Doctoral School of Materials Sciences and Technologies
Óbuda University
HUN-REN Centre for Energy Research

Óbuda University
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Report of First Semester

Testing and examination of cladding design for Accident Tolerant Fuel

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Introduction

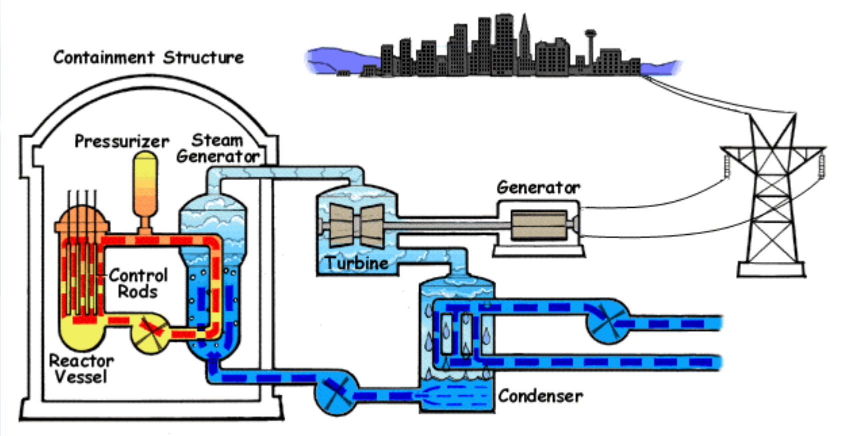
Accident Tolerant Fuel (ATF) designs are now being developed in several countries with the goal of enhancing nuclear reactor safety and efficiency.
The major purpose is to develop new or improve the existing fuel and cladding materials that perform better under accident conditions.

- **High Temperature** : oxidation, embrittlement, ballooning
- **Oxidation** : Interaction with steam or air
- **Radiation Damage :** microstructural changes in the cladding material
- **Mechanical Stress** : PCMI , cracks or strain in the cladding
- **Hydrogen Production :** Hydrides accumulating, causing embrittlement

Plan

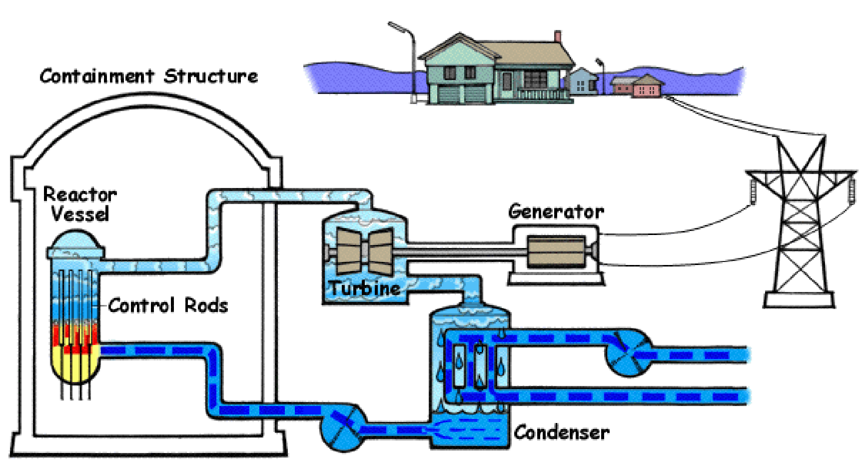
- Current types of materials
- Cladding materials for ATF designs and advanced fuel
- oxidation tests with Cr coated cladding tubes
- The CODEX-ATF-AIT Bundle Experiment

1 Pressurized water Reactor .



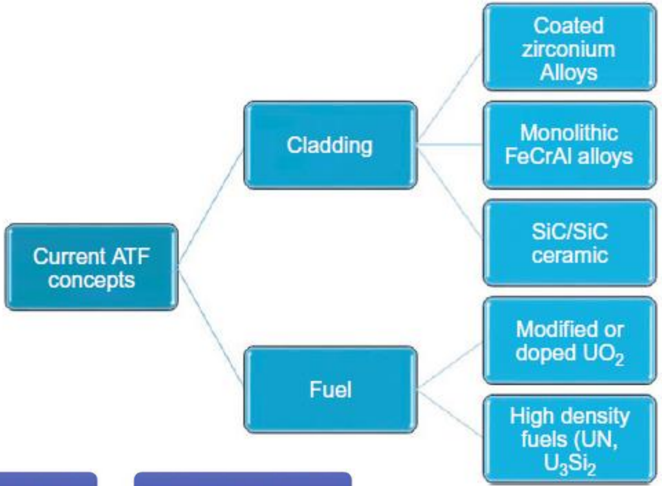
- **Pressurized water** prevents boiling.
- **Two water loops**: one for cooling and one for steam.
- **Separate steam system** for non-radioactive steam.
- **Safety** systems control pressure, temperature, and reactions.

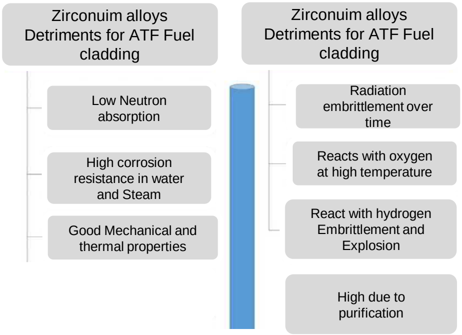
2 Boiling water Reactor

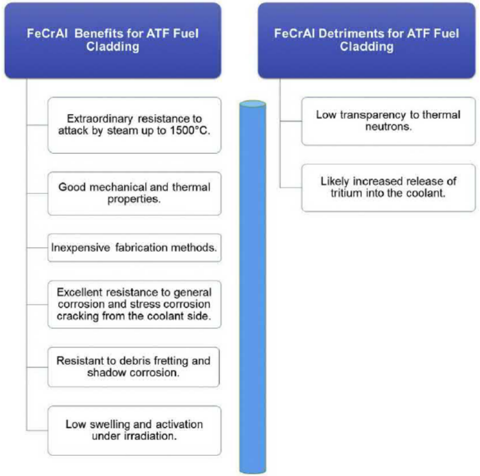


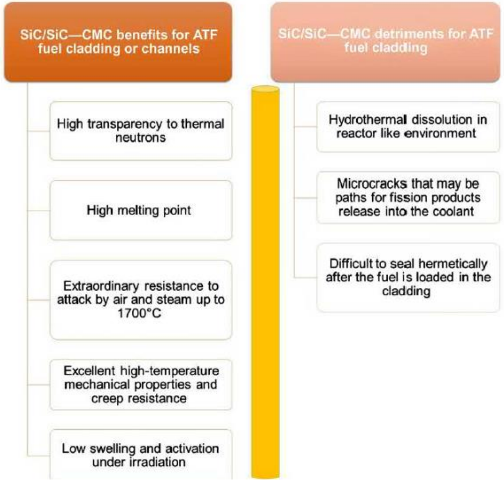
- **Water partially boils** inside the reactor core, lower pressure.
- **Steam** directly drives turbines.
- **No secondary loop** like in PWRs.

Cladding materials for ATF designs and tolerant fuel





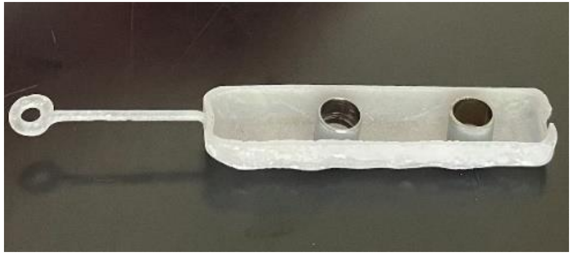




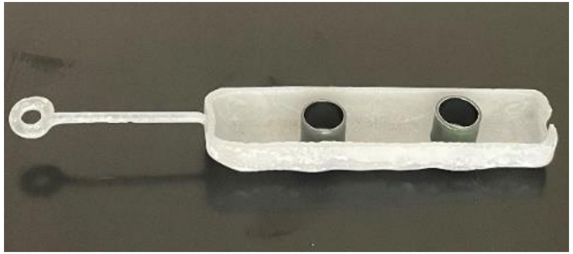
Participation in separate-effects oxidation tests

High temperature oxidation furnace in air and steam

-The Cr-coated and uncoated zirconium tube samples were provided by CTU (Czech Technical University of Prague).
- Cladding tube external Diameter 9.1 mm
- 8 mm long specimens
- The specimens were degreased and cleaned in acetone
- Measure the mass gain of claddings after oxidation

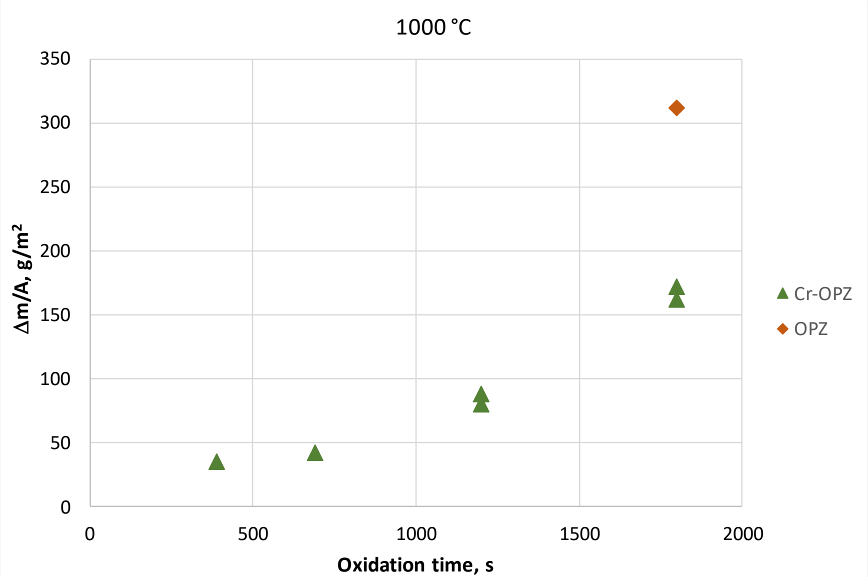


- CRTR-31 samples before (left side) and after oxidation



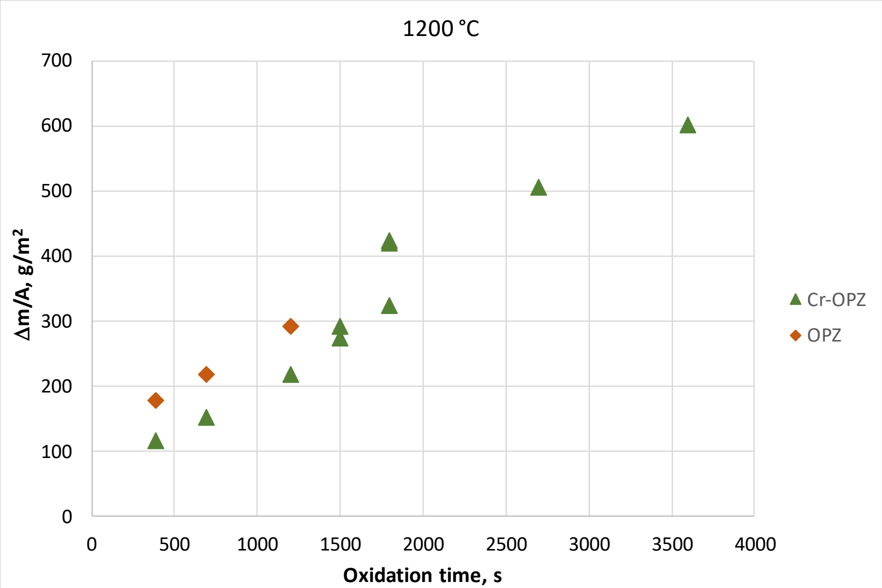
and CRTR-32 samples before (left side) and after oxidation

Participation of Supporting oxidation tests



Mass gain of uncoated and coated optZIRLO alloy

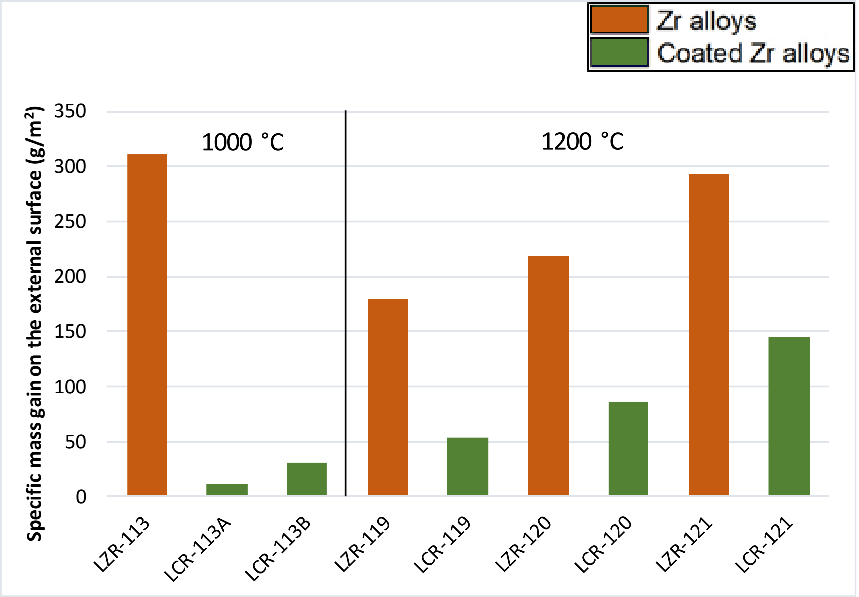
at 1000 °C



Mass gain of uncoated and coated optZIRLO alloy

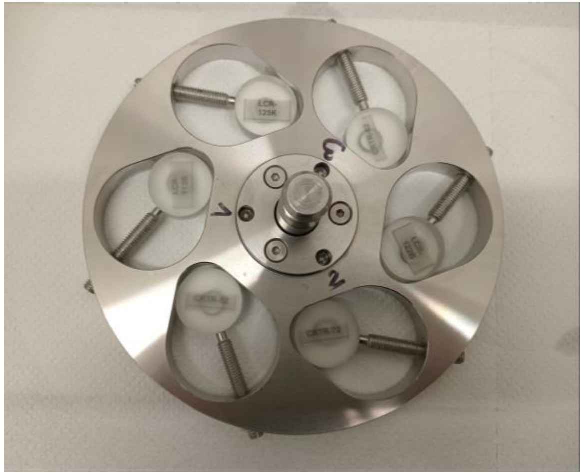
at 1200 °C

Participation of Supporting oxidation tests and Specimen preparation



Comparing of Specific mass gain at isothermal Temperature :

- Less oxidation of chromuim coated Opt Zr alloys than uncoated cladding
- Higher oxidation of chromuim layer at 1200 °C versus 1000 °C

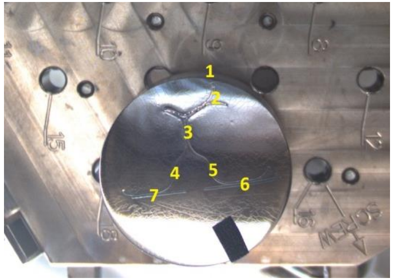


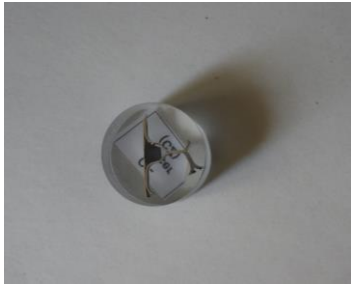
Specimen preparation :

- Embedding into epoxy resin
- Grinding with SiC
- Polishing
- Etching
- Sputtering with a thin carbon layer to ensure electric conductivity.

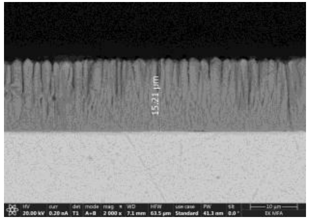
Coated OptZIRLO cladding and spacer pre-test SEM Image

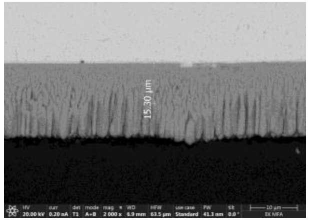
Cr-coated OptZIRLO cladding sample



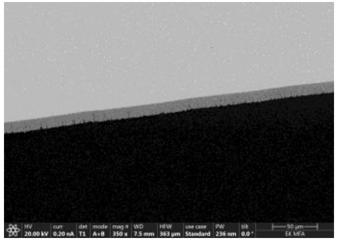


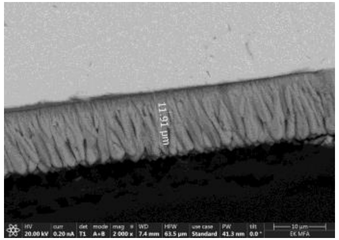
Cr-coated spacer sample





- Uniform Cr coating layer surrounding the circumference of the cladding ~**15.20 µm**





Thickness of the Cr layer on spacer grid :

-Uniform cross section :**10 – 12 µm**

-Uniform curved parts : **2 – 3 µm**

Participation in the CODEX-ATF-AIT-Bundle experiment

1.Water tank & gas inlet

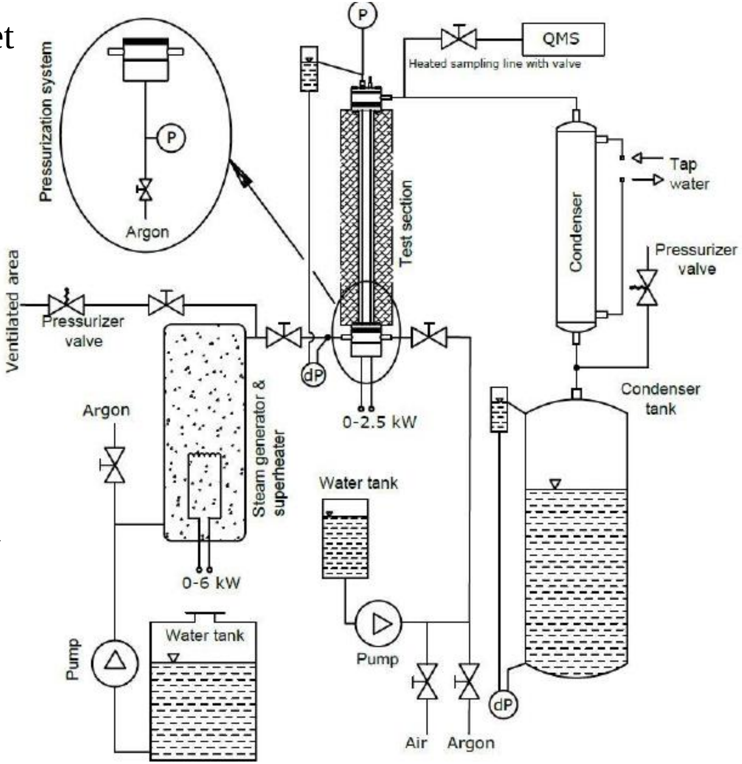
2.Steam generator & superheater

3.Test section

4.Condenser

5 .Condenser tank

6.Pressurisation system



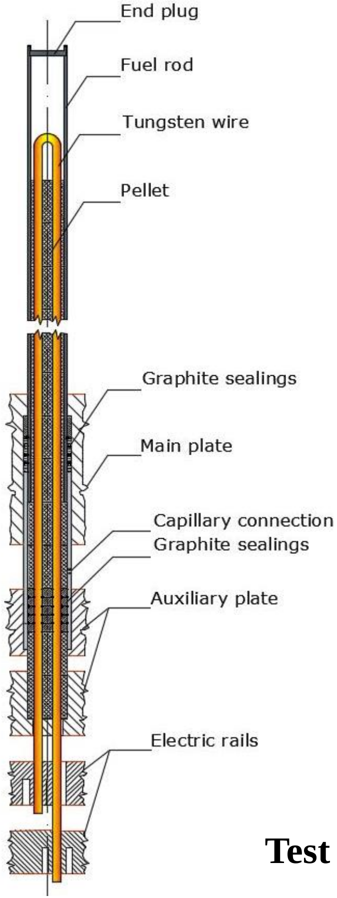
Participation in the CODEX-ATF-AIT-Bundle experiment

Bundle design

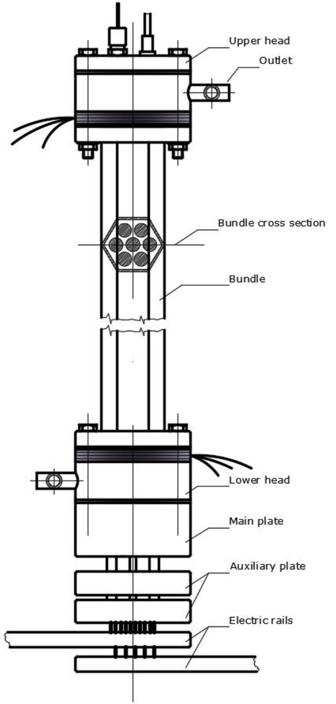
- VVER bundle type:
  hexagonal arrangement of 7 rods
- Height of rods: 920 mm

  electrically heated - pressurized

- Cladding material: Cr-coated ZirloTM
- ZrO_2 ceramic pellets
- Tungsten heaters
- 3 spacer grids (Zr1%Nb alloy, Cr-coated)
- Hexagonal shroud (Zr2.5%Nb alloy, Cr-coated)

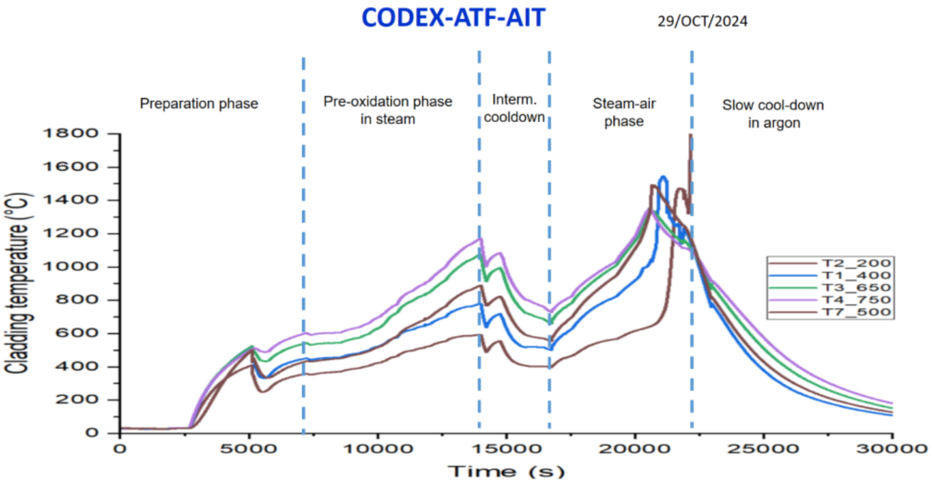


Heated fuel rod



Test section with seven-rod bundle

The CODEX-ATF-AIT-Bundle Experiment and Simple Preparation



- In the CODEX-ATF-AIT test, only 1.4 g of hydrogen was produced, indicating less reactivity of the ATF cladding.

- The maximum pre-oxidation temperatures 1171 °C

-The cladding burst between 800 - 900 °C was initiated by increased pressure inside the rods.

-This enabled the steam/air to penetrate the rod, generating chemical reactions on both sides of the cladding

-The bundle was cooled in argon to avoid any interactions with water

Bundle specimen Preparation :

- Cutting the specimen in length = 25 mm
- Embedding into epoxy resin .
- Grinding with SiC
- Polishing
- Sputtering with a thin carbon layer to ensure electric conductivity

Future plan

- ✓ Preparation of the samples, microstructural examination and evaluation the result of CODEX-ATF-AIT to understand how coated zirconium material behave after oxidation in steam and air ingress
- ✓ Post-test examination of the bundle is ongoing
- ✓ Developing a numerical model of Accident Tolerant Fuel (ATF) is an essential tool to predict the behavior of these advanced materials under various reactor accident scenarios.

Thank you for your attention!