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Interfaces Between Storage & Transportation Casks

– Panel on High Burnup Fuel – Industry's View on Cladding

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Topics

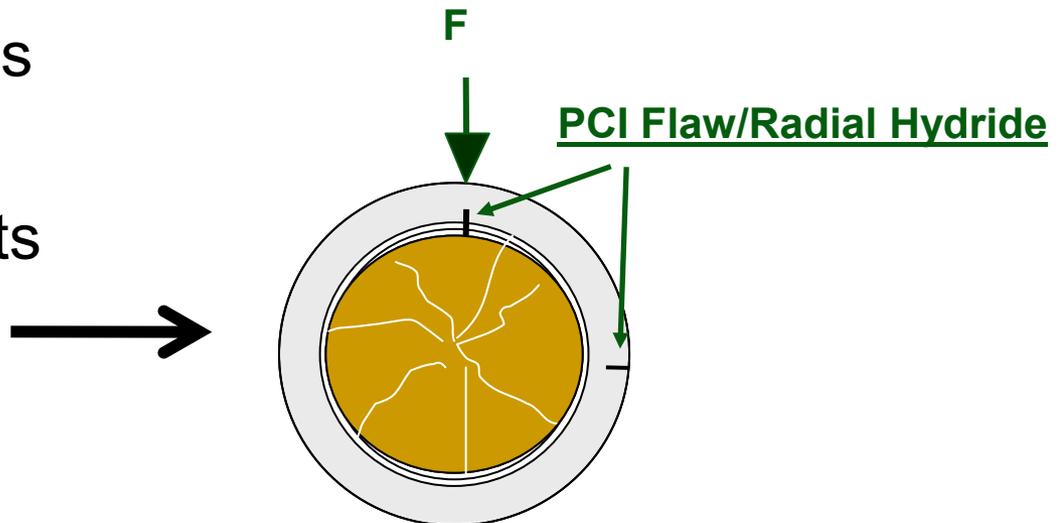
- Cladding Performance
 - Dry Storage
 - Impact of dry storage
 - Transportation
 - Mechanical loading challenges
- Selection of R&D Results
 - Thermal Creep
 - Hydride Re-orientation
 - Delayed Hydride Cracking
 - Impact of Liner
- Conclusion

Cladding Performance

- Dry Storage
 - Explicit cladding material performance requirements
 - “... spent fuel cladding must be protected during storage against degradation that leads to gross ruptures ...”
 - “... degradation of the fuel during storage will not pose operational safety problems with respect to its removal from storage.”
 - Existing acceptance criteria largely chosen for limiting negative impact on cladding’s mechanical properties out of concern for transportability-related issues

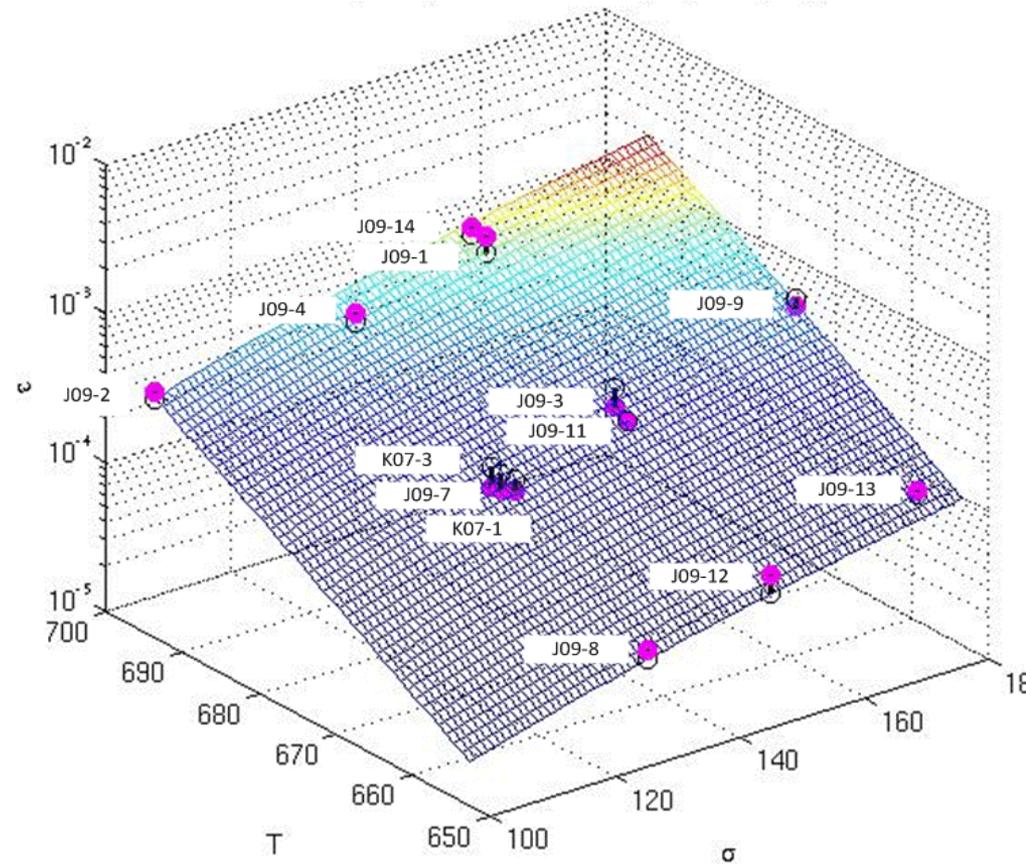
Cladding Performance (continued)

- Transportation
 - Normal Conditions
 - “... geometric form of the package contents would not be substantially altered”
 - Accident Conditions (*to be discussed at a later time*)
 - “... most reactive credible configuration ...”
- Mechanical loadings
 - Buckling loads
 - Bending moments
 - Pinching loads



Selection of R&D Results – Thermal Creep

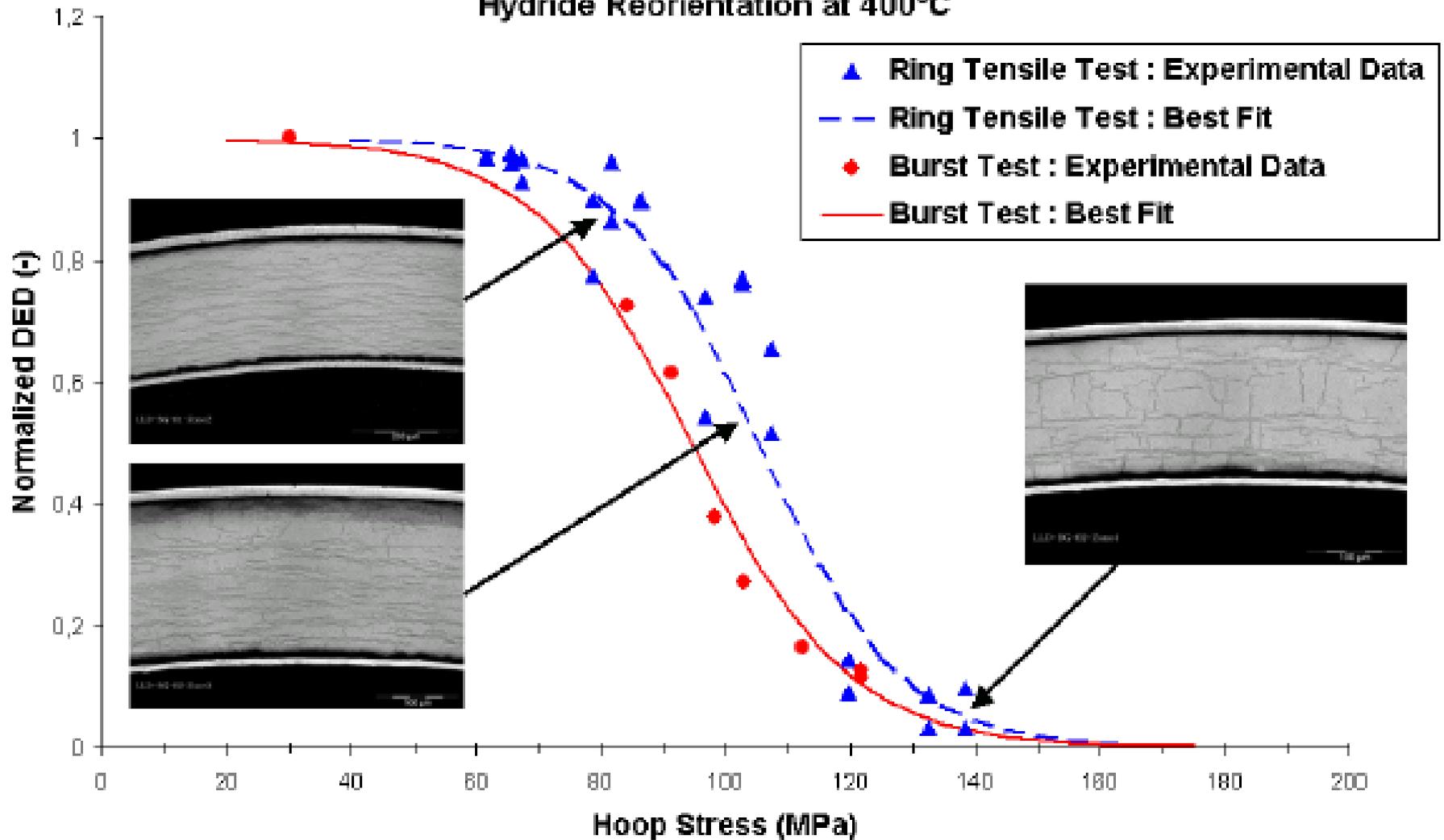
- Fuel rods are closed systems → deformations are self-limiting
- Large differences in creep strength among non-irradiated claddings, but somewhat similar in irradiated claddings
- Creep can be beneficial in limiting the effect of hoop stress on other modes of degradation



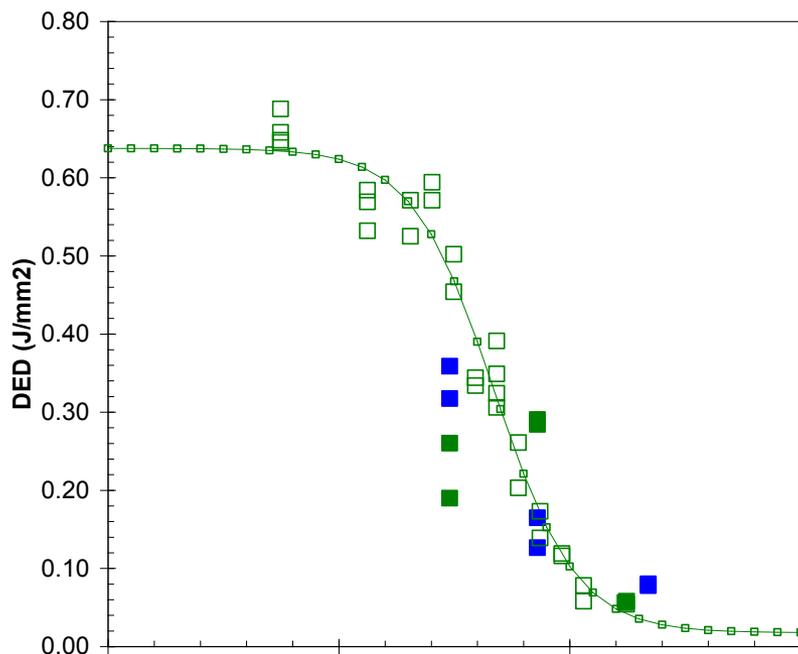
Reference: Testing and Modeling of Long-term Creep of Modern PWR Cladding in Dry Storage and Transport, by G. Wikmark et al., 2011 Water Reactor Fuel Performance Meeting, Chengdu, China, Sept. 11-14, 2011

Selection of R&D Results – Hydride Re-orientation (Brittle-to-Ductile Transition)

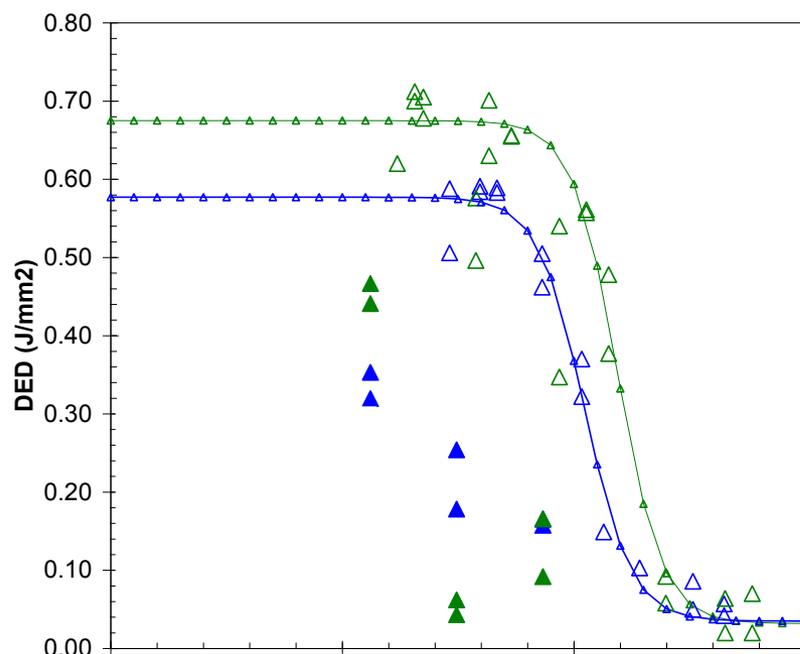
Hydride Reorientation at 400°C



Selection of R&D Results – Hydride Re-orientation (Non-irradiated vs. Irradiated Materials)



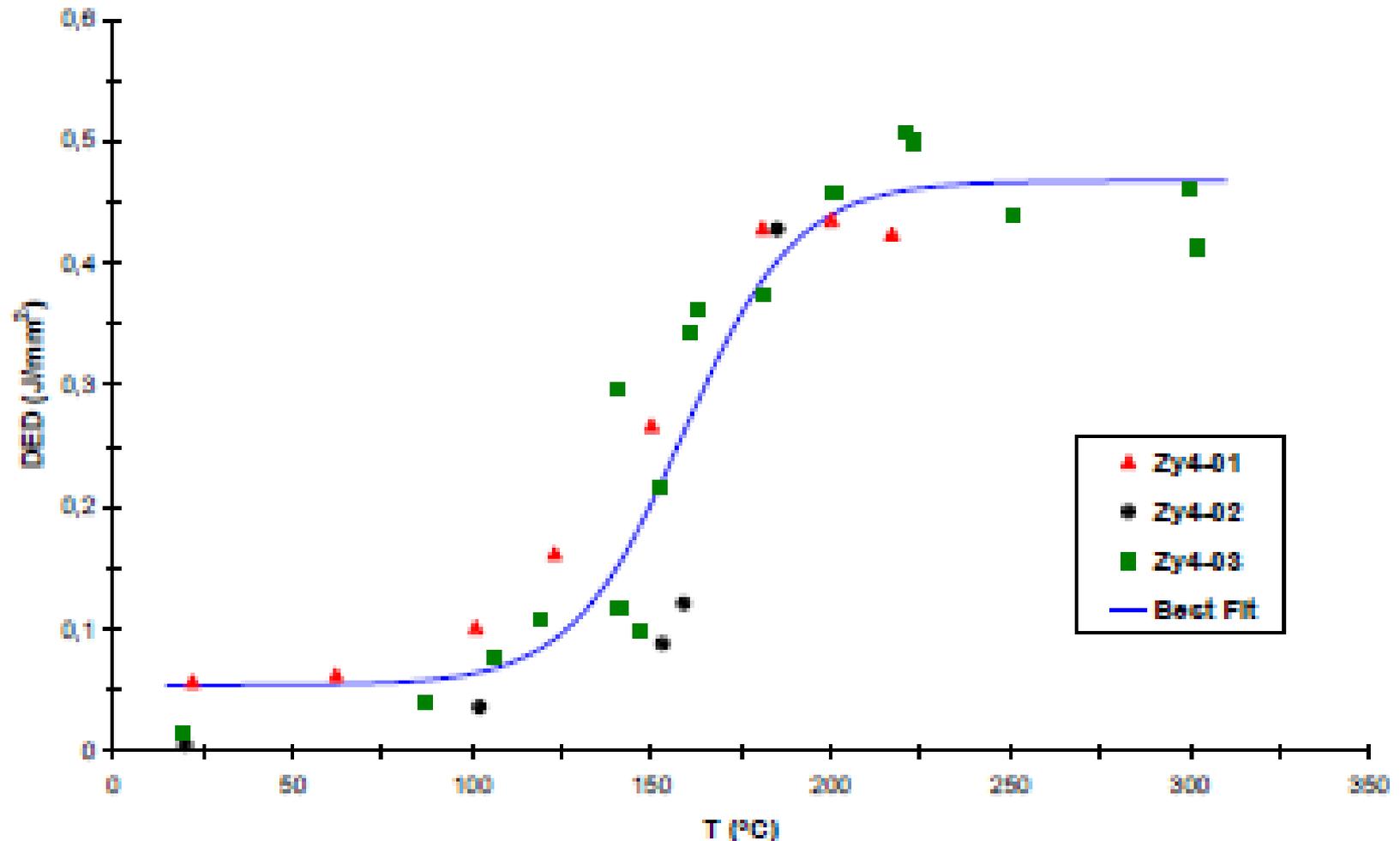
Reorientation hoop stress (MPa)



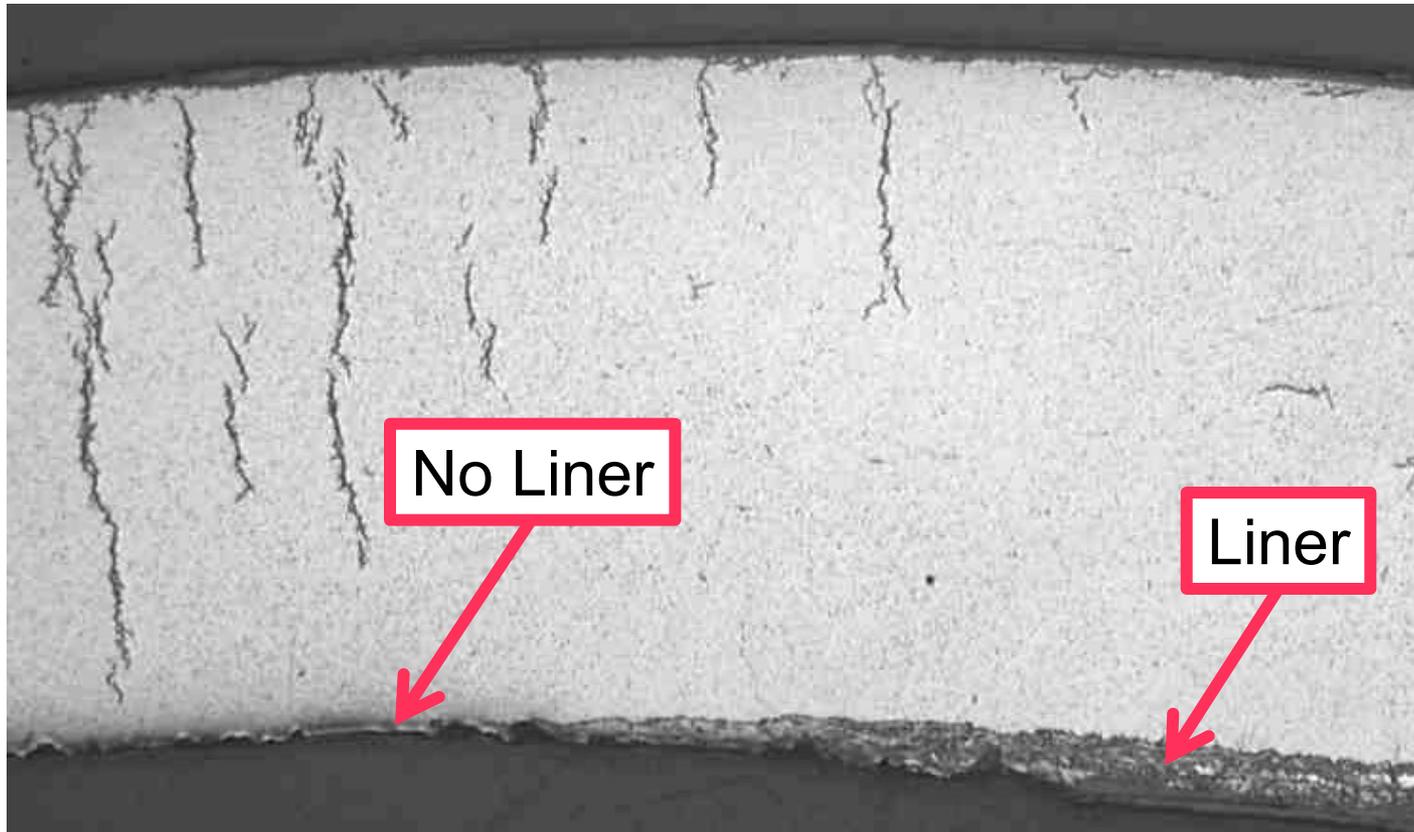
Reorientation hoop stress (MPa)

- Some differences among non-irradiated and irradiated materials

Selection of R&D Results – Hydride Re-orientation (Ductility Recovery Driven by Temperature)



Selection of R&D Results – Hydride Re-orientation (Impact of Liner)



Brief Selection of R&D Results – Delayed Hydride Cracking (DHC)

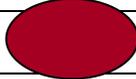
Maximum depth, a , of surface flaw that can be tolerated without crack growth:

$$a = (K_{IH}/\sigma)^2 \times (Q/1.2 \pi)$$

K_{IH} = threshold stress intensity factor (Range of 4.5 – 12 MPa*m^{1/2})

σ = stress

Q = flaw shape factor (~1.5 for elliptical flaws and ~1 for long flaws)

K_{IH} [MPa*m ^{1/2}]	Tensile Stress [MPa]	Flaw Depth [mm]	
		Elliptical flaw	Long flaw
4.5	90	0.98	0.65
4.5	120		
4.5	150	0.35	0.23

Flaws have to be unrealistically large

Conclusion

- Dry storage and especially transportation are drivers for extending the scope of work associated with high-burnup fuel, particularly with regard to cladding performance
 - Effects of neutron fluence and hydrogen/hydride contents
- Much R&D work has been performed over the past decade, especially with regard to:
 - Thermal creep
 - Hydride re-orientation
- R&D work will continue especially in concert with introduction of new cladding materials
- Key question: Given what we learned, how does that knowledge support existing –or coming up with new– regulatory guidance?

Selected Publicly Available EPRI References

- *Dry Storage of High-burnup Spent Fuel – Responses to Nuclear Regulatory Commission Requests for Additional Information and Clarification*, Report 1009276 (November 2003)

<http://mydocs.epri.com/docs/public/0000000000001009276.pdf>

- *Delayed Hydride Cracking Considerations Relevant to Spent Nuclear Fuel Storage*, Report 1022921 (July 2011)

<http://mydocs.epri.com/docs/public/0000000000001022921.pdf>