OSIRIS

NUCLEAR REACTORS AND SERVICES DEPARTMENT

NUCLEAR ENERGY DIRECTORATE
DIVISION FOR NUCLEAR ACTIVITIES, SACLAY

NUCLEAR ENERGY AUTHORITY
SUB-DIVISION FOR NUCLEAR ACTIVITIES, SACLAY
NUCLEAR REACTORS AND SERVICES DEPARTMENT

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OSIRIS
[from the Greek for Us-yri “he who sites on the throne”, i.e. “the king”].

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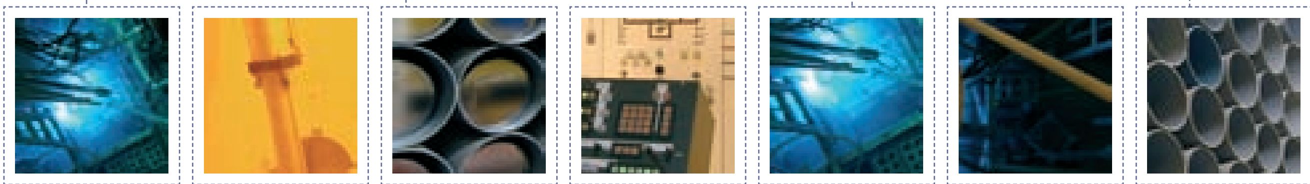
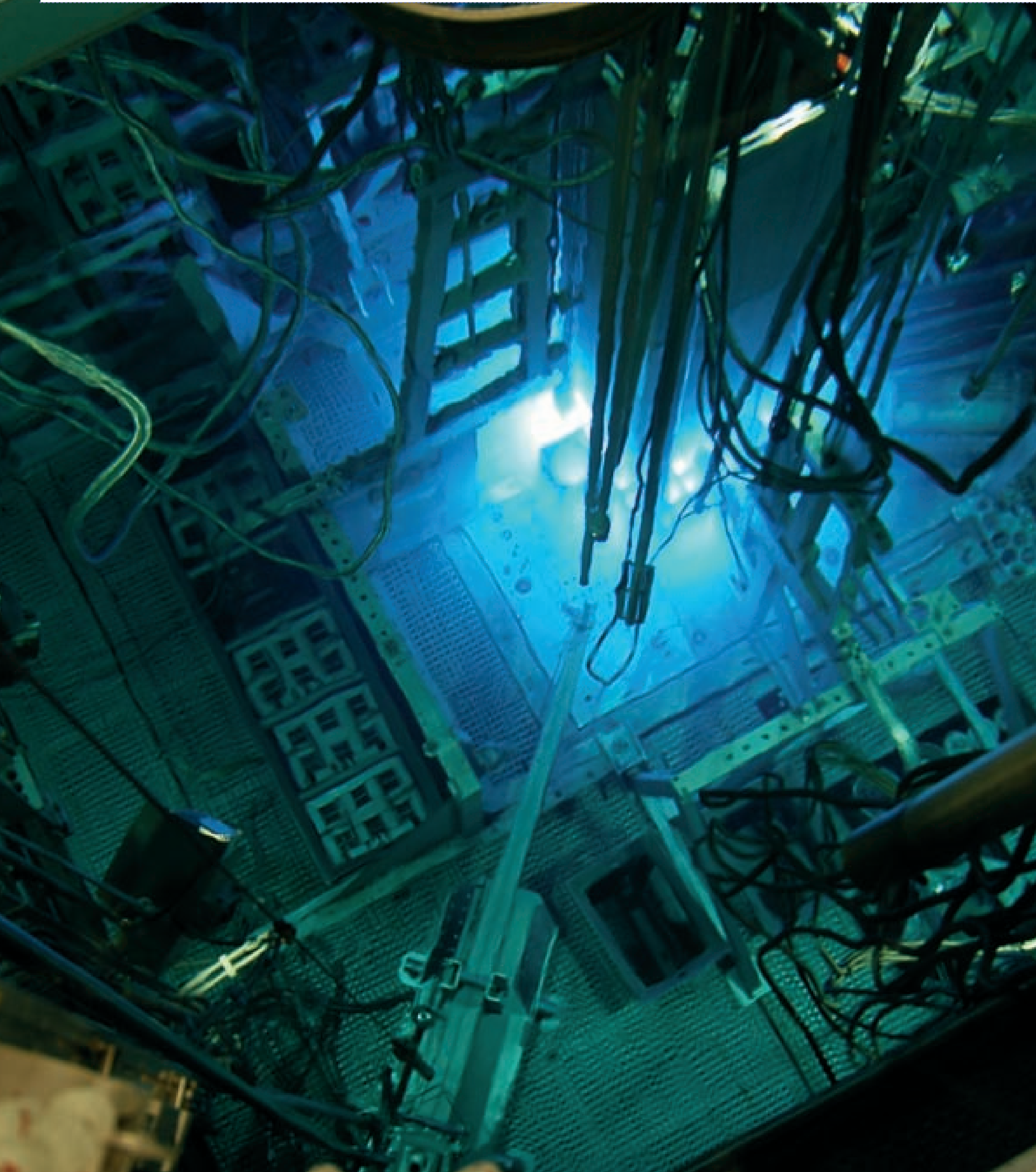
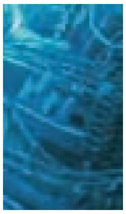




THE OSIRIS REACTOR




THE OSIRIS REACTOR

OSIRIS is an experimental reactor with a thermal power of 70 megawatts. It is a light-water reactor, open-core pool type, the principal aim of which is to carry out tests and irradiate the fuel elements and structural materials of nuclear power stations under a high flux of neutrons, and to produce radioisotopes.

Located within the French Atomic Energy Commission (CEA) centre at Saclay, it is close to many research teams and inspection laboratories and has a large-scale technological infrastructure.

The Saclay Centre is located a few kilometres south-west of Paris.

THE SACLAY CENTRE

The centre (certified ISO 14001) is one of the 9 research sites of the French Atomic Energy Commission (CEA). It is a top-ranking innovation and research centre at the European level. More than 5000 people work in the centre. t plays a major role in the regional economic development. The centre is multidisciplinary, with activities in fields such as nuclear energy, life sciences, material sciences, climatology and the environment, technological research and teaching.

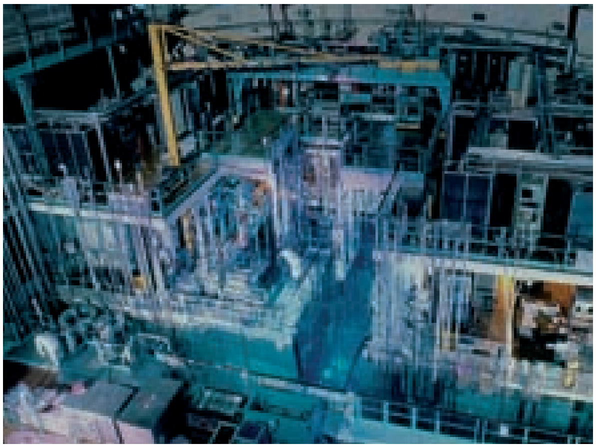
The OSIRIS Reactor.

Background

Innovative solutions were implemented as of the design phase of the reactor and the additional facilities required for its operation, in order to satisfy five essential criteria or requirements:

- high neutron performance characteristics,
- reliability,
- flexibility in use,
- quality of the services provided for users,
- ease of control.

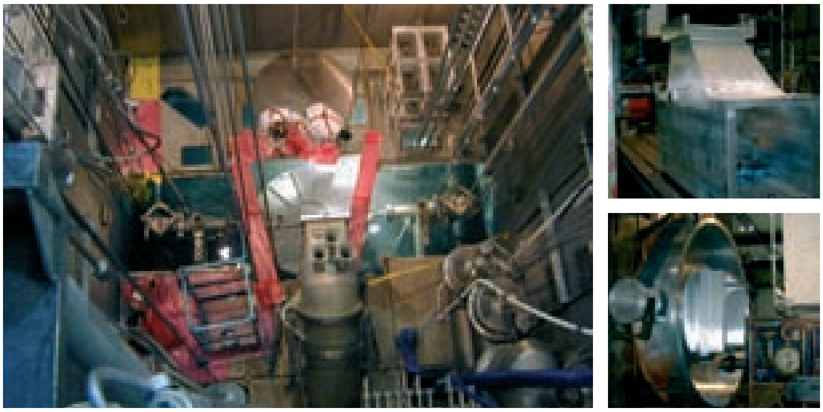
The design engineering for the reactor began in the 60’s. The decision to build OSIRIS and its ISIS neutron model was taken in March 1964 and initial civil engineering work began in June 1964. The criticality of ISIS took place on April 28, 1966 and that of OSIRIS on September 8 of the same year.



View of the reactor hall.

After two years of operation at 50 MW, the nominal thermal power of 70 MW was reached in 1968. From 1966 until the start of 1980, the reactor operated with an U-Al fuel enriched to 93% and from 1980 to 1994 with a UO_2 fuel enriched to 7%. The gradual conversion of the reactor to using U_3Si_2 Al fuel enriched to 19.75% began in January 1995 and was completed in April 1997.

An on-going refurbishment program has been established to avoid the ageing of the components in the flux and the obsolescence of the materials. The following major operations have been undertaken to maintain the degree of reliability and improve the safety level of the reactor: rebuilding of the effluent tanks and the de-activation tanks, the overhaul of the control/command system, the replacement of the core housing which maintains the fuel elements, and the replacement of the core vessel surrounding the fuel elements.



Refurbishing work on the reactor.

REPLACING THE CORE VESSEL

Major refurbishment work on the reactor took place in 2001-2002. It involved the replacement of the core vessel in particular and the installation of new elements of the steam supply system of the reactor, such as the core housing, the upper base and the water outlet casing.

Characteristics

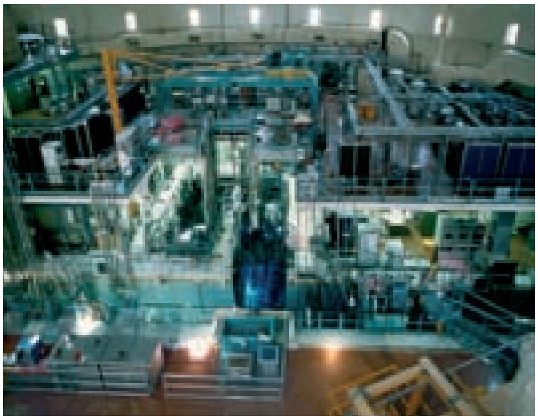
In order to maintain direct access to the core, the reactor does not comprise a pressurization vessel, resulting in a high level of flexibility for laying out experiments and handling operations. The fact that the configuration of the core can be changed also means considerable ease of experimentation from a neutronic point of view. The principal characteristics of OSIRIS are indicated below. The reactor functions on average 200 days a year, in cycles of varying lengths from 3 to 5 weeks. A shutdown of about 10 days between two cycles is necessary to reload the core with fuel, carry out light maintenance operations and the handling operations required for the experiments. More consequential maintenance operations are carried out during dedicated shutdowns of longer duration.

REACTOR
> Thermal power: **70 MW**
> Moderator: **H_2O**
> Reflector: **H_2O, Beryllium**
> Thermal neutron flux in the core: **$3\ 10^{18}$ neutrons.$m^{-2}.s^{-1}$**
> Fast neutron flux in the core (E > 0.1 MeV): **$4.5\ 10^{18}$ neutrons.$m^{-2}.s^{-1}$**

CORE
> Dimensions (m): **0.57 x 0.57 x 0.60**
> **38** fuel elements + **6** control elements (absorbent hafnium)
> Fuel: **U_3Si_2 Al enriched 19.75%**

COOLING
> Core inlet temperature: **38 °C**
> Core outlet temperature: **47 °C**
> Pool temperature: **35 °C**
> Primary core flow rate: **5600 $m^3.h^{-1}$** (ascending direction of circulation)
> Pool flow rate: **500 $m^3.h^{-1}$** (downward direction of circulation)

The reactor hall.



Reliability

Reliability comprises two main, complementary issues. The first issue consists in ensuring an operating rate compatible with the conditions as defined in order to avoid any dangerous situation.
To do so, there are:
- override automation obtained by interlocking to prevent any operation incompatible with authorized conditions,
- safety operations resulting in emergency shutdowns in the event of abnormal changes in the parameters representative of the operating rate. Each safety operation is carried out using redundant devices that are regularly tested for correct operation.

The second safety issue consists in taking all the measures to limit the consequences of an incident, based on permanent self-protection devices rather than automatic starting devices.
The most important should be noted:
- to mitigate any accidental cooling shortage, the circulation pumps of the core and pool primary circuits are fitted with fly-wheels dimensioned to ensure flow rates compatible with the after-power levels of the reactor to be evacuated until the switchover to natural convection takes place,
- the components of the primary circuit are all installed in concrete compartments with individual capacities such that in the event of accidental communication with the reactor pool, the water level in the latter cannot descend below the level - 4.5 m and thus cannot drain the core.

Flexibility in use

OSIRIS is a multi-purpose reactor, used for:
- technological irradiation for the purposes of the nuclear power industry or those of fundamental research,
- production of radioelements and doped silicon,
- analysis by activation.

The basic principle of design of an open-core, pool-type of reactor enables direct access to the core, facilitated by the absence of any pressurization vessel.

Furthermore, the location of the rod mechanisms under the reactor pool ensures they are completely free of any irradiation. To create dynamic pressurization, an ascending direction of circulation has been adopted for the fuel cooling water inside the core.
The thick walls of the side vessel avoid any need for interior bulkheads to resist pressure. Furthermore, these walls act as a screen against gamma radiation for any experimental devices placed outside the vessel.
The direct visibility and accessibility of the core make the handling operations involving fuel elements and experimental devices (loading, unloading and permutations) extremely easy, avoid positioning errors and facilitate observations and control.
The core housing comprises 56 slots, 44 of which are occupied by fuel elements, 5 by experimental devices and 7 by reflector elements made of beryllium.
On the periphery of the core, on 3 sides of the vessel, three lattices are installed to trap irradiation in the reflector. Researchers thus have a wide choice of positions with varied flux levels of fast and thermal neutrons.
The lattices have been provided for irradiation experiments of long PWR fuel elements (up to 2 meters) extracted from assemblies from nuclear reactors.
Displacement systems can be used to adjust the position of the experimental device in relation to the core, to precisely adjust the irradiation conditions and to vary power (cycling, ramp testing), and thus represent the normal or incidental operating conditions in nuclear power stations. In addition, these displacement systems have been designed to load and unload the experimental devices, with the reactor in operation.

CERENKOV effect
around the core vessel.

Service quality

Scheduled and mandatory downtimes are limited, thanks to:

- the use of the ISIS reactor: a neutron model of the OSIRIS reactor, operating on request, with a maximum power of 700 kW, to carry out:
    - Neutron studies,
    - Check the calculated loading configurations,
    - Establish the flux maps,
    - Dosimetries,
    - Instruction for trainees in reactor physics.
- strict definition of the templates for the experimental devices, in order to organize the loading, unloading and transfer systems and reduce handling times to the minimum.

Two electric generators driven by diesel engines with automatic recovery are used to ensure the operation of the reactor at full power, in the event of failure of the normal power supply (EDF mains).

Service quality for users is also related to the facilities and installations placed at their disposal:
plenty of space around the reactor pool, five different levels in the reactor container and one level in the crown gallery, outside the container, to accommodate the land-based circuits for the experimental devices.

- An evacuation and distribution network for all the usual fluids (normal power supply, uninterruptible standby power supply, uninterruptible power supply, water, evacuation of active liquid or gas effluents etc.)
- a service during irradiation, provided 24 hours a day by specialists in installation, as well as an information processing system for the follow-up, storage and processing of data.
- a service after irradiation including:
    - 2 hot cells connected, by a channel, with the OSIRIS and ISIS reactor cavities
    - equipment for non-destructive testing, before, during and after irradiation.

Ease of control

A control and command system that is both combined and prioritised facilitates the overall monitoring of the installation, reduces the displacements of operating staff, and selectively draws their attention to the essential indications in order to increase the speed of interventions when necessary.

Furthermore, OSIRIS is equipped with a Centralized Information processing system (IPC) to facilitate control.

Buildings

The OSIRIS complex primarily comprises the controlled leakage container in the centre of which are located the reactor pool and the additional buildings mainly housing the 2 hot cells and ISIS reactor.

The reactor building is a cylindrical shape with the following main dimensions: internal diameter 32 m, external height 21 m, total volume of the container 20,000 m^3.

It has a dual purpose:

- to provide protection for the reactor, its auxiliary systems and the experimental equipment,
- to provide total containment, in relation to the outside, of all the radioactive products liable to be released in the event of a nuclear accident, before filtration and their discharge.

The general installation of the OSIRIS and ISIS reactor cavities, channels and buildings has been designed:

- to make it impossible to drain the pool below -4.5 meters, thereby leaving 4 meters above the core, which is a sufficient height to ensure biological shielding,
- to directly and easily transfer underwater new or irradiated fuel elements and experimental devices between OSIRIS, the hot cells and/or ISIS,
- to ensure direct communication with the Hot Cell room by a special airlock above the connection channel, as well as an airlock for personnel and an airlock for equipment.

Reactor pool

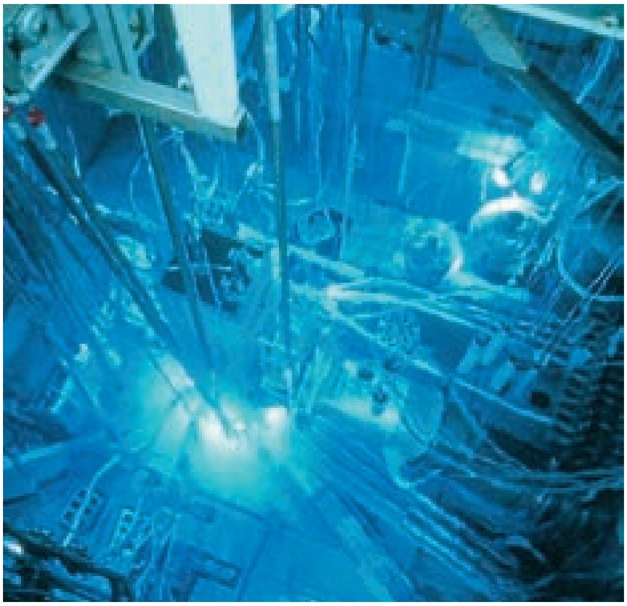
The reactor pool is 11 m deep, 7.5 m long and 6.5 m wide. On its southern face, it has a cavity 5 m high, to accommodate a gate, in order to isolate the reactor pool from the channel.

Core unit

The pool contains the core unit with its supply pipes as well as the mechanisms to ensure the positioning of the measuring chambers of the command and control system.
The control rods are controlled by mechanisms installed in a room located under the cavity (level -15 m). The core unit consists of a stack of four casings used to channel cooling water:

- the **base** enables the inlet of water into the base of the core and the homogeneity of reactor speeds. It also supports the lattices installed around the core and on which the experiments can be placed,
- the core **vessel** contains a rack with 56 cells, that are used to position fuel elements, the reflectors, the controls and the experimental devices placed inside the core,
- the water outlet **casing** comprises a side pipe through which the cooling water leaves the core,
- the **chimney** limits the mixture between water leaving the core and the water in the reactor pool. It contains a lattice on which removable stoppers can be placed in order to reduce the cross-section of the flow of water from the pool.

Instrumentation near the reactor vessel.



The core vessel with its rectangular cross-section is made of zircaloy 40 mm thick. All the items placed in the core (fuel elements, control units, reflectors, experimental water tanks) are linked at their lower part by a rod crossing the bottom of the reactor pool. Locking is done by simple rotation, controlled from the machine room.
An additional safety system is provided for the fuel elements: it consists of a locking system at the upper part in the core housing. The control rod mechanism ensures the displacement of a unit consisting a fuel element, an absorbent (hafnium) and a counterweight.

Fuel

Model of a fuel element of the standard type.

The core of the OSIRIS reactor is loaded with:

- 38 standard fuel elements with plates,
- 6 control elements,
- 7 reflectors made of beryllium (located on the southern face of the core) some of which can receive irradiations in a central hole.

At the end of each cycle, approximately one element out of six is unloaded to be replaced by a new fuel element.

OSIRIS uses a fuel made with alloy U_3Si_2 Al, known as silicide. This fuel elements consist of 22 plates, each plate being made of alloy U_3Si_2 Al, 0.51 mm thick, with an aluminium sheath 0.38 mm thick. The thickness of the coolant channel is 2.46 mm.
The uranium is enriched to 19.75% with isotope 235. The two edge plates contain boron (a burnable neutron poison) to comply with the regulatory safety margins to control the reactivity available at the beginning of cycle. It is thus possible to have long operating cycles (4 to 5 weeks). Each control element comprises 17 plates of a constitution identical to that of the standard elements. The thickness of a coolant channel is of 2.79 mm.

Control

Six control rods are necessary to ensure the control of core configurations. Two rods, known as the safety rods, ensure the emergency shutdown of the reactor should the threshold of a safety parameter be crossed, or when ordered by the operator. The four other rods are used one after another as shim rods for the poisoning caused by the fission products and at the same time as fine control rods. Only one control rod can be installed at any time.

Control-command principle

The control-command system has been organised with a constant concern for simplicity and separation of functions.

The control systems are combined in two rooms:

- the control room with a mimic panel, display consoles and a control panel, which respectively provide:
    - an exhaustive view of all the parameters required for the control and safety of the reactor and its auxiliary systems,
    - remote control of the main active bodies of the installation.

- the operations room with:
    - all the other equipment (electronics for nuclear and thermodynamic measurements, safety circuits, radiation protection electronics),
    - the data processing system.

The data processing system is of significant help in control, but does not interact with the safety systems.
The command-control system uses digital techniques (programmable controllers) to manage the safety circuits, the control system, nuclear measurements and part of thermodynamic measurements described below.

Measurements

▶ Nuclear measurements

The nuclear measurements for the control and monitoring of the reactor comprise:

- 3 starting chains (low level), which ensure the follow-up and control of the divergence of the reactor from the source value until intermediate power of 1 MW,
- 3 safety chains (high level) that take over the starting chain to control the power build-up to nominal value (70 MW) and to limit power to 10% above this value,
- a control channel that generates commands for the fine control rod.

▶ Thermohydraulic measurements

In addition to traditional measurements on various circuits, the primary coolant circuit of the core is supervised by 3 differential pressure pick-ups and 3 water temperature sensors at the inlet and the outlet of the core. Control at the nominal power output can be corrected using the measurement of activity of nitrogen 16, which is periodically readjusted in relation to the heat balance.

▶ Measurements of nuclear ventilation

Three pressure pick-ups monitor the vacuum pressure of the containment building (3rd barrier) to ensure it is leak-proof with respect to the environment.

Safety system

The main rules that are applied in the design of the safety circuits are as follows:

▶ Single failure criterion

The safety system is designed so that a single failure and its possible consequences do not mean the system is incapable of fulfilling its function. This criterion is satisfied by implementing 3 redundant channels and duplicating the emergency shutdown systems of the reactor.

▶ Independence criterion

Items of safety system equipment are separate and physically insulated from each other. They are also separated and isolated from the control system.

▶ Operating tests

The safety system is designed so that its capacity to develop the orders for protection operations (anomalies, emergency shutdowns) can be checked:

- on the one hand, by a permanent control of correct operation (self-checking),
- in addition, by periodic tests, with the reactor shut down.

Control system

The control system is based on the use of 2 programmable controllers.
One of the controllers acquires and processes all the data to control the reactor from the point of view of safety and a comfort.

Reactor control room.

The other controller acquires and processes:

- the information required to monitor the main auxiliary systems of the reactor,
- the parameters strictly necessary for manual control of the reactor that is safe but less comfortable.

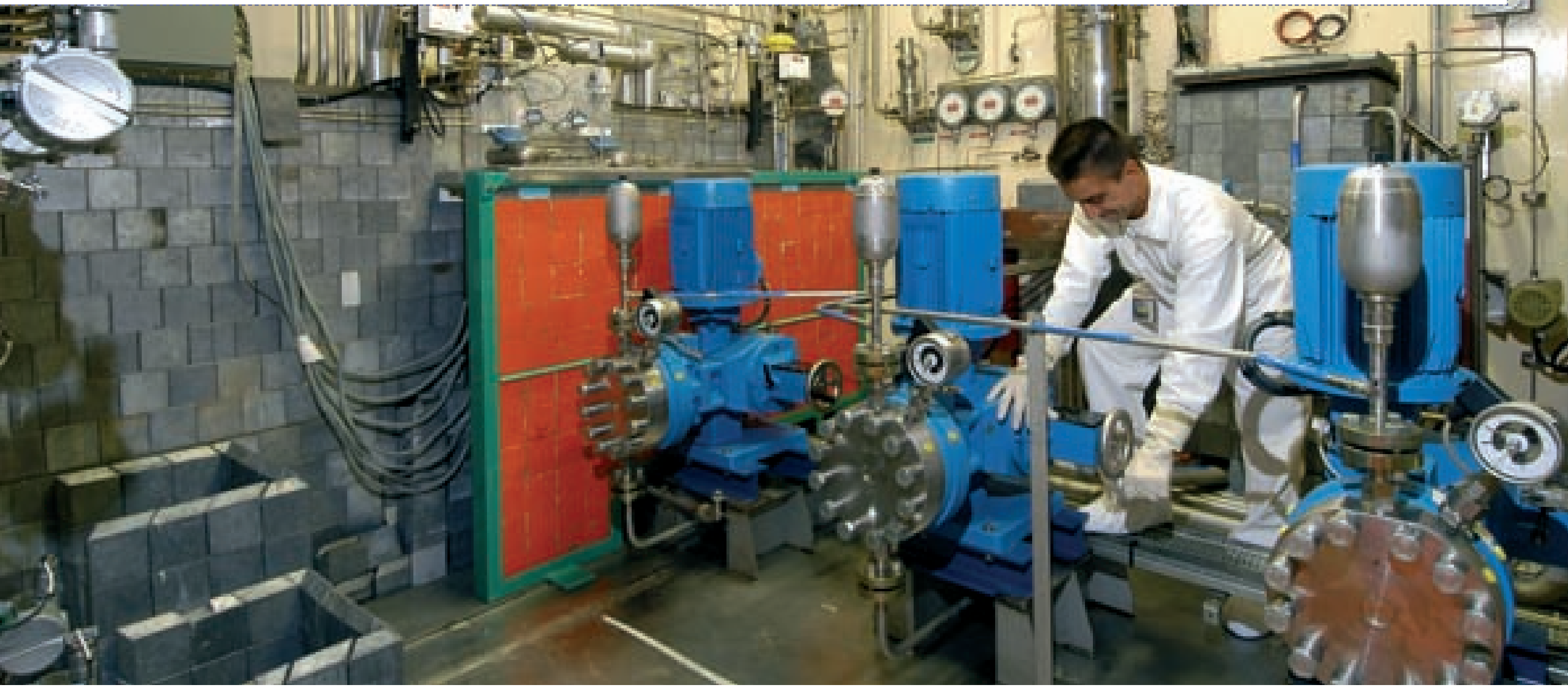
This organization ensures continuity of operation in the event of failure of one of the two controllers.

A central calculator connected by network to the safety and control controllers, collects all their output and processes the data off-line. The central calculator is connected to a high-speed data acquisition centre, which is used to supervise 12 analog channels with a sampling period of 10^{-2} s and 256 logical channels (including the logic on-off channels) with a resolution of 3.10^{-3} s.

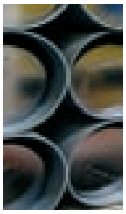
Radiation protection

Because of the risks present in the facility, the measures taken to protect against radiation relate in particular to the detection of external beta and gamma irradiation, and atmospheric contamination by radioactive dust or gases.
A network of detectors is used to supervise the buildings where such risks exist.
Each measurement is processed individually by a processing unit that develops the physical value that can be exploited direct. This calculator is connected to a polychrome display unit located in the control room, which provides a map of the level of activity of all the buildings supervised. These buildings contain signal boxes equipped with sound and light alarms for the various radiation protection thresholds, providing the technicians present with precise information about the action to be taken.

To supplement the information of the control team and help it in monitoring, a mimic panel shows the state of all the sensors and a series of multichannel records is used to continuously monitor the activity of certain areas according to the operator's wishes.



IRRADIATION POSITIONS AND EXPERIMENTAL CONDITIONS




IRRADIATION POSITIONS AND EXPERIMENTAL CONDITIONS

The core of the reactor can house up to 16 experimental devices in 4 positions where the fast neutron flux (E > 1 MeV) ranges from 1 to 2. 10^{18} n.m^{-2} s^{-1}. Structures are also provided outside the core, on 3 faces of the vessel, making it possible to install up to 27 experimental devices on the first periphery, where the maximum fast neutron flux is 10 times weaker than in the core, and many others on the second and third peripheries.

Core position geometry

Each of the four experimental positions in the core contains a water box 8.27 cm square. These water boxes can house and maintain the experimental devices in the core. Several types of water box are available as shown in the diagram below. This means various sizes of devices can be housed.

Various geometric configurations can be chosen:

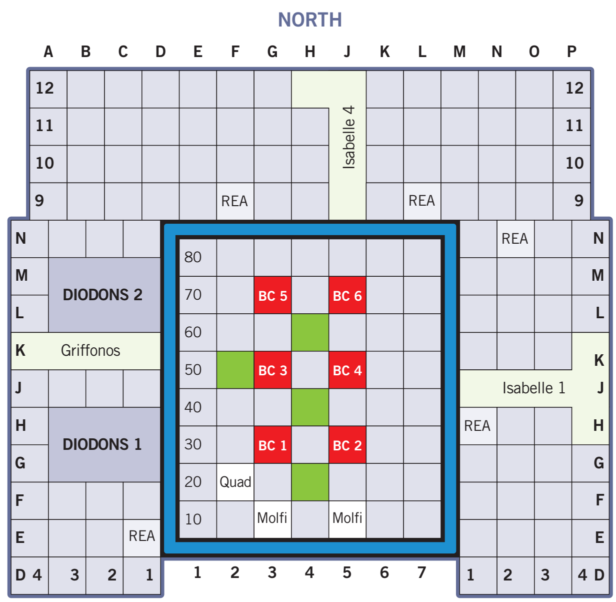
- 4 holes with a diameter of 37 mm
- 2 holes with a diameter of 44.5 mm and 2 holes with a diameter of 28 mm
- 1 hole with a diameter of 44.5 mm and 2 holes with a diameter of 37 mm
- 1 hole with a diameter of 76.6 mm.

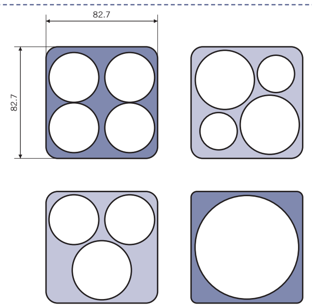
The diameters of the devices are slightly smaller to maintain a water gap.

Neutron flux

Basic information about the neutron flux throughout the core is provided by the neutron calculations required for its operation and management. In order to qualify and supplement these calculations, measurements are made in the considered position using techniques suited to the type of flux measured (fast flux and heat flux).

The figure below schematically represents the core of the reactor in its vessel (shown in blue) the control rods in red, and the experimental positions of the core (in green).





Several types of water boxes are available.

Thermal flux

To measure the thermal neutron flux, three special techniques are used:
- activation detectors known as “resonant” giving an absolute but off-line measurement,
- collectrons which output an electrical current proportional to the flux,
- fission chambers for measurement in real time.

The maximum value recorded in the middle of the side on the 1st periphery of the reactor is close to 3.10^{18} $n.m^{-2}.s^{-1}$. That in experimental position 64 is approximately 2.10^{18} $n.m^{-2}.s^{-1}$.

Fast flux

The flux of fast neutrons is measured by activation detectors with a response in a certain range of energy characterized by a threshold value. The highest fast flux in the core is present in the experimental position 64 and its value is $2.2.10^{18}$ $n.m^{-2}.s^{-1}$. This is used to reach damage rates of about 7 displacements per atom (dpa) per year for certain materials.

Gamma heating

Samples irradiated in the core of the reactor or its vicinity are subjected to the flux of gamma radiation, which looses part of its energy through interaction with the matter met. The energy lost is transformed into heat, causing a rise in temperature of the samples. This phenomenon depends on the materials present in the samples and the intensity of the radiation to which they are subjected. This parameter is of primary importance because it defines the input datum for the temperature control of the samples during irradiation. For the safety criteria, it also influences the temperature reached in the various structures of the experimental device housing the experimental load. Gamma heating is the parameter that quantifies this effect and is expressed in $W.g^{-1}$ of graphite for each experimental position in the reactor. Based on this reference value, we can calculate the heating in all other materials using suitable conversion factors. Gamma heating is measured with differential calorimeters with graphite samples.

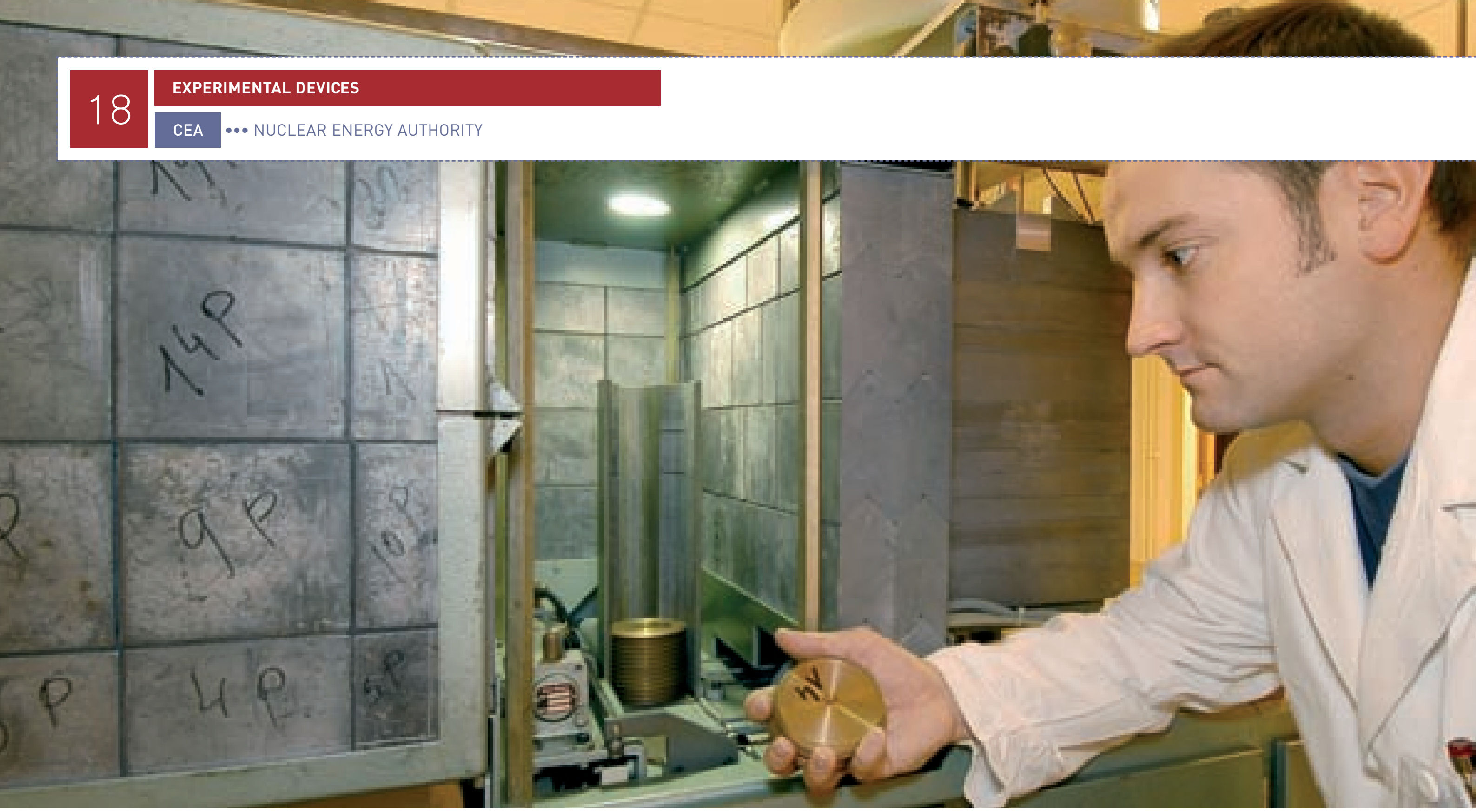
The maximum value of gamma heating reached in the core position is 13 $W.g^{-1}$ whereas it always remains lower than 2 $W.g^{-1}$ on the periphery of the core.

Mobile calorimetry

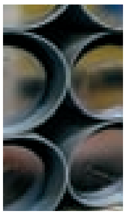
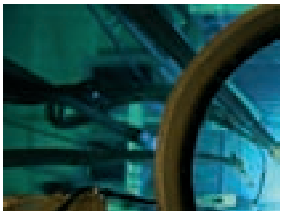
Determining the nuclear heating in irradiation positions is done by calorimetry, i.e. by measuring the rise in temperature of a sample placed in the radiation field.

Calorimeters are generally used in static fashion, and only for heating measurements in certain points distributed over the height of the reactor core. The advantages of a mobile calorimetry system compared with a fixed installation are:
- *it is possible to obtain a continuous axial distribution of heating instead of a specific distribution,*
- *it enables access to measurements in the upper par of the core, where the levels of heating still remain high,*
- *it reduces the irradiation fatigue of the transmitter, with a measurement crew that only remains under the flux for the time required to examine the transmitter,*
- *it provides a tool that simultaneously measures the fast neutron flux using the fission chambers and nuclear heating, in order to precisely evaluate the share of neutron heating in the overall heating measured at the irradiation positions.*

The measurement system used is a calorimeter of the differential type. It is used to provide an approximate measurement in absolute terms of the nuclear heating and, in addition, only requires a simple calibration procedure. A mechanical system ensures the vertical displacement of the measuring cell in the device.



EXPERIMENTAL DEVICES

Technological irradiations carried out in experimental reactors are used on the one hand to meet the industrial needs of the present fleet of power stations as well as for the developement and support to that fleet, and on the other hand to meet the needs of new types of reactors satisfying the broad objectives of sustainable development and reconciling reliability, economy, safety and ecology. One of the principal advantages of experimental reactors is to be able to carry out experiments up to limits that could not be achieved in a power reactor since instrumented irradiation can be produced by adjusting experimental parameters such as temperature and neutron flux.

The issues at stake

The industrial stakes in the short and medium term consist in ensuring the operation of the current installed base and improving its performance characteristics. In the longer term, the stake lies in the development of new types of reactors.

OPERATION OF THE CURRENT INSTALLED BASE

To ensure the operation of the installed base of reactors and to improve their competitiveness under optimum conditions, the industry must:

- *optimise the performance characteristics of fuels and their consumption,*
- *evaluate the increase in the service life of power stations,*
- *anticipate the requests from the safety authorities.*

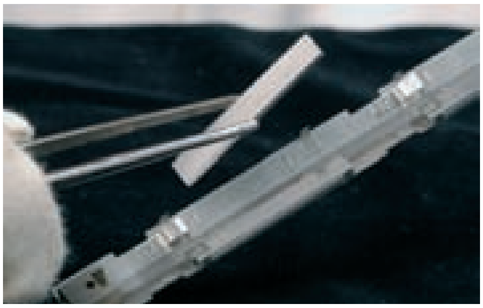
Preparing an experimental device.

Issues	Requirements in research and development programmes (R&D)
Optimisation of fuel performance characteristics	• *Behaviour of fuels during power transients* • *Behaviour of fuels with high burnup rates: core temperature, clad deformation, fission gases release, densification, clad corrosion* • *Qualification and characterization of new fuels* • *Development of clad alloys optimised in relation to the mechanical behaviour and corrosion resistance*
Increase the service life of power stations	• *Behaviour of the assembly and internal structures: corrosion, growth, creep kinetics* • *Behaviour of vessel materials and internal assemblies for lengthened operations: changes in the mechanical properties of vessel steels, corrosion resistance*
Safety	• *Reaction of fuels in incidental situation* • *Behaviour of materials in specific areas (welding etc.)* • *Determination of fuel residual power*

The development of the new reactor types

Apart from the broad objectives to which the new families of reactors will reply, and in particular those retained for the Generation IV program, the principal issues at stake relate equally as well to the operation of the core and the fuels as to the behaviour of the structural materials used.
R&D requirements therefore involve studies on the behaviour of fuels and their technological limits, as well as the qualification of structural materials in the conditions required by these new types of reactors.
The irradiation programs associated with these needs must be designed so that they enable access to the important parameters and are representative of both the phenomena and the conditions encountered in power reactors.

Loading a sample-holder.



Irradiation devices can be classified into 3 categories:

- Capsules designed to irradiate materials under conditions similar to those of water reactors. In these devices (CHOUCA and IRMA) the coolant is static. These capsules exist in various types:
  - Passive capsules in which only the temperature is controlled and measurements of the neutron flux and the temperature are made. These capsules are used for the accumulation of fluence on materials.
  - Capsules in which, in addition to the capacities of the preceding family, the samples are subjected to stress or strain under irradiation.
  - metrology capsules, which are used to measure the dimensional changes of the samples in situ.
- The PHAETON capsules designed to irradiate materials and fuels under conditions similar to those in high temperature reactors for the new families of reactor.
- Loops reproducing the thermohydraulic, neutronic and chemical conditions encountered in power reactors (loops GRIFFONOS and ISABELLE).

In addition of these 3 families of devices, there are 2 other more specific devices; MERCI and IRIS.

CHOUCA

The CHOUCA system is a device dedicated to the irradiation of materials in the core or on the periphery of the reactor. This device, when placed in the core of the reactor, cannot be introduced or withdrawn when the reactor is in operation.
It consists of 2 concentric tubes delimiting a gas gap, which is used:

- to adjust the temperature inside the internal tube depending on the position and the sample load by modifying the nature of the gas it contains,
- to control the leak from either one of the tubes ensuring the containment of the samples.

Electric heating elements are placed on the internal tube, quenched by a spray of metal particles gauged by further finishing. This heating method ensures fine control of the temperature of the samples throughout the irradiation by responding instantaneously to variations in heating from the reactor.
Sample-holders are inserted inside the capsule to house the samples specific to each type of experiment, such as:

- irradiation of acquisition of fluence at controlled temperature,
- irradiation of samples placed under stress,
- irradiation of samples under stress with dimensional follow-up during irradiation.

The experiments carried out in CHOUCA systems typically relate to:

- fuel cladding materials,
- materials for the internal structures of various types of reactors,
- neutron-absorbing materials.

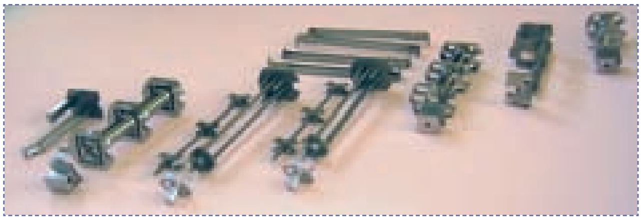
The principal characteristics of this device are:

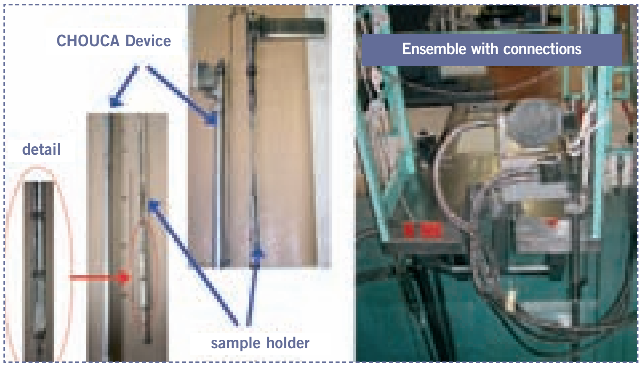
- *Effective diameter:* 24 to 30 mm
- *Height under flux:* 600 mm
- *Fast neutron flux (E > 1 MeV):* up to 2.10^{18} $n.m^{-2}.s^{-1}$
- *Acceptable gamma heating:* up to 13 $W.g^{-1}$
- *Medium:* NaK
- *Usual operating temperatures:* 250 to 400 °C, adjusted to ± 5 °C

Instrumentation:

- 12 thermocouples on the CHOUCA and 18 on the sample-holders,
- activation foils for dosimetry to access the neutron fluence received by the samples,
- pressure pick-ups and measurement of the clad diameter for certain specific experiments.

Barrels for the GONDOLE sample-holder.



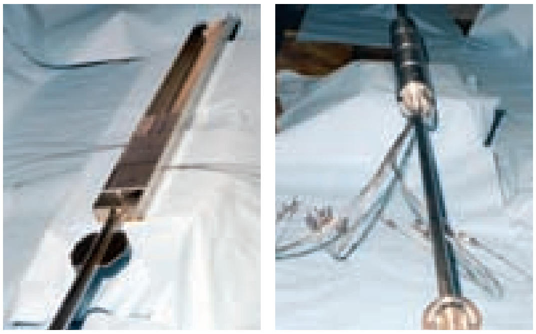


CHOUCA device.

IRMA

IRMA is a capsule designed for the irradiation, in an inert environment, of structural materials and more particularly, the steels used in pressurized water reactors.

An IRMA sample-holder (lower and upper sections).



In the field of vessel steels, this device is used for example:

- to characterize the effects of temperature and dose,
- evaluate the toughness of areas thermically affected by welding operations,
- study the influence of the neutron spectrum on embrittlement,
- study the influence of annealing on the ductile/brittle transition temperature.

Situated on the periphery of the core, this device can be used for irradiation or withdrawn without stopping the reactor.
Just like the CHOUCA, it comprises a double jacket constituting a heat shield, heating elements distributed all along the capsule and a sample-holder suited to the experimental load.

The principal characteristics of this device are:

- *Effective loading volume:* 700 cm^3 i.e. a cross-section of 6.2 x 2.5 cm^2 over a height of 45 cm
- *Neutron flux (E > 1 MeV):* up to 5.10^{16} $n.m^{-2}.s^{-1}$
- *Gamma heating:* lower than 0.5 $W.g^{-1}$
- *Temperature:* 250 to 320°C, adjusted to ± 6 °C
- *Medium:* inert gas

Instrumentation:

- 18 thermocouples distributed over the length of the sample-holder,
- activation foils for dosimetry.

PHAETON

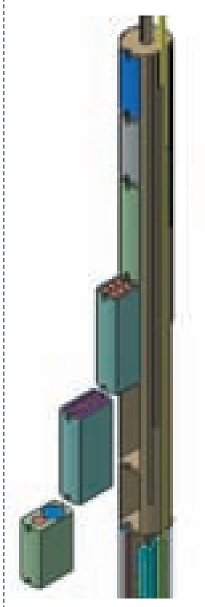
The PHAETON device is designed to irradiate materials and fuels at high temperature and in an inert environment. It can be installed:

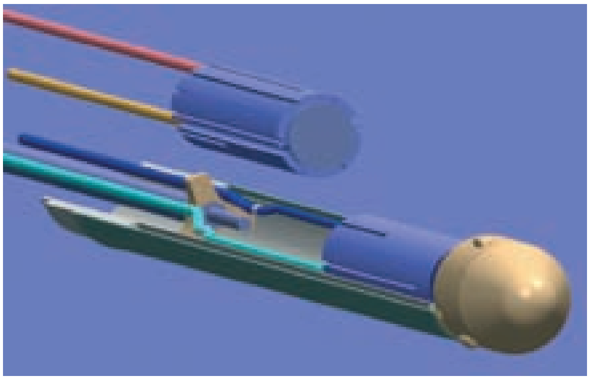
- in the core of the reactor for damage accumulation or burn-up experiments,
- on the periphery for experiments based on power transients.

It comprises a double jacket constituting a heat shield, heating elements distributed over the length of the capsule and a sample-holder suited to the experimental load. The six heating elements are designed to withstand temperatures higher than 600°C.

The temperature of the experimental load is controlled up to 1300°C for behavioural experiments and studies, and up to 1600°C for power transient experiments. Control is by two independent means: heating by the ovens and the adjustment of the gas mix in the internal clearance of the device.

Lower part of the sample-holder for high-temperature fuels.





Lower part of the sample-holder for high-temperature materials.

A shielded compartment located outside the reactor pool contains the systems required to condition the cooling gases and the measurements (sampling, counting etc.).

PHAETON is characterized by:

- a height controlled by the ovens of 580 mm,
- an effective diameter of 24, 32 or 64 mm according to the size of the irradiation cell,
- a fast neutron flux (E > 1 MeV) of up to $2\ 10^{18}$ $n.m^{-2}.s^{-1}$ (in the core) and of $4\ 10^{17}$ $n.m^{-2}.s^{-1}$ (on the periphery).

Instrumentation:

- 12 thermocouples.

GRIFFONOS

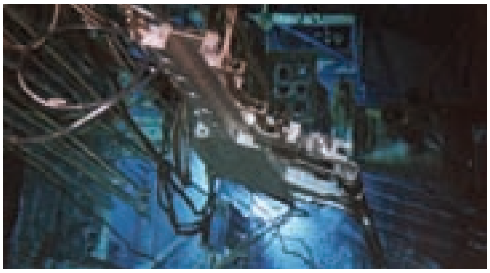
GRIFFONOS is designed to irradiate fuel rods under neutron flux conditions and fuel rod temperatures as close as possible to those met in pressurized water reactors. This device, placed in the periphery of the core, can be irradiated or withdrawn without shutting down the reactor. It can house various types of fuel rods: new or pre-irradiated, UO_2, MOX, whether instrumented or not, produced by pressurised or boiling water reactors.
The experiments carried out with GRIFFONOS produce information required to understand the behaviour under flux of fuel rods, both current and future, in order to optimise their performance characteristics. The physical phenomena under study are varied: the central temperature of the fuel rod according to the power and burnup rate, deformation of the clad during the pellet-clad interaction, generation of gas etc.
The GRIFFONOS device is of the subsidiary shell type in which the evacuation of the power generated by the fuel rod is ensured by natural convection of water under pressure. Heat is evacuated by an ascending flow of water driven by the thermosiphon effect, with a return downward path coaxial to the outward path.
A shielded compartment located outside the reactor pool contains the systems required to condition the coolant.
The principal characteristics of the installation are:

- Experimental load:
  - *Outer diameter:* 9.5 to 12.5 mm
  - *Maximum height:* 2 m (irradiation on 0.63 m)
- Geometry of the test channel: F 33 mm
- Power
  - *Maximum gamma heating:* 1.7 W.g -1
  - *Maximum linear on the fuel element:* 600 $W.cm^{-1}$ adjustable by displacing the device in relation to the core
- Coolant
  - *Type:* demineralised light water, degassed and chemically processed
  - *Loop pressure:* 130 bar
  - *Temperature:* 35 to 240 °C
- Maximum temperature of the clad on the surface: 336 °C

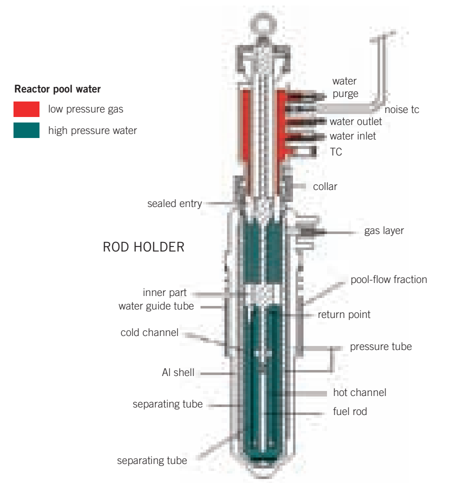
Instrumentation:

- the power released by the fuel element during irradiation is measured by neutron balance using collectrons. It is then readjusted by quantitative GAMMA spectrometry,
- any rupture in a clad is detected by a sensor measuring the gamma activity in the water of the circuit on the return line to the shielded compartment,
- the pH, oxygen rate and hydrogen rate in the water are continuously monitored. The anions, cations and metals present in water are analysed in a chemistry laboratory using samples of water from the loop.
- the fuel rod can house specific instrumentation:
  - a core thermocouple,
  - a clad thermocouple,
  - a pressure pick-up to monitor the release of fission gases,
  - around the fuel element: a sensor for diametrical measurement under flux.

The GRIFFONOS device in the reactor pool.



Diagrammatic view of the part in the reactor pool.



ISABELLE loops

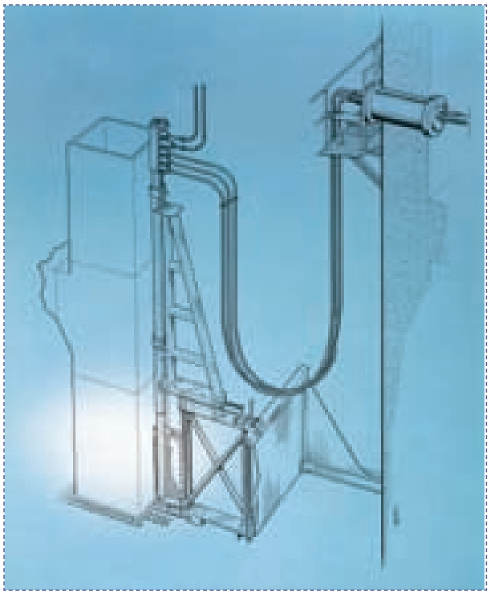
ISABELLE loops are designed for the irradiation of fuel elements under thermohydraulic and chemical conditions representative of those of light water reactors.

Two devices exist:

- The ISABELLE loops particularly well suited to the production of power ramps. The experimental load consists of a short fuel rod, either new or re-manufactured in hot laboratories by the FABRICE process using a fuel element irradiated in the power station. The power that can be evacuated by the loop is 60 kW and the maximum linear power on the fuel element is 620 W cm^{-1} with a maximum ramp speed of 700 $W.cm^{-1}$ min^{-1}.
- The ISABELLE 4 loop, can also be used for qualification of qualification irradiations comprising powers cycles on two levels of power. The loop can house from 1 to 4 fuel elements as well as plate fuels or absorbent elements. The geometry of the fuel elements is similar to those accepted by ISABELLE 1. The power that can be evacuated by the ISABELLE 4 loop is 90 kW and the maximum linear power on the fuel elements is 500 $W.cm^{-1}$.

The design of these loops and their positioning on the periphery of the core enable irradiation and withdrawal with the reactor in operation. These devices are placed on mobile supports, the displacement of which in relation to the core of the reactor is used either to adjust the power of the fuel element, or to automatically control the power ramps or the cycles at variable speeds, slaved to the neutron power.

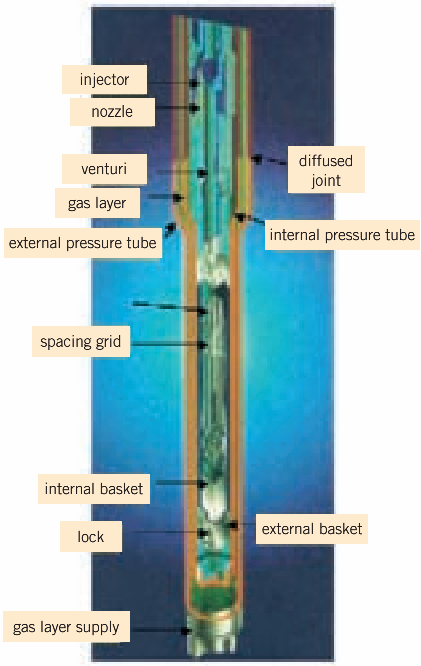
The fuel elements are cooled by forced convection produced by a flow of light water, demineralised, degassed and chemically processed, created by a nozzle injector system amplifying the flow generated by the pump unit of the loop feeding circuit.



The ISABELLE 1 loop displacement system.

The bunker of the installation.

The test channel of the ISABELLE 4 loop.



This system reduces the dimensions of the flowlines to the shielded compartment where the systems required to condition the coolant are located (pressurizer, pumps, exchangers etc.) and thus make them flexible to authorize movements in the reactor pool. An electric heating element placed at the head of loop and an exchanger in the reactor pool control the thermics of the system.

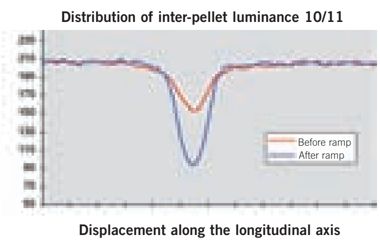
Instrumentation:

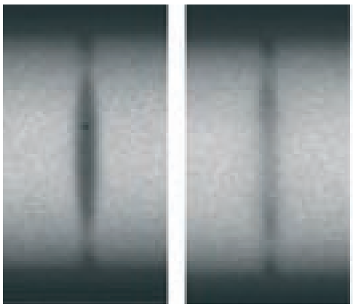
- The power released by the experimental load during irradiation is measured in real time by a heat balance produced by means of the flux, pressure and temperature sensors, as well as by a neutron balance carried out using collectrons.
- The detection of break in the clad of a fuel rod is provided by the measurement of the gamma activity conveyed in the water of the loop, together with the measurement of delayed neutrons.
- The control of the chemistry of the water used in the installation is ensured by a conditioning plant. It is controlled by analysing the water samples that are taken during reactor operation at various points of the circuit.
- The ISABELLE 1 loop is also equipped with a sensor of the type LVDT to continuously monitor the lengthening of the fuel element during variations in power.

Power ramps

The power ramps located in the ISABELLE 1 loop are designed to simulate the power transients, whether normal or incidental, in LWRs. They are used to improve our understanding of the mechanisms of the interaction between the pellet and the sheath of a fuel rod and reply to the industrial issue of increasing the manoeuvrability of LWRs. The variation in power is obtained by displacing the loop perpendicular to the core of the reactor, and slaving the displacement to the neutron power.

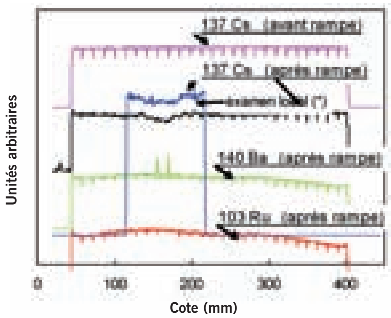
Neutron beam photography of the inter-pellet distance (with break of fuel element sheath).



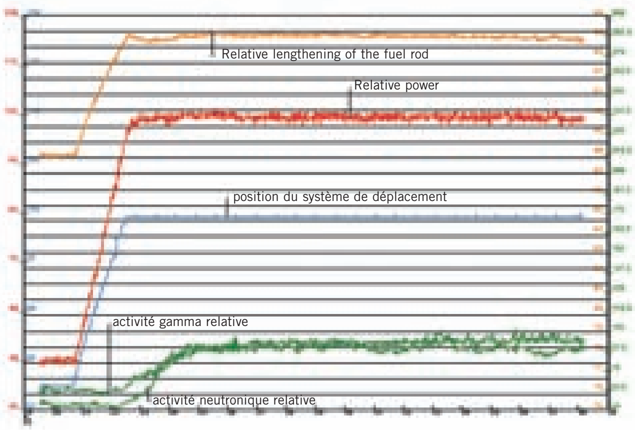


Before ramp *After ramp*

The changes in the various parameters are monitored throughout the experiment.



Gamma spectrometry: axial distribution of activity before and after ramp (with break in fuel element sheath).



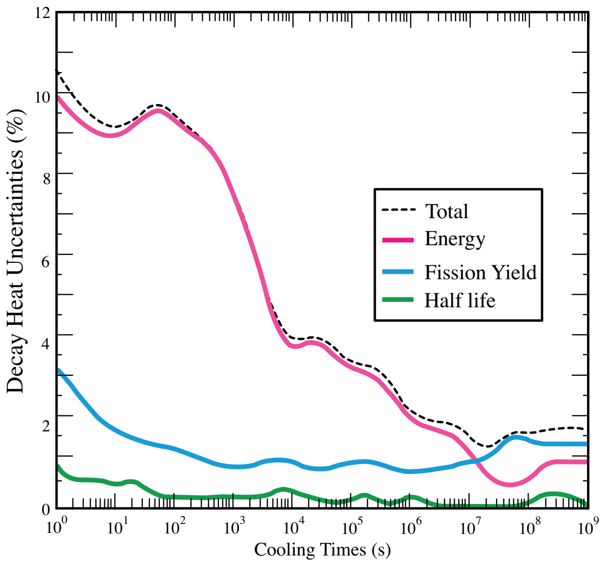
Fine characterization of fuel by non-destructive testing is also carried out.

MERCI and MOSAÏC devices

MERCI and MOSAÏC are two devices dedicated to the accurate characterization of the residual power of a shortened PWR fuel rod immediately after its irradiation. This energy, produced after reactor shutdown, is mainly generated by the desexcitation of unstable nuclei created during reactor operation. The knowledge of this physical quantity is of major importance for safety evaluation of a nuclear power plant including thermal aspects (residual heat) and radioprotection aspects (radiations spectra).
This residual power is involved in the design of the cooling circuits of the core (normal or accidental operations) and of the pool (spent fuel storage). Transportation and reprocessing is also concerned.
At present, according to the consequences for safety, engineers are brought to add uncertainties to the calculated residual power in proportion with the gravity of the accident. They can reach 1, 2 or even 3σ. The economic consequences of such margins are strong enough to motivate efforts for improvement.
These experiments, receiving UO2 or MOX fuels initially new or pre-irradiated in PWR power plant, aim at :

- decreasing decay heat uncertainties ;
- qualifying FAKIR and DARWIN/PEPIN CEA computer codes ;
- displaying anomalies in cross section evaluations.

Decay Heat Uncertainties



MERCI and MOSAÏC devices are successively used during the experiment including three phases :

- **first phase:** irradiation during approximately 50 EFPD of a shortened PWR fuel rod within MERCI device in the reflector of the OSIRIS reactor core ; there, the mean lineic power reached is about 300 W/cm ; MERCI device can be divided in 2 items : the experimental charge (mobile part intended to be transferred to the hot cell) and its support structure (part fixed to the reactor pool wall) ; the fuel rod is is inserted inside a fully instrumented channel : thermocouples and a complete neutronic instrumentation : Self Powered Neutron Detectors, a removable fission chamber and two stacks of activation dosimeters at the front and at the rear side of the rod ; indeed, the quality of the experiment strongly depends on the knowledge of irradiation history ;
- **second phase :** transfer of the experimental charge after a scheduled shutdown of the reactor from its irradiation location to the hot cell for its introduction inside MOSAÏC calorimeter ; this transfer is pe formed in a 20-30 minutes period; a trained team including 20 persons (operating staff, experimenters, radioprotection technician) must be mobilized during this operation to combine performance and safety ;
- **third phase:** real time measurements of the decay heat released by the fuel using the MOSAÏC device during 60 days ; over this period the power decreases from several hundreds to a few Watts ; the main components of this device are the calorimeter itself settled inside a hot cell, and outside an elaborated acquisition / regulation system, coolant systems as well as hydraulic / electric and safety bays.

The innovative nature of these experiments relies on :

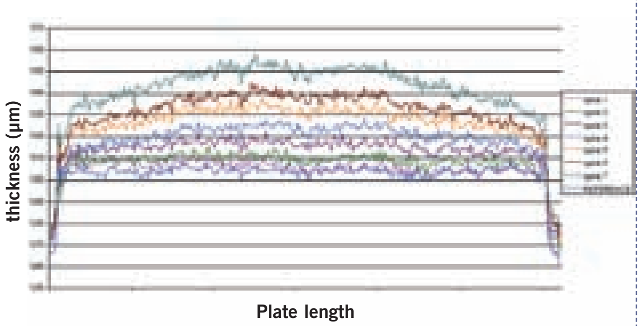
- the study of a "real" PWR fuel rod ;
- the consideration of actinides ;
- a measurement of the decay heat starting 20 minutes after shutdown toseveral weeks ;
- the use of an original measuring device (MOSAÏC calorimeter) specifically conceived and developed to reach an aimed precision of 1 %.

IRIS

The IRIS device has been designed to irradiate fuel plates for experimental reactors. It has the same external geometry as a standard OSIRIS fuel element and is placed in the core of the reactor. The device is cooled by the water of the primary circuit. Manufactured out of aluminium alloy, it is equipped with a latch in its upper section to avoid plate movement due to the effect of the ascending circulation of water. The latch can be removed to extract the plates during reactor shutdowns in order to carry out dimensional measurements of swelling and visual inspections.

The IRIS device can be loaded with 4 different fuel plates, separated by inert aluminium plates.
The dimensions of the experimental plates are 641.9 mm long, 73.3 mm wide and 1.27 mm thick. The maximum mass of uranium U^{tot} per plate is 500 g and that of the Uranium 235 is 100g.

Transfert of the experimental load



Change in thickness of a plate between each irradiation cycle.

The IRIS device.

The principal characteristics of the IRIS device are as follows:

- reusable device,
- loading and unloading of the plates underwater,
- mixed loading of new plates with plates already irradiated,
- a wide range of irradiation conditions depending on the position chosen in the core of the reactor,
- an increase in thickness of the plates of 0.25 mm considered as the authorized limit for proper cooling during irradiation.

The plates irradiated in this way are subjected to a dimensional check on each cycle on a dedicated measurement bench.

Instrumentation of the devices

Instrumentation is one of the key parameters for the performance of the experiments undertaken in the reactor. This is because during irradiation, various physical parameters must be measured on-line in a reliable and precise way. The experimental devices implemented at OSIRIS are equipped with various sensors and measurement systems, according to need.
The instrumentation usually used include:

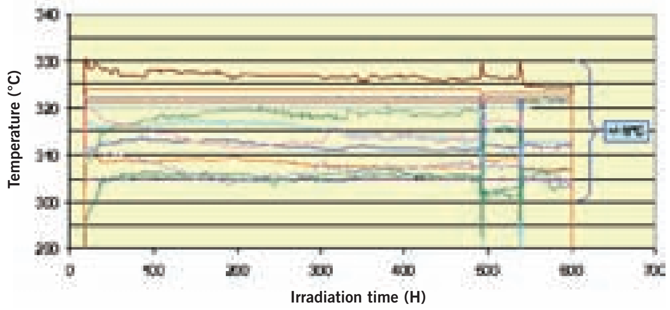
- measurements of the nuclear radiation characterizing the irradiation (neutron flux, heating or gamma radiation) using collectrons (SPND), activation dosimeters, calorimeters or sub-miniature fission chambers,
- temperature measurements by thermocouples, placed on or near the samples, but also in the core of the irradiated nuclear fuels,

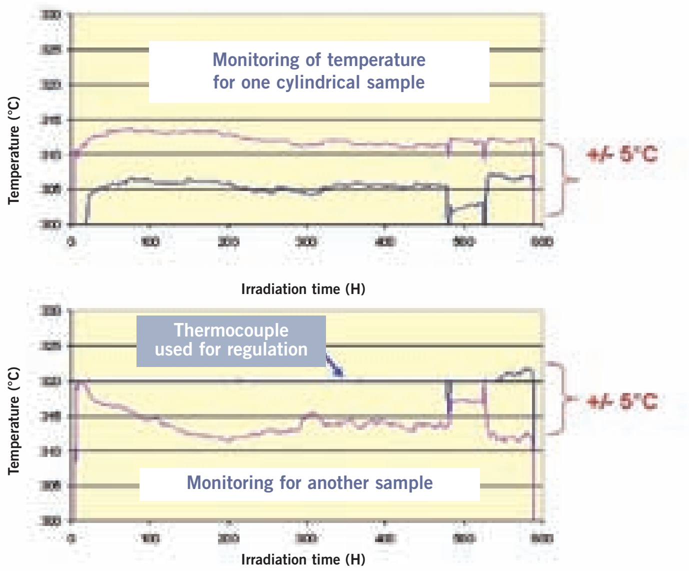
- measurements of the dimensions of samples: sensors of the LVDT type to measure the lengthening of fuel sheaths, or off-line strain gauges for on-line measurements of the diametrical strain of materials or fuels,
- measurements of the mechanical stress applied to samples when loading, the stress being created by systems of bellows using a pressure controlled outside the irradiation devices,
- the measurement of the release of fission gases in fuels under irradiation, using a backpressure sensor installed at the end of the fuel rods.

Temperature measurement in a CHOUCA device

The temperature of the experimental load during the irradiation is an important parameter that conditions the quality of the experiment.
This is particularly true for studies related to the behaviour under flux of materials with mechanical properties sensitive to irradiation temperatures.
The example below illustrates the change in temperatures measured near pressurized cylindrical test specimens irradiated in a CHOUCA device.
The upper part of the first figure shows the change during an irradiation cycle of the temperatures measured by 2 thermocouples near the same test specimen.
The lower part of the figure highlights the influence of the axial variation of gamma heating on the temperatures.
The second figure illustrates the stability of the temperatures measured during a cycle.

History file of the temperatures measured by the thermocouples installed in the sample holder.





Local temperature stability.

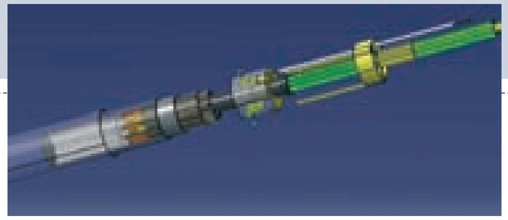
Qualification of the instrumentation

The qualification under irradiation of the instrumentation is a crucial stage of its development. This qualification concerns for example:

- the mobile calorimetry device, which can measure the nuclear heating in all the experimental positions of OSIRIS. This tool enables a vertical examination over the entire height of the core and the upper parts of the irradiation devices,
- the pressure transmitter of fission gases,
- the new type of high-temperature thermocouple containing molybdenum and niobium, designed and developed specifically by the CEA in close cooperation with an industrial specialized in thermometry for the nuclear power industry.

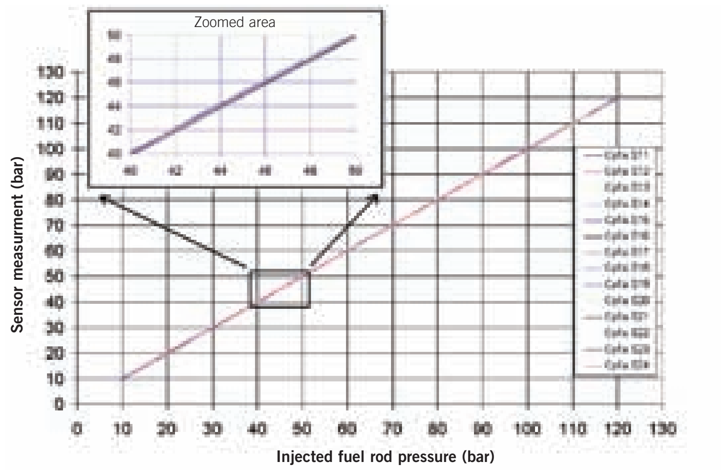
QUALIFICATION OF THERMOCOUPLES AT HIGH TEMPERATURE

High temperatures (above 1200°C) during the irradiation of materials or fuels are measured using C-type thermocouples. The prolonged use of C-type thermocouples (W/Re) under a neutron flux induces a drift caused by an irreversible modification in their thermoelectric capacity because of the transmutation of metals constituting these couples.
Mo/Nb thermocouples have a response similar to those of other couples of the C type and in theory are not affected by the phenomena of transmutation. Qualification of the Mo/Nb thermocouples consists in quantifying their drift under flux and at high temperatures in relation to the fluence received and to compare it with that other couples of the C or K type.
The fixed point principle (the melting point of copper) is used to measure the change in the signals caused by the neutron fluence. The thermocouples are inserted into a graphite core in a copper receptacle equipped with heating elements. The assembly is embedded in a graphite barrel and introduced into an irradiation device of the CHOUCA type.

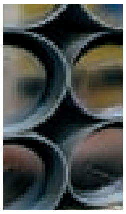


QUALIFICATION OF A PRESSURE PICK-UP

The qualification in operation under irradiation of the “backpressure” pressure pick-up takes place while mounting the sensor on a false fuel element, the internal pressure of which is controlled and measured via a pressurized circuit. Qualification is based on the comparison between the pressure injected into the fuel element and that provided by the sensor.
The performance characteristics are tested at high temperature and throughout the effective range.
Because of its design, no drift in measurement in the nuclear environment is observed.



MORE ABOUT IRRADIATION




Within the OSIRIS Nuclear Installation, many facilities are provided to guarantee the quality of the irradiations carried out in the reactor:

- the ISIS reactor model,
- hot cells,
- non-destructive inspection means,
- the chemical control of the water,
- tools for on-line data acquisition and follow-up of experiments,
- the calculation and modelling group.

The ISIS Reactor

Associated with the OSIRIS reactor, the ISIS neutron model is a reactor with the same geometry but a thermal power limited to 700 kW. This model is more particularly dedicated to neutronic measurements of the reactor and the irradiations. ISIS is used to carry out tests of new core configurations, new fuel elements or irradiation experiments, by measuring the effects of reactivity, the levels of neutron flux or gamma heating. The reactor is also used to teaching and train a large number of trainees.

The reactor is characterized by the possibility of loading the core with irradiated elements from OSIRIS. It is equipped with an installation enabling it to operate by adjusting a weak boron concentration in the water of the primary circuit.
The control-command of the reactor is designed to meet the requirements specific to this reactor, such as:

- various approaches under criticalities and divergences,
- fine measurements over a wide range of power,
- the use of detectors in various nuclear environments.

The core of the ISIS reactor.

Hot cells

Two hot cells are located in a building contiguous to the OSIRIS and ISIS reactors. They are connected to the pools of the two reactors by a water channel. This layout enables a direct transfer of all the devices or radioactive materials, without using special containers, with simple handling systems ensuring the protection of the operators.

The biological protection and the size of the cells are dimensioned to accommodate complex and highly radioactive devices without disassembling them. Each cell is equipped with a heavy remote manipulator and two light remote manipulators, in order to:

- repair the radioactive materials,
- dismount and repair the experimental devices,
- recover the samples and activation foils for dosimetry,
- load the samples into the experimental devices,
- dismantle the unutilised devices,
- prepare containers to evacuate waste.

Non-destructive examinations

Two non-destructive examination facilities (E.N.D.) are installed in the pool of the OSIRIS reactor. It comprises an immersed neutron radiography facility and a gamma spectrometry bench.

Neutron radiography installation

This device placed on the bottom of the reactor pool consists of 3 main parts:

- a pyramidal collimator with a slightly truncated top on which is located an aluminium-alloy plate constituting the neutrons inlet path,
- at the back of the collimator is the chamber to house the object to be examined,
- the support located at the back of the chamber houses the metal cassette containing the neutron converter during the irradiation phase.

The unit is mobile and can advance towards or move back from the core of the reactor.
The technique is known as a “transfer” because the radiographic image is obtained after two consecutive sequences:

- irradiation of the converter,
- exposure of the photographic film.

The method has two advantages:

- it enables the control of an object directly in the vicinity of the core without withdrawing it from the reactor pool,
- it can image highly radioactive objects, because the photographic film is never in their vicinity.

All the fuel rods irradiated in an experimental device at OSIRIS undergo neutron beam photography before and after irradiation, to see the changes in the state of the fuel and the effect of the irradiation.

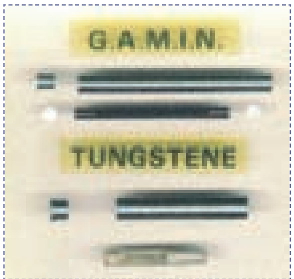
Gamma spectrometry installation

This installation consists of two distinct parts: the mechanical bench located in reactor pool which houses the object to be characterized, and the gamma radiation detector located outside the reactor pool. The gamma photons emitted by the object are transmitted to the detector via a sealed plug and crossing through the entire wall. A mechanical shutter collimator is used to define the cross-section of the transmitted beam.
The bench in the reactor pool is used to place each point of the object opposite the collimator with programmable, adjustable displacement rates. After each displacement has been completed, a data acquisition sequence starts and the corresponding data are filed.
The detector is an extremely pure germanium/lithium junction placed inside shielding designed to protect it from parasitic radiation. The data processing software is used to edit the spectra of interesting photons. Cooling after irradiation and the acquisition times are optimised in relation to the radionuclides examined.
The spectrometer is characterized by a high yield (40%) and a good energy resolution (< 1.8 keV to 1352 keV).
In general, if the fuel has already been irradiated in a power station, the examination of the gamma spectrometry can be used to validate the data provided on delivery of the fuel element. Data processing can be qualitative and/or quantitative. In particular, it is possible to retrieve the value of the power developed in the fuel element during the irradiation phases of the fuel in its experimental device.

The gamma inspection bench.

Damage dosimetry

Damage dosimetry is designed to experimentally evaluate the fluence of damage, or the displacement per atom (dpa), of irradiated materials. It requires detectors such as G.A.M.I.N dosimeter, comprising a graphite rod, or a tungsten detector. The technique is based on the use of ultra-pure materials and the change in electrical resistance under irradiation.



Detectors used in damage dosimetry.

Based on the "integral" spectrum indices provided by these dosimeters and in connection with activation dosimeters (^{58}Ni), the neutron spectrum is characterised by the spectrum indices in order to deduce the damage flux of the considered object.
Damage dosimetry is carried out before the irradiation itself, using a model irradiated with low fluence. This model simulates the real irradiation and therefore respects the quantities and proportions of the various materials present in the irradiation experiment.
The operation of damage detectors requires:

- A thermometry laboratory equipped with a thermostated bath at ± 0.001°C to measure the electrical resistance, before and after irradiation, as well as G.A.M.I.N and tungsten detectors,
- An activation-based dosimetry laboratory to measure the ^{58}Ni dosimeters.

Water chemistry

A conditioning plant provides water for the irradiation loops under the conditions required for demineralisation, degasification, hydrogenation and additive contents. The installation comprises:

- The demineralised water purification unit,
    - the processing plant,
    - degassers to eliminate dissolved oxygen,
    - tanks to prepare and control the injection of chemical additives (boron, lithium oxide etc.),
    - hydrogenation tanks,
    - the slaved sampling circuit for the control and adjustment of water quality,
- The analysis equipment: U.V. spectrophotometer for metal titration, liquid/ionic chromatographs to measure the anion, cation and metal contents, conductimeter and pH-meter, and calcination apparatus.

The chemical conditioning of water.

Data processing

Real-time data acquisition and processing

Depending on the type of experiment to be realized, two types of systems are available to acquire data from all the sensors and to carry out the real-time calculations required to control them. The first, highly integrated with the control-command facilities is used, via a supervision network, to carry out all the calculations. It is dedicated to experiments not implementing fast transients. The second system communicates with the control-command facilities, but in addition has its own acquisition chains, enabling it to process fast transients, in particular during the control of power ramps.

Supervision tools

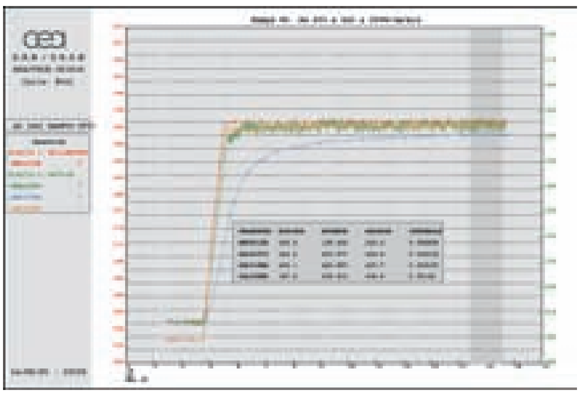
Whatever the acquisition system, the man/machine interface is built on a redundant supervision network that is used to guarantee a single interface with the user whatever the experiment concerned.

The MMI is installed either on workstations local to the OSIRIS reactor to control the experiments, or on the Intranet network of the CEA, enabling the various contributors to follow the irradiation procedure in real time.

The information system and data post-processing

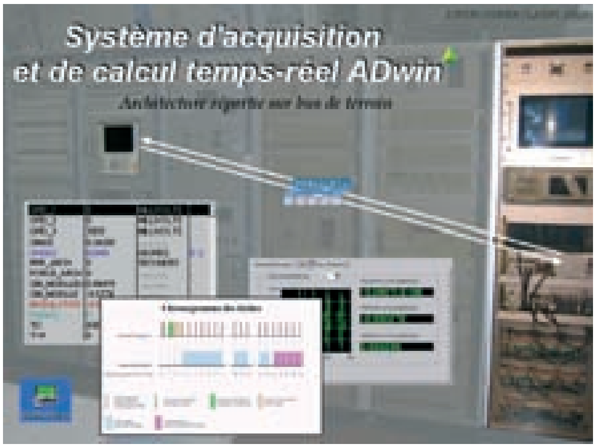
All the data acquired in real time are centralized in a relational database (GDEX). Due to its design, this system, which combines the data implemented to carry out the irradiations, guarantees the overall quality of the data.

In addition, connected to this information system, various tools are used to help the researchers to carry out post-processing such as the GDEX (curves processing), CRPI (tools to generate partial irradiation reports) etc. In addition, since the GDEX information system is based on an Oracle database, any software with Oracle access can be used to retrieve information (Excel for example).

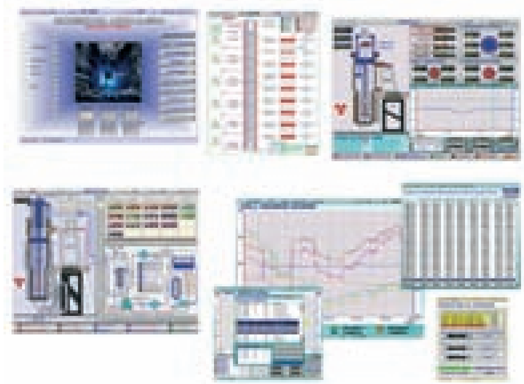


The GDEX relational database.

Adwin high-speed system.



Supervision of OSIRIS experiments.



Digital simulation to support irradiation

A large number of modelling tools on the cutting-edge of data-processing development and state-of-the-art physical models are used, in particular the simulation codes developed by the CEA/DEN within its business units, such as the Systems and Structures Modelling Department (DM2S) in Saclay, or the Reactor Studies Department (DER) in Cadarache and Grenoble.

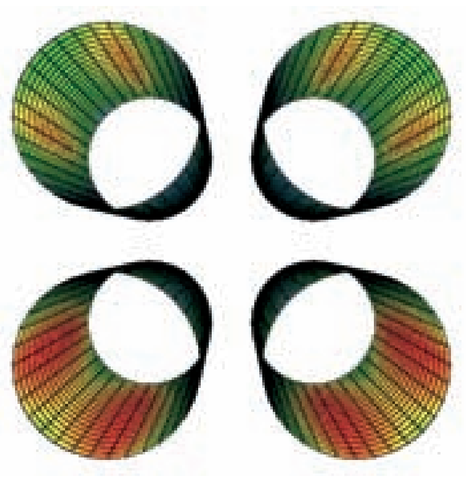
Digital simulation is used in several ways in the preparation and production of irradiations. As of the design phase, business engineers use modelling in order to dimension the sample-holder that will house the test specimens to be irradiated.

The codes used are for example:

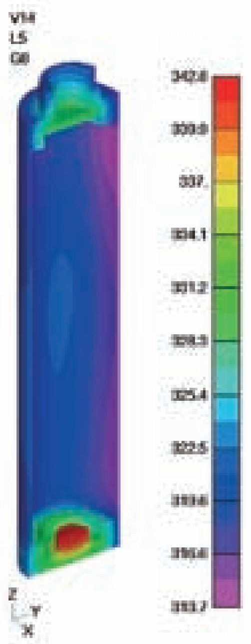
- Neutronics: ANUBIS system,
- Double-phase water-steam thermohydraulics: FLICA4 and CATHARE,
- Thermomechanics and fluid mechanics: CAST3M.

These calculations are used to design the device in order to respect the customer's requests with the highest degree of accuracy, in particular the temperature of the samples and the duration of irradiation.

Temperature distribution in the sheath of four UO_2 fuel rods loaded in the ISABELLE 4 loop.



Temperature mapping in a creep test specimen in a CHOUCA device.

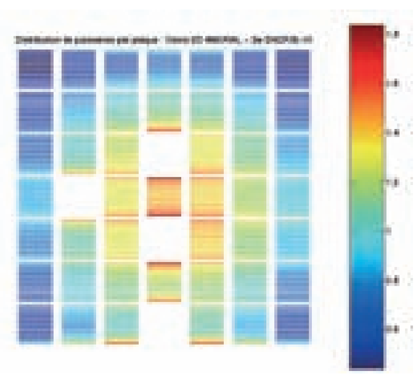


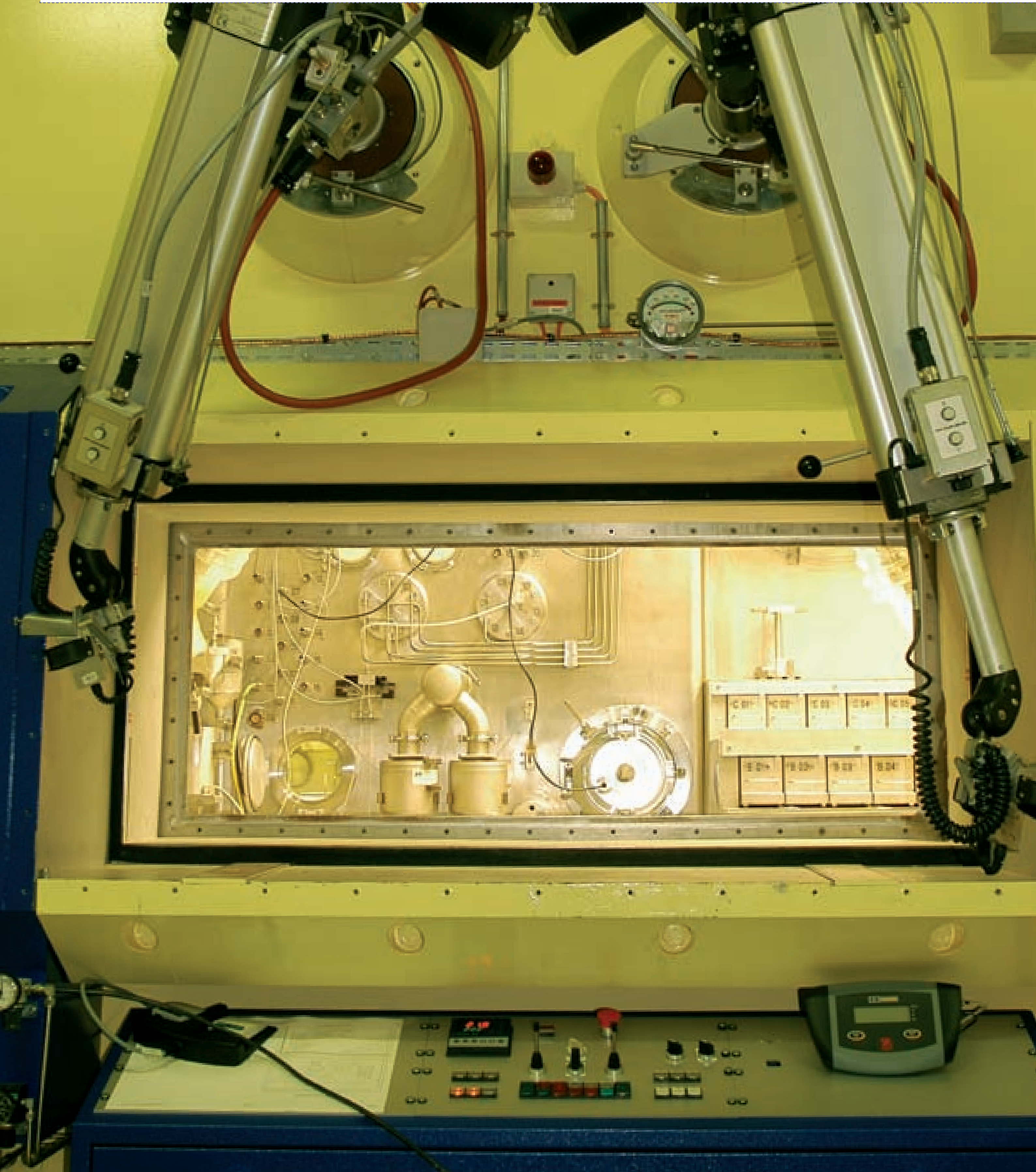
Output set:
Pg + 86-81-11-94-89 W/cm
Contour:
Temperature

ANUBIS

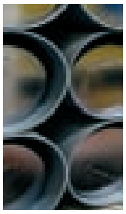
The CEA is currently designing a new generation of the neutron calculation procedure (ANUBIS). It is based on the APOLLO2 (deterministic lattice code), CRONOS2 (deterministic code core) and TRIPOLI4 (Monte Carlo code) codes, all three of which have been developed at the CEA. ANUBIS implements the latest functionalities of these codes, which are already used by our industrial partners. APOLLO2 is used by EDF and Framatome ANP in their respective neutron calculation chains (the SCIENCE chain of Framatome ANP is certified by NRC). "Standard" core calculations are 3-D diffusion calculations for 6 groups of energy. ANUBIS is also used to carry out calculations of the complete core of OSIRIS with its irradiation load, using the characteristics method. Reference calculations can also be carried out in 3-D Monte Carlo using the TRIPOLI 4 code (see the illustration below).

Distribution of fission rates per plate: calculation of EXP benchmark (TRIPOLI4).





THE HOT LABS ASSOCIATED TO OSIRIS




THE HOT LABS ASSOCIATED TO OSIRIS

The OSIRIS reactor has the benefit of the infrastructure of the CEA and all of R&D facilities both from the point of view of material studies with the LECI near the reactor at the Saclay centre, and from the point of view of fuel studies with the LECA-STAR in Cadarache.

LECI

The LECI, a hot laboratory located on the Saclay site and mainly designed for the study of irradiated materials, comprises shielded cells in which destructive testing, non destructive testing, machining as well as conditioning and waste evacuation are carried out. These cells are used to house irradiated materials and short fuel rods.

The R&D work and the related activities concern:

- The metallurgical and mechanical characterization of irradiated materials from power reactors, or experimental irradiations, in order to determine the change in their reactions under irradiation,
- Studies on irradiated metallic materials (interpretation of experiments and modelling),
- Studies on the corrosion behaviour of cladding materials,
- The manufacture of test specimens, samples and experimental fuel rods.

The installation offers a wide range of scientific means and equipment to:

- prepare samples from irradiated materials (electroerosion machining, pressurization of fuel rod clad etc.),
- manufacture short experimental fuel rods using an irradiated section of a PWR fuel element (the Fabrice process),
- carry out post-irradiation examinations of fuels, such as sampling fission gases, and metallography. The non-destructive examinations carried out on the fuel rods use diametral metrology, zirconia thickness measurements, measurements of eddy currents by specific wrap-around probes as well as gamma spectrometry,
- carry out post-irradiation examinations and measurements on materials such as:
    - Mechanical tensile, inflection, hardness, toughness, impact strength, uniaxial and biaxial creep tests,
    - Metallography,
    - Dimensional measurements by laser metrology.

Uniaxial creep machine.

LECA STAR

Located on the CEA site in Cadarache in the south of France, these facilities supplement those of Saclay for fuel studies.

LECA

The LECA, a hot laboratory more specifically designed for studies and examinations of irradiated fuels, comprises shielded cells used to house fuel rods whether sealed or not, up to 2.5 m long.
The principal activities of the LECA involve:

- post-irradiation, non-destructive, and destructive examinations of irradiated fuel rods,
- reconstitution of fuel rods (FABRICE) using sections of fuel elements from power reactors. Coupling with STAR enables the reception of long fuel elements from power reactors, their non-destructive examination, drilling and cutting. Ceramography, optical Microscopy and Macroscopy, Electronic scan microscopy (MEB), Microprobe, WDX analyses on polished surfaces and fractures, image analysis, x-ray diffraction, density, open porosity, quantitative g spectrometry, determination of burnup rate, O/M ratio, SIMS (active in 2002) constitute the analysis and examination equipment available, and are used to carry out the characterizations and the basic research applied to the behaviour of fuels.

STAR

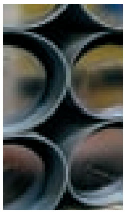
STAR is a laboratory for handling b and g radioactive products, as well as the processing and (re)conditioning of irradiated fuels, and the monitoring of irradiated fuels from research or power reactors.
This hot laboratory comprises 3 concrete cells able of receiving fuel rods up to 5 meters long, whether sealed or not. The laboratory can accommodate shipping casks up to a maximum weight of 60 tons.

STAR activities include:

- processing of UNGG fuel elements stored in reactor pools (identification, decladding, drying, decomposition of hydrides, oxidation, container conditioning),
- non-destructive post-irradiation examinations of fuel rods from power reactors,
- studies on the behaviour of fuel elements under very long-term storage conditions,
- visual examinations with video recordings, metrology, gamma scanning and quantitative g spectrometry, eddy current “health” examinations, zirconia thickness measurements, x-ray examination, gas release measurements - drilling - and measurement of free volume).

The laboratory couples with the LECA for the related non-destructive examinations.

IRRADIATION FOR **INDUSTRY**




Silicon neutron transmutation doping

For more than 25 years, silicon manufacturers have called upon the nuclear research reactors to carry out the neutron doping of their production. This is the case with OSIRIS, where equipment is used to accommodate several tons of silicon a year.
Natural silicon is composed of three isotopes with a mass of 28, 29 and 30. The latter is capable of capturing thermal neutrons (effective cross-section) to produce the following reaction: $Si_{30}+n \rightarrow Si_{31}^* \rightarrow P_{31}+\gamma$
This reaction thus causes the disappearance of an atom of silicon and the appearance of a phosphorus atom in the silicon crystal such that we can reproduce a doping operation of the N type by neutron irradiation.
Typically, each irradiation lasts from a few hours to several dozens of hours. A decay period (a few days) must be observed before conditioning the ingots to return them to the producer, where they will undergo thermal processing to anneal the defects created by the fast neutrons during their stay near the reactor.
Several tons of silicon are processed annually at OSIRIS for Japanese industrials in particular.

Removal from the pool of silicon ingots after irradiation and decay.

The irradiation device.

Artificial radio-isotopes

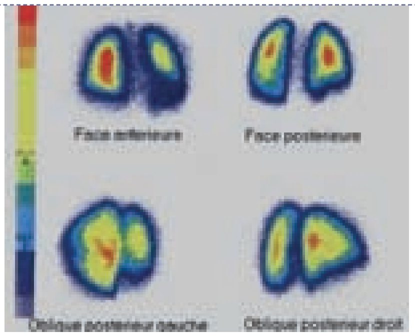
The high flux of the OSIRIS reactor is also used to produce artificial radio-isotopes for nuclear medicine and to a lesser extent for industry.

The main medical uses include:

- Gamma-emitting radioelements used in processing cancers and tumours, such as iodine 131 or iridium 192.
- Beta-emitting radio-isotopes used for certain local treatments, such as articular pains, the prevention of the certain forms of myocardial infarction or the inhibition of certain forms of pain.

These two applications are obtained by irradiating stable bodies contained in crimped aluminium cartridges with a diameter of 25 mm. Radio-isotopes used in imagery for medical diagnoses: this involves the use of gamma cameras to examine the operation of organs onto which a radioactive molecule has been fixed. The product most frequently used is ^{99m}Tc obtained from targets made of enriched ^{235}U. The targets are in tube form, 160 mm high and 22 mm in diameter.

Production is part of a joint program with the other European reactors in order to ensure a regular supply for hospitals.
Industrial applications include depth control (motorway bitumen), oil geophysics, and so on.
About 1000 tubes or targets are irradiated each year in the OSIRIS reactor for French and European industrials.



Pulmonary scintiscanning.

IRRADIATION WITH OSIRIS

YOUR CONTACT

For use of the reactor and production irradiation:	For the design and follow-up of technological irradiation
Service d'Exploitation du Réacteur OSIRIS (SEROS)	**Service d'Irradiation en Réacteur et d'Etudes Nucléaires (SIREN)**

Commissariat à l'Énergie Atomique - Saclay
Direction de l'Énergie Nucléaire
Direction déléguée aux Activités Nucléaires de Saclay
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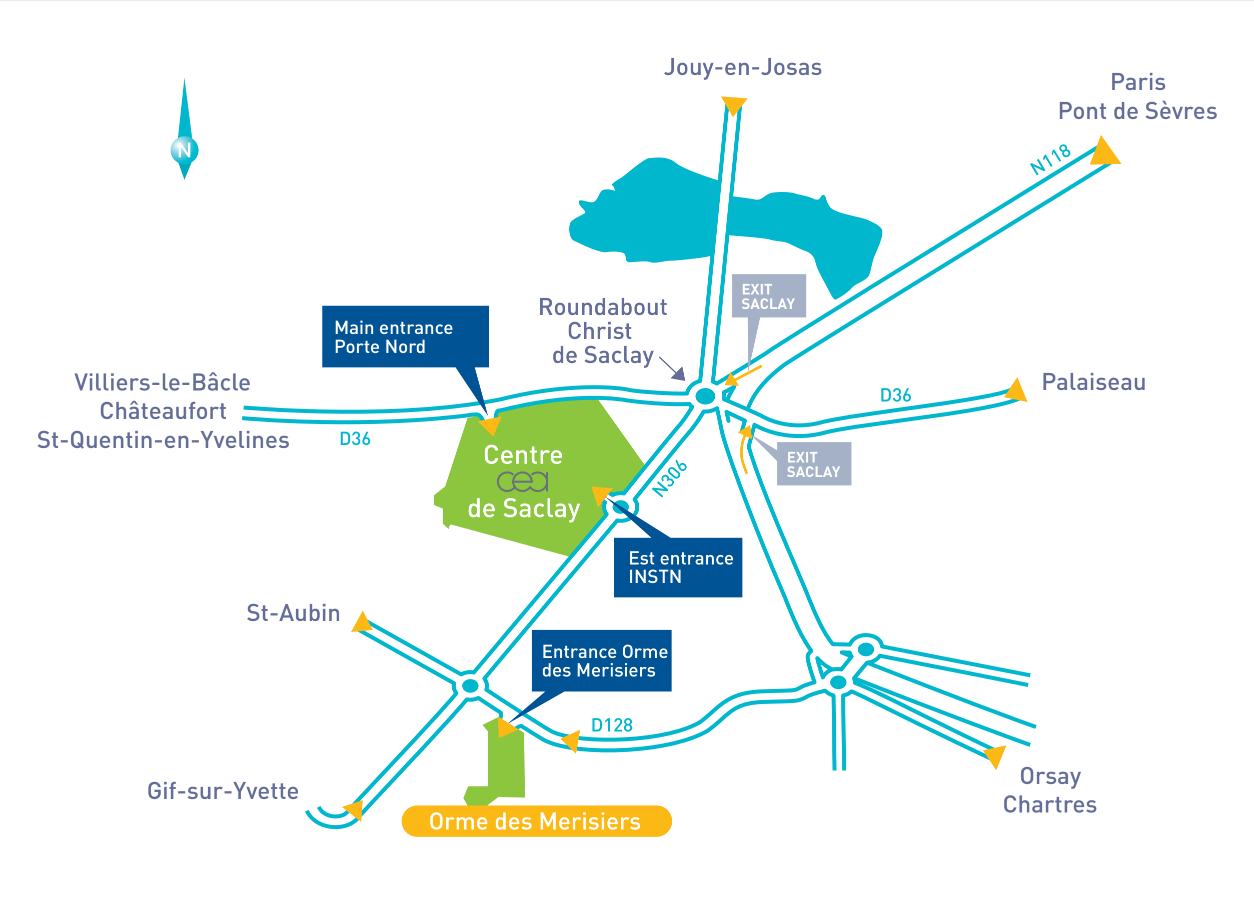
The quality of irradiation experiments

The irradiation process of fuels and materials in the OSIRIS reactor was certified in 2003 according to the ISO 9001: 2000 standard. This process involves all the operations and activities required to design, produce, irradiate and operate experimental devices in the OSIRIS and ISIS reactors. With an overriding concern for rigour in project management and safety control, the process is used in all the units involved in irradiation experiments.

Certificate AFAQ.

ACCESS TO THE SACLAY CENTRE



From the pont de Sèvres

South/west of Paris (approximately 40 minutes).
On the west ring road of Paris, take the exit [**Direction Bordeaux / Nantes**].
Take the main road N118 direction [Chartres / Orléans] and the exit at [Saclay / Gif-sur-Yvette].
From there take D36 roads direction [Châteaufort].
The CEA Saclay is less than one kilometre on the left.

From the Porte d'Orléans

South of Paris (approximately 40 minutes).
On the south road of Paris, take the **A6** highway at the [porte d'Orléans] and follow the directions:
[Orléans / Lyon], [Chartres / Orléans] (by highway), [Versailles / Igny-Bièvres - Cité scientifique], then [Saclay].
At the roundabout of the Christ of Saclay, take the D36 road direction [Châteaufort].
The CEA Saclay is less than one kilometre on the left.

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