

**EPRI**

**ELECTRIC POWER  
RESEARCH INSTITUTE**

# Industry Test Milestones

**Public Workshop  
10 CFR 50.46(b) ECCS Performance Requirements**

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**Ken Yueh (EPRI)**

**Project Manager**

**Regulatory Technical Advisory Committee**

**EPRI Fuel Reliability Program**

# Presentation Outline

- High Temperature Oxidation Test
- PQD and Breakaway Oxidation Round Robin
- Impact of Limited Inner Diameter Oxygen Source on PQD
- Breakaway Oxidation

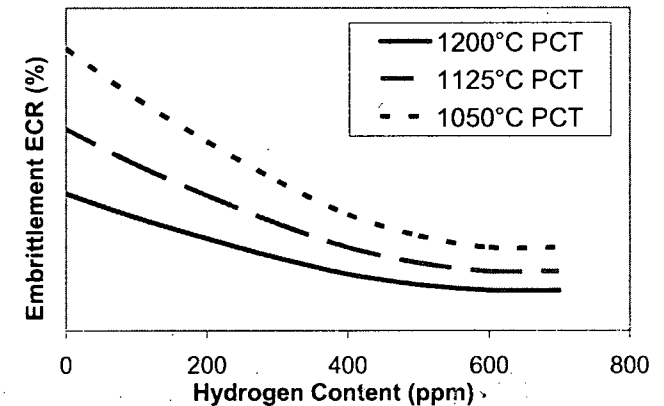
# High Temperature Oxidation

## Motivation

- ANL test data indicates ECR accumulated at lower temperatures are not as detrimental to ductility for Zircaloy-4
- Effects of cooling and quenching effects not well understood

## Objectives

- Generate sufficient test data to propose alternative lower temperature acceptance criteria
- Develop mechanistic understanding of embrittlement mechanisms



## Test Plan

- PQD at multiple temperature-hydrogen combinations, different cooling and quench conditions

## Completion Date

- December 2010

# LOCA Round Robin

## Objectives

- Collect sufficient information to establish ASTM test procedures
  - Expand on test parameters
- Evaluate potential sources of PQD and breakaway oxidation test variability
  - Experimental and Laboratory-to-laboratory

## Test Plan

- PQD at 1200°C and breakaway at 800°C and 1000°C
- Other optional tests to expand test parameter range

## Potential participants

- ORNL, AEKI, KAERI, Studsvik, AREVA, GNF and Westinghouse

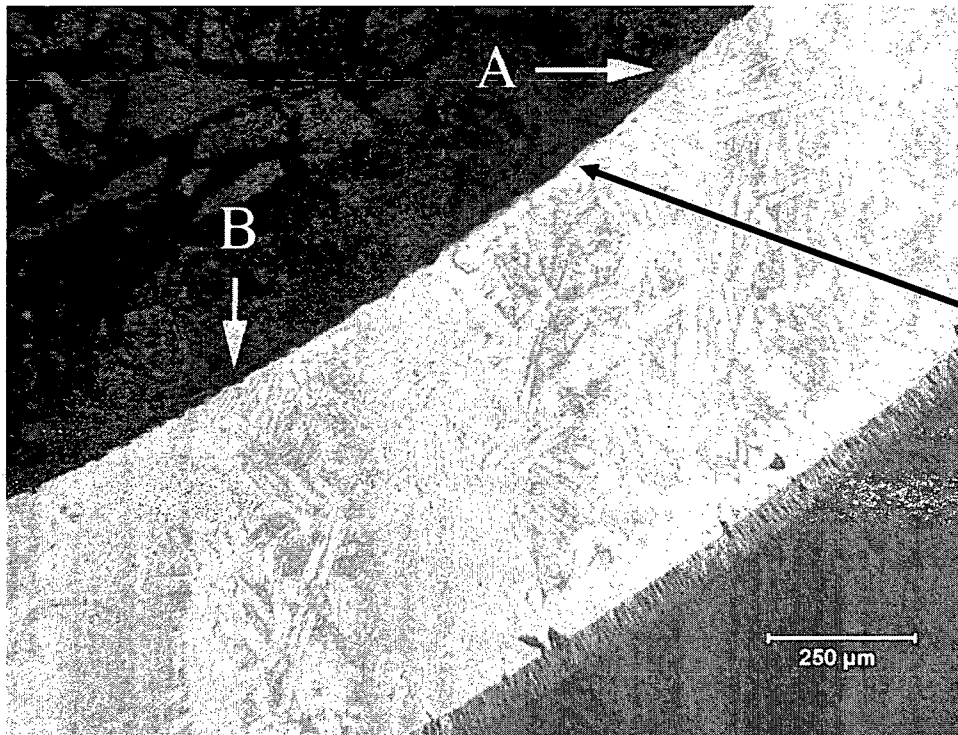
## Completion Date

- Target test completion by middle of 2011

# Impact of Limited ID Oxygen Source on PQD

## Motivation

- ANL Limerick integral test indicates clad/fuel bonding layer is not an unlimited oxygen source



No presence of an oxygen stabilized alpha layer on the ID surface

# Impact of Limited ID Oxygen Source on PQD

## Objective

- Evaluate impact of limited ID oxygen pickup on PQD

## Test Plan

- Compare PQD of open and sealed samples
  - Open unrestricted two-sided oxidation
  - Sealed samples with pre-oxidation

Preliminary results indicate limited ID oxygen source does not result in equivalent 2-sided oxidation embrittlement

## Completion Date

- October 2010, but additional scope may be added later

# Breakaway Oxidation

## Motivation

- Interest in breakaway oxidation is precipitated by extremely short breakaway oxidation time observed in E110

## Objectives

- Investigate the cause of short breakaway oxidation in electrolytic sourced zirconium based alloys
- Determine if the phenomenon could be detected in early processing

Test data shows phenomenon can be detected in the as-melted condition

## Completion Date

- Fall 2010

# Summary

- Industry is generating additional PQD data
  - Lower test temperature ductile-to-brittle transition curves (2010)
  - Mechanistic models to predict brittle transition ECR (2011 goal)
- Coordinating international LOCA round robin testing
  - Establish ASTM test procedures (2011/2012)
  - Identify potential sources of variation (2011)
- Evaluating Impact of limited ID oxygen source on PQD
  - Preliminary data indicates limited ID oxygen source does not result in equivalent two-sided embrittlement at the same time exposure (October 2010)
  - Follow-up tests to quantify impact planned (2011)
- Evaluating Breakaway oxidation (2010)
  - Preliminary data indicate phenomenon can be detected during ingot processing
  - Cause of short breakaway oxidation still being evaluated





# Together...Shaping the Future of Electricity

# High Temperature Oxidation Test

## ANL Test Data

- Limited ANL test data indicates ECR accumulated at lower temperatures are not as detrimental to ductility for Zircaloy-4

Oxidation Temperature (°C)	Target ECR (%) / WG (mg/cm <sup>2</sup> )	RT Offset Strain
1000	15/9.8	7.5
1100	15/9.8	5.4
1200	15/10.2	0.8

# High Temperature Oxidation Test

## Test Matrix for Lower Temperature Testing

- Test condition confirms to ANL specification
- Designed to generate complete ductile-to-brittle transition curves at 1050 and 1125°C
- Allow for comparison to ANL test results

Temperature	Hydrogen		ECR	
	Range (ppm)	# of Levels	Range (%)	# of Levels
800	15-800	4	2-10	3
900	15-800	4	2-10	3
1050	15-800	4	2-20	6
1125	15-1000	6	2-20	6
1200	15-1000	6	2-20	6

# High Temperature Oxidation Test

Test matrix for Developing Mechanistic Understanding

- Oxidation at 1100 and 1200°C

Quench	Cooling Rate	Hydrogen		ECR	
		Range (ppm)	# of Levels	Range (%)	# of Levels
No	Slow/Quick	15, 400	2	TBD	2
	Intermediate	15-600	4	10-15	2
From 800°C	Slow/Quick	400	1	TBD	2
	Intermediate	15-800	5	10-15	2
From temperature	N/A	15-800	5	4-15	3

- Detailed sample examination planned

# LOCA Round Robin

## Basic Round Robin Plans

- Conduct a set of PQD and breakaway oxidation tests
  - Multiple laboratories
  - Slightly different test procedures, but conform to ANL recommended key parameter specifications
  - Common lot of Zircaloy-4 cladding material
- Generate critical ductile-to-brittle transition at 1200°C for multiple hydrogen concentrations
- Determine breakaway oxidation time at 800 and 1000°C to within 500 seconds

# LOCA Round Robin

## Optional Round Robin Plans

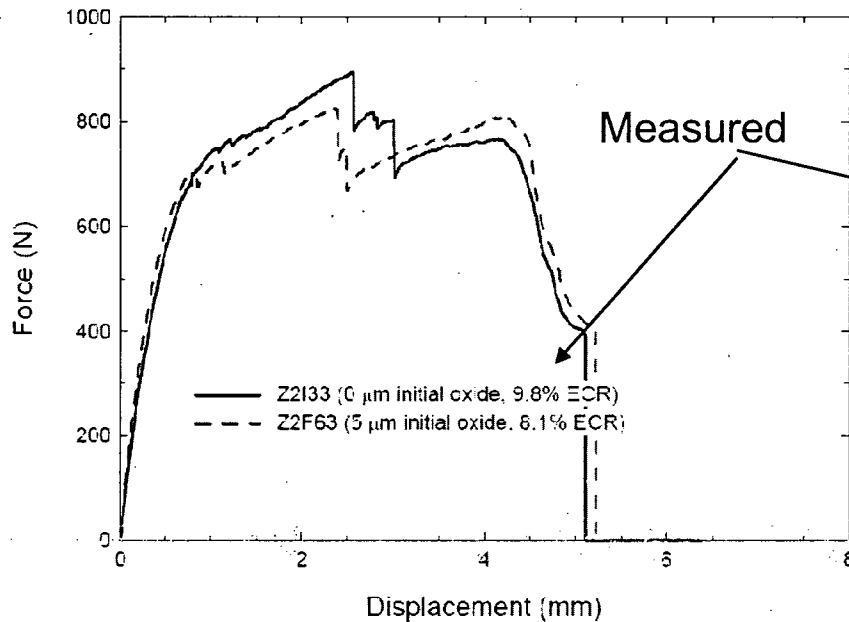
- Expand on test parameters

Test	Variation/Sensitivity/Effect	Test Condition	Material Hydrogen (ppm)
PQD/RCT	Lab-to-lab equipment/procedure	Sample material prepared by one laboratory	As-Built and 400
	Test temperature	130 and 140°C +/-2°C	As-Built and 400
	Loading rate	0.01 and 0.1 mm/s	As-Built and 400
	Quench temperature	1200°C oxidation 600°C and no quench	400
Breakaway	Surface finish	With surface scratch(es)	As-Built

# Impact of Limited ID Oxygen Source on PQD

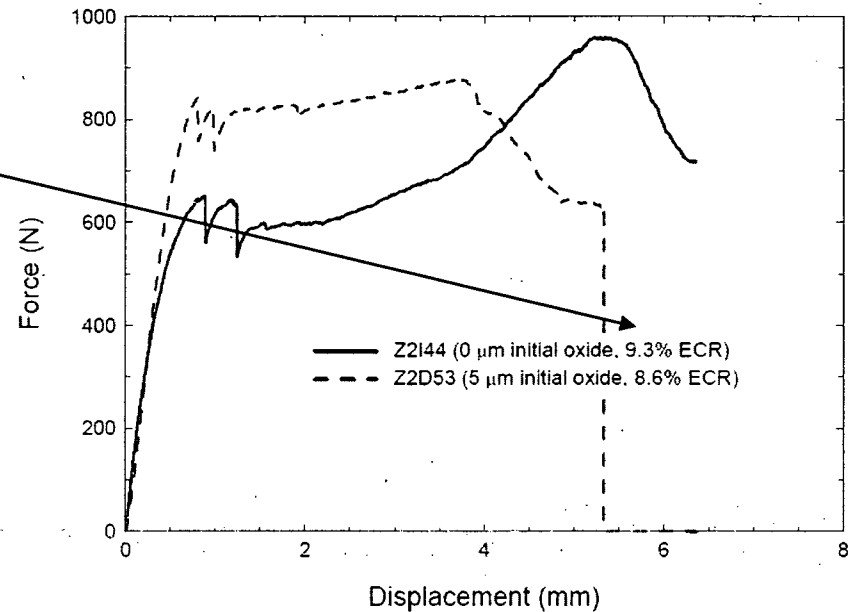
## Preliminary results

Ring compression tests  
(Oxidation at 1200 °C, open)



150 Second Exposure

Ring compression tests  
(Oxidation at 1200 °C, sealed)

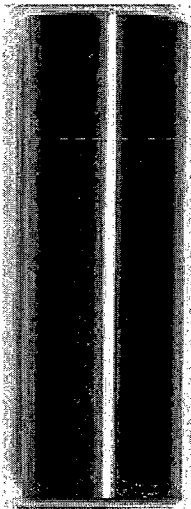


460 Second Exposure

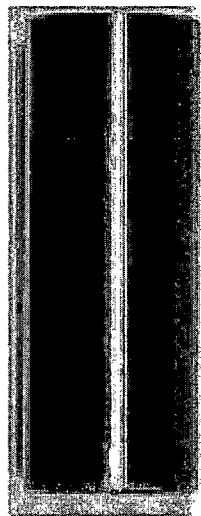
Limited ID oxygen source does not result in equivalent  
2-sided oxidation embrittlement

# Breakaway Oxidation

- Phenomenon detection
  - Samples exposed to steam at 1000°C for 3000 seconds



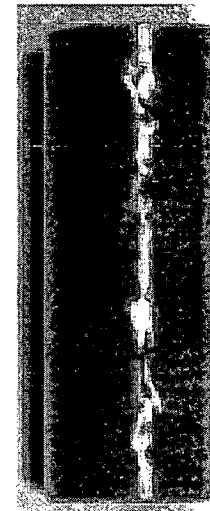
Zircaloy-4  
Control



Kroll Zircaloy-2  
Re-melted



Electrolytic  
Zircaloy-2  
Original Bar



Electrolytic  
Zircaloy-2  
Re-melted

Short breakaway oxidation can be detected  
at the ingot processing stage