

Studsvik

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2016-04-14



Studsvik Facilities – Fuel and material analyses

Fuel pond



Fuel PIE



Mechanical testing



Development



Transport mgn



Materials integrity



Customer Types & References, examples

- ***Joint international program***
 - Studsvik Cladding Integrity Project (SCIP) OECD NEA: 14 countries, about 30 org.
- ***Safety Authority***
 - USNRC, NRA Japan, CSN Spain, IRSN France, SSM Sweden, GRS Germany, ENSI Switzerland
- ***Fuel vendor***
 - WEC, GNF, AREVA, MNF/MHI Japan, KEPCO NF/Korea, TVEL/Russia, ENUSA/Spain
- ***Larger Commercial Utility***
 - EDF France, EDF Energy UK, ENUSA Spain, TVO Finland, Vattenfall and EON Sweden, Kansai Japan, CGN China, Exelon and Duke US
- ***Research Organisations***
 - EPRI US, CRIEPI and JAEA Japan, CEA France, PSI Switzerland, Halden (IFE)



Studsvik will work with IFE on ATF

- *After irradiation in Halden advanced investigations will be performed in Studsvik lab on ATF concepts*
- *Characterization of cladding, pellet and autoclave corrosion behaviour*



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SCIP

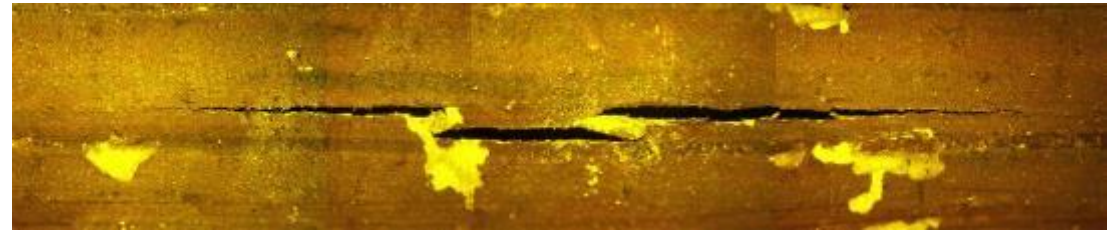
Studsvik Cladding Integrity Programme

- An OECD-NEA project with Studsvik as the operating agent
- SCIP 2004-2009. Cladding failure mechanisms at high burnup
- SCIP II 2009-2014. PCI mitigation and behaviour of additive fuels
- **SCIP III 2014-2019.** LOCA and overheating transients
 - The main task is to determine the thresholds of fuel fragmentation in a LOCA transient
 - Other tasks include: LOCA in the spent fuel pool and PCI behavior
 - Modeling is an integrated part of the SCIP-III project

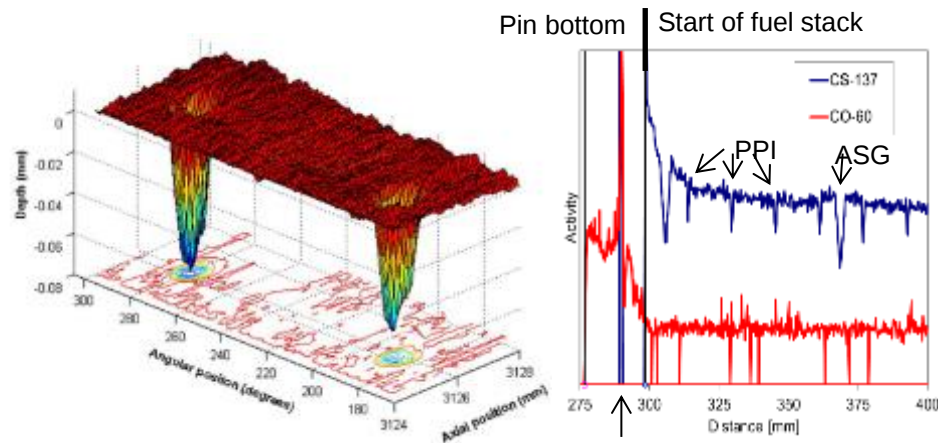


PIE methods

- Rod handling & sectioning
- Rod puncture, FGR
- Visual inspection
- Gamma scan and BU
- Profilometry
- Eddy current oxide thickness
- Gap measurement
- Refabrication of rod
- Metallography/Ceramography
- Advanced microscop
- Heat treatment
- LOCA testing
- Fuel density



Visual inspection



Surface profile measurements
Contact grid to rod fretting on BWR clad

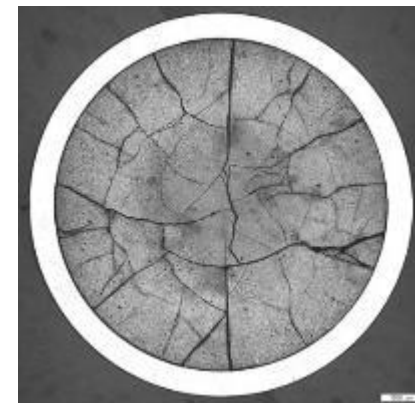
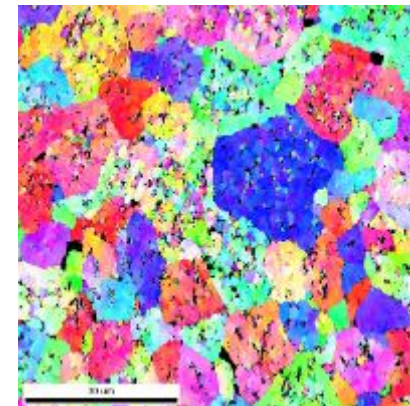
Cs redistribution
AGR fuel pin GS profile



LOCA testing



Microscopy – Fuel and cladding



Integral LOCA simulations

- Conducted in a hot cell facility
- External heating provided by a clam-shell, radiant furnace
- Pressurized single test fuel rod
- Controlled temperature transient up to 1200 °C
- Variable environment (steam, argon, air)
- Quenching
- Axial load

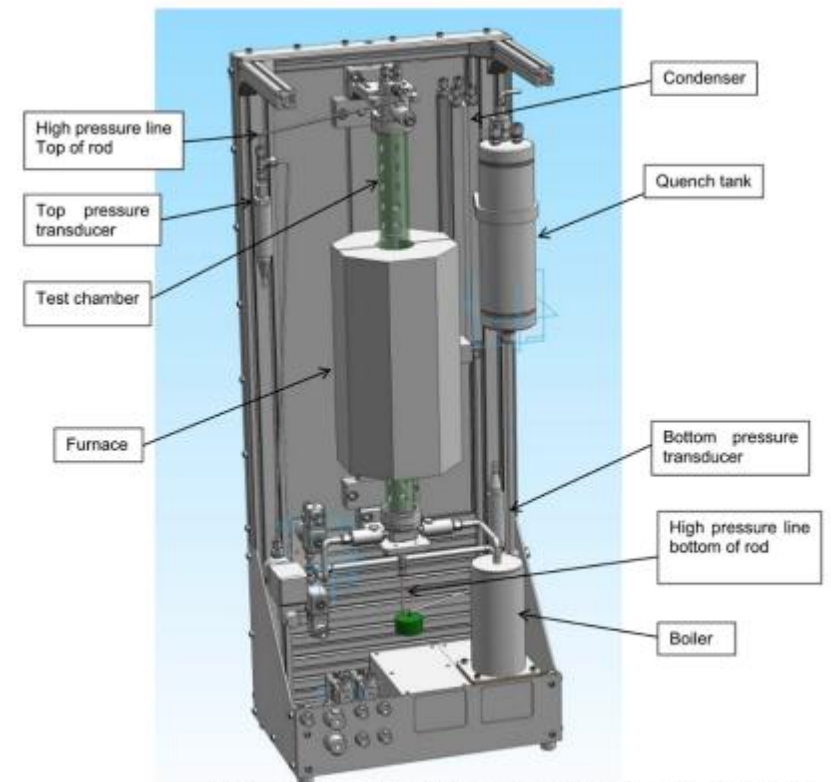
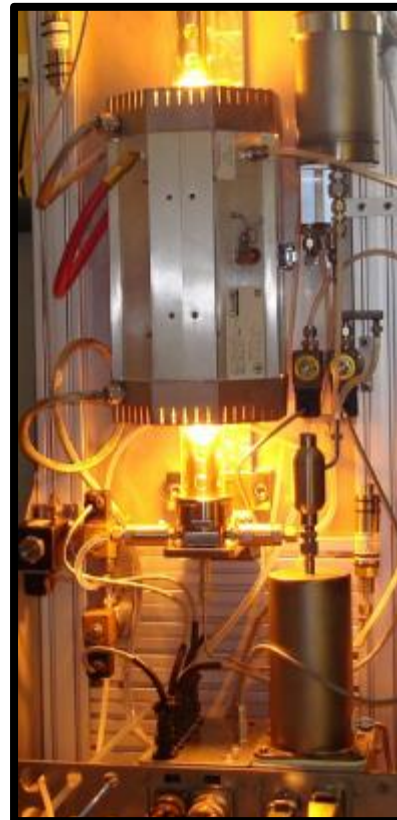
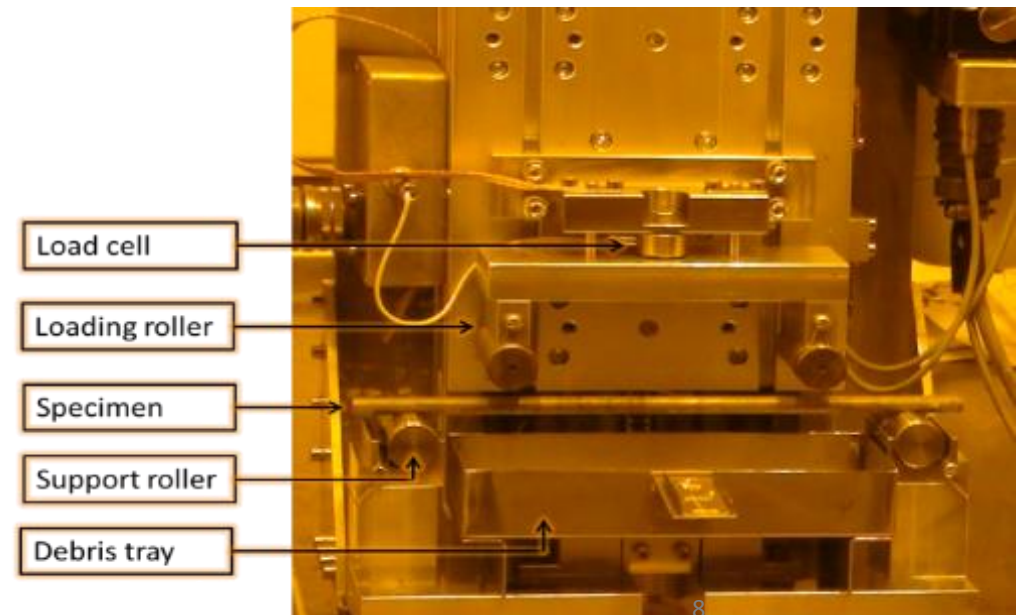
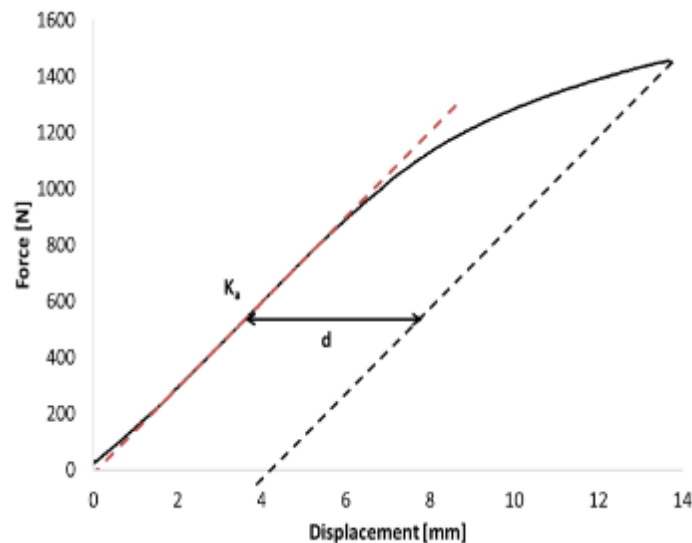
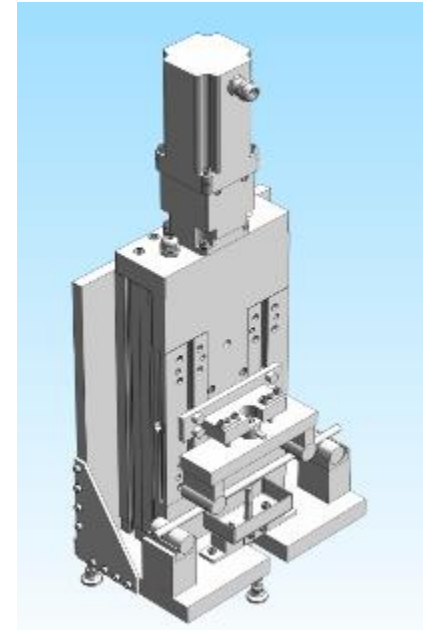


Fig 1. Front view of the LOCA apparatus showing the main parts. The total height of the apparatus is 1145 mm.



4-point-bend testing

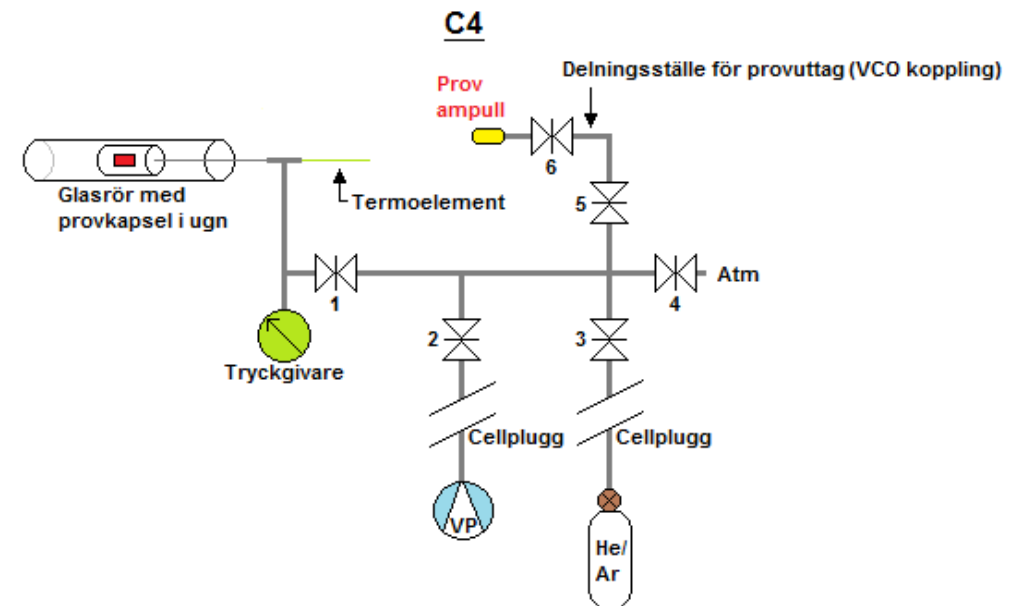
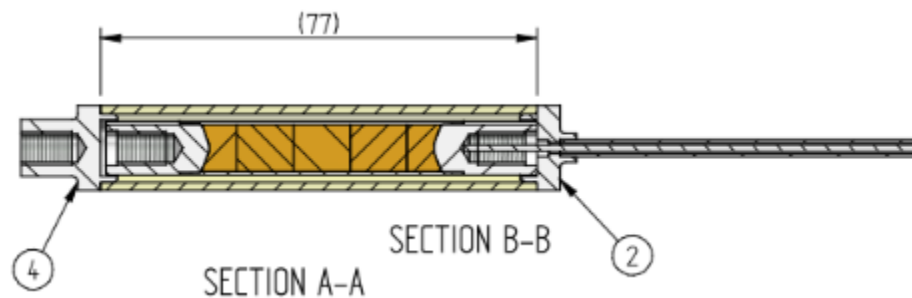
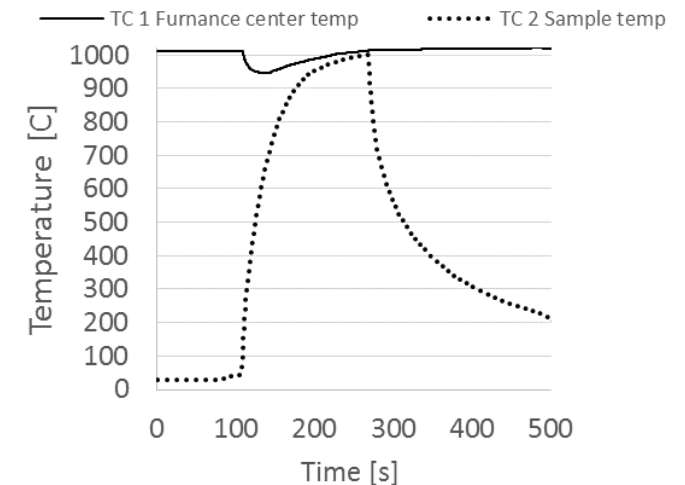
- 4pb - Advantage constant bending stress
- Evaluation of bending stiffness, ductility and strength of fuel rods. Applications:
 - Transport accident evaluation
 - Seismic response modeling
 - Reveal strength and ductility for weakest point on tested length, e.g. after LOCA semi-integral testing, or rods with hydride blisters



Heat treatment w/wo gas collection



- Furnace for heat treatment up to 1150 °C
- Air or inert gas atmosphere
- Gas collection system available

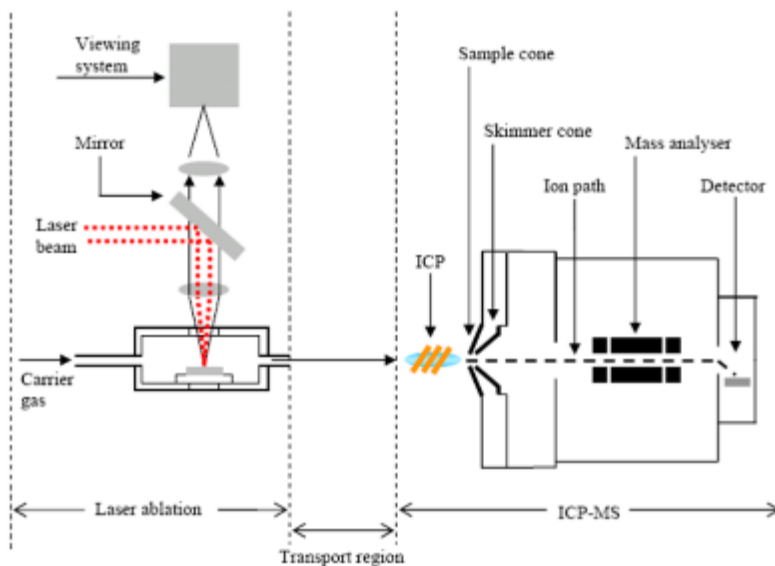
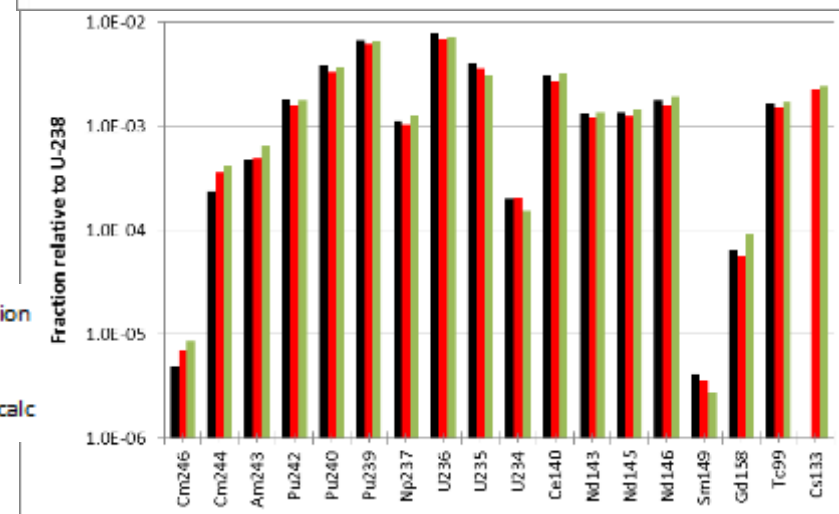
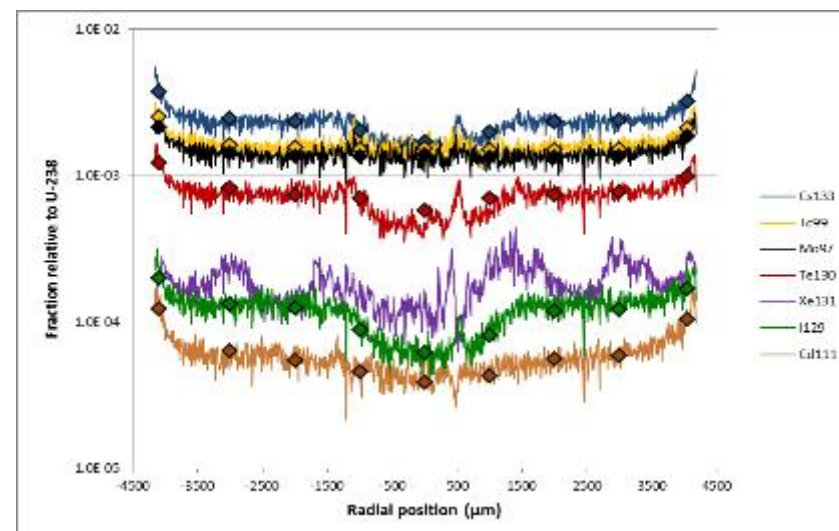


Laser ablation – ICP MS



- Isotopic profiles
- Distribution of volatiles, incl. Iodine
- Depth profiling

M. Granfors, TopFuel 2012, UK



Mechanical testing methods

Cladding / Structural materials :

- Axial tensile test (ATT)
- Ring tensile test (RTT)
- Ring compression testing (RCT)
- Creep and burst test
- Pin-load test (PLT)
- C-ring fatigue test
- PCI: Mandrel tests
- RIA simulation tests
- Hydrogen conc.
- Fracture toughness
- Impact tests
- Fatigue tests
- Stress corrosion cracking in environment

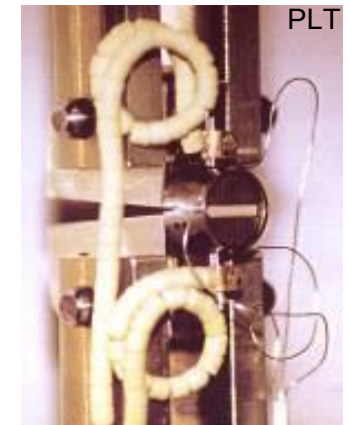


ATT



After test

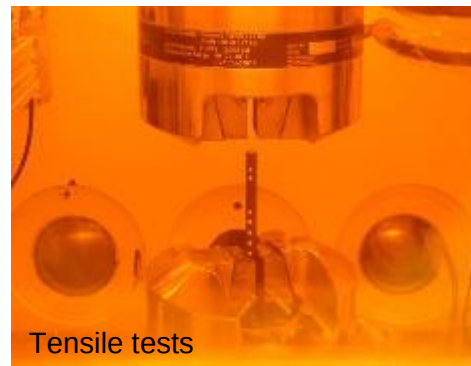
RTT



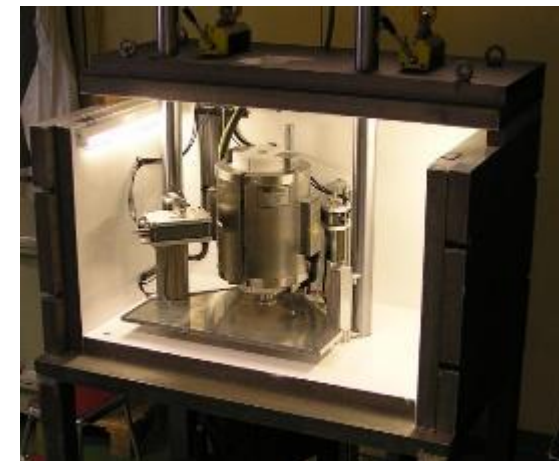
PLT



C-ring fatigue



Tensile tests

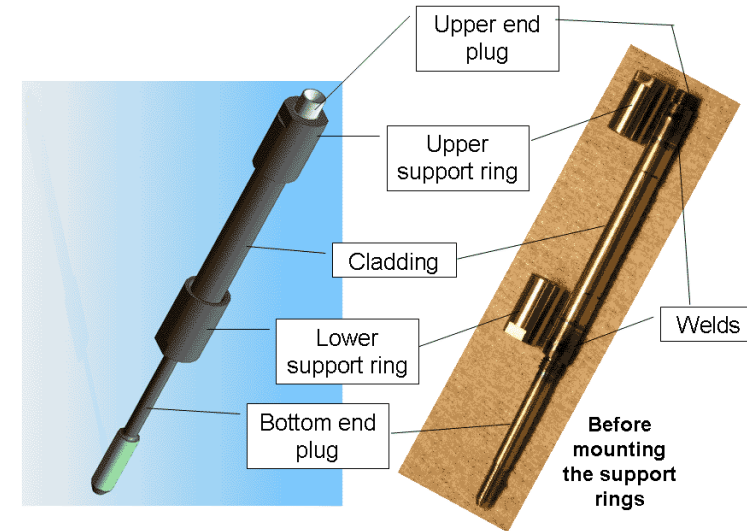
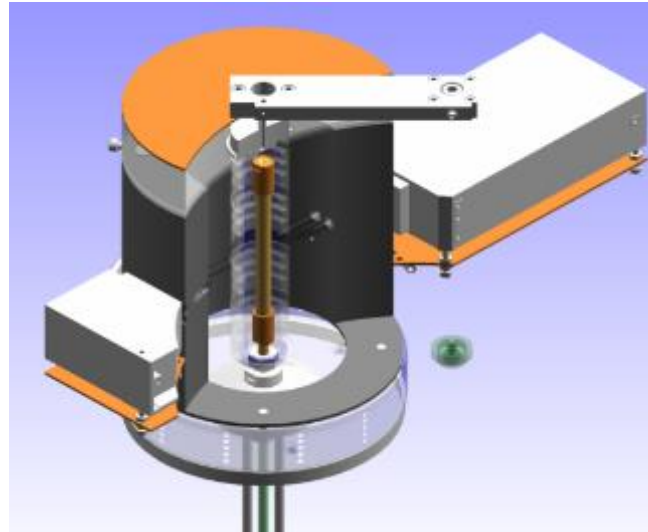


PCI mandrel

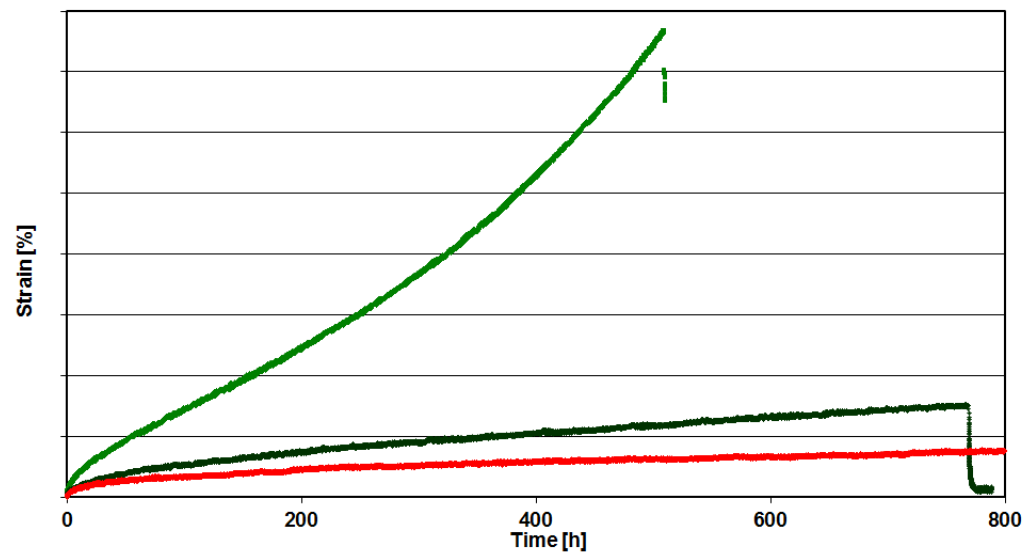


MBT

Creep testing



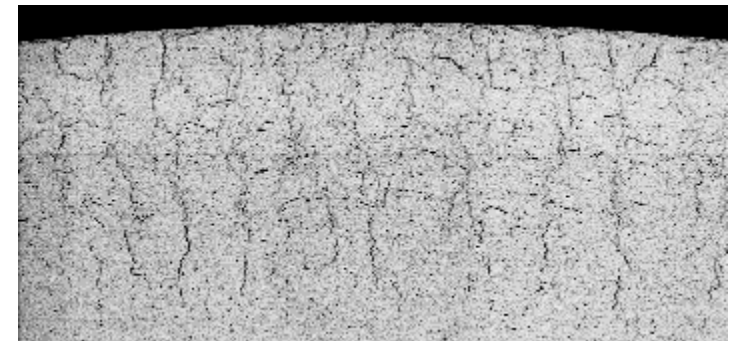
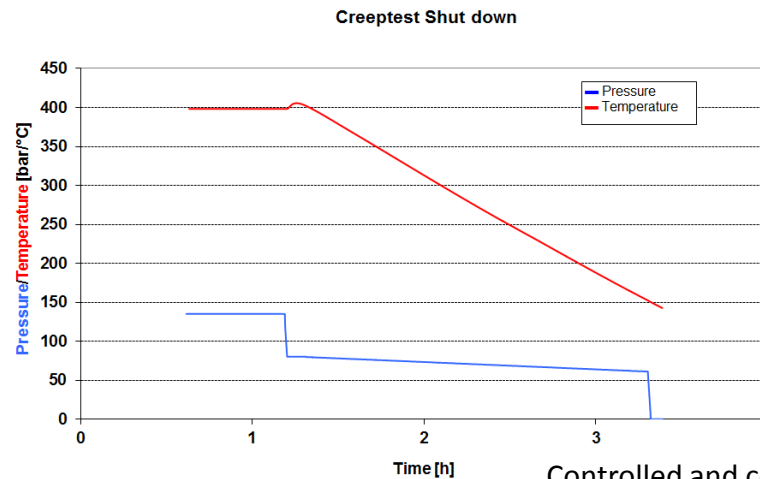
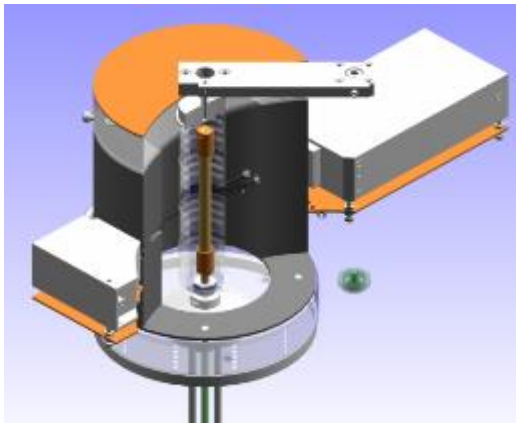
Creep curves for different temperatures



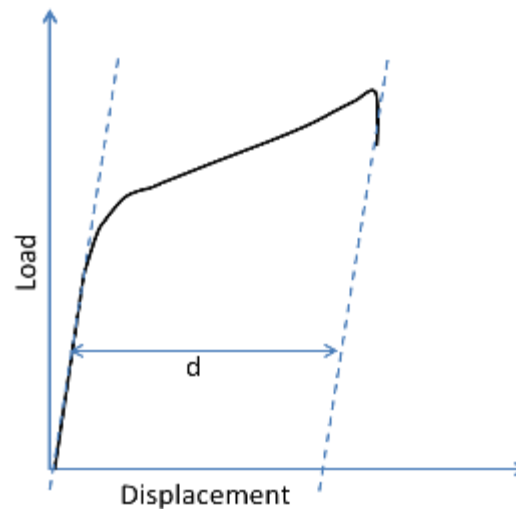
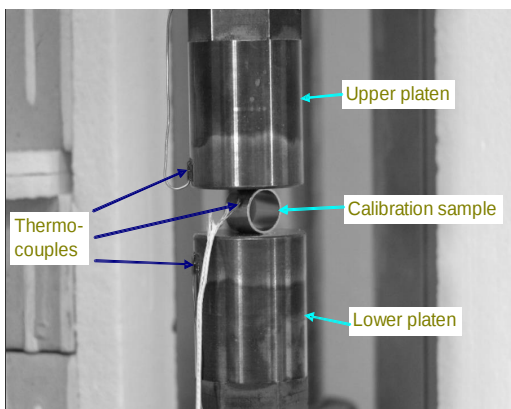
Capabilities:

- Internal pressure
- Control on pressure or deformation
- Controllable temperature
- Pre- and post-test characterization by visual inspection, profilometry and metallography

Hydride reorientation and remaining ductility by RCT



Controlled and coordinated furnace cooling and pressure decrease after creep testing resulting in radial hydrides (Test for ENUSA)

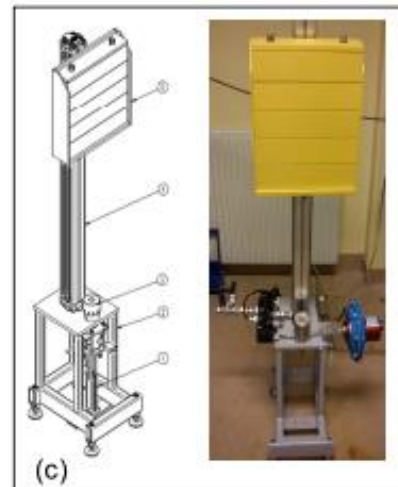
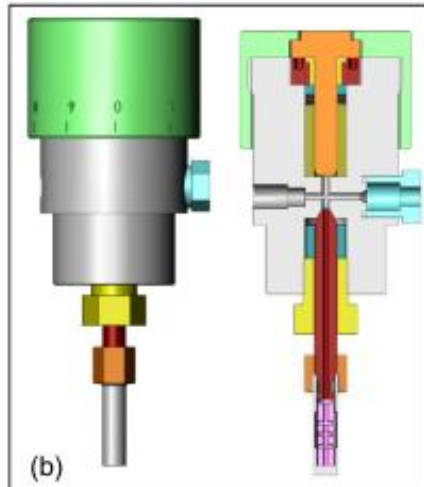
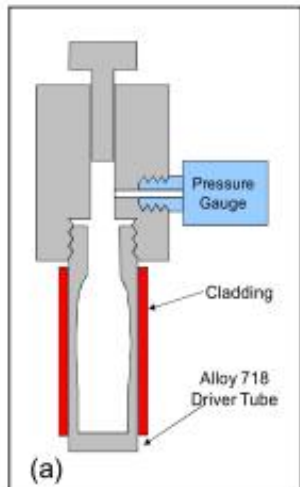
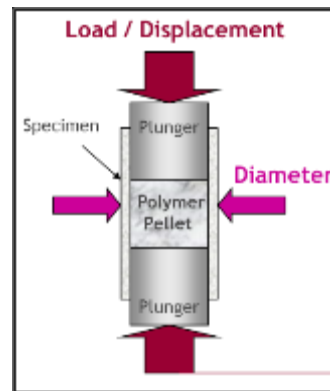


- RCT for ductility (PQD, annealing)
- Determination of ductility after hydride reorientation
- Determination of Ductile to Brittle Transition Temperature (DBTT)

RIA test methods

EDC Test characteristics:

- Pulse lengths from 25 ms
- Strain rates, 100-1000 % s⁻¹
- Laser monitoring of diameter
- Test temperatures: RT – 380 °C
- Recent development: Slow strain rate controlled EDC



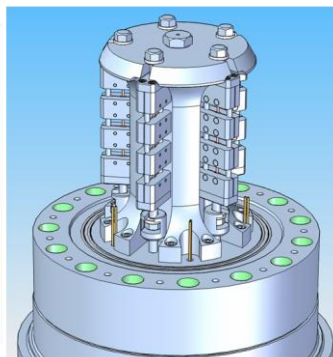
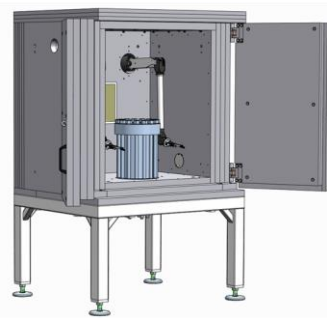
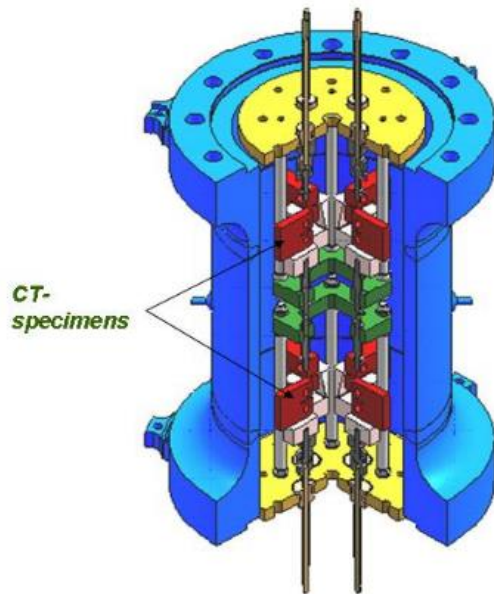
MBT Test characteristics:

- Pulse lengths 2-3 ms to ~15 ms
- Laser monitoring of diameter
- Test temperatures: RT – 280 °C

MBT a) driver assembly, b) hydraulic piston, c) machine setup

Ref: K. Yueh, TopFuel 2012, Manchester, UK.

Testing of active material in simulated environment



- Materials integrity autoclave tests
 - IGSCC
 - Effects of temperature and K
 - PWSCC
 - Effects of hydrogen, temperature and K
 - Effects of Li, B, Zn and impurities
 - Irradiated materials IASCC
 - Crack initiation testing
 - Fracture toughness
- In simulated environment
- Using active material
- High flow loop autoclave

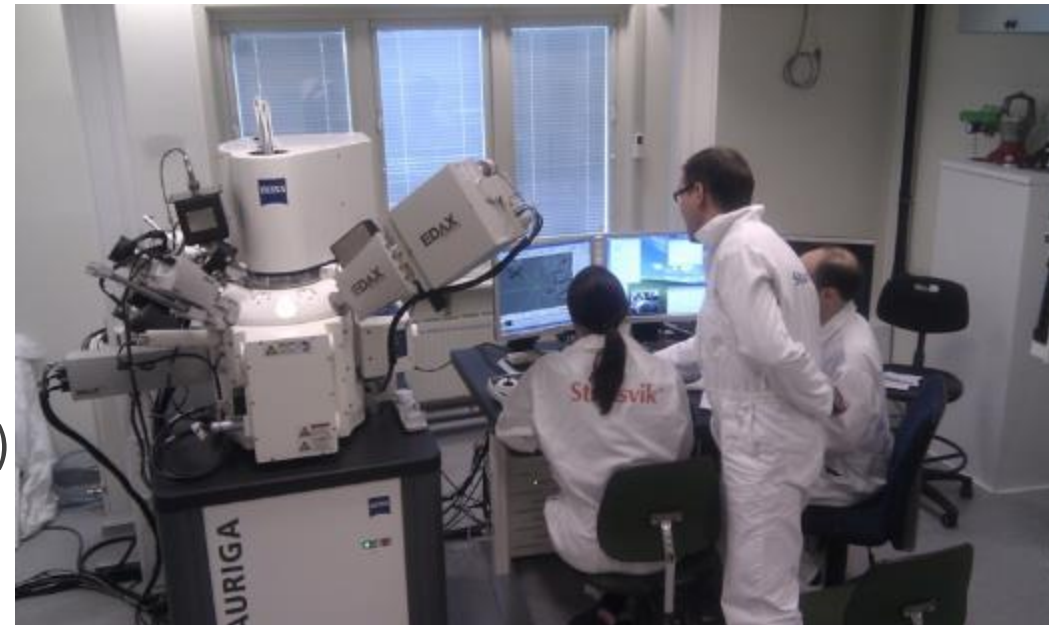
Microscopy equipment at Studsvik

- LOM Light Optical Microscope
 - In cell and out of cell
 - Used also for microhardness measurements
- SEM Scanning Electron Microscope
 - Three out of cell – Two standard and one Field Emission Gun (FEG)
- FIB Focused Ion Beam
 - Added to the FEG-SEM
- TEM Transmission Electron Microscope
 - Not in-house – Irradiated materials are prepared at Studsvik and microscopy is performed at KTH



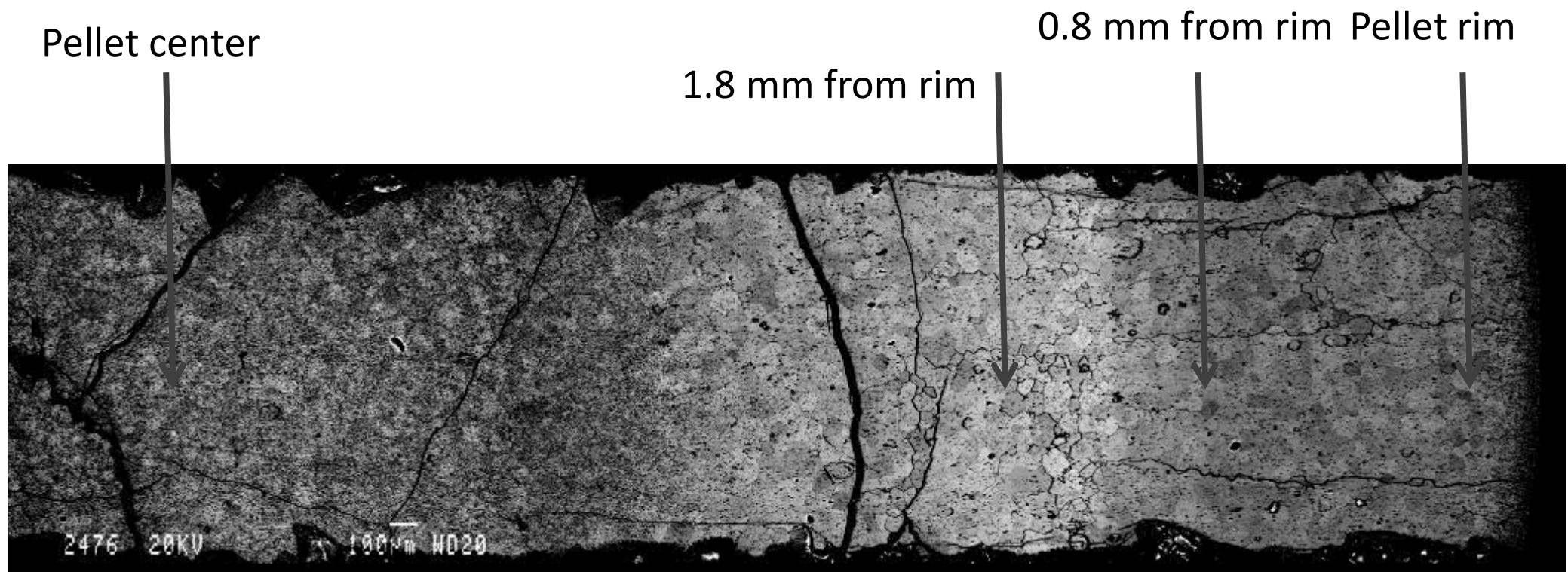
Field Emission Gun SEM (FEG-SEM)

- Zeiss Auriga CrossBeam®
 - High spatial resolution
 - Two secondary electron (SE) detectors
 - Two backscattered electron (BSE) detectors
 - Electron backscattered diffraction (EBSD) detector
 - Grain size and orientation
 - Phase identification
 - Texture
 - Strain
- Chemical analysis
 - Energy dispersive X-ray spectroscopy (EDS)
 - Wavelength dispersive X-ray spectroscopy (WDS)
- Focused Ion Beam (FIB)
 - Milling and polishing
 - Micromanipulator for in-situ lift out of TEM samples

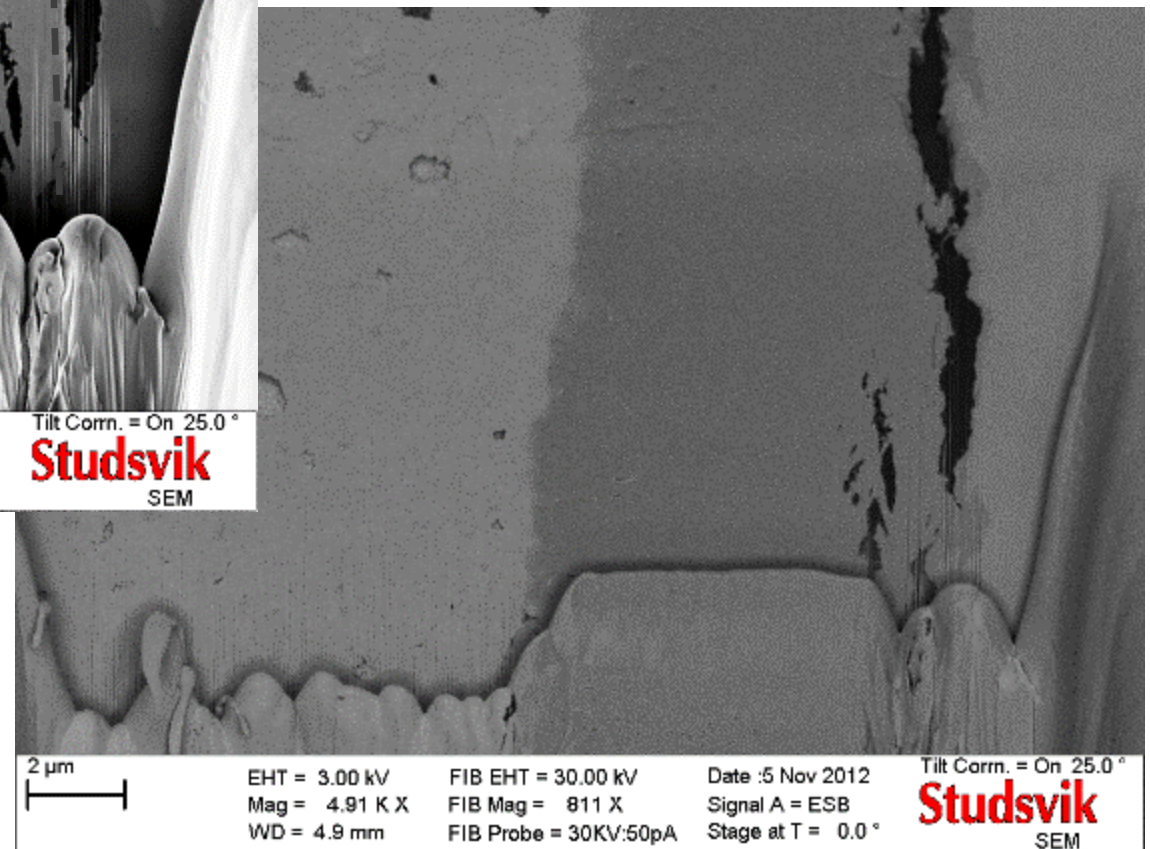
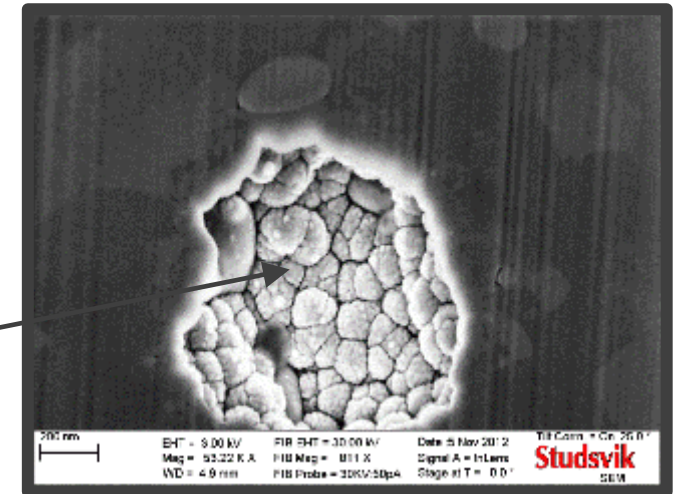
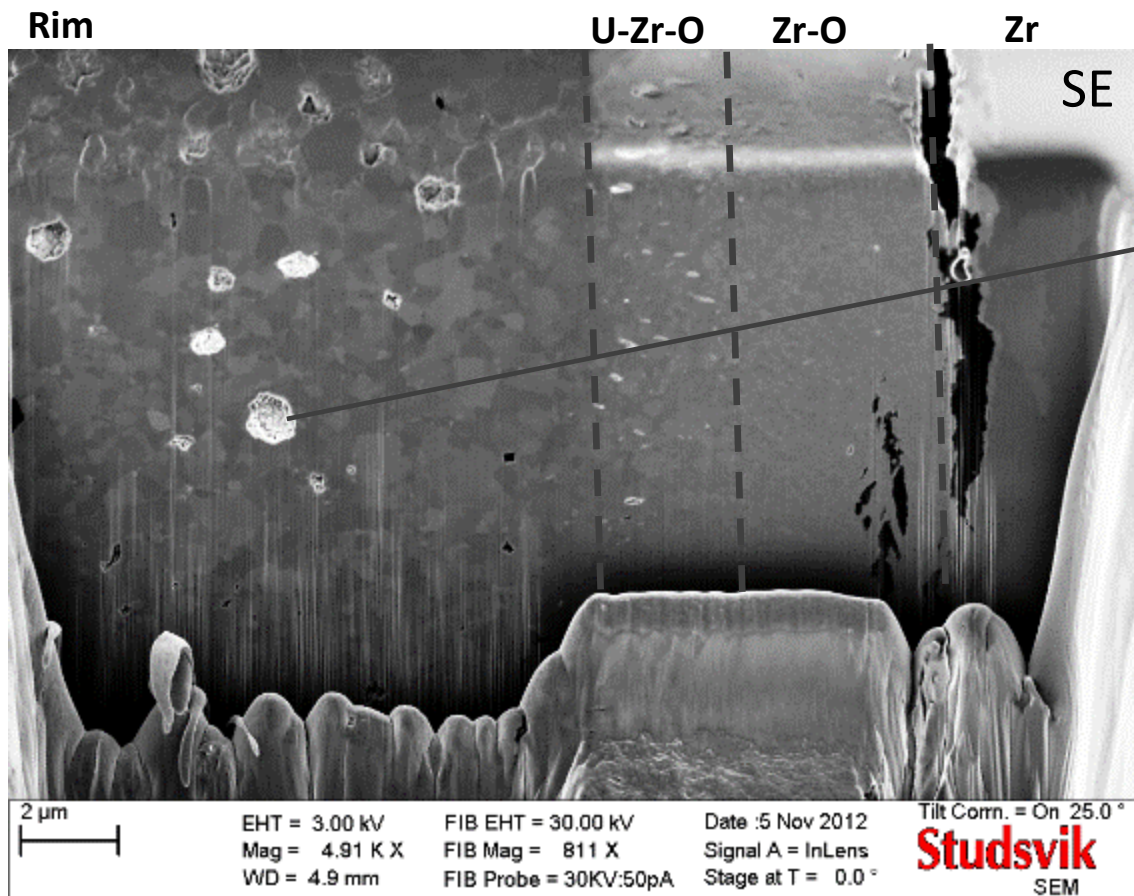


High resolution analysis on fuel

- SEM, FIB and EBSD from different positions along the pellet radius

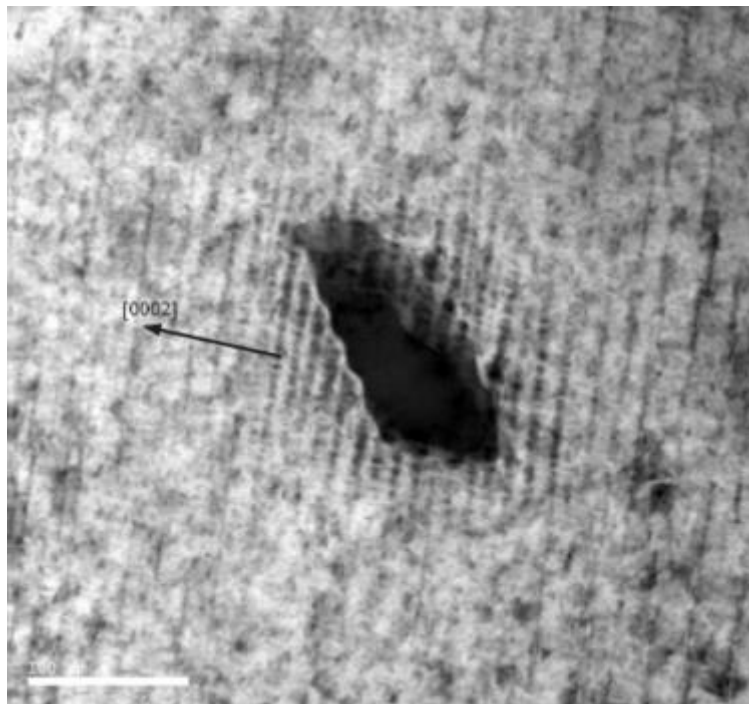


Rim structure

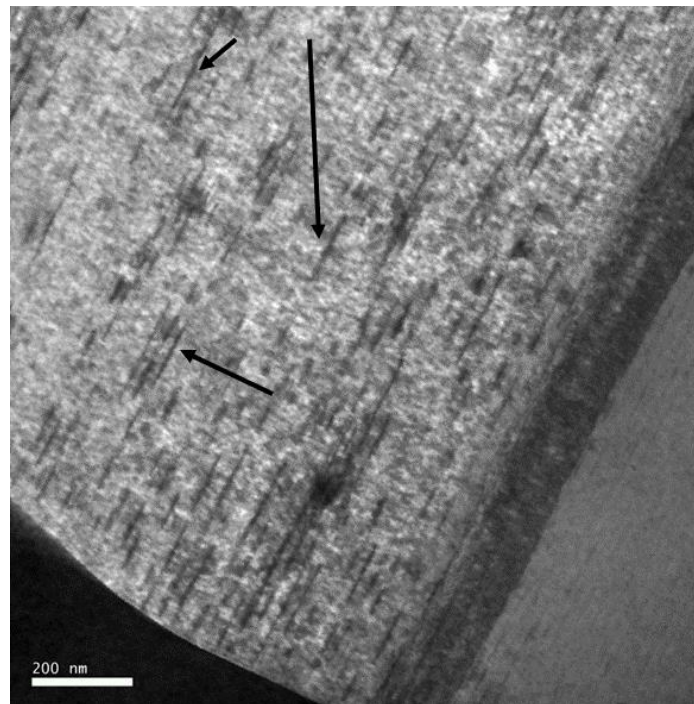


Transmission Electron Microscopy (TEM)

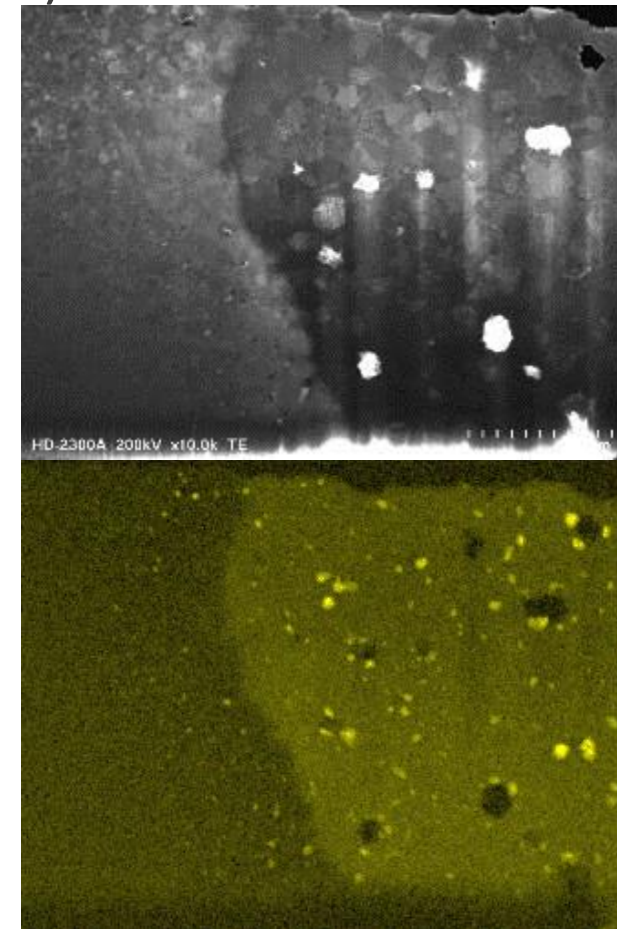
- Sample preparation at Studsvik (electropolishing or FIB)
- Analysis at e.g. KTH
- Examples of investigations:



SPP analysis in cladding (dissolution, amorphization, number densities...)



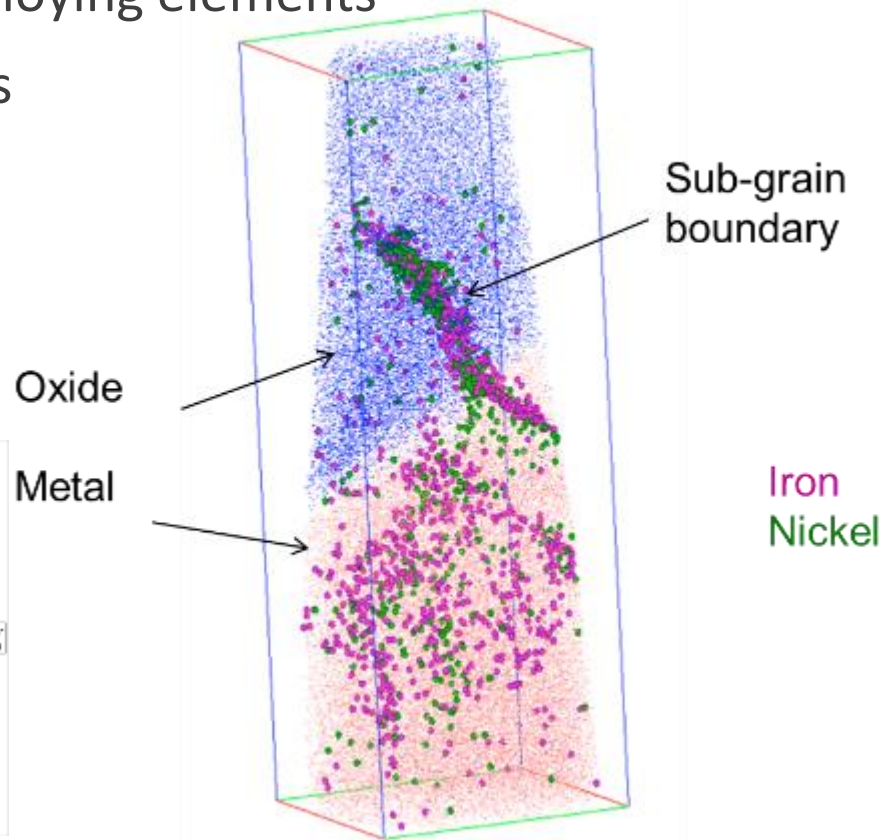
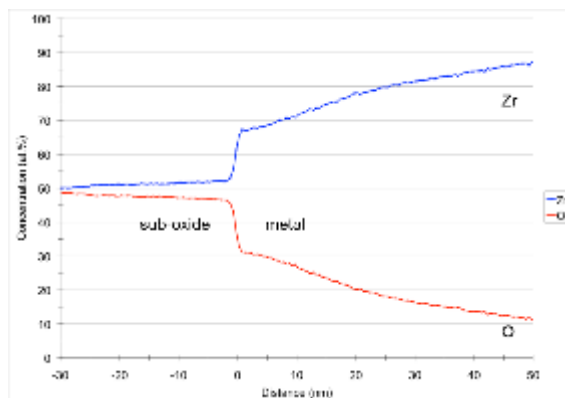
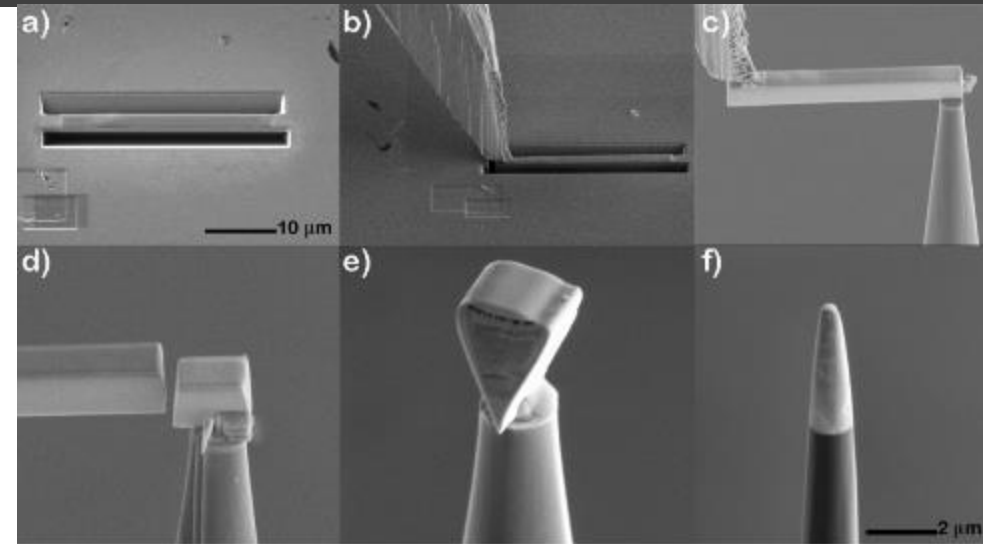
Dislocations and irradiation damage in cladding



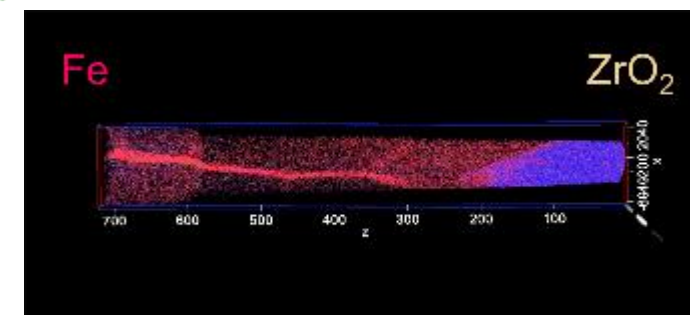
Detailed microstructural investigation of fuel

Atom Probe Tomography (APT)

- Sample preparation by FIB at Studsvik
- Analysis at e.g. Chalmers
 - Distribution of alloying elements
 - Grain boundaries
 - Thin layers
 - Precipitates
 - Light elements



Iron
Nickel





Thank you for your attention!

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