PWROG
PWR Owners Group

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WCAP-17788-NP, Revision 0
Project Number 99902037

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

Subject: PWR Owners Group
**Clarifications for WCAP-17788 Volume 5 NRC RAI Responses Related to PWROG Comprehensive Analysis and Test Program for GSI-191 Closure**

References:

1.) OG-15-296, "Submittal of WCAP-17788: "Comprehensive Analysis and Test Program for GSI-191 Closure (PA-SEE-1090)", July 17, 2015.
2.) NRC letter, "Acceptance for Review of the Pressurized Water Reactor Owners Group Topical Report WCAP-17788, "Comprehensive Analysis and Test Program for GSI-191 Closure (TAC No. MF6536)," (ML15351A425), dated January 8, 2016.
3.) NRC Letter, "Request for Additional Information Regarding Pressurized Water Reactor Owners Group Topical Report WCAP-17788, 'Comprehensive Analysis and Test Program for GSI-191 Closure" (TAC NO. MF6536)", (ML16070A261) dated April 13, 2016.
4.) OG-17-167, "Submittal of Responses to NRC Requests for Additional Information (RAIs) and Revisions to Topical Report WCAP-17788-P/WCAP-17788-NP, Revision 0, "Comprehensive Analysis and Test Program for GSI-191 Closure" related to Volume 5 in Support of the Closure of GSI-191(PA-SEE-1090)", June 1, 2017.

On July 17, 2015, the Pressurized Water Reactor Owners Group (PWROG) requested formal NRC review and approval of WCAP-17788-NP, Revision 0, in accordance with the Nuclear Regulatory Commission (NRC) Topical Report (TR) program for review and acceptance for referencing in regulatory actions (Reference 1). The NRC staff issued an acceptance for review letter to the PWROG on January 8, 2016 (Reference 2). Reference 3 provided RAIs for Volume 5 which the PWROG responded to via Reference 4.

The purpose of this letter is to provide further clarifications on Reference 4 responses.

Enclosed is:

1. RT-LTR-18-79, Attachment 2, "Clarifications for WCAP-17788 Volume 5 NRC RAI Responses Related to PWROG Comprehensive Analysis and Test Program for GSI-191 Closure"

Correspondence related to this transmittal should be addressed to:

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1000 Westinghouse Drive
Cranberry Township, Pennsylvania 16066

If you have any questions, please do not hesitate to contact me, Ken Schrader, at 805-545-4328 or Mr. W. Anthony Nowinowski of the Owners Group Program Management Office at 412-374-6855.

Sincerely yours,

Ken Schrader, Chief Operating Officer and Chairman
PWR Owners Group

KJS:jdb:am

cc: PWROG SEE Committee
PWROG Licensing Committee
PWROG Steering Committee
PWROG PMO
PWROG Tiger Team
J. Spring – W
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G. Wissinger – Framatome
D. Page-Blair – Framatome
V. Cusumano – NRC
A. Smith – NRC
L. Perkins – NRC

Enclosure: RT-LTR-18-79, Attachment 2, "Clarifications for WCAP-17788 Volume 5 NRC RAI Responses Related to PWROG Comprehensive Analysis and Test Program for GSI-191 Closure" (Non-Proprietary)

# RT-LTR-18-79, Rev. 0
# Attachment 2

# Clarifications for WCAP-17788 Volume 5 NRC RAI Responses Related to PWROG Comprehensive Analysis and Test Program for GSI-191 Closure

## 1. Background

The Nuclear Regulatory Commission (NRC) has requested further clarification on responses to Requests for Additional Information (RAIs) that were provided previously (Reference 1) for WCAP-17788-P/NP Volume 5 (Reference 2), which documents the autoclave chemical effects testing that was performed for Generic Safety Issue (GSI) 191 related to Long-Term Core Cooling. Clarifications and results of further evaluations are provided herein.

## 2. RAI 5.1 (Comment 1)

*A factor of 12x WCAP aluminum release was used to bound the experimental data. Can you provide insight on how much did the WCAP-16530-NP aluminum release under-predicted the autoclave experimental data on average for the different buffers?*

Westinghouse Response:

Several plants were evaluated to compare the aluminum release predicted by GSI-191 Chemical Effects model (Chemical_Effects.xls Version 1.1) documented in WCAP-16530-NP-A (Reference 3) to the results of the chemical effects testing (Reference 2). Two plants were selected for each of the three buffer chemicals, sodium hydroxide (NaOH), trisodium phosphate (TSP), and sodium tetraborate (NaTB), for a total of six plants. Plants were selected that were close to the group average for the maximum target pH (8.6) and temperature (254°F). Table 1 lists the test runs that were chosen to model, along with the actual maximum pH and temperature.

For each test run, the runsheets and temperature profiles were used to develop the curves for pH and temperature with time for the model. From system calculations described in Volumes 1 and 4 of WCAP-17788-P/NP, it is critical that significant chemical effects do not occur within the first six hours after initiation of recirculation so that core cooling can be maintained using normal (not alternate) flow paths. Therefore, to accurately model the first six hours of the test after debris addition, smaller time steps (12 minutes) were selected for this critical time period.

For each test run, a correction factor was applied to the results of the Chemical Effects model to bound the experimental data at the 6 hour mark. These results are shown in Table 1 and Figure 1 through Figure 6. The Chemical Effects model under-predicted the test data on average by a factor of 4.2, with an overall range of 1.4 to 5.9.

Another TSP buffer test was modeled as part of the RAI 5.1 Comment 2 response, and the fit of the WCAP-16530-NP-A model to the autoclave data is shown in Figure 9. The pH for this test was 8.1, and the maximum temperature was 254°F. The bump-up factor was 1.8. This brings the average bump-up factor to 3.9. The average NaOH factor was 3.2, TSP was 3.8, and NaTB was 4.7. Given the scatter in the results for each buffer, one cannot say that the bump-up factor was different for different buffers. Also, the factor of 12 that was used as a maximum bump-up factor in the original RAI 5.1 appears to be reasonable considering the comparisons that have been done to this point. The shape of the WCAP-16530-NP-A aluminum release curves also looks to be appropriate for fitting the WCAP-17788-P/NP autoclave data.

**Table 1: Summary of Actual Maximum Test Conditions**

| Buffer | Test | Figure | Max pH | Max T (°F) | Factor |
|---|---|---|---|---|---|
| NaOH | OB 06-11 | Figure 1 | 8.8 | 262 | 1.4 |
| NaOH | IBOB 15-01 | Figure 2 | 8.5 | 272 | 4.9 |
| TSP | IBOB 34-03 | Figure 3 | 8.5 | 252 | 4.4 |
| TSP | IBOB 43-01 | Figure 4 | 9.0 | 270 | 5.2 |
| NaTB | OB 19-01 | Figure 5 | 8.3 | 191 | 3.5 |
| NaTB | OB 27-02 | Figure 6 | 8.3 | 258 | 5.9 |

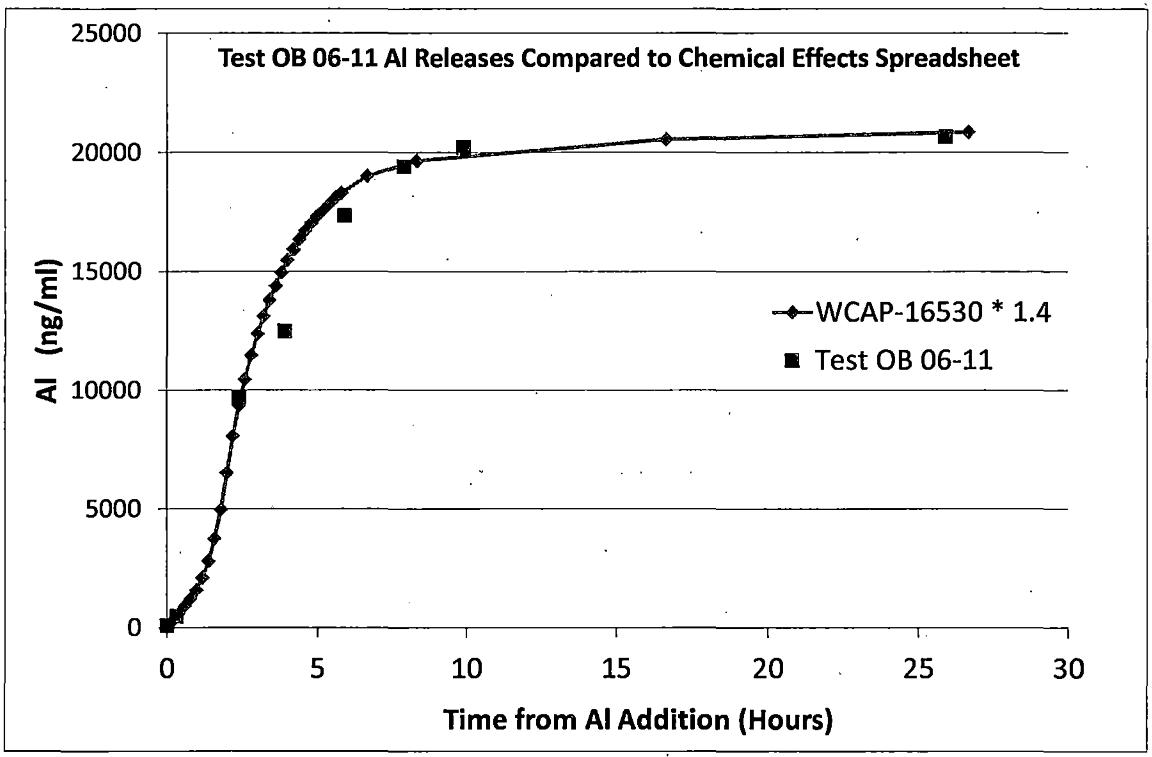


**Figure 1: Test OB 06-11 (NaOH, pH 8.8, 262°F)**

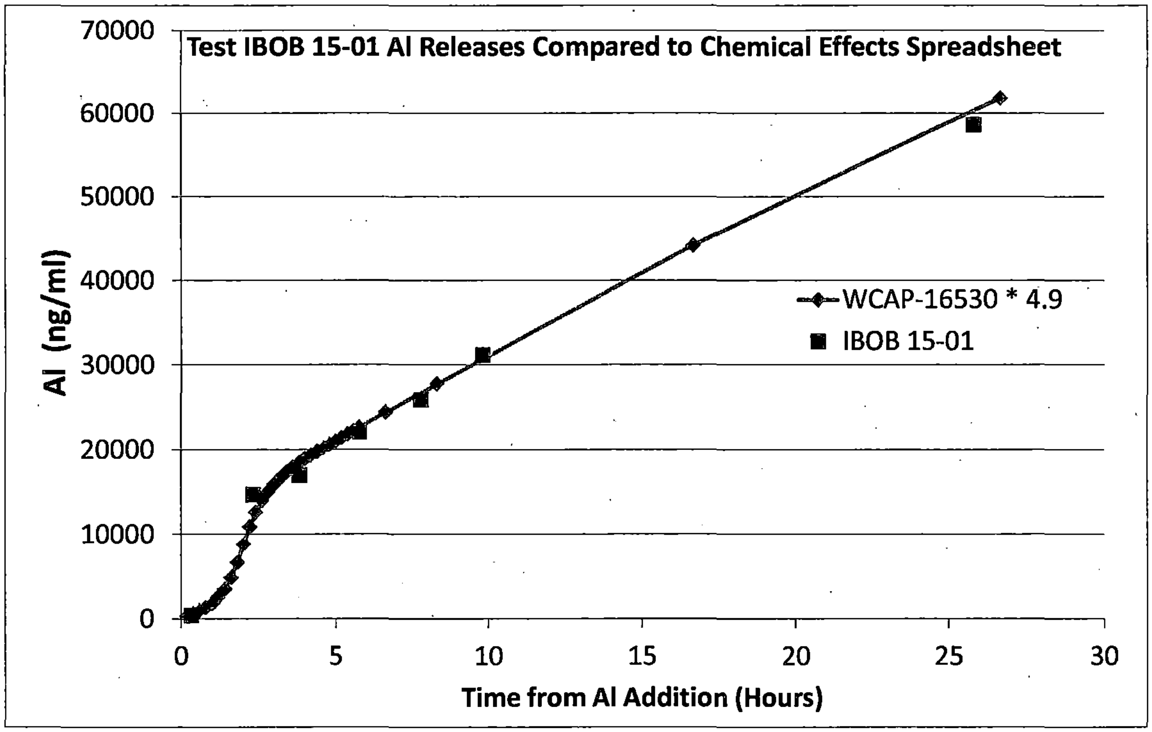


**Figure 2: Test IBOB 15-01 (NaOH, pH 8.5, 272°F)**

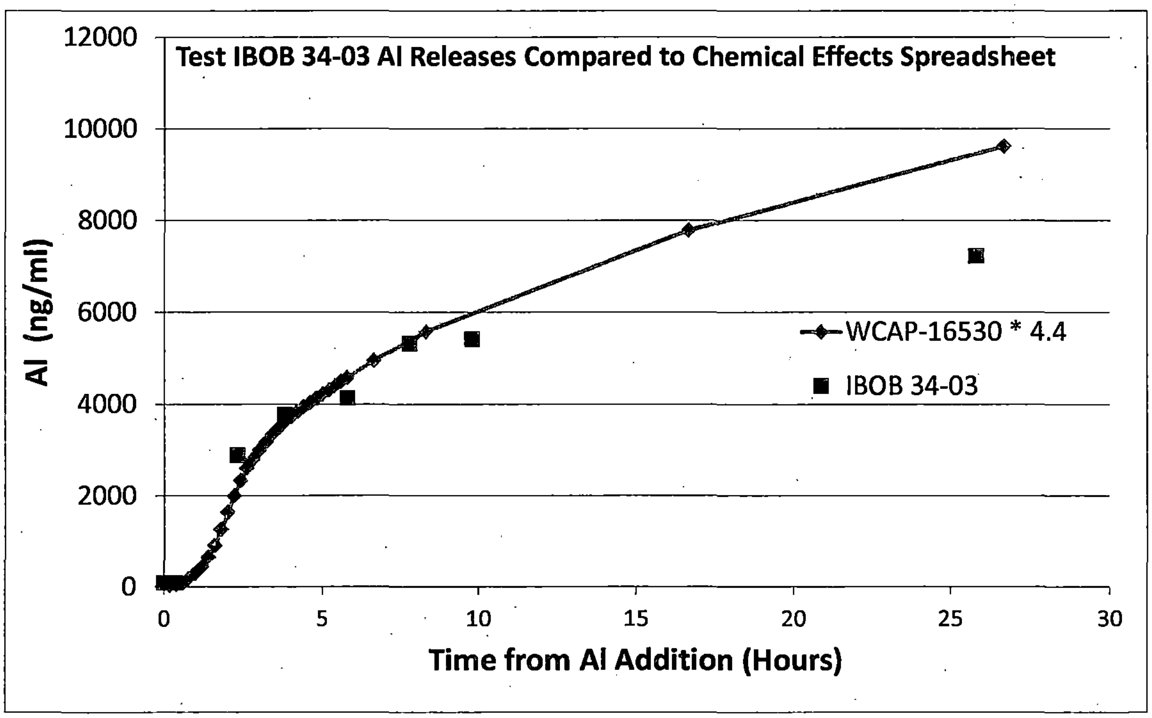


**Figure 3: Test IBOB 34-03 (TSP, pH 8.5, 252°F)**

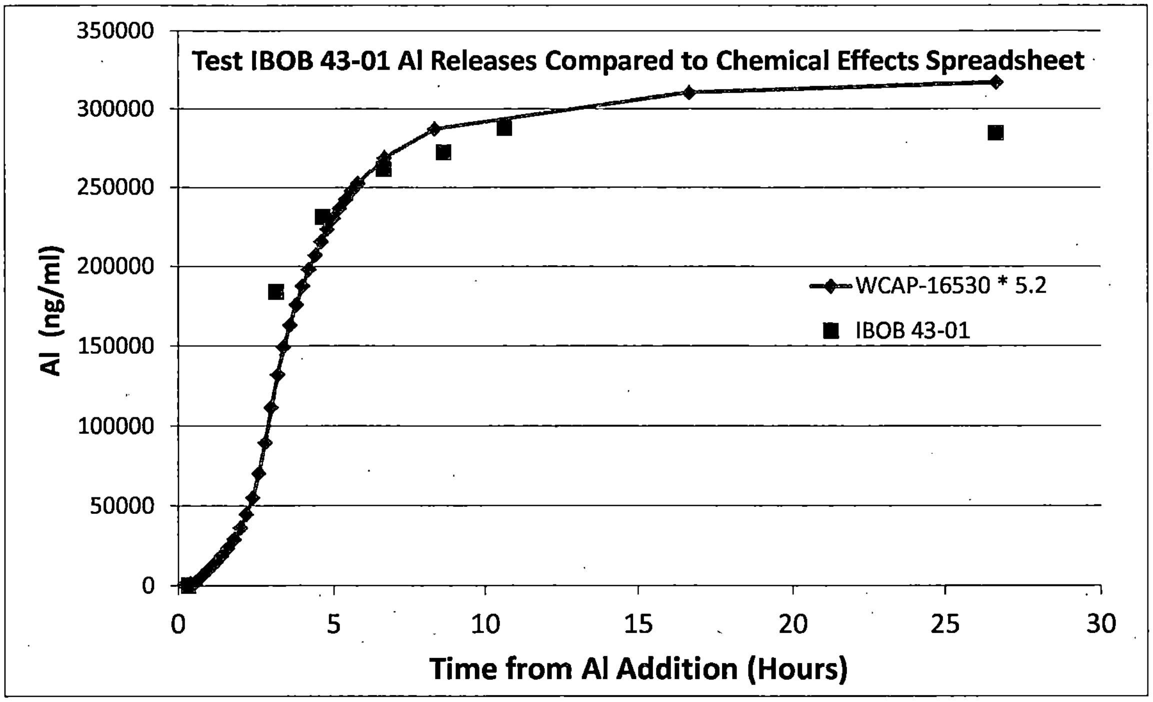


**Figure 4: Test IBOB 43-01 (TSP, pH 9.0, 270°F)**

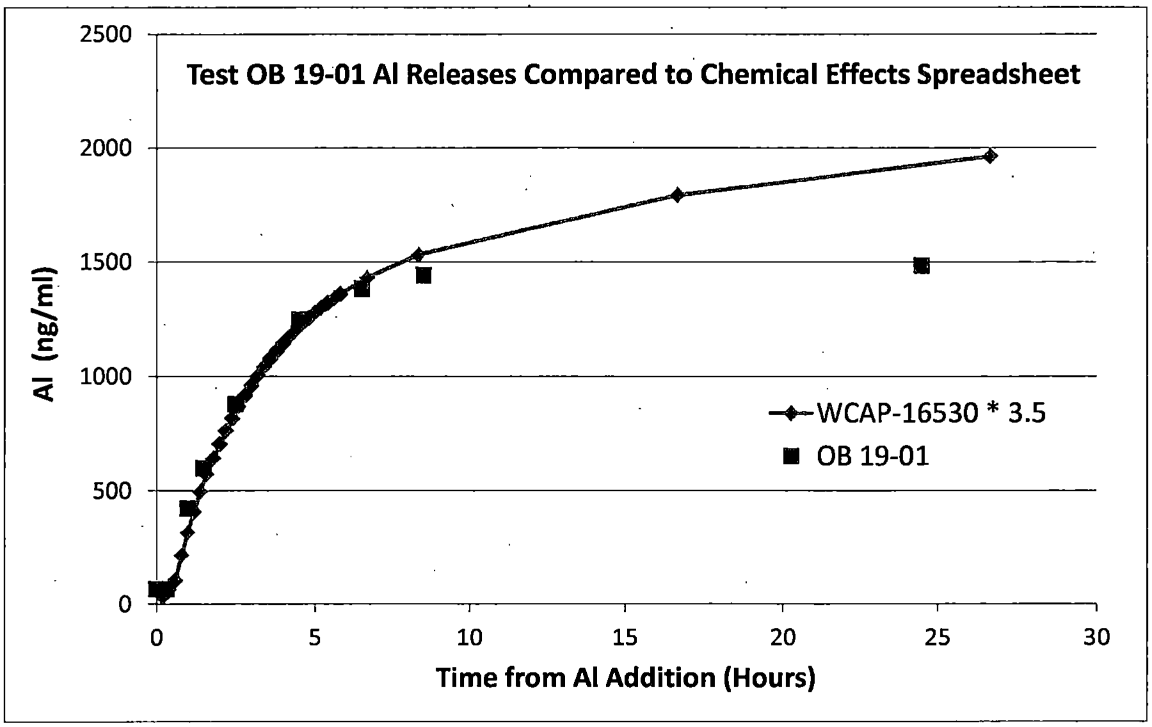


**Figure 5: Test OB 19-01 (NaTB, pH 8.3, 191°F)**

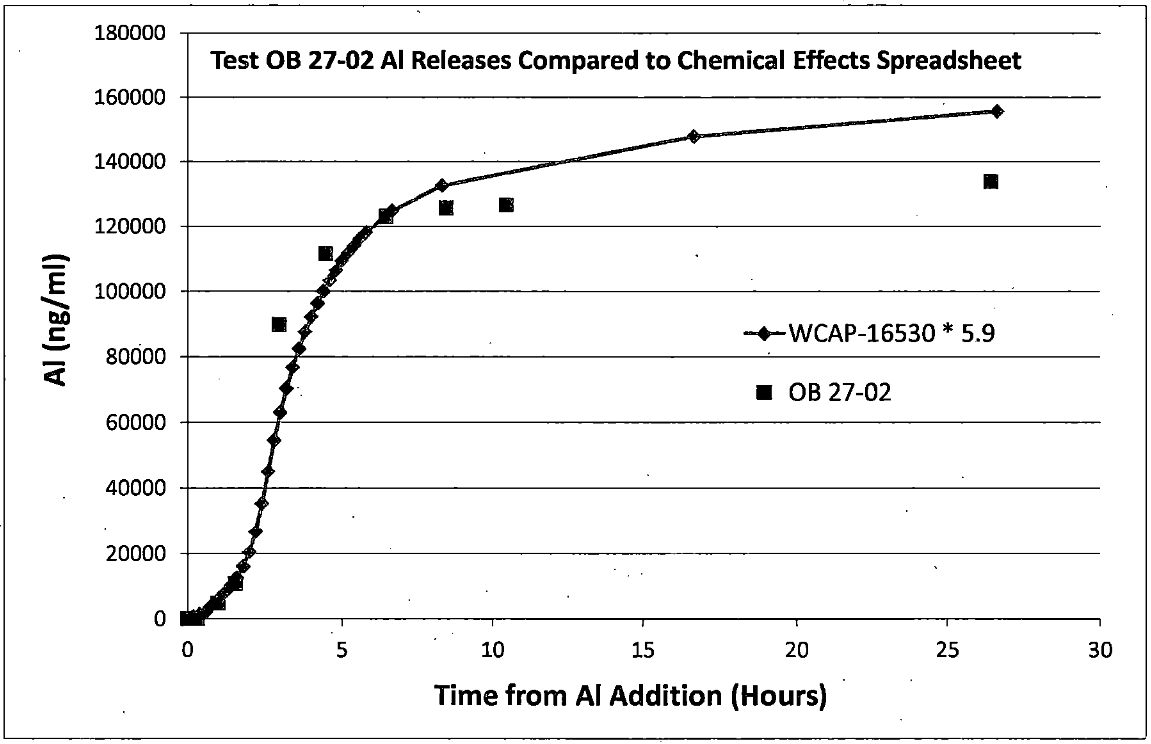


**Figure 6: Test OB 27-02 (NaTB, pH 8.3, 258°F)**

**3. RAI 5.1 (Comment 2)**

*Page 8 states with respect to the default function cooling curves, "the effect of the faster cooling rate is not known, but the unquantified conservatisms of using a maximum sump temperature, extra corrosion generated during the autoclave heat-up, and sample cooling before filtration will still lead to a conservative result." Please pick a representative case and quantify the impact of each of these three items. For maximum sump temperature, a comparison could be made with a best estimate maximum post-LOCA temperature.*

Westinghouse Response:

To demonstrate the conservatism in the temperature profiles used for autoclave testing, a representative case was selected. The representative case had a non-extreme pH of 8.1 and a maximum temperature of 254°F, which is the same as the average maximum sump temperature of 254°F reported in the industry survey. The autoclave results for this case are reported as Group 40-01 in WCAP-17788-P/NP (Reference 2). This was a TSP plant with a moderate level of aluminum. The temperature profile had been originally estimated using the exponential fitting function described in WCAP-17788-P/NP, page 3-2 and the maximum temperature and hot leg switchover temperature and time provided in the survey. This "bounding" profile is shown in Figure 7 where it is compared to the temperature profile programmed into the autoclave controller and a "best estimate" temperature profile that was later provided by the utility operating the two plants represented by Group 40.

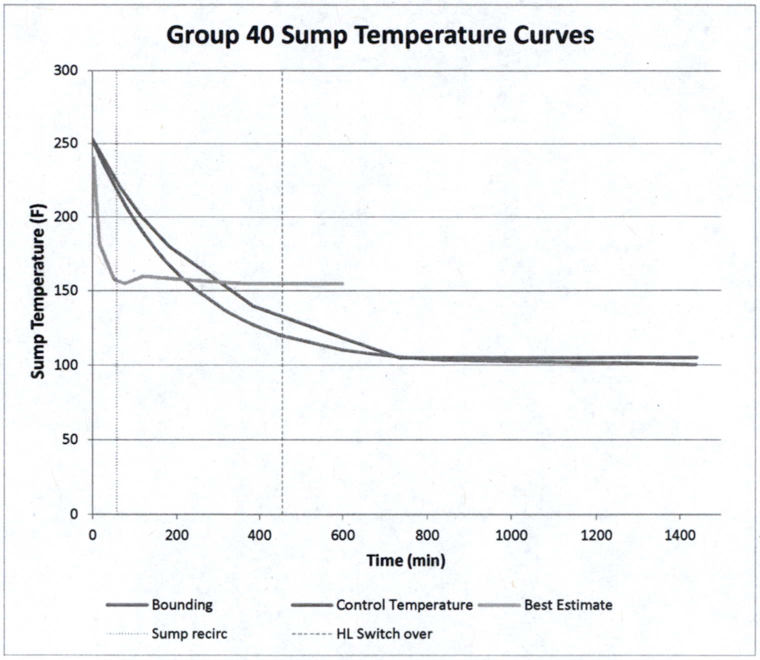


**Figure 7: Group 40 Sump Temperature Curves**

The actual temperature recorded in the autoclave test for Group 40 is shown in Figure 8. The temperature profile included a soak time of 30 minutes at 200°F, and then a temperature ramp to the maximum temperature that took 83 minutes. Thus, aluminum was corroding for a period of 113 minutes before the maximum temperature was reached and the bounding temperature curve was followed.

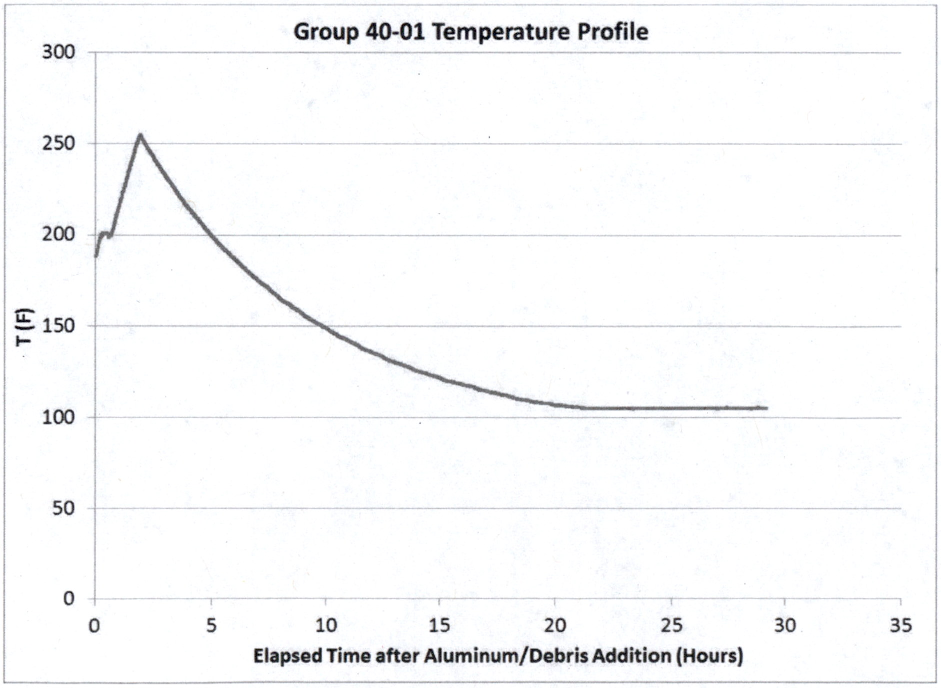


**Figure 8: Test 40-01 Autoclave Temperature Curve**

No sample was taken when the peak temperature was reached. However, the WCAP-16530-NP-A aluminum corrosion model (Reference 3) can be used to calculate the aluminum present at this time, provided that an appropriate bump-up factor is applied to the results. This will give a measure of the conservatism added by not accounting for corrosion during the heat-up period. The model can also be used to quantify the effect of using the bounding temperature curve compared to the best estimate.

A fit to the Al data was made using the WCAP-16530-NP-A model. A bump-up factor of 1.8 was needed to match the dissolved aluminum measured in the autoclave solution. The fit is shown in Figure 9 where the predicted aluminum is compared to the measured aluminum concentrations.

Aluminum release was then predicted for three scenarios. The first was for the bounding temperature curve with corrosion during heat-up included. The second was for the bounding temperature curve with no heat-up, and the third was for the best estimate curve. The results are plotted in Figure 10.

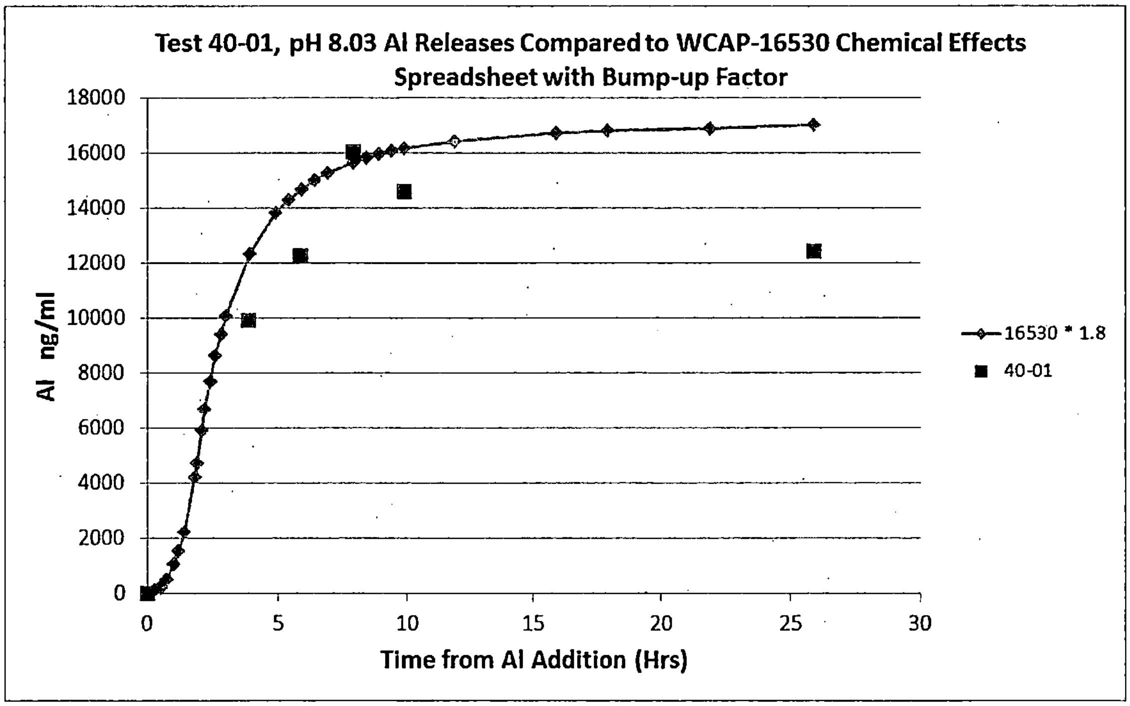


**Figure 9: Fit of Model to Data with a Bump-up Factor of 1.8**

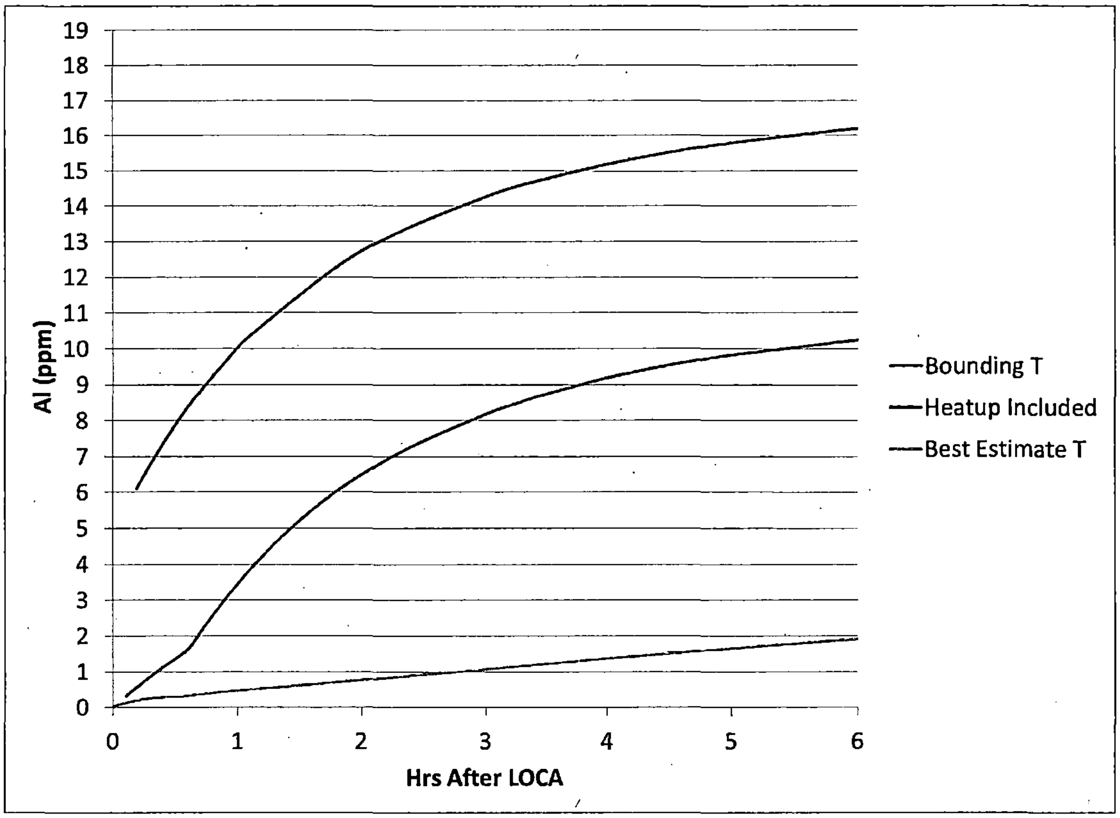


**Figure 10: Aluminum Release for Three Temperature Curves: Bounding with Heat-up, Bounding, and Best Estimate**

The amount of conservatism in the bounding curves compared to the best estimate decreases with time but it is still significant at the 6 hour mark when all plants should have adequate core flow through alternate flow paths. At 6 hours, the aluminum concentration generated by the exponential bounding curve with heat-up that was used for testing was 16.2 ppm compared to 1.91 ppm for the best estimate curve, a factor of 8.5. If the heat-up is not considered, the predicted aluminum concentration was 10.2 ppm, a factor of 5.3.

The aluminum released from the three temperature scenarios was used to calculate the precipitation risk as a function of time using the precipitation boundary function in Section 7.5 of WCAP-17788-P/NP, Volume 5. The aluminum content presented as a percentage of the precipitation boundary is shown in Figure 11. At the 6 hour mark, the best estimate precipitation risk was 0.85%, compared to values of 3.3% for the bounding curve, and 5.3% when the heat-up aluminum corrosion is included. Thus, by using the bounding curve and including the aluminum from the 83 minutes required to reach the maximum temperature, the autoclave experiment was conservative by a factor of 6.2.

It should be noted that even though the three different temperature curves produced different estimates of precipitation risk, all of the results indicated that the risk was low.

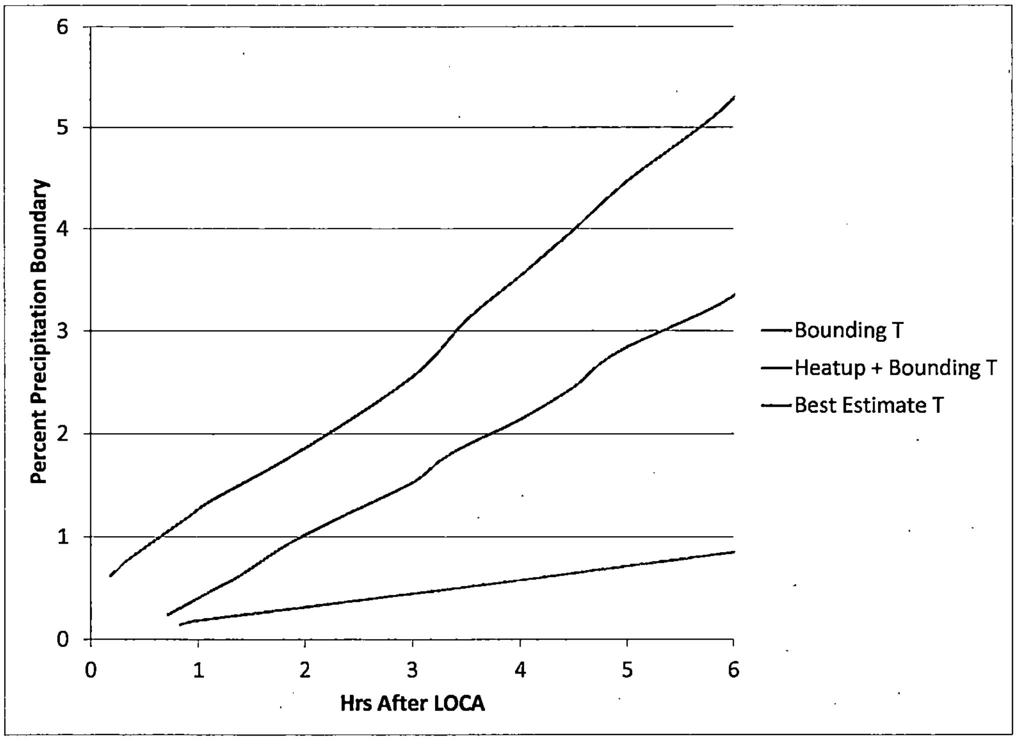


**Figure 11: Aluminum Release for Three Temperature Curves Expressed as the Percentage of the Precipitation Boundary**

The amount of conservatism introduced by holding the samples one hour before filtration is somewhat harder to quantify. There are two aspects of the conservatism. The first is the length of time the sample was held for precipitation, and the second is the hold temperature compared to the actual minimum temperature that would be experienced in the Emergency Core Cooling System (ECCS). The most significant chilling of the ECCS fluid as it is pumped from the sump back into the reactor vessel occurs in the residual heat removal (RHR) heat exchangers. At full ECCS flow, the ECCS coolant only spends three seconds in the RHR heat exchangers at the plants represented by Group 40. The extended hold time of one hour at a reduced temperature in the autoclave testing procedure is quite conservative when one considers that precipitation of aluminum hydroxide is known to be slow in boron-containing solutions (Reference 4). In the plant, coolant that is cooled in the RHR to a point where aluminum is slightly supersaturated will be quickly transported to the reactor vessel before precipitation takes place. There it will be heated, returning to the unsaturated state.

Regarding the magnitude of the temperature reduction, the sample holding temperatures scheme used in testing was:

1. Sampling temperature 210°F-300°F → Oven temperature 160°F
2. Sampling temperature 150°F-210°F → Oven temperature 120°F
3. Sampling temperature <150°F → Hold at 70°F (room temperature)

The temperature range where there is the greatest risk of aluminum precipitation would be the third sampling temperature where aluminum concentrations are high and temperatures are low. The conservatism in this area is evaluated for a coolant temperature of 140°F. The design temperature drop for the RHR heat exchangers at this inlet temperature is 22.2°F. The temperature drop employed in the autoclave testing would have been 140°F to 70°F, a difference of 70°F.

**4. RAI 5.1 (Comment 3)**

*Figure RAI-5.1-13 shows a plot of the percent of the precipitation boundary for Group 18 that used actual temperatures since the minimum temperature reached was already close to the ultimate sink temperature. How do the "provided" and "function" plots compare if instead of using the actual temperatures the temperature plotted is the oven hold temperature prior to hot filtration (per the Appendix E procedure)?*

Westinghouse Response:

The plot shown below in Figure 12 was generated using the oven hold temperatures to calculate the precipitation boundary for both the temperature profile "Provided" by the Group 18 utility and the profile generated using the temperature "Function" described in Section 3 of WCAP-17788-P/NP Volume 5 (Reference 2).

The precipitation risks are quite similar for the Provided and the Function curves until just after 3 hours, when the Function sump temperature drops below 150°F. At this point, the sample hold temperature jumps from 120°F to 70°F, causing the step increase in precipitation risk. The Provided temperature curve does not go below 150°F, so the large increase in the precipitation risk is not observed. In conclusion, the Function temperature profile produces roughly the same precipitation risk as the Provided temperature profile at short times, and is conservative at longer times.

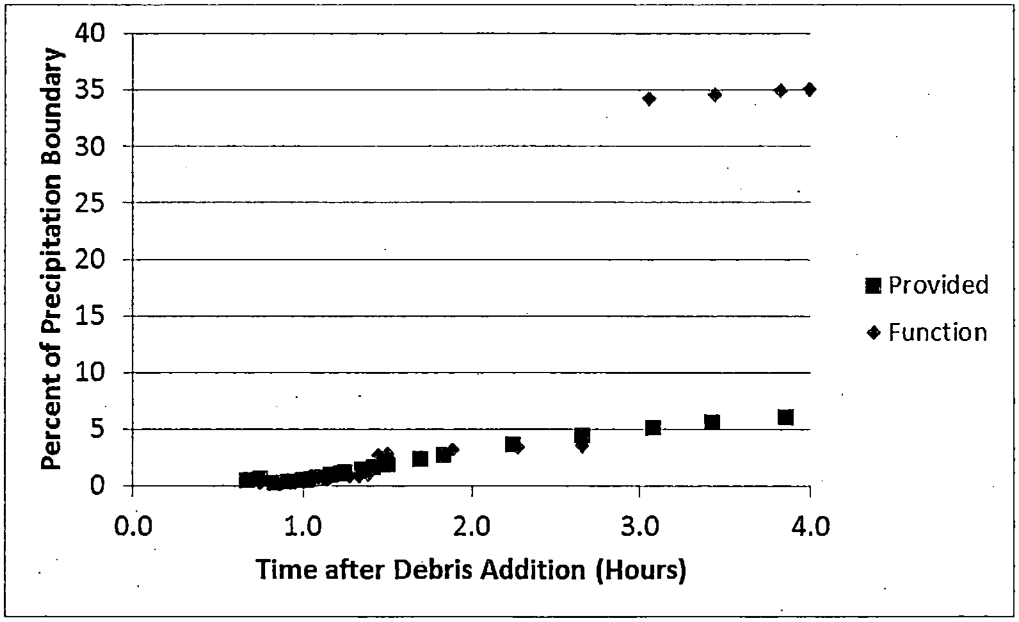


**Figure 12: Group 18 Precipitation Risk using Oven Hold Temperatures to Calculate Precipitation Boundary**

## 5. RAI 5.8

*This question was intended for the nonmetallic materials (RAI clarification call on 12-14-15). The majority of the response addresses zinc and aluminum. The response should provide additional justification for why the variation between batches of insulation materials is not a concern.*

Westinghouse Response:

The state of the insulation is further discussed in the RAI 5.11c clarification.

## 6. RAI 5.11c

*While the WCAP chemical effects focus on aluminum is appropriate, the staff thinks plants with TSP buffer need to limit the amount of insulation materials that are capable of leaching significant amounts of calcium since this could produce an early chemical precipitate. NUREG/CR-6913 testing has some data (e.g., Figs 7 and 19) showing effects of incremental calcium addition on vertical loop flat screen pressure drops that shows different results depending on the debris bed constituents.*

*For the IBOB and OB TSP tests with calcium silicate, was all the calcium silicate crushed? If it was added in pieces, what was the size of the pieces? How was it determined that a longer drain time was physical debris rather than chemical precipitate?*

Westinghouse Response:

The differences in dissolution rates for different varieties of CalSil, Microtherm, Min-K, and Fiberglass insulation will be largely a function of how much insulation surface area is exposed to coolant flow. The Microtherm and CalSil that were used in this testing were both fine powders, as had been used in the WCAP-16530-NP-A testing (Reference 3). Photographs of the debris material can be found there. SEM images of typical CalSil and Microtherm particles are shown in Figure 13 and Figure 14, respectively. The particles were often held together in clumps by the insulation fiber content, but the clumps were loose and dispersed well in the autoclave out-of-bag testing. The fiberglass and mineral wool and aluminum silicate insulation materials were shredded before use and were observed to disperse within the autoclaves. The concrete was crushed to a powder. By using the debris materials in a highly dispersed state in the out-of-bag testing, one extreme for exposed insulation surface area was tested. For the in-bag testing, the insulation was held within a small volume, representing an accident scenario where insulation was wetted but not severely damaged. Thus, the testing covered a wide range of debris dispersion and dissolution rates.

Regarding the determination of whether a longer drain time was due to a chemical precipitate or debris, it was done on a test-by-test basis as indicated in Section 5.5 of Reference 2. The appearance of the filter cake was an important factor in the determination. If there was a thick filter cake which looked like undissolved fiber or powdered insulation and there was no gelatinous material, then particulate debris was suspected. The immediate appearance of somewhat elevated drain times, which varied from sample to sample, was also an indication of simple particulate debris rather than a chemical product.

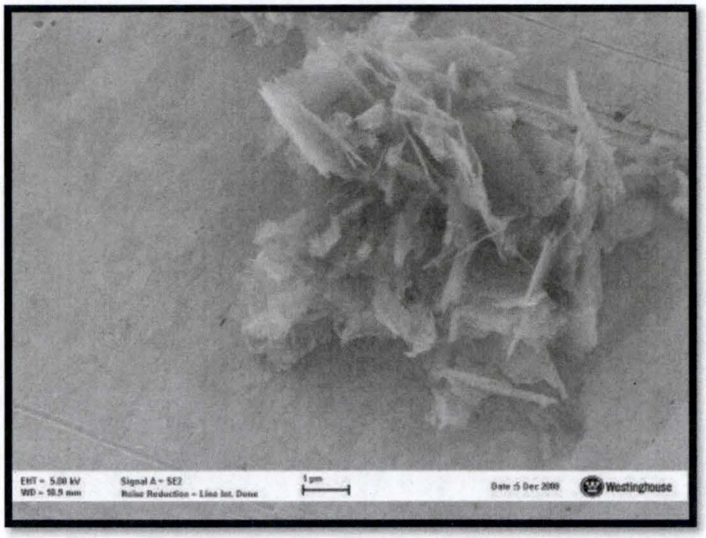


**Figure 13: Scanning Electron Micrograph of CalSil Powder Particle**

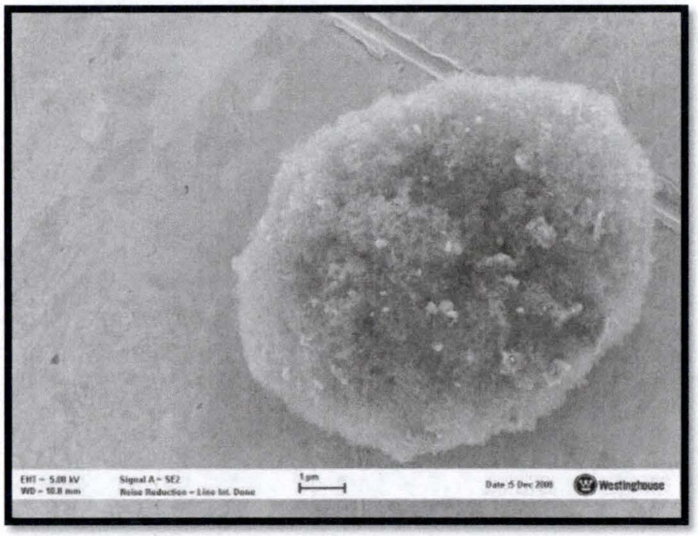


**Figure 14: Scanning Electron Micrograph of Microtherm Microporous Silica Powder Particle**

**7. RAI 5.13**

*Staff is considering a C&L for evaluating plant changes that result in less margin to the precipitation boundary.*

*Is the PWROG considering inserting additional language into the WCAP that refers to the RAI 5.13a response as example guidance to be used when evaluating potential changes relative to a precipitation boundary, and pH changes?*

*In general, staff does not think plants should make changes to buffer type or amounts unless it reduces the probability of post-LOCA chemical effects.*

Westinghouse Response:

Table 5.13-1 of Reference 1 shows the maximum percent increase in aluminum release that would be permitted due to plant changes. The values were selected while taking into account possible uncertainty in the boundary position as a function of pH and temperature. The values at 76°F were questioned, since the allowable aluminum release increased when going from 100°F to 76°F, while at high temperatures, a decrease in temperature resulted in a lower allowable increase in aluminum release. The values in the table were checked, and no errors in calculation or data transcription were found. The reason for the change in the temperature trend is that the boundary function curve (boundary ppm vs. temperature) is starting to flatten at temperatures below 85°F. Thus, temperature uncertainty has less of an effect at lower temperatures.

The PWROG promotes the use of the precipitation boundary presented in WCAP-17788-P/NP (Reference 2) as a means for plants to assess how changes in plant materials or operation can affect the risk of experiencing chemical effects after a LOCA. Plant modifications that affect the buffer type and/or quantity and any other design parameters that could adversely impact precipitation and the timing thereof will need to be evaluated. It is therefore incumbent upon the plant to assess these changes using the precipitation boundary and other methods as appropriate. The method presented in the response to RAI 5.13 will support a plant's assessment and provide guidance as to whether a change in precipitation risk is inconsequential. This guidance will be included in the next revision of WCAP-17788-P/NP.

## 8. RAI 5.18

*A balance was used to measure mass on the filters that was accurate to 0.1 microgram?*

Westinghouse Response:

The balance that was used to measure the filters before and after filtration, to determine the total filtered solid mass, was a four place balance (accurate to 0.0001 g). These results were reported in Table 6-10 and Appendix F of WCAP-17788-P/NP (Reference 2). Note that the mass units reported in Appendix F.1 (grams) are correct and that the units reported in Table 6-10 should be grams instead of milligrams.

The method used to determine the elemental masses of precipitate on the filters as reported in Table 5-2 and Appendices F.3 and F.4 is described below. The units reported (milligrams) are correct. Note that this method does not use a balance.

1. The filter samples were prepared for digestion using 6 mL of deionized water, 0.5 mL HCl, and 0.5 mL $HNO_3$, for a total sample volume of 7 mL.
2. The concentration of each metal was determined using ICP-MS.
3. The corresponding mass of each element was calculated based on the sample volume.

For example, for the IBOB 41-03 2hr Fe filter, there was 2871 ppb (ng/mL) present. This was converted to milligrams as follows:

2871 ng/mL * 7 mL = 20,097 ng = 0.020097 mg (reported as 0.0201 mg in Table F-17)

## 9. REFERENCES

1. OG-17-167, Rev. 0, "PWR Owners Group - Submittal of Responses to NRC Request for Additional Information and Revisions to Topical Report WCAP-17788-P/WCAP-17788-NP, Revision 0, 'Comprehensive Analysis and Test Program for GSI-191 Closure' Related to Volume 5." NRC ADAMS Accession No. ML17293A215, June 2017.
2. WCAP-17788-P/NP, Volume 5, Rev. 0, "Comprehensive Analysis and Test Program for GSI-191 Closure (PA-SEE-1090) – Autoclave Chemical Effects Testing for GSI-191 Long-Term Cooling," July/September 2015.
3. WCAP-16530-NP-A, Rev. 0, "Evaluation of Post-Accident Chemical Effects in Containment Sump Fluids to Support GSI-191," March 2008.
4. WCAP-16785-NP, Rev. 0, "Evaluation of Additional Inputs to the WCAP-16530-NP Chemical Model," May 2007.