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Overview of Regulatory Guidance to support Emergency Core Coolant System rulemaking

Public meeting on Regulatory Guidance Documents with 50.46c
April 30, 2014

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Background

- Rulemaking initiated to revise ECCS acceptance criteria to reflect the research findings
- The revisions are also intended to develop performance-based features of 10 CFR 50.46

- Therefore, 10 CFR 50.46c calls for:
  - Material-specific analytical limits which account for material-specific burnup effects
  - ECCS performance consistent with avoiding measured breakaway behavior
  - Periodic testing for breakaway behavior

Regulatory Guidance

- DG-1261: Test procedure for measuring breakaway oxidation behavior and periodically confirming consistent behavior
- DG-1262: Testing procedure for measuring post-quench ductility using ring compression tests
- DG-1263: Developing analytical limits from measured data

Regulatory Guidance

These regulatory guides make it possible to revise 10 CFR 50.46c in a performance-based manner by:

- Providing a means of consistent, comparable generation of data to establish regulatory limits for peak cladding temperature (PCT) and oxidation
- Providing a means of consistent, comparable data generation to establish, and periodically confirm regulatory limits related to breakaway oxidation
- Providing a consistent means of using experimental data to establish regulatory limits
- Simplifying the staff's review process
- Reducing regulatory uncertainty, minimizing the costs associated with the implementation of the regulatory requirements proposed for 50.46c.

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Approach

Through stakeholder interaction and public comment, ensure that:

- the details and expectations of acceptable methods for measuring zirconium-based alloy behavior and developing limits are communicated effectively and completely
- measured behavior is expected to be repeatable within a laboratory
- measured behavior is expected to be repeatable between laboratories
- analytical limits will be developed consistently across fuel designs

Context

Relationship to rule language

DG-1263

To ensure that the zirconium-alloy cladding material's susceptibility to breakaway oxidation is beyond the realm of postulated LOCA core temperature excursions, the total accumulated time that the cladding is predicted to remain above a temperature at which the zirconium alloy has been shown to be susceptible to this phenomenon shall not be greater **than a specified and acceptable limit** which corresponds to the measured onset of breakaway oxidation for the zirconium-alloy cladding material **based on an acceptable experimental technique**. The onset of breakaway oxidation shall be measured periodically on as-manufactured cladding material and any changes in the time to the onset of breakaway oxidation shall be reported at least annually as specified in § 50.4 or § 52.3 of this chapter, as applicable, and shall also be addressed in accordance with § 21.21 of this chapter.

DG-1261

Context

Relationship to rule language

DG-1263

Specified and acceptable analytical limits on peak cladding temperature and time at elevated temperature shall be established which correspond to the measured ductile-to-brittle transition for the zirconium-alloy cladding material **based on an acceptable experimental technique**. The calculated maximum fuel element temperature and time at elevated temperature shall not exceed the established analytical limits.

If the peak cladding temperature established to preserve cladding ductility is lower than the 2200º F limit specified in (d)(1)(i), then the lower temperature shall be used in place of the 2200º F limit.

DG-1262

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DG- 1261: Conducting Periodic Testing for Breakaway Oxidation Behavior

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Context

Relationship to rule language

DG-1263

To ensure that the zirconium-alloy cladding material's susceptibility to breakaway oxidation is beyond the realm of postulated LOCA core temperature excursions, the total accumulated time that the cladding is predicted to remain above a temperature at which the zirconium alloy has been shown to be susceptible to this phenomenon shall not be greater **than a specified and acceptable limit** which corresponds to the measured onset of breakaway oxidation for the zirconium-alloy cladding material **based on an acceptable experimental technique**. The onset of breakaway oxidation shall be measured periodically on as-manufactured cladding material and any changes in the time to the onset of breakaway oxidation shall be reported at least annually as specified in § 50.4 or § 52.3 of this chapter, as applicable, and shall also be addressed in accordance with § 21.21 of this chapter.

DG-1261

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Objective
DG-1261

The objective of this regulatory guide is to enable performance-based rule language in 10 CFR 50.46c by providing a means of consistent, comparable data generation to establish, and periodically confirm, regulatory limits related to breakaway oxidation for zirconium-based alloys.

Thereby:

(1) Simplifying the staff's review process
(2) Reducing regulatory uncertainty, minimizing the costs associated with the implementation of the regulatory requirements proposed for 50.46c.

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Objective
DG-1261

Criteria for success:

(1) Through stakeholder interaction and public comment, it is determined that:
- the details and expectations of one acceptable method for measuring a zirconium-based alloy's breakaway oxidation behavior are communicated effectively and completely
- using the test procedures produces repeatable measurements within a laboratory
- using the test procedures produces consistent measurements between laboratories

(2) Therefore: Differences in measured values of time to breakaway behavior are a reflection of allowable differences in material behavior, and not the result of differences in experimental protocol.

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Development of *DG-1261*

- Captures the experimental technique used in NRC's LOCA research program
- Includes flexibility, where possible, to allow variation of equipment and procedures in use at other laboratories
- Draft of the procedure published for comment in conjunction with the "Advance Notice of Proposed Rulemaking (ANPR)" in August 2009
- The experimental procedure provided has been revised in consideration of the comments received in response to the ANPR.

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Guidance
DG-1261

Establish the onset of breakaway oxidation

- Use experimental procedure in Appendix A
  - Test matrix defined which includes temperatures of interest and degree of replicate testing to characterize variability
- Provide experimental results as part of the documentation supporting the staff's review and approval of the new fuel design

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Guidance
DG-1261

Periodic Testing

- Use experimental procedure in Appendix A
  - A reduced test matrix focuses on the temperature at which the minimum time to breakaway oxidation was measured and states that 5 repeat tests are sufficient if breakaway is not observed
- Demonstration that breakaway was not experienced can be linked to time of established analytical limit

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Guidance
DG-1261

- Reporting results
  - Objective of periodic testing is to confirm that a cladding's susceptibility to breakaway oxidation has not been altered.
  - Therefore, it is acceptable to report only changes in the time to the onset of breakaway oxidation.
  - Results of periodic testing shall be provided within the annual reports "specified in § 50.4 or § 52.3 of this chapter, as applicable, and shall also be addressed in accordance with § 21.21 of this chapter"

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DG- 1262: Testing for Postquench Ductility

Public meeting on Regulatory Guidance Documents with 50.46c
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Context

Relationship to rule language

DG-1263

Specified and acceptable analytical limits on peak cladding temperature and time at elevated temperature shall be established which correspond to the measured ductile-to-brittle transition for the zirconium-alloy cladding material **based on an acceptable experimental technique**. The calculated maximum fuel element temperature and time at elevated temperature shall not exceed the established analytical limits.

If the peak cladding temperature established to preserve cladding ductility is lower than the 2200º F limit specified in (d)(1)(i), then the lower temperature shall be used in place of the 2200º F limit.

DG-1262

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Objective
DG-1262

To enable performance-based rule language in 10 CFR 50.46c by providing a means of consistent, comparable data generation to establish regulatory limits on peak cladding temperature and time at elevated temperature that corresponds to the measured ductile-to-brittle transition for a specific zirconium-alloy cladding material.

Thereby:

(1) Simplifying the staff's review process
(2) Reducing regulatory uncertainty, minimizing the costs associated with the implementation of the regulatory requirements proposed for 50.46c.

Objective
DG-1262

Criteria for success:

(1) Through stakeholder interaction and public comment, it is determined that:
- the details and expectations of one acceptable method for measuring a zirconium-based alloy's post quench ductility behavior are communicated effectively and completely
- using the test procedures produces repeatable measurements within a laboratory
- using the test procedures produces consistent measurements between laboratories

(2) Therefore: Differences in measured values are a reflection of differences in material behavior, and not a result of differences in experimental protocol.

Development of *DG-1262*

- Captures the experimental technique used in NRC's LOCA research program
- Includes flexibility, where possible, to allow variation of equipment and procedures in use at other laboratories
- Draft of the procedure published for comment in conjunction with the "Advance Notice of Proposed Rulemaking (ANPR)" in August 2009
- The experimental procedure provided has been revised in consideration of the comments received in response to the ANPR.

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Guidance
DG-1262

- Use experimental technique to measure the ductile-to-brittle transition for a Zr-based cladding alloy
  - Can be used for generating data for any zirconium-alloy cladding material
  - Can be used for generating data at peak oxidation temperatures less than 1200°C
  - Includes discussion of using the procedure for testing irradiated material

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DG- 1263: Establishing Analytical Limits for Zirconium-Based Alloy Cladding

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Objective
DG-1263

To enable performance-based rule language in 10 CFR 50.46c by providing a consistent means of using experimental data to establish regulatory limits related to cladding embrittlement and the breakaway behavior of zirconium-based alloys during LOCA conditions.

Thereby:

(1) Simplifying of the staff's review process
(2) Reducing regulatory uncertainty, minimizing the costs associated with the implementation of the regulatory requirements proposed for 50.46c.

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Objective
DG-1263

(1) Establish an acceptable analytical limit for time at elevated temperature for the materials tested in NRC's LOCA research program

(2) Provide Guidance on requirements for:

- New cladding alloys to demonstrate comparable performance with the established database and use the analytical limit provided in the guide
- New or existing cladding alloys to establish a zirconium-alloy-specific limit other than the limit provided in the guide
- Establishing analytical limits at peak oxidation temperatures less than 1,204 °C (2,200 °F).

(3) Provide guidance on establishing an acceptable analytical limit to demonstrate that ECCS performance precludes the occurrence of breakaway oxidation

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Objective
DG-1263

Criteria for success:

(1) Through stakeholder interaction and public comment, it is determined that the expectations for establishing analytical limits on peak cladding temperature and time at elevated temperature under LOCA conditions are determined to be communicated effectively and completely

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Guidance
DG-1263

An acceptable analytical limit for time at elevated temperature for the materials tested in NRC's LOCA research program:

(1) Based on the data from NRC's LOCA research program
(2) Applicable to Zry-2, Zry-4, ZIRLO™, and M5
(3) PCT is related to limitations of experimental data
(4) Demonstrating that ECCS performance is such that local oxidation and peak cladding temperature are calculated below the analytical limits is acceptable to demonstrate compliance with 10 CFR 50.46c.

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Guidance
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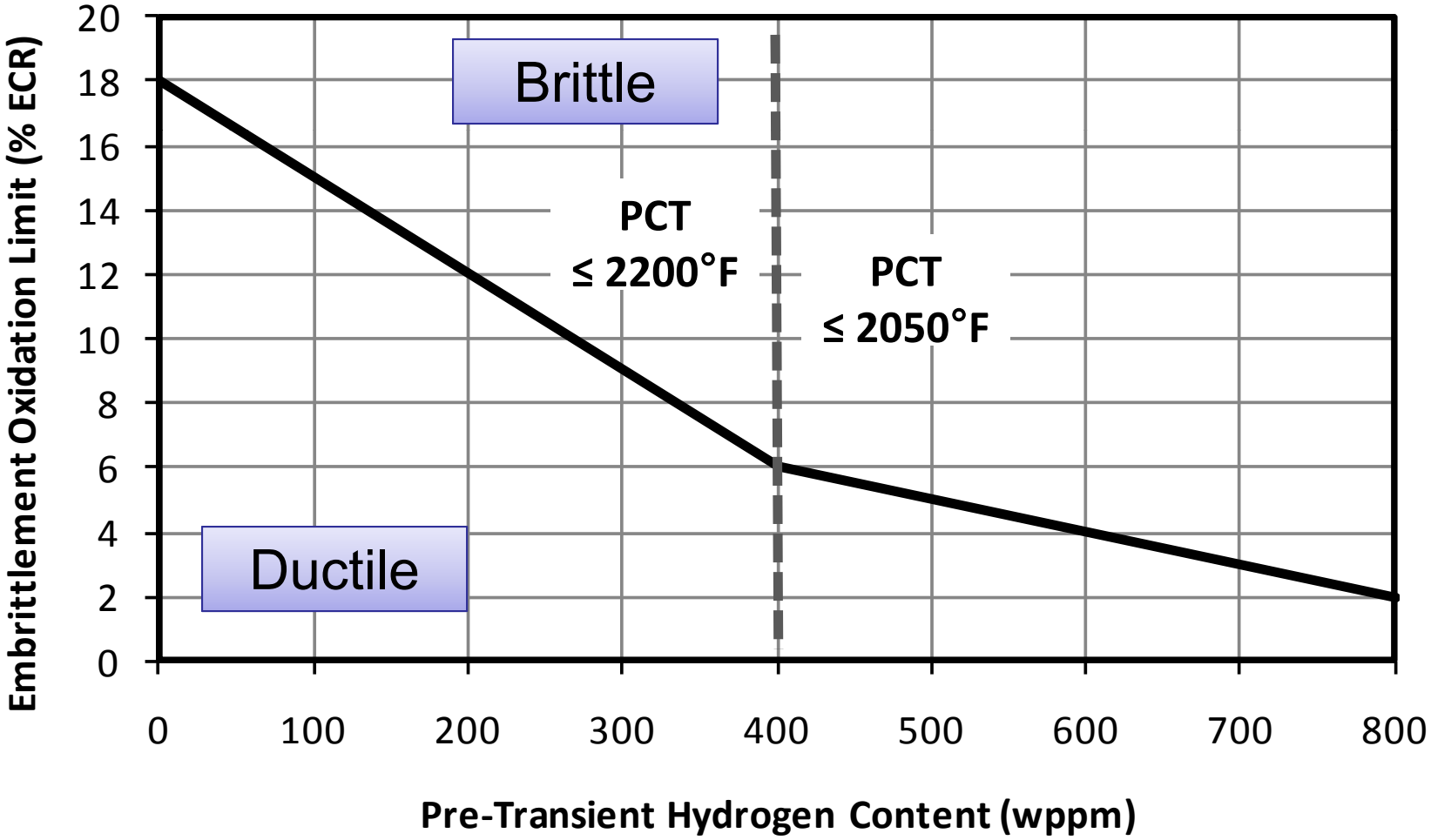
Acceptable analytical limit for time at elevated temperature for the materials tested in NRC's LOCA research program



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Guidance
DG-1263

Demonstrating comparable performance for new cladding alloys:

(1) Focus on confirm that the transition to brittle behavior does not take place at a lower equivalent cladding reacted (ECR) than the provided limit
(2) Methodology includes testing of as-received, prehydrided, and irradiated material
(3) Methodology uses the experimental procedure in DG-1262 to generate RCT data
(4) Experimental results submitted as part of the documentation supporting the NRC staff's review and approval of the new fuel design
(5) Demonstrating that ECCS performance is such that local oxidation and peak cladding temperature are calculated below the analytical limit is acceptable to demonstrate compliance with 10 CFR 50.46c.

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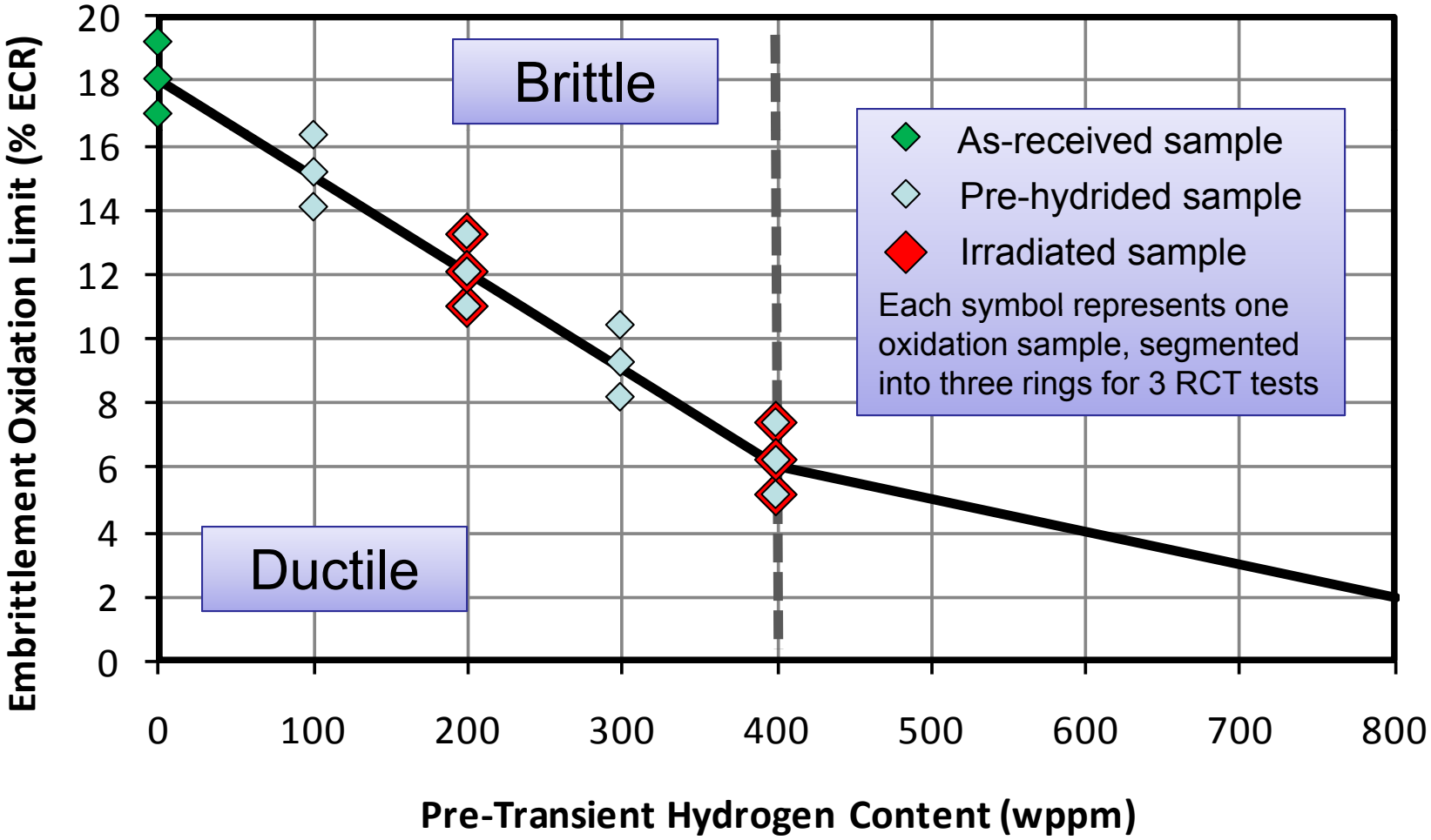
Guidance
DG-1263

Demonstrating comparable performance for new cladding alloys

an acceptable test matrix for a cladding material that is anticipated to have a maximum hydrogen content of 400-wppm hydrogen at end of life



Guidance
DG-1263

Establishing Alloy-Specific Limits or Limits at a PCT Lower than 2,200°F:

(1) Methodology is designed to characterize a cladding alloy's embrittlement behavior through the entire spectrum of conditions expected during operation
(2) Methodology includes testing of as-received, prehydrided, and irradiated material
(3) Methodology uses the experimental procedure in DG-1262 to generate RCT data
(4) Experimental results submitted as part of the documentation supporting the NRC staff's review and approval of the new fuel design
(5) Demonstrating that ECCS performance is such that local oxidation and peak cladding temperature are calculated below the analytical limit is acceptable to demonstrate compliance with 10 CFR 50.46c.

Guidance
DG-1263

Establishing Analytical Limits for Breakaway Oxidation:

(1) Provide experimental results for testing for breakaway oxidation behavior
(2) Methodology uses the experimental procedure in DG-1261 to generate data
(3) Establish time limit for the total accumulated time that the cladding may remain above 650 °C as part of the documentation supporting the NRC staff's review and approval of the new or existing fuel design
(4) Applicants may elect to establish the analytical limit for breakaway oxidation with conservatism relative to the measured minimum time (i.e., reduce the time) to the onset of breakaway oxidation
(5) Demonstrating that ECCS performance is such that the total accumulated time that the cladding is predicted to remain above a temperature at which the zirconium alloy has been shown to be susceptible to this phenomenon is not greater than the proposed limit is acceptable to demonstrate compliance with 10 CFR 50.46c.

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Other topics covered:

(1) Qualification of Hydrogen Pickup Models
- Submit PIE data and a hydrogen update model as part of the documentation supporting the NRC staff's review and approval of the new or existing fuel design

(2) Accounting for Uncertainty and Variability in Hydrogen Content
- Uncertainty should be quantified
- Allowable CP-ECR based on predicted peak circumferential average hydrogen content for the individual rod

(3) Application in the Rupture Region
- define the cladding thickness as the cladding cross-sectional area divided by the cladding circumference, taken at a horizontal plane at the elevation of the rupture
- calculate two-sided oxidation using the CP correlation

Guidance
DG-1263

Other topics covered:

(4) Accounting for Double-Sided Oxidation Due to the Fuel-Cladding Bond Layer
- One acceptable approach would be to calculate two-sided local oxidation for fuel rods with a local (nodal) exposure beyond 30 GWd/MTU
- A different threshold may be proposed by a licensee and provided as part of the documentation supporting the NRC staff's review and approval of the new or existing fuel design
- A different threshold could be supported by metallographic images of bonding layers as a function of burnup

(5) Breakaway Oxidation Analytical Limits
- identify the limiting combination of break size, break location, and initial conditions and assumptions that maximize the total accumulated time
- Operator actions can be credited

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Extended Example for DG-1263

- The following slides depict the extent of testing required for establishing an alloy specific limit or a limit at a lower temperature.
- The example assumes a EOL [H] content of 400 wppm
- For illustration, the figures declare some points “brittle” or “ductile” only to show how the move to the next step is dictated by the previous measurements.

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Guidance
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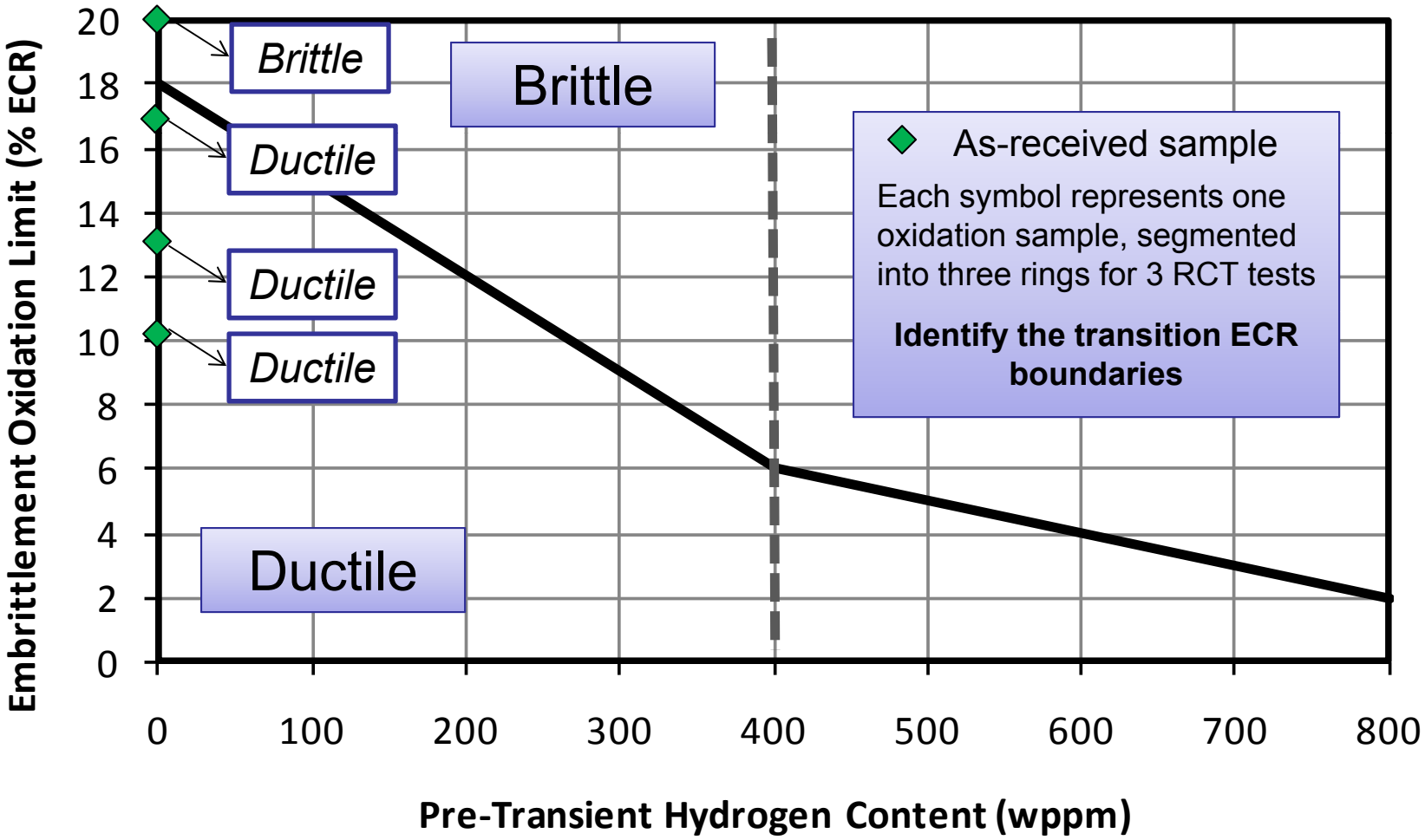
Establishing Alloy-Specific Limits or Limits at a PCT Lower than 2,200 °F

an acceptable test matrix for a cladding material that is anticipated to have a maximum hydrogen content of 400-wppm hydrogen at end of life



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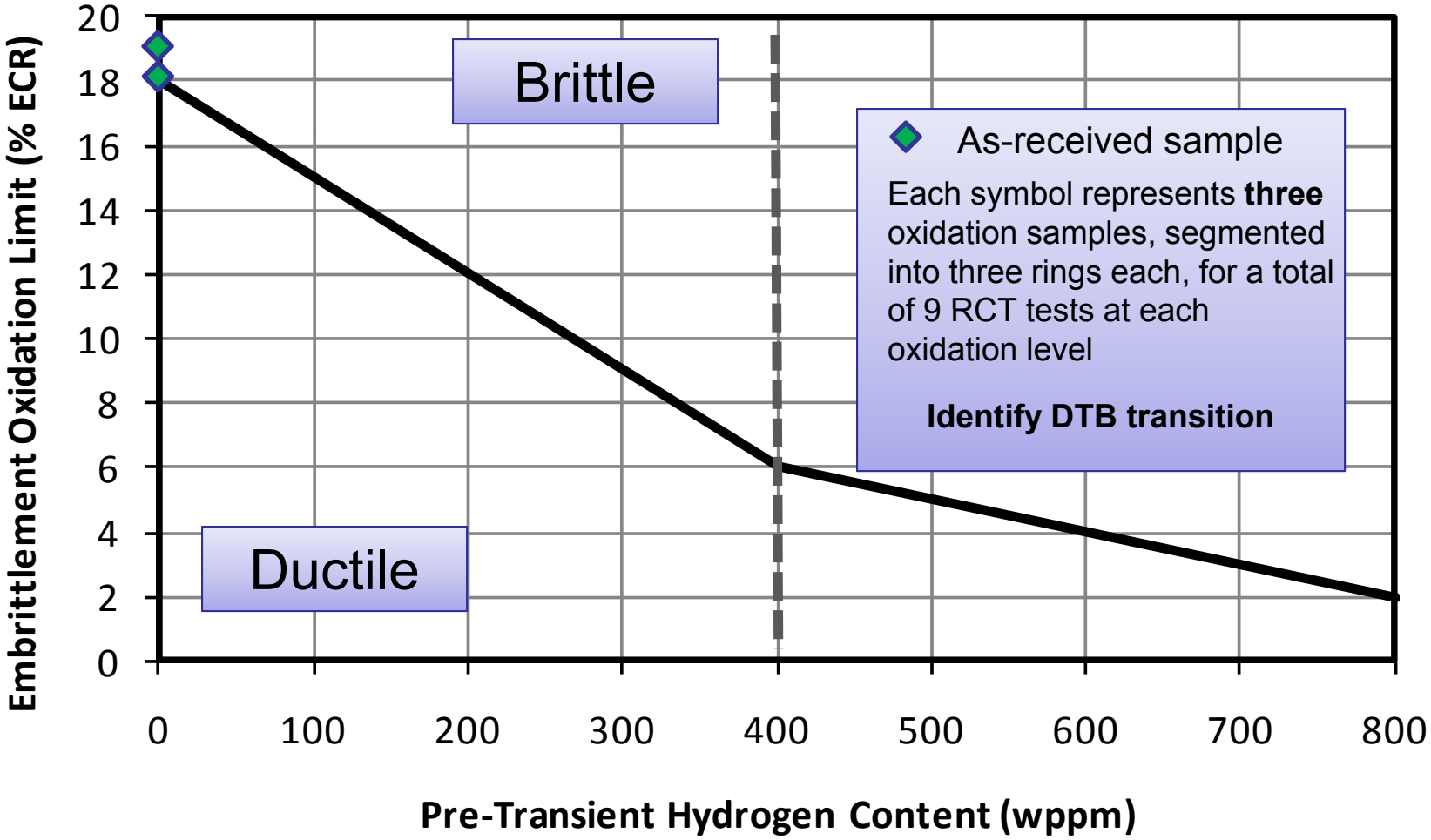

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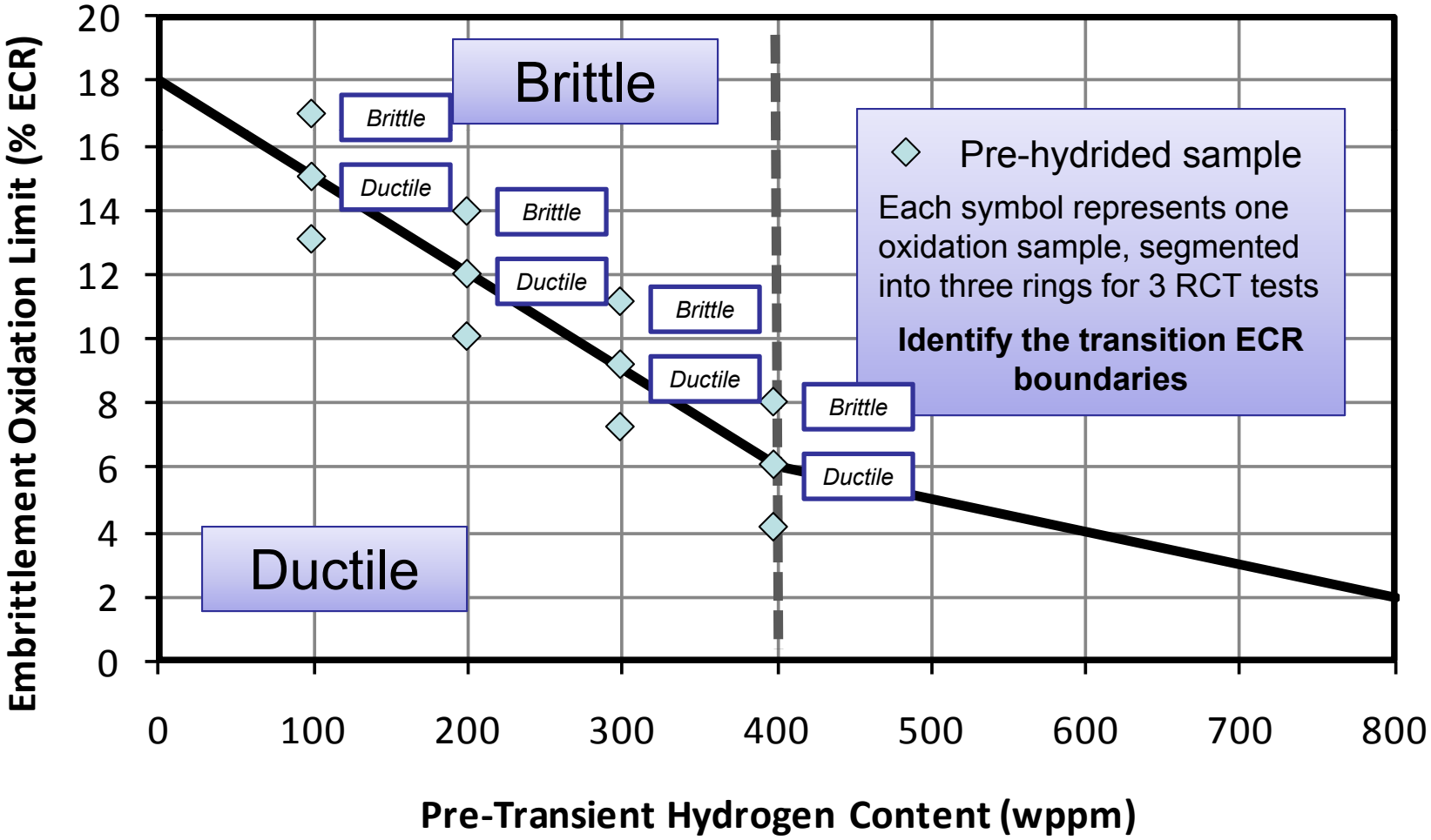

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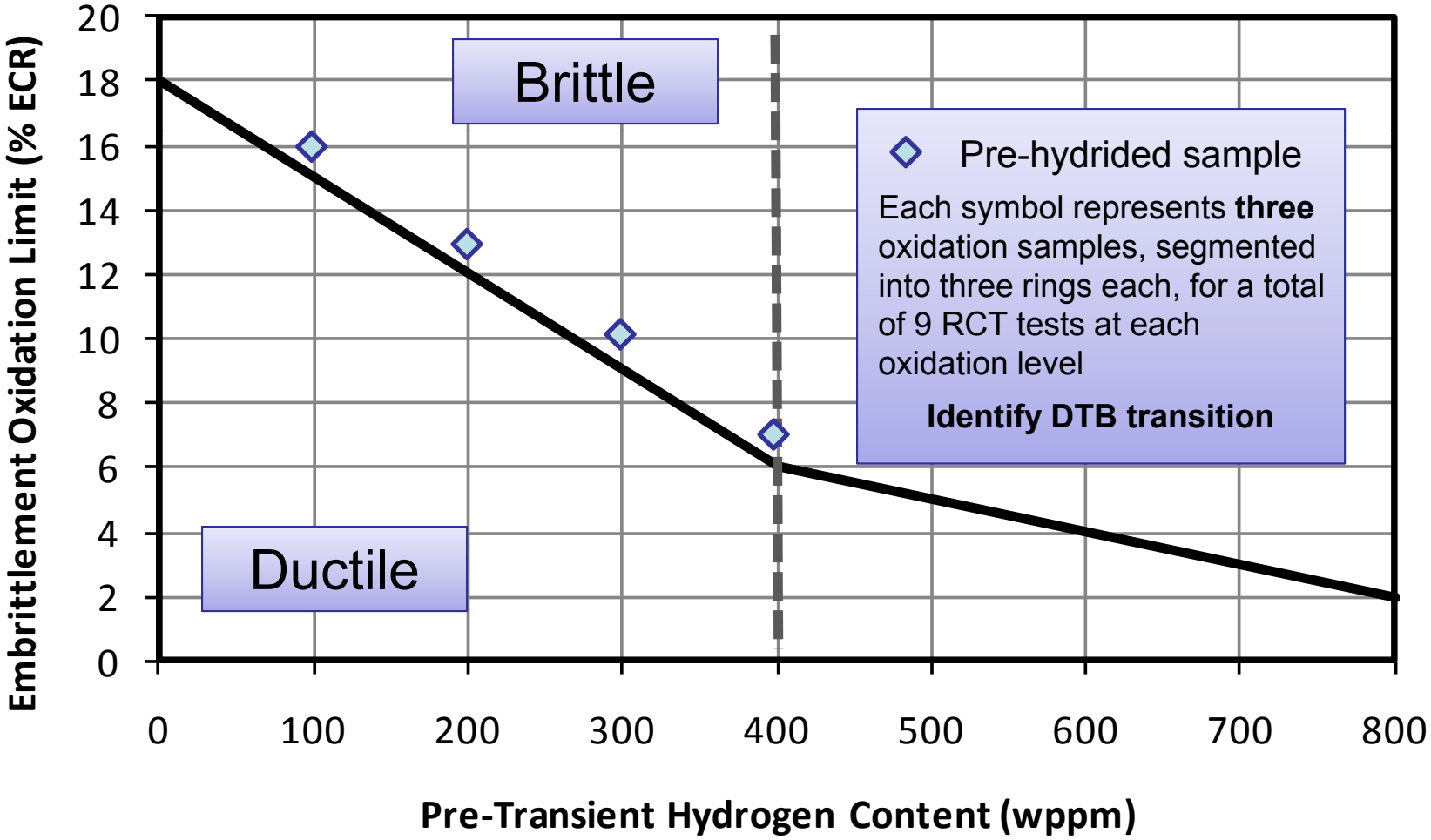

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