

October 4, 2006

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: WESTINGHOUSE
OWNERS GROUP (WOG) TOPICAL REPORT WCAP-16530-NP,
"EVALUATION OF POST ACCIDENT CHEMICAL EFFECTS IN CONTAINMENT
SUMP FLUIDS TO SUPPORT GSI-191" (TAC NO. MD1119)

Dear Mr. Bischoff:

By letter dated March 27, 2006, the WOG, now known as PWR Owners Group, submitted for U.S. Nuclear Regulatory Commission (NRC) staff review Topical Report (TR) WCAP-16530-NP, Evaluation of Post Accident Chemical Effects in Containment Sump Fluids to Support GSI [Generic Safety Issue]-191". Upon review of the information provided, the NRC staff has determined that additional information is needed to complete the review. On a telephone call on September 25, 2006, between Mr. Thomas Laubham, WOG Project Manager, and I, it was agreed upon that the NRC staff will receive your response to the enclosed Request for Additional Information (RAI) questions by November 24, 2006. If you have any questions regarding the enclosed RAI questions, please contact me at 301-415-1842.

Sincerely,

/RA/

Sean E. Peters, Senior Project Manager
Special Projects Branch
Division of Policy and Rulemaking
Office of Nuclear Reactor Regulation

Project No. 694

Enclosure: Request for Additional Information

cc w/encl:

Mr. James A. Gresham, Manager
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REQUEST FOR ADDITIONAL INFORMATION

BY THE OFFICE OF NUCLEAR REACTOR REGULATION

TOPICAL REPORT (TR) WCAP-16530-NP, " EVALUATION OF POST ACCIDENT
CHEMICAL EFFECTS IN CONTAINMENT SUMP FLUIDS TO SUPPORT GSI-191"

PWR OWNERS GROUP

PROJECT NO. 694

1. Dissolution testing was performed with small volume reaction vessels. Please identify the fluid volume in these tests.
2. Given the small sample sizes tested, is it possible that some test samples (e.g., insulation material) would not be representative of the bulk material? For example, could the amount of binder present in an insulation sample vary significantly depending on the sample location? Was any quantitative analysis performed on multiple samples obtained from the non-metallic materials to assure the tested samples were representative?
3. Testing was performed using a closed system at elevated temperatures and the reaction vessels were evacuated to aid the introduction of test fluid. Therefore, the air volume to water volume ration does not appear to be representative of plant conditions. Discuss how more representative levels of carbon dioxide could affect the amount of precipitate (e.g., by formation of carbonates).
4. Sample preparation for energy dispersive spectroscopy (EDS) analysis provided a source of carbon that would mask carbon present in precipitates from other sources, such as organics or carbonates. Discuss whether alternate analytical tests (or alternate sample preparation techniques for EDS analysis) should be performed to permit reliable detection of carbon in the test materials and chemical precipitates.
5. Page 37 of the TR states that dissolution rates measured for each containment material are expected to be higher than that obtained from containment material mixtures. The TR further states that trisodium phosphate (TSP) may inhibit the dissolution of calcium silicate. Because calcium levels can reach saturation very quickly, pure dissolution tests with no additions of TSP can provide an underestimate of the amount of calcium silicate that can dissolve and precipitate in a environment buffered with TSP. The presence of phosphate (from TSP) can react with dissolved calcium to form calcium phosphate precipitate thereby removing calcium from solution promoting additional dissolution of calcium silicate. Provide the basis for the statement that TSP may inhibit the dissolution of calcium silicate.
6. Dissolution testing and precipitation testing (Tables 4.2-1 and 4.2-2) evaluated sodium hydroxide (NaOH) environments at pH 8 and pH 12. The pH, however, can strongly

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influence the amount and form of precipitation products and many plants with NaOH are postulated to have post-loss-of-coolant accident (LOCA) containment pool pH in the range of 9 to 10. Why were no tests performed to evaluate this pH range?

7. Describe the sample preparation for non-metallic materials (e.g., NUKON, high density fiberglass, Interam). With the exception of those samples that were crushed, were all other non-metallic materials shredded? What method was used to shred the materials and is the size produced representative of what would occur during a LOCA? Were any processed beyond shredding (e.g., placed in a blender).
8. According to Section 5.1.2.1 of the TR, some insulation material (i.e., NUKON) was baked, some materials (e.g., mineral wool, high density fiberglass) were not baked, and it is not clear if other materials (e.g., Interam, calcium-silicate) were baked. Provide the thermal history (time and temperature) for all the test materials and a rationale as to why some were thermally treated and others were not.
9. The TR indicates that (unbaked) high density fiberglass had a larger mass release than baked Nukon fiberglass. Given the short duration of these bench top tests, were any direct comparison (i.e., the same material baked and not baked) tests performed to evaluate how baking could affect the amount and composition of elements released during dissolution testing?
10. Both temperature and pH can affect solubility. It appears from Table 4.2-2, that all pH adjustments in the precipitation test matrix are accomplished by adding TSP or sodium tetraborate (Borax) to the borated, pH 4 environments to raise the pH to 8. None of the pH 12 tests were adjusted to lower pH values. Given that aluminum solubility decreases as the pH is adjusted downward towards 8, would a test with initial higher pH subsequently adjusted to a lower pH be more conservative (i.e., result in more precipitate) than a low pH test buffered to a higher pH? Is it plausible for a containment pool at higher pH (e.g., 9 pH) to move a pH unit or more lower due to formation of nitric or hydrochloric acid after an accident? If so, why was no testing performed by adjusting pH from a higher value to a lower value?
11. Table 3.1-1 summarizes the pressurized water reactor (PWR) survey response concerning containment materials and buffering agents. These results show 55 units with carbon steel and 62 units with concrete. Since all PWRs contain these materials, one would expect 69 PWR units would report both concrete and steel. Do the survey results indicate the number of units with (and maximum amounts of) carbon steel and concrete that are not coated?
12. The TR chemical model contains algorithms based on results from the single effects chemical tests. A linear combination of the chemical products from individual test results is used to obtain a total amount of material precipitated. While single effect testing can provide useful information about material behavior, the linear precipitate combination does not consider the possibility of synergistic effects. Given the complexity of the chemical system, that changes to the chemical system have been observed to affect the types and amounts of precipitate and the amount of pressure drop across a debris bed,

- (a) justify why dissolution and precipitation tests with material combinations are not needed to evaluate possible synergistic effects
 - (b) justify why filterability testing should not be performed for combinations of precipitates for comparison to single precipitate tests
13. Previous integrated chemical effects testing (ICET) was performed with 100 ppm chloride addition. Page 38 of the WCAP states that hydrochloric acid was not added to these tests since the products of acidic radiolysis are not expected to be significant early in a postulated event prior to completion of buffering agent addition. The TR also states that after addition of the buffering agent, the long term generation of hydrochloric acid will have little effect on pH. However, chlorides could leach from other containment materials (e.g., coatings) and enhance corrosion of metallic materials. Estimate how much chloride could be present in the containment pool and discuss any expected difference in dissolution rates for the metallic coupons in the presence of chloride.
14. Potential corrosion products that could be released from the internal surfaces of the reactor coolant system (RCS) during a LOCA are discussed on Page 39 of the TR, which states that based on experience with plant shutdown chemistry, it is considered likely that no more than a small quantity (< 5 kilograms) of oxide would be released from the internal surfaces of the RCS. Figure 5.1-1 shows nickel released from the RCS during shutdowns for three-loop and four-loop PWRs. Discussion on Page 46 states that it is expected that the amount of material released during a LOCA would be expected to be similar to that experienced during a normal PWR shutdown. Discuss the mechanism for release of corrosion products during a normal shutdown relative to a LOCA. Given the thermal hydraulic transient associated with a large break LOCA, wouldn't substantially more oxide be released from the internal RCS surfaces compared to a controlled plant shutdown? Provide an estimate for the amount of material (e.g., magnetite, nickel ferrite) that would be released from RCS internal surfaces during a large break LOCA.
15. The TR chemical model does not consider the release of radioactive species during the LOCA and their subsequent affect on the containment pool chemistry. Among the potential influences of these species are:
- (a) contribution of additional particulate loading
 - (b) radiolysis of water within the containment pool that could modify the reduction potential (i.e., redox potential) of the water depending on the relative amounts of H_2 , O_2 and H_2O_2 produced. This could potentially affect corrosion rates, chemical speciation, and the solubility of compounds
 - (c) possible alteration of a debris bed, if radioactive species were transported to and concentrated within a bed to produce locally oxidizing conditions that could increase the probability of precipitation or co-precipitation of oxides
 - (d) effect of radiolysis on materials that comprise the debris bed and the ability to break down into more soluble components that may subsequently precipitate.

Please discuss potential influences from the presence of radioactive species in the containment pool including any data that may provide insight into the potential influences described above.

16. The concrete used in bench top testing was ground and aged for 28 days prior to use. This concrete was supplied by Performance Contracting Inc. Please provide the composition and applicable specifications for the concrete tested. Was the concrete tested representative of concrete in the United States PWR plants? Given the variability in concrete composition in the various regions where nuclear plants are constructed,
 - (a) discuss whether these test results are sufficient to represent industry wide concrete dissolution and precipitation.
 - (b) discuss how variability in concrete composition may affect the output from the chemical model for a plant with a large area of uncoated concrete.
17. Table 5.1-3 shows normalized (oxygen and carbon removed) compositions of the test materials. Based on the reported EDS results, the staff has several questions:
 - (a) The reported sulfur content is much greater than allowed in the SA 508, Class 2 material specification. Is there an additional source of sulfur in the analyzed sample or is the reported amount resulting from interference between sulfur and other elements (e.g., molybdenum X-ray wavelength overlap with sulfur)?
 - (b) For the SA 508 sample composition, what is the source of the aluminum? Is the reported aluminum a result of electron beam interaction with other aluminum containing materials in the Scanning Electron Microscopy (SEM) vacuum chamber? If so, what are the ramifications for the reported aluminum analyses of the other test materials or for the precipitate analyses?
18. Table 5.1-4 presents the amount of material used in the dissolution tests. On Page 61, the TR states that the target ratios were the maximum ratios from Table 3.1-1 reported in the industry survey. The values in Table 5.1-4 appear to be consistent with the values shown in Table 3.1-1, with the exception of fiberglass. The maximum fiberglass insulation/coolant ratio listed in Table 5.1-4 is 0.14 ft³/ft³. The maximum fiberglass to recirculation water volume ratio shown in Table 3.1-1 is 0.23 ft³/ft³. Please clarify the discrepancy and discuss if this affects the chemical model.
19. Section 5.2.3 indicates a total of 88 bench top tests were accepted and of these 22 tests were considered as replicate tests. Describe the amount of variability observed in the replicate tests and discuss how the results from the replicate tests are factored into the chemical model? Was there a stated data quality objective for these tests with respect to repeatability? If not, why not?
20. At the completion of the dissolution tests, were the remaining samples and the filter examined (e.g., by using a stereoscope, scanning electron microscope) to look for evidence of deposits or chemical products within the non-metallic samples or on the filter? If so, provide results from these examinations. If not analyzed with microscopy, indicate why this was not done.

21. The precipitation test matrix shown in Table 5.2-3 indicates that the precipitation of phosphates with calcium silicate (PPT run #35) was tested by buffering the dissolution run #7 with trisodium phosphate. Dissolution run #7 was performed at 265 °F. Given that more calcium is dissolved from calcium silicate at 190 °F than at 265 °F, would more calcium phosphate have precipitated in PPT run #35 if a dissolution run at 190 °F had been used? Please discuss how the chemical model uses the data from different temperatures to determine the release rate of calcium from calcium silicate insulation.
22. The apparatus in Figure 5.2-15 was used to measure the mass of precipitate settled. The cones used in this test are standard cones used for testing sub-micron particulate matter in fuel oil using a high speed centrifuge. The chemical precipitates generated during TR testing would have different sizes and hydration spheres from the material assumed in the fuel oil test. Explain how the settling characteristics of the chemical precipitates would not be affected by the settling cone shape and dimensions.
23. The coefficients provided for the aluminum release in Equation 6-1 (Page 93) appear to be incorrect. Please provide corrected values for this equation.
24. Table 6.2-1 provides an average aluminum corrosion rate for the ICET 1 coupons equal to 12.2 mg/m²-min. Please describe how this rate was calculated. If it was calculated from coupon weight loss measurements, indicate how corrosion product remaining on the coupons was considered since the coupons were not cleaned before post-test weighing. How does the corrosion rate shown above compare to a rate calculated based on using the measured ICET dissolved aluminum concentrations during the first 10 days of ICET 1 (i.e., 25 mg/l/day)?
25. For aluminum release rate, the TR chemical model uses Equation 6-2, developed from fitting several aluminum corrosion data sets. The TR indicates that the fit to this data is poorer than the fit to the aluminum bench test data alone. Given that aluminum corrosion rates increase with increasing pH, the corrosion rate of most interest is associated with environments with pH values greater than 8. For example, for plants with sodium hydroxide, aluminum corrosion rates in initial high pH containment spray and in equilibrium containment pool pH conditions are most important. Is there an alternate to Equation 6-2, such as a corrected Equation 6-1, or other alternate, that would provide a better data fit in the pH range of most interest?
26. Discuss the basis for the maximum pH (i.e., pH 12) that could occur in containment spray fluid for plants using sodium hydroxide. Is it possible for the spray system pH to reach these values? Were these maximum plant pH values determined based on calculations that used plant specific values or with calculations that used conservative assumptions? If the pH of 12 was used for conservatism, demonstrate how this would be conservative.
27. In Section 6.2.6, the TR discusses verification of the chemical model aluminum dissolution rates. Verification was performed by comparing the average amount of hydrogen generated per minute from the chemical model to the amount obtained with the computer code GENNY for the first three hours after a LOCA. Was the data used to develop the computer code GENNY independent from the data that was used to

develop Equation 6-2? If the data is independent, how would inclusion of this data affect the Equation 6-2 coefficients?

28. Discussion of precipitate formation on Page 78 states that measurable quantities of precipitates were formed in 25 experiments and the volume of precipitate formed for these cases is shown in Figure 5.2-16. This figure identifies the volume of precipitate observed for 14 run/reaction vessel designations. Later in the discussion, the TR indicates that Table 5.2-4 lists the experiments (13 of 60 experiments) where measurable precipitation occurred. Some of the run/reactor identities in Figure 5.2-16 (e.g., P1, P8, Q1) do not match with the identities in Table 5.2-4 (e.g., K2, K4, N2). Please clarify the discrepancy in the number of experiments with measurable precipitation and test run identifications between Table 5.2-4 and Figure 5.2-16. For all experiments with measurable precipitate, please provide a table showing:
 - (a) the run/reactor identification,
 - (b) material(s) and test conditions (e.g., pH, temp), and
 - (c) the amount of precipitate.
29. Table 5.2-5 provides elemental analysis of the precipitates formed during testing. Based on the elemental values shown in this table, a “best guess” precipitate is identified.
 - (a) If the compositions reported in this table are average values, please indicate the number of areas analyzed to obtain an average and the range in the percentages for each element when an average value was reported.
 - (b) Was the precipitate rinsed with deionized water prior to analysis?
 - (c) Was the energy EDS system used to obtain these results capable of detecting boron? For example, would boron be detected by this analysis if it was adsorbed onto the surface of an aluminum oxyhydroxide precipitate?
 - (d) What is the source of the copper reported for most of the precipitates?
 - (e) Since identification of precipitates provides the basis for chemical surrogates that may be used in strainer head loss testing, explain why supplemental quantitative chemical analysis is not needed to establish the precipitate identity with greater accuracy?
30. Within Section 5.4, Precipitate Filterability Tests, the terms filter cake coefficients, filtration constants, filter solids constant, and filterability coefficient are used. Please define these terms and indicate if they refer to the same parameter.
31. The filterability tests provided information about the hydraulic characteristic of the precipitates. It is stated that the lower filtration constants can be used as an initial guess for calculating pressure drops. Please describe the formation of the filter cake and the material composition of the cake. Evaluate the relevance between the filter cake and

debris bed under plant LOCA conditions, and demonstrate why Equation 5-1 can even be used as an initial guess without the real debris bed formation sequence and material compositions.

32. Equation 5-1 is used as the basis to correlate the test data collected from the filterability tests. According to Equation 5-1, the pressure drop across the debris bed appears to be a function of flow velocity, specific dry solids loading (lb/ft²), water viscosity and total screen/filter flow area. Assuming that we have two filter cakes with different flow area, but the same water viscosity, flow velocity, and specific dry solids loading, the pressure drop across the screen decreases with larger flow area (using this equation). The NRC staff would expect the pressure drop under these conditions to remain constant. Please explain the origin of the equation and justify the correctness of the correlation.
33. Equation 5-2 through Equation 5-5 were developed to account for a debris bed with different layers of material compositions. Please explain how these equations could be applied to plant conditions following a postulated LOCA where the debris bed material compositions, particulate/fiber ratios, and chemical precipitate specific mass are not measured or the bed morphology is not known.
34. In Section 5.4.4, discussion of filterability test results, the TR states, "For PPT runs 1, 14, and 16, the head loss with debris laden filters is comparable to or less than the clean filter head loss. This anomaly may be attributed to either some bypass of the filter or slight errors in the pressure measurements that could cause a negative number when the difference of two small numbers is determined." Please discuss how the filter could have been bypassed. If filter bypass potentially occurred during these tests, discuss the implications on the reliability of all the test results including justification why all the filterability test results should not be repeated using a test that ensures filter bypass will not occur.
35. Filterability tests were conducted using a 1 micron glass fiber filter. Previous evaluation of chemical product particle sizes indicate simulated ICET 1 chemical products range in size depending on agglomeration of nanoparticles. For example, Los Alamos National Laboratory (LANL) identified particle size aggregates of approximately 0.5 micron. In addition, particle sizing (after ultrasonic deflocculation) of ICET 1 simulated chemical product at Argonne National Laboratory showed approximately one third of the particles were less than 1 micron. Discuss how the potential range of precipitate sizes could affect the filterability test results.
36. Table C-1 provides a summary of filtration results. The method of precipitate formation (e.g., PPT on cooling, concrete, pH 4) shown for the various precipitation test runs in Table C-1 does not match the descriptions previously provided in Tables 5.2-4 and Table 5.4-1. Please clarify.
37. The mass of precipitate filtered for PPT 16 in Table C-1 is shown as a negative value. In addition, the K_{fx} for PPT 3 in Table C-1 does not match the K_{fx} reported in Table 5.4-1. Please clarify.
38. Please interpret the meaning of the data provided in Figure C-2.

39. The chemical model spreadsheet does not provide an input value for zinc although it shows zinc released in subsequent Excel sheets. Although testing has shown zinc may not be an important contributor to chemical effects, discuss why there is not a link between the input sheet and the “zinc released submerged” and “zinc released unsubmerged” sheets for consistency?
40. The TR determines the amount of sodium aluminum silicate relative to aluminum oxyhydroxide based on previous thermodynamic based chemical speciation work (NUREG-CR-6873). This thermodynamic work, however, did not consider reaction kinetics or potential influences of one material on another. Discuss how these could affect the relative amounts of these precipitates that are formed.
41. In Section 7.1, the TR states that after generation in the particle generator unit, the chemical products may be treated as another class of inert debris for strainer testing purposes. Please clarify this statement. Is this statement intended to signify that product generated using the procedures provided in the TR can be considered as surrogate chemical product or does it indicate that these products will not interact with any other materials/environments in strainer vendor testing? If this statement should be interpreted as the latter, provide the basis for this conclusion, considering that these particles may provide an environment for entrapment of additional materials through co-precipitation and flocculation.
42. In Section 7.1 concerning the particulate generator, the TR states that the filtration and settling behavior of the key precipitates are influenced by the amorphous and hydration properties of the materials. The TR further states that if crystalline, non-hydrated, or other manufactured solid starting materials are used for screen testing, it is suggested that testing be performed to demonstrate their acceptability. How were the chemical products generated using the directions shown in Section 7.3.2 verified to be amorphous?
43. TR guidance for chemical precipitate formation is provided in Section 7.3.2. The directions for forming aluminum oxyhydroxide call for the addition of aluminum nitrate to potable water followed by sodium hydroxide addition. Calcium phosphate and sodium aluminum silicate precipitates are also generated using potable water. Considering that LANL work (presented at the June 2006 Advisory Committee on Reactor Safeguards (ACRS) Thermal-Hydraulic Subcommittee Meeting) suggested that the ICET 1 precipitate remained amorphous as a result of boron inhibiting crystallization,
 - (a) Are the chemical precipitates generated using the TR directions representative (e.g., similar response to pH and temperature changes, produce similar pressure drop across a fiber bed) of the amorphous chemical products observed in ICET?
 - (b) Is the aluminum oxyhydroxide generated using the WCAP procedure a crystalline or amorphous product?
 - (c) Would a different chemical precipitate structure be formed if sodium hydroxide were first added to borated water to create an alkaline solution with subsequent aluminum nitrate addition?

- (d) Discuss why precipitation from homogeneous solutions will form precipitates that are representative of those formed as a result of leaching and bulk chemical addition in the presence of non-dissolved containment materials (i.e., insulation).
44. Within the particulate generator qualification testing discussion, the TR states the settling and filtration characteristics of the particle generator products were consistent with those in the bench scale testing. Settled volume is provided in Tables 7.5-1 and 7.5-2 but filtration results are not shown. Please provide the filterability test results for the particulate generator products.
45. Figures 7.6-1 and 7.6-2 show the settling rates for aluminum oxyhydroxide and calcium phosphate, respectively, as a function of mix tank concentration. The y-axis in these figures show the precipitate settled volume. For the plots provided, clarify if the y-axis values represent the amount of volume containing precipitate. In other words, if there were 2 ml of clear solution above a cloudy solution containing precipitate, would the settled volume shown be 8 ml?
46. Section 7.6 discusses the effects of concentration of generated precipitate on its settling characteristics. Bench scale testing was performed to determine the settling characteristics of generated precipitate as a function of mix tank concentration. After 60 minutes, the change in settled volume between the allowable aluminum oxyhydroxide concentrations appears to be much greater than the change in settled volume between the allowable calcium phosphate concentrations. Discuss the rationale used to determine the mix tank concentrations that should not be exceeded for aluminum oxyhydroxide and calcium phosphate precipitates.
47. Table 7.8-1 provides the minimum physical characteristics of surrogate precipitates. For precipitate settling, the table shows a criterion for a one-hour settled volume greater than 4.0 ml for the three precipitates. For strainer performance testing, it is more conservative to have precipitates remain in suspension. Therefore, discuss the rationale for the settled volume requirement greater than 4.0 ml. In addition, discuss how consistency in surrogate settling data interpretation and settling test technique are maintained between these tests and those that may be performed by strainer vendors.
48. Section 7.8 discusses settling rate and filtration characteristics that should be met if alternate (other than recommended in the TR) precipitate materials are used by strainer vendors. The TR states that in such cases, it may be necessary to pre-soak the material in water for several hours/days to ensure the proper degree of hydration is obtained. Thermogravimetric analysis performed by LANL (presented at the June 2006 ACRS Thermal-Hydraulic Subcommittee Meeting) indicated that chemical surrogate generated with aluminum in sodium hydroxide and boric acid solutions are highly hydrated.
- (a) Discuss how it is determined that the proper degree of hydration is obtained for the precipitates formed per Section 7.3.2 in the TR.
- (b) In addition, it appears the formulas for determining plant specific chemical products do not include waters of hydration. Discuss how waters of hydration are accounted for

in the chemical model output that would be used to inform subsequent sump strainer performance testing.

49. Bench test dissolution results (Page 134) indicate that for most tests with Durablanket in pH 8 solution, there is little change to the solution pH during the test. For test Runs Q4-1, Q4-2, and Q4-3, however, the pH drops significantly during the test duration. Provide any insight (e.g., sample variability, testing anomaly) you may have to explain this data.
50. It is the NRC staff's understanding that there have been some changes to the TR chemical model spreadsheet. Please provide an updated copy of the chemical model spreadsheet and discuss the impact of any changes that have been made to the spreadsheet.