



## Keys Figures and Services at the CEA LECA-STAR Facility

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# KEYS FIGURES AND SERVICES AT THE LECA STAR FACILITY

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## ABSTRACT

The LECA-STAR is a CEA nuclear Hot Lab facility which is dedicated to R&D on irradiated fuels. It has been designed to analyze the behavior of a wide range of nuclear industrial and MTR fuel under irradiation. These capabilities are a key point in the fuel qualification/development cycle.

The facility is divided in two parts, the LECA (Laboratoire d'Examens des Combustibles Actifs, 1964) and STAR (Station de Traitement, d'Assainissement et de Reconditionnement, 1994) which are dedicated to:

- Non-destructive and destructive examinations (PIE) and annealing tests on irradiated fuels of different types and geometry, in order to characterize and determine the fuel behavior. Collected data and mechanisms understanding are used to establish laws and models which allows predictive in service-behavior and performance.
- Manufacturing of fuel rodlets from irradiated industrial rods for in-pile testing in MTR,
- CEA irradiated spent fuel processing and packaging.

Over 180 people work daily on the different processes and technical examinations tools available in the fifteen different hot cells (size up to 9m long) and in the LECA microanalysis laboratory which offers a unique and complementary combination of analytical equipment. The work of the staff is organized on the basis of the time slot of opening of the facility, (ie 6h-21h), in normal or shifted schedule either in round-the-clock operation, according to the function and type of activity.

Inside the facility, the operating team insures the maintenance, operation and nuclearization of devices in compliance with the Safety and Security rules and is responsible for the deployment and supervision of the processes (design and manufacturing), with the aim to provide high availability for the activities of the experimental teams.

Based on its current supply of services, and in view of the future CEA Jules Horowitz (JHR) reactor startup, the LECA-STAR launched actions to renew some of its equipment and launched an approach in order to upgrade its processes through innovative technologies.

The presentation will aim at putting forward the prospects of the installation in connection with the future reactor JHR located on Cadarache site.

## 1. Introduction

The LECA STAR nuclear facility (**Erreur ! Source du renvoi introuvable.**) is located in the CEA Cadarache center, (south of France). It has been designed to perform R and D activities on irradiated nuclear fuels.

It consists of two different parts:

- LECA (Laboratoire d'Examens des Combustibles Actifs), in operation since May 1964 which occupies the western part of the building
- STAR (Station de Traitement, d'Assainissement et de Reconditionnement) which occupies the eastern part of the building, and has been used since 1994 for treating

and conditioning CEA spent fuel, as well as performing non-destructive examinations.

In its hot cells and microanalysis laboratory, the LECA STAR carries out transformations on fuel rods, performs tests and destructive or non-destructive examinations on fuel irradiated in different industrial reactors or research reactors.

LECA STAR intervenes at different stages of the realization of experimental programs on nuclear fuel, especially during irradiation process of these fuels in research reactors. Since its refurbishment in the years 2001-2008, the LECA STAR has made changes in its processes and organization, and incorporated new equipment.

These dynamics continues today with the aim of the startup of the future experimental reactor JHR on the Cadarache site. Currently, the LECA STAR R & D activities continue to meet the needs expressed by the CEA and its industrial partners. Some ageing equipment are being replaced (SEM, optical microscope, cutting machines, drilling machines,..) and new ones are or will be implemented (MEXICO HIP furnace, NDE bench, ..) to maintain the laboratory at the required level of excellence.

During the period 2015-2020, while continuing the current missions of the LECA STAR, it is planned to focus on development of experimental tools in order to have a supply of high technical level and be competitive on the economic point.

At the end of this time, the LECA STAR should be able to submit proposals that meet the needs expressed by future JHR clients when defining their experimental programs.

The main axes that are explored concerned the increase in the fuel rodlets manufacturing capacity (instrumented rodlets or not), the non-destructive examinations techniques, and the destructive examination in a renovated microanalysis laboratory.

All developments will be carried out with a long-term perspective, in particular taking account of the possibility of transfer to the future hot laboratory of CEA.

Thus, the proximity of the LECA STAR with the new experimental reactor JHR will offer the opportunity of a unique experimental platform on the theme of fuel experimental programs in CEA Cadarache.



**Fig. 1: The LECA STAR building**

## 2. Structure, organization, objectives and services

### 2.1 Structure and organization

The LECA STAR is a nuclear facility of the CEA/Fuel Research Department (DEC, Nuclear Energy Direction) at Cadarache. A general description of this department is provided by the diagram in Figure 2. The missions of this department are to:

- Contribute to define the working limits of fuels in nuclear reactors (normal, incidental and accidental conditions),
- Develop, design, manufacture optimized or new products (increase the performance/safety of LWR fuels, qualify fuels for future systems (SFR, GFR,)),
- Contribute to the development of fuels for Research Reactors (future JHR reactor in Cadarache), for the navy, for transmutation,
- Characterize, understand and model the macro and microscopic behavior of fuel and develop the necessary experimental and modelling techniques,
- Perform the simulation of fuel behavior for normal operation, incidental and accidental situations,
- Develop process to stabilize spent fuel.

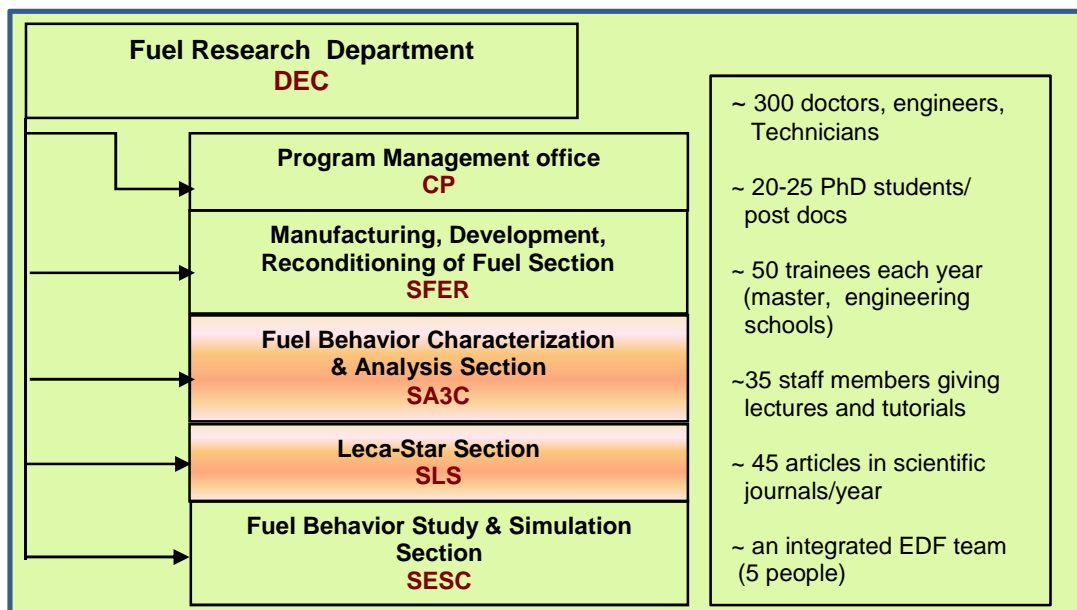


Fig. 2: The CEA Fuel Research Department

The LECA STAR dedicated to operations on irradiated fuel, contributes to these missions through its activities in experimental programs and is involved in the different phases of the experimental programs on fuel (figure 3) from the non-destructive examinations on the entire industrial rod to the microscale analysis of the fuel. The main services offered by the facility (figure 3 and 4) are:

- Performing non-destructive and destructive examinations, and annealing tests on irradiated fuels (of different types and geometry)
- Manufacturing instrumented fuel rodlets from irradiated industrial rods for in-pile testing
- Treating and reconditioning spent fuels stored at the CEA.

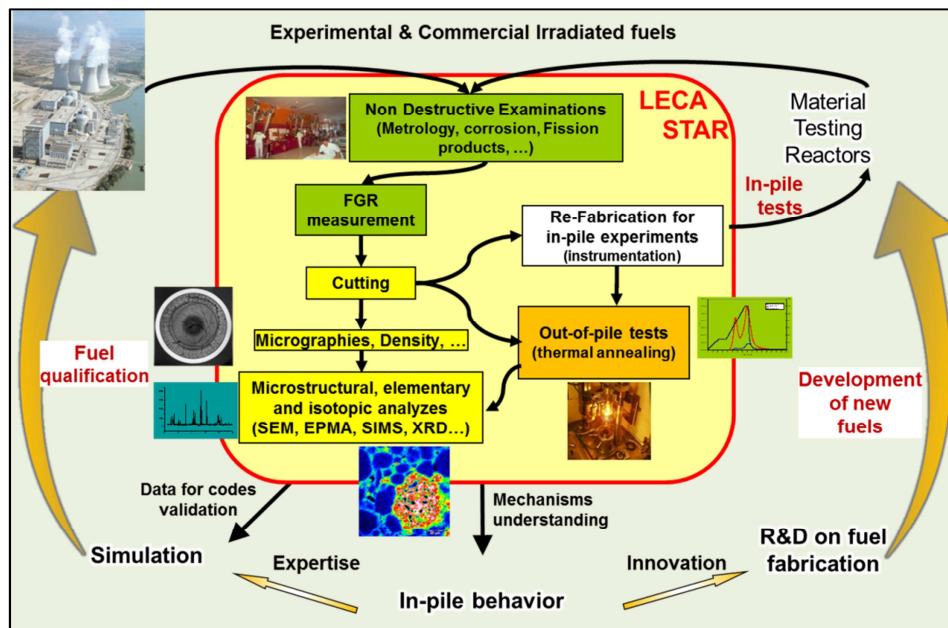


Fig. 3: The CEA Fuel Research Department

With its 20 hot cells of different sizes (up to 9m for the larger one ), the diversity of the processes, the experimental equipment available and the ability to receive and use a large variety of casks (200 operations/year), the LECA STAR is able to meet a wide range of requirements on a large diversity of fuels :

- Fuel for Light Water Reactors (LWR) (monitoring and security, Generation 2 and 3)
- End of the cycle (storage) and transport of LWR irradiated fuels,
- Fuels for the driver cores of Research Reactors especially for the JHR)
- Fuel for naval propulsion
- Generation 4 fuels

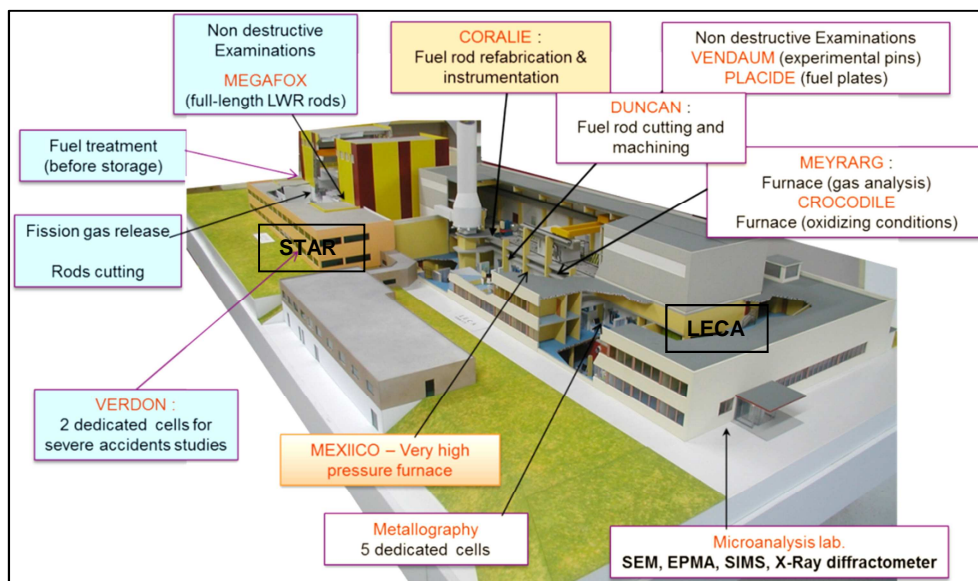
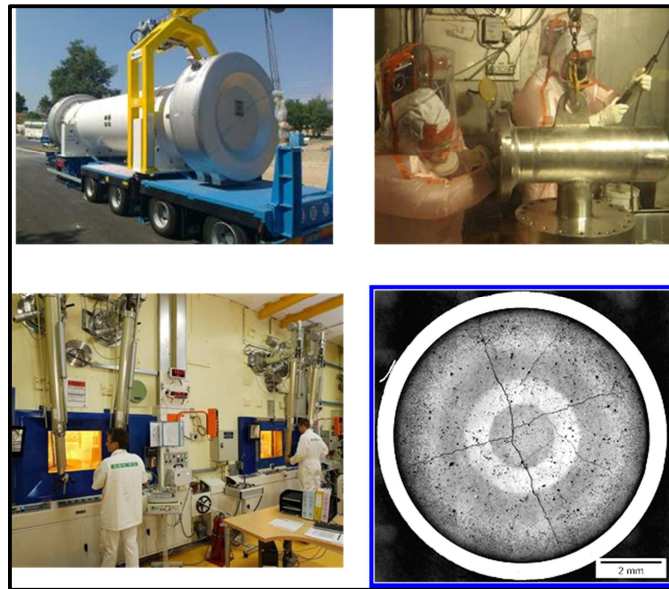


Fig. 4: The LECA STAR services

Approximately 180 people (about 150 CEA employees and 50 subcontractors' employees ) are working every day on the twenty LECA STAR hot cells. Two different sections carry out their duties in the two buildings; thus are in a permanent co-activity.

The co-activity is managed through a general schedule of the facility (monitoring of about 200 lines of tasks), which takes into consideration all the actions carried out in the installation. This schedule is revised and consolidated weekly during a meeting that brings together representatives for each type of activity (figure 5) and allows defining priorities.



**Fig. 5: Examples of activities carried out on the LECA STAR**

The two entities in place on the LECA STAR are responsible for:

- the achievement of scientific and manufacturing activities related to the experimental program in response to customer needs,
- monitoring, maintenance and evolution of processes, in support of the experimental activities,
- providing the required level of availability in the different parts of the facility to carry out these activities, in compliance with security rules and safety.

## **2.2 LECA**

The LECA is the original part of the facility, commissioned in 1964. In its hot cells, it allows the realization of tests and examinations to destructive or non-destructive examinations on irradiated fuel from power or research reactors.

To perform these tasks, the LECA has essentially:

- Ten hot cells and two shielded glove boxes ("concrete" chain, Figure 4) ,
- A laboratory microanalysis located in the basement (Figure 4 and 6).

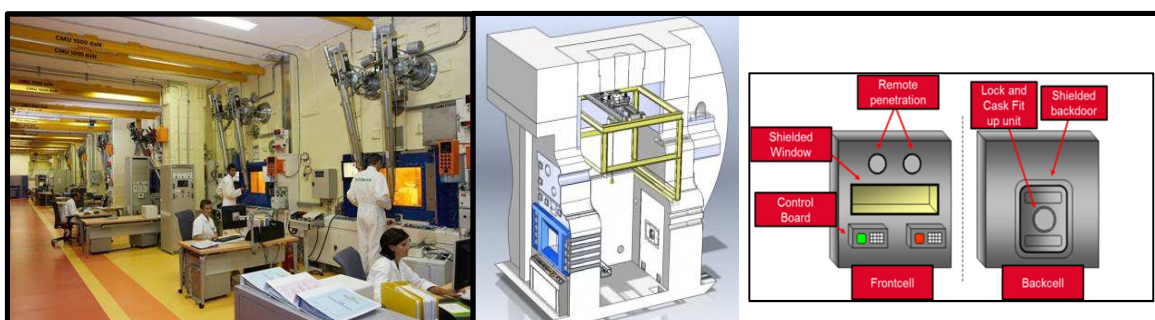




**Fig. 6: Panoramic view of the microanalysis laboratory**

The concrete chain of the LECA is the central part of the installation. It consists of ten shielded cells. In its extension are located two small lead cells equipped with glove boxes used for macroscopic and optical microscopic examination. All activities on fuel (cutting, manufacturing, containerization, sample preparation, examinations) are conducted from the front zone (figure 7) of the hot cells using remote control manipulators.

The back zones are areas specially designed for accosting casks and introducing objects by specific locks (figure 7.b).



**Fig. 7.a. Front zone of LECA    Fig 7.b. Overview and 3D graphic of a typically LECA cell**

Above the concrete chain is a handling hall with a 30-ton crane, which covers the entire surface of LECA building. It is equipped with a mobile armored lock rail that allows to position above one or other of the cells to enter or exit the material, or to facilitate the interventions inside the cells.

## 2.3 STAR

In the 1990s, the CEA has decided to build a facility for treating its spent fuel (figure 8). STAR (Station de Traitement, d'Assainissement et de Reconditionnement), is an extension of LECA and was commissioned in 1994 to meet this objective.

STAR consists mainly of 3 hot cells, 2 concrete cells in the basement dedicated to the VERDON program, and an upper handling hall equipped with a 60-ton bridge.



**Fig. 8: Container for fuel reconditioning at STAR**

STAR can also host fuel rods up to 4.4m long from PWR, and allows carrying out:

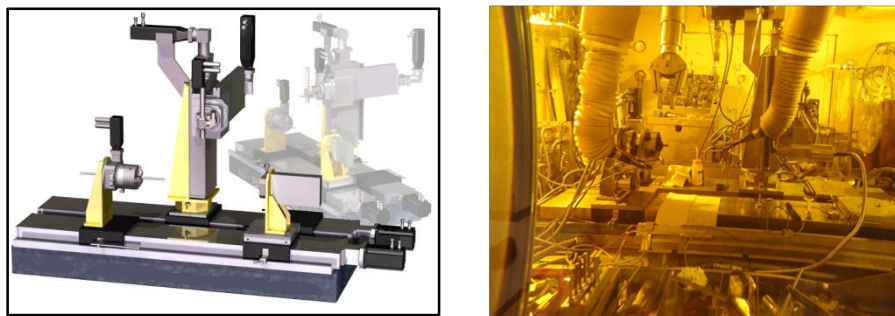
- non-destructive examinations on these industrial fuel rods,
- characterization of gases contained in the fuel rods (drilling )
- and cuts of sections to be sent to other nuclear facilities

It should be noted that STAR is nowadays the only french nuclear facility able to receive entire PWR rods. The samples sections cut and collected at STAR are transferred to the LECA for examinations, rodlets manufacturing, or transfer to other facilities.

In 2011, VERDON facility began to operate in the STAR basement; it is dedicated to the studies of release of fission products in severe accident situations.

## 2.4 Fuel rodlets manufacturing

In the 2000s, the CEA had to develop a new process for the manufacture of fuel rodlets in the context of its R & D studies on fuel elements of PWR reactors. It has been called the FABRICE process. It allows obtaining experimental rodlets (fissile column of about 600mm) from entire long rods (~4m long) irradiated in power reactors. The rodlets can be instrumented or not, and are dedicated to parametric studies research reactor. As the FABRICE process uses long of pre-irradiated rods, it requires specific handling conditions. A manufacturing bench specially designed for this purpose, called CORALIE was installed (figure 9) in a hot cell of LECA (Cell 2).



**Fig. 9: The CORALIE bench**

The different steps to manufacture a FABRICE rodlet are detailed below (figure 10).

In STAR facility by:

- Receiving the entire long rod from power reactor
- Before any operation on the fuel, performing visual examination and visual checking of the entire rod,
- Determining the part of the fissile column to be cut, by means of non-destructive examinations (dimensional inspection and spectrometry) and cutting the selected section.

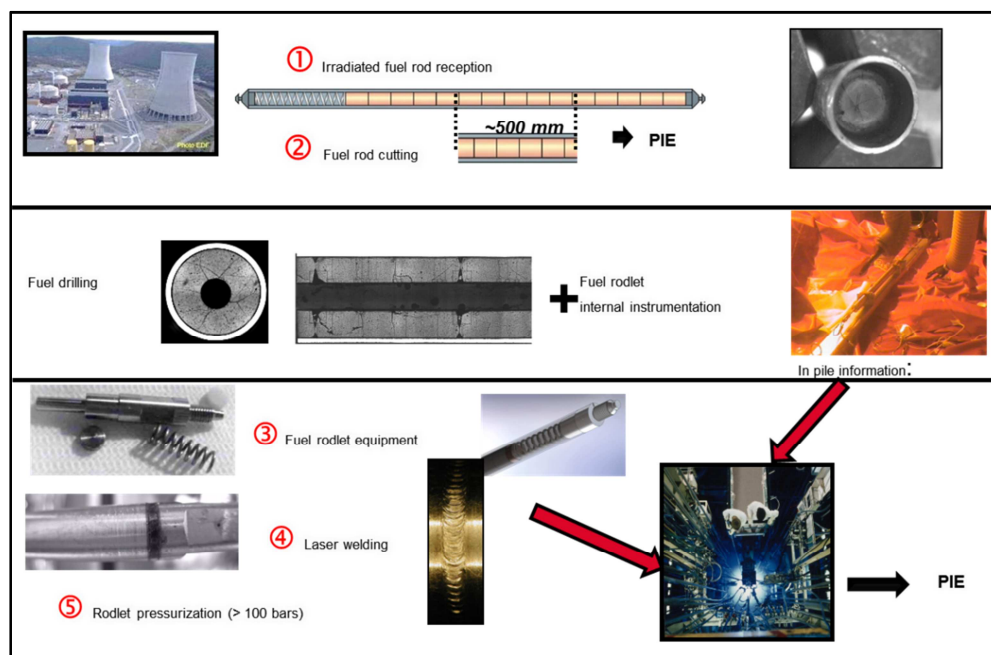
The cut length is then transferred to LECA for the operation of manufacturing on the CORALIE bench, ie:

- Machining of the clad ends to obtain a surface finish as required for welding a plug at each end,
- If the pencil must be instrumented, fuel pellet drilling and insertion of instrumentation (thermocouple, pressure transducer, .. )
- Before closing the rodlet ends, positioning of two zircaloy wedges and a spring at the ends, to maintain the fissile column,

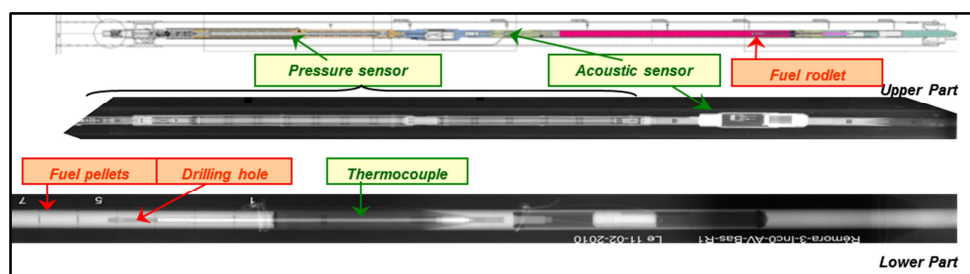


- Welding of the two plugs by laser shot,
- When the two plugs are properly welded, determination of the free volume present in and gas pressurization, then measurement of the pressure obtained in the rod.
- At the end, checking of the welds and of the sealing of the rod.

Since the installation of the CORALIE bench in the LECA STAR FABRICE, experimental rodlets have been regularly manufactured, primarily for irradiation programs in the CEA experimental reactor OSIRIS. They include the REMORA instrumented rods (figure 11) (pressure sensor, thermocouple, .. ) whose objectives were to provide online information on the thermal aspects of the fuel and the kinetics of release of fission gas [1]. Currently, FABRICE rodlets are being manufactured for the CIP (CABRI International Project) in the CEA CABRI reactor.



**Fig. 10: Main operation of the FABRICE process**



**Fig. 11: REMORA rod manufactured using the FABRICE process**

The feedback of the first manufacturing as well as changes in the organization (working patterns, training of the operators to maintain the right level of competence, establishing a quality control process) have allowed improvement in terms of product traceability, reliability and increased manufacturing capacity [2].

This must be consolidated and developed to be able to submit proposals that meet the needs expressed by future JHR client on the horizon of the 2020s. To this end, while continuing its current activities, LECA STAR is committed for the next five years in a process of innovation on both its manufacturing processes and generally the operation on fuels (automation, control techniques) and techniques for examinations.

## 2.5 Thermal Treatment

In order to study the fuel behavior during incidental or accidental transients, LECA STAR has implemented different devices dedicated to heat treatment under several conditions.

### **MERARG:**

This device is designed to characterize the release of fission products (FP) and Helium from irradiated nuclear fuel rods subjected to thermal transients. This device comprises three main parts: induction furnace, gamma spectrometry detector on line, and micro-chromatograph [3]. A picture of a sample heated by the induction furnace is given Fig. 12.



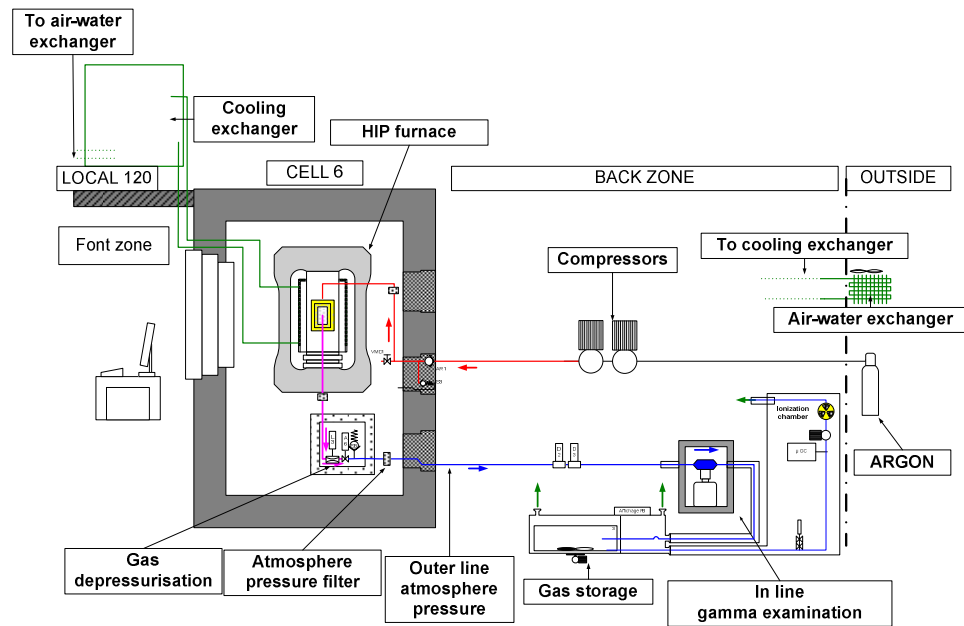
**Fig. 12: Sample heated in the MERARG loop**

### **MEXIICO:**

During normal or incidental ramp transients, nuclear fuel is submitted to stress that affect its behavior. For instance, fission gas release as well as fuel fragmentation are phenomena depending on local stress state. Since these phenomena are taken into account in safety analysis, like for LOCA conditions, it is of great interest to be able to perform analytical experiments during which stress and temperature can be independently monitored. In this context, to complete MERARG device, a new experimental loop has been launched, named MEXIICO which enables to perform temperature transients under pressure within a large domain up to 1600°C and 1600 bars.

The MEXIICO experimental loop is worldwide a unique equipment in a hot laboratory. It is located in the C6 hot cell of the LECA-STAR facility. The experimental team has just finished the associated commissioning tests and it will soon operate tests on irradiated fuels. The first tests will be performed under the frame of the international NFIR program.

Fig. 13 (a and b here after) shows the implantation of MEXIICO at LECA.

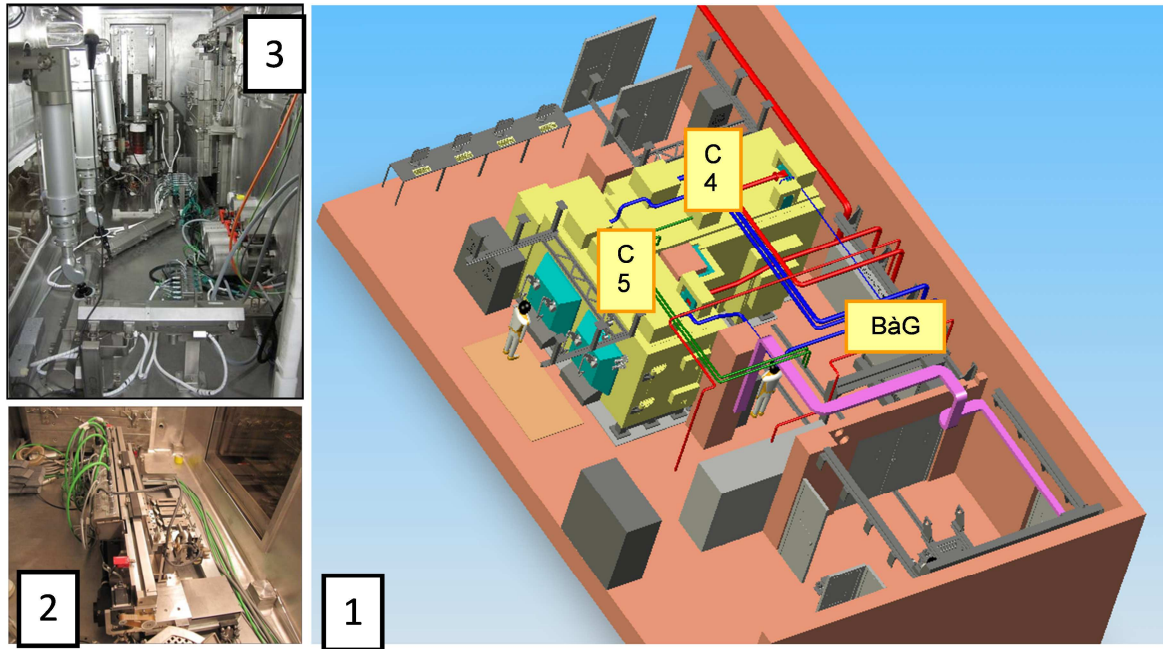


**Fig. 13: Implantation of MEXICO HIP Furnace**

### VERDON:

Fig. 14 shows an overview of the VERDON facility. The only facility of its kind worldwide, VERDON is used to heat fuel samples to very high temperatures (up to meltdown) in an induction furnace under a controlled atmosphere to reproduce severe accident scenarios [4]. All the parameters can be measured in this facility due to the very precise instrumentation equipping the experimental loop (three continuous gamma spectrometry stations, temperature gradient tubes, iodine filter, etc.).

In particular experiments are being performed on re-irradiated fuels (today in OSIRIS, tomorrow JHR) which yield a complete Source Term evaluation.

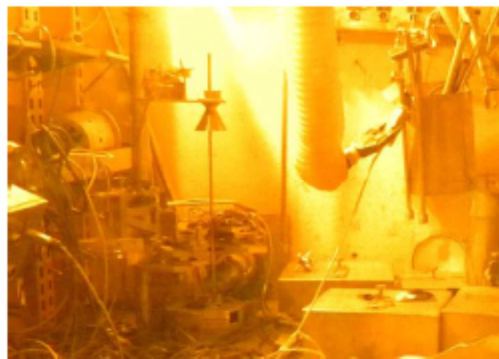


**Fig. 14: VERDON facility**

## 2.6 Non Destructive Examinations

The Non Destructive Examinations on fuel rods irradiated in nuclear power plants allow an effective monitoring of the good behavior of these elements under nominal operation. Moreover these examinations also have a main interest for studies on the fuel and the cladding behavior studies.

For PWR fuel, Non Destructive Examinations are usually carried out on the MEGAFOX bench in the STAR facility. In addition, we use another bench, in order to widen the range of such measurements beyond the PWR standard (nominal diameter of 9.5 mm and lengths up to 4,5 m). This second bench, located in LECA facility is named VENDAUUM for Vertical END AUtomatic and Modular (figure 15). It allows all the classical Non Destructive Examinations, (visual, length measurement, diameter measurement, oxide thickness measurement, health measurement and gamma spectrometry), of irradiated elements with the same good accuracy as the MEGAFOX's one. But, thanks to the VENDAUUM's characteristic, these examinations are feasible in a broad range of diameters, going from 4 to 40 mm, and lengths, up to 2.7 m [5].



**Fig. 15: VENDAUUM bench**

This large range thus allows Non Destructive Examinations on irradiated elements coming from a wide range of reactors: fast reactors, as PHENIX for example, or experimental reactors (CABRI, Osiris, Halden... and the JHR reactor in a near future). Thus, the Non



Destructive Examinations realized on the VENDAUUM bench can support programs on fuels for transmutation, fast reactors, ....

In addition to the support for the qualification of fuels in nominal condition, measurements realized on VENDAUUM can give information on fuel elements under incidental and accidental situations with strong and exacerbated deformations, or on storage conditions.

Lastly, thanks to the calibrations with standards, to the relevant choice of the axial and angular origins, and to the excellent storage of our measurements, this bench is perfectly adapted to the follow-up and the analysis of a fuel element at each stage of experimental processes such as successive heatings, re-irradiations and power ramps.

## 2.7 Destructive Examinations

The development of advanced nuclear fuels for Generation II & III reactors and innovative fuels for future reactor designs (Generation IV) leads the research community and the nuclear industry to request more and more detailed experimental characterization and post-irradiation examination (PIE) of highly irradiated nuclear fuels [6-9].

Thus, LECA is equipped with a metallographic line, comprising devices used to prepare samples and make density measurements. An optical macroscope and microscope and the related data acquisition and image analysis systems are used to observe the evolution of the microstructure with irradiation.

In order to characterize phenomenon involved at a lower scale, the microanalysis laboratory is equipped with complementary devices:

- A FIB SEM from Carl Zeiss (Fig. 16) on which are mounted an EBSD Oxford and a removable in situ nano-indenter from CSM (2 nN-500 mN) in the chamber of the microscope.
- An electron microprobe (EPMA)
- A secondary ion mass spectrometer (SIMS)
- An X-ray diffraction
- A profilometer (confocal microscopy).



**Fig. 16: FIB SEM in the microanalysis laboratory**

In order to answer the increasing demand for validation of fuel modeling codes which require experimental information continuously at a lower scale, a Transmission Electron Microscope will be installed at the LECA in 2016. The acceptability of irradiated fuels from LECA facility to MARS beam line at SOLEIL synchrotron will be another way to significantly improve our understanding of fuel.



### 3. Conclusion

Because of its capabilities, both in terms of operations on fuel and remanufacturing of experimental pencils (instrumented or not), the LECA STAR offers a range of services to meet the diverse needs of customers for their experimental programs, from non-destructive examinations on entire long rods to microscale analysis of the fuel via analytical tests to study accidental conditions.

This offer is now evolving to maintain the facility at the level of excellence required to meet the demands of future customers for the startup of the CEA new reactor experimental JHR.

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