training actions, 2013 was clearly highlighted by the start of several construction sites for reactor projects devoted to training, the use of neutron beams and the production of artificial radioelements, e.g. the 5 MW JRTR in Jordan, and the KJRR in Korea which only used to produce Mo-99 and silicon dopping.

From a safety perspective, most of the stress tests have been performed for the reactors deemed to be a top priority by the French regulatory body, ASN, following the nuclear accident on 11 March 2011 at the Fukushima plant in Japan. Various modification and improvement programmes destined to render our facilities even safer are either underway or pending. IAEA has also clearly expressed its intention to standardise the safety requirements applicable to research reactors, particularly within the scope of stress-test studies: guidelines are currently being drafted.

Throughout the world, numerous facilities devoted to neutron beams have seen their programmes extended and their capacities enhanced, e.g. guide halls expanded and neutron beams added. This is the case in the US, Korea and Europe.

The production of artificial radioelements – chiefly Mo-99 – remains an increasing concern for research reactors. This is the case in Europe with the problems at Petten and in Canada with the future of their reactor called into question. Several countries have elaborated projects to adapt their experimental capacity in order to produce Mo-99, such as in Germany with the FRM2.

The experimental reactor policy in France has been clarified in light of the decisions recently made on the future of our facilities. The refurbishment of research reactor such as Cabri and Masurca is continuing at a steady pace so they can soon be ready provide a unique range of experimental possibilities.

JHR is still considered a vital asset. This is reflected through our partners' commitment to financing the experimental devices, together with the fact that the English (via the National Nuclear Laboratory) have also joined the JHR consortium.

Our facilities must continue to attract new partners, whether nuclear industry players or research organisations. The quality of our research programmes, together with our capacity to innovate are just as many advantages that must keep us at the forefront of the international scene.

To be continued...



Jérôme ESTRADE
Chairman of the CER



Marie-Noëlle PAOLI
CER secretary

French reactors and their main applications...

	Pages	Medical applications	Material irradiation	Fuel irradiation	Training	Industrial applications	Neutronography	Structure of matter	Neutronic	Safety studies	National defence
AZUR	33				●				●		●
CABRI	36									●	
CALIBAN	44			●	●	●		●	●	●	●
EOLE	48					●			●		
ISIS	32				●	●			●		
MASURCA	54					●			●		
MINERVE	50				●	●			●		
ORPHEE	12	●	●			●	●	●			
OSIRIS	22	●	●	●		●	●				
PHEBUS	40									●	
PHENIX	27		●	●							
PROSPERO	46		●			●				●	●
RES	58					●					●
HFR-ILL	16						●	●			
JHR	61	●	●	●		●	●		●	●	

2013 Highlights

AZUR (p.33)
310 criticalities, modification of core configurations and 14 partial or total loading/unloading operations solely devoted to core naval propulsion qualification, training and qualifying AREVA TA personnel to operate the facility and training personnel from the French navy in reactor operations.

CABRI (p.36)
The facility refurbishment operations were continued (modernisation of the radiation protection equipment, design change of the primary pump of the experimental pressurised water loop, reinforcement of seismic supports…) and end of the reloading operation. The commissionning test program was continued (testing of the control and safety rod drop, calibration tests on the two flowmeters, test of the transient rod depressurisation systems..)

CALIBAN (p.44)
More than 50 days of experiments were conducted, either in a prompt supercritical (power excursion) or a sub-critical configuration to qualify a number of electronic components and detectors, especially for the MegaJoule Laser project. The dosimeter experiments were continued, including the benchmark of results. Programme of qualification of new gamma and neutron detectors.

EOLE (p.48)
End of the AMMON programme (the calculation route for the JHR was checked): a last power measurements in a configuration with the rod tracker's central mandrel ejected, representing an incidental condition in the JHR was tested. A new configuration was installed for an experimental programme to qualify the neutron propagation and fluence computer tools for the reactor vessels of PWRs (extension life duration programme)

ISIS (p.32)
The reactor operated for 61 days to conduct a number of experimental radiations and for training of about 340 researchers: engineering school students, international master students, ASN staff, and technicians. An Internet Reactor Laboratory project was launched in 2013: a live demonstration was performed in September 2013 during the IAEA general conference.

MASURCA (p.54)
Beginning of the removing materials operation as decided within the scope of the post-Fukushima stress test. A number of renovation operations were also continued.

MINERVE (p.50)
The second and third phases of the MAESTRO programme (improving nuclear data on the different materials used in LWRs).

ORPHEE (p.12)
The reactor operated for 184 days, refurbishment actions in the facility, some of which resulted from requests and commitments made following the 2010 safety review. The Léon Brillouin laboratory was able to conduct a significant number of experiments. ORPHEE reactor produced 800 kilograms of silicon dopping and 145 tubes of radioisotopes (including 75 tubes of iridium), as well as providing industrial-scale neutron radiography services to meet the demands of clients

OSIRIS (p.22)
The reactor operated for 145 days, interrupted for a long shutdown for major testing and maintenance projects (refurbishment of the internal lining of the core cooling system deactivation tanks, non-destructive testing of the core primary system's natural convection check valves, first main improvement work determined in the context of the stress test following the Fukushima accident). Concerning the experimental programme: MUSICA (qualification of innovative sensor), VERDON-3 (behaviour of a MOX fuel rod under accident conditions), DIAMINO Mock-up (transmutation) and RAJAH 1' (test of the mechanical properties of the JHR vessel under irradiation). Important production of Moly.

PHEBUS (p.40)
The dismantling and removal of experimental equipment was continued, and reconstruction of fuel assemblies for the CABRI reactor core. Discussions were held with the French Regulatory Body (ASN) to recommend a solution as to how the different preparatory operations prior to final shutdown should be organised.

PHENIX (p.27)
Conduct the dynamic stacking test in the context of investigating the origin of negative reactivity emergency shutdowns, restart of the operation in the Irradiated Elements Cell, refurbishment the plant's chillers, complete dismantling of the electricity generating system (IPE) equipment and simplification of the plant's external power supply. Start assessment of the file requesting authorisation for dismantling and of the safety review case file.

PROSPEÉRO (p.46)
The reactor operated for 80 days for experiments and used to qualify electronic components and detectors relative to their resistance to radiation and to qualify the EDAC sensor.

RES (p.58)
A new industrial organisation was defined. Performance of fossil-fuel-powered steam tests and start of ventilation test.

HFR-ILL (p.16)
The reactor provided 136 days of scientific activities in 2013. The upgrading of the circuits and equipment was continued, and actions associated with the post-Fukushima stress test were launched.

JHR (p.61)
The concrete pouring operations for the nuclear auxiliaries building, the reactor containment and the reactor pool were continued. Installation of the polar crane and the reactor building dome. The qualification tests for the first fuel elements of the EVITA programme were continued. Receipt of the JHR simulator version V0 which will be used to teach future operators. Several Experimental device design reviews have been carried out.

2013 Review

The *Club des Exploitants de Réacteurs* (Reactor Operators' Club) provides a forum for discussions and meetings between French operators of research reactors.

These reactors primarily belong to the French Atomic Energy Commission (CEA) located on the Saclay, Cadarache, Marcoule and Valduc research centres. The club also includes the high flux reactor (HFR) which belongs to the Laue-Langevin Institute (ILL) in Grenoble, and the reactors owned by the Areva Group. These reactors rely on the direct involvement of about 1,700 highly-qualified staff spread over all these sites. Since late 2012, the CER has been joined by a representative from the EDF Tricastin nuclear power plant which, among others, gives the club access to a broader range of experience feedback.

All the different types of facilities are represented by the club which provides a network for sharing the diverse operational issues encountered, from design through to dismantling.

Among the various facilities:
- Under construction: RES and JHR
- In service: OSIRIS, ORPHEE, HFR/ILL, EOLE, MINERVE, AZUR and facilities on the VALDUC (CALIBAN and PROSPERO) site
- Undergoing refurbishment: CABRI and MASURCA
- Shut down pending clean-up: PHEBUS and the VALDUC facility


Visit of Airbus Industrie

- Shut down for clean-up prior to dismantling: PHENIX, PAT and RNG.

The club sets out to:
- Pool experience feedback on operation, incidents and any technical issues
- Compare performance levels between facilities, as well as safety and security issues
- Share knowledge on nuclear facilities (technical visits)
- Discuss problems encountered when applying new regulations and recommendations, as well as any issues raised during inspections
- Propose joint training courses for operating staff members
- Organise technical discussions between members to gauge their opinion.

The club got together twice in 2013:
- At Airbus Industrie in Toulouse on 20 and 21 March 2013.

The first day was devoted to discussions with the senior technical management

of Airbus: different processes were presented, from design studies up to delivery. Discussions also focussed on:

- Use of numerical simulation for design and training, as well as for validating design changes and maintenance procedures
- Configuration management
- Definition of maintenance plans and procurement strategies for spare parts.

The next date was fixed with Airbus to continue these discussions at the Cadarache Centre. The meeting was concluded with a visit of the A380 assembly line.

- At the Marcoule Centre on 6 and 7 November. Discussions focussed on:
  - New organisation in place at EDF to manage operations (work permits, tagout and related documentation)
  - Feedback from the Phenix reactor to prepare the files supporting the final shutdown decree, as well as any operations planned or conducted during the OPMAD phase, i.e. the preparatory operations for final shutdown. Phenix will be the first reactor to apply the Nuclear Safety and Transparency Act in this field.

A visit of the Phenix plant and the Celestin reactor made it possible to illustrate the discussions in more concrete terms.
These seminars also offer the perfect occasion to give presentations on the various key events of each facility, including descriptions of certain incidents that provide a wealth of feedback.

In 2013, the CER continued a number of actions aimed at collecting information on good practices in the following fields:

- Training and preserving of skills
- Management of maintenance operations and planned tests
- Change and configuration management.

Additionally, the CER has held discussions on the implementation of the new INB Order (Nuclear Facility) published in 2012, as well as on ASN decisions affecting the content of the future General Operating Rules and Safety Reports. It has also raised concerns about the follow-up to the stress tests for some of our reactors, which were performed to take into account feedback from the Fukushima accident, together with the definition of the 'hard core' requirements.

In conclusion, the club members all agree that these regular meetings provide the perfect opportunity to discuss and share issues related to reactor operation. The CER annual report also provides an effective means of communication on the activities and utilisation of our experimental resources.



PHÉNIX command control room



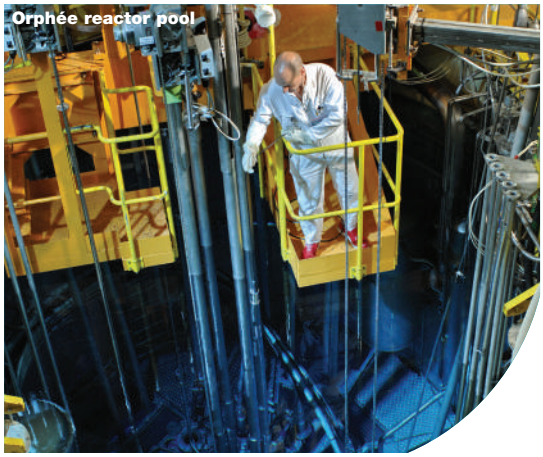


Neutron Beam Reactors

Neutrons, as compared to X-rays, electron beams or light... display a particular property: being without electrical charge, they deeply penetrate most materials. This means that large samples of semi-finished products or even components can undergo neutronic testing. No prior surface treatment is required and tests are not destructive.

The results are applied in varied fields such as:

- mobility of organic molecules in soils,
- optimization of magnetic properties of multilayer materials,
- setting of bioactive regeneration products for bone growth,
- study of carbon nanotubes properties,
- study of magnetic correlations in superconductors,
- study of surfactants,
- crystallography and under stress modifications/measurement of residual stresses,
- stetting of new polymers,
- general support to nanotechnologies.
- ...


Orphée reactor pool

Orphee Reactor

ORPHEE

Presentation

This nuclear facility includes the 14 MWth experimental reactor called ORPHEE and the Leon Laboratory (LBL) where CNRS and CEA researchers work together in the field of neutron spectrometry. This facility is located at the CEA Saclay Centre.
ORPHEE reactor was built between 1976 and 1980 and went critical on 19 December 1980. Its design reflects the experience gained by the CEA and TECHNICATOME (responsible for construction quality control) through the construction of other research reactors (SILOE, OSIRIS, HFR, etc.).

ORPHEE is a pool-type reactor specifically designed to produce thermal neutron beams primarily used by researchers working on experiments conducted at LBL. This technique of using neutrons generates information that no other method can provide.
Neutron diffraction is used for studying the structure of materials and magnetism on an atomic scale (by the elastic scattering of neutrons). Neutron spectroscopy is employed for studying the energy states of condensed matter (by inelastic neutron scattering). Both methods, which complement X-ray analysis, are also used for visualising light atoms (hydrogen and carbon) among heavy atoms, e.g. in a metal structure.

A device for neutron radiography analysis has been installed on one of the neutron beams of the ORPHEE reactor. This method is used for several industrial applications including spatial techniques.

Lastly, the vertical irradiation devices – generally located in the reflector – are used to:
- Produce radio-elements for medical and industrial applications
- Analyse by means of activation, which has many applications including medicine, archaeology, chemistry, biology, etc.
- Irradiate various specimens to produce products for industrial application, e.g.: silicon doped by nuclear transmutation.▶▶▶

Main characteristics of the Orphée reactor

- Pool-type reactor
- Coolant: Light water
- Reflector: Heavy water
- Thermal power: 14 MW
- Max thermal flux in the reflector: 3.10^{14} n/cm^2/s
- Fissile height of the core: 90 cm
- Flow rate in the core: 7.5 m/s
- Fuel: UAlx with enriched uranium
- Cycle length: 100 EFPD
- Average burn-up: 30% at unloading
- 2 cold sources (20 K) and 1 hot source (1400 K)
- 9 horizontal channels, 20 neutron beams
- 9 vertical irradiation channels
- 26 experimental areas

Review of 2013

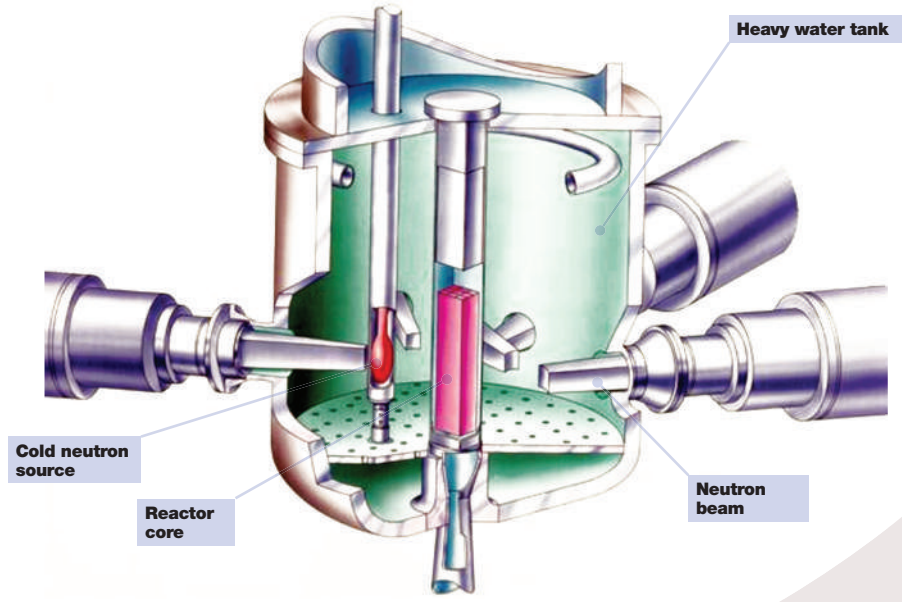
ORPHEE reactor operated for 184 days in 2013.
The year was marked by a number of refurbishment actions in the facility, some of which resulted from requests and commitments made following the 2010 safety review. Some of the highlights include:

- Backfitting of fuel element storage rack attachments in the pool
- Implementation of a new fire extinguishing system for the back-up generators
- Installation of emergency shutdown devices on the heavy water circuits
- Backfitting of installations to meet lightning specifications
- Replacement of chillers using gases that damage the ozone layer
- Qualification of new measuring devices for rare gases and tritium.▶ ▶ ▶

The Léon Brillouin Laboratory

The Léon Brillouin laboratory employs engineers, technicians, administrative agents, post-doc students and 44 permanent researchers (19 from the CEA, 18 from the CNRS and 7 university researchers).
The laboratory's own scientific activities cover three main fields: physical chemistry, structural & phase transition studies, and magnetism & superconductivity.

View of ORPHÉE block core





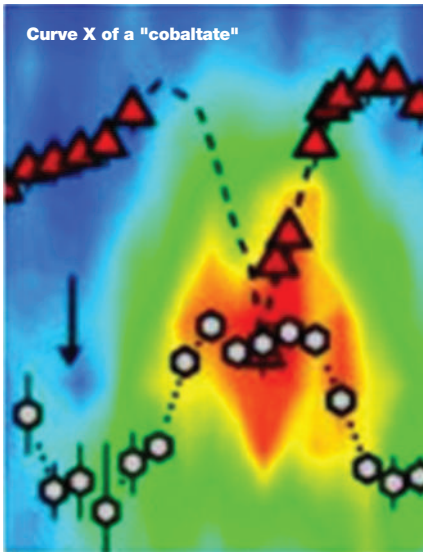
water chiller unit

▶ ▶ ▶ The Léon Brillouin laboratory was able to conduct a significant number of experiments thanks to the implication of its laboratory staff and 495 external experimenters. Interesting scientific results were also obtained in the following fields: magnetism and semi-conductors; the effects of Fe-14%Cr oxide dispersion steels (ODS); the absence of Tb2Ti2O7 gel; and cuprates (see figure below). A cuprate is a chemical compound in which copper forms an anion or a complex whose overall charge is negative. In the case of complexes, the ligands are generally cyanides, hydroxides or halides. Most high-temperature superconductors were actually cuprate semiconductors up until 2008. Johannes Georg Bednorz and Karl Alexander Müller discovered the superconducting property of cuprates in 1986.

ORPHEE reactor produced 800 kilograms of silicon dopping and 145 tubes of radioisotopes (including 75 tubes of iridium), as well as providing industrial-scale neutron radiography services to meet the demands of clients in the sector. The reactor was also used to dope a number of germanium plates required to make neutrino detectors.



Experimental area in the hall guide


Curve X of a "cobaltate"

Six events occurred in the ORPHEE reactor during the course of 2013: four were related to control rod drops, one was related to the inadvertent triggering of the fire extinguishing system for the back-up generators, while the last one involved the dropping of a fuel element during its handling.
In the Léon Brillouin laboratory, a concrete block was dropped during handling which only produced material damage (new guiding components were broken). ❖


Gaz and tritium measurment device


ORPHÉE command control room

NEUTRONS FOR SCIENCE®

High Flux Reactor (HFR)
Laue-Langevin Institute

HFR

Presentation

Laue-Langevin Institute (ILL) is the top neutron research installation in Europe. It operates High Flux Reactor (HFR), the world's most intense neutron source and delivers neutron beams for almost 40 high-technology scientific instruments. Due to its unique, highly compact fuel element and the excellent thermohydraulic conditions, the reactor delivers a thermal neutron flux of 1.5×10^{15} $n.cm^{-2}.s^{-1}$ with a thermal power of 58.3 MW.

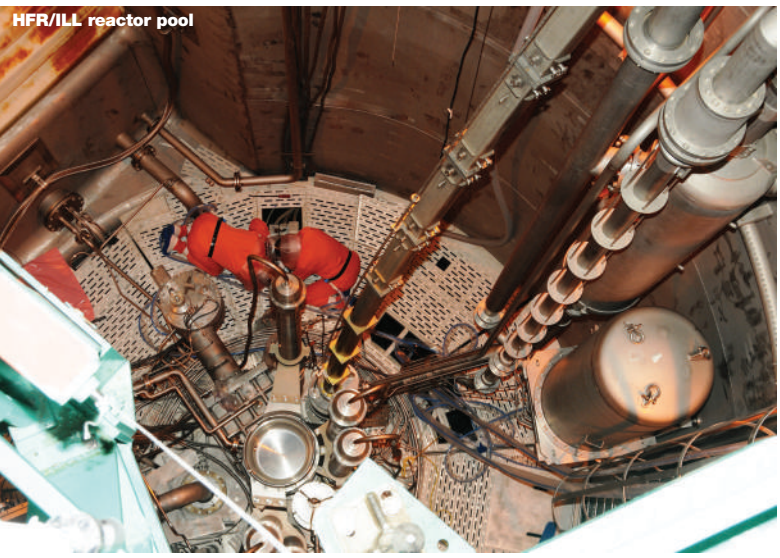

Laue-Langevin Institute

ILL is managed by France, Germany and Great Britain. It has set up scientific partnerships with 11 other countries: Austria, Belgium, the Czech Republic, Denmark, Hungary, Italy, Poland, Slovakia, Spain, Sweden and Switzerland.

In conjunction with the neighbouring Synchrotron (ESRF), ILL forms a unique complex worldwide for the exploration of matter. ILL provides services and expertise for scientists from the entire world. Each year, the institute attracts 1,200 researchers from more than 40 countries. Research is focused on fundamental science in numerous fields including biology, chemistry, soft matter, nuclear physics, science of materials, etc.

Among the 1,500 experiment proposals received each year, around 800 are selected for their excellence by the international scientific committee. The number of experiments is restricted by the operating time of the reactor producing neutrons and by the number of instruments available.

At present, the research projects conducted at ILL have generated more than 600 scientific papers each year, among which 150 were published in high-impact journals. ▶▶▶


HFR/ILL reactor pool

Main characteristics of the HFR/ILL reactor

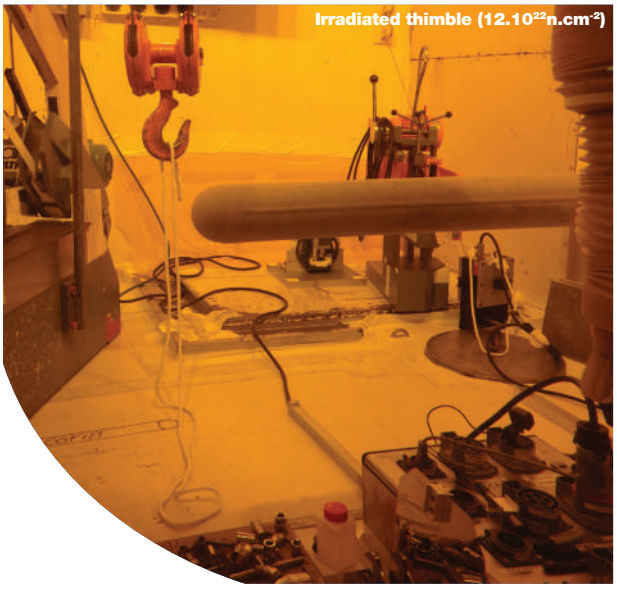
- Pool-type reactor
- Coolant: Heavy water
- Reflector: Heavy water
- Thermal power: 58 MW,
- Max thermal flux in the reflector: $1.5x10^{15}$ $n.cm^{2}.s^{-1}$
- Fuel: UAlx with enriched uranium
- Cycle length: About 50 days
- 2 cold neutron sources and 1 hot neutron source
- 19 neutron beams
- 40 experimental areas.

Review of 2013

Reactor operation

Three reactor cycles were completed in 2013, representing 136 days of operation for scientific research activities.

The reactor was shut down as a result of a manual rod drop during the second cycle. The reactor was restarted after the period of Xenon poisoning.


Irradiated thimble (12.10^{22}n.cm^{-2})

Programme for key reactor components

In order to guarantee safety and reliability over the next years of reactor operation, a programme has been put in place, i.e. a programme for key reactor components. Its purpose is to replace and improve some of the main components. This programme started in 2005 and will last until 2017, which is when the next ten-yearly nuclear safety review is to take place.

The main work to be performed in relation to this programme includes:

- Replacement of thimbles
- Refurbishment of the out-of-pile part of the horizontal cold source, including its I&C system
- Fabrication of hafnium safety rods
- Overhaul of the nuclear measuring lines
- Procurement of spare cells for the cold sources.


New emergency centre located at the first floor of this new building

Operations performed during technical shutdowns in 2013

- Removal of 6 fuels which were transferred to La Hague
- Testing of 2 shutdown-cooling pumps on the heavy water system
- Modification of the reactor safety system
- Fabrication of a hafnium control rod prototype to replace the silver-indium-cadmium rods
- Nuclear pressure equipment: inspection of the cryogenic system for the cold sources and delayed release plugs
- The heavy water management building (GEL) was built in under a year, including all the process components. It has therefore been possible to receive 20 m^3 of heavy water and send 10 m^3 of heavy water from the primary system to Canada. Technical problems which occurred at the Canadian site led to a break in transport operations, which will restart at the end of March 2014
- Installation of sheet piling to ensure the safety of the "hard core"-reactor interface buildings construction area, ILL 5E and 5F

Post-Fukushima stress test

Studies have demonstrated that ILL behaves well under extreme conditions: the scenario investigated was based on an earthquake causing significant damage in the Grenoble area, together with the destruction of the dams in connection with the Drac River resulting in a 10-metre rise in the water level in the centre of Grenoble.

A seismic reinforcement programme called REFIT had already been implemented in late 2007. In 2011, the studies demonstrated the reactor's good level of resistance to a design basis earthquake together with the simultaneous loss of 4 dams in connection with the Drac River. In late 2011, the decision was made to reinforce the reactor containment and to set up a new emergency centre from which the all back-up systems are controlled. The civil engineering work for this emergency centre has been completed. The remaining work will be completed over the next three years without having any impact on reactor operation.

The studies conducted in 2011 and presented to the standing groups in November demonstrated that:

- There are significant margins for the design-basis earthquake
- The loss of a single safety function never causes a cliff edge effect
- The cumulative loss of reactivity and containment never causes a cliff edge effect
- There are always at least 2 strong barriers to prevent and mitigate feared accidents
- Melting underwater never causes a cliff edge effect

In order to meet the requirements of the stress test specifications, a "hard core" must be provided, by:

- Finalising the installation of the emergency reflooding system and the seismic depressurization system
- Installing an underground water system, an emergency unloading system and the new emergency control room (emergency centre)

Beam tubes in HFR block core





Horizontal cold source located inside of its thimble

Cycle No.	Start of cycle	End of cycle	Number of days in operation	Number of planned operating days	Number of rod drops
168	19/02/2013	06/04/2013	49	49	0
169	29/04/2013	13/06/2013	42,1	45	1
170	25/06/2013	09/08/2013	45	45	0
Total			**136,1**	**139**	**1**

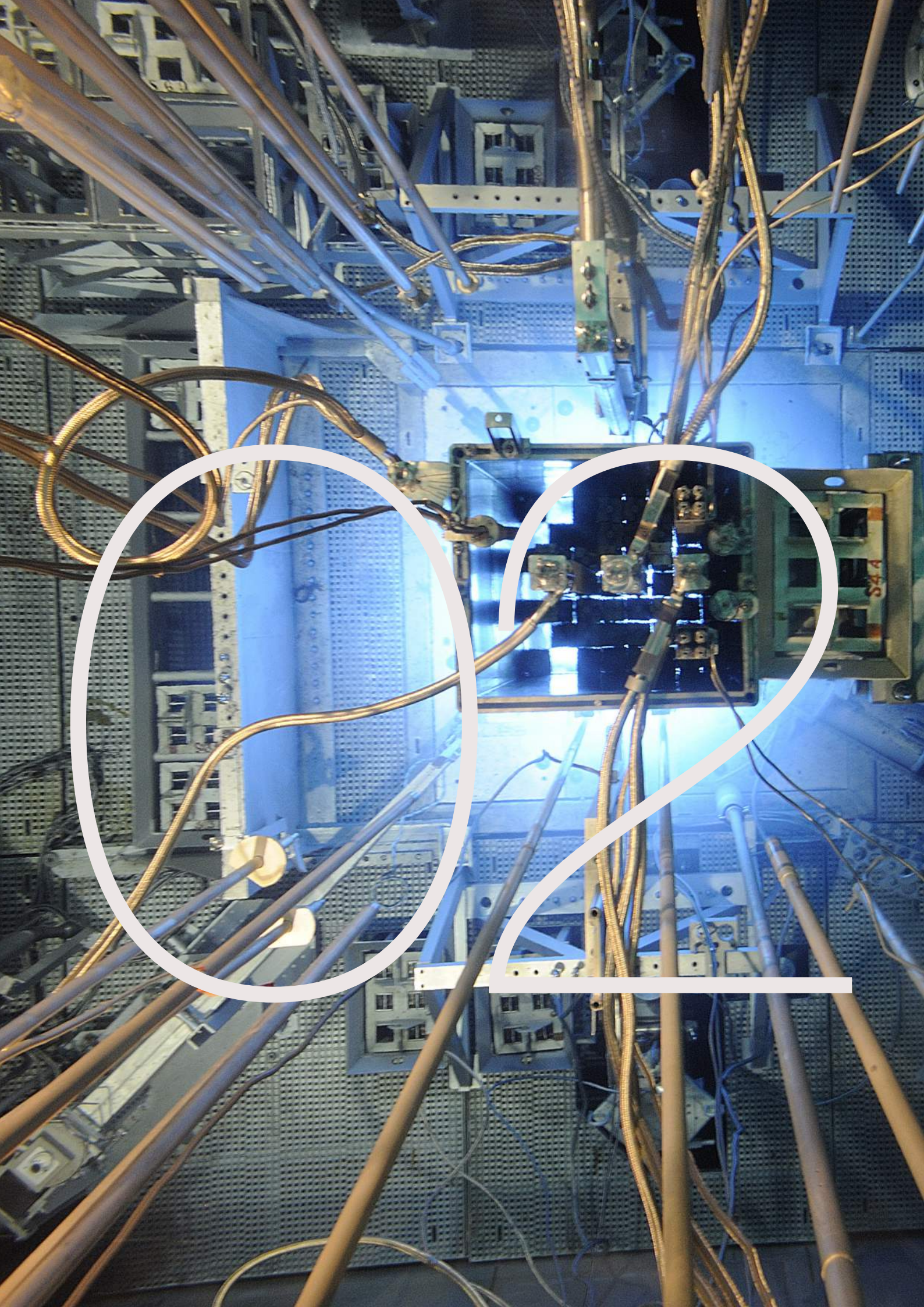
These operations should be completed in 2016.

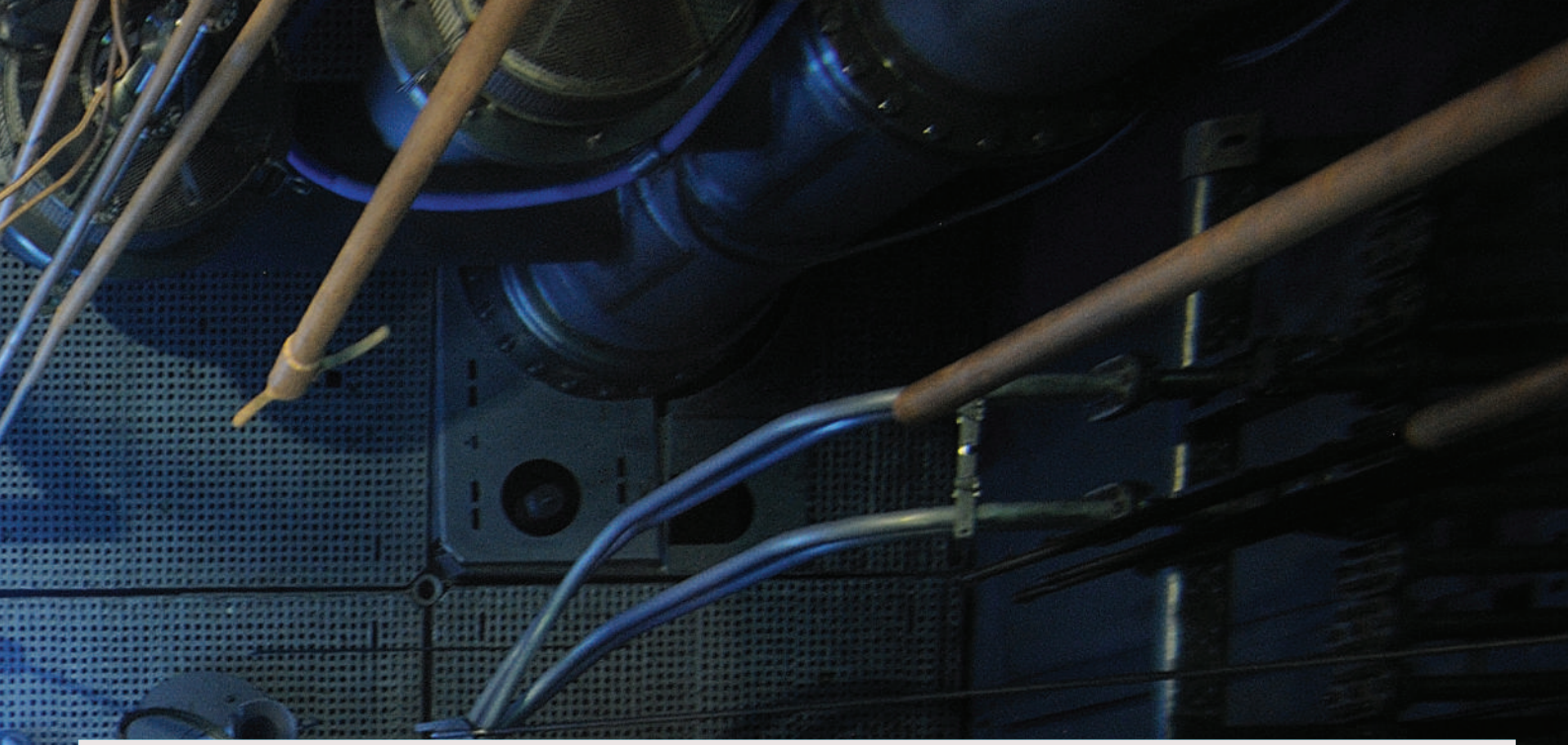
The ASN's decision was given on 6 December 2013. It validates our studies, but its detailed implementation has led to various additions to our "hard core", with the creation of a new seismic electronics room, carrying out work to reduce the movement of the main office building in the event of an earthquake, and the replacement of the fresh air intake building.

Work scheduled for winter 2013/2014

This is a very ambitious programme, which includes:

- Homogenisation of the ion exchange resins in the primary system and the reactor pools, and conditioning in concrete shells acceptable to ANDRA. These operations require the use of SOCODEI's MERCURE machine, and will enable the active resins generated by 20 years' operation to be removed
- Replacement of the top part of a safety rod
- Maintenance of the control rod mechanism
- In-depth maintenance of the main diesel generators (not classified)
- Replacement of thimbles IH3 and H13, modification of the internals of thimble H5 excluding the horizontal cold source
- Installation of vessel feedthroughs and bridges for laying the "hard core" cables and systems
- Refurbishment of the lighting and installation of scaffolding in the space between the 2 containment vessels
- Modification of the filters on the cooling water from the Drac river, and cleaning of the exchangers
- Replacement of the seals on the sleeve-holder flange in channel H13
- Continuation of exchanges of heavy water with Canada according to a very restricted schedule
- Replacement of emergency main LV switchboards AS0, 1, 2 and 3,
- Strengthening of the gantry crane
- Construction of the seismic electronics room
- Installation of the cables (measurement and control) for the "hard core"
- Installation of the 2 seismic depressurisation systems
- Installation of the 2 underground water systems
- Equipping the emergency control centre so that it can deal with any type of emergency ❖





Technological Irradiation Reactors

Using the neutrons generated and confined in the core of the reactor, the irradiation facilities provide applications in many different fields such as:

- **R&D (Research and Development):**
  - research on current and future nuclear power plant structure materials, and their behavior over time,
  - studies of fuel behavior for fuels in current nuclear facilities and those being designed for the future,
  - studies the transmutation of long-life fission products and/or minor actinides to improve management of nuclear waste.
- **Medicine (Production of radioisotopes used for certain medical examinations and therapies).**
- **Electronics industry (doped silicon).**

Osiris Reactor

OSIRIS

Presentation

Located on the CEA Saclay Centre, Osiris is a pool-type research reactor with an open core in which water is the moderator, coolant and biological shielding. It has a rated power of 70 MWth. OSIRIS was authorised by decree dated 8 June 1965 and went critical for the first time in 1966 before reaching maximum power in 1968.

Main characteristics of Osiris reactor:

- pool-type reactor
- compact core: 57 × 57 × 60 cm
- fuel
  - ➥ 38 standard elements
  - ➥ 6 elements with Hafnium as absorber
  - ➥ U_3Si_2Al plates (enriched at 19.75 %)
- moderator, cooling and biological protection: H_2O
- thermal power: 70 MW
- maximum neutron flux
  - ➥ Fast (E>0.1 MeV): 4.5×10^{14} n.cm^{-2}.s^{-1}
  - ➥Thermal: 3×10^{14} n.cm^{-2}.s^{-1}

Purpose

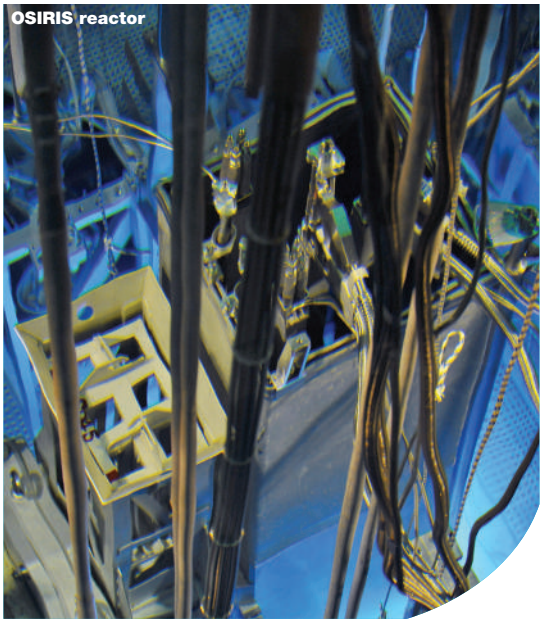
OSIRIS is designed to conduct technical irradiation experiments on nuclear materials and fuels for the needs of the nuclear industry and research. These experiments help improve our knowledge of materials and fuels currently in use, as well as to develop new materials and fuels that will be used in the nuclear power plants of the future. The irradiations are carried out in experimental devices (loops and capsules) which are installed (from the top) either directly in the core or on the edge in places reserved for this purpose.

OSIRIS is also used to:

- Produce radioisotopes for medical and industrial requirements
- Produce silicon dopping to meet the increasing needs of the microelectronics sector
- Analyse materials by means of neutron activation.



Osiris in operation

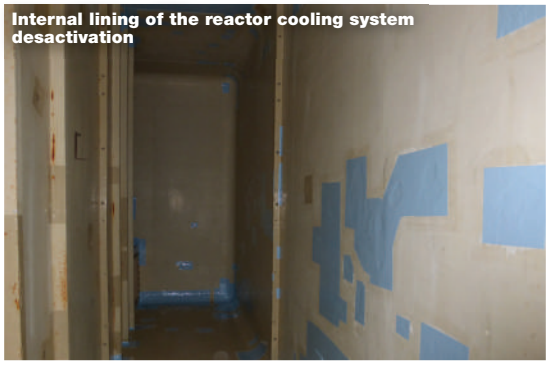

OSIRIS reactor

Review of 2013

Osiris operated for 145 days in 2013. A total of 6 operating cycles were completed, lasting between 18 and 27 days. This operation was interrupted intentionally for a long shutdown of 5½ months for major testing and maintenance projects. Some of the operations are described below.

Maintenance and upgrades

The internal lining of the reactor pool and core cooling system deactivation tanks has been refurbished. A total of 63 m² of these walls have been stripped then coated with resin.


Internal lining of the reactor cooling system desactivation

Video non-destructive testing (using eddy current tests and gamma radiography) was carried out to check that the welds and reinforcement plates of the core primary system's natural convection check valves were in good condition. These tests confirmed that the welds, which had previously been checked in 2006, were still in very good condition. This complex operation required the use of divers in the reactor pool.


New back-up diesel generator

The main improvement work, determined in the context of the stress test following the Fukushima accident, was carried out during 2013. This work included the installation of a new back-up generator set capable of re-supplying, following a total loss of power supplies, the equipment for monitoring the safety parameters, for ensuring any necessary make-up of the reactor pool water and providing ventilation of the reactor building.



Préparation of MOLY target

Production of Radioisotopes for medicine

The high flux of the OSIRIS reactor is used to produce radioisotopes for nuclear medicine and, to a lesser extent, for industry. The main medical uses include:

- radioisotopes for therapeutic use, such as iridium-192, yttrium-90, samarium-153, erbium-169 and rhenium-186
- radioisotopes used in medical imaging, such as technetium-99m, produced from molybdenum-99.

The production of molybdenum-99 in 2013 was characterised by long shutdowns of the HFR in Petten (usual capacity ~ 30% of the global market and 50% of the European market), requiring better coordination with the operating periods of the other reactors, and a higher production level.
OSIRIS therefore had to complete an additional operating cycle in May 2013 and then achieved “record” production of 114 targets during its December cycle in 2013. The production of Mo-99 in 2013 from the OSIRIS MOLFI targets is estimated to have met on average ~ 35% of European requirements (and the production of the IRE) over the year, and up to ~ 75% during the weeks when OSIRIS was the only reactor operating in Europe (April-May and December-January). This means that approximately 1.5 million scintigraphy scans were carried out in 2013 thanks to the OSIRIS reactor.▶▶▶



Transportation cask for radioisotopes



Handling MOLY target in reactor pool

Technological irradiations

MUSICA irradiation:

After 3 years of design, building and testing, the MUSICA experiment was installed in the core in March.

This experiment, conducted with the CEA Cadarache DER/SPEx/LDCI, consists in qualifying several sensors under neutron irradiation in the context of the INSNU (INStrumentation NUcléaire) project: 2 acoustic sensors [measurement of gas pressure and composition], 1 LVDT sensor [measurement of elongation] and 1 DG sensor [measurement of diameter].

During irradiation, the sensors are positioned on a support structure called the sample-holder, placed in an Ola-type Chouca furnace, inserted in the core of the OSIRIS reactor. With the nuclear heating in the OSIRIS core, the Chouca (containing NaK in its lower part) maintains the appropriate temperatures at the sensors by means of its heating elements and the insulation of its thermal barrier.

The measurement campaigns are carried out in another location in the reactor over several months to monitor the changes in the different signals.

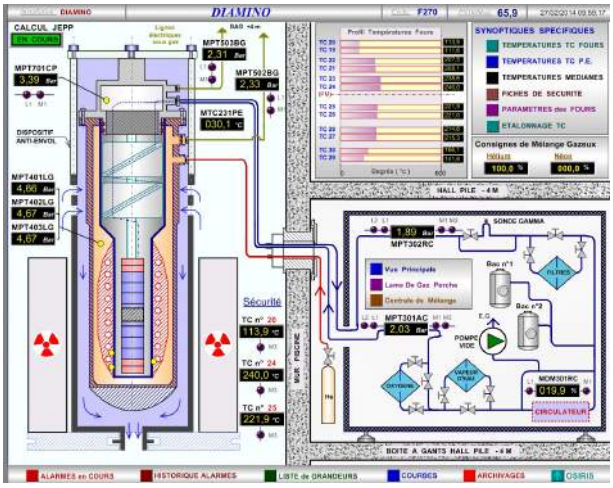
VERDON-3 test:

The VERDON tests are part of the International Source Term Programme (ISTP) and aim at investigating the kinetics of fission products released from PWR fuels in the event of a severe accident. The tests involve heating a few fuel pellets up to a high temperature in water and hydrogen vapour and monitoring the release of fission products online using gamma spectrometry.

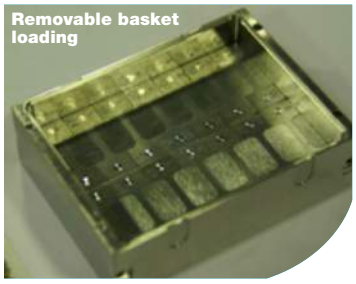
A third VERDON test was performed in April on a MOX fuel with a high burn-up rate.

DIAMINO mock-up irradiation:
Within the context of the studies on transmutation, the DIAMINO experiment is designed to check the behaviour of fuel matrices containing americium under a neutron flux at high temperature. This experiment is due to start in 2014. A thermal mock-up was built then irradiated in OSIRIS at the end of 2013 to qualify the thermal calculations (adjustment of the thermal calculation model by altering the main adjustment parameters: gamma heating, electrical power of the furnaces, etc.). It is loaded with pins with identical geometry to that of real pins.

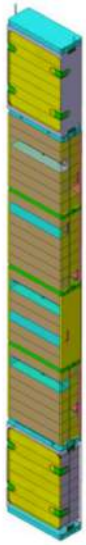
RAJAH 1' irradiation:
The RAJAH 1 Prime experiment carries on from RAJAH 1, an experiment conducted in the OSIRIS reactor pool between May 2008 and May 2011. This time, the device (using the same sample-holder) is carrying 11 baskets of test specimens for qualification and monitoring (comprising fracture toughness, tensile strain and Charpy impact tests) made of aluminium from the JHR reactor vessel, as built.
RAJAH 1 Prime was installed in the core in December 2013 and will continue for the next 2 years. The test specimens will then be tested in the SEMI/LCMI hot lab. This will provide information, in advance, on changes to the mechanical properties of the JHR vessel, subjected to neutron irradiation.❖



Main diagram of DIAMINO






Loading set-up


Phénix Facility

Phenix Unit

PHENIX

Presentation

Situated on the banks of the Rhône River and part of the Marcoule nuclear site in the Gard Department, Phenix is a sodium-cooled fast reactor (SFR) prototype. After going critical for the first time in 1973, the reactor began supplying the grid with power later that year in December. The facility only used two secondary systems and two steam generators between 2003 and 2009. It therefore operated at two thirds of its rated power, i.e. 350 MWth.

The facility stopped generating electricity definitively on 6 March 2009.

The remainder of 2009 was devoted to conducting the final reactor tests to help improve our knowledge of sodium-cooled fast reactors.

The preparatory operations for final shutdown were also launched.

The reactor went critical for the last time on 1 February 2010 at the end of the final tests.

Since then, the preparatory operations for final shutdown have been continued, especially in the non-nuclear parts of the facility (turbine and steam generators).

PHENIX

Following the construction of Phenix, an association was created between the French Atomic Energy Commission (80%) and Electricité de France (20%). The two partners each contributed to the plant's operational budget in proportion to their participation in the association. The teams working in the facility therefore comprised staff members from both companies. CEA was responsible for running this association which was disbanded at the end of 2009; CEA also remains the nuclear operator.

Objectives

The main objectives for 2013 were to:

- Conduct the dynamic stacking test in the context of investigating the origin of negative reactivity emergency shutdowns
- Restart the Irradiated Elements Cell. ▶▶▶

- Refurbish the plant's chillers
- Complete the dismantling of the electricity generating system (IPE) equipment
- Simplify the plant's external power supply
- Start assessment of the file requesting authorisation for dismantling and of the safety review case file.

Review of 2013

Operations

Dynamic stacking test

A test campaign was conducted to ascertain the dynamic behaviour of the core and explain the reactivity transients observed in the reactor in 1989 and 1990 by a stacking movement of the sub-assemblies.

The experimental data will also help to validate the core dynamics models which will be used for the conceptual design of the ASTRID core.

The principle of the test was to initiate mechanical stress on the sub-assembly grid, using a spacer device inserted in the core in place of a sub-assembly, and to measure the movement of the heads of sub-assemblies located in several of the core's rings.

The spacer device was positioned in two positions in the core one after the other: centrally then at the periphery.

The reactor was in a isothermal shutdown configuration.

Two sodium temperatures were tested (180°C and 320°C) to vary the compactness of the core, by altering the various thermal expansions of the diagrid and the sub-assemblies.

Three core configurations were tested at various temperatures between May and October 2013. Each of the configurations required handling of components and sub-assemblies to obtain the required state of the reactor block.

The tests took place under very good conditions and provided the required data, which is the process of being analysed in CEA's laboratories.



Dynamic stacking test device

Partial restart of the Irradiated Elements Cell

In 2012, a new Irradiated Elements Cell (CEI) main lifting unit and two new remote handling devices for heavy operations were installed in the cell.

With this equipment, the Irradiated Elements Cell was restarted for dismantling the experimental capsules.

The FUTURIX Cercer capsule was dismantled at the end of March then sent by transport cask to the LECA/STAR facility at Cadarache in June.

The remainder of 2013 was devoted to overhauling the Irradiated Elements Cell and the Annex Cell in order to resume dismantling the irradiated sub-assemblies:

- New saws for cutting the sub-assembly structures were qualified and integrated in the annex cells
- A new bench for welding casings for containing irradiated pins was qualified

A working group, made up of staff from the plant, defined a refurbishment programme for the equipment used for unloading the irradiated fuel, in order to improve its reliability.▶▶▶


TNI06 transportation cask for experimental fuel pin

Refurbishment work

Replacing the plant's chillers
The plant's chillers, which were showing signs of obsolescence, were replaced in 2013 to improve the reliability of this function.

Preparatory operations for final shutdown

Dismantling the electricity generating system (IPE)
The dismantling of the IPE equipment was completed in February 2013.
The entire dismantling of the electricity generating system involved removing 3000 tonnes of metal.

Simplifying the plant's external power supplies
The PHENIX Plant had been supplied directly by 2 independent substations, one 220 kV and the other 20 kV, for 40 years. These substations were designed for a plant generating electricity and were therefore oversized for the plant's current and future needs.
The decision was therefore taken to replace these two substations with two power supplies via the 5.5 kV network managed by the Marcoule Centre.
The changeover to this network, which required two years' preparation, was successfully carried out at the end of November 2013.

Safety

The Regulatory Body and the environmental authority gave their opinion on the file requesting authorisation for dismantling during 2013.
The assessment of the file requesting authorisation for dismantling and of the safety review case file continued throughout the year.
The public enquiry and the advisory group in charge of nuclear reactor, which are the next steps towards obtaining authorisation for dismantling, are planned for 2014.
The commitments made in the context of the safety review case are currently being carried out (checking of the travelling cranes, inspection by earthquake experts, etc.).
New waste zoning was set up to optimise the management of both nuclear waste and conventional waste. ❖


03



Training Reactors

The training facilities on "small" reactors, provide for training and practice of:

- nuclear plant operators (technicians and engineers) in charge of operating their installations,
- operators (deputy officers and officers) of nuclear-propelled ships (submarines, aircraft carrier, etc.),
- all personnel involved in nuclear facilities operations (safety Authority, R&D, etc.) on theoretical subjects (neutronics) and practical subjects (control, instrumentation).

These training reactors can also be used for some research activity.

Isis Reactor

ISIS

Main characteristics of Isis reactor

- pool-type reactor
- compact core : 57 x 57 x 60 cm
- fuel: 38 standard elements
- 6 elements with Hafnium as neutron absorber
- U_3Si_2Al plates (enrichied to 19,75 %)
- moderator, coolding and protection biological H_2O
- maximum thermal power: 700 kW
- maximum neutron flux:
  - ➥ fast : (E> 0.1 MeV): 4.5×10^{12} n.cm-². s^{-1}
  - ➥ thermal : 3×10^{12} n.cm-². s^{-1}
- possibility to introduce borated water



ISIS control desk

Presentation

ISIS reactor is the neutron mock-up of the OSIRIS reactor, which are both located within close proximity of each other on the CEA Saclay Research Centre. It belongs to OSIRIS facility. It has a rated power of 700 kW. ISIS reactor is used to test new core configurations and fuels, as well as to perform irradiation experiments by measuring the effects of reactivity, neutron flux distributions under different spectrums, and gamma heating. These measurements can be extrapolated to cover OSIRIS reactor. ISIS is also used to qualify instrumentation designed for other reactors.

The instrumentation and control (I&C) system and the control room were renovated between 2004 and 2006. It can now be used to train people from different fields i.e. technicians, apprentice engineers, master students, and staff from diverse organisations, whether French or foreign. These trainees are taught by instructors from the INSTN[1].

Thanks to its efficient man-machine interface, trainees can easily monitor the many parameters (counting rate, doubling time, etc.) in real time from the control room as part of practical work sessions, which enables them to better understand the physical phenomena occurring.

Review of 2013

ISIS operated for a total of 61 days in 2013, including 93 half-days of practical work sessions for about 340 trainees (students from engineering schools, French regulatory body staff and technicians), 14 half-days for experimental irradiations (data acquisition tests for fission chambers and dosimetry).

The Internet Reactor Laboratory project was launched in 2013. This project is partially funded by the IAEA and aims at providing some countries with access to the ISIS practical work sessions by means of live video-conferences. Video and numerical signals (all parameters relevant to reactor operation) will be transmitted while ensuring the strictest conditions of safety and security. A live demonstration was performed in September 2013 during the IAEA general conference. ❖

[1] French National Institute for Nuclear Sciences and Techniques

Azur reactor

AZUR

Introduction

AZUR – a French abbreviation for zirconium and uranium alloy – is an experimental reactor located at Cadarache and primarily devoted to neutron studies, criticality experiments and radiation protection measurements.
This reactor uses fresh fuel. It is also used for training purposes, being particularly well-suited for observing, demonstrating and understanding the phenomena involved in nuclear physics.

Having reached criticality for the first time on 9 April 1962, AZUR has since tested all the reactor cores intended for nuclear propulsion (land-based prototype, submarines and Charles de Gaulle aircraft carrier). It has been used to study other types of core lattices composed of uranium oxide rods or plates.
AZUR was upgraded in 2002 and a dedicated core was specifically installed for training purposes.

General description

AZUR reactor operates at atmospheric pressure and ambient temperature. The lightweight aluminium vessel is designed to host cores of different sizes. The cores are controlled by absorbers that come in different shapes: crosses, bundles, curtains, etc.
The instrumentation and control (I&C) is the latest generation of computers and software for safety I&C which has been developed and qualified for use on nuclear submarines, as well as RES reactor.

Experimental Options

AZUR reactor offers the following main experimental possibilities:

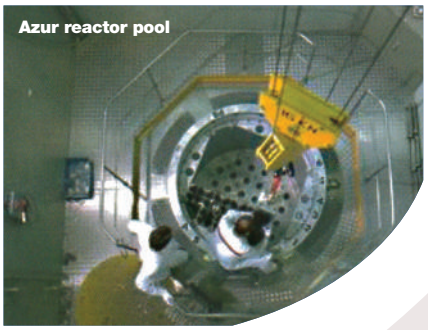
- Characterising neutron parameters
- Measuring worth (boron, water, etc.)
- Measuring absorber worth
- Measuring temperature coefficients
- Measuring flux and power distributions
- Analysing critical lattices (safety studies)
- Monitoring reactor core loading and unloading operations performed underwater
- Measuring radiation protection conditions
- Testing nuclear instrumentation in dynamic conditions
- Irradiating samples.

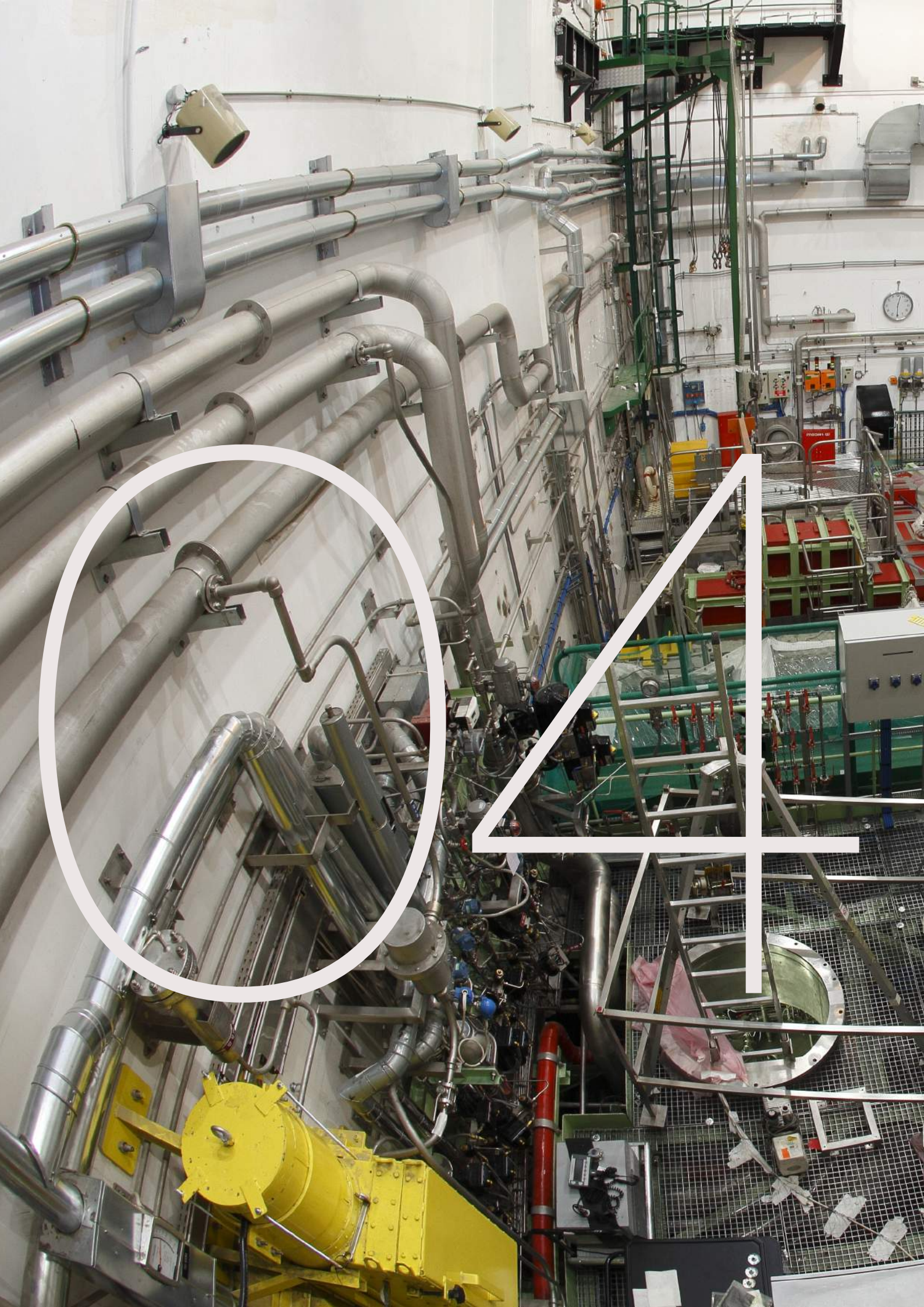
Review of 2013

Operations in the core in 2013 focussed on:

- Characterising and calculating the neutron conditions of two cores devoted to naval propulsion
- Training and qualifying AREVA TA personnel to operate the facility
- Training personnel from the French navy in reactor operations (one session).

These activities resulted in 14 partial or total fuel loading and unloading operations, as well as 310 criticalities spread over a 42-week nuclear phase. ❖


Azur reactor pool


04



Reactors for Safety Research Purposes

A nuclear power plant is designed to operate in a given field (speed, loading,...). Nevertheless, the plant must be able to "stand" limited deviations to the normal operating characteristics without consequences for the users or the surrounding environment.
A nuclear plant is designed, and dimensioned, with this in mind.
Research reactors dedicated to safety-related research are used to study the consequences of certain accidental situations and the behavior of the fuels used in the nuclear plants: these are called design basis accidents.
This involves visualizing the behavior of the fuel when these accidents are reproduced.

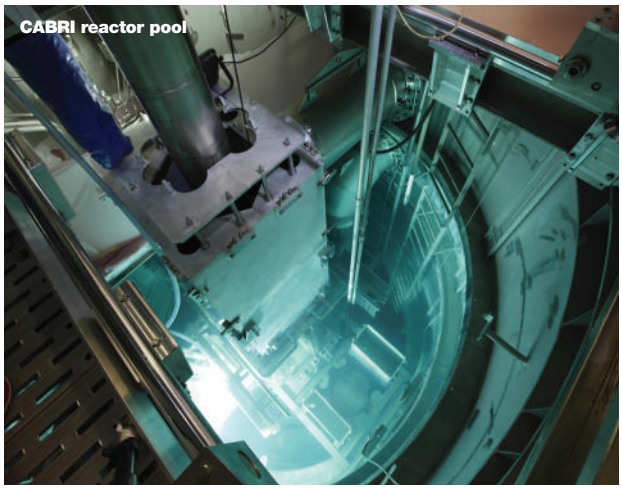
Cabri Reactor

CABRI

Presentation

CABRI is a research reactor located at the Cadarache Centre which is used to reproduce the conditions occurring during a severe accident on a sample of irradiated nuclear fuel. This reactor is particularly used to replicate the conditions of a reactivity-initiated accident (RIA). This reactor comprises a breeder core and an experimental loop. The section of the loop located in the centre of the breeder core hosts the test device which contains the fuel rod to be tested. The breeder core is designed to generate the neutron flux needed to reach the relevant power level in the experimental rod. Depending on the power level, core cooling is ensured either by natural convection with the pool water (when below 100 kW) or by forced convection with a rising flow thanks to the cooling system. The distinctive feature of this reactor lies in its reactivity injection system.

The outer ring of four sub-assemblies in the breeder core called 'transient rods' are equipped with empty cylindrical tubes instead of fuel rods. These transient rods can be filled with pressurised helium-3 (neutron-absorbing gas) which are depressurised by opening motor-operated valves to suddenly change the reactivity and thus the power of the breeder core. For instance, the power can rise from 100 kW to 20 GW in a few milliseconds before dropping just as quickly to about 40 MW owing to neutron feedback (Doppler effect). Depending on the test objectives, the power excursion can lead to failure of the experimental fuel rod cladding in the in-pile section of the pressurised water test loop, as well as to the ejection of some of the fuel contained in this rod.▶▶▶



CABRI reactor pool

Reactor characteristics

- UO_2 enriched with 6% ^{235}U
- 1,488 fuel rods
- 304L stainless steel cladding
- 800 mm fissile height
- maximum thermal power in normal operation: 25MW
- maximum thermal power in pulse operation: 20GW


Control rod of CABRI reactor

Review of 2013

A few years ago, the operator defined a series of major reactor changes concerning:

- Installation of an experimental pressurised water loop in the reactor core to replace the former sodium loop. This pressurised water loop will be used to test fuel rods from PWR power plants under representative thermohydraulic conditions
- Facility safety review.

Other than continuing normal reactor operations and activities in preparation for future experiments, the main actions focussed on moving ahead with the CABRI+ refurbishment and requalification programme.

Main works conducted in 2013

A large project to modernise the radiation protection equipment and to reorganise the equipment's power supply was started 3 years ago. This project was successfully completed in September 2013. One of the main objectives was to improve the redundancy and reliability of the power supply for the radiation protection equipment in the event of power cuts, and to incorporate thirty or so new items of equipment needed to restart the reactor ("RADAIR" contamination detection monitors and "CIEP" irradiation detection monitors at the various workstations, signalling units, C14 bubbler, etc.). During these operations, the team took advantage of the opportunity to upgrade the facility's power supply and bring it into compliance with standards.

To complete this work, it was necessary to organise a staggered timetable (6 am - 9 pm) of complex power cuts spread over three weeks according to a rigorous schedule and in strict compliance with the safety baseline for the reactor.

The following main work was carried out on the systems:

- The heating power of the pressurised water loop was increased
- The pressurised water loop primary pump was modified and factory-tested. The changes were made to improve its thermal barrier, before refitting it on the primary system of the CABRI test loop, prior to hot performance tests
- The "worksite" valve was removed from the temporary ventilation in the reactor hall
- Renovation continued on the cell shielded support structures, tank 60, IRIS and the PW filter. ▶ ▶ ▶


Injection reactivity system (helium 3) Cabri

Commissioning tests

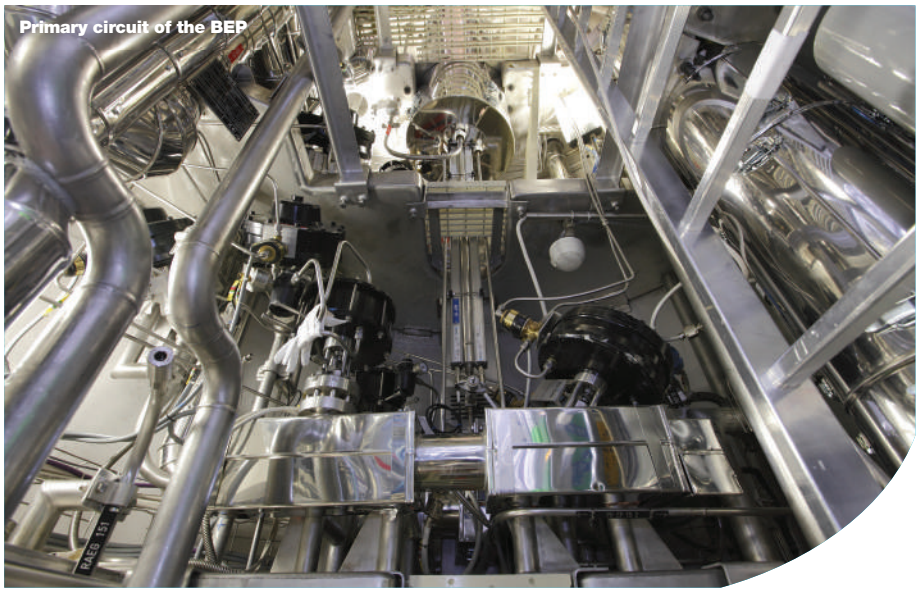
Commissioning tests are needed to re-qualify CABRI facility. To do this, around one hundred tests covering a range of fields were defined: neutron behaviour, ventilation, reactor block, handling, conventional systems, pressurised water loop systems, I&C, experimentation stations, and general operation.
Some tests must be performed after core reloading, others must take place prior to divergence, while the last tests must be conducted before the first experimental test of the CABRI International Programme (CIP).

To date, just over half of these commissioning tests have been completed.

Completion of the core reloading operations, between 5 April 2013 and 19 April 2013, then enabled the mechanical tests to be conducted on the core block immersed in water. The functional tests and testing of the control and safety rod drop times in natural and forced convection modes were also performed, along with the main core cooling system tests.

The CABRI core control and safety rod drop times were tested in June 2013. Each control and safety rod was tested individually and was subject to 3 separate measurements in order to check the reproducibility of the measurement.
The tests confirmed that the rod drop times in forced convection mode (at 3,250 m^3/h) were totally consistent with the tests conducted in both 2002 and 1988. They thus comply with the safety criteria.
Following on from core reloading, these tests represent an important stage and one of the last hurdles to obtaining the CABRI critical situation authorisation. They utlimately lead to the first CIP-Q test.
Beyond the strict safety aspects, the excellent reproducibility of the drop time tests will improve our global control over the test, particularly in terms of the experimental uncertainty on the energy deposited.

The calibration tests on the two flowmeters with vacuum-producing devices (ANNUBAR sensors) in the CABRI core primary water system were carried out by comparison with benchmarks established by draining the main tanks. This type of calibration requires the best possible accuracy when measuring the flow rate of the core water system.
The neutron chambers (used to monitor the power excursion during the CABRI tests) are calibrated by adjusting them via thermal balances of the water used to cool the core during power stages.
▶▶▶


Primary circuit of the BEP

The commissioning tests were continued on the transient rod depressurisation systems. In 2012, the hydraulic operation of the CABRI reactivity insertion system was first tested with no power. This required around 100 depressurisation tests using ^{4}He and/or N_2. In 2013, the injection system was definitively validated during the second test phase, using all the LV systems and with ^{3}He[1] as the depressurised fluid. As the purity of ^{3}He is an essential parameter for the success of the experiments, the gas was first purified before a phase of depressurisation tests which showed a net increase in the depressurisation rate. This result and those obtained from the analysis of stored and purified ^{3}He samples, show that the purification stage was very effective and that the reactivity insertion system in CABRI is operational.

All the results during these tests have been used to create an experimental database to both improve the depressurisation models of the SRES/LPRE experimenters, and to prepare for the future start-up tests dedicated to the Cabri power transients.

[1] Stored in it's storage tank since 2003

Prospects for 2014

The pressurised water loop will be tested in hot conditions, which will determine whether it is operating correctly in terms of reaching the nominal test conditions (155 bar, 300°C).

Low-power neutron behaviour tests will also be started. These tests will enable us to proceed to the sub-critical configuration and the first core divergence. Furthermore, we will be able to measure the efficiency of the control rods and more generally to carry out detailed neutron characterisations of the CABRI core under pressured water loop conditions. ❖

Phebus Reactor

PHEBUS

Presentation

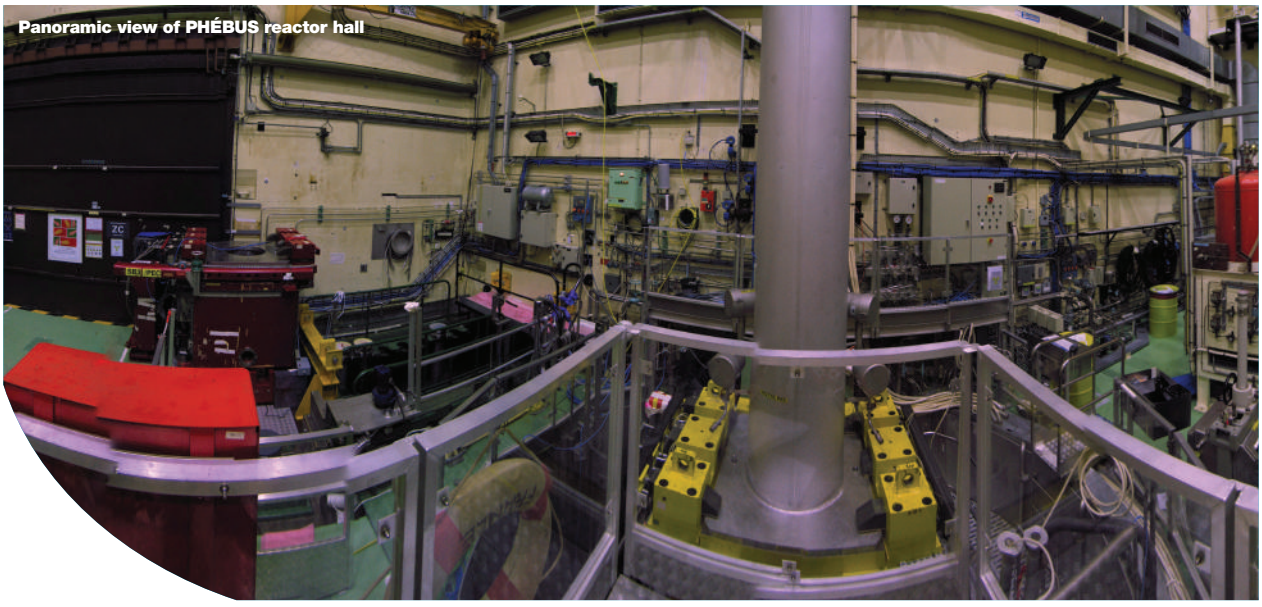
PHEBUS is operated by the CEA at the Cadarache Centre. This unique facility is designed for conducting integral research on severe accidents. It was commissioned in 1979 and underwent significant refurbishment in the 90s. It was decided to stop the safety tests in Phebus in late 2007. PHEBUS is currently in its PHEBUS-FP experimental post-programme stage. The nuclear fuel has been unloaded from the core and is now pending removal.

Review of 2013

In addition to maintaining the facility in a safe operational state, the year 2013 was marked by:

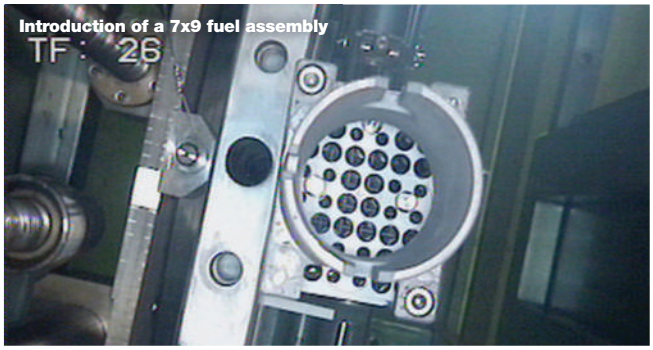
- Continuation of the dismantling and removal of experimental equipment which are no longer required
- Reconstruction of fuel assemblies for the CABRI reactor core.

Discussions were held with the French Regulatory Body (ASN) to recommend a solution as to how the different preparatory operations prior to final shutdown should be organised. A safety case is currently being drafted which will then be submitted to the ASN.



Panoramic view of PHÉBUS reactor hall


Implementation of the fuel reconstruction device



Introduction of a 7x9 fuel assembly

Dismantling and removal of experimental equipment

A total of 31 devices and equipment were dismantled between March 2011 and April 2013. The work was finalised and the job completion report was validated on 15 October 2013. The dismantling of all this equipment generated almost 150 tonnes of various types of waste, including solid parts.

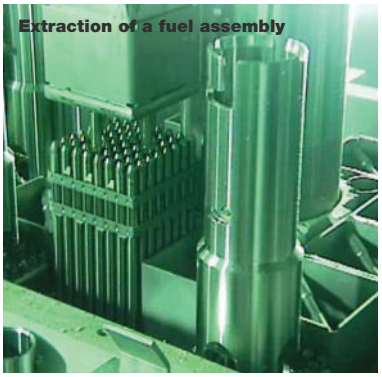
Reconstruction of fuel assemblies for the CABRI core

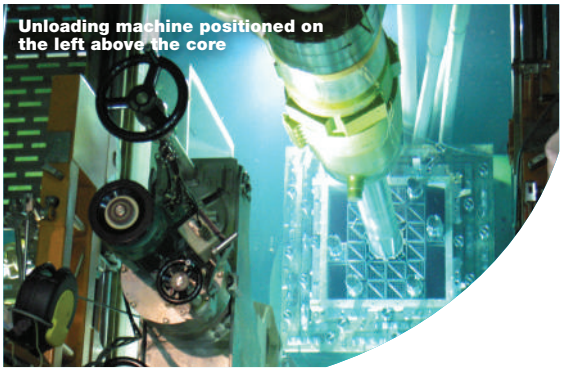
The two fuel assemblies for the CABRI core were reconstructed during the last quarter of 2013. The replacement of a fuel rod in the triangular fuel assembly and the loading of the 7x9 fuel assembly base were performed with the 'reconstruction' unit in the reactor hall storage tank (see photos of the 7x9 fuel assembly below).

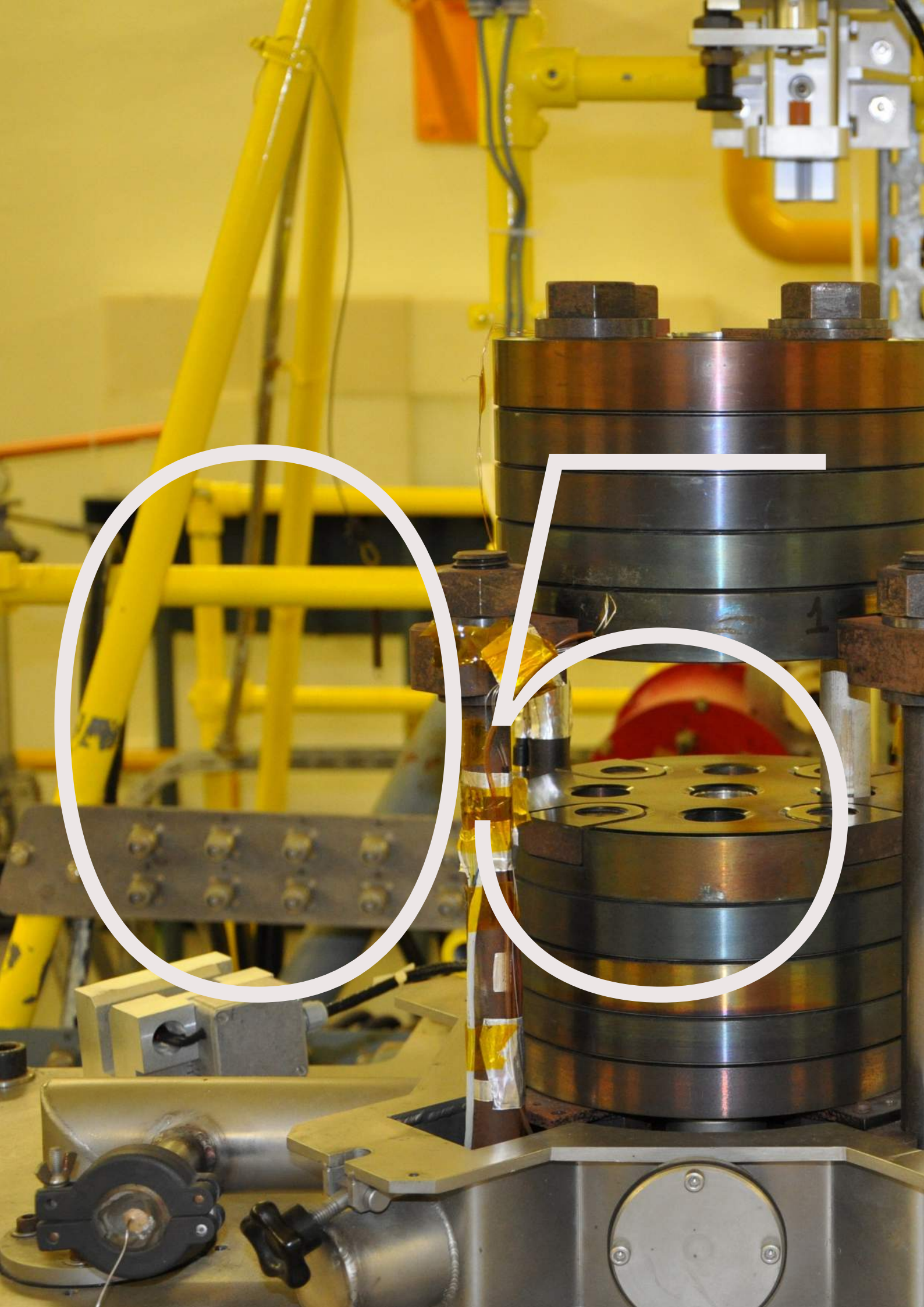
Future prospects for 2014

The year 2014 will be mainly devoted to:

- Maintaining the facility in safe operational conditions
- Continuing the equipment dismantling and removal activities (new worksites) under the responsibility of the licensed nuclear facility manager
- Sampling and removing liquid effluents resulting from experiments
- Preparing:
  - equipment dismantling files which require ASN authorisation
  - orientations report for the safety review
  - plan for the 'final shutdown and dismantling' decree
  - conceptual design for the removal of spent fuel.


Extraction of a fuel assembly


Unloading machine positioned on the left above the core


05



Reactors for Neutronic Studies

The critical models are very low-power reactors (a few hundred Watt) used to obtain precise neutronic data on the fission reaction.
To obtain this data, neutronic experiments are conducted in the three reactors called EOLE, MINERVE and MASURCA which simulate various types of industrial reactor cores:

- EOLE is used for core with thermal neutron and pressurized water (PWR) or boiling water (BWR) reactors,
- MINERVE is mainly used to measure cross sections of core component materials. Core with sodium or gas, the Fast Neutrons Reactors, are tested in MASURCA, which is also used to study minor actinide transmutation, in response to the 1991 and 2006 laws on management of high activity long lived nuclear waste,
- CALIBAN and PROSPERO reactors are irradiation tools used, among others, to test, in hardening conditions, components for the National Defence.

Caliban Reactor

CALIBAN

Presentation

CALIBAN reactor has been operating since 1970 at the CEA Valduc Centre. Caliban is a compact experimental pulsed-type reactor with a highly enriched metallic core. This reactor produces an intense pulse of fission neutrons and gamma rays. It was developed to meet the needs of the DAM, to simulate the radiation effects of nuclear hazards on electronic systems and components.



Qualification test for EDAC probes

Purpose

CALIBAN is a fast reactor designed to operate in pulsed conditions, near the critical state in prompt neutrons. The reactor is installed in a large cell (length: 10 m, width: 8 m, height: 5 m).

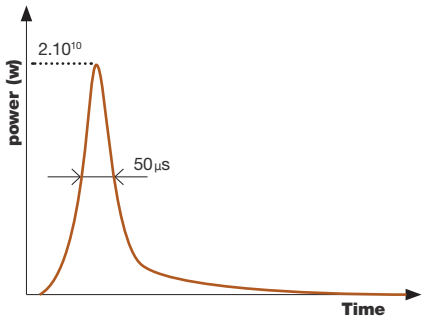
The objects to be irradiated are inserted:

- either in the reactor's central cavity,
- outside the reactor,
- or in neutron-gamma converters (CH_2-Cd).

The reactor core is essentially composed of a cylindrical enriched-uranium fuel sub-assembly along a vertical axis, divided into two practically identical units. One is fixed, while the other is attached to a rapid-withdrawal device and constitutes the safety element.
The sudden insertion of a so-called "excursion rod" brings the reactor to a prompt supercritical state. The neutron population grows according to an exponential law until the instant when fuel expansion, due to the heating of the fissile matter, causes a decrease in reactivity and thus in power. ▶▶▶.

Performances

The minimal width at mid-height of the burst of neutrons is 50 µs. The maximum peak power is on the order of 20 GW.



Applications

- electronic hardening against fission neutrons and gammas,
- neutronics,
- hysics of materials under radiations,
- low dosimetry / high fluence,
- digital code benchmark,
- criticality accident in metallic medium,
- intercomparison of radiation protection measurements,
- nuclear physics.

Review of 2013

A total of 50 days' of experiments were conducted in CALIBAN reactor, either in a prompt supercritical (power excursion) or a sub-critical configuration.

The experiments were mainly performed within the scope of:

- continuing the qualification of electronic components (electronic hardening) and the equipment irradiation campaigns in support of the MegaJoule Laser project for the military directorate (DAM) of CEA.
- a nation-wide annual exercise to compare the different dosimetry systems used in the event of a criticality accident. This action involved CEA and AREVA radiation protection services.
- qualifying new detection instruments (EDAC) and studying the behaviour of shielded EDAC probes and radiation protection devices (continuity of detection and dosimetry functions in the event of a criticality accident) on behalf of AREVA/Canberra and IRSN respectively.

The last campaign mobilised the CALIBAN and PROSPERO reactors for several weeks. It was configured so it could provide information for both AREVA/Canberra and IRSN at the same time.
Owing to the obsolescence of the EDAC probes, AREVA/Canberra actually had to develop new types of gamma and neutron probes (new generation of EDAC-2 and EDAC-3 probes). The company therefore asked to sign a collaboration agreement with CEA to qualify its new equipment and to make sure of its same features compared with the equipment currently in place.
In light of a certain number of configurations existing in nuclear facilities, IRSN realised that it needed to instigate studies on the behaviour of 'shielded' EDAC probes by combining them with radiation protection equipment capable of contributing to the early detection of criticality situations, particularly those with slow kinetics.
The SMNC therefore devised several experimental configurations to subject the EDAC probes and radiation protection equipment to irradiation conditions with diverse spectrums and n/γ dose ratios. The objective was to cover as many types of criticality accidents with different kinetics.
The EDAC probes – positioned in either a free or a shielded field – together with about 60 radiation protection devices were first irradiated in the PROSPERO hot cell at steady-state power or with variable doubling times. They were then irradiated in the CALIBAN hot cell at different power levels.
Lastly, a dosimetry campaign was performed in the PROSPERO reactor to precisely determine the neutron fluxes and thus the doses deposited at the irradiation points on the equipment.. ❖

Prospero Reactor

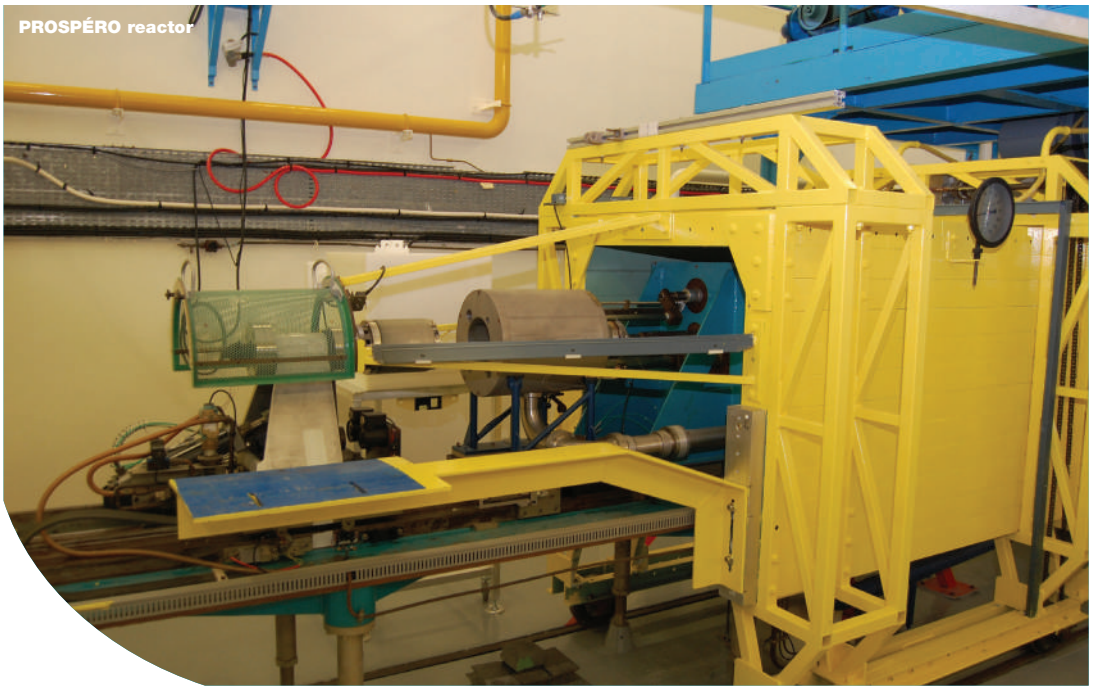
PROSPERO

Presentation

PROSPERO reactor has been in operation since 1968 at the CEA Valduc Centre. Prospéro reactor operates at delayed critical state and at continuous power; it has a highly-enriched metallic core surrounded by a reflector. This reactor produces fission neutrons and gammas and was developed to simulate the radiation effects of nuclear hazards on the components of electronic systems.

Principle

The reactor is a horizontal axis cylindrical sub-assembly. The nuclear core is composed of two blocks of enriched uranium, surrounded by a depleted uranium reflector. Three control rods penetrate the reflector, controlling the reactor near the critical state in delayed neutrons. ▶▶▶



PROSPÉRO reactor

Performances

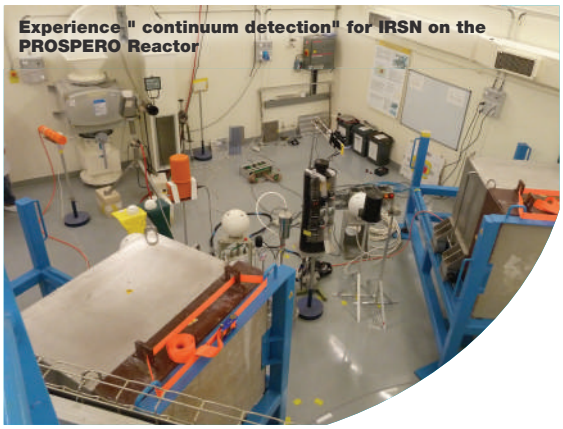
The reactor operates in continuous conditions at a maximum power of 3 kW. The maximum reactor temperature is 200°C. The reactor is installed in a large cell (length: 10 m, width: 8 m, height: 6.5 m).
Prior to starting up, the elements to be irradiated are positioned as a function of their volume and mass:

- Either on a cylindrical basket which fits on the upper half of the reflector.
- On a platform that is part of the protection tunnel (300 to 700 mm from the reactor axis).
- Or on a mobile table placed in the cell (> 1 m from the reactor axis).

Review of 2013

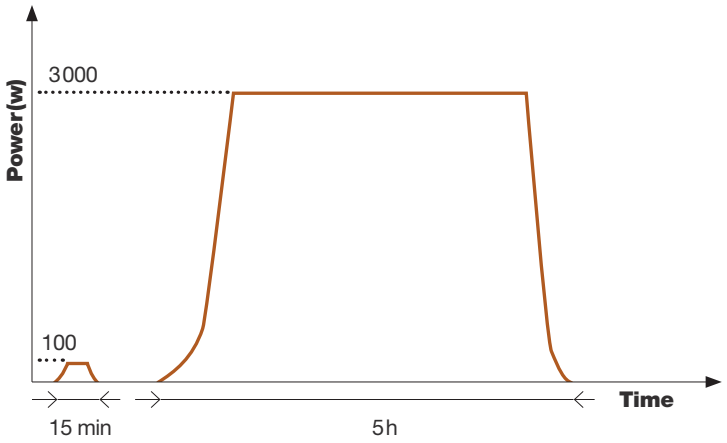
PROSPERO reactor was operated for a total of 80 days of experiments which mainly focussed on:

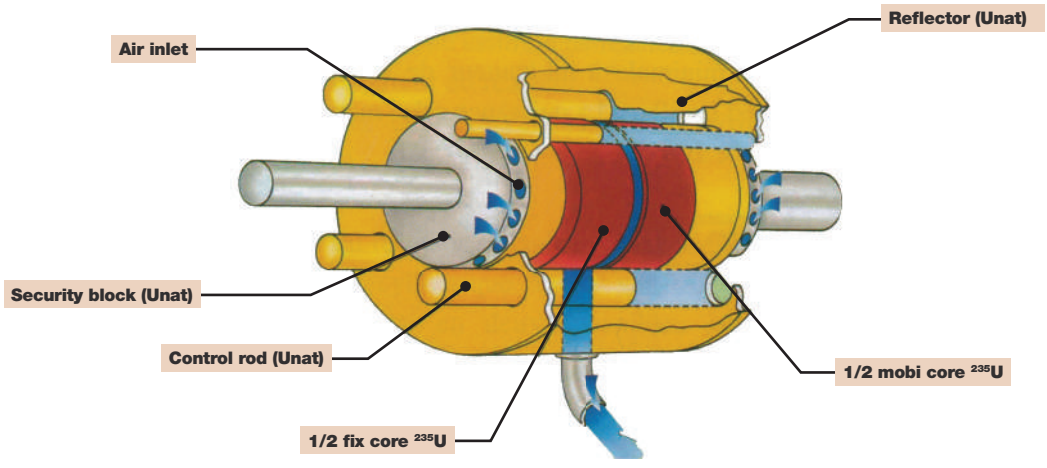
- continuing experiments to qualify electronic components and detectors in terms of their resistance to radiation
- qualifying new EDAC probes and conducting experiments to check the continuity of detection and dosimetry functions in the event of a criticality accident.❖



Experience " continuum detection" for IRSN on the PROSPERO Reactor

Exemple of experimental programme





Schematic diagram of the Prospéro reactor

Éole Reactor

ÉOLE

Presentation

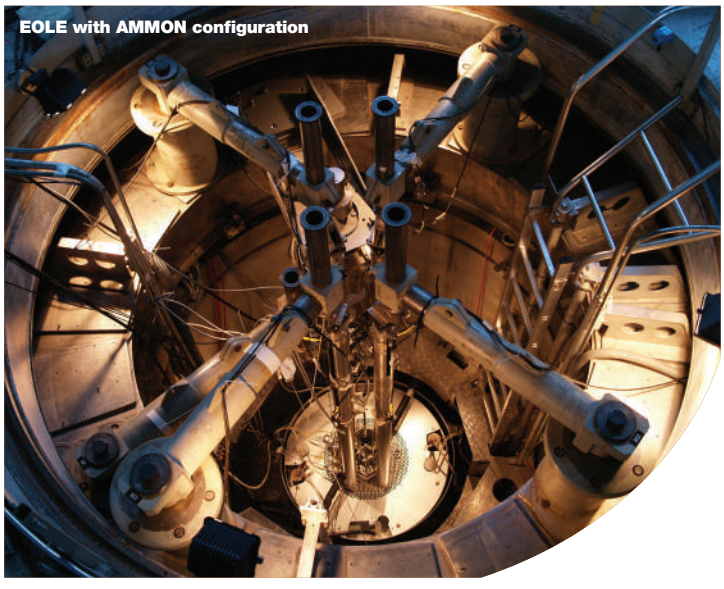
EOLE, critical mock-up, is a very low-power experimental reactor which is used to conduct neutron studies on light-water moderated lattices, in particular for pressurised water reactors (PWR) and boiling water reactors (BWR). This mock-up went critical for the first time in 1965.

The main vessel is approximately 2.3 m in diameter and 3 m in height. A smaller vessel (about 1 m in diameter, 1 mm high) in the centre of the main vessel accommodates for all types of water reactor lattices by means of a set of interchangeable grids. Four control rods help to control reactivity at all times. Criticality is obtained by adjusting the moderator's soluble boron concentration or by adjusting the number of fuel rods.

A regulating rod enables divergence and stabilises the power between 0 W and 100 W (maximum power authorised). Several types of fuels (MOX, UO_2, PWR and BWR fuel, JHR-type U_3Si_2 fuel), as well as absorbers, poisons and structures (natural and enriched B4C, AIC, Hf, UO_2-Gd_2O_3, pyrex, Zy-4, steel, etc.) can be used. EOLE's flexibility and the experimental techniques used make it an unparalleled and practically unique tool worldwide for light water reactor physics.

Physical measurements

The physical measurements recorded during the programmes are used to fully characterise the configurations (critical size, weight of absorbers, fine power distribution, spectrum index, buckling, boron and/or temperature reactivity effect, kinetic parameters, etc.) through proven experimental techniques such as gamma spectrometry, fission chamber measurements and neutron background noise measurements, as well as thermoluminescent detectors and activation dosimeters. ▶▶▶



EOLE with AMMON configuration


EOLE with AMMON configuration

Review of 2013

Since 2010, the facility has been configured to carry out the experimental programme, AMMON. This programme was part of an overall qualification process for neutron- and photon-based tools for the JHR, including the calculations for the core physics which are processed by the HORUS3D calculation route.

This programme involved providing a set of measured parameters to determine the controlled uncertainties so as to finalise certain options for the JHR and substantiate the safety demonstration.
The main experimental objectives involved controlling:

- Refined power distribution in the fuel sub-assemblies and plates
- Reactivity effect of the absorbers
- Gamma heating, especially in the hafnium control absorber
- Effect of experimental devices in terms of the reactivity and power distribution
- Reactivity effect of the beryllium reflector and the neutron spectrum both in and near the reflector area
- Void reactivity and temperature coefficients.

For this programme the core comprised a central experimental area in the "reference" configuration, which includes seven JHR assemblies (composed of a new type of fuel: curved U3Si2 plates) and a breeder area containing standard PWR fuel rods.

The programme required implementing several configurations representative of the JHR core in normal and accident conditions: successive insertion of a hafnium control rod (or half a rod), a beryllium block, a cell in water, and simulation of the ejection of the control rod tracker.

In 2012, the study particularly focused on the control rods and their effects on the axial and azimuthal power distribution in the plates, the conversion ratios and the gamma heating in the hafnium and beryllium.
In 2013, the reference configuration was re-assembled in order to carry out temperature coefficient measurements using the EOLE dual thermo-station, both in the central area and in the breeder area.
This programme was completed in the first quarter, with the last power measurements in a configuration with the rod tracker's central mandrel ejected, representing an incident condition in the JHR.
All the systems were dismantled immediately afterwards, and the AMMON set-up underwent a detailed metrology campaign to quantify the technological uncertainties.
In July 2013, a new set-up was installed in the EOLE reactor vessel. The objective of the associated experimental programme is to qualify the neutron propagation and fluence computer tools for the reactor vessels of Gen-II UOx/MOX mixed load PWRs. Operating phases at powers above the technical requirements (1000 W, with 100 W currently authorised) are planned to achieve the targeted accuracies in the structures. The experimental programme can start as soon as the authorisation to load the core is issued by the French Regulatory Body (ASN). ❖

Minerve Reactor

MINERVE

Presentation

MINERVE is designed for neutron studies mainly which aim to improve the nuclear database for fuel systems representative of various nuclear reactor technologies.
Initially installed on the Fontenay-aux-Roses research centre (1959), it was then transferred to Cadarache in 1977.

The reactor is contained in a 140 m^3 stainless steel parallelepiped pool. Demineralised light water is used as the moderator. The core is cooled by natural convection.

The experimental systems are inserted into a 70 cm square cavity in the centre of the driver zone, making it possible to reproduce neutron spectrum characteristics of fast systems (ERMINE), light water systems (MELODY), RSM (MORGAN), and even heavy water (ELOISE).
The reactor is controlled with four hafnium rods used indifferently for control and safety purposes. The entire control system and the reactor control room were upgraded in 2002.▶▶▶


Minerve reactor

Main characteristics of Minerve reactor

- pool- type reactor
- fuel: UAlx (plate)
- cooling: H_2O
- reflector: graphite
- maximum thermal power: 100W
- termal neutron flux in the vessel : 10^9n. $cm^{-2}.s^{-1}$
- neutron absorber: hafnium

Experimental Techniques

The oscillation technique is mainly used in MINERVE. An oscillator prints a regular vertical movement (sinusoidal, or pseudo-square) corresponding to a sample (fissile, fertile, absorber or structural material) whose neutron effect needs to be characterised between two positions located inside and outside the central cavity respectively. Variations in the sample reactivity are compensated by a rotational automatic control system calibrated to cadmium sectors.

Physical measurements (spectral index, conversion rates, axial and radial fission rate distributions, neutron activation) are also performed to characterise the neutron behaviour of both the core and the samples under investigation.

Others Activities

MINERVE is also used to test the performance of mini fission chamber prototypes developed by CEA and its partners. It is clearly identified as a reference facility for international collaborations on various aspects of experimental physics.

Review of 2013

The year 2013 was almost entirely devoted to phases 2 and 3 of the MAESTRO experimental programme which focuses on moderators, absorbers and structures studied by oscillations. This programme aims to improve knowledge of nuclear data on the different materials used in light water reactors, particularly the industrial alloys such as Zy4, M5, 304L stainless steel, 316L stainless steel and Inconel, and their main components. It supplements programmes such as CREDIT BURN-UP devoted to fission products, OSMOSE devoted to heavy nuclei, and OCEAN devoted to absorbers and neutron poisons.

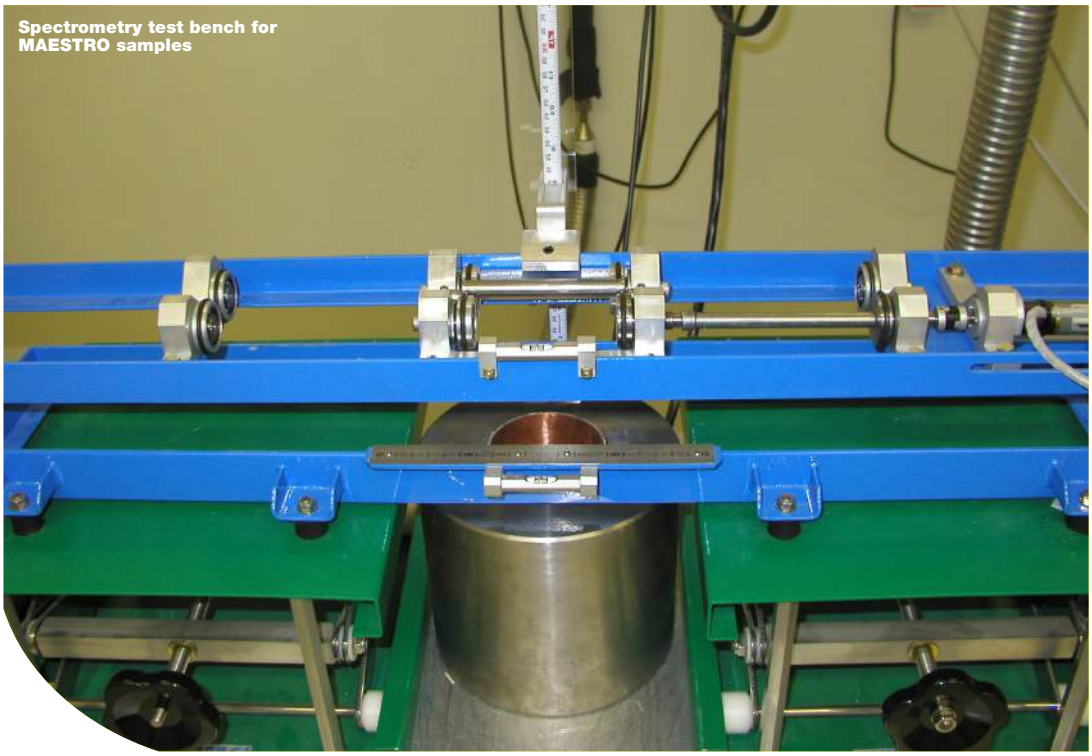
The driver core is composed of MTR-type aluminium/uranium alloy plates under 3 m of water. It is surrounded by a graphite reflector. The thermal neutron flux in the vessel is 10^9 n.cm^{-2}.s^{-1} (100 Watt).



Loading sample in the oscillation device

Among the elements proposed for this programme, cobalt, manganese and vanadium were considered top priority since they are used as detection materials. Their characterisation in the R1-UO_2 configuration of MINERVE – representative of a PWR spectrum loaded with UO_2 fuel – constitutes Phase 1 of the MAESTRO programme, carried out in 2011. Phase 1 of the MAESTRO programme helped to significantly reduce the experimental uncertainties on the sample measurement results to less than 1%.

▶▶▶



Spectrometry test bench for MAESTRO samples

▶▶▶ In 2012 and then 2013, the MAESTRO programme entered the second phase, focussing on the physical characterisation of the MAESTRO lattice and then on the analysis of 14 measurement samples by means of activation. Their component elements, isotopes and materials are as follows: ^{nat}Mg, ^{nat}Al, ^{nat}Si, ^{nat}Cl, ^{nat}Ca, ^{nat}Ti, ^{nat}Cr, ^{nat}Fe, ^{nat}Ni, ^{nat}Cu, ^{nat}Zn, ^{nat}Mo, ^{nat}Sn, ^{nat}V, ^{nat}Mn, ^{nat}Co, ^{nat}Nb, ^{nat}Rh, H_2O, ^{nat}Be, ^{nat}C, polyéthylène, ^{nat}Cs, ^{nat}Ag, ^{nat}In, ^{nat}Cd, ^{nat}Eu, ^{nat}Gd, ^{nat}Dy, ^{nat}Er, ^{nat}Hf, ^{107}Ag, ^{109}Ag, ^{153}Eu, Zy4, M5, SS304, SS316 and Inconel. Phase 3 of MAESTRO, which started in the second quarter of 2013, focussed on determining the reactivity worth of all the measurement samples using the oscillation technique.
Concerns about the uniformity with which some of the samples were created, revealed by spectroscopy, led to reconditioning. These will form the subject of the fourth phase of the programme, scheduled for the first half of 2014.

The objective of MAESTRO is to reduce uncertainty due to the standard nuclear data of these materials to 1% to 2% as appropriate.



Oscillator in the center of the MINERVE reactor

EOLE and MINERVE safety re-assessments

Following the advisory group in charge of nuclear reactor meeting on 28 September 2011, some of the CEA's commitments have been fulfilled and others are in the process of being carried out. This includes:

- Alteration and upgrading of the handling equipment (mainly the travelling cranes), the fire risks and the ventilation I&C system
- Conducting a series of additional studies, in particular on criticality issues and taking extreme climatic conditions into account
- Updating the safety baseline (safety report and general operating rules) to take these studies and changes into account

The seismic assessments were examined by IRSN in 2013. Pending the final conclusions, the ASN has asked CEA to implement compensatory measures to enable the facility to operate until 2020. These compensatory measures call for operations for gradual removal from storage, starting with fuels that will no longer be used in future experimental programmes.

CEA initiated discussions on the long-term future of EOLE and MINERVE in 2006.
In view of the substantial investment required to keep these facilities in service beyond the current decade, it became apparent that the construction of a new reactor combining the functionalities of both mock-ups would be the most economically viable solution and would also minimise the risks involved: the construction of this reactor is the subject of a new project, ZEPHYR (Zero Power PHYsics Reactor), which is expected to be commissioned at Cadarache by 2025. ❖


Fission chamber fabrication workshop

Instrumentation and Measurement at the Department of Experiments

The success of any experimental programme is mainly determined by the relevance and quality of the measurements performed. The internationally renowned expertise of the DEN/DER/SPEX in reactor instrumentation, together with the development and fabrication of sensors and measuring systems are some of the key assets of the three CEA critical mock-ups. These mock-ups boast instrumentation resulting from state-of-the-art knowledge consistent with the experimental needs.

The following technical means for experiments are worth highlighting:

- Instrumentation platform used to develop and test sensors and related measurement lines
- Platform for modelling nuclear sensors, particularly fission chambers and self-powered neutron detectors
- Fission chamber fabrication workshop in which an X-ray generator is being installed to consolidate end-of-fabrication inspections
- Dose measurement platform with 5 gamma spectrometry lines (2 of which are high-efficiency), 2 X-ray spectrometry lines and an automatic transfer unit. This platform has been certified by COFRAC
- Gamma scanning benches and a thermoluminescent dosimetry measurement bench.

The following skills are required for such experiments:

- Design, development and qualification of sensors and related measurement lines, particularly for measuring the neutron flux, gamma rays, nuclear heating, kinetic parameters, temperature, strain and fission gas releases inside the reactor
- Measurement techniques and signal processing
- Design, development and fabrication of fission chambers
- Design and fabrication of dosimeters by activation means
- Setting up and conducting of gamma and X-ray spectrometry measurements
- Elaboration and implementation of methods for interpreting dosimetry measurements.


MASURCA facility

Masurca Reactor

MASURCA

Presentation

MASURCA is a very low-power (5 kW) reactor designed to study the neutron characteristics of fast reactors, as well as the development of measurement techniques.

MASURCA went critical in December 1966. This reactor, which can contain cores ranging up to 6 m^3, is composed of square section tubes individually loaded with fuel blocks or plates, absorbers and coolants representing the fast neutron or epithermal lattices to be studied. This facility is used to study an almost unlimited number of combinations representing the issues to be addressed (MOX, metallic PU, depleted, natural and enriched UOx, thorium, graphite, gas, sodium, lead, steel, ferrites, CaH_2, ZrH_2, etc.).

This facility is very flexible in terms of loading activities and operation, which is why it is used to validate innovative epithermal and fast reactor core solutions such as gas fast reactors (GFR), high-temperature reactors (HTR), Accelerator Driven Systems (ADS) and currently the new core concept based on a low void coefficient for the future ASTRID reactor.

CEA decided to renovate the MASURCA facility in January 2010. This decision followed an analysis in 2009 on the role and importance of MASURCA to meet the neutron physics requirements for the fourth generation of fast reactors. Other than upgrading the auxiliary systems and the I&C, this refurbishment also involves civil work to strengthen the earthquake resistance of the facility, including the construction of a new nuclear material storage and handling building.
As for the project schedule, commissioning has been programmed for mid-2017 so the core loading operations and experiments can start in 2018.

The renovation is funded within the scope of the major national loan and is covered under the French Government-CEA agreement dated 9 September 2010 which appeared in the official gazette on 11 September 2010.

Review of 2013

Removing fissile material from storage

The removal of fissile sources and materials of no use was instigated following the post-Fukushima stress test for the facility in 2011. The temporary removal of all material in the warehouse, however, is a prerequisite before any renovation work can take place in the nuclear material storage and handling building.▶▶▶

Operations on safe box No. 1 in the nuclear material storage and handling building were completed in December 2013. It is now completely empty. These operations were launched in October 2012 with an extremely tight schedule and resulted in the removal of about 20 batches of uranium- and plutonium-base material. Some items were transferred directly to MAGENTA facility to be stored in the Category I hall. The remaining batches were not properly conditioned according to the MAGENTA interim storage specifications, thus requiring reconditioning or sometimes even an oxidation treatment in the LEFCA facility. Prior to these operations, specific authorisations had to be obtained so that the relevant facilities could not only dispatch or receive the material, but so they could also use the TNBGC transport cask for their transfer needs. By focusing on the removal of material no longer in use from MASURCA, CEA will be able to finalise the entire fissile material removal process for this licensed nuclear facility in 2014 as stipulated in the ASN decision.


MASURCA - loading in the transportation cask TNBGC

The MASURCA renovation project (PRMSK)

The following key regulatory steps and studies were instigated in 2013:

- Drafting of the Basic Design file by the prime contractor
- Preparation of the Preliminary Safety Report, which will be assessed by the ASN before launching the construction of the new nuclear material storage and handling building
- Start of compliance assessments for safety-important equipment
- Continuation of the stress test
- Collection of data in the field for the environmental impact assessment.

At the same time, the preparatory work for refurbishment was continued with:

- Development and implementation of the supervisory system in the Monitoring and Operation Room
- Renovation of the computer and telephone systems
- Conformity upgrades of certain effluent systems and vessels
- Refurbishment of the compressed air production unit. ❖



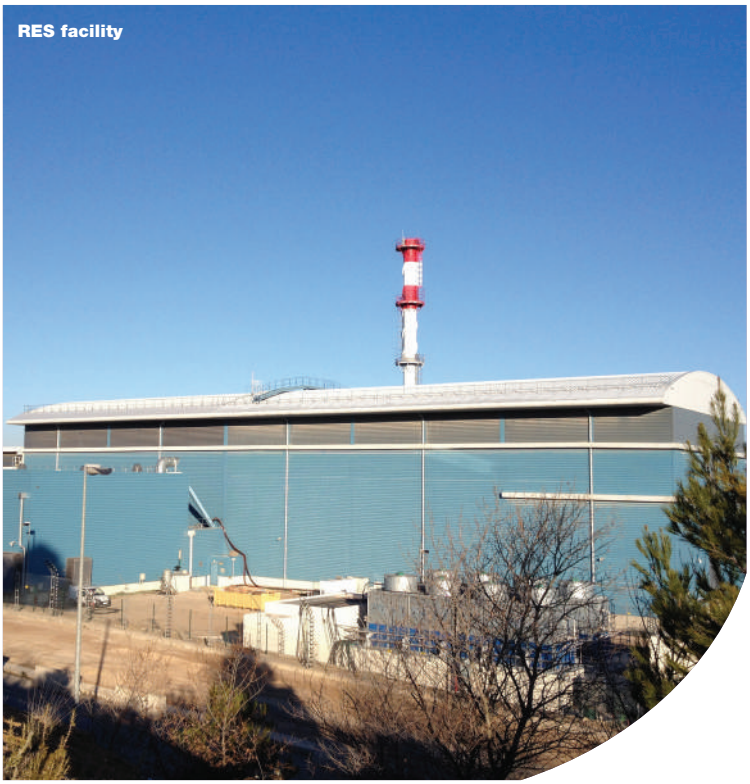


The New Research Reactors

Reactor ageing and the changes in standards lead to safety re-assessments which are increasingly long and costly.
After the safety re-assessment at Phenix, completed in 2003, Cabri, Masurca, HFR... reactors were in the heavy works phases required by safety upgrades. And they will be new re-assessments for the other facilities.
In addition, due to new developments in techniques and to the use of the experience gained on operating reactors, the characteristics and possibilities of new reactor can be improved.
Reflecting this attitude, and in preparation for the future, two new reactors are currently being built on the Cadarache site and prepare the future of French and European research reactors.

RES Reactor
Test facility contributing to French nuclear deterrence

RES


RES facility

Presentation

RES facility is located at the CEA Cadarache Centre, the historical hub for the French Navy's nuclear propulsion test resources. This state-of-the-art installation falls within the scope of France's broad policy to preserve its means of nuclear deterrence.

RES facility follows on from a series of land-based reactors that were used to qualify various on-board reactor concepts and technologies: PAT[1] was devoted to the first nuclear-powered ballistic missile submarines (SNLE-M4), CAP[2] to nuclear attack submarines (SNA), RNG[3] to new generation ballistic missile submarines (SNLE-NG) and the Charles de Gaulle aircraft carrier. RES is primarily used for R&D with its main objectives being to qualify computer codes, new fuels and different on-board nuclear steam supply systems for today and tomorrow.

This INBS-PN* comprises two modules: the pool module was integrated in the summer of 2005 while the reactor module is pending.

The RES programme is managed by the Nuclear Propulsion Division (DPN) which belongs to the Military Applications Directorate (DAM). attended by the reactor designer, AREVA TA. About a hundred local, regional and nation-wide contractors and OEMs are involved in the construction of the facility. ▶▶▶

Secret licensed nuclear facility dedicated to nuclear propulsion as decided by the Prime Minister in compliance with the provisions of Article 17 of Decree No. 63-1228 dated 11 December 1963 amended.

[1] French abbreviation for Pilote A Terre (land-based nuclear unit).

[2] French abbreviation for Chaufferie Avancée Prototype (advanced NSSS prototype).

[3] French abbreviation for Réacteur de Nouvelle Génération (new generation reactor).


Steam test

Objectives and issues

The main objectives of RES are:

- Supporting the fleet of nuclear propulsion vessels
- Qualifying fuel and cores for the nuclear steam supply systems of today and tomorrow
- Developing and qualifying new concepts, starting with the BARRACUDA programme for the new generation of nuclear attack submarines.

The stakes at hand involve ensuring availability of the French Navy's nuclear propulsion vessels, thereby guaranteeing its future capabilities while lending more credibility to France's nuclear deterrent strategy.

RES is an unequivocal experimental reactor that will eventually be equipped with high-tech innovative tools and in-core instrumentation to reach its objectives. This includes neutron mapping and real-time monitoring of the core neutron flux, not to mention a gammametry test bench for the non-destructive characterisation of burn-ups.

Lastly, arrangements have been made throughout the design and construction to meet any training requirements in the field of nuclear reactor operation, as well as to meet the increasing demands for support from the in-service fleet and the backend of the industry. ▶▶▶


Cooling tower

Review of 2013

In 2013, the RES project was marked by the effective implementation of the new industrial organisation needed to finalise the reactor construction phase: the new suppliers have arrived on site to finish the remaining construction work on the basis of the detailed studies provided by the designer.

Previous supplier contracts were either validated in late 2013 or are currently in the process of being validated for acceptance in 2014.

A number of key stages were completed, such as the performance of fossil-fuel-powered steam tests and the start of ventilation tests.

The next key phases include:

- Second half of the type-2 tests related to electricity, instrumentation and control (EI&C)
- End of the closed and independent worksite with the reactor module being connected to the INBS-PN facility
- Type-2 tests for the sub-systems (ventilation, circuits, etc.)
- Overall tests
- Loading of new fuel elements
- Reactor criticality. ❖

The next key phases include:

- 400,000 m^3 of earthworks,
- 6.5 hectares of prepared surface,
- 5,000 m^2 built-up surface area,
- 37,000 m^3 of concrete,
- 7,000 tonnes of metal framework,
- Up to 350 kg/m^3 of reinforcement steel,
- 400 km of electrical cable,
- 33 km of pipework,
- 62 tonnes of ventilation duct, 6 local air coolers,
- 3.6 million hours on the worksite (late 2012).

Jules Horowitz Reactor

JHR


Installation of the reactor building dome

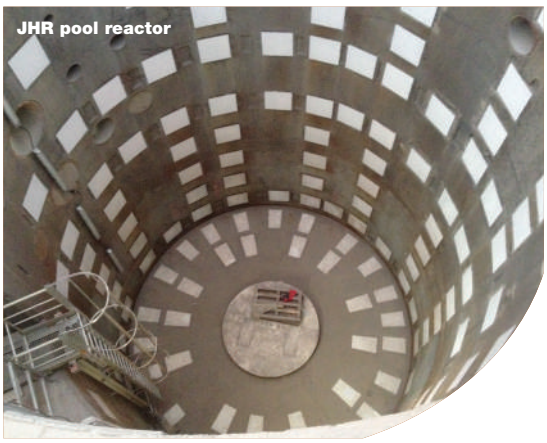
Presentation

In a strained energetic context, research In a strained energy context, research work for further improving performance and safety in the nuclear field represents a major issue. Yet the research reactors in Europe required for this type of study date back to the sixties. The availability of modern research tools which can be used to maintain a high level of expertise in France and in Europe is becoming a pressing matter in the field of nuclear energy. Jules Horowitz research reactor (JHR) is a solution for this scientific and technological issue.

Three generations of reactors co-exist in the 21st century: the current reactor fleet in service, the third generation of reactors currently under development, and the fourth generation of reactors programmed for 2040.

JHR is expected to meet our experimental needs for the next 50 years in terms of new materials and fuel. One of the major advantages of this facility is the flexibility of its 'test platform' which will be used to recreate the physical and chemical conditions of all types of reactors, whether present or future. Powerful, polyvalent and modular, the JHR is designed to perform about 20 experiments at the same time. It will be provided with a 'double-peak neutron spectrum' capable of producing intense neutron fluxes i.e. both in the thermal range (applications for research carried out in current standard reactors) and in the fast range (applications for Generation IV fast reactors).

JHR is located in the Vallée des Piles (reactor valley) at the CEA Cadarache Centre and will therefore be supported by the other experimental facilities onsite. Most of the samples to be placed in the Jules Horowitz reactor core will be prepared and analysed in the CEA Cadarache fuel study laboratories, including the Active Fuel Examination Laboratory (LECA). ▶▶▶


JHR pool reactor



JHR reactor building

▶▶▶ Developing fast reactors of the future involves implementing innovative new materials and fuels capable of withstanding extreme loads. To guarantee the performance and safety of these concepts, experiments must be carried out with research reactors so as to select the most promising solutions and to test the limits of their behaviour.

Lastly, JHR will also be one of the main radioisotope reactors for medical purposes and will meet 25% to 50% of Europe's requirements in this field.



JHR Polar Crane

Review of 2013

The following activities were carried out within the scope of Jules Horowitz Reactor project in 2013:

- Continuation of the JHR fuel qualification programme by means of the EVITA experiment in the BR2 reactor in Belgium
- Continuation of construction of the reactor containment and pool, and the auxiliary buildings
- Continuation of studies for the electromechanical, ventilation, back-up systems, fluid systems, reactor block and I&C packages
- Starting of work to install the water supply pipework for the tertiary cooling system for JHR
- Installation of the polar crane
- Installation of the reactor building dome.

In terms of operation and experimentation, 2013 was marked by several key actions:

- The development of a training programme for future operators and experimenters based on a "pyramid" approach
- Discussions on the development of specific instrumentation to support the start-up tests
- Receipt of the JHR simulator version V0 which will be used to teach future operators how the reactor operates and to validate the initial rules for normal operation

Main characteristics of the Jules Horowitz reactor

- pool-type reactor, cooled with light water,
- beryllium reflector,
- power: 100 MWth,
- fissile height: 60 cm,
- maximum thermal flux: $> 5 \times 10^{14}$ n.cm^{-2}.s^{-1},
- maximum fast flux: 5.5×10^{14} n.cm^{-2}.s^{-1},
- fuel: U_3Si_2 for the core at start-up.

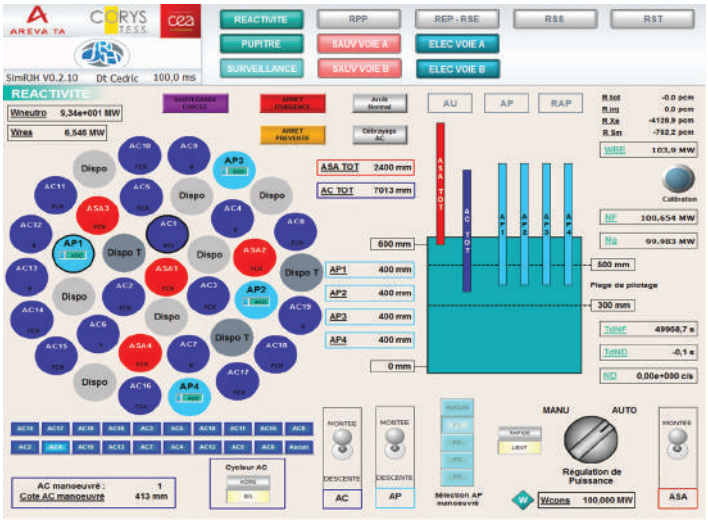
- The completion of neutron studies for the start-up core defining the number of fuel elements and their management over time until equilibrium is reached
- The definition and building of a work management tool (work authorisation, tagout management, setting to steady-state operation), based on the GIE tool used at PHENIX

With regard to the experimental aspect, the CEA organised its third international conference on the JHR programmes and experimental resources. The first meetings of the working groups with the members of the consortium took place. The objective is to define the requirements and develop the future experimental programmes for JHR.

The tender documentation has been finalised with a view to contractualising the building of the ADELINE experimental loop for investigating power transients.

Several design reviews have been carried out in order to finalise the options chosen: neutron radiography examination bench, certain equipment in the MADISON loop, the devices for producing Mo-99, etc.

With regard to safety, a guide for drafting the experimental device documentation is currently being drawn up to facilitate the process of obtaining authorisation for conducting experiments. ❖



JHR simulator



Reactor building dome

2014 Heads of facilities



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