July 21, 2011

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 LICENSING 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 Accession No. ML110140479), 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." Upon review of the information provided, the NRC staff has determined that additional information is needed to complete the review. On June 6, 2011, Mr. Robert Whelan, Project Manager, and I agreed that the NRC staff will receive your response to the enclosed Request for Additional Information (RAI) questions within 10 weeks of receipt of this letter. A proprietary version of the RAI questions was provided electronically to Mr. Whelan on July 12, 2011. Therefore, enclosed is the non-proprietary version. Information that has been redacted due to it being proprietary is indicated by double brackets [[ ]]. If you have any questions regarding the enclosed 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

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Boiling Water Reactor Owner's Group Project No. 691

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REQUEST FOR ADDITIONAL INFORMATION

BY THE OFFICE OF NUCLEAR REACTOR REGULATION

NEDC-33608P, REVISION 2, BOILING WATER REACTOR

EMERGENCY CORE COOLING SUCTION STRAINER

IN-VESSEL DOWNSTREAM EFFECTS

BOILING WATER REACTOR OWNERS' GROUP

PROJECT NO. 691

1. Please provide adequate technical basis for concluding that the analysis of a single accident scenario (a recirculation suction line break) for a reference Boiling Water Reactor (BWR)/3 plant can be considered bounding for all relevant in-vessel blockage impacts of post-loss-of-coolant accident (LOCA) debris for all BWRs to which the Licensing Topical Report (LTR) is intended to apply. Please consider the following specific items in the response:

a. The recirculation suction line break scenario analyzed in the LTR appears to have been selected based on its potential to be limiting with respect to peak cladding temperature in the absence of post-LOCA debris. Adequate justification was not presented to conclude that this scenario is necessarily limiting once the impacts of post-LOCA debris have been included, particularly with regard to long-term cooling over the duration of the system mission time.

b. According to the LTR methodology, the impacts of post-LOCA debris blockage are to be shown to be acceptable on an individual basis for four separate cases considered independently (i.e., lower plenum refill, core reflood, core inlet blockage, and core outlet blockage). The LTR presumes that the recirculation suction line break scenario results in the limiting impacts from post-LOCA debris for all of the cases. Adequate justification has not been provided to conclude that the limiting accident scenario (e.g., break location, available emergency core cooling equipment) need not be determined and analyzed for each of the four cases on an individual basis.

c. LOCA scenarios in which core sprays are unavailable exist for most operating BWR designs. Therefore, if debris blockage at fuel assembly inlets and support grids could impede the operation of the low-pressure coolant injection (LPCI) system, an accident scenario with core sprays unavailable could potentially be more limiting than the analyzed scenario, particularly with respect to ensuring adequate long-term core cooling.

ENCLOSURE

d. Adequate justification has not been provided for the LTR's position that blockage of the entire core or some number of adjacent fuel assemblies could not result in a more limiting condition than the case of a single blocked fuel assembly that was analyzed in the LTR. Although the BWR/3 reference analysis in the LTR appears broadly representative of post-LOCA behavior for the majority of operating BWR plants with jet pumps, adequate basis was not presented to support the BWR Owners Group (BWROG) conclusion that it can be considered bounding with respect to all operating BWRs to which the LTR is to be applied.

f. Different pipe breaks can generate different debris loadings, with different debris constituents. It is not clear that the most limiting break can be determined generically without regard for plant-specific differences in debris loading.

2. Please confirm whether the LTR methodology is applicable to BWR/2s. It is unclear to the NRC staff that the limiting scenarios, analytical results, test descriptions, and test acceptance criteria included in the LTR adequately consider unique aspects of the BWR/2 design that are fundamentally different from later BWRs with jet pumps and enhanced emergency core cooling system (ECCS) designs. Therefore, if applicable to BWR/2s, please provide, or else clarify why the LTR does not need to provide, separate analysis, test descriptions, and test acceptance criteria that are tailored to BWR/2 reactors.

3. Please provide the following additional information regarding Tables 4-1, 4-2, and 4-3:

a. Confirmation that the information in these tables has been validated against plants' current licensing bases as documented in the current versions of their Final Safety Analysis Reports (FSARs). Based on a sampling review conducted by the NRC staff, apparent inconsistencies were identified between Tables 4-2 and 4-3 and plant FSARs. If corrections are necessary, please provide the revised information and update the LTR.

b. Clarification as to how the most limiting ECCS configurations were determined in Table 4-3, and whether the effects of post-LOCA debris were accounted for in the determination. For example, depending upon the assumed single failure, a LOCA on the high pressure core spray system piping of a BWR/6 could presumably lead to a scenario with two LPCI pumps available or the scenario with one core spray pump and one LPCI pump designated in Table 4-3 as representing the "minimum ECCS available." In light of the as-yet-undetermined impacts of post-LOCA debris, it is not clear to the NRC staff that definitive conclusions can be reached regarding which single failure would result in the most limiting condition.

4. Debris laden coolant flows may be injected into the reactor vessel for core cooling for an extended period of time following a design-basis LOCA. During this extended period, continual boil-off of injected water has the potential to lead to significantly elevated concentrations of debris within the reactor vessel. The consequent effects on formation of additional solids and debris accumulation behavior inside the core do not appear to have been considered in the LTR. For example, the static debris concentrations specified in the "Range of Key Test Parameters" (e.g., in Table 5-1) all specify time periods of [[   ]] hour(s) or less and appear to reference debris concentrations in the inlet flow stream. Please clarify how the phenomenon of

long-term debris concentration inside the reactor vessel is being addressed in the BWROG analysis and test program for downstream in-vessel effects.

5. A significant number of BWR licensees have adopted the alternate source term. As such, the standby liquid control system (SLCS) would be used to inject sodium pentaborate solution into the reactor vessel following a LOCA to control the pH in the suppression pool. The LTR does not address whether significant debris blockage in the reactor core could inhibit mixing and thereby promote boron precipitation inside the reactor vessel. Please address this concern, if possible generically, accounting for the fact that differences in plant configurations would influence the expected behavior. For instance, considering a plant design with LPCI into the recirculation lines and SLCS injection through a core spray line, could boron precipitation occur if significant debris blockage occurred at the core inlet?

6. The current BWROG approach appears to treat in-core debris accumulation and chemical scale/crud buildup as separate and independent issues. However, in that the formation and buildup of scale or crud deposits could affect debris accumulation via impacts to available debris quantities, clearance dimensions, and surface characteristics such as roughness, it is not clear to the NRC staff that the interactions between the two phenomena can be presumed to be negligible. Therefore, please provide adequate justification that debris accumulation tests performed with clean fuel assemblies can adequately represent the debris accumulation behavior that would be experienced by prototypical plant fuel assemblies that have experienced deposits of scale/crud in the post-LOCA environment as well as during normal operation.

7. The LTR presumes that core heatup would not occur after the completion of reflooding based on an expectation that future testing of fuel assemblies with debris-laden coolant would not result in significant debris accumulation. However, the ultimate outcome of these future tests is not certain, and it is possible that this expectation may not materialize. Furthermore, even if the test acceptance criteria are satisfied, analytical Sensitivity Case 4 results in two additional cladding temperature increase cycles, each with an amplitude of approximately [[ ]] °F, when significant debris blockage is postulated to occur in the process of quenching the fuel. Therefore,

> a. Please discuss the extent to which testing for degradation mechanisms associated with significantly reheating and quenching previously quenched or partially quenched fuel rods demonstrates that the ductility and strength of the cladding remains sufficient to satisfy the criteria in Title 10 of the *Code of Federal Regulations* (10 CFR) 50.46.
>
> b. Please clarify whether it is necessary to establish acceptance criteria (e.g., reheatup limits for cladding temperature and oxidation) to ensure that additional heatup and quenching cycles and/or steady-state heatup due to the accumulation of post-LOCA debris would not result in noncompliance with the criteria in 10 CFR 50.46.

8. With the exception of the modifications described in Section 3.3.5, please confirm that the application of SAFER/GESTR-LOCA used to generate the analysis documented in the LTR was performed in a manner that is consistent with the method accepted in the NRC staff's safety evaluation, including conditions and limitations specified therein, or else identify and justify areas where deviations exist.

9. Please provide additional physical explanation for the calculated result that blockage of bypass leakage paths (Sensitivity Case 2) has a more significant impact in extending the duration of the reflood phase than blockage of the side entry orifice (Sensitivity Case 1).

10. Please define the variable X as used in the last equation on page 11 and clarify the intent of the final steps of the derivation.

11. While potentially justifiable for application to non-predictive simulation of single-phase pressure drop induced by post-LOCA debris accumulation in the core, the technical basis for the LTR's conclusion that a blockage multiplier may be used to modify the geometrically restricted area associated with the countercurrent flow limitation is not clear to the staff. In particular, it is not clear that this approach adequately considers geometric aspects associated with countercurrent flow that typically require correlations to be based on experimental data obtained using a representative geometry. Please provide adequate technical basis to conclude that the effect on countercurrent flow due to potentially significant porous-medium flow restrictions constituted by post-LOCA debris can be adequately modeled through an area reduction multiplier to the existing analytical formulation that does not consider debris blockage.

12. Please specify the elevations of the top and bottom of the active fuel and the peak cladding temperature for the reference analysis.

13. The LTR methodology treats the four test conditions separately and independently of each other. That is, each test condition is begun with a clean fuel assembly/bypass region, even those that simulate conditions that would exist at later stages of an accident; whereas, at an analogous accident stage, a prototypical plant fuel assembly/bypass region may have already accumulated non-negligible quantities of post-LOCA debris. Therefore, the LTR's approach appears justified in general only in the case that preceding tests simulating earlier phases of the accident result in negligible debris accumulation. Please identify whether the BWROG agrees with this statement; if not, please provide adequate basis for considering testing conducted with a clean assembly/bypass region to be sufficiently representative of actual plant conditions in which non-negligible quantities of debris may have accumulated in the fuel assembly/bypass region prior to the phase of the accident simulated in the test.

14. For Tests 1 and 2, the acceptance criteria are based on the principle that each test should not individually result in a calculated peak cladding temperature increase greater than 50 °F. These criteria appear to have been derived from 10 CFR 50.46 in a manner that is inconsistent with language in the rule indicating that the rule's criterion applies to "a cumulation of changes and errors such that the sum of the absolute magnitudes of the respective temperature changes is greater than 50 °F." Therefore, rather than being applicable to individual tests, this temperature criterion is to be evaluated against the temperature increase resulting from all of the tests taken together, as well as other potential post-LOCA debris effects that could affect the peak cladding temperature, even those outside the scope of the present LTR (e.g., scale buildup, obstruction of core spray nozzles). Furthermore, the regulatory purpose of the 50 °F criterion is specifically in reference to the permissible time limit for reporting changes and errors to the NRC; even below this threshold, 10 CFR 50.46(a)(3)(ii) requires that smaller temperature changes be reported at least annually, along with an estimate of the effect on the limiting

analysis. Please revise the acceptance criteria for Tests 1 and 2 for consistency with the requirements of 10 CFR 50.46, or else provide adequate justification that the existing acceptance criteria are consistent therewith.

15. Based on a sampling of peak clad temperatures reported in licensing basis documents for several plants with Global Nuclear Fuel (GNF)- and General Electric (GE)-supplied fuel that demonstrate higher temperatures than those analyzed in the LTR, it is not clear why the LTR's analysis is characterized as bounding. Although its intent is not transparent, the LTR itself seems to acknowledge this circumstance in Section 3.4.1, where it states that, for some jet-pump plants, the core reflood time could be closer to [[ ]] seconds rather than the [[ ]] seconds used in the reference analysis. The time at which core heatup ceases for BWR/2s is not provided, but the LTR implies it is in excess of [[ ]] seconds.
Therefore, please provide acceptable guidance and criteria to clarify the applicability limits of the LTR analysis; or else, please provide additional analytical cases addressing fuel heatup conditions that are bounding for all operating BWRs. Alternately, please provide adequate justification that results derived from the LTR reference analysis can be generally applied, even in plant-specific cases where heatup durations and peak cladding temperatures are significantly greater.

16. The LTR indicates in Section 3.3.3 that GE14 fuel was used in the reference analysis. However, the LTR does not document a systematic evaluation justifying that GE14 fuel is bounding relative to other GE or GNF fuel types currently in use at BWRs. The LTR further indicates (e.g., pages 39 and 49) that the peak power factor is the only relevant fuel characteristic necessary to ensure that the reference analysis is bounding for a given plant. However, in the staff's view, other design features such as lattice geometry and design linear heat generation rate are also relevant. Consideration of such parameters suggests that fuel designs other than GE 14 that are currently in use at operating BWRs may be more limiting with respect to peak cladding temperature and other regulatory limits. Therefore, please provide adequate justification to support the following LTR positions:

a. An analysis with GE14 fuel provides limiting peak cladding temperature results relative to the other fuel types manufactured by GE or GNF that are currently in use at BWRs.

b. Peak power factor is the only fuel-related parameter that BWR licensees need to consider in validating that their plants are bounded by the reference analysis with respect to peak cladding temperature and other regulatory limits for fuel cladding.

17. The LTR calculates heatup rates from the reference analysis that are intended for general application in estimating core heatup due to delays in lower plenum refill (Test 1) and core reflood (Test 2) resulting from post-LOCA debris accumulation. These heatup rates are presented empirically, without theoretical basis or physical limitations on their usage.

a. Please provide adequate physical basis for the validity of these rates of temperature increase for time delays and temperature ranges that may exceed those in the reference analysis and identify any limitations on their usage. For instance, a calculated heatup rate that accounts only for initial stored heat and generated decay heat would be inapplicable in regimes where exothermic metalwater reactions contribute substantively to the heat load.

b. Regarding Test 2, please provide adequate physical basis for using a reduced average heatup rate for delays caused during reflood as compared to refill. Based on the calculated analytical results, it appears to the NRC staff that the rate of temperature increase is roughly constant prior to the water level reaching the approximate location of the peak clad temperature; thus, the primary effect of a delay may be to extend the linear portion of the temperature increase.

c. To the extent not adequately addressed in responses to other requests for additional information, please clarify why the heatup rate associated with GE14 fuel is bounding relative to other fuel types, such as those having higher design linear heat generation rates and/or more thermally limiting lattice geometries.

18. Please provide further clarification concerning the following items associated with Tests 1 and 2:

a. For Test 1, the LTR indicates on page 33 that the typical flow rate presented in Figure 3.1-4 for the early refill period will be used. Please clarify whether the intended reference is Figure 3-4 or a different figure.

b. Please clarify whether the use of the hot bundle flow rate for Test 1 as opposed to an average bundle flow rate would be conservative or prototypical.

c. Please clarify whether LPCI flow is intentionally neglected (e.g., as a conservatism) or is otherwise accounted for in the scaling of Test 1 in determining the heatup impacts of a delay in lower plenum refill associated with post-LOCA debris blockage.

d. The flow rate is specified for Test 2 on page 33 through reference to the typical flow rate in Figure 3-3 for the reflood period. However, this specification does not appear sufficient to determine the flow split between the upward and downward branches of the test setup. Please clarify.

19. Please clarify why it is not necessary to model the control blade and top guide in Test 2.

20. Please provide adequate basis for the criterion in the LTR that the measured flow rate in Tests 1 and 3 shall not exceed 200 percent of the maximum predicted flow (as well as the equivalent criterion for Test 2 that the rate of water level rise shall not exceed 200 percent). Although some variation is expected, it is not clear to the staff that the proposed limit of 200 percent is sufficiently restrictive. One explanation for increases in flow rate and rate of water level rise relative to analytically calculated values is that the code results are overly conservative; in some cases, the absence of boiling in the test setup may also contribute. Alternatively, the discrepancy could imply that clearances in the test setup and mock fuel assembly are non-conservatively large (and thus less capable of capturing debris) relative to the prototypical plant condition, that the introduction of flow is not prototypical (and thus may tend to carry debris through the assembly more readily), that the scaling of the lower plenum in the test

setup was not correct, etc. Please discuss the extent to which the analytical model should be expected to underpredict conservatively the flow rate and rate of water level rise, referencing previous experiments, if available, that demonstrate prototypical behavior (e.g., test data used to benchmark code predictions).

21. Please revise the plan for Test 3 (core inlet blockage) to include consideration of long-term behavior; or else, provide adequate basis for considering a test length of [[ ]] minutes to be adequate. As noted above, accidents within most BWRs' licensing bases (e.g., core spray discharge line break) may require long-term cooling through the fuel assembly inlets using the LPCI system. As further noted above, the potential exists for debris blockage to occur at more than one fuel assembly. Therefore, it is not clear why long-term testing using the Test 3 configuration to demonstrate acceptable heat removal from the core is unnecessary.

22. Please provide adequate technical basis for considering [[ ]] hour to be a sufficient period for Test 4 to model the accumulation of debris that can occur over a 30-day period. The NRC staff's position is that, while tests can generally be designed with durations much shorter than system mission times, all relevant effects from debris accumulation in the reactor core that could occur within the system mission time should be considered in the test. Therefore, for Test 4 and, as applicable per the previous request for information, Test 3, please provide adequate basis to demonstrate that the planned testing will model all relevant post-LOCA debris accumulation effects inside the reactor core that could occur during the system mission time.

23. The LTR states that the testing of fuel assemblies with debris-laden water will be conducted at room temperature. Testing at room temperature would not account for two phenomena that would affect the quantity of debris that could accumulate in a fuel assembly, as well as its distribution within the assembly. Sufficient justification was not presented to justify the neglect of these phenomena. Please consider the Test 4 condition (for plants with and without jet pumps) in responding to the following items:

a. Please provide adequate basis that it is not necessary to model explicitly or otherwise account for the potential behavior of debris entrained in cooling water flows contacting and, following vaporization of the entraining water, stubbornly adhering to or "burning onto" hot, unsubmerged fuel rods, tie plates, grids, and other heated surfaces. Please further identify predicted surface temperatures for unsubmerged fuel rods and other relevant structures following a LOCA.

b. Please provide adequate basis that the absence of boiling in the test condition would not lead to excessive washing of debris from the upper tie plate, spacer grids, and even out of the test fuel assembly, in a manner that is not prototypical of the plant condition. As noted on page 66 of the LTR, in the plant condition, very little of the debris-laden water flows through the lower tie plate.

24. The acceptance criteria for Test 4 would permit a flow reduction at the upper tie plate or any spacer grid not greater than [[ ]] percent over the first [[ ]] minutes after injection, and not greater than [[ ]] percent in the long term. Please provide adequate technical basis for the conclusion that exceedance of a specified flow rate (and in particular the chosen flow rates) at the upper tie plate and spacer grids is in itself sufficient to ensure that the criteria of 10 CFR

50.46 would be satisfied and that unacceptable re-heatup due to post-LOCA debris accumulation would not occur, for each of the fuel rods in an assembly. In so doing, please clarify why it is not necessary also to specify criteria for the flow distribution entering and passing through a fuel assembly, considering the following specific items:

a. Should significant blockage occur such that core spray flow drains into (or through) the fuel assembly predominately through one or several discrete openings at unspecified locations in the upper tie plate (or a spacer grid) at a rate exceeding the test acceptance criteria, what is the basis for having assurance that adequate cooling is provided to fuel rods not directly exposed to drainage?

b. The degree of debris blockage can significantly influence the efficiency of the heat removal process by affecting the proportion of flow that enters an assembly in the form of dispersed droplets with high interfacial area, as opposed to liquid streams pouring through openings in a debris bed and interacting significantly less with the fuel rods and surrounding steam environment. It is unclear whether this effect has been adequately considered in the analysis used to determine that acceptable cooling would be assured by satisfying the Test 4 acceptance criteria.

c. It is not clear that an accumulation of debris at multiple elevations within the fuel assembly (i.e., upper tie plate and upper spacer grids), even if less than [[ ]] percent at each elevation, could not lead to results more limiting than the analyzed case. For example, blockage at multiple elevations within the fuel assembly could result in additional locations where countercurrent flow limitations are significant.

d. Similar limitations to those noted for flow rate measurements above are also associated with the planned measurement of differential pressure in Test 4 using air flows.

e. The response should explicitly include discussion of BWR reactor designs with and without jet pumps. In particular, it is not obvious that satisfaction of the acceptance criteria for Test 4 provides assurance that temperature and oxidation limits will not be exceeded over all elevations of fuel rods, nor that the cooling to the core would be adequate to prevent unacceptable re-heatup, for scenarios in which water coverage of the majority of the reactor core could not be provided.

25. Please provide adequate basis for designing the setup for three of the tests with an inlet hopper that is elevated significantly above the top of the channel box. The height of the inlet hopper is significant because, should debris accumulate at the fuel assembly outlet, the static head of liquid above the fuel assembly outlet would provide a source of energy to drive water through this accumulated debris. Under plant conditions, however, should significant differential pressure result from debris accumulation at the fuel assembly outlets, the prototypical plant geometry may not be capable of accumulating a substantial height of cooling water above the upper tie plate. Rather, relatively small differential pressures at the fuel assembly outlet could lead to the diversion of a significant portion of the core spray flow to bypass regions (or possibly other fuel assemblies). Please discuss relevant details of prototypically modeling the geometry at the fuel assembly and bypass region outlets in the test setup, the use of a sparger to model

core spray injection in Test 4 but not for the downward flow in Tests 1 and 2, and the maximum static head available to drive water through a debris bed formed at the fuel assembly outlet at different stages of the event. Please clarify how the design of the test setup will ensure that the potential for core spray flow diversion away from the active core region is modeled prototypically for the time periods considered in the tests.

26. Please provide adequate basis for concluding that the technique of measuring the pressure drop across a wetted porous medium of accumulated debris using an air flow is capable of providing results that can be accurately correlated to the pressure drop associated with liquid and two-phase flows. It is unclear to the staff that difficulties associated with the difference in process fluid, moisture content, bed compressibility, and debris bed deformation would not have substantial adverse effects on the measurement. Please include reference(s) to experiments where this technique has been validated or otherwise demonstrated to be effective and characterize the associated uncertainty. Please further clarify the extent to which an asymptotic approach to a steady-state pressure drop can be demonstrated in the initial testing to establish duration, given the uncertainty associated with the measurement technique and the expectation of relatively sparse data as a function of time. Finally, please clarify how test technicians will verify that degradation to debris accumulations in the fuel assembly has not occurred during the initial testing to establish duration, due to effects such as the stoppage and restarting of liquid/two-phase flow and dryout of the debris bed, arising from the measurement of differential pressure with air flow.

27. The LTR reflects the BWROG's conclusion that Test 4b, which would model core spray cooling with countercurrent air flow, would be less limiting than the similar Test 4a that does not include countercurrent flow. Although this conclusion may prove correct for a debris accumulation test conducted at room temperature using total flow rate as an acceptance criterion, under prototypical plant conditions with enhanced debris adherence to heated surfaces, the combination of debris blockage and countercurrent steam flow could potentially create more limiting conditions with respect to satisfying the criteria of 10 CFR 50.46. Therefore, please address the following items:

> a. Please provide adequate technical basis to support the conclusion that satisfying the acceptance criteria for Test 4a provides adequate assurance that core spray cooling will not be prevented by debris blockage.
>
> b. Please provide adequate technical basis to support the conclusion that, if the acceptance criteria of Test 4a are not satisfied, acceptable cooling by core spray could be demonstrated by passing Test 4b at room temperature conditions. Furthermore, it is not clear, even in the case that Test 4b were to pass using a short-term steaming rate, that debris blockage at the core outlet would not be a concern later in the event after high steaming rates have subsided.

28. Please provide further information concerning the method for introducing air into the fuel assembly in Test 4b to support the LTR's conclusion that the influence of the air flow on debris accumulation would be prototypical of plant conditions:

a. Please identify the location(s) at which air would be introduced and the extent to which it would be introduced in a distributed manner that is representative of the generation of vapor during the boiling process, without interfering with the prototypical fuel bundle geometry.

b. In order to scale the test flow rate based on dynamic head, limiting values of primary system pressure and temperature conditions must be considered as a function of time. Please provide this information graphically.

c. Please clarify to what extent the dynamic head and other features of the injected spray flow will be modeled prototypically with respect to the plant condition.

d. Please identify the range of limiting gas phase volumetric flow rates to be considered in the plant and test conditions as a function of time.

e. Please clarify whether corrections to the test air flow rates are necessary to account for steam condensation due to interaction with core spray or other coolant flows in the plant condition.

29. The debris loading for each of the four tests is specified in terms of a concentration at a fixed time following injection. Please address the following items associated therewith:

a. Based on the information available to the NRC staff, the current state of knowledge relative to debris transport behavior is not sufficient to support accurate best-estimate calculations of debris transport at discrete points in time following a LOCA. For instance, shortly after a LOCA occurs, the concentrations of different debris constituents in the suppression pool supplying low-pressure ECCS pumps may be changing rapidly. At longer times after a LOCA, the debris concentration determination may be based on methods for determining debris settlement that lack a robust technical foundation.

Without an understanding of the BWROG's time-dependent transport methodology and associated conservatisms, it is unclear whether the specified times of [[ ]] minutes and [[ ]] minutes for determining the in-vessel test debris concentrations are acceptable.

b. Although specification of a debris concentration appears largely sufficient to determine the debris loading for the short-term, once-through tests (Tests 1 and 2), in the NRC staff's view, specifying a concentration is not in itself sufficient for the long-term tests that recirculate test fluid. For the long-term, recirculation tests (Tests 3 and 4), while modeling representative debris concentrations is appropriate, of primary importance is the total quantity of debris added to the test. Please revise the LTR to include additional requirements for Tests 3 and 4 to ensure that the total quantity of debris added is prototypical (i.e., when scaled per fuel assembly), including the effects of non-uniform flow distributions to the fuel assemblies, or else adequately justify the current approach.

c. Please clarify whether boiling is sufficiently important for the Test 2 condition to require a correction to the debris concentration in the test fluid to ensure that the total quantity of debris injected at the end of the test is prototypical of the plant condition.

30. Please provide the following additional information concerning the modeling of the flow rate in Test 3:

a. Please clarify whether the flow rates as a function of time reproduced in the table below represent acceptance criteria or instructions for controlling the test flow rate. Please further justify the selection of these values relative to the reference analysis results.

Test Time	Flow
1 minute	≥ 75%
2 minutes	≥ 50%
3 minutes	≥ 25%

b. Presumably, the intended flow rate parameters, the acceptance criteria above, and the further criterion of 100 percent blockage not occurring at the lower tie plate (and/or spacer grids) at one or more fuel assemblies within 3 minutes would not be sufficient for scenarios where core sprays are not available. Please provide appropriate test parameters and acceptance criteria for this scenario.

31. Please address the following observations that the LTR has not adequately justified the acceptance criteria for Tests 3 and 4 based on the results of the reference analysis:

a. The Test 4 acceptance criteria are specified in terms of a percentage flow reduction, whereas the analysis of Sensitivity Case 4 on which the criteria are presumably based specifies post-LOCA debris blockage in terms of an identical percentage flow restriction. Directly equating a percentage flow reduction with the same percentage flow restriction appears unjustified; for example, as seen in Figure 3-16 in the LTR, a 50 percent flow restriction in Sensitivity Case 4 appears to result in steady-state flow reductions closer to [[ ]] percent.

b. The acceptance criteria for Tests 3 and 4 would allow partial flow reductions prior to the times at which blockage is imposed as a step function in the associated analytical sensitivity cases. That is, the Test 3 acceptance criteria would permit a 25 percent flow reduction one minute sooner than analyzed, and the Test 4 criteria would permit a 25 percent flow reduction up to ten minutes sooner than analyzed. In that heat loads are most significant immediately following the LOCA, such flow reductions would presumably lead to elevated PCTs that have not been analyzed in the reference analysis.

32. Please provide adequate basis for the allowable ranges of driving head for the fuel bundle debris blockage tests to demonstrate that the allowable ranges are prototypical or conservative relative to limiting conditions for operating BWRs when considering potential blockage effects for both a single assembly as well as all assemblies in the core. Please clarify assumptions regarding the source of available driving head, the limiting core pressure drop in the absence of post-LOCA debris, and how any impacts of scale or crud buildup could affect the available driving head for long-term tests.

a. The use of [[ ]] psid for Test 1.

b. The use of [[ ]] psid for Test 3.

c. Please also clarify why driving head limits are not specified for Tests 2 and 4.

33. The LTR does not specifically address the phenomenon of debris blockage at spacer grids reducing flows through the core to the extent that steam bubbles could form in the relatively stagnant coolant upstream of the debris accumulation. The stoppage of flow and formation of steam bubbles would reduce heat transfer, resulting in increased fuel rod cladding temperatures. Please clarify how this phenomenon has been addressed by the LTR, and the basis for concluding that the differential pressures permitted by the test acceptance criteria would not result in the occurrence of this phenomenon to an extent that would cause unacceptable heatup of the fuel.

34. Please provide adequate basis to support the LTR's position that the flow rate used in Test 4 should be based on the analytically calculated rates of liquid downflow in Figures 3-15 and 3-16 considering the following items:

a. Please clarify whether the liquid downflow shown in these figures is predominately due to core spray or whether it also consists of substantive quantities of spillover from the LPCI system that would not be present if the fuel assembly inlets across the entire core were blocked.

b. Data for Figures 3-15 and 3-16 is only provided to 2500 seconds, whereas Test 4 should consider debris blockage impacts over the entire system mission time. Important phenomena influencing downflow through the fuel assemblies during the period considered in the reference analysis, such as pooling of liquid in the upper plenum, are dependent on the decay heat loading and may be of reduced influence at later stages of the system mission time that were not analyzed.

c. The proposed range of flow rates for Test 4 is 1 to 10 gpm. This is a large range, and in particular, 10 gpm appears somewhat higher than typically expected steady-state values over the system mission time. Use of excessive flow rates may lead to non-prototypical washout of debris from the fuel assembly, particularly in a room temperature test environment.

d. It is not clear that acceptance criteria determined from a generic calculation should serve as test parameter inputs in place of limiting core spray flow rate values from operating BWRs' licensing bases.

35. The LTR indicates that minimal emergency core cooling system flow rates are considered limiting for debris accumulation testing. Although minimal flow rates may prove limiting for some of the tests, it is not clear that minimum flows can generally be assumed limiting, particularly for the Test 3 condition. The NRC staff expects the flow rate to be an important parameter that would influence the distribution of post-LOCA debris in the core and potentially the debris

mixture that results in the limiting differential pressure. Furthermore, higher flow rates may lead to larger differential pressure values in some tests that consider differential pressure among the acceptance criteria. Therefore, please discuss whether a bounding envelope of flow rates will be examined in circumstances where minimum flow rates cannot be presumed limiting.

36. The LTR does not provide sufficient discussion regarding the determination of the limiting debris loadings and addition procedures for the various test scenarios.

a. Please confirm that the BWROG will provide opportunity for NRC staff review of the test plan, including debris loadings, concentration time histories, and characteristics, prior to the commencement of fuel assembly testing.

b. Although the BWROG Source Term Subcommittee may define maximum quantities of post-LOCA debris that passes through the suction strainers, based on previous testing conducted for pressurized-water reactors, it is not clear that the maximum quantity can be assumed to provide the most limiting results. Specifically, certain ratios of particulate debris, microporous debris, fibrous debris, and chemical precipitates may result in more limiting head losses than a case with the maximum quantity of each debris type. Please discuss plans for sensitivity testing or other means of examining limiting debris loadings and addition procedures for the four test scenarios to ensure that the most limiting conditions have been assessed in the test program.

c. Recognizing that the limiting debris loading condition for each of the four fuel assembly debris blockage tests in Table 3.6.5-1 may be different, please clarify how the results of these tests will be integrated to determine an acceptable debris loading for all operating BWRs.

37. Please either demonstrate that the use of parameters from the reference analysis would provide bounding inputs for conducting debris accumulation testing for all operating BWRs, or else include guidance in the LTR that the parameters to be used for testing (e.g., debris loadings, flow and water level rise rates, differential pressures, etc.) are to be verified by BWR licensees to be prototypical or conservative relative to limiting plant-specific values prior to applying the results of the BWROG test program.

38. Please provide the following additional information regarding the bypass leakage paths:

a. Please confirm or correct the NRC staff's interpretation that Figure A-2 of the LTR indicates that the BWROG test setup will model the flowpaths labeled 1, 1a, 2', 7, and 8 on Slide 17 of the BWROG's November 17, 2010, slide presentation to the NRC staff regarding downstream effects.

b. Please specify the characteristic dimensions of the bypass clearances modeled in the testing and clarify the degree of conservatism associated with any leakage paths that will be neglected in the test program.

c. Using the same convention as in part (a) above, please identify the specific bypass path(s) modeled in the reference calculation as LEAK and which were blocked in Sensitivity Cases 2 through 4.

39. Provided the reference calculation is shown to be limiting for all operating BWRs, the NRC staff would largely agree with the options for addressing deviations from test acceptance criteria specified on page 55 in Appendix A of the LTR. However, Sections 6 and 7 of the LTR also contain a non-specific allowance that, if acceptance criteria are not satisfied, “the justification for equivalent cooling to achieve the overall equivalency as in the reference bounding LOCA case will be given.” Section 5 includes a similar provision that plants may justify that a deviation from the test acceptance criteria is inconsequential to cooling requirements. Please clarify whether the cited phrases from Sections 5, 6, and 7 refer to plant-specific actions and methods that are beyond the scope of the LTR, or else provide the methodology that would be used for these demonstrations if different than specified in Appendix A.

40. Please clarify further how the effects of concentrated local debris accumulation adjacent to fuel rods (e.g., at spacer grids) will be evaluated, particularly for the long-term recirculation tests (Tests 3 and 4):

a. Please describe the methodology that will be used to calculate localized heatup and provide adequate technical basis. Please revise the LTR to include this discussion; or else, please specify the future LTR that will contain the methodology.

b. Debris accumulations can be affected by draining of the test rig and removal of the test assembly. Further, it may be challenging to assess the accumulation of debris on the interior of the fuel bundle in an accurate manner. Please clarify how the impacts of these uncertainties will be minimized and/or taken into account.

41. Page 49 of the LTR indicates that the fuel assembly type to be used for debris accumulation testing should have inlet and outlet geometries that maximize the potential for debris collection for a given test.

a. Although consideration of spacer grids may be implicitly intended, spacer grid geometry was not specified as a selection criterion. Due to the expected importance of spacer grids in capturing debris, please clarify whether spacer grid geometry will also be considered in determination of the limiting fuel assembly type for debris accumulation testing.

b. Please identify and provide supporting basis for which fuel assembly type is evaluated to be limiting relative to debris accumulation, and identify the key characteristic clearance dimensions associated therewith; or, alternatively, specify that this information will be submitted in a future LTR.

42. The LTR does not consider the average core power as a significant parameter, apparently based in part on the assumption that a bounding evaluation can be performed by considering blockage of only the hot fuel assembly. However, it is not clear to the staff that blockage of the hot assembly is bounding, particularly with regard to evaluating long-term cooling. Should the

entire core experience blockage at the inlet and/or outlet of the fuel assemblies, average core power may influence the resulting heatup. Therefore, please provide adequate technical basis for not including cases in the reference analysis where postulated blockage from post-LOCA debris is considered over the entire reactor core rather than only the hot assembly.

43. Please clarify which lattice type (e.g., S, C, D) is to be modeled in debris accumulation testing. This parameter may be important for tests examining flow through the interstitial bypass region because it affects the dimensions of clearances between channel boxes and control blades. Please provide justification if a non-limiting lattice type is modeled.

44. Please clarify two statements on page 41 of the LTR:

> a. In the discussion of the recirculation line break, the LTR states that after several hours, the upper section of fuel can become uncovered, and thus limited debris blockage on the upper grid could occur. Please clarify that this statement is consistent with the reference analysis baseline case, where it is assumed that LPCI is shut off after [[ ]] seconds. Specifically, is it correct that, from approximately [[ ]] after the LOCA, core spray downflow through the bypass region that subsequently leaks into the active fuel region provides sufficient core cooling? Please further clarify whether the discussion is applicable for all assemblies in the core or only the hot channel and/or other high-powered channels.
>
> b. The LTR indicates that debris cannot accumulate on the upper tie plate via spray flow in the refill or reflood phase of a recirculation line or steam line break. Please clarify whether this statement applies only to the hot channel and/or other high-powered channels, or whether essentially all of the core spray across the entire core is diverted to the bypass region or pools in the upper plenum during the refill and reflood phases.

45. In Appendix A, repeatability of test results is addressed. For the baseline clean water tests, the LTR states that five tests are expected to be sufficient, but that more tests may be necessary, depending on the statistical relevance of the data. A similar statement regarding statistical relevance of the test data with debris-laden water is not included. While generally expecting the BWROG's plans for addressing repeatability to be sufficient and recognizing that the anticipated variability in tests conducted with debris-laden water is substantially greater than clean water tests, the staff nevertheless expects that large variations in debris accumulation test results be adequately understood. If test results are incoherent, additional testing could still be necessary to develop an adequate understanding of debris accumulation behavior. Please clarify the BWROG's position regarding whether additional debris accumulation tests may be necessary in cases where the results are incoherent and inadequately understood.

46. Please confirm that minimum ECCS flows for BWRs with jet pumps are sufficient to preclude long-term uncovery to less than two-thirds core height for a break on the reactor water cleanup system vessel drain line. If this is not the case, please provide a more detailed technical basis demonstrating generically that this break location would not be limiting with respect to post-LOCA debris accumulation in the core.

47. Please clarify the following items concerning the length of time necessary to refill and

reflood the reactor core:

a. On page 56 of Appendix A, the LTR indicates that the lower plenum refill time can be approximately 5 minutes. However, in the reference analysis the lower plenum refill time appears to be slightly longer than [[ ]]. Please clarify the circumstances under which the lower plenum refill time could be approximately 5 minutes and justify not considering such a scenario in the reference analysis that is considered bounding relative to operating BWRs.

b. Similarly, the reflood phase duration in the reference analysis is [[ ]], whereas Appendix A indicates on page 59 that times can range up to 2 minutes. Appendix A further notes on page 61 that the total length of Test 2 (including both refill of the simulated lower plenum and refill of the test fuel assembly) is expected to be less than 2 minutes. Please clarify why the reference analysis and Test 2 duration adequately represent limiting conditions for operating BWRs.

48. The LTR appears to indicate in Section 3.6.2 that Test 2 will not be terminated until the water level reaches the 12 ft elevation. Please clarify if this is correct. If Test 2 will be terminated at two-thirds core height, as permitted in Appendix A of the LTR, then please provide adequate justification. The elevation of the limiting peak clad temperature location can be above two-thirds height; furthermore, as demonstrated in the reference analysis, coolant recovers to the top of the core for the first several hours of the event. Subsequently, after decay heat subsides, the water level decreases to two-thirds core height.

49. Please provide additional technical justification to demonstrate that BWRs with LPCI injection into the bypass region through the core shroud are bounded by the reference analysis and test plan scenarios that are based on LPCI injection into the recirculation system, accounting for the potential effects of post-LOCA debris blockage. For example, in Test 1, the time for refill could be extended if both core spray and LPCI flows must drain through the bypass region into the lower plenum in the presence of debris.

50. The LTR does not address the potential impacts of bowing of fuel rods and assemblies or swelling and rupture of fuel rods. Please address the extent to which these phenomena can impact clearances within fuel assemblies and adequately justify why the evaluation of fuel assembly blockage does not need to consider these effects.