

December 23, 2015

MEMORANDUM TO: Timothy J. McGinty, Director  
Division of Safety Systems  
Office of Nuclear Reactor Regulation

FROM: Paul M. Clifford, Senior Technical Advisor */RA/*  
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SUBJECT: 50.46C ECCS SAFETY ASSESSMENT – 2015 UPDATE

The purpose of this memorandum is to provide an annual update to the 50.46c ECCS performance safety assessment. This update captures emergency core cooling system (ECCS) model changes and errors reported within the 50.46(a)(3) annual and 30-day reports as well as new loss-of-coolant accident (LOCA) analysis-of-record. The 50.46c ECCS performance safety assessment documents plant-specific safety margin relative to the proposed requirements, confirms continued safe operation for the entire fleet, and informs the implementation plan for the proposed 10 CFR 50.46c rule.

In response to the research findings in Research Information Letter (RIL) 0801, "Technical Basis for Revision of Embrittlement Criteria in 10 CFR 50.46," (Agencywide Document Access and Management System (ADAMS) Accession number, ML081350225), the staff performed a preliminary safety assessment of currently operating reactors (ADAMS Accession number ML081620302 Proprietary, ML090340073 Non-Proprietary). This assessment found that, due to measured cladding performance under Loss-Of-Coolant Accident (LOCA) conditions, realistic fuel rod power history, and current analytical conservatisms, sufficient safety margin exists for operating reactors. Therefore, the U.S. Nuclear Regulatory Commission (NRC) staff determined that immediate regulatory action was not required, and that changes to the ECCS acceptance criteria to account for these new findings can reasonably be addressed through the rulemaking process.

Recognizing that finalization and implementation of the new ECCS requirements would take several years, the staff decided that a more detailed safety assessment was necessary. Working with the Pressurized-Water Reactor Owners Group (PWROG) and Boiling-Water Reactor Owners Group (BWROG), the staff completed a comprehensive ECCS performance safety assessment which confirmed, on a plant-specific basis, the safe operation of the U.S. commercial nuclear fleet. The ECCS performance safety assessment was issued in a memorandum dated September 27, 2011 (ADAMS Accession number ML11262A017) along with the staff's audit report of the PWROG (ADAMS Accession number ML11139A3090) and BWROG (ADAMS Accession number ML1119501390) ECCS margin assessment reports.

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The 2011 ECCS performance safety assessment represents a snapshot of the available Post-Quench Ductility (PQD) and breakaway oxidation margin at the time the plant specific information was compiled. Since that time, changes to and errors discovered in ECCS models, as well as planned license amendment requests (e.g., power uprates, fuel transitions), challenge the continued applicability of the 2011 ECCS performance safety assessment. To ensure continued safe operation until the proposed 10 CFR 50.46c requirements are implemented, Division of Safety Systems (DSS) committed to perform annual updates. This memorandum provides the 2015 annual update and fulfills this commitment.

Enclosure:  
2015 ECCS Performance Safety Assessment



**Attachment 1:**  
**2015 ECCS Performance Safety Assessment**

**1. Scope and Purpose**

The purpose of this memorandum is to provide an annual update to the 50.46c emergency core cooling system (ECCS) performance safety assessment. This update captures ECCS model changes and errors reported within the 50.46(a)(3) annual and 30-day reports as well as new loss-of-coolant-accident LOCA analysis-of-record. The 50.46c ECCS performance safety assessment documents plant-specific safety margin relative to the proposed requirements, confirms continued safe operation for the entire fleet, and informs the implementation plan for the proposed 10 CFR 50.46c rule.

In response to the research findings in Research Information Letter (RIL) 0801, "Technical Basis for Revision of Embrittlement Criteria in 10 CFR 50.46," (Agencywide Document Access and Management System (ADAMS) Accession number, ML081350225), the staff performed a preliminary safety assessment of currently operating reactors (ADAMS Accession number ML081620302 Proprietary, ML090340073 Non-Proprietary). This assessment found that, due to measured cladding performance under (LOCA) conditions, realistic fuel rod power history, and current analytical conservatisms, sufficient safety margin exists for operating reactors. Therefore, the U.S. Nuclear Regulatory Commission (NRC) staff determined that immediate regulatory action was not required, and that changes to the emergency core cooling system (ECCS) acceptance criteria to account for these new findings can reasonably be addressed through the rulemaking process.

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The 2011 ECCS performance safety assessment represents a snapshot of the available post-quench ductility (PQD) and breakaway oxidation margin at the time the plant specific information was compiled. Since that time, changes to and errors discovered in ECCS models, as well as planned license amendment requests (e.g., power uprates, fuel transitions), challenge the continued applicability of the 2011 ECCS performance safety assessment. To ensure continued safe operation until the proposed 10 CFR 50.46c requirements are implemented, DSS committed to perform annual updates.

**ENCLOSURE**

## **2. Background - Research Findings**

Unchanged from 2011 ECCS margin assessment.

## **3. ECCS Performance Safety Assessment**

In summary, the PWROG and BWROG ECCS margin assessment reports provided the following information and analyses:

1. Starting with the staff's "Elements of Prospective Information Request" handout from a public workshop on April 29, 2010 (ADAMS ML1013004901 and ML1011800120), developed revised analytical limits for PQD and breakaway oxidation for which to judge ECCS performance.
  - a. Alloy-specific corrosion and hydrogen uptake properties were used to convert allowable Cathcart Pawell-Equivalent Cladding Resected (ECR) to a function of fuel rod exposure.
2. Collected and tabulated existing LOCA analysis-of-record abnormal occurrence report (AOR) results for all operating plants.
3. Grouped plants based on margin to revised analytical limits, plant design, cladding alloy, and/or evaluation model.
4. Identified plants which satisfy revised analytical limits with no adjustments.
5. For remaining plants, identified conservatisms with regard to assumptions, analysis inputs, methodology, risk assessments and relevant research data that represent inherent margin.
  - a. Quantified and justified any analytical credit.
  - b. Where necessary, performed new LOCA analyses.
6. Documented ECCS margin assessment for the limiting plant within each group.

As part of the 2011 audit of the Owner's Group reports, the staff completed the following activities:

1. Confirmed that the revised PQD and breakaway analytical limits were in accordance with the research findings and that alloy-specific corrosion and hydrogen uptake models were accurate and supported by data.
2. Evaluated the quantification, justification, and application of analytical credits.
3. Reviewed a sampling of the new LOCA calculations and identified any changes to existing, approved models and methods. All of the new LOCA calculations were performed and documented in accordance with the fuel vendor's 10 CFR 50 Appendix B quality assurance program.

4. Compiled plant-specific data and evaluated each individual plant with respect to margin to the revised analytical limits.

The Post-Quench-Ductility (PQD) and breakaway margin assessment for each operating reactor was compiled and documented within the 2011 ECCS Margin Database (EXCEL spreadsheet, available in ADAMS ML11262A017).

### **Annual Updates**

In accordance with 10 CFR 50.46(a)(3)(iii), licensees are required to report any “change to or error discovered in an acceptable evaluation model or in the application of such a model that affects the temperature calculation.” Within these reports, the licensee provides a ‘rack up’ of the changes and errors including an ‘estimated’ change in peak cladding temperature (PCT). The current regulation does not require an estimate to the previously reported maximum local oxidation. This lack of an estimated maximum local oxidation makes it difficult to assess changes and errors on the available ECR margin. Note that the proposed 50.46c rule requires reporting changes in ECR.

The following assumptions were used in assessing the impact of reported changes and errors on available ECR margin:

1. If no errors or changes were reported (i.e., PCT unchanged), then original 2011 ECCS margin assessment (as modified by annual updates) remains applicable.
2. If summation of estimated impacts of errors and changes equaled zero (i.e., PCT unchanged), then original 2011 ECCS margin assessment (as modified by annual updates) remains applicable.
3. If summation of estimated impacts of errors and changes was negative (i.e., PCT reduced), then original 2011 ECCS margin assessment (as modified by annual updates) remains applicable.
4. If summation of estimated impacts of errors and changes was positive (i.e., PCT increased), then an assessment of residual ECCS margin was performed.

If an assessment of residual ECCS margin was required, the following approach was followed:

1. For small PCT increases, the relative change in CP-ECR was calculated based upon the increase in PCT and duration of transient.
  - a. Because the plant-specific transient temperature profile was not available, a simplistic temperature profile was used in the CP-ECR calculations. Cladding temperature is assumed to ramp up at 10 °C/sec, then held at a constant temperature, and then ramped down at 10 °C/sec. The time duration at the hold

temperature was chosen to bound the plant-specific time-at-elevated temperature profile from the updated final safety analysis report AOR.

- b. CP-ECR calculations were performed at hold temperatures corresponding to the original and new PCT values.
  - c. The increase in CP-ECR was then compared with the existing ECR margin.
  - d. Figure 3-1 plots CP-ECR as a function of temperature for various hold times for both a standard BWR 10x10 fuel rod and PWR 16x16 fuel rod. The relative change in CP-ECR as a function of cladding temperature ( $dECR/dT$ ) was used in this calculation.
2. For large PCT increases, analytical credits, similar to those cited in the PWROG/BWROG reports (and previously audited by the staff), were applied to demonstrate positive ECR margin. The plant's 'grouping' category was updated to reflect application of new credits. This, in turn, impacts the implementation priority of the plant.

If the licensee submitted a new LOCA AOR during the past 12 months, then the database was updated to reflect the new results and ECCS margins were recalculated.

For each plant, the updated ECCS Margin Database provides the following information:

- Plant design
- Licensed power
- Fuel vendor
- Fuel rod cladding alloy
- Evaluation model
- AOR results (calculated PCT, MLO, and time above 800°C)
- Plant grouping
- Margin to PQD analytical limit
- Margin to breakaway oxidation analytical limit
- Identify analytical credit(s)
- New AOR (Y/N)
- Reported changes
- Impact on margin assessment
- ADAMS number of 50.46(a)(3) report

**2012 Annual Update:**

The ECCS Margin Database was updated to capture all 50.46(a)(3)(iii) reports, 50.54(f) letter responses, and relevant LARs over the period from September 2011 to September 2012. In summary, the following impacts were reported:

Boiling Water Reactors (35 total reactors)

- 9 plants reported no change in PCT.
- 0 plants reported a reduction in PCT.
- 26 plants reported an increase in PCT.
- 0 plants revised LOCA AOR.

Pressurized Water Reactors (69 total reactors)

LBLOCA:

- 25 plants reported no change in PCT.
- 16 plants reported a reduction in PCT.
- 23 plants reported an increase in PCT.
- 5 plants revised LOCA AOR.

SBLOCA:

- 53 plants reported no change in PCT.
- 4 plants reported a reduction in PCT.
- 10 plants reported an increase in PCT.
- 2 plants revised LOCA AOR.

The first annual update was complicated by two items: (1) original ECCS margin assessment did not account for changes to or errors discovered in evaluation models since AOR (which may be several years old) and (2) ongoing TCD evaluations. All of the reported changes and errors as well as the impact on available margins are documented in the updated 2012 ECCS Margin Database (ADAMS ML122720230). Note that 9 plants require further evaluation to address TCD concerns. The remaining 95 plants continue to show positive ECCS performance margin.

The original 50.46c staged implementation strategy remains unchanged. However, based upon the 2012 annual update, the implementation track assignments for several plants need to be reclassified. Using the original 50.46c implementation plan logic in Table 5-1, implementation track assignments were re-evaluated.

**2013 Annual Update:**

The ECCS Margin Database was updated to capture all 50.46(a)(3)(iii) reports, 50.54(f) letter responses, and relevant LARs over the period from September 2012 to September 2013. In summary, the following impacts were reported:

Boiling Water Reactors (35 total reactors)

- 20 plants reported no change in PCT.
- 0 plants reported a reduction in PCT.
- 7 plants reported an increase in PCT.
- 8 plants revised LOCA AOR.

Pressurized Water Reactors (65 total reactors)

LBLOCA:

- 23 plants reported no change in PCT.
- 3 plants reported a reduction in PCT.
- 32 plants reported an increase in PCT.
- 7 plants revised LOCA AOR.

SBLOCA:

- 61 plants reported no change in PCT.
- 1 plants reported a reduction in PCT.
- 0 plants reported an increase in PCT.
- 3 plants revised LOCA AOR.

Note that the PWR database was reduced from 69 to 65 plants to reflect the closure of Crystal River Nuclear Generating Plant Unit 3, San Onfre Nuclear Generating Station Units 2 and 3, and Kewaunee Power Station.

Also note that the 2013 update maintains the historic changes and errors identified in the 2012 ECCS Margin Database. Hence, even if no changes or errors were reported in the past 12 months, impacts on margin assessments may exist. The original PWROG/BWROG margin assessment used the latest AOR results (e.g., calculated ECR) which may be several years old and does not reflect subsequent changes or errors.

The revised database is available in ADAMS.

ECCS\_Margin\_Database\_Sept2013\_r0.xlsx (ADAMS ML13259A299)

Examination of the 2013 ECCS Margin Database reveals that the majority of plants needed no adjustments to show a positive margin to the revised analytical limits. In summary:

Revised PQD Analytical Limit:

- For BWRs, 27 of 35 plants (77% of BWR fleet) needed no adjustment or new calculations:

- Remaining 8 BWRs performed new LOCA calculations which credit COLR Thermal-Mechanical Operating Limits (TMOL) reduced rod power at higher burnup to satisfy new analytical limits.
- No change from 2011 margin assessment.
- For PWR SBLOCA, 56 of 65 plants (86% of PWR fleet) needed no adjustment or new calculations:
  - Remaining 9 PWRs credit either (1) a switch from Appendix K dictated 120% of 1971 decay heat curve to 1979 +2 $\sigma$  decay heat curve or (2) rod peaking factor burn down.
  - No change from 2011 margin assessment.
- For PWR LBLOCA, TCD issue necessitated significant evaluations (see below).

New Breakaway Oxidation Analytical Limit:

- All 100 plants needed no adjustments or new calculations.
  - Only 1 plant had time-at-temperature duration above 2000 seconds.
  - No change from 2011 margin assessment.

### **2013 Annual Update – Revision 1:**

The 2013 annual update was complicated by ongoing fuel thermal conductivity degradation (TCD) evaluations which made it difficult for the staff to assess ECCS performance safety margin relative to the proposed requirements. In response to staff concerns, the PWROG agreed to revise their ECCS margin assessment report and assess the impact of TCD on ECCS performance margin. This assessment updates the 50.46c ECCS performance safety assessment to capture the results of the revised PWROG margin assessment report (ADAMS Accession number ML13329A086).

The original PWROG ECCS margin assessment (2011) was based on the plants' LOCA licensing basis analysis of record (AOR) results and considered both large break LOCA (LBLOCA) and small break LOCA (SBLOCA) analysis results. The original assessment represents a snapshot of the available post-quench ductility and breakaway oxidation margin at the time the plant-specific analyses were completed. The effect of changes to and errors discovered in ECCS models, as well as planned plant changes, which had been evaluated for peak cladding temperature (PCT) impact (per 10 CFR 50.46(a)(3)(iii)) were not considered in the original assessment.

The revised PWROG report updates the original LBLOCA oxidation margin assessment to consider more recent AORs and the effects of plants' specific PCT rackup assessments (including TCD). Evaluations currently assessed on a plant's LBLOCA PCT rackup sheet have been considered in this update. The SBLOCA analysis and breakaway oxidation margin assessments were not impacted by TCD and therefore not updated.

Following its receipt, the staff conducted an audit of the revised PWROG report. The purpose of staff's audit was to review the underlying Westinghouse engineering calculations and collect necessary plant-specific information to confirm safe operation. Specifically, the staff completed the following activities:

- Review the basis for each of the adjustments.
- Review the magnitude of each adjustment.
- Review the basis for each plant grouping.
- Review the magnitude of adjustment for each plant.
- Collect plant-specific information in order to revise 50.46c safety evaluation.

The staff's audit report is available in ADAMS ML14022A138.

The ECCS Margin Database has been updated to capture the results of the revised PWROG report and document positive margin for all reactors. The revised database is available in ADAMS.

ECCS\_Margin\_Database\_Sept2013\_r1.xlsx (ADAMS ML14022A140)

Examination of the 2013 ECCS Margin Database (Revision 1) reveals that the majority of plants needed no adjustments to show a positive margin to the revised analytical limits. In summary:

Revised PQD Analytical Limit:

- For BWRs, 27 of 35 plants (77% of BWR fleet) needed no adjustment or new calculations:
  - Remaining 8 BWRs performed new LOCA calculations which credit COLR Thermal-Mechanical Operating Limits (TMOL) reduced rod power at higher burnup to satisfy new analytical limits.
  - No change from 2011 margin assessment.
- For PWR SBLOCA, 57 of 65 plants (88% of PWR fleet) needed no adjustment or new calculations:
  - Remaining 8 PWRs credit either (1) a switch from Appendix K dictated 120% of 1971 decay heat curve to 1979 +2 $\sigma$  decay heat curve or (2) rod peaking factor burn down.
  - One less plant required credits relative to 2011 margin assessment.
- For PWR LBLOCA, 41 of 65 plants (63% of PWR fleet) needed no adjustment or new calculations:
  - Remaining 24 PWRs credit either new LOCA calculations (including rebaselined PCTs) or identified credits to satisfy new analytical limits.
  - Less plants required credits relative to 2011 margin assessment.

New Breakaway Oxidation Analytical Limit:

- All plants satisfy new requirement with no adjustments or new calculations.
  - Only 1 plant had time-at-temperature duration above 2000 seconds.
  - No change from 2011 margin assessment.

**2014 Annual Update:**

The ECCS Margin Database was updated to capture all 50.46(a)(3)(iii) reports, 50.54(f) letter responses, and relevant LARs over the period from September 2013 to November 2014. In summary, the following impacts were reported:

Boiling Water Reactors (35 total reactors)

- 16 plants reported no change in PCT.
- 3 plants reported a reduction in PCT.
- 11 plants reported an increase in PCT.
- 5 plants revised LOCA AOR.

Pressurized Water Reactors (66\* total reactors)

LBLOCA:

- 16 plants reported no change in PCT.
- 18 plants reported a reduction in PCT.
- 31 plants reported an increase in PCT.
- 1 plants revised LOCA AOR.

SBLOCA:

- 57 plants reported no change in PCT.
- 6 plants reported a reduction in PCT.
- 1 plants reported an increase in PCT.
- 2 plants revised LOCA AOR.

\* Watts Bar Unit 2 added to database

Note that the 2014 ECCS safety margin database maintains historic changes and errors identified in previous annual updates. Hence, even if no changes or errors were reported in the past 12 months, impacts on margin assessments may exist.

The revised database is available in ADAMS.

ECCS\_Margin\_Database\_Sept2014\_r0.xlsx (ADAMS ML14358A392)

Examination of the 2014 ECCS Margin Database reveals that the majority of plants needed no adjustments to show a positive margin to the revised analytical limits. In summary:

Revised PQD Analytical Limit:

- For BWRs, 27 of 35 plants (77% of BWR fleet) needed no adjustment or new calculations:
  - Remaining 8 BWRs performed new LOCA calculations which credit COLR Thermal-Mechanical Operating Limits (TMOL) reduced rod power at higher burnup to satisfy new analytical limits.

- No change from 2011 margin assessment.
- For PWR SBLOCA, 57 of 66 plants (86% of PWR fleet) needed no adjustment or new calculations:
  - Remaining 9 PWRs credit either (1) a switch from Appendix K dictated 120% of 1971 decay heat curve to 1979 +2 $\sigma$  decay heat curve or (2) rod peaking factor burn down.
  - No change from 2011 margin assessment.
- For PWR LBLOCA, 37 of 66 plants (56% of PWR fleet) needed no adjustment or new calculations:
  - Remaining 29 PWRs credit either new LOCA calculations (including rebaselined PCTs) or identified credits to satisfy new analytical limits.
  - More plants required credits relative to 2011 margin assessment.

New Breakaway Oxidation Analytical Limit:

- All 100 plants needed no adjustments or new calculations.
  - Only 1 plant had time-at-temperature duration above 2000 seconds.
  - No change from 2011 margin assessment.

**2015 Annual Update:**

The ECCS Margin Database was updated to capture all 50.46(a)(3)(iii) reports, 50.54(f) letter responses, and relevant LARs over the period from September 2014 to November 2015. In summary, the following impacts were reported:

Boiling Water Reactors (34 total reactors)

- 12 plants reported no change in PCT.
- 7 plants reported a reduction in PCT.
- 8 plants reported an increase in PCT.
- 7 plants revised LOCA AOR.

Pressurized Water Reactors (66 total reactors)

LBLOCA:

- 44 plants reported no change in PCT.
- 1 plants reported a reduction in PCT.
- 20 plants reported an increase in PCT.
- 1 plants revised LOCA AOR.

SBLOCA:

- 53 plants reported no change in PCT.
- 0 plants reported a reduction in PCT.
- 13 plants reported an increase in PCT.
- 0 plants revised LOCA AOR.

Note that the 2015 ECCS safety margin database maintains historic changes and errors identified in previous annual updates. Hence, even if no changes or errors were reported in the past 12 months, impacts on margin assessments may exist.

The revised database is available in ADAMS.

ECCS\_Margin\_Database\_Sept2015\_r0.xlsx (ADAMS ML15357A116)

Examination of the 2015 ECCS Margin Database reveals that the majority of plants needed no adjustments to show a positive margin to the revised analytical limits. In summary:

Revised PQD Analytical Limit:

- For BWRs, 26 of 34 plants (76% of BWR fleet) needed no adjustment or new calculations:
  - Remaining 8 BWRs performed new LOCA calculations which credit COLR Thermal-Mechanical Operating Limits (TMOL) reduced rod power at higher burnup to satisfy new analytical limits.
  - No change from 2011 margin assessment.

- For PWR SBLOCA, 57 of 66 plants (86% of PWR fleet) needed no adjustment or new calculations:
  - Remaining 9 PWRs credit either (1) a switch from Appendix K dictated 120% of 1971 decay heat curve to 1979 +2 $\sigma$  decay heat curve or (2) rod peaking factor burn down.
  - No change from 2011 margin assessment.
- For PWR LBLOCA, 37 of 66 plants (56% of PWR fleet) needed no adjustment or new calculations:
  - Remaining 29 PWRs credit either new LOCA calculations (including rebaselined PCTs) or identified credits to satisfy new analytical limits.
  - More plants required credits relative to 2011 margin assessment.

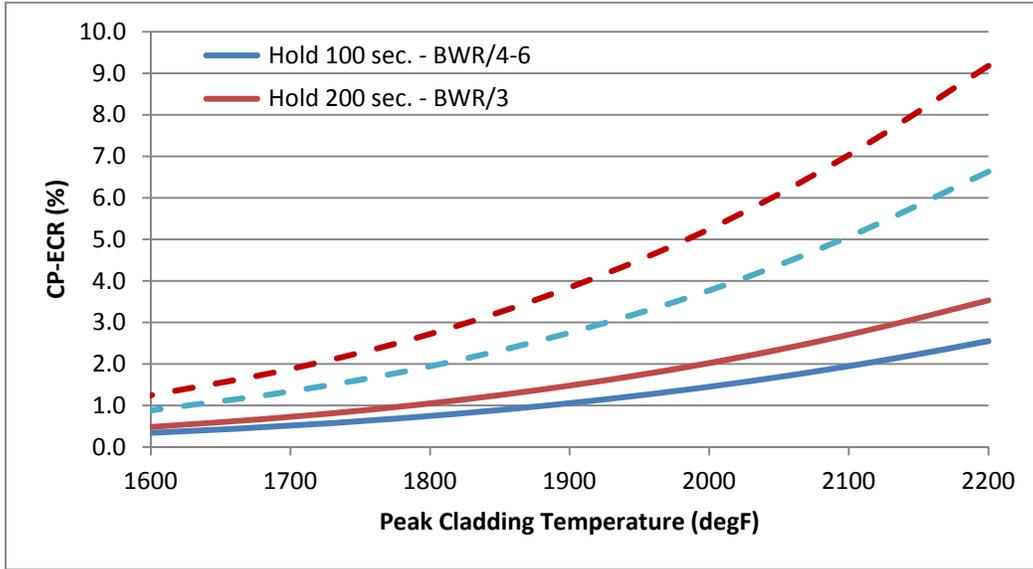
New Breakaway Oxidation Analytical Limit:

- All 100 plants needed no adjustments or new calculations.
  - Only 1 plant had time-at-temperature duration above 2000 seconds.
  - No change from 2011 margin assessment.

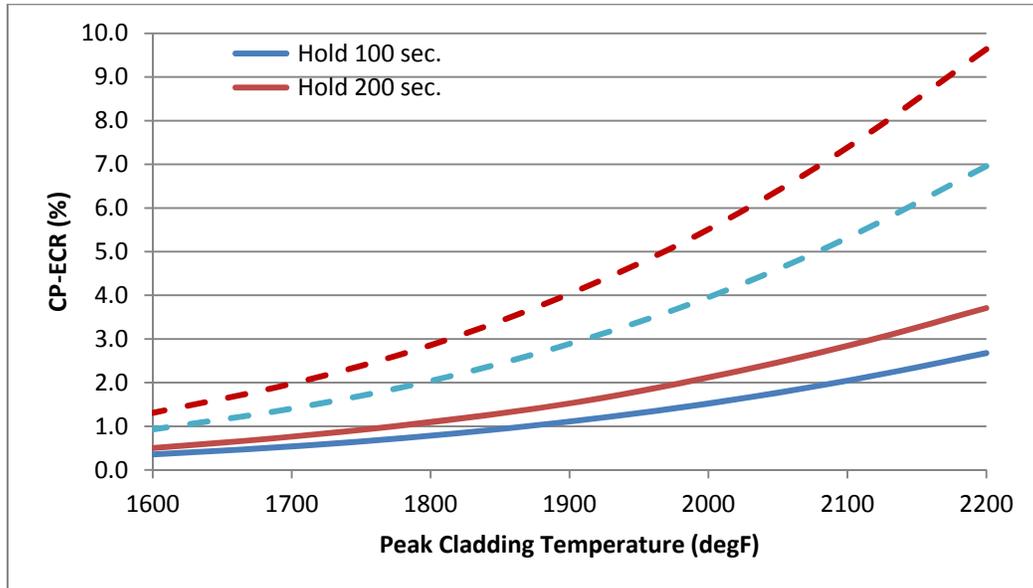
Figure 3.1: Calculated Oxidation (CP-ECR versus Temperature)

(solid line – no burst, dotted line – burst)

BWR 10x10 Fuel Rod



PWR 16x16 Fuel Rod



### **3.1 Safety Assessment of New Reactors**

Unchanged from original 2011 ECCS margin assessment.

### **4 Future Confirmation of Plant Safety**

Unchanged from original 2011 ECCS margin assessment.

### **5. Implementation Plan for 10 CFR 50.46c Rule**

An alternative implementation plan was adopted for the draft final 50.46c rule. The 3-tier staged implementation plan, and plant assignments, were removed. As such, Table 5-1 and 5-2 were deleted from this update.

### **6. Conclusion**

The 2011 ECCS performance safety assessment represents a snapshot of the available PQD and breakaway oxidation margin at the time the plant specific information was compiled. Since that time, changes to and errors discovered in ECCS models, as well as planned license amendment requests (e.g., power uprates, fuel transitions), challenge the continued applicability of the 2011 ECCS performance safety assessment. To ensure continued safe operation until the proposed 10 CFR 50.46c requirements are implemented, the Division of Safety Systems committed to perform annual updates.

The ECCS Margin Database has been updated to capture reported changes and error as well as any new LOCA AORs. The revised database is available in ADAMS.

ECCS\_Margin\_Database\_Sept2015\_r0.xlsx (ADAMS ML15357A116)

Section 3.0 summarizes the impact of these changes on available ECCS performance margin.

In conclusion, the staff has updated the 50.46c ECCS performance safety assessment, captured the latest results and changes, and confirmed safe operation of all nuclear power plants with respect to the new, proposed requirements.