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Industry Position on the Technical Basis for Revision of Embrittlement Criteria in 10 CFR 50.46

50.46(b) Public Workshop
October 24, 2008
Washington, DC

Industry Collaboration with NRC on High Burnup Fuel LOCA Tests

- The industry is supportive of NRC's overall objective with regards to revision of 10 CFR 50.46(b)
  - Endorses the concept of a performance-based approach
  - Expects the new criteria will allow for cladding advances without need for rule exemptions
  - Acceptability assessments of cladding advances much faster if adequate surrogate to irradiation is identified
- The Industry's Fuel Reliability Program (FRP) has been actively participating in the LOCA tests at ANL *(with limited technical input since 2005)*
  - Supplying irradiated high-burnup BWR & PWR fuel rods with standard and advanced claddings for LOCA tests
  - Providing analytic support for design and qualification of LOCA and mechanical property tests

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Summary of Industry Position with Regards to the Proposed Revisions

- The technical information provided in NUREG/CR-6967 is incomplete and not yet sufficient to justify the regulatory criteria proposed in RIL0801
  - Database incomplete
  - Concerns associated with the testing techniques
  - Evidence does not support use of 2-sided oxidation away from balloon region to account for possible ID oxygen pickup
- Data obtained thus far does not indicate the presence of a public safety issue
- A bounding approach will have a significant negative impact on the industry with little or no safety benefit

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Incomplete Database

- Missing results from integral tests on high-burnup PWR rods from HB Robinson
  - Investigate double-sided oxidation concerns
- The PQD database on Zr-2 material is sparse
  - Test data not available on hydrogen-charged and irradiated samples
  - Can lead to undue conservatism being applied to Zr-2
- Not enough data available to understand effect of applied temperature profile and quench initiating temperature
  - Inconsistent testing conditions between different laboratories
  - Non prototypical temperature profiles

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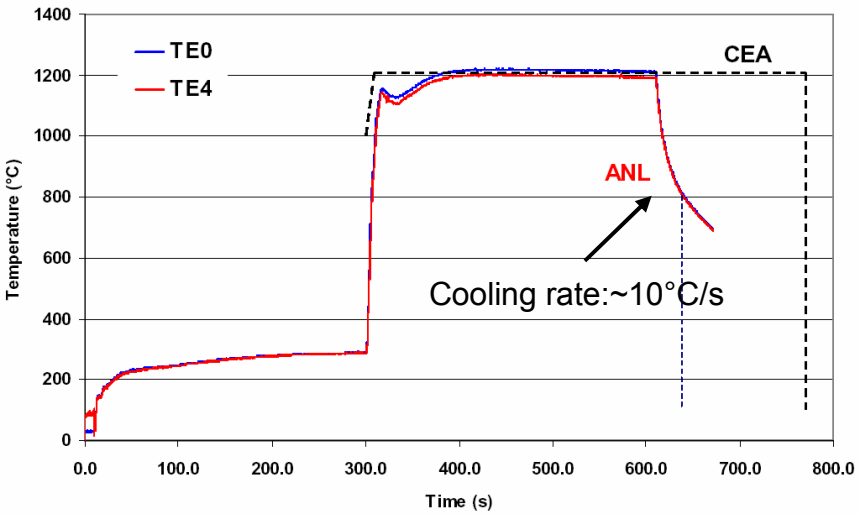
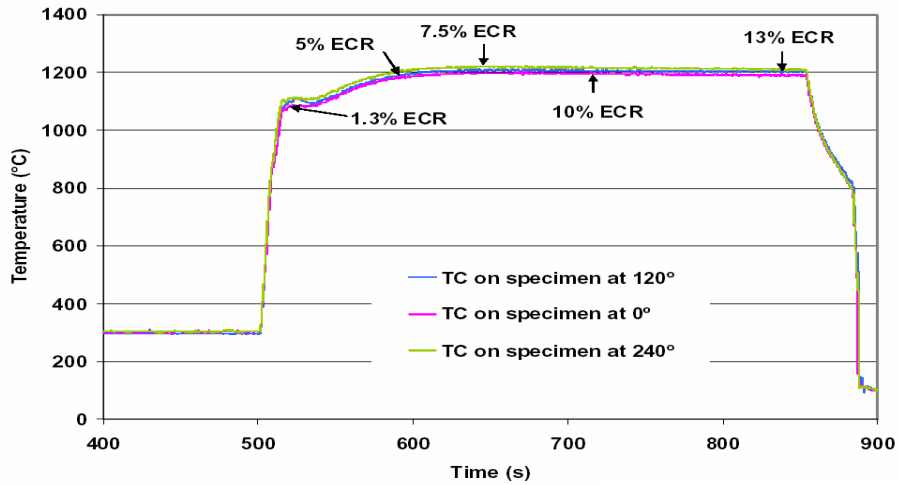
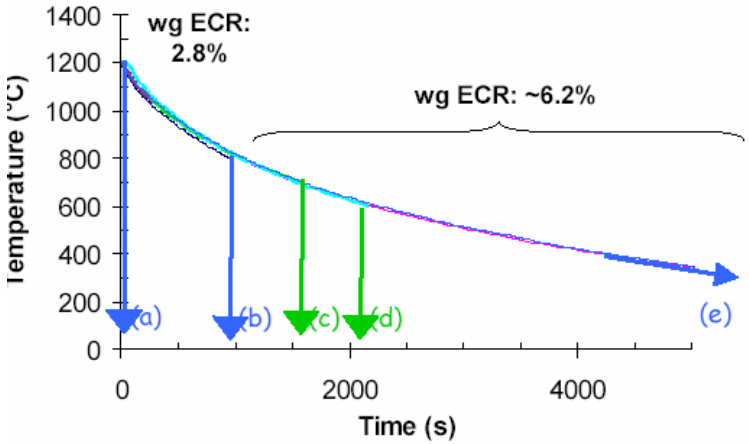
Transient Temperature Profiles



Cooling in steam environment





Cooling rates:

1200 to 800: from 0.5°C/s to 0.3°C/s
800 to 600: 0.17°C/s
600 to 150: 0.05°C/s (3.3°C/min)

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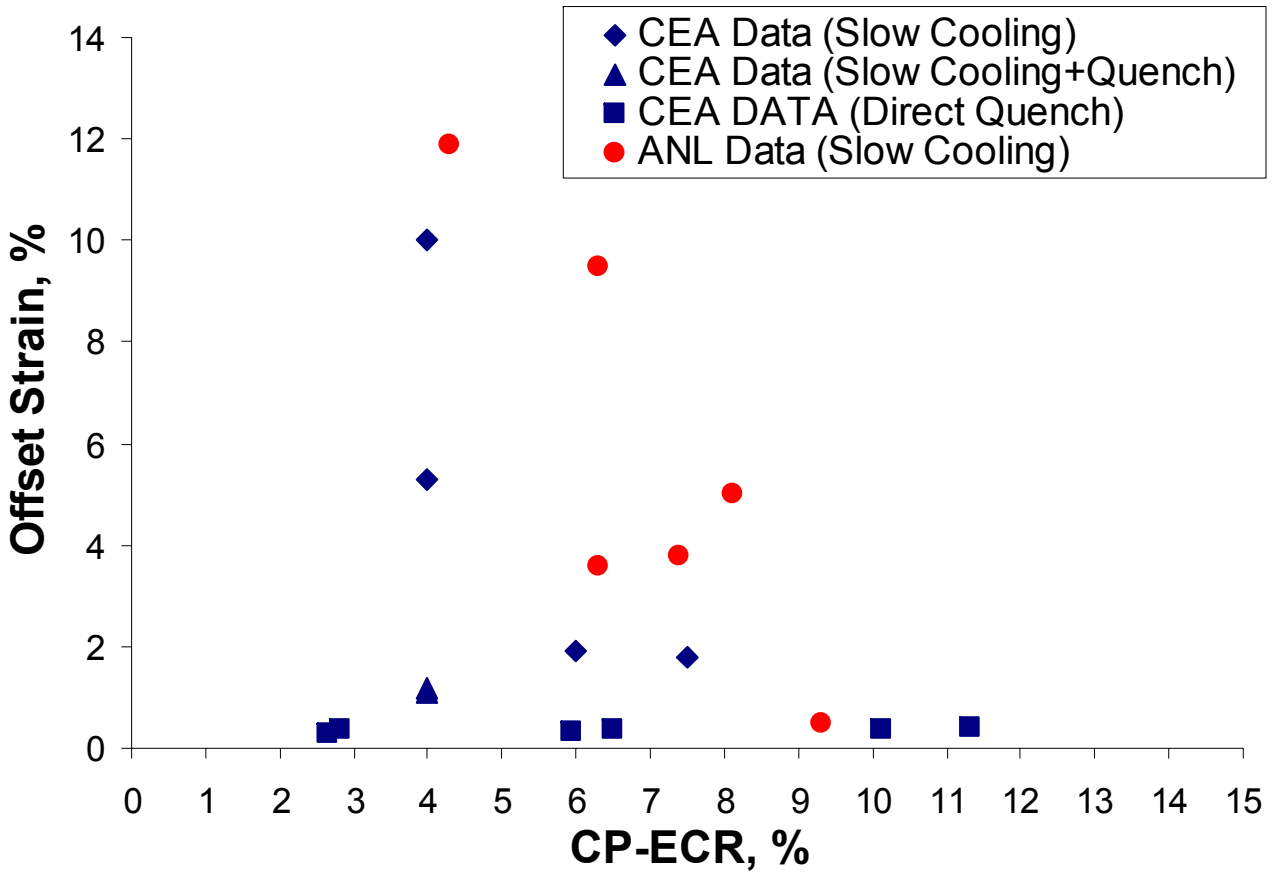
Comparison of ANL & CEA Post-Oxidation Ductility Offset Strain vs. CP-ECR



Samples oxidized at 1200°C and have a hydrogen content of approximately 600 wppm

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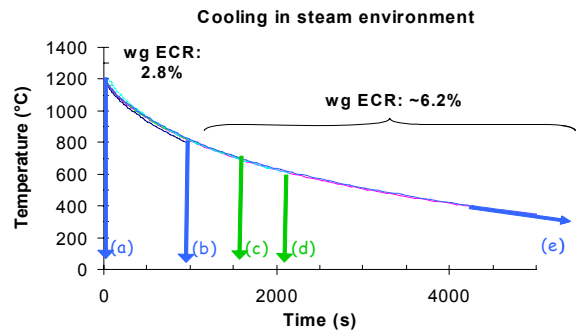
Residual Ductility is Dependent on the Cool Down Rate and Quench Initiation Temperature

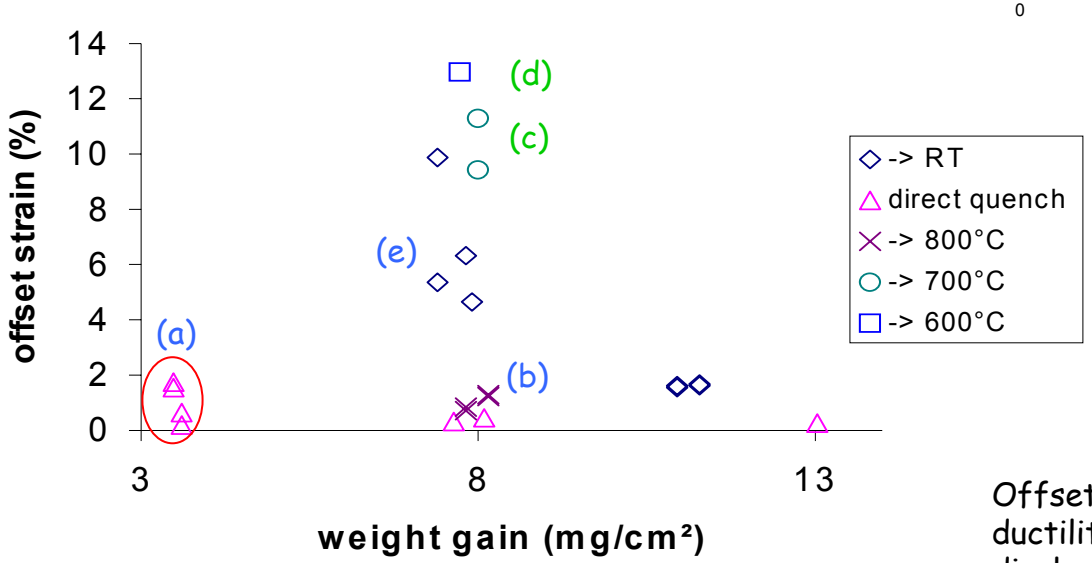
Other dependencies – material phase change kinetics

(Slide from CEA Presentation at ANL June 2006)



Mechanical behavior: RCT at 135°C

(Zy-4 600 ppm H, 50s at 1200°C)



Offset strain = residual ductility = « plastic » displacement / diameter (%)

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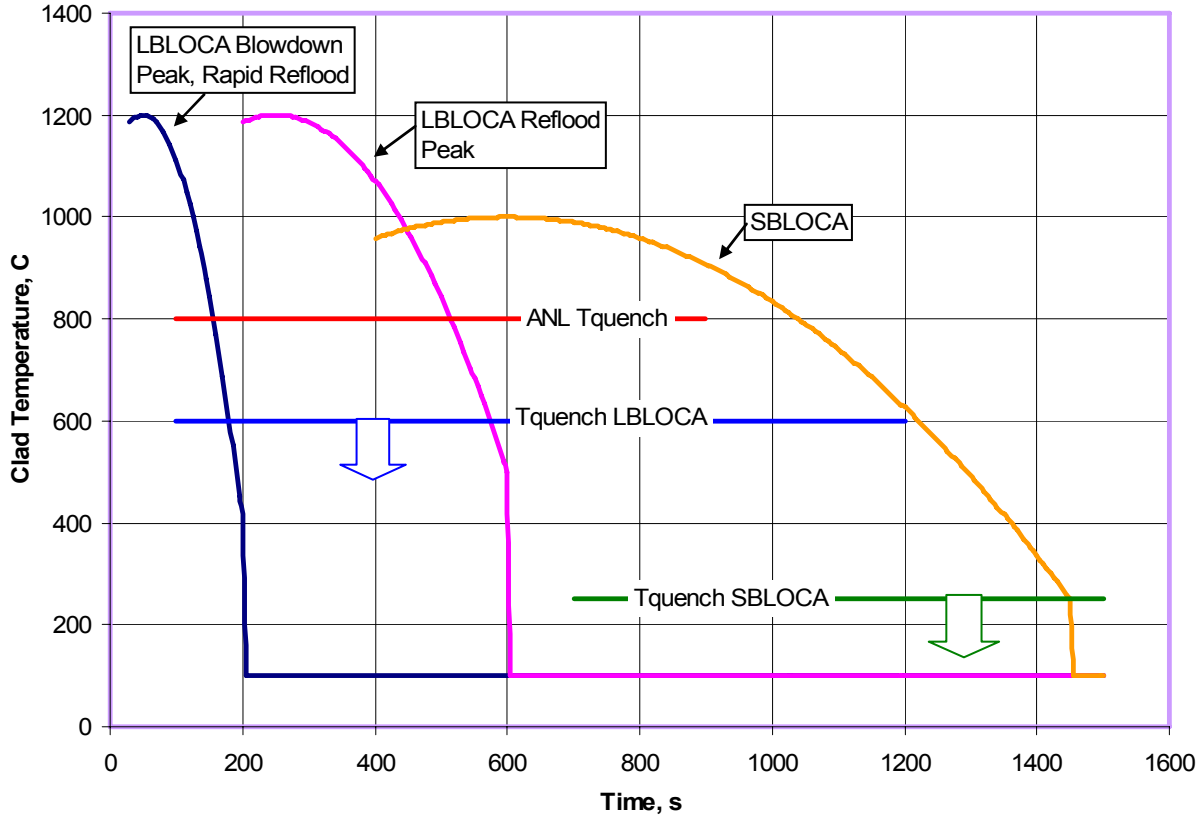
Estimated Cooldown & Quench Temperatures



Note: The 800C Quench Temp used at ANL is much higher than predicted LOCA quench temperatures (<600C LBLOCA, <250C SBLOCA)

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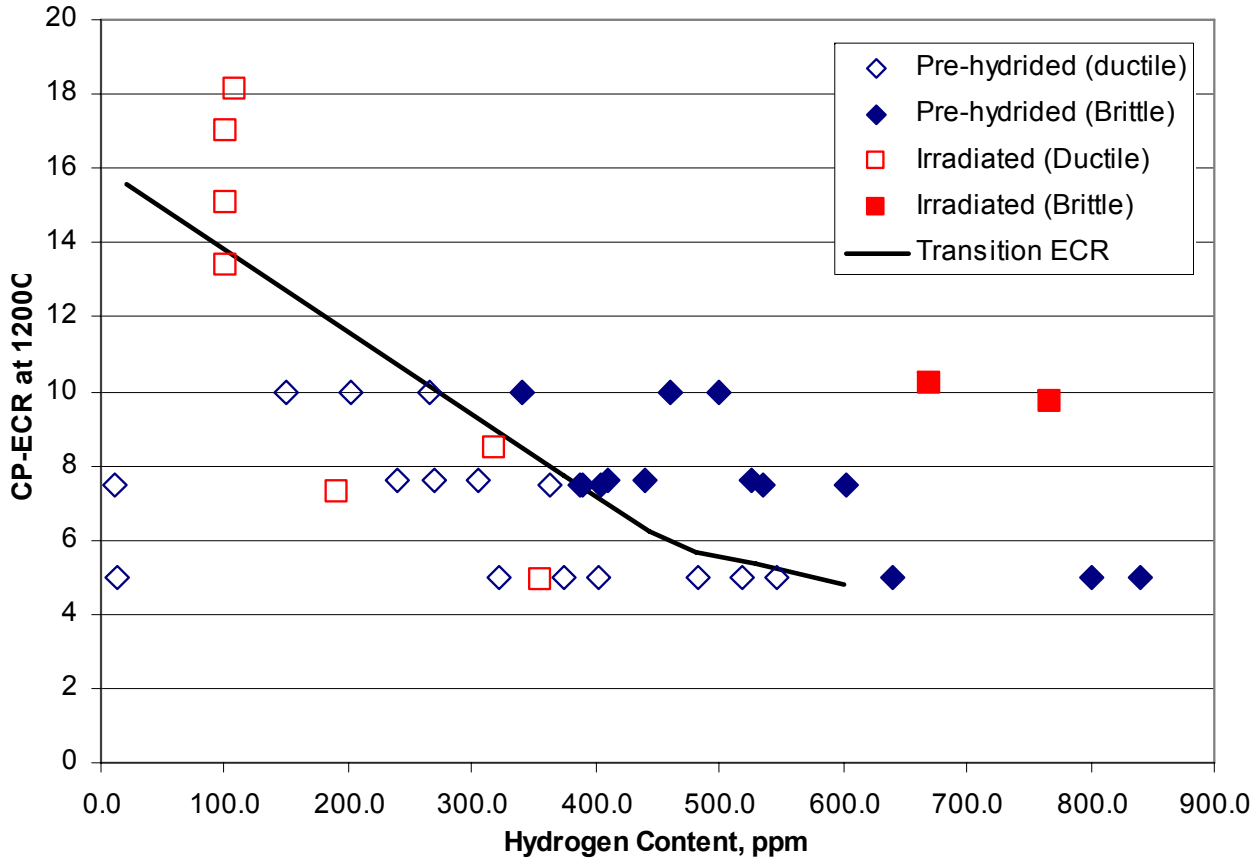
Pre-hydriding Appears to be a Good Surrogate for Irradiation Effects

- Zircaloy-4, ZIRLO and M5 data



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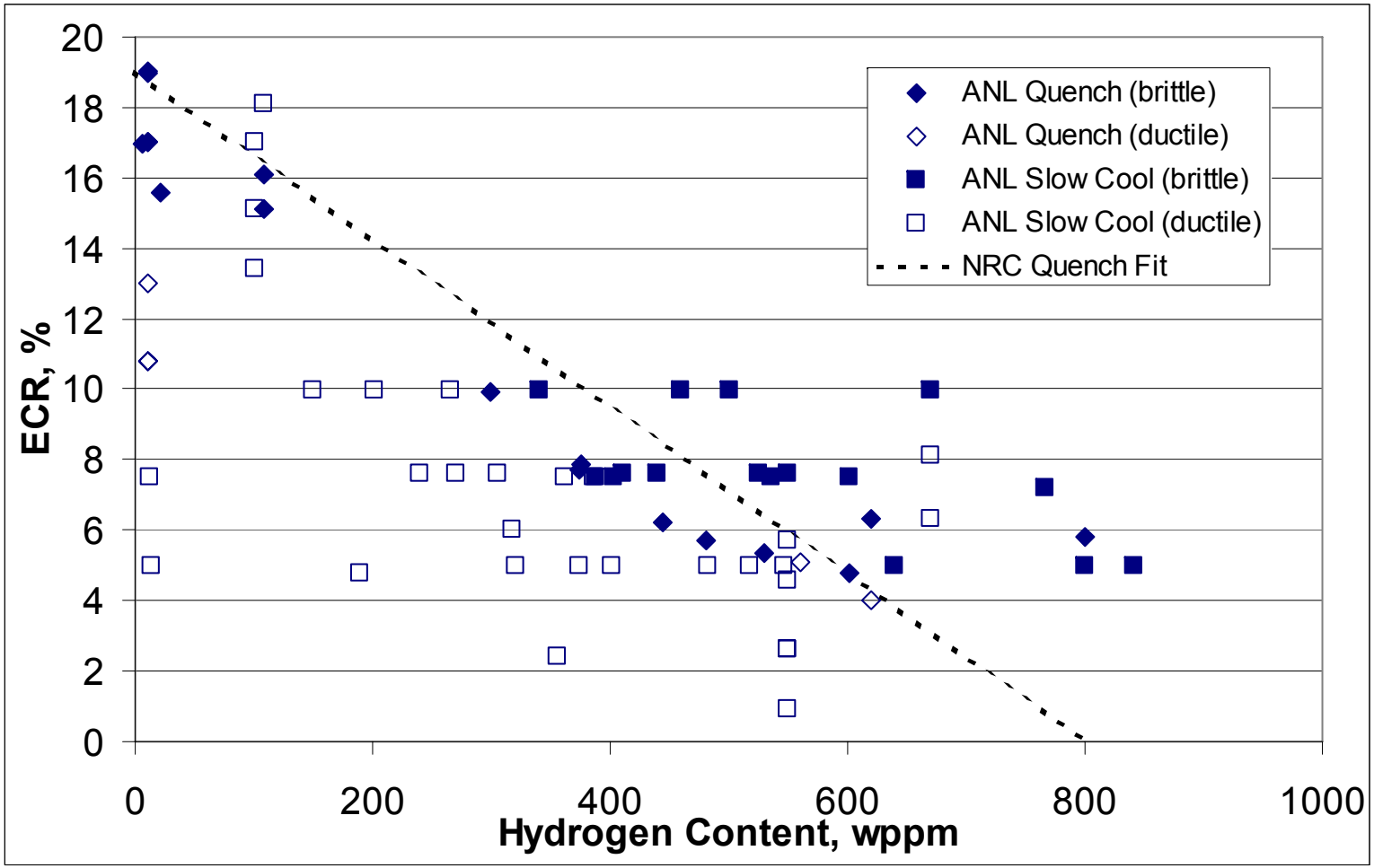
RIL-0801 Interpretation not Consistent With Data



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Concerns with Breakaway Oxidation Studies

- Most tests performed on E110
  - Russian alloy fabricated using an electrolytic process
    - Western alloys use Kroll process
- E110 very sensitive to surface finish
  - Tests on Western alloys show little variation to surface finish
    - Machined and polished
- Differences in test results between ANL and Westinghouse
  - Differences need to be understood prior to establishing criteria
- Limited scope of tests not sufficient to support periodic testing of as-fabricated cladding

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Doubling the Transient Oxidation Exaggerates the Effect of ID Oxygen Uptake

- Assumes amount of ID oxygen uptake is same as the outer surface steam oxidation
  - Need strong pellet-clad contact / bonding for oxygen uptake from pellet
    - Not clear to what extent these apply to a LOCA
  - Data suggests potential of ID alpha layer growth from pre-existing ID oxide layer
    - Limited oxygen source from oxide layer (confirmed by Zr-2 oxidation tests)
- Results from ANL High Burnup LOCA Integral Tests Inconclusive so far
  - No clear indication of inner surface oxygen uptake beyond the balloon region (Limerick tests ECR: 18% in balloon – 7% away)
  - No PWR integral test data

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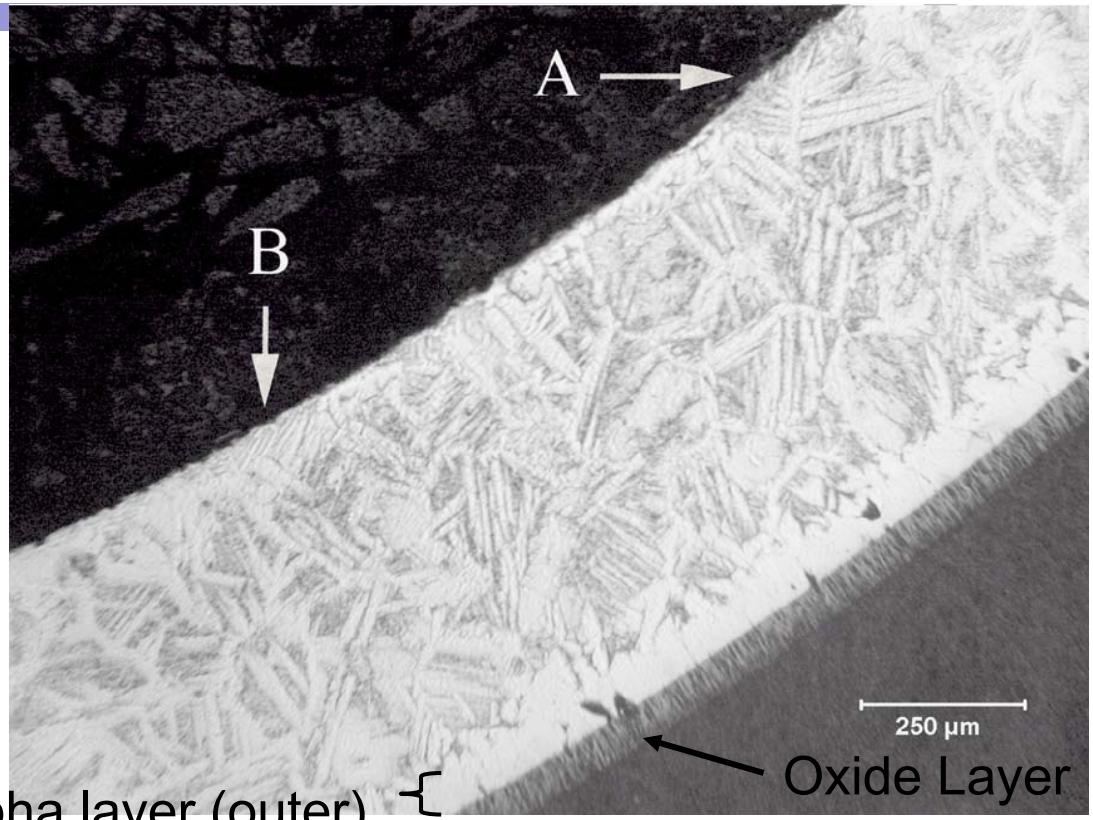
Integral LOCA Experiments on High-Burnup Limerick Fuel Do Not Show Significant ID Oxygen Pickup at 57 GWd/MTU Burnup

NUREG Interpretation

(A): This inner-surface region does not have an alpha layer even though in close proximity to fuel material. More typical of what is observed for most of the inner surface at this axial location.

(B): Evidence of some local inner surface oxygen-stabilized alpha



Alpha layer (outer)

Limerick fuel at 57-60 GWd/MTu

From Figure 175 : for ICL#2 sample at 50 mm above the burst midplane

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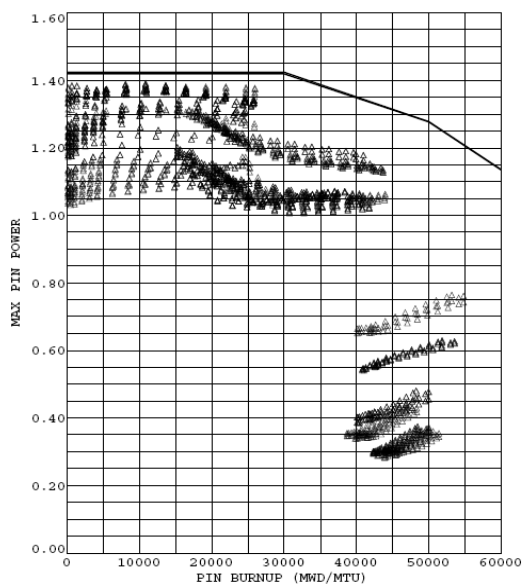
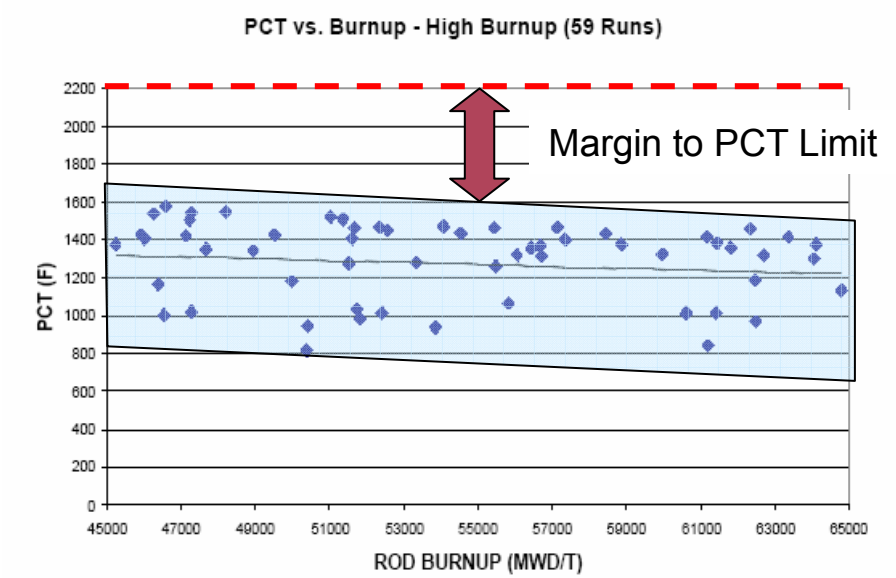
Oxidation of High Burnup Fuel at 1200ºC is Conservative

- Depletion of fissile content at high burnup reduces peak cladding temperature (PCT)
  - 150 to 200ºC margin to PCT limit
- Lower burnup fuel must exceed PCT limit for high burnup fuel to reach 1200ºC





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Data Needed & Issues to Address Prior to Rule-Making

- Additional RCTs on irradiated and prehydrided Zr-2 and Zr-4 samples that have been oxidized and quenched at various temperatures
  - 1000 to 1150°C PCT on samples with 300 to 600 ppm hydrogen content
- Integral LOCA tests using irradiated PWR cladding to confirm the overall LOCA behavior
  - Including need for ID oxygen uptake
- Test type and detailed protocols to establish criteria values
  - Heating and cooling rates, sample size/geometry, ductile-brittle transition (offset strain threshold) for ductility tests
  - sample size/geometry and cleaning, steam flow rates, heating ramp rate and method, and circumferential temperature variation for breakaway oxidation studies

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Conclusions

- The industry is supportive of NRC's overall objective with regards to performance based LOCA criteria, but concerned about an overly-conservative criteria that consumes industry resources with no added benefit to public safety
- Need adequate time to review and understand ANL data/evaluations in relation to other data/experience (CEA, Halden, JAERI have active programs ongoing)
- Key technical questions can only be answered with additional tests/data acquisition

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