CEA VERDON laboratory at Cadarache: new hot cell facilities devoted to studying irradiated fuel behaviour and fission product releases under simulated accident conditions¹

M.P. Ferroud-Plattet, J. Bonnin, A. Gallais-During, S. Bernard, J.P. Grandjean, G. Ducros², presented by J.Y. Blanc

HOTLAB 2009
September 21-23, 2009, Prague, Czech Republic

¹Performed in the framework of the International Source Term Program

²CEA, DEN, DEC, F-13108, Saint Paul lez Durance, France (gerard.ducros@cea.fr)
Outline

- Introduction: context of Severe Accident studies
- VERDON laboratory
  - VERDON furnace
  - CER and CET experimental circuits
  - Glove box
- Fission products measurements
- The ISTP programme and potential other uses
VERDON in the context of Severe Accident studies

Elaborate a realistic data base on FP's release from the fuel and FP's transport within the primary circuit

- Develop models on FP's behaviour used in SA codes
- Source Term assessment and PSA studies

Separate effect tests on small irradiated fuel samples

- Complementary to integral experiments, like the PHEBUS-FP program

FP transport in the RCS
FP release from the core
VERDON laboratory at the LECA-STAR facility

Non destructive examinations on experimental fuel rods

Fuel rod puncturing

Re-fabrication of experimental fuel rods

STAR

Non destructive examinations on LWR fuel rods

Fission gas release

LECA

VERDON laboratory

Micro-analysis:
- SEM
- EPMA
- SIMS
- μ-XRD

Optical microscopy
Overview of VERDON laboratory

- Two new hot cells and one glove box
  - **Cell C4**: sample preparation and storage, pre- and post-test FP measurements
  - **Cell C5**: VERDON experimental circuits (CER and CET), FP release and transport
  - **Glove box**: fission gas recovery and measurements
VERDON laboratory in STAR underground

C5 cell
C4 cell
Glove box
Hot cells setting up

- Stainless steel box
- Lead (gamma protection)
- PNT7 (Neutron protection)
- Frame
- Concrete slab
On site mounting of the cells since September 08

Frame  Floor  Wall 1 (gamma protection)

Stainless steel box  Wall 2 (neutron protection)
The CER experimental circuit: FP release studies

Fuel sample: short PWR fuel rod (2 pellets in their original cladding), previously re-irradiated in a MTR for short half lives FP inventory
VERDON furnace: external design

(1) Heating fuel section up to 2700 °C,
(2) Temperature measurement (pyrometer and thermo-couples),
(3) Gas flow from 10 to 100 cm³/min, in neutral, reducing or oxidizing atmosphere,
(4) On-line gamma spectrometry measurement
(5) Remote-handling devices
Specific developments to elaborate hafnium oxide ceramics in order to support high temperature under oxidising atmosphere.
CER circuit during its qualification phase

(1) Furnace
(2) Aerosol filter
(3) Circuit lines heated at 150°C
(4) Maypack (selective iodine trap)
(5) Condenser
The CET experimental circuit: FP transport studies

TGTM: Four thermal gradient tubes devoted to study FP transport and potential re-volatilisations
The VERDON glove box (1)

- Fission gas recovery in the 3 m³ vacuum vessel
- Fission gas measurements by µ-Gas Chromatography and Gamma Spectrometry
  - On-line → release kinetics
  - Post-test (samplings from the vacuum vessel) → total released fraction
The VERDON glove box (2)

(1) Vacuum vessel (below)
(2) On-line aliquot gas samplings
(3) Cold trap for accumulative gas samplings
(4) μ-Gas Chromatograph
Fission products measurements

- **Main tool:** gamma spectrometry
  - *The only way for measuring the kinetics release of FP on-line*
    - 3 on-line equipments: fuel sighting, aerosol filter sighting, Maypack sighting
  - *The best way for measuring FP balance*
    - By differential measurement of the fuel sample before and after the test
    - By gamma scanning measurement of FP deposits along the experimental loop: sleeve, TGT, filter plates, connection tubes
      - Dedicated gamma scanning bench in C4 cell
    - *The only way for measuring short half life FP*

- **Complementary tools:**
  - *Chemical analyses on the circuit components*
    - By ICP-MS after lixiviation of sleeves, filters … downstream the furnace
    - Complementary release balance and transport for actinides (U, Np, Pu …) and some non gamma emitters FP (\(^{90}\)Sr)
  - *Micro-structural examinations of the fuel sample using the specialized equipments of the LECA-STAR facility:*
    - Optical microscopy and SEM \(\rightarrow\) fuel microstructure changes
    - EPMA and SIMS \(\rightarrow\) remaining FP and identification of potential co-locations
    - \(\mu\)-XRD \(\rightarrow\) changes in the crystallographic structure and chemical phases
On-line gamma spectrometry in sight of the fuel sample

- Motorised pre- and post-collimators, to scan the fuel sample before and after the accidental sequence
- Fixed position during the accidental sequence (top of the fuel)
- FP release kinetics ... and identification of the fuel collapse time
Gamma scanning bench devoted to FP balances (1)

- **Axial scanning**
  
  Nuclear fuel

  ![Diagram of axial scanning]

- **Transverse scanning**
  
  Nuclear fuel

  ![Diagram of transverse scanning]

- *Tomography application*

  - Pre-collimators
  - Collimator plug through the cell floor
  - Post-collimators
  - Rack under the cell
  - Gamma detector
  - Gamma scanning bench inside the cell
Gamma scanning bench devoted to FP balances (2)

The gamma scanning bench under qualification phase in mock-up cell
The International Source Term Programme

Objective of the ISTP

- Reduce the remaining uncertainties for PWR Source Term assessments
- French part: CEA, EDF, IRSN + Europe, USA, Belgium, Canada, Switzerland
- Continuation of the previous French VERCORS program, performed at the CEA Grenoble Centre

4 VERDON tests funded under the ISTP

- High burn-up UO₂ fuel (70 GWd/t) → CER configuration
- MOX fuel (55 GWd/t) → CER configuration
  - 1 test under oxidising conditions
  - 1 test under reducing conditions
- Air ingress test on MOX fuel (55 GWd/t) → CET configuration

Post ISTP programme

- Under elaboration, likely making more use of the CET configuration
Potential other uses of the VERDON facility

- Radiological protections of the cells largely dimensioned, in order to accept various and highly irradiated fuels, such as Am-bearing fuels including neutron emitters

- VERDON facility aimed at studying other kind of fuels under accident conditions
  - Small fuel plates of MTR or naval nuclear reactors
  - Pin samples, made of MOX, carbide or metal fuels for SFR
  - Compact TRISO HTR fuels
  - Innovative ceramics fuels for GFR
**Conclusion**

- The VERDON laboratory was recently set up at the CEA Cadarache in order to study the behaviour of fission products within irradiated fuels during a hypothetical accident.
- It includes two shielded hot cells and one glove box.
- Based on the previous VERCORS technology, this new piece of equipment is a unique tool in nuclear research for simulating such severe accidents.
- FP release and transport are mainly characterized by quantitative on-line and post-test gamma spectrometry.
- Complementary post-test analysis benefit from the broad range of specialized equipment at the LECA-STAR facility, including optical microscopy, SEM, EPMA, SIMS, μXRD and chemical analysis by ICP-MS.
- The first VERDON test under the ISTP is planned in 2010.
Remote handeled devices designed to open and dissolve irradiated PROFIL R targets

G. FERLAY ① - P. HUOT ① – P. GRANGAUD ①
S. EYMARD ② – C. CELLIER ② - P. LEVEQUE ②

① CEA MARCOULE - DRCP/SE2A/LED
② CEA CADARACHE - DSN/SEEC/LECD
**PROFIL R program – main objectives**

**PROFIL R:** Irradiation in Phénix Na cooled fast réactor:

- 110 targets containing:
  - 11 actinides isotopes
  - 33 fission products isotopes

**Objectives:** Collect accurate information on the cross sections of specific actinides isotopes and fission products in the spectral range of fast reactors.

- Isotopic and elemental characterisation before and post irradiation
**Loading and irradiation in Phenix fast reactor**

PROFIL-R consists of two pins of identical geometry each comprising a stack of sample containers, inserted in a standard fuel assembly. Axially distributed $^{235}\text{U}$ containers are used as fluence monitors for each pin.

3 to 5 mg of the isotope powder are conditioned in a 316L stainless steel inner container sealed by a TIG-welded cover and inserted in a 316L stainless steel outer container also sealed by a welded cover.

A standard fuel pin in the central assembly position is characterized to obtain the fluence data.
Main difficulties

- Container constituent elements + Impurities (Mo, Mn, Si...)
  - Inner container mass = 150 mg
  - Powder quantity: 2 to 5 mg
  - Formed isotopes: few µg

- 1 - Remote handling of a few millimeter sized containers in hot cell facility

- 2 - Quantitatively powder recovery

- 3 - Minimizing of the container structural materials on analysis techniques and uncertainties

Conception of a specific remote handling device
Synoptic of opening operations

**Opening container:** 2 technical solution tested: **electrochemical and mechanical treatment**

**Powder recovery:** special extraction devices: **by scrapper**
Opening container- **Electrochemical machinining**

The targets are placed on a gripper to simplify subsequent handling operations.

- This technique ensures that the container is opened without any mechanical stress loading that could distort it and hinder the recovery of its contents.
- Electroerosion is controlled by the duration and immersion depth to erode only the weld bead.
- The cover is mechanically secured to seal the inner container.
Opening container- Electrochemical erosion machining

**Results:**

- This technique dissolves the weld, that allows to open the container
- The immersion depth permits to erode only the weld bead

- A small part of the electrolytic solution (HNO₃ 1,5 M) is introduced in the container during the process
- Some soluble elements in nitric acid like UO₂, AmO₂, are lost in the electrolytic solution

Conception of a dry opening device
Opening container - Mechanical device (1)

Open using a grindstone

- Rotating inner container
- Rotating grindstone

- The metal is distorted that gives difficulties to open and recover the powder
- Some metal powder coming from inner container pollutes the powder of isotopes
Opening container - Mechanical device (2)

Prototype device

Goal: Replace acid electroerosion by a mechanical abrasion of the TIG weld bead,

- Without any liquid
- Using a mill to avoid the metal deformation
- With a containment chamber to avoid pollution of the powder by metal of inner container

Open using a mill

- Containment chamber
- Mill Ø 5
- Fixed dowell
- Inner container
Opening container- Mechanical device (3)

- **Good results of the prototype device**
  - The container is open easily without metal pollution

- **Design of a new device, usable in hot cells and in remote handling system**
- **Easy decontamination**
- **Mill change for each container**

### Designation

<table>
<thead>
<tr>
<th>Designation</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Base and accessories, camera and measurement</td>
</tr>
<tr>
<td>2</td>
<td>Mill motor and positioning device</td>
</tr>
<tr>
<td>3</td>
<td>Container positioning device</td>
</tr>
<tr>
<td>4</td>
<td>Containment chamber</td>
</tr>
</tbody>
</table>
After electroerosion and drying steps, a dowel is bonded to the inner container cover with heat-sensitive adhesive to serve as a grip during the powder recovery step.
Powder recovery device

A special tool is used to recover the maximum quantity of isotope powder from each capsule while limiting the risk of material dispersion and external contamination.

- Recovery in confined atmosphere
- The powder is transferred directly in the dissolution vial
# Dissolution

<table>
<thead>
<tr>
<th>Nature of deposit</th>
<th>Chemical compound</th>
<th>Dissolution medium</th>
<th>Dissolution conditions</th>
</tr>
</thead>
<tbody>
<tr>
<td>$^{232}$Th</td>
<td>ThO$_2$</td>
<td>HNO$_3$/HF – 11 M/0.1 M</td>
<td>10 h at boiling temp.</td>
</tr>
<tr>
<td>$^{233}$U, $^{234}$U, $^{235}$U</td>
<td>UO$_2$</td>
<td>HNO$_3$ – 4 M</td>
<td>1 h at room temp. + 1 h at boiling temp.</td>
</tr>
<tr>
<td>$^{238}$U</td>
<td>U metal</td>
<td>HNO$_3$ – 8 M</td>
<td>2 h at boiling temp.</td>
</tr>
<tr>
<td>$^{237}$Np</td>
<td>NpO$_2$</td>
<td>HNO$_3$/HF – 11 M/0.1 M</td>
<td>10 h at boiling temp.</td>
</tr>
<tr>
<td>$^{238}$Pu, $^{239}$Pu, $^{240}$Pu, $^{242}$Pu</td>
<td>PuO$_2$</td>
<td>HNO$_3$/HF – 11 M/0.1 M</td>
<td>10 h at boiling temp.</td>
</tr>
<tr>
<td>$^{241}$Am, $^{243}$Am</td>
<td>AmO$_2$</td>
<td>HNO$_3$ – 4 M</td>
<td>1 h at room temp. + 1 h at boiling temp.</td>
</tr>
<tr>
<td>$^{91,93}$Zr</td>
<td>ZrO$_2$</td>
<td>HNO$_3$/HF – 12 M/3 M</td>
<td>10 h at boiling temp.</td>
</tr>
<tr>
<td>$^{107,109}$Ag</td>
<td>Ag metal</td>
<td>HNO$_3$ – 14 M</td>
<td>24 h at boiling temp.</td>
</tr>
<tr>
<td>$^{101,102,104}$Ru</td>
<td>metal</td>
<td>HCl – 10 M + KClO$_3$</td>
<td>boiling temp.</td>
</tr>
</tbody>
</table>

The conditions of dissolution were specified and validated by previous tests performed on the non-irradiated powders in Atalante$^1$ and by inactive tests with LARC laboratory$^2$. The resulting solutions do not contain suspended matter.

$^1$ CEA Marcoule DRCP/SE2A/LED – $^2$ CEA Cadarache DEC/SA3C/LARC
Operating procedure and conclusion

Key dates:

- Beginning of irradiation: 24 June 2003
- Removal from reactor: 4 September 2005
- Pin dismantling: 2006
- Fabrication and installation of the electrochemical device in a shielded cell in Atalante and Chicade: 2008
- First dissolution of a fission product target in CHICADE: 2008
- First dissolution of an actinide target in ATALANTE: end of 2008
- First analysis on irradiated fission product target in LANIE laboratory: end of 2008
- Fabrication and first tests of the mechanical device

This ambitious research program involves technological and analytic challenges for numerous CEA laboratories. It has now entered the final phase and is expected to provide major results concerning the use of fast neutron reactors.
Installation in hot cell

• Fabrication and installation of the device in a shielded cell in ATALANTE and CHICADE

C11/C12 hot cell in ATALANTE facilities - CEA/Marcoule
New mechanical device

- Base and accessories
- Camera and measurement
- Mill motor and positioning device
- Container positioning device
- Containment chamber
- Base and accessories, camera and measurement