NON-DESTRUCTIVE EXAMINATIONS OF IRRADIATED FUEL RODS AT THE ITU HOT CELLS

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Outline

Introduction:
ITU hot cells
The NDE hot cell

Main equipment:
Metrology bench
Visual inspection
Dimensional measurements
Gamma scanning
Eddy current examinations
Puncturing and gas analysis

Conclusions
Hot Cell facilities at ITU

• 24 hot cells (licensed capacity $10^6$ Ci = $3.7 \times 10^{16}$ Bq)
• remote handling using telemanipulators through walls > 1 m thick;
• Shielded microscopy, microanalysis, high T, mechanical tools;
• infrastructure: supporting workshop incl. manipulators maintenance
The ITU hot cells

Layout of the 24 hot cells of ITU

NDE hot cell

Circle
Schematic layout of the NDE cell at ITU
(1) gas puncturing system, (2) metrology bench and γ-scanning, (3) docking system for transport containers, (4) stainless steel caisson for sectioning and re-encapsulation, (5) connection for removal of waste containers, (6) x-ray radiography, (7) tube connection to another hot cell, (8) lead glass windows, (9) concrete wall, (10) adjacent hot cell.
The NDE hot cell

Photo illustrating the working configuration of the NDE cell (model with scale 1:25)
Transport of irradiated fuel rods

Irradiated fuel rods are transported in shielded containers

The container is docked at the hot cell B1

Unloading the content in the NDE hot cell

Robot handling of highly active materials
Magazine of the metrology bench

- EC coil for outer oxide measurement
- EC coil for defect detection
- LVDT gauge
- Fuel rod
- Slit in front of the gamma collimator
Visual inspection primarily determines the mechanical integrity and surface appearance of the fuel rod.

Three digital video films along 3 axes at 120° to each of the complete fuel rod length are recorded.

Visual examination of a BWR fuel rod.
(a) 5 cm; (b) 100 cm; (c) 200 cm and (d) 300 cm from the bottom end.
**Objective:**
Quantification of the combined effects of cladding creep and fuel swelling. Evaluation of rod ovalization and detection of any geometrical anomaly.

**Method:**
The measurements are generally made using inductive transducers following calibration on certified standards in the diameter range of interest.
Clad ridges are very well measurable and may be also used for precise sampling.
Objective:
The recording of the γ-ray emission spectrum along a fuel rod allows the fission products to be qualitatively and quantitatively analysed. This technique enables:
• observation of volatile fission product migration (for instance Cs)
• estimation of the fuel’s average burn up
• estimation of the power seen by the rod during a power transient.

Method:
The fuel rod is moved in the front of a detector (generally Ge). A collimation system situated between rod and detector allows emissions from a restricted fuel length to be selected. The detector signals are analysed in terms of energy to determine the isotopic distribution. For quantitative measurements the system is calibrated beforehand using standards sources (Co-60, Eu-152, Cs-134, etc.).
Schematic drawings of the collimating and detector system for the γ-scanning spectroscopy
γ-scans

γ-intensity profile of irradiated UO₂ fuel rods as a function of burn-up.

**First row:** complete spectra (a) 57 GWd/t; (b) 66 GWd/t; (c) 70 GWd/t

**Second row:** corresponding zoom-in graphs of small axial lengths showing migration of volatile fission products in the pellet gaps.
**Objective:**

**Detection of defects** present in the cladding, such as cracks, variable thickness, corrosion, etc. as well as quantification of the outer **corrosion layer thickness** produced in the reactor by the water action on the Zr-alloy cladding.

**Method:**

**a) Defect determination:** Assessment of eddy current variations generated in the examined part by the alternating field of a coil. Geometrical or structural heterogeneities in the cladding (crack, corrosion, etc.) modify the eddy current path.

**b) External corrosion thickness:** High frequency eddy current proper for measurements of coating/substrate associations (nonmagnetic/ferromagnetic, insulator/conductor) are applied. The magnetic force lines are modified in the vicinity of a ferromagnetic material (concentration of the field in the material). The amount of the concentration varies with the distance of the probe from the ferromagnetic material.

In both cases the apparatus is calibrated beforehand on tubes, identical in geometry and nature to the rod cladding.
Eddy current examinations
Outer clad corrosion

The coil unit for outer clad corrosion measurements before placing on the metrology magazine
Typical axial profiles of Zirconia thickness outside irradiated UO2 fuel rods. (a) BWR and (b) PWR rod.
Defect detection

**Left:** Distortion of the magnetic field due to cladding defects.

**Right:** The through-type coil unit of the defect detection system before placing on the metrology magazine.
Detection of clad defects by means of eddy current system. Detailed examination took place on the successfully prepared metallographic sample.
**Objective:**
Determination of the released fission gas amount, its composition and free volume in a fuel rod.

**Method:**
The fuel pin is introduced with the plenum side into the sealed chamber of a puncturing station. After puncturing the gas mixture (essentially He, Xe, Kr) is leaked out into two storage tanks and fed into a mass spectrometer to determine the isotopic composition.

![Diagram of a fuel rod](image)

**Fig. 8.2.** Radioactive elements in PWR fuel rod [3].
Rod puncturing and gas analysis

Left: Scheme of the fuel rod puncturing device

Right: The puncturing device before installation in the hot cell.
Gas analysis and differences between UO$_2$ and MOX fuels

<table>
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<th>Reactor type</th>
<th>BWR</th>
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<td>Fuel type</td>
<td>UO$_2$</td>
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<td>Average burn up GWd/tM</td>
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<td>Free volume of the pin (cc)</td>
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<td>Pressure before puncturing (mbar)</td>
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<td>Normal Gas volume (cc)</td>
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<td>Total amount Kr (cc)</td>
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<td>Total amount Xe (cc)</td>
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<td>Ratio Xe/Kr</td>
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<td>He (cc)</td>
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Inside the NDE hot cell

- Heavy duty manipulator
- Magazine of the metrology bench
- Sliding motor for translating the fuel rod

Inside the NDE hot cell.
Inside the NDE hot cell

- drilling machine
- puncturing chamber
- Valves
- sliding motor for pulling the fuel rod
- expansion volume
Visual observation combined with axial outer oxide thickness, γ-scan and diameter measurements
# Fuel rod segmentation

## Diagram

![Diagram of fuel rod segmentation](image)

### Table: Fuel Rod Segmentation

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<th>Cut Length</th>
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</table>

**General Remark:** Thickness of the cutting blade 0.4 mm

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**Rod Segmentation Plan**

- Reactor
- Series
- Rod
- File Name
- Date
- Author
- Released by
Conclusions

The NDE tools, a significant part of the PIE programme, are performed in one of the oldest hot cells in ITU, but still fully functional due to the skilful work of the operators and continuous improvement and update of the equipment.

The NDE is an essential set of analysis that allows to consistently acquire reliable data needed for validation of the fuel rod safety and efficient performance in pile and to provide a valuable basis of information to plan and implement successful sampling and destructive PIE.
Thank you for your attention!

Questions?