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LTR-NRC-14-52

August 19, 2014

Subject: Submittal of Comments for Docket ID NRC-2008-0332 on the Proposed Performance-Based Emergency Core Cooling System Cladding Acceptance Criteria

The NRC is proposing to amend its regulations to revise the acceptance criteria for the emergency core cooling system for light-water nuclear power reactors. The proposed rule was issued for public comment in the Federal Register, Volume 79 Number 56 on March 24, 2014. Westinghouse Electric Company LLC (Westinghouse) is pleased to have the opportunity to provide comments and insights on the proposed rule. The attachment to this letter transmits comments and responses on the proposed rule from Westinghouse. This attachment provides four sets of comments:

A. General comments on the proposed rule and associated draft regulatory guides
B. Responses to several of the questions posed by the NRC in the Federal Register notice of the proposed rule
C. Specific comments on the draft regulatory guides
D. Recommendations for a proposed long-term cooling (LTC) regulatory guide.

For convenience and simplicity, comments on the proposed rule and the draft regulatory guides are transmitted in the same letter.

Westinghouse participated in the effort to prepare the industry comments that are being provided through the Nuclear Energy Institute to the NRC and supports those comments. This letter provides additional comments which reinforce and/or supplement the industry comments.

Westinghouse agrees with the proposed rulemaking and draft regulatory guidance while noting the following:

- The amount of testing and complexity of licensing new cladding alloys will likely have a detrimental effect on the introduction of improved cladding materials
- Performance-based criteria should be utilized for risk-informed approaches rather than analytical limits
- Additional research is needed concerning a LTC peak cladding temperature limit along with associated regulatory guidance.

These items are described in more detail in the attachment.

If you have any questions or require additional information, please contact Tom Rodack, Director of Licensing and Engineering Programs, at (412) 374-3769.

Very truly yours,

James A. Gresham, Manager

Regulatory Compliance

Comments for Docket ID NRC-2008-0332 on the Proposed Performance-Based Emergency Core Cooling System Cladding Acceptance Criteria (Non-Proprietary)

August 2014

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A. General Comments on the Proposed 50.46c Rule and Draft Regulatory Guides

1. While the proposed rule seeks to maintain the level of protection contained in the current regulation by requiring that new technical matters be addressed, the level and complexity of testing associated with licensing a new cladding alloy under the proposed rule will have a detrimental effect on the introduction of improved cladding materials that would benefit public health and safety. Specific recommendations are provided in the comments pertaining to draft regulatory guide DG-1263 in Section C of this attachment.
2. The proposed requirements for periodic measurement and reporting of the time to reach breakaway oxidation for batches of manufactured cladding material are excessively burdensome and unnecessary. Early breakaway oxidation for the Russian Zr-1Nb alloys such as E110 was recognized as a phenomenon which could adversely impact cladding performance in loss of coolant accident (LOCA) scenarios. Western cladding alloys using a different manufacturing process have not exhibited breakaway in time frames relevant for small break LOCA (SBLOCA). Extensive testing has been done on a range of cladding materials from different manufactured batches, with no significant batch-to-batch variation. The 10 CFR 50 Appendix B Quality Assurance Programs for each cladding vendor are sufficient to assure that requirements on the time to breakaway oxidation are maintained. The requirement for ongoing measurement and reporting of time to breakaway oxidation should be dropped from the rule.
3. There is no safety benefit associated with revision of legacy documentation which currently references 50.46(b) simply to reference the proposed rule. Changes to existing documentation should not be required unless modification is needed to address requirements of the proposed rule.

B. Responses to Questions Posed by the NRC in the Federal Register Notice

Question 1: Performance-Based Peak Cladding Temperature Limit

The NRC requests comment on the retention of the prescriptive peak cladding temperature (PCT) criterion, and questions whether it should adopt a performance-based requirement for zirconium alloy cladding to protect against high temperature ductile failure and autocatalytic oxidation and if established test procedures already exist for demonstrating high temperature cladding performance.

Westinghouse Response

1. Maintaining the current prescriptive PCT criterion in the rule is inconsistent with the objective of a performance-based rule. It is recommended that the current 2200°F criterion be moved to DG-1263, where it should be stated that its use in conjunction with the Figure 1 integral time at temperature limit is an acceptable combination of performance-based criteria for avoiding cladding embrittlement for any dilute zirconium alloy.
2. The 2050°F limit for hydrogen content greater than 400 weight part per million (wppm) should be removed from Figure 1, as it is redundant. Consistent with the Argonne National Laboratory (ANL) testing, a calculated LOCA transient that achieves PCT above 2050°F will likely exceed the integrated time at temperature limit for cladding above 400 wppm hydrogen, and thus will fail the criterion in proposed rule 50.46c(g)(1)(ii). Also, use of a discontinuous PCT limit as a function of hydrogen can make the identification of a limiting case ambiguous.
3. Regarding performance-based requirements to protect against high temperature ductile failure and autocatalytic oxidation, it is recommended that DG-1263 stipulate that the applicant address these concerns if requesting a PCT limit higher than 2200°F.

Question 2: Periodic Breakaway Testing

The NRC requests specific comment on the type of data reported and the proposed frequency of required testing for breakaway oxidation. The goal of the NRC is to use this testing to monitor for changes in the onset of breakaway oxidation at least annually and to perform periodic breakaway oxidation tests on an every reload basis.

Westinghouse Response

Type of Data to be Reported

As explained previously in Westinghouse's general comments (Section A), the proposed requirements for periodic measurement and reporting of times to reach breakaway oxidation for batches of manufactured cladding material are excessively burdensome and unnecessary. These requirements should be eliminated.

If measurement and reporting requirements are required, despite the evidence showing they are unnecessary, the requirements should be established with consideration of manufacturing practices and the practical aspects of breakaway oxidation testing. It is proposed that cladding samples be tested during production on a go / no-go basis to confirm that the production alloy batch exceeds the established analytical limit. Therefore, no breakaway time measurements would be reported only that the material met the requirement.

Frequency of Required Testing

1. It is suggested that the frequency of testing be sufficiently flexible to allow for sampling at either the cladding lot (covering a small number of tubes) or at the cladding ingot (covering a large number of tubes) levels as a means of addressing the requirement to evaluate the breakaway oxidation behavior for each reload of fuel.

   An ingot will produce several lots of cladding tubes. These lots may be used in different reloads and at different times. During the initial testing for breakaway behavior, it may be preferable to do testing on each lot of cladding to minimize the risk of a large amount of inventory being found to be unacceptable. As data from multiple lots are obtained, the frequency of sampling within the reload would decrease. It is recommended that information about the frequency of testing be included in the draft regulatory guide and not incorporated directly into the proposed regulation, to retain the flexibility to update the frequency requirements as additional breakaway oxidation data are obtained.

2. Early breakaway was primarily an issue with zirconium alloys fabricated with zirconium produced by non-Kroll processes such as E110. It is suggested that the requirement to perform periodic testing for breakaway oxidation be removed from the rule and replaced with a requirement to account for breakaway oxidation. Recommendations for periodic testing should then be included in a revised DG-1261. This provides for future revisions to the regulatory guides to remove or modify the periodic testing requirement as ongoing test programs yield more information.

3. The proposed requirement in 50.46c(m)(3) for licensees to report breakaway testing results is unnecessary as vendors will ensure that breakaway performance is acceptable, via their quality assurance program.

Question 3: Analytical Long-Term Peak Cladding Temperature Limit

The NRC requests input regarding the performance-based metric to judge an acceptably low long-term peak cladding temperature based on an overall goal of preserving ductility. The objective of the performance metric is to provide reasonable assurance that the fuel rods will maintain a coolable bundle array. Additionally, the NRC seeks comment on the long-term cooling acceptance criterion and whether there is justification for a different temperature limit than the 800°F provided in WCAP-16793-NP, Revision 2.

__Westinghouse Response__

1. The long-term cooling (LTC) requirement is based on demonstrating PCT is below the ductile-to-brittle transition (DBT), but the scenario for determining the PCT is not defined. The method to demonstrate compliance needs to be defined. Is the expectation that the risk informed approach be used with core damage frequency being the metric for acceptance?
2. The schedule of the BWR Owners Group program to investigate debris blockage does not appear to be in sync with the proposed rule implementation schedule. The proposed rule includes a requirement to demonstrate emergency core cooling system (ECCS) performance in the post-accident recovery period considering the effects of debris. Clarification is requested on how this will be met if the rule is implemented before the debris issue is resolved, which could be beyond the compliance dates in the proposed rule.
3. As noted in response to Question 1, maintaining the PCT criterion in the rule is inconsistent with the objective of performance-based criteria. As suggested previously, the PCT criterion should be moved to DG-1263. A "significance level" PCT should also be specified that could be used as a screen for determining when performance-based testing may be required. When performance-based testing is required, cladding material acceptance can be related to a maximum PCT or to a time at temperature.
4. It is suggested that 50.46c(g)(1)(v) should remain non-specific regarding acceptable long-term fuel cladding heat-up. As written, the proposed rule appears to require an analytical limit on long-term PCT, supported by an NRC-approved experimental technique, even when very small long-term heat-ups occur. For plants that can demonstrate continued and sustained fuel quench, or for plants with very small long-term fuel cladding heat-ups, long-term fuel cladding performance testing is unwarranted. Therefore, it is suggested that the following words, shown as bold, italic font, should be added to 50.46c(g)(1)(v).

    > Long-term cooling. ***Where significant long-term fuel cladding heat-ups are predicted,*** an analytical limit on long-term PCT shall be established which corresponds to the measured ductile-to-brittle transition for the zirconium alloy cladding material based on a NRC-approved experimental technique. The calculated maximum fuel element temperature shall not exceed the established analytical limit. The analytical limit must be approved by the NRC.

    This wording will allow significance and long-term to be defined by the NRC staff in a LTC regulatory guide. Fuel cladding heat-ups below this significance level would be considered acceptable with regards to 50.46c(g)(1)(v) with no need for material-specific testing using NRC-approved experimental techniques. This will allow many plants that can demonstrate stable and sustained quench in the long-term, or plants that have small long-term fuel cladding heat-ups, to achieve timely compliance with 50.46c(g)(1)(v). A proposed 50.46c(g)(1)(v) compliance strategy is provided in Section D "Recommendations for a Proposed LTC Regulatory Guide"

Question 4: Acceptance Criteria for Risk-Informed Alternative

The NRC seeks comment on whether acceptance criteria for a risk informed approach to addressing the effects of debris on LTC should be contained within forthcoming draft regulatory guidance or should be set forth in 50.46c.

Westinghouse Response

1. Westinghouse supports a risk-informed alternative to address debris effects on all time frames of core cooling. It is recommended that the detailed acceptance criteria be placed within a Regulatory Guide rather than in the proposed rule itself. This provides for flexibility and avoids the need for an exemption request for issues that could be resolved with the staff if the acceptance criteria were in a Regulatory Guide.
2. The proposed regulatory guidance should be consistent with existing guidance and acceptance criteria (for example, RG 1.174).
3. Models such as the 50.48(c)(4) risk-informed alternative to comply with the NFPA-805 fire protection requirements should be used to guide the level of detail needed for acceptance criteria in the 50.46c rule.
4. The NRC staff's proposal for a specific LTC PCT limit has not been adequately studied. Westinghouse concurs with the industry in recommending that, similar to the regulatory approach for other elements of the proposed rule, additional research by the NRC and the industry be conducted and a new Regulatory Guide prepared on this subject prior to implementing the proposed rule. The existing rule language remains sufficient until the research is complete and a new Regulatory Guide is developed.

Question 8: Exemptions Needed to Implement the Risk-Informed Alternative

The NRC seeks input on whether conforming changes are required to regulations other than General Design Criteria 35, 38, and 41 to implement the risk-informed alternative to address the effects of debris on LTC. Identify the specific regulation and provisions for which a change would be made, language or a description of the objective of the conforming change, and the reasons why an exemption from the regulation would be needed if the conforming change were not made.

Westinghouse Response

Westinghouse has not identified any additional regulations that would need to be changed to avoid exemption requests when implementing a risk-informed approach to debris effects on core cooling.

Question 9: Staged Implementation

The NRC requests specific comment on the staged implementation plan, track assignments, or alternative means to implement the requirements of the proposed rule.

Westinghouse Response

1. Westinghouse supports the use of a staged implementation plan that allows a reasonable schedule for coming into compliance while recognizing that many of the proposed regulatory requirements do not yet have a clear success path. For example, the proposed rule envisions use of an NRC-approved LTC method, although many aspects of LTC remain unresolved (e.g., performance-based cladding criteria, boric acid precipitation, resolution of GSI-191 for Option 2a, 2b, and 3 plants). It is likely that some plants currently assigned to Track 1 will not have approved methods for all of these issues before the proposed compliance date.
2. In order to avoid the need for wide-spread exemption requests, it is recommended that the rule allow each licensee to submit a compliance plan within a specified number of days after the rule is finalized that would provide compliance dates linked to generic resolution of industry issues. This approach would allow track definitions and plant names to be removed from the final rule language.

Question 10: New Reactor Implementation

The NRC requests input regarding the implementation plan for new reactors including suggestions for alternate approaches.

Westinghouse Response

1. Section VI.K of the Statements of Consideration for the proposed rule states that "Paragraph (o)(6) would require standard design certifications under 10 CFR Part 52 issued before the effective date of the rule to comply no later than the time of renewal of certification." Depending on when the final rule is made effective, a conflict could arise between the compliance date and submittal of the certification renewal application for the **AP1000**® Pressurized Water Reactor (PWR) plant design certification, which by regulation, must be submitted between February 2018 and February 2020. For example, the date of rule could coincide with intended certification renewal submittal. This could create unintended issues for both vendors and Combined Operating License applicants. It is recommended that the compliance timing requirements be elaborated on and/or a "grandfather clause" be added to prevent unanticipated and costly unintended consequences.
2. Section VI.K of the Statements of Consideration for the proposed rule states that "Those entities that are issued combined licenses prior to the effective date of the rule must comply with the rule no later than the first refueling outage after initial fuel load." Depending on when the final rule is made effective, a conflict could arise between the compliance date and the first refueling. For example, the date of rule could immediately precede the first refueling. This may not allow sufficient time for reanalysis efforts which could in turn necessitate licensing basis modifications. Additionally, if any of the licensing basis changes require prior NRC approval, additional time will be needed to comply. It is recommended that the compliance timing requirements be elaborated on and/or a "grandfather clause" be added to prevent unanticipated and costly complications.

Question 11: Re-structuring 10 CFR Chapter I with Respect to ECCS Regulations

The NRC seeks comment on the estimated costs for conforming changes to topical reports, licensing amendments, and other technical documents for the following potential administrative changes surrounding the restructuring of the ECCS regulations:

- Codify the performance-based ECCS and cladding requirements as a new section, 50.181.
- Reserve Section 50.183 for the potential future risk-informed ECCS requirements rule (currently the draft 50.46a rule)
- Codify the requirements for risk-informed submittal to address the effects of debris in the long-term recovery period as a new section, 50.185 (currently the draft 50.46c(e) section).
- Duplicate the content of 10 CFR 50, Appendix K as a new section, 50.187.
- Along with the restructure, the following administrative changes would be made:
  - Completely remove the current 50.46 rule.
  - Completely remove Appendix K to 10 CFR 50.
  - Renumber 50.46a, "Acceptance criteria for reactor coolant system venting systems" 50.46.

Specific comment is requested on whether the anticipated benefits and efficiencies would outweigh the administrative burden, costs, and complexities.

Westinghouse Response

There is no benefit from restructuring the ECCS regulations. The subject rule (50.46) is referenced in numerous places in licensing basis documents. Any attempt to do a complete renumbering throughout those documents would require considerable resources with little benefit. It is recommended that the restructuring, as proposed, not be undertaken.

Question 12: Cumulative Effects of Regulation (CER)

The NRC requests specific comment on the proposed rule with regard to any existing CER challenges, specifically:

- Do the proposed effective date, compliance date, and submittal dates for the rule provide sufficient time to implement the new requirements, including changes to programs, procedures, and the facility?
- What suggestions are there to address ongoing CER challenges?
- Identify any unintended consequences of the proposed rule.
- Comment on the NRC's cost and benefit estimates of the proposed rule (ADAMS accession number ML12283A188). Specifically, the vendor hydrogen uptake and LOCA model costs, costs of Post-Quench Ductility (PQD) and breakaway testing, and licensee analysis costs.

Westinghouse Response

Westinghouse supports the industry response to this question. As a LOCA-specific example where NRC cost estimates may be understated, it is recommended that NRC review their invoices under TAC ME5244. Although Table 2 of the Regulatory Analysis estimates that LOCA Evaluation Models (EM) to address post-quench ductility and breakaway can be developed and licensed for $300K, the NRC review costs alone are approaching an order of magnitude greater than this. Furthermore, the cost of setting up, qualifying and then performing just the PQD testing of irradiated cladding following the protocols proposed by the NRC has been explored and cost estimates exceed $1,000,000. This assumes that the irradiated fuel is already present at the hotcell and no shipping costs are incurred.

C. Specific Comments on the Draft Regulatory Guides.

Comments on Draft Regulatory Guide DG-1261 (Docket Number NRC-2012-0041): "Conducting Periodic Testing for Breakaway Oxidation Behavior"

1. For purposes of determining the temperature with the minimum breakaway time, the use of a Thermogravimetric Analyzer (TGA) should be allowed along with sample sizes suited to TGA use. The TGA will provide a nearly continuous measurement of weight gain vs. time. The results of the various temperature runs can be plotted together and the temperature where the earliest increase in the rate of weight gain can be readily identified.

2. Table 1 identifies the critical temperature for breakaway oxidation of ZIRLO® High Performance Cladding Material as 970°C with the onset of breakaway oxidation occurring at 3000 seconds. These results are inconsistent with Westinghouse results on ZIRLO cladding. In particular, Westinghouse has never observed breakaway oxidation on ZIRLO cladding at 970°C for times of 5000 seconds. In addition, Westinghouse has shown that the onset of breakaway oxidation for ZIRLO cladding is in excess of 5000 seconds when using heating rates that are prototypic of SBLOCA. Due to the discrepancy in test results between laboratories, it is recommended that Table 1 not be included in the draft regulatory guide.

3. Section A-2 identifies a scratch with a depth of 50±5 μm and width of ≥50±5 μm if no documentation of a "design-basis" scratch is provided. It is recommended that the width be more clearly stated as ≥ 45 μm. Maintaining a tolerance of ±5 μm on a scratch with a width ≥50 μm is an excessive burden as the intent is to use a bounding scratch, not one that is excessively uniform.

4. A distinction is made between hydrogen pickup and hydrogen content in Section A-2. Section A-9.5 identifies the hydrogen criterion for breakaway oxidation as 200 wppm hydrogen pickup. However, the tree diagrams in Appendix E identify the criterion as "hydrogen content below 200 wppm. Consistency should be maintained throughout the guide regarding the hydrogen criterion for breakaway oxidation.

5. Section A-6.2 refers to relating sample temperature to holder temperature. However, alternate means for establishing sample temperature without measurement of holder temperature should be permitted. For example, the large uniform hot zone in a resistance furnace permits the inclusion of cladding specimens that are instrumented with a thermocouple along with the actual test specimens. This eliminates the need to establish a correlation between holder temperature and specimen temperature as each oxidation run can include instrumented, non-oxidized cladding specimens to establish specimen temperature.

6. Section A-6.3 specifies that Zircaloy-2, Zircaloy-4, and ZIRLO cladding oxidized at 1000°C for ≤ 2000 seconds should be in good agreement with the Cathcart-Pawel (CP) correlation predictions. Extensive testing at Westinghouse of ZIRLO cladding shows that CP does not accurately predict weight gains of ZIRLO cladding oxidized in steam at or below 1000°C. In addition, results reported in NUREG/CR-6967 show that Zircaloy-4 weight gains exceeded CP predictions by more than 10% at 1000°C. It is recommended that sample weight gains be compared to well-established vendor-generated data for all alloys instead of the CP correlation. Details can be found in the Westinghouse presentation, "10 CFR 50.46c Proposed Rule and Associated Draft Regulatory Guides Westinghouse Electric Power Company Recommendations," ML14175A148, from the June 24 to 26, 50.46c public meeting.

7. Section A-7.1 specifies the water quality to be Grade A with ≤ 45 ppb oxygen (ASTM G2). Grade A water does not imply low oxygen levels as the low oxygen levels are achieved by steaming or venting an autoclave prior to heating to temperature. Grade A is defined as having a pH of 5.0 to 8.0 and an electrical resistivity of not less than 1.0 MΩ-cm. In comparison, Type I water has a minimum resistivity of 18 MΩ-cm while Type II water has a minimum resistivity of 1.0 MΩ-cm. It is recommended that water quality be specified as Grade A or Type II with no requirement for steaming to achieve low oxygen levels.

8. Section A-8.2 identifies a specific protocol for purging the steam chamber and stabilizing steam flow that is suitable for tests that utilize radiant heaters for steam oxidation. Stabilization of steam flow for a resistance furnace occurs with the steam chamber at temperature and the samples outside of the hot zone. Requiring the samples to be heated to 300°C in a stable steam flow is incompatible with use of a resistance furnace. The protocol should permit heating of samples from room temperature or an intermediate temperature (e.g., < 400°C) to the target oxidation temperature following stabilization of the steam flow.

9. Section A-8.3 recommends that the heating time from 650°C to the target temperature be < 100 seconds. Section A-5.1 states that the total ramp from 650°C to the target temperature and from the target temperature to 650°C should be <10% of the isothermal test time. The rationale provided for the restriction on heating and cooling times is based on the expectation that longer times may induce earlier breakaway times. This is contrary to Westinghouse experience that has shown that slower heating rates that are representative of the heating rates for a SBLOCA result in longer times to the onset of breakaway, as presented in the letter from J.A. Gresham (Westinghouse) to Harold H. Scott (NRC), LTR-NRC-09-24, "Westinghouse Results from Study on Impact of Specimen Preparation on Breakaway Oxidation (Non-Proprietary)," May 7, 2009. ML091350581. It is recommended that heating rates that are representative of those for a SBLOCA be permitted.

10. Section A-10 describes a methodology for establishing the temperature and minimum time for the onset of breakaway oxidation. The guidance provided in this section should be clarified to address the following comments.

    - Section A-10, paragraph 3 states that if all samples are lustrous black following 5000-second exposures at the seven test temperatures, four additional tests should be conducted at 1000°C, one test at 800°C, and <u>one</u> test at 1000°C on a sample with a bounding or design-basis scratch. Appendix E states that in addition to the four tests at 1000°C and a test at 800°C, <u>five</u> tests be performed on a sample with a bounding or design-basis scratch. A consistent set of guidelines for breakaway oxidation testing should be provided.
    - The maximum test time of 5000 seconds should be modified to be "5000 seconds or the time to exceed the limiting equivalent cladding reacted (ECR) for the ductile-to-brittle transition."
    - Appendix E appears to require testing of scratched samples only after defining the temperature and minimum time using non-scratched samples. While the logic diagram in Appendix E is useful, paragraph 7 of Section A-10 disregards Appendix E by stating that <u>all</u> breakaway oxidation tests be conducted with scratched samples. Section A-10 or Appendix E should be modified to provide one consistent set of guidelines for establishing the minimum breakaway oxidation time.
    - Paragraph 7 of Section A-10 states that all five tests run at 1000°C for 5000 seconds must exhibit lustrous black oxide or < 200 wppm hydrogen to conclude that the breakaway oxidation time is > 5000 seconds. This is contrary to the guidance in Section A-9.4 that discusses the case of multiple (e.g., five) samples. Section A-9.4 states that the average minus one standard deviation should be compared to the 200 wppm hydrogen pickup to

determine if breakaway has occurred. It is recommended that the criterion provided in A-9.4 be used to assess the onset of breakaway oxidation.

- Paragraph 8 of Section A-10 describes another approach for establishing the minimum breakaway time where testing at all seven temperatures (1050°C, 1030°C, 1015°C, 1000°C, 985°C, 970°C, and 950°C) may not be required. It is recommended that additional details on this approach be provided.

It is recommended that Section A-10 be more clearly written to identify acceptable options for establishing the minimum time for the onset of breakaway oxidation.

11. The relevance of paragraph 9 of Section A-10 is unclear. The paragraph indicates that there is larger data scatter within the critical temperature range for breakaway. However, the larger scatter in Figure A-3 than in Figure A-2 may also be due the larger temperature range of the breakaway tests, the larger number of tests, and a larger variety of sample types. It is recommended that Figures A-2 and A-3 be eliminated along with paragraph 9 as the conclusion regarding temperature sensitivity of breakaway oxidation is not clearly supported by the data.

Comments on Draft Regulatory Guide DG-1262 (Docket Number NRC-2012-0042): "Testing for Post Quench Ductility"

1. For performing PQD testing when the cladding is tested in target hydrogen bins, it is recommended that there be provision for the hydrogen level in each bin to vary from the target. For each target hydrogen content, if the results are to be analyzed in the same bin, a maximum allowable difference in hydrogen content should be established. Westinghouse experience shows that a maximum difference of 60 ppm is appropriate. The average hydrogen content of the samples analyzed in the same bin will then be used to evaluate the DBT against the limit.

2. Since the bins 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.

3. Section 6.1 specifies Type S thermocouples. Westinghouse recognizes that Type K thermocouples can degrade during extended operation at 1200°C. However, Type K thermocouples can be successfully used by implementing suitable controls. It is recommended that the use of Type K thermocouples be allowed provided their accuracy in measuring temperature can be demonstrated and local quality assurance procedures are followed.

4. It is requested that attachment of thermocouples to the sample during thermal benchmarking (Section 6.2) include welding thermocouples or strapping sheathed thermocouples to the outer surface. For resistance furnaces, strapped thermocouples adequately reflect the sample temperature due to the much more uniform temperature than achieved in radiant furnaces.

5. As noted in the Westinghouse comments on DG-1261, there is a discrepancy between measured and CP weight gains at an oxidation temperature of 1000°C. It is recommended that the weight gain bench mark to CP be eliminated for testing at 1000°C. Westinghouse agrees that the CP weight gain is a suitable benchmark at the higher oxidation temperatures of 1100°C and 1200°C.

6. Section 7.1 specifies the water quality to be Grade A with ≤ 45 ppb oxygen (ASTM G2). Grade A water does not imply low oxygen levels as the low oxygen levels are achieved by steaming or venting an autoclave prior to heating to temperature. Grade A is defined as having a pH of 5.0 to 8.0 and an electrical resistivity of not less than 1.0 MΩ-cm. In comparison, Type I water has a minimum resistivity of 18 MΩ-cm while Type II water has a minimum resistivity of 1.0 MΩ-cm. It is recommended that water quality be specified as Grade A or Type II with no requirement for steaming to achieve low oxygen levels.

7. Section 8.2 identifies a specific protocol for purging the steam chamber and stabilizing steam flow that is suitable for tests that utilize radiant heaters for steam oxidation. Stabilization of steam flow for a resistance furnace occurs with the steam chamber at temperature and the samples outside of the hot zone. Requiring the samples to be heated to 300°C in a stable steam flow is incompatible with use of a resistance furnace. The protocol should permit heating of samples from room temperature or an intermediate temperature (e.g., < 400°C) to the target oxidation temperature following stabilization of the steam flow.

8. Section 8.4 specifies that steam flow is maintained until the sample temperature reaches 800°C. This is followed by a flow of water to quench the sample. The protocol needs to include an acceptable temperature range of the sample (e.g., 700°C-800°C) prior to immersing the sample in water. The

protocol should be written to accommodate a facility in which steam flow is maintained during the entire quenching process and the sample is quenched by dropping it into water. Some tolerance on the actual quench temperature is required, as it is not possible to confirm that sample temperature was 800°C when it entered the water.

9. Section 9.3 states that "post-test hydrogen values should be corrected for weight gain so that the reference weight for hydrogen content is the pre-test weight." It is recommended that details for performing the correction be clearly stated.

10. Section 12.1 specifies the test time from 300°C to the quench be reported. The test time should be defined as the time from the initial rapid temperature ramp to the quench, as the initial sample temperature may not be 300°C.

Comments on Draft Regulatory Guide DG-1263 (Docket Number NRC-2012-0043): "Establishing Analytical Limits for Zirconium-Based Alloy Cladding"

1. The draft regulatory guide should be modified to make provisions to determine the DBT by:

    - The use of curve fitting of the test data to determine DBT within each hydrogen bin.
    - Determination of the final curve by fitting the DBT points from the individual hydrogen bins.
    - As an alternative, performing a fit of the DBT as a function of both the hydrogen and ECR using the same bins as above.

    These are based on the recommendations made in the Westinghouse presentation, "10 CFR 50.46c Proposed Rule and Associated Draft Regulatory Guides Westinghouse Electric Power Company Recommendations," ML14175A148, during the June 24 to 26, 2014 public meeting on 50.46c.

2. The draft regulatory guide specifies three repeat tests at the DBT. It is not clear what the intent of these tests is, given that significant scatter in ductility is expected at the transition point. The use of repeat tests above or below the detected limit to confirm ductile or brittle behavior should be permitted, as opposed to average tests with inherent and expected variability.

3. To account for the potential impacts of test setups, 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.

4. 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).

    For alloys meeting these requirements, the levels of original and transmuted elements both from alloying additives and from impurities would be within the levels of previously tested irradiated zirconium alloys. Therefore, any impact on oxygen solubility would be the same. For this reason, only pre-hydrided testing would be required to determine the DBT.

    For alloys where condition b. cannot be met, the guidance should be to perform testing of irradiated cladding to show similarity in terms of PQD behavior to the pre-hydrided cladding at only one hydrogen level which is at or above two-thirds of the maximum best estimate hydrogen level. This is a level of hydrogen content that is practical to achieve in lead test assembly irradiations and is high enough that any difference in the impact of hydrogen between irradiated and un-irradiated cladding would be observed.

5. The guidance should be clarified to indicate that it is acceptable to use the best-estimate predicted circumferential average hydrogen content for the individual fuel rod to establish the allowable ECR for the rod. Accounting for uncertainty in the prediction of clad hydrogen content would be excessively conservative, given the considerable conservatism in the derivation of the "Embrittlement Oxidation Limit vs. Pre-transient hydrogen content" curve associated with the assumptions inherent in the testing method (e.g., data generated at clad temperature at the temperature limit of 2200°F), and the very conservative criterion of assuring clad ductility to maintain coolable geometry.

6. The guidance for demonstrating acceptability of the hydrogen model used for determining the allowable CP ECR specifies that radial, circumferential and axial variables should be accounted for within the database used for building the model. However, elsewhere in the draft guide it is stated that comparison with the analytical CP ECR limit should be performed on the basis of the circumferential average peak axial hydrogen content evaluated from such a model. The typical method for measuring hydrogen uptake is the hot-gas extraction technique which yields the circumferential average for a given axial height of the fuel rod segment. The requirements for utilizing the analytical limit seem to be in contradiction with the requirements placed on the model development and validation.

7. The draft guide discusses the requirement for accounting for inner oxidation before burst, but does not explicitly identify an acceptable approach. From this, it could be concluded that applying CP-ECR without the oxidation reaction heat would be an acceptable approach. An acceptable approach for accounting for inner oxidation before burst should be described in the draft guide.

8. In the Federal Register discussion, it is stated that the CP-ECR formulation used to derive the analytical limits presented in DG-1263 should be used when comparing analysis results to the analytical limits. The CP expressions used to develop the analytical limits are discussed in Section 1.3 of NUREG/CR-6967. NUREG/CR-6967 states in Section 2.2 (page 19) that:

   > "For the ANL work, the integral in Equation 7 is converted to an integral with respect to temperature and the integration for the high-temperature oxidation tests (e.g., Figure 10) *is usually performed for $T \geq 1000°C$*"

   It would be useful to know if the entire temperature range was considered when deriving the CP-ECR used for the analytical limits (i.e., integral time at temperature). Please identify if a lower temperature threshold was considered for the derivation of the analytical limits presented in DG-1263, and if so, list it in the draft guidance.

D. Recommendations for a Proposed LTC Regulatory Guide

1. The draft wording of the proposed 50.46c rule is non-specific regarding LTC methodology and many of the requirements are subject to interpretation. Thus, compliance with the proposed rule will require regulatory guidance, most appropriately provided in an LTC regulatory guide. The recommended LTC regulatory guide should clarify and/or provide the following:

   - Definition of Long-Term Cooling

     The proposed rule introduces a number of new requirements related to LTC. The period of LTC is not defined. In several places in the Federal Register discussion, wording indicates that post-accident recovery and LTC are synonymous. However, post-accident recovery would better describe the time period beyond ECCS EM predictions where maintaining the safe condition of the plant would be assured by recovery procedures under the direction of the Technical Support Center (TSC).

     In the proposed rule, paragraph 50.46c(d)(2)(iv) states "ECCS performance must be demonstrated for the accident, and the post-accident recovery and recirculation period." Since this requirement is likely to be satisfied with different approved methods for the different phases, and since NRC detailed requirements for each phase will likely be different, clarifying guidance on the use of these terms needs to be provided. It is suggested that the following PWR analysis phases be defined in the recommended regulatory guide.

     Short-term Cooling Period – This is the period covered by large break (LB) and small break (SB) EMs. While the analysis may end when conditions described in the EM are satisfied, the short-term analysis would be applicable until assumptions in the LOCA EM(s) are no longer valid. This would normally be when ECCS performance is affected by realignments for the transfer to sump recirculation. Note that some LOCA EMs model the ECCS performance during the switch to sump recirculation. For these EMs, the short-term cooling would end when the transfer to sump recirculation is complete.

     Long-term Cooling Period – This period would begin when the assumptions in the LOCA EM(s) are no longer valid (i.e. the short-term period ends). For some LOCA EMs this would be when realignments are initiated for the transfer to sump recirculation. For other LOCA EMs that model the ECCS performance during the switch to sump recirculation, this would be after transfer to sump recirculation is complete. In either case, sump debris would become relevant only with the start of LTC. LTC would end when the measures to control boric acid precipitation and the effects of in-vessel sump debris are complete. For most PWRs, measures to control boric acid precipitation would be the transfer to hot leg, or simultaneous hot leg / cold leg recirculation. Other plants may control boric acid with passive measures. With respect to the effects of in-vessel debris, LTC would end when the full effects of sump debris have been considered and further accumulation of debris is not predicted.

     Post-Accident Recovery Period – Following the short-term cooling and LTC periods, this period begins when measures to control boric acid precipitation and the effects of in-vessel sump debris are complete, the core is quenched, and additional fuel heat-ups are not predicted. At this point ECCS EM predictions are largely not applicable and the safe condition of the plant would be ensured by recovery procedures under the direction of the TSC.

In the NRC's request for response to Question #3, a LTC period of 30 days was proposed. While this may be a workable definition to address additional corrosion and hydrogen pickup, it does not seem to be a practical definition for the duration of a LTC analysis that must consider all events and possible plant conditions during this 30 day period.

- Definition of Long-Term PCT

  50.46c(g)(1)(v) specifically requires that an analytical limit on long-term peak cladding temperature be established. It is not clear if this use of the phrase long-term corresponds to a PCT limit during the period covered by an NRC-approved or NRC-accepted LTC analysis, or if the phrase refers to a cladding temperature that remains above some limit for a long period of time. If it is the former, it is not clear if this limit applies to secondary or tertiary fuel cladding heat-ups during the LOCA EM. If it is the latter, there should be some heat-up minimum time duration that would be below the threshold for "long-term" If reheats are the issue, then there should be some specified temperature below which the fuel cladding must be cooled to constitute a reheat. Furthermore, if there is some concern over short duration fuel cladding heat-ups during LTC, there needs to be guidance on how these short duration heat-ups are treated as compared to multiple fuel cladding temperature rises allowed in current licensing basis LOCA EMs (those with distinct blowdown, and multiple reflood peaks). It is not clear if a long-term PCT is relevant if there is no significant fuel cladding heat-up in the short-term (e.g., for a non-limiting SB transient).

- Define the relationship between ECCS EM, debris EM and LTC EM

  The proposed rule language uses the terms ECCS EM and debris EM and LTC without defining the relationships between the terms. For example:

  > 50.46c(b) states "ECCS evaluation model means the calculational framework for evaluating the behavior of the reactor system (including fuel) during a postulated LOCA. It includes one or more computer programs and all other information necessary for application of the calculational framework to a specific LOCA, such as mathematical models used, assumptions included in the programs, procedure for treating the program input and output information, specification of those portions of analysis not included in computer programs, values of parameters, and all other information necessary to specify the calculational procedure."
  >
  > "Debris evaluation model means the calculational framework used to quantify the impact of debris generation, transport, sump head loss, in-vessel effects, chemical precipitation, and other phenomena important to long-term cooling. It includes one or more computer programs and other information necessary for application of the calculational framework to a set of initiating events, the mitigation of which requires LTC via recirculation. It also includes mathematical models used, assumptions used by the programs, procedures for treating the program input and output information, specifications of those portions of analysis not included in computer programs, values of parameters, and all other information necessary to specify the calculational procedure. The debris evaluation model is used, along with the probabilistic risk assessment (PRA), to quantify the portion of core damage frequency and large early."
  >
  > 50.46c(d)(2) states "ECCS performance must be demonstrated using an ECCS EM meeting the requirements of paragraph (d)(2)(i) or (d)(2)(ii) of this section, and satisfy the analytical requirements in paragraphs (d)(2)(iii),(d)(2)(iv), and (d)(2)(v) of this section. Paragraph (e) of this section may be used for consideration of debris as

described in paragraph (d)(2)(iii) of this section. The ECCS EM must be reviewed and approved by the NRC.

It is not clear how LTC or debris EMs would integrate with existing EMs or with EMs approved under the proposed rule, or if separate NRC-approved LTC and debris EMs are required. Normal ECCS EMs (SB and LB) are not generically approved for LTC, and are not well-suited for modeling LTC transients due to the emphasis on short-term phenomena, complexity, excessive computer run times, and specified conditions and limitations in NRC SERs. In principle, it would seem that the debris EM and a LTC EM are somewhat synonymous, in that both must address decay heat removal in the long-term. If a risk-informed debris EM is submitted and approved, the rule would seem to require a separate deterministic LTC analysis. For example, for the period between cold leg recirculation and hot leg recirculation, or simultaneous hot and cold leg recirculation there could be two separate EMs and two separate analyses that demonstrate decay heat removal: one for debris with risk-informed methods and one with no debris with deterministic methods. If both EMs have the same analytical limit (e.g., 800°F), it is not clear how the results of these analyses relate to one another. This potential source of confusion needs to be addressed.

- Establish acceptable assumption and methods for LTC analyses

  LTC analysis methods, and debris EMs that consider the LTC period, must use assumptions that are acceptable to the NRC staff. Clarification and guidance on the following subjects are needed.

  - Applicability of Appendix K requirements
  - Realistic decay heat
  - LTC period initial conditions
  - Allowable assumptions for operator actions and response times
  - Rules for alternate or multiple equipment failures (for a 30-day mission time)
  - Rules for allowing credit for equipment restoration (for a 30-day mission time)

- Establish the staff's expectations regarding licensee compliance to 50.46c(g)(1)(v).

  Prior to establishing a schedule for compliance to the proposed rule, an LTC regulatory guide should be issued, indicating the staff's expectations regarding 50.46c(g)(1)(v) compliance. It is suggested that an LTC regulatory guide be developed to establish the following 50.46c(g)(1)(v) compliance criteria:

  - A PCT significance level for both long-term (indefinite) and short-term heat-up durations. A short-duration PCT limit would allow brief fuel cladding reheats due to ECCS realignments for cold leg or hot leg recirculation or other temporary ECCS interruptions that may be necessary as part of post-accident recovery. A more conservative long-duration limit would address extended fuel cladding reheats (up to 30 days). Fuel cladding heat-up temperatures below the long duration and short duration PCT limits would be considered acceptable with regard to 50.46c(g)(1)(v) with no need for material-specific testing using NRC-approved experimental techniques.
  - A long-duration (indefinite) significance level PCT limit that would represent the threshold where oxidation becomes a concern for long periods of elevated fuel cladding temperature. It is recommended that evaluations to demonstrate compliance with this limit be permitted to use simplified methods with realistic assumptions. The simplified methods would include such things as comparing injected ECCS flow to core boil-off, thus maintaining core liquid inventory. For many plants with uninterrupted ECCS flow to the core, this comparison would show continued and sustained fuel quench, and thus would show compliance with 50.46c(g)(1)(v).

- A short-duration significance level PCT limit that would represent the threshold where additional oxidation becomes a concern for short periods of elevated fuel cladding temperature. It is recommended that this limit be based on existing zirconium/water oxidation tests that support Baker-Just or CP correlations. Evaluations to demonstrate compliance with this limit would be allowed to use typical LOCA thermal/hydraulic (T/H) methods with realistic assumptions.
- Acceptance criteria for significant long duration fuel cladding heat-ups or significant short duration fuel cladding heat-ups (as defined previously) would be based on the results of material-specific testing using NRC-approved experimental techniques. NRC approval of the LTC EM would be required prior to licensee's being able to demonstrate compliance with the new requirements.
- As an example, using a long-duration PCT limit of 800°F and a short duration PCT limit of > 800°F, and <1700°F for <1 hour, a 50.46c(g)(1)(v) compliance strategy table could look like this.

Table 1: 50.46c(g)(1)(v) Compliance Strategy

LTC Fuel Cladding Heat-up Prediction	Evaluation Method[1]	Material-Specific Testing Requirement
PCT< 800°F	Simplified T/H methods with realistic assumptions, NRC accepted	Not Required
800°F < PCT < 1700°F for < 1 hour[2]	Typical LOCA T/H methods, with realistic assumptions, NRC accepted	Not Required
800°F < PCT < 1700°F for > 1 hour[2] or PCT > 1700°F	NRC approved EM	Required using NRC approved experimental technique

Notes:

(1) "NRC accepted" refers to acceptance in a plant-specific license amendment request, while "NRC approved" refers to generic NRC approval of the EM.

(2) For multiple fuel cladding heat-ups, total duration will be the sum of individual excursions.

- It is suggested that the initial issuance of an LTC regulatory guide specify a long-duration limit based on current industry test data, and that it be generically applicable to zirconium alloy fuel cladding. The suggestion of 800°F, while conservative, may not represent the best available information. As new industry test data becomes available, this limit could be updated accordingly.

- It is not clear why a short duration heat-up in the LTC period after a LOCA is different than multiple fuel cladding temperature peaks that might be seen during blowdown and reflood, that are judged acceptable against a 2200°F limit. It is suggested that a conservative and practical temperature limit on a short duration heat-up could be the lower zirconium/water reaction threshold observed in the data used to establish for Baker-Just or CP correlations, and a time above temperature limit of 1 hour or less would accommodate short term fuel cladding heat-ups that might be predicted as the result of ECCS realignments and plant system changes that are part of recovery operations.