September 10, 2007

Mr. Gordon Bischoff, 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 (PWROG) TOPICAL REPORT (TR) WCAP-16793-NP, REVISION 0, "EVALUATION OF LONG-TERM COOLING CONSIDERING PARTICULATE, FIBROUS AND CHEMICAL DEBRIS IN THE RECIRCULATING FLUID" (TAC NO. MD5891)

Dear Mr. Gresham:

By letter dated June 4, 2007, (Agencywide Documents Access and Management System Accession No. ML071580139), the PWROG submitted for U.S. Nuclear Regulatory Commission (NRC) staff review TR WCAP-16793-NP, Revision 0, "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 August 22, 2007, Christine DiMuzio and I agreed that the NRC staff will receive your response to the enclosed Request for Additional Information (RAI) questions by October 5, 2007. The PWROG should request an extension, in writing, if it requires additional time beyond October 5, 2007, to respond to this request. Additional RAIs in the area of chemical effects will be provided by separate correspondence. The date for the additional RAIs will be established later. If you have any questions regarding the enclosed RAI questions, please contact me at 301-415-3610.

Sincerely,

/RA/

Tanya M. Mensah, Senior Project Manager
Special Projects Branch
Division of Policy and Rulemaking
Office of Nuclear Reactor Regulation

Project No. 694

Enclosure: RAI questions

cc w/encl:
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Regulatory Compliance and Plant Licensing
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Letter to Gordon Bischoff from Tanya M. Mensah dated: September 10, 2007

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REQUEST FOR ADDITIONAL INFORMATION

BY THE OFFICE OF NUCLEAR REACTOR REGULATION

TOPICAL REPORT (TR) WCAP-16793-NP, REVISION 0, "EVALUATION OF LONG-TERM COOLING CONSIDERING PARTICULATE, FIBROUS AND CHEMICAL DEBRIS IN THE RECIRCULATING FLUID"

PRESSURIZED WATER REACTOR OWNERS GROUP (PWROG)

PROJECT NO. 694

By letter dated June 4, 2007 (Agencywide Documents Access and Management System Accession No. ML071580139), the PWROG submitted for U.S. Nuclear Regulatory Commission (NRC) staff review TR WCAP-16793-NP, Revision 0, "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.

To facilitate an efficient and expeditious review, the NRC staff requests responses to the following questions in order to continue the review of TR WCAP-16793-NP, Revision 0. All section, paragraph, page, table, or figure numbers in the questions below refer to items in TR WCAP-16793-NP, Revision 0, unless specified otherwise.

NRC Questions

1. What is the basis for stating that blockage of the core will not occur on page xviii? What is the maximum amount of debris that can enter the core and lower plenum and what is the maximum potential blockage from debris at the core inlet and the first spacer grid location?

2. Page 2-3 states that recent observations from testing of a partial-length fuel assembly using plant-specific fibrous and particle debris have confirmed that the NUREG/CR-6224[1] correlation is quite conservative for application at the core inlet. Please provide a complete description of this test facility, the tests that were performed, and the results.

3. To show that the pressure drop correlation of NUREG/CR-6224 is adequate to evaluate core inlet blockage, please provide a comparison of the materials and flow velocities of the test data used to develop the correlation to those which would be expected at a reactor core inlet during long term cooling. Upper Plenum Injection (UPI) plants should be included in this comparison.

4. Page xvi and xvii state that 99.4 percent blockage results in adequate flow to the core to provide cooling. This result is not surprising since the vessel is in a boiling pot condition

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[1]NUREG/CR-6224, "Parametric Study of the Potential for BWR ECCS Strainer Blockage Due to LOCA Generated Debris," dated October 1995.

which will enable the fluid levels to balance under such low flow hydrostatic conditions. However, the injection water contains boric acid. Since the core is boiling, the boric acid will build up in the core and because the 99.4 percent of the core inlet is blocked, the higher density boric acid solution in the core will not mix with the water in the lower plenum. The boric acid concentration in the core will increase. Evaluations need to be performed to show that with the maximum credible blockage, boric acid precipitation is prevented. What is the minimum blockage that enables the boric acid to mix sufficiently with the lower plenum to preclude precipitation? Can the concentrated boric acid mixture combined with the blockage materials at the inlet prevent flushing of the core following the switch to simultaneous injection? If not, please explain why. What happens as boric acid settles on top of potential blockages at the inlet to the core of the core and spacer grid locations?

5. Page 2-4 states that analyses using WCOBRA//TRAC demonstrated that with even as much as 99.4 percent of the core blocked, core decay heat was adequately removed.

    A. So that this analysis may be related to a plant-specific core blockage condition, please relate the results of the WCOBRA/TRAC analyses for the minimum blockage for which adequate core cooling can still be provided to an equivalent fiber bed using the pressure drop correlation of NUREG/CR-6224.

    B. As debris and chemicals are concentrated within the core by the boiling process, the density of the fluid in the core will increase. This increase in density will act to retard core flow. Provide an evaluation of the effect of increased core density on the results from the WCOBRA/TRAC analysis of core blockage.

6. Page 2-7 states that two sample calculations were provided in Section 5 for predicting chemical deposition on fuel cladding.

    A. The NRC staff was only able to find one sample calculation in Section 5 and in Appendix E. Please provide the other sample calculation.

    B. For a plant-specific submittal to reference a sample calculation as bounding for that plant, a list of critical input parameters would need to be compared. Please provide a table giving these parameters and the values assumed in the sample calculations.

7. Page 2-12 states that the effect of settled debris in the lower plenum on licensing basis boric acid precipitation analyses is judged to be small and plant-specific evaluations are not required. Please provide evidence that this statement is true for all pressurized water reactors (PWRs) or provide criteria that plants should meet to demonstrate that this concern is not an issue in plant-specific submittals.

8. Page 2-13 states that for limiting boric acid precipitation scenarios (i.e., relatively stagnant core region), the alternate core flow paths would not see significant blockage since the flow areas are not effective debris traps or filters. Please demonstrate that for such a cooling scenario, boric acid and other dissolved and suspended substances would not accumulate in the core and precipitate.

9. Page 2-15 states that debris buildup on mixing vanes and fuel grids will occur over time. Since the boric acid is also concentrating over time, a combination of the debris in vanes and grids over time may form a localized blocked region or regions (containing debris and boric acid) that could cause localized precipitations that could collectively build over time and eventually block large regions of the core. The combination of the debris and the higher concentrate boric acid could form sustained blockages at the vanes and/or grids or core inlet. Please explain the consequences of the sustained blockages. In addition, please discuss the calculations performed to show how the boric acid mixes through the core and lower plenum with debris in the vanes/grids and lower plenum. Current long-term cooling analyses assume perfect uniform mixing of the boric acid in the core, lower plenum, and upper plenum. Localized gradients that may occur due to the debris/boric acid concentrations could cause local concentrations to exceed the precipitation limit. Since the lower plenum contains cooler injection water plus debris, a higher concentration will be needed in the core to initiate mixing into the lower plenum during the long term. Please demonstrate that the limiting plant would not develop boric acid concentrations that approach the precipitation limit with the largest amount of debris.

   Also, how does high concentrate boric acid (up to 32 weight percent) diffuse downward through fibrous and/or debris blockages plus the strainers at the core inlet while the water flows upward to keep the core covered? Please explain.

10. Page 2-14 in Section 2.7.2, dealing with UPI plants, states that for a hot-leg break, the coolant flow-through from the cold leg through the core and out the break is sufficiently large to maintain debris introduced by the UPI flow entrained in the flow and to transport it out the break. Please provide justification for this statement. The NRC staff understands that for some UPI plants, cold-leg emergency core cooling system (ECCS) flow is terminated when sump recirculation begins. Under these conditions core flow would be stagnant and debris will accumulate.

11. Page 2-15 states that complete compaction of debris that might collect at the bottom of the fuel at the debris trapping features will not occur for a UPI plant and that the packing will likely be less than 60 percent. Please provide the flow loss coefficient which would occur for this condition and give guidance as to what maximum loss coefficient would be acceptable.

12. Page 2-15, regarding UPI plants, states that if coolant flow is sufficiently restricted through a debris bed and clad temperatures increase to about 15 ^{O}F to 20 ^{O}F above the coolant temperature, the coolant would begin to boil. The steam formed would be about 40 to 50 times the volume of the water, and would cause the debris bed to be displaced, allowing for coolant to flow and to cool the cladding surface. Please justify that cooling will be maintained for a debris bed blocking the bottom of the core with steam rising through the top. Provide justification that boric acid and chemicals dissolved in the coolant would not increase to an unacceptable concentration under these conditions.

13. Calculations for cladding heat up behind fuel grids are presented in Section 4.1 and Appendix C. The ANSYS code was used in these calculations. Please provide a reference for this computer code and for the review of this computer code by the NRC staff.

14. The maximum debris thickness that was evaluated using the ANSYS computer code was 50 mills. Is 50 mills the maximum acceptable thickness for debris collection behind a fuel element spacer grid? If not, please provide the acceptance criterion. What would be the thickness of debris if a spacer grid were to become completely filled? Provide an analysis of the resulting peak cladding temperature (PCT) if the location between a spacer grid and a fuel rod were to become completely filled with debris.

15. Section 4.1.4 states that in using the ANSYS code, debris is assumed to have the same thermal properties as crud. A value for thermal conductivity of 0.5 BTU/(hr*ft*deg-F) is recommended, and the lowest value of thermal conductivity examined was 0.1 BTU/(hr*ft*deg-F). If a debris bed trapped behind a fuel element spacer grid were composed of fibrous insulation, the thermal conductivity would be much lower. Please justify not using a thermal conductivity appropriate for fibrous insulation.

16. Page xvi and Appendix A state that clad temperatures of 800 ^{O}F are considered acceptable. From a long-term cooling perspective, 800 ^{O}F clad temperatures establish a low rate heat oxidation process similar to the problem that developed at Calvert Cliffs Nuclear Power Plant during the late 1970's. Clad temperatures were increased to 800 ^{O}F so that operation for several weeks caused the oxide layer to build on the cladding. Please discuss the impact on long-term cooling and the long-term build-up of oxide and the potential to approach or even exceed the 17 percent limit in accordance with Section 50.46 of Title 10 of the *Code of Federal Regulations*.

17. Appendix A states that a PCT of 2200 ^{O}F is acceptable for the post-quench, long-term evaluation. This limit is inconsistent with previous statements by the PWROG and not supported by the autoclave data. In a teleconference with the NRC staff on July 26, 2007, PWROG representatives acknowledged that this was not the intent - instead, the previously stated 800 ^{O}F was the proposed upper limit on local cladding temperature. Please revise TR WCAP-16793-NP to clarify.

18. Page A-7 states that the maximum allowable fuel clad temperature for short transients such as “hot leg switch over” and for localized “hot spots” is 2200 ^{O}F during long-term cooling. Please provide the methodology as to how transient cladding temperatures during hot leg switch over will be calculated. Include processes and phenomena included in the methodology which cause cladding temperatures to increase during hot leg switch over and those which act to mitigate the transient.

19. The proposed 800 ^{O}F upper limit on local cladding temperature is based on long-term autoclave data and focuses solely on the formation of nodular corrosion.

    A. Please provide results of long-term oxidation tests on pre-hydrided specimens which have previously been exposed to loss-of-coolant accident (LOCA) heat-up and quench conditions or provide an alternative justification for use of the 800 ^{O}F limit under these conditions.

    B. Post-quench fuel rod damage mechanisms should be identified and dispositioned relative to the proposed 800 ^{O}F limit. Mechanisms include: (1) further evolution of post-quench microstructure and its impact on ductility, (2) hydride formation and re-orientation, (3) crack propagation near burst region,

(4) cladding creep/ballooning (non-burst rods), and (5) degradation of oxide layer and hydrogen absorption.

C. The stability of the oxide layer and the tetragonal-to-monoclinic transformation are sensitive to alloying elements, surface finish, and temperature history (due to local stress states within oxide layer). Please address these items with respect to the proposed upper limit and 30 day duration.

20. Page A-7 gives two examples of when reactor fuel experienced significant damage and a coolable geometry was maintained. One example is “operational experience at Three Mile Island.” The NRC staff does not believe that the 1979 accident at Three Mile Island, Unit 2, resulted in a coolable geometry. The other example given is “operational experience at the International PHEBUS-FP Program.” Please provide the PHEBUS-FP data referred to and discuss the relationship of this data to local hot spots which might occur during the long-term cooling period at PWRs following a large LOCA.

21. Section A.4 on page A-5 states that the acceptance basis for boric acid precipitation and chemistry effects of debris will be as follows: A core flushing flow will be established that is sufficient to prevent the calculated maximum boric acid concentration in the core region from exceeding the precipitation limit. Please provide acceptance criteria for other species of chemicals and debris which might be washed into the reactor core during the recirculation process.

22. Calculations for cladding heat up between fuel grids are presented in Section 4.2 and Appendix D. The maximum debris thickness evaluated was 50 mills. Is 50 mills the maximum acceptable thickness for debris collection between fuel grids? If not please provide the acceptance criterion.

23. Methodology for calculating the cladding temperature that would result from post-LOCA crud deposition on the fuel rods is presented in Appendixes C, D, and E. Methodology for calculating crud thickness is only presented in Appendix E. Please describe methodology which licensees would use to calculate crud thickness using Appendices C and D.

24. Appendix C is titled “Fuel Clad Heat-up Behind Grids” whereas Appendix D is entitled “Fuel Clad Heat-up Between Grids.” Please describe the specific treatment of the grids in Appendix C which make these calculations different from the methodology in Appendix D. Section D.7 indicates that if the same inputs were used for the methodology of Appendix D as was used for Appendix C, similar results would be obtained.

25. Appendix E describes the LOCADM computer code which calculates dissolution of materials from the containment to the sump water and deposition of the dissolved material on the surfaces of the reactor core. Please discuss how the LOCADM code will be made available to utilities to calculate individual plant responses. Discuss any training that the PWROG plans to provide to utility personnel to help ensure the code is being used properly.

26. The LOCADM computer code performs the evaluations for the concentration of debris and chemicals within the reactor core. An important feature in the concentration evaluation is the volume of water which is available to mix with the concentrating material. Please describe how this mixing volume is calculated. Include assumptions for the liquid fraction within the core, upper plenum, and lower plenum. Compare the assumptions used by LOCADM to those which the NRC staff has accepted in licensing calculations for post-LOCA boric acid concentration. Provide a comparison to the volume of water assumed to be available for mixing by LOCADM with that calculated by WCOBRA/TRAC.

27. Please provide the decay heat model which is used in LOCADM to determine coolant boil off from the core and justify that the model is conservative for safety analysis.

28. Page E-8 states that the LOCADM computer code can model the core with up to 200 radial nodes and 10 axial nodes. Please provide the criteria which should be utilized in selecting adequate noding detail. Please discuss how local chemical and debris concentrations are determined for the fluid volume adjacent to each of the core nodes.

29. Page E-11 states that high-solubility species will not precipitate, and their concentration is limited to back-diffusion into the coolant or transport along the chimney walls. Boiling in the core before hot-leg recirculation is initiated will act to increase the concentration of the high solubility species. Describe how the LOCADM code tracks the concentration of high solubility species to ensure that the solubility limit is not exceeded.

30. Describe the treatment of suspended solids by the LOCADM computer code. Discuss the treatment of these concentrated solids in the core as to the effect on core density, core heat transfer, and plate out on fuel rods.

31. Page E-11 states that the LOCADM computer code assumes that deposition occurs through the boiling process if conditions at a core node predict any boiling. Please discuss and provide the calculational methodology by which coolant channel thermodynamic conditions are determined. Include discussions for hot-leg recirculation as well as for cold-leg recirculation. The NRC staff understands that for some UPI plants, ECCS flow to the cold legs is terminated during recirculation. For a UPI plant which experiences a hot-leg break, please provide the methodology by which LOCADM would determine core concentrations for the resultant countercurrent flow which would be relied upon to cool the core during the recirculation period.

32. Page E-14 indicates that the initial fuel oxide thickness to be input to the LOCADM code for the start of the post-LOCA deposition calculation could be based on post-operational fuel examinations. The NRC staff does not believe that use of post-operational data would be appropriate for fuel which has experienced a LOCA. Please provide methodology by which the post-LOCA oxide thickness will be determined for input to LOCADM. This concern also needs to be addressed for the methodology of Appendix C and Appendix D.

33. Page E-15 provides a comparison of the results by the LOCADM computer code and the SKBOR computer code are described for a post-LOCA boric acid concentration

calculation. Please provide more details of this comparison including core boric acid concentration as a function of time. Provide a reference available to the NRC staff describing the SKBOR computer code and including any review and approval by the NRC staff.

34. Figure E-3 gives a comparison between an experiment and LOCADM for fouling resistance. The LOCADM results are shown to be conservative. The LOCADM results would be sensitive to the thermal conductivity of calcium sulfate used in the test. Provide a comparison for the thermal conductivity assumed in the LOCADM simulation to experimental values for calcium sulfate. Figure E-3 shows LOCADM to become more conservative as the simulation progresses. The NRC staff is concerned that use of a slab geometry to model crud buildup on a cylinder (i.e., fuel pin) may be excessively conservative. Please comment on this concern.

35. Page E-16 describes a sample calculation using LOCADM. A high fiberglass loading of 7000 cubic feet was assumed. Please provide the assumptions regarding transport of this fiberglass into the core, including the effect of the sump screen and settling on the containment floor. What fiberglass concentration was assumed in the incoming ECCS flow? Eighty cubic feet of calcium silicate was also assumed to be present. Provide the concentration of calcium silicate assumed in the incoming ECCS flow. Discuss any difference in assumptions for plate out of suspended fiberglass and calcium silicate on the core fuel rods. Compare these assumptions with the PWROG recommendations stated in Section 2.3 “Collection of Fibrous Material on Fuel Cladding.”

36. The Example Run, in Appendix Section E.9, states that a high fiberglass loading of 7000 cubic feet was used to determine the thickness of scale which might form on the fuel rods. Section 2.3 indicates that fibrous debris that is carried to the core will not adhere to fuel rod surfaces and, therefore, will not adversely affect heat transfer. Fibrous material in the core will be concentrated by the boiling process as calculated by LOCADM. Provide a discussion as to the effect on core cooling of high fiber content. What is the maximum loading of fibers which could be concentrated within the core without adversely affecting core heat transfer?

37. Appendix F describes the AREVA methodology for predicting solubility of containment materials in the containment sump water. Appendix E describes a similar Westinghouse model that is documented in TR WCAP-16530-NP. Which model should utilities utilize for plant analysis? For a given reactor core how would the results differ in using the two models?

38. Please describe StreamAnalyzerVersion 1.2 as it is used to calculate the concentration of post-LOCA materials within the core in more detail. How are concentrations determined in the presence of boiling? Are concentration gradients within the core accounted for? How is hot-leg recirculation accounted for?

39. What is the significance of the quantities in Table F-2 “Steam Masses Utilized in Solubility Calculation?” How were they determined? How is the “Total Core Feed” determined? What is meant by “Core Residual After Steaming?”

40. Other inputs in the methodology of Appendix F are described as the sump mass, reactor inventory, and steaming information. Please describe how these inputs are determined so as to be conservative for reactor safety analysis. For the reactor inventory, discuss how voiding within the reactor vessel and limited circulation in the lower plenum is taken into account in determining the mass of water available to mix with the material being concentrated within the core.

41. Tables F-5.1 and F-5.3 indicate that chemical precipitates would form in the core for the sample calculations that were performed. Since boiling occurs at the surface of the fuel rods, the NRC staff assumes that is where the chemical precipitates calculated in Appendix F would be located. Please provide a comparison of the deposit thickness calculated by the methodology of Appendix F to that of Appendix E. How will the power peaking in the core be taken into account in determining the Appendix F deposits?

42. It is not clear how a licensee will utilize the information in TR WCAP-16793-NP. Please provide guidance that the licensees may utilize to perform specific assessments of (but not limited to) for example:

A) maximum debris that enters the core and lower plenum.
B) debris accumulation in the reactor vessel.
C) calculation of debris and chemical concentration in the reactor core.
D) the maximum debris blockage at the core inlet.
E) the debris that collects on mixing vanes and spacers and the impact on boric acid buildup when the debris and boric acid concentrate combines at these locations.
F) impact of debris on the long term cooling boric acid precipitation analyses.
G) the impact of the debris on boric acid buildup for plants with low elevation suction legs if the break is located on the top of the discharge piping.

Also, what calculations are performed to show that once the switch to simultaneous injection is made, the injection can flush the core with boric acid and debris at all collection locations? How would a licensee perform this calculation?

It is also suggested that a sample calculation be performed for a plant illustrating how one would utilize the information to show acceptable long-term cooling ECCS performance following all break sizes. A plant with the largest potential debris source should be selected. The sample analysis should address all calculations covering the multitude of issues discussed in the report.

43. The NRC staff understands that at some plants the equivalent of hot-leg recirculation may be obtained using the pressurizer spray. Under these conditions the pressurizer spray nozzles might become clogged with debris. Please provide guidance on how the occurrence and consequences of such blockage may be evaluated in plant-specific evaluations.

44. Following a large-break LOCA, many of the fuel rods in the core may swell and rupture leaving sharp edges at the rupture locations and a diminished channel flow area. Debris may collect in the restricted channels and at the rough edges at the rupture locations. Please provide results of evaluation of the possibility of excessive blockage being produced by the combination of swelling and rupture and debris collection. Such

blockage might produce the occurrence of the hot spots above the blockage location. Please provide guidance for licensees on evaluating the occurrence and magnitude of such hot spots.

45. The mixture of chemicals within the core is postulated to include a mixture of epoxy and non-epoxy paint chips, insulation, ablated structural material, small particles from corrosion of system materials, dissolved corrosion products, buffering agents, boric acid, and lithium hydroxide. This material will be in a high radiation field from release of the fuel rod gap activity as the result of the LOCA and from gamma radiation from the fuel rods. Please describe the chemical and physical changes which may occur within this mixture within the core and the effect on core heat transfer.