cea news

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Contents

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P. Avavian: p.7 bottom – S. Brooke: p.20 – Cadam: p.4 top – p.24 top – P. Dumas: p.11 top – p.13 bottom – M. Dureuil: p.3 – A. Gonin: P.12 bottom – PF. Grosjean: p.5 bottom – p.11 bottom – p.12 top – p.27 – p.28 top – p.30 middle – Iter France: p.17 – Iter organization: p.15 – M. Jary: p.23 top – S. Le Couster: p.9 – p.13 top – P. Lesage/ AREVA: p.10 bottom – G. Lesénéchal: p.2 – D. Morel: p.7 top – F. Rhodes: p.24 bottom – Solaronix: p.29 bottom – P. Stroppa: p.2 top right – p.5 top – p.10 top – p.14 – p.19 bottom – p.23 bottom – p.25 – p.26 – JM. Taillat/AREVA: p.2 top left – p.8 – D. R. p.4 – p.6 – p.16 – p.18 – p.19 top – p.21 – p.28 bottom – p.29 top – p.30 – p.31

An Exhibition for a Safe and Sustainable Nuclear World in Paris 2014

Three years after Fukushima, nuclear energy is once again a key component of energy policies, with 72 reactors currently being built around the world.
After pausing between 2011 and 2013, China has restarted its industrial policy in this sector, paralleling its approach to the development of renewable energies. The United States announced that they would be retaining nuclear energy as part of their energy mix. Even in Japan, the political option of keeping a nuclear component is back on the table.
Finally, France can build on its strong NPP fleet to gradually integrate renewables into a robust and competitive energy mix.
This is the backdrop against which the recently created Association of French Nuclear Industry Exporters, AIFEN, representing more than 300 French companies and large associations, will next October be organising its first world nuclear exhibition – along the same lines as the Paris Air Show – which will bring the world leaders in the field to Paris.
There are numerous parallels between aeronautics and the nuclear industry: a small number of players, a very high level of technology, a prominent position for France, covering the entire technological spectrum, up to integration into sophisticated systems with a global reputation.
France, which for more than 40 years has developed a complete industry, building up an exceptional level of expertise, is therefore in a perfectly legitimate position to organise this type of event, allowing business meetings between global players, covering all aspects related to civil nuclear energy.
In addition to promoting its industrial offering, France – alongside the countries using or wishing to develop nuclear energy – is committed to setting up the international conditions for the safe and responsible development of nuclear technologies.
The goal is first of all to develop expertise and reinforce capacity. Nuclear technologies first emerged more than fifty years ago in a few countries which, following a pioneering research and development phase, developed the industrial products, reactors and fuel cycle plants with which we are today familiar. The aim now is to maintain the level of expertise in the leading nuclear countries, renew them in countries which are restarting their programmes (United Kingdom, South Africa) and develop them in the new entrants (such as the United Arab Emirates, Turkey, Vietnam, etc.). We can therefore see that building skills and organisational capacity is a common global challenge requiring active collaboration.
One of the main pre-conditions for the development of nuclear energy is its acceptance by the countries as a whole. This involves gradual harmonisation of standards through international consensus. This is the role of the international conventions on the safety of facilities and the management of nuclear materials, on physical protection, on nuclear civil liability, etc. The collective work done within multilateral bodies such as IAEA or NEA is essential in this respect, and France plays a proactive role in them.
The international harmonisation of standards defines the state of the art to be achieved by each country so that confidence and safety form the foundations of their nuclear programmes. Of course, for countries which are initiating a nuclear programme, the challenges are considerable, because they have to set up organisations and the corresponding expertise in order to implement these international standards and the associated best practices. France is committed to cooperation with these countries, to help them create the necessary environment.
In the priority field of safety, the Convention on Nuclear Safety, adopted on 17th June 1994 (for which there are 77 Contracting Parties), the IAEA International Safety Standards, the work done by safety regulator associations across Europe and worldwide define the state of the art to which each nuclear country must refer in order to assume its prime responsibility for the operation of nuclear facilities.
With regard to management of the back-end cycle, the national debate on the Cigéo project for a radioactive waste deep geological disposal facility, demonstrates France's commitment to dealing with this issue, in a way that is completely transparent, until concrete implementation of this solution. At the international level, the Joint Convention on the Safety of Spent Fuel Management and the Safety of Radioactive Waste Management, adopted on 5th September 1997 and for which there are 69 Contracting Parties, defines the general framework for this key subject. More recently, the European waste directive made further progress by guaranteeing the coherence between European countries in terms of waste management. On this complex topic, we can therefore see the gradual construction of a roadmap for the future consisting of national initiatives implementing the international and regional framework, thus guaranteeing overall consistency.
The question of nuclear civil liability is also a very good example of the need for international convergence. The global nature of the market and the fact that a nuclear accident that occurs in one country can have significant consequences in others, affect the way in which international public opinion measures the advantages and drawbacks of nuclear technology. This is why it is essential that a worldwide system of nuclear civil liability be gradually implemented, based on conventions between States, so that in the eventuality of a nuclear accident, however very unlikely, rapid and fair compensation can be ensured for the victims, in accordance with simple procedures approved by all. France and the United States are therefore urging the entire international community to sign up to the reinforced conventions on nuclear liability.
To conclude, I would like to restate France's firm conviction of the major role to be played by nuclear energy in the 21st century, in order to make a sustainable contribution to meeting the world's energy needs.
This is why France wanted to organise the WNE exhibition, as a contribution to the industrial dynamic in this field, and is working within multilateral and bilateral bodies to help ensure international convergence on the best standards, to underpin the deployment of nuclear energy in the various countries.

/Bernard Bigot
CEA Chairman

World Nuclear Energy, WNE 2014, aims to become the world's reference event for the nuclear energy sector and will enable nuclear players to present their products and their services for the many countries today interested in nuclear energy.

If a Tsunami Floods the European Coasts

The CEA Military Applications Division (DAM) is taking part in the European project Astarte. Led by Portugal and Turkey and involving 25 partners, this programme aims to pursue research into the tsunami hazard in the Euro-Mediterranean area. The goal is to transfer results to warning centres in the area, including the Cenalt (Tsunami Warning Centre) run by CEA-DAM for France in Bruyères-le-Châtel. Within the framework of Astarte, CEA will be leading one of the tasks relating to this transfer to the management of warning centres. It will take part in sensitivity studies on rapid characterisation of tsunamigenic sources, in numerical testing to prepare a method for forecasting detailed impacts on the coast, and in prospective studies on the efficiency of GPS networks.

European Next-Step High-Performance Computing

Europe recently created a technology platform dedicated to high performance computing (HPC) with the aim of becoming a major player in this field which is vital to science and company competitiveness.

To guide its research programmes and define their content, the European Commission uses technology platforms - associations consisting predominantly of industrial manufacturers in a given field. The forty some European Technology Platforms (ETP) develop "research agendas" of topics deemed the most appropriate to give Europe a competitive edge in each field and to grant funding. ETP4HPC - the European platform for HPC - identified high performance computing as a new priority[1], at a time when the Commission's next Horizon 2020 framework research programme was being prepared and planning its budgets.

// CEA's Key Role

ETP4HPC was created in 2012 by major European industrial firms (ARM, Bull, Eurotech, ST-Microelectronics, Xyratex), SMEs (Allinea, CAPS, ParTec), two global stakeholders in supercomputing (IBM and Intel) and major research organisations or computing centres (Barcelona Supercomputing Centre, CEA, Cineca, Fraunhofer Institutes, FZJ/Jülich, LRZ). This association led by Bull now has fifty-three members. From the outset, CEA played an active role thanks to its relations with both the academic and industrial spheres. In fact, its involvement is a logical and fitting follow-up to the actions taken as part of its Tera programme and to the opening already undertaken with Teratec.

// An Ambitious Research Program With Contribution From 100 European Experts

The Strategic Research Agenda was developed by seeking input from some 100 European experts, several of them from CEA. On this basis, the first Horizon 2020 calls for proposals were defined. The technical topics listed are consistent with the objectives and milestones of the CEA Tera programme - including energy efficiency, robustness, efficient programming - while expanding the targeted applications markets and technology base. This roadmap strengthens the positions of the industrial partners and helps them gain new openings and develop new cooperation opportunities thus reinforcing the European HPC ecosystem. The scale of problems to solve for the next generation machines (around the exaflop/s, a billion billion operations per second, approximately a thousand times Tera 100) indeed requires more extensively pooled efforts by all stakeholders dismiss this.

// Funding Planned

The ETP4HPC has now been launched, with a first part of funding for 2014-2015 planned for R&D on High Performance Computing technologies (hardware and software). Horizon 2020 has now been launched, including a first so-called FETHPC call in the Work Programme 2014-2015, with close to 100 M€ of funding from the EC to start implementing the ETP4HPC recommendations. A contractual Public Private Partnership has also been signed between the EC and ETP4HPC, that structures the dialogue about European HPC and secures continued EC funding all along H2020 lifespan.

[1] High-Performance Computing, Europe's Place in a Global Race: http://ec.europa.eu/information_society/newsroom/cf/document.cfm?action=display&doc_id=891
Competitiveness Council Meeting of May 2013: www.consilium.europa.eu/uedocs/cms_data/docs/pressdata/en/intm/137344.pdf.

When CEA's Specialists Spur Spanish Nuclear Drill

Specialists in radiological defence from CEA Saclay took part in an European emergency drill at the nuclear plant located in Almaraz, Spain, between 5 and 7 November 2013. Emergency management and radiation protection professionals from six countries were involved in the drill in order to test the organisation of the authorities, emergency services and experts in the event of an accident. The CEA specialists were responsible for measuring radioactivity in the environment. The evacuation of 6,000 residents, within a radius of 10 km around the plant, was organised virtually, without actually being implemented.

CEA Hosts Second French-German Research Summit

Sharing Information and Bolstering Up Cooperation

Organised by Bernard Bigot, CEA Chairman, and Jürgen Mlynek, Helmholtz President, the second French-German research summit was held on January 8, 2014 in Paris. At this informal event attended by representatives of the main French and German research organisations[1], talks focused on three themes:
- implementation of the European research area;
- cooperation between national research bodies, particularly between universities and research centres;
- funding for research.

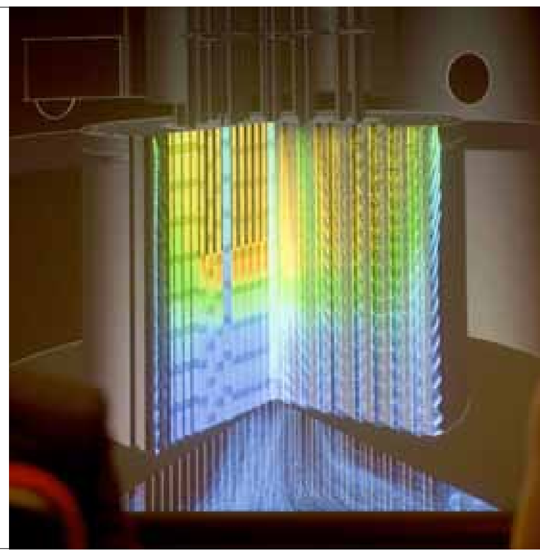
Emphasis was set on comparing the organisation, regulation and funding of both countries' various entities to draw lessons and good practices, and enhance bilateral cooperation.
European issues were discussed, particularly the conditions of a more attractive offering for researchers, access to knowledge and data, the impact of the revision of the European state aid system, and ways to improve the involvement of new European Union Member States. At the end of the summit, the decision was made to increase information sharing and strengthen cooperation, particularly with the aim of optimising the two countries' positions in response to research proposals made by the European Commission.

[1] French representatives included CEA, CNRS, Inserm, Inra, Inria, Ifstarr, the Conference of University Presidents, the Academy of Sciences, the Academy of Technologies, and the Conference of Engineering Schools. German representatives included Helmholtz, Fraunhofer, Leopoldina, Leibniz, the Brandenburg Academy of Sciences, the Council of Science and Humanities, the Rectors' Conference, the Centre for Neurodegenerative Diseases, the Academic Exchange Service, and the Foundation for Research.

Two Implementation Agreements Signed with the DoE

In October 2013, the CEA Nuclear Energy Division signed two agreements implementing the framework agreement with the US Department of Energy (DoE). The first one is a joint action plan creating a steering committee and defining the main themes of the cooperation. These themes are organized into four parts:
- new generations of nuclear reactors;
- methods for separating radioactive waste;
- innovative fuels and structural materials;
- modelling and simulation.

The second is a specific agreement on the Advanced Sodium Technical Reactor for Industrial Demonstration (Astrid), under CEA ownership, currently in its design stage. On May 15, 2014, the technical working groups will report on their activities for the first time to the agreement steering committee which will meet in Paris.



Saudi Arabia: Areva, EDF, and I2EN[1] Take Centre Stage

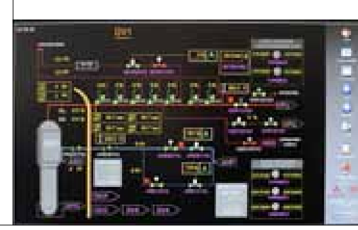
Skills and Expertise

Saudi Arabia, one of the global leaders in oil production, is exploring alternative resources to meet growing domestic demand for energy. It is considering building up to 16 nuclear reactors in the years to come. The future call for tenders has been assessed at between $70 and 100 billion.
During the visit of French President, François Hollande, to Riyadh on December 30, 2013, I2EN, EDF and Areva signed a series of agreements with four Saudi universities: King Saud University in Riyadh, Dar Al Hekma College and Effat University in Jeddah, and Prince Mohammad University in Al-Khobar.

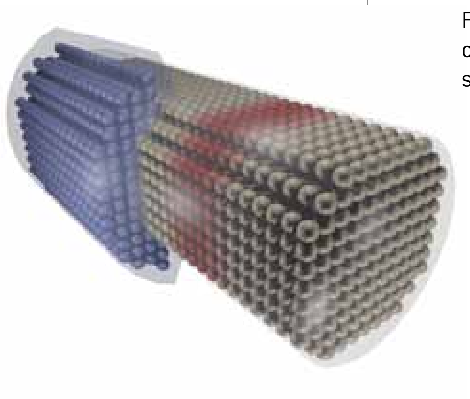
These Memoranda of Understanding aim at contributing to the progress of nuclear skills in Saudi Arabia within the structure of the cooperation agreement for fostering peaceful use of nuclear energy signed by France and Saudi Arabia in Riyadh in February 2011. They create a framework for the development of cooperation in various fields, such as research and academic and professional training.
With the support of its members and partners, I2EN will assist the Saudi universities in developing the skills and expertise necessary to establish their future nuclear fleet. Among other things, the Institute will offer Saudi students gateways to academic courses in French universities or internships in firms.

The steering committees overseeing these activities will consist of representatives of the Saudi universities, representatives of EDF and Areva, and the director of I2EN.

[1] I2EN: International Institute of Nuclear Energy.



Simple Like Kwant



Freely accessible on the Internet, the Kwant software can simulate complex quantum phenomena such as superconductivity, the tunnel effect, graphene flakes, insulators, etc. with just a few lines of code.

This easy-to-use, fast-to-code software programme is provided by physicists from CEA-Inac[1] and their Dutch colleagues from Leiden University and the Delft University of Technology. Named Kwant, it was developed to meet their own needs in nanoelectronics. Theorists and applied scientists can thus compute and simulate quantum phenomena at work in Python Core samples. Based on Python, a very high-level programming language, Kwant can easily solve a broad class of equations in quantum theoretical physics.
Available on the Internet since September 2013, this software programme has already been mentioned in several European publications.

http://kwant-project.org/

[1] Inac: Institute for Nanosciences and Cryogenics.

Kwant's Quick Queries

Franco-Japanese Event at Essonne General Council

On 6 November 2013, a Japanese delegation visited the Essonne council headquarters in Evry. The delegation consisted of several representatives from the town of Genkaï (Saga Prefecture, Kyushu), home to four pressurised water reactors, representatives from the village of Kariwa (Niigata Prefecture, Honshu), home to seven boiling water reactors, and several Japanese electric companies from all over the country.

Welcomed by David Ros, president of the Local Information Commission (CLI) of the Plateau de Saclay, together with Jacques Vayron, CEA Saclay Director, Guy Turquet de Beauregard from Cis bio International, and several members of the CLI, the delegation showed great interest in the presentations given on how this structure operates.
In the post-Fukushima context and pending the possible restart of the nuclear reactors – in Genkaï in particular – the delegation also asked CEA about French energy policy. The presentation given on this topic by Pascal Chaix from CEA International Relations Division prompted extensive discussions.

JHR: Due Under The Dome

On December 13, 2013, the construction of the Jules Horowitz reactor (JHR) at CEA's Cadarache site reached an important stage with the installation of its dome, the metallic structure of which weighs almost 105 metric tons.
For nearly two hours, a giant crawler crane with the ability to lift 600 metric tons moved the torispherical dome that measures 35 metres in diameter and looked rather like a flying saucer.
Once it reached its destination, the structure was meticulously positioned... by hand! This amazing feat was rigorously planned for eight months by teams from the CEA Nuclear Division and Areva TA, Razel-Bec, and Secomoc.
Placed on top of the experimental reactor's area, it can now be steel-reinforced and concreted to give the dome its final function.

// Dome in Place, Electro-Mechanics to Take Over

The installation of the metallic structure is a milestone in the construction of the JHR, launched on March 19, 2007. Under the ownership of CEA and prime contractorship of Areva TA, about twenty inspections by the Nuclear Safety Authority (ASN) have confirmed that the construction work is going well. With 80% of the civil engineering work now completed, mainly by French providers, electromechanical assembly work can begin.
The JHR, built by CEA as part of an international consortium of nine countries[1], will be used to study the behaviour of materials and fuels of current and future nuclear reactors, under irradiation, and should cover 25% to 50% of European needs in radioelements for medical use.

[1] Together with CEA, academic and industrial partners from nine countries: Belgium, Spain, Finland, France, India, Israel, the Czech Republic, the United Kingdom and Sweden. The European Commission also holds access rights to the JHR and has status equivalent to that of a consortium member.

Nanotech and Safety Team Up at CEA

With its expertise in safety, and as a major player in the development of nanotechnologies, CEA now boasts the NanoSafety Platform (PNS). Launched on November 22, 2013, the platform is dedicated to protection and safety issues related to the implementation of nanomaterials and nano-objects. It aims at facilitating the responsible and competitive development of nanomaterials within the French and European industry.

// Comprehensive Research and Expertise...

One of the focuses is particularly to strengthen the confidence of exposed populations, workers and consumers. The platform therefore proposes a global offering of research and expertise, supported by very high-level equipment. Very much directed at industrial players, its ambition is to become the point of convergence of nanosafety management in our country, and to provide the necessary expertise.

// ...Backed Up by High-Level Facilities

To quote a few figures, the PNS can be summed up by 2,000 m^2 of laboratories, seven rooms dedicated to training, 150 people, and a €17.3 million investment by the Rhône-Alpes regional authority and the State within the framework of the "Grenoble University of Innovation" Campus Operation.

Second NanoSafety Conference

On December 11, 2013, some 150 NanoSafety stakeholders, including a large number of industrial players, attended the second NanoSafety Conference, on the theme "NanoSafety - Challenges - Advancements and Hurdles". The speakers addressed nanomaterials safety through various topics (national and European regulations; measurement and characterisation methods; toxicology; occupational health; etc.), then handed the floor over to industrial participants who shared their experiences.

INES2[1] Project, the Quest for an Alternative and Potentially Limitless Source of Energy

On Wednesday, December 18, 2013, Pascale Briand, ANR Director General, and Bernard Bigot, CEA Chairman, signed the financial agreement for the INES2 Institute for Energy Transition (ITE) project in the presence of Louis Gallois, General Commissioner for Public Investment (CGI). The CGI has funded the project with a €39 million grant for the 2014-2018 period within the framework of the 'Investment for the Future' programme.

INES2 aims to further increase the economic impact of research and training activity conducted at INES by targeting high-growth global markets. It will do this by exploiting a highly diverse and dynamic ecosystem for french solar technology, made up of a mix of large companies, SMEs, and start-ups.

Its research programmes relate to the entire solar value chain, from the development of silicon photovoltaic technologies to the incorporation and use of solar photovoltaic and thermal technologies. Its initial and further training programme strengthens the actions of the INES Training and Assessment platform (e-learning, teleoperation of solar systems, support for exporting companies, etc.).
It will involve 500 researchers and professionals from the field.
CEA and its partners[2] in this project focus on three key areas:
- developing innovative solar technologies that are competitive on global markets;
- promoting the rational use of solar energy in all its applications;
- transferring these technologies to industry.

[1] INES: National Institute of Solar Energy
[2] The CNRS, the University of Savoy, the INES Training and Assessment platform, and the Sypartec association (Savoie Technolac Technopole). The Competitiveness Cluster Tenerrdis, the Rhône-Alpes Regional Council, and the Savoy General Council are also stakeholders in the INES2 project, along with Arkema, ECM, Ventilairsec, Socomec, and Urbasolar.

Nuclear Fuel Makes The Rounds

Patrick Philipon – Les Défis du CEA #185 – January 2014

France has opted for a policy of processing and recycling spent fuel. This option has already been deployed commercially since the 1990s, but will reach its full potential with the fourth generation. The CEA developed the processes in use today, and is pursuing research to improve, extend, and adapt these technologies to tomorrow's challenges.

/ Spent fuel storage pit at La Hague.

THE NUCLEAR FUEL CYCLE

France has opted for a "closed cycle" to recycle the reusable materials in spent fuel (uranium and plutonium) and optimize ultimate waste management.

"France's strategy is built on a sustainable approach to nuclear energy, leading to the choice of recycling," says Bernard Boullis, director of the programme on the *"back end of the nuclear fuel cycle"* in the CEA's Nuclear Energy Division (DEN). It is therefore important to provide the best responses to issues about availability of natural uranium resources and management of ultimate waste. For a better understanding of these issues, it is of interest to review what goes in and what comes out of our existing nuclear reactors, or PWRs[1]. "Normal" fresh fuel contains about 4% fissile[2] uranium-235 (^{235}U), with the remainder being uranium-238 (^{238}U). Upon removal from the reactor, the fuel still contains most of the ^{238}U and part of the initial ^{235}U, together with fission products[3] that are highly radioactive with a lifetime of about a century. It also includes 1% of plutonium and 0.1% minor actinides[4]. However, these radioactive elements will still be present after tens of thousands of years. What, then, can be done with the reusable materials (uranium and plutonium) and the unwanted toxic elements?

The Closed Cycle Option

Countries that have decided to abandon nuclear power in the near future have logically opted for an "once-through fuel cycle". In plain language, this means that spent fuel is considered entirely as waste and destined for permanent disposal in a deep geological repository. This was the option in Sweden, for example, after its decision not to build any new reactors. Conversely, the "closed fuel cycle" (with recycling of spent nuclear fuel) makes sense in countries such as France or Japan, and tomorrow China and India, that wish to ensure sustainable nuclear energy. Uranium and plutonium are therefore extracted from the spent fuel to be recycled in fresh fuel assemblies. Only the fission products and minor actinides, considered as ultimate wasteforms, are vitrified[5] for disposal[6]. The result: a much smaller waste volume with a radioactive impact divided by ten because the plutonium has been removed. France had a pioneering role in this area: the CEA developed the reprocessing technologies that are used today in La Hague plant. China is now following a similar route and is interested in French technology.

MOX: the First Step in Recycling

In current practice, the closed fuel cycle consists in blending the recovered plutonium with depleted uranium[7] to obtain MOX[8], which will then be supplied to reactors as fuel. Unfortunately, this only works once: spent MOX fuel contains plutonium isotopes[9] that are difficult to reuse in existing PWRs. In addition, this option does not resolve the long-term problem of resources because the performance of MOX is comparable to that of conventional fuel: only 1% of the potential energy contained in natural uranium was actually "burned".

If nuclear energy is to achieve sustainable development, the "easily" exploitable natural resources may be unable to meet the need beyond a few decades. The solution is to find a way to use ^{238}U (99.3% of natural uranium). Recycling as MOX in light water reactors must therefore be considered as a first step intended to make the best use of available resources in existing reactors, and to condition the ultimate wasteforms as well as possible, while preparing for the future. *"Once through a MOX reactor lasts about fifteen years, then it will be up to fast neutron reactors (FNR),"* adds Bernard Boullis.

Recycling as MOX: Merely a First Step'

Fast Neutron Technologies: Nuclear Energy for the Future

These reactors are capable of using all the isotopes of plutonium, which allows the fuel to be recycled repeatedly. The plutonium burned in the process can also be directly regenerated in the reactors through the capture of fast neutrons by ^{238}U. The production rate can even be adjusted: the reactors can produce more than they consume ("breeding" mode); or they can "burn" the excess ("burner" mode); or they can produce as much as they consume ("isogenerator" mode). CEA is developing the third option. In this case, after initially fueling the reactor with plutonium recovered by reprocessing MOX, the operating FNRs will then produce their

[1] PWR: pressurized water reactor, the principal type of power reactor currently operating in France.
[2] The nucleus of a fissile atom can be split in a neutron flux, releasing a large amount of energy. ^{235}U is the only natural fissile element. On the contrary, ^{238}U — by far the most abundant — is not fissile but fertile: it can form fissile elements after neutron capture.
[3] Fission products: nuclides resulting from the fission of ^{235}U or from the decay of fission fragments.
[4] Minor actinides: heavy nuclei (neptunium, americium, curium) formed in a reactor through successive neutron captures by nuclei in the fuel.
[5] Vitrification: incorporation of radioactive waste in a glass matrix to form a stable package.
[6] Many countries have not yet formulated a national policy, and store spent fuel in a reversible manner. This is the case of the USA, for example.
[7] Residual uranium after enrichment, containing practically no ^{235}U, which was extracted to fabricate nuclear fuel ("enriched" in ^{235}U).
[8] MOX (Mixed OXides): nuclear fuel consisting of a mixture of uranium and plutonium oxides.
[9] The nuclei of the different isotopes of an element all have the same number of protons (characteristic of that element) but not the same number of neutrons: ^{235}U and ^{238}U are uranium isotopes, for example.

/ Remote-manipulator work on the Atalante process shielded line.

/ The shielded line can be used to carry out reprocessing of irradiated fuels: here, screening of fuel pin sections.

own fissile material until depletion of all the initial ^{238}U. FNRs are capable of generating 100 to 150 times more energy from natural uranium than existing reactors. The known uranium reserves would then become the largest natural energy resource — well ahead of fossil hydrocarbons. *"Over the very long term, France could even dispense with mines, since the depleted uranium already stockpiled in the country would be sufficient for several thousand years of electricity production,"* remarks Christophe Poinssot, head of the CEA-DEN Radiochemistry & Processes Department at Marcoule.

Another advantage: FNRs create only one-fourth the quantity of minor actinides as thermal neutron reactors, while producing the same amount of electricity. Above all, they can "burn" these elements to obtain fission products with much shorter half-lives. This process, known as transmutation, has been a subject of extensive research in the last two decades in France by the CEA, as well as in Japan and the United States. The radioactivity of the ultimate waste — consisting mainly of fission products without minor actinides — would decrease to a level comparable with that of uranium ore within three centuries instead of tens of thousands of years: *"This brings us back to a time scale compatible with history and human memory,"* notes Christophe Poinssot.

Meanwhile, the CEA, which developed all the current reprocessing technologies before transferring them to Cogema (now Areva), continues to improve the processes implemented at La Hague. At the same time, teams at Saclay, Marcoule and Cadarache are now developing the fuel cycle of the future.

Only 0.7% Fissile ^{235}U

FRONT END OF THE FUEL CYCLE: FROM CRUDE ORE TO ENRICHED URANIUM

From the mine to the reactor, a vast industrial system ensures the conversion of uranium contained in the ore to obtain uranium oxide (UOX) fuel pellets. Selective extraction, purification, enrichment — key scientific and technical challenges for CEA-DEN teams.

Operating of nuclear reactors requires uranium of high purity, which is a significant challenge for chemistry because the uranium must be purified of all the other elements present in the ore. Marc Delpech, head of the CEA-DEN programme on the "front end of the fuel cycle", sums up the situation this way: "*Uranium accounts for no more than a few weight percent of the ore. In addition, natural uranium contains only 0.7% fissile ^{235}U (the remainder being ^{238}U), whereas PWR fuel must contain 4% ^{235}U.*" In the 1950s and 1960s, CEA-DEN designed and implemented the entire industrial chain from crude ore[10] to enriched uranium.

After a period of relatively abundant resources on the market, the rebound of the nuclear industry in 2005 has changed the situation, as has the reduction in secondary resources. Today nearly 55,000 metric tons of uranium are mined annually compared with a consumption of 65,000 metric tons[11]. *"Eventually, with the depletion of existing mines, we will have to learn to exploit poorer deposits at reasonable cost under the best environmental conditions,"* cautions Marc Delpech. R&D on the entire front end of the fuel cycle has adapted to the situation.

/ Uranium concentrate in the form of yellowcake, obtained after dissolving uranium ore in acid.

Uranium Extraction and Purification

Everything begins at the mine where uranium is extracted. The ore is crushed, ground, and then impregnated with an oxidizing acid solution to dissolve the uranium to a few grams per liter. Uranium is then selectively extracted from solution by a specific molecule that has been used since the 1970s. This is followed by several purification steps to obtain an uranium concentrate called yellowcake. *"We want to eliminate the final steps, which consume large amounts of water and reagents, by developing a new extractant molecule to obtain a sufficiently purified solution after the first operation,"* explains Marc Delpech. Over the longer term, the chemists seek to further diminish water consumption by rethinking the extraction phase itself.

Another mode of operation is also used: *in situ* leaching[12]. With favorable geology, excavation is unnecessary: uranium is recovered directly by injecting an oxidizing acid solution into the deposit and then pumping the solution. Here again, the researchers seek to eliminate the purification steps by improving the method of extraction[13].

From Yellowcake to Enriched Uranium

At the Comurhex Malvési conversion plant, yellowcake undergoes further purification before being converted to uranium tetrafluoride, which is then converted at the Comurhex Pierrelatte plant to uranium hexafluoride by fluorination. As this is a very expensive product, CEA experts are working on recycling it. Then comes enrichment, in which ^{235}U is diffused in a fraction of the gas stream, creating another depleted fraction (0.2 to 0.3% ^{235}U). The first enrichment plant, named after Georges Besse, used gaseous diffusion — the only mature technology at the time it was commissioned (1978). Today, the Georges Besse II plant uses gas ultracentrifuge technology, which consumes 40 to 50 times less energy. The enriched

[10] The CEA was initially responsible for mining exploration before this activity was transferred to Cogema in 1976.
[11] 2012 data.
[12] An increasingly used method — especially in Kazakhstan — also known as in situ recovery.
[13] Extraction occurs when the solution from the well is filtered on an ion exchange resin.

hexafluoride is once again converted to solid uranium oxide for fuel fabrication. Chemists are now attempting to recover the valuable fluoride during this operation for reuse during the preceding enrichment step — while keeping an eye on emerging processes that could supplant ultracentrifugation.

BACK END OF THE FUEL CYCLE: THE SECOND LIFE OF NUCLEAR FUEL

The back end stages of the fuel cycle for recycling the reusable materials in spent fuel and conditioning the final wasteforms have reached maturity. CEA teams are pursuing their research in support of industry to optimize these processes.

Since 1987, EDF has supplied about twenty reactors with MOX in fuel assemblies containing one-third MOX and two-thirds UOX[14]. Plutonium thus generates about 10% of the nuclear electricity in France. *"By adopting the closed fuel cycle[15], France no longer stockpiles plutonium in the final waste: it is all recycled as MOX,"* says Christophe Poinssot. Each year, French nuclear power plants thus generate only 50 metric tons of ultimate waste – compared with 1,200 tons for an once-through fuel cycle – and 200 metric tons of spent fuel, placed in interim storage pending subsequent reuse.
In France, the back end of the nuclear fuel cycle – extraction of uranium and plutonium from spent UOX fuel, MOX fabrication with the recovered plutonium, vitrification of ultimate waste – is fully operational in La Hague and Melox plants, based on technologies created mainly by CEA-DEN[16]. The processes are so efficient that more than 99.9% of the plutonium is currently recovered. Contaminants represent only a millionth or even a billionth of the initial amount. Does this mean that all the processes have been finalized?

Optimizing Waste Vitrification Processes

"The performance is already outstanding, but CEA-DEN is pursuing its R&D in close cooperation with Areva. The objective is to adapt the processes to new fuel developments. We also want to optimize them in order to obtain the same results at lower cost and further optimize ultimate waste management," adds Bernard Boullis. Most of this work is carried out at Marcoule. For example, the extraction and purification of plutonium and uranium — as effective as they are now — are performed in three steps in three different facilities. *"We are working on a new approach that would allow everything to be accomplished in a single step, in a single facility, with smaller amounts of chemicals that would diminish plant discharges,"* explains Christophe Poinssot.
Once the plutonium and uranium have been recovered, the ultimate waste — fission products and minor actinides — is calcined, vitrified, and poured into "packages" intended for deep geological disposal. Although the packages themselves are fully defined, optimization of the processes is still possible. The molten glass containing the waste is typically produced at temperatures above 1,000°C in metal melting pots that are damaged by corrosion and heat, and must regularly be replaced, resulting in technological waste that must then be managed. Marcoule has developed a new technique that was implemented in 2010 on one of the six vitrification lines at La Hague: the "cold crucible melter." In this process, the metal wall of the melting pot is water-cooled. The crucible is filled with glass that is melted by induction before the waste is added. A thin layer of solid glass forms in contact with the cold wall, separating the melter wall from the molten glass and radioactive waste. The crucible is protected from the heat and radiation, and thus lasts much longer and can be used to melt more corrosive materials.

A New Process for MOX Production Waste

Another development project is being conducted by the CEA[17], in liaison with Andra[18] and Areva: the treatment and conditioning of solid technological waste, a mixture of metals and organic matter (vinyl, polyethylene, polymer gloves) from the Melox plant, which produces MOX. Although much less radioactive than spent fuel waste, it must nevertheless be stored in suitable packages. This is where an innovative process, called PIVIC, could be used to treat and condition the waste in a single step. The waste is introduced in a furnace and incinerated by a plasma torch on a molten glass bath; the ashes are incorporated into the glass and the molten metal sinks to the bottom of the crucible, which

[14] UOX (Uranium OXides): nuclear fuel containing uranium oxide commonly used in reactors.
[15] Closed cycle: technical option in which spent fuel is processed for recycling, as opposed to an once-through fuel cycle in which all the elements in the spent fuel (including uranium and plutonium) are considered as waste.
[16] Today, Areva is the only producer of MOX fuel in the world.
[17] Under France's government borrowing initiative sponsored by the Prime Minister through the Environment and Energy Management Agency.
[18] Andra: French National Radioactive Waste Management Agency.

Working on a Single-Step Operation for extraction and Purification

/ Overview of a scalable vitrification prototype equipped with the nuclearized cold crucible.

/ Archaeological glass from Embiez.

The End of the Fuel Cycle: Waste Storage and Disposal

In 2006 Andra was assigned the task of designing and implementing an industrial geological repository site (Cigéo). The waste will be shipped to the site in "packages". The CEA has largely contributed to their design, and continues to conduct studies in liaison with the industrial partners that produce the packages in order to provide Andra with extensive data on their long-term behavior, and especially their evolution during the coming millennia under repository conditions. The CEA carries out accelerated aging experiments on inactive and radioactive glass samples (at Marcoule in the Atalante complex) to identify the physical and chemical alteration mechanisms. As these experiments alone are not sufficient to extrapolate the long-term behavior of the glass in a geological waste repository, other studies are conducted on natural analogs (volcanic rocks) and archaeological analogs (ancient glass specimens found on the Mediterranean sea bed, Embiez Island for example). The results are used to develop and qualify mathematical models describing the evolution of the packages. *"They show that the package lifetime in an underground repository of the type currently envisaged for the Cigéo project should exceed several hundred thousand years,"* concludes Luc Paradis.

Goals Aimed at: No Natural Uranium, No Plutonium in Waste

constitutes the primary waste container. *"This process, now under developed, draws on all our skills and knowledge: incineration by plasma torches, vitrification, induction melting, off-gas treatment, etc."* says Luc Paradis, head of the CEA-DEN Waste Treatment and Conditioning Research Department. Development work on PIVIC, which is expected to begin operating at La Hague around 2020, now mobilizes about fifteen people at Marcoule. In general, CEA-DEN teams provide ongoing support to Areva for upgrading La Hague plant. These experts regularly intervene on the site — often using numerical simulation codes of the plant developed by the CEA — to examine issues such as shutdown and restarting, or equipment aging. *"This plant will be here for a long time, but we are already working on innovative processes for future plants,"* adds Christophe Poinssot.

AND TOMORROW: MULTIPLE RECYCLING, LESS AND LESS WASTE

Multi-recycle plutonium, make even better use of uranium resources and, over the longer term, explore the possibility of transmuting the most highly radioactive waste: these are the challenges future nuclear systems have to face.

"The fuel cycle of the future first implies multiple recycling of plutonium in an installed reactor base that includes FNRs[19]*. Transmutation of the minor actinides and other features will then follow,"* says Bernard Boullis. If France decides to deploy this technology, spent fuel reprocessing will have to be adapted. Initially, the issue will be to extract the plutonium from spent MOX currently in storage, and blend it (about 15%) with depleted ^{238}U for the first cycle in FNRs. *"Reprocessing MOX fuel does not raise any serious problems: Areva has already reprocessed 70 metric tons of spent MOX fuel in its La Hague plants. The main difficulty is due to the higher proportion of plutonium,"* says Christophe Poinssot. This requires upgrading the plant to handle the plutonium flow, but the basics of the process remain essentially the same.

Repeated Plutonium Recycling

When all the plutonium from spent MOX fuel has been exhausted, the FNRs will begin to "burn" the plutonium they have themselves created by irradiating ^{238}U . Their spent fuel will then have to be reprocessed. *"The basic principle is the same: dissolve the fuel in acid and extract the plutonium with very specific molecules,"* explains Bernard Boullis. However, FNR fuel assemblies have neither the same geometry, nor the same cladding material (they will be made of steel instead of zirconium) as existing fuel assemblies. This will require modifying the plant "head-end" facilities in which the assemblies are cut up. Christophe Poinssot is nevertheless optimistic: *"We have demonstrated that we own the necessary technical expertise, since we already reprocessed 27 metric tons of spent fuel from Phenix and Superphenix, at Marcoule and La Hague. The task is mainly to adapt these processes to industrial scale."* At this point, a series of FNRs with a total power rating equivalent to the current PWRs, operating in a closed cycle, would consume 50 metric tons of depleted ^{238}U each year from the existing stockpile — without requiring any natural uranium — and would produce 50 tons of ultimate waste (containing no plutonium)[20].

[19] *FNR: Fast Neutron Reactors, now being developed for nuclear energy of the future (4th generation).*
[20] *CEA-DEN is now developing a 4th generation sodium-cooled fast reactor. A demonstrator project, Astrid, is currently at the preliminary design stage. CEA-DEN is the contracting authority.*

/Sampling of molten glass from the scalable vitrification prototype.

/Crushing, pressing, sintering of fuel pellets for transmutation on the shielded line.

Separation and Transmutation: Reducing the Activity of Future Waste

Another problem remains: the minor actinides — radiotoxic elements that are currently confined in the glass with the fission products and are the principal source of responsible of very long-term radioactivity in the ultimate wasteforms. Legislative Act 2006-739 dated June 28, 2006, called on the CEA to *"coordinate research on partitioning and transmutation*[21] *of long-lived radioactive elements."* Fast neutron reactors are capable of consuming these nuclides — provided they can be satisfactorily extracted from the spent fuel and reinjected in the cycle, and their transmutation[22] in the FNR core can be mastered. Teams at Marcoule have been working on these issues for the last two decades. First they had to find a molecule resistant to radiation and capable of specifically extracting these elements from the acidic solution in which the spent fuel was dissolved. *"We identified molecules and tested them in the laboratory with 15 kg of actual fuel. We demonstrated that we could recover more than 99% of the minor actinides,"* says Christophe Poinssot. Transmutation can only be tested in an operating FNR core. Since the shutdown of Phenix in 2009, no more research facilities have been available in France. *"To move forward in this area we must count on international cooperation until the demonstration capability of the Astrid project becomes available,"* says Bernard Boullis.

21 Transmutation: transformation of one element into another. In this case, minor actinides would be fissioned to obtain other elements that are still radioactive, but with shorter half-lives.
22 In fact, both types of reactors can coexist for many years.

ATALANTE REWARDED FOR ITS OUTSTANDING SCIENTIFIC ADVANCES

In January 2014, the American Nuclear Society awarded the prestigious Nuclear Historic Landmark distinction to CEA's Atalante facility. This distinction honours sites the world over that have achieved outstanding scientific advances or made a significant contribution to the development of civilian nuclear technologies.

Atalante is an unequalled facility in operation at the CEA Marcoule centre since 1992. It combines the full range of expertise on and research into the fuel cycle, from the most fundamental research through to process validation on a scale of several tens of kilos. Research aims to strengthen downstream processes of the electronuclear fuel cycle, prepare future electronuclear fuel cycles (with plutonium multirecycling as the goal), and reduce the volume and potential hazards of radioactive waste (by separating/transmuting minor actinides). Atalante teams have thus made significant contributions to studies on the management of long-lived high- and medium-level waste[23].

Amidst a Whole Scientific Community

In addition to the facility's infrastructures and equipment and the quality of the programmes conducted, ANS also highlighted the centre's ability to bring together a whole scientific community around the site, as evidenced for example by the Atalante international conferences held every four years on topics relevant to the laboratory.

23 Results obtained within the framework of the French law of 1991 on the management of radioactive wastes and the law of 2006 on the sustainable management of radioactive materials and wastes.

ANS

The American Nuclear Society is a nongovernmental scientific and educational organisation. Founded in 1954, it has developed a membership of approximately 11,000 engineers, scientists, administrators and educators representing over 1,600 corporations and institutions. Its core purpose is to promote the awareness and understanding of the application of nuclear science and technology.

http://www.ans.org/

/ Mixing-settling platform to validate the performance of laboratory scale selective uranium extraction.

/ Advanced separation tests are carried out in the Atalante facility in Marcoule.

The Sun Rises On West

Stéphane Laveissière and Aude Ganier - Les Défis du CEA # 183 - October 2013
Press feature – September 2013
Press release – March 2014

On 9th November 2012, the decree authorising the creation of the ITER basic nuclear installation in Cadarache was signed, marking the actual start of its construction, decided on 2005. The headquarters building was inaugurated in early 2013 and construction has begun on the research facility building. Backed by lengthy and solid experience, the scientific partners are defining the latest technological and scientific options of ITER, with the eventual production of DEMO, an industrial prototype electricity generating reactor, already in their sights.

/ Overview of Tore Supra, in the CEA Cadarache centre.

THE TECHNICAL AND SCIENTIFIC ADVENTURE OF NUCLEAR FUSION

Creating Fusion Plasma on Earth

So what is this exactly about? Nothing less than building the world's most powerful experimental facility, to produce on Earth a reaction that normally takes place in the heart of the stars: nuclear fusion[1]. This reaction releases a vast amount of energy in complete safety and using very little fuel. In theory, the fusion of less than one kilo per day of deuterium and tritium would generate the heat needed to continuously produce 1,000 MW of electricity, or in other words what is done today in a thermal power plant using about 5,000 tons of fossil fuels. This reaction does however require extreme conditions, close to those to be found at work in the Universe, with temperatures of several hundred million degrees Celsius, where matter takes the form of a plasma[2].

To reproduce these conditions on Earth, the scientific community, starting with Russian researchers, developed a machine in the late 1960s capable of confining a hot plasma (150 million °C) in a ring-shaped magnetic cage (torus), called a tokamak[3]. The tokamak principle was adopted by the international community, including CEA, whose experimental facility called Tore Supra, installed in Cadarache Centre, is also attempting to tame this fourth state of matter. *"The performance of the plasma is evaluated on the basis of the amplification factor (Q) which is the ratio between the energy input and the energy output. Roughly speaking, this amplification factor depends on three parameters: the first is linked to the temperature (from 150 to 200 million °C) which should enable the nuclei to fuse together more easily; the second concerns the density of the matter within the plasma (greater than 10^{20} particles per m^3) to create conditions favourable to encounters between nuclei; the last one requires a high confinement time (more than 1 second) so that the plasma loses little energy over time"* explains Alain Bécoulet, director of CEA-IRFM[4], an institute that has been recognised for the past 25 years by the international scientific community for its expertise on long duration plasmas.

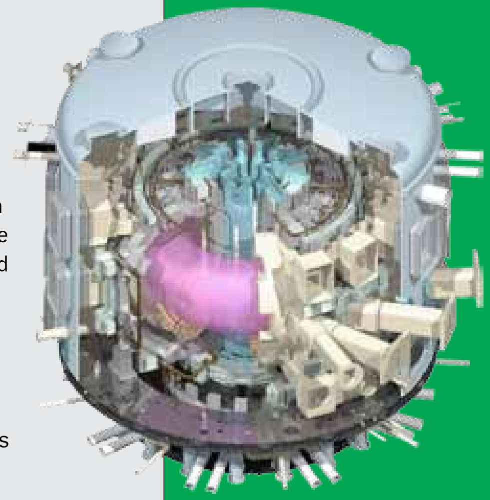
Key Milestones Reached

Since then, several tokamaks have reached major scientific and technological milestones concerning the reference operating conditions, the amplification factor and the duration of a plasma "pulse". With regard to the operation of a tokamak, a number of studies around the world highlighted the fact that plasma confinement improves with the size of the machine and deteriorates as the share of additional heating increases. Based on these conclusions, initiated by the German ASDEX machine, the reference operating mode for ITER, called mode H (High confinement), was defined.

To date, the best performance obtained in mode H corresponds to an amplification factor Q of 0.65, very close to breakeven[5]. It was observed on the European JET tokamak, which in 1996 generated nearly 16 MW for one second. As for the duration of a plasma pulse, it is the technologies developed on the CEA tokamak which enabled plasmas to be produced and studied in steady-state[6] conditions. Tore Supra holds the record[7] for the longest plasma "pulse", for an energy of 1,000 megajoules input and extracted, with a duration of 6 minutes 30 seconds, supported by a power of 3 MW.
In forty years, the observed plasma temperature has been multiplied by 1,000 and plasma duration by 100,000.

A Scale Change to Prepare for DEMO

The ITER stakeholders are looking to combine these major scientific and technological achievements in a single tokamak and carry out two main missions. The first extremely important goal will be to achieve an amplification factor Q = 10, for a time of about 400 seconds, in order to provide 400 MW of energy from an input power of 40 MW. The second will be to understand and control the operating parameters of a reactor in steady-state conditions. The goal will be to pave the way for the operation of a reactor on an industrial scale, because the post-ITER phase is already taking shape, under the generic name DEMO, an industrial prototype for which commissioning is envisaged around 2040 in the roadmaps of the various partners[8]. ITER should provide conclusive evidence regarding the technical-scientific feasibility of the process and establish whether nuclear fusion with magnetic confinement is or is not a process that could lead to a new system of nuclear reactors...



/ Virtual image of ITER, with the plasma (in purple) in the centre.

Find out the main points of the European Fusion community's roadmap for the scientific and technological challenges of fusion, on www.cea.fr/recherche-fondamentale/fusion-thermonucleaire-le-projet-west-au-cea-d and http://west.cea.fr/

[1] Nuclear fusion: a nuclear reaction combining two light nuclei to form one heavier one, which releases energy; while nuclear fission consists in splitting heavy nuclei.
[2] Plasma: fourth state of matter; neither solid, nor liquid, nor gaseous, it is a "soup" in which the nuclei and electrons are no longer bound and circulate freely.
[3] Tokamak: Toroidalnaya Kamera Magnitnymi Katushkami: toroidal chamber with magnetic coils.
[4] IRFM: Institute for research into magnetic confinement fusion.
[5] Breakeven: term referring to an amplification factor Q of 1, i.e. when the power generated by the plasma is equal to the external power input to sustain it.
[6] Steady-state conditions: configuration in which there is no limit on the duration of the plasmas.
[7] World record obtained in December 2003.
[8] The ITER project comprises seven partners: China, South Korea, United States, India, Japan, Russia and the European Union (plus Switzerland, owing to its participation in Euratom), a total of some 34 nations. The High Representative for performance of the ITER project in France is the CEA Chairman, Bernard Bigot.

WHAT ITER WILL DO, WHAT ITER WILL NOT DO

ITER is a crucial step on the road towards the use of magnetic confinement nuclear fusion to produce electricity. In this respect, its functions will be:
- to consolidate plasma physics in thermonuclear combustion;
- to demonstrate the production of fusion energy by producing 400 MW during 400-second pulses, with a gain factor of 10;
- to explore steady-state conditions with a fusion gain Q of 5;
- to demonstrate that the essential technologies are available (superconducting magnets, plasma-facing components, robotic maintenance, etc.);
- to test the tritium breeding blankets;
- to demonstrate the safety of operation and the low environmental impact of fusion.

As an experimental device, ITER will not be tasked with the following missions, which will be more the responsibility of the DEMO industrial prototype:
- qualifying low-activation, neutron-resistant materials (the ITER integrated neutron flux will be too low);
- demonstrating tritium self-sufficiency (only small blanket modules will be tested on ITER);
- demonstrating the availability necessary for an electricity generating reactor;
- producing electricity.

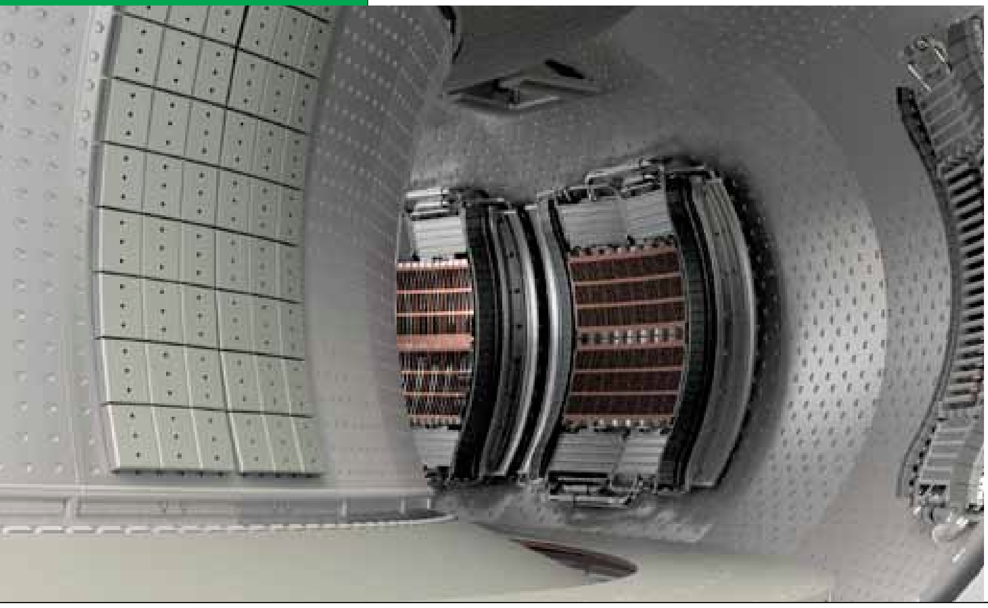
Demonstrating Feasability of Energy Production from Fusion Reactors

FROM TORE SUPRA TO WEST, A TEST BENCH FOR ITER

Through the experience acquired on tokamaks around the world, the missions of the ITER future experimental reactor are now clearly defined. It also clarifies the research efforts needed from the partners if this international project is to succeed. At CEA-IRFM, the scientists are preparing the transformation of Tore Supra into an unique testing platform for ITER's tungsten divertor[9]... This is the challenge of the WEST[10] project.

The developments carried out on the JET and Tore Supra tokamaks led to definition of the main options; concerning the configuration of the plasma itself, the plasma-facing components and power extraction. In CEA's Cadarache centre, Tore Supra made a vital contribution to the problem of "continuous operation": primarily, through the use of superconducting coils to ensure magnetic confinement of the plasma. It also validated various additional heating technologies for long pulses and, finally, experimented with continuous cooling via pressurised water loops. It then created an unique experimentation on plasma-facing materials and documented all the continuous operating characteristics of tokamaks in a "carbon" environment, more specifically ruling out its use in machines handling tritium.

Tore Supra is today working for ITER and its partners to ensure the success of the demonstration of the fundamental feasibility of energy production from fusion reactors. With this project, Tore Supra is destined to become an unique testing laboratory, notably for testing one of the key components of ITER: the actively cooled tungsten divertor...



/ Virtual image of the Tore Supra tokamak, configured for the WEST project, with tungsten components, notably for the divertor.

The Actively Cooled Tungsten Divertor Option

The divertor consists of various sections, or "cassettes", themselves comprising "targets" in direct contact with the plasma. These targets are placed at the intersection between the lines of force of the magnetic field, where the plasma particles encounter the components, releasing their energy in the form of heat. They are subjected to an extremely intense thermal load and are cooled by circulating water. We then talk of actively cooled components. In order to evacuate this considerable heat flux without the surface temperature at which the plasma-facing material would melt or vaporise, it is necessary to circulate the water at high speed, at a distance of less than one centimetre from

[9] Divertor: module running round the floor of the tokamak chamber which extracts the heat and the helium produced during the nuclear fusion reaction.
[10] WEST: Tungsten (W) Environment in Steady-state Tokamak.

/ The foundations of ITER.

Divertor's Performances

the surface of the wall. The thermal amplitude between the surface (temperatures over 1,000°C) and the cooling channels in which the pressurised water circulates (less than 200°C) creates expansion of the wall materials, combined with high mechanical (shear) stresses.

The divertor, which follows the floor of the tokamak's vacuum chamber, receives most of the heat flux (which can be up to 20 MW per m^2, a power density comparable with that to which the space shuttle is subjected at atmospheric re-entry) and charged particles from the central plasma. Its function is to extract the helium produced by the fusion reaction and evacuate the heat generated by the system, while minimising contamination of the plasma by other impurities. For ITER, the "actively cooled" divertor configuration was chosen. The choice of materials is extremely limited. Although carbon is well able to withstand such heat and particle fluxes, it retains the fusion fuel, in particular radioactive tritium. With tungsten, there is very little absorption of the isotopes of hydrogen, thus avoiding tritium retention in the machine.

The WEST Project

The WEST project will be studying the resistance and ageing of tungsten in these conditions, by installing and testing a divertor of this type in Tore Supra, which thus becomes a test bench for ITER.

WEST will allow a reduction in the risks and lead-times linked to industrialisation of the component. Improved definition of the acceptance criteria for industrial production will follow runs. An initial series of ITER divertor components will accordingly be produced for WEST by selected suppliers, which will help optimise the manufacturing procedures. WEST will therefore allow accelerated testing of the resistance and ageing of these materials during long pulses and so detect any operational problems that ITER might encounter. WEST will also be able to develop a range of component operating and monitoring procedures. The programme will make it possible to learn about tokamak operation in a tungsten environment and this way aims at preparing the ground for the scientific operation of ITER.

The Main Scientific Objectives of WEST

WEST should enable the CEA-IRFM teams to conduct experiments to address several scientific objectives. Firstly, with regard to heat extraction, assessment of the performance of the divertor's tungsten components. These components will be subjected to heat fluxes equivalent to those expected for ITER, or about 10-20 MW/m^2. Operation with a degraded component (with local melting of the tungsten for example) will also be tested.

The real-time components monitoring system (infrared system associated with plasma flux simulation models) will also be optimised in order to constitute a basis for the device to be used in ITER. Over and above the questions linked to the divertor components, WEST will be able to explore the problems of hot plasma physics over long durations in a tungsten environment. Only the Cadarache facility is today able to provide pulse durations close to those of ITER (several hundred seconds). The aim will also consist in studying the "mode H" (high confinement) reference conditions over long time periods, more specifically addressing the problem of controlling plasma contamination by the tungsten.
Finally, in a limited number of pulses, WEST should accumulate particle fluences[11] on the plasma-facing components comparable with those expected on the ITER divertor. This will allow exploration of the plasma/wall interactions at high fluence (erosion by the plasma, evolution of the morphology of the surface of the material, fuel retention, etc.) which determine the lifetime of the component and have consequences on its operation.

[11] *Fluence: integral value linked to the density of a flux of particles versus a measured time period.*

WEST

/ Various reconfiguration works on the Tore Supra tokamak for the WEST project.

European and Japanese Agencies plus French and International Partners

Replacing Carbon With Tungsten

Finally, later on, WEST will function in support of the JT-60SA machine, under the "Broader approach" collaborative agreement between Europe and Japan, with the development of advanced technologies (improved plasma confinement).

Reconfiguring Tore Supra

To ensure success of these experiments, Tore Supra will have to be reconfigured. Since it was built in the 1980s, it has been continuously upgraded to improve its performance, and it even set a world record for steady-state plasma of 6 minutes 30 seconds. This record was notably achieved thanks to the second generation of actively cooled components, installed in the early 2000s: some 12,000 small blocks of carbon assembled above copper tubes through which pressurised cooling water circulates. In the run-up to ITER, the transformation of Tore Supra into WEST implies replacing these assemblies with tungsten elements, perfectly representative of the elements of the divertor of the future experimental tokamak. Other projects are in the pipeline: poloidal field coils will be added to obtain an "X point" magnetic configuration, identical to that of ITER: the plasma goes from a circular shape to a D-shape. The reconfiguration of Tore Supra will also concern the vacuum chamber protection panels, adaptation of the plasma heating means (heating antennas by injection of electromagnetic waves), modification of the cooling system and of the instrumentation necessary for the plasma physics science programmes.

Removal of the old internal components from Tore Supra began in Spring 2013 and the design studies for the new components are currently ongoing and have to a large extent been finalised. Thus, the first calls for bids have been launched and the production of certain elements has started. Assembly of the first WEST components should begin in late 2014 with the aim of a start-up in early 2016, in order to meet a schedule aligned with that of ITER, for which start-up is planned for the early 2020s.

Opening Up to Research and to Academia and Industry

"The WEST project brings Tore Supra into the family of machines that is preparing the ground for ITER" Alain Bécoulet happily adds. In this context, CEA will be in good company at carrying out these experiments. First of all working with European and Japanese domestic agencies (F4E and JAEA) in charge of building the ITER divertor will allow the best possible use of the WEST project. CEA is also revising all of its collaborations with French and international research partners inside and outside Europe, in order to focus them on WEST. Several laboratories in the French Research Federation for Magnetic Confinement Fusion (FR-FCM)[12] are thus already partners in the WEST project. The laboratories of Aix-Marseille University are particularly active in this respect. At an European level, numerous laboratories involved in studying the plasma-metal walls interaction have already expressed their interest in this project and have begun discussions with CEA to define their contribution.

Finally, the WEST project is open to international collaboration outside Europe, including all the partners in the ITER international agreement. CEA has already signed a series of partnership agreements with the two main fusion research organisations in China (ASIPP and SWIP), the Institute for Plasma Research (IPR) in India, the Department of Energy (DoE) in the United States and two Korean research institutes (NFRI and UNIST). These various agreements lead either to the supply in kind of elements for WEST, or the creation of joint research laboratories, or the participation by researchers from around the world in the WEST research programme. They demonstrate the international scientific community's interest in this project and spotlight the worldwide fusion hub that is being built up around the WEST and ITER projects.

[12] *FR-FCM: Federation created at the initiative of CNRS, CEA, Inria and six higher education establishments, the Universities of Aix-Marseille, Nice, Nancy and the École Polytechnique.*

EU AND JAPAN IN THE "BROADER APPROACH" PARTNERSHIP

In February 2007, the European Atomic Energy Community (Euratom) and the Japanese Government signed a ten-year agreement called the Broader Approach, concerning an R&D programme to support ITER. The projects included in the Broader Approach supplement everything being done worldwide to build ITER. The committee meets twice a year, alternately in Japan and in Europe. On 16th December 2013, the Japanese and European representatives of the steering committee met in Saclay. In 2014, they will meet in Germany.

The Broader Approach comprises three major research projects:

// IFMIF-EVEDA, Prototype Facility Dedicated to Qualification of Materials for the DEMO Reactor

Qualification of materials capable of withstanding the intense neutron irradiation of 14 MeV is the main objective of the IFMIF project (International Fusion Materials Irradiation Facility), for which the engineering phase (IFMIF-EVEDA, Engineering Validation and Engineering Design Activities) is carried out within the framework of this Broader Approach agreement.
This instrument aims to qualify advanced materials withstanding the specific extreme conditions of the future fusion reactors. IFMIF will comprise two deuteron accelerators, outputting parallel and continuous beams with a total power of 10 MW on a liquid lithium target, to generate the intense neutron flux (10^{17} neutrons/s) of 14 MeV. This value corresponds to the annual flux of the future reactors. This ambitious project initially requires the construction of prototypes of the main subsystems. This is the purpose of IFMIF-EVEDA which, in addition to providing an engineering report, must validate the working of the accelerator, the lithium target and the high-flux test modules. The activities, which are scheduled to last ten years, are shared between the coordination team based in Rokkasho (Japan), where the prototype accelerator is to be installed (LIPAc), and other teams spread around Europe and Japan.
Europe is supplying the vast majority of the prototype accelerator, while Japan is primarily supplying the test infrastructure. Four European countries are concerned: France (CEA-Irfu[13] in Saclay), Spain (CIEMAT in Madrid), Italy (INFN in Legnaro) and Belgium (SCK-CEN in Mol). Coordination of studies and production of the LIPAc is the responsibility of a European team located in Garching (Germany) within F4E[14].

/Visit of "Broader approach" partnership at Saclay.

// JT-60SA, Transformation of the Japanese JT-60 Tokamak Into a Superconducting ITER Satellite Tokamak

JT-60SA (SA for Super-Advanced) is an experimental fusion facility designed to support ITER operations and optimise the operating conditions for the fusion reactors to be built after ITER. The programme uses the existing and partly reconfigured JT-60 tokamak in Naka (Japan): the facility is in particular receiving superconducting coils. The JT-60SA programme will provide data for physics studies into the plasma conditions in the "advanced" scenarios.

// IFERC, International Modelling and Simulation Computer Centre

CEA was mandated by F4E to set up and operate the International Fusion Energy Research Center, situated in Rokkasho, Japan. In March 2012, it received the Helios supercomputer enabling the European and Japanese researchers to model the many challenges posed by fusion: behaviour of the plasma, study of materials, for example. This supercomputer is designed and operated by Bull and its power is now nearly 2 petaflops[15], making it among the most powerful supercomputers in the world. It provides modelling and simulation capacity for all European and Japanese researchers working within the framework of the Broader Approach.

The new Intel® Xeon PHI™ coprocessors will offer the researchers exceptional performance. Their massively parallel architecture and their controlled energy consumption are paving the way for exaflop[16] technologies. *"Simulation plays a key role in the development of fusion research, both for understanding the extremely complex physical phenomena and for designing future tokamaks. The fusion community already has highly advanced parallel simulation software. Adapting them to highly parallel processors is essential to ensuring that they can be used to their full extent by the future supercomputers"* explains Gabriele Fioni, Director of Physical Sciences at CEA. The centre of expertise for parallel programming set up by Bull in close cooperation with Intel and based at Bull Grenoble is associated with this project for training, porting and optimisation of the computer codes dedicated to this key field of energy research.

/IFMIF facility for irradiation of steels for the DEMO prototype.

13 Irfu: Institute of research into the fundamental laws of the Universe.
14 F4E, Fusion For Energy, European "domestic" agency for the construction of Iter and the Broader Approach. http://www.fusionforenergy.europa.eu
15 Two Petaflops correspond to 2 million billion operations per second. If each inhabitant on Earth performed one operation per second, it would take a day and a half to do what Helios does in a single second.
16 Or 1 billion billion operations per second, or 500 times the power of Helios. The first exaflop power computers should appear in around 2020.

CLIMATE

Heatstroke on Marine Biomass

/ Cold-water coral reef, vulnerable to global warming.

Global warming is not only damaging pack ice. Over time, it could also cause a significant reduction in marine biomass and a drastic disruption in the fauna of great sea floors.

There is no question about it: global warming will eventually result in modifying ecosystems all over the planet. And not only on the surface! These disruptions will affect the great sea floors, reducing their biomass by 5% worldwide by 2100 and by up to 38% locally in North America!

Cycle of Nutrient Salts Altered

// Phytoplankton Production Slowdown

To achieve such conclusions, scientists worked on the forecasts produced by the eight most cutting-edge climate models and particularly the one developed at the Pierre-Simon Laplace Institute (IPSL) of which LSCE[1] is a part. These models point to a large-scale slowdown in ocean circulation and a marked separation – called stratification – between bodies of water that differ in temperature and salinity, as a result of a warmer climate. This interaction between ocean circulation and warming alters the cycle of nutrient salts found in small amounts in surface waters where phytoplankton is produced, leading to a drop in this production. This in turn causes a decline in deep-sea flows of organic material proceeding from phytoplankton decomposition. *"According to the models, this flow of organic carbon - the staple diet of bacteria, worms, crustaceans and other deep-sea fish - will decrease by 7 to 18%"* announces Marion Gehlen, CEA biogeochemist, who instigated the study.

// Major Impact on Biodiversity

This data was then coupled with empirical relationships resulting from biological observations across the globe and statistical analyses of deep-sea flows of organic material and biomass. Enough data to ultimately assess, in a relatively reliable manner, the reduction in biomass at the end of the century. In addition to the conclusive figures, the scientist explains: *"We have particularly detected a strong impact in some areas known for their biodiversity, such as canyons, seamounts or certain cold-water coral reefs, parts of which are supposed to become marine protected areas."* It is difficult to be more precise, even though scientists believe a negative impact on fisheries is likely long-term. One thing is certain: global changes are inexorably making their mark on every nook and cranny of Planet Earth.

Matthieu Grousson - Les Défis du CEA #186 - February 2014

[1] LSCE: Laboratoire des Sciences du Climat et de l'Environnement (Laboratory of Climate and Environmental Sciences), a joint CEA/CNRS/Versailles-Saint-Quentin University unit located on the Saclay and Gif-sur-Yvette sites.

ASTROPHYSICS

ArTéMiS, the Stellar Image Hunter

ArTéMiS is up and running! The camera was successfully tested in Chile during a recent run of scientific observations on the Apex[1] telescope. It produced exceptional images of the sky, including one of the Cat's Paw Nebula... A bright future lies ahead for an instrument that was entirely developed at CEA!

The ArTéMiS camera is finally installed in May 2014 on the Apex telescope, the world's highest observatory perched at an altitude of 5,100 metres in Chile. The device will be dedicated observing the clouds where stars form. These vast swathes of gas and dust are considered to be the nurseries of the cosmos: they are arranged in long filaments which eventually break up and heat up under the effect of their own gravity, giving birth to stars. However, owing to their very low temperatures (a few tens of degrees above absolute zero, or -273°C), these gas masses cannot be detected by telescopes operating in visible or infrared light wavelengths. Hence the use of systems capable of producing images in submillimetre[2] and millimetre wavelengths, which are the most sensitive to the cold Universe.

// Images of Extreme Cold

This is the challenge addressed by ArTéMiS, one of the world's finest cameras, conceived between 2006 and 2009 at CEA. Its development was coordinated by CEA-Irfu[3] and benefited from the expertise of the CEA laboratories specialising in cryogenics and pixel imaging. It is based on the technology already employed on the PACS instrument for ESA's Herschel space mission: arrays of bolometers cooled to 0.3 °K (-272.85°C). These highly specific detectors originated in the silicon industry and are capable of converting electromagnetic radiation energy into heat and then an electrical signal. Once all the arrays are in place on ArTéMiS, they will create a highly sensitive focal plane over three wavelengths, with 5,800 pixels. *"There is nothing exceptional about this number of pixels for a photo camera, but it is a real challenge at these wavelengths for this type of device, of which Apex only carried 37"* states Michel Tavard, in charge of the camera. If any proof were needed, one need only look at the image of the Cat's Paw Nebula, produced with "only" 1,000 pixels...

Vahé Ter Minassian – Les Défis du CEA #187 – March 2014

[1] Apex (Atacama Pathfinder Experiment) is the prototype instrument for the international Alma radio telescope, currently under construction on Chajnantor plateau in the Atacama region of Chile.
[2] Submillimetre wave: visible radiations, from violet to red, comprise photons with a wavelength between 0.4 and 0.8 microns. Beyond this are the infrared, far infrared and submillimetre wavelengths, that is 0.2 mm, 0.35 mm and 0.45 mm, which are the three wavelengths of ArTéMiS.
[3] Irfu: Institute of research into the fundamental laws of the Universe.

/ Apex camera on Chajnantor plateau, at an altitude of 5,100 metres, in the Atacama region of Chile.

Watching the Nurseries of the Universe

AEROSPACE

Successful Launch of the Swarm Mission: Three Satellites in One Go!

The three satellites which make up the Swarm scientific mission were successfully launched on 22nd November 2013 from the Plesetsk base (Russia).
The main purpose of Swarm is to study space and time variations in the geomagnetic field, as well as the ionospheric environment (upper atmosphere) of the Earth. The three satellites are carrying sophisticated measuring instruments and will be positioned so that they simultaneously acquire measurements in three different locations and time zones. They were specially developed for this European Space Agency (ESA) mission and will be placed in an orbit at an altitude of 460/530 km.
Each satellite is equipped with three measuring instruments dedicated to the study of the Earth's magnetic field:

- a relative vector magnetometer, measuring the orientation of the magnetic field;
- a star camera, to situate this orientation in space;
- an Absolute Scalar Magnetometer (ASM), for measuring the intensity of this field, with no drift or bias (in other words with no systematic error), offering unparalleled precision and resolution. Furthermore, its unique ability to simultaneously measure the field direction will also be experimentally implemented in orbit.

The ASM is a magnetometer specially designed by CEA-Leti[1], with the help of CNES[2]. Development of this instrument required its adaptation to the conditions of a space environment. The IPGP (CNRS/Université Paris Diderot), which initiated this mission with the Danish DTU and the German GFZ, will now be tasked with the scientific validation phase for the data supplied by the ASMs, and will participate in the scientific operation of this mission, which is scheduled to last four years.

Press Release - November 2013

[1] Leti: Electronics and Information Technology Laboratory.
[2] CNES: National Center of Spatial Studies.

Presentation of a Swarm satellite
- Size: 9.1 m long (mast deployed); 1.5 m wide; 0.85 m high
- Shape: trapezoid (reduces aerodynamic drag in these low orbits and makes the satellites more compact)
- Weight: 473 kg (at launch)
- Cost of the ESA mission: 229.6 million euros

ENVIRONMENT

Transfer of Contaminated Particles to the Rivers in the Fukushima Region

Radionuclides: Binding With Soil and Exported to the Pacific

Researchers at the Laboratory of climate and environment sciences (LSCE – CEA/CNRS/UVSQ), in collaboration with a Japanese team from the University of Tsukuba, published the results of their first four measurement campaigns carried out in Fukushima Prefecture, as part of the TOFU[1] programme.

This programme was launched six months after the accident in March 2011 and aims at studying the transfer of contaminated particles in the watercourses situated under the main plume of radioactive pollution, covering an area of about 3,000 km². These results will give a clearer understanding of the transfer mechanisms involved, more specifically the role of typhoons, dams and vegetation.

// River Sediments

During the Fukushima accident, gamma emitting radionuclides escaped from the nuclear fuel and were released into the atmosphere. These radioisotopes, primarily Cesium-134 and Cesium-137, which can still be traced today, have the particularity of strongly and irreversibly binding with soil and sediment particles. Under the effect of erosion, the soil particles and the radionuclides they are carrying can be transferred to the rivers and then gradually exported to the Pacific Ocean, passing through the coastal plains which were to a large extent spared by the initial fall-out from the plume. River sediments have been sampled and their radioactive dose rate measured along the main rivers (such as the Ota, Mano and Nitta).

// The Role of Typhoons

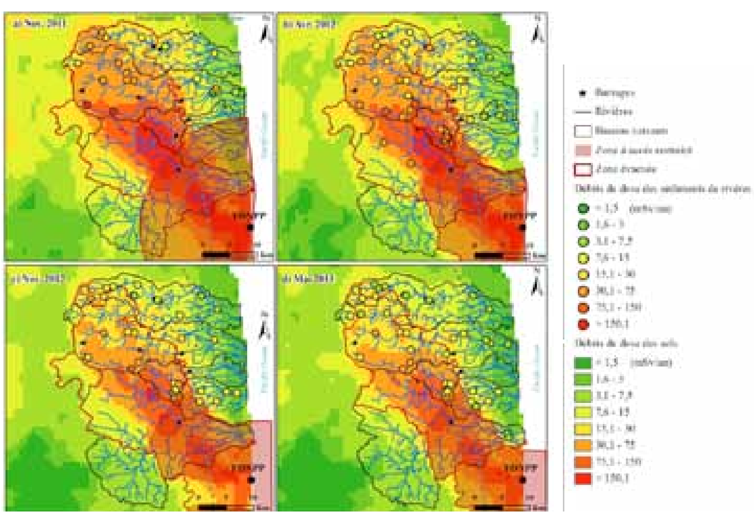
Typhoons accelerate soil erosion and lead to the evacuation of the eroded particles in the watercourses. The inland mountain ranges, which experienced the highest levels of radioactive fall-out, were marked by significant erosion after the series of violent typhoons in the summer of 2011. In twenty months, a drop in the level of radioactivity at altitude, with gradual redistribution of contamination to the downstream zones, was observed. In 2012, a general reduction in the contamination levels was measured. The May 2013 campaign confirmed this drop in the contamination levels in the rivers, which was faster than expected. This can be explained by the occurrence of less violent typhoons in 2012 than in 2011. This drop is however more significant and more linear in the mountains than on the plains. The change in the ground occupancy in the crop-growing areas at altitude contributed to limiting soil erosion in the upstream part, which is the most contaminated. The ban on cultivation of this land in fact encouraged the growth of denser vegetation which has the effect of protecting the soil from erosion. The resumption of rice-growing activity in the regions at altitude could once again promote soil erosion. In this case, close monitoring of the downstream contamination levels will be necessary.

// The Role of Dams

On the plains, the drop in contamination is less regular and varies according to the catchment area: the presence or absence of dams has a major role in that they constitute areas of temporary storage of the contamination. The contaminated sediments carried by the watercourses therefore accumulate in the reservoirs of the dams in the region. The dose rates temporarily exceeded 20 mSv per year, the limit adopted by the Japanese authorities to define a prohibited access area. These results mean that the impact of future dam releases must be monitored as they are liable to release contamination into the downstream section of the watercourse, with the corresponding necessary regulation of fishing and leisure activities.

This study, initiated under the Franco-Japanese "Flash" call for proposals from the French National Research Agency and the Japan Science and Technology Agency, is the first to provide a complete time and space picture of the evolution of the dispersion of these radioactive pollutants.
The research work will continue until 2019, under the Amorad project financed by the investing in the future programme concerning radiation protection and nuclear safety, piloted by IRSN[2], which began in early 2014.

Press Release - November 2013



/ Series of maps plotting the spread versus time of radioactive pollution in the soil and sediments deposited by the watercourses in the most heavily contaminated area of Fukushima prefecture.

[1] TOFU Programme: Tracing the environmental consequences of the TOhoku earthquake triggered tsunami and the FUkushima accident.
[2] IRSN: Institute for Radiological Protection and Nuclear Safety.

MICROELECTRONICS

The Power and Accuracy of Nowadays Sensors: A Short Story of the Tronic's Start-up

With their increasingly high-tech components, the smartphone can now position itself in its environment, the video game console can recognise the player's movements, automobile airbags inflate at just the right moment, pacemakers function perfectly, the hard disk in your computer is protected against being dropped... Even if they are hard to see, because of their microscopic size (less than one hundred thousandths of a millimetre), Mems (Microelectromechanical systems) are gradually invading our everyday lives. This trend will only accelerate, because these micro-components are now capable of detecting the slightest variation in speed, direction, or weight.

// Irresistible Growth

Although initially reserved for a number of highly sophisticated applications: aeronautics, space, defence, Mems have more recently moved into mass market sectors: mobile phones, gaming consoles, tablets, etc. This is a change of scale, because more than one billion telephones are produced worldwide every year and some devices – smartphones for instance – can contain more than ten or so Mems each.
The world's automobiles also represent significant potential owing to the fact that nearly 70 million vehicles are built every year, each of which can contain dozens of sensors (movement, pressure, etc.). This global market already represents more than 10 billion euros and is growing by 13% per year. It is even approaching the 20% mark for consumer products.

// A Project Combining Tronic's, Movea and CEA Leti

To strengthen its position on this promising global market (several hundred million items per year), the Tronic's Microsystems company is preparing to take a new technological step that is vital for its future. It is currently industrialising a new sub-micron technology, based on resistive piezo nanowires, called M&Nems. This new technology for micro-component manufacture is protected by more than twenty or so patents.
So what is the goal? Within a collaborative R&D project -ULTIMES- involving Tronic's, Movea and the Leti[1], the aim is to create an inertial platform which, on the same support of a few square millimetres, carries three accelerometers, three gyroscopes and three magnetometers. Tronic's is currently finalising the first demonstrator designed to validate a "6-axis" platform and should produce it industrially in late 2014. The next step will be 9-axis sensors (accelerometer, rate gyro, magnetometer) capable of meeting the needs of the consumer industries (telephony, gaming, etc.). In the longer term, Tronic's envisages broadening its market to other industrial sectors and utilising the M&Nems concept to develop new sensors, including a pressure sensor.

Marc Jary - Le Mensuel de Grenoble #168 - December 2013

[1] Leti: Electronics and Information Technology Laboratory.

A little history

- 1997: creation by transfer of a technology from CEA Leti.
- 2001: CEA-Valorisation acquires a stake.
- 2008: takeover of the Californian company MedTech Development specialising in medical devices.
- 2009: creation of Tronic's Mems Inc, in Texas, on a site equipped with about 2,000 m² of clean rooms.
- The company has also been present in Japan for more than 10 years and in China since 2011, with the creation of China Tronic's.
- 2011/2012: agreement with Leti for the transfer of the new M&Nems submicron technology.

MEDICAL IMAGING

CEA Developed New 12 Times More Effective Contrast Agents

A CEA team has developed MRI[1] contrast agents that are 12 times more effective than the commercially available reference products, thanks to an original method of encapsulating the active component. The latter, gadolinium, increases the contrast, but is toxic for the organism. To prevent it diffusing, it is usually encapsulated in organic ligands.
The researchers used original ligands containing hydrophobic functions. This allowed the encapsulation in nanoparticles of porous silica, 25 nanometres in diameter. This structure allows free circulation of the water molecules and increases the MRI contrast. Several patents have been filed on this technology, which shows considerable promise for molecular imaging.

Mina-News #27 - December 2013

[1] MRI: Magnetic Resonance Imaging.

COMPUTATIONAL BIOLOGY

France Genomics Computational Resources

The France Genomics project aims at significantly expanding France's capability to produce and analyse genomics data.These data are stored and processed at the CEA Computing Center for Research and Technology (CCRT).

While it took more than 10 years – from 1990 to 2003 – and $300 million to sequence three billion human genome bases, a few days and a few thousand dollars now suffice to complete the same operation. This example illustrates the spectacular advances performed in life sciences over the past 20 years – advances that are closely linked to the development of genomic sequencing technology. Mass sequencing, which is now possible, paves the way to a number of research fields across all disciplines (biology, medicine, agronomy, biodiversity, etc.). We can now therefore look forward to remedial therapies tailored to each patient or targeted drugs.

In response to this evolution, which radically changes our approach to life sciences, French research launched the national France Genomics framework. Strengthening genomics resources and offering a new nationwide organisation of work were indeed becoming vital to enable France to maintain its independence and ownership of its results in this strategic field. Life sciences involve high economic stakes and France must keep up with the continuous development of major US, European and Asian centres.

// Embracing the Scientific Community

France Genomics brings together the majority of France's sequencing and computational biology platforms within a consortium in which CEA[1], Inra, CNRS and Inserm are the main partners. The project offers a one-stop entry point for the management of large and mid-size projects and access is open to the entire French public and private scientific community - which thus benefits from high-level expertise, support and shared skills.

Interactif #65 - January 2014

[1] The Genomics Institute of CEA's Life Sciences Division, based in Evry, is responsible for the coordination of France Genomics.

The gigantic volumes of France Genomics data hosted and processed over five years amount to five petabytes. Data from DNA sequencers is analysed by a dedicated extension of the Airain computer (located at the CCRT) comprising 3,000 processing cores with very high storage capacity (60 teraflops). In addition, France Genomics has a specific storage system with an unique architecture particularly adapted to handling very large volumes of data.

/ Data storage for the France Genomics project in the CCRT.

GENOMIC

400 Exomes Sequenced

Under a partnership with the Rare Diseases Foundation, the National Genotyping Centre (CNG) at the CEA - Genomics Institute sequenced 400 exomes of persons affected by rare diseases[1]. An exome is the group of genes of an organism, representing about 1.5% of the human genome. The investigation of the human exome is of vital interest for research in rare diseases: comparing the exomes of healthy and sick people can lead to the identification of the mutations responsible for these diseases.

// An Extreme Diversity

Rare diseases affect more than 3 million people in France and the vast majority are serious and incapacitating. The extreme diversity of rare diseases (auto-immune,infectious, neuromuscular, cancers, etc.), the number of which is estimated at 7,000, requires a multidisciplinary approach, allying scientific expertise with medical competence.

To support research on this important topic, the CNG sequenced exomes concerning myopathies, metabolic and mitochondrial disease, retinitis pigmentosa, certain forms of hereditary neuropathies and congenital renal diseases. The sequences produced were sent to 22 research teams (Inserm, APHP, several hospitals, etc.) collaborating in this national project, in order to identify causal mutations.

/ Plating of DNA samples for genotyping.

CEAbio #1 - March 2014

[1] Rare disease: a disease is said to be rare when it affects fewer than one person in 2,000.

Prosavin®: A Promising Vector for Parkinson's Disease

The Prosavin® lentiviral vector, developed by the Oxford Biomedica company, gives hope for a future gene therapy against Parkinson's disease. The results of its use in the clinical phase, carried out by a Franco-British team[1] in which CEA-I²BM took part, were presented at a press conference at the Henri-Mondor Hospital in Créteil (near Paris) in January 2014.

With nearly 120,000 people affected in France, Parkinson's disease is the most common degenerative neurological disease after Alzheimer's.
Its cause: the gradual degeneration of the neurons of the ventral midbrain[2] which produce dopamine, leading to a drop in the secretion of this neurotransmitter involved in motor control. These biochemical changes then lead to disabling symptoms of increasing severity, such as trembling, limb rigidity or reduced body movement. At present, therapeutic treatment is based on the administration of a drug mimicking the dopamine missing from the brain. Called levodopa (L-Dopa) and administered orally, it enters the bloodstream (once in the digestive tract) and rapidly reaches the brain where it transforms into dopamine.

The contribution of this recently synthesised neurotransmitter then allows an improvement in motor control during the early stages of the diseases. Unfortunately, after about ten years, this ends with the appearance of severe complications, such as fluctuations in the action of the treatment, accompanied by involuntary abnormal movements, called dyskinesia[3]. *"For several years now, the hypothesis adopted to explain these symptoms is that the intermittent administration of L-Dopa leads to dopamine concentration peaks in the brain, responsible for isolated overdoses causes the appearance of dyskinesia,"* summarises Professor Stéphane Palfi, Head of the Neurosurgery Unit at Henri-Mondor Hospital. The investigations then turned towards a treatment offering continuous and local secretion of dopamine. The strategy employed was to resort to gene therapy to restore the functions of the damaged dopaminergic neurons.

// Ten Years Ago...

The British biotechnology company Oxford Biomedica was highly effective in positioning itself in this field of research[4]. More than ten years ago, it developed a vector expressing the genes of three enzymes[5] essential for the biosynthesis of dopamine and for taking them to the neurons. Called Prosavin®, this vector was derived from a horse lentivirus[6], equine infectious anemia virus (EIAV), in which the viral envelope and the genome had their pathogenic properties removed. Its envelope merged with the membrane of the host neuron and then released the therapeutic genes, enabling the cell to be reprogrammed and fabricate *de novo*[7] dopamine. Following these preliminary tests, preclinical trials began in March 2008 on primate models.
The phase 1 and 2 biomedical study, coordinated by Professor Stéphane Palfi, was then conducted on fifteen patients (twelve in France, three in the United Kingdom) aged between 48 and 65, who had been suffering from Parkinson's disease for at least five years and presented the severe motor control complications traditionally observed with L-Dopa treatment.
Each of them was operated: about a hundred microlitres of the solution containing the viral particles was injected into each hemisphere of the brain. During the study, these injections were made at different doses for three different cohorts: three patients received a low viral load, six a medium load and the last six a higher dose.

// Doubly Positive Results: Tolerated, Effective Therapy

Following this operation, the health of the patients was closely and regularly monitored. Four years after the first *in situ* injection, the results obtained confirm the long-term harmlessness and tolerance of Prosavin® by man. No viral particle from the vector has been detected in the blood or urine and no lentiviral vector has been integrated into the T lymphocytes, the immune cells which are usually the targets of this virus. There has been no inflammatory response or serious undesirable effects linked to the surgery. 6 months and 12 months after the injection, the patients all presented improvements in body rigidity and a reduction in the fluctuating effects linked to the administration of L-Dopa. The benefits were found to be proportional to the dose injected.
To complete these clinical results and understand what happened in the brain from a biochemical viewpoint, the patients underwent *in vivo* and non-traumatic imaging examinations: PET[9] at CEA's Frédéric Joliot Hospital Unit in Orsay and MRI[10].
This methodology then confirmed the restoration of local *in vivo* dopamine production in the fifteen patients.

// Research Continues...

Despite this crucial step forwards in gene therapy, the researchers and doctors are remaining prudent with regard to this test. The next phase in the clinical study of Prosavin® is scheduled for around 2020. Other studies will also be carried out to validate the effects of an improved vector: OXB 102. The pre-clinical trials in primate models are currently ongoing at MIRCen. The ultimate goal would be to be able to offer all patients personalised treatment, regardless of the stage of their disease. Without actually healing the affected persons, this gene therapy could prolong their quality of life by several years.

Amélie Lorec - Les Défis du CEA #186 - February 2013

1 The team (AP-HP, Inserm, CEA/Mircen, UPEC, Oxford Biomedica, Cambridge University) coordinated by Pr. Stéphane Palfi.
2 Midbrain: region of the brain located at the top of the brainstem.
3 Dyskinesia: involuntary, slow and stereotyped motor activity affecting the face and extending to the trunk and limbs.
4 The entire project was 98% financed by Oxford Biomedica.
5 AADC, Aromatic L-amino acid decarboxylase; TH, tyrosine hydroxylase; CH1, GTP-cyclohydrolase 1.
6 Lentivirus: virus of the retrovirus family, which includes the HIV.
7 De novo: in biology, this means newly synthesised.
8 Ligand: molecule which binds reversibly with a specific target.
9 PET: Positron Emission Tomography.
10 MRI: Magnetic Resonance Imaging.

Clinical Trial: A Four-Stage Long-Distance Race

Developing a new therapeutic treatment involves several clinical phases:
- **Phase 1** is the safety phase to evaluate tolerance and the absence of undesirable effects in man, through the use of increasing treatment doses;
- **Phase 2** is used to obtain preliminary data on the effectiveness of the treatment;
- **Phase 3** will allow large-scale validation of the results of the previous two phases and compare the effectiveness of the treatment either with a placebo, or with a reference treatment. Following this, the marketing authorisation will either be granted, or not;
- **Phase 4** is the very long-term monitoring of the treatment after marketing authorisation. It aims to discover any rare side effects which were not identified during the phase 3 clinical trials.

Key figures:

- **15 patients treated**
- **1 lentiviral vector used for the first time in humans**
- **3 dose levels tested**

HEALTH

"Wake and Kill": A New Concept to Eliminate Malaria Relapse

A team of researchers coordinated by Professor Dominique Mazier (AP-HP, UPMC, Unité Inserm 1135, CNRS ERL 8255) and Doctor Georges Snounou, Research Director at the CNRS (UPMC, Unité Inserm 1135, CNRS ERL 8255) succeeded in cultivating the dormant hepatic form of the malaria parasite, previously inaccessible to researchers. The first results arising from this technical advance led to a new concept for eliminating relapses of malaria caused by the reawakening of these dormant forms and implementing a new strategy for treating this disease.

// Malaria Today

After the bite from an infected mosquito, the parasite responsible for malaria reaches the liver, where it multiplies. It then propagates through the bloodstream, where its proliferation causes a potentially fatal disease. In certain cases, including that of the *Plasmodium vivax* parasite in man, a fraction of the hepatic parasites can remain "dormant" for a year or more, hence their name hypnozoites. They then "wake up" after a period of time and infect the blood.
For the control/elimination of malaria, the hypnozoite represents a two-fold challenge: a larger number of cases to be dealt with and increased transmission. Unfortunately, primaquine (and its recently developed equivalent, tafenoquine), the only drugs capable of killing the hypnozoites, have side-effects that can sometimes be serious for the organism. This is why the identification of safe replacement molecules is a matter of urgency for public health. So far the search for new anti-hypnozoite drugs relied on observations conducted in people infected with *P.vivax*, or in primates infected with a parasite similar to *P.vivax, P.cynomolgi*.

// Discovering an Innovative Strategy

Through collaboration with the CEA IDMIT[1] national infrastructure at CEA and the BPRC[2] in the Netherlands, the team of Professor Dominique Mazier and Doctor Georges Snounou first of all succeeded in maintaining infected hepatic cells in a culture for up to 40 days, which is early four times longer than had been generally achieved. They then showed the persistence of the dormant forms throughout the culture period, with some of them waking up during the period, thus reflecting what happens inside the human body. They also tested new molecules on these hypnozoites to inhibit epigenetic factors targeting histone methyltransferases, capable of killing the blood form of the parasite (discovered in the Pasteur Institute, Paris). Paradoxically, one of them caused the hypnozoites to wake up. This unexpected result led the team to adopt a new strategy: "Wake & Kill" consisting in combining a molecule capable of reawakening the dormant parasite with one of the numerous available treatments which have proven themselves effective on the multiplying parasite.

// Promising Results for Malaria Treatment

Thanks to this methodology developed through collaboration both internationally and between a number of French institutes[3], it is now possible to conduct *in vitro* screening of drugs for their anti-hypnozoite effect, thus limiting the need to use animals. The challenge is to adapt this technique to screening of a large number of compounds. Moreover, the possibility of cultivating hypnozoites will finally enable the scientists to study this enigmatic parasitic form, described 100 years after the discovery of the causal agent of malaria by Alphonse Laveran in 1880.

Press Release - February 2014

Results published in the review Nature Medicine.

[1] IDMIT: Infectious Diseases Models For Innovative Therapies.
[2] BPRC: Biomedical Primate Research Centre.
[3] Inserm, CNRS, CIMI, CEA, UPMC, AP-HP, Pasteur Institute Paris.

/ Underside of the Azalee table, one of the equipment items on the Tamaris experimental platform.

SEISMIC RISK

Tamaris Shakes Up Home Design

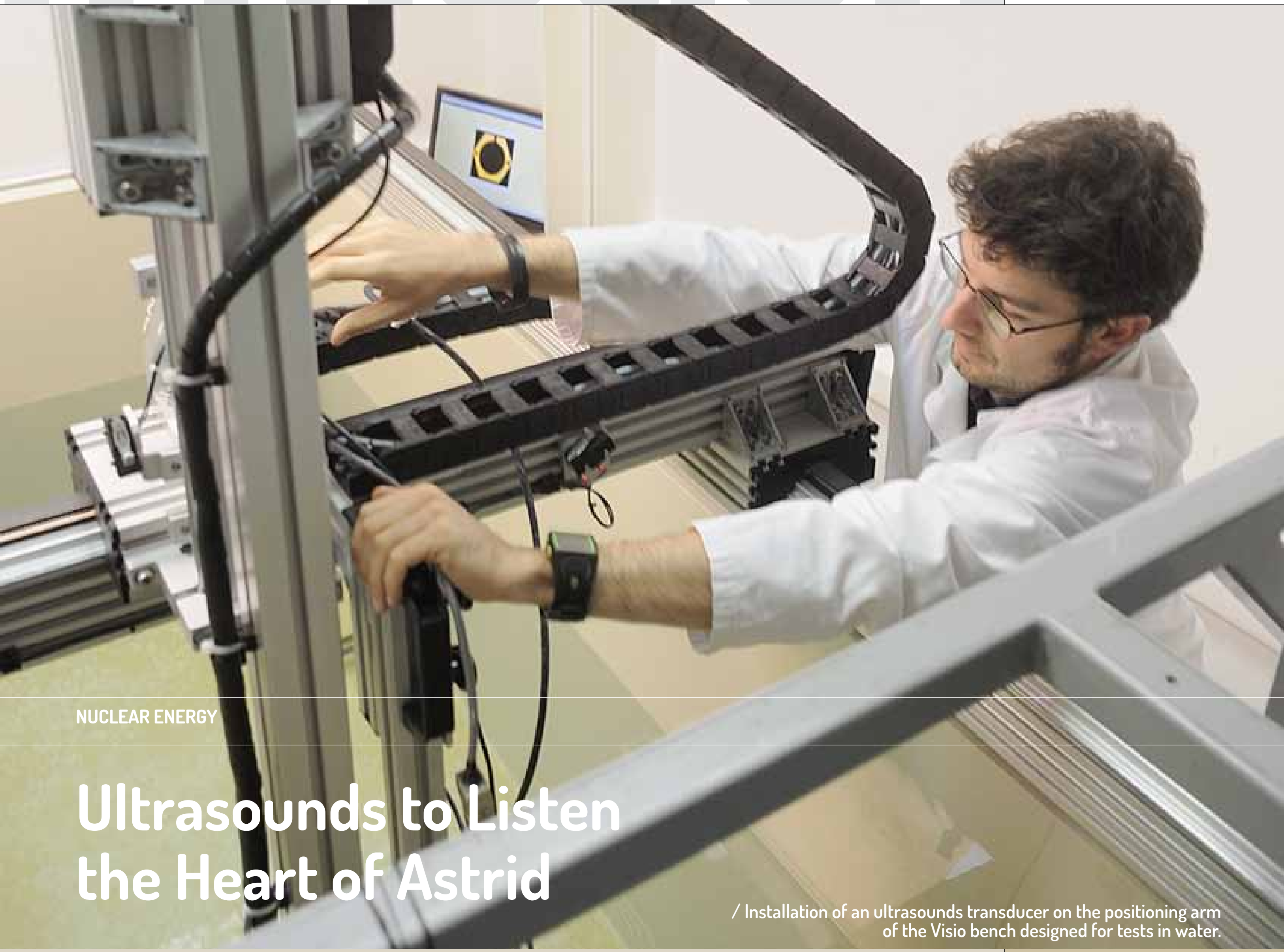
Backed by its expertise in seismic risk management for nuclear facilities, the CEA Nuclear Energy Division has turned its attention to individual homes. It was contacted by the FCBA[1] Institute, the sponsor of the SISBAT project financed by the French National Research Agency, to conduct seismic tests on the Tamaris platform. The experimental framework consists in testing the seismic resistance of two houses, one built on a wooden framework and the other with masonry walls, each one with an industrial wooden roof. The goal is to develop a reliability-based tool to analyse the seismic vulnerability of this type of home.

// Assessing Seismic Risks

These tests should provide experimental data to validate the modelling. The wooden framed house was tested in September 2013, while the second, currently under construction at Tamaris, will be tested in December 2014. This multi-partner[2] project consolidates the position of Tamaris as the leading European experimental platform for seismic risk management.

Les Défis du CEA #184 - November 2013

[1] FCBA: Forêt Cellulose Bois-construction Ameublement.
[2] FCBA, CSTB, CEA, BRGM, 3S-R, LaMI, LMT, University of Shizuoka, SCIBO, MiTEK, AGINCO.



NUCLEAR ENERGY

Ultrasounds to Listen the Heart of Astrid

/ Installation of an ultrasounds transducer on the positioning arm of the Visio bench designed for tests in water.

How to monitor Astrid demonstration reactor's liquid sodium core operation? A new acoustic method based on ultrasonic inspection is being tested and developed by CEA-Liet[1] so as to "watch" inside sodium.

Sodium is an opaque substance making any visual inspection totally impossible, while safety demands that everything that is happening be known, any time, anywhere... including in the core.
This semantic artifice does however reflect a key problem for reactors which do not benefit from the transparency of the water used in PWRs; hence the use of ultrasounds as a "visual" inspection tool. The principle is to emit a wave which propagates in the liquid sodium, or follows the structure, and returns different echoes according to the obstacles it encounters, provided the relevant sensors can interpret and transmit the signal.
The team in this laboratory designs and tests this type of sensor. As they can be installed outside or inside the reactor vessel, these sensors must be able to withstand very high temperatures, as the sodium circulating in the primary reactor coolant system reaches 550°C. The TUSHT is a good example: this high-temperature ultrasonic transducer using a crystal of lithium niobate in a sealed box was tested in the Phenix and SuperPhenix reactors and was patented in 2011.
Such instruments today offer accuracy of about a millimetre and the most powerful devices use multiple elements. Finally, the sensor must also be capable of active monitoring (with reception of the echo from the wave it produced) or passive monitoring; in this case, it listens to the operation of the reactor in order to identify boiling, a cavitating pump or a shifting part. The necessary precision is such that in the near future, ultrasonic inspection could be capable of measuring the sodium temperature (because the wave's propagation rate varies accordingly).

Atout Cadarache #36 - January 2014

[1] Liet: Technological Instrumentation and Testing Laboratory.

News from the Liet

One third of the laboratory's activity is devoted to acoustics and several international collaborative ventures in the field of sodium imaging are ongoing (with Japan, India and Belgium). The research under way concerns gas measurements in sodium, signal processing methods and the use of computer models. The Liet also working with industrial partners on the design of sensors capable of withstanding very high temperatures.

NUCLEAR SECURITY

A Worldwide Challenge: Detecting Nuclear and Radiation Threats

The CEA-List[1] Institute and the Saphymo company, a world leader in radioactivity monitoring, are strengthening their partnership by creating a joint laboratory to develop cutting-edge nuclear instrumentation technologies.

// A Security Problem

At a country's borders, one of the main reasons for controls is to detect illicit materials. This is done using plastic scintillators, combining low cost and large detection volume. Although these sensors can measure radioactivity, they cannot as yet identify the nature of the radioisotopes responsible for tripping the alarm.

In 2011, neutron/gamma differentiation was the first step in an overall improvement in the performance of these detection systems and was the subject of an initial license. These detectors remain the main subject of research, which today focuses on the energy categorisation of gamma radiation, the identification of radioisotopes, the reduction of false alarms and improvements in the detection limits.

The two partners thus took part in the FP7 Scintilla project for the development of neutron detection systems using plastic fluorescent materials.

Press Release - November 2013

For more information:
http://www.saphymo.fr/fr/page.htm?_ref=170

[1] List: Laboratory for Integration of Systems and Technology.

/ Analyses of alpha and gamma radiation spectra.

MOLECULAR CHEMISTRY

If Platinum is Too Expensive, Try Enzymes!

Next Inside Fuel Cells?

Researchers at CEA are developing an "artificial" active site to grow large quantities of hydrogenases, enzymes which could thus replace platinum in the manufacture of electrodes for fuel cells and electrolysers.

So far, platinum remains the most widely used catalyst to speed up reactions which transform energy into hydrogen and vice-versa. Its days are no doubt numbered, because hydrogenases are increasingly looking like extremely interesting solutions to replace this rare and therefore expensive metal. Hydrogenase is a natural enzyme present in certain bacteria and is capable of catalysing the same reactions extremely efficiently, using nickel and iron on its active site, where the chemical reactions of interest take place. However, there is a major limitation for biotechnology applications, because it is hard to produce in large quantities.

// Separate Production of the Inactive Enzyme and the Active Site

With his team, Marc Fontecave, scientific adviser to CEA-iRSTV[1], has succeeded in developing a small molecule capable of performing the same role as the active site, and in integrating it into an apohydrogenase (inactive hydrogenase with no active site). As it is inactive, the enzyme can be grown abundantly using the *E.Coli* bacterium. Incorporating said molecule restores its full activity, with a level equivalent to that of a conventional hydrogenase.

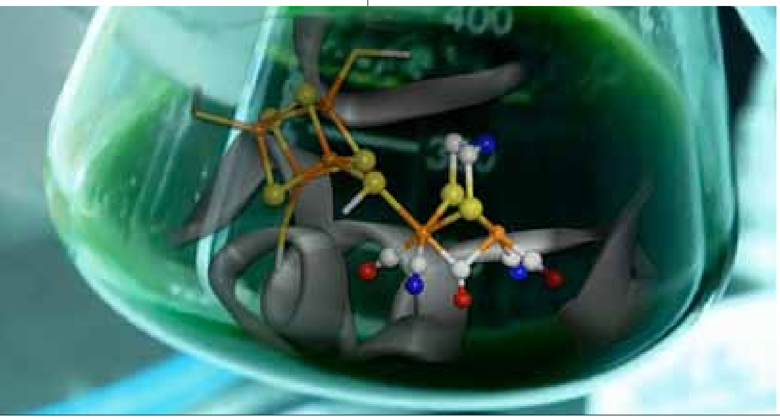
These results were obtained using biomimetic chemistry which, through chemical synthesis, reproduces what is otherwise found in nature. This is a significant advance because thanks to this process, several types of hydrogenases will be screened and tested in order to identify those which have the best activity and which are the most resistant to air. They may soon be finding their way into fuel cells...

Amélie Lorec - Les Défis du CEA #185 - January 2014

These results were published in Nature in July 2013.

[1] iRSTV: Institute of Life Sciences Research and Technologies.

/ Virtual image of the composition of the hydrogenase artificial active site.



ENERGY TECHNOLOGIES

The Sensitive Part of the Fuel Cell

Nanometre Scals Simulation

Fuel cell optimisation involves a detailed understanding of the molecular mechanisms taking place inside, more specifically at the electrodes. A team from CEA-Inac[1] is developing a nanometric scale model to simulate the interactions between the water and the materials of the ultra-thin film coating these electrodes.

The proton exchange membrane fuel cell (PEMFC) converts chemical energy into electrical energy, from hydrogen and oxygen, with a little water being the only waste product. This performance is determined by the slightest detail, such as the physical-chemical characteristics of the catalyst layer, the interface between the membrane and the material of the electrodes.
It is therefore essential to be fully aware of its parameters, notably in the presence of the water responsible for the transport of the protons. A team from CEA-Inac looked particularly closely at the 5 nm thick polymer film which surrounds the platinum-coated carbon of the electrode of a PEMFC.
In collaboration with the researchers from the CEA-Liten[2] and a Canadian colleague, they performed nanometre scale simulation of this structure using molecular dynamics simulation tools. With the model developed, the wettability properties of the materials making up the electrode were reproduced, in other words their attraction or rejection of the water present in the PEMFC.

// Water Pockets in the Thin Film

The catalyst layer in fact has a disordered structure consisting of hydrophobic (carbon) and hydrophilic (platinum) particles. The innovation of this approach is, within the same framework, to simulate the behaviour of both hydrophilic and hydrophobic materials. Even though slightly less precise than standard "atomistic" methods, this continuous study avoids having to change models while taking account of different chemical compositions. The researchers were thus able to demonstrate that the water molecules are transported through the ultra-thin film heterogeneously, forming "pockets" of water in places.
The new results, which supplement the information produced by resources for the experimental study of matter on a small scale (X rays, neutron diffusion, etc.) will provide avenues for optimising the sensitive part of the cell...

Amélie Lorec - Les Défis du CEA # 186 - February 2014

[1] Inac: Institute for nanosciences and cryogenics.
[2] Liten: Laboratory for Innovation and New Energy Technologies and Nanomaterials.

/ Wettability measurement device for fuel cell membranes.

SOLAR

The New Shades of Solar Cells Break the Efficiency Barrier

10.2% conversion efficiency as against 6% for the previous generation: the performance of solar cells with organic dyes, developed by the researchers at CEA, has made a giant leap forwards. The absorption coefficient of these dyes is three times that of the reference dyes, the drawback of which is that they contain ruthenium, a rare and expensive metal which generates toxic by-products. This 10.2% efficiency, verified during testing by two industrial project partners, places these solar cells among the world's best performers. They also offer excellent stability, showing no signs of deterioration after 2,000 hours of accelerated ageing. The researchers also associated these dyes with a new electrode material, thereby approaching state-of the-art performance levels.

Mina-News #26 - Septembre 2013

/ Photovoltaic panels produced with ruthenium-free dyes on the façade of the EPFL conference building in Lausanne.

Nuclear Training: New France/IAEA Agreement

On November 29, 2013, IAEA and France signed a new agreement to strengthen the role of French research organisations and industrial players in IAEA education and training activities, particularly in newcomer countries.
The details of this agreement were finalised by Alexander Bychkov, IAEA Deputy Director General and IAEA Head of the Department of Nuclear Energy, and Frédéric Journès, Governor for France to the IAEA Board of Governors and CEA Director of the Division for International Affairs. The agreement was signed in the presence of John de Grosbois, IAEA Section Head for Nuclear Knowledge Management.
"We hope our cooperation will continue to grow and support the needs of Member States to develop new generations of nuclear scientists, engineers and professionals and to secure an adequate and competent workforce for safe and sustainable nuclear programmes," said Alexander Bychkov. Among other things, the agreement provides for access to French research reactors and nuclear facilities for education and training purposes; courses on nuclear education and training for newcomer countries; scholarships providing nuclear research and engineering students with the opportunity to pursue their academic curricula in France; and meetings and conferences to share knowledge, experience and good practices in training.
"France is fully committed to sharing its expertise and to assisting Members States seeking to develop nuclear programmes to build the necessary capabilities and competencies," said Frédéric Journès.

/ Practical work in the control room of the ISIS experimental reactor.

Thomas Zemb Received the Thomas-Graham Award

In September 2013, Prof. Dr. Thomas Zemb received in Paderborn the Thomas-Graham medal attributed by the "Deutsche Kolloid Gesellschaft" in recognition of his international work on "catanionic" systems and ion transfer in complex fluids.
Thomas Zemb is Director and founder of the CEA Institute of Separative Chemistry at Marcoule (France) and professor of chemistry at INSTN.

The speech given at this ceremony is available in open access in "Colloids and polymers".
http://www.kolloid-gesellschaft.de

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CEA's Capabilities Show-Cased to Japanese Industrialists

Like the *Leti Days*, which have now been organised for 16 years in France and abroad, the first *Liten Day* took place on February 25, 2014 in Tokyo, Japan. This event is both a workshop and a business meeting designed to promote CEA-Liten[1] technologies to Japanese industrial players.

Around a dozen experts, programme leaders and managers presented their activities and state-of-the-art equipment to nearly 100 industrial players during conferences and personalised business meetings. These presentations demonstrated the wide expertise and offering of CEA-Liten, the only European institute to master every level in the value chain of fuel cells and batteries (R&D, innovation, state-of-the-art equipment, demonstrator, pilot lines and industrial transfer).
This event served as a prelude to the international exhibition *Battery Japan* organised in Tokyo from February 26 to 28, 2014, where the French partners shared a *"France Pavilion"*.

[1] *Liten: Laboratory for Innovation and New Energies Technologies and Nanomaterials.*

/ CEA-Liten stand in the "France Pavillon" during the "Battery Japan" exhibition.

ENC 2014, May 11-14, 2014, Marseille, France

The European Forum to discuss Nuclear Technology Issues, Opportunities & Challenges

The European Nuclear Conference (ENC) is the international get-together of nuclear science and industry in Europe. This European Nuclear Society (ENS) event has a multidisciplinary approach, looking at nuclear science and technology in energy production, non-power industrial and life science applications.
ENC 2014 will be an unique networking event for scientists, nuclear industry representatives and policy makers, who can consider and discuss ideas and innovations that will drive the technological developments of the future.
The ENC is known for the high standard of papers presented. Key themes of ENC 2014 will include state-of-the-art research and development in areas such as:

- Plant operations and safety
- Education, training and knowledge management
- Fuel cycle
- Reactor technologies
- New Build
- End of Use management
- Life science applications
- Non-power applications
- Nuclear in the civil society

The ENC 2014 conference programme will evolve around a number of plenary keynote sessions, panel debates and highly focused topical tracks.
The conference will also be a showcase of products and services from some of the world's leading nuclear industry and research organisations.

/ Bernard Bigot, Chairman, on the CEA stand.

WNE, October 14-16, 2014, Le Bourget, France

WNE will bring together all the major international players involved in decision-making and regulations for nuclear energy projects: purchasing, engineering design, research and development, operation, checks, maintenance, safety, environment, etc.
Governmental organizations in charge of inspections, checks and safety, engineering and consultancy firms, technical and research centers, higher education institutions and universities will also be invited. More than 400 international exhibitors are expected 6,000 international visitors are expected to attend. The programme: technical and business-focused economic conferences, daily round-table discussions, visits to industrial sites and research centres.

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