IFA-774: The first in-pile test with coated fuel rods

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INTRODUCTION

Need for improvement of fuel rod cladding

- More demanding conditions
  - Longer cycles, higher burn-up
  - Higher initial Lithium hydroxide (LiOH)
  - More corrosive environment (temperature, chemical)
- Need for increased safety
  - Avoid excessive corrosion and hydrogen release during accident conditions
- Reduction of failures
  - Avoid fuel failures induced by fretting
  - Reduction of hydrogen uptake (and embrittlement)

INTRODUCTION (contd)

Different approaches

- Evolutionary
  - Modified Zr-based alloys (Opt. ZIRLO, M5, MDA, NDA, HANA, etc.)
  - Surface modifications (such as ODS treatment) and coatings
- Revolutionary
  - SiC, Fe-Cr-Al, metal-ceramic hybrid cladding, Mo-based alloys (Accident Tolerant Fuel, Gen IV)

Screening tests to make coating selection

- Work was initiated in 2009 in order to improve instruments and to provide protective coatings for fuel and materials Gen IV (liquid lead, supercritical water)
- Presentation at EHPG in Sandefjord, 2011
  - “Coatings and plasma treatment for nuclear applications”, R. Van Nieuwenhove, J. Balak and B. C. Oberländer, HWR-1028, December 2011

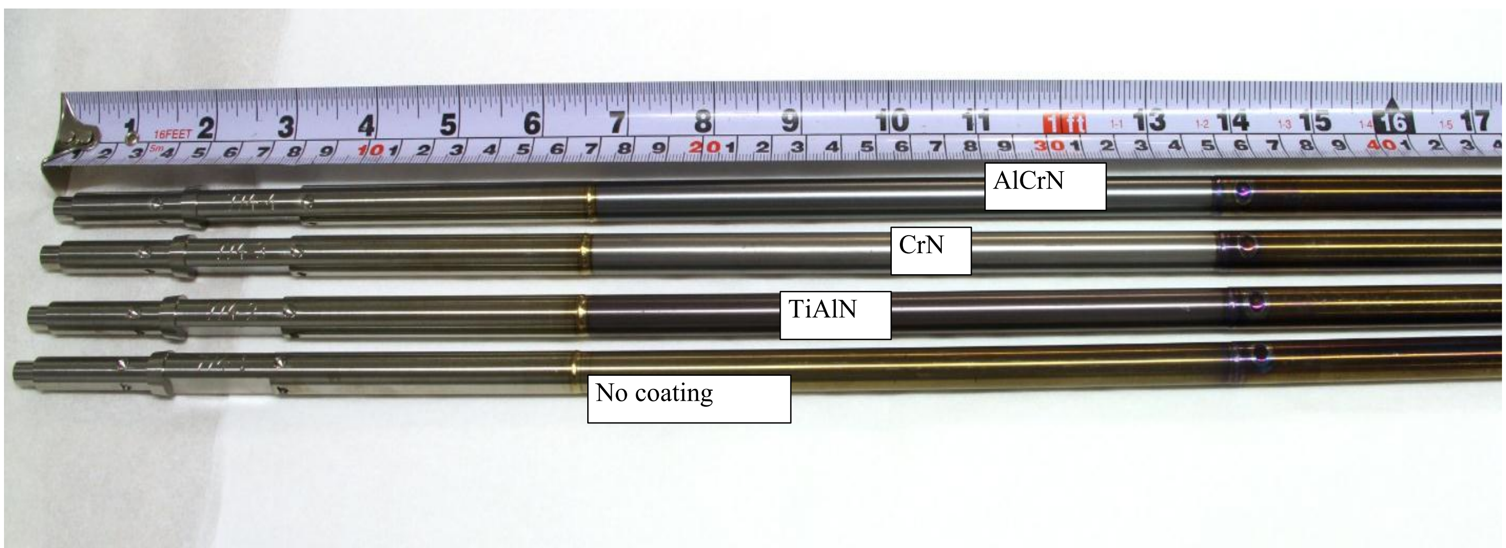
Note: Fukushima accident 11 March 2011

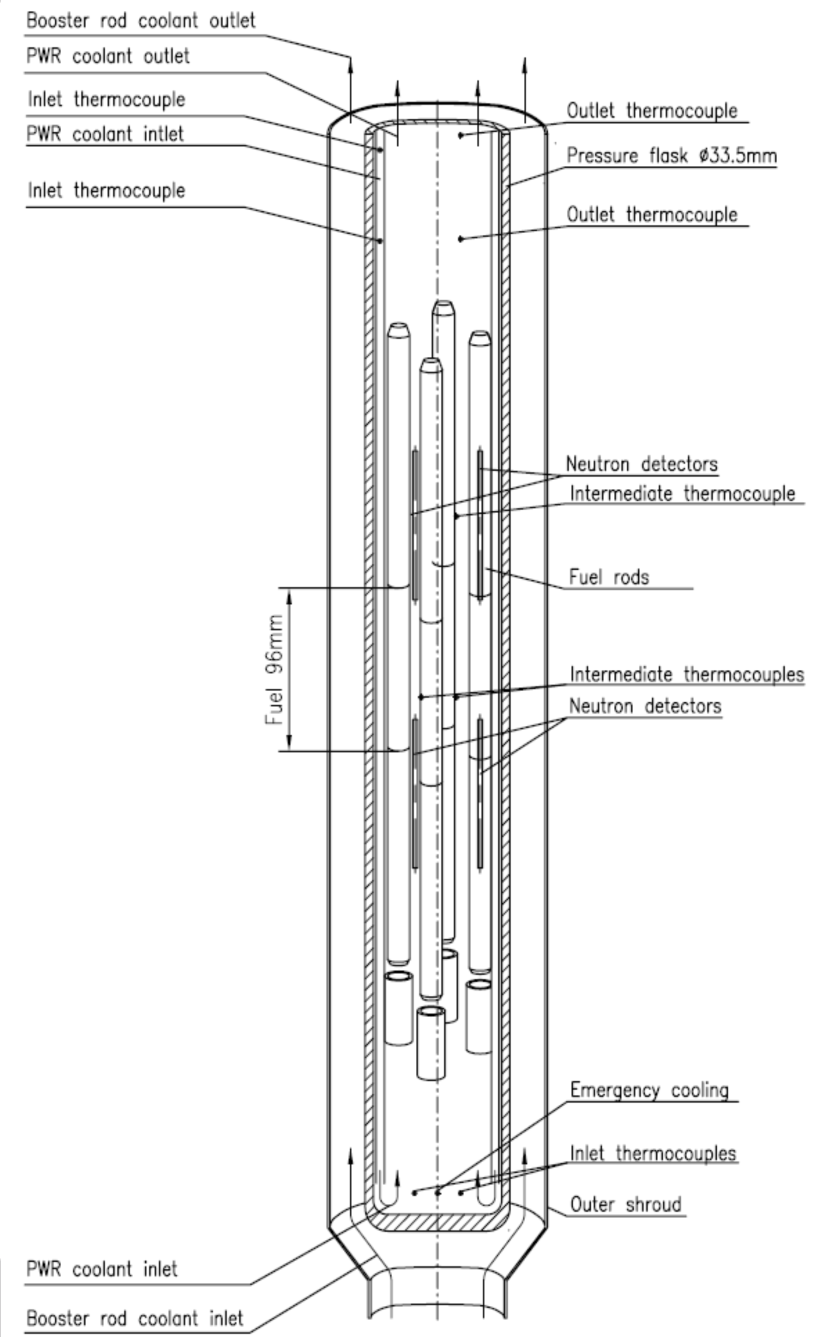
Highlights

- CrN (PVD) provides corrosion protection in SCW (650 °C, 1000 h)
  - R. Van Nieuwenhove, et al., international Symposium on SCW reactors, ISSCWR-6, Shenzhen, China, March, 2013
- TiAlN and AlCrN (PVD) provide corrosion protection in liquid lead at 550 °C (3000 h).
- Under PWR (IFA-731) and BWR (IFA-733) conditions, CrN performs very well, performance is unclear for TiAlN

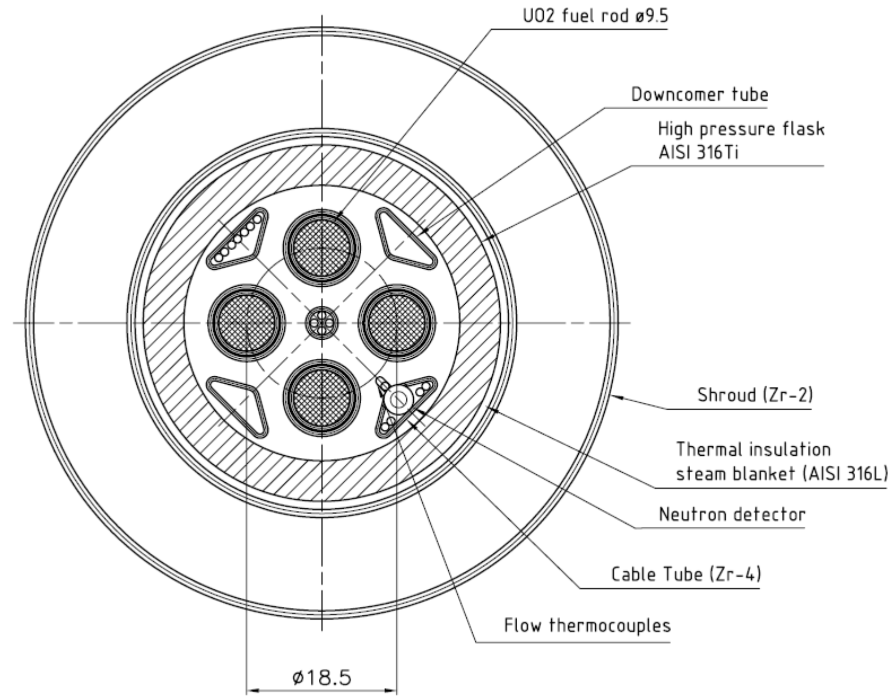
IFA-774: Description of experiment

- First experiment with coated **fuel rods**
- PWR conditions (2 reactor cycles) at 320 ºC
- Three rods with coatings: TiAlN, CrN, AlCrN (PVD)
- One reference rod
- Irradiation started on 15.03.2014. Reached now 93 days (FPD)



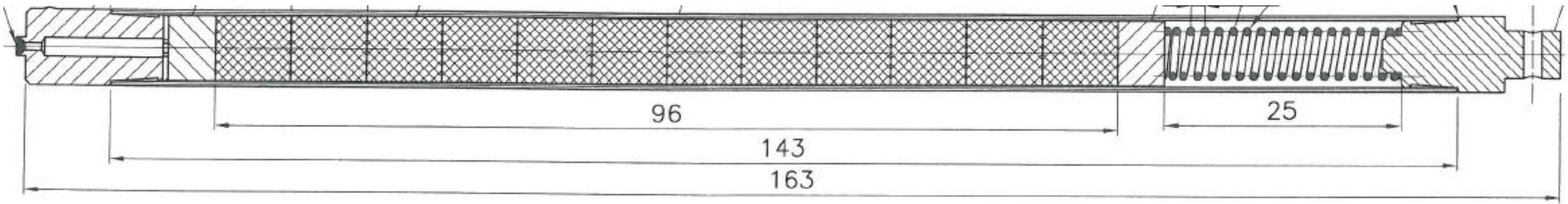


Booster rod coolant outlet
PWR coolant outlet
Inlet thermocouple
PWR coolant intlet
Inlet thermocouple
Outlet thermocouple
Pressure flask ø33.5mm
Outlet thermocouple
Neutron detectors
Intermediate thermocouple
Fuel rods
Fuel 96mm
Intermediate thermocouples
Neutron detectors
Emergency cooling
Inlet thermocouples
Outer shroud
PWR coolant inlet
Booster rod coolant inlet



UO2 fuel rod ø9.5
Downcomer tube
High pressure flask
AISI 316Ti
Shroud (Zr-2)
Thermal insulation
steam blanket (AISI 316L)
Neutron detector
Cable Tube (Zr-4)
Flow thermocouples
ø18.5

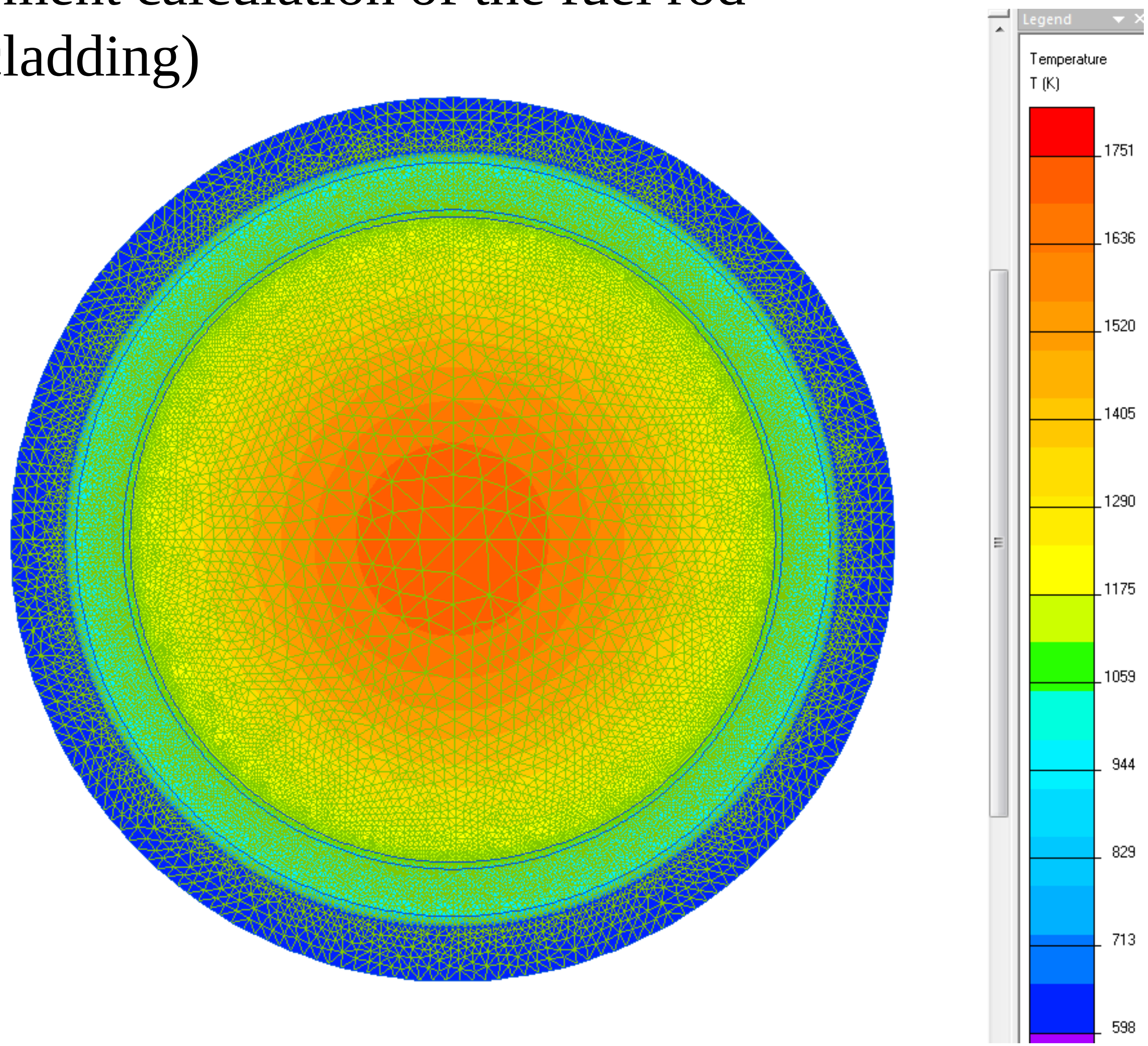
Fuel rod characteristics



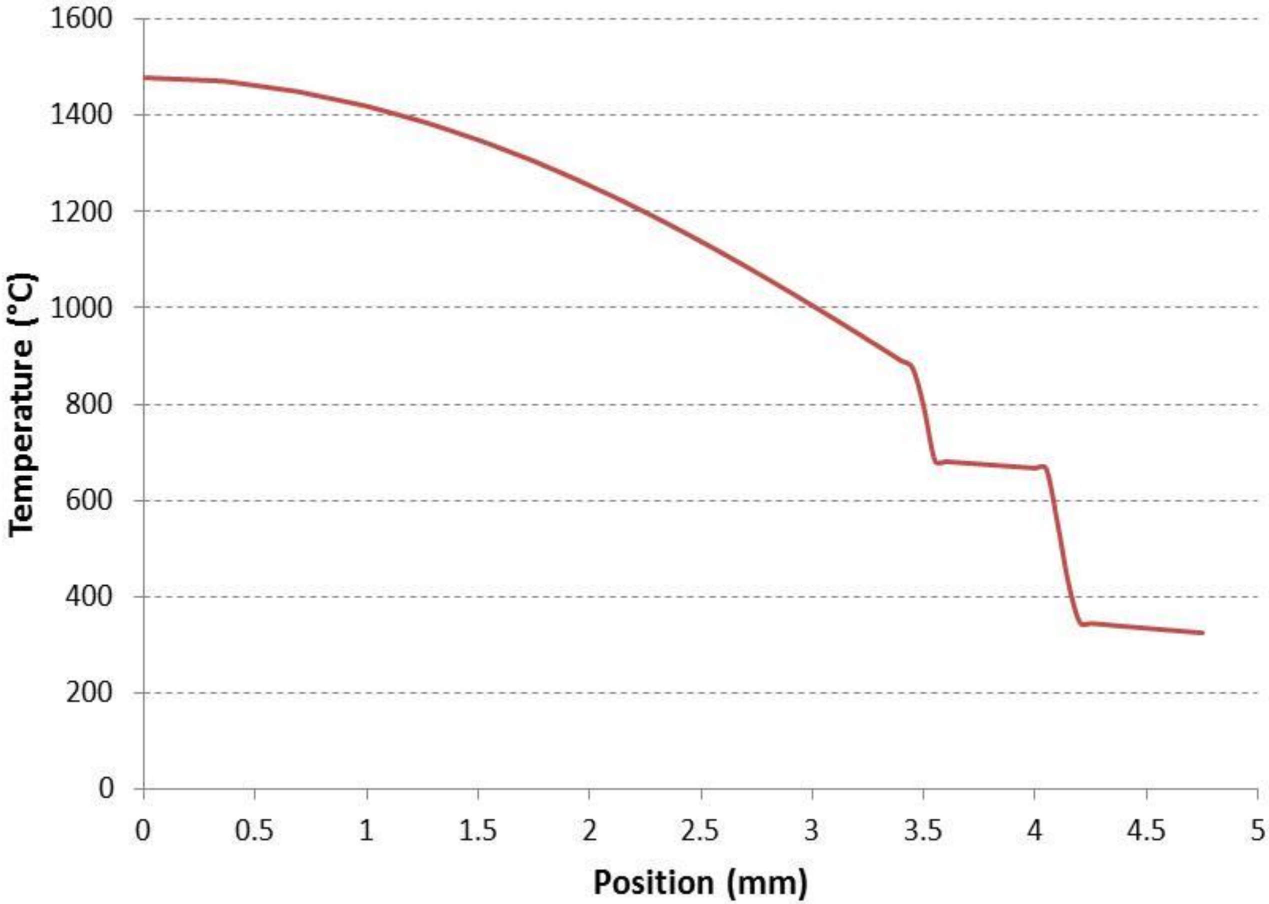
Double cladding: In view to ease PIE examination of the coated cladding

- Outer, coated cladding (Zr-4): 9.5/8.36 mm
- Inner cladding, not coated (Inconel 600): 8 / 7 mm
- Pellet outer diameter: 6.83 mm
- Fuel rod enrichment : 5 %
- Fill gas : He
- Designed to reach a linear heat rate of 20 kW/m

Finite element calculation of the fuel rod (double cladding)



Calculated temperature profile for a coated fuel rod with an inner Inconel 600 cladding and an outer Zircaloy-4 cladding (20 kW/m)



Coating evaluation methodology

1. Pre-characterization of the coatings
   - SEM of cross section (coating thickness)
   - Hardness measurements
2. After irradiation, the outer cladding will be retrieved and cut into sections
   - SEM, hardness measurements
   - Check what remains of the coating

Expected end of irradiation: November 2014

Conclusions

- In screening testing of PVD coatings performed in IFA-731 (PWR) and IFA-733 (BWR) CrN performs very well, unclear for TiAlN. CrN also survives steam tests (15 min) at 1100 C.
- In IFA-774, fuel rods coated with CrN, TiAlN and AlCrN are being irradiated (stop irradiation in November 2014)
- PIE and hardness measurements will be used to evaluate the coatings.
- The coating evaluation can also be seen as a step in the development of Accident Tolerant Fuel.
- Coatings have applications in Gen-IV type of reactors
  - CrN provides corrosion protection in supercritical water (demonstrated)
  - TiAlN and AlCrN provide corrosion protection in liquid lead (demonstrated)