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SUBJECT: AUDIT REPORT – PRESSURIZED WATER REACTORS OWNERS GROUP – AUDIT TO OBTAIN CLARITY ON RESPONSES TO REQUESTS FOR ADDITIONAL INFORMATION FOR WESTINGHOUSE COMMERCIAL ATOMIC POWER-17788-P (EPID NO. L-2015-TOP-0007)

Dear Mr. Nowinowski:

By letter dated July 17, 2015, the Pressurized Water Reactors Owners Group (PWROG) submitted a licensing Topical Report (TR) intended for Generic Safety Issue (GSI)-191 closure, "Comprehensive Analysis and Test Program for GSI-191 Closure" (Agencywide Documents Access and Management System (ADAMS) Accession No. ML15210A668). The TR is a methodology to define in-vessel fibrous debris limits and provides a means for increasing the approved fibrous debris limit used by licensees to resolve GSI-191. By letter dated December 19, 2017, the PWROG submitted responses to NRC staff requests for additional information (RAIS) (ADAMS Accession No. ML18029A203).

The NRC conducted the audit from June 26 to August 6, 2018, to increase its level of knowledge and understanding of the PWROG RAI responses to Volume 4 of the TR, and the associated methodologies. The audit report is enclosed.

If you have any questions, please contact me at 301-415-2375 or by e-mail at Leslie.Perkins@nrc.gov.

Sincerely

/RA/

Leslie Perkins, Project Manager
Licensing Processes Branch
Division of Policy and Rulemaking
Office of Nuclear Reactor Regulations

Enclosure: Audit Report (Non-Proprietary)

SUBJECT: AUDIT REPORT – PRESSURIZED WATER REACTORS OWNERS GROUP – AUDIT TO OBTAIN CLARITY ON RESPONSES TO REQUESTS FOR ADDITIONAL INFORMATION FOR WESTINGHOUSE COMMERCIAL ATOMIC POWER-17788-P (EPID NO. L-2015-TOP-0007) DATE: MAY 24, 2019

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ADAMS Accession Nos.:
ML19101A438 (Package);
ML19101A437 (Non-prop Audit Report) ***concurrence via e-mail** **NRR-106**

OFFICE	PLPB/PM	PLPB/LA*	STSB/BC*	PLPB/BC	PLPB/PM*
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AUDIT REPORT
OBTAIN CLARITY ON PWROG RESPONSES TO REQUESTS FOR ADDITIONAL INFORMATION IN WESTINGHOUSE COMMERCIAL ATOMIC POWER-17788-P PRESSURIZED WATER REACTOR OWNERS GROUP

1. SCOPE AND PURPOSE

By letter dated July 17, 2015, the Pressurized Water Reactors Owners Group (PWROG) submitted a licensing Topical Report (TR) intended for Generic Safety Issue (GSI)-191 closure, "Comprehensive Analysis and Test Program for GSI-191 Closure" (Agencywide Documents Access and Management System (ADAMS) Accession No. ML15210A668). The TR is a methodology to define in-vessel fibrous debris limits and provides a means for increasing the approved fibrous debris limit used by licensees to resolve GSI-191. By letters dated September 7, 2017, and December 19, 2017, the PWROG submitted responses to NRC staff requests for additional information (RAIs) (ADAMS Accession Nos. ML17293A218 and ML18029A203, respectively).

The audit included technical discussions of the WCAP-17788 Volume 3 and Volume 4 responses to NRC RAIs pertaining to the Framatome and Westinghouse methodologies, assumptions, and results in the PWROG responses.

Specific topics discussed during the audit were limited to clarifications regarding NRC staff questions to the RAI responses referenced above.

The audit was held at the Westinghouse offices in Rockville, Maryland, June 26 through June 28, 2018. Follow up phone calls were conducted on July 16 and July 31, 2018; August 2 and August 6, 2018, to allow the NRC staff to obtain additional clarifications on the RAI responses. A list of the NRC and PWROG staff that were present during the audit is included below.

<u>NRC Audit Team</u>:

- Ashley Smith, Reactor Systems Branch Technical Reviewer, Office of Nuclear Reactor Regulation (NRR)
- Ben Parks, Nuclear Performance and Code Review Branch Technical Reviewer, NRR
- Steve Smith, Technical Specifications Branch Technical Reviewer, NRR
- Leslie Perkins, Licensing Processes Branch Project Manager, NRR
- Victor Cusumano, Chief, Technical Specifications Branch, NRR
- Vesselin Palazov, Contractor, Information Systems Laboratories (ISL), Inc.

PWROG Representatives:

PWROG:
Ken Schrader
Jay Boardman

Framatome:
Gordon Wissinger
Kent Abel
CK Nithianandan
John Klingenfus (via telephone)
Bob Baxter (via telephone)
Danielle Page Blair (via telephone)

Westinghouse Electric Company (Westinghouse):
James Spring
Katsuhiro Ohkawa (via telephone)
Aaron Everhard (via telephone)

2. DOCUMENTS AUDITED

The PWROG discussed the responses to RAIs that the NRC staff asked regarding Volume 4 of the TR. Specific questions were transmitted to the PWROG via the audit plan (ADAMS Accession No. ML18171A099). There were no formal presentations during the audit, but more detailed information regarding the RAI responses was made available to the NRC staff. The information provided was proprietary. Therefore, it was made available to the NRC audit team members only during the audit. The presented materials were not provided to the NRC staff and cannot be included with this audit report. A list of documents referenced during the audit follows:

ANP-3583-P, Rev. 1 – RAI responses for Volume 4 submitted on the docket
ANP-3593-P, Rev. 1 – Low Pressure / Low Flow Test Facility Benchmark Predictions for Long Term Applications
Calculation Note 32-9268522-001 – GSI-191 Core Blockage Calculations - RAI Responses Packages B, C, D, E and G
ANP-3584-P, Rev. 1 – RAI responses for Volume 4 submitted on the docket

Calculation Note 32-1178279-00 – Baffle Gap/Hole Velocity Prediction for 177 FA Plant
Calculation Note 32-9266615-000 – WCAP-17788 Package BW.B RAIs with HL Break Comparison

Although not listed here, numerous Westinghouse documents were audited. The list of these documents was unobtainable for this audit report.

3. AUDIT ACTIVITIES AND OBSERVATION

3.1 S-RELAP5 Combustion Engineering (CE) Plant Analyses

In response to Combustion Engineering (CE) audit question 10 and Babcox & Wilcox (B&W) audit question 7, included in Appendix A, "Questions for Discussion," to the audit plan, the PRWOG discussed the benchmarking used for CE (and B&W) interfacial drag coefficient code validation. Rod Bundle Heat Transfer (RBHT) low pressure and low temperature tests were referenced in response to these questions. The analyzed 7 such RBHT tests were identified as **[ ]**. Framatome provided information on how the modeling of the test was implemented in the S-RELAP5 (CE) and RELAP5/MOD2-B&W RBHT simulations. The comparison between test measurements and RELAP5 results was presented. The void fraction data from the tests was compared to S-RELAP5 results and good agreement between the measured and predicted void fractions was demonstrated. Some of the RBHT tests resulted in uncovery of the heated 7×7 rod test bundle. In simulations of these cases, S-RELAP5 **[ ]**. The code also predicted **[ ]** compared to what was observed in the testing. In part, these results occur because **[ ]**.

These findings revealed a certain degree of conservatism in the code predictions of the RBHT test results. Framatome also stated that the same comparison plot was erroneously included as Figure RAI-4.8-1, "RBHT Summary S-RELAP5: Calculated vs. Measured Void Fraction for Seven RBHT Tests," found in ANP-3583-P, Rev. 1, and as Figure RAI-4.8-1, "RBHT Summary RELAP5/MOD2-B&W: Calculated vs. Measured Void Fraction for Seven RBHT Tests," shown in ANP-3584-P, Rev. 1. The correct RBHT vs. RELAP5/MOD2-B&W comparison plot will be provided in the updated version of ANP-3584-P, Rev. 1.

Framatome discussed the heat transfer modes being used by the code. **[ ]**.

Relative to the above discussed CE audit question 10, Framatome stated that the code uses **[ ]**. This assumption results in faster dryout and higher peak cladding temperature (PCT) in the long-term core cooling (LTCC) plant analysis (and in the validation runs). Even though some of the RAI responses showed **[ ]** as a heat transfer mode, it was not implemented in the code.

Framatome had performed a code comparison with S-RELAP5 and MOD2-B&W that **[ ]** and which showed that both codes performed similarly. Comparisons to void fraction correlations were made with good agreement.

Continuing its response to CE audit question 10, Framatome provided information on the axial flow areas provided in the response to RAI 4.9. The axial flow area initially provided was an incorrect value of **[ ]** ft^2 and it was corrected to **[ ]** ft^2 in the RAI response. The area was back calculated and validated for this audit as **[ ]** ft^2. The RAI response provides a vapor cross-flow velocity of 24 ft/s in Table RAI-4.9-1, "CE Base Case – Results observed at the PCT axial elevation, at 20600 seconds," found in ANP-3583-P, Rev. 1, which the result was found excessively high and out of correlation with the cross-flow vapor mass flow rate and flux listed in the same table. Framatome stated that the void fraction in the axial and cross-flow calculations may be different. In this case, the void fraction should be close to one so a significant difference should not occur. There is additional information in the response to RAI 4.8 for this topic.

When discussing cross-flow transport (CE audit question 10.h), Framatome stated that the **[ ]**. The nodalization used in the CE plant model was the same as in the large break loss-of-coolant-accident (LBLOCA) model in EMF-2103, Rev. 0. Framatome stated that the downcomer (DC) was also nodalized similarly, represented in **[ ]**. A 50% increase in cross-flow resistance was used for a sensitivity study on flow patterns within the core region because it was judged that this value would result in a meaningful change without getting too far from the modeled value. The sensitivity showed that a typical chimney or recirculating convective flow pattern was maintained. Framatome discussed the model's radial peaking power distribution for the peripheral core region.

In response to CE audit questions 10.g, Framatome stated that there was an error in Table 1, "CE Base Case – Results observed at the PCT axial elevation, at 20600 seconds," of the response to RAI 4.9 provided in ANP-3583-P, Rev. 1. The vapor cross-flow velocity should be about 4.5 ft/s instead of the reported value of 24.72 ft/s. The cross-flow junction area is **[ ]**. The table will be corrected in the updated version of ANP-3583-P, Rev. 1, to include the proper velocity.

In response to CE audit question 11, Framatome stated that the void fraction at the PCT node was 1.0 at the time of PCT (around 20,580 s). It is not less than 1 (about 0.95) as shown in Figure RAI-4.9-9 of RAI 4.9 response. The cause of displaying a void fraction less than 1 was that the node inlet value was used, not the value at the PCT location.

In response to CE audit question 3, Framatome discussed modeling of the upper plenum (UP) and draining of the UP into the core. The UP noding below the hot leg was implemented with **[ ]** in the CE plant model used in the initial submittal. Because of questions asked in the NRC staff RAIs, **[ ]** for the GSI-191 analysis as described in RAI response 4.23. Framatome stated that the steam velocity in the broken hot leg is very high so that it sweeps excess liquid out of the UP into the broken hot leg nozzle.

Framatome stated that **[ ]**, of relevance to UP liquid draining into the core, was modeled at the exit junctions for the **[ ]**. The LBLOCA model in EMF-2103, Rev. 0, applied **[ ]**. In addition to these **[ ]** in the GSI-191 CE plant model. **[ ]**. The **[ ]** resistances were **[ ]** the calculated nominal resistance values and provided a significant reduction to the ability of coolant to enter the core from the UP. **[**

].

[ ]. At the beginning of the response to the simulated core blockage, there was some liquid flow draining from the UP down into the CC channel even though [ ] was applied as described above. The vapor velocity that would prevent liquid drain flow down into the core was assessed at about 50 ft/s. The vapor velocities exiting the core were about 20 ft/s for all of the core channel junctions except the HA junction, which had a velocity of about 25 ft/s. These velocities occurred around 200 seconds after blockage was applied. Around 20,000 seconds (blockage time) the void fraction in the UP was about 0.5. The applied CCFL model was identified as being based on a [ ] correlation with a slope constant of [ ] and an abscissa intercept constant of [ ]. Framatome stated that this model was based on guidance provided in a reference that was not provided to or noted by the NRC staff.

The NRC staff expressed concern that [ ] zones of the core would allow steam to exit the core in those areas and provide a lower steam velocity for CCFL calculations in the [ ] channel. Framatome stated that the peripheral core area was large and steam velocities were low enough to allow liquid flow into the core. The peripheral core area was [ ] and the predicted liquid mass flow rate was about 20 lb/sec, which allowed coolant flow into the core. The responses to RAI 4.1 and RAI 4.23 have details on the UP modeling and prediction results.

Framatome stated that the original LBLOCA model [ ] because it did not affect the results for the short-term core cooling analysis. For the LTCC analysis however, most of the flow was expected to go into the top of the core instead of the UP because of the presence of a large opening gap below the upper core plate that allows flow to the UP. In the GSI-191 analyses, this flow path was modeled by [ ]. The outlet K-factor included the resistance of a 90 degree turn into the top of the core and accounted for physical parameters for the flow path. The resistance into the UP is much higher than that into the top of the core and, therefore, almost all the baffle flow goes into the core periphery. This discussion is related to RAI 4.1 and RAI 4.3.

Framatome provided additional information on UP draining since the NRC staff expressed concern on how the liquid above the core was draining. The core and UP regions are in a boiling pot condition before the application of core inlet blockage. When core blockage is modeled, the liquid in the UP drains into the peripheral core region. The steam flow velocity at the periphery exit is below the critical limit that would prevent liquid fallback from the UP. As mentioned previously, the flow from the UP down into the core periphery was about 20 lb/s which was comparable to the boiloff rate. This liquid drainage provided for some coolant inventory prior to the activation of the alternate flow path (AFP) when it could supply liquid to the core. A boiling pot circulation pattern was observed with flow upwards in the central and average assemblies and downwards in the core periphery. A low radial power peaking factor of [ ] specified for the core [ ] contributed to this core circulation pattern. The RAI 4.23 response contains additional information on this issue. Draining of the UP occurred within a period of about 200 seconds. The inventory in the UP prior to core blockage was about 4,000 lb. There were [ ] as discussed above.

The flow area through the PC channel at the top of the fuel was [ ]. The [

]. The **[** **]** and the **[**

]. The flow areas account for areas blocked by core internals, the upper core plate, and other physical obstructions.

The flow areas modeled at the limiting flow junctions at the upper core plate for CCFL calculations were **[** **]**. The flow areas account for **[** **]**, and other physical obstructions. As such, these areas are more limiting than those at the top of the core for CCFL. The results were based on these flow areas and the draining was as described above.

Framatome stated that the volume needed to make up the shortfall in the core inventory is proportional to the plant size and that the CE UPs are similar to each other. The UPs are similar and proportional to the reactor size and will provide liquid amounts proportional to that in the LTCC model.

In response to CE audit question 1, Framatome discussed assumptions and treatment of axial power profile. The PWROG noted that some of the discussion applied also to Westinghouse and B&W plant designs. The RAI 4.5 response contains information on this topic. The core axial power shape was set at +21% offset, at about 10 ft. Framatome stated that the core exit peak would not be sustained into the LTCC period of interest and that the profile used was conservative based on the transient time when blockage was applied in the GSI-191 analyses.

Westinghouse used a similar axial power shape and stated that a more skewed shape cannot sustain into the time period of interest. Westinghouse stated further that after about 1,000 seconds from the start of the event, the power offset will not be greater than the steady state profile. Uncertainty was handled by using the bounding, steady state technical specification (TS) values. Westinghouse also stated that the axial power profiles used for the GSI-191 analyses were similar to those used for small break loss-of-coolant-accident (SBLOCA) analyses, although somewhat smaller axial peaking factors were applied in the LTCC GSI-191 analyses.

In response to CE audit question 2, Framatome discussed the decay heat multiplier used for the analysis. Framatome stated that a decay heat multiplier of 1.1 was used only for the t_{block} analysis and a decay heat multiplier of 1.2 was used for the k_{max} and k_{split} analyses. Therefore, the underprediction of the decay heat, which is stated to occur for the first 1,000 seconds of the event in the response to RAI 4.1.b, does not affect any analysis except for t_{block}. By the time t_{block} occurs (20,000 seconds), Framatome stated that the uncertainty in the decay heat value is much less so uncertainty is accounted for by the 1.1 multiplier.

In response to CE audit question 8, Framatome referred to the decay heat curve in Figure RAI 4.10-1. The curve includes decay heat plus actinides and is not a power ratio. It assumes decay heat at time zero is 1 and the power is normalized to that value. In response to CE audit question 4, Framatome stated that core resistance is accounted for in the k_{split} and m_{split} calculations and that this accounts for steam flow changes. For CE plants, the only safety injection (SI) flow when sump recirculation occurs is from HPSI, which results in a low SI flow rate. Sump turnover time is relatively long due to the low SI flow rate. Framatome stated that the only factor that will change the m_{split}/k_{split} is decay heat and that decay heat is relatively flat during the time period of the analysis. Framatome also stated that the flow resistance on the core side was insignificant compared to the core inlet resistance. Therefore, the core side resistance was dominated by the core inlet resistance. The response to RAI 4.20 provides information for this part of the evaluation.

In response to CE audit question 5 in the audit plan (and Westinghouse audit question 3.c), Framatome stated that it is a plant-specific responsibility to evaluate the range of single failures for their plants and to assess how the TR analysis is affected by potential single failures at each plant. The Volume 4 analysis did not make any single failure assumptions. Instead, it examined a range of conditions that would allow plants to implement the TR. Utilities will do plant-specific analysis of single-failure fiber tracking to ensure the greatest amount of debris at the core inlet is produced. The analysis used low reactor water storage tank (RWST) levels and high flows to minimize pool inventory and swapover time and maximize decay heat. The analysis showed that low flows were limiting for k_{max} and t_{block}. High decay heat assumptions result in a limiting PCT. High flows result in more debris delivered to the core inlet. Therefore, maximum flows are used to maximize decay heat and fiber at the core inlet. Information for this issue was provided in the response to RAI 1.c. The response to this issue is the same for all plant design categories.

In response to CE audit question 7, Framatome stated that they examined the results of all the sensitivity studies for non-physical behavior. Specifically, they looked at cases where recirculating flow anomalies could occur. CE determined that non-physical behavior was not occurring, and no evidence of recirculating flow anomalies was observed.

In response to CE audit question 10.f, the NRC staff noted that the response to RAI 4.9.c included documentation of unusual variations in instantaneous void fractions for the HA and AC. Framatome stated that the observed behavior was the result of slug flow and that the observations were typical of such flow regimes. Framatome stated that the void distribution over a period of time was inspected and the information in question was not indicative of code issues. The void fractions were variable as presented in the graphs in response to RAI 4.9 because of slug flow, plotting frequency, and randomness in the data. Framatome stated that plotting the slug flow would show that the “canyon” moves and void fraction oscillations swing between 40-60% because of slug flow (if the slug void is 60%, then, after the slug clears the node the void decreases to 40%). This is typical of slug flow.

Following the simulation of complete core blockage at 20,000 seconds, Figure RAI 4.17-8 shows that during a certain time period the flow through two of the cold legs (CLs) decreased and became negative (from the DC into the cold leg) while the flow remained positive (from the cold leg into the DC) and increased through the other two CLs. Thus, this figure shows that Loop 1A receives flow from the DC while Loop 1B continues delivering flow into the DC at increased rates. The NRC staff was concerned because such a recirculatory flow pattern involving a pair of CLs connected to the same SG seemed unrealistic. Framatome stated that once the DC is refilled at about 20,600 seconds, as shown in Fig 4.16-10, the water entering the CLs begins spilling into the loop seals/crossover legs. All loops eventually fill and the observed behavior does not affect the critical part of the analysis as it occurred after the PCT peak was predicted and at which time the DC was filled.

In response to CE audit question 9, Framatome stated that both high and low containment pressures were used for the WCAP-17788 Volume 4 analyses. It was determined that using the lowest pressure results in the greatest voiding, which minimizes the mass of liquid in the core. These results were stated to be consistent for all plant designs.

In response to CE audit question 12, Framatome stated Case 25, discussed in RAI 4.16, did not result in core uncovery because of greater subcooling during recirculation. Higher subcooling results in a greater mass of liquid inventory in the core, reduced core voiding, and thus a lower PCT. The subcooling was applied from the time of swapover, so it could make a significant difference in the resulting liquid mass in the core. This was shown to be consistent for decay heat multipliers of 1.1 and 1.2.

In response to CE audit question 13, Framatome stated that CE plants don't have coolers in the emergency core cooling system (ECCS) so the temperature of fluid entering the RCS during recirculation will be closer to saturation than some other plant designs. By assuming saturation temperature for the injected fluid, the mass in the core is minimized resulting in a higher PCT.

In response to CE audit question 29, Framatome provided additional information regarding assumptions for the timing of debris arrival at the core inlet (related to RAI 4.26). Testing was accomplished using a 30 minute injection time for all of the debris. The curve in the analysis was based on this testing. Framatome stated that 30 minutes is shorter than an actual sump turnover time, partially because the injection rates for CE plants are much lower than some other plants. The PWROG noted that a test run with a 300-minute debris injection time resulted in the same differential pressure (dP), it just took longer to reach the value. The conclusion from the testing is that debris amount is the controlling factor for debris headloss, not debris arrival timing. Based on testing, the highest dP occurs at the lowest flow rate because the lowest flow rate created the most stable debris bed. However, the highest flow rate is used to determine the debris arrival timing. This adds conservatism to the analysis.

In response to CE audit question 33, Framatome discussed the code versions used for its analysis. The code is from the transition package of EMF-2103, Rev.3. The code version was examined to determine if there were any changes that would affect how it is being applied for the GSI-191 analysis. For each code version, a significant number of benchmark cases are run and compared with the previous code to be sure that the results are coherent. That is how the UMAY15 version of the code was developed. CE started with UFEB15 code that is traceable back to the NRC approved code. Internal validation and verification was performed by running benchmarks. Only one change was made from the UFEB15 to the UMAY15 version. The benchmarking and results analysis verified that no unanticipated changes occur and that the change resulted in the expected outcomes.

Framatome defined a "developmental version" of the code as one that is under review internally. Also, "conditionally certified" for the GSI-191 case indicates that it was valid only for LTCC analyses. It is basically a single application code, not for LBLOCA, SBLOCA, etc.

Framatome clarified that the AFP resistance calculations were all performed under a quality assurance (QA) program for all plant categories. Both Westinghouse and Framatome stated that all documents sent officially to the NRC were developed in accordance with appropriate QA programs. For example, all RAI responses were developed under a QA program. This is also related to Westinghouse audit questions 34, 35, and 36.

In response to CE audit question 37, Framatome clarified that m_{dc} is the mass that actually enters the DC. It is not ECCS flow. However, for the purposes of tracking fiber transport, all fiber is assumed to go to the core. Fiber distribution is based on the ECCS flow rate and is split between the core inlet and AFP for each time step. The mass of fiber for each time step is derived from the sump concentration, strainer filtration efficiency, and flow to the core. No debris is credited as flowing to the broken hot leg. The PWROG stated that this is a significant conservatism in the core fiber load calculation. The PWROG also stated that anything that delays arrival of debris at the core will be less conservative.

3.2 RELAP5/MOD2A B&W Plant Analyses

In response to B&W audit question 7, Framatome provided information to show that the modeling for the B&W void fraction validation is basically the same as the CE modeling discussed earlier. The code predictions for the void fraction validation were similar to the CE predictions. As discussed in the previous section this audit report, Framatome stated that a new figure will be supplied for the void fraction prediction in the updated version of ANP-3584-P, Rev. 1 (B&W) similar to the one that was provided in Figure RAI 4.8-1 in ANP-3583-P, Rev. 1 (CE). In the B&W RAI response to RAI 4.8, Figure RAI 4.8-1 was inadvertently replaced with one for the CE plant category. The corrected figure, which showed predicted vs. measured void fraction, was displayed.

Framatome stated that for the B&W plant design, the blockage is applied at the start of recirculation. For this plant design there is no long term because of the reduced AFP resistance. For void fraction predictions, the B&W plant model used **[** **]**. Prior to blockage, the mixture level in the UP is high with some flow spilling out the large holes in the top of the UP cylinder. When the blockage is imposed, the AFP allows flow to the core relatively quickly. The mass in the UP and core are both used to offset the loss of flow that occurs when blockage is modeled. The void fractions in the UP increase following blockage because the fluid drains to the core. The core never becomes uncovered for the B&W plant category. The baffle region is refilled very quickly because the baffle/AFP resistance is low. Even with the drainage of the liquid in the UP into the core, a small amount of liquid is retained in the UP. For the B&W design category, the AFP is established within 30 seconds. The mixture level returns to the point where liquid is flowing out the hot leg relatively quickly. The minimum predicted mixture level is about 1 - 2 ft. above the top of active fuel. Refer to RAI 23, Fig 5. Framatome estimates that even if uncovery occurred, reflood would occur quickly.

In response to B&W audit question 1, Framatome stated that the AFP passages are large enough that the Reynolds number (Re) is not important in the determination of form loss coefficients. Therefore, the full power flow loss coefficients are acceptable for use in the LTCC calculations. All holes are greater than 1 inch. It is recognized that Re will be different, but the form losses factors would be similar for the two conditions.

In response to B&W audit question 2, Framatome stated that no openings less than ¼ inch were credited for the AFP. Slots **[** **]** were credited. The geometry and orientation of the slots and flow holes was determined through review of plant drawings. Framatome does not expect significant radiation effects on the credited AFP passages sizing.

In response to B&W audit question 6, Framatome provided a description of the B&W plant response during the event. They stated that HPI is initially injected into each of the CLs and lower pressure injection (LPI) is injected into the core flood tank nozzles. When recirculation is initiated in the model, the LPI flow is throttled back to 200 lb/sec and high-pressure injection (HPI) is secured. After sump switchover (SSO), Emergency Operating Procedures allow the operators to throttle ECCS flow, while monitoring core exit subcooling, to manage pump Net Positive Suction Head (NPSH) or other issues with long term pump operation. For such reasons, operators can terminate HPI and reduce (throttle) LPI flow with a reasonable minimum targeted flow of 2,000 gpm if core exit subcooling is maintained. To bound the possible flow rates after SSO in the plant and to account for the limiting single failure, a total constant ECCS (LPI plus HPI) flow rate of 1,500 gpm (200 lbm/s) to the RCS was modeled in the GSI-191 analysis. Framatome stated that the flow rate assumed in the analysis is well below the minimum available at all B&W plants. There are coolers on the ECCS injection, so the injected coolant temperature is reduced from that of the sump. A 200°F injection temperature was assumed for the B&W design category. The actual temperature would be lower. It is unlikely for the borated water storage tank (BWST) to be exhausted within 20 minutes, so swapover would occur later. If the entire BWST was injected within 20 minutes, the core would be fully subcooled. The B&W design plants do not interrupt flow during swapover.

In response to B&W audit question 12, Framatome discussed nodalization used for the analysis. A noding diagram was viewed and compared to the actual plant to understand how the AFP supplies flow to the core and how the UP is connected to the hot leg (HL) and other areas in the vessel. The noding is the same as that used in current LOCA analyses. In response to B&W audit question 13, Framatome discussed the cell heights for the top nodes in the core. For the most limiting cases, if the upper nodes were not uncovered, the top two core nodes are less important. Since the mixture level is predicted to stay in the UP and not uncover the core, there was no need to use more refined noding below the UP.

3.3 WCOBRA/TRAC Westinghouse Plant Analyses

Westinghouse discussed the axial power profile used in the analysis in response to Westinghouse audit question 1 of the audit plan. A profile was chosen based on inputs similar to those used by Framatome for the CE and B&W design categories. The axial power shape and the total peaking factor (Fq) used for the LTCC analysis was similar when compared to a typical SBLOCA axial power shape (about 2.5 for SBLOCA and 2.3 for GSI-191). SBLOCA analyses typically use a +13% axial offset and the GSI-191 used a similar input.

Westinghouse discussed the modeling and radial peaking factor used in the analysis in response to Westinghouse question 2 in the audit plan. The response to RAI 4.29 has the information related to this issue. A standard, 4-loop Westinghouse model was used. No modeling changes were made to the vessel for the LTCC analysis. There are two average channels (one guide tube channel with 45 fuel assemblies (FAs) and one non-guide tube channel with 103 FAs), one HA channel, and the core periphery channels (44 FAs). The analysis assumes 193 FAs total. The break location was changed from the cold leg to the hot leg. The model used is the best estimate LBLOCA model for a cold-leg double ended guillotine break (DEGB). Westinghouse performed two sensitivity studies to justify the conservatism of the assumed value for radial peaking in the core periphery. Westinghouse concluded that modeling a lower radial peaking factor in the core periphery would promote draining from the UP in this region.

Westinghouse stated that a more skewed profile will not be maintained into the time period of the analysis. Westinghouse believes that NRC technical staff will corroborate the time period in which a significantly skewed power distribution can be maintained for the LTCC event.

The modeling of ECCS flow rates was discussed in response to Westinghouse question 3 in the audit plan. Westinghouse stated that the modeling of ECCS flow rates used step changes at the time of switchover to sump recirculation. Plots in the RAI responses appeared to ramp the ECCS flow upward because of a smoothing function that Westinghouse used in presenting the results from the analyses.

Westinghouse stated that during injection, the minimum SI flow was used. However, the sump swapover time was assumed to be 20 minutes which is more aligned with maximum SI flow. These assumptions result in minimum vessel inventory and maximum boiloff and decay heat values. Westinghouse used plant data to determine a range of flow rates to be used in the analyses. An injection flow rate sensitivity study was performed, which showed that the flow rate did not significantly affect the debris induced heatup. RAI response 4.23.d presents the sensitivity study for the k_{max} case. It shows that the 18/18 gpm/FA (injection/recirculation flow) case is limiting. The sensitivity study shows that varying the injection flow rate does not impact the parameters of interest. The SI flow rate modeled during the injection phase does not directly impact k_{split}, m_{split}, or k_{max}, because there is no debris assumed in the injection flow, and the primary effect of the SI flow relates to the liquid inventory in the vessel at swapover. The upflow plant used 18 gpm/FA and the downflow plant used 24 gpm/FA for injection flow in the analyses. Recirculation flow rates were varied in the analyses to examine the effect on PCT. The recirculation sensitivity studies were done around the 18 gpm/FA flow rate. A flow rate of 18 gpm/FA is the minimum that should occur at any plant, so it is considered bounding. For the k_{split}/m_{split} cases, there were studies with flows down to 8 gpm/FA. This was done to allow plants to verify that the maximum SI case is limiting since it results in more debris reaching the core at an earlier time. Additional sensitivity studies (RAI response 4.24) varied the flow rate to show that it had minimal impact on PCT.

Continuing its response to Westinghouse audit question 3, Westinghouse stated that single failure assumptions will be determined by the plants as they implement the TR (i.e., consider the worst case regarding single failure and ensure they are within the range of conditions in the TR). The TR analysis was intended to bound the potential range of parameters including failures. Additionally, the flow rates per FA were determined based on the number of FAs in the analysis and the flow rates from the ECCS pumps.

Westinghouse addressed the assumption that all of the injection flow to the CLs is split equally between them. Since there is no break in the cold leg, all injection goes to the DC no matter which leg it is injected to.

Westinghouse stated that 20 minutes was determined to be a limiting value for SSO based on RWST volumes and the maximum possible injection rate.

In response to Westinghouse audit question 4, Westinghouse discussed RAI 4.16.d, which shows a sensitivity study for the injection temperature. The study varied injection temperature between 76 and 120°F and demonstrated that there is no significant effect on PCT. The sensitivity was done for the upflow 2B case for k_{max}. The recirculation temperature was assumed to be 212°F for all cases.

Westinghouse discussed the importance of DC height and the assumptions regarding M_{boil} in the analysis in response to Westinghouse audit questions 5 and 6. It was clarified that the DC volume was a relevant parameter because the volume needs to be refilled following the simulation of core inlet blockage so that the flow to the core is recovered. In this sense, filling time is dependent on DC volume. The calculation of M_{boil} covers the core side losses and the number of FAs in the analysis. The geometry of the reactor coolant system (RCS)/DC/baffle regions is important because the bottom of the cold leg is above the top core elevation. The height of water column (height of the DC) does provide driving head to push the coolant into the core, but the height is similar for the plants in the analysis leaving the DC volume to be the controlling parameter. Scaling in the analysis includes reactor power plus uncertainty. Plants will have to assure M_{boil} calculated for their plant is acceptable when implementing the TR.

Westinghouse provided information on UP drainage in response to Westinghouse question 7 in the audit plan and stated that the RAI 4.7 response includes information on this issue.

The analysis was performed based on comparison to the Kutateladze number (Ku). The analysis showed that after about 500 seconds after the break, downflow will occur for a conservative steaming rate based on the comparison to hand-calculated CCFL parameters. Recirculation does not start until 1,200 seconds so downflow from the UP into the core is expected prior to the arrival of any debris at the core inlet. Nodalization in the area of the upper core and UP was examined to understand the draining from the UP into the core. During the transient, draining from the UP is mostly down though the core periphery with flow entering the HA closer to the bottom of the core. There is minimal draining directly into the HA. The upper core plate is the most restrictive flow path axially (equal to about half of the FA flow area). This is where CCFL is most likely to occur because it is the smallest flow area between the UP and the core region. However, CCFL was not observed to occur at this location. Westinghouse stated that there were no CCFL models or checks activated in the upper core or UP regions in the GSI-191 analyses. As discussed above, while the code does not do a CCFL calculation, Westinghouse performed a post-processing check for CCFL. The velocities observed would not prevent downward flow of liquid from the UP at the top of active fuel. A verification that CCFL is not limiting at the upper core plate was performed because that area is about half of the area at the exit of the core.

Westinghouse stated that the UP level approached zero (complete drainage) shortly after blockage was applied for the t_{block} analysis. Figures RAI-4.23-32 to 34 show UP levels for upflow case 1B. It is seen that UP levels recover by about 9,500 seconds and that recovery begins shortly after core inlet blockage by debris is modeled at 8,580 seconds. The downflow results were similar to the upflow model for UP draining.

Westinghouse stated that the response to RAI 23 did not include two-phase mixture liquid levels because two-phase mixture levels require more processing. RAI 4.9 provided the collapsed liquid levels. As the fuel begins to uncover, fluid flows in from the sides, so a two-phase mixture level is difficult to be calculated. RAI 4.9 shows the HA level trend including uncovery. The minimum two-phase mixture level for the upflow model was 8.52 ft. The downflow model level decreased to 6.68 ft. (Note: Top of active fuel is at 12 ft.) Westinghouse stated that the downflow plant probably has deeper uncovery due to more resistance in the UP drain path. The PCT location was about 3 ft above the lowest two-phase mixture level. (10.48 ft, and 9.42 ft were the PCT elevations.) Collapsed liquid levels in the UP can indicate when fuel uncovery is predicted to begin.

Continuing its response to audit question 7 (7.b), Westinghouse stated that the interfacial drag multiplier in the models was set at 0.8 for the core region only and this multiplier was applied during recirculation. During injection, a multiplier of 1.0 was used. Using a higher multiplier during injection reduces inventory by increasing voiding. Using the lower multiplier during recirculation reduces two-phase mixture swell leading to a deeper core uncovery. For the UP, a multiplier of 1.0 was used throughout the analysis. For evaluation of the interfacial drag coefficient multiplier, Westinghouse relied on a sensitivity study that varied the multiplier in the core region during recirculation from 0.6 to 1.0 (0.8 was used in the analyses). The sensitivity study showed a change in PCT of 100°F for the upflow plant category and 50°F for downflow plant category. The observed change in PCT was not monotonic with the change in the multiplier. Westinghouse stated that PCT appeared to be driven more by local void fraction and the timing of void fraction compared to timing of blockage. Given the variability and nonmonotonic behavior associated with the drag multiplier sensitivity studies, Westinghouse suggested that the interfacial drag multiplier of 0.8 was appropriate for the GSI-191 analyses. Westinghouse recognizes that there is uncertainty in the code behavior for interfacial drag and believes that the use of a conservative modeling approach, which relies on the application of a different interfacial drag multiplier for each phase of the transient, as described above, should provide an offset to the variability in the prediction results that was exhibited in the sensitivity studies.

Westinghouse stated that none of the sensitivity studies done for both plant categories (50+) resulted in large changes in PCT. The parameters that had the strongest influence on PCT were core inlet resistance ramp rate and decay heat multiplier; not the interfacial drag multiplier. Relative to the interfacial drag and as discussed above, Westinghouse stated that to maximize PCT a high interfacial drag multiplier would have to be used prior to blockage followed by implementation of a low multiplier after the blockage. This minimizes inventory before blockage and then minimizes core level swell after the core inlet blockage resulting in a higher PCT.

Westinghouse performed cases with k_{max} and t_{block} for the upflow plant using a plant-specific model, which was slightly different from the base model. The runs with the alternate model resulted in lower PCT and a reduced core uncovery. Westinghouse concluded that this showed a higher propensity for core uncovery due to the void fraction instability in the base LTCC upflow model. Westinghouse stated that it had looked at the void fraction/drag multiplier issue closely and verified that the submitted results were appropriate.

In response to audit question 10, Westinghouse discussed validation and verification of the code capabilities to predict core void fraction and the selection of an interfacial drag multiplier. The code version used to simulate selected G1/G2 tests for these purposes was older than the one used for the GSI-191 LTCC analyses. Code version WCOBRA/TRAC-MOD7AR4 was used for interfacial drag multiplier validation to the G1/G2 tests. The validation was done to support AP1000 analyses. Westinghouse performed one of the test validations again using the code version for the LTCC analysis (MOD 7AR8). The analysis verified that the results were consistent with the earlier validation. Westinghouse stated that the drag multiplier sensitivity studies showed that the results from the LTCC code runs were acceptable. Westinghouse stated that the G1/G2 validation model had the same number of axial nodes as the plant core model. The response to RAI 4.8 has information on this topic.

Westinghouse stated that the results from the G1/G2 validation runs performed with the prior code version were applicable to the code version used in the TR. In addition, the sensitivity studies demonstrated that the interfacial drag multiplier did not have a significant effect on the code results, which were not sensitive to the interfacial drag coefficient based on the examined drag multipliers. See followup call information in Section 3.4 of this audit report for more information on the G1/G2 validation as it relates to the GSI-191 scenario. Further discussion on this issue is included in Section 3.4 of the audit report which discusses audit followup conference calls.

In response to audit question 12, Westinghouse discussed the flow into the reactor vessel via the intact hot legs and liquid discharge through the broken HL shortly following core inlet blockage. In the response to RAI 17, Figures RAI-4.17-10 and 4 show the flows through the intact hot leg nozzles and the SG side of the DEGB in the broken hot leg, respectively. The loops were voided before the blockage. When blockage was applied, the loops get a surge of flow. This was stated to be conservative because less flow went to the core via the DC. Westinghouse verified that mass was conserved throughout the transient. The rapid blockage rate applied to the core inlet caused the surge into the crossover legs and steam generators (SGs). The physical reason for this was not explained. Westinghouse performed confirmatory calculations with the WCOBRA/TRAC-TF2 code. The calculations were run for different core inlet blockage time and without nitrogen injection from the accumulators. The surge only occurred in Case 1B. Westinghouse stated the behavior was likely due to the fact that the loops are cleared. It did not occur in cases where the loops are filled. Westinghouse concluded that the behavior was conservative because the flow to the vessel via the DC was reduced. The plots in the response to RAI 30.b provide information on this issue. Westinghouse stated that the loops were filled by the time liquid was delivered to the DC and the SG tubes were partially filled by this time. Further discussion on this issue is included in Section 3.4 of the audit report which discusses the audit followup conference calls.

In response to Westinghouse audit question 21, Westinghouse discussed the AFP resistance calculations. The issues associated with the Westinghouse calculations were similar to those discussed for CE design plants. A new averaging scheme was used for holes in parallel. The method in the initial submittal was incorrect. The updated method used industry standard methodology to ensure mass flow rate and differential pressure is preserved through the parallel passages.

In response to Westinghouse audit question 14, Westinghouse discussed the observation that the code predicts flow diversion toward the crossover legs when the collapsed liquid level in the DC was below the nozzles of the CLs. The observation was that flow was diverting to the crossover legs prior to the DC being filled up to the cold leg nozzles. Westinghouse stated that this diverted flow from the vessel DC and was conservative. The NRC staff stated that validation that the code was providing a realistic representation of the behavior was desired. Westinghouse stated that the version of the code used (WCOBRA/TRAC MOD 7AR8) did not have a stratified flow modeling capability. This could be an important phenomenon for this calculation in the primary loops. Westinghouse maintained that if the code was diverting liquid into the UP via the intact hot legs, instead of delivering it into the DC, then this liquid would not enter the barrel/baffle channel and eventually feed the core, which was conservative. Further discussion on this issue is included in Section 3.4 of the audit report which discusses the audit followup conference calls.

In response to Westinghouse audit question 15, Westinghouse discussed the cause of fluctuating DC levels in the k_{max} analysis as observed in Figure RAI 4.18-4. Following blockage, liquid flowed into the loops, which starved the DC of flow. Eventually, the DC refilled and it was taking time for the manometric balance to be established and stabilize. The behavior could be artificially driven by the code. However, the trend tended to minimize the level in the DC, which reduced the driving head into the core.

In response to Westinghouse audit question 24, Westinghouse stated that no large vessel mass errors were identified during the GSI-191 analysis. The results were evaluated for vessel mass error and found to be less than 0.2% for the upflow cases. For the downflow cases, the error was slightly lower. The code performs a check at each time step, which calculates the difference from the previous time step. If an anomaly is detected, the calculation is performed again with a smaller time step. Westinghouse also performed a separate check of the error trends. These results were evaluated and found as acceptable by Westinghouse.

Westinghouse provided additional information on the vessel mass error (Westinghouse audit question 24.h). They stated that the RAI 17 response showed that about 750,000 lb of coolant accumulated in the primary loops from 1,200 to 9,500 seconds. The NRC staff questioned what caused this enormous accumulation. Westinghouse stated that the observed accumulation is the ECCS flow into the primary loops. See followup conference call information in Section 3.4 of this audit report for more information about this item.

In response to Westinghouse audit question 25, Westinghouse discussed the treatment of non-condensable gases in the analysis and stated that the RAI 4.7 response has information on the topic. Nitrogen injection from the accumulators was eliminated from the analysis. Westinghouse concluded that the presence of nitrogen volume in the DC region was non-physical. The presence of nitrogen displaced coolant. The NRC staff questioned why the code did not model the nitrogen correctly. It appears that the code did not allow the nitrogen to leave the DC. A valid explanation for the code behavior was not provided. Westinghouse speculated that trapping of the non-condensable gas could be caused by blockage of the piping on the CL side. Westinghouse also stated that eliminating the nitrogen from the model caused the PCT results to be higher, and therefore conservative. See followup conference call information in Section 3.4 of this audit report for more information on this item.

3.4 Followup Conference Calls

The face-to-face audit concluded on June 28, 2018. Both the NRC staff and PWROG agreed to keep the audit open to discuss the remaining open items efficiently by teleconference. Conference calls were held on July 16, July 31, August 2, and August 6, 2018.

The conference calls on July 16 and 31, 2018 discussed the open items remaining for the Westinghouse methodology. The open items and the discussions are included below.

1. Liquid flow into vessel UP from intact hot legs (i.e., loop flows)

   Westinghouse prepared plots of integrated mass flows through the intact and broken hot leg nozzles, AFP, core, and boiloff between 8,580 sec (complete core blockage) to 8,810 sec for uflow case 1B (a PCT of 780 °F occurred at 8,803.5 seconds for this case). This was a zoomed-in region of Figure RAI-4.17-11. The Integrated flows over the time interval of interest was plotted. The results were close to zero for the flow integrals into the intact HLs (indicating that the flow through the intact HLs was insignificant compared to the AFP flow). Westinghouse considered the flow into the UP through the intact hot legs to be insignificant.

   During the call with PWROG on August 6, Westinghouse stated that a plot would be included in a revised response to RAI-4.17 to include the information discussed during the call.

2. Mass balance concerning response to RAI-4.17 (Relating to audit question 24.h)

   Westinghouse described that there was an error in how the figures were generated. There was not a mass error in the code. A mass balance check exercise determined that the individual components maintain balance correctly with the updated calculations. The integral flow rates presented in this RAI response were incorrect. Figures were regenerated and put into the Westinghouse corrective action program. An update to the response to RAI-4.17.c and d will be provided to correct the figures that were in error along with any other figures that are found to have similar issues.

   The original method used to plot was to smooth the oscillatory curves (at every 0.5 sec) then integrate. This was corrected by not smoothing the curves. The results were dumped at

0.5 sec frequency and the raw data was then integrated.

The correction for the mass balance results showed new values of 27,000 lbm of liquid accumulated in the loops. This is evenly distributed among all 4 loops so there was about 6750 lbm in each loop.

3. Code behavior in the presence of non-condensable gas and resolution

Westinghouse provided the outcome from an investigation of the non-condensable behavior. Plots were presented for DC level over the time of the transient. WCOBRA/TRAC does not track nitrogen transport. The code works very well for CL breaks, but HL breaks caused non-condensable gas to be trapped in the DC for a very long time. Westinghouse used a separate code (WCOBRA/TRAC-TF2), which has an explicit modeling scheme for non-condensable gasses, to compare results of tracked non-condensable gases. The transient was run without non-condensable gases (re-analysis run in RAI response 4.7), which showed favorable results.

Results from 3 cases were compared: The cases were started at 1,100 seconds (blockage at 1,220 seconds).

1. Original downflow 2B case- Loops are liquid solid, DC is being pressurized by presence of nitrogen from the accumulators, which pushes the liquid down and forces it into the core and UP.

2. Downflow 2B reanalysis with removed the nitrogen gas - more liquid enters the core and UP.

3. TF2 case still shows voiding in the CLs, the DC liquid level is suppressed due to the presence of nitrogen and additional liquid in the core and UP.

Westinghouse stated that the downflow 2B case reanalysis was chosen as the AOR case because liquid inventory in the core was the most conservative. The reanalysis results were included in the response to RAI-4.7. The downflow 2B case was modeled without accumulators, which were replaced with FILL tables to deliver the correct amounts of liquid without injecting any nitrogen.

The NRC staff replied that additional information was needed in order to agree with the Westinghouse conclusion. Westinghouse should provide justification for the use of FILL tables instead of using accumulators. Also, Westinghouse should demonstrate that this is not an issue for the 3 other cases (i.e., provide table of PCTs for the runs with accumulators vs runs using FILL tables). This should demonstrate that the results are comparable or conservative to the cases run with the accumulator. In addition, Westinghouse should provide information that justifies, for the remaining 3 cases, that keeping the accumulators in the model was acceptable in terms of code performance.

In response to the NRC staff's comments, Westinghouse provided a FILL table showing time, mass flow rate, and velocity. This table was created by plotting accumulator mass flow rate over time and selecting some points. This information is entered into the FILL tables and the accumulators were replaced with these FILL tables.

Westinghouse also provided a PCT comparison for Cases 1A and 2B both with and without nitrogen injection. Case 1A (complete blockage) changed PCT from 872 °F with nitrogen injection and increased UHSN resistance of 5.1×10^6 (as described below, corrected as a result of recalculating the AFP resistance in an RAI response) to 848 °F without nitrogen. Case 2B showed a PCT of 645 °F with nitrogen vs 780 °F without nitrogen. Ultimately, 780 °F is what is used for the Volume 4 revised AOR.

The original TR submittal (Rev. 0) had a resistance of 3.1×10^6 for UHSN resistance. When providing the response to RAI 4.2, an error was identified for the UHSN resistance calculation increasing it to 5.1×10^6. The PWROG reran Case 2B (the k_{max} case) to get a PCT of 780 °F (which is what will be included in Revision 1 of the WCAP). The t_{block} time case, Case 1A, was not changed. Instead, t_{block} is only valid if plant-specific UHSN resistance is shown to be $<3.1\times10^6$. Only one plant that was not bounded by this resistance and they will use an alternate HL switchover time or other plant-specific implementation to account for the higher AFP resistance.

Westinghouse provided results for upflow plant cases where the same process was applied as for the downflow plants. For Case 1B (t_{block} case), PCT changed from 770°F with nitrogen to 410°F without nitrogen. For Case 2B (k_{max} case), the PCT changed from 798°F with nitrogen to 495°F without nitrogen. Therefore, Westinghouse believes that the cases in the submittal are more conservative when accounting for treatment of non-condensable gases.

4. G1/G2 code assessment for GSI-191 validation considering the presented assessment was completed with a version and revision of the code that were unknown.

   The code version for the G1/G2 analyses was same one that was developed for the AP1000 LTCC (Mod7A, Revision 4). This was not the same code version (Mod7A, Rev. 8) used for GSI-191 analysis. The NRC staff requested an accounting of changes made to the code between Rev. 4 and Rev. 8 to verify relevance of the simulation data between the G1/G2 code version and the version used for GSI-191 analysis.

   The PWROG provided a table showing revisions to WCOBRA/TRAC from MOD7A, Rev. 4 to MOD7A, Rev. 8 including the appropriate reporting letters to NRC. Westinghouse stated during the call that the code change process followed Appendix B QA requirements.

The conference calls on August 2 and 6 discussed the audit questions related to the Volume 3 RAI responses. After the audit plan was issued, the NRC staff decided to include the questions from the Volume 3 RAI responses as part of the audit. The questions were sent to PWROG before the call on August 2 and were included in the discussion below. They are categorized in a similar way to the questions from Volume 4 included in the audit plan. The audit discussions are included after each question.

Volume 3 Audit Questions and PWROG Responses – Cold Leg Break Evaluation

The following questions pertain to inadequately justified assumptions that could have a significant effect on a plant's ability to confirm the cold leg break (CLB) debris limits proposed in WCAP-17788 Volume 1 or to develop plant-specific limits. These limits could significantly affect the validity of the CLB analysis.

1. What went into the engineering judgment that ended up with a 1.2 multiplier on boil-off flow in computing the fiber amount at the core inlet? There are uncertainties in flow to the core (carryover), debris concentration in the coolant entering the core, sump screen and fuel assembly fiber testing, and how the test data is applied to the plant (including timing assumptions). Provide information to show how "the unknowns and/or uncertainties associated with the 1.2 multiplier" have been accounted for to justify this value. (RAI 3.24 and RAI 3.25)

   PWROG stated that the 1.2 multiplier was not applied to the boiloff flow; it was applied to the amount of debris arriving at the core inlet (fiber concentration). PWROG stated that the flow multiplier was based on NUREG/CR-6885 (NRC testing) where various strainer hole sizes were tested with flow holes down to 1/16" and showed about 4% of flow delivered passed through the sump screen. Testing has shown that slower velocities result in less fiber penetration through the screen. 5%x1.2 is what was used in analysis. PWROG felt that this was a conservative analysis.

   The 4% penetration quoted by the PWROG was determined at a velocity of 0.21 ft/s. This flow velocity is high compared to actual plants where it could be 0.1 ft/s or lower. The PWROG stated that if the plant flow is less than that during the test, then the use of 5% fiber bypass is conservative. Turbulent mixing is going to occur even as pool builds (15-30 minutes) until recirculation is initiated, i.e., PWROG believes that the fine fiber in the pool is well mixed with the fluid.

   The NRC staff questioned how fiber preparation was done for the cited NUREG report and whether the test quoted was valid considering currently accepted guidance for penetration testing. Recent penetration tests showed about 40% of the fiber initially added to a test passed through the strainer at a velocity of about 0.01 ft/s. The NRC staff had witnessed testing where there was 40% penetration. Penetration is dependent on many variables and not just velocity. The NRC did not remember any 5% value being used in the TR and did not agree with the use of the NUREG data as stated by the PWROG.

   PWROG stated that the CLB method says that the plant will provide penetration fraction. The 5% is not provided in the TR anywhere. The plant-specific analysis will have to show fiber bypass results because plant-specific fiber bypass history can be put into the calculation scheme.

2. The response to RAI-3.20 states that a uniform debris bed will not form at the core inlet under CLB conditions based on observations from a 4-in x 4-in test section geometry. This is not a viable conclusion as a uniform debris bed formed during the testing. What supporting information is available to justify that a uniform debris bed will not form at the core inlet under CLB conditions? (RAI 3.20, RAI 3.34, and RAI 3.5)

   PWROG stated that the subscale brine test showed that uniform debris beds could form. With fiber amounts of up to 20 g/FA, buoyancy driven flow precluded a debris bed from forming or, if a debris bed did form, the debris bed was disrupted, and exchange transport was established. There were also 3x3 heated rod bundle tests and WCOBRA/TRAC results, which show that a continuous bed is unlikely to from and that there is downflow at the periphery after recirculation that would tend to prevent a uniform bed from forming. The code analyses become suspect later in time because of simulation effects using WCOBRA/TRAC. (COBRATRAC does not model density gradients due to boron concentration).

PWROG was not crediting any settling of fiber before it would reach the core inlet, which was considered as a conservatism in the calculation of the core inlet fiber amount for comparison against the CLB fiber limit.

The NRC staff questioned how it was determined that debris collection at the core inlet would not have detrimental consequences on the core (inadequate cooling) prior to debris bed disruption. PWROG stated that the brine testing facility was built to promote fiber capture and formation of a uniform debris bed. Under prototypic conditions in a real reactor, the formation would not be as uniform as in the testing. Brine testing focused on transport of boron solution from the core to the lower plenum (LP). This test is related to boric acid precipitation (BAP) and not to decay heat removal. PWROG felt that they did not need to justify that a uniform debris bed will not form. Testing conducted for WCAP-16793 showed less than 1 psi pressure drop across the core prior to the occurrence of chemical effects (RAI-3.27 response). Therefore, the driving head in the DC would sufficient to drive liquid into the core to replace boiloff and cool the fuel.

The subscale tests were run at a minimum velocity of 7.6 gpm/FA and were stated to indicate that head loss would not exceed the 1 psi driving head available. The NRC staff questioned how a lower flow rate and velocity would affect the outcome of the tests. PWROG stated that they thought the lower velocity would compact and compress the fiber bed less and create lower resistance through the debris bed.

The NRC staff asked if bore holes were observed during testing. The PWROG stated that they were only observed during the highest flow tests equivalent to 40 gpm/FA.

PWROG concluded that it is important to evaluate decay heat removal and BAP separately. They also stated that a uniform debris bed is not expected in the GSI-191 scenario, but if one did form, from a decay heat removal perspective, the core would still be cooled even if the **[ ]** bed was uniform.

3. How are the fiber loads for the tests known considering the once-through debris delivery method used in the test set up? How much fiber penetrated the test FA and was not captured? (RAI 3.8, RAI 3.12, RAI 3.13, and RAI 3.27)

   PWROG stated that the **[ ]** limit for the CLB is not assigned a location like it is for the hot leg break (HLB) scenario. That is, it is assumed to all fiber will be at the core inlet for the CLB. Thus, the **[ ]** limit is the total in-vessel debris limit for the CLB scenario. PWROG stated that if **[ ]** of fiber arrived at the core inlet, the buoyancy driven convection is enough to allow communication between core and LP to continue. The subscale tests showed the fiber penetration at the FA inlet was less than 10%. PWROG stated that there is not much fiber penetration expected for the CLB scenario because the approach velocity is lower for this CLB scenario than for the HLB one.

4. Does Section 7.1.1 in WCAP-17788 Volume 1, Rev. 1 only consider the initial phase of debris arrival? If so, why? LTCC should be considered per the requirements of 10 CFR 50.46(b)(5). (RAI 3.5.b)

For later phases, WCOBRA/TRAC does not predict recirculating currents in the core for LTCC properly. For later phases of LTCC, the brine test and 3x3 boiling tests are relied on (to show that a uniform bed will not form at the core inlet). The NRC staff commented that the 3x3 test was not prototypical so it would be hard to be credited fully.

5. Why is it believed that the flow distribution is not significantly affected? Under low flow conditions associated with low pressure differential, even small variations in resistance can affect flow and flow distribution. (RAI 3.5.a)

   PWROG stated that they agree that uniform beds formed in the brine testing, but as discussed under question 2 above, they stated that if a bed forms, LTCC would continue and exchange flow with the LP would occur to prevent BAP in the core. PWROG also noted that the brine test facility was designed to form a uniform bed at the core inlet. Even though the brine test showed that a debris bed will form, the buoyancy forces were sufficient to break the debris bed and allow flow exchange between the core and the LP. The 3x3 tests showed no bed formation.

6. Justify with experiments or other evidence that “the dP is not large enough to significantly influence the redirection of flow” and that “other processes (e.g., buoyancy-driven convention) will generate secondary flows that preclude formation of a uniform debris bed”. How is the response adequate to show that fiber buildup at central FAs will not cause flow to reroute to peripheral FAs to some extent? (RAI 3.5.c and RAI 3.5.b) PWROG stated that these experiments were small scale tests so redirection of flow was not part of the experiments. There is not larger scale testing that demonstrates how the flow redistributes. PWROG stated that decay heat removal is not a concern even if the low probability event of uniform debris bed formation occurs for core inlet fiber loads below **[ ]**.

   Additional discussion regarding flow redistribution is included in the documentation of the questions considered above.

7. How was the driving head in the DC for the CLB scenario established? What are the supporting analyses and what assumptions and values were used in these analyses? (RAI 3.27)

   In the RAI response to RAI-3.27, the assertion was made that the driving head in the DC is sufficient to overcome head loss of up to 1 psi. The calculations to support this were from the Westinghouse HL switchover methodology (BAP calculations), which were reviewed and approved by the NRC staff. No additional calculations were done as part of the GSI-191 program. Westinghouse and CE HL switchover analyses were reviewed to show that dP available was below 1 psi head loss during the HLB scenario for the GSI-191 analysis. The calculations that were reviewed were considered the most limiting. For example, one of the Westinghouse calculations reviewed was for a plant with 14-ft FAs. All other plants had 12-ft FAs. This adds significant head loss on the vessel side of the calculation. The loop configuration for the 12- and 14-ft fuel plants are similar so the 2 ft of additional head to overcome was a conservative estimate. The CE plant that was reviewed had a limiting loop configuration. A separate calculation for each plant was not performed.

   PWROG provided a summary of assumptions used in the BAP calculations:

   - No credit was taken for DC liquid level above the bottom of the CL.

- 10% voiding in the DC was assumed to reduce the driving static head.
- dP in the core region was taken from the bottom of active fuel (BAF) to top of active fuel (TAF).
- Collapsed liquid level was assumed to be below the TAF.
- 10% SG tube plugging and a locked reactor coolant pump (RCP) rotor were assumed.

Calculations were based on values just prior to hot leg switchover (HLSO). The PWROG stated that this increased the degree of conservatism since there was less boiling later in the event and, therefore, a higher collapsed level in the core, which would increase the head on the core side.

8. Two minutes without ECCS flow due to interruption at cold leg recirculation was assumed in the CLB calculation. Could an interruption, like that described for the CLB occur during switchover following a HLB? Why is it included in the CLB analysis, but ignored in the HLB analysis? Note: This question is related to HLB analysis in WCAP-17788 Volume 4 and is yet to be resolved. (RAI-3.7)

   PWROG stated that the flow interruptions and reductions during SSO are plant specific and not dependent on break location. Most Westinghouse plants do not have a flow interruption like the one described in the CLB analysis. The interruption was taken from a calculation from one specific plant. This was an existing analysis to show that the core inlet flow patterns were adequate to ensure decay heat removal during flow interruption.

   The NRC staff questioned how a plant with a flow interruption can apply the HLB analysis since it did not consider a flow interruption. PWROG responded that the potential for flow interruptions was not ignored in the HLB analysis. The PWROG stated that it is not possible to bound all potential plant responses because of differences in plant designs. Case 3 from the Westinghouse RAI-4.19.b response showed a delay of 200 seconds prior to debris arrival after the initiation of sump recirculation. This was done because core liquid inventory at switchover appeared to be decreasing (questioned previously by the NRC staff) due to a drag multiplier change, which affected liquid inventory in the core. This resulted in the same flow behavior as a flow interruption associated with boiloff and loss of inventory in the core. PWROG stated that Case 3 showed the ramp rate for resistance to the core inlet was more than enough to offset the liquid decrease due to flow interruption.

   The NRC staff questioned how it was determined that the ramp rate was more significant than the flow interruption. PWROG referred to the response to RAI-4.19.b. Table RAI-4.19-1 showed results from a sensitivity study for a downflow plant. Case 1 and 2 delayed both SSO and arrival of debris (both event occurring simultaneously at 1,400 and 1,600 seconds, respectively) and used close to instantaneous (60 sec) ramp rates. Case 3 simulated a delay in debris arrival of 200 seconds after SSO at 1,200 seconds and used a ramp rate of 5 minutes (300 seconds). Figure RAI-4.19-1 showed a sustained heatup did not occur for Case 3 (temperature was much less than for the other cases). Figure RAI-4.19-2 showed the liquid level in the DC in Case 3 had a reduction in inventory due to a ramp rate change. Liquid inventory was significantly lower in Case 3, similar to a flow interruption case. Upflow cases were considered in the response to RAI-4.7 and showed a similar behavior with these models.

The NRC staff stated that it will likely develop a limitation and condition for plants that have an interruption to demonstrate acceptability for this situation.

9. Froude number (Fr) criteria for the proposed fiber limit (RAI-3.12 and RAI-3.18)

    a. Provide justification for calculating Fr using the simplifying assumptions made (i.e., volume-averaged concentration). Calculating Fr in this way poses scalability and uncertainty concerns.

    b. There are large differences between the test and plant conditions. How can the calculated Fr be applied accurately considering these differences?

    c. The **[ ]** fiber limit assumes no bypass in calculating the mass of fiber accumulated at the test bundle inlet and assumes applicability of test results to a real core if per-fuel-assembly fiber loads are preserved. Provide justification for these assumptions.

    The PWROG stated that the Fr is only used in the response to RAI-3.12. It was not used to justify the **[ ]** limit. Observations from tests and test data are the information used to show that a debris bed will not form or that if a bed does form it will be disrupted.

    The NRC staff stated that the Fr criterion should not be used to predict plant responses beyond determination of which parameters have the greatest effect on the exchange phenomenon. PWROG agreed with this statement from the NRC staff.

    PWROG stated that bypass of the core inlet is not assumed and there is no tracking to determine whether the fiber is at the core inlet or the core region. All fiber is assumed accumulated at the core inlet.

10. List head loss tests performed to support WCAP-16793-NP-A, Rev. 2, related to WCAP-17788 that have produced reliable head loss measurements applicable to a core fiber load of **[ ]** at limiting particulate loads. (RAI-3.27)

    WCAP-16793 testing referenced in the RAI response was cited. The tests were CIB29 through 33, and had 18 grams of fiber at various p:f (particulate-to-fiber) ratios. The PWROG stated that the test assemblies were prototypical and should collect/bypass debris similarly to assemblies in the plant. The PWROG also stated that dP across the FA inlet will decrease over time because the flow rate decreases.

    Regarding Framatome fuel design, one test was performed with 18 grams of fiber at a p:f of 45 and the head loss was **[ ]**. Even after chemicals, the dP was **[ ]**, which is less than the 1 psi limit. There were two other cold leg break tests. One had 100 g of fiber and a high p:f and had a dP of **[ ]**. A test at 75 grams of fiber with a p:f of 5 had a dP of **[ ]**. The trend is similar to observations that indicate relatively low fiber amounts will not sustain high dP.

11. The response to RAI-3.28 states that it is not necessary to preserve the time scale. How can the results be applied to real plant conditions if time scale is neglected? (RAI-3.28) PWROG referred the NRC staff to the response to RAI-3.30. There cannot be a 1:1 timescale in the test facility. PWROG stated that this was satisfactory because the

density gradient between the core relative to the LP and the inlet flow rate were maintained in the testing as they would occur in the plant. These two parameters most strongly influence the exchange flow between the core and LP. It also serves as the mechanism to preclude **[** **]** if formed at the core inlet. Figure RAI-3.30-3 plots boric acid concentration in the core as a function of time. The brine test picked a couple spots from this curve to get a range of density gradients over the time of plant transient (20,000 seconds). Figure RAI-3.30-4 was referenced as well. The potassium bromide (KBr) and inlet flow rate and timing of injection were varied to capture some data points within the expected range of operating parameters for that transient time.

12. There is an inconsistency in the methods to determine time step. The response to RAI-3.32 in Attachment 1 covers the CLB methodology and that to RAI-3.32 in Attachment 2 covers the HLB methodology. The response provided in Attachment 1 included results from sensitivity studies on the time step for the CLB scenario to show that this parameter did not matter and the response to RAI-3.32 in Attachment 2 stated that plant-specific evaluations should be completed to ensure the time step chosen is justified for the HLB scenario.

    The NRC staff questioned the reason for the proposed opposite approaches to determining the time step being applicable to the CLB case and to the HLB case related to RAI-3.32. PWROG said that both methods used equations that were solved explicitly. The time step sensitivity should be considered applicable to the HLB methodology. PWROG stated that the RAI response will be revised to reflect that. PWROG to provide a revised response.

13. The response to RAI-3.3.b states:

    "The solid red line connects the boil-off rate at the start of recirculation to the sump to boil off rate at the start of hot-leg switch-over estimated to be at <u>two hours</u> after the event initiation." This is inconsistent with the expected timing.

    PWROG will clarify the figure and text in Revision 1 of the TR. PWROG stated that the line needed to be moved 0.5 hours and noted the figure was only supposed to be illustrative of the concept and was not a precise representation of the case that was discussed.

14. The response to RAI-3.26 discusses flow delivery to the core when both the core inlet flow rate and the fiber concentration in the ECCS fluid contribute to the debris amount delivered to the core inlet. Provide assurance that factors affecting each of these two parameters have been adequately accounted for in the proposed methods. (RAI-3.26) PWROG stated that containment pressure was slightly lower than what would be in the reactor pressure vessel resulting in a higher boiloff rate (which is considered to be conservative). The use of maximum sump temperatures maximizes boiling due to removal of sensible heat. PWROG listed other conservatisms, which were not quantified. The debris delivery is also based on the Appendix K decay heat model and includes an additional multiplier of 1.2. PWROG considered these factors to be adequate to account for any uncertainty in the calculation of debris amounts arriving at the core inlet.

15. Provide bounding values for the parameters in response to RAI-3.9(a). (RAI-3.9)

PWROG stated that the SKBOR sensitivities were shown in the RAI response. Table RAI-3.9-1 had the SKBOR key variables and the basis for choosing the associated values. The values described were considered bounding values for the plant that was analyzed. Bounding values for each plant would be considered on a plant-specific basis.

The discussion of each parameter is included below.

Decay Heat – Appendix K decay heat model (ANS-1971+20%). (Standard used for licensing calculations). Mixing Volume- This is a function of transient time. The volume is minimized to have the highest boron concentration. The mixing volume is skewed in a conservative direction. This is done by conservatively estimating void fraction (maximizing) and minimizing other mixing volumes that would be available (e.g., ignoring any coolant in the hot legs).
Boron Source Concentration – The TR assumed a constant 2,500 ppm value. No dilution from the sump water is credited. The source value would decrease because of the volumes from the RCS (except the accumulators).
Solubility Limit – Used 29.27wt%, unbuffered boric acid at 14.7 psia. Buffering agents would increase solubility limits (per testing results). In addition, the reactor pressure is assumed to be atmospheric and it would be higher, which increases solubility.
Source Coolant Temperature- Assumed to be saturated, which is a limiting value. Core Blockage Area – 0, 25, 50, 75, 100% cases were evaluated (Table 7-2 in CLB supplement to WCAP-17788 Volume 1)). One case was performed with no LP volume credited, 100% blockage, and included a delay in debris accumulation. These cases were compared with the licensing basis case.

3.5 Path Forward

The PWROG plans to submit some information on the docket to correct errors in earlier submittals. Based on the NRC staff's improved understanding of the issues and future review of the information being submitted, the NRC staff plans to continue their review of the TR. The review of the TR will continue to follow the typical processes for NRC staff review and approval. This TR is planned to be reviewed by the Advisory Committee on Reactor Safeguards.

4. CLOSING BRIEFING

The NRC staff provided the following feedback to the PWROG based on the discussions held over the three-day face-to-face audit and numerous follow-up conference calls.

The NRC staff stated that they appreciated the time and resources dedicated by the PWROG and vendor representatives to improve the NRC staff understanding of the RAI responses and the associated methodologies used for the Volume 4 analyses.

The NRC staff stated that they had adequate information to continue to finalize their review of the CE and B&W plant categories. For the Westinghouse plant designs, the NRC staff identified that some aspects of the code behavior were not adequately explained. However, during followup phone calls, information was discussed, which allowed the NRC staff to continue to finalize their review these plant categories.

Overall, the audit was effective, informative, and productive and the objectives defined in the audit plan were accomplished. The information, knowledge, and understanding obtained during the audit will enhance and support the ongoing review of the TR submittal.