LEAD TEST RODS PROGRAM WITH Cr-COATED OPTIMIZED ZIRLO CLADDING AT DOEL-4

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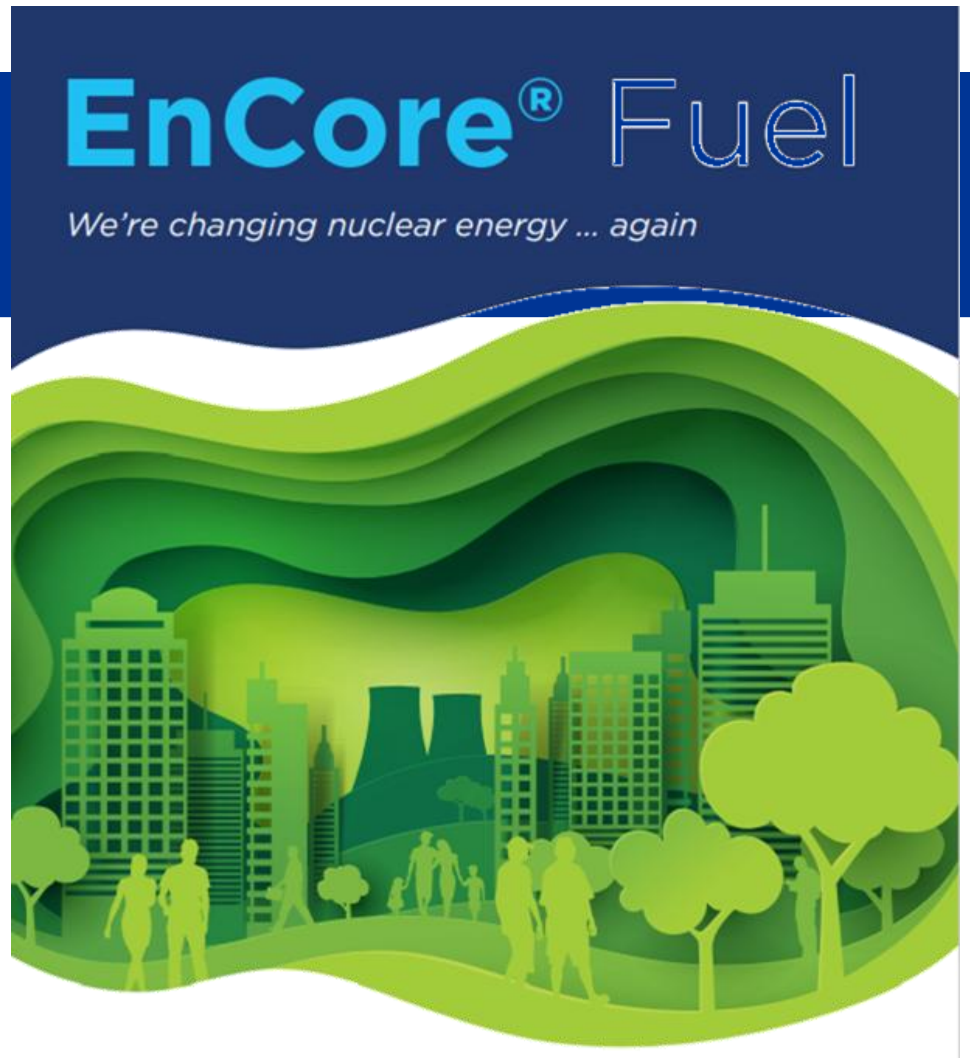
Outline

- Introduction
- Cr-coated Cladding Demonstration Program at Doel-4
- Design and licensing process
- Visual inspection results
- Conclusions

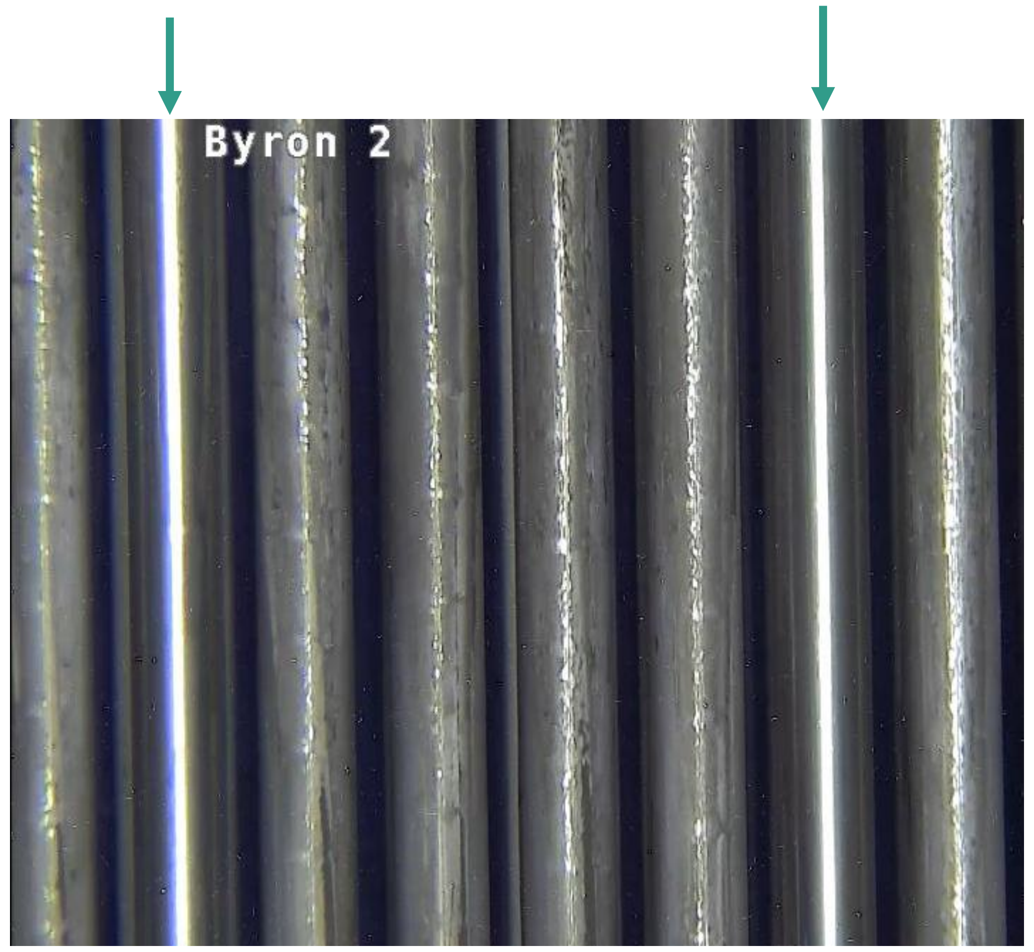
Introduction



- One of the most mature ATF cladding technology:

Cr-Coated cladding

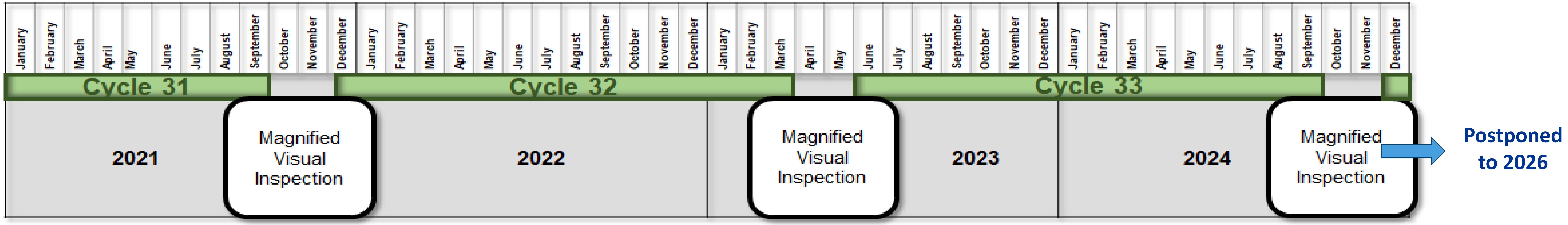
- Byron 1st Demonstration Program of Cr-coated **Optimized ZIRLO™** cladding
  - 16 Lead Test Rods (LTRs) introduced in 2 OFA Fuel Assemblies (2019)
  - Completed ≈ 75 GWd/tU
  - Detailed poolside and hotcell examinations



Source: Westinghouse

Introduction

- 2019: Agreement for the Demonstration Program at Doel-4 of ENGIE-Electrabel
  - Obtain in-pile experience of the Cr-coated cladding
  - Analyze the behavior of the Cr-coating during irradiation
- Summer 2020: Introduction of 32 Cr-coated LTRs in 4 fuel assemblies
- Fall 2024: Third irradiation of Cr-coated rods completed
- Visual inspection campaign after each irradiation cycle



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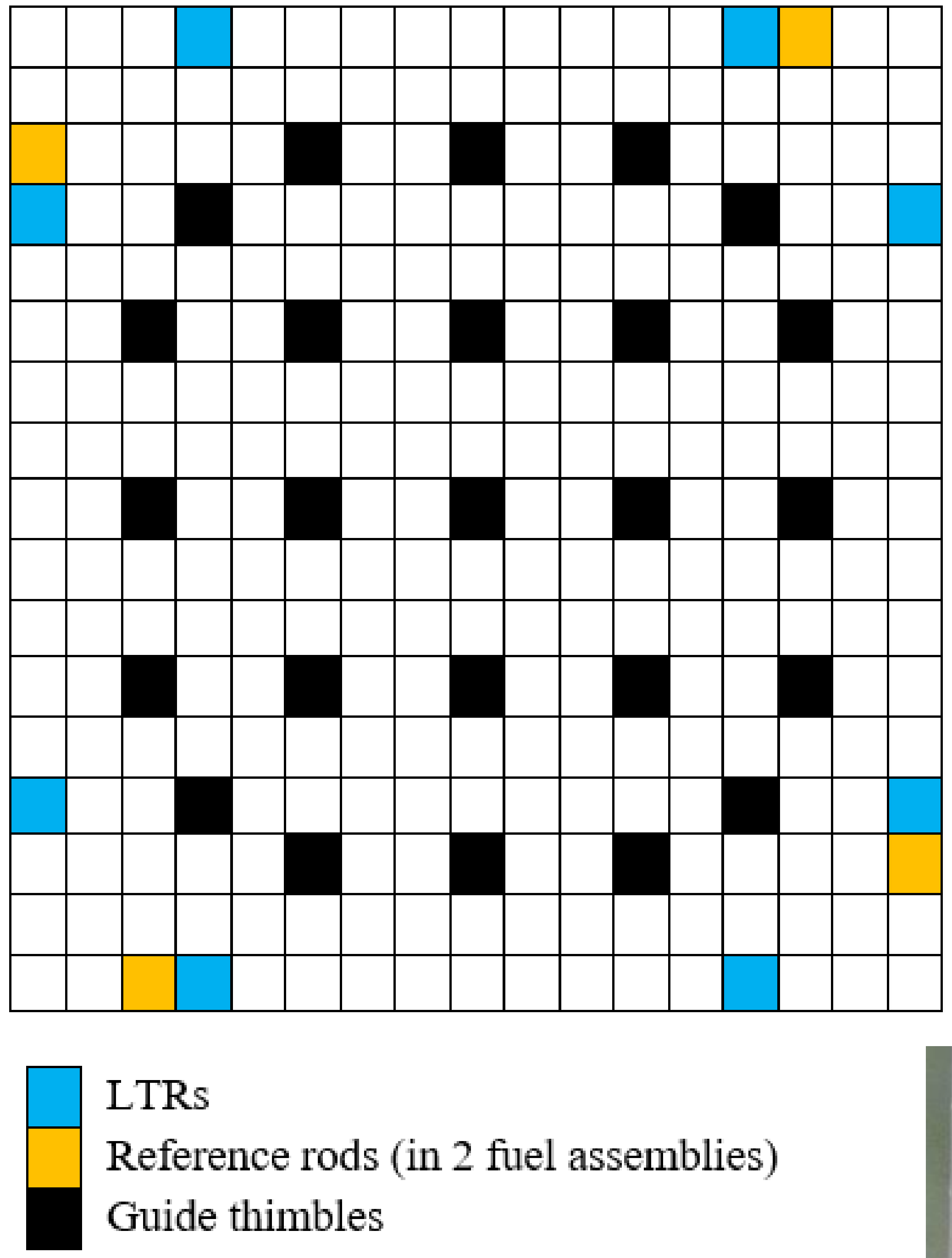
Cr-coated Cladding Demonstration Program at Doel-4

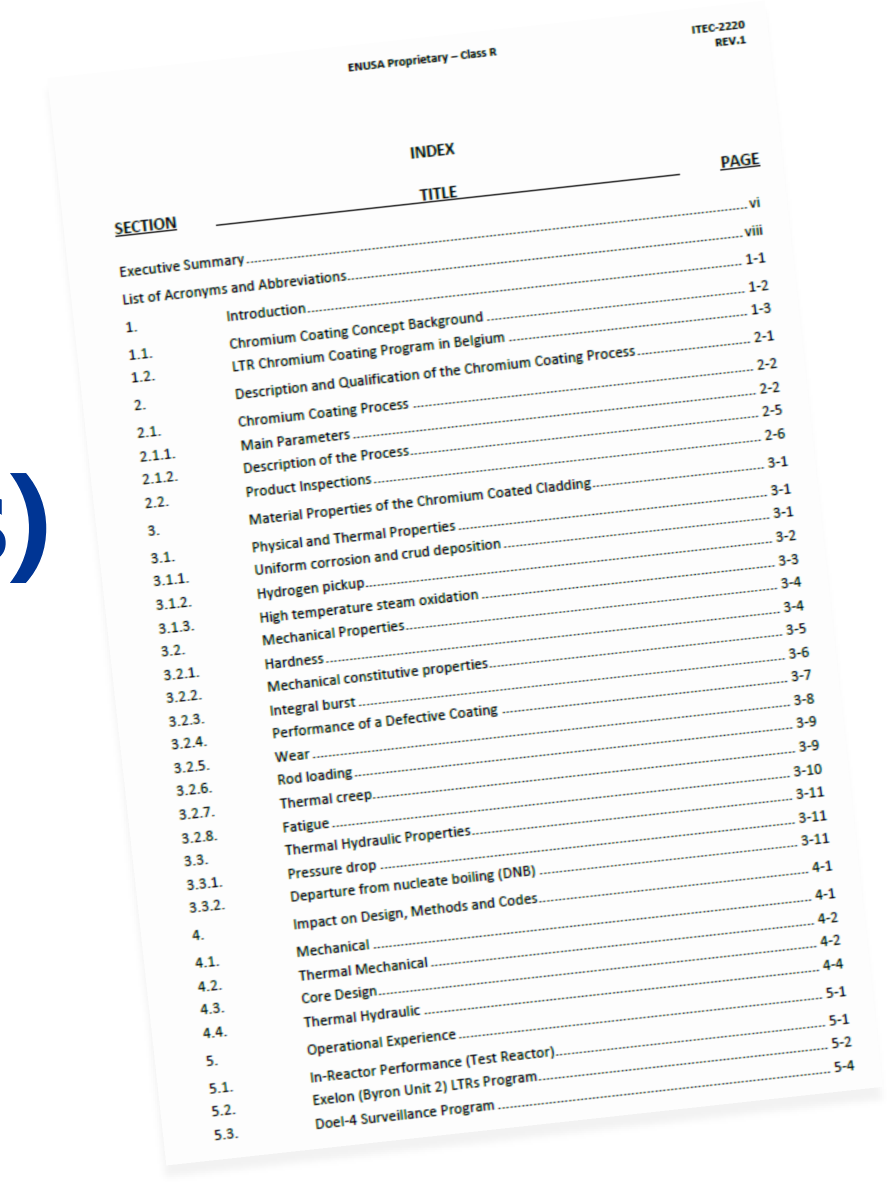
- **Doel-4 W-3 loop. 17x17 RFA XLR OPT fuel**
- **32 Cr-coated LTRs**
  - Optimized ZIRLO Cr-coated cladding (Cold sprayed Chromium coating)
  - Upper and lower areas uncoated
- **8 Reference rods**
  - Optimized ZIRLO rods (un-coated)
- **Different UO_2 pellet densities and backfill pressures**



Photos before irradiation (in ENUSA manufacture)

Design and Licensing Timeline

- **ENGIE Electrabel/Tractebel, ENUSA and W decision on LTRs <u>May 2019</u>**
- **Design without credit to the benefits throughout documents**
  - Topical Report Cr-coating cladding <u>September 2019</u>
  - ENUSA and Westinghouse Engineering Review Process <u>October 2019</u>
  - Compatibility and Safety, Fuel Rod Design and LOCA addendum <u>November 2019</u>



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- **Review and audited by Bel V (TSO of Belgian Safety Authorities) <u>February 2020</u>**
- **Manufacturing to delivery of LTRs <u>May 2020</u>**
- **Loading in Doel 4 core <u>June 2020</u>**

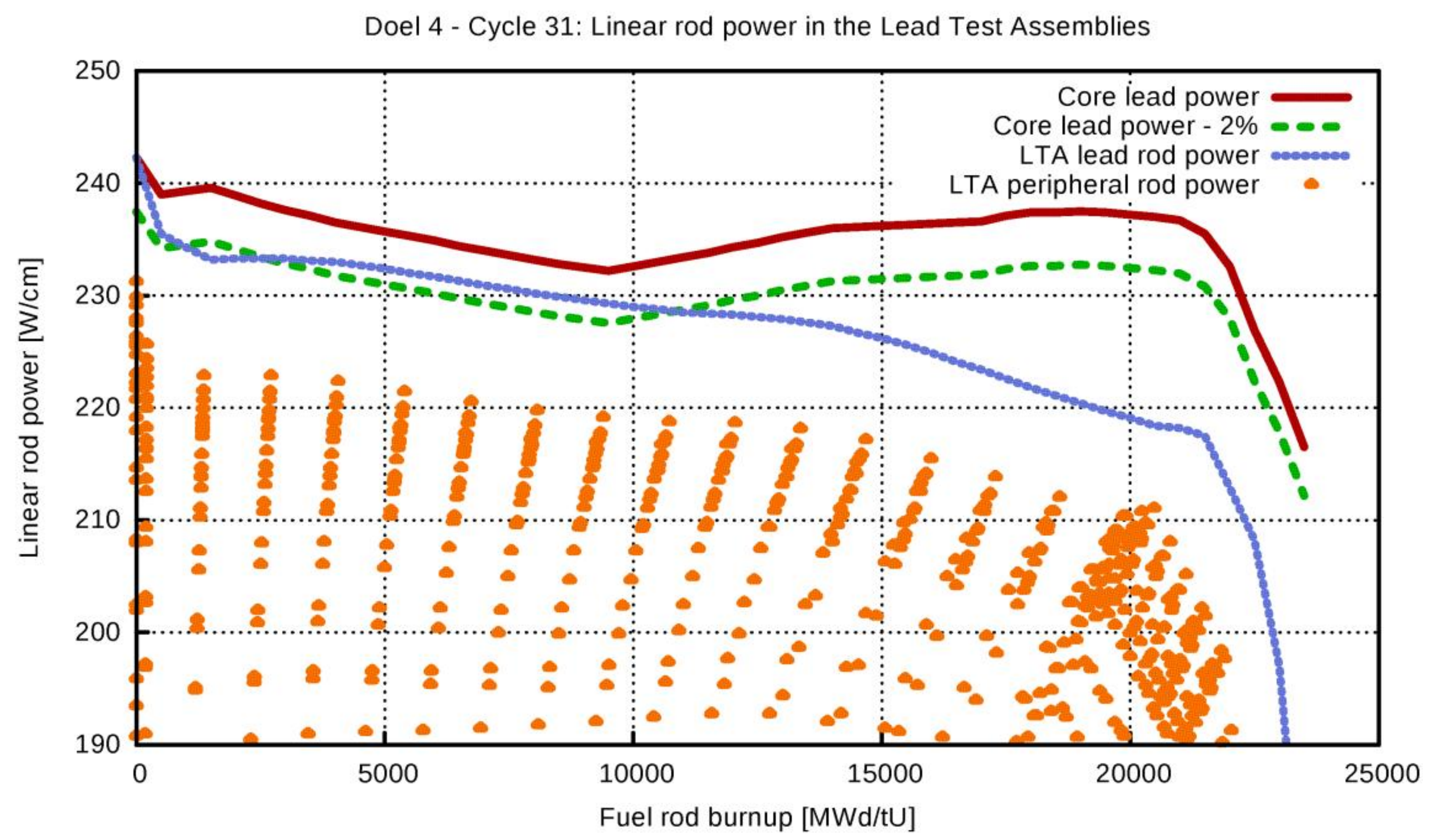
Design Approach for Licensing

Area	Impact
Nuclear Design	• No impact except a recommendation of 2% lower power compared to the lead assembly (good practice)
Mechanical	• Insignificant change in rod outer diameter due to coating • No change in surface roughness
Thermal Hydraulic	• No adverse impact on margin to DNB ✓Insignificant change in rod outer diameter due to coating ✓No change in surface roughness or fuel pressure drop
LOCA	• Coated cladding is expected to be a benefit but not credited ✓Reduces operational (pre-transient) corrosion ✓Reduces high temperature oxidation and the breakaway oxidation ✓Improve burst temperature and expected to reduce burst strains
Fuel Rod Design	• Thermal mechanical code, method and limits remain applicable • Verification of the high backfill pressure and density assuming conservative condition

- **Only 32 LTRs**
- **No credit to the Cr-coated benefits**
- **Non limiting core location**

Core Design and Safety process

- The core design and safety evaluation were performed according to the Tractebel reload safety evaluation methodology, consistent with the licensing requirements of Bel V.
- The insertion of LTRs into the four fuel assemblies has no significant impact and the Cr coating does not need to be explicitly modelled.
- The vendor recommendations of a margin of 2% for the average rod power of the LTRs compared to the peak power in the core during the first irradiation cycle was assured.



Licensing Agreements

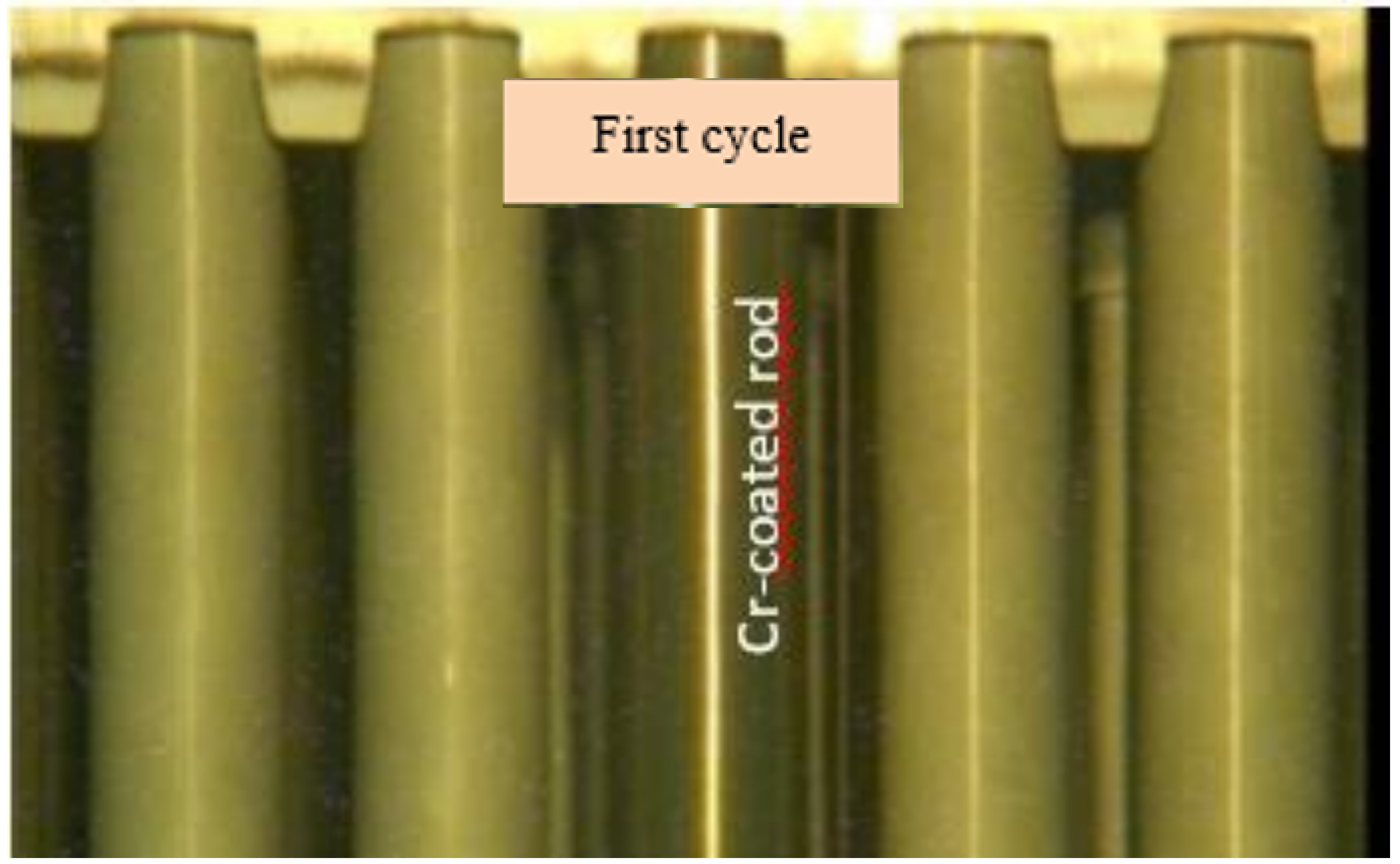
- After an extensive licensing review, the Doel-4 LTR program was approved by **Bel V** in February 2020.
- The vendor recommendation to load the concerned assemblies in non-limiting locations in the core was set as a requirement by **Bel V**.
- The **Bel V** agreement was granted for one cycle and for each of the two additional planned cycles will be given cycle per cycle, if applicable, after assessment of the international feedback and of the results of the inspection program required at the end of each cycle.

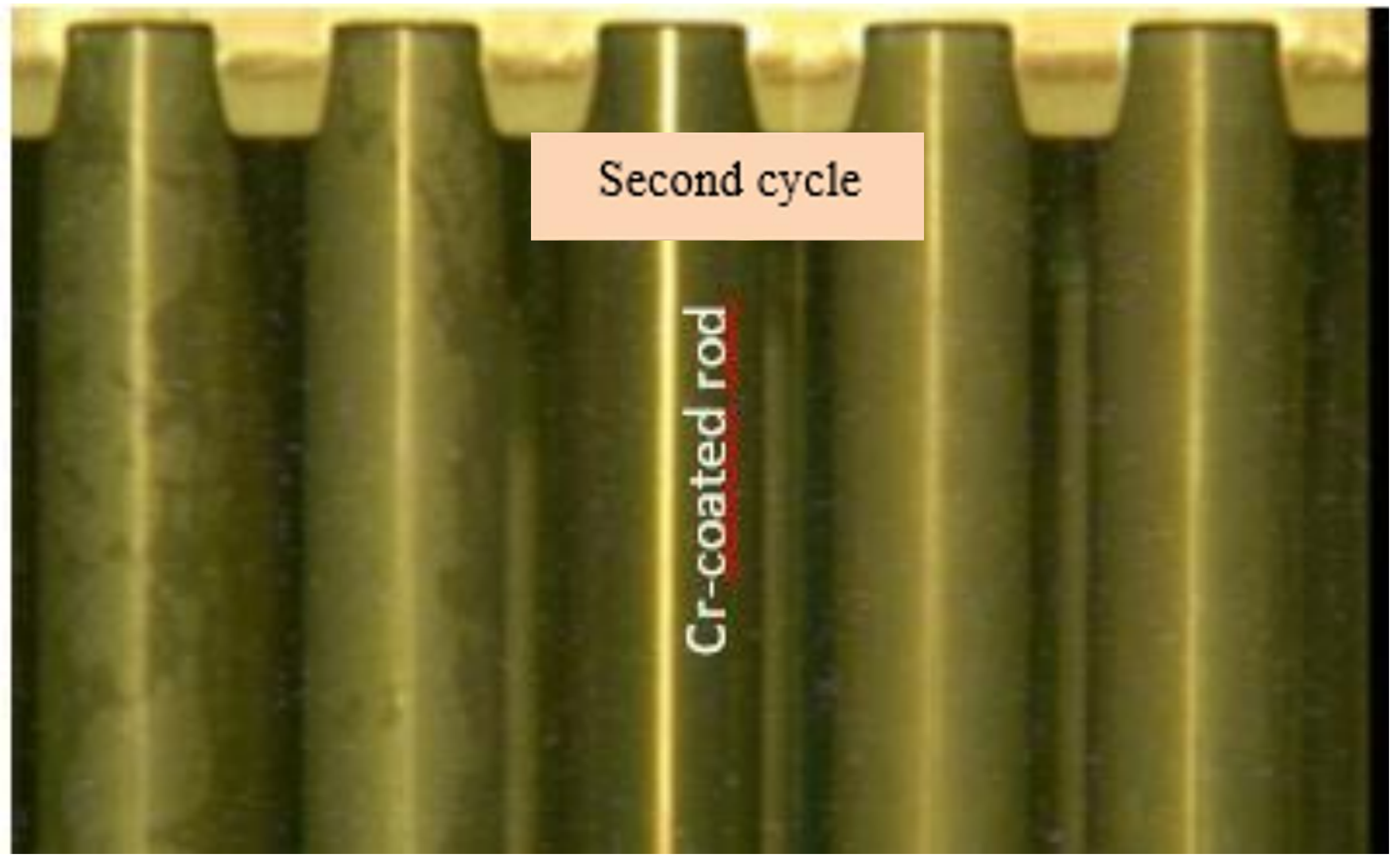
2021 and 2023 visual inspection results were presented to Bel V prior to loading the LTRs in Doel-4

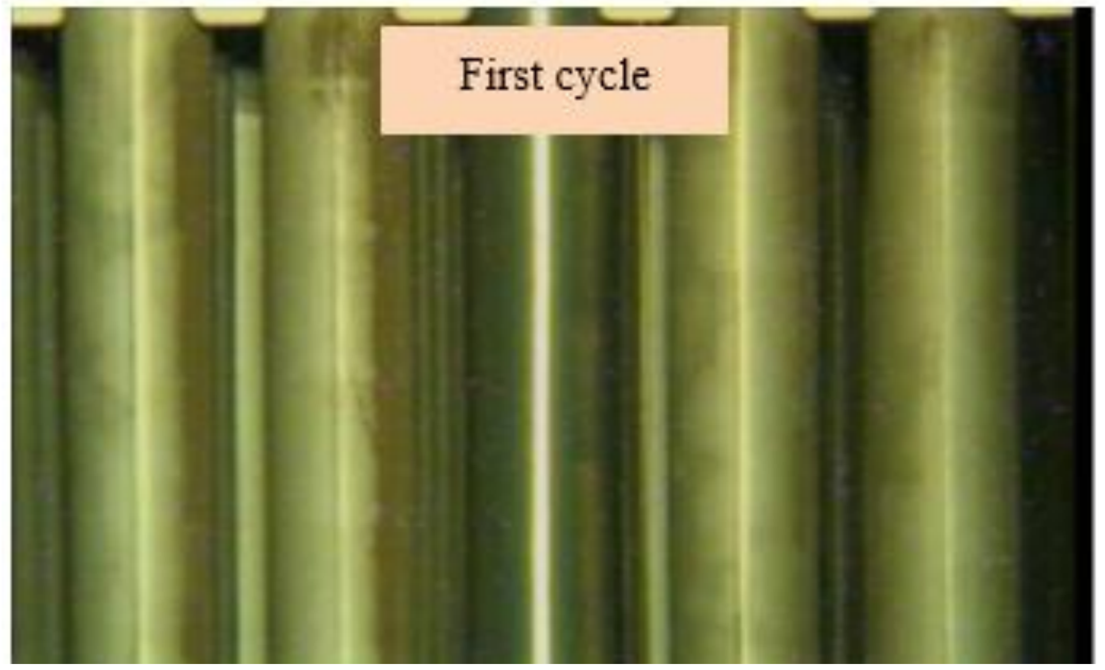
In both cases Bel V accepted the continuation of irradiation

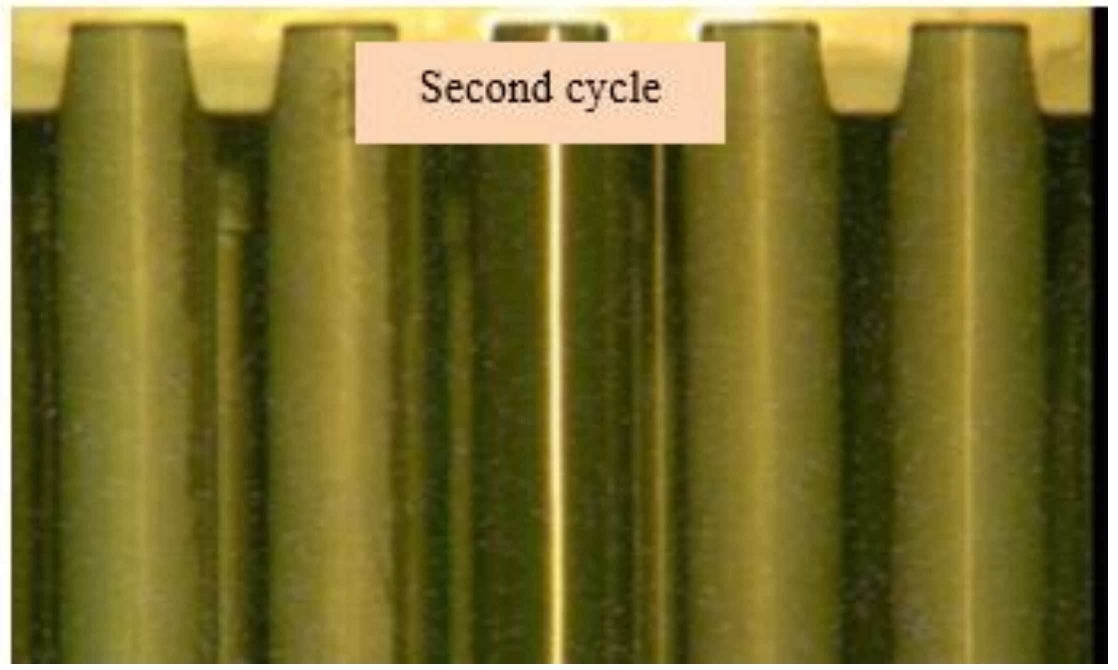
Visual Inspection Results

- **LTR Surfaces**: clean, bright and uniform after two cycles
  - No delamination, no cracks
  - No oxide transition observed on LTRs
- No differences between the different types of Cr-coated LTRs (pellet densities and backfill pressures)
- Crud deposits in less quantity on Cr-coated rods



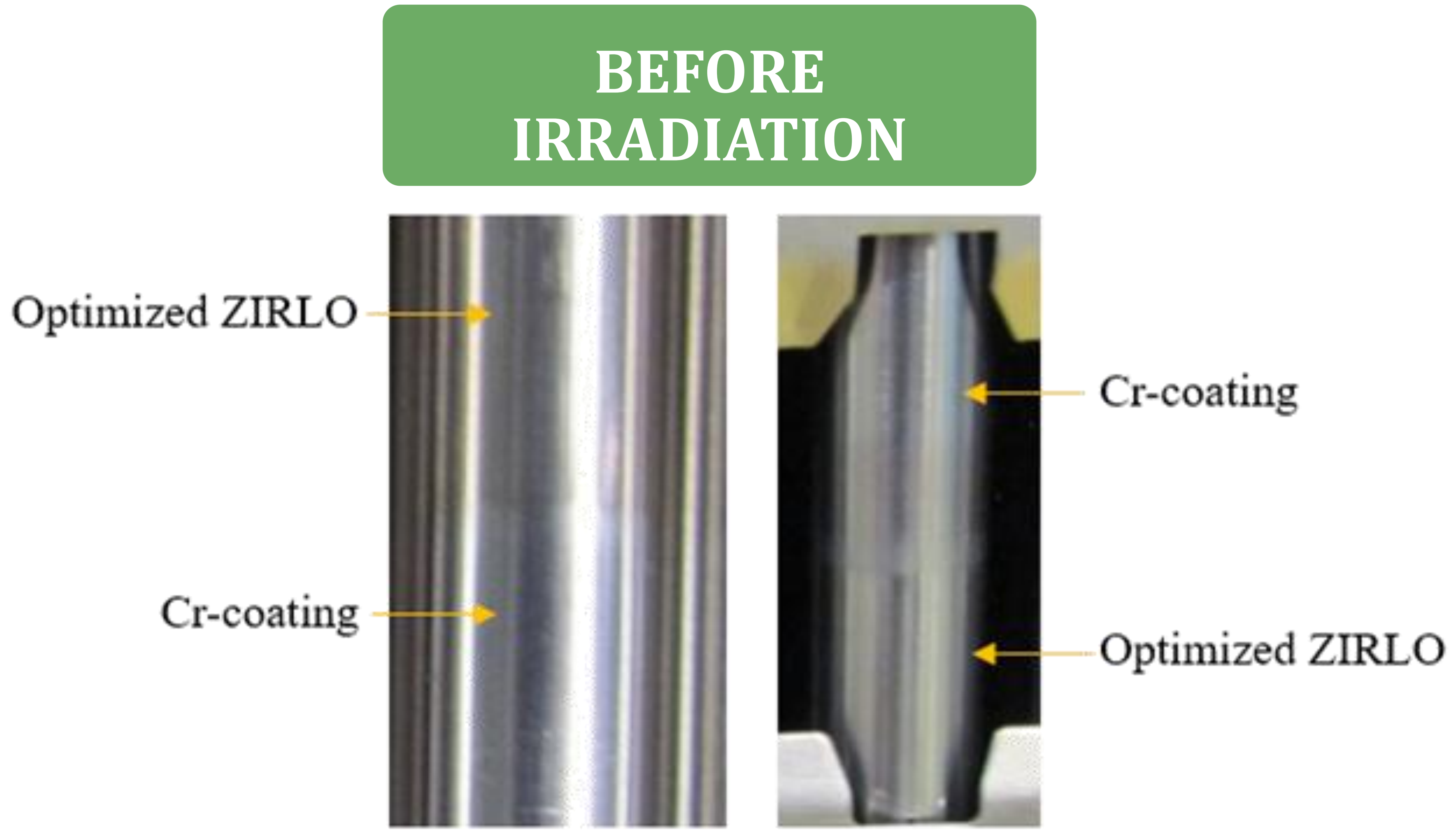


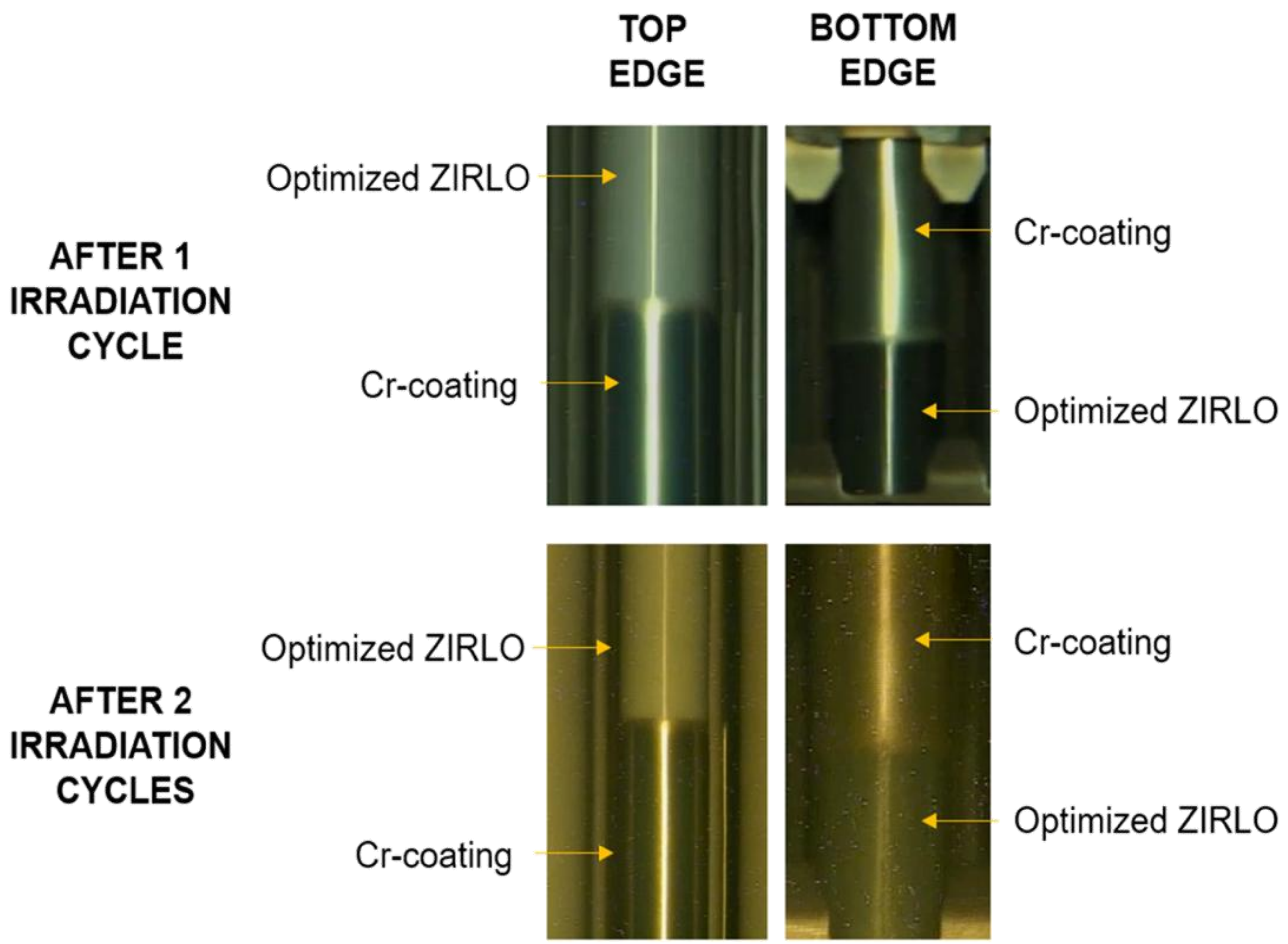




Visual Inspection Results

- **Ends of Cr-coating**: no changes due to irradiation were detected





Top and bottom Cr-coating edges after one and two cycles of irradiation

Visual Inspection Results

- **Qualitative LTRs growth:** similar to the Optimized ZIRLO un-coated rod growth
  - **Welding area**: similar aspect for LTRs and un-coated Optimized ZIRLO rods

The rods pointed out by the blue squares are Cr-coated LTRs.

Conclusions

In 2019, ENGIE Electrabel/Tractebel, Westinghouse and ENUSA agreed to load four RFA-2 OPT XLR fuel assemblies with 32 EnCore Cr-coated cladding LTRs at Doel-4

- Full set of licensing documentation was successfully prepared and submitted to Bel-V
- Following a thorough audit received regulatory approval in February 2020

LTRs inspection campaigns were successfully performed during the refueling activities in Doel-4 after first and second cycle of irradiation

- The Cr-coated rods remained bright, clean and uniform after two irradiation cycles
- The excellent behavior of the LTRs led to the acceptance of the Belgian safety authority for the last third cycle of irradiation, finished in Fall 2024. Last inspection campaign is planned for Spring 2026.

The initiative represents a milestone in the ATF technology deployment in Europe.

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Thank you! Any questions?

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