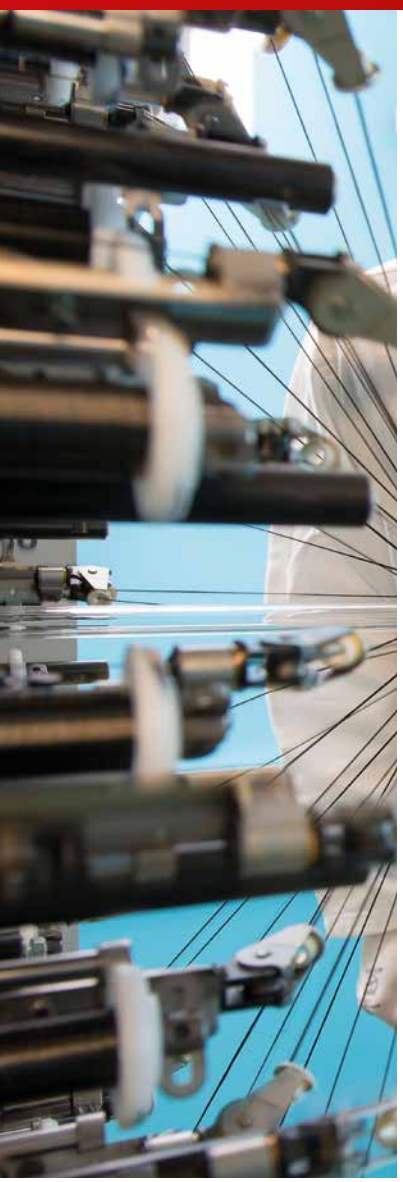
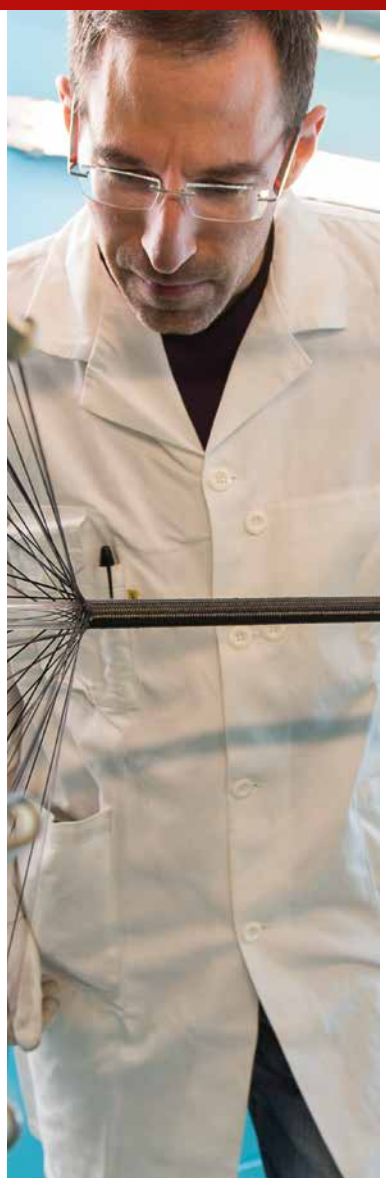
FROM RESEARCH TO INDUSTRY

cea den





NUCLEAR ENERGY DIVISION

Activity Report

2014

PROFILE

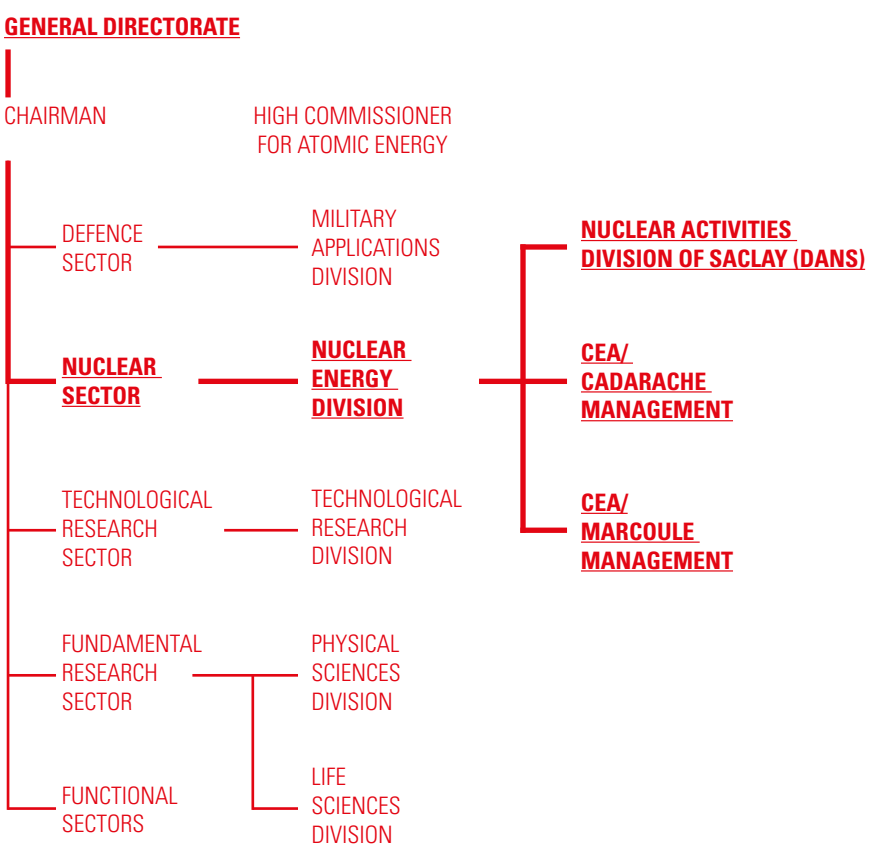
Within the CEA, the Nuclear Energy Division (DEN) provides the French government and industry with technical expertise and innovation in nuclear power generation systems to develop sustainable nuclear energy that is both safe and economically competitive.

To meet these objectives, the DEN is engaged in three main areas of investigation:

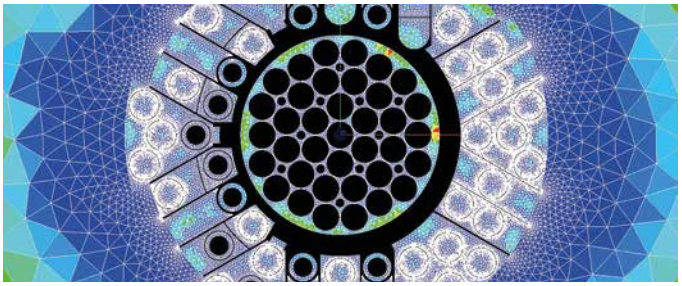
- Developing nuclear systems of the future - dubbed "4th generation" reactors - and their fuel cycles;
- Optimising the current nuclear industry;
- Developing and operating large experimentation and simulation tools needed for its research programmes.

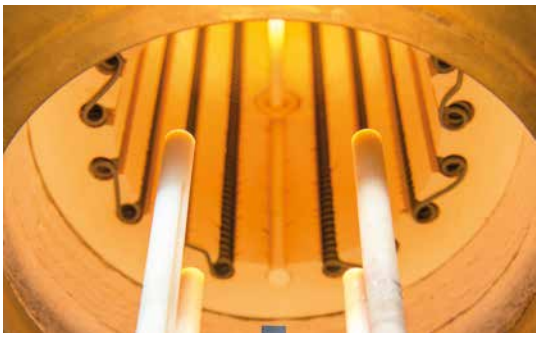
As nuclear operator, the DEN also has to manage and upgrade its own fleet of nuclear facilities. It carries out numerous construction and refurbishment programmes on its facilities, together with clean-up and dismantling programmes for those that have reached the end of their service life.

ORGANIZATIONAL CHART



CONTENTS





MESSAGE FROM CHRISTOPHE BÉHAR

CEA DIRECTOR OF NUCLEAR ENERGY

Controlling our energy supply is not only a vital need and a factor of growth, but also a major issue for tomorrow's world. In this respect, the nuclear industry has a number of solid advantages even if it must guarantee technical and economic control over issues of safety, resource sustainability and accountable waste management, which all call for the pursuit of innovation in technology. This innovation is the backbone that defines the Nuclear Energy Division's core mission. Within the CEA, the Nuclear Energy Division (DEN) provides the French government and industry with technical expertise and innovation in nuclear power generation systems to develop sustainable nuclear energy that is both safe and economically competitive.

Some figures speak for themselves: in 2030, the global energy consumption is expected to have increased by 50% compared with that of 2005 owing to the combined effect of the population rise and growth in emerging countries. There are a number of constraints that must be factored in with respect to this demand, such as the fight against global warming, the depletion of energy resources, the security of energy supplies, the control over energy costs, and the attainment of a favourable balance of trade.

The 5th report from the Intergovernmental Panel on Climate Change (IPCC) published last year is unequivocal: global warming is indisputable and without precedent (the past three decades have been the hottest for at least 1,400 years), and the impact of human activity is clearly established. Acting now to keep the temperature rise to less than 2°C is vital. This issue will be central to discussions at the 21st international conference of climate change to be held in France at the end of the year. In practical terms, the fight against global warming means reducing our use of fossil fuels and increasing the fraction of electricity in the energy mix. Within this context, nuclear energy has a vital role to play in synergy with renewable energies since they represent the only green method of electricity generation available today.

In France, the draft bill on the energy transition and green growth put forward by the French government was adopted in its revised version by the *Assemblée Nationale* on 26 May 2015. This act is founded on enhancing our energy efficiency and implementing a low carbon energy mix in which nuclear energy and renewable energy play a complementary role: large baseload units for nuclear power generation and small decentralised units operating intermittently for renewable energy. Though their synergy is a significant advantage to improve the future energy mix, innovation is an absolute necessity if we wish to keep this advantage in the long term.

"NUCLEAR ENERGY HAS AN ESSENTIAL ROLE TO PLAY IN SYNERGY WITH RENEWABLE ENERGY. THESE TWO SOURCES OF ENERGY ARE THE ONLY ONES THAT GENERATE GREENHOUSE- GAS-FREE ELECTRICITY."

The most significant results obtained by the DEN in 2014 are detailed throughout this activity report. This is why I will only mention a few in this foreword because I want to stress what they mean to me: they are key links to building sustainable nuclear energy, making it both safer and more competitive; they are the fruit of top-quality work from the men and women devoted to giving their best at the DEN on a daily basis.

In the field of future nuclear systems, I would like to draw attention to the efforts made to consolidate and finalise the choice of options for the Astrid technological demonstrator within the scope of the conceptual design phase (AVP2) which will continue through to late 2015. I am particularly referring to the design work on the sodium-gas power conversion system (PCS) and core qualification. I am pleased that the French nuclear safety Authority (ASN) considers the safety orientations for the Astrid project "have satisfactorily taken into account operating experience from sodium-cooled fast reactors throughout the world and the conclusions of safety reviews for this type of reactor in France" as stated in its follow-up letter in April. Concerning the future fuel cycle, the year was marked by the continuation of studies led by the DEN in association with EDF and AREVA on industrial scenarios for integrating fast reactors into the French fleet. These studies are focusing on the industrial transition between the current fleet which allows for the once-through recycling of plutonium in water reactors, to a fleet able to recycle plutonium multiple times, which is a considerable gain in terms of sustainable material management.

As for supporting the current nuclear industry, we clocked up great results in terms of increasing the operating life of reactors and their fuels while enhancing nuclear safety, with significant progress made in chromium-coated fuel cladding which led to a CEA patent. Other results highlight support focusing on the needs of fuel cycle plants, with help provided to adapt the industrial processes currently used at La Hague.

Our research programmes could not be conducted without the large experimental tools and simulation devices that we both develop and operate. Activities continued throughout the year on the site of the Jules Horowitz Reactor (JHR) which is under construction at the Cadarache centre. The detailed design and qualification studies for the large components of the reactor block have been validated by the technical review committee, thus giving the green light for their fabrication from 2015.

The smooth operation of our research programmes also relies on our activities as nuclear operator. Great progress has been made with our clean-up and dismantling projects in our nuclear facilities that have been shut down such as at Fontenay-aux-Roses and Marcoule. I am also pleased with the favourable opinion issued with "no reservations" by the public enquiry commission for two public enquiries respectively pertaining to the request for authorisation to build the waste interim storage facility called Diadem and the final shutdown of the Phénix reactor.

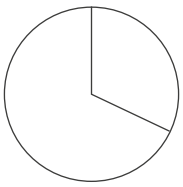
I would like to finish with a word about our efforts to promote our resources and expertise. Two major projects were instigated in 2014. Firstly, our expertise was confirmed in the field of fuel cycle chemistry with the signing of a partnership agreement last July, which led to the inauguration of the European Hydrometallurgical Institute (EHI). Secondly, the cluster for the promotion of industrial sites (PVSI) was launched to drive the development of innovative technologies, their standardisation and their industrialisation. These two initiatives will continue to be deployed and fine-tuned in 2015 to enhance their visibility at the entrance of the Marcoule centre.

I leave this report in your hands to discover the rest of our key actions from 2014 in greater detail, which reflect our main missions and strategy.

KEY FIGURES

4,290 EMPLOYEES

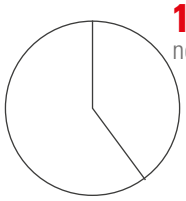
including…



1,346 women

2,944 men

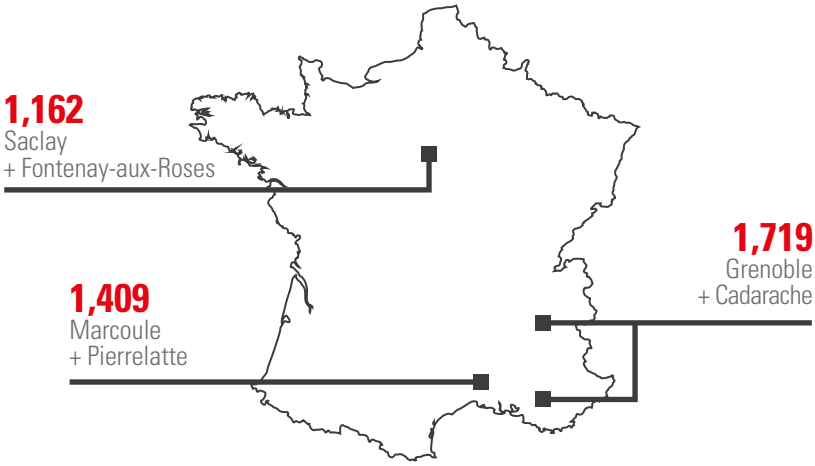
including…



1,789 non-executives

2,501 executives

spread over 5 centres



153
NEW HIRES

242
DOCTORAL CANDIDATES
INCLUDING 135 FUNDED BY THE DEN

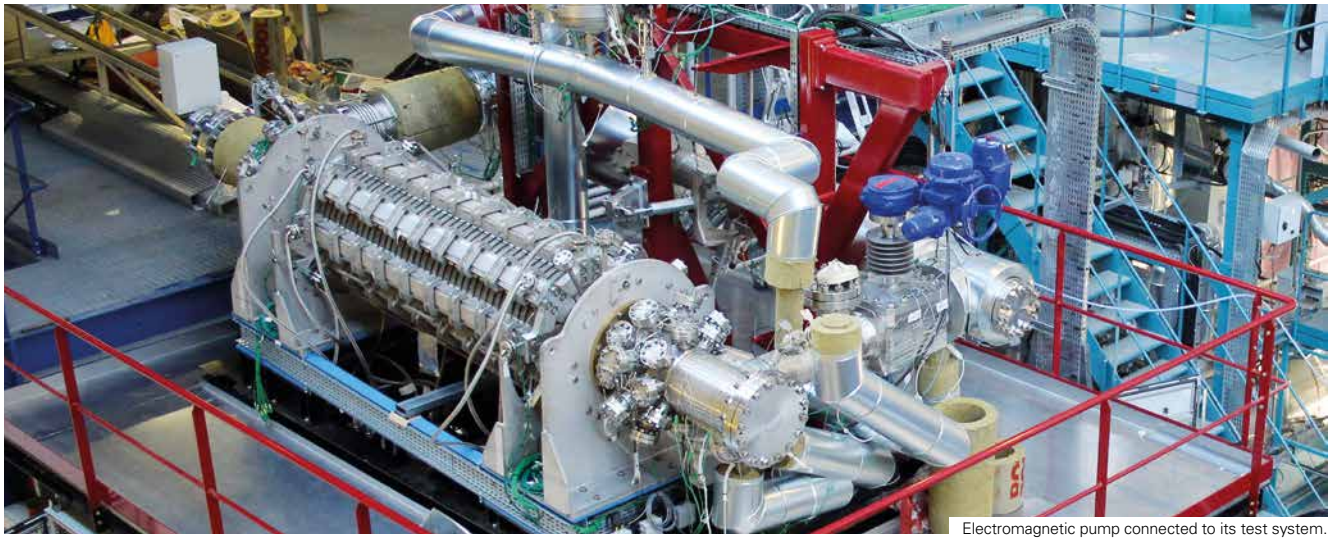
40
POST-DOCTORAL RESEARCHERS

475
PUBLICATIONS

58
PATENTS FILED

FUTURE INDUSTRIAL NUCLEAR SYSTEMS

The Nuclear Energy Division (DEN) is currently working on the 4th generation of fast reactor systems for the future. Their development is needed to better meet requirements with respect to secure energy supplies and energy independence. These systems can optimise the material management process thanks to the possibility of better exploiting uranium resources, while enabling the multiple recycling of plutonium and minimising radwaste production. The options for the related future fuel cycle are also being investigated in coherence with studies led by the DEN on the Astrid project - an integrated technology demonstrator for the 4th generation of sodium-cooled fast reactors - for which the CEA is the project owner. This project is currently in its conceptual design phase.



Electromagnetic pump connected to its test system.

4TH GENERATION REACTORS

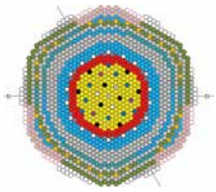
IN FRANCE, THE CEA IS RESPONSIBLE FOR LEADING RESEARCH ON INNOVATIVE NUCLEAR SYSTEMS DUBBED THE 4TH GENERATION WITH BUILT-IN TECHNOLOGICAL BREAKTHROUGHS COMPARED WITH THE PREVIOUS REACTOR GENERATIONS. RESEARCH IS FOCUSING ON TWO FAST REACTOR TECHNOLOGIES: FIRST AND FOREMOST ON THE SODIUM-COOLED FAST REACTOR (SFR) THROUGH THE ASTRID TECHNOLOGY DEMONSTRATOR FOR WHICH THE CEA IS THE PROJECT OWNER, AND ON THE GAS-COOLED TECHNOLOGY TO A LESSER EXTENT WHICH APPEARS TO BE A LONGER-TERM OPTION. THE YEAR 2014 WAS MARKED BY A NUMBER OF IMPORTANT STEPS FORWARD.

TECHNOLOGICAL INNOVATIONS FOR THE ASTRID INTEGRATED TECHNOLOGY DEMONSTRATOR

The conceptual design phase (AVP2) of the Astrid project covers the 2013-2015 period and aims at both consolidating and finalising the design options chosen for the technology demonstrator. Within this scope, technology innovations were pursued throughout 2014. They included:

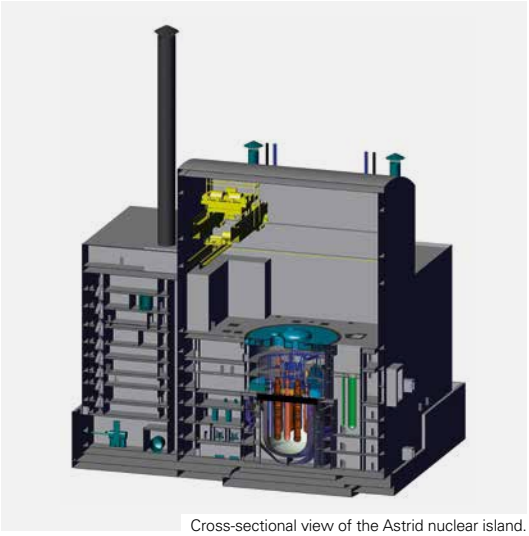
■ Progress made on the sodium-gas power conversion system designed to eliminate any sodium-water reactions *de facto*. The baseline concept under investigation is centred on a compact sodium-gas Plate-Machined (PMHE) or Printed-Circuit Heat Exchanger (PCHE), assembled by diffusion welding using hot isostatic pressing. Two alternatives were explored at the same time in 2014 by the CEA and Rolls-Royce. In 2014, the first tests on a 40 kW heat exchanger mock-up were also carried out in the Diademo facility at Cadarache. These tests validated the heat exchange models used to support the design. The options for the sodium-gas heat exchanger will be chosen in November 2015 at the end of the conceptual design phase (AVP2).

■ Qualification studies for the CFV core concept based on a low sodium void coefficient which continued throughout the year. This concept harnesses the core's natural behaviour in case of loss of coolant, making it inherently safer. This is a major safety improvement and represents one of the features that differentiates the Astrid design from those of previous sodium-cooled fast reactors. The 2014 version of this core (called CFV V3) with AIM1 steel cladding takes into account the impact of recommendations regarding safety and neutronic objectives (best-estimate negative void coefficient, activation of secondary sodium < 10 Bq/cm^3), by complying with the performance levels stated in the Astrid specifications. Furthermore, this version includes a number of complementary safety measures currently being considered for the prevention (hydraulic rods and rods that trigger at the Curie point) and mitigation (devices penetrating the core support system to allow corium to flow into the catcher) of severe accidents. Optimisation of this version of the core will continue up to the end of the basic design.

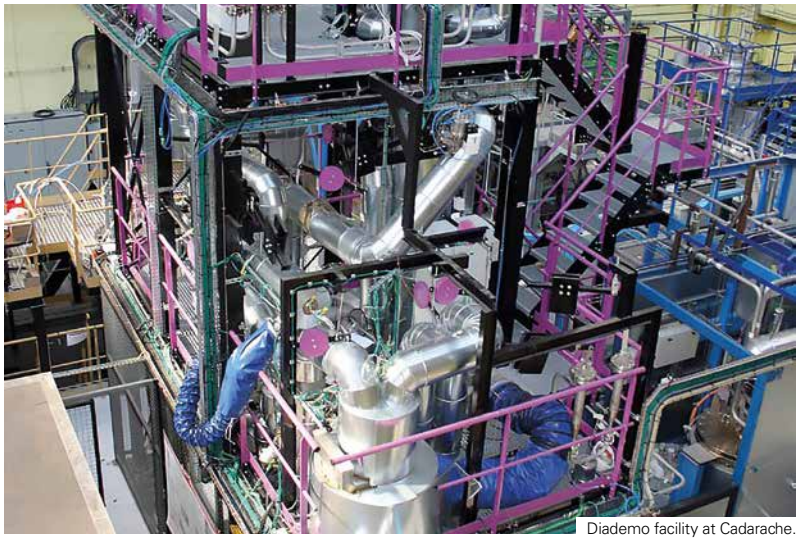


Version 3 of the Astrid CFV core.

■ Development of the dynamic electromagnetic pump called PEMDYN. The Astrid project has chosen to use electromagnetic (EM) pumps for the circulation of sodium in the secondary systems. To support the design of these EM pumps, numerical magneto-hydrodynamic models have been developed to represent the physical phenomena occurring with this type of pump (in a yet unexplored flow range). In 2014, the DEN designed a one-of-a-kind sodium test loop in Europe to validate these models. It is called PEMDYN and its main component is its electromagnetic pump. It is 5 m long, weighs 7.5 tonnes and provides a maximum sodium flow rate of 1,500 m^3/h (¼ scale of the Astrid pumps), which is a European record. The pump is now connected to the test circuit, with the first results expected to be collected in 2015.



Cross-sectional view of the Astrid nuclear island.



Diademo facility at Cadarache.

DISCUSSIONS WITH THE FRENCH NUCLEAR SAFETY AUTHORITY (ASN)

Two important conclusions were reached for the 4th generation of sodium-cooled fast reactors (SFR) and the Astrid project in 2014.

- On 10 April 2014, the 'nuclear reactors' standing group confirmed that *"among the different nuclear systems investigated by the Generation IV International Forum (GIF), only the SFR technology was currently mature enough to consider building a 4th generation industrial prototype in the first half of the 21st century ."*
- In its follow-up letter dated 17 April 2014, the ASN stated that the safety orientations for the Astrid project *"have satisfactorily taken into account operating experience from sodium-cooled fast reactors throughout the world and the conclusions of safety reviews for this type of reactor in France."*

This letter summarises the recommendations issued in June 2013 by this standing group following the Astrid safety orientations review (DOrS) that the CEA sent to the ASN in June 2012. The Astrid project team will continue to transpose these safety orientations into design so as to draw up a safety options file (DOS) for which the first consolidated version is expected in late 2015.

ASTRID PROJECT PARTNERSHIP

The Astrid project is based on a rationale of partnership agreements. The scope of collaboration was extended in 2014 with the signature of three new agreements.

Signing of a cooperation agreement with NNL

In April 2014, the DEN and the British National Nuclear Laboratory (NNL) signed a cooperation agreement to cover technological R&D and related fuel cycle issues. This agreement falls within the scope of the Memorandum of Understanding (MoU) signed by the two countries in February 2012 and supplements all of the collaboration agreements for the Astrid project.

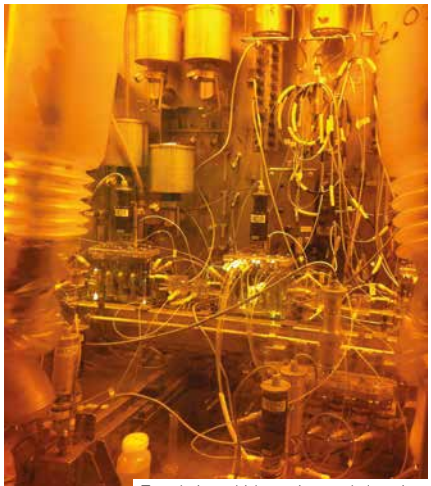
Signing of a cooperation agreement between France and Japan

A cooperation agreement was signed by France and Japan in May 2014 which defines Japan's support on the Astrid design studies and related R&D work. This agreement was signed with the Japanese Prime Minister Shinzo Abe and the French President François Hollande in attendance. It defines the general scope of collaboration on the Astrid project between the two countries and covers all the design phases up to the end of the basic design scheduled for late 2019. This agreement was followed by an implementing agreement signed by the CEA and the Japan Atomic Energy Agency (JAEA), AREVA NP, Mitsubishi Heavy Industries (MHI) and its subsidary called Mitsubishi Fast Breeder Reactor (MFBR), defining the technical aspects of the partnership. This agreement contains a section on the Astrid design (active decay heat removal system, electromagnets for some absorber rods and the reactor's aseismic pads), as well as a section on the different R&D subjects (from support in qualifying the Astrid fuel and thermohydraulic tools, to demonstrating the performance of core materials and reactor structures, developing innovative instruments, jointly developing a new tool to simulate the core degradation phases specific to the CFV core concept in the field of severe accident studies, and helping to qualify mitigation measures). This agreement allows the Astrid project to take advantage of the experimental facilities available in Japan.

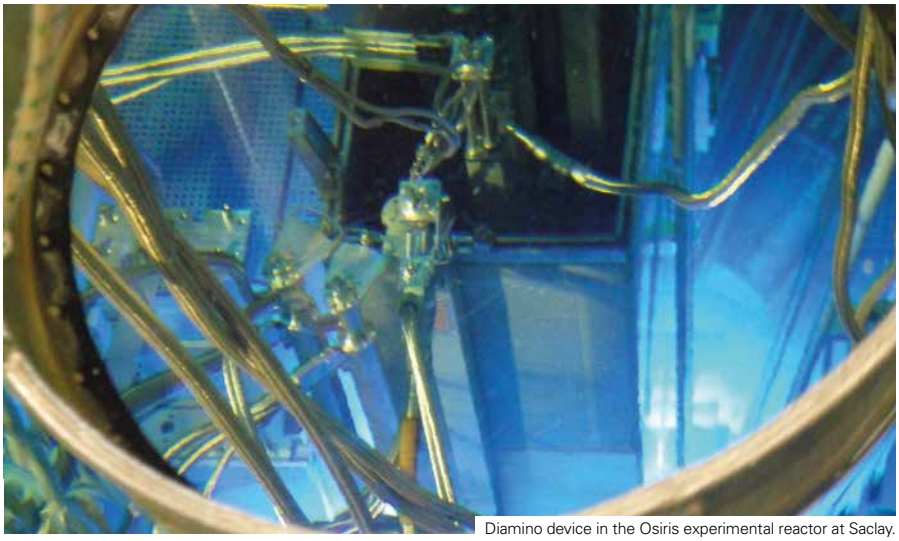
IN MAY 2014, A COOPERATION AGREEMENT WAS SIGNED BY FRANCE AND JAPAN WHICH DEFINES JAPAN'S SUPPORT ON THE ASTRID DESIGN STUDIES AND RELATED R&D WORK.

Signing of a partnership with Velan

The agreement signed in September with Velan - a company specialised in nuclear valves - covers the design and development of sodium isolation valves on the reactor's secondary loop.



Test during which uranium and plutonium are separated from a real spent fuel load in the Atalante laboratory at Marcoule.



Diamino device in the Osiris experimental reactor at Saclay.

BACK-END OF THE FUTURE FUEL CYCLE

IN CONSISTENCY WITH THE ASTRID DESIGN STUDIES, THE DEN IS CONDUCTING RESEARCH ON THE FUTURE FUEL CYCLE. THESE STUDIES AIM TO PREPARE ALL OF THE OPTIONS RELATED TO THE MANAGEMENT OF NUCLEAR MATERIALS FOR THE FAST REACTOR FLEET BY DEVELOPING THE ADVANCED PROCESSES NEEDED FOR THE MULTIPLE RECYCLING OF PLUTONIUM. IN LINE WITH THE EXPECTATIONS OF THE ACT DATED 28 JUNE 2006 ON THE SUSTAINABLE MANAGEMENT OF RADIOACTIVE MATERIALS AND WASTE, THE DEN ALSO ASSESSES OPTIONS FOR THE SEPARATION AND TRANSMUTATION OF LONG-LIVED RADIOELEMENTS.

ADVANCED FUEL CYCLE DEPLOYMENT SCENARIOS

In 2014, the DEN and its partners - EDF and AREVA - continued their collaboration on research into industrial scenarios integrating fast reactors into the French fleet by focusing on the uranium-plutonium fuel cycle, and on the industrial transition from the current fleet which enables the once-through recycling of plutonium in water reactors, to a fleet comprising fast reactors opening the way to the multiple recycling of plutonium. A specific organisation has been set in place to successfully complete this work. A steering committee orients and organises the studies with the help of two standing groups: one is responsible for recommending and elaborating the scenarios, while the other validates the assumptions and results against the industrial reality. In these scenarios, fast reactors are progressively integrated via four successive stages, each characterised by a specific technical objective of increasing ambition.

STUDIES ON PLUTONIUM MULTIPLE RECYCLING

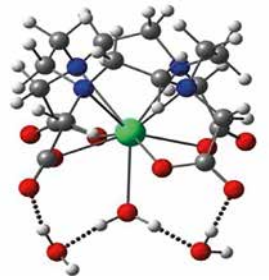
Spent fuel treatment techniques currently used on an industrial scale have proven their remarkable level of technical performance. Nonetheless, further improvements remain feasible in the future, especially in making such techniques more compact (by simplifying unit operations or by enhancing their integration into the process) and safer, while generating even less waste and effluents. One of the main research programmes in this field involves the development of a drastically simple process that recovers and purifies uranium and plutonium without any oxidation-reduction operations. Significant progress has been made in the design of new extraction molecules, which made it possible to conduct a first very promising test on real samples of spent fuels in 2014. This process has considerable relevance within the scope of plutonium multiple recycling in a fleet that includes fast reactors and that requires treating PWR and fast reactor MOX fuels characterised by higher plutonium contents and isotopic properties different to current spent fuels.

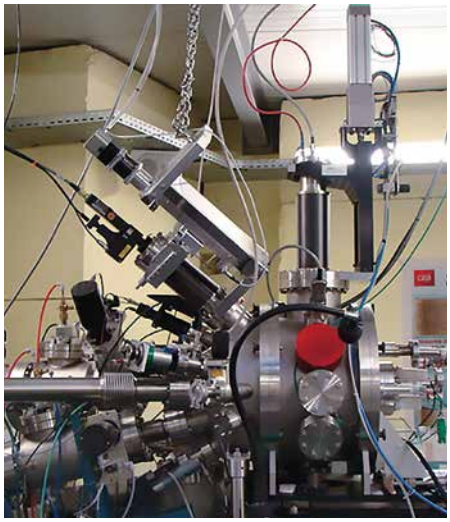
SIGNIFICANT PROGRESS HAS BEEN MADE IN THE DESIGN OF NEW EXTRACTION MOLECULES.

STUDIES ON MINOR ACTINIDE SEPARATION AND TRANSMUTATION

Americium has been identified as a first target for a separation & transmutation strategy whose objective is to reduce the long-term noxiousness of ultimate waste. Transmutation studies are particularly focusing on minor-actinide-bearing blankets (MABB). This concept is based on a heterogeneous mode of transmutation in specific sub-assemblies that are limited in number and positioned on the periphery of a fast reactor (uranium oxide pins loaded with about 10% of americium). Within this scope, the Diamino analytical irradiation experiment was started in the Osiris reactor at the Saclay centre. It sets out to study gas releases and swelling in UO_2 pellets containing americium under different operating conditions and with different types of fuel microstructures. The preliminary results will become available in 2016.

Mars beamline of the Soleil synchrotron 3D representation of molecules with experimental data obtained with the Mars beamline.





Raman probe in the triple-beam chamber of the JANNuS irradiation facility.

BASIC SCIENTIFIC & TECHNOLOGICAL RESEARCH

BASIC SCIENTIFIC AND TECHNOLOGICAL RESEARCH FOCUSES ON ACTIVITIES THAT ARE UPSTREAM OF APPLIED RESEARCH BY RESOLVING CROSS-FUNCTIONAL ISSUES THROUGH OTHER FIELDS COVERED BY THE DEN.
THIS RESEARCH HELPS EXPAND OUR DATABASE AND IMPROVE THE SCIENTIFIC QUALITY OF KNOWLEDGE NEEDED TO CONSOLIDATE THE RELEVANCE OF SOLUTIONS PROPOSED TO SOLVE THE MAIN ISSUES OF NUCLEAR ENERGY IN THREE DIFFERENT AREAS: MATERIALS, FUELS AND SEPARATION CHEMISTRY.
THE BASIC SCIENTIFIC & TECHNOLOGICAL RESEARCH PROGRAMME IS DRIVEN BY DYNAMIC COLLABORATIONS, ESPECIALLY THOSE ON A NATIONAL AND EUROPEAN LEVEL.
FOCUS ON THREE LANDMARK EVENTS IN 2014.

FIRST IN SITU RAMAN MEASUREMENTS IN THE TRIPLE-BEAM IRRADIATION CHAMBER OF THE JANNUS IRRADIATION FACILITY

The year 2014 was marked by the operation of a Raman spectrometry instrument inside the triple-beam irradiation chamber in the JANNuS facility at the Saclay centre. Connected to the spectrometer by a 50-metre optic fibre, this Raman probe is used to finely characterise samples under ion irradiation in real time and in a non-destructive manner. The implementation of this new instrumentation was a technical challenge in itself: operation of the device in a vacuum, distance of the remote system, proximity of the probe and samples without intercepting the ion beams, etc. Despite these constraints, 75% laser power transmission was achieved, which guarantees the good quality of the experiments, as demonstrated by the first test conducted in March 2014 on a sample of silicon carbide (SiC) irradiated with 4 MeV of gold ions at ambient temperature until the complete amorphisation of the material.

PREDICTING THE EFFECTS OF IRRADIATION ON PWR VESSELS AND INTERNALS BY MULTI-SCALE MODELLING

The PERFORM-60 project takes a predictive approach to the effects of irradiation on the materials comprising PWR vessels and internals by using multi-scale modelling. On 16 December 2014, this project was given one of the twelve "Stars of Europe", an award for French-led European projects, recognising the project's quality of research and innovation.

The DEN greatly contributed to this project carried out between 2009 and 2013 within the scope of the 7th Framework Programme (FP) by leading the scientific & review committee and by coordinating two of the eight scientific work packages. These work packages concerned the mechanical behaviour of vessel steels and the mechanical behaviour of vessel internal steels subjected to irradiation.

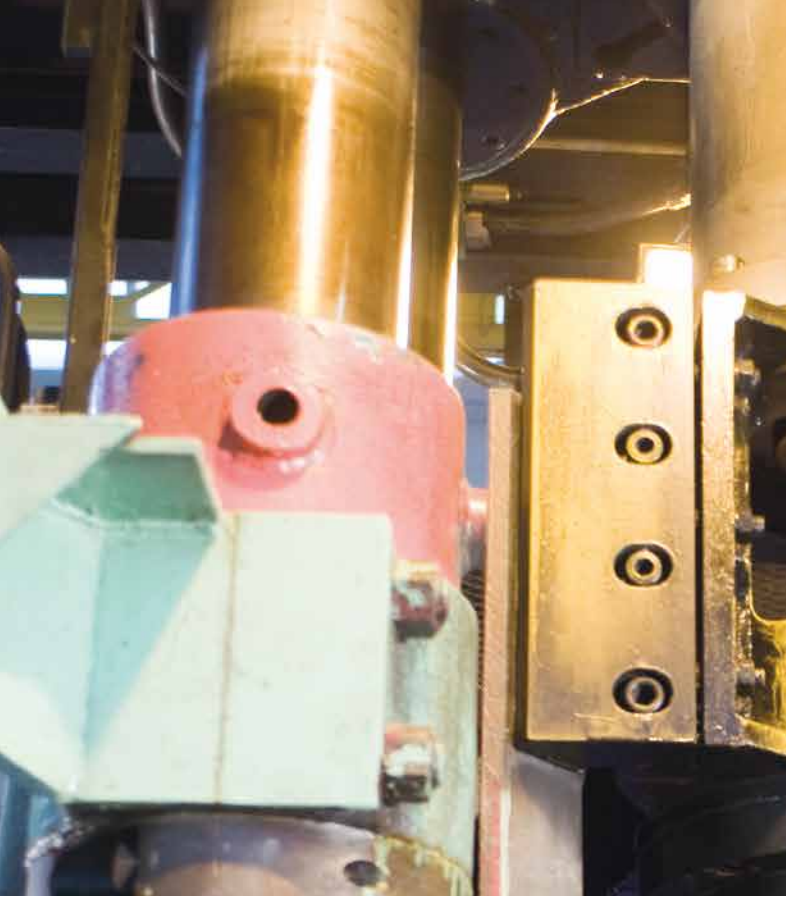
USING THE SYNCHROTRON TO CHARACTERISE THE LOCAL ACTINIDE ENVIRONMENT WITHIN THE FUEL CYCLE CHEMISTRY AND IN TRANSMUTATION TARGETS

The absorption of X-rays (SAX) is a technique used to finely characterise the local environment of atoms under investigation. The Soleil and ESRF[1] synchrotrons with their light beam lines offer numerous possibilities for characterising radioactive samples, such as:

- Studying and understanding the specific affinity of polyamino-carboxylate (PAC) ligands for actinides with respect to lanthanides as part of separation chemistry processes used to treat spent fuels.
- Resolving an inconsistency regarding the stoichiometry of oxygen in $(U_{1-x},Am_x)O_{2\pm\delta}$ transmutation targets, where only americium remains trivalent while uranium is found in a mixed U^{4+}/U^{5+} valence form. This was done in collaboration with ITU[2].

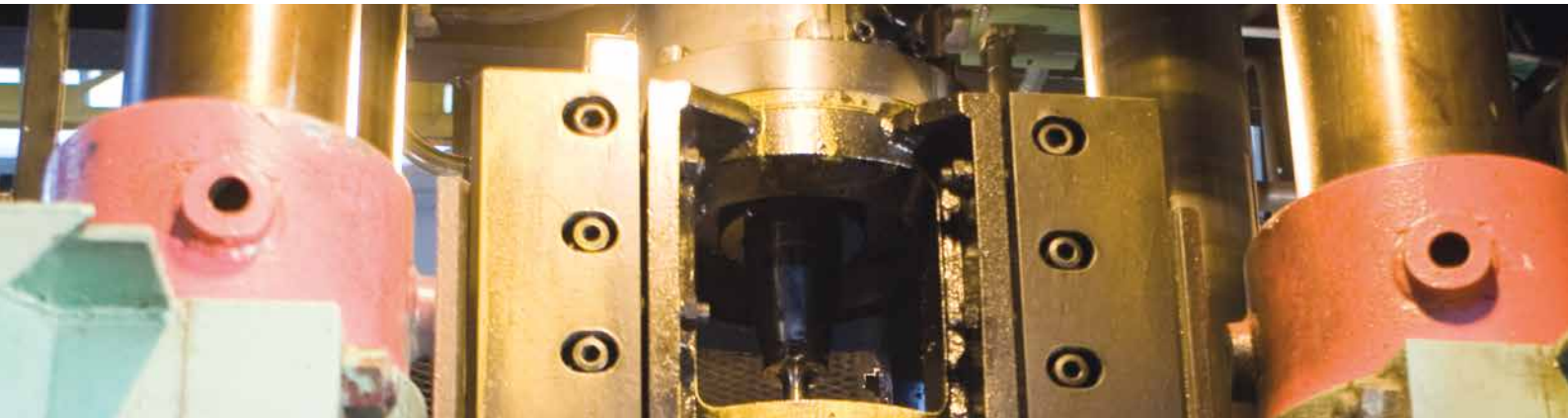
More generally, the DEN collaborates closely with the team running the Mars beamline of the Soleil synchrotron and its related equipment to develop X-ray absorption and diffraction experiments on radioactive components.

(1) European Synchrotron Radiation Facility.
(2) Institute for Transuranium Elements.



OPTIMISING THE CURRENT NUCLEAR INDUSTRY

The DEN is conducting research to address the challenges facing its industrial partners. The first objective is to support EDF in increasing the competitiveness of the French fleet currently in operation, with industrial implications in terms of reactor service life, performance, availability and safety. The second objective, in collaboration with AREVA and Andra is to optimise or adapt the front-end and back-end facilities of the nuclear fuel cycle to meet current and future industrial challenges.



Selective uranium extraction experiment in pulsed laboratory column.

The performance of DEHiBA will be assessed on a set of mixer-settlers.

FRONT-END OF THE CURRENT FUEL CYCLE

IN RECENT YEARS, RESEARCH ON THE FRONT-END OF THE FUEL CYCLE HAS INCREASINGLY GAINED SIGNIFICANT GROUND, WITH THE REDUCTION IN ORE GRADES AND THE NEED TO REFURBISH EXISTING FACILITIES. THIS INVOLVES IMPROVING PERFORMANCE LEVELS IN TERMS OF THE SELECTIVE EXTRACTION OF URANIUM, PURIFICATION AND CONVERSION INTO A FORM OF HEXAFLUORIDE WITH THE REQUIRED LEVEL OF PURITY FOR URANIUM ENRICHMENT, AN ESSENTIAL STEP FOR FUELS FOR 2ND AND 3RD GENERATION REACTORS.

EXTRACTING URANIUM FROM ORES

The processing of ores with ever decreasing uranium contents requires improvement of both the performance of the extraction process and the selectivity of the molecules. The synergistic use of several extraction molecules is widely used in liquid-liquid extraction, but the mechanisms which control the extraction synergy are still poorly reported. In this context, the DEN and ICSM[1] teams published a study in 2014 on the synergistic mechanisms determining the selective extraction of uranium from phosphoric ores. Based on original experimental and theoretical approaches, this study defines the role of each molecule and provides a better understanding of the synergistic phenomena. It represents a step forward in the development of new, higher performance extraction systems.

CONVERSION: PURIFICATION OF URANIUM-BEARING SOLUTIONS

AREVA has solutions with a high degree of natural uranium which can be re-used as long as they are decontaminated beforehand to remove any traces of radioelements so that they are compatible with processing at the Comurhex Malvési plant. To do this, the DEN has proposed testing the extractive and selective properties of the DEHiBA monoamide. The objective is to have a process with very high decontamination factors for the selective extraction of uranium in order to remove radiological impurities, in the presence of large quantities of chemical impurities.

In 2014, process data was collected on real and synthetic solutions which indicated the penalising presence of fluorine in the uranium recovery rate. The extraction step was then modelled and a process proposed. The final processes to be tested will be defined at the beginning of 2015, then the performance levels of DEHiBA will be assessed at laboratory scale, in a set of mixer-settlers in the Proust facility at Marcoule.

ISOTOPE SEPARATION

In the field of isotope separation, the DEN is conducting an active technology watch on uranium enrichment processes, in order to maintain the CEA's expertise in this strategic area. It is working in particular on the Silex process (Separation of Isotopes by Laser EXcitation), for which it is carrying out studies which should contribute to the assessment of the performance levels of this process.

(1) Institut de chimie séparative de Marcoule (Marcoule Institute for Separation Chemistry).

Top view of the corium produced during a test designed to study its simulated in-vessel behaviour by Procor GEN III.

Tamaris seismic simulation platform at Saclay, on which tests for the Smart research programme were performed.

2ND AND 3RD GENERATION REACTORS

THE CEA IS CONDUCTING RESEARCH TO SUPPORT CURRENT 2ND GENERATION FRENCH PRESSURISED WATER REACTORS (PWR_S) AND THE DEPLOYMENT OF 3RD GENERATION REACTORS.
THE RESEARCH IS PRINCIPALLY CARRIED OUT WITH EDF, AREVA AND THE IRSN, AND ADDRESSES THE INDUSTRIAL ISSUES OF IMPROVING THE PERFORMANCE, EXTENDING THE SERVICE LIFE AND INCREASING THE SAFETY LEVEL OF POWER PLANTS.
HERE ARE SOME OF THE KEY RESULTS OF 2014.

STUDIES OF SEVERE ACCIDENTS

Although the Fukushima-Daiichi nuclear accident did not reveal any major shortcomings in terms of knowledge and R&D objectives, it did underline the need to continue with the R&D programmes focussing on increasing the robustness of the mitigation solutions proposed for both 2nd generation reactors and new 3rd generation concepts. The credibility of this R&D is based largely on our ability to maintain high-performance experimental facilities.

In this context, the Petten joint research centre (in The Netherlands) coordinated a benchmark in 2014, in which the DEN took part, on the behaviour of in-vessel corium for a VVER-1000 reactor. This involved a very preliminary analysis of the feasibility of an approach to keep the corium in the vessel in the event of a severe accident for this type of reactor. This benchmark led to an assessment of current knowledge and the available evaluation tools, such as the American Maap code and the French Astec and Procor codes developed by the IRSN and the DEN respectively. It also demonstrated the need to make progress with modelling the stratification of the corium at the bottom of the reactor vessel. This is therefore one of the main objectives of the IVMR (In Vessel Melt Retention) project, coordinated by the IRSN with active involvement of the DEN, which was chosen in the Euratom H2020 initial call for projects.

THE CREDIBILITY OF OUR R&D IS BASED LARGELY ON OUR ABILITY TO MAINTAIN HIGH-PERFORMANCE EXPERIMENTAL FACILITIES.

2014 also saw the delivery of the initial version of the Procor GEN III application to EDF and AREVA. This application is devoted to the behaviour of in-vessel corium formed during a severe accident in 3rd generation PWRs. This version provides initial information on the relevance of an in-vessel retention strategy for the new reactor models being studied by EDF and AREVA.

ASSESSMENT OF THE SEISMIC RISK FOR NUCLEAR FACILITIES

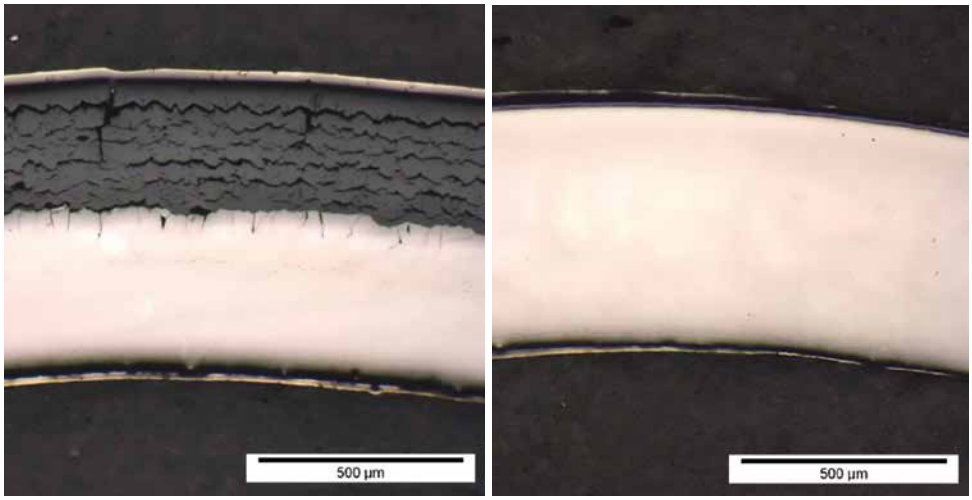
The assessment of the seismic risk for nuclear facilities is an R&D issue whose importance has increased in recent years.

2014 saw the start of the Sinaps@ project (Earthquakes and nuclear facilities: enhancing and sustaining safety). Lasting 5 years, this project is the result of the call for proposals in 2012 by the French National Research Agency (ANR) on the subject of nuclear safety and radiation protection. Its aim is to investigate the uncertainties inherent in the basic data, the knowledge of the physical processes and in the methods defined at each stage in the assessment of the seismic hazard and the vulnerability of nuclear structures and components. The aim is to identify or even quantify the seismic margins resulting from the assumptions made either when selecting the design-basis earthquake level or as part of the design strategy. The DEN is coordinating this programme around the core members of the Seism Institute[1].

(1) The CEA (DEN & DAM), EDF, the École centrale Paris, the École normale supérieure de Cachan, the CNRS, together with academic teams (École centrale de Nantes, IFSTTAR, CEREMA - formerly CETE - Méditerranée, Joseph Fourier University, Grenoble Polytechnic Institute), industrial teams (AREVA & Egis Industries), and also the IRSN.

(2) Physical Vapor Deposition - High Power Impulse Magnetron Sputtering.

Eole research reactor, in which the experiments in the Fluole 2 programme are conducted.



The reference fuel cladding without chromium coating (left) is oxidised over more than half of its thickness, and therefore significantly embrittled. The chromium-coated cladding (right) has very little oxidation, thus maintaining its strength and integrity.

In 2014 the DEN also organised a workshop on the SMART research programme (Seismic design and best-estimate Methods Assessment for Reinforced concrete buildings subjected to Torsion and non-linear effects) to share the results of the international benchmark proposed by the DEN and EDF. This benchmark focused on the test campaign conducted on the DEN's Tamaris platform at Saclay on highly asymmetrical reinforced concrete mock-ups representing an electrical building.

EXTENDING THE SERVICE LIFE OF THE REACTORS IN THE FLEET

2014 included the start of the Fluole 2 experimental programme in the Eole reactor at Cadarache. Carried out by the DEN teams and co-funded by EDF, it aims to contribute to the validation of the dosimetry interpretation model of the irradiation monitoring programme (PSI) for the French fleet of nuclear power reactors. It follows on from the Fluole programme, carried out from 2006 to 2007, representing the 1300 MWe series. Fluole 2 is an integral experiment representing the 900 MWe and 1450 MWe PWR series, designed to supplement the qualification of the calculation models for neutron propagation from the core up to the Irradiation Monitoring Programme (PSI) capsules, to the vessel and beyond the vessel. The experimental programme, scheduled to take two years, requires significant measurement campaigns using neutron activation dosimeters. A development programme lasting several years has enabled the development and qualification of an X spectrometry absolute activity measurement method, which will be used on Fluole 2.

FUELS

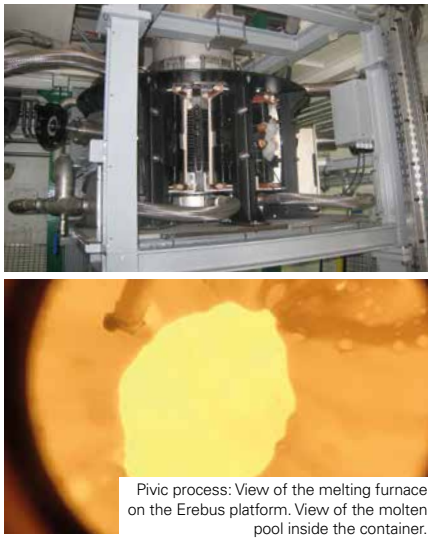
2014 marked the intention to intensify, in the context of the CEA - EDF - AREVA institute, the development of innovative solutions for fuel cladding with the aim of improving their ability to withstand accident conditions (ATF, Accident Tolerant Fuel concept), while maintaining a potential advantage in terms of their behaviour under nominal conditions.

The first part involves the development of fuel cladding coated with chromium using a PVD-HI-PIMS[2] hybrid process, which led to a CEA patent. Developed by the CEA in the context of the CEA - Belfort-Montbéliard technology university joint research laboratory, this coated cladding displays significantly improved resistance to oxidation, both in nominal conditions and in accident conditions at high steam temperatures. Its resistance to hydriding, the potential embrittling effects of which are known, is also increased. These results have been recorded in several publications. The systematic assessment of the performance levels of coated cladding as an ATF solution in service and in accident conditions represents a priority objective, with the possibility of irradiating experimental fuel rods in a research reactor in the short term and then in a power reactor.

DEVELOPING INNOVATIVE SOLUTIONS FOR CLADDING TO IMPROVE THEIR CAPACITY TO WITHSTAND ACCIDENT CONDITIONS.

The second part, which has a longer term perspective, involves the use of cladding made of a silicon carbide composite (SiC/SiC) as an ATF solution. This composite was initially developed for gas-cooled fast reactors (CEA patents). This concept of multi-layer cladding with an internal metal liner makes it possible to envisage cladding that is leaktight during operation and provides improved resistance in accident conditions. The initial assessments carried out in situations representing water reactors confirmed the benefit of continuing work to assess the performance more systematically and looking for ways of optimising the concept.

In this context, the CEA, with its partners AREVA and EDF, has been involved in the very active international collaborations on this subject within the framework of the Nuclear Energy Agency (NEA/OECD) and the International Atomic Energy Agency (IAEA).



Pivic process: View of the melting furnace on the Erebus platform. View of the molten pool inside the container.

Laboratory validation of the rinsing process at the head-end of the plant on samples of actual deposits in La Hague workshop R1.

Building the downstream block of the mock-up in shotcrete to demonstrate the industrial feasibility of sealing Cigéo tunnels.

BACK-END OF THE CURRENT FUEL CYCLE

PROGRAMMES ARE CONDUCTED TO SUPPORT AREVA SO AS TO OPTIMISE OR ADAPT THE PROCESSES FOR SPENT FUEL PROCESSING AT THE LA HAGUE PLANT AND FOR MOX FUEL FABRICATION AT THE MELOX PLANT. THEY ARE ALSO DESIGNED TO SUPPORT ANDRA SO AS TO PROVIDE THE SCIENTIFIC AND TECHNICAL INFORMATION NEEDED FOR THE CIGÉO DOCUMENTS.

LASTLY, SUCH PROGRAMMES SET OUT TO GUIDE EDF IN ITS MANAGEMENT OF CERTAIN TYPES OF WASTE, INCLUDING WASTE RESULTING FROM THE DISMANTLING OF NATURAL URANIUM GRAPHITE GAS (UNGG) REACTORS.

PROGRESS ON THE PIVIC PROCESS

The Pivic in-can incineration-vitrification process, developed by the DEN in the joint vitrification laboratory, in partnership with AREVA and Andra within the context of the French future investments programme, achieved an important step in 2014 with the completion of the first full-scale technological tests to melt mixed glass and metal. During the first test, to qualify the glass-metal melting part of the process, a load comprising 200 kg of metal and 60 kg of glass, was successfully melted directly in the container (called the "can"). Melting of the whole load was observed at 1400°C at a power of approximately 150 kW after 3 hours 30 minutes of gradual heating. The initial tests provided results on the temperatures and circulation movements of the two phases. The next tests will focus on incorporating simulated waste residue (ash, aluminium, etc.) and the behaviour of metal pieces added during the tests.

The Pivic process is designed to treat and condition alpha-contaminated mixed technological waste (both organic and metal) generated by the activities of the Melox and La Hague plants.

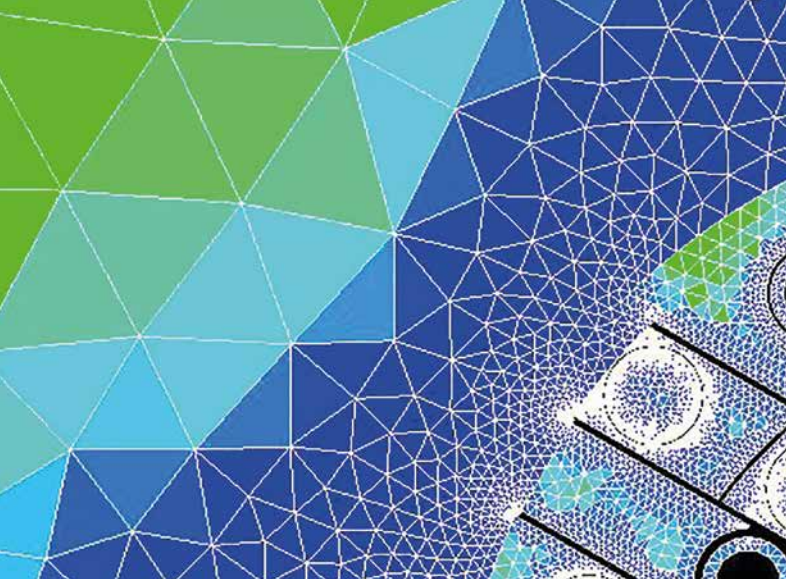
SUPPORTING LA HAGUE

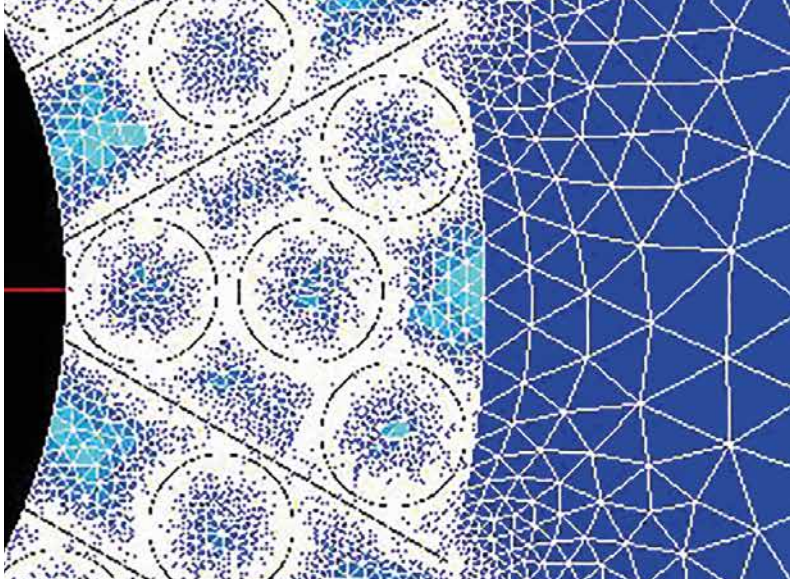
The DEN supports La Hague plant in the procedure for continuous improvement of the treatment-recycling processes implemented by AREVA. In this context, the DEN has developed a substantial R&D programme on plant head-end processes. It has carried out studies to qualify a new rinsing procedure using carbonate instead of sodium hydroxide. After laboratory-scale development and qualification, then active testing in the Atalante facility at Marcoule, the final step in the industrial qualification of this new rinsing procedure was carried out successfully, in September 2014, with the implementation of the rinsing of an entire loop in workshop R1. This qualification campaign has demonstrated the advantage of this process which will improve rinsing efficiency in the future by a factor of 2, decrease the time taken for the operations by a factor of 3 and reduce the amount of effluent produced by a factor of 4.

SUPPORTING ANDRA

In the context of the French Act of 28 June 2006 on the sustainable management of radioactive materials and waste, the DEN is supporting the deep geological repository centre project (Cigéo), of which Andra is the project owner. The project involves the gradual installation of sealing structures, the function of which is the very long term closing and sealing of the excavations. In this context, the DEN has contributed to the building of a full-scale mock-up reproducing the installation of a plug in a portion of tunnel. The installation of the concrete block at the downstream end of the mock-up in September 2014 represents the completion of this work, which is one of the demonstrations for which the Andra is responsible. Associated with this, within the framework of a temporary group of companies[1], the DEN was responsible for defining and qualifying the low pH concrete formulations for the support blocks, to meet the performance requirements for this structure: installation capacity with timescales representing implementation at depth and filling any irregularities, particularly in the roof of the structure. At the end of 2014, the IRSN gave a positive assessment of the low pH concrete support block developed by the DEN.

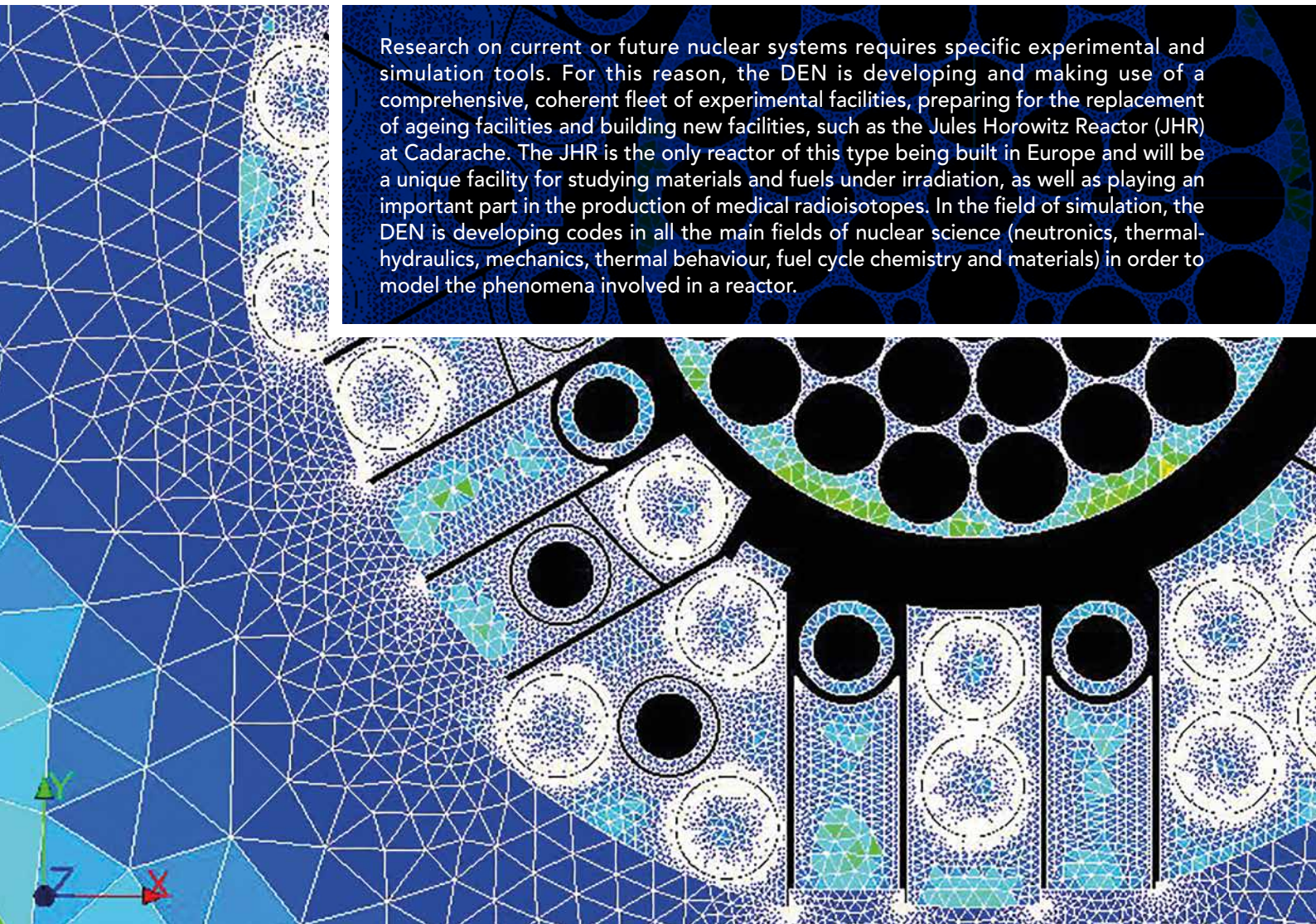
(1) With the industrial companies EIFFAGE TP, LAVIOSA MPC and SOLEXPERTS.

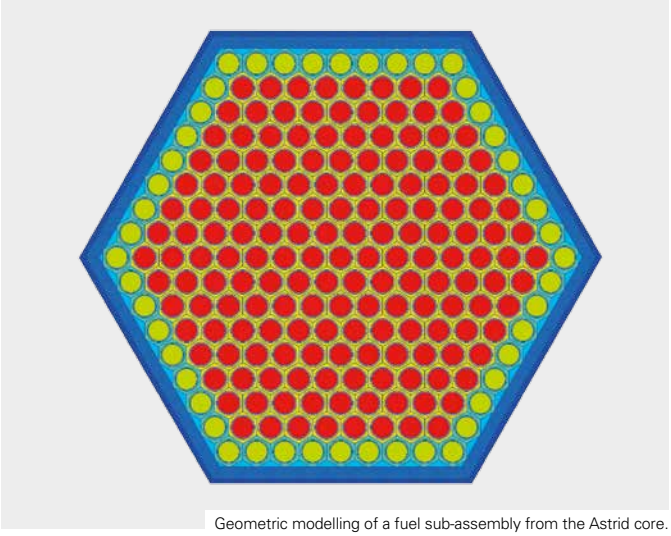




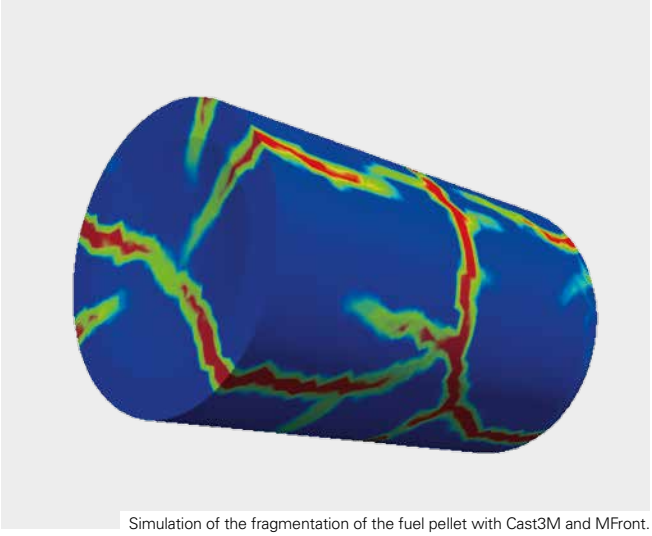
MAJOR TOOLS FOR DEVELOPING NUCLEAR ENERGY

Research on current or future nuclear systems requires specific experimental and simulation tools. For this reason, the DEN is developing and making use of a comprehensive, coherent fleet of experimental facilities, preparing for the replacement of ageing facilities and building new facilities, such as the Jules Horowitz Reactor (JHR) at Cadarache. The JHR is the only reactor of this type being built in Europe and will be a unique facility for studying materials and fuels under irradiation, as well as playing an important part in the production of medical radioisotopes. In the field of simulation, the DEN is developing codes in all the main fields of nuclear science (neutronics, thermal-hydraulics, mechanics, thermal behaviour, fuel cycle chemistry and materials) in order to model the phenomena involved in a reactor.





Geometric modelling of a fuel sub-assembly from the Astrid core.



Simulation of the fragmentation of the fuel pellet with Cast3M and MFront.

NUMERICAL SIMULATION

THE NUCLEAR ENERGY DIVISION (DEN) IS DEVELOPING SOFTWARE PLATFORMS AND COMPUTATIONAL CODES IN ALL THE MAIN FIELDS OF NUCLEAR ENERGY (NEUTRONICS, THERMAL-HYDRAULICS, MECHANICS, THERMAL BEHAVIOUR, FUEL CYCLE CHEMISTRY AND MATERIALS) TO MODEL THE COMPLEX PHENOMENA OCCURRING IN NORMAL REACTOR OPERATION OR IN AN ACCIDENT SITUATION. MOST OF THE CODES DEVELOPED BY THE DEN ARE USED BY THE FRENCH NUCLEAR INDUSTRY. THEY HAVE BEEN DISTRIBUTED TO EUROPEAN R&D ORGANISATIONS UNDER A LARGE NUMBER OF LICENSING AGREEMENTS.

APOLLO3®: FIRST NEUTRONICS SIMULATION OF A FUEL SUB-ASSEMBLY FROM THE ASTRID CORE WITH PRECISE GEOMETRY

The new Apollo3® multi-system neutronics code, developed by the DEN, has recently proved its excellent performance, carrying out neutronics modelling and simulation, with precise geometry, of a fuel sub-assembly from the core of the Astrid technology demonstrator for the first time. This computation is part of the development of the code, which is scheduled for industrial commissioning at the end of 2015. Removing the simplifying geometric assumptions inherent in the computational models used currently, the Apollo3® code thus demonstrates its capacity to handle the heterogeneous geometries of the Astrid core more realistically. The success of this first step, which takes more precise account of the physics of sodium-cooled fast reactors, will enable the subsequent modelling of all the in-core objects so that 3D computation of the whole core can be carried out, which will contribute to the Astrid detailed design studies, scheduled for 2016 to 2019.

THE APOLLO3® CODE DEMONSTRATES ITS CAPACITY TO HANDLE THE HETEROGENEOUS GEOMETRIES OF THE ASTRID CORE.

CATHARE-3 VALIDATION REPORT ON A SET OF 26 SYSTEM TESTS

The CEA is developing the Cathare-3 thermal-hydraulics system code within the framework of a four-party CEA - EDF - AREVA - IRSN project. Its development plan schedules delivery of version 2.1 at the end of 2019, providing the same functions as Cathare-2 and fully validated. In this context, the partners wanted an idea, by the end of 2014, of the maturity of the Cathare-3 version that was being developed. A validation status report on the code was therefore drawn up, based on a varied, representative set of accidental transients for PWRs and carried out on different system loops. The result of this work, which shows an excellent level of maturity of the code (both in terms of its robustness and its validation), was a major industrial deliverable supplied in December 2014. Cathare-3 version 2.1 should be used for the safety files connected with the fourth 10-year inspection of the 1,300 MWe series of reactors in the EDF fleet.

OPEN-SOURCE DISTRIBUTION OF THE PLEIADES PLATFORM MFRONT COMPONENT

The MFront software for the Pleiades fuel platform has been available to download from the internet free of charge[1] since October 2014. This software is used to construct laws for the mechanical behaviour of materials, with numerical performance levels and a quality approach that are compatible with the requirements of fuel applications, in particular those for industrial use. The benefits of MFront are that it standardises and automates the writing of behaviour laws for materials – saving a significant amount of time in simulation studies – and that it is compatible with most mechanical codes worldwide.

(1) http://sourceforge.net/projects/tfel

PHOTO GALLERY

2014, THE YEAR'S WORK ON-SITE AND IN THE FACTORY

2014 was a major year for civil engineering work, with:

- Completion of the framework of the reactor building dome, before being concreted at the start of 2015 (1);
- Continuation of the work in the hot cell area in the nuclear auxiliaries building (2);
- Construction of the backup auxiliaries buildings;
- On-load tests conducted on the polar bridge crane, to demonstrate that it operates correctly (3).

Other work was carried out in the factory, including:

- Qualification tests on the control rod mechanisms;
- Start of the assembly of the heat exchangers (4);
- Factory testing of the backup diesel generators (5).

RESEARCH FACILITIES: JULES HOROWITZ REACTOR (JHR)

THE CONSTRUCTION OF THE JHR AT CADARACHE IS A MAJOR PROJECT FOR THE CEA. THE JHR IS THE ONLY REACTOR OF THIS TYPE UNDER CONSTRUCTION IN EUROPE, AND WILL BE A UNIQUE FACILITY FOR THE STUDY OF MATERIALS AND FUELS UNDER IRRADIATION, IN SUPPORT OF CURRENT AND FUTURE NUCLEAR REACTORS. IT WILL ALSO TAKE ON A LARGE PROPORTION OF THE PRODUCTION OF MEDICAL RADIOISOTOPES.

THE JHR PROJECT HAS RECEIVED FUNDING FROM THE FUTURE INVESTMENTS PROGRAMME AND IS BEING BUILT BY AN INTERNATIONAL CONSORTIUM. THE CEA IS THE OWNER, NUCLEAR OPERATOR AND CONTRACTING AUTHORITY.


1


2


3


4


5

END OF QUALIFICATION OF THE JHR FUEL

The campaign to irradiate five precursor elements of the JHR fuel by AREVA, in accordance with the DEN specifications, was completed in 2014. Conducted in the BR2 Belgian reactor, its aim was to qualify the fuel in nominal JHR operating scenarios. These irradiations demonstrated satisfactory behaviour of the fuel with a view to its use in the JHR.

START OF MANUFACTURING OF THE MAIN COMPONENTS OF THE JHR REACTOR BLOCK

The technical review of the detailed design and qualification studies for the large components of the JHR reactor block was approved at the end of 2014, enabling the project to move to the manufacturing stage.

Artist's impression of the EHI.

PROMOTING RESOURCES AND EXPERTISE

THE DEN'S R&D WORK IS MAINLY CARRIED OUT IN THE CONTEXT OF AGREEMENTS WITH LARGE INDUSTRIAL COMPANIES SUCH AS EDF AND AREVA, BUT IT IS ALSO ILLUSTRATED BY ITS CONSIDERABLE ABILITY TO CARRY OUT TECHNOLOGY TRANSFERS. THE DEN PROMOTES THE RESOURCES AND EXPERTISE IT HAS DEVELOPED FOR THE NUCLEAR INDUSTRY IN WORK FOR THE BENEFIT OF OTHER CEA DIVISIONS, AND ALSO BY TRANSFERRING TECHNOLOGIES TO NON-NUCLEAR INDUSTRIES.

LAUNCH OF THE EHI AND CREATION OF ITS PROMETIA EUROPEAN NETWORK

Making use of its unique experience in extractive chemistry processes developed for the nuclear fuel cycle at the Marcoule site, the DEN initiated the European Hydrometallurgical Institute (EHI) project in 2013. The aim of this project, led by the DEN with academic partners and several European industrial companies, is to speed up innovation in the fields of primary production, recycling of strategic metals and decontamination.

This project was approved at European level in early 2014, in the context of the European innovation partnership on raw materials. In September 2014, the conceptual design of a "low rate" process platform was finalised. The aim is to develop non-nuclear processes in the area around CEA Marcoule, and thus contribute to the creation of value and jobs with industrial companies, promoting the CEA's expertise.

December 2014 saw the official creation of Prometia, the first European academic research network on mineral processing and extractive metallurgy of mineral resources.

COMETE PROJECT: CONTINUATION OF THE COLLABORATION WITH SNECMA

Within the framework of a collaboration dating from 1987, the CEA and SNECMA have been working together since 2005 on a version of the Cathare software dedicated to issues specific to SNECMA, called Cathare Multifluide, to model various situations, including the physical phenomena which occur during the chill-down and operation of space engines. This version is integrated in a chain of numerical computation codes called Comete, which SNECMA uses in the context of its rocket motor and launcher propulsion system design activities. In this computational chain, the Cathare software simulates the two-phase flows to which the cryogenic propellants (hydrogen and oxygen) are subjected when passing through the numerous fluid circuits of the engine subsystems.

In 2014, SNECMA demonstrated its commitment to the long-term continuation of this partnership by signing a licensing agreement for the Cathare software. The CEA and SNECMA are also finalising the terms of an additional development contract with the aim of enhancing the functions of Cathare Multifluide so that it adapts even better to SNECMA's changing requirements.

FOCUS ON

DEN INTELLECTUAL PROPERTY

This focuses on the innovations needed for its key technological challenges: support for the current and 3rd generation nuclear fleet, preparation for 4th generation reactors, fuel cycle technologies, and clean-up and dismantling worksites.
The DEN intends to make its expertise (instrumentation, extraction/separation processes, robotics, etc.) available to companies in the nuclear industry to help them boost their innovation capacity, and also to provide support to industrial companies through the distribution and transfer of technologies, both within and outside the nuclear sector. The DEN currently has 644 active patents.

Rechipper in the platform's test hall.

General view of the technological platform for biomass pretreatment.

ECONOMIC SUPPORT IN THE MEUSE AND HAUTE-MARNE REGIONS: THE SYNDIESE PROJECT

THE DEN IS RESPONSIBLE FOR THE SYNDIESE PROJECT, THE FIRST PHASE OF WHICH INVOLVES BUILDING THE TECHNOLOGICAL PLATFORM FOR BIOMASS PRETREATMENT. THIS PROJECT IS SUPPORTED BY THE FRENCH GOVERNMENT, LOCAL AUTHORITIES AND LOCAL COMPANIES, AND ALSO THE EUROPEAN UNION. IT IS PART OF THE ECONOMIC SUPPORT IN THE AREA NEIGHBOURING THE ANDRA BURE-SAUDRON LABORATORY, REQUIRED BY THE FRENCH ACT ON THE SUSTAINABLE MANAGEMENT OF RADIOACTIVE MATERIALS AND WASTE DATED 28 JUNE 2006.

PROJECT STATUS

In 2014, work continued on preparation of the site and building of the infrastructures for the technological platform for biomass pretreatment, located within the future interdepartmental zone at Bure-Saudron. It was commissioned in the first half of the year and officially opened on 6 October. It comprises a number of buildings:

- A 400 m² test hall housing all the technological equipment on a scale of 1 tonne/hour;
- A 100 m² analysis laboratory with equipment to characterise and analyse the properties of the biomass being processed;
- An area reserved for the operating teams and researchers;
- Annexe buildings such as the reception building and the biomass storage area.

The purpose of this platform is to validate the technologies developed by the CEA, within the framework of its collaboration with the Air Liquide Group, for converting biomass into syngas using a thermochemical process. This project, called Syndiese-BtS (Biomass to Syngas), is divided into two main phases:

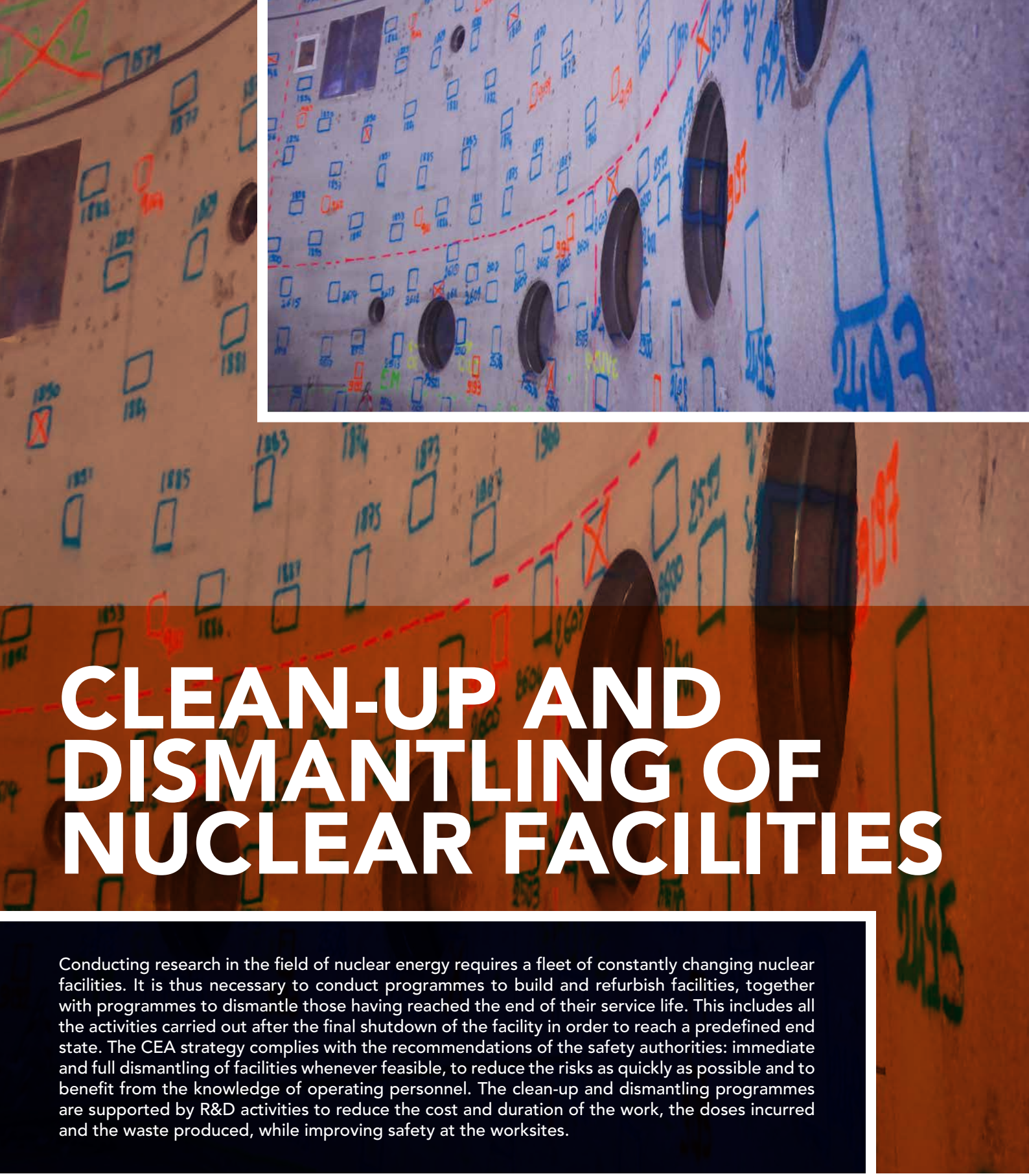
- Phase 1: validation of the equipment in the process chain, in particular with regard to the platform;
- Phase 2: validation of the integrated process chain.

The initial R&D work, carried out in 2014, achieved the various phase 1 technological objectives, in accordance with the request of the high-level committee of 4 February 2013. In 2015 work will continue on this platform which the CEA wishes to open up to other national and local academic and industrial users, by establishing partnerships for the development of innovative technologies in the fields of biomass pretreatment and conversion.

FOCUS ON

OFFICIAL OPENING OF THE TECHNOLOGICAL PLATFORM FOR BIOMASS PRETREATMENT

On 6 October 2014, the technological platform for biomass pretreatment, built at Bure-Saudron by a group of local companies, was officially opened by Bernard Bigot, Chairman of the CEA, Bruno Sido, President of the Haute-Marne Departmental Council and the Haute-Marne public interest group, and Christian Namy, President of the Meuse Departmental Council and the Objectif Meuse public interest group. Local companies were able visit the test hall to see the two rechippers which are used to obtain wood flour with specific rheological properties. They also visited the analysis laboratory and watched wood flour characterisation measurements being taken, to check the flow behaviour properties of the flour obtained.



CLEAN-UP AND DISMANTLING OF NUCLEAR FACILITIES

Conducting research in the field of nuclear energy requires a fleet of constantly changing nuclear facilities. It is thus necessary to conduct programmes to build and refurbish facilities, together with programmes to dismantle those having reached the end of their service life. This includes all the activities carried out after the final shutdown of the facility in order to reach a predefined end state. The CEA strategy complies with the recommendations of the safety authorities: immediate and full dismantling of facilities whenever feasible, to reduce the risks as quickly as possible and to benefit from the knowledge of operating personnel. The clean-up and dismantling programmes are supported by R&D activities to reduce the cost and duration of the work, the doses incurred and the waste produced, while improving safety at the worksites.

End of dismantling work on level 1 of the MAR 400 facility.
Left: view of operations to remove the upstream check valve of the grinder. Right: view of the hole left after having removed the valve.

DISMANTLING SITES

MANAGING THE DISMANTLING OF ITS NUCLEAR FACILITIES IN A SAFE AND RESPONSIBLE MANNER IS ONE OF THE CEA'S KEY OBJECTIVES. THE LONG-TERM FINANCING OF ITS DISMANTLING PROGRAMMES IS GUARANTEED BY TWO SPECIFIC FUNDS; ONE FOR CIVIL ACTIVITIES AND THE OTHER FOR DEFENCE ACTIVITIES. TWENTY-TWO OF THE 43 CIVILIAN NUCLEAR FACILITIES ARE CURRENTLY BEING DISMANTLED.

MAIN SHORT- AND MEDIUM-TERM PRIORITIES

- At Marcoule, continuing the dismantling of the UP1 spent fuel reprocessing plant and launching operations to dismantle the Phénix reactor, which was shut down in 2009.
- In Fontenay-aux-Roses, progressively reducing the scope of the regulated nuclear facilities (INB).
- Complying with deadlines specified in ministerial decrees for the different worksites, and meeting CEA safety milestones with respect to the safety authorities.

MARCOULE

The two top priorities at Marcoule are to continue dismantling the UP1 spent fuel reprocessing plant and to start preparation to dismantle the Phénix reactor, which was shut down in 2009.

UP1 programme

The UP1 plant reprocessed spent fuel from the G1, G2 and G3 nuclear reactors at the Marcoule centre with the goal of producing plutonium to meet the needs of the French Defence. It also reprocessed civil spent fuel from EDF gas-cooled graphite-moderated reactors and from the Vandellos nuclear power plant in Spain.

This site is currently one of the largest dismantling projects underway in Europe. The dismantling programme covers the decladding workshops, the reprocessing plant itself, the Marcoule vitrification workshop (AVM)[2], the support and interim storage workshops (ASE) and the recovery and conditioning of legacy waste (RCD), bitumen and non-bituminous products.

- Regarding the decladding workshops, 2014 saw the complete dismantling of level 1 of the MAR 400 facility after having dismantled G2-G3 in 2013. The last operations involved dismantling the equipment in the uranium warehouse and in the magnesium transport unit.
- As regards the reprocessing plant, 2014 was marked by the entire overhaul of the dismantling baseline scenario to incorporate new data that became available in 2013. It now takes into account the increasing complexity of recovery and conditioning programmes for very-high-level waste (VHLW) such as HA 100 and MAR 200 tanks and ventilation systems. This baseline also reassessed the related costs. The dismantling project budget review process will be audited by statutory auditors with external technical support from the engineering company Tractebel in early 2015. At the same time, clean-up and dismantling operations were continued, e.g. on the ILW tanks, and dismantling of semi-activated corridors in room 71 of the plant was finalised.
- Concerning the Marcoule vitrification workshop (AVM), the dismantling studies were launched and reinforcement work on the facility was started as requested by the ASN following the stress tests carried out in wake of the Fukushima accident. For this reason, two sumps were upgraded to standard and dismantling operations on the top part of the SPF4[1] evaporator were started.
- As regards the support and interim storage workshops (ASE), dismantling is expected to take place as the facilities are progressively shut down. In 2014, both the decontamination workshop (ADM) and the EVA workshop for the liquid effluent treatment plant in Marcoule were shut down and thereby incorporated into the scope of this project, which immediately triggered the preparatory operations for final shutdown.
- There are two main categories of operations in the field of legacy waste recovery and conditioning (RCD): the recovery of drums containing bituminised waste, and the recovery of non-bituminised waste. The second category involves characterising waste in view of recovering other legacy waste - by 2030 - currently stored in decladding pits and in the north area pits, e.g. metal structural waste such as magnesium, aluminium or steel, and powdered waste such as resins, zeolite or sludge, etc. Waste stored in pit No. 94 in the north area was recovered successfully in 2014, which represented a significant safety milestone.

(1) French abbreviation for Stockage Produits de Fission (disposal of fission products).

(2) AVM: a French abbreviation for Atelier de vitrification de Marcoule.

Spent fuel from Phénix in a TN transport cask ready for dispatch to the AREVA plant at La Hague.

Small line of the RM2 facility showing ten vertical cuts and the removal of two concrete blocks.

Dismantling the Phénix plant

The Phénix sodium-cooled fast reactor built at the Marcoule centre was shut down in late 2009.

From an administrative and regulatory viewpoint, a highlight of 2014 was the favourable opinion of the public enquiry commission issued without reservations with respect to the request for authorisation go ahead with the final shutdown and dismantling of this facility. The public enquiry was held over a period of six weeks in June and July 2014 and concerned a total of eleven towns located around the site. Furthermore, the ASN standing group responsible for the facility's safety review also issued a favourable opinion in November on continuing the operation of the Phénix plant in the perspective of its final shutdown and dismantling, as well as on the treatment of sodium and sodium-contaminated objects in the facility using the process recommended by the CEA.

The transport of spent Phénix fuel to the AREVA plant in La Hague for treatment continued throughout 2014 at the same time. The five scheduled transport operations all took place.

Recovering waste from pit 94 at the UP1 plant.

FONTENAY-AUX-ROSES

The clean-up and dismantling operations in facilities at the Fontenay-aux-Roses centre have been grouped under the Aladin project (French acronym meaning: laboratory clean-up and facility dismantling) since 2008. The project organisation was changed in 2013 to strengthen team integration, thereby encouraging communication between the different interfaces of the project and finding the right balance between safety requirements, clean-up & dismantling worksite control, and project cost & deadline prerequisites.

Significant headway was made with the dismantling worksites at each of the two INBs on the centre in 2014.

Waste removal from Building 91 (INB 166) and transfer of 300 drums from Building 18 (INB 165)

Prior to their transfer to an industrial-scale disposal facility run by Andra (Aube disposal centre), the 200-litre drums of low-level waste (LLW) from the Fontenay-aux-Roses site must be characterised to check their compliance with Andra specifications. This is what the Sandra B measuring line does. The month of September was marked by the characterisation of the 1000th waste drum by this measuring line in 2014, which proves its efficiency and represents a significant improvement in the removal of legacy waste drums in Building 91. The space progressively freed up in this building has made it possible to recover:

Ulysse reactor at Saclay.

- Three hundred 200-litre drums of LLW mainly generated by dismantling worksites in Building 18, thus avoiding any congestion and allowing the dismantling operations on the shielded lines to run smoothly.
- Ninety-seven 200-litre drums of LLW stored in Building 53. By freeing up this area, it was possible to start the preparatory work prior to refurbishing this building so it can be used to store "utility waste" (characterisation, expertise and treatment).

Progress on the RM2 worksite (INB 165): cutting up the first concrete blocks

Launched in January 2014, the demolition work on the small line of shielded cells in Building 52.2 forming part of INB 165 in Fontenay-aux-Roses (RM2) led to the production of the first blocks of concrete, a milestone of the final phase of equipment dismantling.

As of early January, the operations involved making 10 vertical cuts with a diamond cable saw through the walls of cells 8, 9, 10 and 11 by pushing movements. A portal frame was specially developed by Bouygues Construction Services Nucléaires to collect any dust during these cutting operations. The horizontal cutting operations then started on 6 March to remove a first block weighing 10 tonnes, which was the first of more than 1,200 blocks for the entire worksite. These blocks will be transferred for disposal at the Andra industrial site for very-low-level waste (VLLW) collection, storage and disposal (Cires).

This milestone first required carrying out a series of preparatory activities. They consisted in: 1) demolishing the rear areas of the shielded cells and the technical galleries, 2) removing the contaminated backscattering chambers from the cell walls, 3) demolishing the structures making up these areas, and 4) dismantling the filter room, as well as 5) installing a containment system to cover the small and large lines of shielded cells on all four levels of the building in mid-2013.

SACLAY

Authorisation for final shutdown and dismantling of the Ulysse reactor

The ministerial decree authorising the final shutdown and dismantling of the Ulysse reactor (INB 18) was signed on 18 August and published in the official gazette on 21 August. The dismantling operations should commence before 21 August 2019.

Delos process in the Atalante facility implemented for active operation to treat contaminated organic solvents: start of treatment on organic effluents from the HA4 tank at Saclay

The hydrothermal oxidation - or wet oxidation - process called Delos designed to destroy contaminated organic solvents was first implemented in late 2014. For the first time, it destroyed a litre of effluent from the HA4 tank of INB 35 at the Saclay centre. Implemented in the Atalante facility at Marcoule, this process - the fruit of 20 years of technological R&D - will be used in particular to treat effluents from this tank.

This process is based on the hydrothermal oxidation of contaminated organic solvents in supercritical water. It uses no chemical reagent other than water and is based solely on the high solubility and reactivity of organic compounds in water under temperature and pressure conditions above 374°C and 221 bar. Under these conditions and in air, the organic compounds are destroyed through their total oxidation in less than a minute, to be transformed into an uncontaminated gaseous phase (CO_2) and a liquid phase essentially comprised of H_2O which also concentrates all the radioelements initially present. The aqueous phase can then be easily treated by the existing treatment facilities, which is not the case for the organic phase.

Transfer of the effluents in the HA4 tank to Marcoule for treatment was completed in late 2013. The year 2015 will be devoted to i) ramping up the process to reach its nominal rate, ii) conducting all validation tests for active operations, iii) checking the good behaviour of materials, iv) training operators to use the process, and v) modifying the reactor in compliance with the regulations.

Operations to drain the pools in INB 56 at the Cadarache centre.

CADARACHE

The clean-up and dismantling activities at Cadarache concern a number of different INB worksites, as well as various operations to recover and condition waste and/or to treat and transfer spent fuels. Several important steps were achieved in 2014.

Removal and transfer of Pégase fuels

Since 1980, the former Pégase reactor has been used to temporarily store irradiated fuels under water and waste drums containing by-products resulting from the production of fuel elements. The removal of araldite-free fuels stored temporarily in this facility's pool, as well as the treatment and reconditioning of these fuels in the Star facility on the centre continued throughout 2014. Once reconditioned, these fuels will be transferred to the Cascad facility for interim storage. These operations must be finalised by late 2016 (key safety objective). They fall within the scope of reducing the radioactive inventory at Pégase in line with the updated seismic standards now applicable to regulated nuclear facilities. As a reminder, all waste drums highly contaminated in plutonium were all removed by late 2013.

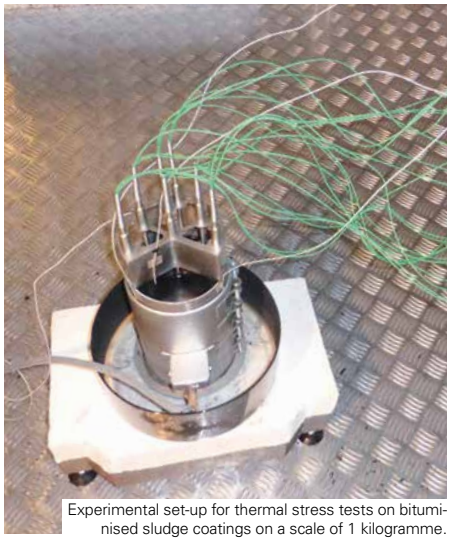
Interim storage facility for solid radioactive waste (INB 56)

INB 56 is a facility designed for the interim storage of very-low-level, low-level and intermediate-level waste. Commissioned in the 1960s, it has been progressively replaced by the Cedra facility which has been commissioned in stages since 2006. Radwaste recovery and conditioning operations are therefore carried out within this context. These operations concern three main parts of the facility: the interim storage facility (containing long-lived intermediate-level waste, LL-ILW), the trenches (mainly containing short-lived intermediate-level waste, SL-ILW) and three pools (built for the interim storage of experimental fuels which have already been removed).

Among the key actions carried out in 2014, it is worth mentioning the start of the active effluent removal operations from the facility's pools to the liquid effluent treatment plant at Marcoule; the final objective is to drain and then clean up these pools. Another major action involved resuming the waste removal operations from the trenches in September. In 2014, these operations focused on trench No. 2. This involved removing the waste after having opened the trench and then reconditioning it so it could be transferred to a suitable waste outlet. A total of 15 m^3 was removed in 2014, bringing the total amount of waste removed from this trench to more than 500 m^3. The full recovery of this waste is a key safety objective to be met by late 2017. The authorisation to implement for active operation the removal of low-irradiating waste from certain pits in the interim storage facility was also granted in 2014. Following the development of waste measurement and removal processes for pit No. 3, operations were resumed on 15 July. About 10 m^3 of waste has thus been reconditioned, with operations to continue throughout 2015.

Solid waste treatment plant

The treatment plant for radioactive effluents and solid waste (INB 37) at Cadarache can be divided into two sub-systems: one for treating liquid effluents (STE) and the other for treating and conditioning solid waste (STD). The first stopped production in late 2013 and has since been replaced by the Agate facility, while the second is being renovated, which implies the removal of any old obsolete equipment in a nuclear environment. Among the improvements made within this scope, the injection line used to fill the packages with a cement matrix and thus block the waste was completely dismantled in 2014.



Experimental set-up for thermal stress tests on bituminised sludge coatings on a scale of 1 kilogramme.

Aerial view of the ITER construction site and location of the future interim storage facility called Intermed.

WASTE AND MATERIAL FLOW MANAGEMENT

MANAGING THE FLOWS OF RADIOACTIVE WASTE, MATERIALS AND UNUSED FUELS IS ESSENTIAL IF WE ARE TO ENSURE THAT OUR R&D ACTIVITIES AND OUR CLEAN-UP & DISMANTLING PROGRAMMES PROGRESS SMOOTHLY AND EFFICIENTLY.

One of the CEA's main objectives is to provide operational treatment and interim storage systems for all categories of waste, as well as the online capability for transferring waste to the Andra's operational repositories (Cires and CSA) under optimised technical and economic conditions. A second major objective is to have disposal sites in the future that can deal with all high-level (HLW) and long-lived intermediate-level waste (LL-ILW) packages[1], as well as all long-lived low-level waste (LL-LLW) packages.

CIGEO ACCEPTANCE SPECIFICATIONS FOR HLW AND LL-ILW PACKAGES FROM THE CEA

The CEA is carrying out technical and scientific work to help establish the acceptance specifications for its HLW and LL-ILW packages so they can be sent for disposal in Cigéo, the deep geological waste repository project for which Andra is the project owner. It also helps with the implementation of operational acceptance specifications governing its HLW and LL-ILW packages for disposal in the Cigéo facility.

More specifically, as owner of mostly LL-ILW packages, the CEA defines and carries out its own R&D programmes on bituminised sludge (about 15% of the design inventory for LL-ILW packages at Cigeo), cemented packages containing soft housekeeping waste[2] (about 10% of the LL-ILW inventory for Cigeo), and waste containing magnesium in metal form (spent cladding from gas-cooled graphite-moderated reactors).

As for demonstrating that the risks for bituminised waste packages are under control in deep geological repository conditions, particularly in the event of a fire, a four-party (CEA - Andra - AREVA - EDF) programme was carried out between 2013 and late 2014. The conclusions of the programme are detailed in a file comprising 17 technical reports which will be presented to the French national evaluation commission (CNE) in January 2015. The programme studies confirmed the fact that concrete waste disposal packages containing four drums of bituminised sludge remained mechanically sound when subjected to a fire in a conservative thermal environment, i.e. 2 hours at 1 000°C. Heating of the bituminised drums in the concrete disposal packages due to the external thermal flux remains very limited and does not result in self-heating or self-ignition. These results, combined with experiments conducted on a representative scale and thermochemical modelling, corroborate the fact that fire risks are controlled when these packages are placed in a deep geological repository.

As for magnesium-based waste, the CEA continued to develop special cement matrices (mineral geopolymers containing alkaline aluminosilicate binders) for conditioning magnesium cladding from spent graphite-gas reactor fuels.

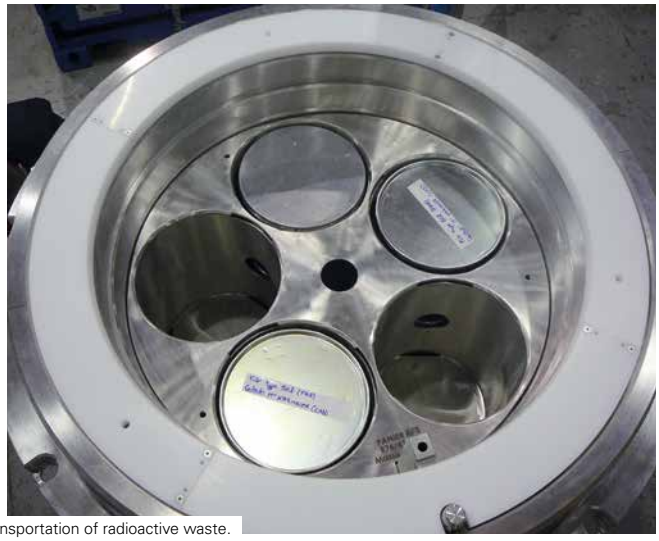
The most recent results for new formulations developed by the CEA significantly reduce magnesium corrosion caused by the binder, thereby considerably reducing the dihydrogen source term to levels compatible with the preliminary acceptance specifications of Cigéo.

SUPPORTING AGENCE ITER FRANCE ON ITER WASTE MANAGEMENT ISSUES

Within the context of the Euratom's commitment to provide an outlet for managing waste generated by the ITER project, the CEA is meeting this commitment through the creation of Intermed. This future facility for the interim storage of waste containing tritium will allow for decay over a period of 50 years, i.e. reduction of the tritium inventory by a factor of about 16 thanks to the natural radioactive decay of tritium which has a half-life of 12.3 years. The project gained much ground throughout 2014, such as the drafting of the safety options report (DOS) for this future regulated nuclear facility which was sent to the ASN in November, with commissioning planned for sometime around 2026. A consultation process was also launched as part of the call for tender to choose the prime contractor for the project, with a final choice expected in January 2015. At the same time, waste package acceptance specifications for the Intermed facility were drafted in collaboration with Andra as part of a strategy to secure the acceptance of such packages into Andra repositories at the end of their interim storage period. Research on complementary solutions is being led simultaneously to further reduce the interim storage period of these tritiated waste packages, along with the surface area required for storage and the storage costs.

(1) Also referred to as ILW-LL, or LL-MLW (for long-lived medium-level waste).

(2) Also referred to as technological waste.



Tirade cask designed for the transportation of radioactive waste.

TRANSPORT

TRANSPORTATION COVERS ALL OPERATIONS AND CONDITIONS RELATED TO THE CARRIAGE OF RADIOACTIVE MATERIALS, FROM THE DESIGN OF TRANSPORT CASKS THROUGH TO THE UNLOADING AND ACCEPTANCE OF WASTE AT ITS FINAL DESTINATION. WITHIN THIS CONTEXT, THE DEN IS IN CHARGE OF DEFINING AND DEPLOYING A FLEET OF TRANSPORT CASKS SUITABLE FOR THE TRANSPORTATION OF ALL TYPES OF RADIOACTIVE MATERIALS FOUND AT THE CEA. THIS TOPIC CAN BE BROKEN DOWN INTO THREE MAIN OPERATIONAL ACTIVITIES: 1) TRANSPORT OPERATIONS, 2) OPERATIONAL AND REGULATORY MAINTENANCE OF THE FLEET OF TRANSPORT CASKS, AND 3) CONSTRUCTION OF NEW TRANSPORT CASKS AND RELATED EQUIPMENT.

OPERATIONAL AND REGULATORY MAINTENANCE OF THE FLEET OF TRANSPORT CASKS

The operational maintenance of transport casks designed to carry radioactive materials and waste is a key issue for the CEA, whether they are used for R&D programmes or for clean-up & dismantling projects. To continuously rise to this challenge in 2014, the DEN consolidated the organisation of this activity, while strengthening coordination between the parties involved and relevant actions from the dismantling of obsolete transport casks, through to the design, construction, approval and reproduction of these casks and their related maintenance requirements. This reinforced organisational structure resulted in the creation of a specially dedicated project.

TIRADE: THE NEW CASK DESIGNED TO TRANSPORT SOFT HOUSEKEEPING WASTE

As part of expanding its fleet of transport casks, the DEN has designed a new cask called Tirade, which is intended exclusively for the transportation of radioactive waste. Its design takes into account all the operational requirements of nuclear facilities (weight, overall dimensions, loading/ unloading method, type of drums to transport, etc.) and complies with the most recent safety case requirements, especially in terms of radiological and explosion risks inherent to the transport of radioactive waste subject to radiolysis or thermolysis.

To do this, innovative developments and specific materials have been harnessed to guarantee, for instance, the robustness of the closing system in the event of an explosion or drop, or the high performance of the biological and thermal shielding required to transport irradiating waste. The year 2014 was marked by the acceptance of four Tirade casks, and the submission of the safety file to the French nuclear safety authority with the target of reaching commissioning in late 2015.

Installing the first stainless steel tank on the waste unloading station for the Stema project at Marcoule.

Artist's impression of the Diadem facility at Marcoule.

NUCLEAR SERVICE FACILITIES

TO MANAGE ITS NUCLEAR MATERIALS AND RADIOACTIVE WASTE, THE CEA RELIES ON A FLEET OF NUCLEAR SERVICE FACILITIES. THESE FACILITIES ARE DESIGNED TO TREAT, CONDITION AND TEMPORARILY STORE NUCLEAR MATERIALS, SPENT FUELS, LIQUID EFFLUENTS AND SOLID WASTE PRODUCED BY R&D PROGRAMMES FOCUSING ON CLEAN-UP AND DISMANTLING. AS THIS FLEET WAS DEPLOYED AT THE TIME THE CENTRES WERE BUILT, THE CEA HAS AGREED TO UNDERTAKE A SIGNIFICANT PROGRAMME OF REFORM WHICH INVOLVES SHUTTING DOWN OLD FACILITIES AND/OR BUILDING NEW ONES, AND REFURBISHMENT) IN VIEW OF ADAPTING TO FUTURE NEEDS AND NEW SAFETY REQUIREMENTS.

FIRST CAMPAIGN TO EVAPORATE RADIOACTIVE EFFLUENTS IN AGATE

The Agate facility at the Cadarache centre is designed to treat the radioactive effluents produced on onsite. It replaces the effluent treatment plant known as INB 37 (built in the 1960s and shut down in 2011), by better complying with the new regulatory requirements.

The Agate facility was commissioned in May 2014. The first campaign to evaporate radioactive effluents in September 2014 proved successful. It confirmed the performance of the evaporator, which had already been validated during a series of non-active tests (evaporation capacity, decontamination factors, capacity to produce the expected distillates, etc.). A second campaign was performed under nominal conditions in November 2014, which confirmed that the facility was fully operational.

TESTING TO SIMULATE A PRODUCTION CAMPAIGN IN THE FUTURE LIQUID EFFLUENT TREATMENT PLANT AT MARCOULE

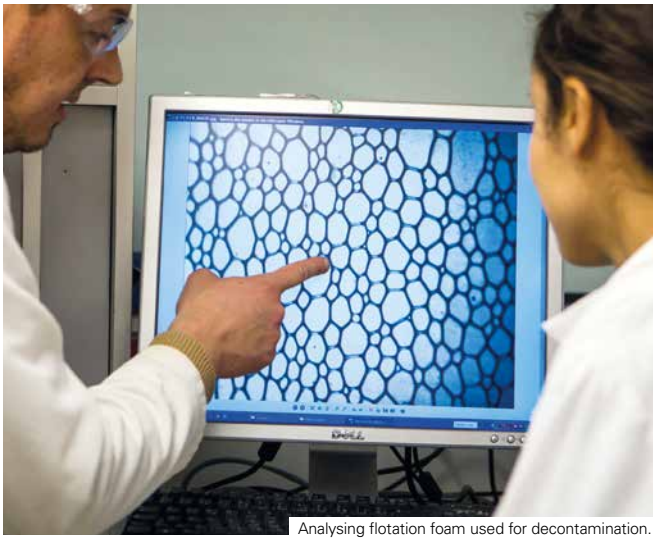
The Stema project is currently underway at the Marcoule centre. The objective of this project is to modify the effluent conditioning process used on low- and intermediate-level waste at the Marcoule treatment plant.

The current process that consists in embedding residues of effluent treatments in bitumen will be replaced by an embedding method that uses a mineral cement matrix. The scope of the Stema project includes the construction of an waste unloading station and that of a cementation building to condition the effluents in cement matrices inside waste drums. The first sludge cementation test was simulated using a prototype platform in April 2014 and proved successful. This 12-hour campaign involved ten successive effluent batches and simulated the nominal production rate of ten 380-litre packages with the aim of testing the new sludge cementation timing chart and a range of different process parameters. The results obtained during this test phase were used to update the facility's process logbook.

DIADEM PUBLIC ENQUIRY

Pending the commissioning of Cigéo by Andra, the Diadem project aims at providing an interim storage facility for highly irradiating radioactive waste and/or for waste containing high concentrations of alpha particles produced by any of the five CEA centres. Within the framework of the facility's licensing process, a public enquiry was organised in June and July 2014 in eleven towns located around the Marcoule site. This enquiry resulted in a unreservedly favourable opinion from the enquiry commission, with the Gard Prefecture granting the building permit for the facility shortly afterwards. The first concrete is expected to be poured in 2015.

Maestro slave arm chosen by MRI to laser-cut corium from the Fukushima Daiichi plant.



Analysing flotation foam used for decontamination.

R&D AND PROMOTION

STRENGTHENED BY ITS EXPERTISE IN CLEANING UP AND DISMANTLING NUCLEAR FACILITIES, THE DEN HAS ORGANISED ITS R&D ACTIONS IN THIS FIELD INTO SIX SUBJECTS:

1) ASSESSING THE RADIOLOGICAL STATUS OF FACILITIES AND SOILS,
2) CHARACTERISING WASTE,
3) CONDUCTING SAFE AND FINANCIALLY OPTIMISED OPERATIONS IN HOSTILE ENVIRONMENTS,
4) DECONTAMINATING STRUCTURES AND SOILS,
5) TREATING WASTE AND EFFLUENTS IN AN OPTIMAL MANNER, AND
6) USING TOOLS AND METHODS FOR COSTING AND MANAGING MATERIALS, WASTE AND TRANSPORT.

FOCUS ON A FEW KEY ACTIONS.

FRENCH DISMANTLING TECHNOLOGIES CHOSEN FOR FUKUSHIMA

Following an international call for tender, the Japanese operators chose the CEA design proposal in partnership with Onet Technologies for the laser-cutting of corium at the Fukushima Daiichi plant using a remote arm with six degrees of freedom called Maestro. This decision was made in February by Mitsubishi Research Institute (MRI) in tandem with the choice of two Japanese proposals.

This is the outcome of a year's of unrelenting work at the DEN in liaison with the Japanese International Research Institute for Nuclear Decommissioning (IRID) responsible for dismantling R&D for the Fukushima Daiichi nuclear power plant. Easy to operate remotely, designed with a high positioning tolerance for cutting heterogeneous layers of materials, and producing few aerosols than most of the thermal techniques available, the process developed by the CEA is particularly well-suited to the conditions existing at the Fukushima Daiichi nuclear power plant.

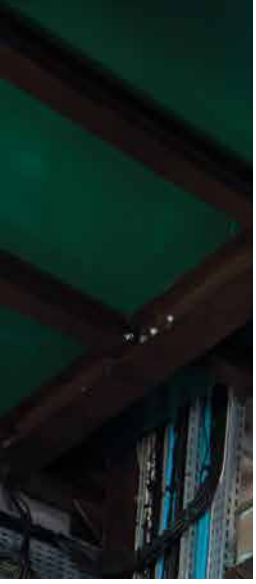
This action not only illustrates the synergy between the four R&D subjects (laser-cutting, knowledge of corium, gas treatments and robotics), but also endorses the role of the DEN in supporting the French nuclear clean-up & dismantling industry in the international arena.

REMEDIATION OF CONTAMINATED SOILS AND EFFLUENTS: PROGRESS IN THE DEMETERRES PROJECT

Launched in 2013, the Demeterres project counts on the involvement of the CEA's life sciences division and several departments at the DEN. It sets out to develop a set of innovative technologies for the remediation of contaminated soils and effluents (mainly caesium-137 and strontium-90). This R&D project with a €19 M budget over 5 years falls within the scope of the "Nuclear safety and radiation protection research" action. For this reason, it is subsidised by the French government via the French national research agency (ANR) under the Future Investments Programme (PIA). Among the key actions carried out in 2014 by the teams at the DEN, it is worth highlighting the development of decontamination processes for debris using supercritical CO_2, the decontamination of soils by particle flotation, a technique that has been validated by tests on contaminated soils in Japan, or the development of new selective absorbers for caesium and strontium used to decontaminate liquid effluents.

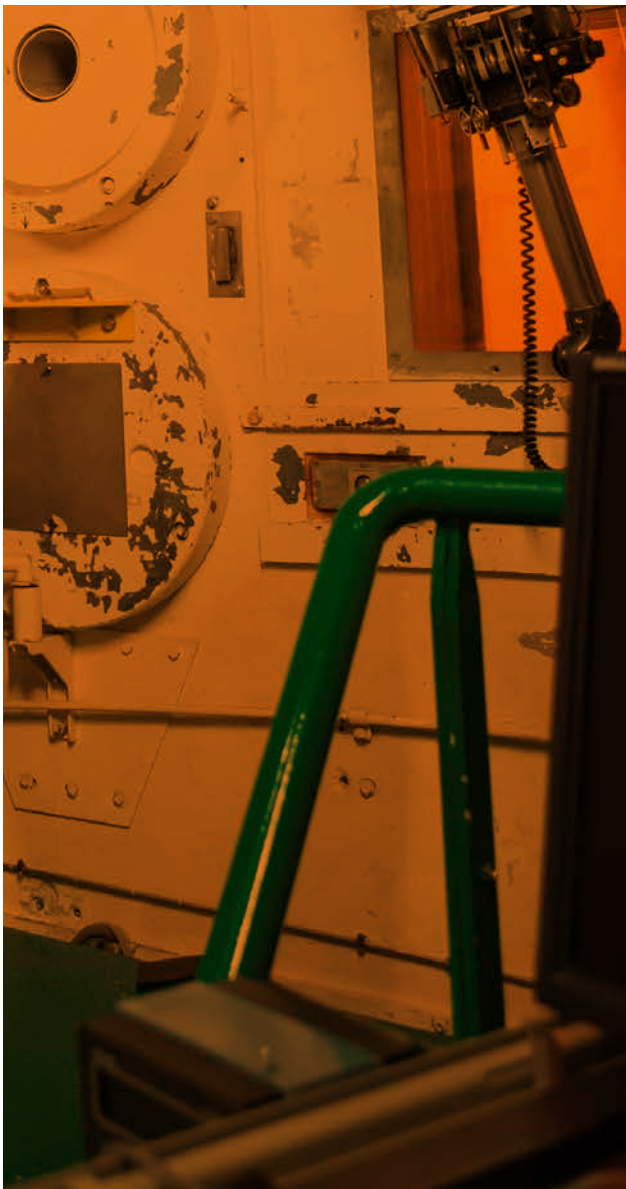
CREATION OF THE CLUSTER FOR THE PROMOTION OF INDUSTRIAL SITES (PVSI)

This cluster was set up in 2014 by the CEA and six other founding members. This centre of excellence sets out to help organise and promote the French clean-up & dismantling services, particularly by providing gateways for French companies so they can easily access opportunities on international clean-up & dismantling worksites. This also implies promoting the skills and experience acquired in nuclear dismantling activities for greater visibility in other economic sectors.



CENTRES

The Nuclear Energy Division (DEN) carries out research activities at three centres: Saclay, which focuses on front-end research, simulation, materials and chemistry; Cadarache, which specialises in reactors and fuels; and Marcoule, which concentrates on the front-end and back-end of the fuel cycle.




Atalante facility in which studies are conducted on the fuel cycle.


Foam for decontaminating polluted soil.

MARCOULE: R&D FOR THE FUEL CYCLE, DISMANTLING, AND TWO KEY PROMOTION PROJECTS DEVOTED TO PROMOTING RESOURCES AND EXPERTISE

THE MARCOULE SITE, FOUNDED IN 1955, IS CURRENTLY HOME TO THE DEN'S PERSONNEL AND RESOURCES INVOLVED IN RESEARCH ON THE NUCLEAR FUEL CYCLE. THE CENTRE ALSO MANAGES LARGE-SCALE CLEAN-UP AND DISMANTLING PROJECTS, AT MARCOULE AND AT THE CEA'S CIVILIAN NUCLEAR CENTRES.

PROGRESS ON THE FUEL CYCLE

At an industrial level, the Marcoule centre has continued with the studies undertaken for AREVA on optimising the operation of the fuel cycle plants, both for the front-end units (mainly the Comurhex conversion plant at Malvési) and for La Hague spent fuel treatment-recycling plant. 2014 also included studies for the selective extraction of uranium for the front-end of the cycle and the assessment of the performance of a very promising optimised process for the separation of uranium and plutonium. Work also continued steadily on studies for the planned polyvalent fuel treatment workshop at the AREVA plant. The planned transfer of the DEN's R&D on MOX fuels from Cadarache to Marcoule was also started. Scheduled to take place from 2015 on, with commissioning in 2017, the main aim of this transfer is to ensure the continuance of this activity and bring it closer to the end customer, AREVA's Melox plant. It will also be an opportunity to strengthen the range of R&D expertise and resources within the Atalante facility. Also supporting AREVA, the Marcoule teams continued their involvement in the development of processes for the design of future fuel cycle plants on an international scale, and on plutonium multi-recycling for 4th generation reactor cycles. Within the framework of fundamental research for the DEN's programmes, the Marcoule Institute for Separation Chemistry (ICSM) carried out a study on the changes to the interface during the dissolution of mixed uranium-based oxides.

In the field of vitrification of waste, in addition to the test campaigns in the reprocessing plants, the experts at the joint CEA - AREVA laboratory carried out several tests on the "Pivic" incineration-vitrification process for the treatment of mixed technological waste (metal and organic waste). The centre also continued its R&D activities on the long-term behaviour of waste packages destined for the Andra's Cigéo deep geological repository. A study was also carried out on changes to irradiated fuel in deep storage conditions.

The Marcoule teams' contributions to the Astrid project focused in particular on building a mock-up of the rotating plug for sealing the reactor core cover.

CLEAN-UP AND DISMANTLING

Significant progress was made on the clean-up and dismantling projects in progress at Marcoule. The main challenge is still to reduce the mobilisable source term in the facilities. The clean-up of two semi-active corridors in the UP1 plant was successfully completed. During the year, full no-load tests were carried out at the premises of an industrial partner, in preparation for the large project for warm dismantling of the dissolver tanks in the plant's "MAR 200" area. Scheduled to be commissioned in 2015, this project combines project engineering, 3D simulation and advanced robotics, with the entry into service of the Maestro robot arm. Finally, also in the context of the UP1 programme, the year was marked by completion of the level 1 dismantling of the "MAR 400" facility.

Cementation studies for waste containing magnesium.

Signature of an agreement around EHI.

The Marcoule centre's work on decontamination processes, stemming from its R&D on clean-up and dismantling, led to the first treatment tests in Japan using flotation foam to treat soil contaminated following the Fukushima accident. This project, called "Demeterres", was selected by the French National Research Agency (ANR) for funding by the French future investments programme. A process to treat organic effluents by hydrothermal oxidation (HTO) was also successfully commissioned in the Atalante facility, in response to the DEN's requirements. Positive results were obtained on the qualification of confinement matrices to take legacy waste from the site and from AREVA.

In terms of regulations, two public enquiries were held in 2014 prior to starting the dismantling of the Phénix sodium-cooled fast reactor and the construction of a facility for storing waste from the dismantling, called Diadem. The investigating commissioners reported "a favourable opinion, with no reservations" from both enquiries.

PROMOTION: TWO KEY PROJECTS

The Marcoule centre moved into a phase of active structuring and increasing its visibility to promote its activities via two flagship projects: the European Hydrometallurgical Institute (EHI) and the cluster for the promotion of industrial sites (PVSI).

The purpose of the EHI is to promote the centre's historical experience in extractive chemistry to the strategic sector for the extraction and recycling of strategic metals. This project is fully in keeping with the French government's industrial recovery plans (recycling-green materials topic), and is in line with the "3S" smart specialisation strategy of the Languedoc-Roussillon region. An initial milestone was passed at the end of the year with the setting up of a European academic network, Prometia, and the completion of the conceptual design phase studies necessary for starting the construction, in 2015, of a "low rate" technological platform (1 l/hour) for industrial companies. This project provides for the setting up of an operating and service company for industrial companies in the sector (mining and recycling companies).

The cluster for the promotion of industrial sites (PVSI) took the form of an association, created in mid-2014. It includes CEA Marcoule and six other founder members. The cluster is very active, with the organisation of "dismantling conferences" and a visible presence at the World Nuclear Exhibition (WNE) which was held in October in Paris. It currently includes a large number of industrial and service companies. Its aim remains to contribute to the structuring of the industry and the French clean-up and dismantling offering. For the CEA Marcoule site, it also involves developing industrial partnerships in the field of clean-up and dismantling that will increase the efficiency of current and future projects through innovation (technologies and methodologies).

The aim of these two projects is to make use of facilities (technological platforms for EHI, technology hall for PVSI) at the Marcel Boiteux regional business park (PRAE), which was developed by the Languedoc-Roussillon region near the site. On 17 July, the DEN and the Languedoc-Roussillon region signed a partnership agreement on this aim of developing the region to create value and employment.

FOCUS ON

AERES EVALUATION

In the first half of 2014, the research and higher education evaluation agency (AERES) published its conclusions following its assessment of the CEA's R&D teams at Marcoule. It highlighted the centre's ability to cover a wide field, ranging from fundamental research to testing processes at pre-industrial pilot facility level, and also the academic influence and attractiveness of the research carried out there.

INAUGURATION OF THE INFODEM EXHIBITION

The Infodem exhibition opened on 19 September: it is an area that is unique in France, devoted to informing the public and companies about clean-up and dismantling. Located in the former G1 reactor, and covering 800 m², it is both informative and educational. The Infodem exhibition is the first display by the cluster for the promotion of industrial sites.

Mock-up supporting qualification of the Molfi devices for the JHR.

Training simulator for the JHR.

CADARACHE: RESEARCH ON REACTORS AND FUELS

CADARACHE IS THE MAJOR EUROPEAN RESEARCH CENTRE DEVOTED TO LOW-CARBON ENERGY: NUCLEAR FISSION AND FUSION, SOLARY ENERGY AND BIOFUELS. THE SITE IS HOME TO A WEALTH OF EXPERTISE AND SKILLS, A WIDE VARIETY OF DEDICATED RESEARCH TOOLS - WITH THREE RESEARCH NUCLEAR REACTORS UNDER CONSTRUCTION - AND TECHNOLOGICAL PLATFORMS THAT ARE UNEQUALLED ANYWHERE IN THE WORLD.

JHR

Initial tests on radio-isotope production equipment

The initial prototype mock-ups of the Molfi device equipment, which will be installed in the pool of the future JHR, have been built. These devices are designed to irradiate uranium targets in order to produce molybdenum 99 which changes through radioactive decay into technetium 99, the most widely used medical imaging tracer. Their development requires out-of-pile qualification of critical components identified during the design phase. Several full-scale mock-ups have therefore been commissioned, including that of a major component for moving the devices according to their different operating positions. The mechanical part was tested for its design and its on-load endurance. Its corrosion-resistance will be tested in 2015.

Commissioning of a training simulator

The initial version of a training simulator was installed. The simulator covers normal, incident and accident operating conditions in the research reactor, including realistic physical neutronics and thermal-hydraulics models. Developed by AREVA and Corys, the teams can use it to learn about the JHR during the construction and commissioning phases, and also to familiarise themselves with part of the facility before drafting the rules and operating instructions and starting the training of the future operators. The purpose of this training is to teach the teams to deal with all conditions and to apply the procedures correctly.

A second version of the simulator, available in 2016, will enable 80 people to be trained to operate the reactor.

RESEARCH REACTORS

Eole

Several important experiments were carried out in the Eole reactor in 2014, including some in context of the Fluole 2 programme, which is part of the studies on extending the service life of EDF's nuclear fleet. Its purpose is to provide a qualification base for the tools for calculating the neutron fluence in a configuration representing the reactors in the French nuclear reactor fleet.

Cabri

The refurbishment of the Cabri research reactor continued in 2014 with the replacement of the sodium loop by a pressurised water loop. This configuration will enable tests representing French PWRs to be carried out. The first test is scheduled for 2016.

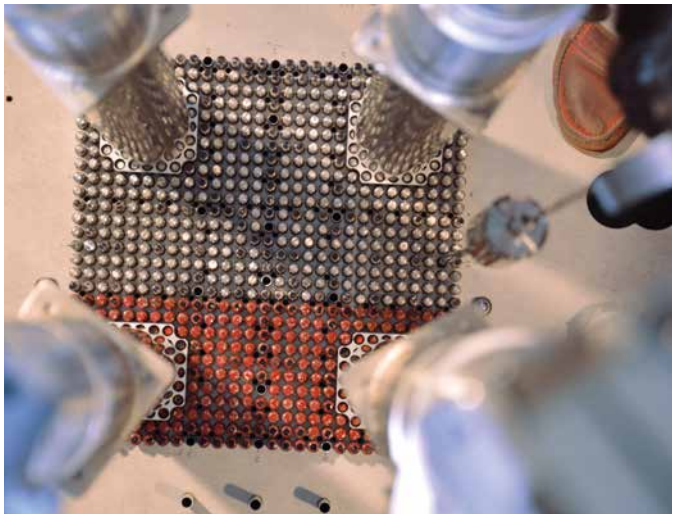
SIMULATION AND MODELLING

Apollo3®: first modelling of the Astrid core

The new Apollo3® multi-system neutronics code, partly developed at Cadarache, has enabled the neutronics simulation of a complete fissile fuel sub-assembly from the Astrid core to be carried out for the first time.

Implementation of a major new version of Alcyone

Version 1.4 of the Pleiades platform Alcyone PWR application for simulating fuel performance was delivered and implemented at the AREVA and EDF industrial partners. It marks a major development as it now incorporates accident conditions.



Eole experimental reactor, in which the experiments in the Fluole 2 programme are conducted.

Thermal-hydraulics platform supporting Astrid R&D.

RESEARCH PLATFORMS

Industrial commissioning of a loop supporting Astrid R&D

Within the framework of the R&D studies supporting the Astrid project, some issues concerning the thermal-hydraulics of sodium cannot be validated simply based on numerical simulations and feedback. An experimental platform has therefore been designed. It combines test devices using a simulating fluid (water), meeting requirements concerning the boiler and core of Astrid in the fields of hydraulics, thermal-hydraulics and vibration analysis during flow. An experimental loop was commissioned on this platform in September. It will take several reduced-scale mock-ups which will be used to measure inaccessible physical values in sodium, to validate the numerical approaches and to study, optimise and validate the concepts of the Astrid components and systems such as its primary system.

Qualification of the sealtightness systems of Astrid's core cover

The DEN now has a machine for qualifying the sealtightness systems of Astrid's rotating plugs as an alternative to the liquid metal seal used on the Phénix and Superphénix reactors. This test mock-up, which is more than 2 metres in diameter (1/3 scale of the cover of the future Astrid vessel), is in the form of plates capable of translational movement and rotation, which can reproduce the operating conditions of the seals so that they are identical to those of the reactor. The qualification will cover various areas: testing the dynamic sealtightness performance and endurance of the rotating seals, development of methods for determining the leak rate which can be used in operational reactor conditions, testing the behaviour of the seals in degraded operating modes, and qualification of the use of a liquid seal for maintenance.

A THERMAL-HYDRAULICS PLATFORM HAS BEEN DESIGNED TO SUPPORT STUDIES ON ASTRID'S BOILER AND CORE.

INNOVATION, SHARING TECHNOLOGIES AND KNOWLEDGE

5th "PACA Region CEA-Industries forum"

This innovation and technology transfer forum for industrial companies, organised on the topic of "Industrial risks and the environment/prevention-protection-treatment" brought together more than 80 industrial companies (small and medium-sized businesses and major groups). Ten of the CEA's innovative technologies were presented to them, seven of which had been developed by the DEN's teams: modelling of pollutant transfers, measurement of complexing power, laser technologies, detection of leaks on pipes, polyarticulated robotic arm, bi-directional filter for decontamination and hydraulic fire protection valve.

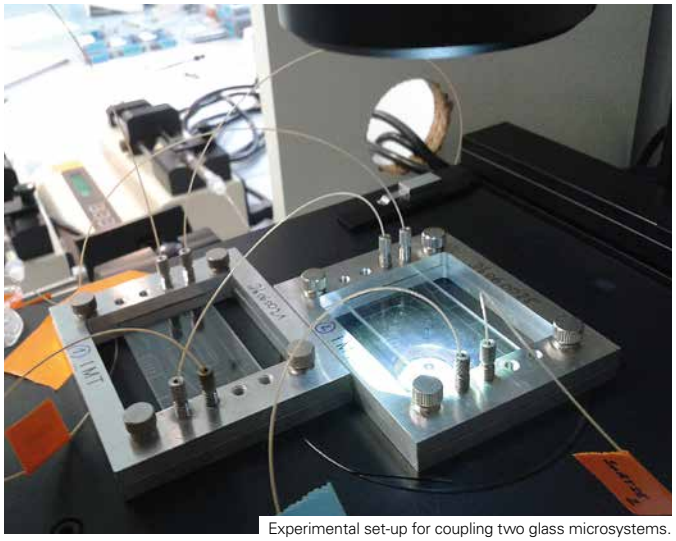
Second "Nuclear medicine in Cadarache" seminar

The objective of this seminar, attended by twice as many participants as the first seminar, was to inform doctors in the PACA Region about R&D activities being carried out at the centre to discuss nuclear and medical practices in research and in the hospital environment, and to present the radio-isotope production capacities of the future JHR research reactor for nuclear medicine (in particular scintigraphy scans).

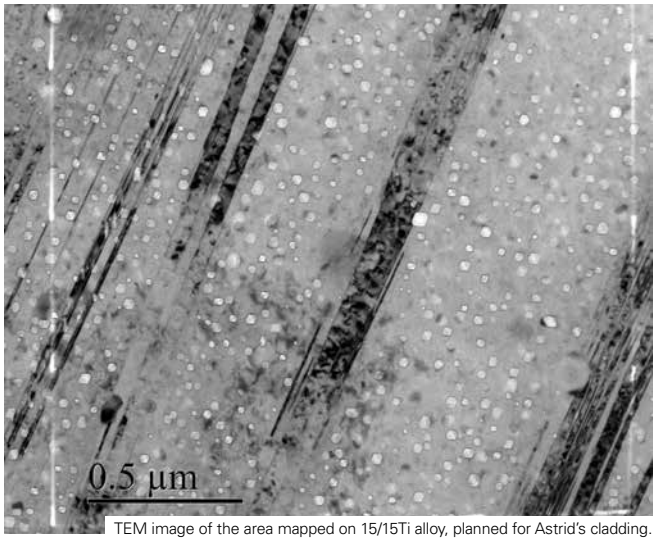
FOCUS ON

COMMISSIONING OF AGATE

2014 saw the commissioning of Agate, the workshop for advanced management and treatment of effluent, the purpose of which is to collect and treat radioactive effluent from the Cadarache centre in order to manage its impact on the environment. Agate transfers radioactive effluent from a transport tank or cylinders to tanks, stores it while awaiting treatment and concentrates it using an evaporation process. Following the receipt of authorisations from the French Nuclear Safety Authority (ASN), it treated the first tank containing 14 m³ of effluent.



Experimental set-up for coupling two glass microsystems.



TEM image of the area mapped on 15/15Ti alloy, planned for Astrid's cladding.

SACLAY: NUCLEAR SCIENCES AND SIMULATING REACTORS AND THE FUEL CYCLE

THE NUCLEAR ACTIVITIES DIVISION OF SACLAY (DANS) COVERS THREE MAIN RESEARCH AREAS: SIMULATION, MATERIALS AND CHEMISTRY.
THE DANS CARRIES OUT TECHNICAL AND ECONOMIC STUDIES FOR THE WHOLE OF THE CEA VIA THE INSTITUTE FOR TECHNO-ECONOMICS OF ENERGY SYSTEMS (I-TÉSÉ).

SIMULATION FOR REACTORS

- The GENEPI+ thermal-hydraulics code is used for 3-dimensional simulation of flows and heat exchanges in steam generators: single-phase flow of the primary fluid inside the steam generator tubes and two-phase flow of the secondary fluid outside these tubes. The initial version of the code was accepted by AREVA NP. During 2015, it will be replaced by the next version, GENEPI2, with which AREVA NP carries out its industrial design and safety studies for steam generators.
- Europlexus is a program for the simulation of fast transient fluid-structure interaction, co-owned by the CEA and the European Commission's Joint Research Centre. It is used to simulate accident transients in reactors. It now has a "high performance calculation capacity" as a result of the development of new algorithms and overcoming obstacles limiting its scalability across large numbers of cores.

R&D FOR 3RD GENERATION REACTORS

As with the first-in-series of the previous stages, the DEN is providing its expertise in neutronics to the operator, EDF, and the designer, AREVA, for the core of the Flamanville-3 EPR, in particular for the physical tests when the reactor is started up and for the first operating cycles. A deterministic neutron calculation sheet, based on the use of the Apollo2.8-4 and Cronos2.12 codes and validated by the Monte-Carlo Tripoli-4 code, can be used to calculate the neutron parameters at zero power and at high temperature for the start-up tests: critical boron concentrations in the moderator and temperature coefficients for various configurations for inserting the control rods into the core, and the efficiency of the control rods (differential and integral, per control rod group or sub-group). This work will be continued in 2015.

R&D FOR THE REACTORS IN THE CURRENT NUCLEAR FLEET

Radiolysis[1] of the water in spent fuel storage pools is being studied to determine the dihydrogen content in the pool hall. The very close agreement between the calculation of the influence of the main parameters (dose rate, temperature, stirring) and the radiolysis experiments carried out using a small cell confirms the relevance of this modelling of the system and validates the results, such as the ratio of approximately 2 to 1 between the dihydrogen H_2 and the dioxygen O_2 that are created, balancing the system and the effect of the temperature.

R&D FOR 4TH GENERATION REACTORS

The study of decay heat removal in accident conditions for Astrid requires precise assessment of the heat flux which may be exchanged via the space between the vessels. A CO_2 laser-heated emissivity measurement bench was specially developed in 2014. The measurements taken at 580°C on samples of 316L steel with different surface conditions were satisfactory. This multi-purpose experimental equipment will enable emissivity measurements to be taken to establish the thermal radiation properties of a wide range of materials.

(1) Decomposition of material by ionising radiation.

(2) Genesis state-of-the-art equipment (Group for study and nanoanalysis of the effects of irradiation).

Elemental and isotopic analysis of uranium and plutonium samples in glove boxes in the LANIE ACTINEO laboratory at Saclay.

R&D FOR THE BACK-END OF THE FUEL CYCLE

Labs-on-a-chip (laboratories on chips) are real "analysis microprocessors" that can be used instead of bulky, expensive instruments. They use channels that are just a few tenths of a micro-metre in size, and only require tiny volumes of fluid (10^{-9} to 10^{-18} litre). Applied to nuclear processes in the broadest sense, these microsystems meet requirements to reduce the volumes used, reduce employees' exposure to radionuclides and significantly decrease the volumes of effluent generated. Liquid-liquid extraction of europium has been carried out in an acid medium by coupling two glass microsystems, and the extraction performance obtained at a macroscopic scale has been improved by a factor of 2.

It is now possible to define, by calculation, microsystem designs that are optimised according to the required type of chemical separation. This will save a significant amount of time in the manufacture of such innovative analytical systems.

EXPERIMENTAL RESOURCES: SCIENTIFIC INVESTMENTS TO MEET PROGRAMME NEEDS

The purchase and development of state-of-the-art scientific equipment to add to the DANS stock and contribute to its standing and attractiveness is continuing. Here are some examples demonstrating this:

- The new ASTAR system, which is now fitted on one of the transmission electron microscopes (TEM) in the DANS, has enabled the first mapping of crystalline phases, after neutron irradiation, of the 15-15 Ti steel planned for the Astrid cladding. This involves in particular understanding, at a nanometric scale, the role of the precipitates in the swelling of the cladding materials for 4th generation reactors under irradiation.
- The initial TEM observations of 6061-T6 aluminium alloy samples irradiated in the Osiris reactor confirm the stability under irradiation of nano-precipitates that are crucial for the mechanical behaviour of this material, which has been chosen for making the vessel-core of the JHR.
- A new radiolysis cell, designed and built in the DANS, will be used to quantify the effect of the radiolysis of water on the corrosion of nuclear materials, in particular zirconium alloys.
- The atomic force microscope (AFM), funded by the Île-de-France region, is a fundamental tribology device. It also opens up new possibilities of nanometric-scale analysis for other application areas, such as corrosion.
- In the context of Equipex Genesis[2], the focused ion beam scanning electron microscope (FIB-SEM) specifically for non-active materials, has enabled a large number of samples to be made for tomographic atom probe (TAP) observation and for transmission electron microscope (TEM) examination. At the same time, the second FIB-SEM, specifically for active materials, is currently operating in a non-nuclear environment before being installed in a shielded cell in the Léci laboratory.

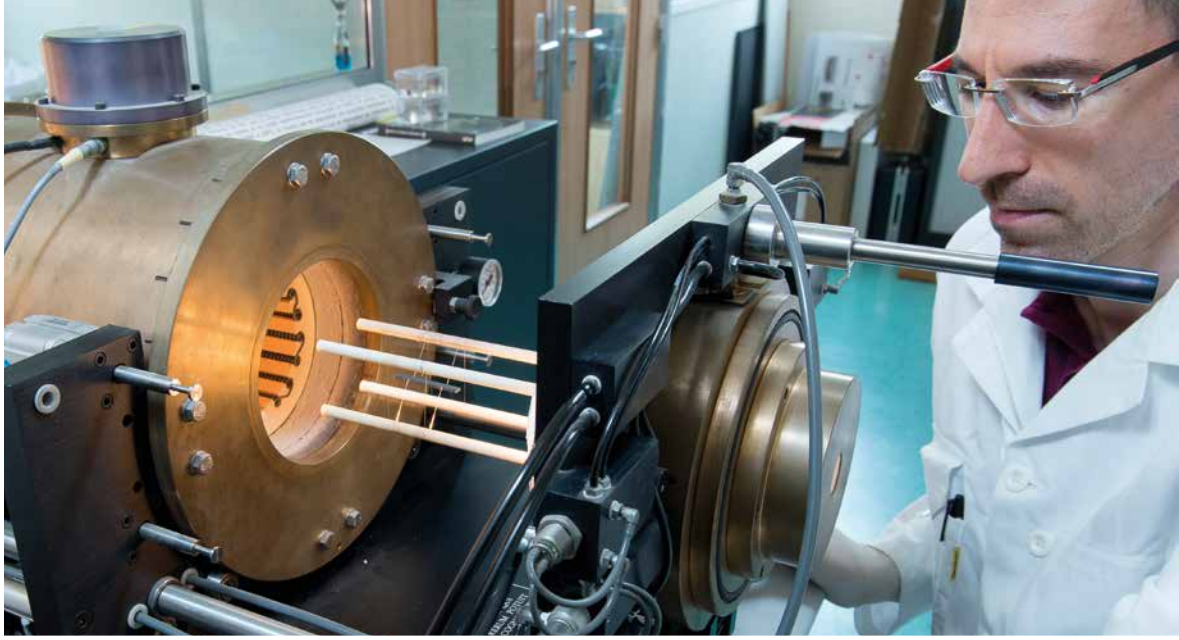
SCIENTIFIC INFLUENCE

- The DANS Isotopic Elementary and Nuclear Analysis Laboratory (LANIE) has been accredited by the International Atomic Energy Agency (IAEA) for isotopic and elemental analyses of uranium and plutonium. It has therefore joined the IAEA's NWAL (Network of Analytical Laboratories) which is dedicated to analyses of samples in the context of its inspection activities in the field of non-proliferation of nuclear materials.
- Three DANS scientists have been awarded a special NASA prize for their exceptional contribution to the building and optimum operation of the ChemCam tool (LIBS technology) equipping the Curiosity Mars exploration robot, and for their contribution to the interpretation of the results obtained. The LIBS technique was developed at the DANS for *in situ* and remote measurement requirements in nuclear systems and hostile environments.
- The DANS is actively involved in the organising bodies defining the MEP department (Mechanics, Energetics and Processes) of the future Paris-Saclay University. It has a presence in this department through six sections and represents more than 40% of the research staff.

FOCUS ON

THE DEN AND RTE SIGNED A COLLABORATION AGREEMENT.

In October 2014, the DEN and RTE (French grid operator) signed a multi-year collaboration agreement on the behaviour of materials. The objective of the R&D studies carried out by the DANS will be to improve knowledge of the ageing processes of materials in the components of the RTE grid so that maintenance activities can be optimised.



PROGRAMME SUPPORT AND EXTERNAL RELATIONS

The DEN has set up an organisation to support its programmes, which includes the Cross-disciplinary Programme on Advanced Materials, the Scientific Division, the International Relations Unit, the Quality and Environment Division and the Institute for Techno-Economics of Energy Systems. All these units contribute to the success and visibility of the DEN's work.

Fractrography of a vapour phase deposit of tungsten on a copper, chromium and zirconium alloy in the context of the West project.

Hybridisation of laser pyrolysis with magnetron sputtering for creating nanostructured coatings in a single step.

CROSS-DISCIPLINARY PROGRAMME ON ADVANCED MATERIALS

DURING 2014, VARIOUS OPERATIONS TO ENHANCE THE CEA'S VISIBILITY AND EXTERNAL REPRESENTATION, TOGETHER WITH STRATEGIC DISCUSSIONS AND COORDINATION, WERE CONDUCTED UNDER THE CROSS-DISCIPLINARY PROGRAMME ON ADVANCED MATERIALS (PTMA).

DEVELOPMENT PLANS AND CHALLENGES

In order to maximise its impact on the CEA's programmes, the PTMA has focussed its activities for a number of years on four integrated development plans:

- High-performance metallurgy;
- Surface engineering;
- Nanomaterials technology;
- Structured composites and materials.

The objectives of these development plans are in particular to:

- Develop robust processes and the means to control them using scaling laws (monitoring, simulation);
- Review the technologies regularly;
- Assess emerging processes;
- Invent new industrialisable processes.

SUPPORT FOR THE METALLURGY SECTOR

In 2014, in the context of its task to represent the CEA externally, the PTMA was a member of the French national metallurgy steering committee. Set up by the French ministry for higher education and research, this committee produced a report on the changes required to revitalise metallurgy in France. In 2014, the CEA also served on the forward planning committee and was then involved in setting up the Lorraine region Institute of Metallurgy in Val de Fensch, in line with the wishes of the President of the French Republic. This institute was set up as a public interest group, MetaFensch, of which the CEA is a founder member.

HIGHLIGHTS

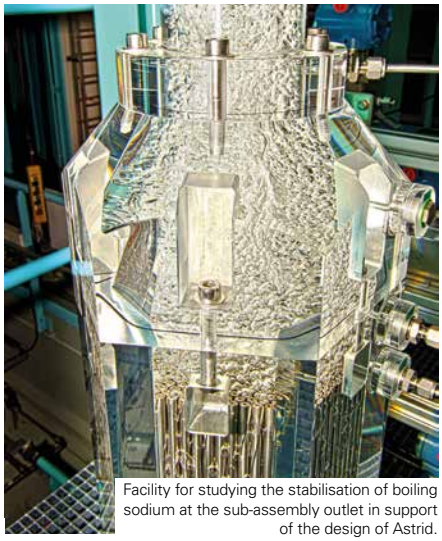
One of the highlights in the field of materials was the setting up of the first internal CEA network on additive manufacturing. The PTMA was also involved in setting up a thematic committee on additive manufacturing within the French Society for Metallurgy and Materials (SF2M) to organise and coordinate this emerging activity nationally.

With regard to the development of materials for fusion, the PTMA has achieved qualification of the physical vapour deposition process (PVD) for thick tungsten coatings on technological prototypes in the context of the West project (ITER project test bench). It has also successfully produced gradient components made of tungsten/copper using Spark Plasma Sintering and tested them under flux.

In the context of the development of high-potential new generic "Nanosafe-by-Design"[1] processes, the Iramis Institute at the CEA's Physical Sciences Division (DSM) finalised the production of the first prototype which couples laser pyrolysis for synthesising nano-objects with magnetron PVD technology. This work involves the creation of nano-composites by choosing the type of nano-objects and that of the matrix independently. In addition, the *in situ* generation of nanoparticles provides a "safe-by-design" process without ever having to handle nanopowders. This technology, which is very promising for a large number of fields (photovoltaics, solar thermal and self-healing materials for extreme environments), will be extrapolated to pilot scale in the HYMALAYAN project, which was approved by the French National Research Agency in 2014 and is due to start in the third quarter of 2015.

(1) Minimisation of the risks of nanomaterials at the product design stage.

The DEN Scientific Advisory Board



Facility for studying the stabilisation of boiling sodium at the sub-assembly outlet in support of the design of Astrid.

DEN SCIENTIFIC ACTIVITIES

THE SCIENTIFIC DIVISION IS RESPONSIBLE FOR THE DEN'S OVERALL SCIENTIFIC STRATEGY. ITS PRIMARY TASKS COVER SIX MAIN AREAS: RELATIONS WITH THE HIGH COMMISSIONER FOR ATOMIC ENERGY, PROMOTION OF THE DEN'S SCIENTIFIC AND TECHNICAL EXPERTISE, ORGANISATION OF THE INTERNAL CHECKING OF ITS UNITS, IDENTIFICATION OF THE MAJOR SCIENTIFIC CHALLENGES TO BE ADDRESSED, PROMOTION OF THE DEN'S SCIENTIFIC PRODUCTION, AND LIAISON WITH UNIVERSITIES.

SCIENTIFIC ASSESSMENT

CEA Scientific Advisory Board

On 15 and 16 December 2014 the CEA's Scientific Advisory Board examined the organisation's research on "material science for low-carbon energy". The DEN contributed to this with five presentations: materials under irradiation, micro-mechanics, ceramics and cladding materials, waste management materials and corrosion.

DEN Scientific Advisory Board

From 20 to 22 October 2014, the DEN's Scientific Advisory Board assessed research activities on severe accidents in light water reactors and fast reactors, and the associated experimental resources. The following topics were investigated: corium management inside and outside the reactor vessel for light water reactors, corium-water interactions, and management of severe accidents in fast reactors, focussing on those cooled with sodium. The Scientific Advisory Board underlined the high quality of the technical presentations, in particular those on hydrogen management and in-vessel corium retention. In particular it recommended the establishment, together with industrial partners, of a roadmap detailing the medium- and long-term national research objectives. The recommendations also underline the need to continue work on validating models and codes in view of the challenge of improving the reliability of the strategies for corium management in PWRs (inside and outside the reactor vessel) and in sodium-cooled fast reactors (SFR), starting with the Astrid demonstrator.

AERES assessments

The research and higher education evaluation agency (AERES) assessed the research work of eight departments at the Saclay and Marcoule centres: the physical chemistry departments (DPC; including the LAMBE, UMR 8587 at the Evry-Val d'Essonne University), the nuclear materials department (DMN), the systems and structures modelling department (DM2S), the radiochemistry and processes department (DRCP), the fuel cycle technology department (DTEC), the waste treatment and conditioning department (DTCD), the Institute for Techno-Economics of Energy Systems (I-tésé) and the Marcoule Institute for Separation Chemistry (ICSM).

NUCLEAR EDUCATION AND TRAINING

The DEN passes on the knowledge and expertise it has developed by making a significant contribution to education on nuclear science and the associated technologies, mainly in France but also through international training courses. This contribution, in response to the nuclear industry's recruitment requirements and to increase the standing of the nuclear industry, focuses mainly on strategic training courses at fifteen or so higher education establishments at the Paris-Saclay University and more widely in the Île-de-France region, and at the Academies (education authorities) in the Montpellier, Grenoble and Aix – Marseille regions, and in north-west France. In 2014, some 500 of the DEN's staff delivered around 10,000 hours of training, the majority of which was for the National Institute for Nuclear Science and Technology (INSTN). Three-quarters of this contribution was for degree courses, while the other quarter was for vocational training.

Laboratory studying leaching of glass.

FOCUS ON

MONOGRAPHS

A monograph on "sodium cooled nuclear reactors" was published in 2014. In addition to the history of this technology and a description of French experience in the field, this monograph details the design principles of these reactors, highlighting their advantages. It concludes with an overview of current projects and a technical and economic chapter analysing the implementation prospects for these reactors.

SCIENTIFIC ACTIVITIES

Scientific publications

During 2014, DEN researchers produced:

- 475 scientific papers in peer-reviewed journals;
- 151 of the above papers were co-written with other international research laboratories.

PhD students, post-doctoral students and researchers authorised to supervise university research (HDR)

In 2014, a particularly active search for co-financing led to an appreciable increase in the number of new PhD students joining (82) - up 10% on 2013. The DEN is also continuing its policy of encouraging researchers to obtain authorisation to supervise university research (HDR). 17 new HDR accreditations were obtained in 2014, bringing the total number of accredited university research supervisors at the DEN to 106, to which 19 PhDs must also be added.

Basic nuclear training (FNB)

The SPIRALE-FNB training scheme provides all new recruits with cross-disciplinary scientific and technical knowledge and gives researchers and engineers a general basic nuclear knowledge of the research topics being studied within the DEN. In 2014, 22 participants at Marcoule, who had already completed levels 1 and 2, attended the level 3 training, comprising eight weeks of courses, conferences and visits to facilities spread out over the year.

EXPERTISE WITHIN THE DEN

The experts programme

The CEA has been running its experts programme since 2009. Its aim is to increase the visibility of its top-level scientists. The DEN currently has 67 level 4 experts (research directors and international experts) and 233 senior experts on its staff. These experts are scientific advisors in their fields. They are called upon when necessary to respond to specific requests from within the organisation, and they help to increase the standing of the DEN outside the CEA.

Scientific seminars

The Scientific Division regularly organises seminars to provide information on important scientific questions for the DEN and its research strategy in order to guide future research choices. In 2014, the following five seminars were led by experts from the DEN:

- R&D for clean-up and dismantling;
- Leaching of radioactive glass;
- Severe accidents in PWRs and SFRs;
- Maintaining skills in the design, operation and safety of water reactors;
- Uncertainties in neutronics.

2014 INCLUDED SIGNIFICANT CONTRIBUTIONS TO THE PRODUCTION OF A SUMMARY REPORT ON ENERGY SCENARIOS.

Technology watch

Literature monitoring activities continued, with the support of Saclay's information development section, on the following subjects: water reactor technology, extraction chemistry, analytical chemistry, steels under irradiation, decontamination, high temperature treatment, treatment of effluent, SFR technology, safety of reactors and pools, and numerical simulation applied to neutronics.

Involvement in ANCRE

The DEN is actively involved in the work of the French national alliance for energy research coordination (ANCRE) through its leadership of the "Nuclear energy" group and the involvement of I-tésé in the "Summary and prospects" group. 2014 included major contributions to the production of a summary report on the energy scenarios studied in the context of the national debate on energy transition, the production of a roadmap on "reactor physics and numerical simulation", and also prospective technical and economic studies on the potential contribution of nuclear energy for the cogeneration of heat for urban heating and for industry.

The ANCRE's energy scenario studies helped to show the need for technological breakthroughs so that France can achieve its objective of a four-fold reduction in its greenhouse gas emissions.

Tasks initiated by the High Commissioner

The DEN is well represented within the High Commissioner's office, with the involvement of a number of its experts: Sages committee, operating committee and senior advisors. In 2014 several DEN experts contributed to analysis tasks defined by the High Commissioner, which included the following subjects: numerical sciences and supercomputing, radiolysis, thermal-hydraulics and neutronics.

Scientific and technical seminar on the JHR.

THE DEN AND THE INTERNATIONAL SCIENTIFIC COMMUNITY

THE DEN COOPERATES WITH MOST MAJOR NUCLEAR COUNTRIES. THE ISSUES FOSTERING SUCH COOPERATION ARE NUMEROUS: ISSUES OF NATIONAL INTEREST WHEN REQUESTED BY THE GOVERNMENT, WHICH MAY ENCOURAGE STRATEGIC PARTNERSHIPS WITH OTHER COUNTRIES THAT COVER NUCLEAR MATTERS; SCIENTIFIC OR TECHNICAL ISSUES, INVOLVING INTERNATIONAL COOPERATION IN AREAS OF EXPERTISE WHICH COMPLEMENT THOSE OF THE DEN; ECONOMIC ISSUES, WHEN THE DEN OFFERS ITS SERVICES TO FOREIGN INDUSTRIAL PARTNERS OR IS LOOKING FOR FOREIGN INVOLVEMENT IN ITS INVESTMENT IN RESEARCH INFRASTRUCTURES. IN PARALLEL WITH ITS INTERACTION WITH THE MAJOR COUNTRIES, DESCRIBED BELOW, THE DEN ALSO MAINTAINS RELATIONS WITH NUMEROUS OTHER COUNTRIES, INCLUDING TURKEY, MOROCCO, ARGENTINA, SOUTH KOREA AND KAZAKHSTAN.

UNITED STATES

The DEN has maintained institutional cooperation within the framework of an agreement with the US Department of Energy (DOE) that was renewed in 2012. The agreement covers future reactors, advanced fuels, waste, advanced fuel cycles, separation processes and simulation. This cooperation has led to exchanges of information and short visits of staff on clearly identified technical subjects. It also led to the signing of a framework agreement in 2013, setting out the DOE's involvement in the Astrid project, following its initial positive assessment of the safety of the Astrid core.

GREAT BRITAIN

Great Britain's decision to resume its nuclear programme opens up new prospects for the DEN, the first of which will be the British National Nuclear Laboratory's (NNL) membership of the JHR consortium, with its acquisition of 2% access rights. The NNL has also expressed an interest in cooperating on the DEN's major R&D programmes, and in particular the Astrid programme. Following the signing of a cooperation agreement in January 2014, the DEN and the NNL are continuing discussions to define a technical roadmap on Astrid in 2015. In the field of dismantling, discussions with the Nuclear Decommissioning Authority (NDA) are continuing with the joint aim of defining priority actions of mutual interest, and in particular feedback from worksites.

INDIA

Though limited to basic research and safety, cooperation with India enables the DEN to benefit from the dynamism of India's programme, in particular in the field of the safety of fast reactors, as India is developing the Prototype Fast Breeder Reactor (PFBR), a 500 MWe sodium-cooled fast reactor (SFR). The other aspect of the cooperation concerns the JHR project in which India has acquired a 2% share, and in-kind collaboration (development of Cloé, an irradiation loop for studying corrosion). At the end of 2014, India also expressed its interest in involvement in the PLINIUS2 investment, an experimental platform for testing the behaviour of corium in various different configurations.

ISRAEL

Cooperation with Israel was resumed in 2010 with the signing of a Memorandum of Understanding (MoU). Israel is very dynamic in the fields of basic and applied research, including the contribution of the Israel Atomic Energy Commission (IAEC) to the JHR consortium, the in-kind part of which (the Lorelei loop, designed for testing a loss-of-coolant accident in the JHR) is progressing well.

JAPAN

Relations with Japan cover three main topics: the Astrid programme, reprocessing, and clean-up of the Fukushima Daiichi nuclear power plant. A general agreement on Astrid was signed in May 2014 between the CEA and two Japanese ministries (the METI and the MEXT), and an implementing agreement was signed in August 2014

FOCUS ON

CHINA

Cooperation with China has been restructured to move towards shared projects and away from a simple training approach supporting industrial projects. Dynamic cooperation covers three topics: R&D on SFRs (China is also carrying out projects in this technology), ageing of materials and safety of PWRs (hydrogen risk). This cooperation will doubtless be stepped up later in the process, with the prospect of the sale of a spent fuel treatment and recycling plant by AREVA to the China National Nuclear Corporation (CNNC).

Visit to the Taishan EPR (China).

between the CEA, AREVA, the Japanese Atomic Energy Agency (JAEA), Mitsubishi Heavy Industries (MHI) and Mitsubishi FBR Systems (MFBR). Active discussions are continuing and could lead to Japan having an even greater involvement in Astrid. Discussions on reprocessing and support for the start-up of the Rokkasho-Mura plant with Japan Nuclear Fuel Limited (JNFL) led to the signing of a trilateral MoU with AREVA, and a bilateral CEA-DEN agreement which will form the framework for the potential provision of services. Finally, the DEN has been called upon as an expert, a supplier of R&D services, directly or with an industrial partner and as a point of contact with industrial companies for the Fukushima clean-up. For example, an agreement was signed in 2014 with the JAEA on the interaction between corium and concrete and the characterisation of the molten cores at Fukushima. From an organisational point of view, a structure for managing the R&D on dismantling was established in August 2014 within the Nuclear Damage compensation and decommissioning Facilitation corporation (NDF). A MoU was signed between the CEA and the NDF for discussions on these fields.

AN AGREEMENT WAS SIGNED IN 2014 WITH THE JAEA ON CORIUM-CONCRETE INTERACTION AND THE CHARACTERISATION OF THE MOLTEN CORES AT FUKUSHIMA.

RUSSIA

Cooperation with Russia, which was resumed in 2010, mainly concerns the development of SFRs. It covers both R&D on Astrid (use of Russian irradiation resources and the BFS mock-up during the Masurca work) and technical design studies for a joint SFR, the "RFFR" (Russian-French Fast Reactor). 2014 included the continuation of tests on BFS, the irradiation of materials in BOR-60, the joint feasibility study for "prototype" irradiation of an Astrid pin bundle in the BN-600 reactor, and further discussions with the aim of finalising the "conceptual technical view" of the RFFR. The agreement with the Kurchatov Institute on clean-up and dismantling was also renewed at the end of 2014 and discussions continued with the nuclear safety institute of the Russian academy of science (IBRAE).

CENTRAL EUROPE

The V4G4 consortium consisting of Hungary, Slovakia, the Czech Republic and Poland was set up in 2013 with the aim of establishing a Central European nuclear R&D centre devoted to R&D on gas-cooled fast reactors (GFR). This consortium will initially focus on the development of new skills for which each of the institutes in these four countries will focus on a particular topic. This will constitute the necessary basis for conducting the R&D programme on Allegro, a small GFR. The DEN is currently working with the four institutes on the development of the technical roadmap defining the basic components of the Allegro R&D programme.

Poland has also expressed an interest in R&D on the very high temperature nuclear reactor (VHTR) in the field of cogeneration.

EUROPEAN COMMUNITY

In 2014, European Community actions mainly concerned the JHR, preparing technical and financial information required for signing the European contract whose principle is contained in the Euratom 2014-2015 programme, and on the ARDECO (Astrid R&D European Cooperation) project in which several European R&D institutes may be involved. This project illustrates the desire to share R&D on the nuclear industry of the future at a European level, with the aim of optimising the financing of the programmes.

DEN INVOLVEMENT IN MULTILATERAL INITIATIVES

The DEN plays a very active role in the European Sustainable Nuclear Energy Technology Platform (SNETP) which is dedicated to nuclear fission, the Generation IV International Forum (GIF), and the International Atomic Energy Agency's (IAEA) International Project on Innovative Nuclear Reactors and Fuel Cycles Forum (INPRO). It has a key role within these bodies. Within the SNETP, the DEN has been involved in the establishment and organisation of the joint research areas, such as the European Sustainable Nuclear Industrial Initiative (ESNII, on sustainable 4th generation nuclear technology) and NUGENIA (R&D initiative on 2nd and 3rd generation reactors). It contributes to major discussions within the GIF, in particular on safety. It has also applied for IAEA designation of its R&D facilities as International Centres of Excellence based on Research Reactors (ICERR), open to the European Community.

Sécuriden day 2014: conference on cybersecurity at Saclay.

QUALITY WITHIN THE DEN

THE DEN IS FIRMLY COMMITTED TO THE QUALITY-DRIVEN MANAGEMENT OF ITS ACTIVITIES. IT HAS SET UP A DEDICATED ORGANISATION, CONSISTENT WITH ITS OPERATIONAL STRUCTURE, TO STREAMLINE ITS PROCEDURES AND CONTINUALLY IMPROVE ITS MANAGEMENT EFFICIENCY, WHILE DEVELOPING ITS CROSS-DISCIPLINARY ACTIVITES AND ENSURING THAT BEST PRACTICES ARE USED AT ALL SITES WHERE IT OPERATES. THE TRIPLE QUALITY, SAFETY AND ENVIRONMENT (QSE) CERTIFICATION OF THIS ORGANISATION, OBTAINED IN 2013, WAS CONFIRMED IN 2014.

SAFETY OF PEOPLE AND NUCLEAR SAFETY WITHIN THE DEN

Although the CEA does not assign direct responsibility for safety to the senior management who run its operational divisions, the DEN is constantly focused on making improvements in this area and has made it a top priority. Its aim is to establish and maintain a culture of personal and nuclear safety in its teams and the suppliers who work in its facilities.

To this end, the DEN organises "Sécuriden" each year at the centres where it is present. This is an event to raise safety awareness in staff, CEA employees and external contractors.

In 2014, it took place on 7 October and focused on the prevention of musculoskeletal problems, protection of the environment by means of the relevant regulatory provisions and tools developed by the DEN, and cybersecurity. In addition to the formal sessions based on presentations by specialists, scenarios illustrating situations likely to cause accidents or medical problems, workshops in the facilities and conferences with external participants helped to raise employees' awareness of these risks.

THE DEN'S AIM IS TO ESTABLISH AND MAINTAIN A CULTURE OF PERSONAL AND NUCLEAR SAFETY IN ITS TEAMS AND ITS SUPPLIERS.

The number of work-related accidents in 2014 remained at the same level as in 2013 for CEA staff and fell for contractors. Travel and accidents described as non-work-related still account for the majority of absences. The number of significant events involving safety, radiation protection or the environment remained at the same level as previous years. Eleven of these had a detectable impact on staff or the environment.

In the context of additional safety assessments (ECS) carried out following the Fukushima accident, the DEN has formalised the organisation of the nuclear rapid response force (FARN) at its Cadarache and Marcoule centres. This organisation was tested during an exercise at the Cadarache centre. Construction work has also started on the new emergency response centre at Cadarache.

PROTECTION OF NUCLEAR MATERIALS

The DEN must ensure that the nuclear materials it uses in its R&D programmes are protected against theft and improper use. This protection is defined according to specific regulations which have recently been updated. Industrial companies which have such materials therefore have to review this protection by means of safety studies of their sites and facilities. The first safety studies were carried out in 2014 and priority work to improve protection was started.

Sécuriden day 2014: visit to a conventional waste management facility at Cadarache.

MANAGEMENT OF CONFIDENTIALITY, AND SECURITY OF INFORMATION SYSTEMS

Subject to the requirement for openness to international collaborations, the DEN continued its confidentiality management action plan to respect the confidentiality of its industrial partners and to protect its own scientific and technical assets.

To deal with the growing threat of the acquisition or improper use of information, the DEN has set up identification procedures within its projects for subjects with high added value for the CEA or its industrial partners, and specific rules for the management of information on these subjects. These rules, similar to those which apply to subjects concerning national defence or the protection of the CEA's facilities, cover the management of documents and the use of computer equipment.

The information protection levels may themselves change, depending on the changing context of the projects concerned. In 2014, to ensure that the protection requirements are as appropriate as possible for these changes, the DEN set up a classification and declassification committee which makes sure that project managers correctly identify the subjects to be protected. If necessary, the committee revises the classification of documents and data media for which the classification is no longer appropriate.

The DEN also continued implementing the measures required to comply with the new regulations on the protection of French national scientific and technical potential (PPSTN).

DEN CONTRIBUTION TO NUCLEAR STANDARDISATION

In order to optimise the implementation of future 4th generation nuclear systems, it is essential to draw up appropriate standards for the design and construction of these systems.

The DEN is therefore carrying out a great deal of work in this area, with significant involvement of the R&D teams, in particular those working in the fields of materials and mechanical engineering.

THE DEN CONTINUED ITS SUPPORT OF THE AFCEN'S POLICY OF OPENNESS TOWARDS OTHER OPERATORS, MANUFACTURERS AND RESEARCH ORGANISATIONS, IN FRANCE AND ABROAD.

The DEN continued its support of the policy of openness, advocated by the French association for the rules governing the design, construction and operational supervision of equipment for nuclear steam supply systems (AFCEN), towards other operators, manufacturers and research organisations, in France and abroad. It was involved in this process in 2014, taking on the chairmanship of a European Committee for Standardization (CEN) workshop, on behalf of the AFCEN. The objective of the workshop is to define the required adaptations of the codes for their potential users in Europe.

FOCUS ON

SAFETY PRIORITIES

Top-priority safety objectives (OPS) are actions and work that the CEA must carry out as a matter of priority over a ten-year period to eliminate situations resulting from the past, which are unsatisfactory in terms of future requirements. Over the current period, 26 OPS have been identified. They cover:

- *The re-conditioning and removal of legacy radioactive waste and effluent in particular at Saclay and Grenoble;*
- *The reduction of the source term of facilities which no longer comply with the current earthquake design standards, and even, where necessary, the replacement of these facilities.*

At the end of 2014, 21 OPS had been completed, in line with the schedule. Discussions are currently taking place with the ASN to continue this approach over the next ten-year period.

The Cabri reactor building, after the seismic reinforcement work (2010)

Retrieval of low dose rate bulk waste from pit no. 3 of INB 56 (2011)

End of removal of Masurca fissile material from storage (2014)

SFEN 2014 convention: round table on the economic and technical challenges of the long-term operation of nuclear power plants.

FOCUS ON

6TH I-TÉSÉ SYMPOSIUM

The 6th I-tésé symposium, on the topic of energy forecasting methods, practices and results was attended by over a hundred people.
It followed on from the 2013 symposium which focused on energy transition.

I-TÉSÉ

THE INSTITUTE FOR TECHNO-ECONOMICS OF ENERGY SYSTEMS (I-TÉSÉ) CONDUCTS MACROECONOMIC AND MICROECONOMIC STUDIES IN SUPPORT OF CEA R&D PROGRAMMES.

PROSPECTIVE STUDIES ON NUCLEAR ENERGY

As part of the tripartite work with AREVA and EDF, I-tésé carried out a technical and economic study putting forward various industrial scenarios for the long-term development of the French nuclear fleet, with deployment of fast reactors. This analysis required the identification of scenarios detailing changing uranium prices up to 2150.

CONTRIBUTION TO ANCRE SCENARIOS

I-tésé was also heavily involved in the "scenarios" report by the French national alliance for energy research coordination (ANCRE) published in January 2014, which details the assumptions and consequences of the energy transition scenarios. The report shows that although CO_2 emissions can be reduced four-fold, this reduction would require a considerable effort and very dynamic R&D activity, irrespective of the scenario chosen. The Institute was also involved in the ANCRE's preparatory work on the national research strategy, making use of the outlooks provided by these scenarios, with a view to discussion of the law on energy transition.

HIGHLIGHTS

In 2014, I-tesé:

- Established the profitability of the current fleet of reactors and the extension of their service life.
- Played an important role within the Saclay Research Centre, contributing to the operation of the scientific bodies (department of humanities and social sciences and the Academic Senate).
- Published the Elecnuc and Memento on energy booklets, summarising the key figures on energy, in particular nuclear energy.
- Contributed to the study *Uranium 2014: Resources, production and demand,* also referred to as the "Red Book", prepared jointly by the OECD's Nuclear Energy Agency (NEA) and the International Atomic Energy Agency (IAEA).
- Organised I-tésé meetings with François Lévêque, Professor of Economics at the École nationale supérieure des Mines engineering school in Paris, on the topic of "Four controversies on nuclear power" and Michèle Pappalardo, Senior Advisor to the National Court of Accounts on the topic "The National Court of Accounts and the cost of nuclear electricity.
- Strengthened its international role, in particular within the OECD/NEA, with its membership of the Nuclear Development Committee.
- Been favourably assessed by a committee of the research and higher education evaluation agency (AERES).
- Organised the round table at the annual convention of the French Nuclear Energy Society (SFEN) focussing on the economic and technical challenges of the long-term operation of nuclear power plants.
- Presented its work at the 13th World Renewable Energy Congress in London.
- Taken part in the World Hydrogen Energy Conference in South Korea and attended the Energy Systems Conference (ENER) in London.

Photos: CEA; F. Nguyen/CEA; PF. Grosjean/CEA; S. Le Couster/CEA; ITER Organization;
G. Lesénéchal/CEA; F. Rhodes/CEA; E. Stanislas/CEA; P. Stroppa/CEA; FGUP NITI; J. Vasquez/OTND; RTE
Médiathèque/Aldo Sperber; SFEN; Synchrotron SOLEIL.

Design and production: Obea communication
This report is printed on paper from sustainably managed forests.

IMPRIM'VERT®

Nuclear Energy Division
CEA Saclay Centre
91191 Gif-sur-Yvette Cedex

www.cea.fr

Communication contact: alexandra.bender@cea.fr