2017

REVIEW OF FRENCH RESEARCH REACTOR

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.
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In 2017, The IAEA listed approximately 240 research reactors in activity in more or less 50 countries.

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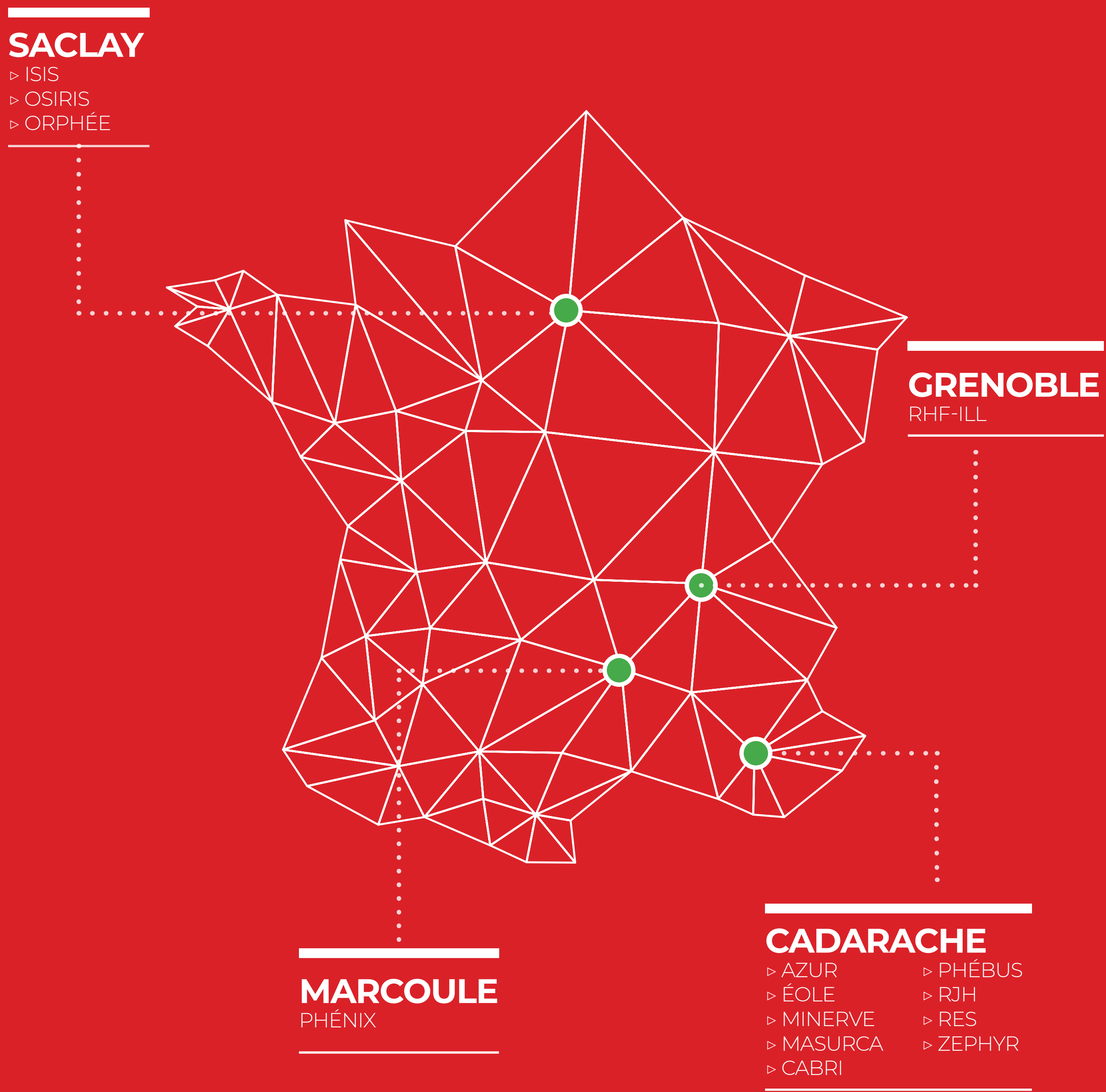
French reactors and their main applications...



Editorial

JEAN-PIERRE CHAUVIN
CHAIRMAN OF CER

MARIE NOËLLE PAOLI
CER SECRETARY

2017 - A TRANSITIONAL YEAR

In the wake of the shutdown of OSIRIS after 50 years of safe operation, the ÉOLE and MINERVE reactors followed suit in late 2017 after 58 and 52 years respectively of excellent service, having long supported the experimental qualification of our neutron calculation tools.

The year 2017 also marked the end of the CABRI re-qualification tests and its reintegration into the fleet of experimental reactors used to qualify severe accident data.

Despite the addition of CABRI, as my predecessor rightly underlined, we are still moving into a period that sailors might compare to "the doldrums" pending the re-commissioning of the MASURCA reactor, the commissioning of the Jules Horowitz Reactor, and perhaps even the ZEPHYR reactor.

As experimental tools are paramount to the success of any research programme, this transitional period must be exploited to its maximum in order to maintain the skills of experimenters and operators at the highest possible level. The reactor operators' club is partially responsible for facilitating dialogue and exchanges between the different research reactors in France regardless of their operational status (design, construction, start-up, operation or shutdown).

The year 2017 was also a period of transition for the club itself, with the departure of its chairman Jérôme Estrade who had been running the show for practically 10 years. On behalf of all the members of this club, I would like to pay tribute to Jérôme Estrade for his unstinting efforts and endless enthusiasm that we all valued immensely over the past years.

In the international arena, the 18th international Group of Operating Research Reactors (IGORR) was held in Sydney (Australia) from 3 to 7 December 2017. This conference was combined with an IAEA workshop on test reactor safety reassessments following feedback from the Fukushima Daiichi accident. This workshop focused on the safety measures implemented in the wake of this accident. The results were very instructive and highlighted differences between the US NRC requirements and those of the European safety authorities such as Germany and France, as well as those of South Korea and Japan.

In the field of test reactor design, the Argentinians from INVAP and the Koreans from KAERI impressed everyone with their proposal to build a multi-purpose reactor in the 5 to 15 MW range.

The Russians (ROSATOM) and the Chinese (CNNC) have also stepped up their research activities and are proactively involved on an international level with a multitude of projects.

Our American colleagues at the DOE have launched a strong initiative to promote activities with the re-commissioning of the TREAT test facility devoted to severe accident studies.

Test reactor designers are also focusing on new technologies such as the small modulator reactor (SMR), which is a compact machine whose power does not exceed 300 MW as defined by the IAEA.

Lastly, the label called "International Centres based on Research Reactors" (ICERR) awarded to the CEA (France) for its facilities at its Saclay and Cadarache centres - including the JHR - has generated an increasing number of training requests from both current and future foreign partners.

In the years ahead, the CABRI tests, the ongoing operations in ORPHÉE and at the ILL, the commissioning of the RES, and the launch of the JHR project will also enhance the visibility of our research programmes. With our experimental tools and our partners that are increasingly more international, we expect to remain a key player in the international arena.

To be continued...

French reactors and their main applications...

		Medical applications	Material Testing	Fuel irradiation	Training	Industrial applications	Neutronography	Structure of matter	Neutronic	Safety studies	National defence
AZUR	**35**				■				■		■
CABRI	**38**									■	
ÉOLE	**46**					■			■		
ISIS	**32**				■	■			■		
MASURCA	**56**					■			■		
MINERVE	**50**				■	■			■		
ORPHÉE	**12**	■				■	■	■			
OSIRIS	**20**	■	■	■		■	■				
PHÉBUS	**42**									■	
PHÉNIX	**26**		■	■							
RES	**60**					■					■
RHF-ILL	**16**						■	■			
RJH	**62**	■	■	■		■	■		■	■	
ZEPHYR	**66**				■	■			■	■	

2017 Highlights

AZUR
500 divergences over 106 days of nuclear operations. Core acceptance testing for the French Navy's nuclear-powered vessels, training and qualifying AREVA TA personnel to operate the facility and training French navy personnel on reactor operations.

CABRI
High-power neutron tests to validate the kinetic parameters of the core and to adjust the parameters of the 3He circuit and the sequencing system needed to perform the 66 pulses. These tests marked the end of the refurbishment and re-qualification of the CABRI facility.

ÉOLE
End of the EPILOGUE programme that supported the in-core instrumentation studies and the studies on effect of loading burnable poisons into an EPR. Final shutdown programmed for 21 December 2017.

ISIS
A total of 44 days of operation, which enabled 28 practical work sessions with about 162 trainees and 9 days of irradiation experiments. These experiments involved the irradiation of Co59 micro-particles, the qualification of start-up detectors for the RES, and the testing of high-temperature fission chambers for ASTRID. There were also 7 days of operation for in-house actions, such as service tests and and verification of safety parameters.

MASURCA
The neutron studies to refine the configuration of the GENESIS programme were continued as part of the facility's safety review and refurbishment actions. This programme supports the qualification of the neutronic calculation tools for ASTRID. Conformity of the suspension plate for the core sub-assemblies was checked following the complete unloading of the 209 shielding rods and deformation in this plate was also measured.

MINERVE
Implementation of the PANORAMIX programme, which aims at improving our knowledge of reactivity losses in MOX fuel over time due to the radioactive decay of 241Pu into 241Am.
At the same time, numerous operational and qualification tests were performed on innovative instrumentation.
Final shutdown programmed for 21 December 2017.

ORPHÉE
A total of 120 days of operation. The reactor produced 700 kilos of doped silicon and 35 tubes of artificial radioelements.
The orientations file was also submitted for the third safety review. The Léon Brillouin laboratory conducted a large number of experiments, including measurements combining nuclear magnetic resonance and neutrons, which were performed on confined ionic liquids and on multiferroic materials by means of neutron diffraction

OSIRIS
The year 2017 was spent preparing for the dismantling of the OSIRIS reactor. Among these preparatory actions, the third containment barrier was reinforced to consolidate its integrity and to comply with the initial state reported in the OSIRIS dismantling file.

PHÉBUS
Operations to reduce the source term in the facility were continued. The year 2017 also saw the application of the safety review file and preparation of the dismantling file

PHÉNIX
Further dismantling of the irradiated sub-assemblies and treatment of capsules and experimental sub-assemblies in the context of the 'Phénix Treasure' initiative for the Astrid programme. Start of finishings and fittings (civil engineering) for the future sodium treatment facility, NOAH. Refurbishment of the raw water system in the plant to increase the reliability and durability of the network. Treatment of the G intermediate heat exchanger, which involved perforating and removing the caps.

RES
Additional tests were performed in inactive hot conditions, such as steam tests on the machine island and recommissioning of equipment that had been mothballed since 2014. These actions minimise the risk of contingencies between reactor divergence and power operation.
An onsite emergency response (PUI) drill was carried out, followed by a specific emergency response drill based on a simulated accident.

HFR
One reactor cycle was completed in 2017, representing 48 days of operation for scientific research activities. Further refurbishment of the systems and equipment, and actions associated with the stress tests.

JRH
Further construction of the reactor containment and the pool, and the auxiliary buildings. Temporary start-up of the tertiary cooling system for the JHR. Acceptance testing of the cranes in the nuclear auxiliaries building. Drawing up of the Accident Operation Rules.

ZEPHYR
Definition of the future facility was continued throughout the year. Partnerships with French and foreign organisations were actively pursued. Numerous scientific seminars in France and overseas were organised.

2017 Review CER

The Club des Exploitants de Réacteurs (CER - Reactor Operators' Club) is a forum that welcomes all operators of French research reactors.

These reactors mostly belong to the French Alternatives Energies & Atomic Energy Commission (CEA²) located at the Saclay, Cadarache, Marcoule and Valduc research centres. The club also includes the Laue-Langevin Institute's (ILL) high flux reactor (HFR) in Grenoble, and the reactors owned by the Areva Group. Around 1700 highly-qualified staff are directly involved across all these sites. In late 2012, a representative from the EDF Tricastin nuclear power plant joined the CER, giving the club access to a broader range of operating experience. At the end of 2014, the CER was joined by ZEPHYR, the CEA's project for a new critical mock-up to conduct neutronic studies and training.

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

These facilities include:
- At planning stage: ZEPHYR
- Under construction: RES and JHR
- In service: ISIS, ORPHÉE, HFR/ILL, ÉOLE, MINERVE and AZUR
- Undergoing refurbishment: CABRI and MASURCA
- Shut down pending clean-up: PHÉBUS and OSIRIS
- Shut down, undergoing clean-up prior to dismantling: PHÉNIX, PAT and RNG

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

PANORAMIC VIEW FROM THE DOME OF THE ILL

CER VISITING THE EPR AT FLAMANVILLE

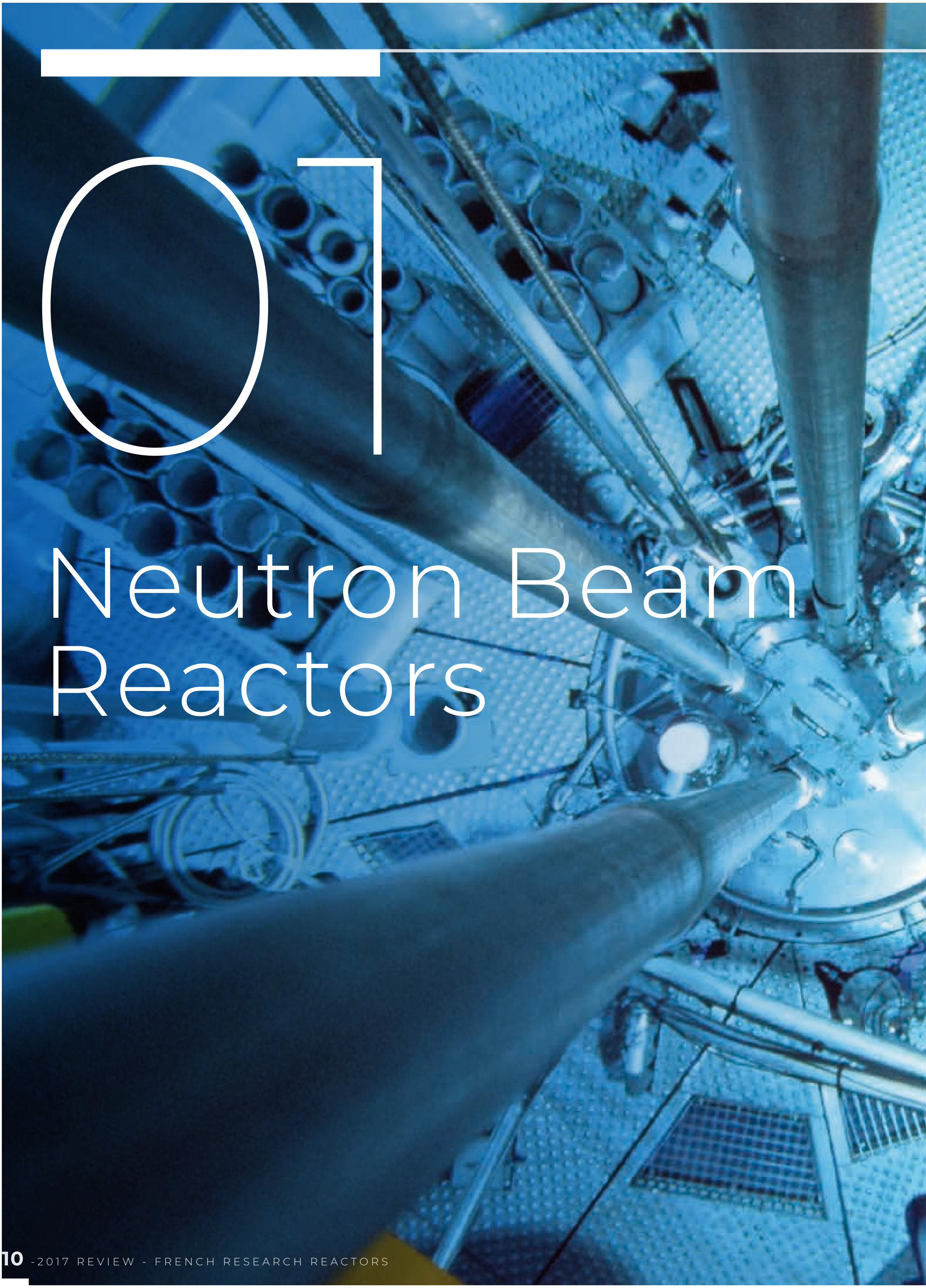
The club also fulfils its mission statement by organising seminars, during which presentations are given on the key events at each facility, including descriptions of certain incidents that provide a wealth of experience feedback.

The following subjects have already been covered: implementation of the new INB Order governing licensed nuclear facilities published in 2012, both draft and new ASN decisions on future General Operating Rules and Safety Reports, the results of fire risk assessments, the follow-up to stress tests on some of our reactors which were carried out to take into account feedback from the Fukushima accident, and the definition of the related “hard core” set of requirements.

In conclusion, these regular meetings provide an ideal opportunity to discuss and share issues on reactor operation. The CER annual review is also an important medium for providing information on the activities and utilisation of our experimental resources.

CER MEETING AT THE "ARSENAL OF TOULON" JUNE 9TH AND 10TH 2015

CER VISITING THE TRICASTIN POWER PLANT OCTOBER 2012



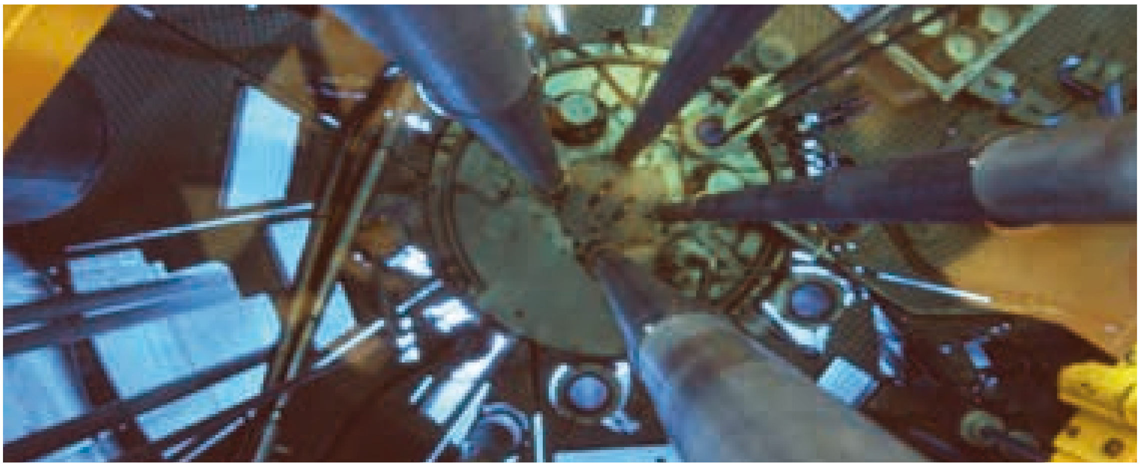
01 Neutron Beam Reactors

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.
- etc.



Orphée Reactor

ORPHÉE

PRESENTATION

Licensed nuclear facility INB No. 101 includes the 14 MWth experimental ORPHÉE reactor and the Léon Brillouin Laboratory (LLB) where CNRS and CEA researchers work together in the field of neutron spectrometry. This facility is located at the CEA Saclay Centre.

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^{-1}
- 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
- 9 vertical irradiation channels

The ORPHÉE 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, such as SILOE, OSIRIS and the HFR.

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

A device for neutron radiography analysis has been installed on one of the neutron beams of the ORPHÉE 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 radioelements for medical and industrial applications
- Analyse objects by means of activation, which has many applications, including medicine, archaeology, chemistry and biology
- Irradiate various specimens to produce products for industrial application, e.g.: silicon doped by nuclear transmutation.

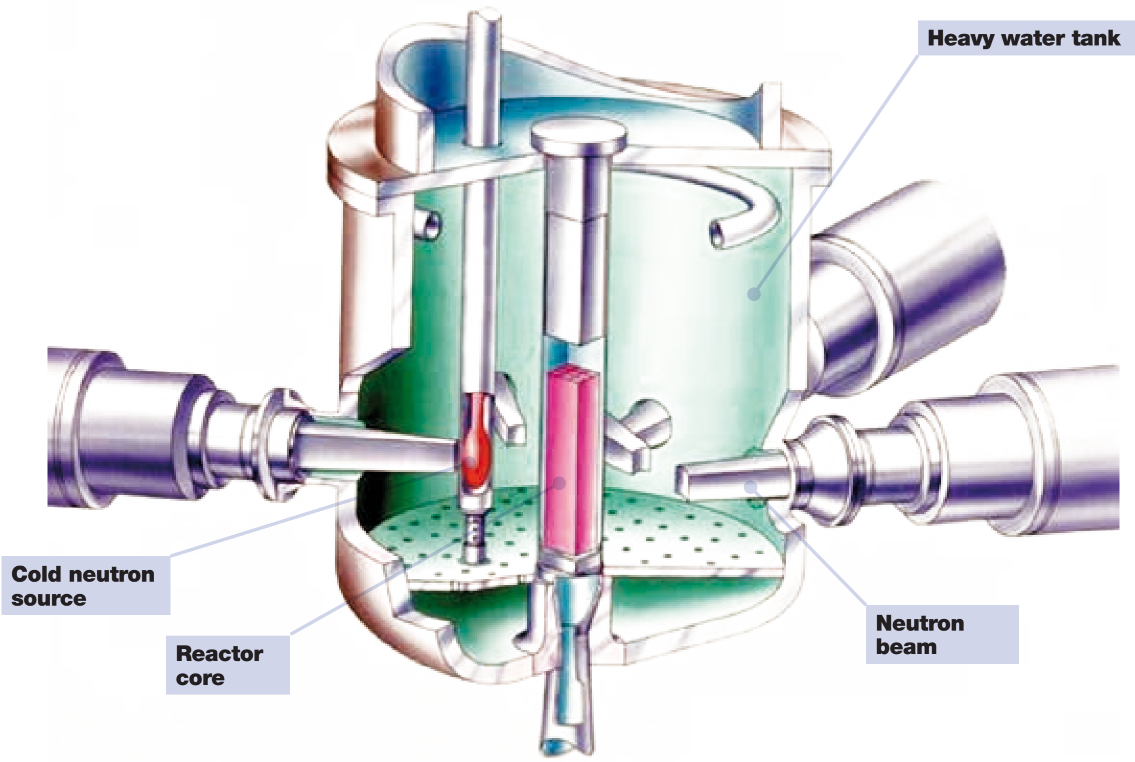
REVIEW OF 2017

The year 2017 was marked by the transition from 120 days of operation to year-round operation. No heavy maintenance operations were carried out but preventive maintenance tasks were conducted throughout the year.

Léon Brillouin Laboratory

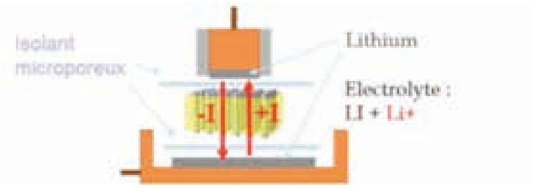
The Léon Brillouin laboratory (LLB) employs engineers, technicians, administrative agents, post-doc students and 37 permanent researchers (18 from the CEA, 14 from the CNRS and 5 university researchers). The laboratory's own scientific activities cover three main fields of research:
- Complex soft matter
- Magnetism and superconductivity
- Materials and nanosciences

View of ORPHÉE block core

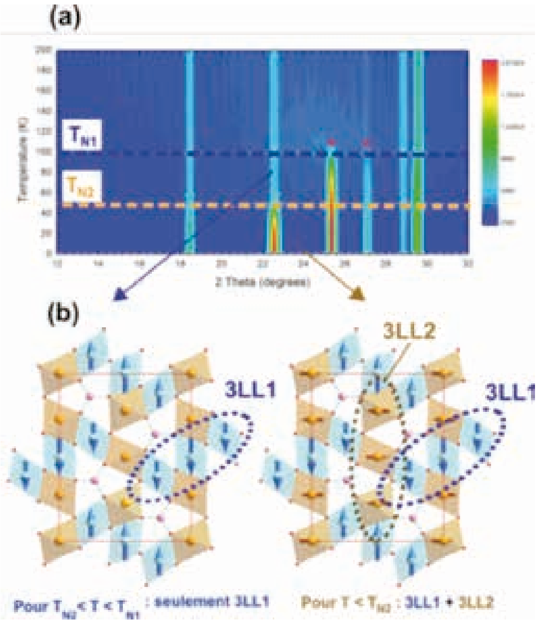


INSIDE THE PA20 DETECTION DEVICE: THE WIDE-ANGLE DETECTION SYSTEM CAN BE SEEN IN THE FOREGROUND, WHILE THE SMALL-ANGLE DETECTION SYSTEM CAN BE SEEN IN THE BACKGROUND.

DELIVERY OF THE WAVE SUPERCONDUCTING MAGNET AND START OF THE FIRST TESTS



LITHIUM ACCUMULATOR WHOSE IONIC CONDUCTIVITY IS GUIDED BY A MEMBRANE OF ALIGNED NANOTUBES. SUCH CONFIGURATIONS PROMOTE IONIC DIFFUSION BY A FACTOR OF 3 COMPARED WITH UNCONFINED IONIC LIQUIDS.



(a) NEUTRON POWDER DIFFRACTION ON A LUDWIGITE COMPOUND: FE3-XMNXBO5. DIFFERENT MAGNETIC PEAKS APPEAR AT TWO TEMPERATURES: TN1 AND TN2. THIS SUGGESTS THE PRESENCE OF TWO UNCOUPLED MAGNETIC SUB-SYSTEMS.

(b) MAGNETIC STRUCTURES OBTAINED AFTER HAVING REFINED THE NEUTRON POWDER DIFFRACTION DATA. BELOW TN1, THE MAGNETIC ORDER CORRESPONDS TO AN ARRANGEMENT ONLY EXISTING ON THE 3LL1 SCALE. BELOW TN2, THE SECOND SCALE, 3LL2, HAS AN INDEPENDENT ORDER WHICH REVEALS THE UNCOUPLED NATURE OF THE TWO MAGNETIC SCALES.

The reactor produced 700 kilos of doped silicon and 35 tubes of artificial radioelements. A total of 1696 shots were taken for neutron radiography (NR) analysis.

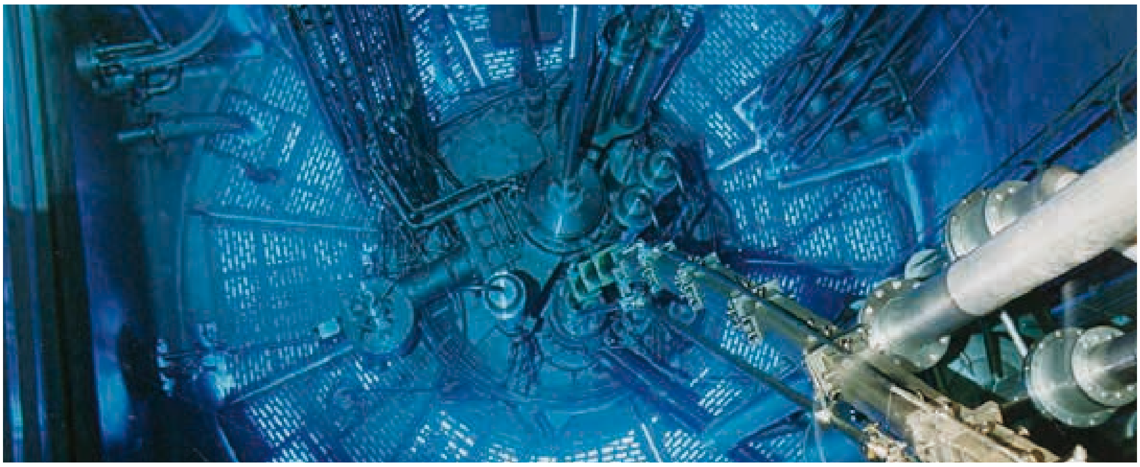
The briefing report for the third safety review of Orphée was submitted to the ASN in September 2017. Official declaration of the reactor's shutdown, which is programmed for the end of December 2019, was sent to the relevant authorities in late 2017.

The year 2017 at the laboratory was also marked by the delivery of the Wave magnet for the 6T2 instrument followed by the first tests. Wave is an innovative superconducting magnet developed in collaboration with the DRF/Irfu and funded by the French national research agency (ANR). It can generate magnetic fields up to 1 T in any given direction in a sample volume of about 10 cm3. It also has a wide angular aperture for performing neutron diffraction experiments to determine complex magnetic structures.

The LLB was able to complete a considerable number of experiments either with in-house staff or together with some 268 external researchers who took part in research at the laboratory over the course of the year. Among the key scientific results of 2017, it is worth highlighting the measurements combining nuclear magnetic resonance and neutrons which were performed on confined ionic liquids using the G1bis spin-echo spectrometers and the G3bis imaging system (DRF/Iramis/Nimbe). These results seem to suggest that 1D confinement offers a promising solution to considerably increase the conductivity of such ionic systems which are high-potential candidates for improving the storage capacity and safety of batteries.

Remarkable progress has also been made in understanding the magnetic properties of multiferroic materials; the existence of two uncoupled magnetic sub-systems was demonstrated by neutron diffraction using the G4.1 powder diffractometer.

ACCESS TO THE EMERGENCY CENTRE FROM THE REACTOR BUILDING



High Flux Reactor (HFR) Laue-Langevin Institute

HFR

NEUTRONS FOR SCIENCE®

PRESENTATION

The Laue-Langevin Institute (ILL) is the top neutronics research facility in Europe. It operates the High Flux Reactor (HFR), the world's most intense neutron source, and delivers neutron beams to 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. ILL is managed by France, Germany and Great Britain. It has set up scientific partnerships with 11 other countries: Austria, Belgium, Czech Republic, Denmark, Hungary, Italy, Poland, Slovakia, Spain, Sweden, Switzerland, and India. 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 around 1,200 researchers from more than 40 countries. Research is focused on fundamental science in numerous fields including biology, chemistry, soft matter, nuclear physics and science of materials.

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.
The research projects currently underway at ILL generate more than 600 scientific papers a year, some 150 of which are published in high-impact journals..

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.

BILAN 2017

Reactor Operation

Only one reactor cycle was completed in 2016, using 1 fuel elements. A total of 48 days of scientific activity were provided.

Cycle n°	Start of cycle	End of cycle	N° of days of operation	N° of days scheduled	Power in MW	Number of unscheduled shutdowns
181	19/01/17	08/03/17	48	48	55,8	0

This reactor cycle was completed without incident.

The winter shutdown allowed us to complete important maintenance:
emptying and cleaning of the pumping station
setting up the shield of protection, for the Chimney (45m)
Preventative maintenance involves, replacement of the batteries of the safety circuit
Maintenance of the natural convection valves and of the siphon breaking system
Maintenance of the inverters of the NS grid
Qualification of the new pumps of the shutdown cooling system with their new bearings.

As the time necessary to ASN and its technical support for delivering the authorization needed for the new emergency circuits, we took advantage of this period to achieve spectacular operations during 2017:
Transfer from PCS2 to PCS3 allowing the PCS2 decommission.
Commissioning of the emergency groundwater circuit and its connexion with the emergency core reflood system.
Commissioning of the complementary seismic reactor shutdown circuit
Commissioning of the automatic power supply cut-off in case of earthquake.
Commissioning of the automatic valve on the secondary circuit to guaranty the containment.
Commissioning of the seismic annular space pressurisation.
Commissioning of the emergency radiological monitoring laboratory.

INTERNAL EQUIPMENT OF THE GROUND WATER WELL PUMPING FOR THE ULTIMATE REFLOODING CIRCUIT OF THE REACTOR

Building of an airlock system for the truck entrance.
Reinforcement of the fuel-handling column and maintenance stand to withstand with an extreme earthquake.
Replacement of three beam tubes and extraction of a fourth one.
Heavy maintenance of the first main diesel.

The “post Fukushima programme” is now completed, so that the safety of the reactor is guaranteed even in case of the conjugation of an extreme earthquake and an extreme flood following dams rupture, well beyond the dimensioning standards.

Major studies and works were also conducted for the instruction of our ten-year whole safety assessment, and for its submission to the ASN on 2 November 2017:
Safety reassessment report
Statutory conformity report
Mechanic important equipment conformity report
Important instrumentation and control conformity report
Decommissioning report
Updated safety report
Updated operation rules
Updated emergency plan
Numerous studies to support this safety reassessment
Numerous checks on the ground and in the on board documentation to support the demonstration of the conformity

As a conclusion, the safety reassessment report lists the necessary work to comply with the latest safety standards for a new reactor. The resulting amount of work is limited thanks to the reinforcement we made with the refit programme (2002 to 2007) and with the “post Fukushima programme from 2012 to 2017.

The Key Reactor Components (KRC) programme
The aim of the KRC programme is to upgrade or replace some of the reactor’s most important components in order to guarantee the reliability of the reactor for the coming years of operation. The programme, which was launched in 2005, is still ongoing.

Main work planned for 2018:
Maintenance operations:
• Heavy maintenance of second main diesel
Work on the Key Reactor Components:
• Replacement of one safety rod
• Replacement of beam tubes H4 and H10

02

Material Testing 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 (silicon doping).

The OSIRIS Reactor

OSIRIS

PRESENTATION

Located at 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. The Atomic Energy Committee reached the decision to shut down the reactor on 9 December 2013. This was confirmed in July 2014, and OSIRIS was definitely shutdown on 16 December 2015.

Main characteristics of the OSIRIS reactor

- Pool-type reactor
- Compact core (57 x 57 x 60 cm)
- Fuel:
  - 38 standard fuel elements
  - 6 fuel elements using hafnium as an absorber
  - U_3Si_2Al plates (enriched by 19.75%)
- Moderator, cooling, and biological shielding: H_2O
- Thermal power: 70 MW
- Max neutron flux:
  - Fast (E>0.1 MeV): 4.5×10^{14} $n.cm^{-2}.s^{-1}$
  - Heat transfers: 3×10^{14} $n.cm^{2}.s^{-1}$
  3×10^{14} $n.cm^{-2}.s^{-1}$

PURPOSE

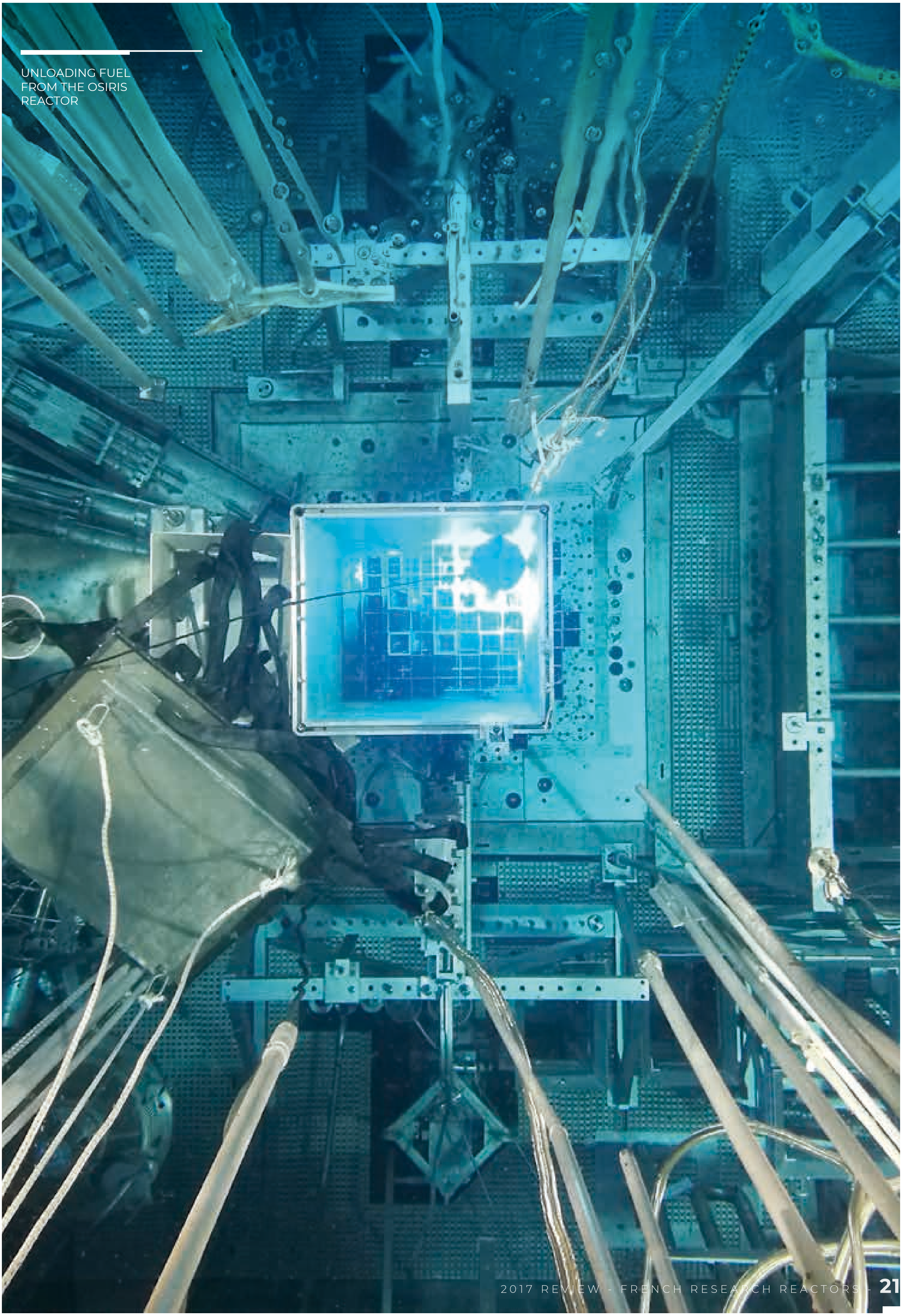
OSIRIS was designed to conduct technological irradiation experiments on nuclear materials and fuels for the needs of the nuclear industry and the scientific community. These experiments have helped improve our knowledge of materials and fuels currently in use, as well as develop new materials and fuels to be used in future nuclear power plants. The irradiation experiments were carried out in experimental devices (loops and capsules) installed, from the top, either directly in the core or around the edge in places reserved for this purpose.

OSIRIS was also used to:
- Manufacture radioelements for medical and industrial purposes
- Produce doped silicon to meet the increasing needs of the microelectronics sector
- Analyse materials by means of neutron activation.

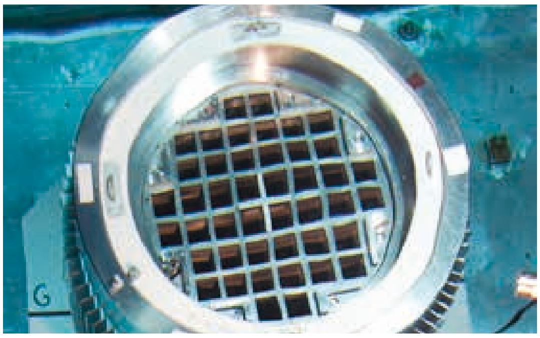
It was equipped with an immersed neutron radiography system and a gamma spectrometry bench.

With the final shutdown of the OSIRIS reactor in 2015, the final shutdown of the ISIS reactor was subsequently programmed for March 2019 at the latest. This date marks the anniversary of the last 10-yearly safety review of licensed nuclear facility (INB) No. 40 at the end of which the ASN authorised the ISIS reactor to continue operations up to 2019. Consequently,

UNLOADING FUEL
FROM THE OSIRIS
REACTOR



TNMTR CASK FOR IRRADIATED FUELS



OPERATION ON SAMPLE IN HOT CELLS LABORATORY

OSIRIS COOLING TOWERS

COOLING TOWER CELL

it is the entire INB composed of OSIRIS and ISIS that will be shut down in March 2019.
In compliance with the French Environmental Code which states the final shutdown of any facility must be announced at least two years prior to the shutdown date, the CEA submitted this declaration in late March 2017 to the minister in charge of nuclear safety and the ASN. This declaration will be shared with the local information commission (CLI) for nuclear facilities on the CEA Saclay centre, and will also be made available to the general public online.
This shutdown declaration included an updated version of the dismantling plan for INB No. 40. This plan describes and substantiates the dismantling strategy, as well as the main principles and measures to be applied to ensure that the dismantling operations are completed according to plan. This dismantling plan also explains the organisation to be implemented, the preparatory actions to perform within the scope of the current operational configuration, the different dismantling phases, the estimated quantities of waste and related waste management procedures, and the clean-up methods to be deployed to reach the final target.
The next step is to send the dismantling file in 2018 to the relevant authorities (nuclear safety and radiation protection board, the ASN and IRSN) for examination, which should lead to the publication of the related ministerial decree granting authorisation to dismantle the INB around 2022.

REVIEW OF 2017

The year 2017 marked the second year following decommissioning of OSIRIS. It was spent carrying out actions in preparation for dismantling the reactor.

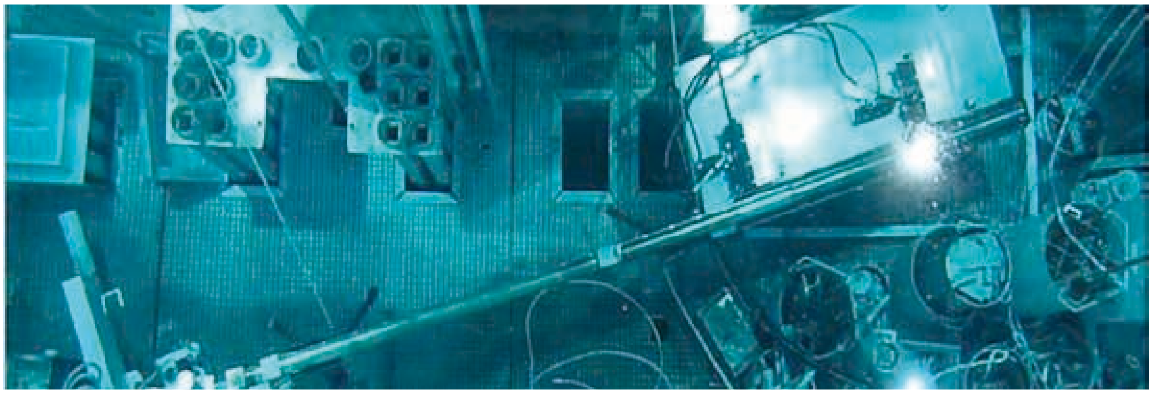
Preparatory dismantling operations

In compliance with ASN Guidelines No. 6, these dismantling operations must be compatible with the INB's licensing decree and the safety standards currently in force. The purpose of such operations to remove all hazardous or radioactive material in the facility and to prepare for the future dismantling operations. After discussions with the ASN, the programme of dismantling operations for OSIRIS currently includes the following:

- Removal of radioactive substances to reduce the source term in the facility
  - Removal of irradiated driver fuels from the OSIRIS, ISIS and ORPHÉE reactors, as well as removal of the fuel sections from the control rods
  - Removal of unirradiated targets (MOLFI)
  - Removal of experimental and 'exotic' fuels (including lithium rods), fuel element mock-ups and an unirradiated non-compliant control rod
  - Removal of spent radioactive sources and fission chambers.

- Removal or neutralisation of hazardous substances and heat loads
  - Neutralisation and removal of active NaK
  - Removal of inactive NaK
  - Removal of fluids used in the NUCIFER experiment and removal of its detector
  - Disassembly and removal of asbestos-containing equipment in the cooling towers
  - Disassembly and removal of hydrocyclones and related equipment when the risk of asbestos is confirmed

CUT UP UNDERWATER THE OLD EXPERIMENTAL DEVICES



- Commissioning of a new back-up generator outside Building 633 to replace the current back-up generators, with the fuel oil and grease to be drained from these generators.

• Modification, adaptation or refurbishment of utilities (electricity, fluids, etc.):
  - Optimisation of the uninterruptible power supplies (UPS)
  - Optimisation of sections of the power supplies

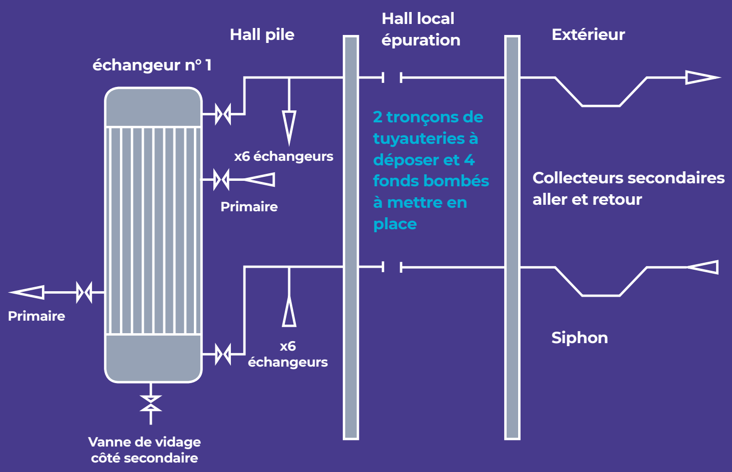
• Housekeeping in the facility:
  - Reduction and consolidation of the second barrier, i.e. installation of blanking plates on the systems and removal of any parts underwater
  - Consolidation of the third barrier, i.e. installation of caps welded to the secondary system to isolate the secondary system from the primary system
  - Disassembly and removal of experimental devices
    ▹ Cutting up of experimental devices and in-core parts
    ▹ Disassembly and removal of out-of-core parts of experimental devices (cubicles, I&C, fluids, fluid systems, etc.)
    ▹ Disassembly and removal of experimental equipment in pools
    ▹ Disassembly and removal of active hydraulic systems
    ▹ Disassembly of the gaseous effluent ventilation system for experiments
    ▹ Cutting up and removal of legacy parts currently in storage, including the old reactor block dismantled in 2001
    ▹ Disassembly of other equipment not used for experiments which are located in pools
    ▹ Disassembly and removal of work equipment associated with channel 1
    ▹ Cutting up of leaktight containers, unused fuel component storage baskets, unused handling rods and the unused tray support.

• Preparation for dismantling operations (reconfiguring rooms, installing equipment required for dismantling):
  - Preparatory works for the construction of a new irradiating waste conditioning facility (ECODI):
    ▹ Disassembly of the BF9 tank and related equipment
    ▹ Relocation of the gaseous effluent system for experiments transiting outside Building 633 and disassembly of the old conduits in the external gallery
    ▹ Disassembly of the inactive hydraulic systems
    ▹ Disassembly of the ultimate emergency generator and its equipment
    ▹ Demolition of concrete blocks, rooms housing the ultimate emergency generator and Building 633C
  - Construction of a new irradiating waste conditioning facility
  - Preparatory work to set up a cutting and conditioning workshop for VLLW and SL-LILW, including an area for characterisation, storage and dispatch:
    ▹ Disassembly and removal of the mechanical workbench in the hot workshop
    ▹ Disassembly of the diesel generator set in the diesel generator room and the related equipment
  - Creation of a cutting and conditioning workshop for VLLW and SL-LILW, including an area for characterisation, storage and dispatch

• Characterisation of the facility (radiological mapping based on intrusive or destructive sampling, collecting information relevant to the dismantling operations).

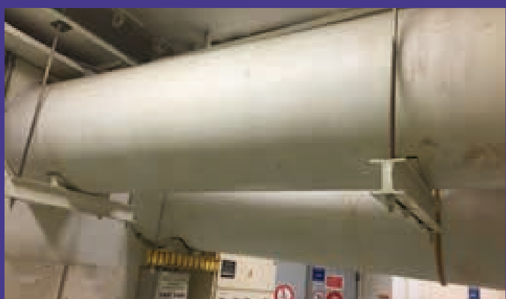
A practical training workshop may be created within the scope of dismantling preparations. This would involve training staff in how to disassembly and remove equipment from one of the OSIRIS core cubicles (heat exchanger, pipes and pumps).

PREPARATORY DISMANTLING OPERATIONS: *CONSOLIDATION OF THE THIRD BARRIER*



ISOLATION OF THE SECONDARY SYSTEM FOR INB 40 (OSIRIS)

BEFORE



DURING THE PIPE CUTTING OPERATIONS:

AFTER

Considering the final shutdown of OSIRIS in late 2015, it has no longer been necessary to operate the secondary cooling system of this reactor. In the beginning, the measures usually implemented in the case of long shutdowns for maintenance on OSIRIS were applied: draining and cleaning of the cooling tower basins, closure of inlet and outlet valves on the secondary-side heat exchangers, and draining of the secondary side of heat exchangers on the core cooling system.

Under such conditions and to monitor the leak-tightness of the second containment barrier composed of heat exchanger tubes, the drain valve on the secondary-side heat exchanger is kept open and the leak detection system in the cubicle is used to detect any leaks from these tubes. The third containment barrier is provided by dual isolation system: 1) closure of the inlet and outlet valves on the secondary-side heat exchangers, and 2) the siphon tubes in water installed on the secondary manifolds outside the reactor hall.

However, the 12 valves installed in parallel cannot guarantee a level of airtightness compatible with the leak rate of the containment and the siphon tubes are not equipped with monitoring devices capable of detecting any deterioration in their filling due to evaporation. These measures therefore cannot be maintained for longer periods. For this reason, it was decided to install a robust isolation device on the OSIRIS secondary system to guarantee the full integrity of the third containment barrier. This modification falls within the scope of facility safety reinforcement work under extended shutdown conditions for OSIRIS. It also falls within the scope of the preparatory dismantling operations. Last of all, this modification makes it possible to upgrade and secure the initial state of the facility as described in the dismantling file submitted for approval.

The isolation system chosen therefore involved cutting the inlet and outlet pipes on each secondary manifold. Caps were then welded to the four openings made by cutting the pipes on the two manifolds.

WORKS

Works were performed from mid-June to early July 2017. The operations were carried out according to the procedure defined in advance with the contractor, as listed below:

- Installation of anchor points to be able to remove the two pipe sections and to weld caps
- Verification of the anchor points by an approved body
- Cutting of two pipe sections
- Preparation of cut pipe ends and welding of caps
- Liquid penetrant tests on the welds
- Painting
- Verification of the OSIRIS containment leak rate.

SIMPLIFICATION OF THE 230V UNINTERRUPTIBLE POWER SUPPLY IN INB 40 (OSIRIS)

The final shutdown of OSIRIS in late 2015 led to a drop in the consumption of power supplied by the 230V single-phase system. This system powers the I&C system of the reactor and the experiments. It is classified as a protection-important component (PIC) in the safety baseline of INB 40 and is composed of three identical circuits of 230V single-phase alternative electrical sources with batteries and UPS. It provides an uninterruptible source of electricity for 30 minutes to the OSIRIS I&C system, the radiation protection system, the supervisory system, and the I&C system for experiments. The three separate circuits independently power the three trains of the OSIRIS I&C system. The other consumers with either simple or no redundancy are shared between the three circuits forming the power supply system.

Furthermore, some equipment associated with these power sources, the entire R1 UPS-battery system, and the UPS batteries for the R3 circuit had all become obsolete.

It was therefore decided to simplify and upgrade this equipment.

This modification involved:

- Replacing the batteries for the R1 circuit
- Replacing UPS 1 by UPS 3 (of the same capacity but a more recent model)
- Distributing the R3 outgoing feeders between the R1 and R2 circuits which do not require a level-3 redundancy in view of reducing the power required for the R3 circuit
- Replacing the R3 UPS by the UPS for the control room lighting after having increased its power level.

This was done in compliance with the redundancy safety requirements. The works were carried out in early 2017 following the authorisation issued by the CEA/ Saclay centre. This work falls within the scope of preparatory dismantling operations for INB 40

REPLACEMENT OF UPS 3

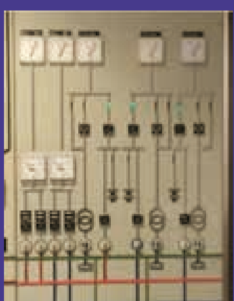
BEFORE AND AFTER

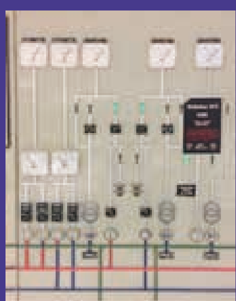
REPLACEMENT OF UPS 1

BEFORE AND AFTER

CONTROL ROOM MIMIC PANEL

BEFORE AND AFTER





Phénix Unit

PHÉNIX

PRESENTATION

Situated on the banks of the Rhône River and part of the Marcoule nuclear site in the Gard Department, Phénix is a sodium-cooled fast reactor (SFR) prototype. After going critical for the first time in 1973, the reactor began supplying the grid in December of the same year.

The facility stopped generating electricity definitively on 6 March 2009.

The preparatory operations for final shutdown were also launched at this time:

- Final shutdown and complete dismantling of the electricity generating equipment
- Complete draining of the secondary systems and reconfiguration for the future carbonation operations
- Extraction of the reactor block, washing and dismantling of large components (intermediate heat exchangers, experimental rods, etc.)

When it was built, Phénix was owned by an association 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 share in the association. The teams working in the facility therefore comprised staff members from both companies. The CEA was responsible for running this association which was disbanded at the end of 2009; the CEA remains the nuclear operator.

- Unloading fuel sub-assemblies from the barrel and treatment of the shielded cells (washing, separation of the pins containing nuclear material from the steel structures, conditioning for transport)
- Simplification of the facility to adapt its services (electricity, hot water, untreated water, etc.) to meet the new requirements.

From a regulatory aspect, an application for authorisation to dismantle the facility was submitted in December 2011. The technical and administrative assessment led to a public enquiry being held in summer 2014 and the setting up of a standing group in November 2014.

The ministerial decree for dismantling INB 71 was published in the official gazette on 2 June 2016. It authorises the CEA to start dismantling the Phénix reactor.

Scheduled to take thirty years and with a budget of more than one billion euros, this project for the clean-up and dismantling of the reactor is divided into six successive steps:

- Unloading the fuel and various removable experimental devices and components from the reactor core
- Dismantling the facility's secondary systems
- Treatment of the sodium used as the reactor coolant and any sodium-contaminated objects
- Treatment of the residual sodium in the vessel after it has been drained
- Dismantling of the reactor block, the systems, shielded cells, etc.
- Final clean-up operations

OBJECTIVES

The main objectives for 2017 were to:

- **Further dismantle the irradiated sub-assemblies**
- **Dismantle the experimental sub-assemblies as part of the 'Phénix Treasure' initiative for the Astrid programme**
- **Treat the G intermediate heat exchanger, remove the borated base, and perforate the dished base**
- **Start work on the finishings and fittings (civil engineering) for the future sodium treatment facility, NOAH**
- **Remove asbestos in the basement of the steam generator building**
- **Implement the global maintenance contract**
- **Upgrade the untreated water network.**

REVIEW OF 2017

Operations

Further dismantling of irradiated sub-assemblies

A major handling programme organised in June made it possible to transfer 13 fertile sub-assemblies and 4 fissile sub-assemblies from the reactor vessel to the drum.

Fifteen spent fuel sub-assemblies (3 fertile and 12 fissile) were treated, dismantled and transferred from the PHÉNIX plant in IR500 transport casks to the ISAI and APM facilities pending their transfer to La Hague site.

Experimental capsules were dismantled for the needs of R&D on Generation IV reactors and for the experimental programme in PHÉNIX designed to study the behaviour of fuels with respect to the transmutation of minor actinides:

Treatment of experimental capsules and sub-assemblies:

- Treatment of central channel devices DCC 3107 and 2172
- Dismantling of the FUTURIX concepts (carbide and nitride fuel pins) and transport to the LECA facility.

CUTTING THE BORATED BASE OF THE G HEAT EXCHANGER

NOAH FACILITY AT THE PHÉNIX PLANT

- Gamma spectrometry:
- Eight PAVIX 8 fuel pins (objective: behaviour of the AIM1 cladding)
- Two fuel pins from the CPd 6157 sub-assembly (objective: dissolution tests on the fissile column).
- Treatment of large components
- Cutting of the borated base in the G intermediate heat exchanger.

All large components removed from the reactor vessel must be washed to destroy any residual sodium having formed a film on the surfaces of the heat exchanger or in retention areas. They must then be sent to the appropriate ANDRA waste outlet.

The following components must first be cut up to make sure the washing operation is effective:

- Thermal mattress (completed in late 2015)
- Borated base
- Dished base.

The purpose of the borated base during reactor operation was to absorb neutrons to reduce the activation of the secondary sodium flowing through the intermediate heat exchanger. The intermediate heat exchangers were placed directly in the reactor vessel.

The boron plate in the bottom part of heat exchanger was 3 mm thick, 96 cm in diameter and weighed 168 kg.

The borated base was cut into pieces in the remote operation maintenance hot cell in March 2017. This made it possible to access the dished base of the heat exchanger.

Preparatory operations for final shutdown

- Start of finishings and fittings (civil engineering) for the future sodium treatment facility (NOAH)

A sodium treatment facility called NOAH is being built to manage the 1,500 tonnes of sodium stored on the plant. Preparatory work completed in 2014 made it possible to start the construction of this facility on 8 April 2015.

The first floor was poured in August 2015 and the structural work was completed in 2016.

The first series of equipment was installed in the last quarter of 2016, as were the soda storage tanks and the stainless steel tank.

In 2017, the building cladding and the emergency staircase were installed. All-trades contracts were then kicked off inside the NOAH building, with the end of works expected in mid-2018.

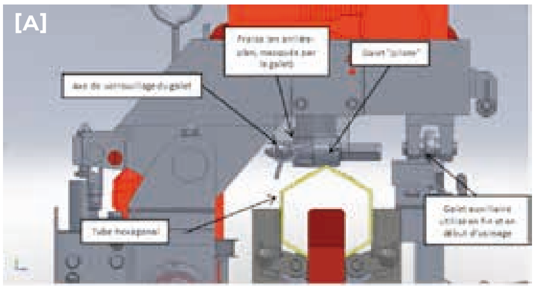
- Asbestos removal in the basement of the steam generator building

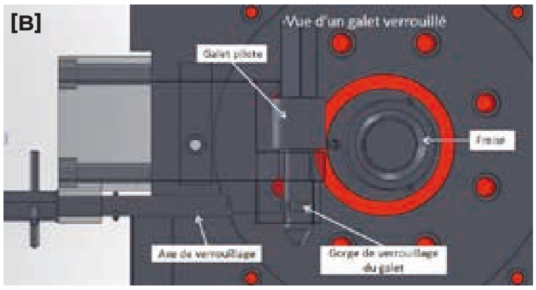
This 6-month operation was completed successfully despite the high level of constraints:

- Asbestos in emissive materials with level-2 dust accumulation (removal operations performed in dynamic confinement systems)
- Work in sodium areas with water restrictions, requiring a dual barrier between water and sodium and the installation of remote shower devices
- Risk of oxygen deficiency in the basement of this building

[A] SOUTH-NORTH VIEW OF THE MILLING MACHINE IN THE ANNEXE HOT CELL, WITH A GUIDE ROLLER CORRECTLY POSITIONED AND LOCKED IN.

[B] VIEW FROM BELOW THE MILLING TROLLEY WITH THE GUIDE ROLLER CORRECTLY POSITIONED AND LOCKED IN.





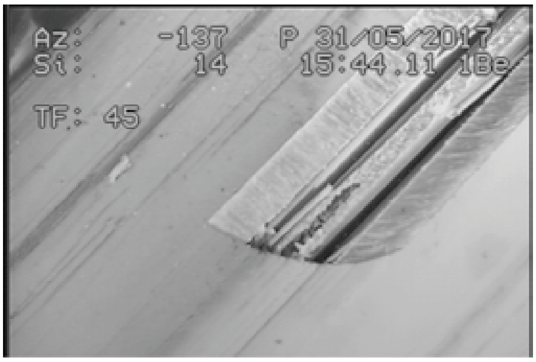
- Congested areas, requiring the creation of 8 work areas in terms of confinement
- High temperatures and limited exposure times.

Refurbishment of the PHÉNIX untreated water system

Works were launched in early 2017 to renovate the PHÉNIX plant's untreated water system. The objective is to make the system more reliable and durable.
Within this context, the pipes between the water tower and the plant were overhauled using a continuous jacketing process with reversion in air.

Refurbishment of the spent fuel removal line (CECU)

The aim of this project was to renovate the equipment in the 'super' hot cell: the door-plug gantry crane was restored, and the lifting unit and cargo lift were replaced to improve the overall reliability of the irradiated sub-assembly treatment system.
This equipment will be the first to be commissioned under the CECU programme.



CLADDING FAILURE DURING A CUT-THROUGH MILLING OPERATION

FIRE EXTINGUISHING SYSTEM OF THE TRUCK HALL

SAFETY

Fuel pin cladding failure caused by hexcan milling

- Fissile sub-assemblies are mainly dismantled in the annexe hot cell (CA) in the PHÉNIX plant. The main phases of the mechanical treatment are:
  - Sawing to remove the top and bottom of the sub-assembly
  - Milling of the hexcan
  - Removal to separate the fuel (pin bundle) from the body of the hexcan.

The milling operation is performed on two opposing edges. The blade cuts right through the first edge but it does not cut through on the other edge, thereby forming a hinge so the hexcan can be opened to remove the fuel.
During the milling operation, two types of guide rollers are available depending on the machining operation used to dismantle the sub-assemblies (cutting right through or not).
On 28 April, during the cut-through milling operation on fissile sub-assembly CPa 5110, the faulty positioning of the guide roller in its sheath caused cladding failure, which was detected by the high level of activity in the annexe hot cell.
The event had no impact either onsite or offsite.
It was classified as a level 0 event on the INES.

Implementation of a fire extinguishing system in the PHÉNIX truck halls

During examination of the safety review file for the PHÉNIX plant by the ASN, the CEA agreed to install a stationary fire extinguishing system in the truck halls of the auxiliary (2 systems) and south handling (1 system) buildings of the PHÉNIX plant. The risk of fire concerns a transport truck parked in a hall which could provoke a major fire in the plant. In such conditions, the site's fire brigade (FLS) now has a stationary fire extinguishing system designed to combat such fires.
The solution involves using water with an additive that is sprayed through a network of sprinklers to cover the entire truck. The FLS can also connect its fire truck to feed the dry risers. The additive is stored in two 500-litre tanks connected to the dry risers. The quality of additive makes it possible to effectively put out the fire on a transport truck.
The location of the three networks was finalised in summer 2017.

"PETIT CARUSO" ARRIVALS

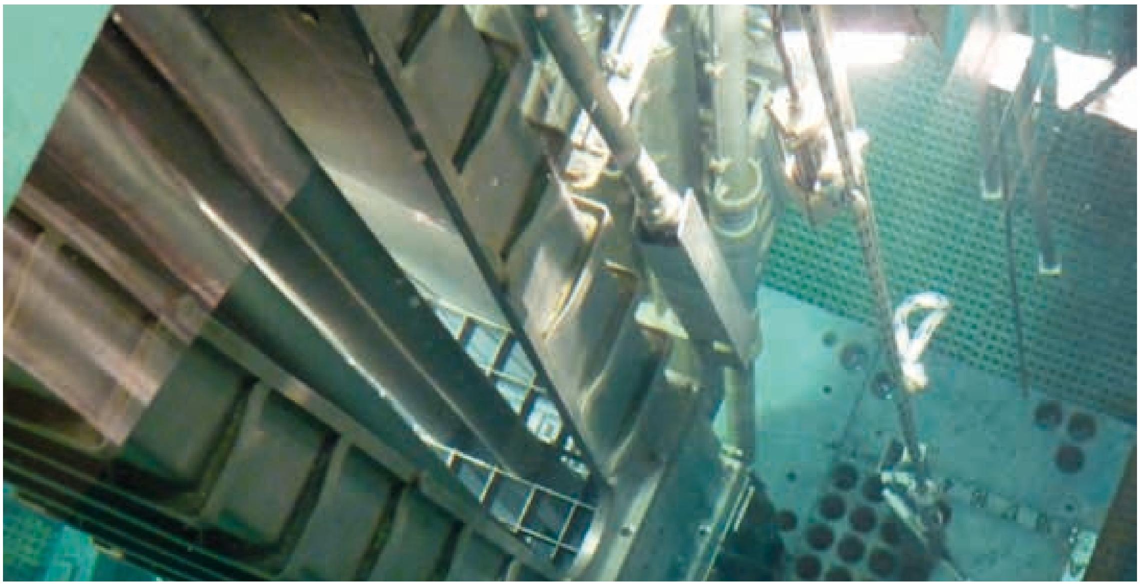
03 Training Reactors

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.

LOADING OF A FUEL ELEMENT IN THE ISIS CORE



ISIS reactor

ISIS

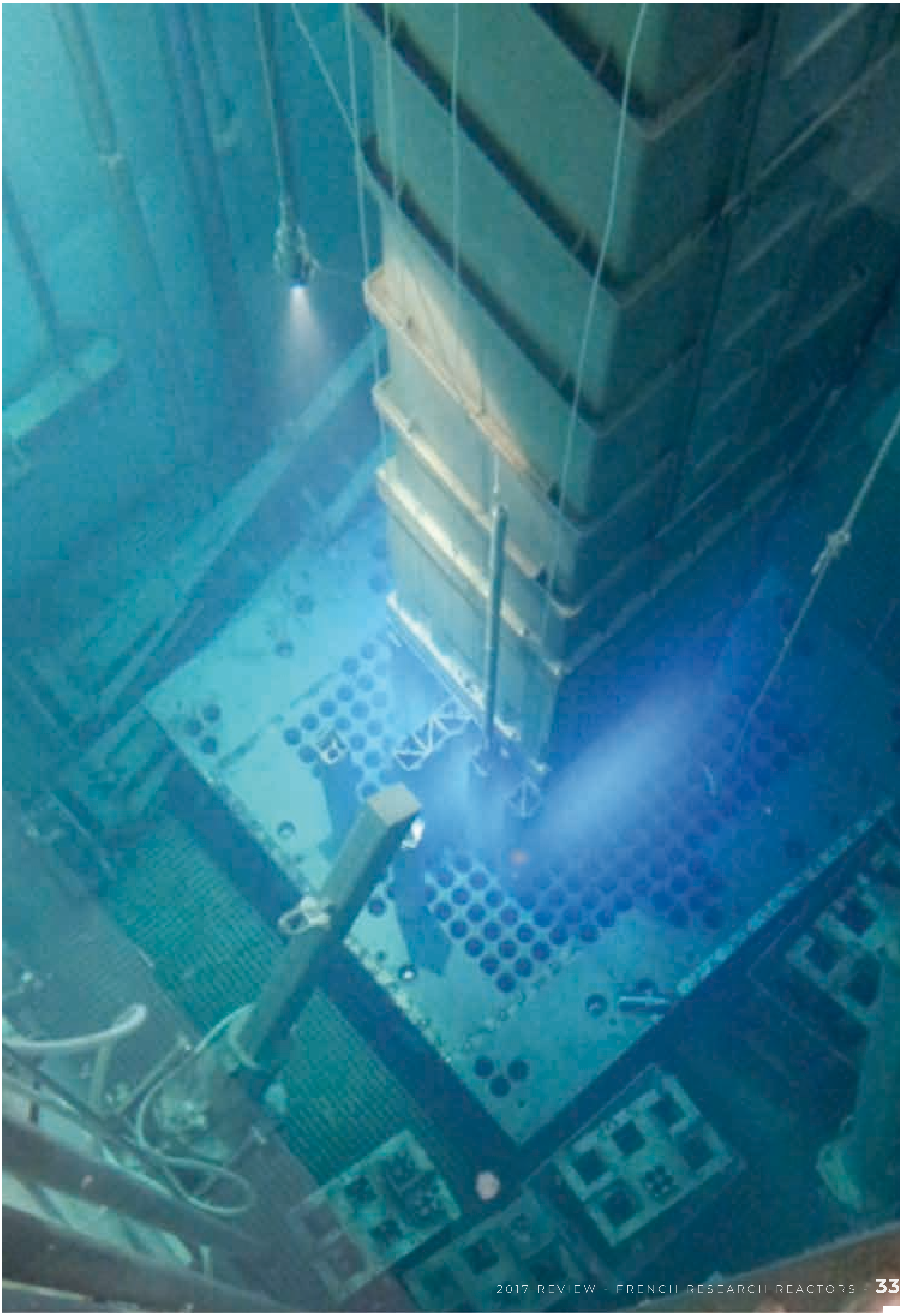
PRESENTATION

ISIS is the neutron mock-up of the OSIRIS reactor which was built alongside it at the CEA Saclay Centre. ISIS is part of licensed nuclear facility No. INB 40. It has a rated power of 700 kW. The ISIS reactor is used to perform irradiation experiments, measure the effects of reactivity, and study the distribution of neutron flux under different spectra or gamma heating conditions. ISIS is also used to qualify instrumentation intended for other reactors.

The instrumentation and control (I&C) system and the control room were renovated between 2004 and 2006, extending the reactor's scope to training people from different fields (technicians, apprentice engineers, masters students and staff from French and foreign organisations). These trainees are taught by instructors from the INSTN.

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



Thanks to its effective 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 enable them to better understand the physical phenomena coming into play.

REVIEW OF 2017

ISIS operated a total of 44 days in 2017, which made it possible to give 28 practical work sessions to about 162 trainees.
A total of 7 days was required to meet the facility's own operating needs, e.g. thermal balances to check the safety parameters, and operational tests after repairs.
The demand for experiments was higher than the previous year, representing a total of 9 days of operation, including:

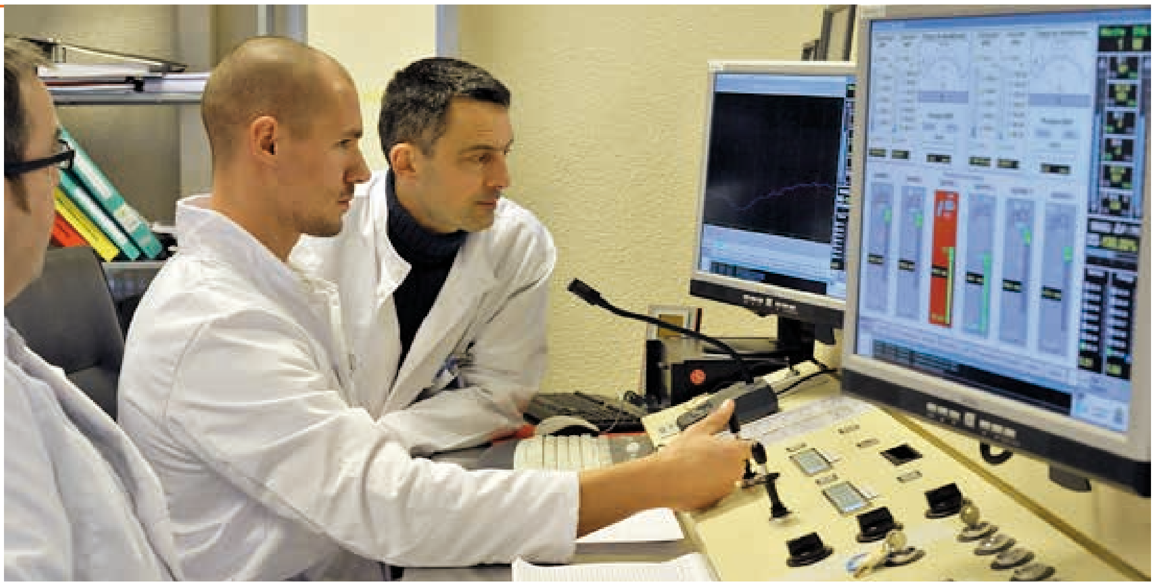
- Irradiation of 59Co micro-particles in liquid suspension for toxicology studies (CEA/ Bruyères-le-Châtel centre)
- Qualification of new electronics with short dynamic responses developed for neutronic measurements of I&C systems in PWRs (collaboration between Rolls-Royce and the CEA/DRT
- Tests on the start-up neutron detector for the RES (CPNB)
- Tests on the high-temperature fission chamber (CFHT) developed for ASTRID
- Test on a scintillation detector for measuring 16N in the primary system of reactors.

Five half-days of online training were provided under the agreement signed with the IAEA and the universities of Belarus, Lithuania, Tunisia and Tanzania. The video-conference system installed in the reactor control room proved to be fully operational.

2017	TP INSTN	Expériences	Besoins internes/ démo	Jours de fonctionnement	Nbre de stagiaires
Total	28	9	7	44	162

Five training sessions were organised with the KTH University in Sweden, with the CEA-KTH contract having been extended for two years.
In anticipation of the pending shutdown of ISIS, the INSTN decided to take a series of 360° shots inside the reactor in view of developing its virtual simulator which is expected to replace ISIS for all teaching needs around 2019.

ISIS TRAINING SESSION



AZUR Reactor Pile

AZUR

PRESENTATION

AZUR – a French abbreviation for zirconium and uranium alloy – is an experimental reactor pile located at Cadarache and primarily devoted to neutron studies, criticality experiments and radiation protection measurements.
This reactor pile 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 designed for nuclear propulsion (land-based prototypes, 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.
The AZUR reactor pile 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 safety instrumentation & control systems use the latest generation of computers and software which have been developed and qualified for use on nuclear submarines, as well as for the RES reactor.

REVIEW OF 2017

Operations in the core in 2017 focused on:
- Acceptance of the cores for nuclear propulsion vessels
- Training and qualification of AREVA TA staff to operate the facility
- Training of French navy personnel in reactor operations.

These activities resulted in numerous total fuel loading and unloading operations, as well as about 500 reactor divergences spread over a 106-days nuclear phase.

Experimental options

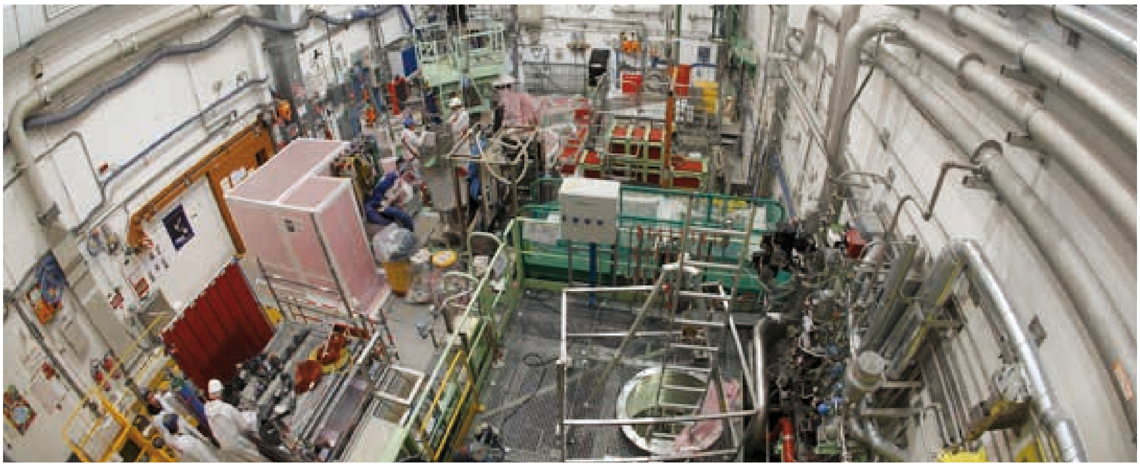
The AZUR reactor pile offers the following main experimental possibilities:
- Characterising neutronic parameters
- Measuring worth (boron, water, etc.)
- Measuring absorber worth
- Measuring temperature coefficients
- Measuring flux and power distributions
- Analysing critical lattices (safety studies)
- Monitoring reactor core loading and unloading operations performed underwater
- Measuring radiation protection levels
- Testing nuclear instrumentation in dynamic conditions
- Irradiating samples.

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 BUILDING
REACTOR



CABRI reactor

CABRI

PRESENTATION

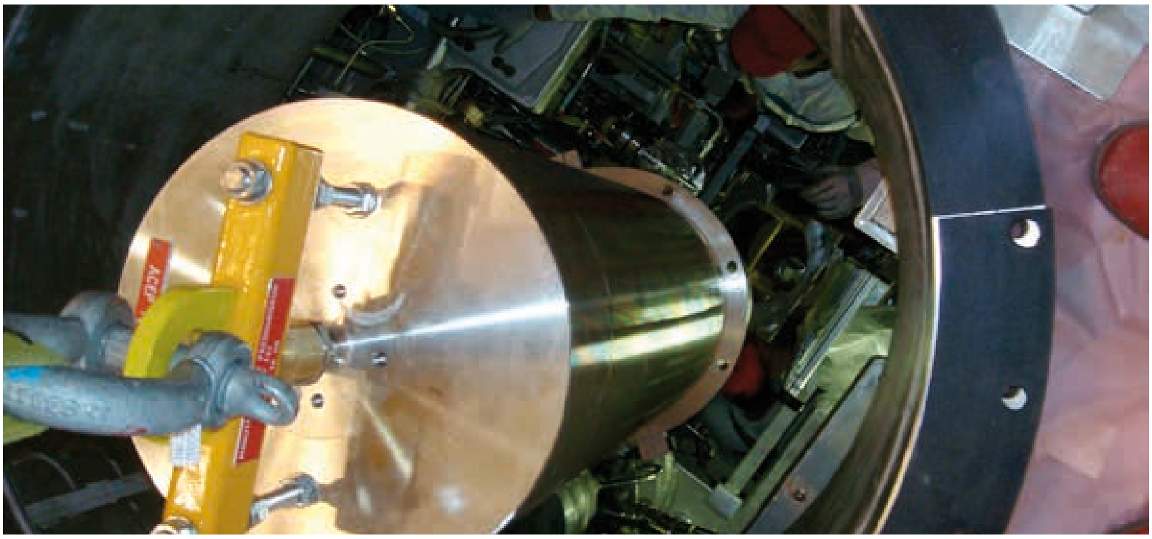
CABRI is a research reactor on the Cadarache Centre used to reproduce the conditions occurring during a severe accident on a sample of irradiated nuclear fuel. This reactor is specifically used to reproduce the conditions of a reactivity insertion accident (RIA). This reactor consists of a driver fuel core and an experimental loop. The loop section located in the centre of the driver fuel core accommodates the test device containing the fuel rod to be tested. The driver core is designed to generate the neutron flux needed to reach the required power level in the experimental rod. Depending on the power level, the core can be cooled by natural convection with the pool water (below 100 kW) or by forced convection with an ascending flow via the primary cooling system. The specificity of the reactor lies in its reactivity injection system. Four sub-assemblies in the driver core are equipped with an outer ring of empty cylindrical tubes - called transient rods - instead of using fuel rods. These transient rods filled with pressurised helium-3 (neutron-absorbing gas) which can be depressurised by opening motor-operated valves to suddenly change the reactivity and thus the power of the driver core. The power can, for instance, increase from 100 kW to 20 GW in a few milliseconds, and then decrease as rapidly down to around 40 MW due to neutron counter-reactions (Doppler effect). Depending on the objectives of the test, the reactivity injection can cause cladding rupture of the experimental fuel rod positioned in the in-core section of the pressurised water test loop and even the ejection of some of the fuel contained inside this rod.

Reactor characteristics

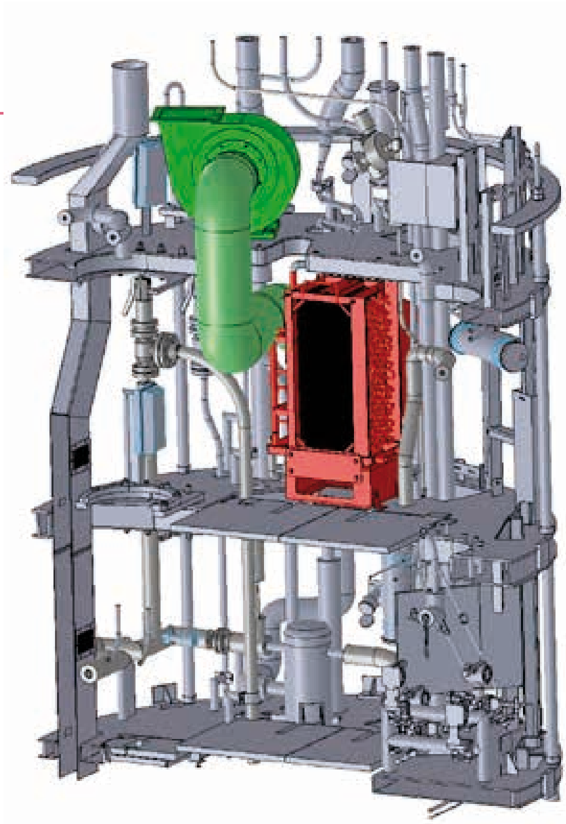
- UO_2 enriched with 6% ^{235}U
- 1,488 fuel rods
- 304L stainless steel cladding
- 800 mm fissile height
- Maximum thermal power in normal operation: 25MW
- Maximum thermal power in pulse operation: 20GW

REVIEW OF 2017

In line with 2016, the start of year was devoted to the last neutronic tests performed at high power. This involved conducting a series of start-up power transients to validate the authorised



BEP PRESSURIZER



SCHEMATIC DIAGRAM OF THE HEAT EXCHANGER

range of transients for the Cabri International Programme (CIP). These actions fall within the scope of the CABRI+ test programme.

Commissioning tests

Commissioning tests provide the best means for re-qualifying the CABRI facility. About hundred tests covering various different fields were defined for this re-qualification phase: neutronic, HVAC, reactor block, handling, standard systems, pressurised water loop systems, instrumentation & control, experimentation stations, and general operation.

Some of these tests were performed after core reloading, while others were performed before divergence. The first experimental test of the CABRI International Programme (CIP) will be carried out once the last commissioning tests have been completed.

After having completed the low-power neutronic tests in 2016 which validated the kinetic parameters of the CABRI core, the high-power neutronic tests were then performed during the first term of 2017. This campaign of start-up power transients involved no less than 66 pulses to adjust the parameters of the helium-3 system and the related digital sequencing system.
This campaign thus validated the authorised transients that meet the requirements of the CIP experimental programme.

These tests marked the end of the CABRI+ programme with respect to the refurbishment and re-qualification of the facility.

In parallel to the CABRI+ programme, IRSN performed the first qualification tests on the hodoscope. This device that measures the fast neutrons emitted by the test fuel in order to monitor fuel deformation and movements.

After having successfully completed the neutronic tests, the operator submitted the safety case to the French Nuclear Safety Authority (ASN) for approval to start the CIP experimental programme. The technical assessment of the file was completed at the end of the year. Authorisation is expected to be granted in the first term of 2018.

Pending this authorisation, the operator has begun preparing the first experimental

TOP VIEW OF THE VESSEL

test called CIP-Q. The experimental device loaded with the test fuel rod was delivered and accepted, with the pre-irradiation non-destructive tests (gamma spectrometry and imaging) having since been completed.

HANDLING THE TRANSFER CASK WITH THE TRAVELLING CRANE

PROSPECTS FOR 2018

The CABRI reactor is now ready for the CIP experimental programme.

The operator will continue the first test campaign (CIP-Q), which involves inserting the experimental device loaded with its test fuel rod into the in-pile cell and preparing the pressurised water loop. The irradiation of the test fuel rod has been programmed for 16 April 2018.

At the end of this campaign, the operator will carry out a 10-yearly inspection on the pressurised water loop in compliance with the French nuclear pressure equipment regulations.

INSERTING THE EMPTY TEST DEVICE INTO A CONTAINER IN TANK 60

TRAVELLING CRANE IN THE PHÉBUS REACTOR HALL

Phébus reactor

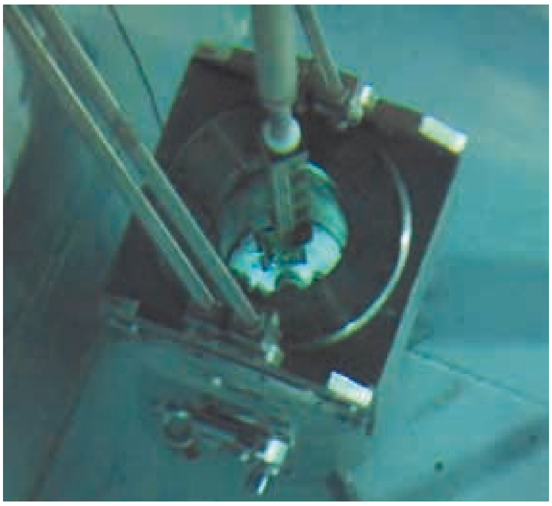
PHÉBUS

PRESENTATION

Licensed nuclear facility No. 92 called PHÉBUS is operated by the CEA at the Cadarache Centre. It has been used for conducting integral tests on severe accidents since 1979.

It was decided to stop performing nuclear safety experiments in the reactor in 2007 and to shut down the facility in 2013. Pending its dismantling, the facility is currently in a post-experiment phase, with the last experimental programme having been PHÉBUS-PF. The nuclear fuel has been unloaded and put in storage until it can be transferred to an appropriate outlet.

CABRI SPENT FUELS IN THE STORAGE TANK



REVIEW OF 2017

In addition to routine operational maintenance to keep the facility in a safe state, the year 2017 was marked by:

- Facility safety review (file sent to the ASN in November 2017)
- Preparation of the dismantling file which should be submitted to the ASN in early 2018
- Start of preparatory dismantling operations in the facility, including removal of the hot layer located above the reactor pool
- Ongoing actions to reduce the facility's source term, which involved removing:
  - Three sources which were sent to the CERISE facility
  - Unirradiated depleted or natural uranium fuels which were sent to the MMB facility
  - Hodoscope rod required for CABRI experiments which was sent to the LECA facility
  - Irradiated fuels from CABRI stored in the PHÉBUS storage tank, which were transferred to the CABRI facility in X transport casks (see photos below).

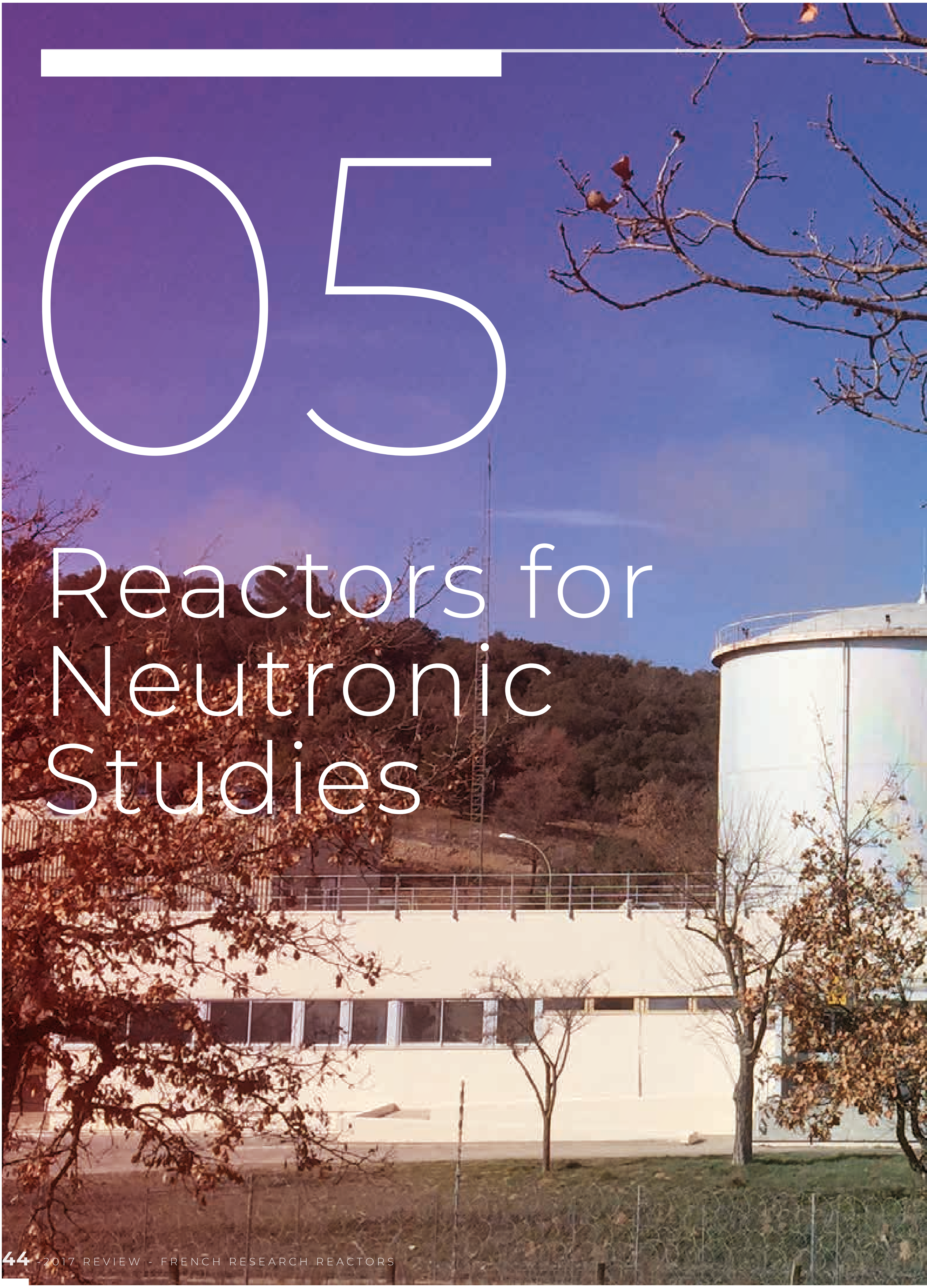
PROSPECTS FOR 2018

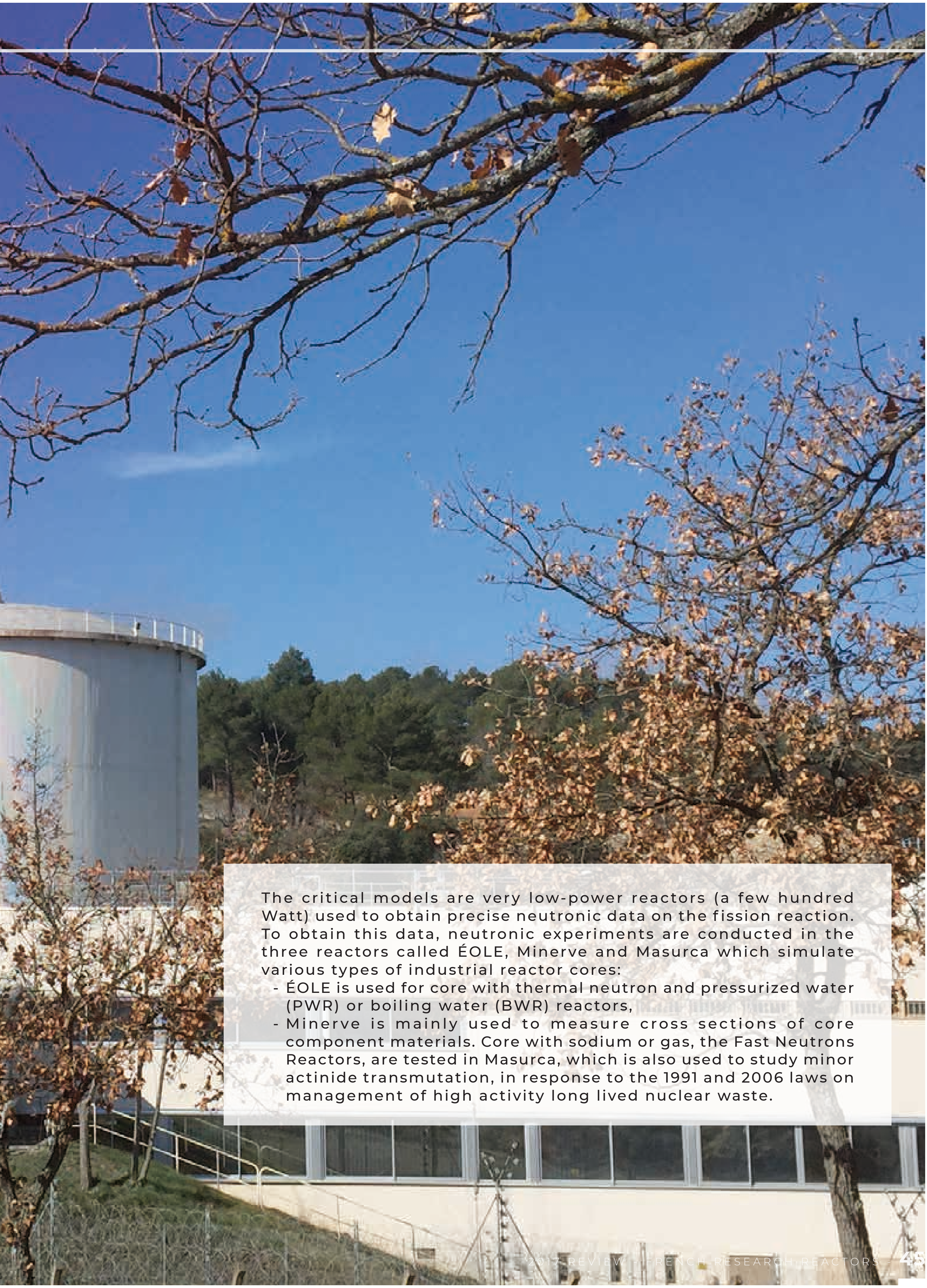
The following actions will be carried out in 2018:

- Maintenance to keep the facility in a safe operational condition.
- Examination of the safety review and the dismantling file
- Detailed design and construction of equipment required to remove and transfer irradiated fuels to the ISAI facility

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 ÉOLE, Minerve and Masurca which simulate various types of industrial reactor cores:

- ÉOLE 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.

ÉOLE PROTECTIVE SLAB

ÉOLE

PRESENTATION

The ÉOLE critical mock-up is a very low-power experimental reactor used to conduct neutron studies on light water moderated lattices, in particular pressurised water reactors (PWR) and boiling water reactors (BWR). This mock-up diverged for the first time in 1965.
The main vessel measures around 2.3 m in diameter and 3 m in height. A smaller vessel (about 1 m in diameter, 1 m high) in the centre of the main vessel accommodates all types of water reactor lattices by means of interchangeable grids. Four safety control rods make it possible to shut down the reactor at any moment. Criticality is obtained by adjusting the moderator's soluble boron concentration or by adjusting the number of fuel rods.

A control rod is used to achieve divergence and to stabilise the power between 0 and 1 kW (maximum authorised power). This mock-up accepts many types of fuel (PWR and BWR fuels such as MOX and UO2, and JHR U3Si2 fuel) and materials whether absorbers, poisons or structures (natural and enriched B4C, Ag-In-Cd, Hf, UO2-Gd2O3, Pyrex, Zy-4, steel, etc.). Due to its flexibility and the experimental techniques employed, ÉOLE is an unequalled and practically unique tool in the world for studying light water reactor physics.

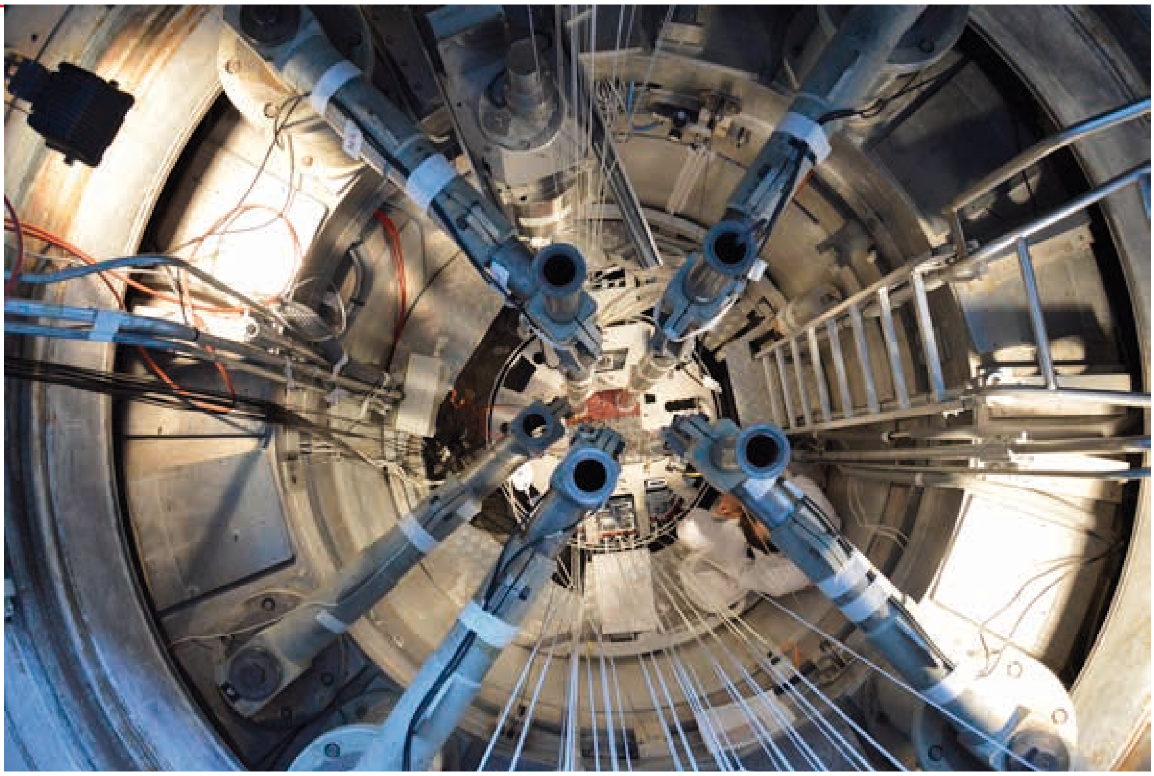
PHYSICAL MEASUREMENTS

By measuring the physical parameters during experiments, it is possible to characterise the configurations in their entirety (critical sizes, worth of absorbing materials, refined power and gamma heating distributions, spectrum indexes, buckling, reactivity effects, boron and/or temperature, kinetics). The team uses proven experimental gamma spectrometry techniques, fission chamber measurements and neutron noise measurements, combined with thermoluminescent detectors or activation dosimeters.

REVIEW OF 2017

The year 2017 was devoted to the EPILOGUE programme which was carried out to support both in-core instrumentation studies and research on the effect of loading burnable poisons.

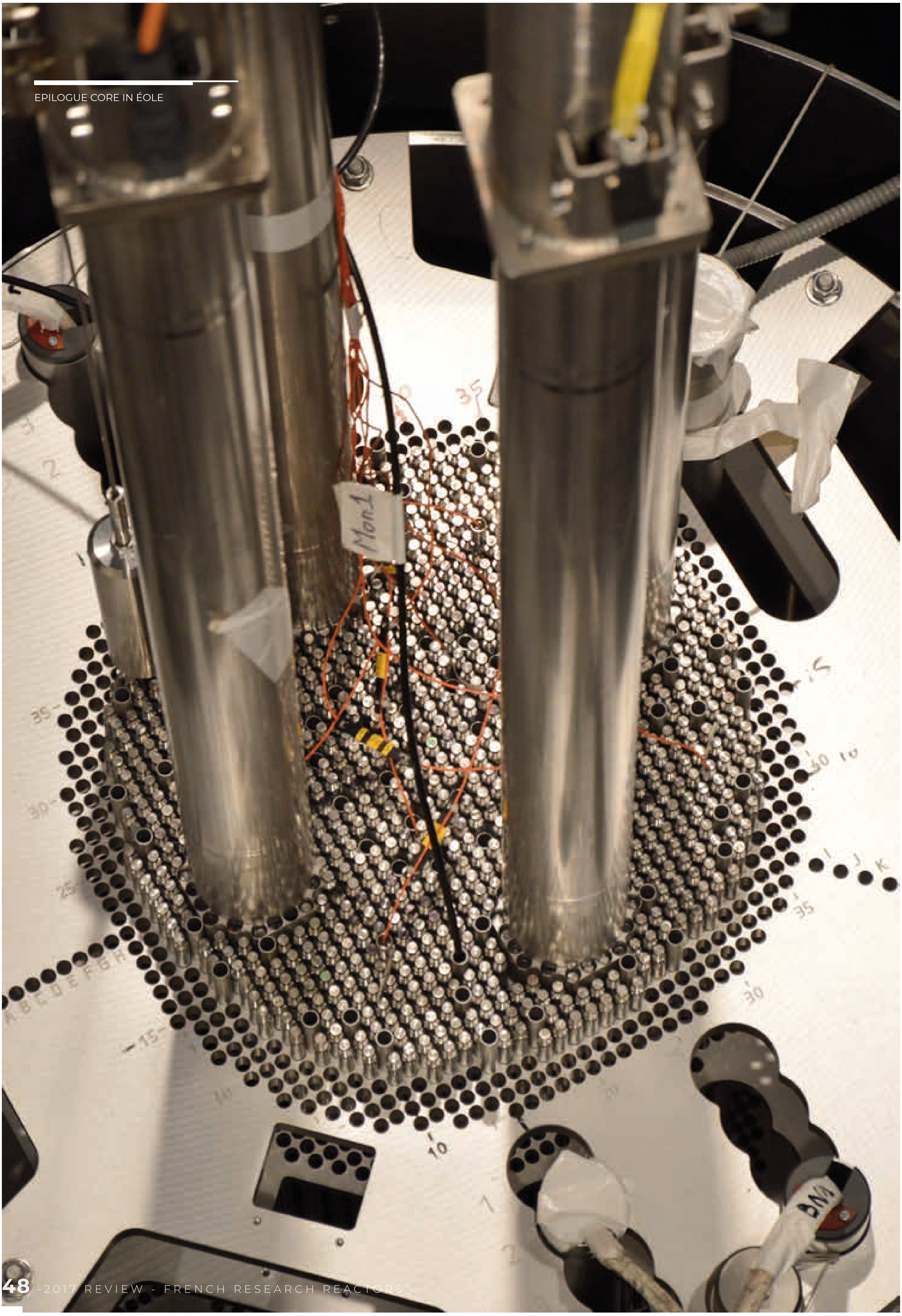
ÉOLE VIEWED FROM ABOVE



EPILOGUE (Experimental Program on Innovative gen III LOadings Gd-U assemblies in ÉOLE) is the last programme to be conducted in the ÉOLE reactor which is scheduled for decommissioning in late 2017. The purpose of this programme is to improve the qualification of PWR calculation systems, such as the APOLLO2.8/ SHEM-MOC/ CEA2005 tool, through a greater understanding of local neutron flux interference caused by singularities in the core. The following five effects were analysed:

- **Effect of in-core instrumentation:** continuous power measurements will be recorded directly in EPR cores, either by self-powered neutron detectors (SPNDs) or via a vanadium ball activation system known as the aeroball measurement system (AMS). In both cases, EPILOGUE aims at characterising the local interference caused by these intrusive sensors for EPRs.
- **Effect of burnable poisons:** the aim is to be able to load highly enriched cores into certain EPRs, but they would then require burnable poison rods to control their reactivity. The effect of these absorber rods (up to 24 gadolinium rods per assembly) on their immediate environment is being analysed under the EPILOGUE programme.
- **Effect of "grey rods":** some units in the fleet may be equipped with "grey rods" made of silver-indium-cadmium or steel to enable load following. There are significant uncertainties associated with existing flux calculations in the vicinity of absorber rods; the purpose of EPILOGUE is to provide new experimental data to help improve the simulation tools.
- **Effect of "pure" water in a section of the fuel assembly:** the flow of even the smallest amount of pure water into the core, where borated water is normally used to help control reactivity, will cause a local increase in flux. By reproducing and characterising this condition in the EPILOGUE campaigns, it should be possible to extend the qualification range of the calculation model.
- **Effect of a larger water layer:** the water layer between two fuel assemblies may, in some cases, expand due to bowing which occurs in fuel assemblies under irradiation. This will generate excess moderation locally and thus cause flux interference. A dedicated EPILOGUE campaign was developed to study this phenomenon.

The design and implementation of this experiment relied heavily on feedback from previous programmes conducted in ÉOLE. The EPILOGUE reference core diverged on 7 December 2016 under the conditions predicted by TRIPOLI4 and the JEFF3.2 nuclear data library.

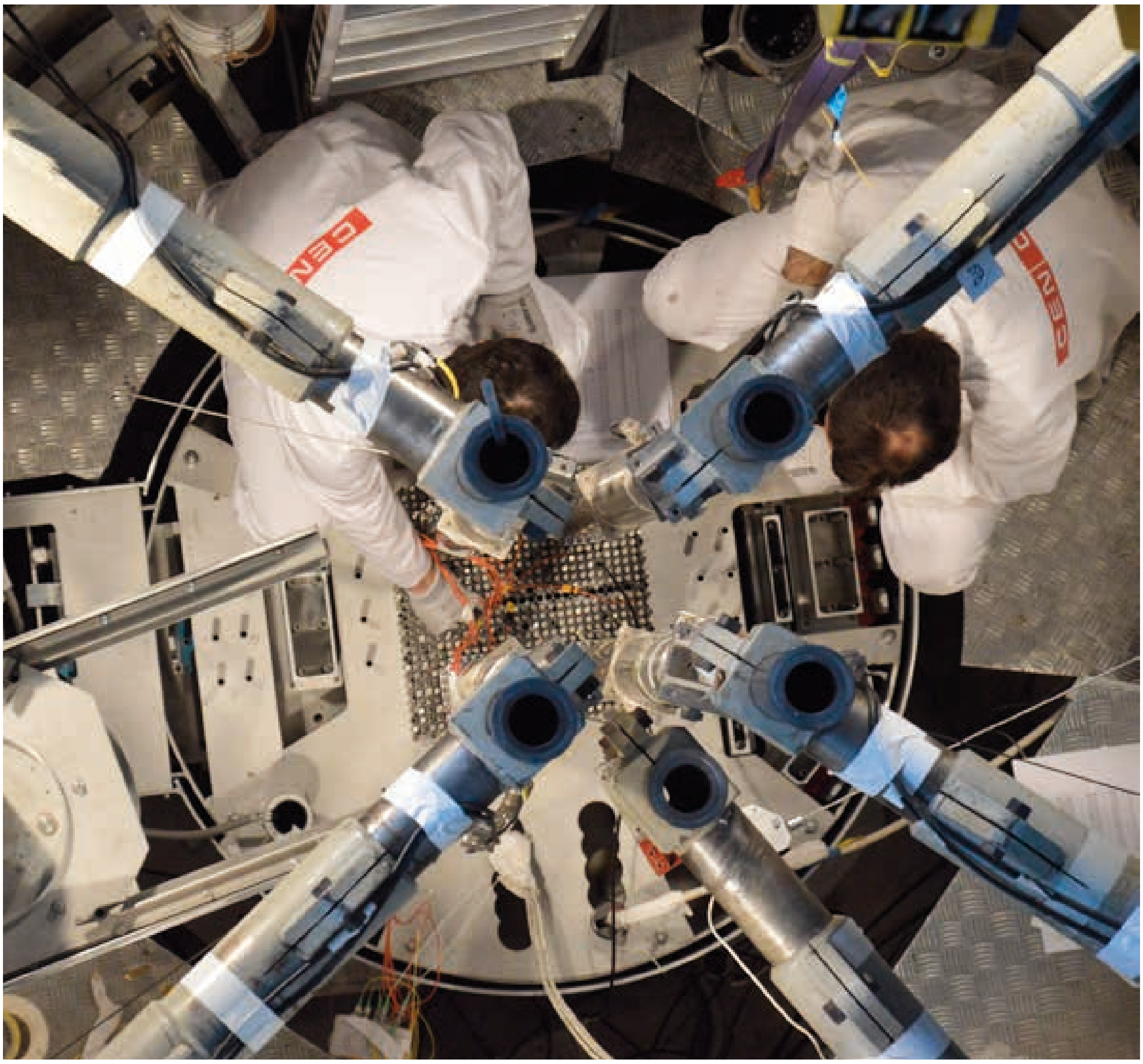

Mon1

This first stage consisted in precisely characterising the core by means of gamma spectrometry measurements on the fuel rods, before reproducing the different singularities consecutively.

Seven core configurations were studied in succession:
• Instrumented reference core
• Core with an expanded water layer
• Instrumented core with 24 gadolinium rods
• Core with 'grey' rods
• Bubble in the median plane of the core
• Bubble at the base of fuel rods
• Bubble at the base of the fuel.

These studies were performed over the entire year and were completed on 21 December 2017.

ÉOLE TOP VIEW



MINERVE reactor

MINERVE

MINERVE is designed for performing neutronic studies and collecting data to improve the nuclear databases on the fuel systems deployed in the different reactor technologies. Initially installed at the Fontenay-aux-Roses research centre in 1959, it was then transferred to Cadarache in 1977.

The reactor is contained in a 140 m3 stainless steel parallelepiped-shaped pool. The moderator is demineralised light water. The core is cooled by natural convection.

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 : 10^9 n.cm^{-2}.s^{-1}
- Neutron absorber: hafnium

The experimental lattices 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 lattices (ERMINE), light water lattices (MELODIE), RSMs (MORGANE) and even heavy water lattices (ELOISE).
The reactor is controlled by means of four hafnium bars operating indifferently in control and safety configurations. The entire I&C system and the reactor control room were upgraded in 2002.

EXPERIMENTAL TECHNIQUES

The oscillation technique is mainly used in MINERVE. An oscillator traces a vertical periodic movement (sinusoidal or pseudo square) on a sample whose neutron effect (fissile, fertile, absorbing or structure materials) is characterised between two positions located inside and outside the central cavity respectively. Variations in the sample reactivity are compensated by a calibrated rotating automatic pilot system with cadmium sectors.

Physical measurements (spectral index, conversion rates, axial and radial fission rate distributions and neutron activation) are

MINERVE POOL

also performed to characterise the neutron behaviour of both the core and the samples under investigation.

OTHER ACTIVITIES

MINERVE is also used to test the performance of new miniature fission chamber prototypes developed by the CEA or its partners, and has clearly been identified as a reference facility for international collaborations in experimental physics.

The reactor is also used for practical work sessions in reactor physics and experimental techniques for trainees from various organisations.

REVIEW OF 2017

In addition to the reactor operations performed to meet fission chamber calibration needs, the year was mainly devoted to the PANORAMIX programme.

The driver core comprises a number of fuel assemblies made from MTR-type aluminium/uranium alloy plates placed under 3 m of water. It is surrounded by a graphite reflector. The thermal neutron flow in the vessel is equal to 109 n.cm-2.s-1 (for a power of 100 Watt).

PANORAMIX programme

The purpose of the PANORAMIX programme is to investigate the loss of reactivity in MOx fuels over time. Such reactivity losses are mainly due to the radioactive decay of 241Pu into 241Am. Several samples containing MOx and 241Pu manufactured for the CERES and OSMOSE programmes were used for the purposes of this study.
The first part of the experimental campaign was devoted to measurements focusing on the operational safety of the reactor and on the characterisation of the experimental lattice. The second part of this programme concerns the oscillation tests themselves; eight different samples will undergo oscillation, including three plutonium samples.

Decommissioning the ÉOLE and MINERVE experimental reactors

Following the second safety review of the ÉOLE and MINERVE licensed nuclear facilities, the ASN instructed the CEA to upgrade the earthquake resistance level of these reactors to the maximum historically probable earthquake level before the end of 2017 in order to extend their operating license to the end of 2019.

After conducting in-depth studies and discovering asbestos and lead paint on components requiring significant reinforcement work, the CEA decided that these complex operations were incompatible with the deadline set by the ASN, and consequently decided to halt the work.

As a result, the ASN issued resolution ref. CODEP-CLG-2016-049370 on 16 December 2016 stipulating that both facilities would be decommissioned by 31 December 2017 at the latest.

The ÉOLE and MINERVE reactors were both definitively shut down on 21 December 2017.

INSTRUMENTATION AND MEASUREMENT TECHNIQUES FOR EXPERIMENTATION PURPOSES

Instrumentation is essential to the quality and competitiveness of experimental programmes conducted in test reactors. In-reactor measurements help to develop, fine tune and qualify nuclear systems and components on many different levels. Instrumentation is used:

- To determine nuclear data, used primarily in simulation models to study, design and qualify components and systems. For instance, this data can come in the form of integral or differential nuclear cross-sections, or fission or capture reaction rates. It is most often determined in very low power critical mock-up reactors using high-performance neutron flux and photon radiation measurement systems.
- During irradiation programmes designed to study and verify the behaviour of components, fuels or systems under nuclear radiation in normal or accident conditions, as well as under the associated thermal or physicochemical stresses. These programmes are conducted in technological irradiation reactors which offer intense neutron flux levels and specific spectra. The instrumentation is used not only to assess the applied neutron doses and to control and monitor the experimental conditions (by measuring the temperature and physicochemical conditions), but also to monitor the parameters required for the experimental programme online (parameters such as sample deformation, thermal conductivity variation and gas release).
- To control and monitor the reactors themselves, primarily through neutron flux and thermal power monitoring systems, as well as to support reactor operation and management.

The specific nature of this instrumentation is dictated, in part, by the high level of accuracy needed to meet the scientific needs of the programmes, as well as by the severe constraints associated with in-reactor measurements, including, for example:

- Constraints associated with irradiation conditions (intense neutron and photon flux causing degradation of materials, change of composition through transmutation, occurrence of stray currents, etc.)
- Constraints associated with the physicochemical conditions of the experiments (high temperatures, pressurised water, liquid metals, etc.)
- Constraints associated with integration conditions (miniature sensors required due to the highly scaled-down versions of the experimental devices, distances between detectors and their electronics, etc.)
- Operational constraints (high availability requirement in view of the difficulty, often impossibility, of maintaining or replacing irradiated sensors)

For all these reasons, the CEA conducts advanced R&D programmes on in-reactor instrumentation. The purpose is two-fold; firstly, to increase the performance of existing measurement techniques and, secondly, to extend the potential range of measurements accessible in experimental reactors.

The activities carried out by the CEA's Instrumentation Sensors and Dosimetry Laboratory (LDCI) at Cadarache include:

- Dosimetry (neutron dose assessment) for all CEA reactors, as well as dosimetry associated with the programme for monitoring the effects of irradiation on reactor vessels for the entire French fleet. This role involves not only taking and interpreting measurements, but also running R&D programmes to investigate how to improve the quality of results and to extend the measurement capabilities.

TOP: ACTIVATION DOSIMETERS USED IN RESEARCH REACTORS; BOTTOM: VIEWS OF THE DER/ SPESI/LDCIMADERE PLATFORM

The LDCI is running an important programme to improve dosimetry measurements. The following are just some of the many studies underway:

- Improvement of X-ray emitting dosimeter activity measurements (niobium and rhodium), through thesis studies completed in 2018 in collaboration with the Henri Becquerel laboratory (LNHB). The purpose of these studies is to gain a more precise assessment of neutron flux for energy ranges above 1 MeV.
- Development and implementation of new dosimeters designed to better characterise the epithermal range, i.e. neutrons ranging between 1 keV and 1 MeV. Based on the use of zirconium, these studies involve the implementation of 95Zr mass activity measurements using gamma spectrometry combined with 93Zr analysis using accelerator mass spectrometry.

The LDCI operates the COFRAC-certified MADERE platform (Measurement Applied to DosimEtry in REactors) located at Cadarache for carrying out mass activity measurements on activation dosimeters. This facility has received significant funding in recent years - particularly from the European Regional Development Fund (ERDF) - which has helped to upgrade the existing measurement systems and to install innovative new systems. This has made it possible to conduct experimental programmes based on very high numbers of simultaneous dosimetry activation measurements (for the AMMON and FLUOLE-2 programmes carried out between 2011 and 2016 in the ÉOLE reactor in particular).

An extensive dosimetry programme is also being developed in preparation of JHR commissioning. The objective is to accurately characterise the core power distribution, the thermal and fast neutron fluxes, and the spectral index in the different experimental locations in the reactor (core and reflector).

- Instrumentation (detectors and measurement systems) for taking online in-reactor measurements of radiation (neutron and photon flux and doses) and physical parameters (temperature, deformation, physicochemical, etc.). The LDCI is continually developing and improving in-reactor measurement techniques to meet the needs of experimental programmes and research reactor operators. The developments outlined below are just a few examples of the LCDI's achievements in this field over recent years:
- Improvement of the measurement potential of fission chambers thanks to better modelling tools and manufacturing processes for detectors, together with the implementation of innovative data acquisition and signal processing systems. These activities were acknowledged by the SFEN 2017 prize for technological innovation awarded to the LDCI for its development of the fast neutron detection system (FNDS). This instrumentation measures the fast neutron flux online in irradiation test reactors.
- Improvement of self-powered neutron detector (SPND) measurements, firstly by optimising the detector system and secondly by developing and validating a computer tool to simulate the current generation regardless of the type, geometry and irradiation conditions of the SPND.

FNDS FOR MEASURING THE FAST NEUTRON FLUX IN REAL TIME IN TECHNOLOGICAL IRRADIATION REACTORS - SFEN 2017 PRIZE FOR TECHNOLOGICAL INNOVATION

• This tool, called MATiSSe, is particularly suitable for optimising SPND design, but is also very useful for interpreting measurements. The model takes account of all free electron sources in the detector materials, and calculates their transfer and deposition in the various components of the SPND. Over the past few years, the LDCI has performed several experimental campaigns to validate the MATiSSe tool using rhodium, cobalt and silver SPNDs in the following research reactors: TRIGA Mark II at the Jožef Stefan Institute (JSI) in Slovenia, the CEA's OSIRIS reactor at Saclay and the MARIA reactor at the National Centre for Nuclear Research (NCBJ) in Poland.
• Optimisation of nuclear heating measurements through the improved design of a differential calorimeter that can measure the heating profile with an extremely high level of accuracy in the experimental locations of the JHR. This sensor - dubbed CARMEN-RJH - is an upgrade of the CALMOS calorimeter which was developed and implemented in the OSIRIS reactor.
• Manufacturing of specially designed detectors for performing measurements in experimental reactors, particularly fission chambers and miniature ionisation chambers.

Another highlight of 2017 was the fabrication of the first mixed fissile-fertile material deposits at the LDCI fission chamber manufacturing workshop which will be used in regenerative fission chambers. These regenerative fission chambers have the advantage of lasting much longer than conventional fission chambers.
The following non-exhaustive list gives an overview of some of the aspects under investigation in the ongoing instrumentation study programmes:
• Detection and characterisation of pellet-cladding interactions in PWR fuels
• Improved monitoring of the phenomena associated with stress corrosion
• Better handling of in-core temperature profiles, specifically through the use of distributed optical fibre measurements (Bragg lattices) or scattered measurements (Raman or Brillouin backscatter)
• Development of in-reactor telemetry and image reconstruction techniques, specifically for opaque zones in the reactor (areas containing sodium or lead-bismuth), using ultrasonic measurements
• Extension of the neutron flux and heating measurement range to cover the full power levels expected in the JHR; these studies have their own testing and validation requirements which call upon the use of high-performance reactors and high-level research.

TOP: PHOTO AND X-RAY OF FISSION CHAMBERS PRODUCED BY THE LDCI (EXTERNAL DIAMETER RANGING FROM 1.5 MM TO 8 MM); BOTTOM: VIEW OF THE FISSION CHAMBER FABRICATION WORKSHOP AT CADARACHE AND ITS X-RAY INSPECTION SYSTEM

The LDCI runs the fission chamber fabrication workshop at the CHICADE facility on the CEA Cadarache site. This workshop designs and manufactures special fission chambers with specific geometries and deposits.
The range of fission chambers has been extended over recent years with the introduction of new detectors offering improved performance to meet the experimental needs of the CEA and its partners. The range now includes, for instance, fission chambers with reduced inter-electrode gaps and double deposit fission chambers (DDFCs).

MASURCA REACTOR

MASURCA

PRESENTATION

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

This reactor, which went critical in December 1966, can contain cores of up to 6 m3. It is composed of square section tubes and can be individually loaded with different fuel blocks or plates, with absorbers and with coolants to represent any fast neutron or epithermal neutron lattice that needs to be studied. It can be used to study a virtually 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, CaH2, ZrH2, etc.).

This facility is very flexible in terms of loading and operation. For this reason, it can be used to validate innovative core solutions for gas-cooled fast reactors (GFR), high-temperature reactors (HTR), accelerator-driven systems (ADS), and now the new low void coefficient core (CFV) for the future ASTRID reactor.

The CEA decided to refurbish the MASURCA facility in January 2010 following discussions in 2009 on the role and importance of MASURCA in meeting the neutron physics requirements of 4th generation fast reactors. As well as overhauling the auxiliary systems and the I&C, this refurbishment also involves civil engineering work to consolidate the earthquake resistance of the facility, including the construction of a new nuclear material storage and handling building.

The refurbishment is funded through the French national loan scheme (known as the Grand Emprunt). It was made official in the French Government-CEA agreement dated 9 September 2010 and published in the Official Journal on 11 September 2010.

After refurbishment, the experiments are expected to resume around 2023 once the reactor has gone critical.

REVIEW OF 2017

Core studies and experiments

Preparation for the GENESIS programme continued throughout 2017. This experimental neutronics programme will support the qualification of the neutronic calculation tool used for the ASTRID design. This preparation included:

- New optimisation of the configuration designed to study neutron effects in the case of sodium voiding (simulated in MASURCA) by replacing the sodium components with empty components
- Preliminary calculations for the development of a programme phase focusing on the study of configurations with an MgO-based radial reflector
- Study focusing on the instrumentation of sub-assemblies containing fuel plates
- Elaboration of a document defining the basic principles of the experimental programme and including: the experimental requirements, the configurations proposed and their main characteristics, the actions

required to upgrade the test equipment, and a general overview of the programme and its schedule.

RNRNA project: Project to qualify the scientific calculation tools used for the ASTRID prototype
PRMSK project: Project to manage the refurbishment work in the MASURCA facility

Operation of the facility
The year 2017 was marked by:
Preparations for refurbishment:
- Preparation of operations to be carried out under the sub-assembly loading grid structure
- Re-commissioning of the automatic handling systems for fuel sub-assemblies
- Unloading of 290 shielding rods
- End of deformation measurements on the suspension plate within the scope of compliance assessments
- Acceptance of the clutches current generators with fast-response
- First tests on the sub-assembly handling grippers.

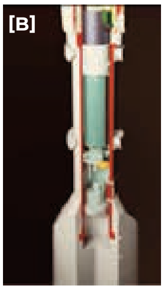
ICCF expertise (software for safety, instrumentation and control)
- Assessment of the equipment and architectures
- Analysis of the nuclear classification standards
- Participation in the group working on the RCCE rules.

MASURCA refurbishment project (PRMSK)
The year 2017 was marked by:
Works:
- Preparation of the asbestos-removal operations
- Short break in the construction of the new storage and handling building.

Documentation:
- Examination of the file concerning Article 31 of the decree concerning the nuclear installation (substantial modification of a licensed nuclear facility)
- Prefectural Decree authorising the CEA to move protected species from the area where the storage and handling building will be erected
- Continuation of the compliance assessments for safety-important equipment, in particular the safety rods.
- Validation of the deformation criterion governing the suspension plate in line with the compliance assessment.

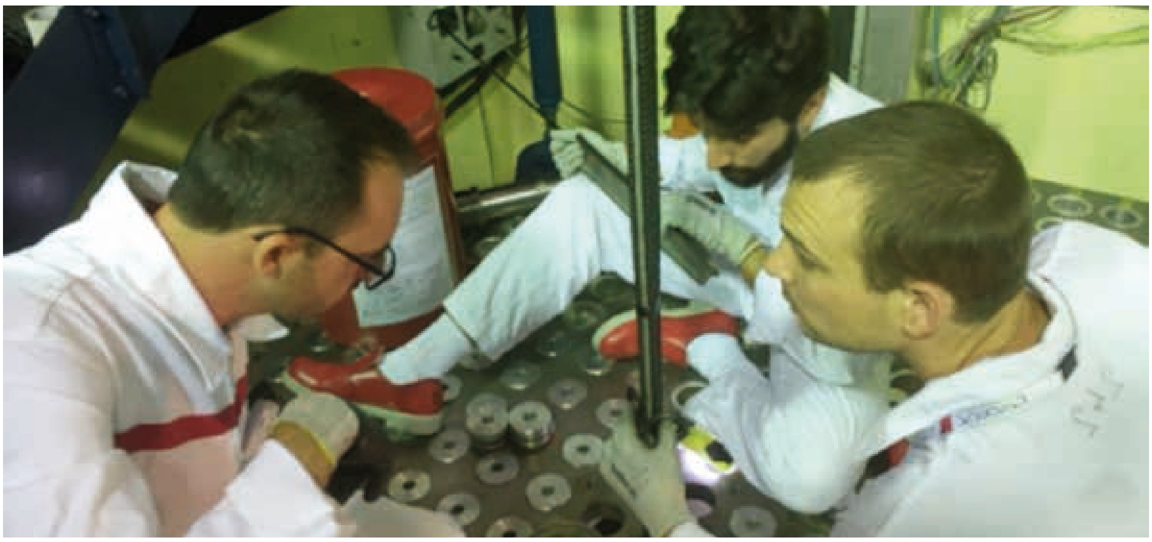
DEFORMATION MEASUREMENTS ON THE SUSPENSION PLATE

[A] [B] REFURBISHING OF SUB-ASSEMBLIES HANDLING SYSTEM

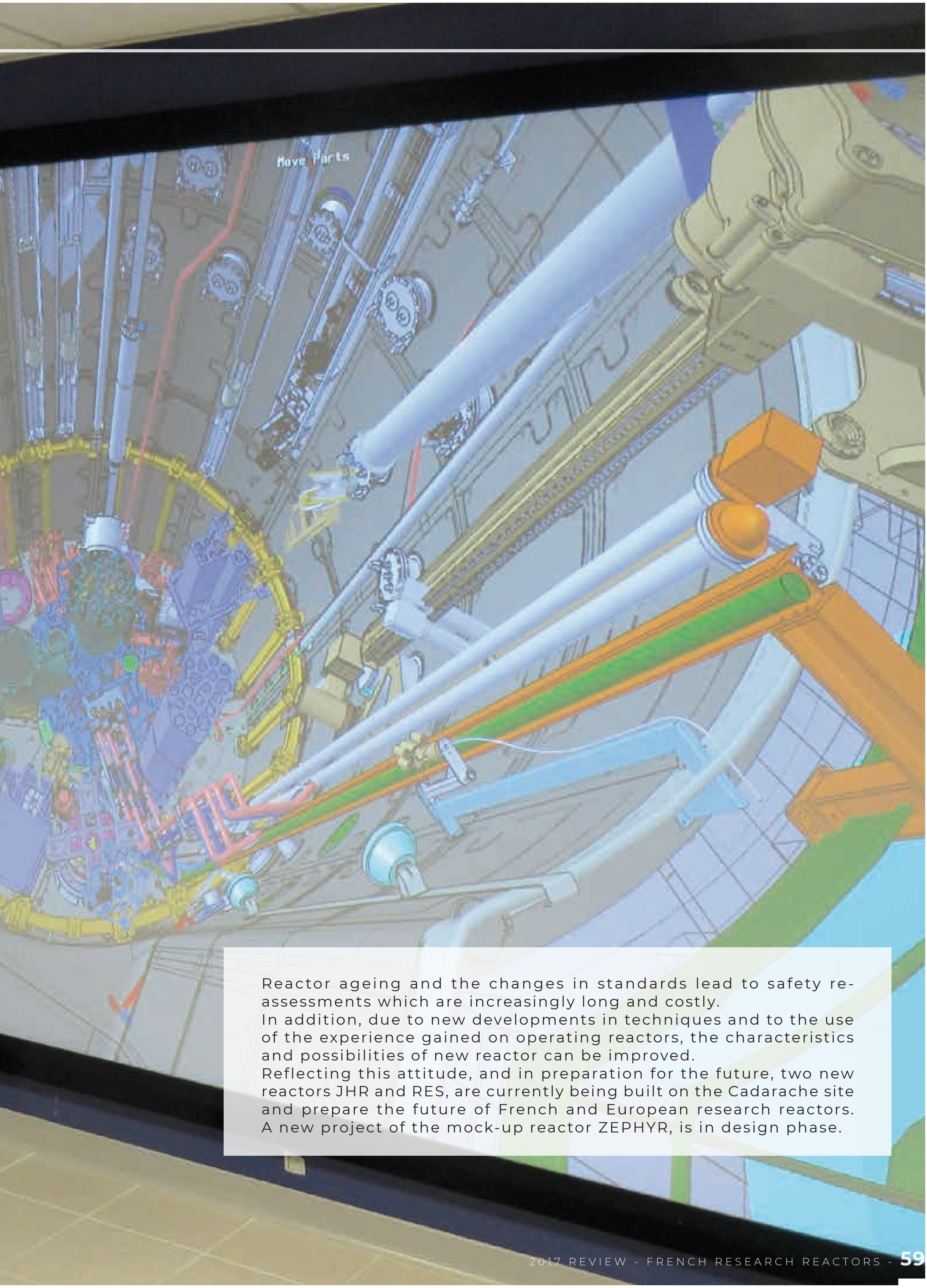


[C] TEST OF CLUTCH SWITCH AMPLIFIER

FONCTIONING TEST OF ASSEMBLIES HANDLING SYSTEM



06 New Research Reactors



Reactor ageing and the changes in standards lead to safety re-assessments which are increasingly long and costly.
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 JHR and RES, are currently being built on the Cadarache site and prepare the future of French and European research reactors.
A new project of the mock-up reactor ZEPHYR, is in design phase.

RES, GENERAL VIEW

Test facility contributing to the French nuclear deterrent

RES

PRESENTATION

The 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 facility contributes to France's overall strategy to maintain its nuclear deterrent.
The RES facility follows on from a series of land-based reactors that were used to qualify various on-board reactor concepts and technologies: the land-based nuclear unit (PAT) for the first nuclear-powered ballistic missile submarines (SNLE-M4), the advanced NSSS prototype (CAP) for nuclear attack submarines (SNA), the new generation reactor (RNG) for new generation ballistic missile submarines (SNLE-NG) and for the Charles de Gaulle aircraft carrier.
The RES is primarily used for R&D, with its main objectives being to qualify computer codes, new fuels and various current and future on-board nuclear steam supply systems.
This INBS-PN* comprises two modules: the pool module was integrated in late summer 2005 and the reactor module at the end of 2015.
The RES programme is managed by the Nuclear Propulsion Division (DPN) which is part of the Military Applications Directorate (DAM).
The prime contractor for the first phase of the project was AREVA TA, which now provides design and project support to the owner.
About a hundred local, regional and national contractors and suppliers have been involved in the construction of the facility.

** Secret licensed nuclear facility devoted 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.*

OBJECTIVES AND ISSUES

The main objectives of the RES are:

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

The challenge is therefore to ensure that the French Navy's nuclear propulsion vessels are readily available, thereby consolidating the credibility of France's nuclear deterrent strategy and perpetuating this mode of propulsion for the Navy.

The RES is an 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, as well as a gammametry test bench for the non-destructive characterisation of burn-ups.
Provisions have also been made throughout the design and construction phases to meet any training requirements in nuclear reactor operations, as well as to respond to increasing demands for support to the in-service fleet and the back-end of the cycle.

REVIEW OF 2017

Owing to the additional requests issued by the ASN regarding the authorisation to load the fuel into the reactor, loading of core R1 had to be postponed to after completion of maintenance operations on the Charles de Gaulle aircraft carrier. This is because this maintenance work calls on the same tools and skills used for the RES nuclear steam supply system (NSSS).

This delay in the RES schedule was put to use to perform additional inactive tests in a hot environment. The reactor block therefore had to be re-assembled and the I&C system was reconfigured in nominal mode with all its associated systems. These tests confirmed the performance levels reached during the first test phase while providing extra training for the operations teams.
At the end of 2017, a NSSS producing steam was connected to the machine island in order to re-commission equipment that had been mothballed since 2014. These tests enabled the operations teams to reacquaint themselves with this part of the facility which is particularly complex to operate, and to thus minimise the risk of contingencies between reactor divergence and operation at power.
Lastly, an onsite emergency response (PUI) drill was organised in November 2017 which triggered a specific emergency plan (PPI) due to a simulated accident in the RES reactor. This large-scale drill required the heavy involvement of the different emergency response units and operations teams at the RES.

STEAM SYSTEM COMISSIONING TEST

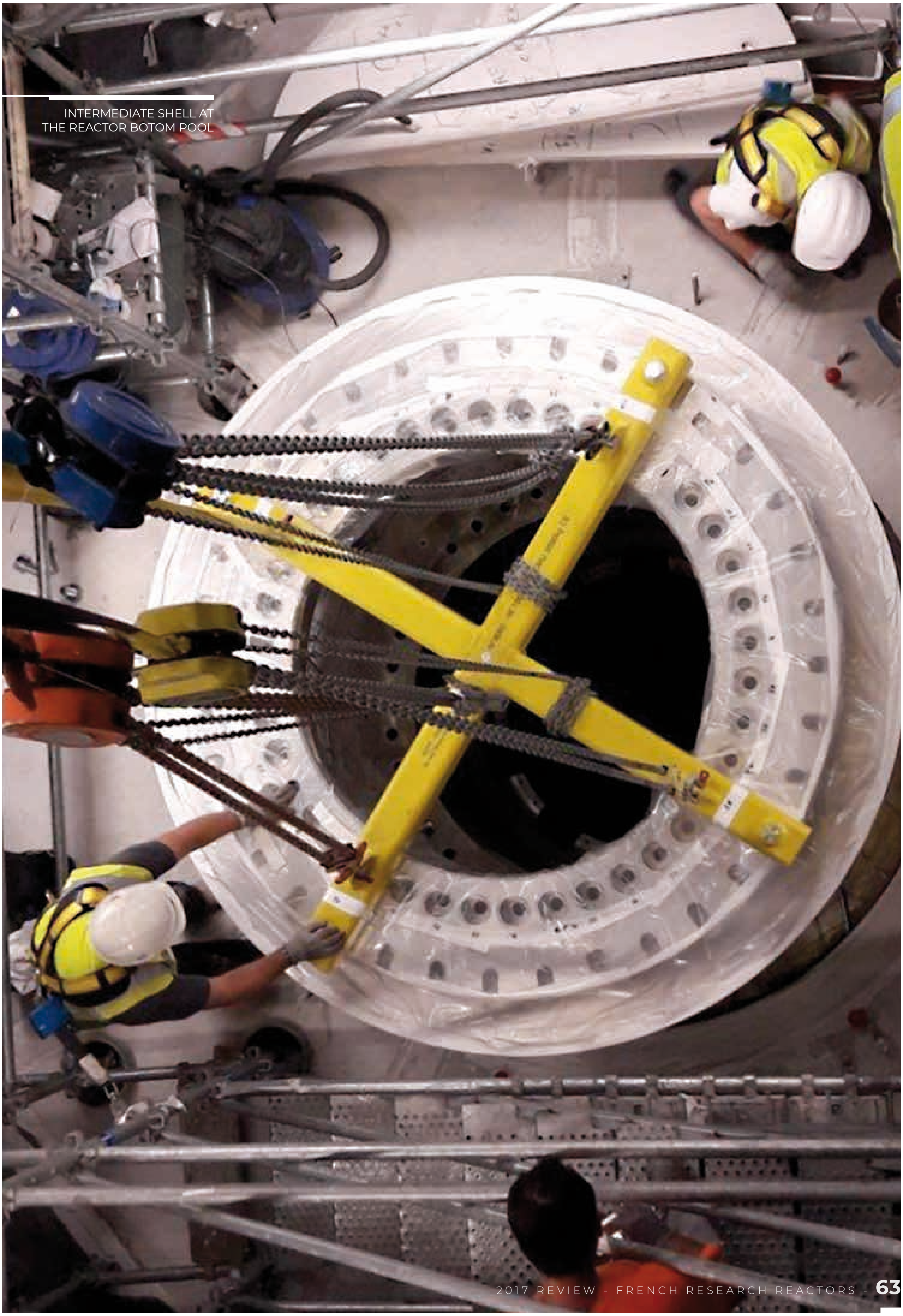
The Jules horowitz reactor

RJH

In an increasingly strained energy context, optimising operations and enhancing nuclear safety are two key issues in the nuclear industry today. Yet in Europe, the research reactors required for this type of study date back to the sixties. The availability of modern research tools to maintain a high level of expertise in France and in Europe is becoming a pressing matter in the field of nuclear energy. The Jules Horowitz research reactor (JHR) provides a solution to this scientific and technological issue.
Three generations of reactors will exist side by side in the 21th century: today's fleet of reactors, the 3rd generation of reactors currently being developed, and the 4th generation of reactors to be deployed by 2040.
Developing reactors for the future entails the development of innovative new materials and fuels capable of withstanding extreme loads. To guarantee the performance and safety of these concepts, experiments must be carried out in research reactors so we can select the most promising solutions and test their behaviour limits.
The JHR is expected to meet our experimental needs for the next 50 years in terms of new materials and nuclear fuel for the nuclear industry. 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 current and future reactors. Powerful, versatile and modular, the JHR is designed to perform about 20 experiments at the same time. It will have a 'double-peak neutron spectrum' capable of producing intense neutron fluxes, both in the thermal range (applications for research on current conventional reactors) and in the fast range (applications for Generation IV fast reactors).
The JHR is located in the Vallée des Piles (reactor valley) at the CEA Cadarache Centre and thus benefits from the support of other experimental facilities onsite. Most of the samples to be placed in the Jules Horowitz reactor core will be prepared and analysed

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: > $5*10^{14}$ n.cm^{-2}.s^{-1}
- Maximum fast flux: $5.5*10^{14}$ n.cm^{-2}.s^{-1}
- Fuel: U3Si2 for the core at start-up and then UMO



INTERMEDIATE SHELL AT
THE REACTOR BOTOM POOL

in the CEA Cadarache fuel study laboratories, including the Active Fuel Examination Laboratory (LECA).

The JHR will also be one of the main producers of radioisotopes for medical purposes and will meet 25% to 50% of Europe's requirements in this field.

REVIEW OF 2017

The following operations were carried out on the JHR site in 2017:

- Further construction work on the reactor pool and the auxiliary buildings (painting of rooms, installation of frameworks in the pools and channels, installation of leaktight liners in the pools, installation of the pool feed-throughs and assembly of the hot cells, etc.).
- Further studies for various work packages: electromechanical, ventilation, back-up systems, fluid systems, reactor block (reflector) and I&C
- Assembly of cranes in the nuclear auxiliary buildings (BUA) and their first tests
- Further testing of the primary pumps and control rods
- Provisional operation of the tertiary cooling system for the JHR
- Provisional commissioning of the electric substation (IRE)
- Provisional operation of the polar bridge in the reactor building
- Completion of the last factory weld on the reactor block
- Continued fabrication of bridge decks for the loading machine.

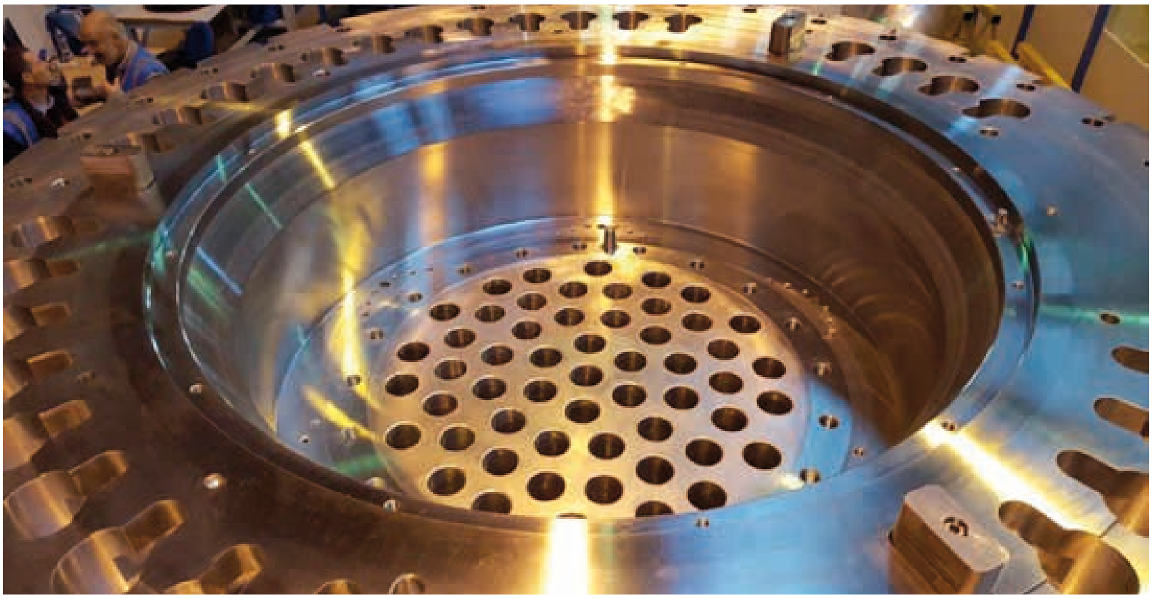
In terms of operation and experimentation, several key actions marked 2017:

- End of preparatory work to develop a complete training programme for the operating teams, which involved identifying the necessary skills by listing the activities to be carried out. Training courses in operator techniques and specific professions were also provided for new recruits
- Further work on drafting the operating documents (7500 documents will be made available upon JHR start-up).
- Start of fuel manufacturing for the JHR start-up core
- Use of the reactor operation simulator to validate the rules applicable to normal and accident conditions and to train future operators in such matters.
- Preparation of the commissioning files, which include the general operating rules (RGE) and the safety report (RS). Within this context, the onsite emergency response plan (PUI) at Cadarache was updated to integrate new JHR data in late 2017
- Preparation and implementation of maintenance operations and of periodic inspections & tests for equipment delivered for provisional operation
- Involvement of the future operator in the various technical groups (with the prime contractor/ designer and the CEA/ project owner) and in end-of-design reviews of JHR equipment in order to check operability and maintainability (tools, loading station, support structure at the bottom of the pool, reflector).

The year 2017 was also marked by several design reviews, highlighting the progress made by the CEA regarding the equipment to be installed in the core compartment and the reflector: the PROSPERI and PROSPERO devices for the irradiation of samples to monitor the in situ

SETTING UP A REACTOR POOL PENETRATION PIPE

JHR INTERNAL CORE RACK



MOCK-UP OF A JHR FUEL ELEMENT

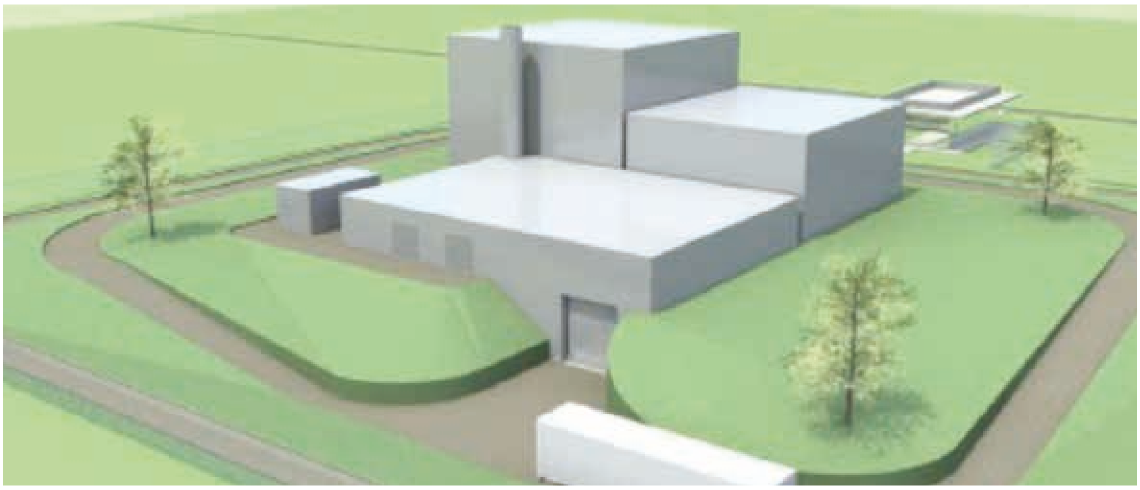
ageing of the core compartment, the vessel and the reflector during operation, as well as the DEM start-up test devices designed to check the nuclear safety characteristics and experimental performance levels during start-up.

The CEA has already specified the experimental devices that must be operational when the reactor is commissioned. In this context, the ADELINE experimental loop that will be used to study power transients is currently under construction. Device-by-device reviews are taking place to track the progress of the different design and construction phases, e.g. the MICA device to study the behaviour of materials under irradiation, the MADISON loop for fuel qualification under normal operating conditions, and the MOLFI device for the production of Mo99, etc.). The experimental devices, some of which are being designed by members of the consortium, also periodically undergo progress reviews (LORELEI boiler for loss-of-coolant accident studies, CLOE corrosion loop, etc.).

International collaborations were actively pursued in 2017, either through staff secondments to the JHR facility or through device design activities. By way of example, the MADISON and CLOE loops were the subject of numerous meetings with JHR partners throughout the year. The various working groups - composed of JHR consortium members - continued their unstinting efforts in defining the experimental requirements for fuels and/or materials, with their progress reported during the JHR seminar organised in May 2017.

Lastly, to support the safety baseline developed in the JHR commissioning file and the development of future experiments, several neutronic and thermohydraulic studies were carried out to further refine i) the safety studies of the reactor, ii) the design of the experimental devices, or iii) the irradiation performance of these devices in the JHR core.

FUNCTIONAL SKETCH OF ZEPHYR IN AN OPEN FIELD



ZEPHYR EXPERIMENTAL REACTOR

ZEPHYR

REVIEW OF PROJECT OBJECTIVES

The aim of this project is to complete the ZEPHYR (Zero power Experimental PHYsics Reactor) critical mock-up facility at the CEA Cadarache research centre by the year 2028. This new mock-up, the name of which was inspired by mythology just like its predecessors ÉOLE and MINERVE, will replace these two research reactors, while expanding on their experimental capabilities.
ZEPHYR is designed to meet 3 key requirements:

- Greater adaptability to different reactor configurations, thus providing the capability to explore nuclear data in the field of fast neutrons via coupled cores
- Improved efficiency in terms of use and availability to significantly reduce implementation times for experiments
- Innovations to expand the areas of investigation in experimental physics (high-temperature Doppler, irradiated materials in a high-power reactor, etc.)

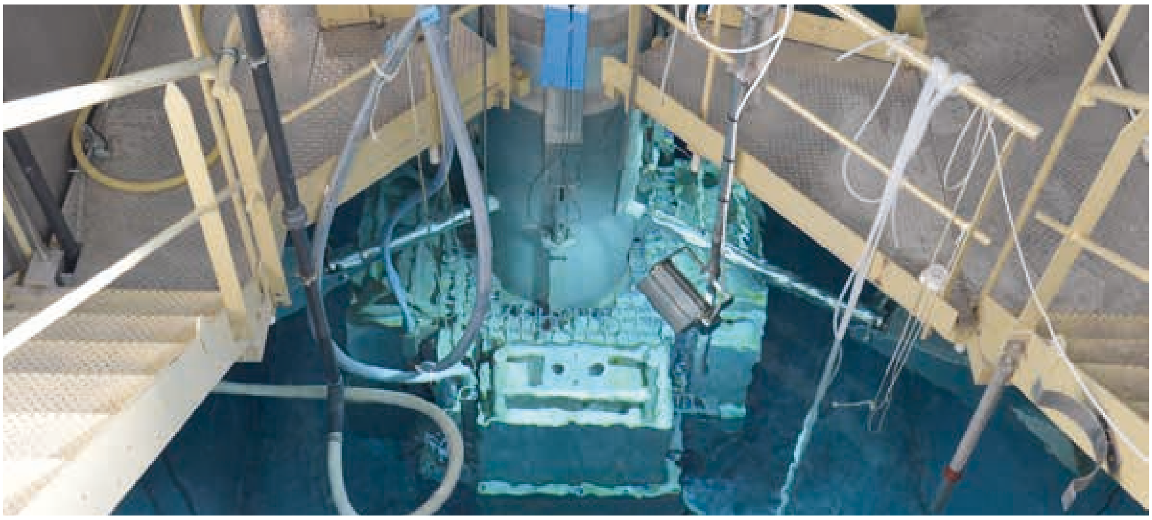
Key Zephyr Characteristics

- Maximum nominal power: 3 kW
- Pool-type reactor with interchangeable or multiple vessels
- 2 possible configurations (solid samples or sample oscillation)
- Possibility of multi-zone core in terms of temperature and boron conditions
- Possibility of oscillating irradiated samples (PWR 120 GWd/t and SFR 150 GWd/t)
- Possibility of a fast spectrum during oscillation (thermal-fast coupled core)
- Heating of samples from -200°C to 1500°C
- Future possibility of a PWR loop in an oscillation configuration
- Possibility of solid Na environment (Masurca or NaK)

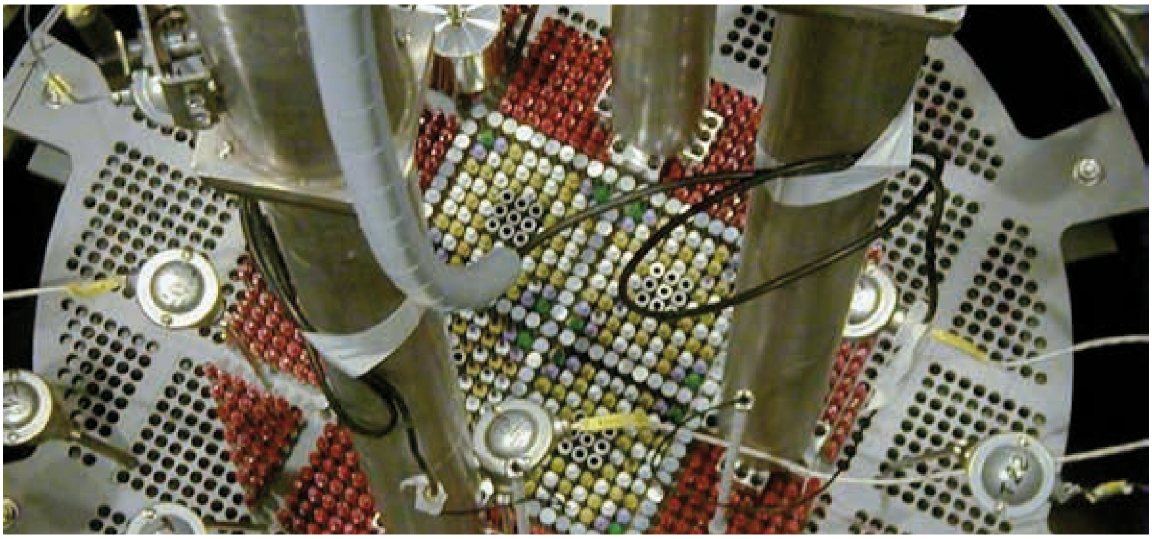
PROJECT STATUS

The year 2017 was devoted to finding French and foreign partners whose participation is a prerequisite to launching the project. To do this, the CEA hosted a number scientific seminars and meetings to organise future international collaborations.
A conference organised in January 2017 brought the CEA, EDF and Framatome together to discuss the industry's needs in the field of computer code qualifications for reactor physics. These discussions confirmed the fact that the functionalities offered by ZEPHYR do indeed reflect the industrial needs of our partners.
A new meeting was scheduled for early 2018 to discuss i) progress in instrumentation, ii) methods for reducing uncertainties, and iii) possible kinetic experiments in the ZEPHYR facility.
Scientists from the British National Nuclear

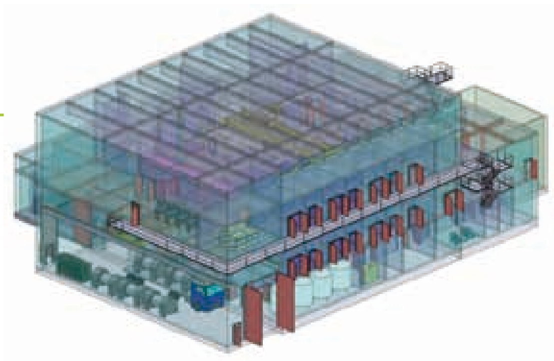
MINERVE, VIEW
OF THE CORE



ÉOLE, VIEW OF
THE CORE



3D VIEW OF ZEPHYR
(SOURCE CEA)



Laboratory (NNL) were also given a presentation on the ZEPHYR facility in January 2017.
This was followed by a scientific seminar between the CEA and IRSN in May 2017. The purpose of this meeting was to present the analysis that led the CEA to develop the ZEPHYR project and to discuss IRSN's needs in nuclear data, neutronic computer code qualifications, and criticality studies. It became apparent that studies on criticality in liquid phases were necessary; the CEA has agreed to examine the possibility of incorporating this need into the ZEPHYR programme.
A technical meeting organised by the SFEN on the contribution of the ÉOLE and MINERVE reactors was held in November 2017; the stakeholders took this opportunity to discuss the scientific prospects for the next 10 years and the research needs that ZEPHYR should be able to meet.
Lastly, discussions were continued on the most appropriate industrial configuration capable of guaranteeing a successful outcome for this project. In light of the strict budget restrictions for 2018 coupled with limited external funding, a functional analysis with a target-cost objective will be carried out to refocus the scientific objectives of ZEPHYR on analytical experiments based on nuclear databases.

2017
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