BONAPARTE
Bench fOr Non-destructive Analysis of Plate And Rod Type fuel Elements

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SCK•CEN operates a dedicated hot cell, equipped with 3 measurement benches for Non-Destructive Testing (NDT) of fuel rods up to 4m.
Fuel rod NDT benches
• Increase in projects requesting NDT of irradiated Material Test Reactor fuel plates
  o Constant adaptations of the benches to fit geometries
  o Non-ideal measurement conditions/densities

• Development project for a non-destructive analysis bench for plate type fuels, also capable of NDT on short fuel rods
  → BONAPARTE
3-Axis modular measurement bench for fuel plate(rod) mapping thickness(diameter) and oxide thickness measurements
Technology and material choices, required to be:

- Compatible with hot cell environment (radiation, decontamination, master slave telemanipulators…)

- Radiation resistance up to 1E+6 Gy total life absorbed dose
  - Equivalence of measuring about 120 fuel plates

- Compatible with extension to 4m measuring benches for future upgrades of existing benches

- Modular build-up for easier maintenance
  - Use of small modules which can fit in a “la calhène” transport system in case for maintenance and repair in glove box

- Modification to fuel rod measurements
BONAPARTE Specifications

- **Dimensional specifications**
  - Flat and curved plates (expansion fuel rods) with length up to 1100mm
  - Thickness fuel plates ~1.2 mm
    - measurement range up to 20mm
  - Flat fuel plates
    - Width up to 150 mm
    - Bench requires an X and Y-axis
  - Curved fuel plates
    - Radii between 20 and 50 mm, angle 120°
    - Bench requires an extra rotation axis instead of the Y-axis
BONAPARTE Specifications

Cross section AA flat plates

Cross section AA curved plates

Top view fuel plate

- length
- width

X-axis movement over plate

Y-axis movement over plate

Thickness/oxide thickness

Rotation axis

Radius

Angle
3-Axis motor controlled positioning:

- Stepping motor devices (radiation resistant)
- Magnetic position feedback encoders (magnescale)
- X and Y-axis: position uncertainty $1\sigma = 0.1$ mm
- Rotation Axis: position uncertainty $1\sigma = 0.1^\circ$
BONAPARTE specifications

- Performs a 3D mapping of a fuel plate: plate thickness and oxide layer thickness measured simultaneously.

  - **Plate thickness:**
    - By means of two opposed contact probes
    - Magnetic linear system – magnescale
    - Measurement range = 20 mm
    - Measurement uncertainty: $1\sigma = \pm 1\mu m$ (probably too optimistic in hot cell environment)

  - **Oxide layer thickness on both sides:**
    - Eddy current technology - perpendicular coil
    - Contact probe on surface (Carbon-filled PEEK tip)
    - Measurement range = 1000µm
    - Measurement uncertainty: $1\sigma = \pm 1\mu m$ (probably too optimistic in hot cell environment)
Measurement bench design consists of the following modules:

- Frame with Linear Guidance and Driving Systems
- Position Feedback Systems
- Clamping Devices
- Measurement Head with Tool units and probes
Stiff frame: stainless steel tube frame construction with a flattened aluminum plate on top.

→ Bends down <50μm
Maintenance free guidance system

- 2 linear Hepco guidance systems with full metal bearings for X and Y axis
Maintenance free linear drive system

- Slo-Syn Stepping motor device Superior Electric
- Full metal SKF ball screw spindle housed in ceramic bearings
Measurement bench design consists of the following modules:

- Frame with Linear Guidance and Driving Systems
- Position Feedback Systems
- Clamping Devices
- Measurement Head with Tool units and probes
Positioning feedback system

- Sony magnescale GB-A-SR... linear encoders for X and Y axis
- Sony magnescale RS310
- Sony PH500 magnetic absolute zero point detector
Measurement bench design consists of the following modules:

- Frame with Linear Guidance and Driving Systems
- Position Feedback Systems
- Clamping Devices
- Measurement Head with Tool units and probes
Interchangeable clamping units

- For measuring different types or size of fuel plates
- Adjustable quick spanner to clamp the fuel plate
- Quick Camlock fastener for mounting the unit
Easy exchange of clamping units

- Quick and easy exchange of clamping units
- Large range of different fuel plate shapes and dimensions possible
BONAPARTE Modular design

- Measurement bench design consists of the following modules:
  - Frame with Linear Guidance and Driving Systems
  - Position Feedback Systems
  - Clamping Devices
  - Measurement Head with Tool units and probes
Measuring head – tool holders - probes

- Easy exchange of different measuring tools
- Capable of measuring various geometries of fuel plates
Measuring head – tool holders - probes

- Thickness probes: air pressure controlled modified Sony DG25 probes
- Oxide thickness probes: air pressure controlled modified Lion Precision U8B probe with ceramic tip
- Measuring simultaneously
Probe calibration

- Thickness probes: certified ceramic standards in special holder
- Oxide thickness probes: certified Mylar foils
Measurement bench
BONAPARTE – V & V phase
Overall uncertainty budget estimation based on the validation measurements:

- X-positioning: $1\sigma = 0,11\, \text{mm}$
- Y-positioning: $1\sigma = 0,07\, \text{mm}$
- Rotation axis: $1\sigma = 0,18^\circ$
- Thickness and oxide measurements:

<table>
<thead>
<tr>
<th></th>
<th>Flat plate conf.</th>
<th>Round plate conf.</th>
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<tbody>
<tr>
<td>Physical thickness</td>
<td>5µm</td>
<td>6µm</td>
</tr>
<tr>
<td>Oxide thickness</td>
<td>3µm</td>
<td>3µm</td>
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BONAPARTE – in cell
Fuel plate irradiation project E-FUTURE

- U-Mo alloy fuel development for low enriched (20%) high density (8gU/cc) MTR driver fuel
- Irradiation of 4 fuel plates to high burn up (70% $^{235}$U) at high power (470 W/cm$^2$ BOL)
- Important swelling in high power zone (pillowing)

Determining fuel swelling evolution with burn up

- requires measurements of plate swelling and oxide layer thickness (correction)
- When net plate swelling (after oxide correction) is known, fuel swelling can be derived by knowing the volume density of fuel in the plate
E-FUTURE visual aspect

- 1.3 mm
- 3.3 mm
- 1.5 mm
Oxide thickness profiles (one side)
Data treatment for fuel swelling

- 4 data matrices per plate available:
  - Burn up (calculated)
  - Thickness profiles
  - Oxide profiles (2 sides)
- Interpolation to put all data on the same grid
- Data treatment:
  - Correct plate thicknesses for oxidation swelling
  - Calculate plate swelling profiles based on initial thickness
  - Calculate fuel swelling from plate swelling profile
  - Average fuel swelling at equivalent burn up locations on the plate
  - Plot fuel swelling in function of burn up
BONAPARTE – Plate swelling

Oxide correction applied!

Lines show burnup
Burn up averaged swelling law

\[ \text{FSwell (\%)} = 7.24 \times \text{FD} + 0.68 \]

FD in \(10^{21}\) f/cm³ U(Mo)

\(2.5 \leq \text{FD} \leq 4.5\)

Pillow region >\(4.5\times10^{21}\) f/cm³ Plate swelling >100%
Spread of measurement averages

Standard deviations $1\sigma$ of each burnup class (0.5% $^{235}$U per class)
1 sigma SD, not error!

Blister region: large variations in local swelling, unrelated to burnup (mechanical failure)
Oxide thickness: comparison NDT & DT

4202 M1 ~48% BU

→ cladding

→ Oxide layer

6301 M4 ~70% BU

→ cladding

→ Oxide layer
Oxide thickness: comparison NDT & DT

Good correlation between the EC and SEM based measurements
For more information on the E-future measurements, see papers:


Thank you for your attention