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Fuel Material Properties and Dry Storage

C.B. Patterson
Principal Engineer
Materials Technology and Fuel Reliability
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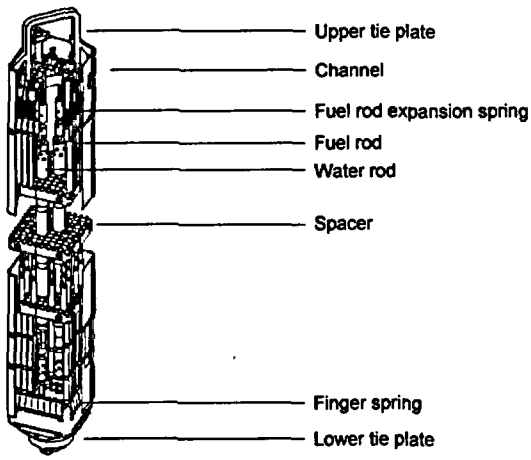
Typical BWR Fuel Assembly



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Fuel Assembly Materials

Component	Material	Principal Storage Issues
Upper tie plate	Cast austenitic stainless steel	None
Fuel rod expansion spring	Ni-Cr-Fe-Ti alloy	None
Fuel rod	Cladding: Zr-2 tube with or without Zr ID liner Fuel: UO_2, $(U,Gd)O_2$ Retainer Springs: Austenitic Stainless Steel or Ni-	Structural integrity of Zry at high burnup Effects of time, temperature and stress on cladding integrity Oxidation of Zr-2 and fuel materials
Water rod	Zr-2	Structural integrity Oxidation of Zr-2 (Water rod expected to have minimal effect on fuel storage)
Spacer	Zr-2 or Zr-4 structure with Ni-based alloy springs All Ni-based alloy	Structural integrity Oxidation of Zry (Spacer expected to have minimal effect on fuel storage)
Finger spring	Ni-Cr-Fe-Ti alloy	None
Lower tie plate	Cast austenitic stainless steel	None
Channel	Zr-2 or Zr-4	Oxidation of Zry (Channel expected to have minimal effect on fuel storage)

Principal concerns center on fuel rod integrity under conditions of drying and storage

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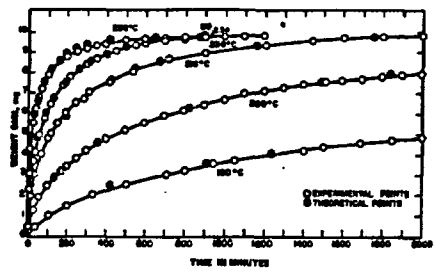
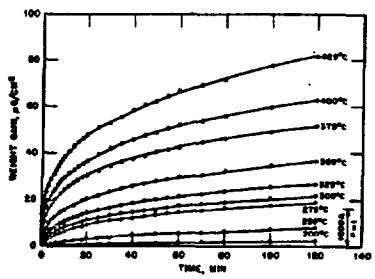
Oxidation



(data after J. Bell)



(data after B. Lustman and F. Kerze)

- Fuel pellets and Zircaloy components oxidize rapidly in air
- Rate of oxidation increases with temperature

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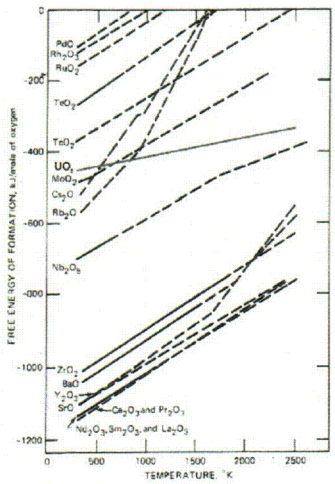
Oxidation - Continued



(data after D. Olander)

- Zry components will oxidize preferentially relative to fuel pellets
- Zry components will getter air during drying phase
- Continued air leakage into a cask presents the possibility of structural decomposition of the cladding followed by similar oxidation and decomposition of the fuel pellets
- Protection against oxidation is assumed to come from the cask design, cask loading and long-term monitoring practices

(Limited options relative to fuel materials or designs in this area)

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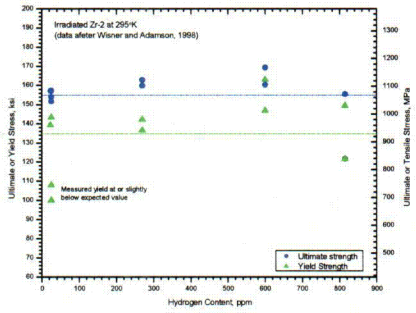
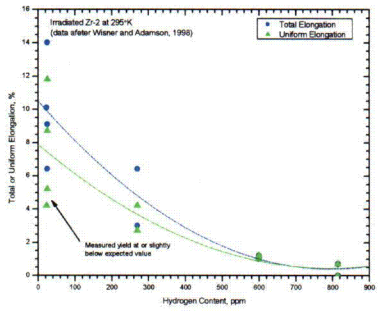
Hydriding

Effect of Hydrogen on Zr-2 Tensile Properties at Room Temperature





- Strength at RT remains high through ~600 ppm hydrogen
- Ductility decreases with hydrogen concentration, becoming small at hydrogen concentrations >600 ppm
- NB: Randomly oriented hydrides and short-term loading

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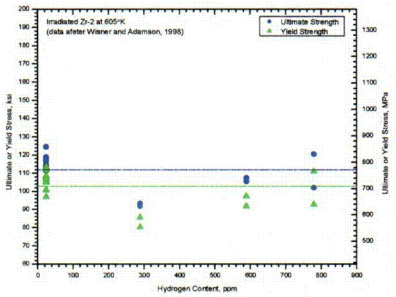
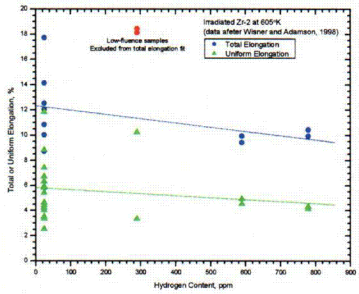
Hydriding

Effect of Hydrogen on Zr-2 Tensile Properties at 332° C





- Strength and ductility at 330°C remain high through hydrogen concentration of ~800 ppm
- NB: Randomly oriented hydrides and short-term loading

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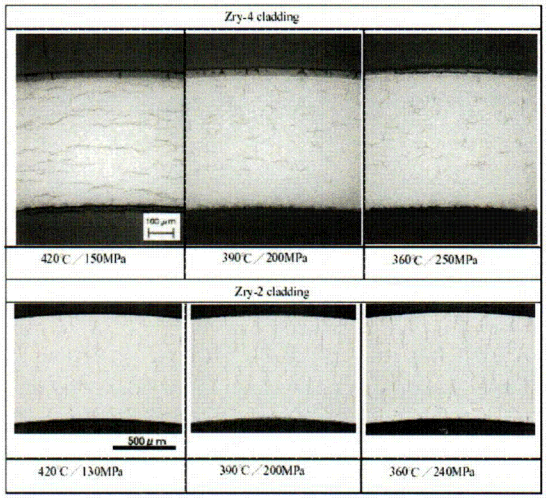
Hydride Reorientation



⇒ Reorientation stress ≥ 110 MPa (16 ksi) for SRA Zr-4

⇒ Reorientation stress < 110 MPa (16 ksi) for RXA Zr-2

(data and assessment after Ito, et al.)

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Planned and Potential Work

Fuel Rod and Materials at Exposures ≥ Current EOL

- Corrosion and hydrogen pickup
  - > Oxide thickness, hydrogen concentration
  - > Hydride morphology
- Mechanical properties
  - > Hardness
  - > Curvilinear axial and plane strain tensile tests
  - > Expanding mandrel tests
  - > (Burst tests)
  - > (Hydride reorientation tests)
- Fuel rod and fuel materials characterization
  - > Burnup and isotopic composition
  - > Fission gas release
  - > Cladding deformation during operation (profilometry, length change)
  - > Cladding structure (optical and electron microscopy)

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GNF BWR Fuel Performance and Characterization

G. A. Potts
Consulting Engineer - Fuel Reliability
Fuel Engineering
August 2006

Agenda

- Fuel Rod Design Description
- Fuel Reliability Performance
- Fuel Rod Failure Mechanisms
- Recent and Ongoing High Exposure Fuel Performance Characterizations

Going Forward

- Some characterization information available today
- More characterization may be desirable based on NRC identified interests
- Opportunity exists with GNF high burnup cladding currently available at GE VNC hotcells
  Additional planned high burnup cladding retrieval provides additional opportunity
- GNF is open to cooperative program with NRC to provide further characterization

[redacted]

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