



November 21, 2006

OG-06-387

Document Control Desk  
U. S. Nuclear Regulatory Commission  
Washington, DC 20555-0001

**Subject:** Pressurized Water Reactor Owners Group  
**Responses to the NRC Request for Additional Information (RAI) on  
WCAP-16530, "Evaluation of Chemical Effects in Containment Sump  
Fluids to Support GSI-191"**

**References:**

1. PWROG Letter, F. Schiffley to Document Control Desk, "Submittal of WCAP-16530-NP," "Evaluation of Post Accident Chemical Effects in Containment Sump Fluids to Support GSI-191" for formal review," WOG-06-113, March 27, 2006.
2. NRC letter from Sean E. Peters of NRR to Gordon Bischoff of PWROG dated October 4, 2006, "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)."
3. WCAP-16530-NP, "Evaluation of Post-Accident Chemical Effects in Containment Sump Fluids to Support GSI-191," February 2006.

In March 2006, the Pressurized Water Reactor Owners Group (PWROG) submitted WCAP-16530-NP (Non-Proprietary), Rev. 0, "Evaluation of Chemical Effects in Containment Sump Fluids to Support GSI-191," for review and approval (Reference 1). In October 2006, the NRC provided the formal Request for Additional Information (RAI) (Reference 2) for WCAP-16530 (Reference 3).

Attachment 1 to this letter provides the RAI responses to the 50 questions received in Reference 2. Attachment 2 presents the revised Section 5.4 from Reference 3 based on the RAI responses. Also included on the enclosed CD are the following documents referenced in the RAI responses:

- RAI #12: References 8-10 and relevant pages from References 11-13
- RAI #14: Relevant pages from Reference 1
- RAI #50: Revised chemical model spreadsheet developed per Reference 3

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Maanshan 1 & 2

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These RAI responses and the revised WCAP section are being provided to support issuance of the draft Safety Evaluation on WCAP-16530.

If you have any questions concerning this matter, please feel free to call Reginald Dulaney at 412-374-6549.

Sincerely yours,



Frederick P. "Ted" Schiffley, II, Chairman  
Pressurized Water Reactor Owners Group

FPS:RRD:mjl

Attachments: 1. RAI Responses  
2. Revision of Section 5.4

Enclosure on CD: 1. Chemical Effects Spreadsheet  
2. Excerpts from References 8-13 from RAI #12 response  
3. Excerpt from Reference 1 from RAI #14 response

cc: Systems and Equipment Engineering Subcommittee  
Steering Committee  
S. Peters, NRC  
W. Rinkacs, Westinghouse  
A. Lane, Westinghouse

OG-06-387 Attachments

TAC No. MD1119

**Response to NRC Request for Additional Information on  
WCAP-16530-NP, Rev. 0, “Evaluation of Post-Accident  
Chemical Effects in Containment Sump Fluids to Support  
GSI-191”**

November 20, 2006

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## Attachment 1

### RAI #1

Dissolution testing was performed with small volume reaction vessels. Please identify the fluid volume in these tests.

### RAI #1 Response

The stainless steel reactors were filled to a nominal 150 ml, while the Teflon vessels were filled to a nominal 120 ml.

### RAI #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?

### RAI #2 Response

All potentially non-homogeneous materials (e.g., insulation and concrete) were ground or otherwise treated to produce small particles for testing. Testing of materials in this condition reduces the effects of non-homogeneity inherent in the material. Based on the consistency of the results of test runs performed at different pH and temperature conditions, there is a high degree of confidence that individual test samples were representative. On this basis, a specific analysis to verify homogeneity was not warranted.

### RAI #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 ratio 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).

### RAI #3 Response

The closed-vessel tests were performed to determine dissolution rates of materials. For metals, the presence of higher levels of carbon dioxide could potentially reduce corrosion due to formation of protective metal carbonates. Thus, performance of the material release determinations in a carbon-dioxide depleted atmosphere is conservative.

Following the dissolution exposure, the liquids in the test vessels were transferred to settling cones to test for the formation of precipitates. The solutions were exposed to carbon dioxide from the air for 24 hours during the precipitation tests. Thus, reaction with atmospheric carbon dioxide to form metal carbonate precipitates was possible.

Regarding the potential effect of atmospheric carbon dioxide on the total quantity of precipitates formed, it is important to note that the chemical model assumes that all dissolved aluminum precipitates either as sodium aluminum silicate or aluminum oxyhydroxide. Any aluminum that precipitated as a carbonate would not be available to precipitate as a silicate or oxyhydroxide. Thus, there is no net effect on precipitate quantity in not considering precipitation of carbonates. In addition, aluminum carbonate

would have better filtration characteristics than the silicate or oxyhydroxide. Thus, not considering precipitation of carbonates in the model is conservative.

#### RAI #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.

#### RAI #4 Response

The exact composition of the precipitates is not as important as their filterability and settling characteristics, so measuring carbon content in the precipitates is not considered to be critical.

#### RAI #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 an 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.

#### RAI #5 Response

Although the original test plan included in the WCAP or Topical Report (TR) proposed that the presence of TSP may inhibit the dissolution of Cal-Sil, conservatively, no testing was performed to take credit for this effect. As a result, the chemical model typically predicts that all of the calcium silicate insulation is dissolved and available to form precipitate.

#### RAI #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 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?

#### RAI #6 Response

The test plan was developed with the intention of bounding the possible range of containment sump pH values in US PWRs. A survey was conducted of the plant conditions prior to finalizing the test plan. Fifteen (15) plants reported a pH greater than or equal to 10.0, so a pH of 12 was chosen to bound the data provided. The dissolution tests were performed at pH values across the entire range, so the model is applicable for plants with a pH between 4 and 12.

RAI #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).

RAI #7 Response

The standard approach that the vendor Performance Contracting Incorporated (PCI) uses for sample preparation is to cut the fibrous insulation into strips and feed them into a wood chipper/shredder. This process yields a combination of fines and small clumps and is consistent with the method generally accepted and used previously in both NRC-sponsored sump performance tests as well as testing performed for BWR and PWR sump performance issues.

RAI #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.

RAI #8 Response

The primary rationale used in the preparation of materials for testing was to maintain general consistency with the approach taken in the ICET program and to achieve realistic and conservative results.

The purpose of "baking" fiberglass insulation would be to remove organic binders present in the manufactured insulation that could decompose at high temperature under service conditions. Although the quantity of such binding agents is low (<5%), there is some potential that the binding agents could alter the dissolution behavior of the base material. For materials in containment, it is not expected that all of the binding agents in all insulation materials would be lost due to decomposition. Thus, it is not strictly realistic to use either all baked or all unbaked material.

To evaluate the potential effects of binders on dissolution behavior, samples of both unheated fiberglass and heat treated NUKON fiberglass were used during testing. The result of this testing showed material release was comparable/slightly higher from the untreated fiberglass material. On this basis, it is judged that the use of non-heat treated specimens is the preferred method.

NUKON fiberglass was heat treated at 450°F prior to testing. No other materials were heat treated. It may be noted that a high degree of dissolution was measured for non-heat treated CalSil insulation and Min-K samples, consistent with results obtained in the ICET program. These results provide further confidence that use of non-heat treated materials for dissolution testing provides good results.

RAI #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?

RAI #9 Response

No direct comparisons tests were performed using the same material in a baked and unbaked condition. The “baking” variable was not fully explored since it was considered to be less important than the primary variables of pH, temperature, and base material. Excluding the baking variable from the study is supported by the following:

- 1) Report NUREG/CR-6885 LA-UR-04-5416, page 10, states that organic binder is removed from fibrous insulation after a short exposure to water at temperatures greater than 90°C (194°F). This was demonstrated in the NUREG report for Nukon fiberglass. This should also be the case for the testing done in WCAP-16530, especially in the high pH and high temperature (265°F) tests.
- 2) Microscopic examination indicated that MIN-K, FiberFrax, and Microtherm do not contain binders. Thus, they should not be affected by baking.
- 3) The Interam material is used as a fire barrier, and would not normally be exposed to high temperatures in containment.

The mineral wool material used in WCAP-16530 testing was coated with a binder that did not appear to be readily attacked by the test solutions, which should be consistent with the effect of the post-LOCA sump solution on the material.

RAI #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?

RAI #10 Response

The pH adjustments were made to reflect the large increase in pH achieved in containment by the addition of the sodium tetraborate or TSP buffers. These tests were conducted to observe whether additional chemical precipitates formed due to the interaction of the dissolved materials from the dissolution tests and the newly introduced buffer. The precipitation tests were not used to determine the quantity of chemical precipitate predicted by the chemical model. The chemical model uses the dissolution test results as opposed to the precipitation test results to determine the amount of precipitate formation.

The chemical model uses the measurements of dissolved aluminum from the dissolution testing to predict the quantity of aluminum released. The model then conservatively assumes that all of the aluminum released forms precipitate. Thus, the amount of aluminum precipitate formed is based on the amount of aluminum released not the amount of precipitate observed in the precipitation tests.

RAI #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?

#### RAI #11 Response

The survey requested the exposed surface area of concrete. The survey also requested the surface area of “uncoated” carbon steel. Therefore, Table 3.1-1 presents the number of units with, and maximum amounts of, uncoated or exposed carbon steel and concrete.

#### RAI #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

#### RAI #12 Response

a) As discussed below, material interactions were considered in the development of the chemical model and key interactions were included. The synergistic effects of material combinations overwhelmingly tend to reduce material release. Thus, not performing testing on material combinations is conservative. A discussion of key material interactions and how they were addressed in the chemical model is provided below.

#### Precipitation Reactions

The material interaction of ultimate interest in the Containment Sump Chemical Effects program is combination of dissolved species to create chemical precipitates (solids) that could potentially increase sump screen head loss. Based on the chemical composition of the containment materials and of coolant additives, the predominant classes of precipitates expected would be metal hydroxides/oxyhydroxides, aluminum silicates and metal phosphates (for plants using TSP buffering). Based on the results from the ICET program, WOG testing and NUREG/CR-6873, the specific precipitates expected to predominate would be aluminum oxyhydroxide, sodium aluminum silicate and calcium phosphate<sup>1-7</sup>.

The chemical model assumes that all dissolved aluminum precipitates as either sodium aluminum silicate or aluminum oxyhydroxide. All dissolved silicon is assumed to precipitate as sodium aluminum silicate. For plants using TSP buffering, all calcium is assumed to precipitate as calcium phosphate. The results of the ICET program and other testing<sup>8-10</sup> showed that some fraction of the dissolved species does not precipitate but remain in solution and do not contribute to the precipitate burden. Thus, the assumption of complete precipitation is conservative.

In practice, some fraction of the available aluminosilicates would precipitate with other cations rather than sodium (e.g., calcium aluminum silicate). However, since all aluminosilicate is accounted for as sodium aluminosilicate, the net effect on total precipitate formation from not including other metal aluminosilicates is zero, discounting the minor differences in molecular weights between the metals.

Also in practice, other metals present in solution may precipitate as phosphates or hydroxides (e.g., zinc phosphate or iron hydroxide). Based on the results of the ICET and the WOG programs, the concentration of other dissolved metals is less than one percent of the concentration of the predominate metals (aluminum and calcium). Thus, the net effect of ignoring these interactions is less than one percent.

#### Common Ion Effect

For any chemical reaction, the reaction rate is dependent on the concentration of the reacting materials and the resulting products according to LeChatlier's Principle<sup>11</sup>. As the concentration of the reaction products increases, the reaction slows. This is true independent of whether the reaction product actually comes from the reaction of interest or is introduced from another source. In practice for the dissolution of sump materials, the rate of dissolution is dependent on the concentration of the dissolved species in the sump fluid, irrespective of the source. In cases where an element of interest is released from more than one material, the dissolution rates would be interdependent. For example, calcium may be released from dissolution of calcium silicate, concrete and mineral wools. As a consequence, the release rate of calcium from the individual materials is slower in the presence of the other materials than would be the case if a single material was present. This is true in both the short and long term. The chemical model provides an option to include this effect by accounting for the concentration of each dissolved element from all sources at each time step in the numerical integration.

#### Loss Due to Precipitation

As a corollary to the common ion effect, the rate of dissolution reactions may increase if a dissolved reaction product combines with other elements or compounds in solution and precipitates as a solid. For example, loss of aluminum due to precipitation as sodium aluminum silicate would tend to increase the dissolution rate of Kaowool and other materials containing aluminum silicate. This effect is not significant during the initial stages of an event when initially rapid material release occurs, and thus there is no net short-term impact from omission of this effect from the model.

Loss due to precipitation would have the largest effect on the dissolution rates of calcium-bearing materials in the presence of trisodium phosphate. Due to the high net release rates for calcium predicted by the chemical model, the net dissolution rate of these materials predicted by the model is in excellent agreement with the results from the ICET program and other published data. Thus, there is no net long-term impact from omission of this effect from the model.

#### Silicate Inhibition of Corrosion

Silicate is a well-known inhibitor of corrosion of most metals<sup>12,13</sup>. Silicate inhibition occurs due to formation of insoluble metal silicates on the metal surface. Although there is a significant source of silicate from dissolution of silicate insulation materials, this effect was not included in the generic chemical model. Plants with high silicate loadings may optionally consider inclusion of silicate inhibition if supporting data are available from testing performed outside of the scope of the work reported in WCAP 16530 NP.

Of most concern for sump materials is aluminum corrosion. Omission of silicate inhibition of aluminum corrosion introduces additional conservatism. Note, this effect does not apply for aluminum release due to dissolution of aluminum compounds.

#### Effects of Dissolved Metals on Corrosion

Dissolved metals such as copper may enhance the rate of corrosion of more active metals due to formation of local galvanic cells on the metal surface<sup>13</sup>. For containment materials, this effect would potentially be most significant for aluminum in the presence of dissolved copper. This galvanic effect would not apply for corrosion of non-submerged aluminum. This mechanism would be expected to be most significant later in the post-accident phase when minor amounts of copper may be present and rapid aluminum corrosion due to extremes in temperature and pH has ceased. However, under these conditions aluminum would be less susceptible to corrosion due to the more neutral pH, lower temperature and the effect silicate inhibition. Additionally, the release rate of more noble metals such as copper is expected to be low under post-accident sump conditions, based on results from the ICET program and literature data<sup>13</sup>. On the basis of the above discussion, the effect of dissolved active metals on corrosion is judged to be insignificant.

#### References to RAI #12 a) response:

1. LA-UR-05-0124, "Integrated Chemical Effects Test Project: Test #1 Data Report," June 2005.
2. LA-UR-05-6146, "Integrated Chemical Effects Test Project: Test #2 Data Report," September 2005.
3. LA-UR-05-6996, "Integrated Chemical Effects Test Project: Test #3 Data Report," October 2005.
4. LA-UR-05-8735, "Integrated Chemical Effects Test Project: Test #4 Data Report," November 2005.
5. Oras, J., et al., "Chemical Effects/Head Loss Testing Quick Look Report, Tests ICET 3-4 to 11," January 20, 2006.
6. WCAP 16530-NP, Rev. 0, "Evaluation of Post-Accident Chemical Effects in Containment Sump Fluids to Support GSI-191," February 2006.
7. V. Jain, X. He, Y.-M. Pan "Corrosion Rate Measurements and Chemical Speciation of Corrosion Products Using Thermodynamic Modeling of Debris Components to Support GSI-191," NUREG/CR-6873, April 2005.
8. Mattigo, S. V., et al., PNNL Report PNNL-13881, "Precipitation of Aluminum Containing Species in Tank Wastes," April 2002.
9. Bolinger, J-C., et al., "Repartition of Various Soluble and Insoluble Species in Supersaturated Solutions," *Pure and Applied Chemistry*, Vol. 70(10), 1998.
10. Addai-Mensah, J., et al., "Sodium Aluminosilicate Solid Phase Specific Fouling Behavior," *Heat Exchanger Fouling and Cleaning: Fundamentals and Application*, Vol. RP1, Art. 11, Berkeley Electronic Press, 2004.
11. Alberty, R. and Daniels, F., *Physical Chemistry*, Fifth Edition, John Wiley & Sons, 1979.
12. Smallman, R.E. and Bishop, R.J., *Modern Physical Metallurgy and Materials Engineering - Science, Process, Applications (6th Edition)*, Elsevier, 1999.
13. Revie, R. Winston, ed. *Uhlig's Corrosion Handbook (2nd Edition)*. John Wiley & Sons, 2000.

b) Filterability tests performed during the test program were conducted to provide a measure of the suitability of the surrogate precipitates, and were not intended to be used to benchmark or to replace testing performed by sump strainer vendors. When applicable, combinations of precipitates have been/will be used in sump strainer testing.

### RAI #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.

### RAI #13 Response

For materials in containment such as coatings, limits are placed on the concentration of leachable chloride and other potentially harmful materials. Thus, a significant source of leachable chloride is not present in containment. This was specifically evaluated during the development of the test protocol for the ICET program, and it was determined that the leachable chloride content of coatings was sufficiently low to justify not considering chloride from this source. Data supporting this determination was previously provided to the NRC during development of the test protocol in the ICET program<sup>1</sup>.

Additionally, as noted in the WCAP, metal corrosion rates determined in this program were comparable, and in most cases higher, than results reported in testing in which chloride was intentionally added.

### References to RAI 13 Response:

1. This information was transmitted by Martin Murphy, Materials and Chemical Engineering Branch, NRC, to a coatings industry representative, Mr. Jon Cavallo, Vice-president, CCCL, and ASTM D-33 Committee chairman, via a 28 page facsimile transmittal on June 14, 2004. The package of information included data sheets of leaching testing performed for coatings manufactured by both Keeler & Long/PPG Industries and Carboline Company. These data sheets documented the small amount of leachable chlorides in coatings used inside containment.

### RAI #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.

RAI #14 Response

Conservative estimates indicate on the order of 189 kilograms of adherent oxides are present within the primary circuit – including fuel surfaces – of a large four-loop plant. Crud build up models have been developed that estimate the fraction of the crud inventory that can be released as particulates due to shear forces and those that can be transported by dissolution followed by precipitation. The estimates of such material ranges between 12 and 25 kilograms<sup>1</sup>. This represents the upper bound of what could be released during a large-break LOCA.

Primary system metal oxides are dense (specific gravity from 3.8 to 6.4), and would not readily be transported to the sump screens. Additionally, the oxides would be easily filterable. This judgment is based on experience during primary side chemical decontamination application as well as plant operational experience.

## References to RAI 14 Response:

1. Jim Henshaw, John C. McGuire, Howard E Sims, Ann Tuson, Shirley Dickinson, Jeff Deshon “The Chemistry of Fuel Crud Deposits and Its Effect on AOA in PWR Plants, Proceedings of the International Conference on Water Chemistry of Nuclear Reactor Systems, Jeju Island, Korea, October 23-26, 2006. Page 17

RAI #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<sub>2</sub>, O<sub>2</sub>, and H<sub>2</sub>O<sub>2</sub> 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.

RAI #15 Response

As discussed in the response to item 14, it is anticipated that oxides released from the primary surfaces would quickly settle due to their high density. Thus, there would be little direct contact with structural materials such as insulation.

Inorganic containment materials (e.g., metals and insulation materials) are predominantly resistant to break down by radiolysis. For example, silicate materials similar to insulation are present in CRUD on the core. Thus, the effect of direct contact by high specific activity oxides would be negligible. For example, borosilicate material, which is chemically similar to fiberglass, is routinely used as a filtration media for high activity particulate.

Although no direct data are available, it is not expected that the presence of highly oxidizing free radicals would strongly affect the dissolution of inorganic containment materials such as insulation since the dissolution does not occur by oxidation. As with possible radiolysis effects, it should be recognized that similar materials (e.g., calcium and aluminum silicates) are present in CRUD and would be subject to high concentrations of free radicals generated from radiolysis of water.

#### RAI #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 U.S. 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.

#### RAI #16 Response

a) Variations in the concrete used at different sites could include differences in the relative percentages of sand, gravel, etc. and cement used to prepare the concrete, as well as environmental conditions during curing (e.g., use of ice to reduce the curing exotherm). However, such variations do not have a significant effect on the base chemical constituents. That is, concrete is predominantly silicon dioxide (from sand, gravel, etc.) and calcium silicates, with minor amounts of other metal silicates (i.e., cement). Changes to the recipe and curing process do not affect this base composition. On this basis, the dissolution behavior of concrete is expected to be consistent between sites.

b) As noted above, variability in concrete composition would have a negligible effect on the model output for uncoated concrete. It is further noted that the material release from concrete (predominantly calcium and silica) per unit surface area is quite low, and concrete is not a major contributor to the overall precipitate burden.

#### RAI #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?

#### RAI #17 Response

a) The “sulfur” reported in SA 508 was actually not present. As was suggested in the RAI, the signal attributed to sulfur was actually molybdenum which is a component of the alloy.

b) The aluminum signal originates from other aluminum containing materials in the vacuum chamber, but the signal was small (1.5% in the case of the steel). This should not affect the chemical model or the conclusions of the report since the aluminum content of the precipitates was not used in modeling. The total aluminum release measured by ICP analysis was the parameter that was used to predict the amount of precipitate generated by post-LOCA chemical reactions.

#### RAI #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  $0.14 \text{ ft}^3/\text{ft}^3$ . The maximum fiberglass to recirculation water volume ratio shown in Table 3.1-1 is  $0.23 \text{ ft}^3/\text{ft}^3$ . Please clarify the discrepancy and discuss if this affects the chemical model.

#### RAI #18 Response

At the start of the testing, not all of the plant surveys had been received and reviewed. The maximum fiberglass insulation/coolant ratio of  $0.14 \text{ ft}^3/\text{ft}^3$  used in testing was based on the survey data available at the time the test protocol was developed. In reviewing the complete survey responses, only two (2) units have fiberglass to recirculation water volume ratios greater than  $0.14 \text{ ft}^3/\text{ft}^3$ , at 0.18 and  $0.23 \text{ ft}^3/\text{ft}^3$ .

Although the stated intent of the bench tests was to use the maximum observed volume ratio for the individual components, the release rate equations are based on the total mass of insulation present, rather than the volume ratio. There is no technical basis or data to suggest that a higher release rate per unit mass would have been obtained if a higher volume ratio sample was used in the test runs. On this basis, there is no effect on the validity of the resulting chemical model and no changes are necessary.

#### RAI #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?

#### RAI #19 Response

The results from the replicate tests were included in the regressions used to formulate the chemical model. Inspection of the repeat runs in Table A1 shows that the run-to-run variability was high, with individual values sometimes varying by more than 50%. There was no acceptance criterion for repeatability since

large run-to-run variations were expected and were thought to reflect real-world variations that would occur between different LOCA events.

#### RAI #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.

#### RAI #20 Response

The samples and filters were not routinely examined microscopically, but were examined visually. There was no visible evidence precipitates formed within the materials or in the vessels during the high temperature tests (190°F and 265°F). The primary focus of the project was to determine release rates of dissolved species from the materials to quantify precipitate formation as a function of chemistry and temperature conditions, and to develop techniques to generate prototypical precipitates. It is not considered likely that precipitates would have formed in the vessel and not have been subsequently observed in the test solution when it was transferred out of the test vessel.

#### RAI #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.

#### RAI #21 Response

More calcium was released in the lower temperature dissolution runs, so more calcium phosphate precipitate would have formed if TSP was added to the 190°F calcium silicate dissolution run. However, the amount of precipitation predicted by the chemical model is not dependent on the quantity of precipitate observed in the precipitation runs. The amount of calcium released in each dissolution run was measured using ICP analysis, and subsequently, a release rate equation was developed from this data. The release rate equations were based on the data from dissolution runs at both temperatures: 190°F and 265°F.

#### RAI #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.

#### RAI #22 Response

The settling tests were used to observe the general settling characteristics of the precipitates and to make relative comparisons between the types of chemical precipitates and surrogates. The settling

characteristics of each chemical precipitate would be affected similarly by the settling cone shape and dimensions, supporting a relative comparison of their settling behavior.

#### RAI #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.

#### RAI #23 Response

The value for the “B” coefficient should have been -0.4371 rather than 0.4371 (sign error). Otherwise, the coefficients are correct. It should be noted that Equation 6-1 was not used in the chemical model. It should also be noted that Equation 6.1 was derived only from the release rate data calculated from solution concentrations (Run E5-1, C5-1, Q7-1, D5-1, K7-1, N7-1, S7-1). Equation 6.2 and Table 6.2-1 included both the release rate data from the solution concentrations and the release rate measurements based on coupon weight loss. The weight loss data and the solution concentration data were averaged.

#### RAI #24

Table 6.2-1 provides an average aluminum corrosion rate for the ICET 1 coupons equal to 12.2 mg/m<sup>2</sup>-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)?

#### RAI #24 Response

The releases calculated from the coupon mass loss were averaged. It was determined to be appropriate not to rinse the compounds since such adherent corrosion products will not be transported to the sump.

It is difficult to compare the dissolved aluminum values and corrosion since there is no way to conclusively determine the quantity of aluminum released that either remains on the coupons as an oxide or oxyhydroxide, or that is released and subsequently precipitates and is thus not measured as “dissolved” aluminum. If one makes the following assumptions:

- all aluminum released is present as dissolved aluminum
- only aluminum released from submerged specimens contributes
- the total submerged coupon surface area was 6 ft<sup>2</sup> (0.56 m<sup>2</sup>)
- the system volume was 949 liters,

then the 25 mg/l/day solution concentration increase corresponds to an area based corrosion rate of 29.6 mg/m<sup>2</sup>/min.

#### RAI #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?

#### RAI #25 Response

One set of data did not correspond well with the remaining data, but was included because the intention was to use all available data. An inspection of the fit of the model to the data suggested that these points did not have a significant effect on the model coefficients.

#### RAI #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.

#### RAI #26 Response

Refer to the response to RAI #6. A pH of 12 was chosen in the development of the test plan to bound anticipated survey responses. The maximum pH is determined by individual plant analyses and was communicated to the PWROG on the plant survey responses. A review of the completed survey responses illustrated that fifteen (15) plants reported a sump pH greater than or equal to 10.0, which provides a good basis for use of a bounding pH of 12 to represent either the sump or spray solutions. The use of the bounding pH value of 12 allows for conservative results over the entire pH range of 4 to 12.

#### RAI #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?

#### RAI #27 Response

The computer code GENNY used data from the Oak Ridge tests and WCAP 7153A and this data was also used in the development of Equation 6-2. Thus, the GENNY database has already been used for Equation 6.2.

#### RAI #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.

#### RAI #28 Response

The precipitation runs have been reviewed and the following clarifications are offered.

The discussion refers to 25 experiments in which precipitates formed which is a larger number than in Figure 5.2-16 or Table 5.2-4. The 25 value included runs that were rejected for experimental difficulties. The correct value is 17.

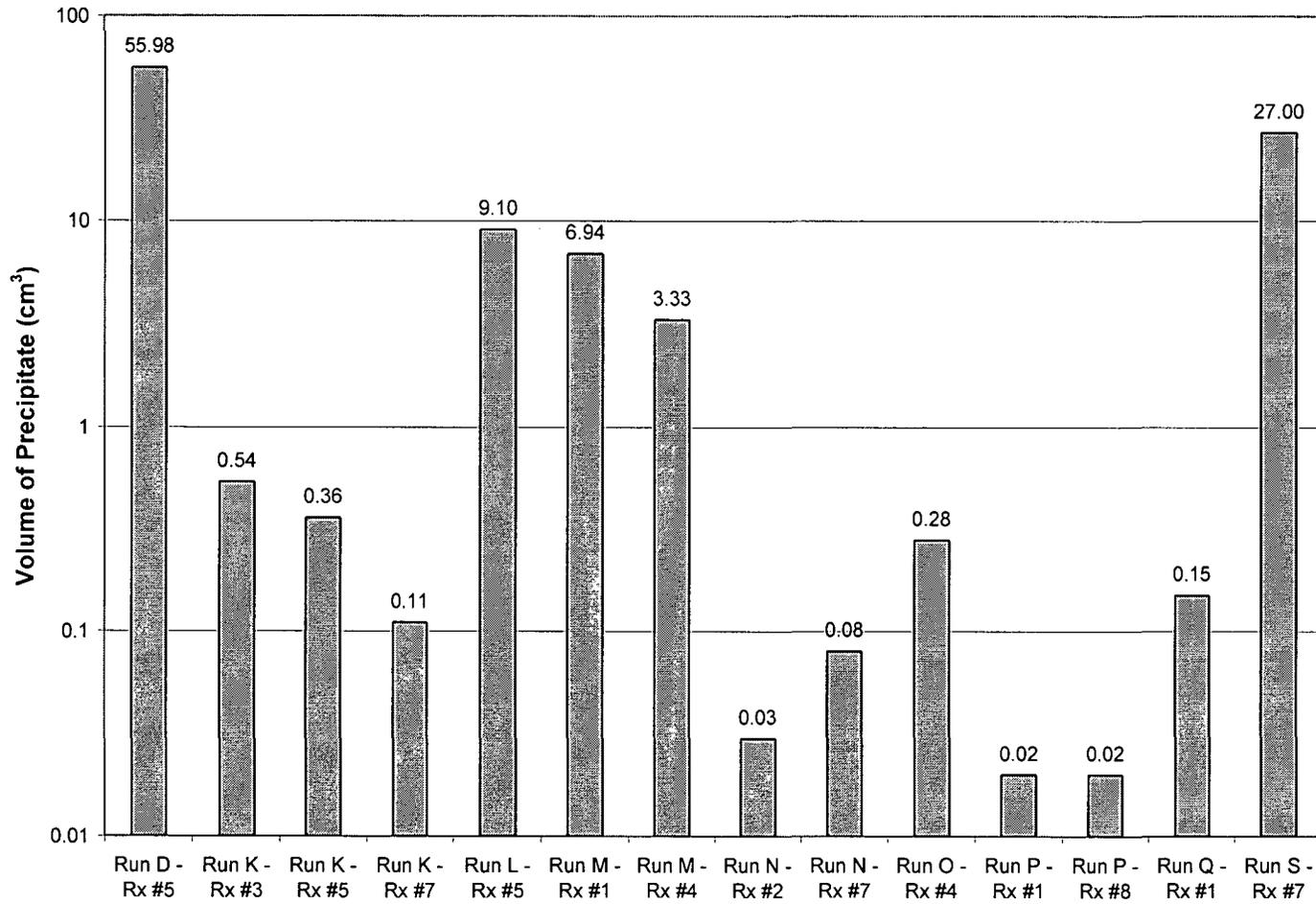
A corrected Figure 5.2-16 is shown below. The original figure included Run M7, a bad run, which has been eliminated. Run N2 was mislabeled as N5, which has also been corrected. The original figure also included only precipitates that formed by cooling from 265 °F. Four runs have been added (D5, P1, P8, and Q1) where precipitates formed upon cooling from 190 °F, even though these runs were not included in the precipitation test matrix. This figure does not include the 3 precipitates that formed by mixing different solutions, since different volumes of solution were involved than for the cooling tests.

A corrected Table 5.2-4 is also shown below. Run M7 was replaced with N7 since M7 was determined to be a flawed run. Also, entries have been added for precipitates that formed from solutions not in the precipitation test matrix. Three columns have been added to clarify the test conditions.

Corrected Table 5.2-4: Experiments with Precipitates

PPT Run	Run/Reactor	Dissolution Run (Soln A)	Material Producing Solution A	pH Solution A	Temperature Solution A	Soln B	Mass of PPT originally in cone	PPT Total Volume settling cone	PPT density	Method of Precipitation
					°F		(g)	(cm <sup>3</sup> )	(g/cm <sup>3</sup> )	
1	K7	1	Al	4	265	-	0.0016	0.11	0.015	Precipitation from cooling
2	N7	3	Al	8	265	-	Not measured	0.08	Not measured	Precipitation from cooling
3	S7	5	Al	12	265	-	0.6154	27	0.023	Precipitation from cooling,
12	M4	23	Other Fiberglass	12	265	-	0.0103	3.33	0.003	Precipitation from cooling
13	K5	25	Concrete	4	265	-	0.0034	0.36	0.009	Precipitation from cooling,
14	L5	27	Concrete	8	265	-	0.0375	9.1	0.004	Precipitation from cooling
16	K3	31	Mineral Wool	4	265	-	-0.0008	0.54	--	Precipitation from cooling
22	O4	43	FiberFax	4	265	-	0.0028	0.28	0.010	Precipitation from cooling
24	M1	47	FiberFax	12	265	-	0.0427	9.94	0.004	Precipitation from cooling
30	N2	59	Galvanized Steel	12	265	-	0.0045	0.03	0.151	Precipitation from cooling, Galvanized, pH 12
35	K2	7	CalSil	4	265	TSP pH 8	n/a	n/a	n/a	PPT with Phosphate
38	K5	25	Concrete	4	265	TSP pH 8	n/a	n/a	n/a	PPT with Phosphate
60	M4	23	Fiberglass	12	265	E3 (pH 4, CalSil, 190F)	n/a	n/a	n/a	Mixing of solutions from different dissolution runs
Precipitates that Formed but not in Precipitation Test Matrix										
n/a	D5	6	Al	12	190		not measured	55.98	Not measured	Precipitation from cooling
n/a	P1	50	Carbon Steel	4	190	-	not measured	0.02	Not measured	Precipitation from cooling
n/a	P8	12	CalSil	12	190	-	not measured	0.02	Not measured	Precipitation from cooling
n/a	Q1	26	Concrete	4	190	-	not measured	0.15	Not measured	Precipitation from cooling

Revised Figure 5.2-16: Volume of Precipitate Observed in the Settling Cones



RAI #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 dispersive spectroscopy 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?

RAI #29 Response

- (a) Typically only one area scan approximately 20 microns in size was performed. Due to the small particulate size, a 20 micron scan was considered sufficient.
- (b) The precipitate was rinsed with deionized water.
- (c) EDS is only sensitive to boron in large amounts. Boron can be detected in boron carbide by EDS (54 wt%), but cannot be detected in thin boric acid deposits (B<17 wt%).
- (d) Copper tape was used to hold down the filter paper.
- (e) The focus of the effort was to identify the general chemical make up of the prototypical precipitates and to investigate the physical attributes of the precipitates that could affect sump screen performance (i.e., settling rate and qualitative filtration behavior). This information was used to develop surrogate materials that are chemically similar and have essentially the same filtration characteristics. For example, testing demonstrated that a key class of precipitates was composed of compounds containing a metal (sodium or calcium), aluminum and silicon (presumably as silicate). Thus, a surrogate was prepared by combining aluminum (as aluminum nitrate), sodium and silicon (as sodium silicate). The surrogate material exhibits the same filtration properties as the precipitate generated in the bench tests. Although it is assumed that both materials are sodium aluminum silicate ( $\text{NaAlSi}_3\text{O}_8$ ), the filtration behavior is the attribute of interest.

RAI #30

Within Section 5.4, Precipitate Filterability Tests, the terms filter cake coefficients, filtration constants, filter solids constants, and filterability coefficient are used. Please define these terms and indicate if they refer to the same parameter.

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RAI #30 Response

Section 5.4 of the WCAP has been revised and will be sent as part of the response to the RAIs. All references to filter solids constant, filtration constants, and filterability coefficients have been replaced in the text by the overall filter cake coefficient ( $K_f$ ) and the filter cake coefficient for a specific precipitate ( $K_{fx}$ ). The terms are defined as follows:

$K_f$  = overall filter cake coefficient ( $\text{gpm ft}^{-2} \text{psi}^{-1} \text{cP}^{-1}$ )

$K_{fx}$  = filter cake coefficient for a specific precipitate or solid x ( $\text{gpm lb}_m \text{cP ft}^{-4} \text{psi}^{-1}$ )

RAI #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.

RAI #31 Response

The data obtained regarding composition of the precipitates can be found in Table 5.2-4 (Experiments with Measurable Amounts of Precipitate) and 5.2-5 (SEM Analysis of the Precipitates). A debris bed was not generated for the experiments due to the highly variable nature of the debris. Instead a commercial fiber filter was used. With respect to Equation 5-1, it was assumed that the bed was impervious to precipitate.

On the other hand, this does not eliminate the possibility of open channels since these also can hold precipitate. Also, the pressure drop data obtained are not intended to be used for calculating actual pressure drop across the plant scale filtration units. Rather, the purpose of collecting this information was to obtain an indication of the filterability of the precipitates. This approach gives a bounding worst case evaluation since there are assumed to be no channels formed. Any channels will tend to decrease pressure drop over the bed.

RAI #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 ( $\text{lb/ft}^2$ ), 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.

RAI #32 Response

As mentioned in our response to RAI #30, the units of F the volumetric flow rate are GPM not  $\text{GPM/ft}^2$  as was indicated in the original version of the equation.

RAI #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.

RAI #33 Response

The response to RAI #31 indicates that this equation can be used if it is assumed that debris has made the filter impervious to precipitate. On this basis, the equation cannot be applied to a plant screen. This is a worst case approach to estimating the pressure drop.

As stated in RAI #31, the pressure drop data obtained in these experiments was not intended to be used for calculating pressure drop across the plant scale filtration units. Rather, the reason for collecting the pressure drop data was to obtain an indication of filterability.

RAI #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.

RAI #34 Response

The filtration tests were performed using filter discs which fit into a housing that screwed together to provide a seal. The referenced sentence in the WCAP recognizes that bypass could theoretically occur in the event that the filter was not properly seated within the housing. In such an event, a "negative" head loss might be measured. In fact, this condition would be more likely to result in a zero or lower-than-expected head loss measurement. As noted, the other potential for apparently negative head loss values is the subtraction of two small delta P values, each with their associated uncertainties.

Although there was some unlimited potential for bypass to occur, there were no indications that bypass did occur in any of the filtration runs. The intent of the filtration tests was to obtain a qualitative indication of the relative filterability of the precipitates tested. In all cases, the precipitates tested created high head loss at low concentration, consistent with the results of the ICET and other test programs. Thus, there is no indication that filter bypass occurred to an extent that would call the results into question.

RAI #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 Lab (LANL) identified particle size aggregates of approximately 0.5 microns. 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.

RAI #35 Response

As discussed previously, filtration testing was performed to provide a measure of the suitability of surrogate precipitates and to provide a qualitative measure of filterability. The testing was not intended to generate data to be used for any other purpose. On this basis, use of filters of a consistent size and porosity for all filtration tests is logical.

It should be noted that the precipitates tested blinded the glass fiber filters at relatively low concentration, consistent with results reported from the ICET program. It is reasonable to expect that the glass fiber filters used in the test have a lower effective porosity than a fiber bed on a sump screen. Thus, the filtration data may reasonably be used as a qualitative measure of whether the precipitates could increase head loss on a strainer.

RAI #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.

RAI #36 Response

The column "Method of Precipitate Formation" in Table C-1 should be revised to be consistent with Tables 5.2-4 and 5.4-1. The adjusted column is provided below.

<b>PPT Run</b>	<i>Original Table C-1</i>	<i>Revised Table C-1</i>
	<b>Method of Precipitate Formation</b>	<b>Method of Precipitate Formation</b>
1	PPT on cooling, Concrete, pH 4	PPT on cooling, Aluminum, pH 4
2	PPT on cooling, Concrete, pH 8	PPT on cooling, Aluminum, pH 8
3	PPT on cooling, Mineral Wool, pH 4	PPT on cooling, Aluminum, pH 12
12	PPT on cooling, FiberFax, pH 4	PPT on cooling, Other Fiberglass, pH 12
13	PPT on cooling, FiberFax, pH 12	PPT on cooling, Concrete, pH 4
14	PPT on cooling, FiberFax, pH 12	PPT on cooling, Concrete, pH 8
16	PPT on cooling, FiberFax, pH 12	PPT on cooling, Mineral Wool, pH 4
22	PPT on cooling, FiberFax, pH 12	PPT on cooling, FiberFax, pH 4
24a	PPT on cooling, Galvanized, pH 12	PPT on cooling, FiberFax, pH 12
24b	PPT of Phosphates, CalSil	PPT on cooling, FiberFax, pH 12
24c	PPT of Phosphates, Concrete	PPT on cooling, FiberFax, pH 12
24d	pH 12 265 Fiberglass with pH 4 CalSil	PPT on cooling, FiberFax, pH 12
30	PPT on cooling, Concrete, pH 4	PPT on cooling, Galvanized, pH 12
35	PPT on cooling, Concrete, pH 8	PPT of Phosphates, CalSil
38	PPT on cooling, Mineral Wool, pH 4	PPT of Phosphates, Concrete
60	PPT on cooling, FiberFax, pH 4	pH 12 265 Fiberglass with pH 4 CalSil

RAI #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.

RAI #37 Response

In the case of PPT 16, the dP versus flow data indicate that the head loss with debris laden filters is comparable to or less than the clean filter head loss. This anomaly may be attributed to some filter bypass or slight errors in the pressure measurements which could cause a negative number when the difference of two small numbers is determined. Additional input regarding this subject can be found in the response to RAI #34.

In the case of PPT 3, the data shown in Table C-1 represents data taken from run PPT 3a. The original PPT 3 was disregarded and PPT 3a became PPT 3.

The disagreement in the values of  $K_{fx}$  for PPT 3 in Tables C-1 and 5.4-1 has been resolved. A value of 0.0008 will be reported in both tables.

RAI #38

Please interpret the meaning of the data provided in Figure C-2.

RAI #38 Response

Reaching equilibrium in the initial part of this test appears to have taken more time than expected. However, once this condition was attained the pressure drop versus flow data obtained was suitable for further analysis. That is, a positive slope was obtained on a pressure drop (dependent variable) versus flow (independent variable) plot. In turn, this resulted in positive values for  $K_{fx}$  and  $K_f$ .

RAI #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?

RAI #39 Response

Because zinc was determined in Section 6.2.2 of WCAP-16530 to be an insignificant contributor to the potential post-accident chemical effects, the input was not included in the "Materials Input" worksheet. The latest version of the chemical model spreadsheet does not include the zinc release evaluation in light of this determination.

RAI #40

The WCAP 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.

RAI #40 Response

The chemical model assumes all aluminum precipitates as either a silicate or an oxyhydroxide. As noted, aluminum is assumed to precipitate preferentially as the silicate based solely on thermodynamic considerations. On a mass basis, this results in a greater quantity of precipitate, and is thus considered

conservative. The filtration properties of sodium aluminum silicate and aluminum oxyhydroxide are qualitatively identical.

#### RAI #41

In Section 7.1, the WCAP 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 WCAP 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.

#### RAI #41 Response

The statement was intended to indicate that the precipitates would not be chemically interactive with other debris. It is recognized that important physical interactions may occur, for example if precipitates caused agglomeration of suspended debris such as small fibers. The significance of such interactions would be obvious in strainer testing.

#### RAI #42

In Section 7.1 concerning the particulate generator, the WCAP states that the filtration and settling behavior of the key precipitates are influenced by the amorphous and hydration properties of the materials. The WCAP 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?

#### RAI #42 Response

The primary basis is that the filtration and settling behavior of the surrogate materials are indicative of hydrated/amorphous material. Additionally, no crystalline structure was observed in high magnification SEM analysis. Finally, subsequent testing with commercially available manufactured crystalline sodium aluminum silicate showed that this material settled rapidly and was far more easily filtered than the material prepared in accordance with the directions in the WCAP.

#### RAI #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 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 WCAP 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)

#### RAI #43 Response

- a) Yes, the characteristics of the precipitates prepared in accordance with the directions in the WCAP are comparable to the precipitates evaluated in the ICET program.
- b) As noted above, the settling and filtration characteristics of the aluminum oxyhydroxide generated in accordance with the directions in the WCAP are indicative of a hydrated/amorphous material.
- c) It is possible that the presence of other dissolved species such as boron could affect the chemical form of the precipitates. However, the settling and filtration characteristics would not be measurably affected by minor changes in the chemical composition due to incorporation of ionic species.
- d) Generation of precipitates in a well-mixed system with all reactants at stoichiometric concentration is conservative with respect to formation *in situ*. In a non-homogeneous system, the rate and degree of precipitation would be controlled by the local concentration of reactants. Precipitation would slow as the concentration of the limiting reactant was reduced. For example, precipitation of calcium phosphate would be controlled by the local concentration of calcium and phosphate. In the event calcium dissolution proceeded slowly, precipitate formation would be slow. In the well-mixed, stoichiometric concentration case, precipitation goes to completion essentially instantaneously.

#### RAI #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.

#### RAI #44 Response

In addition to the settling test results presented in the WCAP, bench scale filterability tests were also conducted. These tests used the same procedures described in the WCAP.

A total of 10 runs were made. Two of the runs produced suitable pressure drop (dependent variable) versus flow (independent variable) plots. However, no weight gain was obtained for these runs. As a result, values for the filter coefficients can not be calculated. Since it would appear that the filter functioned over most of the test, these runs have been incorporated into Table C-1 as runs PG-9 and PG-10. Of the 8 remaining runs, two test conditions were duplicated. One set was duplicated 3 times (a total of 4 runs) while the other test was duplicated once (a total of 2 runs). A summary of these test results is presented in the table below.

**Particulate Generator Test Results**

Run Number	Sample Preparation Method	$K_{fx}$ (gpm lb <sub>m</sub> cP ft <sup>-4</sup> psi <sup>-1</sup> )	$K_f$ (gpm ft <sup>-2</sup> cP <sup>-1</sup> psi <sup>-1</sup> )
PG-1*	2.2 g/l Aluminium Oxide Hydroxide in Tap Water	0.005	0.07
PG-2*	Same as Above	0.0019	0.18
PG-3*	Same as Above	0.0022	0.42
PG-4*	Same as Above	0.0031	1.47
PG-5**	2.2 g/l Aluminium Oxide Hydroxide in 4400 ppm Boron	0.0001	0.04
PG-6**	Same as above	0.0001	0.04
PG-7	1 g/l Calcium Phosphate in 4400 ppm Boron	0.0085	5.34
PG-8	Same Preparation as PG-1 but Sample Volume Doubled to 2 ml	0.0004	0.03
PG-9	1 g/l Calcium Phosphate in 4400 ppm Boron – Sample Volume Increased to 10 ml	Not available	Not available
PG-10	1 g/l Calcium Phosphate in Tap Water – Sample Volume to 10 ml	Not Available	Not Available

\*Set of 4 runs

\*\* Set of 2 runs

RAI #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?

RAI #45 Response

The settled volume in Figures 7.6-1 and 7.6-2 is shown on the y-axis as the volume of the solution which contains observable precipitate. A 10 mL solution for which the bottom 8 mL are “cloudy” and the top 2 mL are clear would have a settled volume of 8 mL. This method is consistent with that used to record the settled volume of the precipitate reported in Table 5.3-1.

RAI #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.

RAI #46 Response

The maximum mix tank concentrations were selected in consideration of the fact that precipitates would be added directly to a flowing test system and would transit through in minutes. The values were selected

to balance practicality (primarily relative size of the surrogate mixing tank with respect to the test flume volume) and the need to use prototypical precipitates. The difference in the settled volume for aluminum oxyhydroxide (3.0 milliliters) and calcium phosphate (2.1 milliliters) in the un-concentrated case versus the concentrated case is not considered large.

#### RAI #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.

#### RAI #47 Response

It is recognized that it is more conservative for precipitates to remain in suspension during strainer testing, and the one-hour settling volume test is a means to ensure that surrogate precipitates indeed remain in suspension for a prototypical duration. The one-hour settling volume criterion was established to provide a consistent basis to evaluate precipitates prepared by individual screen vendors with precipitates prepared during the test program reported in the WCAP. In turn, the characteristics of the surrogates prepared in the PWROG test program were compared with the characteristics of precipitates generated during bench testing of containment materials/buffering agents. This approach provides assurance that the surrogate materials prepared by the vendors are indeed prototypical.

#### RAI #48

Section 7.8 discusses settling rate and filtration characteristics that should be met if alternate (other than recommended in the WCAP) precipitate materials are used by strainer vendors. The WCAP 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 WCAP.

(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.

#### RAI #48 Response

a) As discussed in the response to item 42 above, the filtration and settling characteristics of the surrogate precipitates were compared to the characteristics of precipitates generated in bench testing of containment materials/buffers. These data were used to conclude that the degree of hydration was comparable.

b) The degree of hydration was not determined for either the surrogate materials or the precipitates generated in bench testing. Rather, the settling and filtration characteristics of the precipitates were used to infer that the materials were hydrated to an equal degree. The mass of the waters of hydration was not included in the mass of precipitates calculated in the chemical model. Consistent with this, the recipes for

the surrogate materials only include the mass of the metal (calcium or aluminum) and anion (phosphate, silicate or hydroxide).

#### RAI #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.

#### RAI #49 Response

This was a transcription error. The Q4 runs actually started out at pH 4.1, so the pH increased during the run as would be expected. Run Q4 was a duplicate run, and the erroneous pH values were not used in the model development.

#### RAI #50

It is the staff's understanding that there have been some changes to the WCAP-16530-NP 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.

#### RAI #50 Response

The first error requiring a change to the spreadsheet was communicated to the NRC via Owners' Group letter, WOG-06-107, in March 2006. This error was discovered in the saturation constant coefficients presented in Table 6.2-3 of WCAP-16530 used to determine the release rate equations for the aluminum and silicon released from mineral wool and the silicon released from Interam.

Subsequent changes to the spreadsheet include:

- a) An error was discovered in the Si Release column of the "Results Table" worksheet; the silicon release from silica powder material, i.e., Microtherm and Min-K, was not included in the sum. An additional error was found in Cell F15 of the "Materials Conversion" worksheet. This cell incorrectly referenced the total volume of silica powder insulation as opposed to the total mass.
- b) In three of the worksheets which calculate the calcium releases for concrete (Conc), fiberglass or E-glass (EG) and mineral wool (MW), "Ca from Conc," "Ca from EG," and "Ca from MW," the incorrect row is referenced in the "Time Temp pH" worksheet Column G containing the flag to credit sump mixing. One row above that intended is referenced, so in the time period that sump mixing is credited, the calculated dissolution rates for these materials will still be dependent upon the calcium release from that material alone. The calculated dissolution rate based on the total calcium release from all materials will not be implemented until the subsequent time period.

An updated copy of the spreadsheet has been provided with the submittal of these RAI responses on the enclosed CD.

## Attachment 2

### REVISION of SECTION 5.4

#### 5.4 PRECIPITATE FILTERABILITY TESTS

##### 5.4.1 Summary

Precipitate filterability tests were carried out at the Westinghouse Science and Technology Department to determine the overall filter cake coefficients ( $K_f$ ) for the various precipitates produced in the chemical effects bench testing discussed in Section 5.2. The results of these tests indicated that chemically induced precipitates produced solids with single component filter cake coefficients ( $K_{fx}$ ) (average = 0.0034+/-0.0022) about half that of the Si and Al precipitates (0.0032+/-0.00202) formed on cooling. This indication comes from a relatively limited dataset and so needs to be used with care. However, the lower values could be used as an initial guess for calculating maximum pressure drops.

##### 5.4.2 Filtration Model

The data obtained from this experiment was modelled using the following equation:

$$F = (K_{fx} / m_x) * A * dP / n \quad (\text{Equation 5-1})$$

Where:

F = total flow rate (gpm)

$K_{fx}$  = filter cake coefficient for a specific precipitate or solid x (gpm lb<sub>m</sub> cP ft<sup>-4</sup> psi<sup>-1</sup>)

dP = measured pressure drop across filter with solids (psi or lb<sub>f</sub> in<sup>-2</sup>)

n = viscosity of the liquid in the slurry (assumed to be water) (cP)

$m_x$  = specific dry (1 hour @ 110°C) solids x loading (lb<sub>m</sub> ft<sup>-2</sup>)

A = flow area (ft<sup>2</sup>)

This model makes the assumption that the filter cakes are relatively thin and incompressible. This assumption was made since the applied pressure drops will be very small (on the order of 1 to 6 psi). Note that this assumption was supported by the data in that all the pressure versus flow plots obtained experimentally were reasonably linear in the low delta P regions.

To apply this test data to calculations for screen pressure drops, the following data is required:

1. The method of bed formation, i.e., whether the bed is formed from a mix of solids or formed by layering of various solids
2. Specific dry (1 hour @ 110°C) weight of each solid (lb<sub>m</sub> ft<sup>-2</sup>)
3. Either the temperature to determine the viscosity if water is assumed or the measured liquid (not slurry) viscosity
4. The  $K_{fs}$  of the screen (gpm ft<sup>-2</sup> psi<sup>-1</sup> cP<sup>-1</sup>) determined with the viscosity at the temperature of interest

### 5. Total flow rate (gpm) and area (ft<sup>2</sup>)

If the bed is formed in layers, then the overall  $K_f$  can be determined analogous to the method used to determine an overall heat transfer coefficient. That is:

$$1/K_f = 1/K_{fs} + \sum m_x/K_{fx} \quad (\text{Equation 5-2})$$

Where:

$K_{fs}$  = the screen coefficient (gpm ft<sup>-2</sup> psi<sup>-1</sup> cP<sup>-1</sup>)

$m_x$  = specific mass of each solid (lb ft<sup>-2</sup>)

$K_{fx}$  = filter cake coefficient for a specific for a specific precipitate x (gpm lb<sub>m</sub> cP ft<sup>-4</sup> psi<sup>-1</sup>)

A simple mass-weighted approach may be used as a theoretical means to determine the effective  $K_f$  for a mix of solids as opposed to a single solid.

$$K_{fz} = \sum K_{fx} / m_x \quad (\text{Equation 5-3})$$

where  $K_{fz}$  is the effective  $K_f$  for the mixed solids bed.

This  $K_{fz}$  can then be used along with the screen  $K_{fs}$  in the equation below to determine the overall  $K_f$ .

$$1/K_f = 1/K_{fs} + 1/K_{fz} \quad (\text{Equation 5-4})$$

Finally,  $K_f$  can then be used to determine the pressure drop using the equation:

$$dP = F / (K_f * A / n) \quad (\text{Equation 5-5})$$

#### 5.4.3 Test Procedure

After forming precipitates in the first portion of testing described in Section 5.2, the precipitates were then tested in a filter apparatus to determine their overall filter cake coefficient using the procedure given below and the apparatus shown in Figure 1 below. The solution containing the precipitate was pumped through a filter at different flow rates in order to record the pressure drop at each flow rate. The filtration experiments were done at room temperature (between 70°F and 78°F).

#### Equipment List

- 4-Channel Peristaltic Pump, Pump Head Cole Parmer EW-07519-10 with cartridges Cole-Parmer EW-07519-85 and pump tubing EW-06508-14
- Pressure sensor 1- Omega PX303-0 0A10V 0-50 psia
- Pressure sensor 1- Omega PX303-050A5V 0-50 psia
- Flow sensor- McMillan Co 104 Flo-Sen S/N 1011 3
- Tubing outside pump- Cole-Parmer L/S 14 Tubing, C-96410-14
- Filter Holder-25 mm Filter Holder VWR 28144-164

- Filter – 25 mm glass fibre filter, 1-micron, 28150-134

#### Preparation

- Calibrate the program in order to obtain pump flow rates. Three flow rates are used in order to determine the change in pressure drop with flow rate.
- Select a 1-micron glass fibre filter and weigh it to the nearest 0.0001 g.
- Place the fibre filter in the holder.
- Measure 75 ml of 4400 ppm boron solution into settling cone.
- Place the dip tube and the return line in the settling cone.

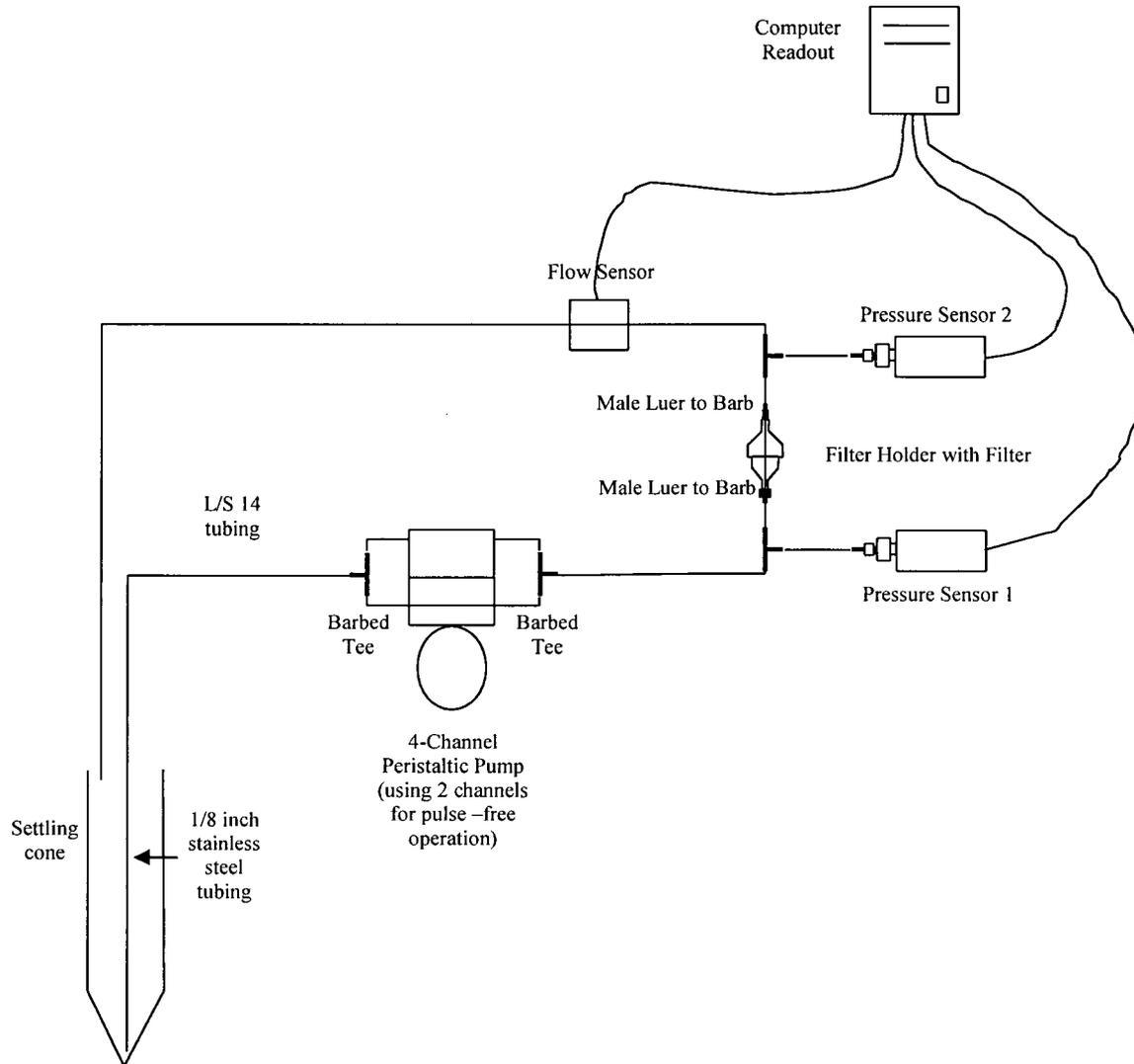
#### Filtration

- Turn on the pump and set flow rate to the highest flow rate in order to load the filter at the beginning of the test.
- Allow sufficient time for the flow to stabilize through the filter (5 minutes). Then thoroughly shake the solution containing precipitate and add approximately 10 ml to the settling cone.
- Record pressure drop across filter with time.
- After the total solution volume has passed through the filter about four times, decrease the pump flow rate.
- Record pressure drop with time.
- After the total solution volume has passed through the filter about four times, again decrease the pump flow rate.
- Record the pressure drop with time, until approximately another 4 solution volumes have passed through the filter.

#### End of Experiment Tasks

- Rinse the filter with 10 ml of de-ionized water.
- Dry the filter at 110°C +/- 10°C for 1 hour.
- Weigh the filter.
- Place filter in a labelled container for later SEM analysis.
- Clean loop before next test with a flow of de-ionized water.

Figure 1 - Filter Test Equipment Schematic



The experimental data obtained were:

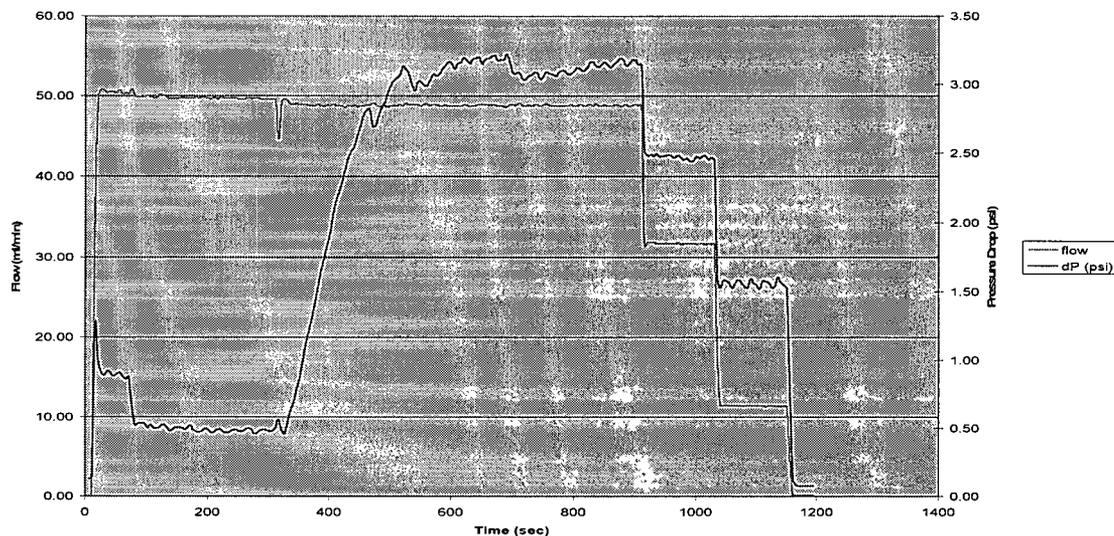
$f$  = flow rate (ml/min) as a function of  $dP$  (psi)

$n$  = water viscosity (cP) from the temperature ( $^{\circ}F$ )

$m$  = dry ( $110^{\circ}C$  @ 1 hour) solids (gm)

$A$  =  $3.8 \text{ cm}^2$  measured exposed filter area

A representative figure (Figure 2 below) containing the  $dP$  versus flow rate data recorded as a function of time is presented below. Similar data is available for all of the runs conducted in order to gauge the filterability of the precipitate.



**Figure 2 -  $dP$  and Flow Rate as a Function of Time for PPT 24D**

Graphs of the  $dP$  versus flow rate (ml/min) are shown in Appendix C. Each set of data was analyzed in the linear portion using least squared regression analysis to obtain the slope of the curve ( $z$  in psi-min/ml). Note that some curves bent over, i.e., the flow increased with little or no increase in pressure drop. The higher flow data from these tests was not used since the upper flow data was likely taken before the solids had finished depositing on the filter. Also, some near-zero point data was not used since at very low delta P values, there were instabilities in some of the delta P measurements. The range of data that was used from each test is indicated on the data plots given in Appendix C. This slope was then combined with the water viscosity, solids weight and effective filter area to determine the overall (filter + cake)  $K_f$  using the equation:

$$K_f = n / A^2 / z / [3785 \text{ ml/gal}] \quad (\text{Equation 5-6})$$

The  $K_{fs}$  (filter cake coefficient for a specific precipitate) was obtained from the slope ( $z$ ) of the  $dP$  versus flow measurement for the filter (Figure C-1) using the equation:

$$K_{fs} = n / A^2 / z / [3785 \text{ ml/gal}] \quad (\text{Equation 5-7})$$

Note that by using the slope, it was assumed that the pressure versus flow data passed through the point 0,0. The  $K_{fx}$  (filter cake coefficient for a specific precipitate ( $\text{gpm lb}_m \text{ cP ft}^{-4} \text{ psi}^{-1}$ )) was then obtained by substituting Equation 5-7 into Equation 5-2 and solving the resulting equation for  $K_{fx}$ :

$$m / A / K_{fx} / [454 \text{ gm/lb}] = 1/K_f - 1/K_{fs} \quad (\text{Equation 5-8})$$

Note that the  $K_{fs}$  was corrected to the viscosity at the temperature at which each filtration test was run.

#### 5.4.4 Results

The results from these tests are summarized in Table 1 below. The dP versus flow data is presented for each run in Appendix C. These results indicate that the  $K_{fx}$  for the various precipitates range from 0.0001 to 0.0066 after discounting results from those PPT tests that had too little precipitate to result in a discernible dP measurement: PPT runs 1, 13, 14, 16, 22 and 30.

For PPT runs 1, 14, and 16, the dP vs. flow data indicate that 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 which could cause a negative number when the difference of two small numbers is determined.

The remaining PPT runs are listed below.

**Table 1: Precipitate Filter Coefficients**

PPT Run	Precipitation Formation Method	Individual Filter Cake Coefficients ( $K_{fx}$ )	Overall Filter Cake Coefficients ( $K_f$ )
2	PPT on cooling, Al pH 8	0.0033	0.15
3	PPT on cooling, Al pH 12	0.0008	0.93
12	PPT on cooling, Other Fiberglass, pH 12	0.0009	1.15
24a	PPT on cooling, FiberFax, pH 12	0.0066	1.81
24b	PPT on cooling, FiberFax, pH 12	0.0043	1.30
24c	PPT on cooling, FiberFax, pH 12	0.0027	0.88
24d	PPT on cooling, FiberFax, pH 12	0.0039	1.19
35	PPT of Phosphates, CalSil	0.0033	1.93
38	PPT of Phosphates, Powdered Concrete	0.0001	0.05
60	pH 12, 265 Fiberglass (high sulfur), with high calcium from pH 4 CalSil.	0.0017	1.87

This data indicates that:

1. Phosphates cause precipitation by super saturation at temperature and have low individual filter cake constants ( $K_{fx}$ ) (average = 0.0034 +/- 0.0022). The other precipitate, PPT 60, has a similar value of  $K_{fx}$  (0.0017). The large uncertainty of the results is due to the limited number of phosphate precipitation runs for which filtration filter coefficients may be developed.

2. The Si and Al precipitates formed on cooling have relatively high individual cake coefficients ( $K_{fx}$ ) (0.008 to 0.0066, average = 0.00321 +/- 0.00202).
3. The repeated PPT24 runs had an average  $K_{fx}$  of 0.00438 +/- 0.00163 with a range of 0.0027 to 0.0066. This is about the same as the entire set of data (average = 0.00276 +/- 0.00196).