Nuclear Fission

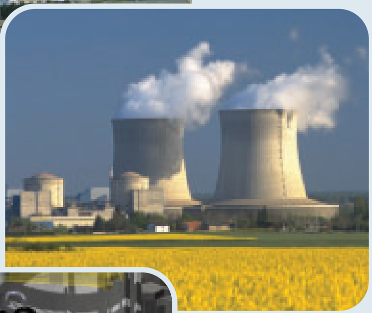
Energy is a key factor in economic, social and sanitary development

The rise in the world's population and the economic development of emerging nations within the next twenty years 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 energy and renewable energies.

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

Chinon: Generation I plant



Belleville: Generation II plant

EPR mockup: Generation III plant

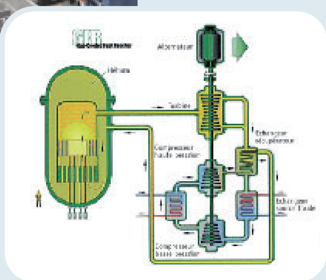


Diagram of a Generation IV plant

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 II 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 2011, the EPR (European Pressurised Reactor) termed, the Third Generation, will optimise the pressurised water reactor type and will be commissioned in Finland and afterwards in France.

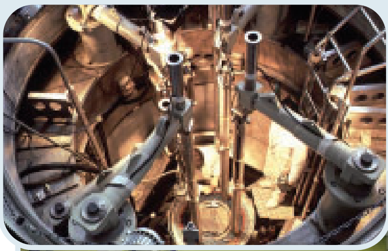
Within the framework of the International Generation IV Forum, six future reactor concepts are now under study and their purpose is to integrate the nuclear industry into a logic of long-term development.

These Fourth Generation reactors will be based on high performance, will be safer and will use natural resources up to fifty-times less thereby limiting the risk of proliferation and considerably reducing the amount of waste produced.

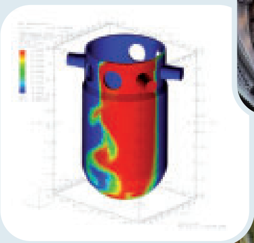
The CEA focuses its research primarily on fast reactor types that use sodium or gas as a coolant for the purpose of commissioning a prototype in France in 2020.

Research in the field of nuclear fission at Cadarache

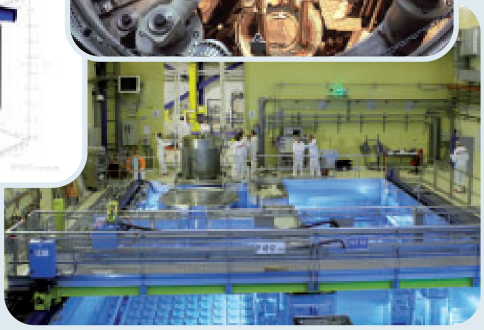
Since its creation in 1959, the Cadarache Research Centre has been one of the major contributors to the development of different nuclear reactor types. At present, it possesses competence and world-renowned facilities in the field of nuclear reactors, fuels and technologies.



The experimental reactor EOLE



Simulation of a water coolant within a PWR



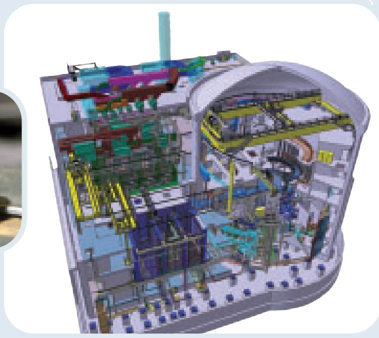
The RES pool reactor for naval propulsion

The nuclear reactors

The activities and competence of Cadarache concern:

- Reactor physics (neutronics and thermal-hydraulics) with the development of simulation computer codes whose qualification is carried out with experimental support, from test benches all the way up to the 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)



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 physical laws concerning the behaviour of materials,
- Developing new fuel concepts and fabricating experimental fuels 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 measurements applied to the characterisation of waste packages, archaeological objects or the detection of explosive matter.

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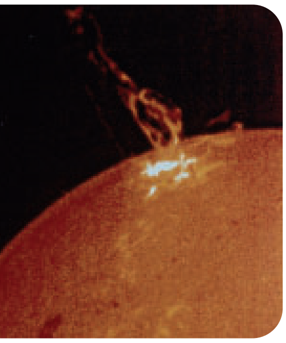
Nuclear Fusion

The aim of nuclear fusion is to produce the energy of the stars on earth.

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

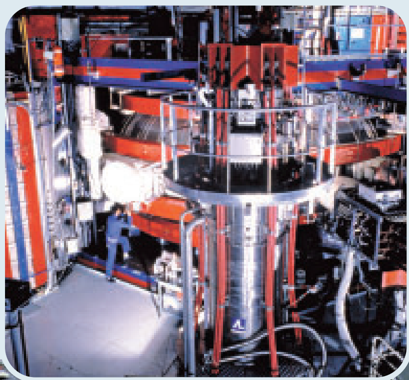
To accomplish this, temperatures at about 100 million degrees must be reached and maintained while isolating the matter in an ionised gas state (plasma) from the walls of the machine through the use of powerful magnets: this is the configuration of the tokamak.

Research on fusion at Cadarache is currently being carried out in the TORE SUPRA facility, a supraconductor magnet tokamak. Beginning in 2018, further research will also be carried out in the international ITER reactor.

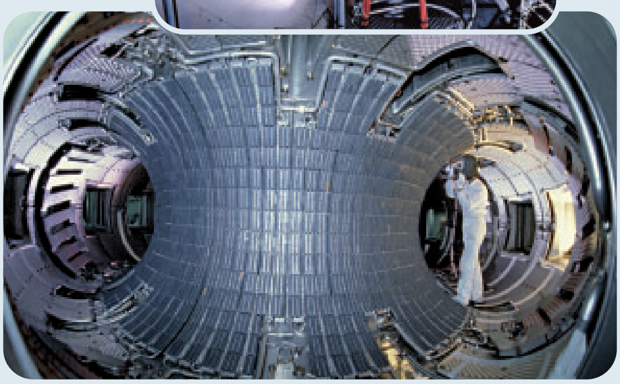


Eruptive protuberance on the edge of the sun

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

In this machine, confinement of the plasma is obtained through the superimposition of two magnetic fields that act as invisible rails guiding the particles. The constant, uninterrupted functioning of its magnet, associated with actively cooled components confers the capacity of TORE SUPRA to produce high performance plasma over long periods of time.

To achieve these scientific objectives, TORE SUPRA has a means of heating the plasma using microwaves for a total available power on the order of 15 MWth*.

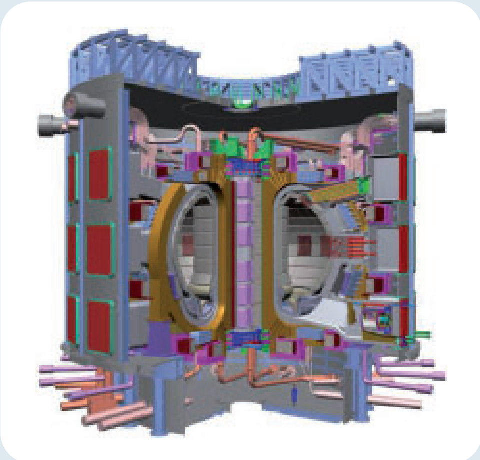
The internal wall of the tokamak is permanently cooled by a high-pressurised water circuit.

In addition to this, a specific device called the circular limiter, enables researchers to evacuate most of the power released by the plasma; this is what allowed TORE SUPRA to obtain a record plasma in 2003 with a pulse of more than six minutes during which time, energy on the order of 300 kWh was injected and extracted.

Teams from Cadarache have also been involved in programmes led by the JET tokamak project in the United Kingdom, which in 1997 succeeded in establishing a world record of 16 MW.

** MWth (thermal Mega Watt) unit measurement of thermal power (heat)*
MWe (electric Mega Watt) unit measurement of electrical power

With ITER, Cadarache prepares to welcome one of the most important research projects of the 21st century



The ITER research facility

In choosing to build ITER on the site of the Cadarache Research Centre, the partners of the ITER project will benefit from an exceptional environment of researchers and remarkable technological and scientific expertise.

ITER, constituting a key stage in the history of fusion research, will be the first research facility in the world to integrate technological developments perfected in Europe with the TORE SUPRA facility at Cadarache, at the JET facility in England and in the rest of the world with the JT-60 in Japan and the TFTR in the United States.
The goal of ITER is to demonstrate the feasibility of fusion as a potential source of energy.
Once this final stage of research has been completed, it will be up to the DEMO demonstrator to produce electricity in 2040.

Very high temperatures must be reached in ITER in order to create fusion reactions that resemble those existing in the centre of the sun. These temperatures allow deuterium and tritium atoms (hydrogen isotopes), introduced in a gaseous state in the core of the research reactor, to fuse. With ITER, the main objective is to obtain fusion reactions ten times greater (500 MW) than those obtained up to the present time (50 MW).
Equipment in ITER must also be tested for future industrial fusion reactors.

ITER is one of the most important international collaborations in the world. The project combines the efforts of China, the United States, Europe, the Russian Federation, India, Japan and the Republic of South Korea – more than half of the world's population.

Artist's view of the ITER site in the Cadarache forest

Boundary of the CEA Cadarache site

Research reactor, TORE SUPRA

ITER in a few figures (estimations)	Construction phase (10 years)	Operational phase (20 years)
Number of people directly employed by ITER	500 in Cadarache	1 000 at Cadarache i.e. 600 for operation and 400 scientists
Indirect or induced jobs	3 000 in France including 1 400 in the immediate PACA region	3 250 in France of which 2 400 will be in the PACA region
Estimated total amount of expenditures	180 million euros per year over a period of 10 years; 100 in the PACA region	165 million euros per year over a period of 20 years of which 135 will be spent in the PACA region

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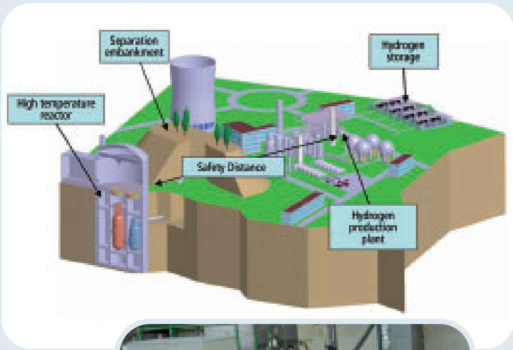
New Energy Technologies

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
- high temperature processes aimed at optimal utilization of the biomass for energy purposes
- photovoltaic component tests performed in real sunshine conditions.

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

BIOCARB pilot unit

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, is a source of renewable energy that does not produce Greenhouse gases. Potentially, it can be used to produce synthetic fuels that are compatible with standard motors. This research programme involves a thermal-chemical process implementing a gasification stage of the biomass at high temperature.

Tests performed on photovoltaic components in real sunshine conditions enable researchers to perform experiments necessitating a specific quantity of real sunlight

Test on photovoltaic solar panels

At Cadarache, solar energy research concentrates on habitat heating (components, integration into building plans) and on electricity production using photovoltaic modules (connections to the grid, isolated dwellings, pumping and water treatment…) These tests are intended to serve within a European or French framework or to provide services to industry. About a thousand photovoltaic modules are available on the site.

Tests carried out in real sunshine conditions at the Cadarache solar platform continue to contribute a technological support to the National Solar Energy Institute, established in Chambéry in 2005.

Vegetal Biology and Microbiology

The research carried out by biologists within the CEA at Cadarache relates to the comprehension of adaptation mechanisms existing in vegetal matter, micro algae and bacteria in highly varied environmental conditions (different types of pollution, ionising radiation, bright light, water shortage…).
This research specifically focuses on the study of energy molecule synthesis routes such as hydrogen or lipid reserves for the purpose of developing new bio carburant production processes.

Work in these fields of research is carried out in a close collaboration with:

- **The French National Centre of Scientific Research (CNRS) – Universities (particularly Aix-Marseille II)**
- **The French National Agronomy Research Institute (INRA) the Research and Development Institute (IRD)**
- **The French National Institute of Radioprotection and Nuclear Safety (IRSN), private companies…**

In-vitro plant culture for the study of photosynthesis

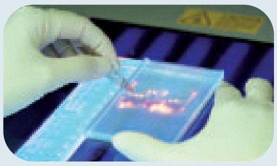
Adapting plants and bacteria to the environment

Study of protection and adaptation mechanisms.
Fundamental processes of photo mechanisms.

Bacterial attack of tributyl phosphate micella to study its biodegradation

Toxicology in plants and bacteria

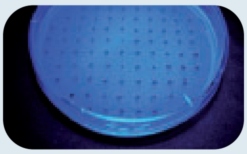
- Study of tolerance mechanisms to toxins, of adaptation and storage
- Study of root interactions – soil bacteria and toxic transfers (particularly heavy metals) in the soil, migrating towards plants.



DNA gel of plants to study irradiation effects

Radiobiology

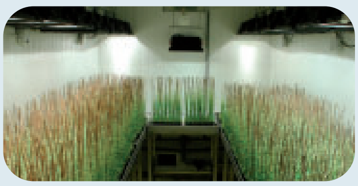
Study of the response of plants and bacteria to ionising radiation.



Research on micro algae with a capacity of modified hydrogen production

Bio-energy

Study of hydrogen production mechanisms or of lipid bio-carburant through micro algae.



Phytotrons for crops produced in controlled conditions

Phytotechnology

- Perfecting a system of measurements and plant cultures in controlled conditions
- Isotopic marking (stable or 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.**

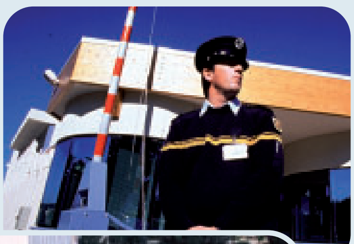
Each facility on the Centre is subject to strict procedures governing its operation. Internal and external monitoring is continually carried out as well as safety updates and improvements designed to deal with fire hazards and earthquakes.

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	Euratom
The Security for Nuclear Materials Cell	The Regional Direction of Industry, Research and Environment (DRIRE)	The International Atomic Energy Agency (IAEA)…
	The Safety Authority of Defence Activities (DSND)	

Remote monitoring of the site

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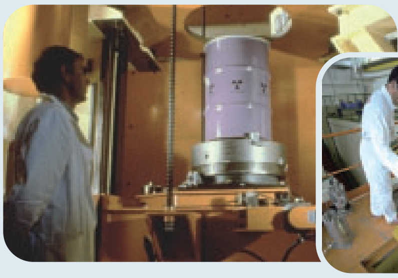
Impact on the environment

In order to achieve the objectives of its research programmes, CEA Cadarache operates a number of nuclear facilities. The waste produced from these reactors, its treatment and its impact on the environment is an 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 submitted to regular monitoring and is assigned a record sheet that identifies its radiological and chemical content.

On the Centre, medium-level radioactive waste is stored in facilities specifically designed for this purpose and it is systematically monitored.

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

Cleaning and dismantling of decommissioned nuclear facilities

Overall view of the RAPSODIE reactor now undergoing dismantling

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

In Cadarache, our teams supervise several worksites dealing with the shutdown of facilities and former technological workshops.

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.

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