EPRI ELECTRIC POWER RESEARCH INSTITUTE

LOCA Round Robin and Related Research

Ken Yueh
Principal Technical Leader

Oak Ridge National Laboratory
April 29-30, 2015

US NRC 50.46c Draft Regulatory Guides
Public Meeting

Background

- EPRI coordinated an international LOCA round robin at the urging of the ACRS

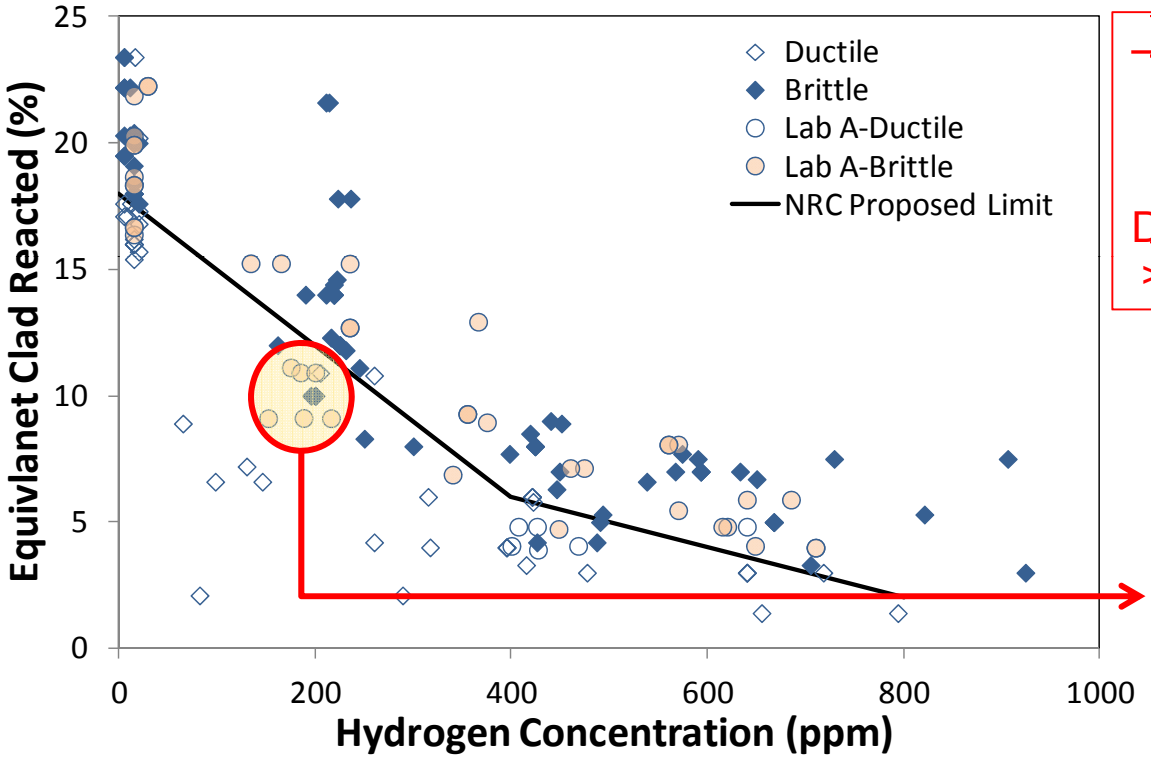
- Six laboratories participated in the round robin
  - CEA/AREVA
  - Global Nuclear Fuel
  - Korea Atomic Energy Research Institute
  - Hungarian Academy of Sciences
  - Oak Ridge National Laboratory
  - Westinghouse Electric Company

Round Robin Scope

- Post Quench Ductility (PQD)
  - Several hydrogen concentrations
  - 1200°C steam oxidation temperature
  - 135°C ring compression test
- Breakaway Oxidation
  - Bracket the on-set of breakaway oxidation of fresh cladding to within a 500 second time window at 800 and 1000°C
- Laboratories use their own procedures and quality assurance programs
  - Conform to a common set of high level requirements
- All laboratories used a common lot of Zircaloy-4

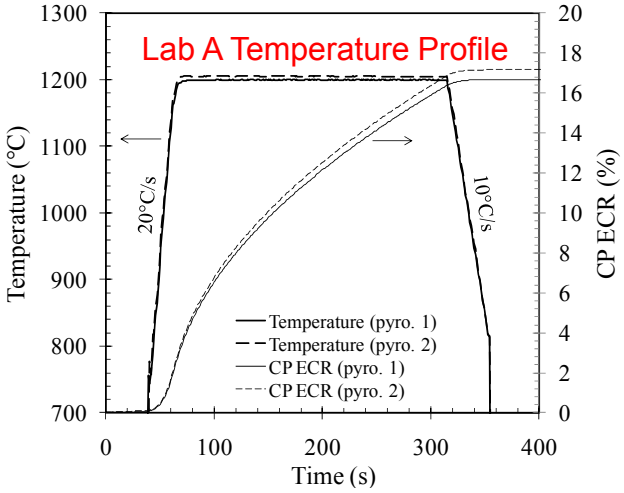
Ring Compression Test Results – Post Quench Ductility

- Difficulty charging sample with hydrogen to target values



→ Ductile-to-brittle transition based on NRC draft guide 2% offset strain criterion

Ductile if off-set strain >=1.41 + 0.1082 ECR(cp)



General embrittlement trend is consistent with NRC proposed limit

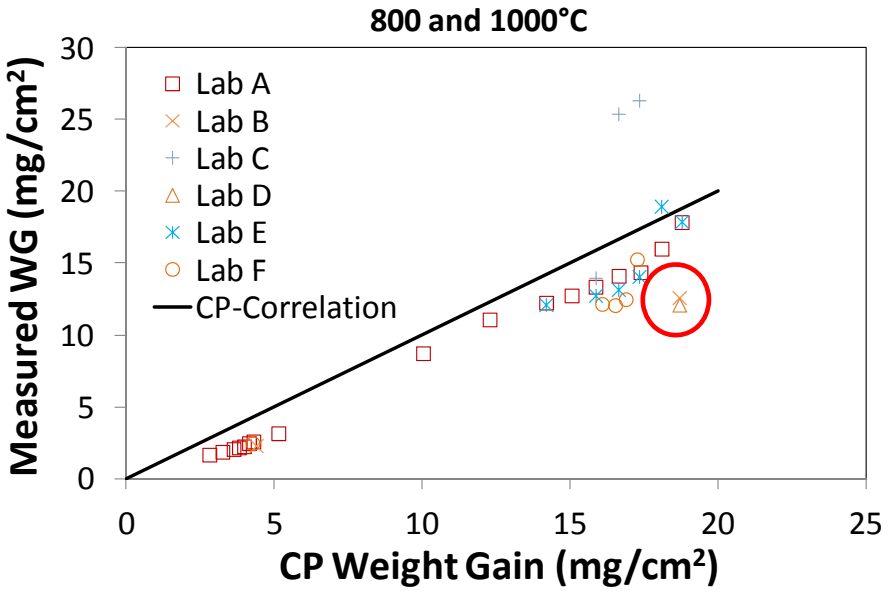
Key PQD Conclusions and Lessons Learned

- Precise hydrogen charging is not practical
  - >50 ppm departure from target for most laboratories
- Predefined prescriptive procedure to map the PQD embrittlement curve could not be followed
  - Embrittlement curve determination procedure in DG-1263 needs to be more flexible
- Combined PQD data trend consistent with the NRC proposed limit

Breakaway Oxidation Test Results

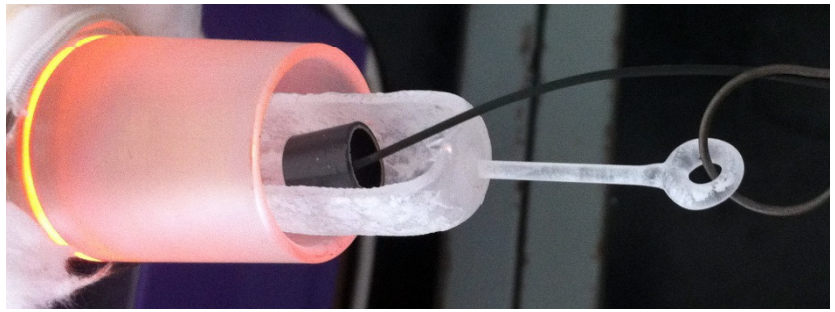
- None of the laboratories experienced breakaway oxidation at 800°C up to 7000 seconds of exposure
  - One laboratory tested to 10000 second without breakaway, hydrogen < 70 ppm
- Four laboratories experienced breakaway oxidation within expected 5000-6000 seconds at 1000°C
  - Two failed to experience breakaway up to 7000 seconds

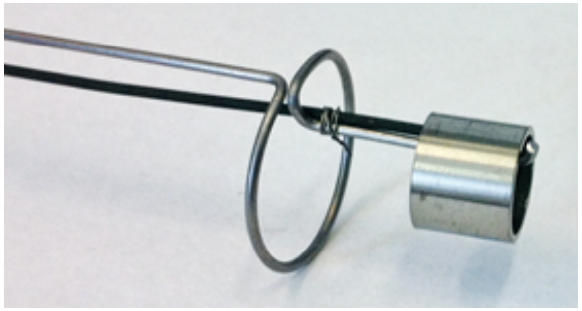
- Initial suspicion on sample temperature - Not the case
- Focus shifted to thermal mass impact



Heat-up Rate Effect On Breakaway Oxidation

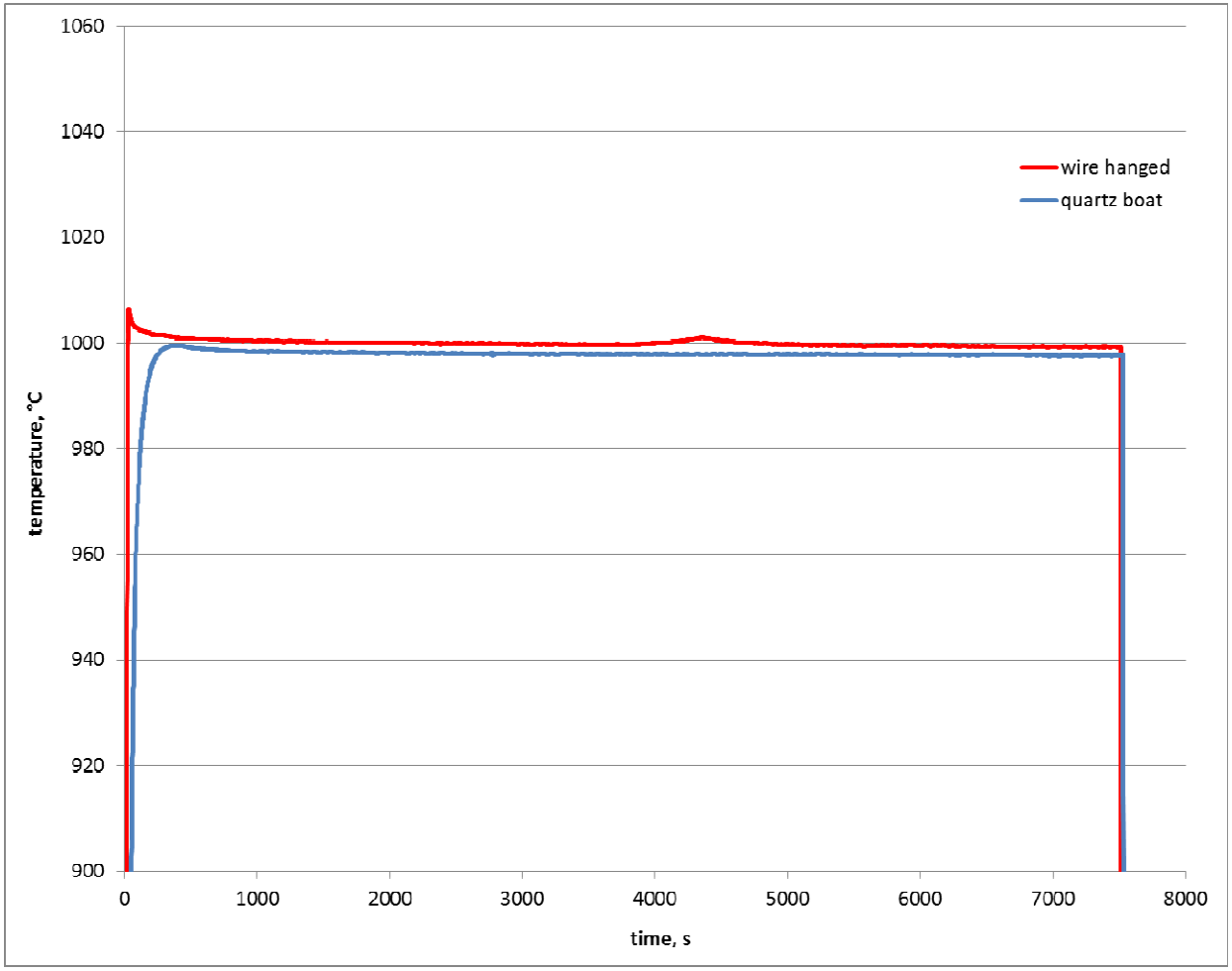
- 7500 seconds at 1000°C





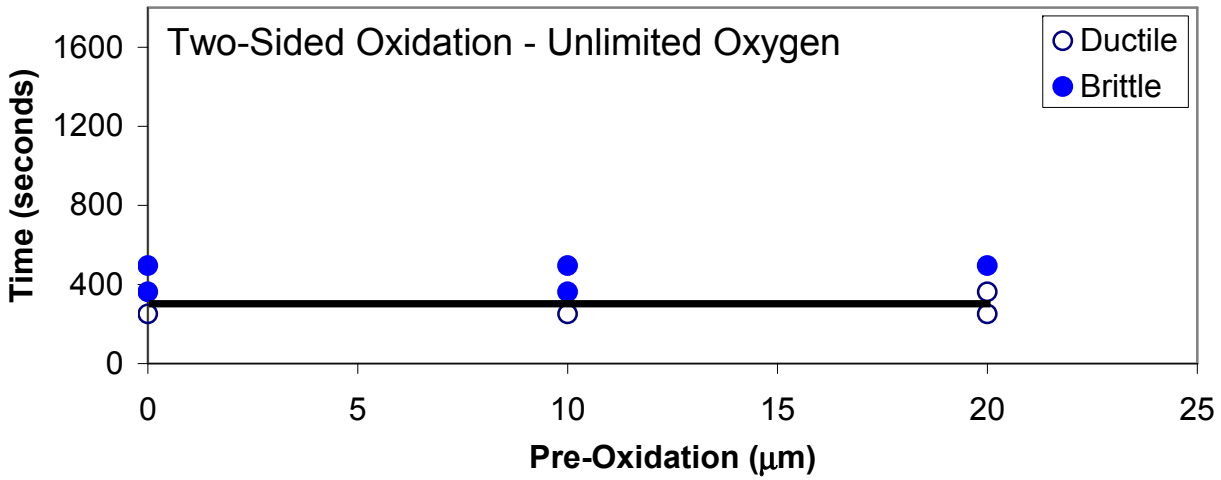
Heat-Up Rates Profile

- Wire hung sample heated up much faster



Other Breakaway Oxidation Testing Results 1/2

- EPRI sponsored research to evaluate the impact of limited ID oxygen source on PQD
  - Pre-oxidation of test samples at 800°C to fix inner surface oxygen source (used lower heat-up rate)
  - Test samples pre-oxidized up to 18,000 seconds
  - No evidence of breakaway oxidation
  - No impact on PQD after oxidation at 1200°C



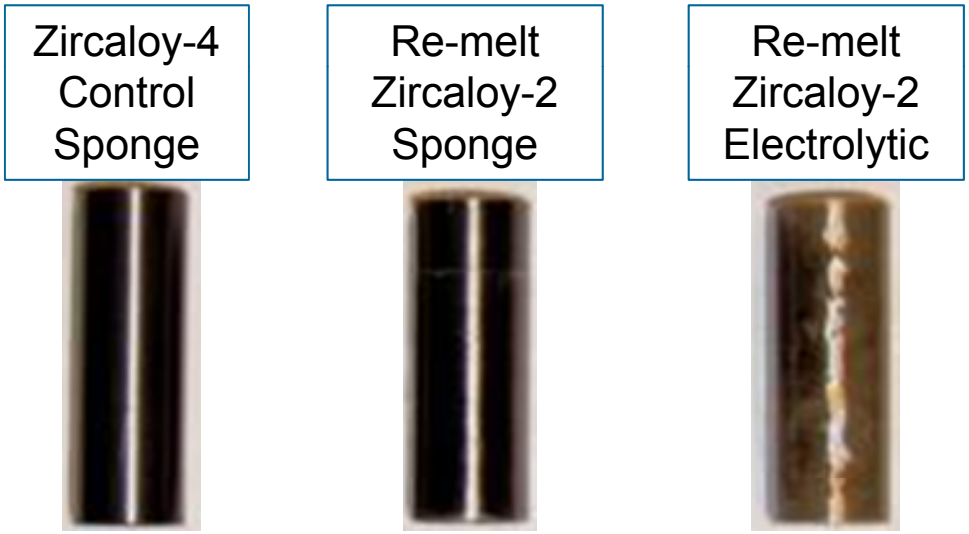
"Changes in Cladding Properties under LOCA Conditions", 2013 LWR Fuel Performance Meeting

Key Conclusions and Lessons Learned

- Time to breakaway oxidation is significantly longer at 800°C relative to 1000°C
- Breakaway time is strongly dependent on the heat-up rate
- Heat-up rate as defined in the draft regulatory guidance is inadequate to ensure repeatability

Other Breakaway Oxidation Testing Results 2/2

- Used sponge and electrolytic source materials
  - Test sample machined from melted solid bars
- After 3000 seconds in 1000°C steam



- Breakaway oxidation is not impacted by thermal-mechanical processing
  - Could be detected at the ingot processing stage

Key Conclusions

- Electrolytic sourced materials are susceptible to premature breakaway oxidation
  - Not influenced by alloy composition or thermal-mechanical processing
- Electrolytic processed materials used a potassium-fluorination process – result in significantly higher product F content
  - Hydrofluoric acid is currently the only known material to aggressively attack zirconium based alloys
  - Hydrofluoric acid etching is known to result in earlier breakaway oxidation
- Phenomenon detection should not require more than per ingot basis

Second Round Robin

- Some of the original LOCA RR participants expressed interest for a second round to verify repeatability
  - Using test samples prepared by a single laboratory
  - AREVA/CEA, GNF, KFKI, WEC and ORNL and Studsvik may join
- Planned scope is smaller than required for ASTM standard, but ASTM B10.03 subcommittee will consider and make decision based on data quality
  - Common test procedure

LOCA Round Robin Samples

- Sample pre-characterization
  - Most sample end-to-end variation within 2 ppm

Hydrogen Concentration (ppm)	Average Bin Range (5 sets)	Maximum Bin S.D. (5 sets)	Maximum Sample End to End Variation
200	183-201	2.4	5
400	365-407	5	12
600	569-592	6.5	14

- Individual labs absorb their own costs and also work at their own schedule

Together…Shaping the Future of Electricity