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

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Industry Cooperation with NRC on High Burnup Fuel LOCA Tests

- The industry is supportive of NRC's overall objective to revise the acceptance criteria in 10 CFR 50.46(b)
  - Endorses the concept of a performance-based approach
  - New criteria will allow for cladding advances without need for rule exemptions
  - May simplify performance assessments of new cladding designs (if adequate surrogate to irradiation effects is identified)

- The Industry is actively participating in the ANL LOCA tests
  - Reviews by EPRI Fuel Reliability Program and Vendors
  - Supplying high-burnup BWR & PWR fuel rods and irradiated cladding
  - Assistance on design and qualification of LOCA and mechanical tests
  - Data, methods, and analytic exchanges with the CEA, AREVA, EDF programs

Summary of Industry Position With Regards to Proposed Initiation of Rulemaking

- Data obtained thus far does not indicate the presence of an urgent public safety issue
- Large safety margins:
  - High burnup fuel can not approach peak temperature limits without fresher fuel exceeding them
  - Even “zero-ductility” fuel has sufficient **strength** to withstand stresses resulting from rapid quench and post-LOCA loads
- Revisions proposed by RES are premature and not adequately supported by data
- Appearance of a “rush to rulemaking” without cause
- A bounding approach will have a significant negative impact on the industry with little or no safety benefit

(slide mainly from NRC-RES presentation to ACRS 2/2/07)

NRC's Proposed New LOCA Criteria

Appropriate For All Zirconium Cladding Alloys

(research result, not yet subjected to public comment or adopted in regulations)

Temperature Limit: 2200°F = 1204°C [50.46(b)(1) no change]

Time Limit: Based on Tests for each Material [50.46(b)(2) new]

"F" factor

- $ECR_{calculated}$ *(percent oxidation)* $\leq ECR_{unirradiated} - 1.2\, ECR_{corrosion}$

  $ECR_{unirradiated}$ = *embrittlement threshold at 1200°C*

  $ECR_{corrosion}$ = *corrosion thickness from burnup*

  Calculate ECR with Cathcart-Pawel weight-gain equation

  Assume 2-sided oxygen pickup

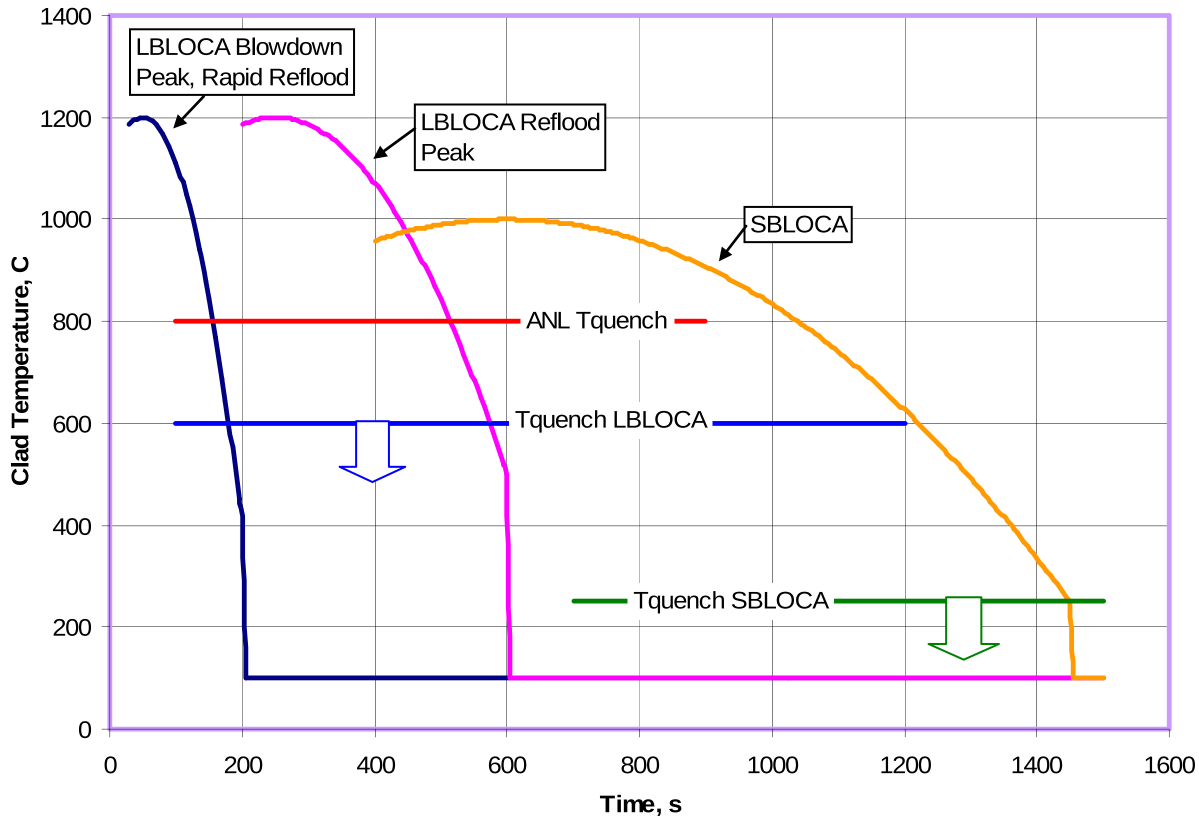
  (Not necessary to apply criteria in balloon)

- *t (above 650°C)* $\leq$ *measured minimum breakaway time*

Shortcomings with the F-factor Approach

- F-factor approach (first proposed IN 98-29) assumes pre-accident corrosion to be a surrogate for hydrogen content
  - No technical basis for such an assumption
  - Not appropriate for BWR environments
- The approach attempts to address multiple effects
  - In-service corrosion or cladding hydrogen content,
  - Cladding design and composition
  - Accident time-temperature history
- Impact of these variables cannot be addressed by a single factor
  - The result is a large scatter in potential F values
  - Quench temperatures lower than those used for the ANL tests result in lower F values (**can be less than 1.0**)

Estimated Cooldown & Quench Temperatures



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

Issues with the Proposed Approach to ID Oxygen Uptake

- ID oxygen uptake is possible when strong pellet-clad contact or bonding is present
  - Conditions apply at high burnups only
  - Not clear to what extent these apply during a LOCA
  - Need Integral LOCA tests on high-burnup fuel to confirm extent
- Results from ANL Integral LOCA Tests inconclusive so far
  - <u>No tests on high-burnup PWR fuel conducted yet</u>
- Requiring that Transient Oxidation to be "doubled" is likely to exaggerate this effect

The technical issues involving ID oxygen pickup and the "F" factor approach can only be resolved by focused testing

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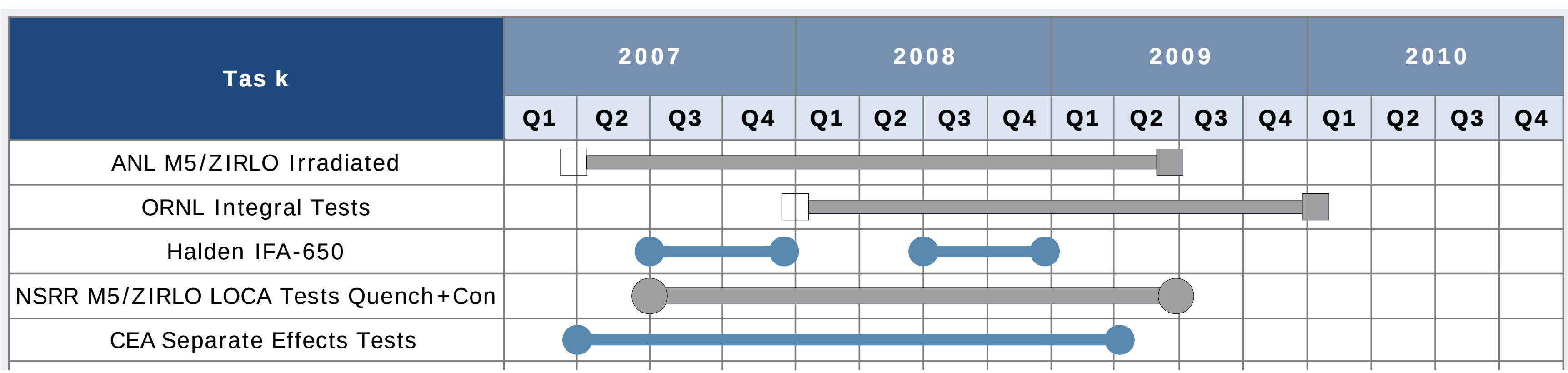
LOCA Tests Are Being Conducted Worldwide

- Key data is expected from ongoing programs in 2007 and 2008
  - HALDEN IFA-650
  - continuation of the ANL Program
  - Other international programs in Europe and Japan



Expected Consequences to Industry

Significant Resource Diversion and Cost with No Real Safety Benefit

- Vendors
  - Re-license EMs, potential need for additional hot cell testing
- Licensees
  - Updated analyses, Tech Specs, FSARs
  - Potential for increased fuel cycle costs, with increased spent fuel
  - Inability to use old Zircaloy clad fuel assemblies from spent fuel pool for core redesign
  - Potential for reduced operational flexibility
- NRC
  - Resources to review vendor and licensee submittals

Conclusion

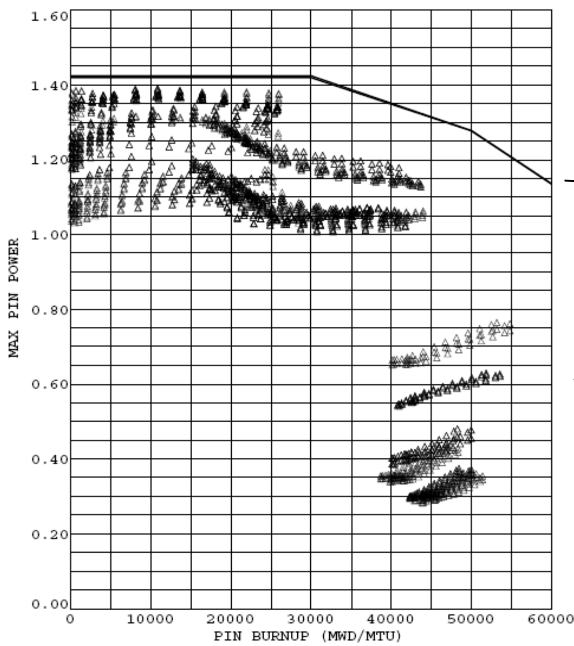
- More data and work is needed to support possible future revision of 10 CFR 50.46(b) embrittlement criteria
- Rule Change and NUREG Should be Developed Together
  - Regulation language should be consistent with compliance approaches

Proposing a Series of Stakeholder Workshops to Refine Data Needs for Possible Criteria Revision

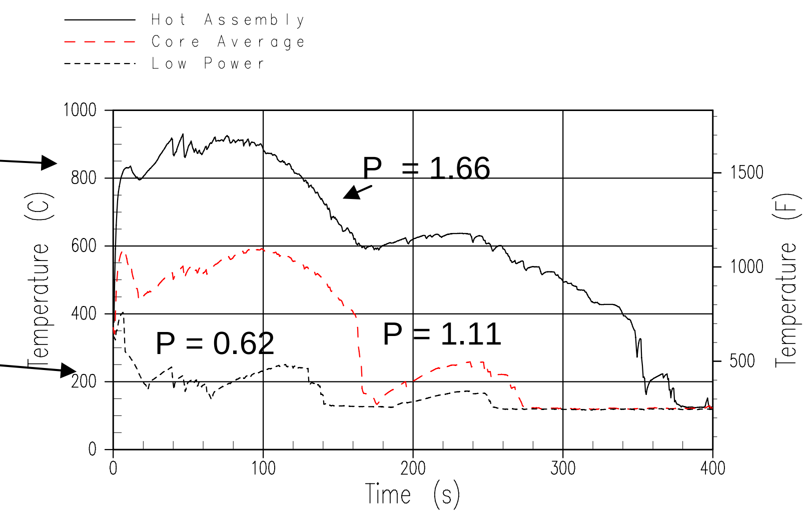
Backup Slides

Large Safety Margins Indicate There is No Issue at High Burnup

Typical 3-Loop PWR
Achievable Pin Power vs. Burnup



Typical 4-Loop PWR
LBLOCA PCT Response for Baseload Operation



High burnup UO_2 fuel cannot approach 1200°C without fresher fuel violating limits

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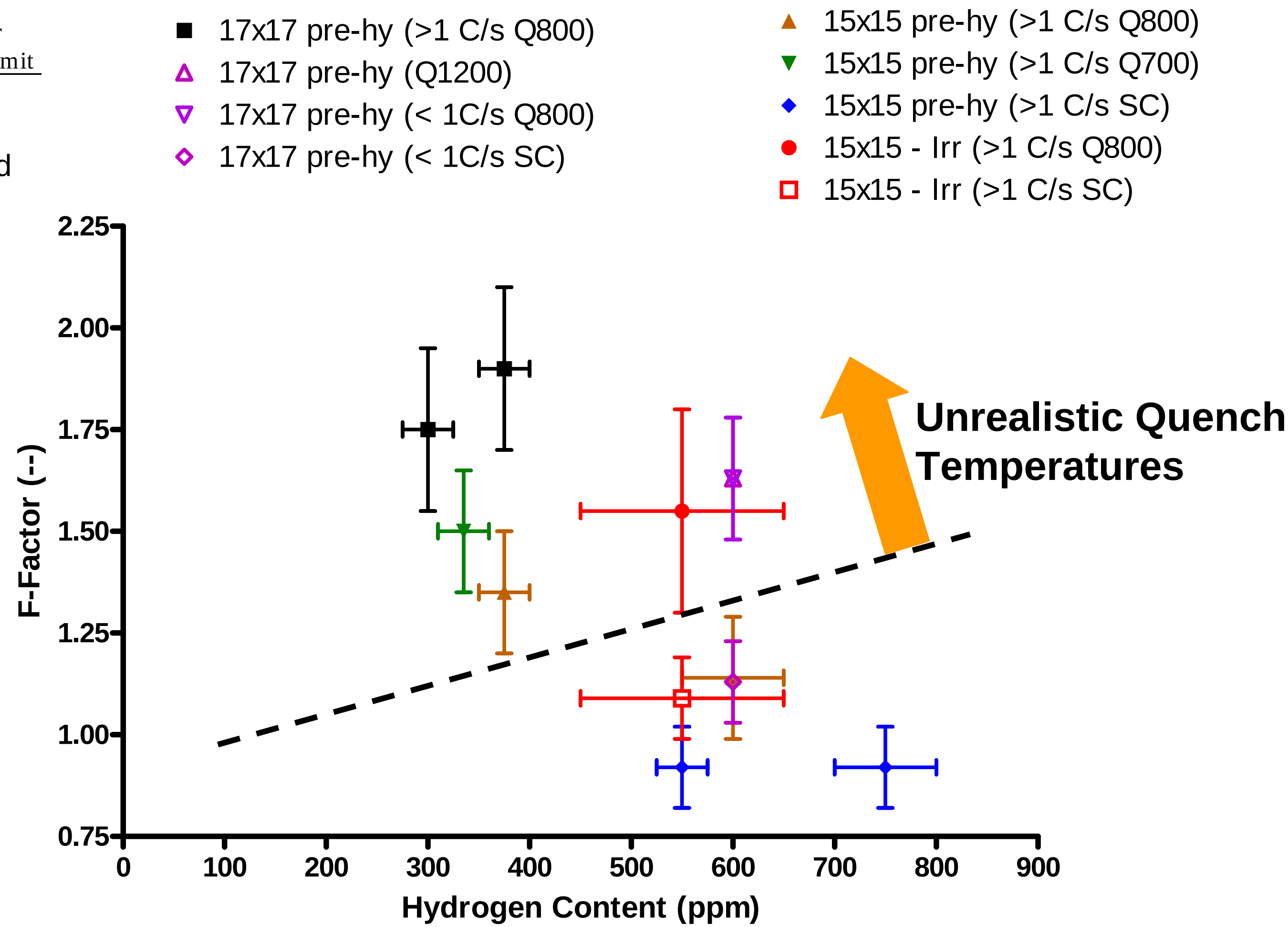
F-Factor Depends on Many Variables

$$F = \frac{ECR^{unirr}_{limit} - ECR^{tr}_{limit}}{ECR^{ss}}$$

ECR^{ss} for the pre-hydrided material calculated using H pickup fraction and Pilling-Bedworth ratio



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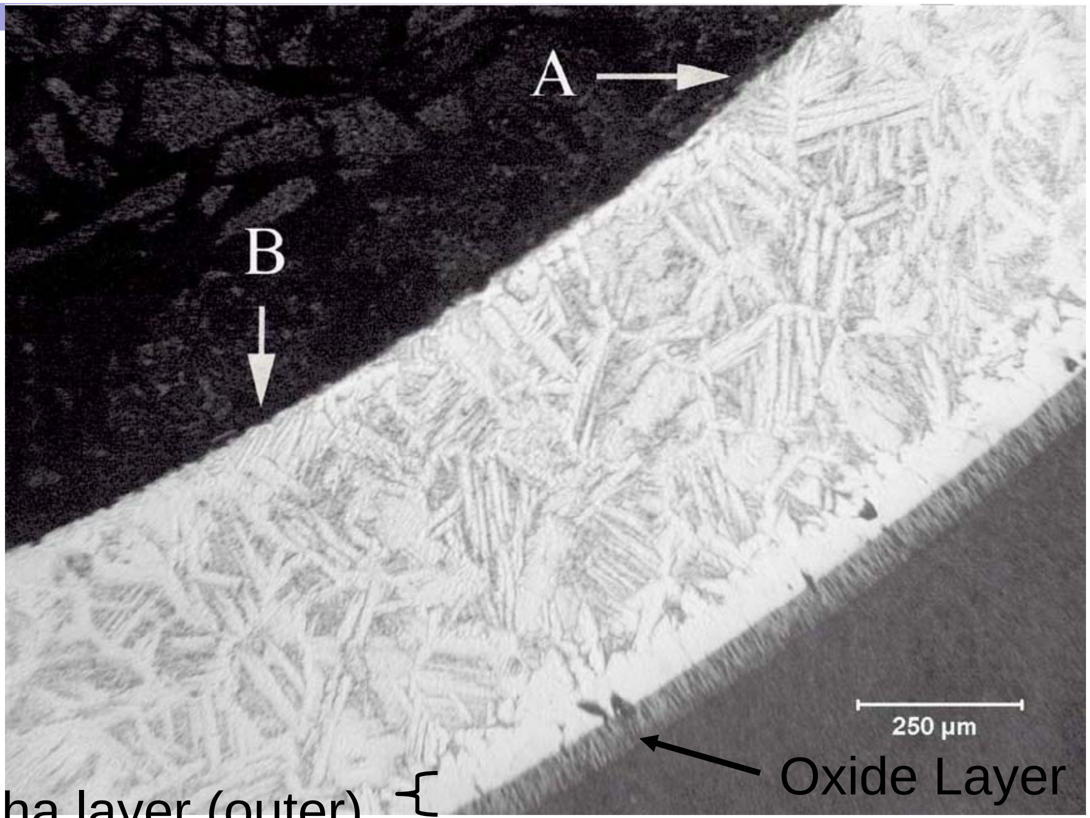
Integral LOCA Experiments on High-Burnup Limerick Fuel Are Inconclusive on ID Oxygen Pickup

(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



Limerick fuel at 57-60 GWd/MTu

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