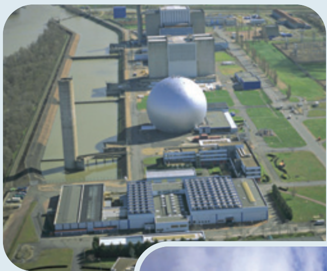
Nuclear Fission

Energy is a key factor in economic, social and sanitary development

The rise in the world's population and the economic development of emerging nations within the next few decades will lead to a doubling in energy needs. Now, at the beginning of the 21st century, the major question is to know how to meet this demand while limiting the use of fossil fuels (oil, gas and coal). These fuels are responsible for global warming and their reserves may be quickly depleted.

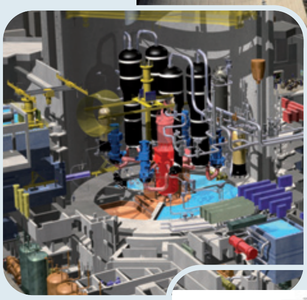
A policy turned towards the future will consist in mastering consumption and developing both nuclear and alternative energies.

Nuclear reactors: from the first generation reactors to those of the future



Chinon: Generation 1 plant

Dampierre-en-Burly: Generation 2 plant



EPR mockup: Generation 3 plant

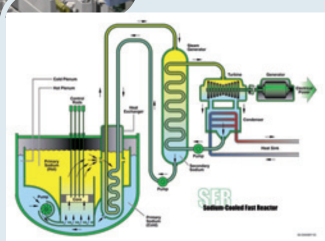


Diagram of a Generation 4 plant

The commissioning of the first generation reactors dates back to 1963 with the natural uranium graphite gas models (UNGG) Operation of these reactors ended in 1994.

Pressurised Water Reactors (PWRs), termed Generation 2 were operated until 1977. France currently operates some 58 reactors of this type and they provide 80% of all electricity produced in the country.

Now, on the horizon of 2013, the EPR (European Pressurised Reactor) termed, the 'Third Generation', will optimise the pressurised water reactor type in the fields of safety and waste disposal. This reactor will first be commissioned in Finland and afterwards in France.

Within the framework of the International Generation 4 Forum, several future reactor concepts are now under study. Their purpose is to integrate the nuclear industry into a logic of sustainable development.

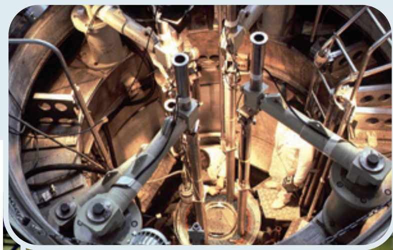
These Fourth Generation reactors will yield higher performances, will be safer and will use up to one hundred times less natural resources thereby limiting the risk of proliferation and reducing considerably the harmfulness of the waste they produce.

The CEA now focuses its research primarily on reactor types that operate on fast neutrons, cooled by either sodium or gas with a view to commissioning the ASTRID* prototype reactor in France by 2020.

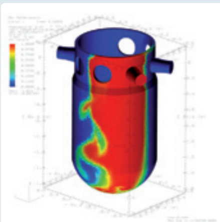
** Advanced Sodium Technological Reactor for Industrial Demonstration*

Research in the field of nuclear fission at Cadarache

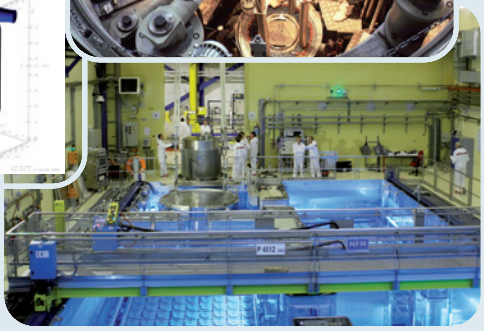
Since its creation in 1959, the Cadarache Research Centre has been one of the major contributors to the development of different nuclear reactor types. At present, it possesses competence and world-renowned facilities in the field of nuclear reactors, fuels and technologies.



The experimental reactor EOLE



Simulation of a water coolant within a PWR



The RES pool reactor for naval propulsion

The nuclear reactors

The activities and competence of Cadarache concern:

- Reactor physics (neutronics and thermal-hydraulics) with the perfecting of simulation computer codes. Their qualification is achieved using a wide range of experimental means, from the test bench to actual research reactors.
- The design of Fourth Generation reactors and on-board nuclear reactors for naval propulsion.
- Improvements continue to be made in the field of nuclear safety, particularly in experimentation carried out in research reactors dedicated to the study of accident situations.

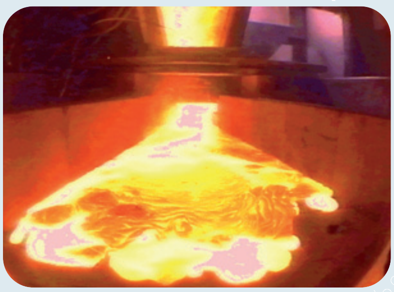
Nuclear fuel pellets currently used (mixed uranium and plutonium oxides)

Artist's view of the Jules Horowitz experimental reactor

The design and qualification of current and future nuclear fuels

Our research associates numerical simulation and experimentation for the purpose of:

- Elaborating physicals laws governing the behaviour of materials.
- Developing new fuel concepts for future nuclear systems.
- Testing the behaviour of fuels under irradiation.



Corium flow experiment for the mastery of accident situations

The evolution of nuclear technologies

Basically this involves defining, testing and qualifying reactor components for different nuclear systems.

These studies integrate the analysis of coolant fluid performances and the technological mastery of accident situations such as the meltdown of a reactor core.

Cadarache is also recognised for its expertise in the field of nuclear instrumentation applied to reactors and to the characterisation of waste packages, archaeological objects or the detection of explosive matter.

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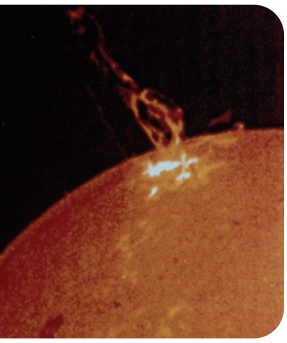
Nuclear Fusion



Eruptive protuberance
on the edge of the sun

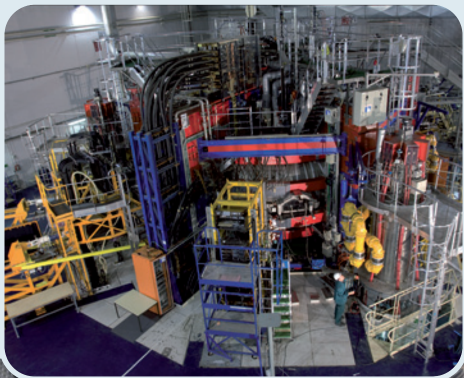
The aim of nuclear fusion is to produce the energy of the stars on earth. When matter reaches very high temperatures, as in the centre of the sun, hydrogen atoms fuse and release great amounts of energy. This is the fusion reaction that scientific researchers are attempting to reproduce on earth.

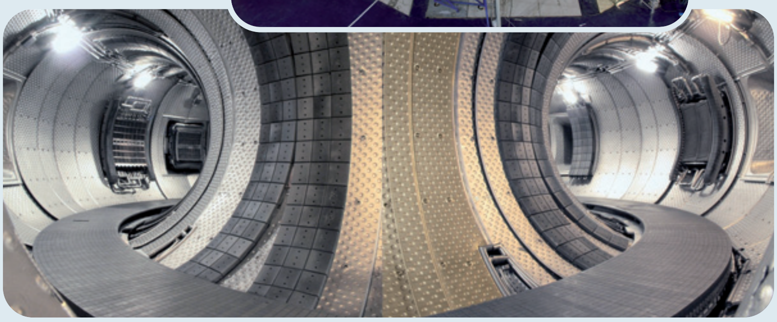
In order to achieve this, hydrogen must be heated and maintained at a temperature of about 150 million degrees, while keeping it at a distance from its surrounding walls. Gas at this temperature is ionised (plasma) and powerful magnets act as invisible rails thereby ensuring the containment: this is known as the tokamak configuration.

Research on fusion at Cadarache is currently being carried out in the TORE SUPRA facility, a supraconductor magnet tokamak. Beginning in 2019 further research will also be carried out in the international ITER reactor.

Since 1988, the date of its commissioning, the TORE SUPRA research facility is the largest supraconductor magnet tokamak in the world. It is supervised by the European association of EURATOM/CEA

Overall view
of TORE SUPRA





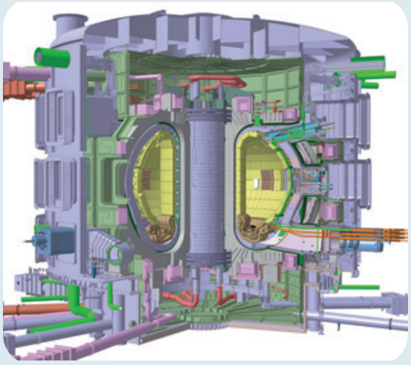
Toroïdal chamber of the TORE SUPRA
in which the plasma circulates during tests

Thanks to its innovative technologies, Tore Supra is now experimenting with long-lasting, high performance plasmas, an indispensable element in the programme aimed at the prospect of developing a fusion reactor.
Hotter, denser and longer lengths of time, such are the challenges facing the experimentation crews at TORE SUPRA.
The use of superconductor materials guarantees an almost uninterrupted operation of the magnet and enables Tore Supra to produce long-lasting plasmas.
Tore Supra has the means to heat the plasma by using microwaves for a total available power on the order of 15 MW. The inner wall of the tokamak is cooled on a permanent basis by a high pressure water circuit. Acting as a complement to this, a special device called the "circular limiter floor" removes the greater part of the power released by the plasma.

In 2003, the world record was reached by Tore Supra with a plasma gaining a pulse of more than six minutes in which energy on the order of 300 kWh. was injected and extracted.
Teams from Cadarache have also been involved in other European programmes especially the JET programme in the United Kingdom which in 1997 succeeded in establishing a world record of fusion power amounting to 16 MW produced within one second.

Since 2007, Cadarache teams have participated in many developments for ITER and in several Japanese projects within the framework of the "enlarged approach".

Set up just alongside the borders of the Cadarache Research Centre, the ITER project is one of the most important research programmes of the 21st century



The ITER "tokamak"

The 40-hectare platform was developed to accomodate the facility

Artist's view of the site: In the centre, the "tokamak" building

Working within the framework of a scientific collaboration that has no equivalent in history, China, the European Union, India, Japan, Korea, Russia and the United States intend to demonstrate the scientific and technological feasibility of fusion energy.
The mastery of fusion will guarantee mankind the access to a new source of inexhaustible energy both safe and practically without impact on the environment.

In June 2005, the ITER partners unanimously declared their preference for the site chosen by Europe: an area of 180 hectares, located in the Commune of Saint-Paul-lez-Durance (13) sharing its borders with the Cadarache Research Centre.
The proximity of the CEA-Cadarache Centre offers ITER resources that can be found in an exceptional environment of research and technological expertise.

ITER is a key stage in the history of research on fusion energy. The facility includes both the experience and technological developments accumulated by fusion programmes throughout the entire world, particularly the European JET Project in the United Kingdom, Tore-Supra (CEA-Euratom) in Cadarache, the JT-60 in Japan and even the TFTR and DIII-D in the United States.

ITER is a scientific experiment on a very high scale.

The objective of this facility is to produce, through the fusion of deuterium and tritium – two hydrogen isotopes – ten times more energy (500 MW) than it receives.

ITER will also test materials and certain systems destined for the forthcoming pre-industrial "demonstrator" DEMO as well as those designed for other future industrial fusion reactors.

ITER in a few figures

Plasma temperature	**150 million °C**	The temperature of the sun is 15,000,000 °C
Temperature of the supra-conducting coils	**4 K (-269°C)**	This is almost the temperature of the spatial void
Void chamber volume	**840 cubic metres**	The volume of the JET void chamber, the largest tokamak in the world is 100 cubic metres
Weight of the machine	**23,000 tons**	The weight of the Charles-de-Gaulle aircraft carrier is 28,000 tons
Weight of each of the 18 toroidal coils	**360 tons**	This represents the weight of a Boeing 747 with a full load of passengers and crew and its tanks filled to maximum fuel capacity
Height of the tokamak building	**57 metres**	The Arc de Triomphe in Paris is 50 metres high
Weight of the largest components delivered on site	**~850 tons**	Weight of the largest Airbus component < 100 tons

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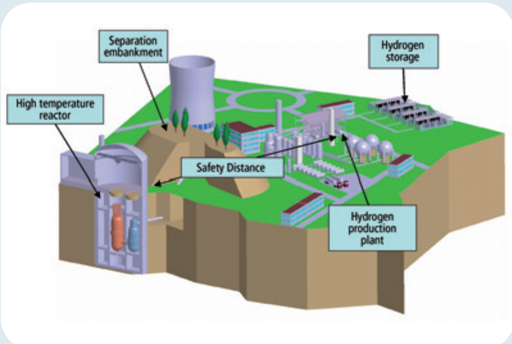
New Energy Technologies

The Cadarache Research Centre is involved in research on hydrogen, the production of synthetic fuels and solar energy.
This research specifically focuses on:

- **the mass production of hydrogen and mastery of its processes**
- **the demonstration of innovative applications of thermal and photovoltaic technologies.**

Moreover, Cadarache is now piloting the pre-industrial demonstrator project, Syndiese, for the 2nd generation biofuels production at Bure-Saudron (Meuse/Haute-Marne).

Hydrogen and synthetic fuels could serve as substitution energy vectors replacing oil within the next few decades.



An artist's view picturing the coupling of a nuclear reactor with a hydrogen production plant

Resources from the forest

At Cadarache, research is being carried out to produce hydrogen based on nuclear energy. Hydrogen production processes necessitate high temperatures that can be reached in the Fourth Generation nuclear reactors.
Technological studies are now underway in order to define and qualify components that in the future will enable us to retrieve and transfer heat produced by these reactors.

Biomass, a resource derived from the forest and agriculture:

The objective of the pre-industrial project, Syndiese, is to demonstrate the economic technical feasibility of a complete chain of 2nd generation biofuel production in France. This would begin with initial collection of biomass materials and cover all stages leading up to the final fuel synthesis. This production begins with local non-edible forest and agricultural resources. The introduction of hydrogen in the process, used to optimise the mass yield, is the first time in the world such an experiment has ever been made.

Demonstration of the innovative applications of solar and photovoltaic energies

Test on photovoltaic solar panels

In Cadarache, this test platform, using real sunlight, is one of the platforms of the National Solar Energy Institute (INES) which was set up in 2005 in Chambéry. A solar power equivalent to approximately 80 MWe will be installed by 2012, using over 120 hectares outside the enclosure of Cadarache. It will be known as the MEGASOL project. Several mini-thermal loops will supplement the experimental devices on the solar platform while more than 10,000 square metres of roofs on the Centre will be equipped with photovoltaic panels by 2011.


Environmental Biology and biotechnologies

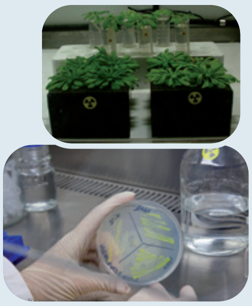
The major challenges facing biology researchers in Cadarache involve understanding the response of bacteria and plants to the environmental constraints, i.e. the metallic pollutants or the ionising radiation, and knowing how to profit from this knowledge by using biotechnological applications (bio/phyto-remediation of the soil or contaminated water, biodetectors…).
Furthermore, their work also consists in studying the energy metabolism of micro-algae in order to develop biofuel production strategies (bio-hydrogen or biodiesel).

This work is carried out within the framework of a mixed research unit combining the efforts of the CEA, the CNRS and the Mediterranean University. These researchers also work in interaction with the socio-economic infrastructures of the region (Competitiveness Centres such as CAPENERGIES, MER-PACA and EUROBIOMED) and industrial partners.


Measurement of gaseous exchanges on an Arabidopsis leaf

Adapting plants and bacteria to the environment

The study of response mechanisms to environmental constraints (drought, CO_2, irradiation, strong light, phosphate nutritive deficiency…).


Growth of plants and bacteria in the presence of radioactive elements

Toxicology in Plants and Bacteria

- The study of resistance and accumulation mechanisms to heavy metals (cadmium, uranium, arsenic, lead), pollutants and nano-particles in plants and bacteria.
- The study of molecular interactions between proteins and metals.
- The development of environmental bio-detectors and bio-depollution processes.


Research on micro algae with a capacity of modified hydrogen production

Bioenergy

- The study of solar energy conversion and storage mechanisms through the use of photosynthetic micro-organisms.
- Applications in bio-hydrogen and biodiesel production.


Crop enclosure for controlled conditions

Phytotechnology

- Perfecting measurement systems and plant cultures in controlled conditions.
- Isotopic marking (stable and radioactive isotopes).

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Safety - Security

Safety: an absolute priority

Any nuclear facility, beginning with its creation up to its decommissioning is placed under the control of the Nuclear Safety Authorities.
Fundamental principles of safety are integrated into its design:

- **Containment of all nuclear materials: successive barriers are set up between the materials and the environment,**
- **Analysis of the associated hazards due to the operation of the facility in both normal and accident situations,**
- **Specific means designed to avoid risks and to reduce the occurrence of any incidents and their possible impact.**

Each facility on the Centre is subject to strict procedures governing its operation. Internal and external monitoring is continually carried out as well as safety updates and improvements designed to deal with fire hazards and earthquakes.

Remote control of irradiated fuels confined in shielded chambers

Radioprotection of the personnel:

At each workstation, the radiological risks are identified and become the object of specific provisions in order to limit, monitor and control all employees' exposure level to ionising radiation.

All members of the personnel are required to undergo routine medical checkups throughout their entire careers. This health service is supervised by the occupational medicine team of the Cadarache Centre.

Guarded access to the site

Fleet of fire-fighting vehicles on the centre

Physical protection of the site

Controlled access to the Centre, road safety, fire prevention and the surveillance of high security zones are tasks assigned to the Security Services in Cadarache.

These teams, highly trained in fire-fighting techniques and in the patrolling of the Centre, are equipped with telesurveillance means. Their task is to intervene in any type of incident or accident: technological, radiological or chemical. They will also be called on to deal with any fires or any attempt at illegal entry on the Centre.

Decontamination of vehicles during an exercise

Accident Management

The Cadarache Centre has an Internal Emergency Plan (IEP). The director of the centre can launch this emergency plan as soon as any irregularity or abnormal occurrence jeopardising the safety of the personnel or facilities is detected. The IEP describes all safety procedures, rescue measures and means that must be implemented in such cases.

More than fifty safety drills are organised each year to train intervention teams.

If the consequences of an accident are likely to spread beyond the boundaries of the centre, a Specific Plan of Intervention (SPI) can be implemented.

Designed and developed by the Prefect of the Department of Les Bouches-du-Rhone and the Direction of the CEA Cadarache Centre, the prime consideration of the SPI is to inform the population, guarantee their safety and to facilitate any safety and rescue operations.

Organisations of Control governing the activities of the CEA Cadarache Research Centre

Internal	External	International
The Establishment Safety Cell	The Nuclear Safety Authority (ASN)	Euratom
The Security for Nuclear Materials Cell	The Regional Direction of the Environment, Land and Develoment and Housing (DREAL)	The International Atomic Energy Agency (IAEA)
	The Safety Authority of Defence Activities (ASND)	
	Senior Official of the Defence and Security Department (HFDS)	

Remote monitoring of the site

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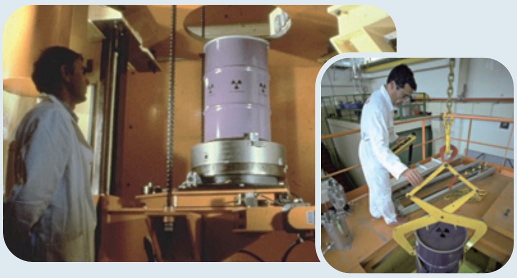
Impact on the Environment

In order to achieve the objectives of its research programmes, CEA Cadarache operates a number of nuclear facilities and research laboratories. The operation of these facilities produces waste and effluents. What becomes of them and their impact on the environment is the object of constant attention:

- Waste management: The major stages involved in the final disposal of this waste include its collection, transport, conditioning, storage and final transfer towards specifically designed storage sites.
- Cleaning and Dismantling of facilities: In Cadarache, several worksites have been launched to deal with the decommissioning of former research reactors and technological workshops.
- Environmental monitoring: Sampling, analyses, measurements and tests are carried out on a daily basis.

All liquid and solid radioactive waste is managed in conformance with rigourously explicit regulations governing its transport, treatment and final disposal



Control and weighing of nuclear waste drums

Collection and transport

The waste is conditioned and placed in special transport containers according to its specific classification.

Approximately 500 external and 1000 internal transport operations are carried out every year at the Cadarache Research Centre.

ROTONDE: the sorting and dispatching of low-level and very low-level waste packages

CEDRA: Interim storage of waste packages

New facilities designed for the treatment and conditioning of waste

Liquid waste undergoes a physico-chemical treatment. Solid waste is treated according to industrial decontamination, sorting, cutting and compacting processes. It is then embedded in cement and conditioned in steel or concrete canisters.

The solid waste treatment station handles one thousand cubic metres on a yearly basis and the effluent waste treatment station deals with a volume on the order of 650 m^3 per year.

After the completion of the new facilities, CEDRA, ROTONDE, AGATE (effluent treatment) and MAGENTA (material storehouses) a whole system of logistics in nuclear services will emerge relying on the latest technologies.

Radiological control on a low-level waste package

Wells for the storage of medium-level radioactive waste

The final disposal of waste packages

Each waste package is assigned a record sheet listing pertinent data that identifies its radiological and chemical content.

On the Centre, medium-level waste packages are stored in facilities specially designed for this purpose where they are closely monitored awaiting their removal to a nuclear repository.

Very low-level and low-level radioactive waste packages are transferred to the repositories of the French National Agency of Radioactive Waste Management (ANDRA).

Cleaning and dismantling of decommissioned nuclear facilities

The Plutonium technology facility undergoing dismantling operations

Decommissioned facilities of the CEA are subject to a national cleaning plan and/or dismantling procedure.

In Cadarache, our teams supervise several projects related to former research reactors or technological facilities.

Environmental monitoring

Laboratory analysis performed in the Service of Protection against Radiation

Sampling for radiological monitoring of the environment

Releases from each basic nuclear facility or any facility classified for the protection of the environment are subject to precise regulations set down by the Public Authorities.

Every day, a considerable number of air, water, soil and vegetal samples are taken and submitted to a series of analyses, measurements and controls enabling researchers to determine at any given moment and in all points the radiological state of the facilities, of the site and of its nearby environment.

In the environment, the radioactive activity induced by Cadarache is not detectable. The major results of these analyses can be consulted on the internet site of CEA, Cadarache.

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