Destructive Examination of Experimental CANDU Type Nuclear Fuel Tested in TRIGA Reactor

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56th Annual Meeting on Hot Laboratories and Remote Handling
HOTLAB 2019
8 - 12 September, 2019
India
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INTRODUCTION

- The facilities of RATEN - ICN Piteşti (TRIGA Reactor and Post Irradiation Examination Laboratory) allow the testing, manipulation, and examination of nuclear fuel and irradiated materials.

- The CANDU experimental fuel was tested using the TRIGA Reactor irradiation devices in order to increase the operating limits of the fuel, for the burn-up efficiency improvement and to help identify possible manufacturing irregularities.

- In order to investigate the Romanian CANDU fuel behavior and to check and improve the quality of the Romanian CANDU fuel, the power ramping and fuel centerline temperature tests have been performed on experimental fuel elements in the TRIGA SSR reactor and their behavior has been analyzed by post-irradiation examination (PIE) in the hot cells.
The TRIGA reactor is a pool type reactor with 2 cores:
- Steady State Reactor (SSR) operated at maximum 14 MW
- Annulus Core Pulse Reactor (ACPR) that can be operated for a maximum pulse of 20,000 MW or can be operated in steady state mod for a maximum 500 KW.

The fuel originally used for Steady State Reactor was HEU type, 93% enrichment. Since 2006 the full conversion of the core to use LEU type 20% enrichment is accomplished.

The Annulus Core Pulse Reactor fuel is LEU type 20% enrichment.
Post Irradiation Examination Laboratory (LEPI)

Hot Cell facility

Universal Examination Machine
LEPI is located adjacent to the TRIGA reactor and is interconnected to the TRIGA reactor pool by a water canal.

The infrastructure of the laboratory includes:

- Two alpha-gamma heavy concrete hot cells (transfer cell and examination cell) licensed for $1 \times 10^6$ Ci;
- Two alpha-gamma steel hot cells (metallography and radiochemistry cells);
- A beta-gamma steel hot cell (the cell of the metallographic microscope).
Main activity domain of LEPI consists of:

- Sealed radioactive sources for medical and industrial use production;
- Nuclear fuel and structural materials used in CANDU CNE Cernavoda Power Plant performance determination and monitoring;
- Experimental CANDU fuel elements irradiated in TRIGA reactor irradiation behavior analysis;
- Telecobalt therapy installations decommissioning.
Post irradiation fuel examination techniques

Non destructive examination:
- Visual inspection
- Eddy currents defectoscopy
- Dimensional measurements
- Gamma scanning

Destructive examination:
- Fuel puncture and fission gasses analysis
- Optical and electronic (SEM) microscopy

Fuel element inside of the transfer cell
Non destructive examination

**Visual inspection**
- It’s purpose is to observe the macroscopic changes of the fuel element surface condition such as failure, corrosion product deposition, corrosion, swelling due to both manufacturing conditions and irradiation conditions.
- Pictures of the fuel element are taken from three rectangular azimuthal directions (0°, 120° and 240°).

**Eddy current defect testing**
- By this method can be detected any cracks, holes, notches in the cladding, oxide layer thickness, any ridges and can be evaluated the size of the defect.

*Examples of visual inspection on TRIGA fuel*

*Longitudinal outer oxide layer profile*
Non destructive examination

Gamma scanning and 3D activity tomographic reconstruction

This method is used for:
• axial and radial distribution of the gamma emitting radioisotopes in the fuel;
• fuel column and gap between pellets measurements
• fuel burn-up estimation.

Tomographic reconstruction of radial gamma emitters radioisotopes reconstruction

Axial distribution of $^{137}\text{Cs}$ inside of the fuel element
Non destructive examination

Dimensional measurements

- Performed in order to obtain the parameters which highlight the dimensional changes of the fuel elements during irradiation: diameter, length, diametral and axial cladding elongation, circumferential cladding ridging height, bow and ovality, diametral and bending profiles.
- The dimensional measurements of the fuel element are done both before and after irradiation to calculate the ratio of the dimensional changes.

![Diameter profile of the fuel element](image1)

![Radial ovalization profile of the fuel element](image2)
Destructive examination

- **Optical microscopy**
  Metallographic examination of radioactive materials: grain size and distribution, phase identification, porosity measurements, corrosion susceptibility (oxide layer thickness), features and orientation of hydride precipitates in the cladding, integrity evaluation of welds, brazes.

- **Fission gas analysis**
  The installation for puncture and fission gases measurement was designed to be able to measure:
  - the pressure and volume of gas inside the fuel rod;
  - the fuel rod internal void volume;
  - the isotopic composition of the fission gas;
  - the chemical composition of fission gas.
Metallographic and ceramographic examination of experimental CANDU fuel

For metallographic and ceramographic examination, a CANDU experimental fuel pin instrumented with a thermocouple was sampled.

Steps for metallographic and ceramographic examination at RATEN-ICN

- Sample cutting inside the Hot Cell using a slow cutting machine;
- Epoxy resin embedding;
- Specimen transfer to the metallography cell;
- Successive polishing operations of the specimen;
- Chemical etching of the specimen in order to highlight its microstructural characteristics;
- Microstructural characterization of the fuel pellet and cladding using an optical microscope.
Metallographic and ceramographic examination of experimental CANDU fuel

Cross section sample

Longitudinal section sample

Fuel element after chemical etching

Fuel grains aspect in the center of the pellet

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Metallographic and ceramographic examination of experimental CANDU fuel

Fuel grain size modification from the outer region to the middle of the pellet
Metallographic and ceramographic examination of experimental CANDU fuel

Cladding hydride aspect
CONCLUSIONS

- The sample longitudinal and cross-section macrographs show connected radial and circular fissures which are normal for CANDU UO$_2$ pellets and the cladding does not present nonconformities, having a uniform thickness.

- The pellet microstructure was analyzed using a magnification of 200x. The examination showed that the fuel pellet consists of unaffected grains and equiaxed grains.

- Hydride precipitates dimension and orientation were analyzed using 500x magnification and no major precipitates were observed, which represent the expected result due to the short irradiation time.
Thank You!