January 8, 2010

Mr. Anthony Nowinowski, Manager
Owners Group Program Management Office
Westinghouse Electric Company
P.O. Box 355
Pittsburgh, PA 15230-0355

SUBJECT: REQUEST FOR ADDITIONAL INFORMATION RE: PRESSURIZED WATER REACTOR OWNERS GROUP TOPICAL REPORT WCAP-16793-NP, REVISION 1, "EVALUATION OF LONG-TERM COOLING CONSIDERING PARTICULATE, FIBROUS AND CHEMICAL DEBRIS IN THE RECIRCULATING FLUID" (TAC NO. ME1234)

Dear Mr. Nowinowski:

By letter dated April 22, 2009 (Agencywide Documents Access and Management System Accession No. ML091180580), the Pressurized Water Reactor Owners Group (PWROG) submitted for U.S. Nuclear Regulatory Commission (NRC) staff review topical report WCAP-16793-NP, Revision 1, "Evaluation of Long-Term Cooling Considering Particulate, Fibrous and Chemical Debris in the Recirculating Fluid". Upon review of the information provided, the NRC staff has determined that additional information is needed to complete the review. On December 23, 2009, PWROG Project Manager, Chad Holderbaum, and I agreed that the NRC staff will receive your response to the enclosed Request for Additional Information (RAI) questions by February 10, 2010. If you have any questions regarding the enclosed RAI questions, please contact me at 301-415-4053.

Sincerely,

/RA/

Jonathan Rowley, Project Manager
Special Projects Branch
Division of Policy and Rulemaking
Office of Nuclear Reactor Regulation

Project No. 694

Enclosure: RAI questions

cc w/encl: See next page

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REQUESTS FOR ADDITIONAL INFORMATION

BY THE OFFICE OF NUCLEAR REACTOR REGULATION

WCAP-16793-NP, REVISION 1, "EVALUATION OF LONG-TERM COOLING CONSIDERING

PARTICULATE, FIBROUS AND CHEMICAL DEBRIS IN THE RECIRCULATING FLUID"

PRESSURIZED WATER REACTOR OWNERS GROUP

PROJECT NO. 694

RAIs for WCAP-16793-NP, Revision 1

1. On page 7-5, the topical report states that a quantitative estimate of the effect of fiber bypassing the sump strainer can be accounted for in LOCADM by use of a bump-up factor. A bump-up factor is applied to the chemical source term since LOCADM does not directly address small fibers that pass through the strainer and transport into the reactor vessel. The wording suggests that use of a bump-up factor is optional. The staff thinks it is appropriate for all plants to calculate a bump-up factor in their plant-specific LOCADM calculations. Please discuss whether the topical report will be revised to provide more definitive guidance related to the use of a bump-up factor for fiber bypass.

2. On page xx and Section 2.2, page 2-1, the acceptance criterion indicates the total deposit including oxide should not exceed an average of 0.050 inches in any fuel region. Please provide details concerning how an average total deposit thickness is determined and also define a fuel region. Further, in Section 2.2, Subparagraph 2, page 2-1, it is stated that 50-mil thickness is the maximum acceptable deposition thickness before bridging of adjacent fuel rods by debris is predicted to occur. Therefore, it would appear that the acceptance criterion should be stated as a maximum of 0.050 inches. Please change the criterion given this information or justify the current criterion.

3. In Appendix E, Section E.4, page E-4, the LOCADM default deposit density discussed is shown in units of lbm/ft^2. Please confirm if the LOCADM default deposit density value should be 35 lbm/ft^3.

4. On page 3-5, Section 3.2.1, the WCAP describes the WCOBRA/TRAC evaluation used to model effect of blockage at the core inlet and makes reference to a dimensionless friction factor (C_D). Please define C_D, as used in your analysis since many possible definitions exist in the literature. Also, the text states that a C_D of 109 was used in WCOBRA/TRAC to model blockage. Please verify that this is not a typographical error.

5. On page 3-2, paragraph 3.1.1, and Appendix B, page B-11, the hand calculation of the pressure drop equation for flow around the system is given as follows:

$$\Delta P_{flow} = \frac{k}{A^2} \frac{\omega^2}{288\, \rho_g\, g_c}$$

ENCLOSURE

The pressure drop due to flow (ΔP_{flow}) should account for two-phase flow in the core. NRC calculations indicate that during post-Loss of Coolant Accident recirculation two-phase flow exists in the core. The inclusion of a two-phase pressure drop will also affect the value of the available head in:

$$\Delta P_{avail} = \Delta P_{dz} - \Delta P_{flow}.$$

Please confirm that the hand calculation of the system pressure drop also includes two-phase flow effects in the hydrostatic head (ΔP_{dz}) or justify not doing so.

6. Appendix B, Section B.5, page B-27 discusses several WCOBRA/TRAC analyses performed to determine the blockage required to block flow to the core. There are two independently analyzed cases which are described as bounding: one in which the inlet flow area was decreased and one in which the C_D was varied. Please justify why these cases are bounding and explain how these assumptions are representative of debris blockage. Please provide the basis for the assumed C_D variations. Since pressure drop across a porous debris bed is approximately proportional to velocity, explain how these analyses relate to a porous medium pressure drop that would characterize a fiber bed. Provide, or make available for staff review, a WCOBRA/TRAC analysis in which the form loss coefficient (which is related to C_D) and area are simultaneously varied. The form loss coefficient could be varied as a function of velocity in order to provide a proportional pressure drop relation with velocity.

7. In Section 4.1, page 4-1, the report states that “smaller particulate and fibrous debris of the order of 0.04 inch is smaller than the clearance about the “springs” and will readily pass through the grid structure”. It can be argued the smaller debris can be filtered by the larger sized debris which has already accumulated in the clearance space. Please provide additional explanation and justification for the statement.

8. Section 4.3.1.1, p 4-4 and Appendix C calculate the cladding heat-up due to debris. The report states that a mesh size of 0.05 inches was used for the cladding thermal analysis model. The description of the noding model is incomplete. Please provide the following information:

   (1) The basis for the mesh sized used for the analysis;
   (2) The type of analysis performed--steady-state or transient;
   (3) Any differences in the node size used to model the rod, cladding and debris; and
   (4) Any variation in the node size along the radius.

   Justify the mesh size used in the calculation or perform a sensitivity study to justify the mesh sized used in the model. It is noted that Table C-1 in Appendix C provides more details regarding the analysis model, but this information is incomplete. For example, Table C-1 states that the outer clad diameter was 0.36 inch and that the cladding thickness is 0.225 inch. However, the text states that the model was divided into 20 zones. The relationship between the stated node size and the actual dimensions is unclear.

9. Appendix C states that the input values for fluid temperatures, heat transfer coefficients and heat flux (Table C-4) were taken from the WCOBRA/TRAC model results discussed in

Appendix B. Appendix B presents a transient analysis. Please state at what transient time the input values for the Appendix C analysis were obtained. Please justify the input values used. Please explain and justify the type of thermal analysis, steady-state or transient, used in Appendix C.

10. Page xx, 1st paragraph states that specific areas addressed in WCAP-16793-NP include boric acid precipitation. However, boric acid precipitation is not addressed in WCAP-16793-NP beyond stating that it is being addressed in a program apart from WCAP-16793-NP. Please correct the document to state that the boric acid precipitation issue is being addressed in a separate Westinghouse program.

11. Page xx, last paragraph states that the evaluations performed for the areas identified provide reasonable assurance of long-term core cooling for all plants. This statement is only true for those plants that show that they are bounded by the sump strainer bypass debris loads, maximum fuel cladding temperature, and maximum deposit thickness stated in the WCAP acceptance criteria. Please justify the statement or modify it.

12. Page xx, 2nd bullet in the last paragraph states that in the extreme case that a large blockage occurs, numerical analyses [presumably the WCOBRA/TRAC analysis referenced in Appendix B] have demonstrated that core decay heat removal will continue. NRC staff understands that the purpose of the fuel assembly head loss testing was to determine the maximum debris load conditions under which adequate coolant flow to the core can be maintained with the available driving head. Further, as stated in the Appendix B, the objective of the evaluation is to provide additional “defense in depth” to the fuel assembly testing to assure that long-term core cooling will be maintained. Please clarify the intent of the above referenced numerical analysis. If the intent is to justify a higher debris load, please justify the conclusion.

13. Page 2-1, paragraph 2.2, item 1 the WCAP states that the core “average” clad temperature will not exceed 800 F. As discussed in RAI responses 17 through 20 dated October 23, 2007 (Reference: WCAP-16793-NP, Revision 1, Appendix H, pages 21 and 22) the cladding temperature acceptance limit for long-term cooling shall be 800 °F. Please revise the WCAP accordingly or justify the use of “average.”

14. Page 3-2, paragraphs 3.1.1.1 and 3.1.1.2, state that the driving head criteria used for the Pressurized Water Reactor Owners Group fuel assembly tests can be found in references 3-1 and 3-2 (AREVA and Westinghouse proprietary reports, respectively). However, the proprietary reports do not provide the methods and design inputs used to calculate the driving head criteria. These calculations are required to enable staff to weigh the arguments presented in WCAP-16793-NP to conclude that there is adequate driving head to ensure adequate coolant flow into the core under the postulated debris loading conditions. Please make available, for NRC staff review, the calculations that establish the available driving head to ensure flow to the core. Please include information that shows that the single value chosen is bounding considering the variety of plant designs covered by the report.

15. The cold leg test results did not meet the acceptance criteria set forth for the test protocol. To show acceptable results, Section 4.2.2 acknowledges only the head loss across the bottom portion of the fuel assembly and argues that turbulence within the core would disrupt

any debris bed that could form on the spacer grids. Further, the WCAP argues that, for a cold-leg break, analyses have shown that if the required make-up flow reaches the core, adequate long-term core cooling can be accomplished. Since the testing did not simulate actual flow conditions through the reactor core, please provide additional information to demonstrate that adequate turbulence would be present in the core to prevent the collection of debris on the spacer grids.

16. Please provide information that justifies the addition of ½ of the microporous insulation prior to the fibrous debris addition and ½ after the addition of fibrous debris and chemical debris. Strainer head loss testing guidance is to simultaneously add particulate insulation (e.g., microporous, cal-sil) and other particulate debris (e.g., coatings, latent dust, etc.). Adding the insulation debris after the chemical debris is potentially not conservative.

17. Please justify the statements in Sections 4.1 and 4.2.2 that debris accumulation will be localized and will not extend across the entire core. Flow through the core will distribute according to flow resistance. Once blockage occurs in a local area, flow of debris laden water will shift to areas with less resistance and debris will be deposited in those locations. Given sufficient debris, a uniform debris bed could be formed across the core inlet.

18. Section 3.1.3.2 states that the cold leg tests demonstrated that the hot leg test results are the bounding condition for in-vessel head loss. The assumption that the hot leg break is more limiting than the cold leg break condition led to the test program concentration on the hot leg break. However, limited cold leg break testing indicates that it may actually be more limiting than the hot leg break. Please provide information that justifies that the cold leg condition has been fully evaluated and that the debris loading acceptance criteria is valid for the cold leg condition.

19. Please provide information that justifies the statement in Sections 4.2.1 that "with boiling, additional turbulence is present in the core region which will tend to remove debris from the spacer grids and confine blockages to isolated regions." Provide the bases and assumptions associated with this assertion. Further, it seems that boiling could add solids (due to precipitation) that combine with the debris, increasing the density and decreasing the likelihood that such material would be removed from the fuel surfaces. Please provide evidence to demonstrate that the lack of boiling in the testing is in fact conservative.

20. In response to the NRC's earlier RAI 42, contained in Appendix H, it is stated that a guidance document is being developed to assist licensees in implementing WCAP-16793. Please provide the status of this document.

21. The AREVA and Westinghouse proprietary test reports indicate that the test for the Combustion Engineering designed plants was conducted at 11 gallons per minute (gpm) and 6 gpm, respectively. Please provide the basis for the difference in flow rates.

22. The testing for WCAP-16793 was based on specific intermediate spacer and mixing grids. Please explain how licensees should evaluate differences between the tested grids and evolving grid designs.

23. In Appendix B, page B-2, paragraph B.3.2, the figure reference in the text is Figure B-3. This appears to be an error. The figure reference apparently should be Figure B-1. Please verify.

24. In the Appendix B figures, please identify vertical and horizontal flows. Do the squared numbers indicate vertical paths and circled number indicate horizontal paths? Please provide better descriptions.

25. In Appendix B, page B-27, paragraph B.5.1, the description of the first bulleted approach is confusing. Please confirm that all the inlet areas except channel 13 were set equal to zero. Please explain more accurately the condition analyzed. Also, the differences in the inlet flow area and the internal core flow area should be described.

26. In Section 3.3.3, on page 3-14, it is stated that "There are no significant PCT excursions" and references Figure 3-9 as evidence. However, Figure 3-9 shows a significant PCT excursion at the end of the plot. The temperature is still rising at the end of the plot. Please explain the apparent contradiction and why this excursion is acceptable.

27. In Section 3.3.3, on page 3-14 it is stated that in Figure 3-13 "the PCT increases until the end of the transient calculation". The temperature rise is not shown in this figure. Could the text actually refer to Figure 3-9? If not, please justify the conclusion regarding the PCT.

<u>RAIs for Proprietary Westinghouse Test Report (WCAP-17057-P)</u>

1. Page 7-2, table 7-2 lists a maximum microporous insulation debris load of 3.2 lbm while the maximum quantity tested was 1.47 lbm: Please discuss why a 2.2x factor above the tested amount is acceptable for microporous insulation.

2. WCAP-16793-NP, Table 10-1 on page 10-3 lists acceptable fiber debris loads for Westinghouse-designed fuel assemblies that are significantly greater than that included in the bulk of the Westinghouse tests (Reference: WCAP-17057-P, Table 3-3). Only two tests (CIB08 and CIB10) were performed with fiber debris loads steadily increased to 200 grams. Several tests (CIB01 through CIB04) conducted with lower quantities of particulate appeared to trend toward exceeding the allowable head loss with significantly less fiber than the suggested acceptance criterion of 200 gram per fuel assembly. Page 5-3, Figure 5-1 graphs the pressure drop versus fiber debris load for the 10 tests for flow introduced from the bottom of the core. Review of the test data shows that increasing fiber loading results in increased head loss. Since the objective of the test program is to determine a bounding amount of debris for a large set of plants, the tests should be conducted to determine the bounding amount of fibrous debris considering the possible range of other debris types and quantities. Please provide information that justifies that the testing has shown that the stated 200 gram fiber limit is valid under the other debris loading scenarios allowed by the acceptance criteria stated in the report. Include justification that the testing bounds conditions for lower flow rates, microporous debris loading, and varied particulate loading.

3. Review of the test data showed that fuel assembly head loss is sensitive to the amount of particulate debris added to the test. The data indicates that lower particulate loads result in higher head loss. Please provide an evaluation of how fuel assembly head loss is affected by the amount of particulate debris. Because the fuel assembly test program is designed to

provide bounding amounts of debris for a large set of plants, the test series should be conducted to demonstrate the bounding amount of debris, i.e., the amount of particulate debris that results in the highest head loss may not occur at maximum particulate debris loading. When this amount is determined, it should be evaluated to determine which plants are enveloped within the limiting amount. Note that the bounding amount of debris may change for various conditions (e.g. cold leg vs. hot leg flow, alternate debris loads such as calcium silicate and microporous insulation, varying fibrous loads, etc.).

4. In a number of tests (e.g., CIB03, CIB04, CIB09) with chemical precipitates in the debris mix, the graphs show that upon the addition of the first batch of chemical precipitate, a quick increase in pressure drop is observed, followed by a decrease in pressure drop with similar or no response to additional chemical precipitate additions. This observation is contrary to observations made during strainer head-loss testing. Please discuss why the addition of chemical precipitates did not result in a sustainable increase in pressure drop.

5. During one of the fuel assembly tests for the AP1000 plant, there was a much greater increase in pressure drop upon adding chemical precipitate than has been observed in the WCAP-17057-P tests for the operating reactors. Please describe any discrepancies between the AP1000 and operating reactors test conditions and explain why a much greater increase in pressure drop from chemical precipitate is not observed in the operating reactor fuel assemblies.

6. In paragraph 6.2.1, the Darcy-Weisbach equation is used to estimate the cold-leg break pressure drop at the core inlet from hot-leg break test results. However, the calculated pressure drop is not corroborated by the cold-leg test or by other tests observed by NRC staff. The staff believes that Darcy-Weisbach equation does not accurately model flow through a porous media. Please justify its use in this application.

7. The Westinghouse tests did not include a test with microporous insulation without having calcium silicate insulation in the debris mix. Please provide an evaluation of how microporous insulation debris affects fuel assembly head loss without calcium silicate present or show that this condition is not applicable to operating reactors. Test CIB06 results indicate that calcium silicate may reduce head loss and it appears that that particulate component of microporous insulation debris may result in an increase in head loss. Unless it can be shown that microporous insulation will only be present when calcium silicate is present, please provide an evaluation of the effect of microporous insulation without cal-sil present. Please also provide an evaluation of how the microporous insulation can affect head loss under various flow and debris loading conditions to assure that the limiting amount of microporous insulation debris has been determined.

8. The data presented in Table 5-1 and Figures 5-1, 5-2, and 5-3, suggests that debris behaves differently in tests at lower flows, (e. g., cold leg testing and CE testing) than in tests at high flow rates (e. g., hot leg testing). Based on high flow rate test results, the tests at low flow rates incurred higher than expected head losses across the bottom nozzle. Further, the lower-flow tests did not include potentially problematic debris types like microporous insulation, nor were the tests conducted with a full range of debris loads. Please provide information to justify that a sufficient range of conditions was evaluated for the cold leg break and other low-flow testing, including information that adequate debris types and load

combinations were considered such that head losses greater than the acceptance criteria will not occur.