FROM RESEARCH TO INDUSTRY

cea

Nuclear Energy Division

2013 Activity Report

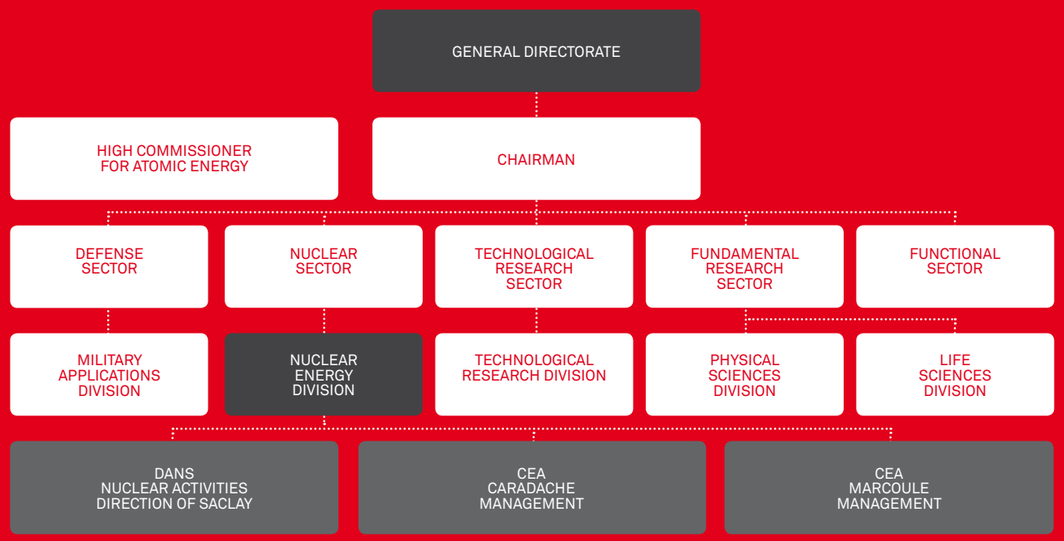
Profile

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

To rise to this challenge, the DEN is engaged in three main areas of investigation:

- future nuclear systems: 4th-generation reactors and their fuel cycle;
- optimising the current nuclear industry;
- development and operation of large-scale experimentation and simulation tools that are essential for its research objectives.

At the same time, as a nuclear operator, the DEN manages and develops its own fleet of nuclear facilities. It implements construction and refurbishment programmes for its facilities, together with clean-up and dismantling programmes for those that have reached the end of their service life.



Contents

Message from Christophe Béhar

CEA Director of Nuclear Energy

Nuclear energy is an advantage in a low-carbon energy mix. Innovation is a prerequisite if we wish to keep it.

Controlling the energy supply of a country is not only a vital need and a factor of growth, but also a key issue for tomorrow's world. In this respect, the nuclear industry has a number of solid advantages even if it must ensure technical and economic control over issues of safety, resource sustainability and accountable waste management, which all call for the pursuit of innovation in technology.

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. Europe must come to terms with a number of constraints 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 preservation of a favourable balance of trade. Among the various sources of CO_2 emissions, electricity generation largely dominates the field; it represents 27% of the total anthropogenic production, which is well ahead of industry, road transport and residential and service sectors. Yet another example is Europe's energy dependency which is constantly increasing. Its import dependency ratio is expected to reach 80% in 2035. Within this context, it is increasingly apparent that we must have access to energy sources that are both competitive and green to ensure a sufficient level of energy self-sufficiency and secure energy supplies.

Faced with these issues, 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. These two types of energy are fundamentally different in principle, which means they can be used complementarily: one uses large-scale plant units for the baseload production of nuclear energy while the other is based on small decentralised power units operating intermittently. 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. Within the CEA, the Nuclear Energy Division (DEN) provides the French government and industry with technical expertise and innovations in nuclear energy systems to develop sustainable nuclear energy that is both safe and economically competitive.

While reasserting the DEN's main missions, this activity report presents the key results achieved by its teams in 2013 in their different fields. Without detailing all the scientific and technological achievements, I would like to acknowledge a few noteworthy ones in this foreword.

In the field of future nuclear systems, I would like to mention the launching of the conceptual design phase (AVP2[1]) of the Astrid project, an integrated technology prototype designed for the industrial-scale demonstration of 4th-generation sodium-cooled fast reactors (SFRs), for which the DEN is the owner. The preconceptual design phase (AVP1[2]) of this project defined the main characteristics of the reactor, its key innovative technological options and its main safety orientations. This second phase from 2013 to 2015 aims at consolidating and finalising the design options chosen.

Regarding the future fuel cycle, the year was marked by a series of studies led by the DEN in partnership with EDF and AREVA, focusing on industrial SFR deployment scenarios. These scenarios aim at optimising exploitation of recoverable (i.e. recyclable) materials in symbiotic fleets comprising EPRs™ and SFRs. Within this context, the DEN also instigated a significant R&D action plan on plutonium multiple recycling in 2013. In association with AREVA, the DEN issued its preliminary orientations to define a process suitable for the quantitative dissolution of plutonium-rich fuels.

We have also made significant progress in the present-day industrial nuclear sector. Such progress includes the publication of a state-of-the-art report describing all of the R&D work led within the DEN to better understand the changes in the characteristics of pressurised water reactor (PWR) vessels and vessel internals with respect to irradiation. Such R&D work aims at providing the information needed to extend the lifetime of PWRs beyond 40 years and therefore supports the files submitted by EDF to the French nuclear safety authority (ASN[3]).

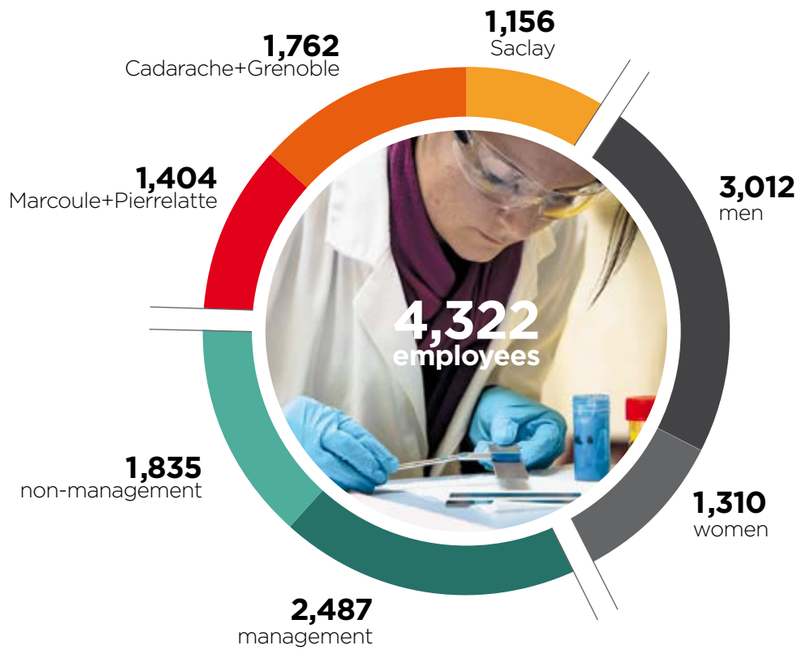
Our research programmes could not be conducted without the major research tools and simulation devices that we both develop and exploit. The Jules Horowitz Reactor (JHR) is a research facility currently being built on the CEA/Cadarache site. The project achieved a major milestone on 13 December with the installation of its reactor dome, marking the completion of 80% of the civil engineering work.

We have also made great strides in the clean-up and dismantling of our nuclear facilities. Marcoule saw the end of the dismantling of the separation units at the UP1 spent fuel reprocessing plant which represented the core of the extraction process. Within the scope of this same UP1 programme, 2013 also saw the first phase of Level 1 dismantling of the decladding workshop. Much headway was also made on the Fontenay-aux-Roses site, e.g. with the end of dismantling of the Gascogne, Guyenne, Eole and Cyrano shielded lines in Building 18 of the process regulated nuclear facility (INB[4]).

The DEN's major milestones achieved in 2013 will be described in greater detail throughout this report which I hope you will enjoy reading. I would like to share my strong conviction with you that the quality of our research, all of our scientific and technical results, and the dedication of the men and women working for the DEN, are all contributing to the consolidation of a sustainable nuclear industry that is even safer and economically competitive than before.

(1) AVP2: a French acronym for *avant-projet sommaire phase 2*.
(2) AVP1: a French acronym for *avant-projet sommaire phase 1*.
(3) ASN: a French acronym for *Autorité de Sûreté Nucléaire*.
(4) INB: a French acronym for Installation *Nucléaire de Base*. Also referred to as "licensed nuclear facility" in English.

Key Figures



103
new hires

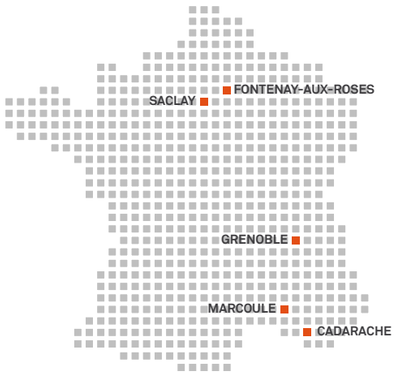
42
post-doctoral researchers

422
publications

241
doctoral candidates

including 143 funded by the Nuclear Energy Division

65
patents filed



Future Industrial Nuclear Systems

The Nuclear Energy Division (DEN) is currently working on "4th-generation" nuclear fast reactor systems for the future. Their development is needed to better meet requirements regarding secure

energy supplies and energy independence. These systems make it possible to optimise the management of materials thanks to the prospects they offer in terms of better exploiting uranium resources, while making plutonium multiple recycling possible 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 of 4th-generation sodium-cooled fast reactors - for which the CEA is the project owner. This project is currently in its conceptual design phase.

4th-generation Reactors

The CEA is responsible for conducting research on "4th-generation" innovative nuclear systems on behalf of France. These reactors must boast a number of technological breakthroughs compared with the previous reactor generations. The CEA is focusing its research efforts on two fast reactor types. Top priority goes to the sodium-cooled fast reactor type with the Astrid integrated technology demonstrator for which the CEA is the project owner. The second is the gas-cooled fast reactor type which the CEA is studying in view of a longer-term option. The year 2013 was marked by several major milestones.

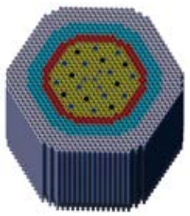
R&D on compact sodium-gas heat exchangers for energy conversion.

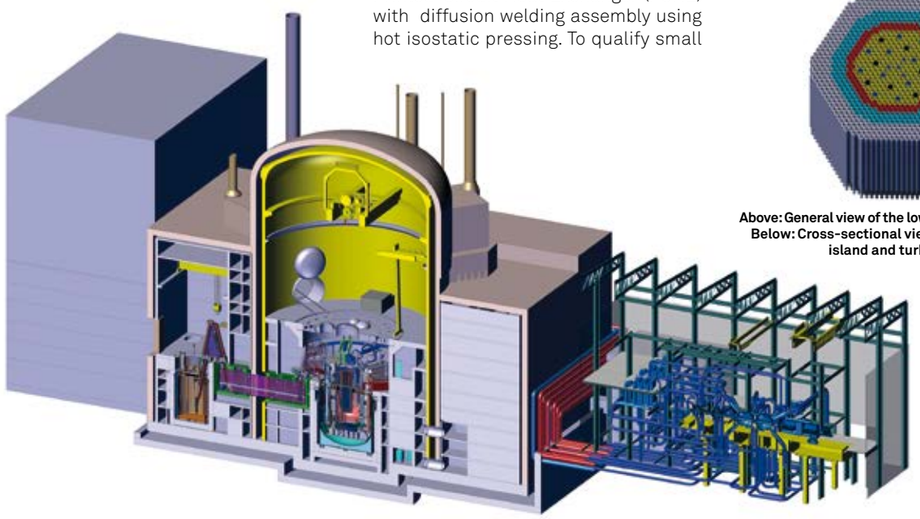
START OF THE CONCEPTUAL DESIGN PHASE FOR THE ASTRID PROJECT

The year 2013 got off to a good start with the kick-off of the conceptual design phase for the Astrid project. The first phase of this project - the so-called pre-conceptual design phase - defined the principal characteristics of the reactor, its key innovative technological options and its main safety orientations. This second phase from 2013 to 2015 aims at consolidating and finalising the design options chosen. Among the achievements clocked up in 2013, the following are worth mentioning:

• **Research focusing on a sodium-gas energy conversion system** designed to eliminate any sodium-water reactions *de facto*. The reference concept under investigation today is based on a compact sodium-gas Plate-Machined (PMHE) or Printed-Circuit Heat Exchanger (PCHE) with diffusion welding assembly using hot isostatic pressing. To qualify small heat exchanger mock-ups, the Nuclear Energy Division (DEN) designed and built Diademo, a multi-fluid test platform which was commissioned in November 2013 at the CEA/Cadarache centre. At the same time, the first compact sodium-gas heat exchanger prototype was immersed in sodium with the aim to assess its thermohydraulic performance and thermomechanical strength.

• **Reactor core qualification studies for the CFV[1] core** which were continued throughout the entire year. The neutronics calculation scheme based on current deterministic codes for fast reactors was validated. Bias was estimated and validated by means of 3D comparisons with reference Monte Carlo type calculations. An improved image was obtained thanks to a cost-to-performance optimisation; the core size was reduced, the efficiency of the neutron shielding was reinforced while keeping costs under control, and the absorber system architecture was optimised to reduce the number of control rods. This new version of the core also includes a number of complementary safety devices to prevent and mitigate severe accidents.

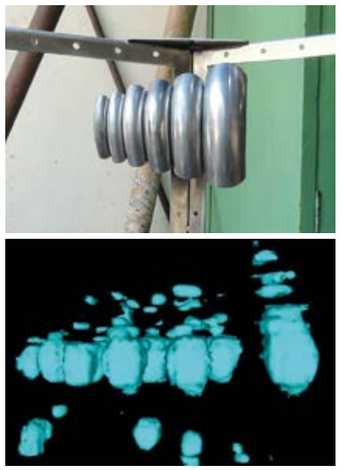




Above: General view of the low void effect core (CFV).
Below: Cross-sectional view of Astrid's nuclear island and turbine hall.

FUTUNA2: Means for testing leak detection systems on secondary pipes.

• **Ongoing studies on instrumentation specially designed to operate in sodium environments for systems required to visualise objects in sodium and to detect leaks.** Visualisation techniques that can be used in sodium are a key issue for the inspectability of sodium-cooled fast reactors (SFRs). In April 2013, studies led in collaboration with the Indira Gandhi Centre for Atomic Research (IGCAR) demonstrated that an acoustic method based on an ultrasonic sensor developed by the CEA could recognise and measure simple parts immersed in a sodium pool. The studies are not only being continued to optimise the ultrasonic sensors and their displacement systems, but also to develop the data processing algorithm. As regards leak detection, test campaigns were conducted on a large-diameter pipe (800 mm) in the summer of 2013. These tests aimed at comparing different leak detection technologies, including a "multi-layer" detector patented by the CEA. This system has proved to be highly efficient at detecting small leaks in very short times. Qualification and robustness studies are continuing.



Visualisation of curved tubes immersed in a tank containing several cubic metres of sodium.

MEETING ON THE ASTRID SAFETY ORIENTATIONS REPORT

On 27 June 2013 as requested by the French nuclear safety authority (ASN) Chairman, the standing group of experts on nuclear reactors got together to discuss the Astrid safety orientations report (DOrS[2]) submitted to the ASN on 18 June 2012. The standing group reached the conclusion that the options described in the DOrS properly took into account the most important feedback on SFRs, together with the studies and safety analyses performed for these reactors. The design method and the main areas of safety improvement were also deemed satisfactory. Furthermore, the standing group issued three recommendations concerning i) the methodology used to take into account the toxic risk involved with sodium, ii) the analysis of all the facility operating conditions with respect to hazards, and iii) the integration of extreme external hazards by defining an "additional category of external hazards". The Astrid project team will continue to transpose these safety orientations into design so as to draw up a safety options file (DOS[3]) for which the first consolidated version is expected in late 2015.

FOCUS ON

INDUSTRIAL COLLABORATION

The number of industrial collaborations for the Astrid project increased with the arrival of the Alcen Group. SEIV - a member of this group - is responsible for designing the irradiated fuel examination units. To boost the project, the DEN has built up a network of industry partners who are taking part in studies through various collaboration agreements. Though the project is owned and run by the CEA, ten industrial partners - both French and foreign - are contributing to the project which already involves more than 500 people, with almost half of them working for these partners.

FOCUS ON

FR13 INTERNATIONAL CONFERENCE

On behalf of France and supported by the French Nuclear Energy Society (SFEN), the CEA hosted the FR13 international conference on "Fast Reactors and Related Fuel Cycles" organised by the International Atomic Energy Agency (IAEA). As part of this event held in Paris over three days, more than 650 participants from 26 countries and four international organisations gave presentations on their scientific achievements in these fields. Owned by the CEA, the Astrid integrated technology demonstrator has been the subject of many publications and has markedly piqued the interest of the international scientific community, particularly in its innovative technological options.

(1) CFV: a French acronym for *Cœur à faible effet de vidange*, i.e. low void effect core. This very different concept developed and patented by the CEA (with the support of EDF and AREVA) in 2010 is designed to reduce the core reactivity if the sodium temperature increases.
(2) DOrS: a French acronym for *document d'orientations de sûreté*.
(3) DOS: a French acronym for *dossier d'options de sûreté*.

Back-end of the Future Fuel Cycle

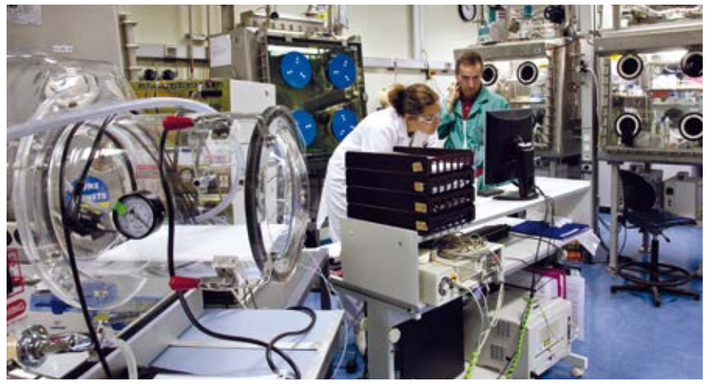
The Nuclear Energy Division (DEN) is conducting research on the future fuel cycle, in consistency with the Astrid integrated technology demonstrator design studies. The objective is to prepare all the options for nuclear material management based on a fast reactor technology by developing advanced processes, especially those required for plutonium multiple recycling. In compliance with the French act on sustainable radioactive material and waste management dated 28 June 2006, the DEN is also examining options for the partitioning and transmutation of long-lived radioelements.

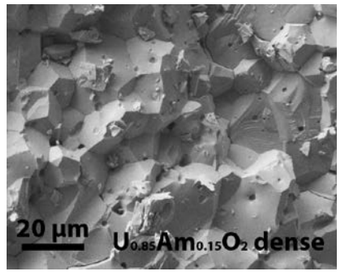
ADVANCED FUEL CYCLE DEPLOYMENT SCENARIOS

Among the highlights of 2013, it is worth mentioning the studies led by the DEN in partnership with EDF and AREVA, which focus on industrial deployment scenarios for fast reactors. These scenarios set out to exploit recoverable materials in an optimal manner - via plutonium multiple recycling and full exploitation of uranium resources - in symbiotic fleets comprising EPRs™ and fast reactors from 2040. The results already obtained and validated by industrial partners show that the recovery of plutonium is particularly relevant since it can be used in MOX fuels for the two types of reactors.

STUDIES ON PLUTONIUM MULTIPLE RECYCLING

Within this context, the DEN is conducting a significant R&D action plan on plutonium multiple recycling. In 2013, in association with AREVA, the DEN presented its preliminary orientations for defining a process suitable for the quantitative dissolution of plutonium-rich fuels (MOX-LWR[1] and MOX-SFR), which could be used in AREVA's planned polyvalent fuel treatment workshop dedicated to special fuels (TCP[2]) at the La Hague.
Concerning fuel fabrication, noteworthy results were also obtained jointly with AREVA regarding the definition of processes to be used in the Astrid core manufacturing workshop (AFC[3]).





From top to bottom: enhanced partitioning tests performed in the Atalante facility at Marcoule. Electron microscopy examination of a fuel pellet containing 15% of americium for transmutation.

(1) LWR: Light Water Reactor.
(2) TCP: a French acronym for *Traitement des Combustibles Particuliers.*
(3) AFC: a French acronym for *Atelier de Fabrication des Cœurs.*
(4) EXAm: EXtraction of Americium.

STUDIES ON MINOR ACTINIDE PARTITIONING AND TRANSMUTATION

A new continuous separation test on americium (Am) alone (EXAm[4]) using a concentrated raffinate was performed in 2013 under inactive conditions in the DEN Atalante facility at the Marcoule centre. This test confirmed the good performance of the process, identified the optimal operating parameters and demonstrated the efficiency of the decontamination operations on the flow containing americium.
The americium transmutation study involved developing mixed uranium-americium oxide fuels ($UAmO_2$) containing 10 to 15% of americium. The feasibility of manufacturing these fuels using a powder obtained by co-conversion from an initial solution of americium and uranium was demonstrated in 2013: the resulting pellets achieved the expected characteristics in terms of composition and density with the implementation of a simplified process and a sintering temperature of 100°C below that used in standard processes, which is a major plus in manufacturing pellets.

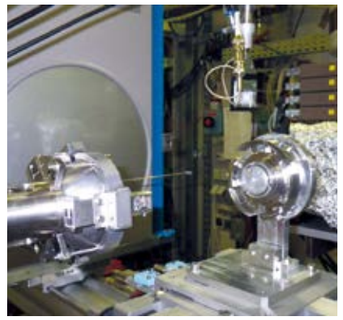
Basic Scientific and Technological Research

Basic scientific and technological research is situated upstream from applied research, in response to cross-disciplinary issues raised within the Nuclear Energy Division (DEN). It broadens the foundations and scientific quality of knowledge and establishes the relevance of answers to the major challenges of nuclear energy in two main fields: materials and chemistry. In each of these fields, the basic scientific and technological research programme relies on dynamic partnerships, especially on a European level. The year 2013 was marked by three major events which are highlighted below.

FIRST EXPERIMENTS ON THE MARS BEAMLINE OF THE SOLEIL SYNCHROTRON

The DEN teams conducted the first experiments on a sample irradiated beyond the "exemption threshold[1]" using the Mars[2] beamline of the Soleil synchrotron facility. This beamline is used for performing analyses in biology, chemistry and radioactive material physics by means of synchrotron radiation. It has two specificities: 1) it can accept extremely irradiated materials and 2) it can be used to perform high-resolution X-ray diffraction measurements in alternation with fluorescence analysis or absorption spectroscopy. This makes for a very unique tool worldwide, both in terms of its authorised radioactivity threshold and its significant analysis potential.

These first experiments focused on samples of ODS[3] steel strengthened by the dispersion of irradiated yttrium nano-oxides; this material is being considered for the cladding of sodium-cooled fast reactor fuel, in particular that of the Astrid integrated technology demonstrator. The main objective is to study i) the stability of the crystal structures after irradiation using X-ray diffraction and ii) the chemical environment of the yttrium atom after irradiation using X-ray absorption spectroscopy. Such studies are needed to confirm the stability of the nano-oxide phases under irradiation so as to ensure the excellent mechanical resistance of the material.



Sample environment for X-ray diffraction and X-ray absorption spectroscopy analysis using the Mars beamline.

MODELLING DIFFUSION PHENOMENA IN METAL ALLOYS UNDER IRRADIATION

The DEN published three articles in the journal "Physical Review B" all about predicting radiation-induced segregation. The first article was written in collaboration with the University of Illinois at Urbana-Champaign. It detailed an automatic calculation method for transport coefficients (atoms and defects) for some metal alloys. The method is based on the self-consistent mean field theory which has been under development for several years now at the DEN. The second article focused on the systematic analysis of transport properties (atoms and defects) for an Ni(Si) alloy as a function of the deformation field. This analysis relied on the same method above. The last article described the development of a new method for simulating the kinetics in alloys, a method capable of reproducing all flux coupling induced by irradiation.

LAUNCHING THE EUROPEAN NETWORK CALLED TALISMAN

The European network called "Transnational Access to Large Infrastructures for the Safe Management of ActiNides" (TALISMAN) was launched in January 2013. Coordinated by the DEN, this European consortium with 12 partners aims at maintaining scientific expertise on actinides at the highest possible level, especially in the fields of separation chemistry, the behaviour of actinides in the environment and actinide-based materials. Taking on four new partners in the process, Talisman replaced the former European consortium called ACTINET-13 which had been federating and coordinating studies in the field since 2004.

(1) The "exemption threshold" refers to a level of radioactivity below which a simple declaration to the French nuclear safety authority (ASN) suffices.
(2) Mars: Multi-Analyses on Radioactive Samples.
(3) ODS: Oxide-Dispersion Strengthened.

Optimising the Current Nuclear Industry

The Nuclear Energy Division (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.

Front-end of the Current Fuel Cycle

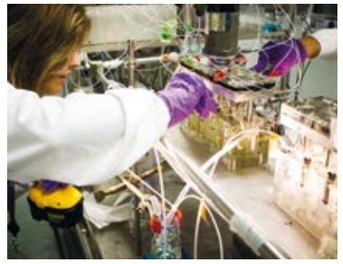
In recent years, research on the front-end of the fuel cycle has increasingly gained significant ground, what with the reduction in ore grades and the need to refurbish existing facilities. This involves improving performance levels in terms of the selective extraction of uranium, purification and conversion into pure hexafluoride, which is the step prior to uranium enrichment in order to achieve the purity level required by fuels for 2nd- and 3rd-generation reactors.

SIX PATENTS REGISTERED IN 2013

Studies carried out over a number of years at the Nuclear Energy Division (DEN) led to the registration of six patents in 2013 covering two study topics: uranium extraction from mines and the conversion of uranium oxide into uranium hexafluoride (UF_6).

The objective for uranium extraction is to define more efficient uranium production techniques by developing new materials which have better selectivity or are suitable for new environments (phosphates for example). In 2013, a patent was registered on behalf of AREVA for a family of bifunctional molecules applied to liquid-liquid extraction in sulphuric environments. These new extractants provide higher uranium selectivity than existing products, which should reduce the number of steps needed to obtain a uranium-bearing concentrate that complies with the ASTM[1] standard. Two patents were also registered for hybrid materials specifically for liquid-solid extraction in phosphoric and sulphuric environments respectively. These materials consist of an inorganic substrate on which an organic molecule is grafted that selectively extracts uranium. They have the advantage of being highly resistant to harsh acidic environments in comparison with organic resins, the technology usually used.

In the field of conversion, three patents have been registered to protect innovative processes for recovering hydrogen fluoride (HF) during defluorination of UF_6. This operation consists in converting the UF_6 used in the enrichment step into uranium oxide to manufacture fuels for nuclear reactors and to store depleted uranium.



Platform of mixer-settlers for laboratory-scale validation of the performance of the selective uranium extraction process.

Selective uranium extraction experiment in pulsed laboratory column.

The chemical reaction which occurs produces hydrated HF, which is difficult to recover. The new processes described in these patents produce anhydrous HF by optimising the operating conditions, in particular the temperature and the amount of water used. As the HF produced is in anhydrous form, it will be directly recyclable to produce UF_6 again.

(1) American Society for Testing and Materials.

FOCUS ON

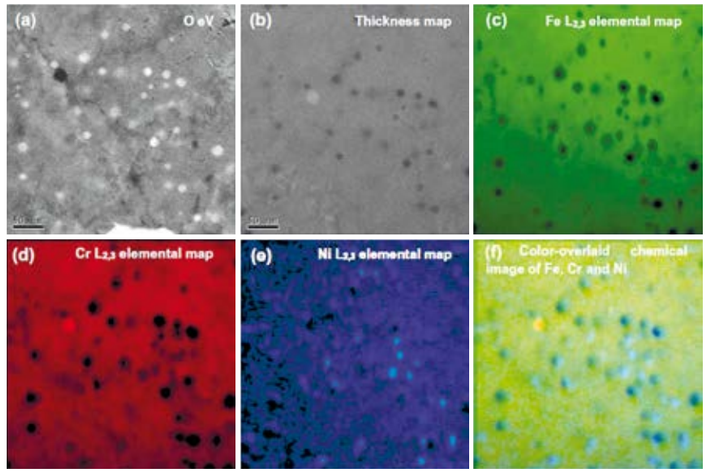
LIQUID-LIQUID EXTRACTION PROCESSES

The DEN is developing new molecules to improve the performance of the liquid-liquid extraction process in order to reduce the production cost of uranium and lessen the environmental impact of extracting uranium from conventional low-grade ores or from phosphoric acid. In 2012, an initial test in the Proust platform at Marcoule validated the selective uranium extraction performance of a new family of particularly high-performance molecules. In 2013, two continuous small-scale tests were conducted on real phosphoric acid and sulphuric acid solutions. These tests confirmed the expectations of the experimenters.

The performance of the extraction programme was better for both environments. The uranium extraction rates were high (greater than 95%) and the uranium concentration in the purified production flow was three times higher. These advances mean that a significant improvement in the current industrial processes is possible. Larger scale tests are planned in AREVA facilities.

2nd-and 3rd-generation Reactors

Responding to industry demand, the CEA is conducting research on the current 2nd-generation French pressurised water reactors (PWRs) as well as on 3rd-generation PWRs to address the industrial issues of improving the performance, service life, availability and safety of the power plants. Although the Fukushima Daiichi nuclear accident did not reveal any major gaps in knowledge and R&D objectives, it highlighted the need for long-term R&D programmes on accidents and on the durability of the related facilities. Here are some of the key results of 2013.



Studying the ageing of vessel internals under irradiation. Evidencing the appearance of cavities and two families of nano-precipitates with high chromium and nickel contents respectively (Phénix irradiation, 36 dpa at 390°C).

UNDERSTANDING THE CHANGING PROPERTIES OF THE PWR VESSEL AND ITS INTERNALS

The year 2013 was marked by the publication of a state-of-the-art report presenting all the R&D work carried out at the Nuclear Energy Division (DEN) on understanding the properties of the PWR vessel and vessel internals, according to the level of irradiation. This work aims at providing the information needed to extend the lifetime of PWRs beyond 40 years, and supports the files submitted by EDF to the ASN.

For the vessel materials, the most significant results concern the validation of the beneficial role of warm pre-stressing on the toughness of the vessel steel and studies on certain cases of atypical embrittlement in the irradiation monitoring programme (PSI[1]) conducted by EDF. With regard to materials used for the vessel internals, studies have focused on their mechanical behaviour after doses representing 40 years of operation and beyond. Technical information has also been provided on the irradiation-assisted stress corrosion cracking (IASCC) sensitivity threshold as proposed by EDF.

(1) PSI: a French acronym for *Programme de surveillance de l'irradiation.*

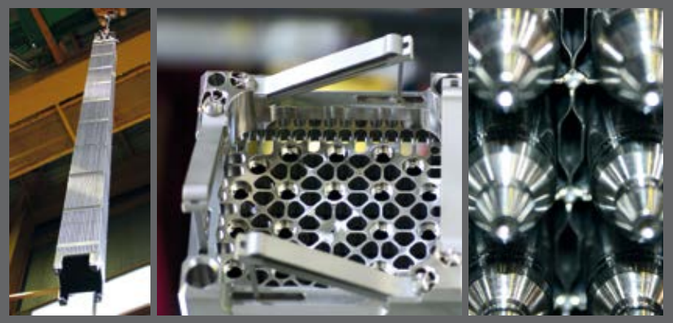
MORE ABOUT

STUDYING THE EFFECT OF WARM PRE-STRESSING ON REACTOR VESSEL STEEL

Currently, the vessel integrity substantiation report considers the toughness of the material for a given isothermal load, which is very conservative, as the actual thermal load is not isothermal. In the context of extending the service life of PWRs beyond 40 years, the beneficial effect of warm pre-stressing (thermomechanical loading) must be taken into account, as accidental transients lead to non-isothermal loads. The campaign conducted by the DEN teams at Saclay in 2013 consisted of 18 warm pre-stressing tests on irradiated material. A particular set-up was required for these tests, alternatively switching between tests under strain measurement conditions and load tests performed according to the temperature of the test specimen. The tests were controlled by software developed at the DEN, which was specially installed and qualified in 2011. These tests confirmed the positive effect of warm pre-stressing on the irradiated steel of PWR vessels for levels of embrittlement representing a service life of 60 years. Information from this research will contribute to the proposal for developing a code for this effect, prepared jointly by EDF, AREVA and the CEA, and also the proposal to cover this effect in the vessel integrity substantiation report.

CHARACTERISING AND QUALIFYING A NEW GENERATION OF FUEL ASSEMBLIES

The DEN is involved in supporting the qualification and development of AREVA's next generation of fuel assemblies. It is providing its expertise and its numerical simulation tools for various studies. Its involvement mainly covers the characterisation and qualification of a new fuel assembly concept: this particularly involves characterising its hydraulic and mechanical behaviour under hydraulic conditions representing those in the reactor. An initial characterisation phase, from 2008 to 2012, helped to draw up the safety report for the new assembly. The first precursor assemblies were inserted in the reactor in July 2012. A new phase of studies was conducted at the end of 2013 on an optimised concept (improved design and fabrication process), reducing the pressure drops in the grids.
These latest pressure drop values were measured in October 2013 on the DEN's Hermès facility at Cadarache and showed a 5% improvement over the first generation developed in 2008. This complementarity of research and engineering is contributing to the overall objective of improving the reliability, robustness and performance of the fuel so as to meet increasingly demanding operating requirements and safety standards.



Left to right: Fuel assembly mock-up suspended from the travelling crane in the Hermès testing hall. Top nozzle of the fuel assembly. Close-up of the grid at the top end of the fuel assembly.

NUCLEAR SAFETY: SUCCESS OF THE VERDON3 TEST

Severe accidents are a priority for the DEN in the field of nuclear safety research. In this context, the aim of the Verdon programme is to improve knowledge of the behaviour of fission products under severe accident conditions. This involves heating a fuel sample that has been irradiated in an EDF reactor, then re-irradiated in the Osiris research reactor at Saclay, to a high temperature in a controlled atmosphere. The test enables the on-line measurement of fission product releases and deposits carried out using gamma spectrometry. In addition to these on-line observations, the fission products remaining in the sample and deposited on the various components of the experimental system are quantitatively measured. The year 2013 saw the successful completion of the third Verdon test performed on 17 April in the Star facility at Cadarache. It examined a MOX fuel that had been irradiated for four cycles. The specific aim of this test was to quantify the release of fission products under oxidising steam conditions, for which very few experimental results were available prior to this experiment.

3 QUESTIONS ABOUT...
The EUROPLEXUS software, awarded the 2013 SFEN Grand Prix

What is the EUROPLEXUS software?

EUROPLEXUS is a software specially designed for simulating fast-transient fluid and structural dynamics, and is used by AREVA and IRSN, amongst others.

What are its industrial applications?

The industrial applications of EUROPLEXUS include simulating the mechanical consequences of accident transients such as the resistance of the core baffle in the event of a PWR LOCA[2] or the integrity of the reactor vessel leaktightness in the event of a CDA[3], both vital for the safety of 4th-generation reactors.

What major results have been obtained in 2013?

The major results obtained in 2013 include:
- the development and validation of hydrogen combustion models, a major issue for checking the correct design of the hydrogen risk mitigation measures in the reactor buildings of French power plants;
- the success of the Repdyn[4] project led by the French national research agency (ANR[5]), designed to expand EUROPLEXUS to a massively parallel scale, as the computation of coupled systems of industrial complexity requires enhanced computing capacity.

This performance was acknowledged when team responsible for the development of EUROPLEXUS was awarded the 2013 SFEN Grand Prix, which recognises scientific or technical excellence.

Meshing of the reactor building (left) and a burn-up calculation result (right).

(2) LOCA: Loss-of-Coolant Accident.
(3) CDA: Core Disruptive Accident.
(4) REPDYN: REaching Petascale for advanced fluid-structure DYNamics.
(5) ANR: a French acronym for *Agence Nationale de la Recherche.*

Back-end of the Current Fuel Cycle

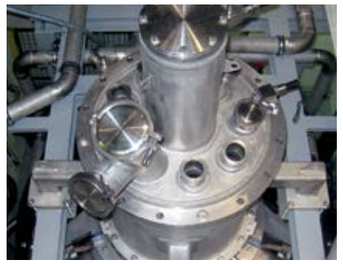
Programmes are conducted to support AREVA so as to optimise or adapt the processes for spent fuel reprocessing at the La Hague plant and for MOX fuel fabrication at the Melox plant. They are also designed to support Andra so as to provide the scientific and technical information needed for the Cigéo 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 year 2013 was marked by significant progress on the in-can incineration-vitrification process, called Pivic. The objective of this process, developed in partnership with AREVA, is to treat and condition alpha-contaminated mixed technological waste (both organic and metal) in a mixed glass-metal matrix: the organic part of the waste is incinerated, and the ash produced is vitrified, while the metal part of the waste is melted. The design review of the furnace was carried out in mid-2013, with implementation planned for 2014 in the Nuclear Energy Division (DEN) laboratories at Marcoule. This will enable the experimental qualification of the glass-metal melting part of the process. The DEN's teams also demonstrated the advantage of using boron-free soda-lime glass for this process (instead of the usual borosilicate glass) in order to optimise the confinement properties of the matrix.

SUPPORTING LA HAGUE

Optimising the management of effluents from the La Hague workshops is a major issue for AREVA. It involves adapting the treatment conditions in certain evaporators so that they are suitable for the specific properties of effluents which have, until now, been treated in another part of the plant. In this context, the DEN was approached by AREVA about the problem of treating an effluent with a high ruthenium content in an evaporator in which the conditions in the boiler are oxidising enough to convert ruthenium into a volatile species. To avoid propagating volatile ruthenium, the DEN has suggested and developed a process which buffers the oxidising capacity of the environment. The final step in the development of this process was successfully completed in late 2013: it involved its transposition to an industrial scale. The tests were carried out at the La Hague plant from October to December.



EREBUS, waste conditioning facility at Marcoule: in-can glass/metal melting module using low-frequency direct induction.

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 Cigéo project for which the Andra is the project owner. The objective of the "Full-Scale Sealing" project is to demonstrate the technological feasibility of the sealing methods for the deep geological disposal tunnels using a full-scale mock-up, built on the surface at Saint-Dizier in the Haute-Marne region. This mock-up consists of a bentonite sealing "plug" and two low-pH concrete support blocks. In 2013, the DEN submitted a summary report to Andra proposing the concrete formulations for sealing the tunnels in line with its requirements: five reference formulations and three alternative innovative formulations.

Filling the mock-up with concrete to demonstrate the technological feasibility of the sealing methods for the Cigéo tunnels.

Major Tools for Developing Nuclear Energy

Research on current or future nuclear systems requires specific experimental and simulation tools. For this reason, the Nuclear Energy Division (DEN) is developing and making use of a comprehensive, coherent fleet of experimental facilities, preparing for the

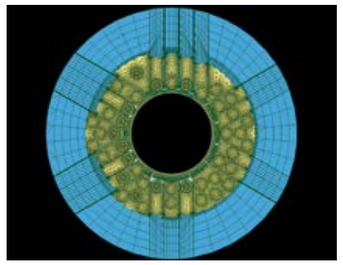
replacement of ageing facilities and building new facilities, such as the Jules Horowitz Reactor (JHR) at Cadarache. The JHR is the only reactor of this type being built in Europe and will be a unique facility for studying materials and fuels under irradiation, as well as playing an important part in 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.

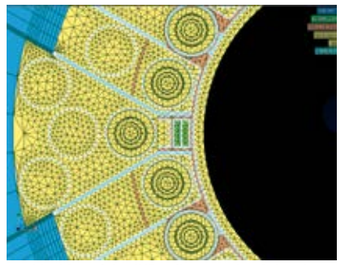
Numerical Simulation

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, chemistry and materials) to model the complex phenomena occurring in normal reactor operation or in an accident situation. Most of these platforms allow multi-scale modelling from atomic scale to the complete system. 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.

ROLL-OUT OF VERSION 7 OF THE SALOMÉ PLATFORM

The year 2013 saw the roll-out of version 7 of Salomé, the platform for the development of pre- and post-processing and coupling of codes for numerical simulation. This platform, jointly developed with EDF R&D and distributed as open-source software, provides various generic services for conducting studies (integration of computation codes in the form of components, pre- and post-processing, supervision of computation, coupling of codes, management of studies, etc.). Version 7, made available to CEA and EDF users, includes enhancement of the functions found in the previous version (6) first used in 2011, with additions or improvements that provide increased functions for display during computation, algorithmic functions and simplified implementation of these meshes for complex geometries.





Meshing of the JHR reflector using Salomé.

SUCCESS OF THE AMMON EXPERIMENTAL PROGRAMME

The year 2013 also saw the successful implementation of the Ammon experimental programme in the Eole reactor at Cadarache, after three years of measurements on seven configurations representing the core of the Jules Horowitz Reactor (JHR) under normal and incident conditions. This programme consisted in providing the physical parameters of the core, measured precisely to determine the controlled uncertainties on certain reactor design options and to substantiate the safety case demonstration. It is part of an overall qualification process for neutron- and photon-based tools, in particular the calculations for the core physics processed using the Horus 3D/N code package, which makes use of the functions of the CEA's main neutronics codes and is based on the use of the JEFF3.1.1 nuclear data library. The experiments in this programme were conducted in the Eole critical mock-up, in which integral neutron experiments can be carried out on lattices and fuels representing research or power reactors.

Experiments in the Ammon programme conducted in the Eole critical mock-up at CEA/Cadarache.

APOLLO2 CODE IMPROVEMENTS

Various industrial partners use the Apollo2 neutronics code in their industrial computation systems.
The NRC, the US safety authority, has approved the use of the new Arcadia computation system from AREVA for calculating the cores of pressurised water reactors with UO_2 fuels. Arcadia uses version 2.8-3 of the Apollo code.
The CEA has also provided its partners with version 2.8-4 of the code, which has been enhanced with additional developments. The unique advances implemented in this new version enable more precise simulation of interactions between neutrons and nuclei, in particular the neutron diffusion model, and significantly reduce the calculation times and the memory size required for these calculations.
Version 2.8-4 of the Apollo code will be the essential component of EDF's future industrial neutron computation system, which will replace the current system (which has been in place since 2002 and uses version 2.5 of Apollo) in production by around 2018.

Research Facilities: Jules Horowitz Reactor (JHR)

The construction of 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 assume a large proportion of the production of medical radioisotopes. The JHR project has received funding from the future investment programme and is being built by an international consortium. The CEA is the owner, nuclear operator and contracting authority.

ORGANISATION

In March 2013, the British Nuclear National Laboratory (NNL) became the 11th partner in the JHR project, when an agreement was signed between the CEA and the British Department of Energy and Climate Change (DECC), at a meeting of ministers on the topic of nuclear energy.

INSTALLATION OF THE DOME

Work continued throughout 2013 leading up to the installation of the reactor dome on 13 December by the CEA and its partners – AREVA and Razel-Bec – who were responsible for this exceptional, complex operation.
It required eight months of preparation and considerable involvement of the Nuclear Energy Division (DEN) teams at Cadarache as well as that of AREVA, Razel-Bec and Secomoc. This operation represented a major step in the reactor construction process, for which 80% of the civil engineering work has now been completed. It also marked the beginning of the electromechanical assembly phase.

PHOTO GALLERY

2013: THE YEAR'S WORK

1. May. Last two concrete lifts completed.
2. June. Concrete poured for level-0 of the reactor building.
3. July-August. Acceptance of the second series of hot cell modules, installed and reinforced with iron in the auxiliary units building.
4. November-December. First reactor pool liner framework module inserted. Track and components of the polar bridge crane installed.
5 and 6. 13 December. Dome installed.

Promoting Resources and Expertise

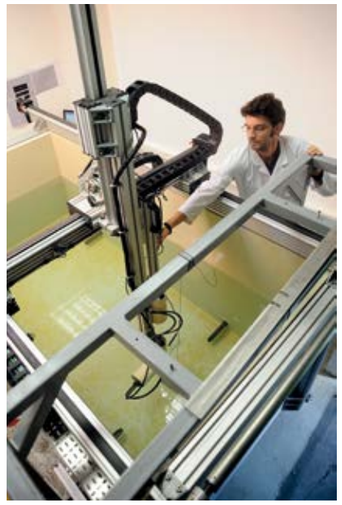
The nuclear industry is ranked as the 4th most innovative industry in France. It is an integrated industry (large industrial groups, public research organisations and several hundred SMEs), in which the Nuclear Energy Division (DEN) has historically played a major role in terms of innovation. The DEN's R&D work is mainly ensured 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's divisions, and also by transferring technologies to non-nuclear industries.

INNOVATIVE INSTRUMENTATION TECHNOLOGIES

At Cadarache, the range of innovative patents in the IMC-A field (instrumentation, measurement, characterisation and their industrial applications) is organised into six fields: heat transfer measurement, thermal-hydraulics, surface characterisation using non-destructive testing, physical characterisation, radiological characterisation, element-based characterisation by non-destructive nuclear measurement, physicochemical analysis and measurement of radiation levels.
One example in the field of heat transfer measurements is the "coefh" sensor. It can be used to ascertain the heat exchange coefficient of any system, in particular cooling systems, with the aim of predicting the service life of its components. An exclusive licence was signed with Kayme, which is to manufacture and sell this sensor. The automotive industry is also interested in this sensor for studying the cooling of brake discs.

STUDYING THE FEASIBILITY OF DRY CLEANING CLOTHES USING SUPERCRITICAL CO_2

In 2013, the DEN teams at Marcoule signed an R&D agreement with the start-up company DFD to study the feasibility of industrialising a dry cleaning process for clothes and textiles using pressurised dense CO_2 (> 75 bar - > 31°C), a solvent which could be an alternative to perchlorethylene or hydrocarbons that are currently used. Studies carried out since 2012, together with the *Centre technique industriel sur la teinture et le nettoyage* (CTTN[1]), have already achieved some interesting results in terms of quality both with respect to the resistance of the materials and the cleaning itself. This R&D agreement will make it possible to develop a pilot set-up to carry out real-life studies (pressure, temperature, duration, additives, etc.), in order to obtain a process that can be used industrially by the dry cleaning sector.



Top to bottom: "coefh" sensor; prototype flowmeter with fluid bearings; visio test bench: water tank for acoustic and ultrasonic experiments.

MORE ABOUT

"FROM RESEARCH TO INDUSTRY" DAY

At the *Maison de la chimie* in Paris on 20 March 2013, during industry week, the CEA highlighted the major role that a public science and technology research organisation plays in the emergence and development of industrial technologies, and also the importance of innovation and technology transfers as factors for competitiveness and job creation. Over 200 people visited the exhibition area displaying examples of DEN technologies that can be applied to industry in the fields of instrumentation, measurement and characterisation, and examples of partnerships with SMEs and ISEs around the building of the Jules Horowitz Reactor (JHR).

(1) CTTN: technical centre for industrial laundry and dry cleaning.

Economic Support in the Haute-Marne and Meuse Regions: the Syndiese Project

The Nuclear Energy Division (DEN) is responsible for the Syndiese project, which aims to demonstrate the commercial feasibility of an entire integrated supply chain for 2nd-generation biofuels produced from forest biomass. This project is one of the French and European priorities for reducing greenhouse gas emissions.

STAKES OF THE SYNDIESE PROJECT

As part of the economic support in the area neighbouring the Andra Bure-Saudron laboratory, the CEA is developing the Syndiese project. This project falls within the scope of the French act on the sustainable management of radioactive materials and waste dated 28 June 2006. Led by the DEN and leveraged by R&D from the CEA's Technological Research Division, this project involves the design, construction and operation of a Biomass-to-Liquid (BtL) demonstrator on the Bure-Saudron site. The demonstrator will produce 2nd-generation biofuels. The objective is to produce synthetic biofuels (diesel, kerosene for aviation) with lignocellulosic biomass using a thermochemical process on a pre-industrial scale (75,000 tonnes/year of dry feedstock, i.e. 10 tonnes/hour for an annual biofuel production of 23,000 tonnes). The end products will meet the industry's fuel standards and will be directly merchantable for land and air transport. This pre-industrial demonstrator will first start with deciduous and/or coniferous wood chips before moving onto other types of resources. It will be supplied by local resources located within a radius of around 75 km.

PROJECT STATUS

In 2013, Syndiese moved towards construction on the Bure-Saudron site with the launching of the first phase of the project. This phase was validated by the High-Level Committee on 4 February 2013 in Bure under the chairmanship of Delphine Batho who was also Minister for Ecology, Sustainable Development and Energy at the time. This first phase involves preparing the site and building a technology platform on which R&D actions can be conducted to ensure the 1 tonne/hour validation of the technologies developed by the CEA for the pre-treatment of the biomass prior to its conversion into syngas.
Within this framework, the CEA is also continuing the Syndiese-BtS (Biomass-to-Syngas) project in collaboration with the Air Liquide Group. Drawing on the research programmes of both parties, the project sets out to develop an innovative technology capable of converting biomass into syngas. Divided into three phases, this project intends to demonstrate and successfully complete the integration of an entire system that is both coherent and reliable in converting lignocellulosic biomass into syngas using a R&D pilot unit with a production rate of 1 tonne/hour. This pilot unit is expected to be built on a 30-hectare site set aside for the Syndiese project which is located in the interdepartmental zone straddling the communities of Bure and Saudron alongside Departmental Road 175. The CEA became the owner of this land on 16 September 2013.
After having obtained the regulatory authorisations needed to start building the technology platform for biomass pre-treatment and to carry out studies[1] and site preparation (roads & underground networks) prior to construction, the work was launched in October 2013 with the installation of a worksite fence and the beginning of earthworks to prepare the building foundations. This platform should be ready for delivery in the first quarter of 2014. Initially, it will include:
- a 400 m² test hall housing all the technological equipment on a representative scale of 1 tonne/ hour;
- a 100 m² laboratory with equipment to characterise and analyse the properties of the biomass being processed;
- an area reserved for operating teams and researchers, including private offices equipped with connector systems to host users on the technological platform.

Before launching the second phase, there will be a "go/no-go" milestone at the end of the first phase designed to validate the technological building bricks forming the front-end of the BtL process chain. The CEA will thus need validation from the High-Level Committee at the next meeting to be organised for the second half of 2014.

Construction site of the technological platform for biomass pre-treatment.

(1) Preventive archaeology, flora & fauna assessment, soil chemical analysis, topographical surveys and geotechnical site investigation.

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 that have reached the end of their ser-

vice 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 complete dismantling of facilities whenever feasible, to reduce the risks as quickly as possible and to benefit from the knowledge of the 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, and to improve the safety of the worksites.

Dismantling Projects

One of the CEA's major objectives is managing the dismantling of its nuclear facilities safely and responsibly. The dismantling programmes are financed in the long-term by two dedicated funds, one for civilian activities and the other for defence activities. 22 of the 43 civilian nuclear facilities are currently being dismantled.

MAIN SHORT- AND MEDIUM-TERM PRIORITIES

In 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: gradually reducing the perimeter of the regulated nuclear facilities (INB[1]).

In Grenoble: continuing the final clean-up and administrative decommissioning of the INBs on the site, with the operations to dismantle these INBs having been completed at the end of 2012 in accordance with the undertakings in the State-CEA target-based performance contract.

Complying with deadlines in ministerial decrees that govern the different worksites, together with the CEA safety milestones regarding the safety authorities.

MARCOULE

At the Marcoule centre, the two main priorities are to continue dismantling the UP1 spent fuel reprocessing plant and to prepare for dismantling the Phénix reactor, which was shut down in 2009.

UP1 programme

The UP1 plant was used to reprocess spent fuel from the G1, G2 and G3 nuclear reactors at the Marcoule centre with the aim of producing plutonium for national defence requirements. Work to rinse and then dismantle the plutonium extraction head-end and core process equipment has been in progress over the last ten or so years. Focus on two major achievements in 2013:

• **Dismantling of the UP1 separation units completed.** The separation units formed the core of the extraction process at the plant. The work concerned two lines of banks and involved their clean-up, removal, and then cutting up. In December 2013, all the banks in line B were removed. The operations to dismantle the banks in line A (completed in 2011) took a total of 60,000 hours while those in line B took 22,000 hours.

• **Completion of the first phase of the Level 1 dismantling of the G2-G3 decladding workshop.** Still within the context of the UP1 programme, the first phase of the Level 1 dismantling of the decladding workshop was completed in 2013. The service duct housed the pipework (filtration, drainage to effluent pits, reagents, demineralised water, etc.) which was needed to operate the workshop's various processes. After the operations to dismantle the pipework, the last operation was to strip the floor and the hot spots in order to reduce the irradiation level. This operation, completed in December 2013, was carried out remotely using a Brokk demolition robot. The work took 18 months, generated 40 tonnes of rubble and very significantly reduced the irradiation level.

Dismantling of the Phénix plant

Within the context of preparing for dismantling, work continued on the Phénix sodium-cooled fast reactor, which was permanently shut down in 2009. Four shipments of spent fuel were sent to the AREVA plant at the La Hague. On an administrative and regulatory level, the teams have been very actively involved in continuing preparations needed to create a "standing group" to review the safety of the facility and to set up a public enquiry prior to dismantling, both being planned for 2014.

(1) INB: a French acronym for *Installation Nucléaire de Base.*

Bitumen recovery worksite at UP1.

Cyrano shielded line.

ALADIN PROJECT AT FONTENAY-AUX-ROSES

The centre's facilities have been grouped into two regulated nuclear facilities (INBs) since 2006: the "process" INB (INB 165), and the "support" INB (INB 166). Significant progress was made in 2013 in the work to dismantle these two INBs.

Completion of dismantling the Gascogne, Guyenne, Eole and Cyrano shielded lines in Building 18.
This work was spread over a number of years, with several intermediate milestones being reached on time:
• **mid-2011,** end of dismantling the Gascogne shielded line. Its main programme was R&D on aqueous reprocessing of irradiated fuels in solid state or in solution;
• **late 2011,** end of dismantling the Eole and Guyenne shielded lines. The Eole line was designed for activities concerning hulls (cementation, rinsing and leaching of hulls from PWR fuel elements, gamma scanning measurement of the activity of plant hulls, etc.). The Guyenne line was designed to conduct high-frequency inductively coupled plasma emission spectrometry analyses;
• **late 2013,** end of dismantling the Cyrano shielded line. This line, which operated for 30 years, was dedicated to the aqueous reprocessing of various fuels.

3 QUESTIONS ABOUT..... the end of demolition of the rear of building RM2

What was the main objective of this work?

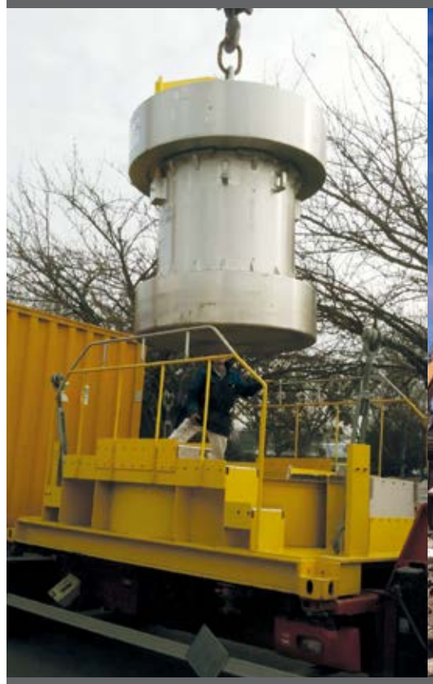
This work, which was completed in early April 2013, had to be done before the containment could be installed so the shielded cells could be cut up, an operation that will start in 2014.

What work was required to demolish the rear part of the building?

The first phase of the work started in June 2012 and involved installing a site ventilation system so a form of containment could be installed for demolition of the rear part, and removing all the equipment from the former filter room.
The second phase started in late November 2012 and mainly involved demolishing the rear part and the service duct with a Brokk demolition robot fitted with a crunching tool.
The operations consisted in removing the contaminated backscatter chambers in the walls of the cells and then demolishing all the structures in these areas.

What are the main operations planned for 2014?

The main work in 2014 will start in January with the operations to cut up the shielded cells from the small line. An innovative cutting technique will be used: the sawing operations will be carried out by "pushing" the sawing cable with a gantry crane, thus obtaining perfectly straight saw cuts with a faster cutting speed. The gantry crane will also be fitted with a dust extraction device. More than 1,200 blocks will be cut, extracted and removed during the work.



Transport of effluents from the HA4 tank in a SORG transport cask.

Demolition of the Siloé research reactor.

SACLAY

The year 2013 was marked by the removal, in late November, of the remaining effluents from tank HA4 in INB 35 on the Saclay centre. These effluents were transferred to the Delos treatment unit in the Atalante facility at Marcoule. The objective of removing all effluents from tank HA4 by 8 January 2014 was to reduce the source term of the Saclay site. This was one of the provisions in the modification decree governing INB 35, a top-priority safety objective for the CEA, and a milestone of the State-CEA target-based performance contract. This last removal operation ends a long-term programme for the Saclay and Marcoule centres which lasted six years.
In view of the Atalante transport capacities and receiving tanks, five shipments were needed to empty tank HA4 between March 2010 and the end of 2013. A total of 2,700 litres were transferred to Marcoule in a type-B transport cask called SORG designed in 2006.

PASSAGE PROJECT AT GRENOBLE

Work to demolish the walls of the Siloé research reactor symbolically marked the end of INB dismantling at the CEA's Grenoble centre. Additional operations continued in 2013 to comply with further ASN requirements, consisting in cleaning up the Siloé reactor basemat, the active materials analysis laboratory (Lama[2]) and the basement of the effluent and waste treatment station (Sted[3]). This project is a unique example of clean-up and dismantling of an entire site. The operations concerned six INBs (three research reactors, one laboratory and two radioactive effluent and waste treatment stations) the oldest of which dated back to 1958, and the last of which was in operation until 2003. The dismantling of all the INBs on the site was completed in late 2012, meeting the milestone in the State-CEA target-based performance contract and three years ahead of the initial schedule.

(2) Lama: a French acronym for *Laboratoire d'analyse des matériaux actifs.*
(3) Sted: a French acronym for *Station de traitement des effluents et déchets.*

CADARACHE

Important progress has also been made on the dismantling work at Cadarache.

Conditioning of the Pégase storage drums
A total of 2,714 waste storage drums highly contaminated with plutonium were placed in interim storage in the buildings of the CEA's former Pégase reactor. They have now been removed from the facility after being conditioned in 619 870-litre packages, cemented and qualified. This meets one of the CEA's top-priority safety objectives on schedule.
Special workshops were designed and set up for these operations: a workshop for receiving drum pallets, a non-destructive characterisation workshop (X-ray imaging, gamma spectrometry and passive neutron measurement), a treatment-conditioning workshop (set of ten glove boxes), and a cement production workshop. Special equipment was also used: sealed chamber, specific ventilation for the process, high voltage panels and associated fixed generator set, low voltage equipment, etc. The project started in late 2006 and the design phase was completed in mid-2007. The work was then carried out between the end 2007 and the end of 2008, and the workshops commissioned on 17 April 2009, with the production of the first package in June 2009. Carried out at the same time as the removal of the irradiated fuels from interim storage in the reactor pool, this important step is part of the preparation for dismantling Pégase, planned for 2017 onwards.

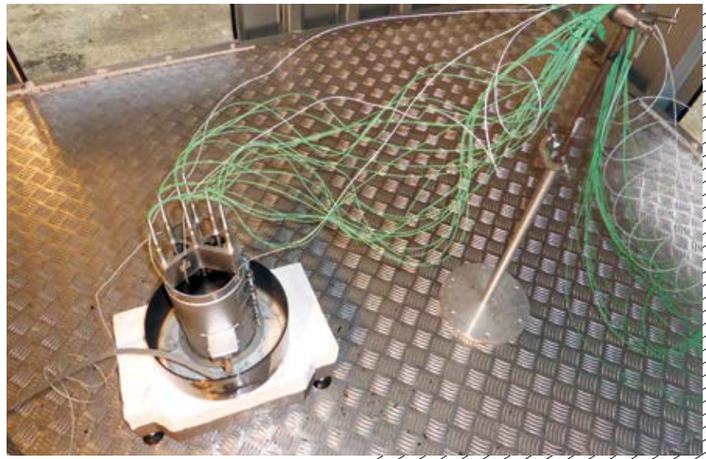
Interim storage of drums highly contaminated with plutonium in Pégase.

End of demolition of the "UO_2" building in INB 55 at Cadarache
The year 2013 was marked by the demolition of the "UO_2" building in INB 55 (Leca-Star), thus meeting the top-priority safety objective of preventing interaction between the Leca and Star facilities in the event of an earthquake. Commissioned in 1966, the UO_2 building housed a shielded line consisting of five cells called the "lead line", which was used for R&D on irradiated fuels.
This demolition is part of the work to ensure INB 55 complies with the current seismic regulations, in parallel with the refurbishment of Leca. The work for end of operation of the "lead line" was started in 2003. It was followed by a clean-up phase and then the dismantling of the shielded cells and all the line's auxiliaries, lasting until 2010. This was followed by the in-depth civil engineering clean-up operations with the objective of ensuring that no radioactivity had been added by the operation of this R&D facility. Final decommissioning of the nuclear waste areas was thus granted in March 2013. The last step, completed on 27 June, was the conventional demolition of all the structures of the UO_2 building. The R&D activities of the "lead line" were transferred to Cells 8 to 12 of the refurbished Leca facility.

Waste and Material Flow Management

Managing the flows of radioactive waste, materials and unused fuel is a vital issue for ensuring the nominal progress of R&D activities and clean-up and dismantling programmes.

One of the CEA's main objectives is to have operational treatment and interim storage systems for all categories of waste (VLLW, LILW, LLW-LL, HLW, ILW-LL), as well as the on-line capability for removing routine radioactive waste classified as very-low-level waste (VLLW) and short-lived low- and intermediate-level waste (LILW-SL) to the Andra's operational waste 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 waste (HLW) and long-lived intermediate-level waste (ILW-LL) packages on the one hand, and long-lived low-level waste (LLW-LL) packages on the other hand.



Experimental set-up for thermal stress tests on bituminised sludge waste, scale: 1 kilogramme.

ACCEPTANCE SPECIFICATIONS FOR CEA WASTE PACKAGES IN CIGÉO

The CEA is carrying out technical and scientific work to help establish the acceptance specifications for its HLW and ILW-LL waste packages so they can be sent for disposal in Cigéo, the deep geological waste repository project for which the Andra is the project owner. Following the request made by the national assessment committee at the end of 2012, the CEA has defined, jointly with Andra, AREVA and EDF, a specific R&D programme to confirm the demonstration of risk control under deep geological disposal conditions for waste packages of bituminised sludge, in particular with regard to the fire risk.

ACCEPTANCE OF THE CEMENTATION UNIT

The building of the cementation unit in the Hera facility at Marcoule was officially accepted in May 2013. This marks the end of the work phase and the beginning of the operating phase for its new laboratories.
Spread over two 250 m² floors, the laboratories will house the activities for formulating the cement matrices used for homogeneous and/or heterogeneous waste immobilisation and encapsulation, their manufacturing methods, and characterisation methods for cement-based materials.

SUPPORTING AGENCE ITER FRANCE ON ITER WASTE MANAGEMENT ISSUES

Within the context of the Euratom's commitment to set up a stream for managing waste generated by the ITER project, the CEA is meeting this commitment through the creation of Intermed, a future facility for the interim storage of waste containing tritium (tritiated waste) so it can decay (cool down) over a period of 50 or so years. A great deal of progress was made in 2013, such as: i) the choice of the reference site for the Intermed facility on a site adjoining the ITER project site; ii) all the preparatory work required to launch prime-contracting in 2015 and the drafting of the safety options report which will be submitted to the ASN in 2014. R&D programmes have been conducted in parallel, culminating in the publication of a summary report on the techniques available for treating tritiated waste. A summary of the assessment of the methods available for managing tritiated water will be drawn up in 2014. The final objective is to define the technical bases for drafting the terms of an agreement by mid-2015 to be signed with ITER for the management of tritiated operational waste.

Nuclear Service Facilities

The CEA uses a fleet of nuclear service facilities to manage its waste. These facilities are used for the interim storage of nuclear materials, conditioning and interim storage of spent fuel from the CEA's research reactors or from experiments carried out on EDF fuels, and for the treatment of liquid effluents and solid waste. As some of this fleet dates back to the creation of the centres, the CEA has started a major programme to reconfigure and adapt the fleet to meet future needs and comply with current safety requirements. This has led to the closing of facilities, refurbishment work and creation of some new facilities.

COMMISSIONING MAGENTA

The year 2013 saw the commissioning of the Magenta central warehouse at Cadarache which was built to replace the central fissile material warehouse (MCMF[1]). The Magenta facility is designed for the interim storage of fissile materials used for research programmes and also for checking the conditioning of nuclear materials, taking measurements and if necessary reconditioning nuclear materials.

POURING THE FIRST CONCRETE FOR STEMA

The year 2013 also marked the pouring of the first concrete for the Stema facility, which is designed to treat intermediate-level liquid effluents from the Marcoule site. This includes the construction of two new buildings near the liquid effluent treatment plant (Stel[2]): a building for sludge cementation and the effluent receipt building which will collect effluents from outside the Marcoule site and some of the site's own effluents transported to the building by tanker trucks. The concrete pouring operation for the basemat of the cementation building started on 25 April 2013, marking another milestone of the State-CEA target-based performance contract.

CLOSING THE ADM

The equipment decontamination workshop (ADM[3]) at Marcoule closed its doors on 15 December 2013 after more than 50 years of treating equipment and waste from the Marcoule facilities, other CEA centres and for customers such as AREVA (La Hague). The ADM's notable operations in 2013 included: compacting the banks from room 60 in the UP1 plant; receiving, treating and disposing the four tanks from hall 10 of Building 18 at the CEA/Fontenay-aux-Roses centre; treating and decontaminating all the irradiating waste and remote handling devices from the Marcoule vitrification workshop (AVM[4]).

(1) MCMF: a French acronym for *Magasin central des matières fissiles.*
(2) Stel: a French acronym for *Station de Traitement des Effluents Liquides.*
(3) ADM: a French acronym for *Atelier de Décontamination de Marcoule.*
(4) AVM: a French acronym for *Atelier de Vitrification de Marcoule.*

Opposite: Aerial view of the Stema effluent receipt building. Below: Assembling the shell of the Stema cementation building.

R&D and Promotion

With its expertise in the field of nuclear clean-up and dismantling, the Nuclear Energy Division (DEN) decided to organise its 2013 R&D and promotion activities in this field, setting up a dedicated programme.

The programme is structured around two main areas:
• **optimising R&D** in the field of clean-up and dismantling. The challenges mainly concern reducing costs, timescales and the amount of waste produced while improving the safety of clean-up and dismantling worksites;
• **developing and promoting R&D and expertise** offered to French and international parties, through various types of partnership or technology transfers with specialist companies, all within a context of international development of industrial clean-up and dismantling activities.

ACTIONS TO SUPPORT THE IRID

In 2013, the DEN was heavily involved in providing expertise to Japan on the dismantling of the Fukushima-Daiichi nuclear power plant. This work was carried out within the framework of the International Research Institute for Nuclear Decommissioning (IRID) established in August 2013 by the Japanese ministry for the Economy, Commerce and Industry to increase international cooperation on the dismantling of the plant. In this context, the DEN's role was as an expert and supplier of R&D, and as an interface between the IRID and French companies during the two "calls for information" issued by this institute.
The first was issued at the end of 2013 and focused on the problem of contaminated water. The DEN responded by recommending eight technological topics and carrying out an assessment mission in Japan. The second concerned the problem of recovering fuel debris and will be issued in early 2014. These calls for information will be followed by calls for proposals during 2014.

DID YOU KNOW?

AREAS OF EXPERTISE AND R&D

Since 2013, the R&D and expertise activities in the field of clean-up and dismantling have been organised into six main categories:
• assessment of the radiological state of facilities and soils;
• characterisation of waste under optimum safety and cost conditions;
• safe and financially optimised operations in hostile environments;
• decontamination of structures and soils;
• optimised treatment of waste and effluents;
• tools and methods for costing and managing materials, waste, transport, etc.

Virtual reality simulation of a remote controlled operation.

Decontamination foam for contaminated soil.

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.

Marcoule: Progress and Future Prospects

Marcoule, the birthplace of the French nuclear industry, was founded in 1955 on the banks of the Rhône River. Today it is home to CEA 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. The CEA is the main economic player in the region, employing nearly 5,000 people on the site and injecting more than 300 million euros into the local economy each year.

PROGRESS ON THE FUEL CYCLE

On 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 the La Hague spent fuel treatment-recycling plant. The teams are also involved in the development of processes supporting AREVA for the design of future fuel cycle plants on an international scale.

The teams are also heavily involved in continuing current studies on plutonium multiple recycling. The development of a new extractant molecule and the R&D supporting the planned polyvalent fuel treatment workshop dedicated to special fuels (TCP) at the La Hague plant illustrate this important field of R&D. Research scientists at Marcoule have continued their work in the context of the French Act of 28 June 2006 on the sustainable management of radioactive materials and waste. This includes investigating the recycling of actinides in 4th-generation reactors, especially the processes for manufacturing actinide-bearing fuels with the production of mixed uranium and americium oxide pellets. In addition, in the context of the Nuclear Energy Division's (DEN's) "4th-generation reactors" programme, a core physics test campaign, conducted on the shut-down Phénix reactor, has provided valuable information for the Astrid integrated technology demonstrator project for sodium-cooled fast reactors (SFRs).

After contributing to the progress report issued by the DEN in 2012, the Marcoule teams continued their R&D activities on the long-term behaviour of waste packages destined for the Andra's Cigéo deep geological repository. These activities are part of the new national radioactive material and waste management plan (PNGMDR[1]) signed at the end of 2013.

Research remains a strong, long-term field for the Marcoule centre, where all the units concerned underwent an assessment campaign in autumn, conducted by the research and higher education evaluation agency (AERES[2]). The results of this assessment will be published sometime in 2014.

Finally, the project to set up a European Hydrometallurgy Institute (EHI) was defined and launched at the end of 2013. This project will include an academic research network and appropriately sized technological platforms on which the CEA intends to offer technological developments for developing processes to extract and recycle strategic metals, for interested industrial companies working in the mining and recycling industries. It will soon be operational at the Marcel Boiteux regional business park (PRAE), which is currently being set up by the Languedoc-Roussillon region near Marcoule.

(1) PNGMDR: a French acronym for *Plan National de Gestion des Matières et Déchets Radioactifs.*
(2) AERES: a French acronym for *Agence d'évaluation de la recherche et de l'enseignement supérieur.*

Dismantling conference: unveiling of the future cluster for the promotion of industrial sites (PVSI).

STEMA WORKSITE: FIRST CONCRETE POURED

On 19 June 2013 the first concrete was poured for the construction of the Stema building on site at the Marcoule liquid effluent treatment plant. This infrastructure will replace the process to bituminise sludge from the site's radioactive effluents with a cementation process. Not only is a new infrastructure being built, but a new cement material has also been specially developed for this technique, as well as a new high-energy mixing process. The commissioning of Stema is planned for 2016.

Experiment for selective uranium extraction in a pulsed laboratory column.

MAJOR DISMANTLING PROJECTS

Significant progress has been made on the numerous clean-up and dismantling projects in progress at Marcoule. The main challenge is to reduce radioactivity levels in the facilities. Several operations carried out on the former UP1 plant or its workshops have contributed to progress made in this area: for example the dismantling of the plutonium extraction equipment, which was previously an essential component in this spent fuel reprocessing plant, and which formed the subject of a CEA milestone vis-à-vis the State at the end of 2013. Other key points: completion of the "level 1" dismantling of the former spent fuel decladding workshops, and the green light from the laboratory and plant safety commission (CSLU-D[3]) for dismantling the Marcoule pilot unit (APM).

As part of preparing for dismantling, work continued on the Phénix fast reactor, which was permanently shut down in 2009, and four shipments of spent fuel were sent to the AREVA plant at the La Hague. On an administrative and regulatory level, the teams have been actively involved in continuing preparations for creating a standing group for reviewing the safety of the facility and in setting up a public enquiry prior to dismantling, planned for 2014.

Clean-up and dismantling have also progressed via R&D work carried out to develop materials suitable for reconditioning certain legacy waste, and with the first full-scale tests of a robot arm, called Maestro, designed to perform remote controlled operations.

At the end of the year, the CEA organised, together with various local companies and organisations, the first "dismantling conference" at Marcoule. This was to support the upcoming establishment of a cluster for the promotion of industrial sites (PVSI[4]) at the Marcel Boiteux regional business park and thus promote Marcoule's unique expertise in the field of clean-up and dismantling.

(3) CSLU-D: a French acronym for *Commission de sûreté des laboratoires et usines.*
(4) PVSI: a French acronym for *Pôle de valorisation des sites industriels.*

ATALANTE WINS AN AWARD

The CEA's Atalante research laboratory at Marcoule has been recognised as a "Nuclear Historic Landmark" by the American Nuclear Society (ANS). This prestigious award acknowledges the accomplishments of sites or facilities throughout the world which have made outstanding scientific progress or have significantly contributed to the development of civilian nuclear technologies. The Atalante facility, which was gradually commissioned from 1992, still has no equivalent today worldwide in the field of R&D on the different stages involved in the nuclear fuel cycle.

Philippe Guiberteau, Anne-Yvonne Le Dain, Donald Hoffman and Christophe Béhar at the official Nuclear Historic Landmark awards ceremony.

Cadarache: Energies of the Future

Cadarache is the major European research centre devoted to low-carbon energy: nuclear fission and fusion, solar energy and biofuels. This 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 PROJECT

There were three key events in the Jules Horowitz Reactor (JHR) project in 2013:
• an eleventh partner, the Nuclear National Laboratory (Great Britain), entered the JHR consortium;
• the Ammon programme was conducted in the Eole reactor which, after three years of experiments, has helped significantly reduce uncertainties on the neutronics calculations for the reactor's start-up core;
• installation of the reactor dome.

MORE ABOUT

INSTALLATION OF THE JHR DOME

On Friday 13 December, the CEA and its partners, AREVA and Razel-Bec, installed the 34-metre diameter reactor dome weighing 105 tonnes. This exceptional operation marked a major milestone for the JHR in which divergence will take place by the end of the decade. The only facility of this type under construction in Europe, the JHR will provide high-performance experimental capacities on the behaviour of materials and fuels under irradiation, and will supply radioisotopes for medical purposes, in particular molybdenum-99.

INNOVATION, SHARING TECHNOLOGIES AND KNOWLEDGE

There were many fruitful discussions throughout 2013, on both a national and an international level, between the centre's scientists and universities, industrial companies, the academic community and the general public, with the aim of integrating science into the local economy. They included:
• the success of the 3rd ANIMMA international conference in Marseille on nuclear instrumentation and measurement, with 450 delegates from some forty countries;
• the first annual "Cadarache and nuclear medicine" seminar, at which more than 30 doctors from districts close to the centre received information connected with medical and nuclear science, as well as learning about the centre's R&D activities in these fields: effects of radiation, medical imaging and scintigraphy, radiological monitoring of employees, JHR and production of radioisotopes for nuclear medicine;
• organisation of two meetings between the CEA and industries in the Provence-Alpes-Côte d'Azur (PACA) region for innovation and technology transfer in the fields of instrumentation, measurement, characterisation and non-destructive testing. These meetings brought together 200 participants from small-, medium- and intermediate-sized enterprises and industries, as well as large groups and institutions, all involved in innovation and economic development.

Participants at the 2013 ANIMMA conference.

FUTURE NUCLEAR SYSTEMS

The preconceptual design phase of the Astrid project (AVP1[1]) was completed as planned at the end of 2012. The objectives were achieved: the industrial set-up was established, the studies were conducted satisfactorily and the planned documents distributed within the required timescales. These results meant that the authorities gave the green light for the start of the conceptual design phase (AVP2[2]).
The year 2013 was devoted preparing the conceptual design in terms of planning, technical and economic analysis, choice of options and feedback from the preconceptual design. This preparatory phase was completed in September with a configuration review which finalised the design which will be studied until the end of 2015.
Another major event in 2013 was the meeting of the standing group on reactors appointed by the ASN, which analysed the safety guidelines document submitted in 2012.
Finally, the circle of industrial collaborations around Astrid was widened with the arrival of SEIV, a member of the Alcen group (irradiated fuel examination unit).

NUMERICAL SIMULATION FOR REACTORS

The benchmarking of the Astrid core carried out between the Nuclear Energy Division (DEN) and two US Department of Energy (DOE) laboratories - Idaho National Laboratory and Argonne National Laboratory – made it possible to compare the neutronics calculations with those of transient behaviour of Astrid's CFV[3] core. The consistent results confirmed the DEN's assessments for the key parameters associated with reactor performance and safety.

Pleiades, the software platform for simulating the behaviour of fuels under irradiation, developed within the framework of the three-party CEA-EDF-AREVA agreement, celebrated its tenth birthday in 2013. During these ten years, significant progress has been made in the simulation of nuclear fuels from various different current and future research and industrial nuclear reactor types. The Germinal application (made available to industrial partners) is currently used to simulate the behaviour under irradiation of pins representing the future Astrid core.

Version 2.8-4 of the Apollo code was delivered to AREVA and EDF in 2013. It is used for neutronics calculations of reactor cores, provides a more precise simulation of interactions between neutrons and nuclei, and also reduces the calculation times and memory capacity required for carrying out these simulations.

TEST PLATFORMS AND REACTOR TECHNOLOGIES

Reactor safety
The core of the Cabri research reactor has been completely reloaded. Equipped with a new pressurised water loop, it is now dedicated to performing tests on reactivity accidents in pressurised water reactors. Following a major refurbishment programme, it was possible to launch the testing phase prior to divergence authorisation. Cabri will also be used to simulate the behaviour of pins for the future Astrid core.

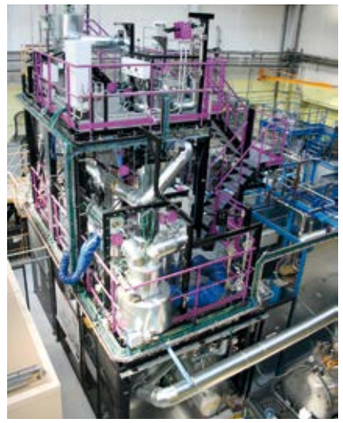
Astrid project
Among the technological innovations associated with the Astrid project, the DEN has been studying the development of a compact sodium-gas heat exchanger. It has designed, built and commissioned the Diademo test platform, which mainly consists of a gas circuit (nitrogen at 10 MPa and 530°C) and a sodium circuit (560°C). The first prototype heat exchanger was filled with sodium and the first experimental heat exchange measuring points have been acquired. Three other test mock-ups are scheduled on this technology platform.

Manufacturing nuclear fuels
The new unit for manufacturing uranium carbide ceramics has been commissioned at the UO_2 laboratory. There are two interconnected glove boxes in an argon atmosphere, protected from pollution: one is dedicated to handling powders while the other is used with a carboreduction synthesis kiln and is dedicated to sintering. This will improve the quality control and reproducibility of uranium carbides for a number of research projects.

Severe accident studies
The Plinius-2 project is a multi-technology facility dedicated to severe accidents. Studies on this platform started in 2013. As part of the "4th-generation reactors" programme, this facility will extend the functionalities of the current Plinius platform (which is used for studying corium-water and corium-concrete reactions) to rise to the challenges posed by the Astrid project. Combined with the programme concerned, it will also support industrial companies for 2nd- and 3rd-generation reactors. Construction should start in 2016 with the aim of start-up in 2019.

Environment
The laboratory for modelling transfers into the environment at Cadarache has been designated the reference unit for hydrogeological studies at the DEN. This new organisation supplements that set up in 2012 to manage environmental impact studies for the CEA centres. It will simplify and coordinate the processing of documents, while ensuring that studies are both consistent and coherent, and that full use is made of the data collected.

(1) AVP1: a French acronym for *avant-projet sommaire phase 1.*
(2) AVP2 : a French acronym for *avant-projet sommaire phase 2.*
(3) CFV: a French acronym for *Cœur à Faible effet de Vidange*, which refers to a core concept with a low sodium void effect - "low void effect core" -.
(4) Cinphonie: a French acronym for *Cellule d'Irradiation Neutronique et PHOtoNIquE.*



The Diademo facility.

MORE ABOUT
RADIOACTIVE WASTE MANAGEMENT

CINPHONIE: NEW PLATFORM FOR HIGH-ENERGY IMAGING

Unique within the DEN, the neutron and photon irradiation cell called Cinphonie[4] is located in the Chicade regulated nuclear facility (INB). It is used to perform non-destructive characterisations with radiography and X-ray tomography equipment on large, heavy waste packages. It received authorisation for commissioning in early December 2013, which was quickly followed by its first examination, conducted on a radioactive waste package for Andra. From 2014 onwards, all high-energy imaging tests will be performed in Cinphonie.

Saclay: Nuclear Sciences and Simulating Reactors and the Fuel Cycle

The Nuclear Activities Division of Saclay (DANS) covers three main areas: simulation, materials and chemistry. The DANS also carries out technical and economic studies via the Institute for Techno-Economics of Energy Systems (I-tésé).

SIMULATION FOR REACTORS

Several noteworthy results illustrate the progress made in the field of simulation by the Nuclear Energy Division (DEN) teams at Saclay and Grenoble.

Major codes. The latest industrial version of the Apollo2 reference neutronics code, enhanced with new functions, has been delivered to DEN, EDF and AREVA users. Apollo2 is a cornerstone of EDF's and AREVA's neutronics calculation systems. It has been approved by the US safety authority for calculating the cores of pressurised water reactors using UO_2 fuels.

Thermal hydraulics. The European Ercosam[1] project combines experimentation and simulation for studying scenarios that represent severe reactor accidents with dispersion of hydrogen into the containment. Initial tests of hydrogen catalytic recombiners have been carried out on the Mistra facility.

Code coupling. The Corpus tool combines a set of DEN software using the Salomé platform to calculate interactions between physical phenomena in pressurised water reactors. The Apollo3® neutronics code has been incorporated and coupled with the Flica4 core thermal hydraulics code, for the precise simulation of normal and accident operating conditions.

R&D ON MATERIALS AND INTERFACES

Ceramic matrix composites could be used as refractory cladding in the form of sandwich cladding consisting of two concentric tubes incorporating a metal liner. The process used to close the tube ends has been validated in collaboration with the CEA/Valduc centre, and the first closed cladding was made in 2013. EM10 steel was chosen as the reference material for the hexagonal tube (wrapper) in the Astrid project after microstructural analyses, which confirmed its dimensional stability up to high doses (155 dpa).
The use of hard, cobalt-based alloys (stellites) in friction areas results in the activation of the cobalt under neutron flux. To replace these alloys in a sodium environment, processes for depositing nickel alloys have enabled high-quality samples to be produced, which have undergone tribological corrosion tests in sodium.

The Mistra facility at Saclay, dedicated to studying hydrogen risks.

Top: mock-up of the timber framework house on the Azalée vibrating table.
Bottom: detail of reinforcement in the base of the brick-built mock-up.

R&D ON SEISMIC RISK MANAGEMENT

The DEN's expertise on seismic risk management has been applied to houses, for example via the SISBAT project, supported by the national research agency (ANR) and numerous partners. Earthquake resistance tests have been carried out on a house with an industrial timber framework and roof, and on a house with brick walls and reinforced concrete footings and tie beams assembled with an industrial timber roof. The aim was to improve scientific knowledge of the behaviour of this type of house when subjected to seismic loads. These tests have confirmed the position of Tamaris as the leading European platform on seismic risk management.

(1) Ercosam: Containment thermal hydraulics of current and future LWRs for severe accident management.

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

The DEN is contributing to various aspects of Cigéo, the Andra's future deep geological repository. This includes calculating the hydrogen flows produced by radiolysis by 500-litre intermediate-level waste (ILW) packages with cement matrix, using the definition of an average package based on knowledge of the seven hundred or so packages produced between 1990 and 2009. These results are helping to control the hydrogen risk in the Cigéo project. In the context of the "Full-scale sealing" project, the DEN is helping to demonstrate the industrial feasibility of sealing the tunnels of the future repository. The sealing concept consists of a plug with swelling clay pellets, held between two low-pH (pH <11) concrete blocks. The formulation of the self-compacting concrete has been finalised and satisfactory behaviour of the material has been demonstrated up to full-scale injection.

SCIENTIFIC RADIATION: INVOLVEMENT OF THE "DANS" IN THE MARS SCIENCE LABORATORY MISSION

DEN scientists at the Saclay centre have been involved in the design and development of the ChemCam instrument, mounted on board the Curiosity rover. Using the DEN's expertise in analysing the nuclear environment, ChemCam, which combines an HD camera and LIBS technology, is used for remote, contactless determination of the chemical composition of rocks and soils: it relies on spectral analysis of the visible UV radiation emitted by the plasma produced by laser ablation of the material. The performance of this instrument was recognised by:
• publication in the prestigious journal *Science,* in September 2013, of the results it obtained during the first 100 days of the mission on Mars, namely the recording and transmission of over 10,000 spectra. Two DEN research scientists at Saclay are the co-authors of this article;
• NASA prize awarded to these two research scientists and one of their colleagues for their exceptional contribution to the building and optimum operation of this instrument, and to the interpretation of its results.

EXPERIMENTAL RESOURCES BENEFITTING SOCIETY

In 2013, the Osiris reactor more than doubled its production of artificial radioelements for diagnostic nuclear medicine in France and Europe. It has thus helped avoid any disruption in the supply of technetium-99m, the most commonly used radioelement in this field. Over the year, Osiris irradiated more than 400 uranium targets from which molybdenum-99, the precursor to technetium-99m, was extracted, enabling 1.6 million medical examinations to be conducted. In coordination with the other European reactors, the production effort on Osiris meant that there was no break in the supply to European hospitals.

CERTIFICATION OF THE DEN'S OCCUPATIONAL HEALTH AND SAFETY MANAGEMENT SYSTEM AT SACLAY

The DEN at Saclay set itself the objective of complying with the OHSAS 18001 standard on occupational health and safety. The 2013 audit involved a considerable amount of work from of all the units, and led to successful certification, which is fully in line with the CEA's values.

EXPERIMENTAL RESOURCES: SCIENTIFIC INVESTMENTS TO MEET PROGRAMME NEEDS

Simulation and nuclear science are fuelled by experimentation and new scientific equipment. Studies on corrosion in a sodium environment are benefitting from the new CORRONa² [2] platform. The state-of-the-art GENESIS equipment concerns tools for observing irradiated materials on a nanometric scale: a tomographic atom probe and an electron microscope equipped with an ion beam sampling system were added to the fleet in 2013. The commissioning of a high-capacity press will enable mechanical tests to be carried out on large components weighing up to 500 tonnes.

Samples of Sic-Sic composites after testing on the CORRONa² platform.

MORE ABOUT

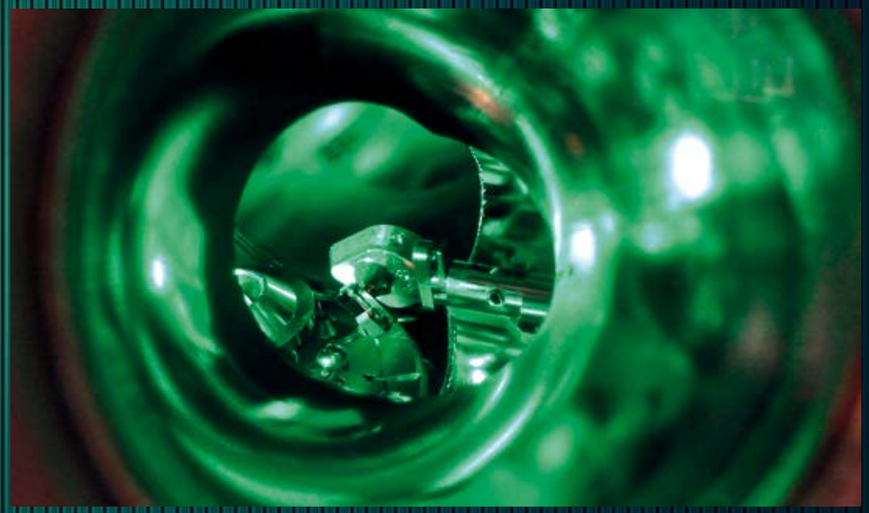
2013 SFEN PRIZE: THREE AWARDS FOR THE DEN'S WORK AT SACLAY

Each year, the French nuclear energy society (SFEN) awards prizes for research in the field of nuclear energy. The SFEN *Grand Prix,* which recognises scientific or technical excellence, was awarded to the EUROPLEXUS code, developed at Saclay. Specially designed for simulating fast-transient fluid and structural dynamics, EUROPLEXUS has a number of high-profile industrial applications, including reactor safety.
The Jacques Gaussens prize, awarded to a young research scientist by the industry, was won by Yannick Robert for his study of creep behaviour in zirconium alloys under neutron flux in PWR assemblies. Finally, the Jean Bourgeois prize was awarded to Arthur Hellouin de Menibus for his thesis on hydride blister formation and its effects on the fracture of Zircaloy-4 cladding during a reactivity initiated accident (RIA).

Winners of the SFEN *Grand Prix.*

(2) CORRONa²: CORROsion Na, i.e. corrosion in liquid Na.

Programme Support and External Relations



The Nuclear Energy Division (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.

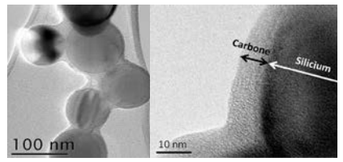
Cross-disciplinary Programme on Advanced Materials

During 2013, 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[1]).

EVENTS, ORGANISATION AND STRATEGIC DISCUSSIONS

One of the actions to increase the CEA's visibility was the launch of the "CEA materials" website, which aims to showcase the CEA's knowledge in terms of the elaboration, advanced characterisation and simulation of materials and processes. It also provides access to the website on the MINOS centre of excellence for nuclear materials.
The PTMA's contributions to external representation of the CEA have included:
• discussions held by the steering committee on the future of metallurgy at the French ministry for higher education and research;
• scientific assessment of the material-related activities of the French aeronautics and space research centre (ONERA);
• drawing up the "Metallurgy in and for Europe" roadmap, as requested by the European Commission.

Strategic discussions covered additive manufacturing technologies and even 3D printing. For this work, which will continue in 2014, the PTMA relied on the marketing research department to draw up an overview and define a CEA strategy for this fast-growing sector. Identifying the industrial technologies, the main players involved at every stage in the value chain, and the types and strengths of the limitations, were essential prerequisites for drawing up an integrated CEA strategy.
And finally, with regard to its coordination activities, the PTMA has started setting up coordination between the divisions on critical metals, which will be extended in 2014.



Left: Silicon particles with a carbon shell produced by the 2-stage laser pyrolysis process. Right: Close-up of the shell.

Detailed view of the tomographic atom probe at the DMN at Saclay.

HIGHLIGHTS

In the field of innovation for light water reactors, it is worth highlighting the excellent oxidation behaviour reached with PVD[2] coatings at high temperatures.
Very encouraging results have been obtained in the acoustic monitoring of the mechanical alloying process for oxide dispersion steels (ODS) developed for the future 4th-generation of nuclear systems. This work will make the mechanical alloying process more robust while making it easier to control scaling laws. In the field of fusion and particularly to support the WEST project (ITER project test bench), the programme has achieved controlled production of gradient function components using spark plasma sintering (SPS), and also qualification of the PVD technology for thick tungsten coatings.
In terms of new energy technologies, the Iramis Institute, which is part of the CEA's Physical Sciences Division, has produced "core-shell" nano-powders to optimise materials for lithium-ion batteries.
Highlights in the materials field include expansion of the CEA's technological capacity, with:
• commissioning, by the Nuclear Materials Department (DMN) at Saclay, of the first equipment for the GENESIS platform for nano-analysis of irradiated materials, which will make the Nuclear Energy Division (DEN) and its partners world leaders in the analysis of irradiated materials;
• commissioning of a completely new high-temperature CVI/CVD[3] facility at the CEA's Ripault centre. This facility which will significantly increase the CEA's potential regarding ceramic matrix composites, as well as in a great many other fields (thermal solar, ultra-refractory, etc.);
• setting up of the nanosynthesis platform by the Iramis Institute in conjunction with the University of Orléans. This platform will combine laser pyrolysis and inductive plasma on a pilot scale for synthesising representative amounts of complex nano-powders, and will play a decisive role in the implementation of nanomaterial technologies;
• new business start-up called Nawatechnologies which will sell carbon nano-tubes on various substrates for a wide range of applications.

(1) PTMA: a French acronym for *Programme transversal matériaux avancés*.
(2) PVD: Physical Vapour Deposition.
(3) CVI/CVD: Chemical Vapour Infiltration/Chemical Vapour Deposition.

Nuclear Energy Division Scientific Activities

The Scientific Division is responsible for the Nuclear Energy Division's (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 17 and 18 December 2013, the Scientific Advisory Board examined the CEA's plasma and laser physics activities. The physical-chemistry department (DPC) at Saclay presented its achievements in the field of laser spectroscopy (LIBS) and highlighted the success of ChemCam, the camera mounted on-board the Curiosity rover.

DEN Scientific Advisory Board
From 14 to 16 October 2013, the DEN Scientific Advisory Board assessed the research activities on light water reactors, including the associated experimental resources. The fields of research ranged from simulation to severe accidents and also included fuel studies. The Scientific Council underlined the excellent quality and consistency of the studies supporting the industry, which are designed to help continuously improve the performance of the current fleet and ensure it is operated under optimum safety conditions. The CEA's approach combines assessment, simulation and dedicated experiments, and is systematically based on understanding physical phenomena through basic science. This approach was considered to be outstanding by the Council. Recommendations made included substantial support for the initiative to create an AREVA-EDF-CEA research institute on water reactors, continuation of excellent basic research at the DEN and increased recruitment of young PhD students and post-doctoral students of a high academic calibre.

AERES
In the autumn, the research and higher education evaluation agency (AERES[1]) examined the most research-oriented departments within the DEN based in Saclay and Marcoule (DMN, DM2S, DPC, I-tésé, DRCP, DTEC, DTCD and ICSM). The results of the assessment are due to be published in 2014.

The DEN Scientific Council.

"Learn about the DEN" session.

PHD STUDENTS, POST-DOCTORAL STUDENTS AND RESEARCHERS AUTHORISED TO SUPERVISE UNIVERSITY RESEARCH (HDR[3])

The substantial reduction in the DEN's subsidies has led to a significant fall in the number of new PhD students. In 2013, the DEN hosted:
- 241 PhD students, 72 of whom were new arrivals;
- 42 post-doctoral students;
- around 100 researchers authorised to supervise university research.

The DEN is continuing its policy of encouraging researchers to obtain authorisation to supervise university research, and seven researchers achieved this level in 2013.

SCIENTIFIC ACTIVITIES

Scientific publications
During 2013, DEN researchers produced:
- 422 scientific papers in peer-reviewed journals;
- 129 of the above papers were co-written with other international research laboratories.

Basic nuclear training (FNB[2])
The SPIRALE-FNB training scheme provides all new recruits with cross-disciplinary scientific and technical knowledge and enables researchers and engineers to acquire a basic general nuclear knowledge of the research topics being studied within the DEN. In 2013, the DEN held two "Learn about the DEN" sessions, attended by 89 people, and two level-2 sessions – one at Marcoule and the other at Saclay – attended by 66 people.

A total of 181 course participants and 102 managers completed a post-FNB survey on the level-3 session, leading to the creation of a new version of this level (course organisation and content), which is to be introduced in March 2014.

EXPERTISE WITHIN THE DEN

The experts programme
The CEA has been running its experts programme since 2009, the aim of which 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.

Special seminars
The Scientific Division regularly organises scientific seminars to provide information on important and strategic topics that guide choices for future research. The following three seminars were led by experts from the DEN in 2013:
- choice of coolant for fast reactors;
- leaching of active nuclear glass;
- recycling of critical elements using hydrometallurgical separation technologies derived from those developed for the nuclear fuel cycle.

The DEN was also responsible for the overall organisation of three international conferences in France in 2013: FR13 (4-7 March)[4], ANIMMA (23-27 June)[5] and SNA+MC (27-31 October)[6].

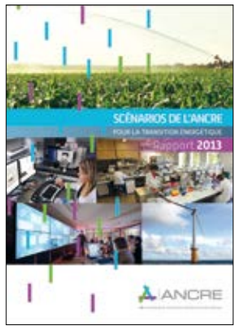
Critical skills analysis
The DEN's Scientific Division and HR Division updated the inventory of expertise within the DEN in relation to a reference list of 81 areas of expertise. This work helped to flag up the lack of expertise in some areas (due to lack of activity and/or experts having left). A closer analysis of three potentially critical areas of expertise (isotope separation, nuclear fuel and thermal hydraulics) helped define a preventive action.

Technology watch
Literature monitoring activities, started in 2012, have continued with the support of Saclay's information development section, using the VISA literature search tool.

Involvement in ANCRE
In 2013 the GP3 "Nuclear energy" programmatic group of the French national alliance for energy research coordination (ANCRE), co-managed by the DEN, drew up a roadmap on reactor physics and numerical simulation. GP3, together with I-tésé, also made a major contribution to drawing up the energy scenarios proposed by ANCRE in the context of the national debate on energy transition, and to ensuring the coherence of these scenarios. One of these was selected by the debate's steering committee as the reference for the diversity route. These studies made it possible, amongst other things, to define the potential contribution of nuclear energy both for provision of diversified energy (cogeneration of heat for urban heating, cogeneration for industry) and as a controllable energy source enabling intermittent energies (wind, solar) to be fed into the grid. Finally, GP3 helped to draw up several national strategic positioning documents, including those on major research neutron irradiation tools, research priorities for water reactors, contribution to the national research strategy and to the future programming of the national research agency (ANR).

MORE ABOUT
MONOGRAPHS

A monograph on "neutronics" was published in 2013. It describes the basic concepts, including the neutron transport equations (Boltzmann) and radioactive decay equations (Bateman), methods, computer codes, qualification and various industry-oriented applications (core calculation, radiation protection, fuel, criticality, etc.).



Work of the High Commissioner
In 2013, several experts representing the DEN on the various bodies within the High Commissioner's office, were responsible for preparing scientific policy reports on topical nuclear issues such as the ageing of the materials of PWRs, storage of bituminised waste and separation chemistry. Other experts were actively involved in a mission to analyse the energy scenarios proposed within the framework of the French national energy transition debate in order to assess their technical feasibility and overall coherence, in particular in terms of the maturity of the technologies used to produce and exploit energy, its storage, the networks used and diversification of the energy options (electricity, heat, hydrogen, etc.).

NUCLEAR EDUCATION AND TRAINING

The DEN is responding to the nuclear industry's recruitment requirements and increasing the standing of nuclear technology by targeting strategic training courses in fifteen or so higher education establishments in the Île-de-France, north-west France, Montpellier, Grenoble and Aix-Marseille regions as a matter of priority. In 2013, some 500 of the DEN's staff delivered over 10,000 hours of training, including almost 6,000 hours for the National Institute for Nuclear Science and Technology (INSTN).

(1) AERES: a French acronym for *Agence d'évaluation de la recherche et de l'enseignement supérieur.*
(2) FNB: a French acronym for *formation nucléaire de base.*
(3) HDR: a French acronym for *habilité à diriger des recherches universitaires.*
(4) FR13: Fast Reactors and Related Fuel Cycles.
(5) ANIMMA: Advancements in Nuclear Instrumentation Measurement Methods and their Applications.
(6) SNA+MC: Supercomputing in Nuclear Applications + Monte Carlo.

The Nuclear Energy Division and the International Scientific Community

The Nuclear Energy Division (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.

CHINA

In China, cooperation with the Nuclear Power Institute of China (NPIC) and the China National Nuclear Corporation (CNNC), in the form of associated laboratories, is gathering steam with the introduction of a new topic on severe accidents. It concerns studies on in-vessel corium retention.
The DEN is also involved in AREVA's project to sell a spent fuel reprocessing plant to the CNNC, which should be followed by the sale of a MOX fabrication plant.

INDIA

Though limited to basic research and safety, cooperation with India is very dynamic, in particular in the field of the safety of sodium-cooled fast reactors (SFRs). Seven new agreements or extensions to agreements were signed in 2013, including two on waste management. Through this cooperation, the DEN benefits from the dynamism of India's programme, in which the construction of the 500 MWe Prototype Fast Breeder Reactor (PFBR) is due to finish for start-up in 2014. India is also a member of the JHR consortium and is working on innovative devices which could be incorporated in the Jules Horowitz Reactor (JHR) in the future.

ISRAEL

Cooperation with Israel was resumed in 2010 with the signing of a Memorandum of Understanding (MoU). It is extremely dynamic in the fields of basic and applied research (materials, migration of radionuclides in cemented waste, thermal hydraulics, etc.). Israel is a member of the JHR consortium and is working on the building of the Lorelei loop, designed for a loss-of-coolant accident (LOCA) test in the JHR.

The NNL joins the JHR consortium: signing of the agreement with the British Department of Energy and Climate Change on 12 March 2013 in London.

JAPAN

Relations with Japan cover two main topics: Astrid and the clean-up of the Fukushima-Daiichi nuclear power plant. Negotiations have progressed with the definition of the terms for Japan's entry into the Astrid programme, and the relevant agreements should be signed in 2014. Discussions with the Japanese Atomic Energy Agency (JAEA) on a programme for taking and characterising corium samples simulating the corium in the damaged Fukushima reactors are at an advanced stage and will involve the DEN's Cadarache and Marcoule centres.
In 2013, Japan set up a new programme agency, the International Research Institute for Nuclear Decommissioning (IRID), which coordinates research supporting the dismantling of the Fukushima site. The DEN has established close contacts with this organisation to offer its services and coordinate the French proposals for treating the contaminated water and examining the reactor cores which are severely damaged.

GREAT BRITAIN

Resumption of the British nuclear programme, the British National Nuclear Laboratory's (NNL) membership of the JHR consortium and its clear desire to join the Astrid programme are at the heart of the prospects for strategically strengthening the Franco-British partnership on current and future nuclear systems. Great Britain is continuing to express considerable interest in joining the DEN's major R&D programmes.

UNITED STATES

The relationship with the US Department of Energy (DOE) was strengthened in 2013 with its publication of the results of a study carried out in conjunction with the DEN on the behaviour of the Astrid reactor under accident conditions. A framework agreement on Astrid and an action plan covering future reactors, the fuel cycle, waste and numerical simulation were signed, so that cooperation can continue in the long-term. The DOE then immediately initiated a new study to assess the safety options for the Astrid core.

CENTRAL EUROPE

The V4G4 consortium consisting of Hungary, Slovakia, the Czech Republic and Poland was set up in 2013 to support the Allegro project. This is a small gas-cooled fast reactor (GFR) which will create new skills in nuclear R&D in the four member institutes of the consortium (one per country). The DEN is supporting this as an associate partner. The construction project is expected to last beyond 2020.

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, in the Generation IV International Forum (GIF), and in the International Atomic Energy Agency's (IAEA) International Project on Innovative Nuclear Reactors and Fuel Cycles Forum (INPRO). It is involved in the governance of these organisations.
During 2013, the DEN helped the SNETP define the strategic guidelines for the platform and was involved in updating its strategic agenda, in particular for the European Sustainable Nuclear Industrial Initiative (ESNII) and for the R&D initiative concerning 2nd- and 3rd-generation reactors called NUGENIA. The DEN also contributed to major European projects such as ESNII PLUS.
The GIF plays a strategic role in promoting R&D on 4th-generation reactors. In 2013, it drew up design safety criteria for SFRs. This is the first time that an international initiative has proposed such criteria within research organisations. The revision of the GIF's roadmap was proposed and the development schedules for the six key technologies were updated.

Signing of a trilateral MoU with the US DOE and Rosatom on the future MBIR Russian research reactor in June 2013 in Saint-Petersburg.

RUSSIA

Cooperation with Russia was picked up again with the renewal of the CEA-Rosatom agreement in 2010. This was then strengthened in 2013 when a new agreement was signed with the Kurchatov Institute on reactors and the future fuel cycle, along with a trilateral CEA-DOE[1]-Rosatom MoU on the MBIR SFR project.
Discussions on the future prospects for joint construction of a 4th-generation commercial SFR (the RFFR - Russian French Fast Reactor) led to the production of a joint document. The following activities are also ongoing: an irradiation feasibility study in the BN-600 Russian fast reactor to qualify the fuel for the Astrid SFR, physics tests on its core in the BFS critical mock-ups (similar to the Masurca reactor at Cadarache) and irradiation of cladding materials in the BOR-60 Russian fast reactor.

(1) DOE: Department of Energy.

Quality within the Nuclear Energy Division

The Nuclear Energy Division (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 and continually improve its management efficiency, while developing its cross-disciplinary activities and ensuring that best practices are used at all sites where it operates.

In 2013, this organisation took over responsibility for certifying all the programme activities carried out at the DEN in the fields of the environment and occupational health & safety. A specific coordination unit was set up to define the DEN's policy in these two fields and establish an implementation plan. Obtaining the triple quality, safety and environment (QSE) certification in 2013 marked an important step in this integrated management process.

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 all staff, CEA employees and external contractors. In 2013, it took place on 17 October and focused on the prevention of handling accidents and addiction. There were sessions based on scenarios illustrating situations likely to cause accidents, which had already been successfully tried out in previous years. Furthermore, workshops within the facilities and round tables with external contributors also helped to raise employee awareness of these risks.
Although lower than the 2012 rate, the number of work-related accidents resulting in absence from work has returned to the level of previous years. Travel and accidents described as non work-related still account for the majority of absences.

INB 165 at Fontenay-aux-Roses, winner of the DANS poster competition.

Biodiversity trail at Cadarache (in collaboration with the French national forestry commission).

Following an increase in 2012, the number of significant events involving safety, radiation protection or the environment returned to the level of previous years in 2013. Seven of these had a detectable impact on staff and the environment. There were a few cases of injuries in controlled areas with suspected contamination which were all found to have no significant consequences.
The DEN also carried on complementary safety assessments (ECS[1]) of its facilities to take into account the Fukushima nuclear power plant accident in Japan, as well as implementation of the improvements called for by these studies.

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 changed. Industrial companies which have such materials therefore have to review this protection by means of safety studies of their sites and facilities. The DEN started this review in 2013 for its centres and their main facilities.

EXPERT ADVICE IN THE EVENT OF NUCLEAR EMERGENCY

In order to fulfil its role as an advisor to the government, in the fields in which it has expertise supported by many years of R&D, the DEN has set up a system to provide an immediate response to any request for expert advice as a result of a nuclear emergency in France or elsewhere in the world. A panel of experts and specialists can be mobilised very quickly to analyse and clarify any accident conditions. This system is not intended to replace the CEA's operational emergency management system, which remains in force. It can, however, provide support to this system if necessary. This system was not called upon in 2013, except for a practice drill.

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.
In 2013, as in 2012, this topic was included in the Sécuriden day.
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.
As part of this activity, the DEN has joined the board of the French Association for the rules governing the design, construction and operating supervision of equipment for nuclear steam supply systems (AFCEN). This association was founded by EDF and AREVA to draw up and publish French nuclear codes and standards. Under the aegis of the association, the DEN has proposed the publication of a code dedicated to new, innovative systems, to supplement those covering current power-generating reactors.
From its position on the board, the DEN has supported the AFCEN's policy of openness to other operators, manufacturers and research organisations, including those in other countries. This position was reaffirmed at the association's triennial conference, which took place in March 2013 in Paris with a large number of international delegates.

MORE ABOUT

PROTECTION OF FRENCH NATIONAL SCIENTIFIC AND TECHNICAL POTENTIAL

**Since 2010, the DEN has continued to tighten its protection of sensitive information connected with its R&D programmes. It has therefore updated and supplemented its procedures manual in order to formalise the practices used and to incorporate the changes in the regulations on the protection of French national scientific and technical potential (new PPSTN decree). A plan for applying the provisions of this decree has been drawn up and implemented.
A classification/declassification committee has also been set up. This process directly involves project managers and line managers, and also all staff, for whom training on the management of sensitive information has been set up. An encryption tool has been installed on workstations to protect information on digital media, and staff awareness of new computer threats has been increased.**

Workshop on movements and postures at work, organised by the local security guard force at Marcoule.

(1) ECS: a French acronym for *évaluation complémentaire de sûreté.*

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

In 2013, I-tésé continued to contribute to the CEA's work on the economics of 4th-generation reactors and uranium resources. The Institute was involved in the "Fast Reactors and Related Fuel Cycles (FR13)" international conference which took place in Paris in March 2013, contributing to discussions on 4th -generation reactors and uranium resources, and also on the economics of the fast neutron reactor (FNR) market. The main conclusions on the fast reactor market were:

- there will be a market, even before it becomes economically competitive, in the coming decades. This market, or the "initial phase", will be greatly influenced by national strategic considerations, as China, Russia and India are the countries most involved outside France;
- the development of the processing of spent fuels will precede and then continue in parallel with the development of FNRs. Significant spent fuel processing capacities will have to be built worldwide by 2050;
- the high scenario for the first phase of the development of FNRs is approximately 60 GWe by 2050, i.e. forty or so 1500 MWe reactors;
- when the competitive period or "second phase" is reached, the global growth rate will probably be around 10 to 15 reactors/year given the constraint of the availability of plutonium, which will be the limiting factor.

At the 10th European Energy Market (EEM) international conference, which took place in May 2013 in Stockholm, Sweden, I-tésé also presented a paper on the construction of future scenarios favouring investment in the 4th-generation.

The tripartite activity on "industrial scenarios" for the development of the French nuclear fleet, carried out with AREVA and EDF, also started at the beginning of 2013. Its objective is to further "industrialise" the scenarios for the introduction of FNRs and for the development of the French nuclear fleet. These scenarios were examined in the context of the report on the sustainable management of nuclear materials published by the CEA in 2012. The methodology proposed by I-tésé for calculating changing uranium prices was chosen. The calculations will be carried out in 2014 and used by I-tésé to assess the economic aspects of the scenarios. Other activities of I-tésé in the nuclear field mainly concern the costs of storing radioactive waste and the markets for small and medium sized reactors (SMRs).

TECHNICAL AND ECONOMIC EVALUATION OF ELECTRICAL SYSTEMS, NEW ENERGY TECHNOLOGIES AND ENERGY POLICIES

I-tésé has continued its involvement with other energies (hydrogen, solar, mobility, electrical systems, climate change, etc.) through numerous projects (Grhyd, Polinoten, Hyunder, Winpower, Climix, etc.) in partnership with renowned institutions and industries. Several thesis studies on the complementarity of nuclear power and new energy technologies were started in 2013.

CONTRIBUTION TO ANCRE SCENARIOS

I-tésé has carried out important work on the energy scenarios of the French national alliance for energy research coordination (ANCRE) in the context of the energy transition debate organised by the French government. Wanting to make a contribution to this, ANCRE called upon researchers who are members of its programmatic groups. The work carried out highlighted the importance of dynamic national R&D, coordinated with R&D on a European level, so as to contribute to an energy transition that is successful and creates jobs.

PATENTS

In the field of intellectual property, I-tésé has continued to coordinate and lead the "patents" activity in the DANS and is involved, together with the programme for promoting resources and expertise, in managing patent portfolios.

MORE ABOUT

I-TÉSÉ MEETINGS

In 2013, the "I-tésé meetings" welcomed a number of keynote speakers: Jan Horst Keppler from the Organisation for Economic Cooperation and Development (OECD) who spoke on the topic of "Nuclear and renewables: system effects in integrated electricity system", Jean-Louis Bal from the French renewable energies association (SER) who spoke on "the major economic challenges for renewable energies" and François Kalaydjian from IFP Énergies nouvelles (a French public sector research, innovation and training centre in the fields of energy, transport and the environment) who spoke on "non-conventional hydrocarbons: geological, scientific and economic aspects".

5TH I-TÉSÉ SYMPOSIUM

The 5th I-tésé symposium took place on 4 June 2013 and was attended by over a hundred people. Its topic was "Energy transition: challenges and prospects for the CEA".

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FROM RESEARCH TO INDUSTRY

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