

Evaluating Ring Compression Test Results for Developing Analytical Limits

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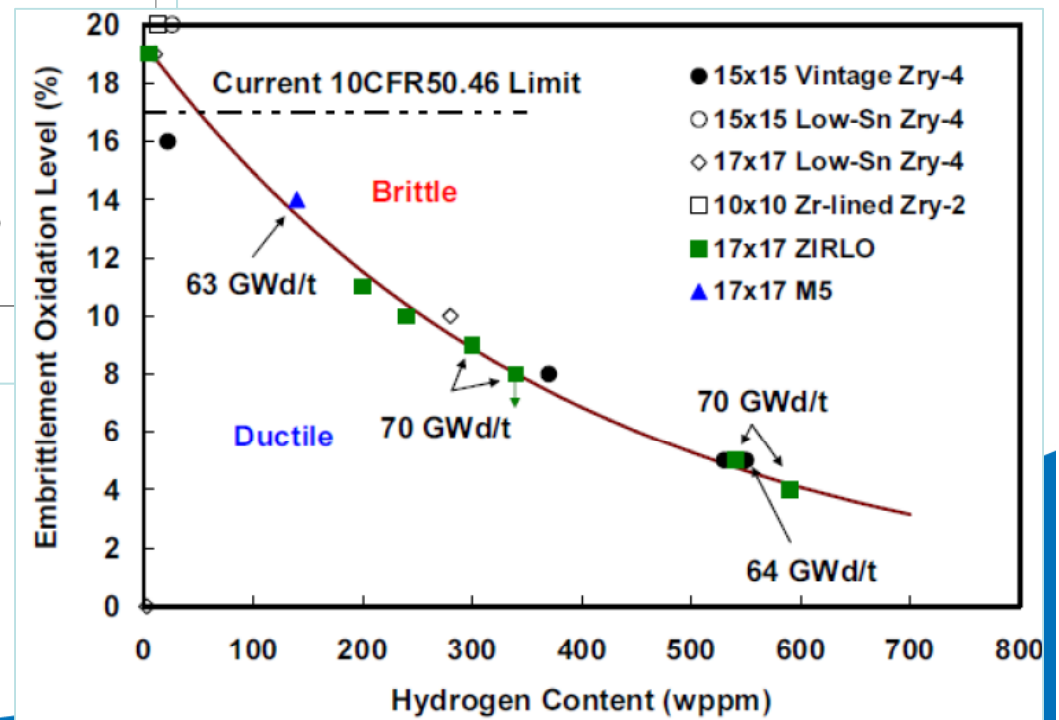
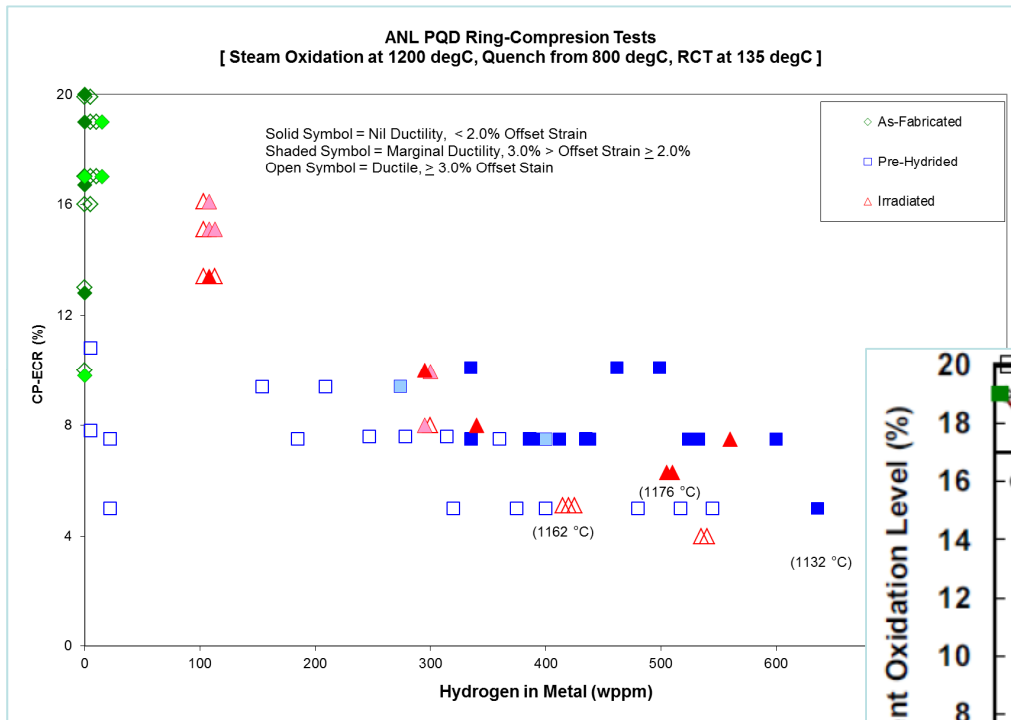
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Background

- The NRC received a number of comments on the subject of formulating an analytical limit from ring-compression test data. Comments covered the following general areas.
 - Using a curve fit for ring-compression test (RCT) data to determine the ductile-to-brittle transition
 - Identifying the appropriate number of repeat tests to support an analytical limit
 - Grouping RCT data into bins for evaluation
 - Interpolation and extrapolation of RCT data
 - Discussion of averaging offset strain values – when it is and is not meaningful.



Background



Objective of Today's Discussion



- Provide an outline of possible revisions to DG-1262 and DG-1263 to ensure that the evaluation of ring compression test (RCT) results to develop analytical limits is clear, repeatable and addresses anticipated data scatter.
- Seek clarification on the alternative approaches envisioned in the comment submissions



Review of Guidance

DG-1262, section 12.2, Determination of Ductile-to-Brittle Transition CP-ECR

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The ductile-to-brittle transition CP-ECR is defined as the CP-ECR corresponding to **1.0% permanent strain** (i.e., the maximum CP-ECR for which ductility is retained). For multiple data points at the same sample and test conditions, the average permanent strain should be calculated. The ductile-to-brittle CP-ECR should be based on average permanent strain $\geq 1.0\%$. As it is unlikely to measure exactly 1.0% permanent strain, the CP-ECR may be determined from **interpolation between** an oxidation level for which the **permanent strain is $>1.0\%$** (ductile) and an oxidation level for which the **permanent strain is $<1.0\%$** . These CP-ECR values should **differ by no more than 2%**. In this case, the transition should be identified to occur at the **highest CP-ECR at which the permanent strain is $\geq 1.0\%$** . The ductile-to-brittle transition oxidation level should be reported to the **nearest percent**.

















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As-Received Cladding Testing



























DG-1263; Table B-1. Sample Test Matrix for Scoping Tests for As-Received Cladding Material

Scoping test	Oxidation Level (ECR)	10% 			13% 			17% 			20% 		
	Ring compression Sample	1 	2 	3 	1 	2 	3 	1 	2 	3 	1 	2 	3 
	Offset Strain Measurement	___ %	___ %	___ %	___ %	___ %	___ %	___ %	___ %	___ %	___ %	___ %	___ %
	Average of 3 RTC samples	_____ %			_____ %			_____ %			_____ %		
	Average ≥ Offset strain Criterion?	Offset strain Criterion of 10% ECR =	2.5	Yes / No	Offset strain Criterion of 13% ECR =	2.8	Yes / No	Offset strain Criterion of 17% ECR =	3.2	Yes / No	Offset strain Criterion of 20% ECR =	3.6	Yes / No

Assuming 17% was ductile, and 20% was brittle....

Proceed to test 18% and 19%

































DG-1263; Table B-2. Sample Test Matrix for Testing As-Received Cladding Material in the Identified Transition Region













Transition Region	Oxidation Level (ECR)	18% 			18% 			18% 			19% 			19% 			19% 		
	Ring compression Sample																		
	Offset Strain Measurement	___%	___%	___%	___%	___%	___%	___%	___%	___%	___%	___%	___%	___%	___%	___%	___%	___%	___%
	Average of RTC samples	_____ %									_____ %								
	Average \geq Offset strain criterion?	Yes / No									Yes / No								

Review of Guidance

As-Received Cladding Testing

DG-1263; Table B-4. Sample Test Matrix for Scoping Tests for Prehydrated Cladding Material

Scoping Tests	Hydrogen Level (wppm)	100						200						300						400											
	Oxidation Level (ECR)	1 st test at 15.5% 		If 15.5% was brittle, 2 nd test at 13.5% If 15.5% was ductile, 2 nd test at 17.5% 				1 st test at 12% 		If 12% was brittle, 2 nd test at 10% If 12% was ductile, 2 nd test at 14% 				1 st test at 9% 		If 9% was brittle, 2 nd test at 7% If 9% was ductile, 2 nd test at 11% 				1 st test at 6% 		If 6% was brittle, 2 nd test at 4% If 6% was ductile, 2 nd test at 8% 									
	Ring compression Sample	     						     						     						     											
	Offset Strain Measurement	___ %	___ %	___ %	___ %	___ %	___ %	___ %	___ %	___ %	___ %	___ %	___ %	___ %	___ %	___ %	___ %	___ %	___ %	___ %	___ %	___ %	___ %	___ %	___ %						
	Average of RTC samples	_____ %			_____ %			_____ %			_____ %			_____ %			_____ %			_____ %			_____ %								
	Average ≥ Offset strain Criterion?	Yes / No		Yes / No				Yes / No			Yes / No			Yes / No			Yes / No			Yes / No			Yes / No								
	Ductile-to-brittle transition identified?	Yes - continue tests at ECR between ductile and brittle level; No - conduct test additional scoping tests						Yes	Hydrogen Level						Repeat for each hydrogen level						between ductile and el; nal scoping tests										
							No	Oxidation						Transition						Transition						Transition					

Transition Region	Hydrogen Level	Repeat for each hydrogen level								
	Oxidation Level (ECR)	Transition ECR 			Transition ECR 			Transition ECR 		
	Ring compression Sample	1 	2 	3 	1 	2 	3 	1 	2 	3 
	Offset Strain Measurement	___ %	___ %	___ %	___ %	___ %	___ %	___ %	___ %	___ %
	Average of RTC samples	_____ %								
	Average ≥ Offset strain Criterion?	Yes / No								

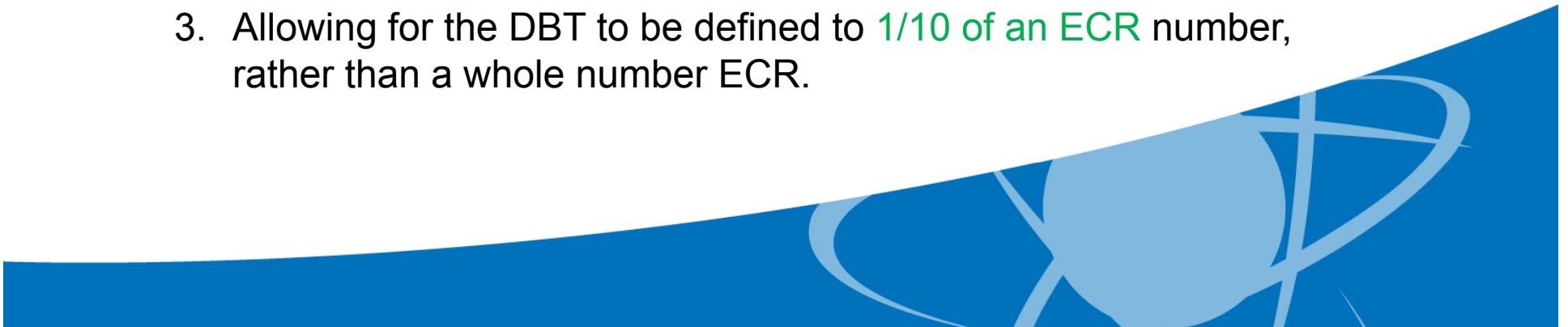
DG-1263; Table B-5. Sample Test Matrix for Testing Prehydrated Cladding Material in the Identified Transition Region

Summary of Comments

- Need to increase clarity on interpreting the outcome of a set of RCT results, sectioned from a single oxidation and quench sample, when the results include both ductile and brittle results
- There should be a provision for grouping pre-hydrated test samples in “bins” of similar hydrogen content.
- There should be provisions to determine the DBT by (1) the use of curve fitting of the test data to determine DBT within each hydrogen bin, (2) determination of the final curve by fitting the DBT points from the individual hydrogen bins, or alternatively, (3) performing a fit of the DBT as a function of both the hydrogen and ECR using (1) or (2).
- A scatter plot approach should be acceptable to determine the DBT line from RCT data.
- There is no need to specify three tests near each ECR level being tested.
- The definition of the ductility criteria is not clear
- The term “best-estimate” in reference to the DBT line is not clearly defined.

Revisions being considered

1. Revised definition of the ductility criteria:
 - Average permanent strain $\geq 1.0\%$ or,
 - If permanent strain cannot be measured, use Equation A3 for the average ring compression test offset strain as a function of the Cathcart-Pawel equivalent cladding reacted (CP-ECR):
 - Average RCT offset strain $\geq 1.41 + (0.1082 \cdot \text{CP-ECR})$
 - Where the offset strain and CP-ECR are in units of percent, rounded to the nearest tenth of a percent.
2. Allowing for “binning” test results within a range of $\pm 10\%$ or ± 30 wppm [H], whichever is less, to evaluate the DBT against the limit.
3. Allowing for the DBT to be defined to $1/10$ of an ECR number, rather than a whole number ECR.



Revisions being considered

4. Allowing for interpolation and extrapolation.
5. Scaling the guidance for repeat tests with data scatter
6. Adding discussion of averaging offset strain values – when it is and is not meaningful.
7. Adding guidance to outline a pure “scatter plot” approach or performing a fit of the DBT as a function of both the hydrogen and ECR is not being considered at this time. If more details were provided on how such a demonstration of testing technique would be conducted and reported, this approach could be reasonable



Approach to Conservatism

There are multiple areas where conservatism can be introduced when determining the DBT ECR value as a function of hydrogen:

1. The DBT **offset-strain criterion** is an empirical correlation that includes some conservatism
2. Rounding down to the nearest **whole number ECR** for each [H] bin provides conservatism
3. Generating a curve fit for RCT data on the strain vs. ECR plot can introduce conservatism by electing a (mean - 1σ) trend line
4. The DBT as a function of hydrogen trend line can be drawn **below** the ECR level for each [H] bin to show conservatism



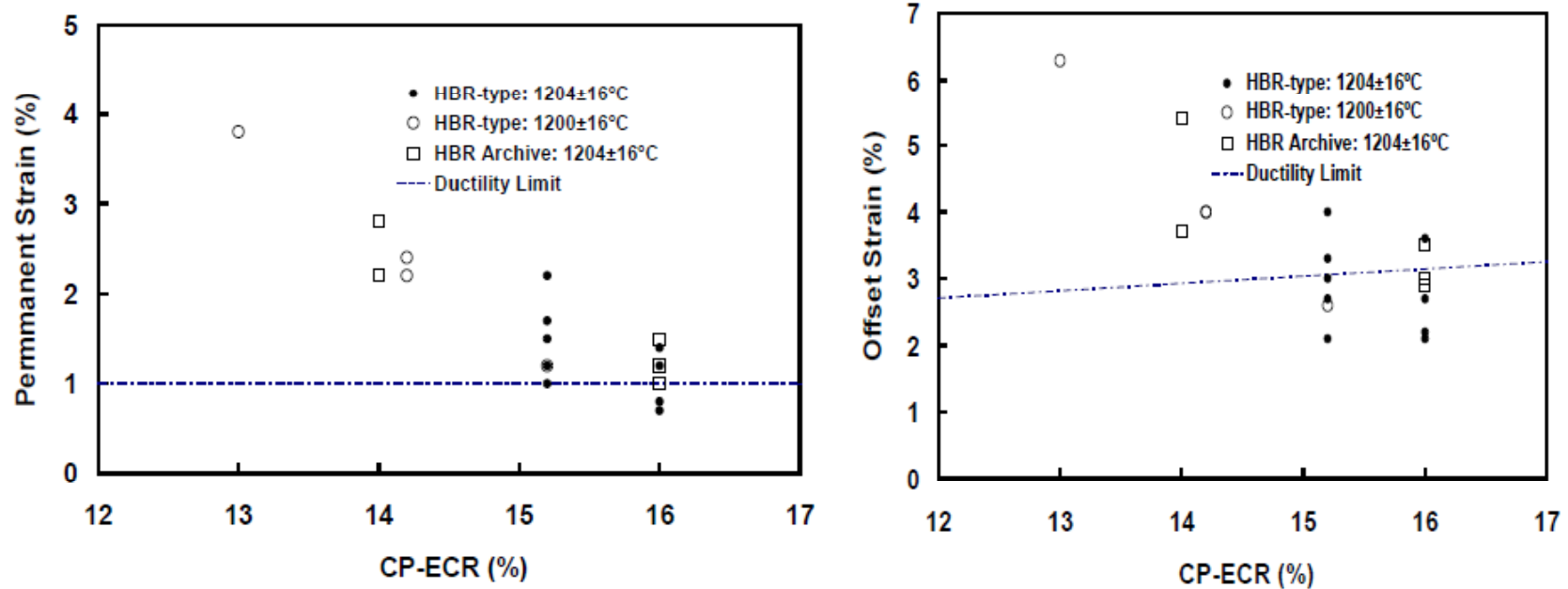
Possible approach to use “binning” of samples with similar hydrogen contents

- Complete a set of oxidation and quench tests on cladding samples pre-hydrated to a target hydrogen level, where the average [H] content of the adjacent ends is within $\pm 10\%$ or ± 30 wppm [H], whichever is less, of the target hydrogen level.
- Segment each oxidation and quench sample into 3 ring compression samples
- Conduct RCT on each ring compression sample at $135 \pm 1^\circ\text{C}$
- Measure values of [H] for each ring in the bin should follow RCT to confirm binning is accurate



Possible approach to use interpolation

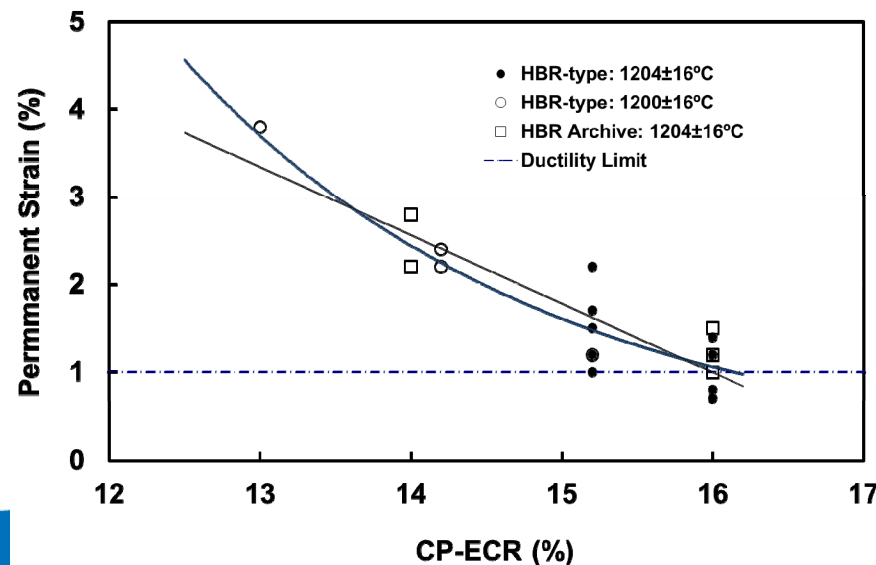
- Generate one plot that contains all RCT data for each set of results in the same [H] bin, either permanent or offset strain vs. CP-ECR



ANL PQD results for 15×15 Zry-4 (HBR-type) following oxidation at 1200°C and quench at 800°C

Possible approach to use interpolation

- A line can be drawn through RCT data to interpolate the DBT provided:
 - RCT data is measured above AND below the appropriate ductility criteria
 - RCT data below and above the ductility criteria resulted from tests no more than 1.0% ECR apart
 - The line is drawn through only RCT data with less than 7% offset or 5% permanent strain
 - Intersection ECR should be rounded to the nearest 0.1% ECR
 - Both linear and exponential fits could be used in this range to determine the intersection of the data trend with the ductility criterion



Possible approach to minimize repeat testing when little data scatter is expected

- If all RCT results from a single oxidation sample are ductile, declare that oxidation level ductile
- If all RCT results from a single oxidation sample are brittle, declare that oxidation level brittle
- If the RCT results from a single oxidation sample include both ductile and brittle results declare that oxidation level transitional
- Values of [H] for each ring should be measured following RCT and noted in the table
- The DBT could be determined as the CP-ECR, rounded to the nearest 0.1%, from interpolation between an oxidation level for which the RCT results were ductile and an oxidation level for which the RCT results were brittle and the CP-ECR values differ by no more than 2.0%.
- Alternatively, the DBT could be determined as the CP-ECR, rounded to the nearest 0.1%, from interpolation between an oxidation level for which the RCT results were ductile and an oxidation level for which the RCT results were transitional and the CP-ECR values differ by no more than 1.0%.

Formulate a table/flow chart similar to those provided in the current DG

Scoping Tests	Hydrogen Level (wppm)	100			200			300			400		
	Oxidation Level (ECR)	1 st test at 15.5% If 15.5% was brittle, 2 nd test at 13.5% If 15.5% was ductile, 2 nd test at 17.5%			1 st test at 12% If 12% was brittle, 2 nd test at 9% If 12% was ductile, 2 nd test at 15%			1 st test at 9% If 9% was brittle, 2 nd test at 7% If 9% was ductile, 2 nd test at 11%			1 st test at 8% If 8% was brittle, 2 nd test at 4% If 8% was ductile, 2 nd test at 8%		
	Ring compression Sample	1	2	3	1	2	3	1	2	3	1	2	3
	Offset Strain Measurement	___ %	___ %	___ %	___ %	___ %	___ %	___ %	___ %	___ %	___ %	___ %	___ %
	Average of RCT samples	___ %			___ %			___ %			___ %		
	Average 2 offset strain Criterion?	Yes / No			Yes / No			Yes / No			Yes / No		
	Ductile-to-brittle transition identified?	Yes - continue tests at ECR between ductile and brittle level. No - conduct test additional scoping tests			Yes - continue tests at ECR between ductile and brittle level. No - conduct test additional scoping tests			Yes - continue tests at ECR between ductile and brittle level. No - conduct test additional scoping tests			Yes - continue tests at ECR between ductile and brittle level. No - conduct test additional scoping tests		

Note [H] of each RCT

Conclusion



- The NRC received a number of comments on the subject of formulating an analytical limit from ring-compression test data.
- A fundamental concept in the performance-based rule is that guidance provides a clear and technically valid approach to develop an analytical limit from RCT data.
- The NRC is considering revisions to DG-1262 and DG-1263 to ensure that the evaluation of RCT results to develop analytical limits is clear, repeatable and addresses anticipated data scatter.
- The NRC would like to seek clarification on the alternative approaches envisioned in the comment submissions before implementing specific revisions to DG-1262 and 1263.

