March 7, 2013

Mr. Frederick Schiffley
BWROG Chairman
Exelon Generation Co., LLC
Cornerstone II at Cantera
4300 Winfield Road
Warrenville, IL 60555

SUBJECT: REQUEST FOR ADDITIONAL INFORMATION RE: BOILING WATER REACTOR OWNERS' GROUP TOPICAL REPORT NEDC-33608P, REVISION 2, "BOILING WATER REACTOR EMERGENCY CORE COOLING SUCTION STRAINER IN-VESSEL DOWNSTREAM EFFECTS" (TAC NO. ME5345)

Dear Mr. Schiffley:

By letter dated January 13, 2011 (Agencywide Documents Access and Management System (ADAMS) Accession No. ML110140482), the Boiling Water Reactor Owner's Group (BWROG) submitted for U.S. Nuclear Regulatory Commission (NRC) staff review, licensing topical report NEDC-33608P, Revision 2, "Boiling Water Reactor Emergency Core Cooling Suction Strainer In-Vessel Downstream Effects." The NRC staff issued a Request for Additional Information (RAI) on July 1, 2011 (proprietary version, ADAMS Accession No. ML11171A193), and July 21, 2011 (redacted version, ADAMS Accession No. ML11194A107). The BWROG responded in two submittals dated April 20 and May 22, 2012 (ADAMS Accession Nos. ML121110282 and ML121440157).

Upon review of the information provided, the NRC staff has determined that the additional information requested in the enclosure is needed to complete the review. A draft version of the RAI questions was discussed with BWROG representatives at the downtown Washington DC offices of General Electric on December 11 and 12, 2012. The enclosed RAI questions reflect some changes as a result of those discussions. The enclosure is a publicly available redacted version of the proprietary version sent to you in a letter dated January 31, 2013 (ADAMS Accession No. ML13009A157). If you have any questions regarding the enclosed supplemental RAI questions, please contact me at 301-415-1002.

Sincerely,

/RA/

Joseph A. Golla, Project Manager
Licensing Processes Branch
Division of Policy and Rulemaking
Office of Nuclear Reactor Regulation

Project No. 691

Enclosure:
RAI questions

cc w/encl: See attached page

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ADAMS Accession No.: ML13051A636 **NRR-106**

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Boiling Water Reactor Owner's Group Project No. 691

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<u>REQUEST FOR ADDITIONAL INFORMATION</u>

<u>BY THE OFFICE OF NUCLEAR REACTOR REGULATION</u>

<u>NEDC-33608P, REVISION 2, "BOILING WATER REACTOR</u>

<u>EMERGENCY CORE COOLING SUCTION STRAINER</u>

<u>IN-VESSEL DOWNSTREAM EFFECTS"</u>

<u>BOILING WATER REACTOR OWNERS' GROUP</u>

<u>PROJECT NO. 691</u>

Request for Additional Information 1 Supplement 1 (RAI 1 S1):

Based on the information presented in response to RAI 1, the U.S. Nuclear Regulatory Commission (NRC) staff could not confirm the original reference analysis is bounding for all operating boiling water reactors (BWRs). Therefore, please address the following requests:

(a) Please include the supplemental analysis cases in Attachment A of the second RAI response in the topical report's (TR's) reference analysis since some of these scenarios define conditions that are not bounded by the original reference analysis.

(b) Please justify that the generic reference analysis in the TR that is used as a basis for the methodology for calculating plant-specific values of the pre-quench peak cladding temperature (PCT) is bounding and consistent with regulations in response to the following items:
   i. Relative to the requirements of Title 10 of the *Code of Federal Regulations* (10 CFR) 50.46, please clarify the statement in Section 3.1 of the TR that the nominal analysis "is selected consistent with licensing procedures that avoid distorted or masked sensitivities that could result from the use of bounding conservative inputs and correlations."
   ii. Please confirm that the pre-quench heatup rates used in the reference analysis (including the supplemental analysis cases) are bounding for all operating BWRs current analyses, or else commit to using the plant-specific heatup rates in existing licensing analyses for assessing the impact of increases to licensing basis PCTs due to invessel debris blockage delaying quenching of the fuel.

(c) Although the selection of certain reference analysis parameters may bound a number of BWRs, the TR and RAI responses do not provide adequate basis for the NRC staff to conclude that the generic reference analysis (including the supplemental analysis cases) is bounding for all operating BWRs for assessing the potential for long-term heatup of the fuel cladding due to debris blockage. Specifically, the TR asserts that the reference analysis may be considered bounding based on consideration of (1) [[ ]] and (2) [[ ]]. However, it is not clear that [[ ]] is strongly correlated with long-term heatup, since some key factors that drive the former, such as pipe diameters and emergency core cooling system (ECCS) pump start times and maximum flows, may have little or no impact on the latter. Furthermore, there is no basis to conclude that [[ ]] is the only other parameter needed to rank BWRs in terms of the potential for long-term cladding heatup. Rather, the potential for long-term heatup due to blockage from debris generated in a loss-of-coolant accident (LOCA) can be a complex evaluation of interactions between a number of factors, such as fuel design parameters, bundle power, core power distributions, total core power (see RAI 42 S1), available driving head, countercurrent flow limitation (CCFL), core spray distribution, etc. Therefore, to support application of the limiting reference analysis cases to operating BWRs, please tabulate the key parameters influencing long-term heatup due to debris blockage, along with the reference plant parameter values that should be demonstrated to be bounding. Due to differences in BWR designs (e.g., BWR/2, BWR/4, BWR/6) that are reflected in the reference and supplemental analysis cases, two or three design-specific tables may be necessary to specify appropriate bounding parameter values for the entire BWR fleet. Please further include justification that the chosen set of key parameters is sufficient to ensure the applicability of the reference analysis to all BWRs bounded by these parameters.

RAI 3 S1:

(a) The NRC staff's RAI 3 had requested that the BWROG address inconsistencies between Tables 4-1, 4-2, and 4-3 of the TR and information reviewed by the NRC staff in several BWRs' Final Safety Analysis Reports (FSARs). However, the response to RAI 3 did not provide the requested validation of and/or corrections to this information. Lacking this information, the NRC staff is unable to evaluate the BWROG's contention that the TR bounds all BWRs. Therefore, please provide revised tables for the NRC staff's review that accurately reflect operating BWRs' current licensing bases.

(b) The response to RAI 3 states the BWROG's view that the minimum core cooling has been used in the reference analysis, but does not explain how the limiting single failure for analyzing the impact of debris blockage was evaluated. Furthermore, a limited review by the NRC staff indicates that the bounding single failure assumption analyzed in some BWRs' FSARs results in fewer operating ECCS pumps than assumed in the reference and supplemental analyses. Therefore, please provide the technical basis for concluding that the reference and supplemental analyses used to derive test acceptance criteria have considered the most limiting single failures for analyzing the impact of post-LOCA debris, factoring in the corrections discussed in part (a) above.

RAI 4 S1:

Please adequately address the remaining issues identified in the response to RAI 4:

(a) An impact of long-term boiling that was not addressed in the response to RAI 4 is the potential for significantly increased concentrations of suspended debris within the reactor vessel. Long-term boiling within the reactor vessel can result in concentrations of suspended debris in the core and its hot channel significantly in excess of the concentration passing through the ECCS suction strainers. Head loss testing experience shows that increasing the concentration of fine suspended debris leads to agglomeration into larger elements. In-vessel agglomeration is a potential concern because larger agglomerates may block clearances within the core more readily and/or more persistently than individual fines. Please clarify how the BWROG has addressed or will address this issue.

(b) Please clarify why the BWROG considers it justified to neglect potential impacts of suspended debris concentration and scale formation if debris accumulation occurs mainly outside the active fuel region in the fuel assembly blockage tests. The impacts of scale formation and suspended debris concentration (potentially in combination with other effects such as thermal adhesion, crud buildup, cladding oxidation, and rod swelling) could change the location where limiting debris accumulation occurs. With reference to the actual clearance dimensions and flow areas requested in RAI 41 S1, please provide adequate technical basis to support the conclusion that the factors discussed above would not result in (1) the limiting condition for debris accumulation occurring within the active fuel region or (2) the creation of additional pressure drop across the reactor core that degrades core cooling.

RAI 5 S1:

The response to RAI 5 proposed to address separately the potential for the concentration of boron in the reactor core beyond its solubility limit due to the continued addition of borated coolant to a fuel assembly, the blockage of flushing paths by post-LOCA debris, and ongoing coolant vaporization. However, the NRC staff has determined that, if the quantity of fibrous debris determined to reach the reactor core is such that the formation of a restrictive debris layer within one or more fuel assemblies may occur, then it is necessary to evaluate the potential for interaction between debris accumulation and boric acid precipitation as part of the in-vessel blockage program. Therefore, please clarify how it will be ensured that the debris limits derived by the BWROG's invessel debris blockage program are sufficient to preclude adverse effects and interactions associated with boron precipitation, accounting for non-uniform core spray and fuel channel inlet blockage distributions as well as differences in the configurations of the ECCS and standby liquid control system that have the potential to affect the potential for boron precipitation in the presence of post-LOCA debris.

RAI 6 S1:

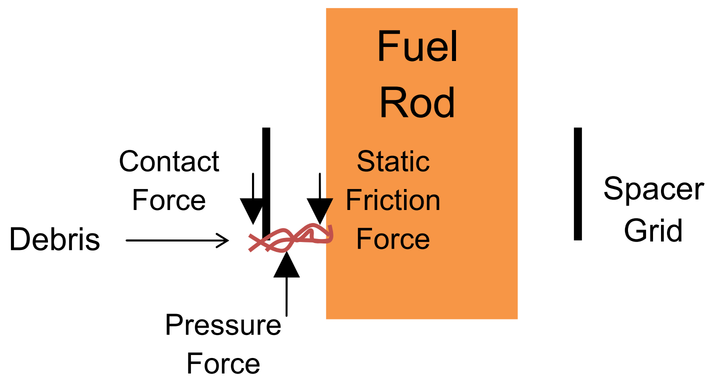
(a) In the long term, scale buildup and crud deposition may lead to reduced clearance dimensions, thereby promoting increased levels of debris blockage and retention relative to a clean assembly. For two main reasons, the response to RAI 6 does not adequately address this issue.

    1. First, the constituents that form scale need not be suspended debris (e.g., a primary source of scale formation may be dissolved species concentrating in the reactor vessel).
    2. Second, the marginal harm from scale formation creating nucleation points at minimal clearances that allow filtration of very fine suspended debris may exceed the benefit of debris holdup at non-limiting locations, particularly when considering maximum debris quantities bounding the entire BWR fleet.

    Therefore, please clarify why head loses derived from tests performed with clean assemblies that neglect scale and crud deposition are prototypical of a postulated LOCA.

(b) Please characterize and quantify typical levels of crud buildup on fuel bundles prior to removal by brushing. Please further clarify the expected behavior of this material during the LOCA and provide justification if it is considered not to affect or contribute to debris accumulation in the core.

(c) Crud buildup and oxidation may increase the surface roughness of fuel rods and other susceptible core structures. Consideration of surface characteristics is important because, in contrast with ECCS strainers, debris accumulations in a fuel bundle would not generally be fully supported by contact forces on their reverse face; rather, the persistence with which a debris accumulation is retained against the differential pressure generated by coolant or steam flows would be dependent, not only on contact forces, but also the frictional forces developed at lateral surfaces parallel to the direction of flow. This is illustrated in the figure below for the case of debris accumulation in the gap between a spacer grid and fuel rod. Therefore, please (1) clarify why head losses derived from tests performed with clean assemblies that neglect the influence of surface characteristics on debris retention in the fuel bundle are prototypical of a postulated LOCA, or (2) clarify how the BWROG program will address this issue.



RAI 7 S1:

(a) The response to RAI 7 did not discuss testing of previously quenched or partially quenched cladding that was subsequently reheated and requenched, as had been requested. As discussed in a letter to the Pressurized Water Reactor Owners Group (Agencywide Documents Access and Management System Accession No. ML062070451), the criteria in 10 CFR 50.46 (b)(1) through (b)(3) are based on testing that considers a single heatup and quench. Therefore, compliance with criteria (b)(1) through (b)(3) does not guarantee that cladding ductility and strength is adequate to satisfy the requirement for adequate long-term core cooling in criterion (b)(5) if the cladding experiences significant reheating (i.e., one or more additional thermal cycles). Further discussion of this topic occurs in Appendix A of TR WCAP-16793-NP, Rev. 2. Considering this information, please discuss testing and/or analysis demonstrating that the ductility and strength of cladding that has been previously heated and quenched remains adequate following subsequent reheating and eventual requenching from [[ ]] (or alternate value).

(b) Please clarify the intent and significance of the [[ ]] Fahrenheit (°F) acceptance criterion established by the BWR Owners Group (BWROG) as a reheatup cladding temperature limit, since one of the supplemental analysis cases (Figure 1 from Attachment A of the second RAI response) exhibits a PCT in excess of this value.

(c) Please clarify the BWROG's analytical predictions regarding the timing and impact of scale formation in relation to the proposed [[ ]] reheatup limit. In certain cases, the

TR's supplemental analyses demonstrate that the proposed debris blockage limit could result in cladding being reheated to temperatures near or even in excess of [[ ]]. Please clarify whether the formation of scale, in concert with debris blockage, could result in even higher cladding temperatures and discuss how the combined impact will be assessed relative to the acceptance criterion for cladding temperature.

RAI 11 S1:

The response to RAI 11 states that the BWROG considers the blockage multiplier for the geometrically restricted area affected by CCFL to serve as a "knob" for simulating the impact of debris blockage. However, this response does not adequately address the distinction made in RAI 11 between the use of a blockage multiplier as a knob for tuning (1) differential pressure due to single-phase flow and (2) CCFL. In the former case, the tuned parameter is measured during the experiment; thus, the blockage multiplier can be considered a "calibrated knob." However, with respect to CCFL, because the tuned parameters are not experimentally measured, the blockage multiplier represents an "uncalibrated knob." Ultimately, because there is no general analytic relationship between an arbitrary cross-sectional flow geometry and the empirical constants required by a CCFL correlation, when considering significant blockage of unspecified geometry covering up [[ ]] of the area of the fuel assembly outlet, it cannot be presumed in generality that the CCFL constants determined for an unblocked fuel assembly outlet geometry continue to apply. Therefore, following the debris blockage testing, please commit to either (1) providing validation and justification that debris blockage had a negligible effect on the geometry of the fuel assembly outlet such that continued applicability of CCFL constants for unblocked fuel assemblies may be assumed or (2) if testing indicates that debris blockage may influence CCFL, performing additional testing and/or analysis to assess the impact of debris blockage on CCFL realistically, and, if warranted, reanalyzing the consequent effect on PCT with modified CCFL constants appropriate for a blocked fuel assembly.

RAI 13 S1:

The response to RAI 13 states that a flow reversal occurs at the fuel channel-bypass leakage flowpaths between the times simulated in Tests 1 and 2. Please clarify whether this statement applies to BWRs with low-pressure coolant injection (LPCI) discharging into the bypass region and provide justification.

RAI 16 S1:

(a) The NRC staff agrees with the clarification in RAI 16 that fuel designs with enhanced thermal performance may require additional analysis to demonstrate acceptable performance under post-LOCA debris blockage conditions. However, designs involving reductions to minimum flow areas (e.g., at the limiting CCFL elevation or at critical debris accumulation points) or the potential creation of new critical debris accumulation points (e.g., new type of inlet filter or grid design) may also require additional fuel assembly blockage tests to validate acceptable performance under post-LOCA debris loadings. Please specify conditions under which additional fuel bundle blockage testing shall be necessary to support the loading of fuel designs not analyzed in the TR.

(b) The comparison of relative peaking factors between different plants proposed in response to RAI 16 may introduce error if the reference value of average power per bundle differs. Therefore, please replace the relative peaking factor proposed in the TR with an appropriate absolute metric, or else justify that use of a relative peaking factor has equivalent precision.

RAI 18 S1:

(a) For Test 1, please clarify and provide justification regarding whether separate tests with differently scaled lower plenum volumes are planned for BWRs with LPCI injection into the bypass region and those that inject into recirculation lines. If a single test is planned, please clarify whether the contribution of LPCI flow into the recirculation lines to refilling the lower plenum is neglected in Test 1, or how it is accounted for only where appropriate.

(b) For Test 2, please clarify and provide justification regarding whether separate tests planned for BWRs with LPCI injection into the bypass region and those that inject into recirculation lines. For BWRs with LPCI injection into the bypass, could the limiting restriction be associated with downflow from the bypass to the lower plenum? Please explicitly specify and provide justification for the minimum and maximum rates in Test 2 for upflow and downflow for BWRs with LPCI injection into the recirculation lines and BWRs with LPCI injection into the bypass region.

RAI 20 S1:

The NRC staff considers the fuel assembly blockage testing to be applicable only to those BWRs that are bounded by the test parameters. While the test parameters proposed appear indicative of the upper range of values, since they come from the specification of flows via percentages and the basis of a reference calculation that has not been demonstrated to be bounding for all BWRs, it is not clear that the flowrates are bounding on an absolute basis when considering factors such as the number of pumps that may operate, plant-specific pump capacity differences, variations in fuel bundle power, and the potential for variation in the flow splits between the side entry orifice (SEO) and bypass leakage paths for different break scenarios. Therefore, please confirm and provide the basis for concluding that the planned test flowrates bound the minimum and maximum values for all BWRs on an absolute basis (e.g., mass flow to the limiting bundle).

RAI 21 S1:

Please provide further description of the parameters and assumptions for the supplemental analysis calculations in Attachment A to the second RAI response:

(a) Please clarify how the inlet blockage timing is determined for different scenarios for which the timing of events varies (e.g., initiation of low-pressure ECCS injection). For example, complete blockage of the hot channel SEO and bypass leakage paths at [[ ]] is assumed in the TR's reference analysis for a double-ended suction line break. However, in a similar scenario in Case A-1 of the supplemental analysis in Attachment A to Enclosure 2 of the second RAI response, blockage for the hot and average channel inlets is assumed to depend on flow history in a manner that is not fully specified. Adequate clarification and justification for the flow history-dependent blockage model appears necessary to support assumptions made in calculations for smaller break sizes that have been modeled (e.g., core spray line break) as well as to confirm that explicit analysis of other break locations (e.g., discharge line break) is not necessary. Therefore, please explain the assumptions and/or models used to determine when blockage initiates for the SEO and bypass leakage paths in the reference and supplemental analysis scenarios and justify their adequacy.

(b) Regarding Case A-4 of the supplemental analysis (i.e., core spray break / opposite core spray train failure), please clarify the steam separator water return elevation(s), clearance dimension(s), and flow area(s) for the reference plant and confirm whether the modeling of the steam separator in SAFER is prototypical with respect to calculating the downflow of water into the core shroud in this scenario. Please further clarify whether the reactor vessel water level necessary to provide adequate downflow through the steam separators is above or below the minimum water level specified in the applicable emergency operating procedure. If the vessel water level necessary for adequate spillback through the separators cannot be confirmed to be above the minimum water level required by emergency operating procedures, then please further provide justification for the operator behavior and human factors / timing assumptions regarding manual control of ECCS flows for Case A-4 of the supplemental analysis relative to the guidance for controlling water level in the emergency operating procedures.

(c) Please provide information similar to that provided in Table 3-1 for each of the supplemental analysis cases (no need to repeat the initial sequence common to all large suction break cases). Please clarify other differences in the major assumptions of the supplemental calculations relative to the original reference analysis (e.g., difference in fuel types, peaking factors, ECCS flows, etc.).

(d) Please specify the area of the small break simulated in Case A-2.

(e) Please identify the axial power shape used in the simulation of debris blockage for the BWR/2 case in the supplemental analysis and justify that it is conservative.

(f) Please state whether leakage between the lower plenum and core bypass region was assumed in the analysis for Cases A-1 and A-4 in Appendix A of the second RAI response. If so, please identify the flow area assumed and the minimum clearance dimensions associated with these flowpaths. Please provide justification that any flowpaths credited will not become blocked by debris during a LOCA or have a negligible impact on the calculation; otherwise, please perform a revised analysis demonstrating acceptable results with an appropriate degree of blockage imposed at these flowpaths.

(g) Please confirm whether CCFL would have a significant effect in the steam separators for a core spray break scenario with the coincident single failure of the opposite train of core spray. If CCFL may occur in the steam separators, please clarify whether it is necessary to model this phenomenon in the analysis.

(h) Please provide additional explanation regarding the lack of long-term heatup following fuel channel outlet blockage for supplemental analysis Case A-3, which simulates BWRs with LPCI injection into the shroud. Considering Case A-3 relative to the reference analysis Case 4, based on conditions just prior to [[ ]], it is not obvious why one case experiences a heatup and the other does not. Please clarify whether the difference is attributed to differences in channel power, ECCS flows, or other factors.

(i) Please clarify the ECCS fluid temperature and containment pressure boundary conditions used in the analysis and provide justification for the selected values.

(j) The formation of scale on fuel rods due to materials suspended or dissolved in the post-LOCA coolant may reduce heat transfer from the core (e.g., via convection, radiation, conduction), especially for the BWR/2 analysis. Therefore, please (1) clarify how heat transfer assumptions in the analysis were modified to account for scale formation, or (2) confirm that additional analysis will be performed if future testing or analysis demonstrates that scale formation may impact cladding temperature limits.

RAI 23 S1:

(a) The results from the international knowledgebase report on strainer clogging, NEA/CSNI/R(95)11, presented in the response to part (a) of RAI 23 pertain to hot, submerged surfaces. The response does not provide adequate basis to conclude that thermal adhesion can be neglected for hot, unsubmerged surfaces that were the subject of part (a) of RAI 23. Thermal adhesion to unsubmerged, hot surfaces may affect all BWRs, but is presumably most significant for those without jet pumps, since the fuel cladding of hotter channels may remain at elevated temperatures for extended periods of time (e.g., [[ ]]). In these limiting scenarios, post-LOCA cladding temperatures could exceed the melting point for some types of debris (e.g., fiberglass). Although the period of spraying unquenched rods is expected to be significantly shorter for BWRs with jet pumps, thermal adhesion may still prove to be an important phenomenon that (1) increases the resistance of debris accumulations to removal by countercurrent steam flow and (2) generates nucleation sites for debris accumulation at larger grid openings where very fine debris that passed through the ECCS strainer might otherwise have significant difficulty being captured. Finally, as noted in RAI 24 S1, with [[ ]] blockage imposed at the fuel assembly outlet and CCFL present, the BWROG has not demonstrated that liquid coolant will be distributed to all fuel rods. Therefore, in light of the discussion above, please provide adequate technical basis to disposition the issue of thermal adhesion to unsubmerged, hot surfaces, or discuss plans to address the issue experimentally.

(b) Although testing of a submerged core is appropriate, Tests 4b and 4d do not address the issue raised in part (b) of RAI 23 related to boiling in the fuel assembly. The issue is associated with the redistribution and nonuniformity of debris transport and accumulation in the fuel channel, namely, the excessive washing of debris out the bottom of the fuel assembly by liquid water, some of which would have been vaporized under realistic thermal conditions. The transport of debris tends to correlate with the transport of liquid water via the entrainment process. Therefore, performing Test 4 at room temperature will result in excess liquid downflow through the fuel channel, which presumably will lead to excess debris entrainment and transport to lower spacer grids and potentially out the bottom of the fuel bundle. Whereas, in the plant condition, vaporization of the liquid coolant in which the debris is entrained would presumably result in substantially more of the debris being retained at the locations where vaporization occurred. Because all tests will be performed at room temperature, the potential for excessive washdown exists in 4b and 4d just as it does in 4a and 4c. Therefore, in light of the discussion above, please provide adequate technical basis that excessive washdown of debris with the fuel channel will not adversely affect the planned fuel assembly blockage tests.

RAI 24 S1:

The response to RAI 24 did not fully demonstrate the adequacy of a test acceptance criterion based solely on the coolant flow rate entering the bundle. Please address the following remaining issues:

(a) Sufficient information was not provided to conclude that a test acceptance criterion of [[ ]] blockage of the fuel channel outlet flow area (or similarly a [[ ]] reduction in flow) is adequate for Test 4. Depending on the specific configuration, blockage of this magnitude could interfere with the formation of falling liquid films on fuel rods and channel walls, result in a flow maldistribution within the fuel bundle, and/or shield some fuel rods from direct exposure to spray. Furthermore, this extent of blockage would presumably tend to reduce the fraction of droplets in the flow. These effects may degrade core spray heat transfer relative to the reference analysis predictions based on the SAFER evaluation model for BWRs with and without jet pumps. It is further unclear whether bench tests such as those alluded to in the response to RAI 24 part (a) would be capable of addressing these unresolved technical issues if significant debris blockage occurs. Therefore, if prior approval of the test acceptance criterion is desired, please provide additional information demonstrating that [[ ]] blockage at the fuel channel outlet will not degrade core spray heat transfer. Alternately, it may be possible to establish the conclusion of negligible degradation to core spray heat transfer due to the accumulation of post-LOCA debris *a posteriori* based on observed test results.

(b) The response concerning the potential for debris accumulation at multiple spacer grids does not account for (1) the potential for multiple CCFL locations (e.g., due to variation in flow area and steam flow along the bundle elevation) or (2) the additive nature of differential pressures due to debris accumulation at multiple spacer grids along the elevation of a fuel bundle. In both cases, despite satisfying the test acceptance criterion of no more than [[ ]] blockage at any given spacer grid, cumulative detrimental impacts may occur that are not bounded by the analysis performed by the BWROG which accounts for a single differential pressure drop due to [[ ]] blockage of the fuel channel outlet flow area. Please either (1) provide further technical basis to address the adequacy of the current approach in generality or (2) commit to addressing the technical issue *a posteriori* based on actual test results (e.g., by providing further technical basis for the adequacy of the current approach, modeling the actual test results in a revised analysis, etc.).

RAI 26 S1:

For the following reasons, the response to RAI 26 does not provide confidence that the technique of measuring differential pressures of post-LOCA debris accumulations with a slight airflow can provide a representative "loss coefficient" applicable under accident conditions with two-phase, counter current flow:

- Use of the "loss coefficient" concept implies that a flow restriction is geometrically invariant (e.g., as with an orifice). However, in general the dynamic differential pressure response of a compressible porous medium is affected substantially by factors such as the process fluid, flowrates for both liquid downflow and countercurrent steam upflow, and moisture content. Neglecting the impact of these factors on compressibility by measuring a "loss coefficient" under a slight single-phase airflow may significantly underestimate the impact of debris accumulation at the fuel assembly outlet under actual post-LOCA flow conditions.

- The references provided in the response discuss metal foams that, although porous, appear to be essentially incompressible under flow. Additionally, the porosities of the metal foams examined in the references generally appear somewhat greater than the porosity range at which post-LOCA debris accumulations are expected to become problematic. Furthermore, the references do not appear to demonstrate the utility and accuracy of single-phase air measurements under variable moisture levels as an estimator for two-phase differential pressure. Therefore, the relevance of the cited references to the proposed measurement technique appears limited.

- Staff confirmatory analysis suggests that, in the vicinity of the [[ ]] blockage limit proposed by the BWROG, the post-quench reheatup cladding temperature reached due to the imposition of debris blockage can be sensitive to modest changes in the percentage of area that is blocked. Aside from the potential sources of systematic error noted above, the uncertainty associated with the measurement technique may be significantly larger than the margin between the proposed debris blockage limit and the calculated blockage fraction at which the reheatup temperature criterion is exceeded.

- It is unclear that effects such as the stoppage of two-phase flow in the test rig and dryout of a debris accumulation in bench tests will not degrade its structure and properties.

In light of the issues listed above, please demonstrate that the methods currently proposed are adequate or propose alternate, technically defensible methods for determining the impact of outlet blockage on the capability to provide adequate long-term core cooling.

RAI 27 S1:

(a) The response to RAI 27 does not provide sufficient basis to conclude that satisfying the acceptance criteria for Tests 4a and 4c is sufficient to demonstrate adequate core spray cooling. For example, a [[ ]] (or [[ ]]) flow reduction in Tests 4a and 4c without CCFL suggests that an identical debris blockage restriction in the presence of CCFL would result in a larger reduction in liquid downflow than has been analyzed. Therefore, please justify the compatibility of the acceptance criterion for Tests 4a and 4c (which omits CCFL) with the criterion derived from the reference analysis (which models CCFL).

(b) The countercurrent upflow of steam may have a significant impact in delaying and/or reducing the impact of debris blockage at fuel channel outlets. However, lacking demonstration of the insignificance of a number of effects that could increase the resistance of debris to removal by steam upflow (e.g., thermal adhesion, boiling agglomeration, scale formation, oxidation, and crud buildup), performing clean-assembly room-temperature tests simulating the effect of steam upflow (Test 4b and 4d) may be nonconservative. Although the BWROG's RAI responses provided some information regarding the perceived impacts of these phenomena, ultimately that information (1) depends on unvalidated assumptions (e.g., regarding where debris blockage would occur, that core spray cooling would not be degraded) and (2) does not appear applicable to all operating BWR designs (e.g., BWR/2s). Therefore, please demonstrate that the above effects have a negligible impact on debris accumulation and retention in the core, explain how these effects can be accounted for in room temperature tests, or else refrain from crediting countercurrent gas flow with degradation or removal of debris accumulations from the test assembly at room temperature conditions.

RAI 28 S1:

(a) The NRC staff considers the countercurrent air flow in Tests 4b and 4d to be a critical parameter that should be chosen to bound operating BWRs. Therefore, please provide a graph of relevant simulation results showing the limiting flowrate and velocity of countercurrent steam flow versus time for the hot bundle and the average bundle at the channel outlet and most restrictive bundle elevation for (1) a partially submerged bundle, (2) a fully unsubmerged bundle, and (3) a fully submerged bundle, for the duration over which Tests 4b and 4d will be performed. Please further identify the air flowrate and injection velocity to be used as a function of time for Tests 4b and 4d and provide justification that these parameters are bounding for operating BWRs with and without jet pumps.

(b) Please clarify whether the air and liquid flows considered in Test 4b encompass accident conditions for which the upper plenum is covered and for which it has no accumulated liquid. If both conditions will not be tested, then please provide justification.

(c) Please clarify whether the proposed Tests 4b and 4d will consider the potential for CCFL at the most restrictive spacer grid that engages all partial length fuel rods. This spacer grid may represent a limiting location for CCFL in the presence of debris accumulation.

(d) Please confirm or correct the NRC staff's understanding that the statement in part (e) of the response to RAI 28 that a correction for steam condensation is unnecessary because coolant in a fuel channel is completely saturated is a description of the SAFER evaluation model that approximates the actual post-LOCA condition for the reactor. Please further explain whether the statement holds for all operating BWRs regardless of whether or not the core is fully submerged (as simulated in the newly added Test 4d) or whether coolant has accumulated in the upper plenum.

RAI 31 S1:

(a) In various places, the TR and RAI responses use percent blockage and percent flow reduction interchangeably, although these parameters are in general not equivalent. Also, while the response to RAI 31 states that Test 4 does not include the CCFL phenomenon, this only appears to be true for Tests 4a and 4c. To avoid ambiguity, please specify the acceptance criteria for Tests 3 and 4 unequivocally and justify the equivalence of the test acceptance criteria with the blockage assumptions made in the reference and supplemental analyses.

(b) The requested justification for the acceptance criteria specified for Tests 3 and 4 relative to assumptions in the reference analysis was not fully provided in the responses to RAIs 30 and 31. In particular, the responses do not demonstrate that allowing intermediate flow reductions earlier than has been analyzed (i.e., while fuel temperatures remain elevated) would not result in values of PCT and cladding oxidation that are higher than the BWROG has predicted. Therefore, please provide the results of revised analysis of the limiting case(s) (considering both the reference and supplemental analysis scenarios), demonstrating that a flow reduction schedule commensurate with the actual acceptance criteria proposed for Tests 3 and 4 will not result in increased PCTs or otherwise violate the proposed test acceptance criteria. If this analysis shows the intermediate acceptance criteria proposed for Tests 3 and 4 are nonconservative, then please propose new acceptance criteria that have been shown to be adequate in revised analyses that directly incorporate the allowable flow reductions.

(c) Please clarify the statement that the Case 4 reference analysis applies a spray flow that is lower than allowed by CCFL. Specifically, is the hot bundle spray flow simulated in the Case 4 reference analysis less than the CCFL downflow limit for both [[ ]] and [[ ]] blockage at the fuel assembly outlet? Please further address this question for the spray flow assumed in the BWR/2 supplemental analysis scenario (A-5) in Attachment A to Enclosure 2 of the second RAI response.

RAI 32 S1:

(a) With respect to assessing the impact of debris blockage, post-LOCA core flows for operating BWRs can largely be considered to be driven by static heads (e.g., due to the coolant level in the downcomer, bypass region, or upper plenum), rather than pump discharge heads. Thus, for test conditions where debris accumulations may be sensitive to removal by high differential pressures, ensuring adequate flow at the minimum available driving head represents a realistically conservative test. As such, please clarify the response to RAI 32, which appears to suggest in part (b) that the maximum driving head would be conservative.

(b) Part (c) of the response to RAI 32 suggests that the BWROG considers it conservative to simulate the fluid velocity with a higher priority than the available driving head. However, due to the potential for excessive differential pressures to break up and/or sweep debris accumulations from the core, it is unclear whether this assessment is correct. Furthermore, rapid flow changes or oscillations induced by automated pump control systems seeking to maintain constant flow in the test could degrade debris accumulations nonprototypically. Therefore, please clarify why it is not necessary to enforce a (time-dependent) limiting driving head for each test flow (i.e., some tests have upflow and downflow) that is based on the minimum driving head for the BWRs being represented by the test (considering the potential for reduced mixture densities under post-LOCA conditions), meanwhile ensuring adequate flow is delivered.

RAI 33 S1:

The response to RAI 33 does not distinguish between two cases: (1) a flow area (e.g., tie plate or spacer grid) that is [[ ]] blocked and [[ ]] open and (2) a similar flow area covered by a largely contiguous porous medium that develops a differential pressure equivalent to the first case under single-phase flow test conditions. Although the staff agrees with the technical analysis and reasoning in the BWROG's RAI response for the first case, it is not clear that the response adequately addresses the second case, when the potential for two-phase flows and CCFL are taken into account. Specifically, both from intuitive considerations associated with the change in the effective hydraulic diameter of the flow area, as well as empirical observations of significantly elevated porous medium head losses under two-phase flow, it is not apparent that two-phase flow through an arbitrary porous medium may be accurately modeled as flow through a non-porous flow restriction of equivalent single-phase pressure loss. Therefore, please provide additional technical justification specific to countercurrent flow through a porous medium that demonstrates that flow stoppage and formation of steam bubbles is not a concern for operating BWRs. Alternately, it may be possible to establish this conclusion *a posteriori* based on observed results of fuel assembly blockage tests.

RAI 34 S1:

The time duration of interest for Test 4 covers the full range of post-LOCA upper plenum conditions over the ECCS mission time. To ensure test prototypicality, please clarify the response to RAI 34 part (b) as to how liquid levels and flow conditions in the upper plenum and fuel channel that correspond to times beyond the analytical calculations (e.g., beyond [[ ]]) are identified and simulated in the test condition. In other words, as decay heat diminishes, do the mixture levels, fluid conditions, and flows in the upper plenum and fuel channels deviate meaningfully over the ECCS mission time from the analytically derived values used to define the test condition?

RAI 36 S1:

Please describe the sensitivity study that will be used to determine the limiting debris loading for Tests 1 through 3 and provide justification that the sensitivity study is capable of identifying the debris mixture for both the fuel assembly inlet and bypass leakage paths that is conservative in terms of its overall effect on PCT.

RAI 38 S1:

The response to RAI 38 references as-fabricated bypass clearance dimensions at room temperature. Please justify that any impacts to the clearances credited in the testing program due to installation in a reactor (e.g., thermal expansion, compression forces, crud and oxide buildup) are either negligible or are accounted for in the test setup.

RAI 40 S1:

The benchtop tests discussed in the response to RAI 40 appear useful for characterizing the debris accumulation properties and local impacts. However, factors that may significantly impact the characteristics of an accumulation that may not be modeled in the benchtop tests include (1) thermal adhesion, (2) flow characteristics governing local debris accumulation, (3) boiling/concentration of debris, and (4) the buildup of crud, oxide, and/or scale. Please describe the extent to which these factors will be considered in the characterization and provide a basis for any factors considered to have a negligible effect on the properties of debris accumulations.

RAI 41 S1:

The NRC staff does not agree with the technical justifications for (1) excluding the debris shield porous mesh filter from testing and (2) ranking the fuel filter designs in terms of expected debris accumulation behavior based on projected area that were provided in response to RAI 41. Rather, experience indicates that debris capture at locations with minimal clearance is a determining factor regarding whether and the extent to which blockage occurs. Furthermore, although a general conclusion cannot be made due to the wide variety of possible designs, the dynamic response of head loss per unit of accumulated debris may tend to be more limiting for flat porous mesh fuel inlet filters than those that rely on tortuous geometry. Therefore:

(a) In order to exclude non-limiting fuel designs from testing, at a minimum, please provide the following additional information:

i. Actual minimum clearance dimensions at each flow restriction (e.g., filters, tie plates, spacer grids).
ii. Actual flow areas for each flow restriction.
iii. A diagram of the limiting restriction(s).
iv. An evaluation of inertial capture at the openings of porous mesh fuel channel inlet filters and other restrictions (i.e., filtration), which cannot be determined solely or primarily through consideration of maximum changes in projected area.
v. As applicable, an evaluation of the expected difference in the dynamic response of head loss per unit of accumulated debris for porous mesh and tortuous fuel channel inlet filters, particularly in light of the short mission time the BWROG has proposed for crediting inlet flow.

(b) If test results from a porous mesh filter are to be used to justify not testing tortuous filters (or *vice versa*), then please justify the applicability of conclusions from one filter design to a fundamentally different design that is governed by different debris capture mechanisms and design parameters, and presumably has a different dynamic response to the accumulation of debris.

(c) Please confirm that the three fuel designs listed in Table 41b-1 are currently the only General Electric Hitachi (GEH)/Global Nuclear Fuels (GNF) fuel types that may be limiting hot bundles at operating BWRs. If this is not the case, then please provide design information relevant to debris blockage potential for the additional fuel types.

(d) Please clarify the statement in Table 41b-1 that the upper tie plate grid projected flow area is specified with "All Rods Inserted." Does the quoted phrase denote the projected flow area is for fuel bundles with only full length fuel rods?

(e) Please clarify whether there are GEH/GNF fuel assemblies that may be in service at operating BWRs with smaller fractions of long and short partial length rods than the BWROG plans to test. Please further clarify whether other fuel designs may have the uppermost fully rodded spacer grid at a higher elevation than those in Table 41b-1. With regard to the Test 4 condition, as well as the supporting analysis, it is not clear that the BWROG's program would bound such fuel assemblies, even if they are not hot bundles. Therefore, please either (1) include such fuel assemblies in the test program or (2) provide adequate justification if the BWROG intends to apply the results of the test program such assemblies.

(f) Please clarify the location of Flow Area 11 on Figure 41b-1.

RAI 42 S1:

The NRC staff understands GEH's observation regarding the limited influence of the core average power level for extended power uprate calculations. However, it is not clear that this experience applies to the scenario where debris blockage is postulated across the entire core inlet, which the supplemental analyses in Attachment A to the second RAI response now show to be limiting cases for BWRs with jet pumps. As noted by the BWROG in its discussion of these results (i.e., A-1 and the similar A-4), it is the higher coolant enthalpy in the upper plenum that influences the hot channel level and hence the hot channel PCT. Because upper plenum coolant enthalpy is presumably influenced by the core power, please provide additional technical basis and/or analysis showing that core power does not impact the magnitude of the hot channel heatup when debris blockage is postulated across the entire core inlet.

RAI 46 S1:

Please provide the requested information below that was not included in the RAI 46 response:

(a) Are minimum ECCS flows for all operating BWRs with jet pumps sufficient to preclude long-term uncovery below two-thirds core height for a pressure boundary rupture on reactor vessel bottom head penetrations (e.g., reactor water cleanup system vessel drain line, control rod drive housing)?

(b) If the response to part (a) is negative or undetermined, then please provide a more detailed technical basis and/or analytical calculation demonstrating that the rupture of reactor vessel bottom head penetrations would not become limiting for BWRs with jet pumps when post-LOCA debris accumulation is considered.

RAI 49 S1:

Please provide further clarification regarding the applicability and scaling of Tests 1, 2, and 3.

(a) Test 1 requires the injected ECCS flows to pass through bundle- or cell-specific leakage paths. For all jet pump BWRs, please identify whether the associated analysis credits additional leakage paths (e.g., bypass-to-lower plenum leakage paths) that are not included in the blockage test program, and whether such leakage paths are susceptible to debris blockage that could increase the time required to fill the lower plenum. If so, please discuss how this was factored into the test scaling.

(b) The description of Test 1 in Appendix A to the TR indicates that this test will be run for five minutes. Please confirm whether the integrated flow through the bypass flowpaths in this test will encompass the calculated integral flows for these flowpaths on a per bundle basis over the full time period these flowpaths are credited in the reference and supplemental analyses (i.e., including BWRs with LPCI injection into the core shroud). If integral flows corresponding only to lower plenum filling will be considered, please clarify whether Test 1 is sufficient to demonstrate that bypass leakage paths will not become blocked over the entire period for which they are credited for BWRs with LPCI injection into the core shroud.

(c) Please clarify whether potential reductions in the flow rate for Test 1 could impact Tests 2 and 3 and associated analysis for BWRs with LPCI injection into the core shroud. Specifically, significantly reduced flow rates in Test 1 at integrated flows corresponding to the reflood phase could imply that the minimum upflow rate intended for Test 2 cannot be provided due to upstream debris restriction at the bypass flowpaths. Similarly, significantly reduced flow rates in Test 1 at integrated flows corresponding to the post-reflood period prior to the assumption of inlet blockage could imply that the minimum flow rate intended for Test 3 is not achievable. How would the BWROG propagate potential flow reductions in Test 1 into succeeding tests and associated analysis if it becomes necessary for BWRs with LPCI injection into the core shroud?

RAI 50 S1:

According to data from the Multirod Burst Test Program in NUREG/CR-0103 and NUREG-0630, fuel cladding swelling of 5 to10 percent was measured adjacent to spacer grids. While this range is significantly lower than the swelling measured between grids, based on typical fuel rod dimensions, it corresponds to an increase in cladding outer diameter greater than the length of over three-quarters of the fibers reported to have passed through the strainers of PWRs in WCAP-16793-NP. As such, it is not clear that the potential for the swelling of fuel rod cladding, when taken in combination with other effects, such as crud buildup, scale formation, and oxide formation, can be considered negligible with respect to the accumulation of the very fine debris that passes through a strainer. In light of the discussion above, please clarify the rod-to-spacer grid dimension and provide additional technical basis that fuel cladding swelling, in concert with other effects that can affect fuel assembly minimum clearances and surface properties, need not be considered in the fuel assembly blockage testing program.