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October 16, 2008
LIC-08-0107

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

References: Docket No. 50-285 (See Reference List on Page 5)

**SUBJECT: Notice of Completion of Corrective Actions Taken in Response to Generic Letter (GL) 2004-02 and Response to Request for Additional Information (RAI) for Fort Calhoun Station (FCS) Unit No 1**

The purpose of this letter is to provide notification of the completion of corrective actions associated with Generic Letter (GL) 2004-02 (Reference 2) and respond to the request for additional information (RAI) provided via email to the Omaha Public Power District (OPPD) on July 28, 2008, in Reference 11.

The U. S. Nuclear Regulatory Commission (NRC) issued Reference 2 to request that addressees perform an evaluation of the emergency core cooling system (ECCS) and containment spray (CS) system recirculation functions in light of the information provided in the GL and, if appropriate, take additional actions to ensure system function.

OPPD provided initial and follow-up responses and various extension requests to GL 2004-02 in References 3 through 6. In Reference 7, the NRC approved OPPD's request for an extension of the Fort Calhoun Station (FCS) GL 2004-02 Generic Safety Issue (GSI)-191 sump modifications and corrective actions completion due date from December 31, 2007, to the end of the FCS 2008 refueling outage (RFO) completed in June 2008. A supplemental response to GL 2004-02 was submitted as Reference 9, which also identified a list of remaining action items needed to complete closure of GL 2004-02. In response to Reference 9, the NRC requested additional information via email to the Supervisor–Nuclear Licensing in Reference 11. OPPD's responses to these RAI questions are provided as the Enclosure to this letter. This letter contains no proprietary information.

With the exception of the issues concerning the in-vessel downstream effects, whose resolution are pending the completion of the NRC's review of WCAP-16793-NP, the actions required for close out of GL 2004-02 as listed in reference 9 are complete. The resolution of issues in regard to WCAP-16793-NP and provision for a formal response to the in-vessel downstream effects are dependent on activities being undertaken by the Pressurized Water Reactor Owners Group (PWROG) and issuance of a safety evaluation report (SER) for WCAP-16793-NP by the NRC. As such, resolution of the in-vessel downstream effects will be addressed in a separate response to be submitted to the NRC within 90 days of the issuance of the final NRC SER. Other regulatory commitments delineated in References 4 and 5 were previously completed as identified in Reference 9.

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The specific remaining actions identified in the supplemental response (Reference 9) and OPPD's resolution to each action is summarized below:

1. Confirm if existing cyclone separators are acceptable or replace as needed.

   Resolution: Wyle Laboratories conducted a test commissioned by OPPD using debris-laden fluid representative of a fluid that has passed through the strainer. For added conservatism the debris concentrations in the fluid used for the cyclone separator testing were higher than the values obtained from previously conducted strainer bypass testing. Two different types of cyclone separators were tested in parallel loops: a Doxie 5 cyclone separator (representative of the installed cyclone separators) and a John Crane 20 cyclone separator, which has been identified by the industry as an acceptable replacement for existing cyclone separators.

   The test results indicated that the Doxie 5 cyclone separator plugged with debris and lost flow after a short time. The test continued with the John Crane 20 separator with no loss in flow. Samples taken upstream and downstream of the separator confirmed that the separator was performing its cleaning function. At the end of the test, the John Crane 20 separator was disassembled and inspected and it was confirmed that the separator did not show any indication of blockage.

   Based on the test results, the Doxie 5 cyclone separators on the three HPSI pumps were replaced with John Crane Model 20 cyclone separators during the 2008 RFO. This action is complete.

2. Enhance Standing Order O-25, "Temporary Modification Control" regarding configuration control of insulation in containment.

   Resolution: The Standing Order (SO) O-25 related to temporary modifications and associated forms was revised (Revision 70, dated May 16, 2008) to include specific details for controlling any changes to insulation, coatings, and aluminum in containment. The SO was modified to require that, if changes are made to any of the materials described above inside containment, then specific engineering evaluations must be performed to ensure that the proposed configuration does not affect the debris generation and transport of materials as evaluated in design documents. The revision also includes changes to the temporary modification evaluation form to require approval of the appropriate program owner for any changes to insulation, coatings, or aluminum containing materials in containment that would be installed under a temporary modification. This action is complete.

3. Evaluate the final conditions issued by the NRC in regards to WCAP-16793-NP and provide a formal response.

   Resolution: OPPD GL 2004-02 submittal refers to performing an assessment in accordance with the draft WCAP-16973-NP, "Evaluation of Long-Term Cooling Considering Particulate, Fibrous, and Chemical Debris in the Recirculating Fluid." The NRC staff has not issued a final Safety Evaluation (SE) for WCAP-16793-NP. OPPD intends to show that plant conditions are bounded by the final in-vessel downstream effects WCAP-16793-NP and the corresponding final NRC staff SE, including the conditions and limitations in the SE. OPPD will report how FCS addresses the in-vessel downstream effects issue within 90 days of issuance of the final NRC staff SE on WCAP-16793-NP. This will be done in coordination with the anticipated NRC Regulatory Issue Summary (RIS) that will inform the industry of the staff's expectations and plans regarding resolution of this remaining aspect of GSI-191. Commitment action request AR 35967/14 is tracking completion of this task.

4. Validate flashing evaluation utilizing NRC Safety Evaluation for LAR-07-04.

   Resolution: An assessment of FCS sump strainer potential for void formation was conducted and documented. The assessment was performed with the following conservative assumptions which provide additional margin: the worst case total head loss across the strainer, conservative containment pool level, and the maximum flow rate through the strainer. In addition, the submergence of the strainer was assumed to be only from the post loss-of-coolant accident (LOCA) pool water level to the top of the strainer. This is conservative since the strainer perforated flow plates are below the top of the strainer, at a greater submergence; hence there is a higher hydrostatic head with the consequential smaller void fraction. The calculations indicate that for fluid temperatures equal to or less than 205°F the void fraction downstream of the ECCS strainer less is than 3% (at 205°F, the void fraction was estimated to be 2.62%, with no credit for containment overpressure). For the maximum calculated fluid temperature of 213°F, a containment overpressure of 5.4 ft water is required to keep the void fraction less than 3%. Long-term sump temperature and containment pressure analyses for various alignments show that only one case results in sump temperatures above 200°F, for a period of time no longer than 4 hours. The ~ 5 ft. overpressure credit to ensure that the void fraction remains below 3%, is consistent with the overpressure required to ensure adequate net positive suction head (NPSH) available for the high pressure safety injection (HPSI) pumps, as described in references 8, 9, and 10. The credited overpressure is considerably lower than the available overpressure during that time period, which is well above 20 ft. This action is complete.

5. Validate strainer head loss test results and obtain final report from vendor.

   Resolution: The preliminary test data, presented in Section 3f and summarized in Table 19 of Reference 9, were verified and the final report was issued by GE in May 2008. The final head loss results are slightly lower than reported in Reference 9. The final large break LOCA (LBLOCA) with chemical precipitates total head loss was 3.43 ft vs. 4.41 ft reported in the supplemental response (Reference 9) and the final small break LOCA (SBLOCA) with chemical precipitates total head loss was 3.315 ft vs. the 3.38 ft. reported in Reference 9. The difference between the final and preliminary test results is negligible. The final head loss test results are bounded by the preliminary test results reported in Reference 9. This action is complete.

6. Provide GL 2004-02 close-out letter.

   Resolution: This letter, the responses to the NRC RAI for GL 2004-02 contained in the enclosure to this letter, and the corrections required to the GL 2004-02 supplemental response, provided in Attachment 4, as a result of typographical errors and updated (verified) information, which was not available at the time of the supplemental response, are provided for close out of GL 2004-02.

   Compliance with GL 2004-02, with the exception of the in-vessel downstream effects, is achieved through analyses, plant specific testing, installation of new sump strainers, implementation of a no spray configuration during a LOCA (References 8 and 10), plant modifications reducing sources of debris, programmatic and process changes to ensure continued compliance. The final results reported in the GL response are based on conservative assumptions, which ensure that additional margin is available, especially in the critical areas of pump NPSH during recirculation and head loss across the strainer. The following assumptions ensure that bounding conditions were used in analyses and strainer testing:

- The CFD analyses were performed assuming flow from three HPSI pumps. Physical modifications to the plant and changes to the plant's operating procedures restrict operation to a maximum of two HPSI pumps. This results in a conservative calculation of the amount of debris transported to the vicinity of the strainer.

- Strainer testing was conducted using bounding conditions such as minimum water level in containment, the maximum debris load, the maximum flow through the strainer and the minimum available NPSH margin even though the actual pump alignments in a post-LOCA condition would preclude such a condition.

- Available NPSH was calculated using the highest sump temperature, lowest NPSH margin for multiple pre and post-RAS pump alignments and assuming that the head loss across the strainer was at the maximum design limit. The "best estimate" highest head loss across the strainer shows 1.5 ft margin.

This action is complete.

OPPD implemented the regulatory requirements in the three following areas: (1) evaluate the potential for excessive head loss across the containment sump screen, (2) evaluate related upstream and downstream effects, and (3) implement needed plant modifications and procedure changes. All of these items have been implemented at FCS and documented via References 3 through 10.

The resolution of the in-vessel downstream effects (WCAP-16793-NP and how it applies to FCS) will be considered in a separate submittal provided within 90 days of issuance of a final NRC SE on this matter. This formal response is being tracked as a regulatory commitment. (AR 35967/14).

In addition, provided in Attachment 4 of the Enclosure, please find corrected pages of the supplemental response submitted in Reference 9. These corrections are being made as a result of final testing and analysis, additional information obtained from closure of the remaining open items discussed above, and various typographical errors identified during the preparation of the RAI responses. Attachment 4 pages supersede those pages previously submitted in Reference 9.

If you should have any questions regarding this submittal or require additional information, please contact Mr. Bill Hansher at 402-533-6894.

I declare under penalty of perjury that the foregoing is true and correct. Executed on October 16, 2008.

Jeffrey A. Reinhart
Site Vice President

Enclosure: Omaha Public Power District's Response to Request For Additional Information, Fort Calhoun Station, Unit 1, Supplemental Response To Generic Letter (GL) 2004-02

c: E. E. Collins, NRC Regional Administrator, Region IV
A. B. Wang, NRC Project Manager
J. D. Hanna, NRC Senior Resident Inspector

## Reference List

1. Docket No. 50-285
2. Letter from NRC (B. A. Boger), Generic Letter (GL) 2004-02, "Potential Impact of Debris Blockage on Emergency Recirculation During Design Basis Accidents at Pressurized-Water Reactors," dated September 13, 2004 (NRC-04-0115) (ML042360586)
3. Letter from OPPD (R. L. Phelps) to NRC (Document Control Desk), "90-Day Response to Generic Letter 2004-02, Potential Impact of Debris Blockage on Emergency Recirculation During Design Basis Accidents at Pressurized-Water Reactors," dated March 4, 2005 (LIC-05-0017) (ML050630538)
4. Letter from OPPD (H. J. Faulhaber) to NRC (Document Control Desk), "Follow-Up Response to Generic Letter 2004-02, Potential Impact of Debris Blockage on Emergency Recirculation During Design Basis Accidents at Pressurized-Water Reactors," dated August 31, 2005 (LIC-05-0101) (ML053070109)
5. Letter from OPPD (H. J. Faulhaber) to NRC (Document Control Desk), "Request for Extension to the Completion Date for Corrective Actions taken in Response to Generic Letter 2004-02, Potential Impact of Debris Blockage on Emergency Recirculation During Design Basis Accidents at Pressurized-Water Reactors and Information Regarding Actions taken as a Result of Information Notice 2005-26," dated November 18, 2005 (LIC-05-0131)
6. Letter from OPPD (H. J. Faulhaber) to NRC (Document Control Desk), "Revised Request for an Extension to the Completion Date for Corrective Actions taken in Response to Generic Letter 2004-02," dated June 9, 2006 (LIC-06-0067)
7. Letter from NRC (C. Haney) to OPPD (R. T. Ridenoure), "Fort Calhoun Station Unit No. 1-Generic Letter 2004-02, 'Potential Impact of Debris Blockage on Emergency Recirculation during Design Basis Accidents at Pressurized Water Reactors,' Extension Request Approval (TAC No. MD2323)," dated August 11, 2006 (NRC-06-0103)
8. Letter from OPPD (D. J. Bannister) to NRC (Document Control Desk), "Fort Calhoun Station Unit No. 1 License Amendment Request (LAR), Modification of the Containment Spray System Actuation Logic," dated July 30, 2007, (LIC-07-0052) (ML072150293)
9. Letter from OPPD (R. P. Clemens) to NRC (Document Control Desk), "Supplemental Response to Generic Letter 2004-02, Potential Impact of Debris Blockage on Emergency Recirculation during Design Basis Accidents at Pressurized Water Reactors," dated February 29, 2008 (LIC-08-0021)
10. Letter from NRC (M. T. Markley) to OPPD (D. J. Bannister), "Issuance of Amendment Re: Modification of Containment Spray System Actuation Logic and Dampers in Containment Air Cooling and Filtering System (TAC Nos. MD6204 and MD7043)," dated May 2, 2008 (NRC-08-0049)
11. Email from NRC (M. T. Markley) to OPPD (B. R. Hansher), Request for Additional Information, Fort Calhoun Station, Unit 1 - Supplemental Response to Generic Letter (GL) 2004-02 (TAC No. MC4686), dated July 28, 2008

Omaha Public Power District's Response to

Request For Additional Information

Fort Calhoun Station, Unit 1

Supplemental Response To Generic Letter (GL) 2004-02

By letter (LIC-08-0021) dated February 29, 2008, Omaha Public Power District (OPPD) submitted a supplemental response to NRC Generic Letter 2004-02, "Potential Impact of Debris Blockage on Emergency Recirculation during Design Basis Accidents at Pressurized Water Reactors." The staff has reviewed the information provided and determined that additional information is required in order to complete the evaluation.

1. **Please describe how the assumed pipe break locations were moved systematically to ensure that the amount of debris created within zones of influence (ZOIs), which are smaller than the entire compartment, was conservative.**

   OPPD Response RAI #1:

   Break locations were evaluated by moving spherical ZOIs along the pipes selected for evaluation as described in the supplemental response starting on page 9. The smallest spherical ZOI had a radius of 6.4 length/diameter (L/D). Locations that were known to be near large concentrations of insulation such as the reactor coolant pump suction/discharge and the steam generator nozzles were carefully evaluated. Break locations were systematically moved along the cold and hot leg piping inside each of the steam generator (SG) compartment depicted on page 19 of the supplemental response (LIC-08-0021) to determine the break location that resulted in maximum debris generation. This approach adds conservatism, as it targets high density areas of various types of insulation (e.g., particulate). Pivot tables were generated to evaluate the amount of debris that could potentially result from a break at a specific location (based on insulation inventories).

2. **Please describe how the assumed pipe break locations were moved systematically to ensure that a conservative amount of fine debris was created based on the licensee-created sub-ZOIs used to determine the proportion of debris sizes created.**

   OPPD Response RAI #2:

   As noted above, spherical ZOIs were moved along hot and cold leg piping to determine the maximum generation of insulation debris. The amount of fines debris using the sub ZOI method was systematically compared for the break locations evaluated using pivot tables to assure the conservative potential debris generation location was identified. Also, areas known to have large concentrations of either fibrous or particulate insulation were evaluated because of their potential for generating the most amounts of fines. The insulation inventory results were utilized to systematically evaluate break target locations. The sub-ZOIs for fibrous and particulate insulation were evaluated using computer-aided design (CAD) models to identify potential key high density insulation locations along with mapping from pivot tables. Identification of key high density insulation locations along with the mapping from CAD models and pivot tables yields a conservative amount of fine debris since it maps out an area which has the largest debris generation potential for each type of insulation.

3. **Please identify the source of the test data used to support the debris size distribution assumed for calcium silicate and compare the banding method, jacketing properties, and the manufacturing process for the calcium silicate debris installed at Fort Calhoun to the material used for destruction testing.**

OPPD Response RAI #3:

The supplemental response (LIC-08-0021), page 14, second paragraph, identifies Reference 3 as the source for the methodology of the refined size distribution (ALION-REP-ALION-2806-01, Revision 3, "Insulation Debris Size Distribution for Use in GSI 191 Resolution"). The basis for the development of the refined size distribution came from the Safety Evaluation by the Office of Nuclear Reactor Regulation Related to NRC Generic Letter 2004-02, Nuclear Energy Institute Guidance Report (Proposed Document Number NEI 04-07), "Pressurized Water Reactor Sump Performance Evaluation Methodology," Appendix II. Test data available for pressures up to 65 psi was utilized to develop the amount of small calcium silicate (CalSil) debris, and the ZOI was expanded from 5.5 to 6.4 D (extended to 70 psi to be conservative). The test data was derived from the Ontario Power Generation (OPG) CalSil testing performed with two phase jets. The Alion refined size distribution report was reviewed by NRC staff as part of the Indian Point 3 (IP3) GSI 191 audit (December 2007), and no outstanding items were reported related to this size distribution report.

The predominant type of CalSil insulation (more than 90%) in the FCS containment is CalSil with asbestos reinforcement fibers. This type of CalSil was not included in the OPG CalSil testing. However, it is known from discussions with insulation manufacturers that CalSil containing asbestos fibers as reinforcement was produced through a Post Autoclave process (post high pressure steam in an autoclave was used to complete the calcium silicate crystallization). Asbestos fibers were used in CalSil manufacturing pre-1972 due to their high strength. The CalSil products manufactured by this process are extremely hard and more durable than other types of CalSil products. Thus, the CalSil with asbestos would be a stronger product than CalSil used in the OPG test, which contained no asbestos. Based on this information, CalSil with asbestos is expected to have higher mechanical strength than CalSil without asbestos; therefore, the results from the OPG test would bound the predominant FCS material.

All CalSil insulation installed at FCS inside containment (with asbestos and without) is jacketed with the exception of three locations. Two of those locations are outside the bioshield and not within a break ZOI. The third location is behind the primary shield wall and on piping between the vessel and the primary shield wall. Thus, all CalSil insulation installed at FCS inside containment that is within a ZOI that is outside the primary shield wall is jacketed with aluminum jacketing. The OPG tests involved impacting aluminum jacketed CalSil insulation targets as documented in Appendix II (page II-18) of the SER.

4. **Please state whether there are any post-LOCA conditions within the plant design basis under which emergency operating procedures (EOPs) would either direct or allow plant operators to actuate containment sprays manually. If such conditions exist, please justify the assumption in the debris transport calculation that the containment sprays would not be operated under design-basis post-LOCA conditions.**

OPPD Response RAI #4:

There are no post-LOCA conditions within the plant design basis that would direct or allow use of containment spray (CS). The EOPs allow manual actuation of the CS in a beyond design basis condition, only if the minimum required number of containment fan coolers is not available and containment pressure cannot be maintained below 60 psig.

As stated in response to an RAI associated with the FCS water management implementation LAR [RAI Question #5, entitled USAR Section 6.2.2 for LAR 07-04, LIC 08-0015 (ML080580407)], the CS pumps may be used in the "cooled high pressure safety injection (HPSI) suction mode;" however, the system alignment for this mode of operation requires that the CS valves HCV-344/345 be placed in

OVERRIDE and hand-jacked closed prior to initiating the cooled SI flow. These actions are taken specifically to preclude the possibility of spraying flow into containment during this mode of operation.

5. **Please describe how the potential for a low-pressure safety injection (LPSI) pump failing to trip was accounted for in the debris transport analysis. The increased flow rates associated with this pump would be expected to create conditions more favorable to debris transport throughout containment. Since both strainers are located in the same general area, there is a potential for higher transport fractions to both sump strainers than for the normal case in which both LPSI pumps trip following receipt of a recirculation actuation signal (RAS). Also, please state whether conditions could exist in a LOCA for which EOPs would either direct or allow plant operators to operate a LPSI pump in recirculation mode under design basis conditions (e.g., during hot leg recirculation). If such conditions exist, please justify the assumption in the debris transport calculation that a LPSI pump would not be operated under design-basis post-LOCA conditions.**

OPPD Response RAI #5:

As stated in the GL supplemental response on page 65, the 4th paragraph, additional CFD evaluations were performed and showed that only one strainer would be affected by such a failure. The effect that a LPSI pump failing to trip, taking suction from the containment pool and discharging water into the containment pool, has on debris entrainment was conservatively modeled using a turbulent jet analysis. The limiting case is a break in the SG B bay, because of its location relative to the sump and the higher potential for debris transport to the sump. The analysis concluded that entrainment of larger debris does not occur, entrainment of mid-size debris could occur but would fall out of the jet before reaching the sump and the small debris is already transported to the sump under scenarios without the LPSI pump running. The analysis showed that large and mid-size debris initially at the containment floor will not be entrained by the turbulent jet. The analysis further showed that while mid-sized and small debris could be subject to incipient tumbling, they would not be entrained in the flow.

Attachment 11 of the EOP/AOP Attachments allows use of a LPSI pump for Alternate Hot Leg Injection, if only one HPSI pump is available (for cold leg injection). However, the hot leg injection path used for LPSI pump operation is via the SDC header warm-up line which is a small diameter, high resistance line. Hydraulic calculations show that the maximum LPSI flow that can be achieved in this alignment is less than the 450 gpm (HPSI flow) that was used in the transport calculations. Therefore, LPSI flow through the alternate hot leg injection flow path is bounded by the hot and cold leg injection flow using two HPSI pumps.

6. **Please state the wash down percentage that was assumed for each type of debris that was assumed to be blown into the upper containment. Please justify any deviations from the Nuclear Energy Institute (NEI) Guidance Report and/or the NRC staff Safety Evaluation methodology applicable to this evaluation.**

OPPD Response RAI #6:

The following table documented in Reference 52 of the supplemental response (LIC-08-0021) provides the wash down percentage by debris type for both fines and small pieces of insulation. With implementation of Amendment No. 255, FCS no longer has CS initiation upon a LOCA. The wash down transport is a phenomenon that is highly dependent upon CS initiation and, to a small degree, condensation within containment. Therefore, all debris that is transported to upper containment as a result of the blowdown phenomena would remain intact on retained structures/components/ equipment until such time as some condensation can build up. Without spray motive force at time zero, there will be no wash down. The only potential wash down will come from condensation on vertical and horizontal surfaces and/or wash down caused by condensate from the containment fan cooling units, which is discussed in more detail in response to RAI #7. The condensation impact is more of a time dependent and buildup factor type application. However, to be conservative, it was assumed that this buildup is instantaneous and the transport fractions due to condensation were applied as such. Since coating and CalSil fines would be on the order of a similar size to fibrous fines debris, the same wash down transport fractions were applied. With regard to CalSil small pieces, although CalSil is a factor of about 6 denser than low density fiberglass (LDFG) materials, the fibrous debris transport fraction was still applied. TempMat™ small pieces are considered denser than LDFG by a factor of 5 in density, but to be conservative, for purposes of the assessment, the same transport factors were used as for LDGF.

**Wash down from Upper Containment**

| Debris Type | Fines[1] | Small Pieces | Unjacketed Large Pieces | Jacketed Large Pieces |
|---|---|---|---|---|
| Stainless Steel RMI | 1% | 0% | 0% | NA |
| Nukon™ and LDFG | 5% | 2% | 0% | 0% |
| Temp-Mat™ | 5% | 2% | 0% | 0% |
| Cal Sil | 5% | 2% | NA | NA |
| Qualified Epoxy Coatings | 5% | NA | NA | NA |
| Unqualified Coatings | NA | NA | NA | NA |
| Dirt/Dust | NA | NA | NA | NA |
| Latent Fiber | NA | NA | NA | NA |
| Sand | 5% | NA | NA | NA |

[1] All dirt/dust and latent fiber was assumed to be in the lower containment. Unqualified coatings were evaluated based on location.

**7. Given all the uncertainties involved with condensation wash down over a 30-day period and the distribution of debris in containment following blowdown, please provide the technical basis for the assumption of 5% wash down transport for fibrous debris and coatings from upper containment (and potentially for other fine debris such as calcium silicate particulate). NUREG/CR-6762 Vols. 1 and 4 consider 5% wash down a favorable estimate for minimizing transport and consider 10% an unfavorable estimate. The estimated wash down fractions used in NUREG/CR-6762 as well as Appendix VI to the staff's SE were ultimately based on NUREG/CR-6369, which indicates that directly applicable experimental data for condensate (from steam in the containment atmosphere) drainage transport is non-existent and that the wash down fractions therein are essentially based on engineering judgment. This suggests that use of the 10% estimate might be more appropriate.**

OPPD Response RAI #7:

OPPD utilized the values that were reported in the volunteer plant assessment Table VI-16 for fines that were wetted by condensate as documented in Appendix VI, "Detailed Blowdown/Washdown Transport Analysis for Pressurized Water Reactor Volunteer Plant."

In the no spray configuration, which is the current FCS design basis, the post-LOCA containment air temperature and pressure are controlled by the FCS containment air cooling and filtering system (CACFS). Since CS is no longer initiated during a LOCA, the CS will not wash down debris from the upper containment elevations or atmosphere. The CACFS utilizes cooling fins to remove the heat load from the containment atmosphere. The cooling fins and all filtering units such as the HEPA, charcoal and mist eliminators are enclosed in housing units. Moist containment air with potentially entrained debris is drawn in through dampers and passes through the filters and then the cooling coils. Water from the atmosphere is removed by moisture separators, mist eliminators and the majority of the moisture is condensed on the cooling coils. The long-term containment cooling analysis established the condensation rates during a post-LOCA condition. Assuming the most conservative case (with all the ventilation units running and the minimum time to recirculation), it was determined that the condensation rate peaks at about 82 seconds at 75 lbm/sec then drops off rapidly. At the time recirculation is established, the total condensation rate is about 40 lbm/sec or approximately 280-300 gpm. Two thirds of the condensation (27 lbs./sec) is produced by the containment cooling and filtering units (CACF) and one third (13 lbs/sec) is produced by the containment air cooling units (CAC). The water condensed in the CACF units is piped via large drain lines to the 1045' elevation, where they terminate at approximately 6 inches above the concrete slab elevation. There are a total of 6 drain lines from CACF units (three per unit). The drain lines are 4 inches (two lines from the cooling coils) and 6 inches (four lines from the mist extractors and HEPA filters) in diameter and hence, can handle a significant amount of condensation. The containment cooling units have two 6-inch drain lines, which terminate 6 inches above onto concrete slab at the 1013' elevation.

Review of the location of the drain lines shows that three of the six drain lines terminate immediately adjacent to the refueling cavity, and hence any water draining out of these lines would predominantly cascade into the refueling cavity. A portion of this water will drain to the reactor cavity, which is an inactive area. Some of the flow could be diverted to the 4-inch drain line that exits the refueling cavity and dumps near the reactor coolant drain tank (RCDT) near steam generator (SG) A bay area, but this flow path would not be established until the level in the refueling cavity is above the 994' elevation to provide sufficient static head. Two of the other drain lines terminate near a 4-inch floor drain at the 1045' elevation (concrete slab) and the drainage from those drain lines would be anticipated to dump into the floor drain as the floor is sloped towards the floor drain. This floor drain is piped to the reactor cavity area which is an inactive area. The remaining drain line terminates near a stairwell, and it is expected that the drainage would cascade down this stairwell to the 1013' elevation below.

Of the two drain lines from the containment cooling units which discharge on the 1013' elevation, one is located near a floor drain which discharges to the reactor cavity, which again is an inactive area. The flow from the other line could either go to the drain line and the reactor cavity or discharge inside the reactor coolant pump cubicle RC-2B.

The debris generation calculation determined that the largest debris load is created by a break in A SG bay. The CFD model shows that for such a break, the only active transport path is from the A SG, while the B SG cubicle is a stagnant area. (See Figure 9 on page 43 of the supplemental response LIC-08-0021). Any wash down due to condensation from the CACFS will increase the debris in or around the B SG cubicle, but will not be entrained in the flow path from the A SG break. A break in B SG (See Figure 1 below) results in a smaller debris load and an increase in the wash down from 5%, as assumed in the transport calculation, to 10%, as suggested by the RAI, is still bounded by a the debris load from A SG case for which the strainer was tested.

This evaluation is based on the worst case possible, with all the containment fan coolers and the safety injection (SI) pumps running, to maximize the condensation and minimize the time to RAS. The CFD model is also based on all three HPSI pumps running. Physical modifications to the plant and changes to plant operating procedures restrict operation to a maximum of two HPSI pumps. None of the fine debris was assumed to be deposited on the filtration media or components and structures.

In addition, as stated on page 62 (last paragraph) of the supplemental response (LIC-08-0021), the testing modeled the "B" sump strainer because of the higher flow rates that could be associated with this strainer (two HPSI pumps), while conservatively using the higher debris loads associated with the "A" strainer. Based on these assessments, a condensation wash down to the pool of 5% is considered conservative.

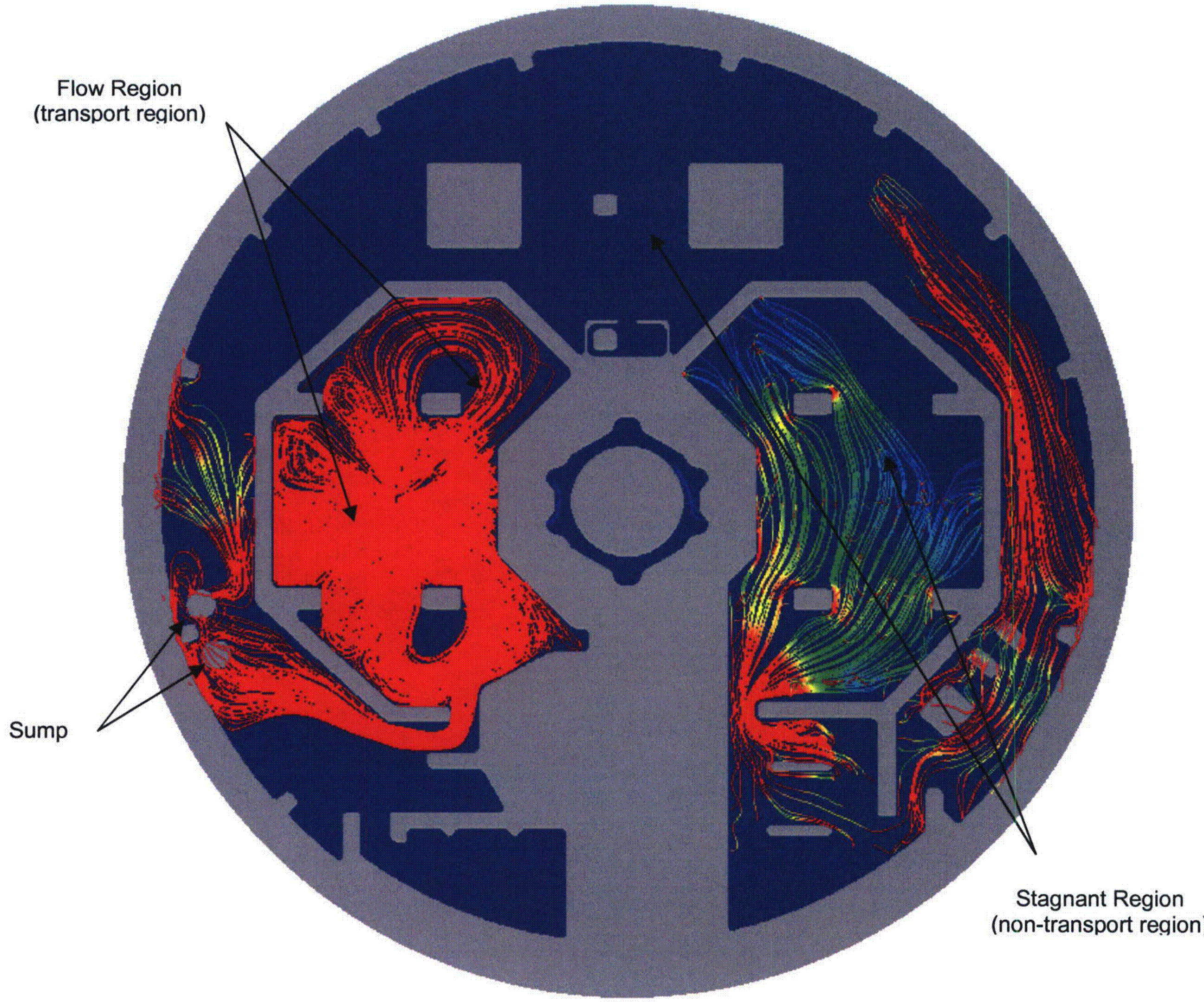


Figure 1 – Flow streamlines in the containment pool illustrated by releasing massless particles from Compartments A and B (Case 6, Break B)

8. **The supplemental response states on page 47 that 100% transport was assumed for the small-break LOCA case, and Table 17 on page 48 provides the transported latent debris masses broken down into three categories. On page 48, Table 18 indicates that 100% transport was also assumed for latent debris for the reactor vessel (RV) nozzle break, but the transported latent debris masses are twice as large as the latent debris masses in Table 17. In addition, these latent debris transport results for the small-break and RV nozzle break do not seem consistent with the supplemental response's statements that latent debris is analyzed by assuming 90% is in active pools (page 37), of which a fraction of 0.72 transports (page 73), which seems to be the basis for the large-break latent debris transport results in Tables in 15 and 16. Please clarify these apparent inconsistencies.**

OPPD Response RAI #8:

The supplemental response (LIC-08-0021) Table 18 results for the RV Nozzle Break contains an error for reporting the transport fractions. The transport fractions for the dirt/dust, latent fiber and other latent debris should have been listed as 65% instead of 100%. This was a typographical error and the transport fractions were the same for RV Nozzle Break as those for a Large Break. The assumption regarding the SBLOCA latent debris was that half of all the containment latent debris would be immediately adjacent to the strainer, and thus be completely available for transport onto the strainer. This is considered conservative as the latent debris is dispersed throughout containment. The assumption was made that half of the latent debris was on the 994' elevation and thus, available to be transported instantaneously to the strainer. In addition, as stated on page 77 of the supplemental response, the results of the latent debris collection for the 2006 RFO showed the latent debris to be on the order of 15-16 lbm; a factor of 5 lower than assumed in the SBLOCA transport. This statement also bounds the latent debris found during the 2008 RFO.

9. **Similar to the previous question, the supplemental response states on page 47 that 100% transport was assumed for unqualified coatings for the small-break LOCA case, and Table 17 on page 48 provides the transported mass of unqualified coatings. On page 48, Table 18 indicates that 100% transport was also assumed for unqualified coatings for the RV nozzle break, but the transported debris mass for unqualified coatings is significantly higher for the RV nozzle break case than for the small-break LOCA case (22 lbm versus 215 lbm). Presumably, based on statements that all unqualified coatings that reach the sump are in the form of chips (e.g., on pages 57, 72, and 75 of the supplementary response), these failed coatings were generated outside of the pipe rupture ZOI. (In a large break LOCA case, more unqualified coatings are destroyed to particulate by the break jet, and therefore there should actually be less unqualified coatings chips failing outside of the ZOI.) Please provide the basis for the difference in the transported masses of unqualified coatings debris for the small-break and RV nozzle break cases.**

OPPD Response RAI #9:

The 100% transport is defined as the transport of all unqualified coatings that are immediately in the general vicinity of the sump strainer for a SBLOCA. Without CS, there will be no significant wash down of unqualified coatings at the upper elevations. As such, a spatial orientation and location assessment was performed to identify which unqualified coatings would be in the vicinity of the SBLOCA location, which was assumed to be near the sump strainer. A justification to reduce the unqualified coatings load throughout containment was performed based on knowing the location of the unqualified coatings by elevation and specific location. With a SBLOCA, the large motive forces are not available to drive unqualified coatings to the strainer. Also, without CS there would be no significant wash down from the upper elevations to move coatings from above the 994' elevation. The sump pool itself has been shown to be very quiescent based on TKE and velocity CFD plots in relationship to moving even fines materials. Thus, based upon a spatial configuration orientation assessment for unqualified coatings, the load was reduced to 22 lbm for the small break LOCA. Predominantly all unqualified coatings (over 80%) at FCS are at the 1013' or above elevation. The remaining unqualified coatings are uniformly distributed at the 994' elevation.

10. **Since the time of the two pilot audits for GSI-191 (Crystal River 3 and Fort Calhoun), the staff has had unresolved concerns associated with the use of turbulent kinetic energy (TKE) metrics for justifying the settling of fine debris, including the following: (1) the lack of experimental benchmarking of analytically derived TKE metrics; (2) uncertainties in the predictive capabilities of TKE models in computational fluid dynamics (CFD) codes, particularly at the low TKE levels necessary to suspend individual fibers and 10-micron**

**particulate; (3) the analytical prediction of settling velocities in quiescent water due to the specification of shape factors and drag coefficients for irregularly shaped debris; and (4) the theoretical correlation of the terminal settling velocity to turbulent kinetic energy that underlies the Alion methodology for fine debris settling. A justification for the settling of fine debris is provided on page 40 of the supplemental response, but this discussion does not appear complete because (1) it tends to focus on velocity, whereas TKE is more closely associated with the turbulence which suspends fine debris, (2) it assumes a velocity transport metric for fines of 0.01 ft/sec, the basis for which is not clearly explained or justified, and (3) it treats all fine debris the same way, although individual fibers and 10-micron particulate would likely behave differently. Please address the four unresolved concerns above, many of which were documented in previous audit reports for licensees who used a similar methodology, to demonstrate that the credit taken for fine debris settling is technically justified.**

<u>OPPD Response RAI #10:</u>

OPPD addresses the four unresolved concerns in RAI #10 above as follows:

**(1) The lack of experimental benchmarking of analytically derived TKE metrics:**

**Response (1):** The FCS analytical CFD calculations were performed conservatively in that a 3-pump HPSI maximum flow runout condition (1350 gpm) was assumed for all CFD evaluations. The actual plant design configuration is for a 2-pump HPSI flow condition (923 gpm). Thus, all CFD transport calculations are inherently conservative as they address the transport from an aspect of a 3-pump HPSI operation. Also, the minimum SBLOCA water level (with spray configuration and water holdup) was utilized for pool turbulence calculations without consideration of additional water sources that are now available in utilizing the no spray configuration post LOCA. Utilization of the 3-pump HPSI and shallow sump pool drive the CFD calculations in the most conservative direction with respect to pool velocity and turbulence.

The measurement for the analytically derived turbulent kinetic energy (TKE) metrics was made using an ultrasonic velocity meter that measured the mean flow velocity in a transport pool. Using the ultrasonic meter, the three velocity components were measured and compared to the CFD predicted velocities to validate them. These validated velocities were then used to determine the TKE as presented in the OPPD CFD calculations.

The objective of the transport flume testing was to measure the localized flow velocities of the transport flume across a range of locations and flow rates. Based on those flow rate measurements, the transport flume bulk flow rate was determined. The locations included a traverse grid of 16 points, 4 additional points 1 inch above the floor of the transport flume, and 1 point in the center of the transport flume for a total of 21 locations. The test points were located in a cross section of the flume perpendicular to the flow at approximately two-thirds the length of the flume from the inlet side. Using those locations allowed for development of a uniform flow for data gathering. A SonTek flow tracker handheld Acoustic Doppler Velocimeter (ADV) was used to measure single point velocities with x, y, z components. The accuracy of the ADV was +/-0.008 ft/s. Two different flow rates were utilized in the test: bulk flow rates of approximately 17 gpm and 32.1 gpm. The bulk flow rate was calculated from a bulk flow velocity, which was obtained by averaging the ADV local velocity measurements at all the different locations noted. The bulk flow rate obtained was also compared with the flow rate measured by an ultrasonic flow meter to verify and compare flow readings. The main purpose of this test was to compare CFD calculations of low velocities in low flow regime areas to measured velocities in the low flow regime areas. Based on comparison of the CFD calculations to the 16-point traverse data set, the CFD model was shown able to predict a bulk flow rate within 2% of the value obtained through testing. Thus, test results provided validation of the ability of the CFD calculations to make accurate predictions of low flow regime areas. Alion chose to utilize this approach for comparison of analytically derived TKE components.

Measuring TKE is possible but very difficult in a stagnant pool. The measurement is made using a Laser Doppler Velocimeter (LDV) system to quantify instantaneous velocity, which is composed of the mean velocity ($\hat{U}$) and the fluctuating term (U'). The fluctuating term is used to estimate the turbulent intensity, which is a ratio of fluctuating velocity to mean velocity. The kinetic energy then is defined as $\frac{1}{2} * U'^2$ as discussed in previous calculations. Thus, to get reasonable experimental values to benchmark the analytically derived TKE metric is very difficult and has not to our knowledge been done to this point. As such, the approach mentioned above using the transport flume with the ADV configuration for evaluating low flow regimes, which was presented at an NRC public meeting with OPPD in December 2006 was utilized. At that time, no disagreements had been raised by the NRC staff in regards to this approach.

**(2) Uncertainties in the predictive capabilities of TKE models in computational fluid dynamics (CFD) codes, particularly at the low TKE levels necessary to suspend individual fibers and 10-micron particulate:**

**Response (2)**: It was due to the uncertainties associated with predictive capabilities of TKE models in computational fluid dynamics codes that drove the testing that was performed in the Alion flume utilizing the measurement system noted above. Page 40 of the supplemental response identified the processes and justification that was utilized. The best way to quantify predictive capabilities of TKE models is through direct comparison to experimental data with its quantified error. In this case, predictive uncertainty was assessed through numerical analysis by considering round-off error and descritization error to determine an approximate uncertainty level of $10^{-4}$ ft/s. The experimental methodology used was only able to accurately measure local flow velocity to within$10^{-2}$ ft/s. Thus, the predictive uncertainty is lower than the measured uncertainty so direct comparison between prediction and measurement was not conclusive.

**(3) The analytical prediction of settling velocities in quiescent water due to the specification of shape factors and drag coefficients for irregularly shaped debris; and**

**Response (3)**: The shape factor issue is not significant since this is gravity driven terminal settling velocities in nearly all cases where shape factors do not play a significant role. Shape factors become important at higher velocities.

Drag coefficients for different shape materials (i.e., paint chips vs. fibers) can be analyzed using two lines of reasoning and both are involved in this discussion.

First, drag is directly related to cross sectional area of an object, which is perpendicular to flow. As the size of an object decreases, the shape of the object becomes less and less important. Thus, for small cross sectional areas, the drag coefficient can be considered constant and thus the shape has no effect on drag and settling.

Second, a force balance on a settling particle includes the drag force and the buoyancy force (gravity term). As the velocity decreases to zero, the drag force goes to zero since it is directly proportional to velocity. Thus, for low velocities (i.e., settling velocity of very small particles), the drag force tends to zero. At the same time, the gravity term is constant and depends on particle mass and never disappears because there is always some mass associated with a particle. Thus, in the limit, as velocity goes to zero, the gravity term dominates, and the drag term, and hence anything related to drag, goes to zero. Thus, particle shape should not matter here either.

The argument can be made, however, that for a suspended particle, the buoyancy force and the drag force are exactly equal so both terms are important and thus particle shape must matter. However, since drag force is directly related to cross sectional area, as debris size decreases, the drag term decreases, so a small sphere (i.e., paint chip) and a small needle (i.e., fiber) have the same settling characteristic and again shape has little effect.

**(4) The theoretical correlation of the terminal settling velocity to turbulent kinetic energy that underlies the Alion methodology for fine debris settling. A justification for the settling of fine debris is provided on page 40 of the supplemental response, but this discussion does not appear complete because (1) it tends to focus on velocity, whereas TKE is more closely associated with the turbulence which suspends fine debris, (2) it assumes a velocity transport metric for fines of 0.01 ft/sec, the basis for which is not clearly explained or justified, and (3) it treats all fine debris the same way, although individual fibers and 10-micron particulate would likely behave differently.**

**Response (4)**: The definition of TKE is as follows:

$$TKE = \tfrac{1}{2}\,\overline{u_i u_i}$$

$$TKE = \tfrac{1}{2}\,\overline{u}^2 = \tfrac{1}{2}\overline{(u_1^2 + u_2^2 + u_3^2)}$$

$$TKE = \tfrac{1}{2}\,3\overline{u_3}^2 = 3/2\ V_t^2$$

Where the over-bar denotes time averaging, "$u_i$" represents the fluctuating part of the velocity, "$u_i u_i$" is the vector inner product, "$u_1$" and "$u_2$" are taken to be the horizontal components of the velocity fluctuation, "$u_3$" is taken to be the vertical component of the velocity fluctuation, and "$V_T$" is taken as the terminal (settling) velocity of the debris.

The two main assumptions in this derivation are that $u_1 = u_2 = u_3$ and $u_i u_j = u_i^2$ if i=j but = 0 if i ≠j. As long as you accept these assumptions, the theoretical correlation is justified. The problem is that the first assumption cannot be true near the floor or a wall where the velocity fluctuations are restricted in one of the three directions (as it would be near a wall or floor) and possibly in two directions as in a corner. In the absence of a more conservative assumption, however, these two assumptions are valid.

In fact, TKE based on the mean calculated velocity from CFD and a TKE based on a measured bulk velocity from the transport pool can be compared to a TKE based on the fluctuating velocity term that is the velocity term that actually keeps debris in suspension. Alion uses the bulk velocity term, which, is very conservative given that the fluctuating velocity term is normally only about 10% of the bulk velocity term. Thus, the TKE values estimated in the calculations which use the mean velocity terms are ten times higher than what is likely more accurate which means the debris transport to the sump estimates are also ten times higher and thus much more conservative.

**(1) It tends to focus on velocity, whereas TKE is more closely associated with the turbulence which suspends fine debris,**

**Response:** The Reynolds number uses velocity to define turbulence. As seen in all experimental quantification of turbulence, chaotic flow is considered turbulent and shown by the flow stream line being twisted and convoluted by the fluid stretching and twisting. Thus, although the justification is based on fluid velocity, it implicitly reflects turbulence as stated above.

**(2) It assumes a velocity transport metric for fines of 0.01 ft/sec, the basis for which is not clearly explained or justified, and**

**Response:** First, the main issue addressed in the flume testing was to establish how well the CFD code predicts low flow velocities. Validation was limited by the experimental procedure used. Based on the experimental procedure, the CFD code was shown to be able to predict flow velocities in a flume to at least 0.01 ft/s. Based on this, it is claimed that transport for debris can be accurately predicted for flows greater than or equal to 0.01 ft/s. This does not say that debris is not transported at velocities less than 0.01 ft/s. Debris transport is based on settling velocities and the associated TKE.

**(3) It treats all fine debris the same way, although individual fibers and 10-micron particulate would likely behave differently.**

**Response**: 10-micron particulates settle the same way in the Stokes region as do fine fibers. Differentiating between the two may be justified theoretically based on exposed cross section that effects drag on the particle but the experimentally measured settling rate is expected to be the same as the drag effect and will be very small at low velocities common in the Stokes' regime.

**11. On page 39 of the supplemental response, a technical basis is not provided to support the assumption of 10% erosion for small and large pieces of fibrous debris, although the response appears to suggest that the NRC accepted this assumption for Fort Calhoun during the pilot audit. However, Section 3.5.3 of the staff's pilot audit report for Fort Calhoun states that "the NRC staff concluded that sufficient justification had not been provided in the course of the pilot audit review to confirm the acceptability of the licensee's treatment of the erosion of fibrous debris." Please clarify the statement made on page 39 of the supplemental response and provide a technical basis to support the assumption of 10% erosion of fibrous debris.**

OPPD Response RAI #11:

Alion conducted numerous tests on LDFG materials such as NUKON™ in a hydraulics laboratory. The duration of tests ranged from 2 hours to 737 hours. The tests were conducted on small, large, and intact pieces of LDFG. The flow velocities for one set of tests were slightly above 0.1 ft/s and for another set even higher. The results of these tests are documented in Alion proprietary report ALION-REP-LAB-2352-77, Revision 2, "Test Report: Erosion Testing of Low Density Fiberglass Insulation."

Based on results of these tests, the 30-day extrapolated erosion fraction was not greater than 10% for pool conditions that were more severe in regards to turbulence and velocity than the FCS predicted sump pool condition. As such, the use of a 10% fraction is considered conservative for FCS.

**12. Please provide information that demonstrates that the 15% calcium silicate erosion fraction that was based on Alion erosion testing is prototypical of the calcium silicate at Fort Calhoun. Specifically, please provide the Alion test hydraulics conditions and the duration of the Alion tests (for comparison with Fort Calhoun containment conditions), and a material properties comparison of the calcium silicate debris that was tested by Alion versus the calcium silicate installed at Fort Calhoun.**

OPPD Response RAI #12:

Three CalSil specimens were tested for FCS in the Alion hydraulics facility. Industrial Insulation Group (IIG) Thermo-12® Gold CalSil was tested as it is readily available and utilized in many plant configurations. Actual FCS CalSil removed from the plant was subjected to erosion testing. Also, a specimen was procured and utilized from A & A Corporation (Super Feather CalSil) to evaluate CalSil containing fiberglass. Thus, three different CalSil specimens were utilized in the erosion test. The erosion testing was completed in the Alion hydraulics test laboratory in a tank filled with Reverse Osmosis water that was regulated to remain below 110°F. The flow velocity of the water flowing in the tank was set to be approximately 0.4 ft/sec. This velocity was chosen to be higher and more conservative than the incipient tumbling velocity of small pieces of CalSil (i.e., 0.25 ft/sec). The erosion flow velocity for all samples (0.4 ft/sec) was not based on FCS pool analyses, but rather the incipient tumbling velocity. Thus, if FCS containment floor pool velocities do not reach 0.4 ft/sec, then the erosion test data would be conservative. If the pool velocities exceeded the 0.4 ft/sec then the CalSil insulation debris would transport to the sump strainer and its flow erosion would be irrelevant. Three duration tests were performed for the IIG Thermo-12® Gold, a 10-, 32- and 101- hour test was performed. For the FCS CalSil and the Super Feather CalSil a 10- and 32-hour test was performed. It was established in the testing that the FCS CalSil and the Feather Light CalSil eroded less than the IIG Thermo-12® Gold for the 10- and 32-hour test durations. The IIG Thermo-12® Gold erosion test was then established to be bounding for the FCS CalSil and the Feather Light CalSil. The 15% erosion fraction over 30 days was based upon the IIG Thermo-12® Gold erosion data as it was conservative compared to the other two specimens. Thus, it is considered conservative that a 15% erosion factor is utilized since the pool sump conditions above the floor are quiescent, and the actual FCS CalSil material eroded less than the IIG Thermo-12® Gold material in erosion testing.

13. **Please provide justification that the silicon carbide used as a coatings surrogate has transport properties prototypical or conservative with regard to the coatings debris it represents. Please verify that the mass of surrogate was adjusted to represent the proper volume of debris based on any density differences between the actual coatings debris and the surrogate. (This RAI is applicable only to early testing and only to the extent the licensee uses results of this testing in its final case to support completion of corrective actions for GL 2004-02. Later testing incorporated staff comments and thus was not subject to this concern.).**

OPPD Response RAI #13:

Testing described in the GL response was performed in accordance with the protocol discussed during the telephone conference call between NRC, OPPD, and General Electric (GE) staff on September 27, 2007.

14. **Please provide the physical properties of the sand used in testing and compare them to the sand that is present in containment. (This RAI is applicable only to early testing and only to the extent the licensee uses results of this testing in its final case to support completion of corrective actions for GL 2004-02. Later testing incorporated staff comments and thus was not subject to this concern.)**

OPPD Response RAI #14:

Testing described in the GL response was performed in accordance with the protocol discussed during the telephone conference call between NRC, OPPD, and GE staff on September 27, 2007.

**15. Please provide a justification for the temperature extrapolation method used for head loss test cases where bore holes were present in the debris bed. It is not clear that the bore holes which occurred at the low test temperatures would have actually occurred at the higher temperatures in the actual sump pool.**

OPPD Response RAI #15:

See Enclosure, Attachment 1: a) Excerpt of GE VPF 6898-650-01, 12/12/07 (2 pages) b) Excerpt of GE VPF 6898-715-01, 2/16/08 (2 pages)

Test 10M-SBLOCA - LDFG (This test utilized a debris load that did not credit jacketing and banding of the insulation at the break location and therefore was not representative of the plant configuration following the 2008 RFO. This test is referred to as the non-design basis test.) Test 10M-SBLOCA was reported to have many boreholes upon post-test inspection, and these boreholes affected the strainer head loss as indicated by the discontinuities in the head loss curve plotted in GE VPF 6898-650-01 (attached). The magnitude of the head loss difference between adjacent peaks and valleys in the head loss curve are approximately the same for the higher-temperature, 95°F portion of the curve (prior to approximately 4800 minutes) as they are for the lower-temperature, 63°F portion of the curve (after approximately 4800 minutes). The range of short-term head loss pressure variations did not change between the high and low water temperatures, thus suggesting that bore hole formation and filling appears to be independent of temperature for the range of 63 to 95 degrees.

Test 11M-SBLOCA - Jacketed (This test utilized a debris load that did credit jacketing and banding of the insulation at the break location and therefore was representative of the plant configuration following the 2008 RFO. This test is referred to as the design basis test.) Test 11M-SBLOCA-Jacketed was reported to have few boreholes upon post-test inspection, and these boreholes appear to have a small impact on the strainer head loss as indicated by less-significant discontinuities in the head loss curve plotted in GE VPF 6898-715-01 (attached). The magnitude of the head loss difference between adjacent peaks and valleys in the head loss curve are approximately the same for the higher-temperature, 93°F portion of the curve (prior to approximately 2200 minutes) as they are for the lower-temperature, 70°F portion of the curve (after approximately 2200 minutes). The range of short-term head loss pressure variations did not change between the high and low water temperatures, thus suggesting that bore hole formation and filling appears to be independent of temperature for the range of 70 to 93 degrees.

The magnitude of the borehole-induced pressure variations appears to increase with an increase in head loss. Test strainer head losses between approximately 50 inches $H_2O$ and 98.8 inches $H_2O$ showed a greater pressure variation than head losses between approximately 30 inches and approximately 50 inches.

Application of temperature scaling to the results of test 11M-SBLOCA-Jacketed is described starting on page 60 of the supplemental response and is reiterated below: Assuming laminar flow, plant debris head loss is calculated based on the repeatability head loss and the differences between plant and test parameters. The parameters are debris bed velocity, viscosity, debris bed thickness and water density. The relationship between plant head loss, test head loss, and the difference in plant and test parameters is based on Darcy's law and the resultant equation is shown below in Equation 3. In this section, all temperature and head loss values are taken from the Design Notes Attachment E of Reference 38, Rev.2, of the supplemental response.

## Equation (3):

$$\text{Headloss}_{\text{Debris}} = (\text{HeadLossTest} - \text{HeadLoss}_{\text{Test.Clean}}) * (\text{ViscosityPlant} / \text{ViscosityTest}) * (\text{Velocity}_{\text{Plant}} / \text{Velocity}_{\text{Test}}) * (\text{DebrisThicknessPlant} / \text{DebrisThicknessTest}) * (\text{WaterDensity}_{\text{Test}} / \text{WaterDensity}_{\text{Plant}})$$

Where:

$Headloss_{Debris}$ = Scaled head loss due to the debris
HeadLossTest = Measured maximum head loss from the test
$HeadLoss_{Test.Clean}$ = Measured clean head loss from the test
ViscosityPlant = Plant water dynamic viscosity at 196.6°F
ViscosityTest = Test water dynamic viscosity at 94.5°F
$Velocity_{Plant}$ = Plant approach velocity
$Velocity_{Test}$ = Test approach velocity
DebrisThicknessPlant = Plant fiber debris bed thickness
DebrisThicknessTest = Test fiber debris bed thickness
$WaterDensity_{Plant}$ = Plant water density at 196.6°F
$WaterDensity_{Test}$ = Plant water density at 94.5°F

Since the head loss from the tests is due to a combination of laminar flow and turbulent flow, the head loss due to laminar flow from Equation 3 must be adjusted to increase the head loss. During testing for SBLOCA, it was evident that bore holes were present in the debris bed. Bore holes cause turbulent flow and will prevent scaling using Equation 3, if there are a significant number of bore holes. If only laminar flow was present, Equation 3 would scale the repeatability head loss of 68.74 inches at 92.5°F, to the theoretical plant head loss at 196.6°F and arrive at the laminar flow head loss of 33.92 inches. To determine the effect of the bore holes on scaling, the test 11M was run at approximately 92.5°F until achieving a maximum head loss of 70.6 inches (corrected for instrumentation accuracy). At this point, the temperature was reduced to 69.7°F and the head loss was allowed to reach a maximum measured head loss of 78.3 inches (corrected for instrumentation accuracy). If the flow had been entirely turbulent, the head loss at 69.7°F would have remained approximately the same as the head loss at 92.5°F. Since the head loss did increase the flow must be a combination of laminar and turbulent flow and would allow for partial scaling, using Equation 4. To determine the scaling adjustment factor, Equation 3 is used to scale the maximum head loss at 92.5°F (70.6 inches) to the theoretical laminar flow head loss at 69.7°F of 89.82 inches. The scaling adjustment factor is equal to the ratio of the theoretical laminar flow head loss at 69.7°F (89.82 inches) to the maximum measured head loss at 69.7°F (78.3 inches). The adjustment factor is then applied to the laminar flow head loss at 196.6°F (33.92 inches).

**Equation (4)**:

Plant partially scaled HL at 196.6°F = (Adjust Factor)(Plant laminar flow HL at 196.6°F)

$$\text{Adjust Factor} = \frac{\text{Test theoretical laminar flow HL at 70°F}}{\text{Test maximum measured HL at 70°F}}$$

$$\text{Plant partially scaled HL at 196.6°F} = \left(\frac{89.82\text{ in}}{78.3\text{ in}}\right) \times 33.92\text{ in}$$

$$= 38.92\text{ in} = 3.243\text{ ft (does not include clean head loss)}$$

Where:

Plant partially scaled HL at 196.6°F: Plant scaled repeatability head loss at 196.6°F using EQ (3), adjusted for turbulent flow.

Plant laminar flow HL at 196.6°F: Plant scaled repeatability head loss at 196.6°F using EQ (3).

Test theoretical laminar flow HL at 69.7°F: Test maximum measured head loss at 92.5°F scaled to head loss at 69.7°F.

Test maximum measured HL at 69.7°F: Test maximum head loss measured at 69.7°F

**16. Please state whether the test results were extrapolated to different flow velocities. If such an extrapolation occurred, explain why any such extrapolations would be conservative or prototypical.**

OPPD Response RAI #16:

GE typically tests at plant conditions, but for FCS scaling the calculated test perforated velocity of 0.00231897 ft/sec was 3% less than the calculated plant perforated velocity of 0.00239662 ft/sec. The 3% discrepancy in velocity was accounted for in the head loss scaling by prototypically increasing the calculated plant head loss. The perforated velocity is defined as the calculated average velocity at which water enters the perforated plates on the strainer.

**17. Please verify that the fibrous size distribution used during testing was prototypical or conservative compared to the size distribution predicted by the transport evaluation. Specifically, please verify that the testing was performed with representative quantities of fine or suspended fibers. (This RAI is applicable only to early testing and only to the extent the licensee uses results of this testing in its final case to support completion of corrective actions for GL 2004-02. Later testing incorporated staff comments and thus was not subject to this concern.)**

OPPD Response RAI #17:

Testing described in the GL response was performed in accordance with the protocol discussed during the telephone conference call between NRC, OPPD, and GE staff on September 27, 2007.

**18. Please provide details of the debris addition procedures used. Please include a description of fibrous concentration during debris addition and the method of adding fibrous debris to the test tank (batching procedure). Please provide verification that the debris introduction processes did not result in non-prototypical settling of debris as clumps or agglomerations. (This RAI is applicable only to early testing and only to the extent the licensee uses results of this testing in its final case to support completion of corrective actions for GL 2004-02. Later testing incorporated staff comments and thus was not subject to this concern.)**

OPPD Response RAI #18:

Testing described in the GL response was performed in accordance with the protocol discussed during the telephone conference call between NRC, OPPD, and GE staff on September 27, 2007.

**19. The licensee's submittal describes how testing was used to determine the worst-case scenario for strainer qualification. Please justify, given the concerns reflected in other RAIs in this document about the test protocol used by the licensee, that the selection of parameters for final strainer performance testing was conservative.**

OPPD Response RAI #19:

Testing described in the GL response was performed in accordance with the protocol discussed during the telephone conference call between NRC, OPPD, and GE staff on September 27, 2007.

**20. For tests that allowed settling (no stirring), please provide a comparison of the flows predicted around the strainer in the plant and the flows present in the test flume during the testing. Please establish that the test velocities and turbulence levels were prototypical or conservative.**

OPPD Response RAI #20:

The CFD model used for the transport analysis was considered for analyzing flows around the strainers, but the lowest flow rate considered in the CFD was 1350 gpm (Case 6), which is 1.46 times higher than the final value of 923 gpm used for the new strainer design. Figures 5-62 and 5-71 of the transport analysis shows the flow velocity arrows near the new strainers to be 'light blue' in Case 6, and the keys for Figures 5-62 and 5-71 indicate that light blue is approximately 25% of the scale range between 0.00 and 0.30 ft/sec, or 0.075 ft/sec. (See Attachment 2 of this Enclosure)

Applying the ratio of 1.46 to 0.075 ft/second yields (0.075/1.46) = 0.0514 feet per second, which is the best estimate of how the CFD results may be extrapolated to estimate a plant velocity. The CFD results do not show any indications that the flow rate is not uniform near the strainers.

The plant velocity near the strainer is calculated to be 0.0516 ft/sec. The test velocity is prototypical; for tests with a flume, the width of the flume was established such that the same velocity of 0.0516 ft/sec is in the flume portion of the test pool, assuming all flow travels to the strainer in the annulus in either the clockwise or counter-clockwise direction, but not both. A schematic of the module test configuration with flume is shown in Figure 15 on page 54 of the supplemental response, and the FCS strainer arrangement is shown in Figure 20 on page 83 of the supplemental response.

**21. Please provide the amount (percentage by type) of debris that settled in the agitated areas of the test tanks for both fully stirred and near-field settling tests. Also please provide the same information for debris that settled in the near-field of the near-field tests.**

OPPD Response RAI #21:

Agitated areas of all tests (not immediately near the strainer) were sufficiently agitated to preclude significant settling of debris in those areas. It is estimated from photographs that less than 1% of debris settled in the agitated areas.

The post-test photographs showed only small amounts of debris settling in the near-field settling areas of the tests (area inside the test flume), specifically underneath the strainer, and on the downstream side of the simulated plant buffer box. It is estimated from photographs that less than 10% of debris settled during testing, and more than 75% of the settled debris, settled immediately adjacent to or underneath the strainer. The exact amount of settled debris by type cannot be determined by the data gathered during testing; however, based on review of the photographs very little or no fibrous debris appeared to have settled.

**22. Please provide the test termination criteria and the methodology by which the final head loss values were extrapolated to the emergency core cooling system (ECCS) mission time or to some predicted steady-state value. Please include enough test data that the extrapolation results can be confirmed.**

OPPD Response RAI #22:

The test termination criteria is included in Section 5.2.2 of Reference 38 of the supplemental response as "Steady state head loss is defined as less than a 1% or 0.1" increase in measured head loss for at least 30 minutes or 5 turnover times, whichever was longer." In addition, GE practice for FCS tests was to terminate any test after 101 pool water volume turnovers, which equates to 30 days of operation in the plant, unless other data from that test was to be obtained.

11M-SBLOCA-Jacketed (design basis test) was terminated at approximately 2700 minutes and 101 turnovers were achieved at approximately 1700 minutes. Test 11M-SBLOCA-Jacketed was terminated based on a stable head loss and well after the plant-representative 101 water turnovers were achieved (See graph provided in Enclosure, Attachment 1).

10M-SBLOCA-LDFG (non-design basis test) was terminated at approximately 5800 minutes for a total of (5800/17) = 341 turnovers; test 10M-SBLOCA-LDFG was terminated based on a stable head loss and well after the plant-representative 101 water turnovers were achieved (See graph provided in Enclosure, Attachment 1). Banding and jacketing of insulation have changed the plant debris loads such that 10M-SBLOCA-LDFG is no longer a representative case. 10M-SBLOCA-LDFG is not the design basis test and is presented for information only.

9M-RPT (a repeatability test) was terminated when the head loss was still increasing. The maximum head loss for 9M-RPT was approximately 33 inches of $H_2O$ and it was terminated approximately 1700 minutes after the test began, when 101 turnovers were reached (see graph provided in Enclosure, Attachment 1). Test 9M-RPT used the same test conditions as test 11M-SBLOCA-Jacketed (design basis test). Test 11M-SBLOCA-Jacketed had a head loss of approximately 68 inches of $H_2O$ at approximately 1700 inches; test 9M-RPT was bounded by test 11M-SBLOCA-Jacketed because 11M-SBLOCA-Jacketed had a higher head loss at 1700 minutes than 9M-RPT had at 1700 minutes.

All other module tests, including repeatability tests, had a final head loss that was less than 2/3 of the design basis test, 11M-SBLOCA-Jacketed. All module tests used the same termination criteria: "Steady state head loss is defined as less than a 1% or 0.1" increase in measured head loss for at least 30 minutes or 5 turnover times, whichever was longer."

**23. Please verify that a small-break LOCA is the limiting break considering that the earlier Fort Calhoun testing for large-break LOCAs and for determination of the limiting break may have been conducted using test protocols that are not considered prototypical or conservative. (In this regard the staff references Waterford 3 Audit Report, ADAMS Accession No. ML080140315 as an example of inadequate testing for a General Electric strainer.)**
OPPD Response RAI #23:

Testing described in the GL response was performed in accordance with the protocol discussed during the telephone conference call between NRC, OPPD, and GE staff on September 27, 2007.

**24. Table 20 provides net positive suction head (NPSH) results for various configurations. Please provide the basis for concluding that these analyzed cases represent the bounding NPSH conditions for Fort Calhoun. The discussion should include clarification as to whether both hot-leg and cold-leg recirculation conditions were analyzed and are bounded by these results. The discussion should also clarify whether single failures were considered for the NPSH calculation other than the failure of a LPSI pump to trip. (The failure of a LPSI pump to trip does not appear to have a substantive impact with respect to the overall NPSH calculation because it does not affect the margins for pumps of the opposite train due to the independent new strainer design at Fort Calhoun.)**

OPPD Response RAI #24:

The NPSH results in the supplemental response Table 20 show the NPSH margin (NPSHA – NPSHR) for different HPSI pumps combinations at RAS, calculated for a clean strainer at 194.7°F sump temperature. The flows indicate if one HPSI (479 gpm) or two HPSI pumps (923 gpm) are operating on the ECCS header. The purpose of the table is to show that the lowest NPSH margin, corresponding to operation of the SI-2B HPSI pump only, was conservatively used for establishing the maximum allowable head loss through the strainers, which was then used as the acceptance criteria for strainer testing.

(As noted, additional conservatism is added by using a lower containment water level than the actual water level after implementation of the Water Management Strategy approved in TS Amendment No. 255.) As stated in the GL supplemental response on pages 66-68, evaluation of the available NPSH vs. time and sump temperature and the available overpressure are detailed in LIC-08-0015, which was submitted in response to the RAI for LAR- 07-04, *Modification of the Containment Spray System Actuation Logic.*

The cases evaluated in response to the RAI include multiple pump alignments during the safety injection and post-RAS, failure modes, and long-term evolutions that would increase the sump temperature and minimize the containment overpressure. Hot leg injection alignments (normal and alternate) were also evaluated as part of the analysis. Single failures considered were the loss of one diesel generator and associated ECCS train, (minimum ECCS) and the loss of one CACF Unit (maximum ECCS). The most limiting conditions were then used to develop the NPSH and containment overpressure curves vs. time.

25. **Page 71 of the GL 2004-02 Supplemental Response references Electric Power Research Institute (EPRI) report #1011753, "Design Basis Accident Testing of Pressurized Water Reactor Unqualified Original Equipment Manufacturer Coatings" dated September 2005. This report states that unqualified original equipment manufacturer (OEM) coatings will only fail as particulate debris. The supplemental response further states on page 72 that a Boiling Water Reactor Owners Group (BWROG) report titled "Failed Coatings Debris Characterization, Prepared for BWROG Containment Group Committee, ITS Services, Duke Engineering and Services" dated July 21, 1998, provides data to support treatment of unqualified OEM coatings as flakes. These references are in direct conflict. The Fort Calhoun analysis described in the GL 2004-02 Supplemental Response treated OEM coatings as chips. The NRC staff accepts the EPRI report that OEM coatings fail only as particulate and not as chips. In addition, the staff has neither reviewed nor accepted the BWROG report. Please provide justification for treating unqualified OEM coatings as chips at Fort Calhoun despite the contradictory data presented in EPRI report #1011753.**

OPPD Response RAI #25:

It is not anticipated that use of the metrics from the OEM EPRI tests would result in a different transport than described in the GL 2004-02 supplemental response. This is based upon the following reasoning:

- Assume for IOZ phenolic epoxy topcoat, test 1 applies as it had IOZ primer in the autoclave, average size of paint debris 83 microns or 3 mil.
- Assume for Galvanox, test 1 applies as it had IOZ primer in the autoclave. Galvanox is predominantly a zinc-based system; since test 1 had IOZ primer in the test, this is justified. Average size 83 microns or 3 mil.

- Assume for zinc chromate, test 1 applies as it had zinc-based systems in the autoclave. Although zinc chromate was not in the testing program, assuming it behaves similarly to an inorganic zinc system is considered acceptable. Average size 83 microns or 3 mil.
- Assume for alkyds, test 2 applies as it had predominantly alkyd systems in the OEM test autoclave. Average size of paint debris is 300 microns; however, to be conservative a 5 mil value shall be used as previously specified in OPPD calculations.

Using the methods prescribed in "Fort Calhoun Station LOCA Pool CFD Transport Analysis," debris transport metrics were calculated for the unqualified coatings, when applying the OEM EPRI average size data for unqualified coatings. Using the density reported in Table 22 of the supplemental response as density inputs, the following metrics were calculated for settling velocity, TKE and incipient tumbling velocity.

| Coating Type | Settling Velocity ft/s | Minimum TKE Required to suspend $ft^2/s^2$ | Calculated Incipient tumbling velocity ft/s |
|---|---|---|---|
| IOZ Primer | 0.049 | 0.0036 | 0.25 |
| Galvanox | 0.057 | 0.0049 | 0.27 |
| Zinc Chromate | 0.027 | 0.0011 | 0.21 |
| Alkyds | 0.027 | 0.0011 | 0.21 |
| Epoxy Paint 5 mil thick chips CFD | 0.08 (ARL data) | 0.009 | 0.24 |

Previously, the CFD calculations (based upon a 3-pump HPSI operation as noted in response to RAI #10) evaluated the unqualified coatings as being equivalent to 5 mil thick epoxy paint chips, which was conservative due to the density of the majority of the unqualified coatings. Also, the transport mechanics are considered conservative due to the 3-pump HPSI operation instead of design basis, which is a 2-pump HPSI configuration, and also do not reflect a deeper sump pool with the no spray configuration. The calculated metrics (TKE and incipient tumbling velocity) for the assumed representative epoxy paint chips based on ARL test data for settling velocity were of the same magnitude as the metrics calculated above for the unqualified coatings. In summary, the transport calculations assumed the unqualified coatings to behave like 5 mil thick epoxy paint chips, however, the unqualified coatings are predominantly higher density inorganic based type zinc coatings. When utilizing the OEM EPRI coating average debris sizes from autoclave testing the calculated metrics for unqualified coating systems are of the same magnitude as that which was assumed for the FCS transport calculations. Those calculations resulted in establishing that coatings with the noted metrics for epoxy chips would not transport during the recirculation phase. Since the calculated metrics for the unqualified coatings result in similar magnitude transport metrics when applying the OEM size data the results would be similar for transport. Due to the higher density of these systems the unqualified coating debris would not be expected to be subject to transport.

Additionally the zinc chromate system is predominantly applied on components above the 994' elevation (i.e., the safety injection tanks (SITs) at 1013' and reactor coolant pump (RCP) motors at higher elevation). The only source of zinc chromate at the 994' elevation is on the pressurizer quench tank which is on the opposite side of containment from the strainers and would have to go through a tortuous path to arrive at the strainers without consideration for transport metrics. Half of the IOZ phenolic epoxy topcoated system is on the RCPs which are at the 1013' elevation, and would not be subject to spray wash down. The remaining locations for the IOZ phenolic epoxy topcoated system are scattered throughout containment on unistrut and conduits.

**26. Please provide a copy of the BWROG report cited above (BWROG report titled "Failed Coatings Debris Characterization, Prepared for BWROG Containment Group Committee, ITS Services, Duke Engineering and Services" dated July 21, 1998)**

OPPD Response RAI #26:

See OPPD Response to RAI #25 for utilization of EPRI OEM test data in lieu of the BWROG Failed Coating Debris Characterization. Also, the requested document is provided in Attachment 3.

**27. Please provide the mass and volume amounts of all coatings debris generated in containment for the worst-case piping break. (These values are presumably in References 1 and 2 of the GL 2004-02 Supplemental Response.) Please distinguish between values for unqualified coating debris, degraded qualified coating debris, and coating debris generated within the ZOI.**

OPPD Response RAI #27:

OPPD erroneously indicated that a degraded qualified coating classification was used as part of the FCS coatings program in the supplemental response. A degraded qualified coating classification is not used in the FCS coatings program. The following table is provided from Reference 1 of the supplemental response for the amount of coatings debris that could be generated within a break ZOI.

Coating Debris Quantities Large Break LOCA Inside SG Compartment

| *Coatings in the Break ZOI* | *Quantity $Ft^3$ (lbm)* |
|---|---|
| 5 L/D Epoxy Basecoat | 1.0 $ft^3$ (25) |
| 5 L/D Epoxy Topcoat | 1.0 $ft^3$ (50) |
| Total 5 L/D Qualified Coatings | 2.0 $ft^3$ (75) |

The total amount of unqualified coatings in containment dispersed throughout all elevations is reported also in Reference 1 of the supplemental response. The following table identifies the unqualified coatings by type. All unqualified coatings are also documented by location for further assessment and disposition in transport calculations.

Unqualified Coatings in Containment

| *Coating Type* | *Quantity $Ft^3$ (lbm)* |
|---|---|
| Zinc Chromate | 3.6 $ft^3$ (540) |
| Galvanox | 0.1 $ft^3$ (25) |
| Alkyd Enamel | 0.48 $ft^3$ (45) |
| Carbo Zinc 11 | 2.31 $ft^3$ (515) |
| Total Unqualified Coatings Estimate in Containment | 1,125 lbm |

**28. The Revised Content Guide for GL 2004-02 requests a summary of the design inputs, loads, and load combinations utilized for the sump strainer structural analysis. The submittal which was provided contains a pointer or reference to a GE calculation which contains this information, but none of the actual information was summarized or provided. Please provide this summary information.**

OPPD Response RAI #28:

**Design Features:**

The FCS containment sump configuration consists of two separate sumps designated as Trains A and B. Each sump has an associated strainer. Strainer SI-12A serves the suction train B, which includes four pumps: CS pumps, SI-3B and SI-3C; LPSI pump, SI-1B; and HPSI pump, SI-2B.

Strainer SI-12B serves the suction train A, which includes four pumps: CS pump, SI-3A; LPSI pump, SI-1A; and HPSI pumps, SI-2A and SI-2C. Each train operates independently and the pumps are sized to provide adequate ECCS flow for the limiting single failure (a single train failure). The structural analysis is based on the SI-12B suction strainer that represents the worst case scenario.

The strainers are mounted on a frame support structure that is bolted to the containment floor. The major strainer components have modular design concepts so that they can be transported throughout the plant, and are bolted in place. All serviceable components are designed to facilitate ease of removal and re-installation. Inspection access ports are provided on the strainers for internal sump areas that are obstructed by the strainer installation and required by the customer to be periodically inspected.

**Design Inputs:**

The following analysis approach was used:

(a) The crush pressure is the pressure when the suction strainer is operating with full debris load. A crush pressure of 3.5 psi (equivalent to 7.68 feet of head loss) is used as a design input, for the stress analysis.

(b) Equivalent solid plate properties (Poisson's Ratio and Modulus of Elasticity) including a stress multiplier are determined by performing a finite element analysis on the perforated plate and the solid plate following the guideline in ASME Code Section III, Appendix A-8000.

(c) A 3-D solid finite element model of the whole strainer assembly is developed with the perforated plates modeled as equivalent solid plates. The equivalent solid plate properties are applied for the modal and structural analyses. The finite element model is shown in Figures 4-1 and 4-2. A crush pressure of 3.5 psi or 7.68 feet of head loss is applied across the equivalent solid plates accounting for debris blockage of the perforated plates.

(d) Modal frequencies in air and in water are derived to determine the appropriate seismic analysis requirements (Static or Response Spectra Analysis). The modal results are presented in Table 6-4 and show that the first mode frequency is 33 Hz, which is seismically rigid. Therefore, a static analysis method is used for deriving seismic responses. The associated seismic accelerations for rigid response are summarized in Table 6-2. However, the more conservative values shown in Table 6-3 were used for analysis.

(e) Various static load cases are performed to determine stresses on key components. Stress plots of the critical strainer components were developed.

(f) Stress results are evaluated according to the ASME Code Section III, Subsection ND Code allowable stress requirements. Acceptable design margins (stress ratios) are summarized for the strainer design (Tables 2-1 and 2-2 on page 25).

The structural analysis utilizes the suction strainer assembly finite element model shown in Figure 4-1. The strainer assembly is modeled with solid elements (ANSYS Element Types 45 and 190). The strainer disks and spacer rings are composed of perforated plates with 1/16" diameter holes on a triangular pitch. The spacer rings are situated between the disks at the inner circle. The holes were not included in the integral strainer analysis model because of the model size limitation. Instead, the perforated plates are modeled with equivalent solid plates with modified material properties.

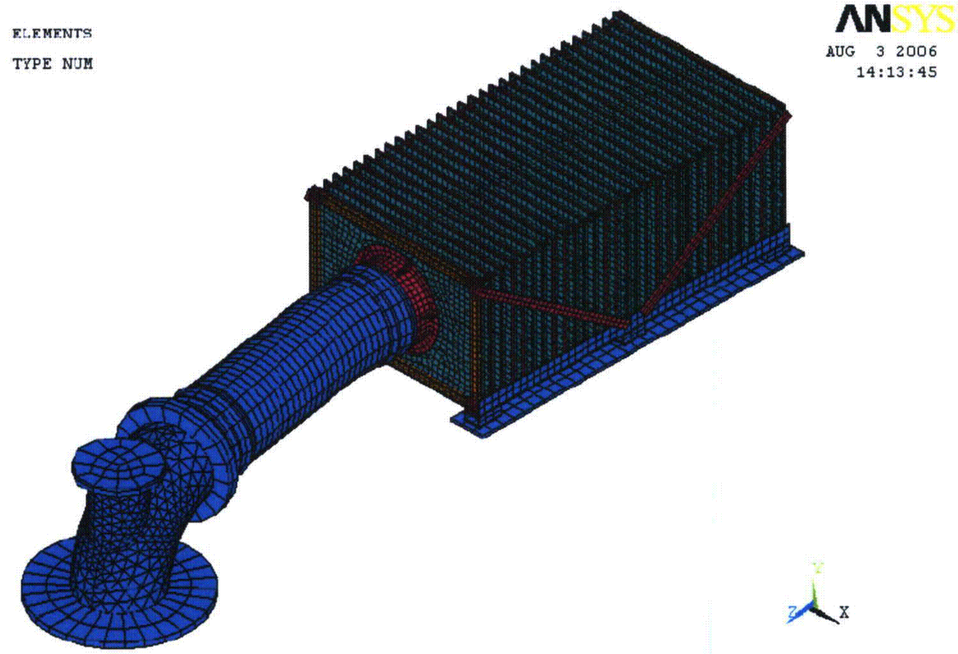


**Figure 4-1 Fort Calhoun Replacement Suction Strainer Assembly Finite Element Model**

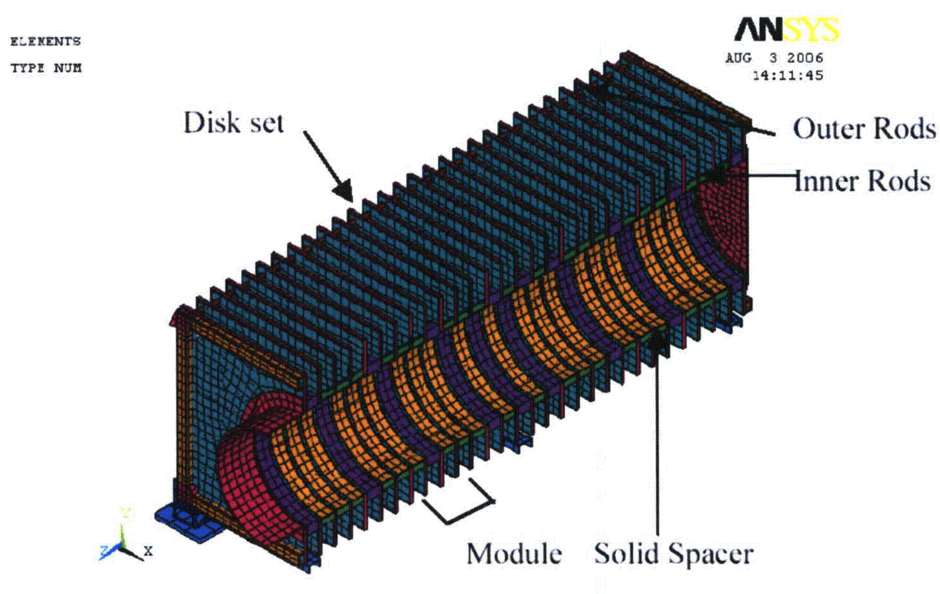


**Figure 4-2 Fort Calhoun Replacement Suction Strainer Assembly FEM Cross Section View**

**Load Combinations**

Table 6-1 shows the load combinations specified for FCS passive suction strainer design.

**Table 6-1 Load Combinations for Strainer Design**

| Strainer Assembly | Load Combination |
|---|---|
| Design | $W + P_o + OBE_1$ |
| Level B | $W_D + P_d + OBE_2 + TE_{max} + P_{cr}$ |
| Level D | $W_D + P_d + SSE_2 + P_{cr}$ |
| **Support Structure** | |
| Design | $W + P_o + OBE_1$ |
| Level B | $W_D + P_d + OBE_2 + TE_{max}$ |
| Level D | $W_D + P_d + SSE_2$ |

Nomenclature:

| | |
|---|---|
| W | Weight (Dry strainer Assembly Weight) |
| $W_D$ | Weight + Debris Weight + Hydrodynamic Mass (LOCA Event with Strainer in Water) |
| Pcr | Crush Pressure (During Suction Strainer Operation in Water-Post LOCA) |
| Pd | Design Pressure (LOCA Event) + Water Head (Strainer Open System) |
| Po | Design Pressure (Strainer Open System) |
| OBE1 | Operating Basis Earthquake, (Inertia Load in Air) |
| OBE2 | Operating Basis Earthquake, (Inertia Load with Strainer in Water-Include Debris Weight + Hydrodynamic Mass) |
| TEmax | Thermal Expansion (Accident Condition) |
| SSE1 | Safe Shutdown Earthquake (Inertia Load with Strainer in Air) |
| SSE2 | Safe Shutdown Earthquake (Inertia Load with Strainer in Water-Include Debris Weight + Hydrodynamic Mass) |

The loads on the strainer consist of the crush pressure acting across the strainer plates (accounting for debris blockage) during the steady state suction pump operation after the accident, strainer weight, debris weight and hydrodynamic mass during seismic event, thermal expansion load (Accident Condition). The seismic loads are based on the static lateral and vertical inertial accelerations from the rigid range of the Response Spectrum, since the first mode of frequency of the strainer assembly in water and air is 33 Hz or greater. The design pressure, $P_o$ or $P_d$, has no impact on the system because the strainer is an open system. The strainer assembly model in air, W, is calculated to weigh 6906 lbs. The strainer assembly model in water, WD, is calculated to be a total of 11,688 lbs with debris weight of 1000 lbs and hydrodynamic mass of 3782 lbs. The hydrodynamic mass and debris weight are assumed to be distributed evenly and are added to the strainer finite element model by adjusting the density of the material.

The crush pressure is applied on the both surfaces of the disk sets accounting for debris blockage. The plates of the disks have adjusted properties in the finite element model and the corresponding stress results are multiplied by the stress factor (k) to account for the presence of holes.

Table 6-2 provides the combined loading for the strainer components stress analysis. However, the stress results presented in this report are based on the finite element model with loading conditions summarized in Table 6-3. This loading condition exceeds all required load levels. Stresses from this load case will be compared to stress allowable according to Design, Level B and Level D.

**Table 6-2 Load Table for the Fort Calhoun Strainer Design**

| Strainer Assembly | Load Combination | Inertia X (G) | Inertia Z (G) | Inertia Y (G) | Pcr (psi) | ΔTemp** (°F) |
|---|---|---|---|---|---|---|
| Design | $W + P_o + OBE_1$ | 0.27 | 0.27 | 1.07 | | |
| Level B | $W_D + P_d + OBE_2 + TE_{max} + P_{cr}$ | 0.27 | 0.27 | 1.07 | 3.5* | 117.7 |
| Level D | $W_D + P_d + SSE_2 + P_{cr}$ | 0.36 | 0.36 | 1.2 | 3.5* | |

*equivalent to 7.68 ft of head loss
**Stress free temperature is assumed to be 70 °F, ΔT = (187.7-70) °F = 117.7 °F
NOTE: Axis Orientation: Y Vertical, X & Z Lateral

**Table 6-3 Actual Loading Condition for the Fort Calhoun Strainer FEM**

| Load Combination | Inertia X (G) | Inertia Z (G) | Inertia Y (G) | Pcr (psi) | ΔTemp** (°F) |
|---|---|---|---|---|---|
| $W_D$ + Seismic Response Spectra + $P_{cr}$ | 0.45 | 0.45 | 1.75 | 3.5* | |

*equivalent to 7.68 ft of head loss
NOTE: Axis Orientation: Y Vertical, X & Z Lateral

**Table 6-4 Replacement Strainer Weight and Frequency**

| Strainer | In Air (fixed b.c ) WD = 6906 lbs | In Water (fixed b.c.) WD = 11688 lbs | In Water (free in Z dir.) WD = 11688 lbs |
|---|---|---|---|
| Mode 1 | 49.957 Hz | 35.674 Hz | 32.187 Hz |
| Mode 2 | 57.473 Hz | 41.043 Hz | 35.704 Hz |
| Mode 3 | 57.593 Hz | 41.130 Hz | 40.313 Hz |
| Mode 4 | 57.678 Hz | 41.189 Hz | 41.064 Hz |

Maximum stresses in each of the strainer components were obtained using ANSYS post-processor and compared with the applicable ASME Code stress limits to calculate the stress ratios.

**Table 2-1 Stress Ratio Summary for Strainer Components based ASME Code Subsection NC**

| Component | Service Level | Stress Ratio* |
|---|---|---|
| Perforated Plates | Design | 3.91 |
| Fingers | Design | 7.86 |
| Frame and End Cap | Design | 13.46 |
| Spacers | Design | 7.39 |
| Base | Design | 5.10 |
| Outer Rods | Design | 3.26 |
| Inner Rods | Design | 3.71 |
| Pipe | Design | 27.32 |
| Perforated Plates | Level - B | 4.30 |
| Fingers | Level - B | 8.64 |
| Frame and End Cap | Level - B | 14.81 |
| Spacers | Level - B | 8.13 |
| Base | Level - B | 5.61 |
| Outer Rods | Level - B | 3.59 |
| Inner Rods | Level - B | 4.08 |
| Pipe | Level - B | 30.06 |
| Perforated Plates | Level - D | 6.26 |
| Fingers | Level - D | 12.57 |
| Frame and End Cap | Level - D | 21.53 |
| Spacers | Level - D | 11.82 |
| Base | Level - D | 8.16 |
| Outer Rods | Level - D | 5.22 |
| Inner Rods | Level - D | 5.93 |
| Pipe | Level - D | 43.71 |

*Stress Ratio = ASME Stress Limit / Calculated Max. Stress

**Table 2-2 Stress Summary for Welds Based on Service Level D Load**

| Weld Location | Weld Stress (psi) | Allowable Stress** (psi) | Stress Ratio* |
|---|---|---|---|
| Perforated Plate to Finger | 4681.42 | 8,164 | 1.74 |
| Perforated Plate to Frame | 9272.5 | 9,342 | 1.01 |

*Stress Ratio = ASME Code Stress Limit / Calculated Weld Stress

** Conservative Level A Stress Limits, ASME Code Section III, Subsection ND-3923 at 188°F

**Conclusion:**

Finite element analyses have been performed for all components of the strainer assembly under various load combinations. Welds are evaluated manually based on resulting stress from the finite element analysis. Analysis results show that the hardware of the suction strainer design meets the stress limits of the ASME Boiler & Pressure Vessel Code, Section III, 1989 Edition, Subsections ND as applicable. The interface loads were used to evaluate the anchorage to the concrete.

29. **Table 24, *Stress Summary for Welds based on Service level D Load,* shows a stress ratio of 1.01 for the Perforated Plate to Frame weld. The values specified in the table are 9722.50 psi for the Weld Stress and 9342 psi for the Allowable Stress. Utilizing this data, the stress ratio is actually calculated to be 9342 / 9722.5 = 0.96 < 1.0. Please address this apparent overstress. With regard to this apparent overstress, please justify the Allowable Stress values of Table 24 by providing the calculations used to determine these values.**

<u>OPPD Response RAI #29</u>:

The value of 9722.50 psi in Table 24 on page 85 of the supplemental response is a typographical error. The correct weld stress value from the report is 9272.50 psi, which then results in a 1.01 stress ratio, which is correct in Table 24 of the supplemental response.

30. **The Revised Content Guide for GL 2004-02 requests a summary of the evaluations performed for dynamic effects such as pipe whip, jet impingement, and missile impacts associated with high-energy line breaks. The submittal which was provided states that, "...strainers are located in areas where there are no pipe whip loads or missile loads...." Please provide a summary of the rationales leading to this conclusion (e.g., protective barriers, the absence of missile sources, separation distance, administrative operational restrictions, etc.).**

<u>OPPD Response RAI #30</u>:

The following lines were evaluated to determine if a break could result in dynamic effects on the strainer (i.e., pipe whip or jet impingement) and the disposition of the break:

1. 32" RCS hot leg, 24" RCS cold leg, 12" Safety Injection (SI) lines connected to RCS loops 1B and 2A, 12" Shutdown Cooling (SDC) line to the first isolation valve, 10" RCS Surge Line to the Pressurizer and 4" Code Safety and PORV lines – These lines are either enclosed in the steam generator compartment and/or adequately separated from the strainers.

2. 12" SI lines connected to RCS loops 1A and 2B up to the first check valves have been evaluated and determined that they are located at distances greater than 25 feet from the strainers. Jet impingement is not a concern due to more than 10 pipe diameters from the target and visual inspections of the lines determined that the routing is such that pipe whip is of no concern.

3. 3" RCS to Spray Control Valves – The pipe is located more than 10 diameters away from any strainer module, therefore jet impingement is of no concern. Pipe whip is also not a concern due to routing of the pipe and distance from the strainer module.

4. 2" charging and letdown lines (CVCS) were rerouted to allow strainer SI-12B installation. The rerouting of these lines put the strainer in the direct path for the jet in either of the 2" CVCS lines. The lines are high energy lines. However, per USAR Section 14.15.6, "Small Break LOCA," analysis demonstrates that for break sizes 0.015 $ft^2$ or smaller, the RCS will refill and achieve a subcooled condition. A circumferential break of the charging line has an area of 0.015 $ft^2$ and a break of any of the line would not require recirculation of water from containment.

**31. In response 3m, it is stated that additional testing of the high-pressure safety injection (HPSI) pump cyclone separators is required to determine if they will function properly under LOCA sump pool conditions. Please confirm that the cyclone separators have been shown to perform satisfactorily, or that they have been replaced with cyclone separators of proven design.**

OPPD Response RAI #31:

Testing was conducted at Wyle Laboratories on two different types of separators: Doxie 5 separators (installed as part of the original equipment) and Crane Model 20 separators, which were identified in the industry as acceptable replacements. The Doxie 5 separators plugged within short period of time, while the Crane separators continued to operate with no degradation in flow or separation capability. Based on the results of the testing the Doxie separators were replaced during the 2008 RFO with Crane Model 20 cyclone separators.

**32. The licensee should show that in-vessel downstream effects are resolved for Ft. Calhoun. The licensee may do this by showing that plant conditions are bounded by the final in-vessel downstream effects WCAP-16793-NP "Evaluation of Long-term Cooling Considering Particulate, Fibrous and Chemical Debris in the Recirculation Fluid" and the corresponding final NRC staff Safety Evaluation (SE), including the conditions and limitations in the SE. The licensee may alternatively resolve this item by demonstrating, without reference to WCAP-16793-NP or the staff SE, that in-vessel downstream effects have been addressed for Ft. Calhoun. The staff recognizes that the licensee has made a commitment in this regard in its supplemental response.**

OPPD Response RAI #32:

The commitment to showing that plant conditions are bounded by the final in-vessel downstream effects WCAP-16793-NP, "Evaluation of Long-term Cooling Considering Particulate, Fibrous and Chemical Debris in the Recirculation Fluid," and the corresponding final NRC staff SE, including the conditions and limitations in the SE was made in the supplemental response (LIC-08-0021) and will be an open item in this letter (regulatory commitment AR 35967/14).

**33. In Section 3n, the licensee states that 5.59 lbm of fiber may bypass the sump strainers. This mass of fiber equates to over 2.3 ft$^3$ of as-manufactured fiberglass insulation. Please provide the results of an evaluation that shows whether this amount of fiber in the vessel can cause unacceptable blockage of flow to the core. Please either provide information that resolves this question, or establish that this question is bounded by the analysis of the final WCAP-16793-NP and the NRC staff Safety Evaluation on this WCAP.**

OPPD Response RAI #33:

The strainer bypass evaluation determined that the actual volume of fiber that was collected during the test was 0.035 ft$^3$ of fiber based on a density of TempMat™ of 162 lbs/ft$^3$, per Table 3-2 of NEI-04-02, Revision 1. This density is more representative of the individual fibers that bypass the strainer. Regardless of the density used for calculating the volume of the fiber, the fiber size distribution shows that more than 90% of the fibers are smaller than 1.2 mm (0.05"), therefore most likely to flow through the core without creating any bridging or plugging it.

**34. Please provide details concerning the use of silicate inhibition of aluminum corrosion including the following:**

**(1) which breaks credited silicate inhibition;**
**(2) the type and amounts of plant debris assumed to provide the source of silicates;**
**(3) the dissolved silicate concentration assumed to inhibit aluminum corrosion and the time assumed to reach that concentration for each break;**
**(4) for cases where silicate inhibition was credited, a discussion of other breaks that produce less calcium silicate which were considered to ensure that these breaks did not produce a more challenging head loss test by having a greater amount of chemical precipitate; and**
**(5) a description of by how much the chemical precipitate test load was reduced by silicate inhibition for the head loss tests performed.**

OPPD Response RAI # 34:

The following details are provided in response to RAI #34:

(1) All breaks that were evaluated credited silicate inhibition.

(2) The types of plant debris that were sources of silicates were CalSil, TempMat™, LDFG, and NUKON™ insulation. Various amounts of these debris sources were evaluated depending upon the break location. The table below lists the amount of each debris source that was evaluated for the break locations evaluated for the chemical debris prediction calculations.

Material Input for Chemical Precipitate Predictions

| *Insulation Material* | *RC 2A Break ($ft^3$)* | *RC 2B Break ($ft^3$)* | *RC 3A Break ($ft^3$)* | *RC 3D Break ($ft^3$)* | *Small Break ($ft^3$)* |
|---|---|---|---|---|---|
| LDFG | 77.05 | 63.76 | 50.18 | 53.05 | 0.98 |
| NUKON™ | 2.48 | 4.69 | 2.47 | 3.0 | 0 |
| TempMat™ | 59.27 | 28.72 | 27.9 | 8.54 | 0 |
| CalSil | 3.35 | 0.61 | 0.17 | 0.03 | 0.24 |
| CalSil/Asbestos | 25.04 | 23.05 | 9.19 | 23.74 | 0.49 |

(3) The refinements from WCAP-16785-NP for silicate inhibition were applied in two stages. The first stage was for plants exceeding the 75 ppm silicon threshold. The second stage was for plants exceeding the 50-75 ppm silicon threshold. The second stage limited silicate inhibition was utilized for FCS. Thus, limited silicate inhibition was credited at dissolved silicon values when the predictions yielded a silicon concentration of 50 to 75 ppm. This was only applied for conditions less than 200°F, and for a pH range greater than 7 and capped at 9.0. The time was not assumed for reaching this concentration, it was a function of the silicon release rate equations that were part of WCAP-16530-NP. The calculated amount of time for the silicon concentrations to reach the 50 ppm value was approximately 2 to 4 days depending on the case that was run.

(4) Various cases were run which looked at larger versus smaller volumes of CalSil materials as noted in the table above. By comparison, in looking at Table 25 of the supplemental response, which documents the predicted chemical precipitates by mass, Case 3 versus Case 4 shows a reduction of total mass, but yet the amount of CalSil present is 1/3 less in Case 3 versus Case 4. Thus, a case was evaluated with a reduced amount of CalSil and compared to the cases that had larger volumes of CalSil. The comparison still indicated that the other cases were more limiting in regards to total precipitates predicted. It should also be noted that cases were run at minimum and maximum pool volumes to evaluate the significance of the concentration effect. It was determined that Case 1 yielded the most bounding predicted chemical precipitates even when evaluating change in the concentrations (i.e., dilutions of silicon).

(5) Case 1 was rerun without any analytical refinements and a total chemical precipitate load of 795.9 lbm was predicted which is approximately 26% more than that which is reported in Table 25 of the supplemental response.

**35. Please provide details concerning how aluminum solubility was credited, including any temperature, pH, and aluminum concentration criteria that were used to credit solubility. Please discuss how solubility credit was implemented during testing and during evaluation of test results. Please provide the amount of precipitate reduction achieved by crediting solubility.**

<u>OPPD Response RAI #35:</u>

Aluminum solubility was not limited itself, the solubility limit of aluminum oxyhydroxide was implemented and that was linked to a concentration of 40 ppm aluminum. Per WCAP-16785-NP, the aluminum oxyhydroxide solubility limit was only valid for temperatures from 140°F to 200°F. Above 200°F, the solubility limit was 98 ppm aluminum. Thus, the aluminum concentration was reduced by the 40 ppm aluminum limit prior to calculation of the quantity of aluminum hydroxide generated. By crediting the aluminum oxyhydroxide solubility limit, the cases that were run did not yield any aluminum oxyhydroxide precipitate. By removing the solubility limit, Case 1 predicted that 72.8 lbm of aluminum oxyhydroxide precipitate would be generated. Thus, there was a reduction in 72.8 lbm of precipitate if aluminum solubility is credited. Case 1 chemical precipitate predictions from Table 25 of the supplemental response were used as the basis for the head loss testing.

**36. Please estimate the percentage of chemical precipitate that settled away from the strainer for the large break and small break LOCA tests.**

<u>OPPD Response RAI #36</u>:

Agitated areas of all tests (not immediately near the strainer) were sufficiently agitated to preclude significant settling of debris in those areas. It is estimated from photographs, that less than 1% of debris settled in the agitated areas. Less than 1% of chemical effects precipitates are believed to have settled in the agitated areas of the tests due to its low density.

The post-test photographs showed only small amounts of debris settling in the near-field settling areas of the test (area inside the test flume), specifically underneath the strainer, and on the downstream side of the simulated plant buffer box. It is estimated from photographs that less than 10% of debris settled during testing, and more than 75% of the settled debris, settled immediately adjacent to or underneath the strainer. Therefore, only 2.5% of the debris settled in regions not immediately adjacent to the strainer. The exact percentage of chemical debris in the settled debris cannot be determined by the data gathered during testing, but because of its low density, it is estimated that only a small fraction, if any, is chemical precipitate.

**<u>Attachments:</u>**

1. Excerpts of GE VPF 6898-740-01, 2/29/08 (3 pages), GE VPF 6898-650-01, 12/12/07 (2 pages), and GE VPF 6898-715-01, 2/16/08 (2 pages).
2. Alion Figures 5-62 and 5-71, Vector Plots
3. BWROG Report titled "Failed Coatings Debris Characterization," Prepared for BWROG Containment Group Committee, ITS Services, Duke Engineering and Services, dated August 26, 1998.
4. Replacement Corrected Pages for Letter from OPPD (R. P. Clemens) to NRC (Document Control Desk), "Supplemental Response to Generic Letter 2004-02, Potential Impact of Debris Blockage on Emergency Recirculation during Design Basis Accidents at Pressurized Water Reactors," dated February 29, 2008 (LIC-08-0021) - (Mark-ups and "Clean" Retyped Pages)

**Excerpts of GE VPF 6898-740-01, 2/29/08 (3 pages),
GE VPF 6898-650-01, 12/12/07 (2 pages),
and GE VPF 6898-715-01, 2/16/08 (2 pages)**

*GE Hitachi Nuclear Energy*

| VPF No. | Base | Seq. | Sheets | Rev. |
|---|---|---|---|---|
| | 6898- | 740- | 00- | 01 |

Transmittal No.
A2008087

Signature: Nick Ramsour
Printed Name: Nick Ramsour
Date: 2/29/08

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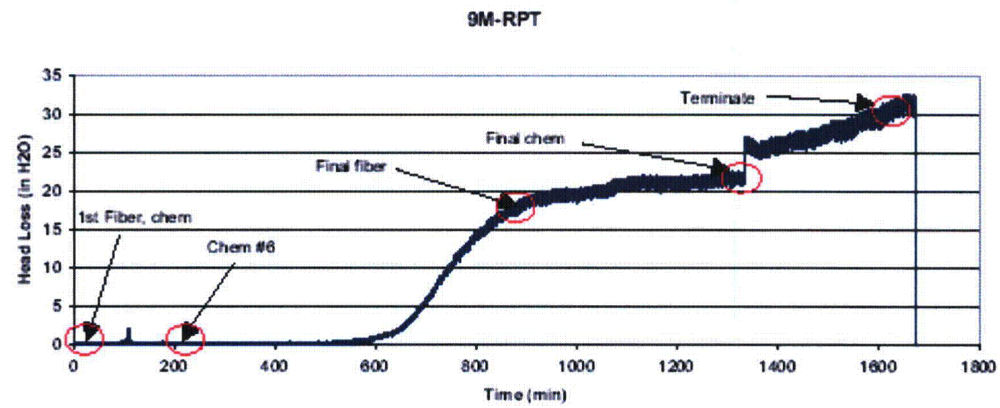


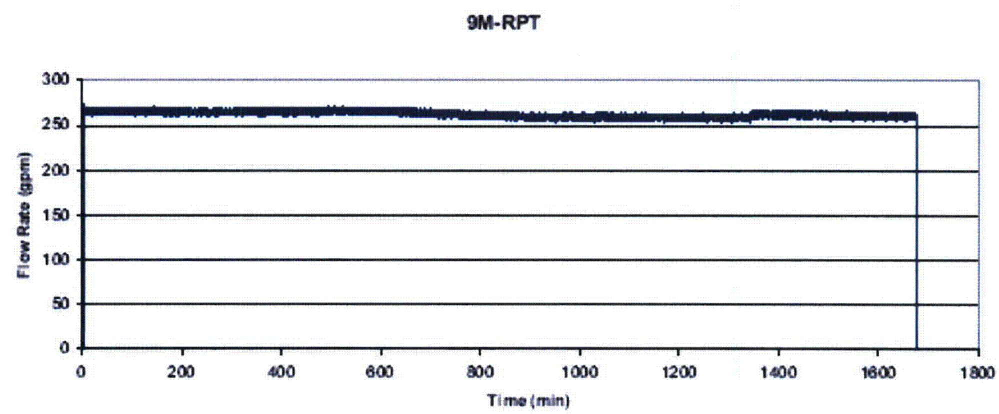

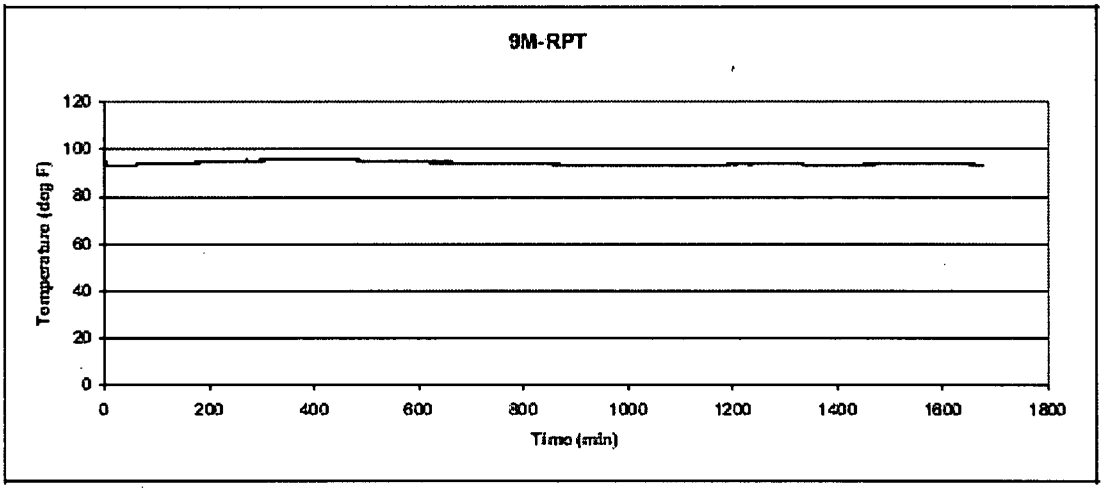
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| GE-Hitachi Nuclear Energy Americas LLC | | | | |
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| Printed Name Nick Ramsour | | | | |
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| 259.2 | 0.2 | 5 | 260.4 | 0.6 | 919 | 262.2 | 0.4 | 1258 | 94 |
| | | | 257.9 | 76.2 | 4067 | 259.8 | 70.6 | 4718 | 95 |
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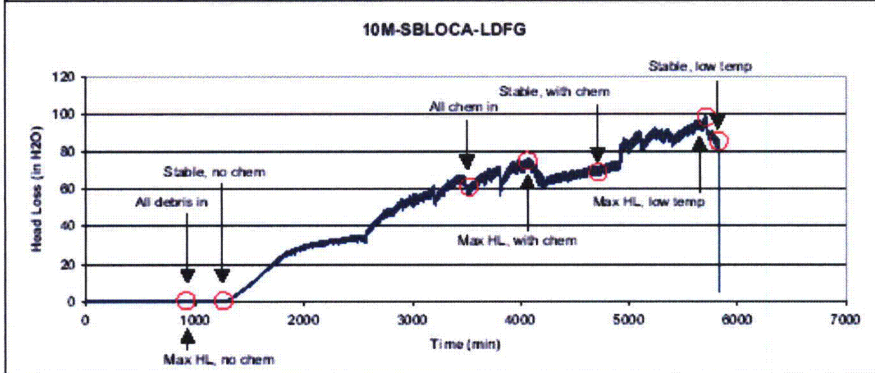


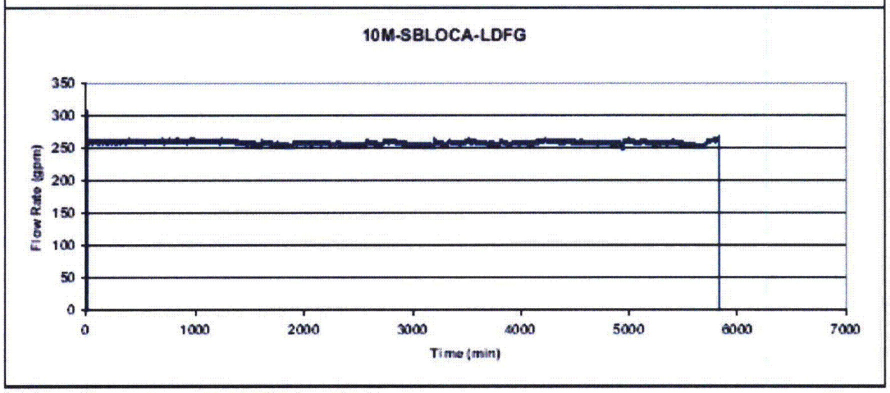


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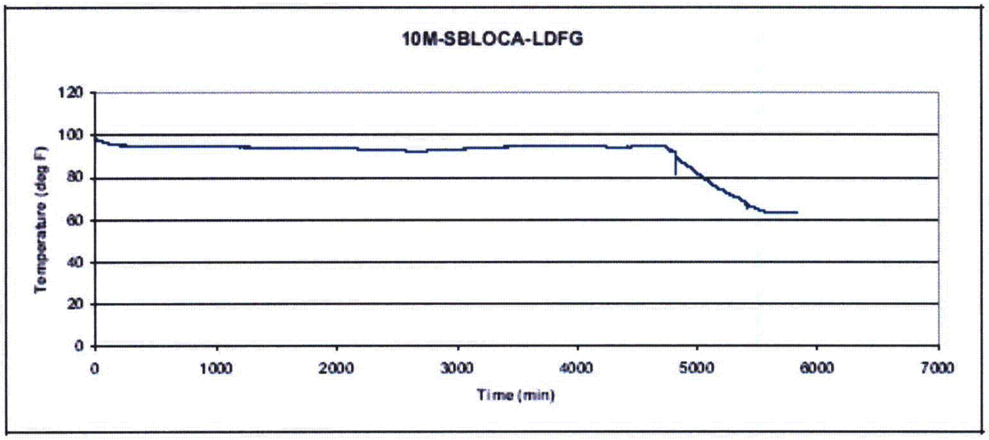

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| Signature Nick Ramsour | | | Date 2/16/08 | |
| Printed Name Nick Ramsour | | | | |
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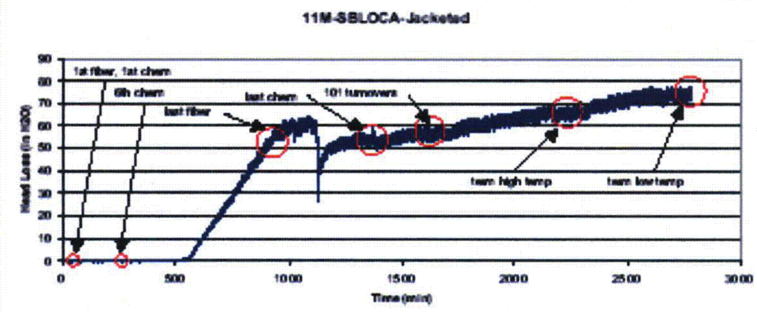
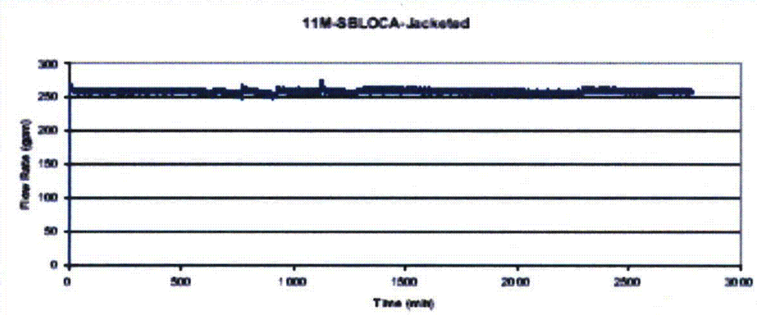
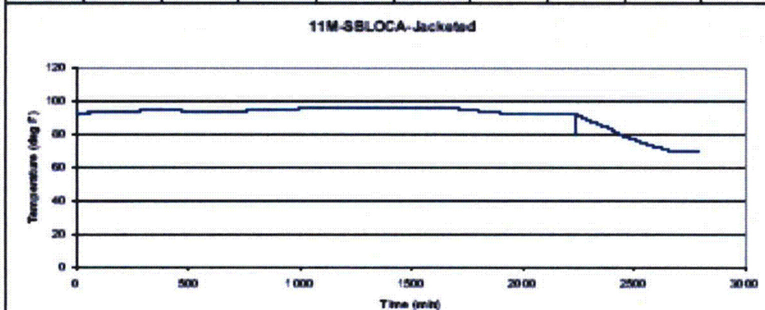
| 263.7 | 0.2 | 5 | 261.3 | 64.4 | 1085 | 261.1 | 56.4 | 1629 | 96 | 135 | 162 | 64.4 | 30849 | 46288 | 46316 | 101 TO |
| | | | 258.1 | 70.0 | 2176 | 257.1 | 65.9 | 2233 | 93 | | | 70 | 61815 | 63432 | 63459 | High temp |
| | | | 260.7 | 77.7 | 2777 | 259.6 | 75.8 | 2780 | 70 | | | 77.7 | 14884 | 14864 | 14891 | Low temp |



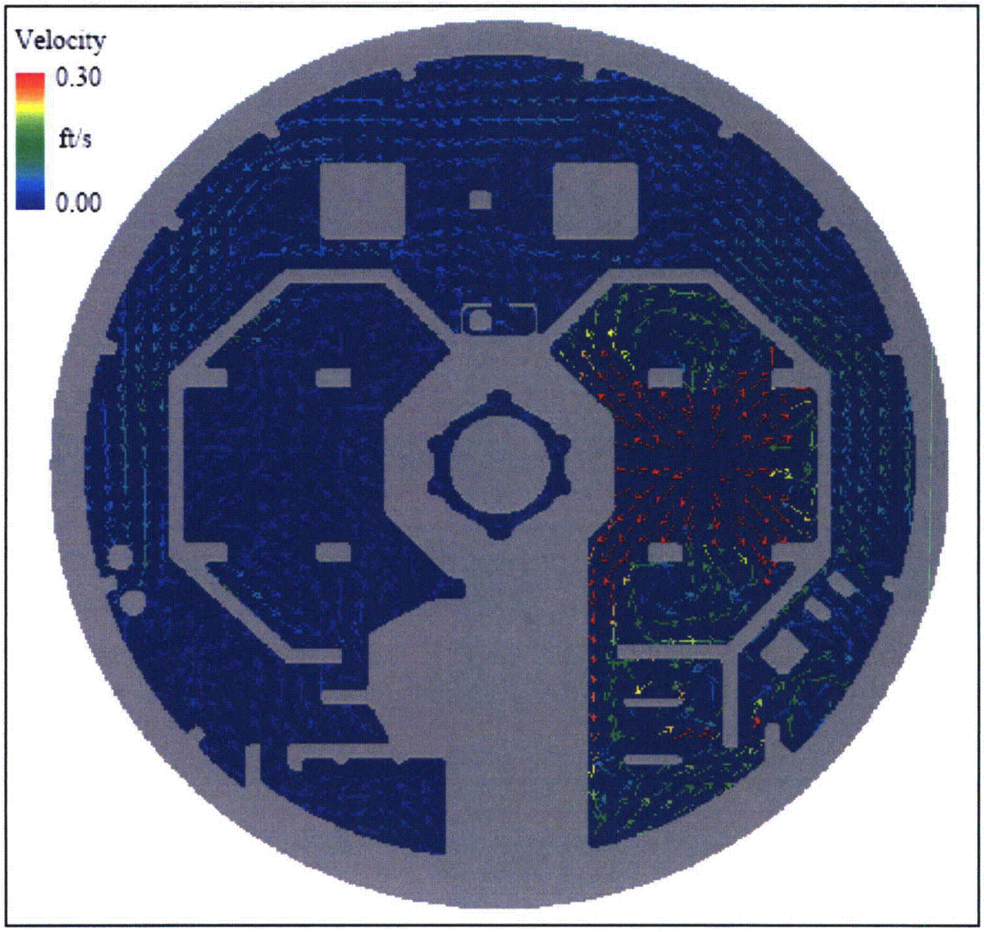



Figure 5-62 – Vector plot with velocity magnitude (Case 6, Break A)

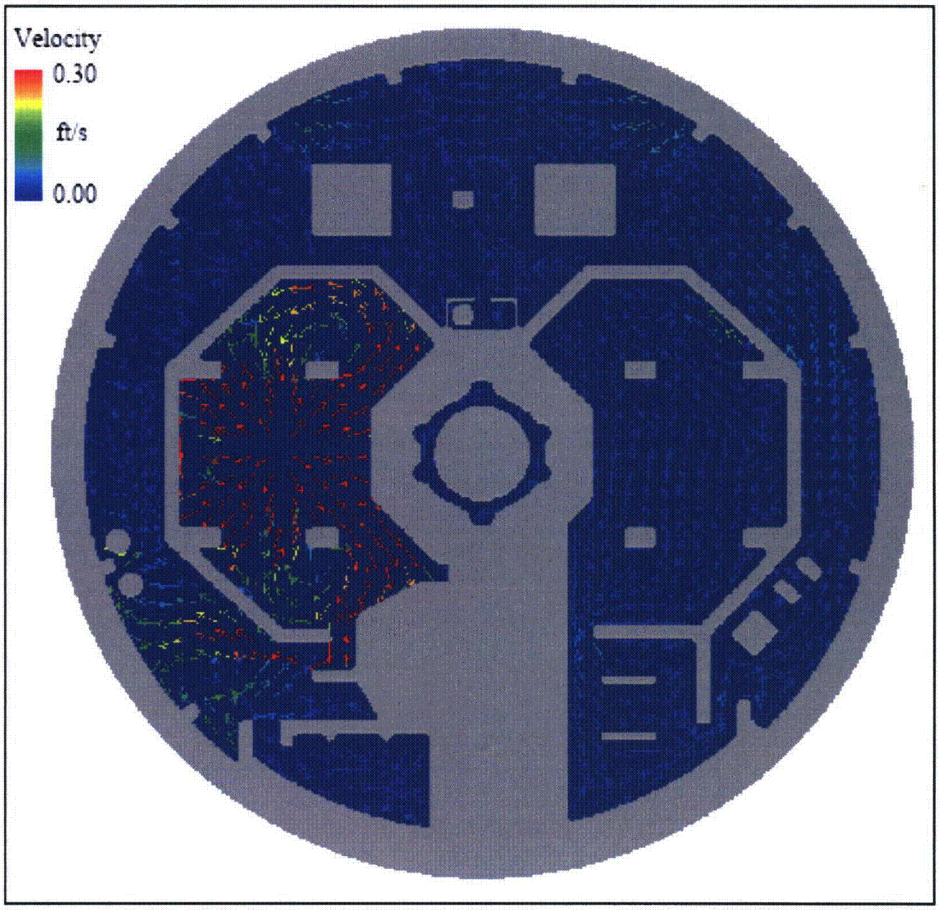



Figure 5-71 – Vector plot with velocity magnitude (Case 6, Break B)

BWROG Report titled
"Failed Coatings Debris Characterization"
Prepared for BWROG Containment Group Committee
ITS Services, Duke Engineering and Services
dated August 26, 1998