Public Meeting on Draft Regulatory Guides for 50.46c – ORNL

Draft Reg Guides and determining acceptable LOCA performance

April 29 – 30, 2015

David Mitchell – Fellow Engineer

Westinghouse

Outline

- Background
- Previous LOCA basis testing
- Comparison of tested alloys
- Observations from testing to establish ductile to brittle transition (DBT)
- Determining ductile to brittle transition (DBT)
- Recommendations and conclusions

Background

- Starting in the mid 1990's a research program was conducted at Argonne National Laboratory (ANL) under NRC sponsorship to evaluate the impact of increasing fuel burnup on accident criteria such as allowable equivalent cladding reacted (ECR) during a loss of coolant accident (LOCA).
- The results of that work were published in 2008 in NUREG/CR-6967/ANL-07-04.
- Based on that work, proposed acceptable methods of testing and data evaluation to qualify LOCA limits for new cladding alloys were published in:
  - DG-1262, "TESTING FOR POSTQUENCH DUCTILITY," March 2012.
  - DG-1263, "ESTABLISHING ANALYTICAL LIMITS FOR ZIRCONIUM BASED ALLOY CLADDING," March 2012.
- Westinghouse is performing both post quench ductility (PQD) and breakaway testing at our research facility conforming as closely to the draft reg guides as possible.

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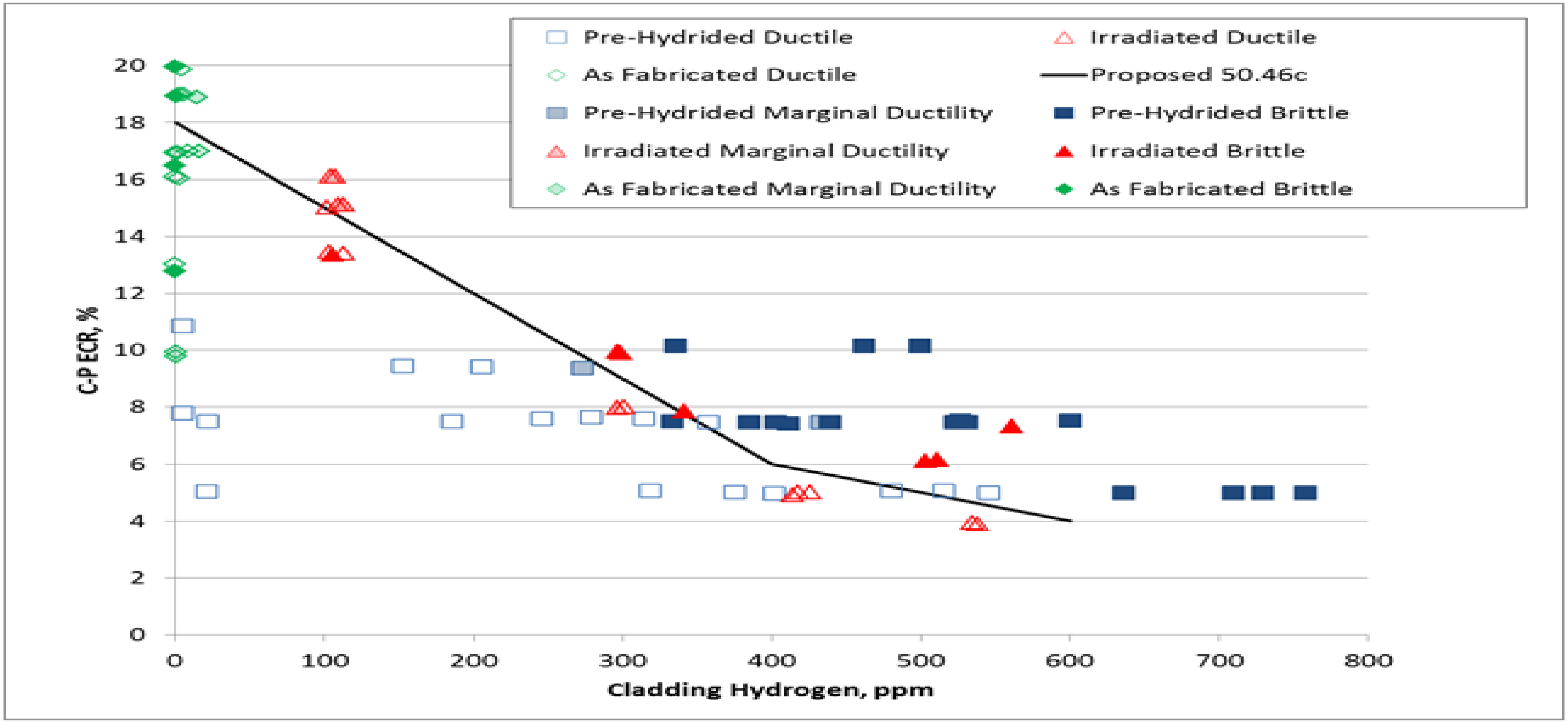
Digitized Plot from NRC presentation at 2009 Fuel Safety Research Meeting with proposed ductile to brittle transition (DBT)



Original test matrix less demanding than draft guide requirements

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Previous LOCA Basis Testing

- Previously Westinghouse tested **ZIRLO®** and Zircaloy-4 cladding using post oxidation ductility (POD – Hobson protocol) testing to demonstrate similarity of ZIRLO and Zircaloy-4 cladding and then later performed similar tests on **Optimized ZIRLO™** high performance cladding.
- AREVA performed and published LOCA basis tests on M5 cladding
- Westinghouse sent detailed information on breakaway testing of ZIRLO and Zircaloy-4 cladding to NRC in five (5) separate nonproprietary letters.

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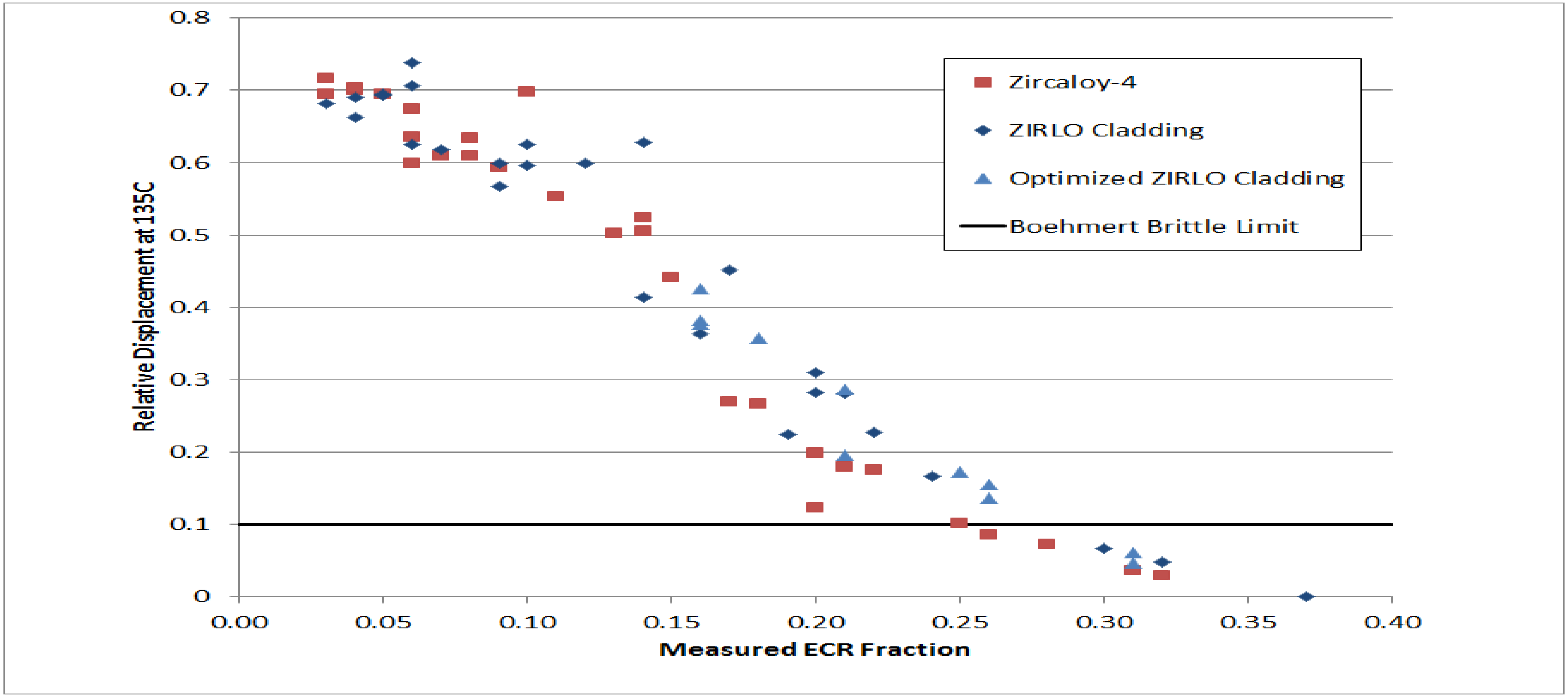
Post oxidation ductility (Hobson's Method) results



Testing demonstrated same behavior for Zircaloy-4, ZIRLO and Optimized ZIRLO Cladding

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Dilute Zirconium alloys show similar behavior in high temperature testing in 1050 to 1200°C range

- Dilute Zirconium alloys show similar behavior in high temperature testing in 1050 to 1200°C range
  - Weight gain from 1050 to 1200°C
  - Microstructure – Nb containing alloys show similar total alpha layer development but also show a more complex prior beta layer development
  - Strain capability as a function of ECR and hydrogen

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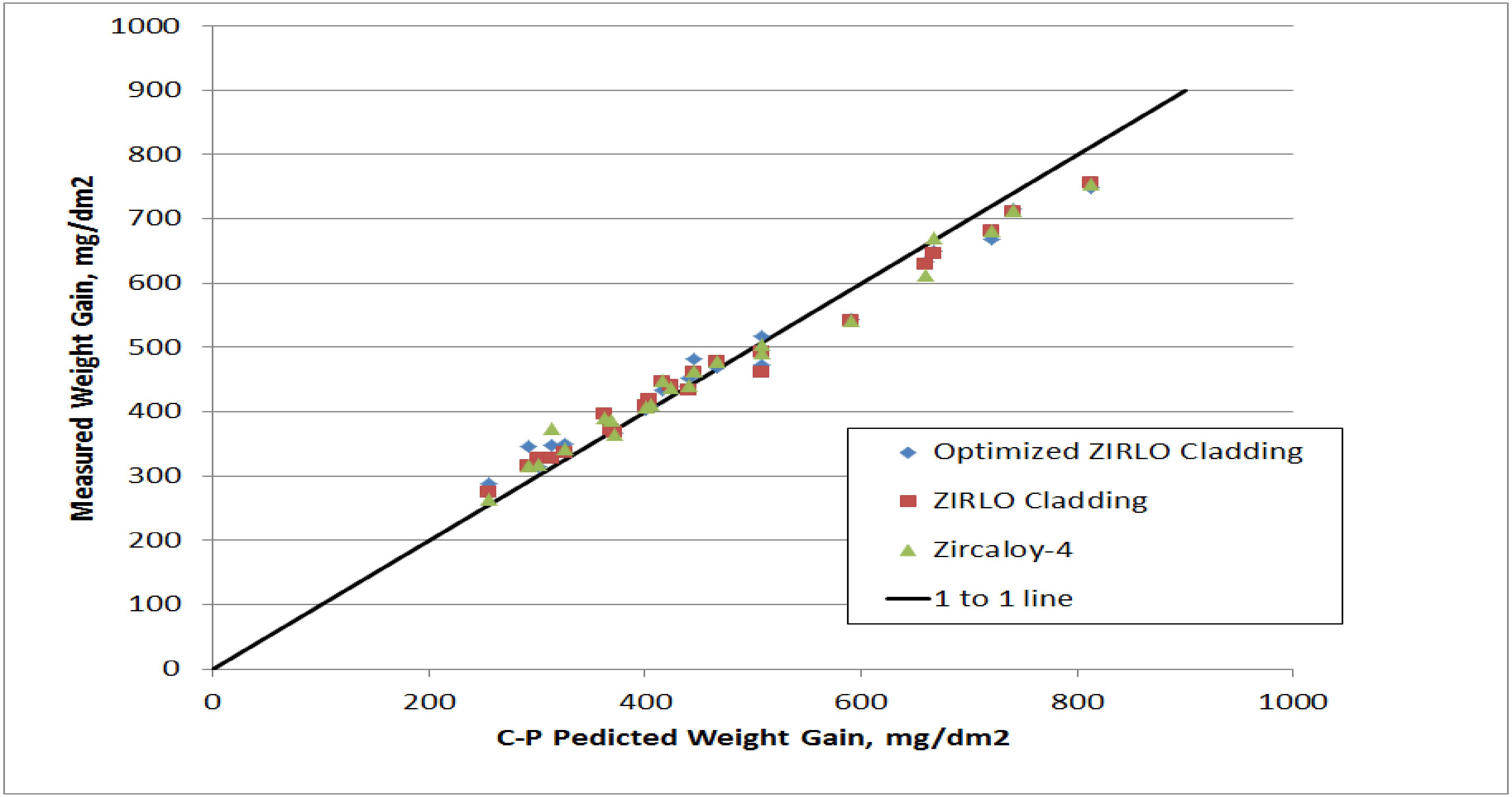
Weight gain benchmark – 1050 to 1200ºC



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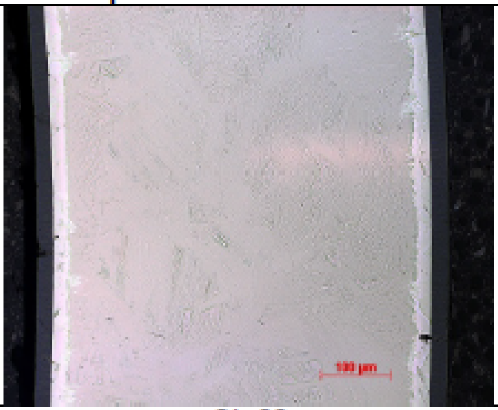
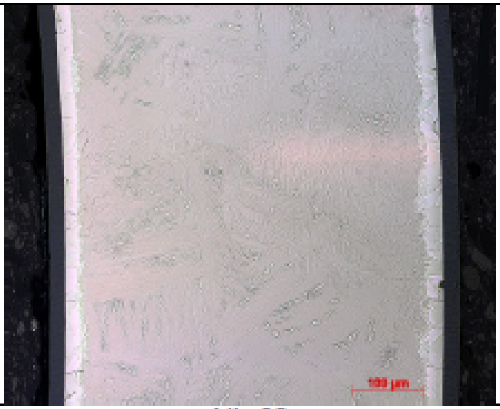
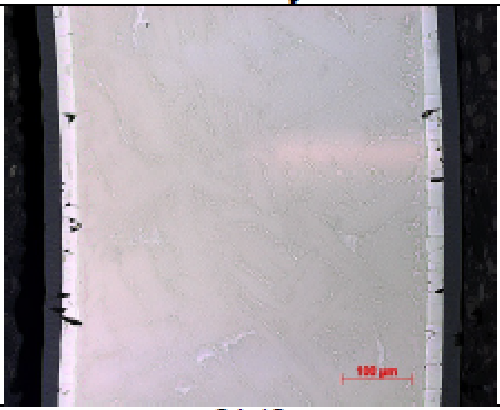
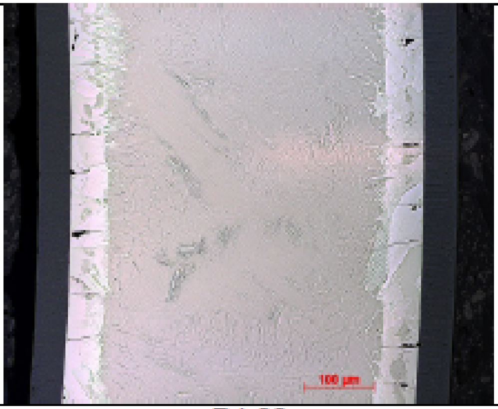
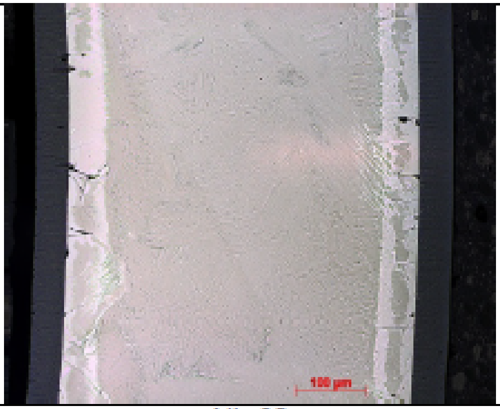
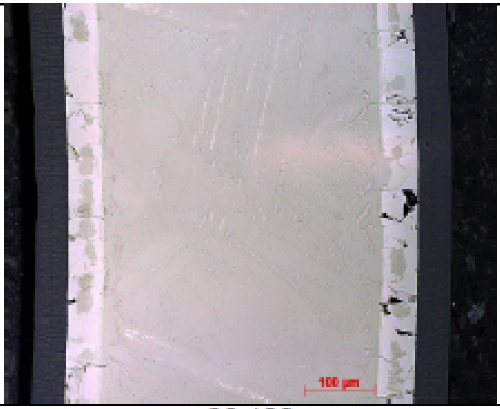
Cross sections following quench show similar microstructure for different materials

ECR	Optimized ZIRLO	ZIRLO	Zircaloy-4
7.1% 300ppm H LOCA580			
	QL-32	NL-62	24-12
15.9% 100ppm H LOCA577			
	R4-32	NL-82	26-102

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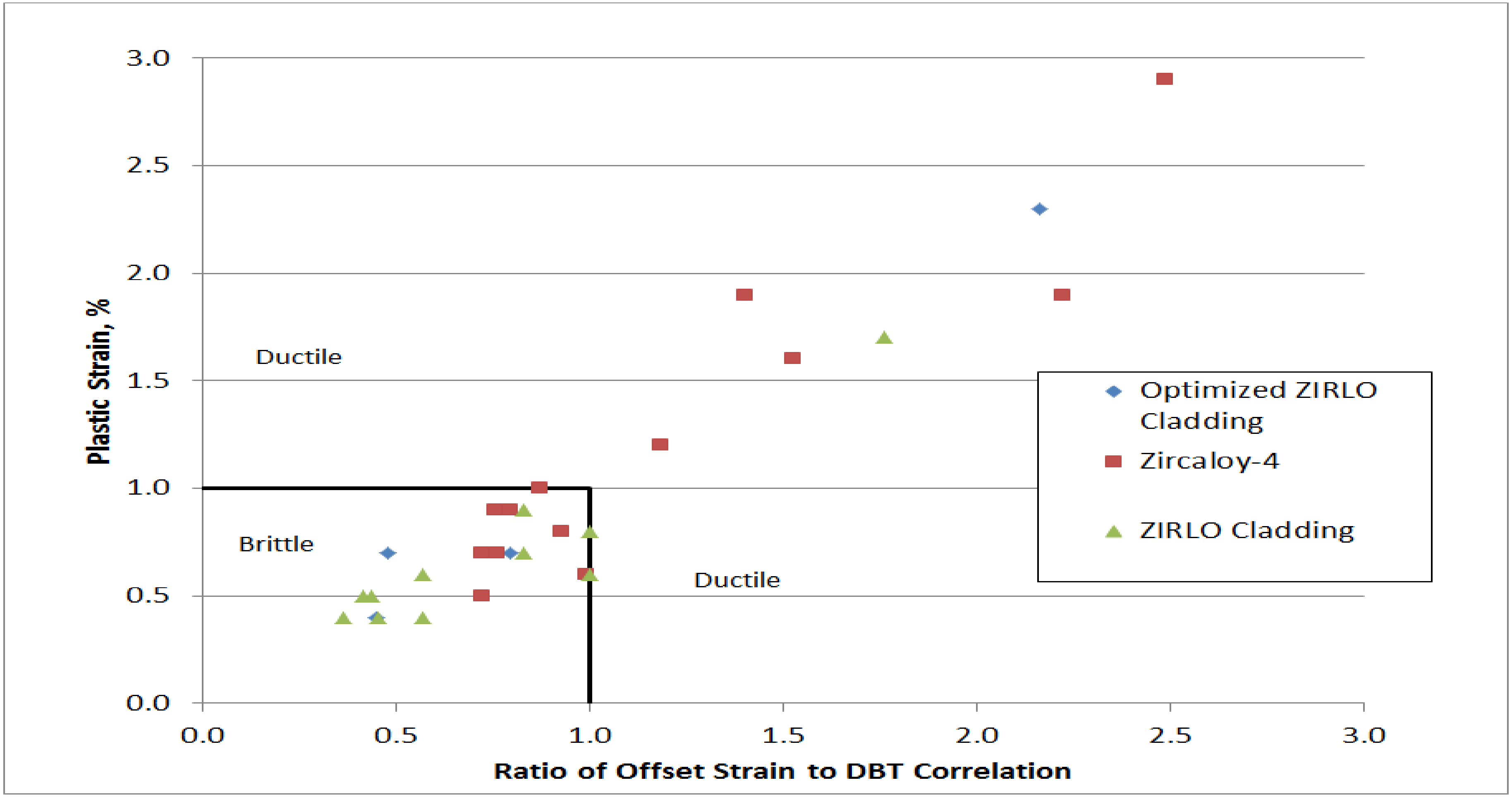
Comparison of plastic strain to DBT offset strain correlation shows similar behavior for different materials



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Results of testing with DG protocols

- Testing has demonstrated equivalence of Zicaloy-4, ZIRLO and Optimized ZIRLO cladding under high temperature oxidation and post quench performance.

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Observations from testing to establish ductile to brittle transition (DBT)

- Westinghouse has observed within-sample variation in measured strain results.
  - Similar variation in strains were also observed in the ANL and the ASTM round robin PQD results, especially as the DBT is approached.
- Given the ECR that accumulates during heat up and/or cool down, it is difficult to test using the DG protocol at 1,200°C cladding sample with 400 ppm hydrogen given the expected DBT [6% ECR, 400 ppm]
- Proposed acceptance test/analysis requirements do not address practical considerations such as within-sample variations
- The Argonne National Labs DBT appears to have been developed using curve fits to determine when the strain as a function of ECR or of hydrogen content intersects the brittle criteria.

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Assessment of ductility

- Permanent Strain
  - Measure post test diameter along loading direction
  - Permanent Strain = $\varepsilon_{perm} = (\Delta d/d_{min})$
  - Ductile when $\varepsilon_{perm} \geq 1\%$
  - Only can be measured when sample stays intact (<50% remained intact).
- Offset Strain
  - Offset strain = ε_{offset} = (Offset Disp/d_o)
  - Ductile when $\varepsilon_{offset} \geq 1.41 + 0.1082*(\%ECR)$, per DG-1262
  - Measured for all samples

Used offset strain to assess ductility

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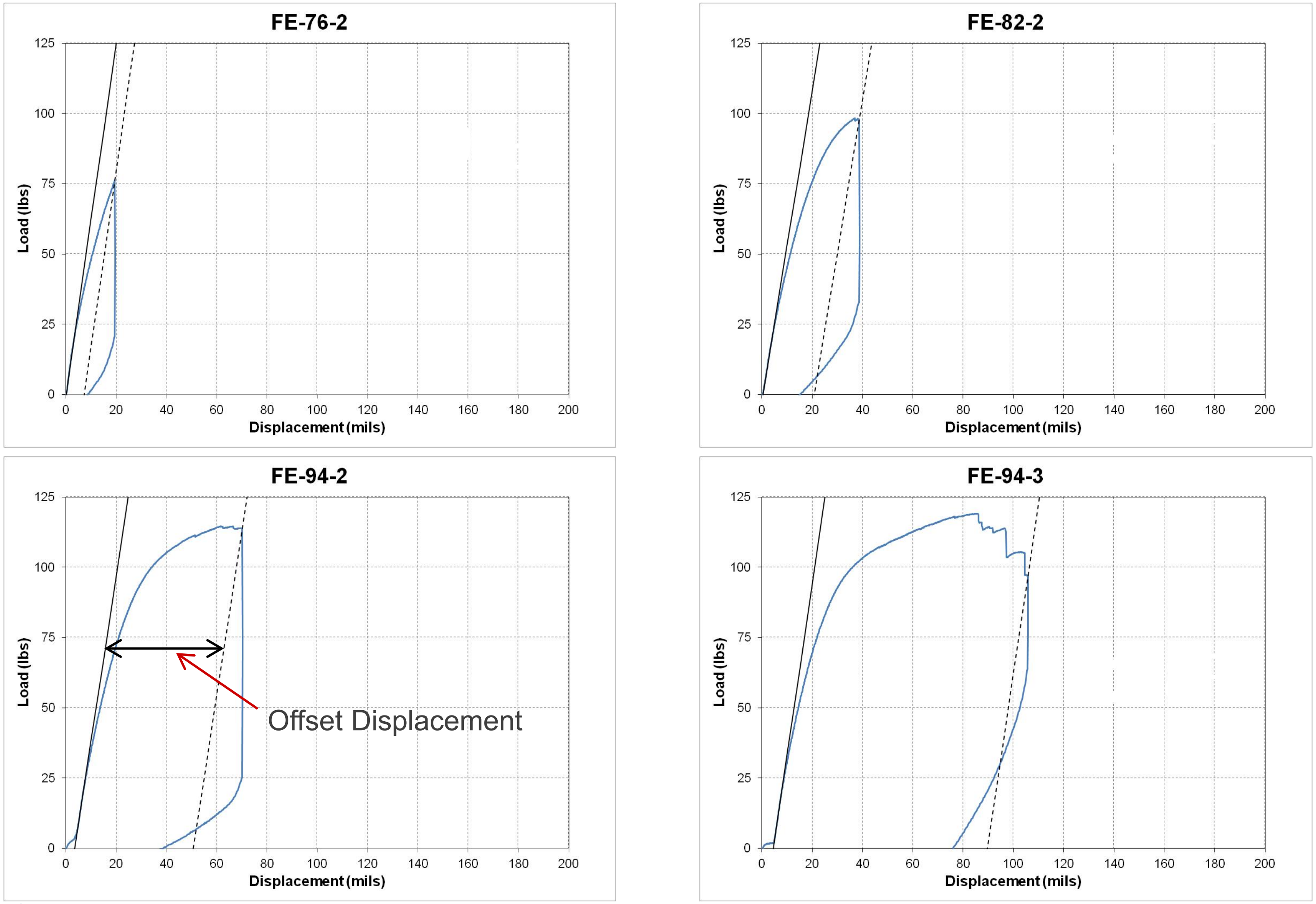
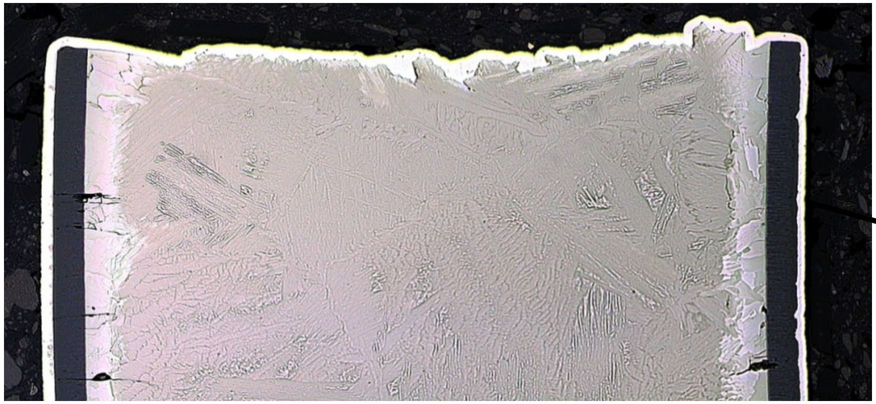
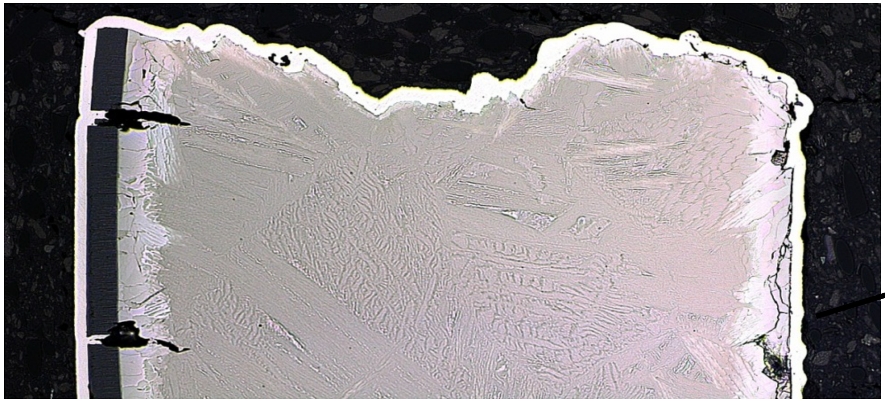
Load versus displacement curves illustrating the determination of offset strain



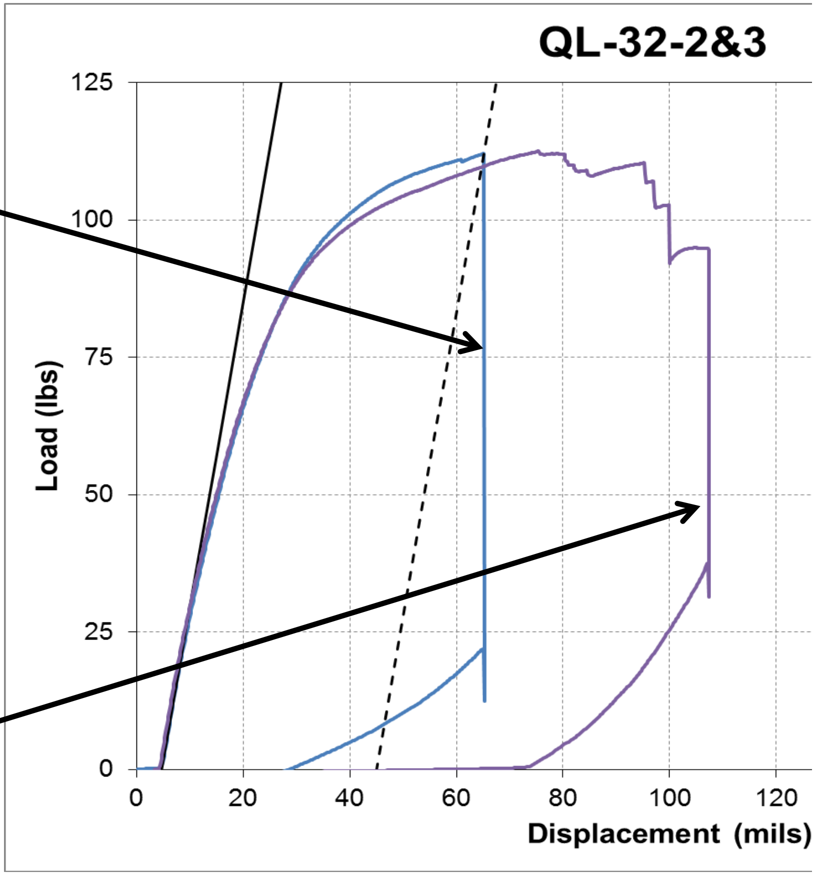
Variation in tests inherent with RCT 300ppm bin and 7.1%ECR

Post Test Micrographs





Load vs deflection



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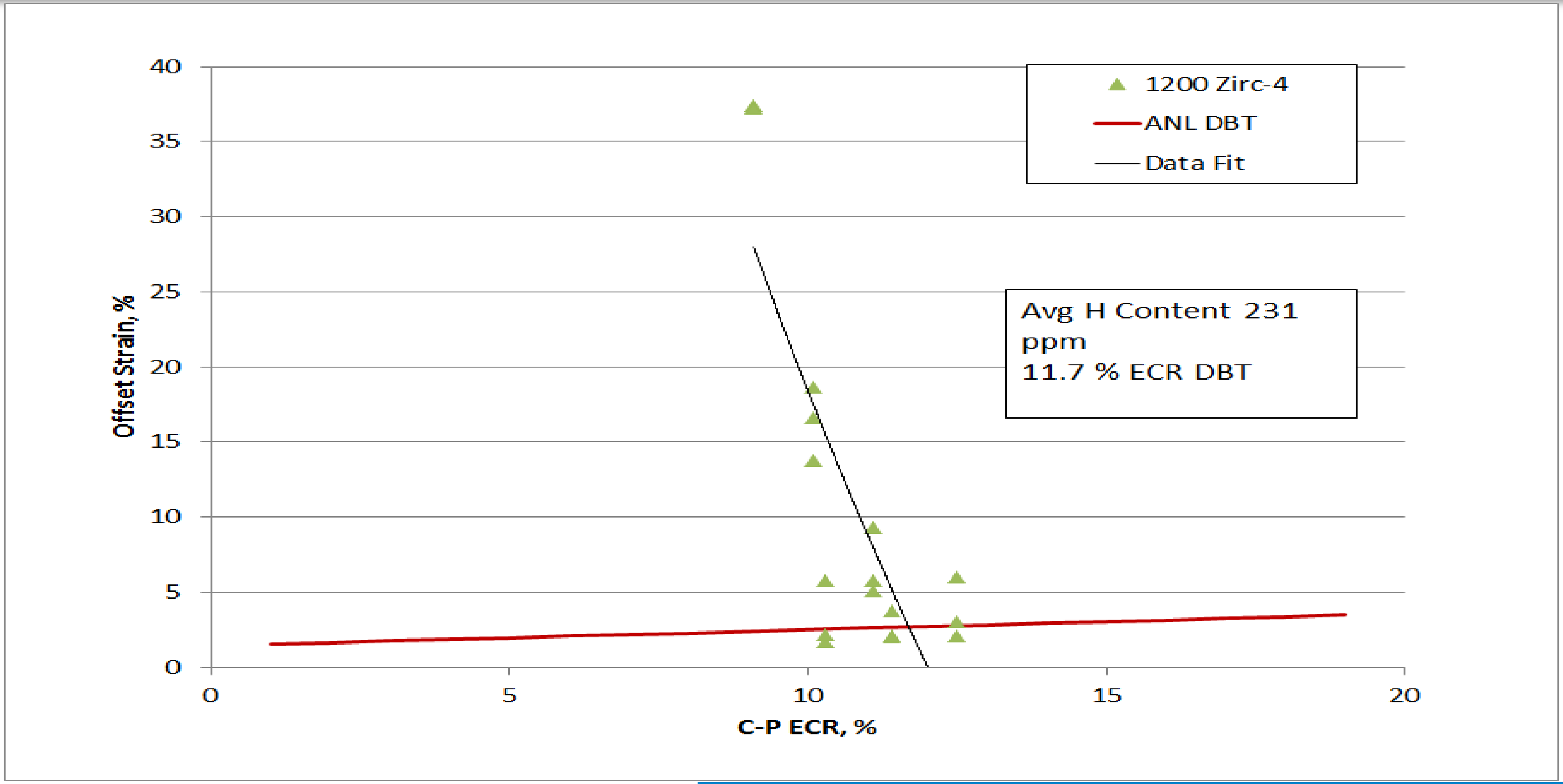
Zircaloy-4 cladding ductility vs ECR for individual RCTs at 200 ppm target bin, PCT 1200°C



Determining DBT intersection can be difficult with narrow ECR range and shallow slope

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Recommendations for DG-1262 and DG-1263

- For performing PQD testing when the cladding is tested in bins there should be provision for the hydrogen level in each bin to vary from the target.
- Since the measured hydrogen in each bin may vary from the target, the resulting DBT should not be required to be at a whole number ECR but could be a fraction, i.e.
  - Bin Target: 200 ppm.
  - Actual bin average: 223 ppm.
  - Resulting curve fit DBT: 12.7% ECR.
- There should be a provision to use:
  - Curve fitting of the test data to determine ductile to brittle transition (DBT) within each bin.
  - Bracketing of the test data to split transition from ductile to brittle behavior [Split range from highest ductile ECR and lowest brittle ECR]

Recommendations for DG-1262 and DG-1263 (Cont'd)

- There should be a provision to test both a new alloy and an existing approved alloy and if similar PQD performance is achieved for both, then the proposed 50.46c DBT limits would be applicable to the new alloy.

Recommendations for DG-1262 and DG-1263 (Cont'd) - Irradiated Cladding

- Sufficient test results from a variety of zirconium alloys exist to demonstrate the equivalence of irradiated and non-irradiated cladding.
- It is recommended that the requirement for testing of irradiated alloys be eliminated for alloys that meet the following conditions based on the results of the ANL testing that showed no difference between the performance of irradiated and non-irradiated materials:
  a. Uses the same zirconium reduction method as the tested alloys.
  b. Uses alloying elements at concentrations that do not exceed the concentrations used in tested alloys.
  c. The planned irradiation does not exceed the fluence of the tested alloys (therefore the level of transmutation elements would be bounded).

Conclusions and Summary on DG-1262 and 1263

- Overall the requirements used to qualify new claddings should be similar to the work done for the currently qualified claddings.
- An alloy with only small changes from an approved alloy specification should only require demonstration of similar performance and not require a complete new qualification.
- Westinghouse has suggested changes to the Regulatory Guides based on extensive test experience to address practical considerations in conducting the tests and interpreting data.

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