DESTRUCTIVE EXAMINATION OF EXPERIMENTAL CANDU FUEL ELEMENTS IRRADIATED IN TRIGA-SSR REACTOR

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Presentation Outline

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The facilities from Institute for Nuclear Research Pitești allow the testing, manipulation and examination of nuclear fuel and irradiated materials. The most important facilities are the TRIGA Steady State Research and Material Test Reactor and the Post-Irradiation Examination Laboratory (PIEL).
Introduction

Post-Irradiation Examination Laboratory (PIEL) enables us to investigate the nuclear fuel and irradiated materials. PIEL is an alpha-gamma hot cell facility. It includes two heavy concrete hot cells, three steel hot cells and one lead hot cell.
Introduction

During the irradiation in the TRIGA SSR reactor, the fuel elements suffer dimensional and structural modifications, and also modifications of the cladding surface status, as result of corrosion process, which can lead to defects and even to the losing of integrity.

The irradiated fuel elements were further subjected to examination in the PIEL laboratory.
Introduction

The performance of nuclear fuel is assessed by studying the following elements:

- Cladding integrity (aspect, effects produced by corrosion);
- Dimensional modifications;
- Fuel burn-up;
- Distribution of fission products in the fuel column;
- Pressure and volume of fission gas;
- Structural modifications of the fuel and cladding;
- Cladding oxidation and hydriding;
- Isotopic composition of the fuel;
- Cladding mechanical properties.
1. The aspect of fuel element cladding surface

After irradiation, the fuel rod was kept in the reactor pool for cooling. The fuel rod was then transferred to the INR hot cells where it was subjected to detailed examinations. An image of the fuel element was obtained using a periscope, coupled with a digital camera. The cladding surface had a normal aspect.
2. Metallographic / ceramographic examination

A LEICA TELATOM 4 optical microscope having a magnification up to x1000 was used for macrographic and microstructural analysis of the irradiated fuel rod. A computer-assisted analysis system is used for the quantitative determination of structural features, such as grain and pore size distribution.

The preparation of the samples includes precise cutting, vacuum resin impregnation, sample mounting with epoxy resin in an acrylic resin cup, mechanical grinding and polishing, chemical etching.

The analyses by optical microscopy provide information concerning:

- the aspect of pellet fissure
- the structural changes of fuel and the sizes of the grains;
- the thickness of the oxide layer and the cladding hydriding.
The cross section of the fuel pellet (x8) presents radial and circular fissures on the whole section. The cladding doesn’t present nonconformities, the thickness of this being 0.431 mm. There are no visible effects on the cladding, due to mechanical or chemical interactions.
Post-irradiation examination

- Equiaxial grains
- Unaffected grains

The structural modifications in the fuel pellet
Post-irradiation examination

The hydride precipitates are orientated parallel to the cladding surface. A content of hydrogen of about 120 ppm was estimated. The fuel element presents on the outer side of the cladding a continuous and uniform zirconium oxide layer (2,5 μm thick).

a) Cladding hydrading  b) Outer oxide layer on cladding

Cladding aspect
3. Mechanical properties determination

After the preliminary tests, three pieces (5 mm long) were cut out of the fuel rod to obtain ring samples for tensile testing.

The tensile testing machine is an INSTRON 5569 model, using Merlin software for data acquisition and processing.
Post-irradiation examination

The tests have been performed in order to determine the following mechanical characteristics:
• the strain–stress diagrams and load extension;
• the yield strengths (offset method at 0.2%);
• the elastic limit;
• the ultimate tensile strength of the samples.

The tests were done under the following conditions:
- constant testing temperature (300°C);
- preload: 25 N;
- constant tensile strain (v=0, 05 min⁻¹).
Post-irradiation examination

Instron Testing Machine

5569 Model
(Twin Columns Table)

50 kN Maximum Load Capacity
Post-irradiation examination

Three zone split furnace and brackets
Maximum Temperature: 1000 °C
Post-irradiation examination
Post-irradiation examination
The aspect of the ring sample after the test
4. Fracture surface analysis by scanning electron microscopy (SEM)

For sample analysis an electron microscop model TESCAN MIRA II LMU CS with Schottky Field Emission and variable pressure was used. The magnification range is $4x \div 1,000,000x$. An outstanding depth field, much higher than in the case of optical microscopy characterizes the scanning electron microscopy (SEM). This makes SEM very appropriate for analyzing fracture surfaces of zircaloy 4 cladding resulted from tensile tests.
Post-irradiation examination

Because of the ring shape of the sample, for rupture surface visualization, the sample was split in two parts, which were mounted in microscope chamber. Both sides of the tensile fracture were analysed on each half of the ring. The dimples from the central zone are rather deep, whereas the ones on the outer side are tilted and smaller. The central zone of the fracture presents equiaxial dimples.
Post-irradiation examination

The aspect of the central zone of the fracture
Conclusions

A full set of non-destructive and destructive examinations of the cladding was performed.

• By metallographic examination we determined that the hydride precipitates are orientated parallel to the cladding surface. A content of hydrogen of about 120 ppm was estimated. The cladding doesn’t present nonconformities. The fuel element presents on the outer side of the cladding a continuous and uniform zirconium oxide layer 2.5 µm thick.

• After the preliminary tests, three ring samples were cut from the fuel rod, and were subject of tensile test on an INSTRON 5569 model machine in order to evaluate the changes of their mechanical properties as a consequence of irradiation.

• Scanning electron microscopy was performed using a microscope model TESCAN MIRA II LMU CS with Schottky FE emitter and variable pressure. The analysis shows that the central zone has deeper dimples, whereas on the outer zone the dimples are tilted and smaller.

The obtained results are typical for CANDU 6-type fuel.
References

Thank you for your attention!

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