Improved in pile measurements for MTR experiments

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THE FUTURE
JULES HOROWITZ REACTOR
JHR Reactor

- 100MWth, pool-type, light-water MTR
- Under construction
- Commissioning 2016
- Consortium Members: CEA, EDF, AREVA, EURATOM, UJV, SCK.CEN,VTT, CIEMAT, VATTENFAL, DAE, IAEC
- Operating within a JHIP
May 2012 : auxiliary unit building
Objectives of the JHR

Radio-isotopes supply for medical application

- 25% of the European demand

Material Ageing under irradiation

- dpa...
- corrosion, radiolysis...

Fuel Behavior under irradiation

- Analytical studies
- Fuel qualification
- Safety studies (power ramps, LOCA testing, etc.)

→ Pellets / cladding interactions
→ Fission gas release

Expertise center

- Formation,...
JHR EXPERIMENTAL DEVICES
JHR experimental capacity & performances at 100 MW power level (70 MW operation also possible)

Thermal neutrons flux in reflector
\[ 5.5 \times 10^{14} \text{n/cm}^2\cdot\text{s} \]

Fast neutrons flux in core
\[ 5.5 \times 10^{14} \text{n/cm}^2\cdot\text{s} \]

Material ageing up to 16 dpa/y

6 displacement systems to:
- Adjust the fissile power
- Study transients

x3 / OSIRIS
In-pile:
Experimental hosting devices
(in core or in Be reflector)
Fixed position
or on a displacement system

Out of pile part:
Experimental cubicles
(thermal-hydraulics, chemistry…)

Handling: Hot cells
(checking, sample holder unloading, maintenance…)

Experiment starting and end

In operation

During intercycle

Specific on-line measurements:
Fission Product Laboratory…

On-site non destructive examinations
Reactor pool (γ and X-Ray coupled tomography, neutronography)
Storage pool (γ and X-Ray coupled tomog.)
Hot cell (sample examination γ and X-Ray tomog.)
JHR EXPERIMENTAL DEVICES

First fleet of hosting devices available at reactor start

ADELINE
For fuel testing under off-normal conditions

CALIPSO & MICA
For material testing under high dpa and controlled thermal gradient

MADISON
For fuel testing under nominal conditions
JHR EXPERIMENTAL DEVICES

Second fleet of hosting devices under feasibility studies (LWR)

LORELEI
Fuel testing under accidental conditions (LOCA)

CLOE
Corrosion loop for “Zr alloy Corrosion” and “Irradiation Assisted Stress Corrosion Cracking”

OCCITANE (IRMA)
For pressure vessel steel testing

MADISON
2nd loop under discussion (VVER)
JHR EXPERIMENTAL DEVICES

Third fleet of hosting devices under conceptual design (high temp. and large capacity)

Transmutation studies

CALIPSO adapted to SFR fuel and material
Normal → in core
Off normal → in reflector

MICA adapted to 1000°C gas conditions

Other topics:
LWR: Adeline «FP» & “power to melt”; severe accident studies
GFR: fuel irradiation (normal and off-normal conditions)
Fuel characterization: basic properties under irradiation (thermal diffusivity, thermal creep,..)
Fuel testing devices: MADISON
Fuel testing under nominal conditions

Selection, characterization and qualification of fuel samples in normal operation conditions:
- Fuel behaviour (FGR, μstructure evolution, corrosion…)
- Long-term irradiations
- Re-irradiation before ramps
- Screening test (fuel) or rod qualification
Fuel testing devices: ADELINE fuel testing under off-normal conditions

LWR fuel rod testing beyond design criteria limits = designed for high power, transients, clad failure...

- Gamma activity measurement
- Connected to FP lab (on-line FP sampling and measurement)
- Purification system
- Fit up to alpha cell

Characterization and qualification of fuel samples (off-normal conditions):
- Power ramp tests
- Rod over-pressure threshold (lift off)
- Water contamination in case of clad failure....

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RECENT INSTRUMENTATION DEVELOPMENTS
IN-PILE MEASUREMENTS

Two types of measurements:

- Radiation measurements in the experimental locations
  → Knowledge of MTR irradiation conditions

- Physical parameters inside irradiation rigs
  → On-line and under irradiation measurements (T, P, Δx, fission gas release rate,...)
  → Following if the evolution of the sample

In-pile sensors characteristics:

- High reliability (no in situ fixing)
- Very high accuracy
- Capability to operate in harsh nuclear environments (radiations)
- Capability to operate in pressurized water, liquid metals, high-temperature gas..
- Miniaturized body (minimisation of the perturbation)
**Objectives:**
Measure with minimized uncertainties
- Thermal and fast neutron flux
- Gamma flux and Nuclear heating

**Sensors:**

**Neutron flux:**
- Activation foil dosimeters and wires (post-irradiation analysis)
- Self Powered Neutron Detectors
- Fission chambers for thermal and fast neutron (FNDS)

**Gamma flux:**
- Ionization chamber
- **Self Powered Gamma Detector (with Bi emitter)**

**Nuclear heating:**
- Calorimeter (Gamma Thermometer and Differential Calorimeter)

**Measurements Techniques:**
- Scanning devices for neutron and photon core mapping
- Combine detectors and analysis methods to improve accuracy on the evaluation of each parameter
**Fast Neutron Detector System** « **FNDS** »

**FNDS characteristics:**
- On-line Measurement of the local fast flux up to $10^{14}$ n/cm²s (+/- 10%)
- Up to a Thermal Neutron Fluence of few $10^{21}$ n/cm²

**Principle:**
- 2 detectors, one for fast neutrons ($^{242}$Pu-FC) and one for thermal neutrons (SPND or $^{235}$U-FC)
- Unfold fast and thermal neutrons components, taking into account the isotopic evolution of the fissile deposit (DARWIN depletion code)
Design and Realization of sub-miniature fission chambers
- Characterized fissile deposits (mass/composition): Th, Np, U, Pu, Am, Cm
- Optimized Geometries

FC Ø 1,5mm / 4mm / 8 mm

3-Bodies FC

FC Ø 3 mm
Self Powered Gamma Detector (with Bi emitter)

**SPGD characteristics:**

- Bismuth emitter with a Tubular geometry design
- Monitoring little power changes (down to 1%) with a relative accuracy of about 0.2%
- Good Linearity selectivity $n/\gamma$ contribution < 1% in typical MTR conditions
- Small dimension gamma sensor
- No burn up effect
- **Operating Temperature** < 271°C(Bi)
- Allows differentiation of the heating from neutrons and gamma rays
- Technical support of THERMOCOAX
Objectives:

Online measurement of materials or fuels temperature
Typical range: 200-400°C (PWR materials) up to 1200°C (fuel)
1000-1600°C for transient / study of incidental conditions

State-of-the-art:

- Thermocouples: type K, N, C
- Expansion thermometers (LVDT)
- Acoustic thermometer
- Melt wires, paint spots and SiC monitors (post-irradiation analysis)

Developments:

- High-temperature Mo/Nb alloy thermocouples
- In-situ calibration of thermocouples:
  - Noise thermometry
  - High-temperature fixed-point μ-cell
- Infrared pyrometer
High-temperature Mo/Nb alloy thermocouples

Mo-Nb Thermocouple characteristics:

- Almost insensitive to the thermal neutron flux (low capture cross section of Nb and Mo)
- Good linearity and sensitivity
- A signal drift lower than 5°C after 1500 hours at 1100°C
- The final qualification (T> 1000°C) and under irradiation (thermal neutron fluence of 10E21 n/cm²) has to be performed

<table>
<thead>
<tr>
<th>Material</th>
<th>Neutron Absorption Cross Section (barn)</th>
<th>Melting Temperature (°C)</th>
<th>Observation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nb</td>
<td>1.1</td>
<td>2477</td>
<td>selected</td>
</tr>
<tr>
<td>Mo</td>
<td>2.5</td>
<td>2623</td>
<td>selected</td>
</tr>
<tr>
<td>Pt</td>
<td>10</td>
<td>1768</td>
<td>expensive</td>
</tr>
<tr>
<td>W</td>
<td>18</td>
<td>3422</td>
<td>difficult welding</td>
</tr>
<tr>
<td>Re</td>
<td>90</td>
<td>3186</td>
<td>expensive, high NACS</td>
</tr>
<tr>
<td>Rh</td>
<td>145</td>
<td>1964</td>
<td>very expensive, very high NACS</td>
</tr>
</tbody>
</table>

INL is developing a similar sensor HTIR-TC
**Objectives:**
Measure dimensional changes of materials and fuels under irradiation (µm accuracy – mm changes):
- Diameter and profiles
- Elongation of materiel samples or fuel rod cladding

**State-of-the-art:**
- Magnetic sensors: LVDT and Diameter Gauges (IFE)
- Constraint Gauges

**Developments:**
- Upgraded LVDT and DG
- Optical Fiber techniques
COSI experiment (OSIRIS 2006) proved the possibility to use OF for in-pile applications.

- Favorable spectral region in the 800-1200 nm range
- Carefully selected fibers - wavelength range: 0.8-1.2 µm
- OF System must be independent of the light intensity like interferometer-based sensors.
Extrinsic Fabry Perot Interferometer (EFPI)

**EFPI characteristics:**
- Compact size (diameter < 2mm).
- Light weight reducing gamma heating.
- High resolution and accuracy: $\varepsilon < 1\%$ for $\Delta x = 100\mu m$ at room temperature.
- Easy remote sensing and multiplexing.

**Main technological issues for the sensor design and its fixing on the sample:**
- Radio induced compaction of silica.
- Temperature induced dilatation (up to 400°C).

Optimized sensors are currently tested under irradiation in the BR2 reactor.
Objectives:
Measure online the fission gas release and its kinetic
an online discrimination of the releases in fuel rod to differentiate fission gas release –
mainly xenon and krypton from helium discharge

State-of-the-art:
- Sampling / on-site Fission Product Laboratory
- LVDT-based sensors or counter-pressure sensors + fuel temperature measurements
  (centerline thermocouple)

Development:
- Acoustic sensors (online gas composition measurement)
For the gas inside the fuel rod, Online measurement of:

- the molar mass (↔ wave velocity)
- the pressure (↔ echoes attenuation)

→ fraction of released fission gas  
(↔ Calibration + VIRIAL State Equation)

Operated successfully in 2010 on a high burn-up MOX fuel rod in the REMORA-3 experiment (OSIRIS reactor)
CONCLUSION
Conclusion

- Long term and constant CEA R&D effort in nuclear instrumentation
- International Collaboration is a necessity
- Needs of information for:
  - highly irradiated components
  - analyzing transient physical phenomena

Trends for the future MTR instrumentation:
- Transition from “cook and look” poorly instrumented to highly instrumented on-line experiments
- (high) temperature measurements without contact;
- On-line and local measurements (temperature, deformations, chemistry,…);
- Cross-analysis of physical parameters measurements
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