Investment and installation project of a Mechanical tensile Machine with a high-temperature furnace with controlled atmosphere in hot cell M18 of the LECI hot lab facility

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The CEA LECI hotlab facility is devoted to the study of the mechanical behaviour and microstructure of irradiated nuclear industry materials. In order to study the behaviour of the materials in nominal, incidental, and accidental conditions for the 4th generation reactors (sodium or gas cooled fast reactors), the Department of Nuclear Materials (DMN) is investing in a tensile test machine with a high-temperature furnace with controlled atmosphere (He, Ar, or high vacuum). After an initial investment in a DMN 'cold' lab (SRMA), which allowed us to validate the choice of equipment and options, the DMN launched the investment of the facility in the M18 hot cell of the LECI. The machine, which will be the only one of its kind in Europe installed in a hot cell, is composed of a metallic furnace that will allow mechanical testing at up to 1200°C, and a graphite furnace that can reach 1800°C. The tests under consideration are bending tests (3 or 4 points) and tensile tests. The machines currently used in the LECI hot cells allow testing at up to 950°C but under a plain air environment. The requirement for a controlled atmosphere comes from the need to avoid oxidation at the very high testing temperatures.

The materials to be tested include reference materials for the nuclear fuel assembly of the first ASTRID core (*Advanced Sodium Technological Reactor for Industrial Demonstration),* ferritic-martensitic ODS (Oxide Dispersion Strengthened) steels, and other advanced metallic materials and ceramic composites, such as SiC/SiC.

To realize this investment, the CEA deals with the technical monitoring of the machine (nuclearization of the equipment, remote handling, space management in the hot cell) and the project management with the following partners:

- INSTRON for the design of the mechanical nuclearized frame;
- AET TECHNOLOGIES for the design of the nuclearized furnace with controlled atmosphere (metallic and graphite furnaces);
- The CEA LECI operating team (SEL) and its subcontractors for engineering studies (introduction of the machine, operation in the hot cell) and for the implementation of utilities in the nuclear installation: electricity (power supply), piping (water, gas), machining walls of the hot cell (drilling, stainless steel, lead, biological shielding….), handling (opening of the hot cell, machine introduction, heavy components (transformer, heat exchanger…));
- The SEL and a subcontractor for the constitution of the safety file for the approval of the hot cell commissioning.

This presentation highlights the different steps of the project, from the technical setup through the work in the nuclear installation. It also gives a short overview of the capabilities of the new facility of the LECI.

Keywords: high-temperature furnace, controlled atmosphere, tensile test machine, hot commissioning, safety file

1. INTRODUCTION

The M line of the CEA LECI hot lab facility, which consists of 19 lead-shielded hot cells, is dedicated to the study of the mechanical behavior and microstructure of nuclear industry materials after irradiation (without fuel). In order to study the behaviour of the materials in nominal, incidental, and accidental conditions for the 4^{th} generation reactors (sodium or gas cooled fast reactors), the Department of Nuclear Materials (DMN) is investing in a tensile test machine with a high-temperature furnace with a controlled atmosphere (Helium, Argon, high vacuum).

After an initial investment in the DMN 'cold' lab: Service for Applied Metallurgical Research (SRMA), which allowed us to validate the choice of equipment and options, the DMN launched the investment of the facility in the M18 hot cell of the LECI. The machine is composed of a metallic furnace that will allow mechanical testing at up to 1200°C, and a graphite furnace that can reach 1800°C. The machines currently used in the LECI hot cells allow testing at up to 950°C but under a plain air environment. The requirement for a controlled atmosphere comes from the need to avoid oxidation at the very high testing temperatures.

2. ORGANIZATION WITHIN THE SEMI

For this project, the CEA/DMN/SEMI/LCMI (Laboratory for Mechanical Behaviour of Irradiated Materials of the Section for Studies of Irradiated Materials) [1], assisted by the CEA/DMN/SRMA/LC2M (Laboratory for Study of the Mechanical Behaviour of Materials) has used the lessons learned during the installation of the 'cold' equipment to organize and execute the technical monitoring of the machine and the project management. Issues involved in the project include the nuclearization of the equipment, remote handling, and space management in the hot cell. The following partners are also participating in the project (see *Figure 1*):

- INSTRON for the design of the mechanical nuclearized frame;
- AET TECHNOLOGIES for the design of the nuclearized furnace with controlled atmosphere (metallic and graphite furnaces);
- The CEA LECI operating team (SEL) and its subcontractors (SALVAREM) for engineering studies and implementation of the work in the nuclear installation: electricity, piping, machining walls of the hot cell, handling (opening of the hot cell, machine introduction, heavy components);
- The SEL and a subcontractor (MILLENIUM) for the constitution of the safety file for the approval of the hot cell commissioning by the Nuclear Safety Authority (ASN).

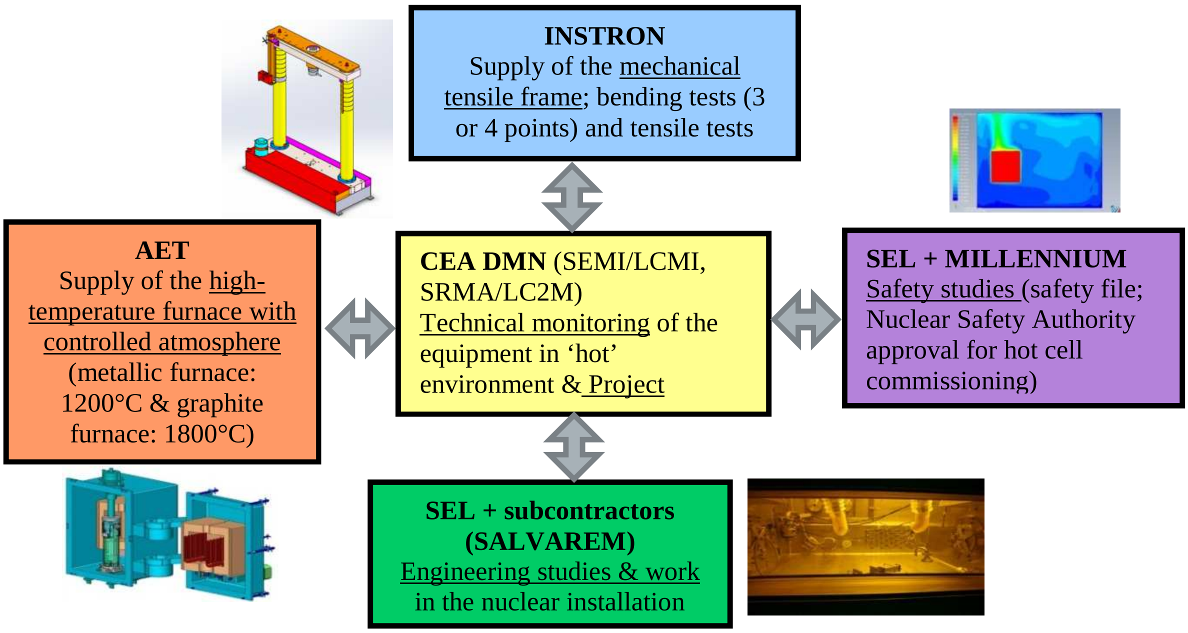


Figure 1: Project management

3. MECHANICAL TEST EQUIPMENT:

3.1 Mechanical test equipment in 'cold' lab SRMA [2]

Based on the experiences obtained from a similar machine that was set up in SRMA in 2009, the supplied equipment has been designed to be compatible with the requirements of operation in a hot cell with remote handling (see *Figure 2*).

Figure 2: 'Cold' equipment in SRMA

3.2 Mechanical test equipment in 'hot' lab SEMI

The equipment to be commissioned in the M18 hot cell of the LECI includes various facilities, which are shown in *Figure 3*.

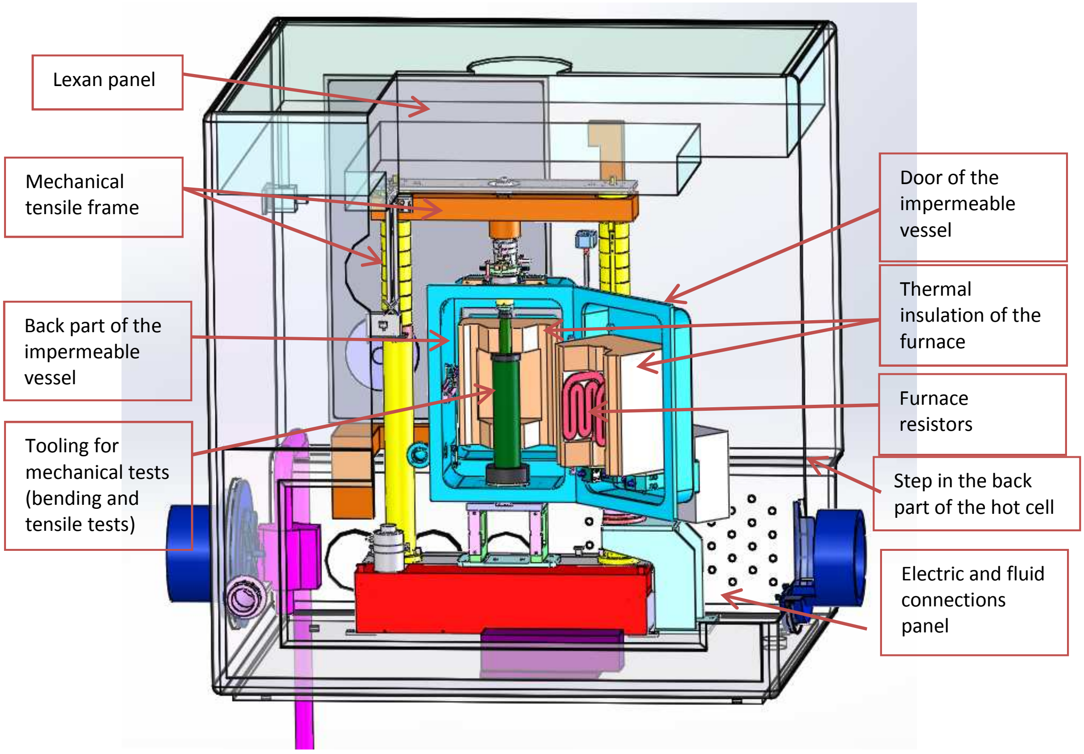


Figure 3: Global view of the M18 hot cell containing the mechanical test equipment (with opened furnace)

- A mechanical tensile machine furnished by INSTRON ([3], [4]) has the following characteristics:
    - two load cells (10 kN or 1 kN) alternatively mounted,
    - a 30 kN capacity with a 650 mm wide space for testing,
    - a maximum travel of the cross rail of about 1135 mm,
    - a supply voltage of 240V,
    - adjustable speed of the cross rail from 0.001 to 500 mm/min,
    - a retraction speed of the cross rail of 600 mm/min with controlled deceleration for precise positioning.
- A furnace with a controlled atmosphere (He, Ar, vacuum) supplied by AET Technologies ([5], [6]) has the following characteristics:
    - water-cooled inner walls in a closed circuit of welded pipes,
    - porthole (movie camera and pyrometer),
    - metallic furnace (molybdenum) for testing at temperatures up to 1200°C, for metallic materials; heating rate: 5 °C/mn,
    - graphite furnace for testing between 1100°C and 1800°C, for ceramics or graphite specimens; heating rate: 30 °C/mn,
    - the controlled atmosphere allows avoiding oxidation at the very high testing temperatures.

- The materials to be tested include reference materials for the nuclear fuel assembly of the first ASTRID core (*Advanced Sodium Technological Reactor for Industrial Demonstration*), stainless steels (ferritic-martensitic ODS steels, austenitic, advanced austenitic), and other advanced metallic materials and ceramic composites, such as SiC/SiC.

- The fixtures for the mechanical tests have been designed to accommodate bending tests (3 or 4 points) and tensile tests (in compression) (see *Figure **4***). They contain elements made of molybdenum, tungsten, or C/C.

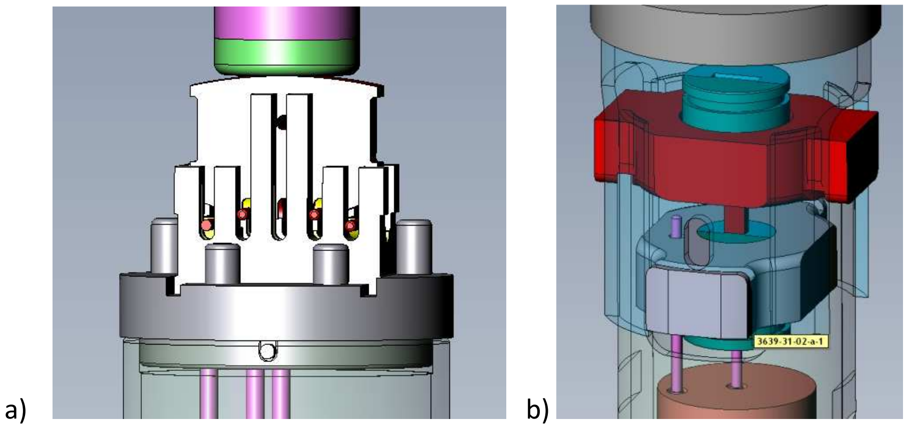


Figure 4: Fixtures for mechanical tests for: a) bending tests (3 or 4 points) ; b) tensile tests

- The instrumentation will be the following:
    - temperature (type C and K thermocouples, pyrometer),
    - displacements (transmission rods + displacement sensors),
    - force (load cells 10 kN or 1 kN),
    - process monitoring (flow rate, pressure, O_2 content…).

- The role of the LCMI consists of leading the acquisition of the equipment and performing the testing once the equipment is operational.

3.3 Technical monitoring of the facility

The nuclearization of the mechanical frame was made easier by the fact that it was similar to another machine currently in use in the M03 hot cell. The main challenge was the remote handling of the different parts of the frame (global access, load cells positioning), because the hot cell is smaller than the others in the M line because it contains a step in the back part of the hot cell.

The nuclearization of the furnace was also complex. However, it was possible thanks to the similar facility in the “cold” lab SRMA and the prototype fixtures that we machined to make sure they were adapted for remote handling: fixtures, tensile assembly, heating casket, thermocouples, optical pyrometer, monitoring of water and gas flow, access to the furnace with the robotic arms, etc.

The space management also had to be studied because of the small size of the hot cell, which was not initially designed for a machine this large. In contrast, most of the other hot cells in the LECI were designed for the machines that they contain. The panel of electric connections in the back part of the M18 hot cell, which is vertical in most cells, is horizontal and prevents the machine from being positioned against the back wall. To make sure the space in the hot cell is sufficient for the future operating, testing, and storage, it was necessary to create solid

models using Solidworks (see Figure 3) of the entire hot cell, including the facility, the fixtures, the furnace, the various pumps, the vacuum and gas sets, and the storage box.
A company specializing in remote handling (Getinge) also performed a study to make sure all of the facilities in the hot cell were accessible and to examine the impact of using robotic arms of different sizes.

4. THE LECI OPERATING TEAM (SEL): ENGINEERING STUDIES AND WORK IN THE NUCLEAR INSTALLATION

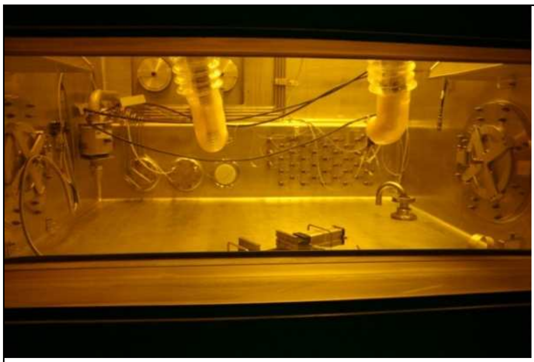
4.1 Engineering studies [7]

A subcontracting society of SEL (Salvarem), in cooperation with the CEA and the societies INSTRON and AET, is carrying out engineering studies, in order to bring to light all of the actions that must be taken and the modifications that must be made to the existing hot cell to connect the new facility (electricity, gas, fluids) once introduced in the hot cell, and then to operate it.
The studies will also allow us to precisely define the method for introducing the machine in the hot cell, as well as the necessary tooling for the introduction and the connection to the electric and fluid circuits.

4.2 Implementation of work in the nuclear installation [7]

The necessary work for the installation of the facility in the hot cell concerns (see *Figure 5*):

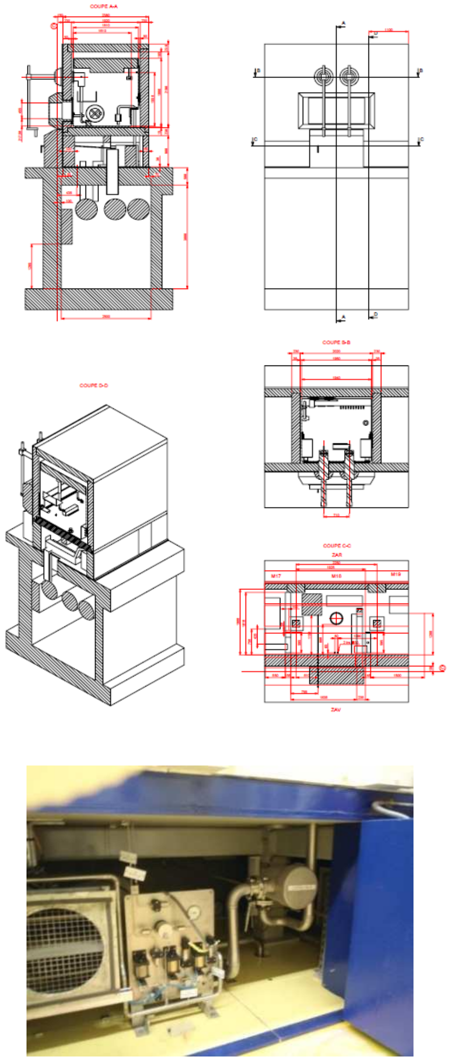
- The connection to various electric and fluid circuits:
  - electric power circuit: installation of the transformer in the technical gallery,
  - cooling circuit: installation of the heat exchanger in the technical gallery,
  - gas circuits: installation of the gas panel (Ar and He) outside the building,
  - circuits for control-command measurement: installation of the control-command system in the front area, positioning of the electric crossings inside the hot cell,
- Machining the walls of the hot cell (drilling, stainless steel, lead, biological shielding….) to provide all of the connections,
- Handling: opening the hot cell, machine introduction, heavy components,
- And the connection of the machine once introduced in the hot cell.


a)


b)

c)

d)



e)

Figure 5: a) Hot cell, b) Front area, c) Technical gallery, d) Unit of the hydraulic generator, e) Hot cell basement

4.3 Safety study [8]

The safety analysis is based on the feasibility study made in 2009 by AET and the CEA for the high-temperature furnace in hot cell M18. Three incidental referenced scenarios, including the failure of the cooling system, were studied with associated thermal calculations and mitigating measures. The conclusions have shown that the integrity of the confinement was not compromised.

The SEL also analysed how well AET's feasibility study addressed the security and safety imperatives of the nuclear installation (INB). They concluded that the results of the feasibility study were consistent with the safety imperatives of the INB and the M line.
On this basis, the society MILLENNIUM wrote the safety file, before sending it to the French Nuclear Safety Authority (ASN) to get the approval for the hot cell commissioning.

4.4 Specifications (electric, design) linked with « hot » commissioning

- Safety in the enclosed hot cell:
  - Hot cell static confinement,
  - Hot cell dynamic confinement with depressurization (-120 Pa min) through extraction,
  - Fire detection, with a maximum temperature threshold in the hot cell of 50°C,
- Behaviour under radiation:
  - Maximum dose rate of 5 Sv/h,
  - Installation lifetime of at least 30 years,
- Remote handling:
  - Maximum load at the tip of the robotic arm of 5 kg,
  - Accomplishment of most movements with a single robotic arm,
  - Possibility to block the mobile parts in position,
  - Adaptation of the masses and dispositions of the materials to the remote handling,
- Handling in hot cell:
  - Use of lifting units (crane in the ceiling of the hot cell: maximum load: 50 kg),
  - Components introduced through the cell roof thanks to an introduction air lock (Φ 320 mm, h 600 mm),
- Calibration (strength, displacement…):
  - Specific measurement lines,
  - Sensors dedicated to verifications,
- Interfaces:
  - Electric connections: C1SH cables and FCI SOURIAU plugs supplied by the CEA per INSTRON/AET specifications; cabling by INSTRON/AET,
  - Cable lengths of 3-4 m in the hot cell, 10-12 m outside the cell,
- Materials:
  - Conform to norms AFNOR, stainless, with an even surface (to facilitate possible decontamination), non-magnetic.

5. CONCLUSION

The project is complex and has many stakeholders with different responsibilities, each of whom has their own schedules with different time scales. However, the different schedules are often interdependent and must all converge at the end of the project. The factory acceptance by INSTRON took place in August 2012; the factory acceptance by AET will take place in October-November 2012.
The delivery of the machine {frame + furnace} to CEA Saclay is planned after installing the utilities in the nuclear installation (beginning of 2013) and the opening of the hot cell, pending the Nuclear Safety Authority's approval for commissioning. The introduction of the machine

in the hot cell will follow these steps, followed by the partial acceptance, and then the global acceptance.
In 2013, we will perform 'cold' qualification tests using non-irradiated materials, before the 'hot' commissioning of the cell for irradiated materials, followed by the first tests on irradiated materials.

6. REFERENCES

[1] C. Vaille, X. Averty, Machine haute température sous atmosphère contrôlée en M18: note bilan 2011 sur l'investissement, DEN/DANS/DMN/SEMI/LCMI/NT/2011-038/A, 12/2011

[2] P. Wident, Machine d'essai haute température sous vide et atmosphère contrôlée: cahier des charges fonctionnel, note technique DMN/SRMA/LC2M/ST/2006-2766/D, Décembre 2007

[3] P. Mongabure, Cahier des charges fonctionnel de la machine de traction compression pour l'équipement d'essais haute température à implanter dans l'enceinte blindée M18 du LECI, DEN/DANS/DMN/SEMI/LCMI/ST/09-013/A, 06/2009

[4] X. Averty, C. Vaille, D. Pueyo, Marché INSTRON pour une machine de traction compression pour l'équipement d'essais haute température implanté en cellule, 10B2442 – PM V5 20-07-11

[5] P. Mongabure, Cahier des charges fonctionnel – machine d'essai haute température sous atmosphère contrôlée à implanter dans l'enceinte blindée M18 du LECI, DMN/SEMI/LCMI/ST/2006-006/C, 01/2008

[6] X. Averty, D. Pueyo, Marché AET pour l'étude et la fourniture de deux enceintes haute température, 10B2441 - AVT2 4000345377/P5B51, 03/2011

[7] L. Roux, C. Vaille, Cahier des charges pour la maîtrise d'œuvre de la réalisation de travaux d'adaptation de la cellule M18 du LECI dans le cadre de l'implantation d'un équipement d'essai à haute température , SEMI-SEL-SP-208-A, 03/2012

[8] L. Poirson, Cahier des charges spécifique pour la prise en compte des exigences sûreté de la machine haute température en M18, DEN/DANS/DMN/SEMI/SEL/DS/067-A, 23/06/06