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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CEA/DEN/DANS/DMN/SEMI/LCMI

DEN/DANS/DMN/SEMI/LCMI
HOTLAB 2012 Marcoule, France | C. Vaille, L. Roux, P. Coffre, J.P. Pizzanelli, M. Bono
24th - 27th of September 2012
DMN: Department of Nuclear Materials (~180 permanent members)
- Characterization of materials for nuclear applications: comparison irradiated // non irradiated
- Modelling: constitutive equations and behaviour models for materials in multi-scales in normal, accidental and long term conditions.

LECI Hotlab = 3 lines of hot cells (I, K, M)
- M line (2005): 19 lead-shielded hot cells
  - (Defueled) irradiated metallic or ceramic materials
  - Mechanical characterization in research, surveillance or investigation programs
  - Microstructural examination

LECI Hotlab within the DMN:

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(268,70),(746,323)
PURPOSE OF THE PROJECT

- Investment of the DMN in two high temperature equipments: cold / hot environments → the DMN is the project manager
- Materials to be tested: reference materials for the nuclear fuel assembly of the first ASTRID core (Advanced Sodium Technological Reactor for Industrial Demonstration), stainless steels (austenitic, advanced austenitic, ODS steel); ceramics, SiC/SiC, graphite...

- The M18 hot cell will house a tensile test machine with a high-temperature furnace (up to 1800°C) with controlled atmosphere (He, Ar, high vacuum).
- Controlled atmosphere → to avoid oxidation at the very high testing temperatures

Purpose: to study the behavior of materials in nominal, incidental and accidental conditions for the 4th generation reactors (sodium or gas cooled Fast Reactors)
EXECUTIVE SUMMARY

Project management

Mechanical testing equipment: CEA/DEN/DMN (Department of Nuclear Materials)
- Mechanical test equipment in “cold” lab SRMA/LC2M (Laboratory for Study of the Mechanical Behaviour of Materials)
- Mechanical test equipment in “hot” lab SEMI/LCMI (Laboratory for Mechanical Behaviour of Irradiated Materials of the Section for Studies of Irradiated Materials)
- Technical monitoring, facility nuclearization and simulated hot cell

Settings in nuclear installation: SEMI/SEL (LECI operating team)
- Equipment integration in M18 hot cell (electric power circuit, cooling water, gas, control-command system)
- Machine introduction in the hot cell
- Specifics of « hot » commissioning
- Safety issues
PROJECT MANAGEMENT
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INSTRON
Supply of the mechanical tensile frame; bending tests (3 or 4 points) and tensile tests

CEA DMN (SEMI/LCMI, assisted by SRMA/LC2M)
Technical monitoring of the equipment in ‘hot’ environment & Project management

AET
Supply of the high-temperature furnace with controlled atmosphere (metallic furnace: 1200°C & graphite furnace: 1800°C)

SEL + MILLENNIUM
Safety studies (safety file; ASN (nuclear safety authority) approval for hot cell commissioning)

SEL + subcontractors (SALVAREM)
Engineering studies & work in the nuclear installation
- Electricity (necessary supply)
- Piping (water, gas)
- Machining walls of hot cell (drilling, stainless steel, lead, biological shielding….)
- Handling (opening the hot cell, machine introduction, heavy components)

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MECHANICAL TEST EQUIPMENT
MECHANICAL TEST EQUIPMENT IN “COLD” LAB

- Initial investment in “cold” lab: delivery in 2009.
- The equipment was designed to be compatible with the requirements of operation in a hot cell with remote handling.

AET system software

Gas panel outside the building
FURNACE AND TESTING DEVICE IN “COLD” LAB

350°C < Metallic furnace < 1200°C

Environment: He / Ar / Vacuum

Ceramic load string

1100°C < Graphite furnace < 1800°C

Environment: He / Ar

Graphite load string

→ All of the devices operate in compression
GLOBAL DESCRIPTION OF THE MECHANICAL TEST EQUIPMENT M18

- Mechanical tensile frame
- Back part of the impermeable vessel
- Tooling for mechanical tests (bending and tensile tests)
- Lexan panel
- Door of the impermeable vessel
- Thermal insulation of the furnace
- Furnace resistors
- Step in the back part of the hot cell
- Electric and fluid connections panel
DESCRIPTION OF THE MECHANICAL TEST EQUIPMENT M18: MECHANICAL FRAME

- **Mechanical tensile machine - INSTRON** (similar to another tensile frame in hot cell M03):
  - Two alternatively used **load cells** (10kN and 1kN)
  - A **30kN capacity** with a 650 mm wide testing space
  - Maximal **travel of the cross rail** of about 1135 mm
  - **Supply voltage** of 240V
  - Adjustable **speed of the cross rail** from 0.001 to 500 mm/min
  - **Retraction speed** of the cross rail: 600mm/min with controlled deceleration for precise positioning

Frame of M18 in INSTRON factory
Furnace with controlled atmosphere (He, Ar, vacuum) – AET
- Water-cooled inner walls in a closed circuit of welded pipes
- 1 porthole (movie camera + pyrometer)
- Metallic furnace (molybdenum): T<1200°C (metallic materials), heating rate : 5°C/min
- Graphite furnace: T<1800°C (ceramics, graphite), heating rate : 30°C/min
- Controlled atmosphere → to avoid oxidation at the very high testing temperatures

Instrumentation:
- Temperature (type C or K thermocouples, pyrometer)
- Displacements (transmission rods + displacement sensors)
- Force (load cells 10 kN or 1 kN)
- Process monitoring (flow rates, pressure, O₂ content…)

DESCRIPTION OF THE MECHANICAL TEST EQUIPMENT M18 : FURNACE
**DESCRIPTION OF THE MECHANICAL TEST EQUIPMENT M18: FIXTURES**

- **Mechanical tests fixtures** (bending tests (3 or 4 points) or tensile tests):
  - Elements made of **molybdenum, tungsten or C/C**
  - Fixtures designed for remote handling in hot cell M18
  - Prototypes verified during the facility tests of the “cold” equipment at the cold lab + fabrication of prototype fixtures

- 3 points or 4 points **bending tests** with a multi-geometry comb
- Specimen 25 x 2.5 x 2 mm, 45 x 4 x 3 mm

- **Inversed tensile tests**
- Monolithic or composite specimen
The furnace is fastened on a **cylinder** positioned around the column of the machine but completely dissociated (sufficient backlash).

A **structure** transfers the furnace’s weight to a **distribution plate** on the floor of the vessel of the hot cell.

The supporting cylinder and the load transferring structure were produced by AET; INSTRON integrated them on the frame during the assembly of the machine in England.

Two **drilled holes** in the lower side of the mobile cross rail will be used to fasten the furnace to extract it from the test space for operating (ex: load cells switching).
**TECHNICAL MONITORING OF THE FACILITY**

- **Nuclearization of the mechanical frame**
  - Similarities with tensile frame in another hot cell (M03) but **hot cell M18 smaller** (step)
  - Reduction of the length of the back feet
  - **Challenge = remote handling and global access** to the frame (load cells positioning)

- **Nuclearization of the furnace**
  - Similar facility in the “cold” lab
  - Use of **prototype fixtures**
  - **Challenge = remote handling**: fixtures, tensile assembly, heating casket, optical pyrometer, thermocouples, monitoring of water and gas flow, global access to the furnace

- **Space management**
  - **Sufficient space** for operating and testing, despite the size of the hot cell
  - **Panel of electric connections** horizontal → prevents machine from being positioned against back wall
  - **Storage requirement** in hot cell: facility, fixtures, furnace, pumps, vacuum and gas sets, storage box
  - **Design with Solidworks**: 3D Simulation of hot cell M18 and integration of the equipment by AET/CEA
  - **Accessibility study** with robotic arms by GETINGE
  - **Simulated hot cell** (*see next slide*)

**Areas to remove**
Simulated hot cell designed for the receipt of the frame and furnace in November-December 2012:

- Validation of the remote handling aspect (end of design, technical development)
- Acceptance visit
- Qualification of the facility

Construction in June - July 2012 in AET factory;

Receipt of the remote manipulators and frame: August 2012

Possible use by SALVAREM (subcontractor for works in the nuclear installation) for engineering studies and especially to validate the introduction method of the facility in hot cell
WORK IN NUCLEAR INSTALLATION FOR THE INTEGRATION OF THE FACILITY IN HOT CELL
INTEGRATION OF THE EQUIPMENT IN M18: VARIOUS INSTALLATION AREAS

- **Water supply:** 8 water crossings in hot cell, 2 pumps and a buffer volume outside – heat exchanger in technical gallery
- **Gas:** manual gates inside the hot cell; gas panel in front area with crossing
- **Vacuum:** vacuum pump and manual gates inside the hot cell
- **Electric connection:** installation of the transformer in the technical gallery
- **Control and command system:** in front area

**Basement + technical gallery**

Hot cell + Front area

Hydraulic generator unit
INTEGRATION OF THE EQUIPMENT IN M18: COOLING WATER CIRCUIT

- Heat exchanger outside the hot cell, *a priori* installed in the technical gallery

- Drilling of stainless vessel for passing of water piping (8 crossings) + installation of impermeable crossings

- Checking of the dimensioning of the piping in technical gallery from the cold generator of the M line to ensure the necessary power

- Creation of an extra hopper in the biological protection (in the floor of the hot cell at the back of the vessel)

- Installation of the piping from the heat exchanger to the furnace through this hopper

- Wiring of the electric elements (actuator and measures)
INTEGRATION OF THE EQUIPMENT IN M18: GAS CIRCUIT

- Gas panel (helium-argon frame) installed outside the building
- Drilling of stainless steel vessel for passing of gas piping + installation of impermeable crossings
- Piping travel between gas supply (He-Ar frame, compressed air supply) and impermeable crossings
- Piping travel between the impermeable crossings (He, Ar and compressed air) and the furnace
- Wiring of potential electric elements on the gas panel
**INTEGRATION OF THE EQUIPMENT IN M18: ELECTRIC POWER CIRCUIT**

- **Electric transformer** outside the hot cell, a priori installed in the **technical gallery** (the basements of the hot cell M18 and of the neighboring hot cell M17 are too full)

- Drilling of hot cell floor or walls (biological protection and stainless vessel) for the **inlets of current for the furnace** (power 30 kW, single-phase current 380V)
Installation of the **control-command system** in front area

Modifying of the distribution and **positioning of the electric crossings** inside the hot cell

Laying of **cable channels** between the control-command frame and the panel of electric crossings of the hot cell

**Electric supply** of the control-command frame
INTRODUCTION OF THE MACHINE IN THE HOT CELL

- **Frame too wide** compared to the back **opening (lexan panel)** of M18
- **Radiological controls** before opening the hot cell (“clean” cell):
  - opening of the roof air lock with radiological controls,
  - opening of the hot cell,
  - fitting of **biological protections** with the neighboring hot cells M17 and M19,
  - “downgrading” of the hot cell M18
- **Removal of the shielding window** in front area
- **Machine introduced in a lying position from front area** thanks to a **travelling crane** of the front area (10 tons) and a **specific transferring tool** (→**definition of anchor points** on frame and furnace)
- **Load recovery** thanks to a **specific lifting unit** through the roof air lock and straightening of the machine inside the hot cell
- **Free access** and exit from M18 through the window to connect the machine
### SPECIFICS RELATED TO THE « HOT » COMMISSIONING

| Safety in the enclosed hot cell | Hot cell **static confinement**  
| Hot cell **dynamic confinement** with depressurization (-120 Pa min) thanks to the extraction  
| **Fire detection** (maximum temperature threshold in hot cell: 50°C) |
| Behavior under radiation | **Maxmum dose rate**: 5 Sv/h.  
| **Installation lifetime**: > 30 years |
| Remote handling | **Maximum load at the tip of the robotic arms**: 5 kg  
| Movements have to be possible with a **single robotic arm**  
| Possibility to **block the mobile parts** in position  
| Masses and positions of the materials **adapted to remote handling** |
| Handling in hot cell | **Use of lifting units** (crane at the ceiling of hot cell: max load: 50 kg)  
| Components introduced through the hot cell roof thanks to an **introduction air lock** (Φ 320 mm, h 600 mm) |
| Calibration | **Specific measurement lines**  
| **Sensors** dedicated to verifications |
| Interfaces | **Electric connections**: C1SH cables and FCI plugs supplied by the CEA per INSTRON and AET specifications  
| Cable lengths: 3-4 m in hot cell, 10-20 m outside |
| Materials | **Conform to AFNOR norms**, stainless, with an even surface (→ possible decontamination), **non-magnetic**, adapted to **decommissioning** |
SAFETY FILE – APPROVAL FOR COMMISSIONING IN HOT CELL

Safety analysis based on the feasibility study performed by AET/CEA for the high-temperature furnace in M18 (10/2008 → 03/2009)
→ 3 incidental referenced scenarios (loss of cooling, etc.) with associated thermal calculations and mitigating measures → the integrity of the confinement is not compromised.

Analysis by SEL of AET’s feasibility study in light of the security and safety imperatives of the nuclear installation (10/2009)
→ Conclusions of the feasibility study consistent with the safety imperatives of the nuclear facility in M line

Writing of the safety file by the society MILLENNIUM:
- Project kickoff in 10/2009, but put on hold in 12/2009
- Re-starting of the project in 05/2011
- Delivery of a preliminary safety file in 12/2011
- Collaboration with Salvarem for a final safety file in 07/2012, to be sent to ASN (French nuclear safety authority)

External wall of the furnace at 120°C after a failure of the cooling system

Limited warming of the hot cell (<55°C) in case of a loss of cooling in the furnace in M18 (AET study)
DMN = project manager of the whole investment

A complex project with many stakeholders, with different time scales but which are often interdependent and must all converge at the end of the project.

Planning:
- **Factory acceptance**: Frame in *August 2012*; Furnace in *November – Décember 2012*.
- **Work** in the nuclear installation and opening of the hot cell (pending the Nuclear Safety Authority’s approval for commissioning): *beginning of 2013*
- **Delivery of the machine** {frame + furnace} to CEA Saclay: *beginning of 2013*
- **Introduction** of the machine in the hot cell, **partial acceptance, global acceptance**: *1st semester of 2013*
- ‘Cold’ qualification tests using non-irradiated materials, ‘hot’ commissioning of the hot cell for irradiated materials, **first tests on irradiated materials**: *2nd semester of 2013*

Purpose: to study and obtain performant materials to work on the 4th generation reactors (sodium or gas cooled Fast Reactors).
Thank you for your attention
GENERAL OBJECTIVES OF LCMI LABORATORY

LCMI Laboratory is in charge of **mechanical testing of (unfueled)** irradiated metallic or ceramics materials. All tests are performed on machines **in sealed lead or concrete cells with remote handling**.

- **TESTING**: Mechanical characterisation of irradiated metallic materials (Steels, Zr or Al Alloys) or ceramic materials for research, surveillance or investigation programs.

- **STUDIES**: Conduct studies with experiments on irradiated materials and perform interpretations in a Project frame.

- **MODELLING**: Constitutive equations and damage development models for irradiated metallic materials (modules linked with FE codes).

- **DATA BANK**: LCMI provides mechanical properties for pre-irradiated materials and for materials as they are irradiated (Zr, Fe or Al Alloys) to DATA BANK.
## PLANNING AND SETUP OF THE M18 PROJECT

<table>
<thead>
<tr>
<th>2008-2009 : first project</th>
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<tbody>
<tr>
<td>✓ Study of the <strong>design</strong> of a Mechanical tensile Machine with a high-temperature furnace with controlled atmosphere in SRMA (laboratory for “cold” tests) / in SEMI (hot cell commissioning)</td>
</tr>
<tr>
<td>✓ <strong>Preparation of the purchase</strong> of the tensile frame for the SEMI (30kN, 0.001 to 500 mm/min: Offers CEA / INSTRON and CEA / AET finalized in Sept. 2009; Markets ready to be set up → put on hold in Nov. 2009)</td>
</tr>
<tr>
<td>✓ <strong>Preparation of the installation</strong> in hot cell M18: Preparatory work in the INB; <strong>Safety file</strong>: start of contract with MILLENNIUM in October 2009 → frozen in Nov. 2009</td>
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<tr>
<td>✓ <strong>Freeze of the project</strong> in LECI: purchase of frame and furnace postponed</td>
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<tr>
<td>✓ <strong>Follow up</strong> of the commissioning of the equipment and reception tests in SRMA</td>
</tr>
<tr>
<td>✓ Study of an option of « <strong>simplification</strong> » of the AET equipment (only one furnace with capacity of 1200°C) to reduce the total cost and spread it over 3 years</td>
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<td>✓ <strong>Budget validated</strong></td>
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<td>✓ Reopening of the <strong>market AET</strong>: start meeting in June 2011, acceptance QIP, before-project file and plans approved for process</td>
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<tr>
<td>✓ Reopening of the <strong>market INSTRON</strong> in August 2011, then acceptance QIP and plans approved for process</td>
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<tr>
<td>✓ <strong>Safety</strong>: initiation of the preliminary safety file with Millennium in June 2011, provisory version in December</td>
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<td>✓ <strong>Market AET</strong>: certified supply of material, <strong>planned</strong>: factory acceptance , delivery to Saclay, putting in hot cell and partial acceptance</td>
</tr>
<tr>
<td>✓ <strong>Market Instron</strong>: certified supply of material, factory acceptance, delivery to AET factory, <strong>planned</strong>: tests and review by AET (frame + furnace), delivery to Saclay, putting in hot cell and partial acceptance</td>
</tr>
<tr>
<td>✓ <strong>Preparatory work in LECI</strong>: engineering study, <strong>planned</strong>: work (electricity, piping, machining walls of hot cell, introduction frame and furnace…)</td>
</tr>
<tr>
<td>✓ <strong>Safety</strong>: <strong>planned</strong>: safety file by Millennium and approval nuclear safety authority for commissioning in hot cell</td>
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<td>✓ <strong>Planned</strong>: provisory reception, global acceptance, first qualification tests in “cold”, “hot” commissioning</td>
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Exercise of the option with 2 furnaces (04/07) – start meeting (06/06)

Acceptation preliminary design

Certified supply of material

Factory acceptance (with frame)

Acceptation quality insurance plan (06/06)

Plans approved for process

Certified supply of material

Factory acceptance

Partial acceptance

INSTRON Market mechanical tensile machine

Starting up of the market (08/01) – start meeting (07/27)

Acceptation quality insurance plan and plans approved for process

Certified supply of material

Tests and review by AET

‘Cold’ qualification tests

CEA Project management DMN (SEMI/LCMI; SRMA/LC2M)

Technical monitoring of the equipment in ‘hot’ environment: detailed nuclearization of the facility, remote handling, space management of the hot cell…

AET Market furnace under controlled atmosphere

Factory acceptance (with frame)

‘Hot’ commissioning

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