U.S. NUCLEAR REGULATORY COMMISSION STAFF REVIEW

OF THE DOCUMENTATION PROVIDED BY

PSEG NUCLEAR, LLC

FOR SALEM NUCLEAR GENERATING STATION, UNITS 1 AND 2

CONCERNING RESOLUTION OF GENERIC LETTER 2004-02

POTENTIAL IMPACT OF DEBRIS BLOCKAGE ON EMERGENCY RECIRCULATION DURING

DESIGN BASIS ACCIDENTS AT PRESSURIZED-WATER REACTORS

1.0 INTRODUCTION

A fundamental function of the emergency core cooling system (ECCS) is to recirculate water that has collected at the bottom of the containment through the reactor core following a break in the reactor cooling system (RCS) piping. This ensures long-term removal of decay heat from the reactor fuel. Leaks from the RCS, hypothetical scenarios known as loss-of-coolant accidents (LOCAs), are part of every plant's design basis. Hence, nuclear plants are designed and licensed with the expectation that they are able to remove reactor decay heat following a LOCA to prevent core damage.

If a LOCA occurs, piping thermal insulation and other materials may be dislodged by the two-phase jet emanating from the broken RCS pipe. This debris may transport, via flows coming from the RCS break or from the containment spray system (CSS), to the pool of water that collects at the bottom of containment following a LOCA. Once transported to the sump pool, the debris could be drawn towards the ECCS sump strainers, which are designed to prevent debris from entering the ECCS and the reactor core. If this debris were to clog the strainers, containment cooling could be lost and the potential for core damage and containment failure would exist.

It is also possible that some debris would bypass the sump strainer and lodge in the reactor core or other components downstream of the strainers. This could result in reduced core cooling and potential core damage. If the ECCS strainer remains functional, even with core cooling reduced, containment cooling would be maintained and the containment function would not be adversely affected.

Long-term cooling following a LOCA is a basic safety function for nuclear reactors. The recirculation sump provides a water source to the ECCS in existing pressurized-water reactors (PWRs) once the primary water source has been depleted.

Generic Safety Issue (GSI)-191, "Assessment of Debris Accumulation on PWR Sump Performance," was initiated because findings from research and industry operating experience raised questions concerning the adequacy of PWR sump designs. Research findings demonstrated that the amount of debris generated by a high-energy line break (HELB) could be greater, that the debris could be finer (and thus more easily transportable), and that certain combinations of debris (e.g., fibrous material plus particulate material) could result in a substantially greater head loss than an equivalent amount of either type of debris alone. These findings prompted the Nuclear Regulatory Commission (NRC) to open GSI-191 in 1996. This resulted in additional research for PWRs in the late 1990s. GSI-191 is intended to provide reasonable assurance that the provisions of Title 10 of the *Code of Federal Regulations* (10 CFR) 50.46(b)(5) are met. This rule, which is deterministic, requires the maintenance of long-term core cooling after initiation of the ECCS. The objective of GSI-191 is to ensure that post-accident debris blockage will not impede or prevent the operation of the ECCS or CSS in recirculation mode at PWRs during LOCAs or other HELB accidents for which sump recirculation is required. The NRC completed its review of GSI-191 in 2002 and documented the results in a parametric study, which concluded that sump clogging at PWRs was a credible concern.

GSI-191 research concluded that blockage of sump strainers could lead to recirculation system ineffectiveness by causing a loss of net positive suction head (NPSH) for the ECCS and CSS recirculation pumps. The resolution of GSI-191 involves two distinct, but related safety concerns: (1) potential clogging of the sump strainers that results in ECCS and/or CSS pump failure; and (2) potential clogging of flow channels within the reactor vessel because of debris bypass of the sump strainer (in-vessel effects). Clogging at either the strainer or in-vessel channels can result in loss of the long-term cooling safety function.

On June 9, 2003, after completing the technical assessment of GSI-191, the NRC issued Bulletin 03-01, "Potential Impact of Debris Blockage on Emergency Sump Recirculation at Pressurized-Water Reactors" (Agencywide Documents Access and Management System (ADAMS) Accession No. ML031600259). The Office of Nuclear Reactor Regulation (NRR) requested and obtained the review and endorsement of the bulletin from the Committee to Review Generic Requirements (CRGR) (ADAMS Accession No. ML031210035). As a result of the issues discussed in the bulletin, the NRC staff requested an expedited response from PWR licensees regarding the status of their compliance with regulatory requirements concerning the ECCS and CSS recirculation functions as determined by a mechanistic analysis. The NRC staff asked licensees who chose not to confirm regulatory compliance within the time requested by the bulletin to describe interim compensatory measures that they had implemented or planned to implement to reduce risk until the analysis could be completed. All PWR licensees responded to Bulletin 03-01.

In developing Bulletin 03-01, the NRC staff recognized that it might be necessary for licensees to undertake complex evaluations to determine whether regulatory compliance exists in light of the concerns identified in the bulletin and that the methodology needed to perform these evaluations was not currently available. As a result, this information was not requested in the bulletin, but licensees were informed that the staff was preparing a generic letter that would request this information.

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, (ADAMS Accession No. ML042360586) was the follow-on information request referenced in the bulletin. This document set the expectations for resolution of PWR sump performance issues identified in GSI-191. NRR requested and obtained the review and endorsement of the generic letter from the CRGR (ADAMS Accession No. ML040840034). The NRC issued GL 2004-02 on September 13, 2004, to ensure the reliability of the ECCS and CSS at PWRs.

GL 2004-02 requested that addressees perform an evaluation of the ECCS and CSS recirculation functions in light of the information provided in the letter and, if appropriate, take additional actions to ensure system function. Additionally, addressees were requested to submit the information specified in GL 2004-02 to the NRC in accordance with 10 CFR 50.54(f).

By letter dated May 28, 2004, (ADAMS Accession No. ML041550279) the Nuclear Energy Institute (NEI) submitted a guidance report (GR) describing a methodology for use by PWRs in the evaluation of containment sump performance. The GR number is NEI 04-07. The report is often referred to as the guidance report or simply the GR. NEI requested that the NRC review the methodology.

The methodology was intended to allow licensees to address and resolve GSI-191 issues in an expeditious manner through a process that consists of a conservative baseline evaluation. The baseline evaluation described in the GR serves to guide the analyst and provide a method for quick identification and evaluation of design features and processes that significantly affect the potential for containment sump blockage for a given plant design. The report offers additional guidance that can be used to refine the conservative baseline evaluation results through use of additional analytical methods.

By letter dated December 6, 2004, (ADAMS Accession No. ML043280631) the NRC issued an evaluation of the NEI methodology. The NRC staff concluded that the GR methodology, as approved in accordance with the NRC staff safety evaluation (SE), provides an acceptable methodology for plant-specific evaluations of the ECCS and CSS sump performance following postulated design-basis accidents. The final revision of the GR, including the SE (GR/SE) was issued in December 2004 as Volumes 1 and 2 of NEI 04-07 (ADAMS Accession Nos. ML050550138 and ML050550156).

In response to the NRC staff SE conclusions on NEI 04-07, the Pressurized-Water Reactor Owners Group (PWROG) sponsored the development of the following Topical Reports (TRs).

- TR-WCAP-16406-P-A, “Evaluation of Downstream Sump Debris Effects in Support of GSI-191”, Revision 1, March 2008 (ADAMS Accession No. ML081000025), to address the effects of debris on piping, systems, and components.

- TR-WCAP-16530-NP-A, “Evaluation of Post-Accident Chemical Effects in Containment Sump Fluids to Support GSI-191,”March 2008 (ADAMS Accession No. ML081150379), to provide a consistent approach for plants to evaluate the chemical effects which may occur in post-accident containment sump fluids.

- TR-WCAP-16793-NP-A, “Evaluation of Long-Term Cooling Considering Particulate, Fibrous and Chemical Debris in the Recirculating Fluid,” Revision 2, July 2013 (ADAMS Accession No. ML13239A114), to address the effects of debris on the reactor core.

The NRC staff reviewed the TRs and found them acceptable to use (as qualified by the Conditions and Limitations stated in the respective SEs). A more detailed evaluation of how the TRs were utilized by the licensee is contained in the evaluation below.

After the NRC staff evaluated licensees’ responses to GL 2004-02, it was determined that there was a misunderstanding between the industry and the NRC on the level of detail necessary to adequately address GL 2004-02. The NRC staff, in concert with stakeholders, developed a content guide that provided additional detail on the information required by the NRC to close GL 2004-02. By letter dated August 15, 2007 (ADAMS Accession No. ML071060091), the NRC issued a content guide describing the information necessary to be submitted to allow the NRC staff to verify that each licensee's analyses, testing and corrective actions associated with GL 2004-02 are adequate to demonstrate that the ECCS and CSS will perform the intended long-term core cooling function following any design-basis LOCA. By letter dated November 21, 2007 (ADAMS Accession No. ML073110389) the NRC issued a revised content guide.

The content guide described the following information needed to be submitted to the NRC. The following areas are those required to be addressed by PWR licensees.

- Corrective Actions for GL 2004-02
- Break Selection
- Debris Generation/Zone of Influence (ZOI) (Excluding Coatings)
- Debris Characteristics
- Latent Debris
- Debris Transport
- Head Loss and Vortexting
- ECCS and CSS Net Positive Suction Head (NPSH)
- Containment Coatings Evaluation
- Debris Source Term
- Sump Screen Modification Package
- Sump Structural Analysis
- Upstream Effects
- Downstream Effects – Components and Systems
- Downstream Effects – Fuel and Vessel
- Chemical Effects
- Licensing Basis

Resolution of GSI-191 has been more difficult than anticipated. Based on the interactions with stakeholders and the results of the industry testing, in 2012 the NRC staff developed three options that are considered to be effective ways to resolve GSI-191. These options were documented and proposed to the Commission in SECY-12-0093, "Closure Options for Generic Safety Issue - 191, Assessment of Debris Accumulation on Pressurized-Water Reactor Sump Performance," dated July 9, 2012 (ADAMS Accession No. ML121310648). The options are summarized as follows:

- Option 1 requires licensees to demonstrate compliance with 10 CFR 50.46, through approved models and test methods. This includes demonstration that in-vessel debris will not exceed a limit of 15 grams of fiber per fuel assembly, as accepted by the NRC staff SE on TR-WCAP-16793, Rev. 2.

- Option 2 allows additional time for licensees to resolve issues through further industry testing or use of a risk-informed approach. The option requires implementation of additional mitigative measures in the interim, until final corrective actions are completed.

- Option 2 Deterministic: Industry will perform additional testing and analysis to allow an increase in the in-vessel debris limit. This testing will be based on plant-specific conditions and should result in debris limits greater than those based on the bounding inputs used in the initial topical report. The report is to be submitted for NRC review and approval.

- Option 2 Risk Informed: Licensees will perform a risk-informed evaluation to show that the presence of debris in containment does not significantly increase risk to the plant. A pilot based on a submittal by South Texas Project (STP) is currently under review by the NRC staff. This option treats both the strainer and in-vessel effects in a risk informed manner.

- Option 3 involves separating the regulatory treatment of the sump strainer and in-vessel effects. The strainer is evaluated deterministically and the in-vessel effects are evaluated using a risk-informed methodology.

The options allow industry alternative approaches for resolving GSI-191. The Commission issued a Staff Requirement Memorandum on December 14, 2012 (ADAMS Accession No. ML12349A378), approving all three options for closure of GSI-191.

By letter dated May 10, 2013 (ADAMS Accession No ML13134A303), the licensee stated that they will pursue Option 1 for the closure of GSI-191 and GL 2004-02 for the Salem Nuclear Generating Station, Units 1 and 2 (Salem).

The following is a list of documentation provided by the licensee in response to GL 2004-02:

RESPONSES TO GL 2004-02		
DOCUMENT DATE	ADAMS ACCESSION NUMBER	
March 4, 2005	ML050740368	90-day response to GL 2004-02
September 1, 2005	ML052510438	Response regarding potential impact of debris blockage
June 7, 2006	ML061640118	Updated Response
February 2, 2007	ML070440138	Response Clarification
February 9, 2006	ML060380101	1st NRC Request for Additional Information (RAI)
February 29, 2008	ML080800469	Supplemental Response (Round 1)
December 17, 2008	ML083300079	2nd NRC RAI
March 31, 2009	ML091000557	Updated Supplemental Response (Round 2)
February 4, 2010	ML100220520	3rd NRC RAI
April 27, 2012	ML121290536	Final Supplemental Response (Round 3)
April 22, 2013	ML13114A048	Bypass Testing Results
July 11, 2013	ML13192A417	In-Vessel Results

The NRC staff reviewed the information provided by the licensee in response to GL 2004-02 and all RAIs. The following is a summary of the NRC staff review.

In addition to the documentation required from all plants, the NRC staff also performed an audit at Salem (and several other plants) to verify the adequacy of their response to GL 2004-02. The NRC staff audit report, dated August 12, 2008, is available in ADAMS under ML082170506.

2.0 GENERAL DESCRIPTION OF CORRECTIVE ACTIONS FOR THE RESOLUTION OF GL 2004-02

The following is a list of corrective actions taken by the licensee at Salem in support of the resolution of GL 2004-02:

- The licensee replaced the existing containment sump strainers for Salem, Units 1 and 2, which had a surface area of approximately 85 ft^2 and a mesh size of 1/8-inch, with strainers which have filtering surface areas of 4,854 ft^2 and 4,656 ft,^{2} respectively. Both Salem unit strainers have 1/12-inch (nominal) perforations.

- The licensee installed a debris interceptor in Salem, Units 1 and 2. A 9-inch tall debris interceptor is bolted to the front feet of the strainer modules to prevent large debris from reaching the strainer pockets strainer train, the debris interceptor wraps around the side and extends to the containment liner to limit debris transport to the back of the strainers.

- The licensee performed downstream effects evaluation using the TR-WCAP-16406-P-A, Revision 1 methodology.

- The licensee performed containment walkdowns using the guidance of NEI 02-01, "Condition Assessment Guidelines: Debris Sources Inside PWR Containments," April 19, 2002 (ADAMS Accession No. ML021490212).

- The licensee revised appropriate administrative procedures. As part of the newly installed containment sump strainers, the licensee revised its administrative procedures to ensure that potential sources of debris that may be introduced into containment will be assessed for adverse effects on the ECCS and CSS recirculation functions. These programmatic controls include requirements related to coatings, containment housekeeping, material condition, and modifications.

- The licensee replaced all the calcium silicate insulation within the zone of influence (ZOI) at Salem, Units 1 and 2. Min-K insulation was replaced with reflective metal insulation (RMI) wherever possible. In some cases, NUKON® insulation was used due to accessibility concerns. In all cases, the added NUKON® and the remaining Min-K insulation were accounted for in the debris generation calculation. The licensee replaced the Salem, Unit 2 steam generator (SG) during the spring 2008 refueling outage. The new SG was insulated with Transco (RMI).

- The licensee performed strainer head loss testing to determine the maximum head loss expected for the limiting break.

- The licensee submitted a license amendment request (LAR) dated August 15, 2007 (ADAMS Accession No. ML072350209), to the NRC for a licensing basis change for the $NPSH_a$ methodology for the ECCS and CSS pumps, as described in the Appendix 3A of the Salem Updated Final Safety Analysis Report (UFSAR). The NRC approved the request on November 15, 2007 (ADAMS Accession No. ML072841247). The LAR allowed credit for partial pressure of air initially in containment to be used in the demonstration of the hydraulic allowable head loss at lower sump temperatures.

- The licensee installed new level switches for both Salem units. The new level switches have an accuracy of ±0.75 inches and are more accurate than the existing level indicators, thus providing a more accurate indication of the containment flood level. The switches alert the control room operators when sufficient containment sump level has been obtained to support initiation of ECCS recirculation.

Based on the information provided by the licensee, the NRC staff considers this item closed for GL 2004-02.

3.0 BREAK SELECTION

The objective of the break selection process is to identify the break sizes and locations that present the greatest challenge to post-accident sump performance.

INITIAL NRC STAFF REVIEW

This area was adequately addressed by the licensee's first supplemental response as discussed below. The licensee provided the content guide specified information.

The licensee used a discrete approach to determine the break locations to analyze rather than the GR/SE-suggested evaluation at 5 foot intervals along the primary coolant loop and other piping being evaluated for potential break locations. The break locations analyzed were chosen to maximize the amount and types of debris generated. Therefore, the breaks analyzed were near large debris sources such as the SGs, reactor coolant pumps, pressurizers, near walls and floors, and in areas where debris would be more easily transported to the strainers. The supplemental response reported on six breaks in the primary loop piping, two on 31-inch (inner) diameter crossover legs, three on the 29-inch diameter hot legs, and one break on a 27.5-inch cold leg. These are the largest pipes and breaks would result in the largest ZOI. The selected breaks are adjacent to the largest insulated components and in close proximity with other large pipes and wall, floor and structural steel surfaces. Therefore, they can be expected to result in the largest amounts of various types of debris generated.

Secondary (main feed-water, main steam) piping breaks were not considered since the associated accident analyses do not credit ECCS recirculation.

NRC STAFF ROUND 3 REVIEW

The NRC staff reviewed the final, round 3, Salem supplemental response and determined that there were no significant changes in the break selection methodology that would affect NRC staff conclusions based on previous responses.

Since the licensee followed staff guidance when performing the break selection evaluation, the NRC staff concluded that it was performed acceptably.

4.0 DEBRIS GENERATION/ZOI (EXCLUDING COATINGS)

The objective of the Debris Generation/ZOI evaluation is to identify materials that may be damaged by a LOCA jet to the extent that they can transport to the ECCS sump strainer.

INITIAL NRC STAFF REVIEW

The first supplemental response stated that the licensee assumed the approved methodology (GR/SE) default ZOI value of 2D for its Transco reflective metal insulation. The supplemental response also stated that the ZOIs assumed for the RMI, the Min-K, and all fibrous (unjacketed NUKON®, generic fiberglass, and Kaowool) insulation except for jacketed NUKON® were taken from approved guidance. These ZOIs are all large enough to encompass all insulation located on two of the four RCS loops. Thus, the assumed MRI, Min-K and fibrous insulation debris totals are the same for all analyzed breaks except for break S3, which is located on the loop opposite the loop with the pressurizer and surge line. These ZOIs are accepted by the NRC staff since they are based on approved guidance.

The supplemental response stated that for Salem, Unit 1, the ZOI for jacketed NUKON® was reduced from 17D to 8D based on a test report WCAP-16710-P, "Jet Impingement Testing to Determine the Zone of Influence (ZOI) of Min-K and NUKON® Insulation for Wolf Creek and Callaway Nuclear Operating Plants," Revision 0, dated October 2007, and a Salem-specific Vendor Technical Document (VTD) 901357, "Comparison of Salem Steam Generator Insulation with Wolf Creek Insulation – Containment Sump Project." The NRC staff had not formally reviewed either document at the time of the initial supplemental response. The WCAP test report was generated from data acquired using two phase jets of a small diameter relative to the jets that are assumed from design-basis breaks. The supplemental response did not indicate that the effects of the differences in the jet sizes were considered relative to application of the WCAP test report data/conclusions. Therefore, the NRC staff requested additional information regarding this testing and its applicability to Salem. Investigation by the NRC staff and Westinghouse determined that the testing may have been non-conservative. Therefore, the NRC staff asked several RAIs on the testing and its applicability to Salem. The RAIs and responses are described in further detail below under the second and third round reviews.

Permanent lead shielding blankets are installed in the containments of both Units. The supplemental response indicated that the debris generation from these lead blankets was evaluated in accordance with a test report WCAP-16727-NP, "Evaluation of Jet Impingement and High Temperature Soak Tests of Lead Blankets for Use Inside Containment of Westinghouse Pressurized Water Reactors," and documented in Salem site calculation documents 6S1-2258, "Hazards Analysis for Installing Permanent Lead Shielding (Inside Salem Unit 1 Containment)," Revision 0, Dated December 12, 2006, and 6S2-2249, "Hazards Analysis for Installing Permanent Lead Shielding (Inside Salem Unit 2 Containment)," Revision 0, Dated May 17, 2006. The initial supplemental response states that these calculations conclude that there would be no debris generated due to jet impingement on the lead blankets. It also indicated that the lead blanket jacketing material has some fiber content, and for conservatism, an additional one cubic foot contribution of fiber was added to the fibrous debris term for all breaks to account for potential lead blanket debris. The NRC staff review determined that Salem did not provide adequate information to support the assumptions made regarding the lead blankets. Therefore, the NRC staff requested additional information regarding debris that could potentially be released from lead blankets within containment. The RAI and response is described in further detail below under the second round review.

The supplemental response stated that walkdowns showed that Salem, Unit 1, contained 555 square feet of labels and 17.3 square feet of placards and Salem, Unit 2, contained 525 square feet of labels. A sacrificial strainer surface area of 500 square feet was assigned to account for these debris items.

The RAIs below were sent to the licensee on December 17, 2008, based on review of the first supplemental response.

1. Please describe what effect that the test jet size, used for acquiring test report WCAP-16710-P data, would have on applying the conclusions of that report to insulation systems at Salem, where potentially much larger jets could be experienced from reactor coolant system loop piping breaks.

2. Please summarize the test report WCAP-16727-NP methodology and describe how its conclusions were determined to be applicable to the lead blankets installed in the Salem containments, especially with respect to materials, construction, and blanket quantity proximity to the analyzed breaks and mounting details.

In addition to the RAIs asked during the round 1 review, the NRC staff identified an open item during the Salem audit. This item was similar to the RAI regarding the reduced ZOI applied to jacketed NUKON®. The evaluation of these two issues was considered to be the same even though the credited ZOIs are different.

SECOND ROUND NRC STAFF REVIEW:

In its response to RAI 1 and in the updated supplemental response, the licensee provided a significant amount of information regarding the Westinghouse testing of jacketed NUKON® and the installation of NUKON® in the Salem containments. The licensee's RAI response concentrated on the fluid conditions and contended that the size of the jet would have no effect on the determination of the zone of influence (ZOI), as tested by Westinghouse.

During its review, the NRC staff determined for Salem, Unit 2, that the debris generation would not increase significantly because the SGs in Unit 2 are not insulated with fibrous debris. For Salem, Unit 1, the NRC staff determined the overall evaluation to be non-conservative because of the large amount of jacketed NUKON® installed in the Unit 1 containment. The NRC staff round 2 review found that the use of a ZOI smaller than the staff-approved 17D ZOI was not justified by the licensee's RAI response.

After RAI 1 was provided to Salem, the NRC staff developed a more comprehensive set of RAIs regarding the testing described in WCAP-16710-P. These RAIs requested detailed information about the thermal-hydraulic qualities of the jet, the modeling of the jet, the test facility, the construction of the targets in the testing, the construction of the insulation in the plants, and how the relatively small scale testing could predict the response of insulation subjected to a design-basis sized break. This set of RAIs was transmitted to Salem as RAI 1 through 10 (Round 2 RAIs).

The licensee's evaluation of the lead blanket ZOI (RAI 2) was found to be acceptable during the second round review because the lead and lead blanket jacketing is unlikely to result in a significant contribution to debris that can transport to the strainer. The NRC staff reviewed information provided by Salem and other licensees on the potential damage effects on lead blankets, and the debris characteristics that would be associated with any debris generated from the blankets. The licensee provided significant information regarding the lead blankets installed in the Salem containments in the response to the RAI. The NRC staff found that the lead blankets outside the ZOI postulated by the license were not likely to result in debris that would transport to the strainer or significantly increase head loss.

The Round 2 review identified one additional issue in that lead blankets were credited for shielding Min-K on two of the intermediate RCS legs. The licensee did not provide justification that the lead blanket insulation would protect the Min-K insulation. The NRC staff requested, in a new RAI (Round 2, RAI 11), that Salem provide justification that the lead blankets would provide adequate protection so that the Min-K would not become debris, or show that the amount of Min-K added to the testing bounds the potential for Min-K debris generation.

<u>THIRD ROUND (FINAL) NRC STAFF REVIEW</u>

In its Round 3 RAI response and final supplemental response, the licensee provided acceptable responses to the two issues that remained open (reduced NUKON® ZOI and lead blanket shielding of Min-K). The licensee abandoned use of a reduced ZOI for NUKON® and re-performed its debris generation calculation using the staff-approved value of 17D. In addition to increasing the ZOI to the staff-approved value, the licensee refined its NUKON® debris sizing as discussed in the debris characteristics section. The recharacterization of NUKON® was found acceptable by that review. The Salem, Unit 2, SGs were replaced and Transco RMI insulation was installed during the replacement. Therefore, the response to this issue was deemed acceptable.

In response to the issue that credited lead blankets for shielding Min-K insulation, the licensee provided additional detail regarding the distance of the insulation from the break, the installation of the insulation, and the installation of the lead shielding blankets. The licensee stated that Min-K protected by lead blankets within 18D of any break was assumed to become debris. The updated response states that the ZOI for Min-K is 28.6D (the NRC approved value). The Min-K in question is installed in the Salem, Unit 2, containment on the four crossover legs between the SGs and reactor coolant pumps. The crossover legs are surrounded by lead shielding blankets. The licensee assumed that all of the Min-K on the two legs on the same side (break side) of the containment becomes debris and that the Min-K on the third leg, about 18D from the break, is undamaged. The fourth leg is outside the staff-approved 28.6D ZOI. The licensee stated that the jet pressure at 18D is less than 6 pounds per square inch guage (psig) and that the lead shielding would provide adequate protection to the Min-K so that it would not be damaged. In addition, the licensee stated that the Min-K is protected with stainless steel jacketing, which also protects the underlying Min-K. The licensee also discussed testing that was performed on lead shielding blankets of similar construction to those installed at Salem. The testing showed that the lead blankets were not damaged at relatively small ZOIs (pressures higher than 6 psig). The NRC staff noted that the approved ZOI for Min-K is based on an unjacketed test. The stainless steel jacketing installed over the Min-K at Salem will increase its resistance to jet impingement and decrease the ZOI. The NRC staff reviewed the testing of lead shielding blankets and determined that they would provide protection for the Min-K from jet impingement outside a ZOI of 18D. The NRC staff concluded that the combination of the lead shielding and stainless steel jacketing would provide protection to the Min-K outside 18D so that it would not be damaged. Therefore, the response to the issue regarding shielding of Min-K by lead blankets was deemed to be acceptable.

Because the licensee generally followed staff-approved guidance, and for other areas provided adequate justification for refinements, the NRC staff concludes that Salem's evaluation of debris generation was performed acceptably.

5.0 DEBRIS CHARACTERISTICS

The objective of the debris characteristics determination process is to establish a conservative debris characteristics profile for use in determining the transportability of debris and its contribution to head loss.

INITIAL NRC STAFF REVIEW

The licensee adequately addressed this area in the first supplemental response. The licensee provided a highly detailed, high-quality response that addressed the information request in the content guide and included some additional information. The information provided was consistent with, and sometimes exceeded, the level of detail in the information provided during the NRC staff's GSI-191 audit for Salem. No open items were identified in this area during the audit. Similarly, the NRC staff's review of the supplemental response found that the licensee had adequately addressed the debris characteristics area.

NRC STAFF ROUND 3 REVIEW

In the Round 3 response, the licensee changed the methodology used for calculating debris characteristics for fibrous debris and refined the methodology for calculating the characteristics for Transco RMI. The new methodology reduced the amount of fine and small debris assumed to be created from the potential fibrous sources. Because this was a reduction in the fine and small debris, the NRC staff concluded that it was non-conservative with respect to the first two supplemental responses and performed a review of the new methodology.

The Round 3 methodology divided the 17D ZOI up into sub-ZOIs and assigned a percentage of fine, small, large, and intact debris that would be created within each sub-ZOI. The NRC staff reviewed the assumed size distribution of debris within each sub-ZOI against data generated from air jet testing of various types of insulation and found the Salem methodology to be consistent with the data. The NRC staff also noted that the data collected at higher pressures likely contained conservative amounts of small and fine fiber because it included data points from tests that attempted to create as much small and fine debris as possible by holding the insulation in the jet for as long as possible. The debris sizing at lower pressures was reflective of prototypical test results and is therefore also acceptable.

In the Round 1 and 2 responses, 100 percent fine generation was assumed for generic fiberglass and Min-K. The Round 3 review reduced the fractions of fine and small debris for generic fiberglass to those generally accepted for low density fiberglass. This was done to remove excess conservatism from the Salem evaluation. Kaowool was treated similarly to generic fiberglass. The NRC staff concluded that the Salem size distributions for generic fiberglass and Kaowool debris are acceptable because they were determined in accordance with staff guidance.

The size distribution for Min-K remained at 100 percent fines, which is conservative or realistic.

Salem did not change the size distribution of metal reflective insulation (MRI) from its initial response. This initial size distribution for MRI was accepted by the NRC staff. Therefore, these material properties were not re-reviewed. The size distribution of Transco reflective metal insulation was changed slightly. The small size category was subdivided into small and fine debris categories. The size distribution is based on accepted testing and includes some conservatism. Therefore, the NRC staff considers the size distribution appropriate.

Coatings and latent debris are reviewed separately.

Material densities were provided that were consistent with the densities previously reviewed and accepted by the staff during the audit.

The licensee assumptions for debris characteristic are consistent with staff guidance. The Round 2 and Round 3 references were also reviewed to determine if the debris characteristics evaluation was affected. The final (Round 3) response changed the methodology as discussed above. Based on the evaluations above, the NRC staff concluded that the debris characteristics area had been evaluated acceptably.

6.0 LATENT DEBRIS

The objective of the latent debris evaluation process is to provide a reasonable approximation of the amount and types of latent debris existing within the containment and its potential impact on sump screen head loss.

INITIAL NRC STAFF REVIEW

The NRC staff reviewed the latent debris area during the staff audit at Salem and also during the Round 1 review of the licensee's supplemental response. The sampling methodology for measurement of latent debris mass and the statistical analysis performed follows the guidance of NEI 04-07 and the NRC SE. In place of the sample mean for each area type, the licensee conservatively used the 90 percent confidence limit. Additional margin was added to the latent debris mass as added conservatism. The licensee provided an estimate of 33 pounds per minute (lbm) of latent debris actually present in containment, based upon a methodology that follows the recommendations of NEI and NRC. A conservative estimate of 200 lbm is used for screen evaluations. Of the 200 lbm, 15 percent was taken as fiber, and 85 percent as particulate. This is acceptable based on NEI and SE guidance. For these reasons, the NRC staff finds the methodology for estimating latent debris amounts to be conservative and acceptable.

The NRC staff reviewed the licensee's walkdown plan for foreign materials and the licensee's report of the quantitative results of this walkdown. The methodology used for Salem, Unit 1 and Salem, Unit 2 is identical. The walkdowns of the Salem, Unit 1 and Salem, Unit 2 containments considered all self-adhesive labels and placards as potential sources of debris that could be transported to the sump screen. The total of the individual label and placard areas for each unit was calculated. The labels and placards are located on conduits, cable trays and junction boxes. Plant drawings were used to identify the number and size of these tagged items, and the total area of the labels and placards was computed based on the total number of tagged items. These materials were assumed to be transported to the sump screen. The licensee's methodology for estimating quantities of foreign material is acceptable because it maximizes the area of labels and placards in the containment that may reach the strainers. The licensee measured 572 ft^2 of foreign materials for Unit 1, and 525 ft^2 for Unit 2, and reduced these to 75 percent, as recommended NRC and NEI guidance. The resulting areas are 429 ft^2 for Unit 1, and 393 ft^2 for Unit 2. Salem adopted 500 ft^2 of sacrificial area for both units. The licensee's treatment of foreign materials is acceptable.

NRC STAFF ROUND 3 REVIEW

The NRC staff reviewed the final, Round 3, Salem supplemental response and determined that there were no significant changes in the latent debris methodology that would affect NRC staff conclusions that were based on previous responses. Therefore, the NRC staff conclusions reached during the initial reviews remains valid.

Because the licensee followed approved staff guidance and included considerable conservatism in parts of the evaluation, the NRC staff finds that the latent debris evaluation was conducted acceptably.

7.0 DEBRIS TRANSPORT

The objective of the debris transport evaluation is to estimate the fractions of various debris types and sizes that would be transported from debris sources within containment to the sump suction strainers.

INITIAL NRC STAFF REVIEW

The debris transport area was evaluated satisfactorily for most topics, but the NRC staff requested additional information as part of its Round 1 review. In general, the licensee provided a highly detailed, high-quality response that addressed the information request in the content guide and also provided additional information. The information provided was consistent with, and sometimes exceeded, the level of detail in the information provided during the staff's GSI-191 audit for Salem. One open item was identified in this area during the audit that was not responded to in the supplemental response. Therefore, the NRC staff's review of the first supplemental response found that the licensee has adequately addressed the debris transport area with the exception of the audit open item. The open item questioned the structural adequacy of the unmodified mesh gate through the crane wall located near the ECCS sump. If the structure failed, debris greater than the amounts calculated in the transport evaluation could reach the sump strainer.

In its initial supplemental response, the licensee stated the transport analysis followed the NEI 04-07 guidance, as modified by the NRC staff's SE, considering blow-down, wash-down, pool fill up, and recirculation phases of the accident. The following provides some details of the licensee's initial methodology. Changes to this methodology are described below.

Blow-down and Wash-down: The licensee assumed that blow-down blew debris both into upper containment and lower containment. No credit was taken for retaining debris in upper containment, although an analysis of the gratings was used to quantify the amount of debris that would wash down on the back side of the strainer, downstream of the debris interceptor.

Pool Fill Up: No debris capture in inactive pools was credited. No detailed model of transport to the strainers was used, which the NRC staff considered acceptable due to conservatisms, interceptors, raised strainer design, etc.

Recirculation: The licensee used the FLUENT CFD code to compute the flow patterns in the containment pool during recirculation. A detailed review of the licensee's modeling and assumptions was provided in the audit report, which concluded that the licensee had performed an adequate analysis. The licensee also performed erosion testing at a conservative velocity (but questionable turbulence conditions), which the NRC staff considered acceptable due to the conservative data analysis and application. The licensee further performed curb lift velocity testing on the debris interceptor that was installed in front of the strainers. Although the staff had some technical concerns with the test protocol, they considered this testing to be reasonable because of compensating conservatisms in the transport calculation that are listed in the audit report. No fine debris was credited as settling in the containment pool; however, the staff understood that the head loss testing would be performed with a debris interceptor installed in the flume. Although the interceptor was not credited analytically with capture of fine debris, fine debris capture could be credited during the conduct of the head loss testing protocol.

Round 1, RAI 3 was provided to the licensee as a result of the Round 1 review and the audit.

3. Please provide a response to Open Item 3.5-1 in the NRC's GL 2004-02 Audit Report for Salem which stated:

    > The licensee needs to demonstrate the capability of the unmodified mesh gate located near the ECCS [emergency core cooling system] strainers to withstand the potential post-LOCA [loss of coolant accident] structural loadings (e.g., jet impingement, subcompartment depressurization, and containment pool flows when obstructed with debris and provide a summary of the results to the NRC staff.

This open item was not included in the draft open item list that was addressed in the supplemental response.

The open item is provided here:

> Open Item 3.5-1: Structural Capability of Crane-Wall Bioshield Door
>
> The licensee needs to demonstrate the capability of the unmodified mesh gate located near the ECCS strainers to withstand the potential post-LOCA structural loadings (e.g., jet impingement, subcompartment depressurization, and containment pool flows when obstructed with debris and provide a summary of results to the NRC staff.

The staff designated Open Item 3.5-1 for the licensee to demonstrate that the unmodified mesh door nearest the strainer can withstand potential post-LOCA structural loadings (e.g., jet impingement, subcompartment depressurization, and containment pool flows when obstructed with debris).

NRC STAFF ROUND 2 REVIEW

In response to the open item, in the second submittal and RAI response, the licensee stated that the mesh door nearest the strainer had been analyzed for structural loadings for debris load, impingement, and hydrodynamic loads. The licensee did not provide details, but stated that the doors passed the evaluations. The NRC staff did not identify any concerns with the response and the item is considered to be adequately addressed.

The licensee's transport discussion in the (second) supplemental response dated March 31, 2009, appeared similar to the discussion in the NRC staff's audit report for Salem. However, the staff noted that the licensee had reduced the erosion percentage assumed in the audit report (40 percent NUKON®/15 percent Kaowool) to a lower value (30 percent NUKON®/10 percent Kaowool). No basis was provided in the response for this reduction in eroded percentage. The staff had identified concerns with the erosion evaluation methodology during the earlier review, but determined that the licensee had included adequate conservatism in the method to offset the potential non-conservatisms. Therefore, the NRC staff concluded that the licensee needed to provide the basis for why it is acceptable to reduce the assumed erosion percentage. This item was designated RAI 12 of the Round 2 review.

NRC STAFF ROUND 3 REVIEW

In response to Round 2 RAI 12, the licensee stated that the erosion fractions had been changed to 20 percent for NUKON® and 15 percent for Kaowool and referenced the updated (Round 3/final) supplemental response to GL 2004-02 for the technical justification for these values. The updated response provided a description of testing that was conducted to determine erosion rates for the materials in question. The licensee stated that most of the erosion testing included in the data set was conducted at flow velocities well in excess of the tumbling velocities of small pieces of fibrous debris and all pieces tested were small. Both of these are stated to be conservatisms since small pieces are likely to experience more erosion than large pieces and higher velocities will also increase erosion. The velocity was also stated to be higher than 98 percent of the areas in the sump pool such that relatively small amounts of debris would actually be subject to higher velocities than those used in the test. In addition, the response stated that most of the sump pool has significantly lower velocities than those used in the test. The updated response also noted that much of the fiber in the plant would be on the floor, surrounded by other fiber so that most of it would be relatively protected while the test suspended the fiber pieces in baskets so that more surfaces of the pieces were exposed to flow.

The NRC staff considers the response to the erosion RAI (Round 2, RAI 12) to be acceptable because the test program referenced by the licensee used conservative parameters to ensure that a bounding erosion fraction was determined. Additionally, the staff agreed that much of the fiber in the post-LOCA pool would be protected by other fiber and be less likely to erode than that at the surface of a debris pile. The staff has also reviewed testing of NUKON® fiber performed by an independent lab which determined that the erosion rate for typical post-LOCA conditions is considerably less than 20 percent (see ADAMS Accession No. ML101540221). This testing also showed that short term erosions rates are greater than long term. The staff agrees that Kaowool debris is likely to erode at a lower rate than NUKON® based on its physical properties. The erosion rates chosen by Salem for both Kaowool and NUKON® are greater than the value approved by the staff based on testing at an independent lab.

The Salem final supplemental response made several changes to the blowdown, washdown, and pool fill transport evaluations as described above. During blowdown, some debris is assumed to be captured on structures within containment. This phenomenon is known as inertial capture and has been studied by the NRC sponsored Drywell Debris Transport Study (DDTS) (see NUREG/CR-6369, Volume I, "Drywell Debris Transport Study, Final Report," September 1999, ADAMS Accession No. ML003728226). The DDTS was referenced as the basis for capture fractions credited by the licensee. Some fibrous and particulate debris, generated by the jet, are credited as being captured by this mechanism. Debris not generated by the jet is appropriately not credited with inertial capture.

For the blowdown evaluation, the licensee also calculated debris transport splits between upper and lower containment, and distribution in upper containment based on flow areas and floor areas. NRC guidance is that blowdown of materials should be split based on the ratio of upper and lower containment volumes. The licensee's evaluation resulted in similar values to those calculated using the simplified guidance. The licensee's results are likely more accurate than a simple split based on volumes. These calculations assume that debris is uniformly distributed in the blowdown flow, which is a reasonable assumption.

The washdown transport evaluation was changed to credit some debris being retained on structures that are not subjected to containment spray. Instead, a portion of the captured debris in non-sprayed areas was assumed to wash down by condensation consistent with DDTS results. The amount of debris assumed to be held up in this manner is small. All fine and small debris blown to upper containment is assumed to return to lower containment via washdown.

The updated pool fill evaluation credits fine debris and small debris in inactive pools. This amount of capture of fines is directly proportional to the inactive to active pool volumes and is an acceptable methodology, as allowed by NRC staff-accepted guidance. The amount of small debris captured in inactive pools is less than for fines since the entrance to one of the inactive volumes is covered with perforated plate which prevents some small debris from passing through.

In performing the transport evaluation, the licensee generally used approved guidance with some refinements that were justified. Conservative inputs were also used for the evaluation. Therefore, the NRC staff finds that the transport evaluation for Salem is acceptable.

8.0 HEAD LOSS AND VORTEXING

The objectives of the head loss and vortexing evaluations are to calculate head loss across the sump strainer and to evaluate the susceptibility of the strainer to vortex formation. The evaluation also determines whether flashing may occur within the debris bed or if degasification of the sump fluid can occur due to head losses across the debris bed.

NRC STAFF INITIAL REVIEW

The licensee's approach to reducing strainer head loss is to install a relatively large passive Control Components, Incorporated (CCI) strainer in each unit. The NRC staff conducted an audit of the Salem response to GL 2004-02 late in 2007. Many aspects of the preliminary head loss evaluation presented during the audit were found to be acceptable. However, some aspects of the head loss testing were identified as potentially non-prototypical. In addition, the evaluation had not been finalized when the audit was conducted. The audit found it likely that the tests were completed using non-prototypical debris preparation and introduction techniques. In addition, the staff had generic concerns with the CCI chemical injection protocol that had been used for several plants' testing. Therefore, Salem retested at CCI using a WCAP chemical effects protocol and a more prototypical test arrangement. This testing resulted in head losses greater than the allowable values. Salem performed bench-top testing to determine the time frame in which chemical precipitates will form in the post-LOCA pool. Precipitates are not expected to occur until the sump pool cools somewhat from the high temperatures at the onset of recirculation. The cooling of the sump water provides additional NPSH margin because the vapor pressure of the fluid decreases with temperature. After the evaluation of precipitate timing was finalized, Salem calculated head losses for two scenarios based on new testing; one with no precipitates, and one with chemical precipitates. The results of these tests are compared to NPSH margins at various fluid temperatures to ensure that the margins remain positive.

A NRC staff's trip to CCI found its application of the WCAP-16530 methodology in conjunction with CCI's upgraded debris preparation and introduction techniques to result in prototypical or conservative head losses. Therefore, Salem's latest testing methodology results in head losses that the staff considers to be prototypical or conservative.

The new strainer areas are relatively large at about 4850 and 4650 ft^2 for Units 1 and 2, respectively. Salem has a single sump for each unit. All large breaks generate fibrous debris. In addition, some breaks generate Min-K. Unit 1 has more fibrous debris, while Unit 2 has more Min-K. The licensee conservatively assumed that there would be 200 lb of latent material within containment of which 30 lb would be fine fibers. The licensee also stated that there is 572 ft^2 of miscellaneous debris in the Unit 1 containment and 525 ft^2 in Unit 2. Five hundred (500) ft^2 of sacrificial area, representing the miscellaneous debris, was included for test scaling purposes. The flow through the strainer is stated to be about 5000 gallons per minute (gpm) for single pump operation and 9000 for dual pump operation. The corresponding approach velocity is about 0.0024 ft/sec for single train and about 0.0044 ft/sec for dual train operation.

The initial submittal stated that the strainer is fully submerged by at least 3 5/16 inches at the onset of recirculation during a small-break LOCA. However, the CCI analysis and testing for vortexing was stated to assume a submergence of 3 inches. The Salem sump is not vented to the atmosphere above the minimum containment water level and is completely submerged at the onset of recirculation.

The Salem flashing evaluation credited accident pressure to assure that no flashing would occur during recirculation. The evaluation maximized both containment pressure and temperature. Minimizing pressure would have been more conservative, but the calculated margin is significant. The limiting case was compared against the other postulated scenarios that result in lower containment pressures and temperatures and it was found to be bounding. The licensee re-performed the flashing evaluation after head loss testing was completed. The results of the flashing evaluation are discussed in the Round 2 review.

Because the final testing and head loss evaluation were not included in the initial supplemental response, a final review in the area of head loss and vortexing was not completed during the Round 1 review. The Round 1 RAIs were written based on the limited information in the first supplemental response and were answered for documentation purposes. The responses and staff evaluation of the responses are documented in the Round 2 review.

NRC STAFF ROUND 2 REVIEW

The second round review resulted in additional questions as detailed below. The licensee responded to these questions in the third supplemental response.

Round 1 RAIs (RAI numbers match Salem's first RAI letter) and Responses as Evaluated in Round 2 Review

4. Please provide verification that the fibrous size distribution used during testing was prototypical or conservative compared to the size distribution predicted by the transport evaluation.

The licensee's second supplemental response and the observations of the staff during a trip to observe strainer testing for Salem provide adequate evidence that the fibrous debris preparation for the qualification testing was appropriate. The methodology used by the test vendor resulted in a conservative amount of fine fibrous debris being introduced into the test flume. This RAI has been addressed adequately.

5. Please provide details of the debris addition procedures used. Please include a description of fibrous concentration during debris addition, the debris addition location, and the method of adding fibrous debris to the test tank. Please provide verification that the debris introduction processes did not result in non-prototypical settling, agglomeration, or deposition of debris prior to addition or as the material was added.

The licensee's second supplemental response and the observations of the staff during a trip to observe strainer testing for Salem provide adequate evidence that the debris addition methods for the qualification testing were appropriate. Stirring was used as necessary to eliminate settling of debris. The debris was well diluted and was not agglomerated prior to or during addition to the test tank. The methodology used by the test vendor resulted in a conservative amount of debris transporting to the strainer in a non-agglomerated form. This RAI has been addressed adequately.

6. Provide the amounts of various debris types added during each test and describe the debris characteristics.

The updated supplemental response provided the requested information regarding the amounts and types of debris added to testing. The debris surrogate types and amounts were appropriate for the testing. This RAI has been addressed satisfactorily.

7. Please provide scaling values used for testing.

The updated supplemental response provided the requested information regarding the test scaling. The scaling of debris and flows were appropriate for the testing. This RAI has been addressed satisfactorily.

8. If the strainer head loss test(s) allowed near-field settling, 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 show that the test velocities and turbulence levels were prototypical or conservative compared to the plant.

The licensee provided information that near-field settling was not credited during testing. The staff witnessed some of the head loss testing for Salem and agrees that excessive settling did not occur during the head loss test. The velocity of the flow across the strainer surface was scaled properly. This RAI has been addressed adequately.

9. If the strainer head loss test(s) allowed near-field settling, please provide the amount of debris that settled in the test tank.

The licensee provided information that near-field settling was not credited during testing. The staff witnessed some of the head loss testing for Salem and agrees that excessive settling did not occur during the head loss test. This RAI has been addressed adequately.

10. If agitation was utilized to prevent debris settling, please verify that the debris bed was not non-conservatively disturbed by the agitation and that non-prototypical transport did not result.

Based on the information contained in the second supplemental response and the observations of the staff during Salem's strainer qualification testing, agitation was used to prevent excessive settling of debris in the test tank. The agitation did not result in disturbance of the debris bed. Because all of the debris was created as fines, non-prototypical transport did not occur. This RAI has been answered adequately.

11. Please provide an overview of the test procedures used during testing (thin-bed and full-load tests).

The licensee's second supplemental response and the observations of the staff during a trip to observe strainer testing for Salem provided the staff with an adequate understanding of the test procedures used for strainer qualification testing. The methodology used by the test vendor resulted in a conservative test. This RAI has been addressed adequately.

12. Please provide any extrapolation performed on the test data to account for flow rates or temperatures different from those present during testing, but actually expected during the ECCS mission time. If temperature scaling is used, please discuss considerations made to identify and account for bore holes or channeling that may have occurred during testing. Alternatively, please discuss how it was verified that these phenomena did not occur.

The second supplemental response provided the methodology, assumptions, and results of the extrapolation methodology used to correct test results to plant conditions. The test results were corrected for both temperature and flow conditions. The flow corrections were small and test conditions were maintained equal to or higher than the plant scaled condition. Therefore, the flow corrections were conducted in accordance with NRC staff guidance. The temperature extrapolations were conducted only for the non-chemical debris loading because evidence of pressure driven bed degradation was noted after chemical debris was added to the test. The temperature corrections were conducted using a straight viscosity correction and a small conservative correction for slightly higher viscosity of sump fluid with respect to test fluid. Because there was no evidence of pressure driven bed degradation and there was adequate debris to form a continuous bed over the strainer it is likely that the flow through the debris bed was laminar prior to the addition of the chemical debris. Based on the information supplied, the staff concluded that the extrapolation of test results to the plant conditions were performed satisfactorily and this RAI was responded to acceptably.

13. Please provide the methodology used for calculation of clean strainer head loss (CSHL) and provide the CSHL value.

The licensee provided the methodology used to determine the CSHL values. The methodology used was a combination of standard industry calculations and CFD analysis (for a complex shaped portion of the header). The CSHL calculation considered that the flow was equalized through all sections of the strainer, which the staff considers to be a proper assumption as this tends to maximize the CSHL for strainer modules connected in a long train. The NRC staff had previously reviewed the CSHL calculation during the Salem audit and found the methodology to be acceptable. The methodology was not changed based on the docketed information. Therefore, this RAI response is considered to be acceptable.

14. Please provide the void fraction downstream of the strainer.

The licensee provided a calculation of void fraction due to vortexing and degasification of the fluid as it passes through the debris bed. The evaluation of the licensee response will be split into two sections and discussed below. Further information was requested for both the vortex formation and degasification areas and is discussed in the Round 3 review.

<u>Vortex Formation</u>

The second supplemental response stated that there is a potential for intermittent vortex formations during two pump operation at the minimum submergence level with little or no debris on the strainer. The response stated that video analysis of the test showed that the air ingestion rate during the test was 0.05 percent by volume. The response further calculated that the total air entrainment would be 0.00356 percent if the entire strainer train is included in the calculation. The licensee showed that with the predicted rate of air ingestion, the pump-required NPSH would not be significantly affected. If the predicted estimate of air intake due to vortex formation is justified, and the air does not collect within the strainer, the NRC staff agrees that there will be a negligible effect on the pump NPSH-required. The licensee also evaluated the potential for vortex formation under conditions where the pump is stopped and restarted with a debris laden strainer and under conditions where a borehole is created in the debris bed with the pumps running. No vortex formation is predicted for these two conditions.

Degasification

The licensee determined that degasification of the fluid could occur as it passes through the debris bed. The licensee postulated that any evolved gasses would be reabsorbed by the liquid prior to reaching the pump suction due to the static head of water above the pump. It was not clear to the NRC staff that any gasses that evolved from the sump fluid would be reabsorbed into the fluid prior to flowing into the pump suction. The staff was unsure that the dynamics of reabsorption were fully addressed or that all possibilities for evolved gasses were considered. For example, could the gasses collect within the strainer and be entrained in the flow as larger bubbles later in the event? This issue could be mitigated if it were shown that higher submergence would result for the large-break LOCA such that degasification were reduced or eliminated and that the head loss across the strainer for a small-break LOCA (SBLOCA) would be significantly lower.

The NRC staff requested more information regarding the video analysis and the calculation to determine whether the methodology used to derive the estimate is realistic. The staff also requested more information regarding the degasification calculation as described above. Therefore, an additional RAI was asked in this area. It is Second Round RAI 14 and is discussed below in the Round 3 review.

15. Please verify that the limiting net positive suction head (NPSH) margin scenario has been considered for both single train and dual train ECCS operation.

The second supplemental response contained detailed evaluations of several scenarios for NPSH margin. The scenarios included single and dual train operation for cold-leg, hot-leg, and containment spray recirculation. Positive margin is maintained for all scenarios.

16. Please evaluate the potential for flashing within the debris bed or strainer based on the head loss values obtained during final head loss testing considering one and two train operation.

The licensee conducted a flashing evaluation for the strainer using containment design-basis conditions, which maximized both containment pressure and temperature. The evaluation compared the strainer maximum structural head loss, which is significantly greater than the head loss determined during testing, to the flashing margin. The evaluation determined that under these containment conditions, the margin to flashing across the strainer exceeds 12 ft for all conditions. Although a more conservative evaluation would compare conditions at the maximum sump temperature and the minimum postulated containment temperature at various times for various scenarios, the licensee concluded that the demonstrated margin at the design-basis conditions showed adequate margin to flashing. The NRC staff concluded that there is adequate margin such that flashing across the strainer should not occur. This RAI has been addressed satisfactorily.

17. Please provide the vortexing evaluation. Please consider the higher flow rates associated with the module closest to the pump suction and the non-uniformity in the flow pattern contributed by the upstream flow in containment.

See the response to RAI 14 above.

Round 2 Responses to Audit Open Items

Open Item 3.6-1: Final Chemical and Non-chemical Integrated Head Loss Testing Not Performed to support NPSH margin calculations for ECCS pumps

The licensee needs to perform the final chemical and non-chemical head loss testing and then calculate strainer head loss. Net-positive suction head (NPSH) margin for the emergency core cooling systems (ECCS) pumps can then be calculated. The licensee should summarize for the NRC staff how the eight aspects of this issue discussed in Section 3.6.6 of this audit report have been addressed.

The licensee has performed final head loss testing. The methodology and results were described in the second supplemental response. Issues found during review of the supplemental response are described above in the Round 2 review and the RAI section. This open item is considered closed.

Open Item 3.6-2: Preparation of Fibrous Debris for Head Loss Tests Not Prototypical

The preparation of fibrous debris for the head loss tests was not prototypical and, as a result, tended to preclude the formation of a fibrous debris “thin bed” in the test strainers. The licensee’s conclusion that a thin bed would not form on the sump strainer may therefore be in error. The licensee should evaluate this issue for its impact on plant testing and summarize the results for NRC staff.

The updated supplemental response described revised testing that was conducted with a debris preparation methodology that results in the creation of prototypical or conservative fibrous debris. The NRC staff witnessed the CCI debris preparation and introduction methodology and found it to result in very fine fibrous debris that entered the test flume in such a manner that agglomeration did not occur and transport was adequate. This open item is considered closed.

NRC STAFF ROUND 3 REVIEW

The third response included the answers to the Round 2 RAIs, but also provided new information that was not included in the first two responses. Most of the information provides additional detail in the areas where RAIs were asked. Only significant changes in the evaluation are discussed in the Round 3 review.

RAI Summary for Round 1 RAI 14 (Also Round 2 RAI 14)

Round 2 RAI 14 requested that the licensee provide additional information regarding the methodology used to estimate the amount of air that could be ingested into a clean strainer by vortex formations. RAI 14 also requested that the licensee provide additional information regarding its conclusion that gasses that evolved from solution as they passed through a debris bed on the strainer would reabsorb into the fluid prior to reaching the suction of the ECCS pumps.

Licensee Response Summary

Regarding vortex formation, the licensee stated that a video analysis was used to assist in quantifying the amount of air that could be ingested into the strainer. The RAI response referenced the final supplemental response, which provides details on how the evaluation was performed. The second supplemental response stated that when the strainer is clean, most of the flow is through the modules closest to the pump suction. This results in high velocities and the potential for vortex formation at these modules. When there is debris on the strainer, the flow is equalized among the modules and localized high velocities do not occur. Therefore, the clean strainer case results in the limiting condition for vortex formation. The methodology used a video to evaluate the size of the vortex created under conditions similar to those expected at Salem. However, the submergence of the strainer in the video was less than half of the calculated minimum submergence at Salem. The final submittal stated that although the vortex only occurred about 20 percent of the time during the test, the evaluation assumed that the vortex would be present 100 percent of the time. The evaluation also neglected the potential for the absorption of air into the water and compression of the bubbles as they were pressurized by the increasing water head as they travel to the pump suction. The video evaluation was used to scale the volume of the air in the vortex to the volume of water flowing into the strainer. The evaluation assumed that the air would only be ingested into the top row of the strainer modules and that only the closest 1/3 module to the pump suction were susceptible to vortex formation. The evaluation also accounted for the assumption that most of the flow was through the closer modules. The evaluation concluded that the calculated amount of air ingested (0.00356 percent) would have a negligible impact on the pump required NPSH.

Regarding deaeration, the licensee eliminated the assumption that gasses that evolve due to the pressure drop through the debris bed would reabsorb into the fluid. The licensee performed a new deaeration analysis to determine the amount of air evolution based on Henry's Law. The amount of evolved gas determined by Henry's Law was used to correct the pump NPSH required using the guidance of in Appendix A of Regulatory Guide (RG) 1.82, "Water Sources for Long-Term Recirculation Following a Loss-of-Coolant Accident." Additional details regarding the analysis were included in the licensee's final response to GL 2004-02, Section 3.f.3.2. The final (Round 3) response stated that two thermal-hydraulic cases were evaluated for containment response to determine the most limiting void fraction. The evaluation also included a transient water lever that increased from the swap-over to recirculation to a final steady state pool level. The evaluation considered each of seven elevations of the strainer separately because air evolution is affected by the water height above the strainer. The analysis credited compression of the air bubbles due to increased head pressure as they travel to the pump suction.

The licensee performed a CFD evaluation to determine whether the bubbles would remain entrained in the coolant flow or collect in the strainer. Inputs to the CFD evaluation were based on testing performed to evaluate bubble sizes that occur due to various pressure drops. Fluid conditions expected during strainer operation were also used along with a model of the Salem strainer. The analysis compared the ability for buoyancy to overcome the drag on the bubbles due to flow and determined that the bubbles would remain entrained and move to the pump suction.

Acceptability of Response and Basis

The NRC staff reviewed the vortex evaluation to determine whether the methodology used provided a reasonable estimate of air ingestion for the Salem strainers. The video methodology provides a reasonable estimate of the volume of air entering the strainer. The evaluation contained numerous conservatisms. The video was taken with the strainer at less than half the conservatively calculated minimum submergence level for the strainer. Had the test been run at the calculated submergence, the vortex formation may never have occurred and would have at least been significantly smaller. Additionally, the amount of ingestion observed during testing was multiplied by 5 (20 percent observed, 100 percent assumed). These conservatisms, along with other less significant conservatisms are adequate to account for potential uncertainties with the video methodology. Other aspects of the evaluation were realistic. Therefore, the NRC staff finds that the vortex evaluation was conducted adequately.

The NRC staff has accepted the use of Henry's Law to calculate air evolution from the ECCS fluid as it passes through a debris bed or some other feature that results in a pressure drop. The methodology for correcting pump NPSH required, as described in RG 1.82, is approved by the NRC staff. The methodology used by the licensee to estimate gas evolution at the various submergence levels of the strainer reflects the plant configuration. Additionally, the CFD model used to evaluate the transport of bubbles is an industry standard program that was implemented such that it represented the strainer's physical layout and other plant conditions. Because the deaeration evaluation was conducted in accordance with staff-approved guidance, industry standard models, and used realistic inputs and assumptions, the NRC staff determined that it was conducted appropriately.

RAI Summary for RAI 13

Round 2 RAI 13 requested that the licensee provide justification that the Unit 1 full load chemical effects test head loss result is bounding of a potential thin bed with chemicals. The NRC staff concern is that a thin bed case may be more limiting than a full load case when chemicals are added to the test.

Licensee Response Summary

The licensee stated that the Unit 1 thin bed test actually contained more debris than the full load test and referenced the final supplemental response for additional details. The final supplemental response provided details of the Unit 1 full load chemical effects test and discussed the results of the thin bed test that appeared to have a higher head loss. The final response stated that the thin bed test used a debris load and a flow rate that was higher than those used in the full load test. Additionally, the final supplemental response stated that the thin bed test was conducted at room temperature, while the full load test was conducted at an elevated temperature. Lower temperatures result in higher head losses due to increased fluid viscosity. The final supplemental response demonstrated that the thin bed test was used to demonstrate a trend and that head loss continued to increase as debris was added to the test. The licensee concluded that the results of the thin bed test and the full load test were comparable, considering the differences in flow rate, temperatures, and debris loads that were present in each test, and that it was appropriate to use the full load for the chemical effects test.

Acceptability of Response and Basis

The staff reviewed the comparison of parameters that were used for each test and concluded that the thin bed and full load cases behaved similarly. Most importantly, the staff concluded that the thin bed test established that head loss for the Salem conditions continues to increase with increasing debris load. The staff accepts that the either the thin bed or full load non-chemical test, whichever incurs the highest head loss, should be used as the debris load case for any chemical effects testing. Therefore, the appropriate case to use for Salem is the full load case. The response to Round 2 RAI 13 is acceptable.

New Area of Review for Round 3 – Discovery of Potential for Additional Chemical Effects

Salem re-evaluated their debris generation and transport evaluations in order to account for debris reduction credit based on debris generation testing that was found to be faulty. The debris generation evaluation determined that additional debris would be created and that this debris would increase the potential amount of chemical precipitates that are present in the post-LOCA sump. Salem's design-basis head loss testing did not include adequate chemical precipitates to represent the updated amounts of chemical debris. However, Salem observed that earlier head loss testing showed that the addition of chemical effects, past a point, did not result in additional head loss.

The NRC staff reviewed head loss testing conducted by Salem to determine the expected effects of additional chemical precipitates on Salem's strainer considering its plant-specific debris loads. Salem provided the inputs and results of 4 tests. Two tests were the final design tests conducted for each unit. Two tests were earlier tests, run to assess the performance of the strainers at an earlier stage of the design process. The staff noted that the behavior was as stated and that past a point, generally at or below the original design-basis chemical load, that increasing chemical loading did not result in significant head loss increases. The design-basis tests resulted in the highest head losses, and were used for further evaluation of ECCS performance.

The NRC staff noted that for the more recent design-basis tests that the initial chemical additions, representing a portion of the chemical debris, resulted in significant head loss increases followed by immediate decreases in head loss. The decreases in head loss were apparently due to bed shifts that occurred when the chemical debris caused head loss to increase to a point where the existing bed became unable to maintain its structure. These bed shifts were observed by the NRC staff during a trip to observe the Salem head loss testing and during review of photographs of the testing. Ensuing chemical additions resulted in little to no increase in head loss. The licensee used the peak head loss for further evaluations related to strainer head loss. The bed shifts acted to limit the amount of head loss that resulted from the debris that collected on the strainer.

The earlier tests were conducted using a chemical injection method that the NRC staff has not generally accepted because it was not conducted according to approved guidance. However, the chemicals added to the tests did result in increases in head loss so that the effects of chemicals and the way in which they affect debris bed behavior can be evaluated. For these earlier tests, the addition of chemicals above the design-basis amounts did not result in significant additional head loss. These tests also resulted in debris bed shifts, although to a lesser extent. The bed shifts may have been limited because the head losses following chemical additions were lower than during the design-basis tests.

The NRC staff reviewed the debris loads that were used for each test based on the staff audit report of Salem and the GL 2004-02 submittals. The staff noted that the non-chemical debris loads were very similar. Therefore, the NRC staff concluded that it is acceptable to draw conclusions regarding the behavior of chemicals on the non-chemical debris bed and apply them to the design-basis debris load.

The NRC staff concluded that Salem conducted a test program that was adequate to demonstrate that the strainer behaves consistently when chemical debris is added to the non-chemical debris bed. The staff concluded that the additional postulated chemical debris would not likely result in ECCS strainer head losses above those used in the plant's design-basis evaluation as related to strainer head loss, and that the current design-basis tests adequately define the limiting head losses for Salem, Units 1 and 2.

<u>New Area of Review for Round 3 – Strainer Bypass Testing</u>

Salem included significant information in its supplemental responses regarding strainer bypass testing that was conducted to estimate the amount of fiber that may bypass the strainer and transport to downstream components. The NRC staff had not required this information from licensees in the past, but the sensitivity of in-vessel response to fibrous debris amount led the staff to evaluate this area and develop factors believed to be important when attempting to determine fiber bypass amounts. The Salem testing described in the supplemental response was conducted prior to the NRC staff development of factors that should be considered for bypass testing. The early Salem testing did not fully address all of the recently identified NRC staff concerns. The NRC staff requested that the licensee provide additional information regarding the testing so that they could determine whether the test results could be credited for determining a bypass amount that represents what can be expected in the plant. The licensee provided additional information regarding strainer bypass testing in its supplemental response dated April 22, 2013 (ADAMS Accession No. ML13114A048), and provided its in-vessel response in its supplemental response dated July 11, 2013 (ADAMS Accession No. ML13192A417). The major areas of staff concern and the staff review of those areas are summarized below.

The licensee testing used a relatively large mesh screen to capture the debris that bypassed the strainer. The NRC staff requested that the licensee provide information regarding how they accounted for the issue that some fiber may not have been captured by the screen. The licensee stated that they also collected grab samples of fluid downstream of the strainer, but upstream of the capture screen, at time intervals after the first fiber addition. The samples were evaluated to determine the size distribution of the fibers. These samples allowed the licensee to gain an understanding of the bypassed fiber size distribution with respect to time. The licensee was able to develop a correction factor and use it as a multiplier to the amount of fiber that was captured by the screen to correct for fibers not captured by the screen. The staff reviewed the test methodology and determined that it did not conservatively address all potential aspects of debris capture, but the testing and evaluation included conservatism in some areas to account for this potential non-conservatism. Based on an evaluation of the potential non-conservatism and conservatism present, the NRC staff concluded that the methodology was acceptable.

The NRC staff requested additional information regarding the location and orientation of the capture screen and whether fiber could be lost from the screen during the test or during removal of the screen from the test flume. The licensee provided details on how the screen was installed and stated that the screen was a 3-sided basket and provided the steps used for weighing, installing, and removing the screen. The staff agrees that the design of the screen and steps for handling of the screen minimize the potential for loss of fiber. Additionally, the licensee stated that after the test was completed, the flume was carefully inspected to determine if any debris was dropped into it. Any debris found in the flume was considered to be bypassed fiber. It was noted that any debris that is left in the flume is easy to collect because it is wet and easy to handle. Based on the methods used to ensure that bypassed fiber was retained on the screen and accounted for, the staff found the methods to be acceptable.

The NRC staff requested additional information regarding whether the collection methodology for grab samples taken downstream of the strainer, but upstream of the collection screen, ensured that they were representative of the average amount of debris present in the stream at the time the sample was taken. The licensee stated that the samples were not used to calculate the amount of fiber, but were used to determine the transient downstream fiber concentrations and size distributions. The staff agreed that this was an appropriate use of the grab sample data.

The NRC staff requested information regarding the strainer approach velocity used during testing, specifically whether it was representative of the maximum potential velocity at Salem because of the higher flow that occurs at the strainer modules closest to the ECCS pump suction. The licensee stated that it would be overly conservative to use the maximum flow rate that may occur at the module closest to the ECCS suction for determination of bypass quantities. The licensee also provided information on how the velocity gradient across the strainer changes as debris collects on the strainer surface. The staff found that the response was reasonable and that the initially higher velocities that exist near the ECCS pump suction would not persist. The NRC staff concluded that the velocity used would not significantly affect the amount of bypass derived from the testing. Therefore, the response to this question is acceptable.

The NRC staff requested that the licensee provide justification for using a value of bypass per unit of strainer area because the test values may not be valid when extrapolated to the larger plant strainer. The licensee provided information on how tests conducted with significantly different amounts of fiber resulted in relatively similar bypass amounts. The results indicated that strainers will bypass an amount of fiber until a debris bed is formed, at which time the bypass approaches zero. The staff concluded that the data indicated that use of the metric of amount of bypass per unit strainer area was appropriate for the Salem conditions. The staff noted that the phenomenon of significantly decreased bypass once a debris bed is formed has been noted during several bypass test programs.

The NRC staff requested information regarding how the amount of bypass occurring during testing could be affected by water chemistry. That is, testing was conducted with potable water while PWR sump fluid contains boric acid and chemicals to buffer the acid. The licensee stated that there have been industry studies performed to determine whether changes in water chemistry affect bypass, and to date no correlation has been identified. The staff has reviewed the available information and concluded that water chemistry did not have a significant effect on bypass in these tests. As of the time of this review, there have been multiple bypass test conducted to determine the effect of water chemistry on bypass and no correlation between bypass and water chemistry has been identified.

The NRC staff requested additional information regarding the batch sizes and timing of batches of fibrous debris due to concerns regarding the potential for large batches to form a debris bed on the strainer more quickly than would occur in the plant. The quickly formed debris bed could result in non-conservative filtration and reduced bypass amounts during testing. The licensee provided the batch sizes and debris addition schedule in a table. The licensee stated that the fiber additions were also made smaller than noted in the table by adding partial debris loads using a pitcher that took portions of the full batch that had been prepared in a bucket. That is, each batch was added over time instead of all at once. The staff reviewed the information and concluded that the batch sizes, debris addition methods, and timing were appropriate to prevent non-conservative test results.

The NRC staff requested that the licensee provide the total amount of bypass that was determined during testing and also provide information regarding how the test results would be used to evaluate the plant condition. The licensee provided the total amount of fiber bypass and stated that the bypass used to evaluate the potential downstream effects was based on a fiber bypass per unit of strainer area. The staff reviewed the data and determined that the licensee's use of the information would provide acceptable inputs to the downstream evaluations because the methods used realistically reflect the amount of debris that could bypass the strainer and transport to downstream equipment.

The NRC staff requested that the licensee provide information regarding control of materials that were added to the test loop to ensure that all intended material was added to the test. The licensee provided information regarding how the fibrous debris was prepared and weighed. In addition, the licensee stated that the total amount of fiber added to the test was not critical to determining the bypass amount because the majority of bypass occurs before a debris bed forms on the strainer. The debris bed acts as a filter and prevents later additions from penetrating the strainer. The steps contained adequate controls to ensure that all debris was added to the tests and that it was adequately prepared. Therefore, the NRC staff found the response to this issue acceptable.

The NRC staff requested that the licensee provide information regarding the methods used to ensure that the weight of the fiber collected on the screen was representative of the fiber that bypassed the strainer. The licensee provided information regarding the pre- and post-test weighing of the screen (without and with fiber). The screen was dried in an oven until the moisture was removed from the fiber. The licensee stated that if all of the moisture was not removed from the fiber, a conservative weight would result. The licensee also provided information regarding the calibrated scale used to perform the weight measurements. The NRC staff concluded that the licensee's methods for weighing and control of the screen, including the information provided regarding the handling of the screen discussed above, would result in accurate measurement of the amount of fiber collected on the screen.

The NRC staff requested that the licensee provide additional information regarding the point at which the debris bed on the strainer prevents significant additional bypass of fiber through the strainer. The licensee did not provide a specific value in response to the question, but provided information regarding the testing that demonstrates that the tests were run for a time period adequate to ensure that a filtering bed had formed on the strainer and that significant bypass was not occurring at the end of the tests. Most notably, a test run for a significantly longer period of time resulted in a bypass amount similar to a shorter test that contained much less fiber. The licensee also noted that the water in the loop was clear at the time that the tests were terminated, indicating that the debris had been filtered from the fluid. The NRC staff concluded that the tests were run for adequate durations to ensure that significant additional bypass was not occurring upon termination.

The NRC staff requested that the licensee provide information regarding the number of times that the debris capture screen was changed during the tests. The licensee stated that the screen was only changed upon test termination and was not removed at other times during testing.

The NRC staff requested that the licensee clarify whether the fibrous debris bypass amounts reported in the supplemental response were based on grab samples or the debris collected on the debris capture screen. The licensee stated that the reported amounts were based on the debris collected on the screen. The grab samples were used only to determine downstream debris concentration with respect to time and to quantify the size distribution of the fiber. Based on issues with the use of grab samples to calculate bypass amounts, the NRC staff agrees that use of the debris captured on the screen is the appropriate method for determining bypass amounts.

The NRC staff requested that the licensee provide additional information regarding how the amount of debris to be added to the bypass tests was calculated. The licensee stated that the debris amounts were calculated using the "as-fabricated" density of the fiber based on measurements of the supplied fiber. This density was measured at 1.94 lb/ft^3. The staff was expecting the licensee to use a density of 2.4 lb/ft^3, which is the nominal density of NUKON®. Since the density used by the licensee was an actual measured density, the NRC staff concluded that the method was acceptable.

The NRC staff requested that the licensee provide information regarding the differences in results between tests that used one-sided and two-sided strainer arrangements. The licensee provided a table that compared the two test setups and stated that the double-sided tests were performed under different conditions than the single-sided tests making comparison difficult. The double-sided tests were performed using test conditions and a strainer configuration that are more representative of plant conditions. The NRC staff concluded that the conditions were different enough that a meaningful comparison is difficult.

The NRC staff requested that the licensee provide information regarding how the results of the test were interpreted considering that there were three different types of fiber, each with a different density, and the test results were provided in units of volume. The licensee stated that the results were presented both by volume and mass per unit strainer area. The mass based results were obtained directly by weighing the fiber that bypassed the strainer and was captured on the screen. The volume results were attained by converting the mass to volume using the density of the lowest density material. This conversion is stated to be conservative because using the lowest density material results in the largest volume. The NRC staff agrees that the conversion to volume, using the lowest density material value, will result in a conservative fiber bypass volume.

The NRC staff requested that the licensee provide additional information regarding the seemingly inconsistent results that a test with a lower amount of fiber resulted in a greater amount of bypass. The staff also requested that the licensee provide information regarding the fiber bed formed on the strainer during a test containing a relatively small amount of fiber. The licensee stated that the small amount of fiber in the test was sufficient to form a filtering bed over the entire strainer surface. The licensee theorized that the test with a smaller amount of fiber, but larger bypass amount resulted due to variations in the types of fiber used in the testing. The NRC staff concluded that the explanation was reasonable, but did not rely on the response to determine the acceptability of the test program.

Based on the discussion above, the staff concluded that the fiber bypass testing conducted by the licensee adequately represents the amount that could pass through the strainer following a LOCA.

The staff concluded that the licensee had performed its strainer head loss and vortexing evaluation in accordance with staff guidance or had used other reasonable methods. The licensee provided information for all of the head loss and vortexing areas described in the content guide. Therefore, Salem adequately addressed the head loss and vortexing area.

References specific to the head loss and vortexing evaluation are listed below. These are trip reports that document staff visits to observe testing of Salem strainers and strainers with similar designs.

Trip Report Regarding Staff Observations of Sump Strainer Testing Performed by Control Components, Incorporated (CCI) (ADAMS Accession No. ML070170235).

The NRC Staff Visit to Winterthur, Switzerland, to Observe Sump Strainer Testing Performed by Control Components, Incorporated – Detailed Report (ADAMS Accession No. ML081640193).

9.0 NET POSITIVE SUCTION HEAD (NPSH)

The objective of the NPSH section is to calculate the NPSH margin for the ECCS and CSS pumps that would exist during a LOCA considering a spectrum of break sizes.

NRC STAFF INITIAL REVIEW

The licensee provided the content guide specified information. The methodology used is a standard industry practice for calculation of NPSH available and margin and used a combination of realistic and conservative assumptions.

Each Salem unit ECCS system consists of two trains, each having a charging pump, high-head safety injection pump, and a residual heat removal (RHR) pump. There is also a safety injection accumulator tank for each of the four reactor coolant system (RCS) loop cold legs. Each unit also has two trains of containment spray, each with a pump that would operate during the injection phase when water is available from the refueling water storage tank (RWST). During the injection phase, all pumps take suction from the RWST with the ECCS pumps discharging into the loop cold legs and the containment spray pumps to the containment spray ring headers. When the RWST low-level alarm is received, the ECCS system is realigned, manually by control room operators in Unit 1 and semi-automatically in Unit 2. During the recirculation phase only, the RHR pumps take suction from the containment sump and discharge to the RCS cold legs. The RHR pumps also discharge to the high-head safety injection pump suctions and charging pump suctions, and also provide flow to the containment spray ring headers. In the case where the break results in RCS depressurization but the RCS remains full, adequate containment pool level (by the NPSH calculation, elevation 80'-10") may not be assured at the typical RWST low-level alarm point. Procedures direct operators to continue injection from the RWST until adequate containment pool level is achieved, or the RWST low-low level set point is reached. After about 14 hours of cold leg recirculation, procedures direct operators to transition to hot leg recirculation by realigning the safety injection pump discharge from the RCS cold legs to the hot legs.

Since the sump strainer head loss testing had not been completed, the initial supplemental response showed allowable strainer head loss values, rather than RHR pump NPSH margins. Three maximum flow configurations (Unit 1 single pump, Unit 2 single pump, and Unit 1 or 2 two pumps) were analyzed for allowable strainer head loss over the expected range of containment sump water temperatures. The first supplemental response indicated that, after subtracting 0.9 ft of head for "retained" margin, the minimum available RHR pump NPSH margins are as follows: (1) 1.80 ft for Unit 1 with one pump running at a maximum 5110 gpm flow at 194 °F; (2) 3.14 ft for Unit 2 with one pump running at a maximum 4980 gpm; and (3) 6.91 ft for both Units with two pumps running with a combined flow of 9000 gpm (rounded up from a maximum calculated flowrate of 8827 gpm).

The assumptions for calculating minimum sump water level include:

- Minimum transfer of water from the RWST to the containment
- Safety injection accumulators containing the TS minimum water volume
- Containment atmosphere water vapor content of 2571 lbm prior to accident.
- Safety injection accumulators that do not inject for the small-break LOCA (SBLOCA)
- Spray additive tank that does not contribute
- Sumps, drainage trenches and piping that are empty pre-accident and are filled at the time recirculation is initiated
- RCS that is at its minimum at power volume post-accident
- Water that does not contribute to the recirculation pool to account for the following:
    - Water to saturate the containment atmosphere
    - Spray header piping filling volume
    - RCS refloods to maximum volume at 100 °F (cooling to a higher water density)
    - Spray water in transit between spray nozzles and containment pool
    - Water held up on horizontal and vertical surfaces, condensation film volume consistent with surface remaining at pre-accident temperature
    - Water filling the reactor cavity and reactor coolant drain tank pit
- Equipment volumes in the containment pool flood zone that do not displace water, only walls, columns and other major structural elements. Flood level is net water volume available divided by the net floor area.

The NPSH required values were taken from the certified vendor pump curves. Although not explicitly stated, they were most likely based on observing the industry standard practice criterion of 3 percent degradation in total developed head for various flow rates. Containment accident pressure is not credited to contribute to NPSH available. A conservative assumption of pre-accident containment partial air pressure (10.1 psia) was assumed present when sump water temperature was below 194 °F. Sump water ranges from 260 °F at saturation pressure for high temperature condition (start of recirculation) to 60 °F at atmospheric pressure for the low temperature condition.

The supplemental response describes the three maximum flow-rate scenarios as bounding any single failure regarding RHR pump NPSH margin and states that Salem emergency operating procedures account for these possibilities.

The first round staff review resulted in the following RAI (Round 1, RAI 18).

18. Please provide description of any changes made to the NPSH calculation and minimum NPSH margins as a result of completion of strainer head loss testing.

NRC STAFF ROUND 2 REVIEW

In response to the RAI, the licensee provided the requested information showing that the NPSH margins remain acceptable throughout the recirculation phase. The NPSH margin was calculated over time. The margin curves were provided in the second and third supplemental response. These curves showed that adequate NPSH margin was maintained for limiting plant conditions. Therefore, the Round 1, RAI 18 response was found to be acceptable.

During the Round 2 review, the NRC staff identified two additional issues regarding the NPSH area. The first issue related to the possibility that a vortex could occur at the pump suctions to the RWST, if the tank was pumped to the low-low level setpoint as directed in the Salem emergency operating procedures (EOPs). The second issue requested that the licensee provide additional details regarding the actions that an operator would take if two entry conditions for swap-over to recirculation could not be met. These issues were transmitted as Round 2 RAI 14 and 15 and are discussed in the Round 3 review below.

NRC STAFF ROUND 3 REVIEW

The review of the second supplemental response found that the NPSH margin question had been satisfactorily addressed, but resulted in two additional RAIs (Round 2 RAI 14 and 15).

RAI Summary for Round 3 RAI 14
RAI 14 requested additional information to determine that that RHR pump suction from the RWST is controlled adequately to provide an adequate suction source and that vortexing in the RWST does not occur. RAI 14, part (a), requested that the licensee provide information regarding adequate pump submergence to prevent vortex formation in the RWST, if the RWST is pumped to the low-low level set point as directed in the plant EOPs under some conditions. Part (b) of the question requested clarification as to whether the licensee Case 1 sump level calculation credited the injection of the accumulators into the sump volume because the accumulators may not inject or fully inject for SBLOCAs.

Summary of Licensee Response to RAI 14

In response to part (a), the licensee stated that the RHR pumps had not been evaluated with respect to vortex formation with the RWST water level at the low-low set point. The licensee stated that this condition is outside of the Salem licensing basis and is very unlikely to occur. The only way that the RWST level would have to be pumped below the low-level set point is if an RWST pipe break occurs outside containment during the injection phase or if the containment level indication fails. Both of these scenarios are outside the Salem licensing basis due to the mechanical design basis of the piping systems and the installation of redundant level indication for the sump. The licensee also stated that anti-vortex devices are installed in the RHR and containment spray pump suction lines at the RWST.

In response to part (b), the licensee stated that Case 1 was evaluated for two conditions. In one condition, the accumulators were assumed to inject. For the other condition, the accumulators were assumed not to inject. Both cases were reported to achieve the minimum required containment flood level prior to reaching the RWST low-low level setpoint. The licensee stated that additional details regarding these cases are provided in the Salem updated supplemental response.

Acceptability of Response and Basis for RAI 14

For RAI 14, the NRC staff agrees that conditions outside the plant licensing basis do not need to be considered when calculating the containment sump level for the GL 2004-02 response. The staff also recognizes that the licensee has installed vortex suppression devices in the pump suction lines to reduce the risk of vortex formation. Because beyond design-basis cases are not required to be evaluated for this response, and adequate sump level is attained without crediting injection of the accumulators into the sump volume, the response to RAI 14 is acceptable.

Summary of Round 3 RAI 15

RAI 15 requested that the licensee provide information regarding what actions operators would take if adequate sump level has not been attained by the time the RWST reaches the low-low level setpoint. This question is based on the direction in the EOP that swapover to recirculation should not be completed until after sump instrumentation indicates adequate level. This question is related to RAI 14.

Summary of Licensee Response to RAI 15

The licensee stated that the Salem supplemental response, Section 3g.5, explains the steps that would be taken if the RWST were exhausted prior to attaining adequate sump level indication. Section 3g.5 states that the operator will continue to operate the RHR pumps, even after the low RWST level alarm is received, until adequate sump level is achieved. However, when the RWST reaches the low-low level, the pumps taking suction from the tank are secured and swapover to recirculation is completed. The licensee also stated that Section 3g.7 of the response explains the only ways in which the RWST could be exhausted prior to attaining adequate level in the sump. These are the two beyond design-basis cases discussed in RAI 14 above.

Acceptability of Response and Basis for RAI 15

Because the postulated condition that resulted in the NRC staff RAI is beyond the Salem design-basis, the response to RAI 15 is acceptable.

The NRC staff has determined that the licensee had used approved methodology for conducting its NPSH evaluation in all areas. The licensee provided adequate responses to the staff RAIs in this area. Therefore, the NRC staff concluded that the licensee has adequately addressed the NPSH area for Salem.

10.0 COATINGS EVALUATION

The objective of the coatings evaluation section is to determine the plant-specific ZOI and debris characteristics for coatings for use in determining the eventual contribution of coatings to overall head loss at the sump screen.

NRC STAFF REVIEW

The NRC staff review is based on documentation provided by the licensee through April 22, 2013.

The break zone ZOI used for calculating amount of qualified epoxy coating debris was 4D, which is acceptable by WCAP-16568-P. There are no qualified inorganic zinc coatings in containment. All qualified and unqualified coatings in the ZOI fail as fine particulate and all debris generated by unqualified coatings in containment failed as fine particulate to maximize transport, which is acceptable by the NRC SE report to NEI 04-07.

Debris transport assumed that 100 percent of the coating debris particulate in the active sump pool would transport to the sump and was used in high level testing, which is acceptable by the NRC SER report to NEI 04-07.

The surrogate material used for testing is acceptable to the NRC staff since the particle size and density are similar to the coating particles.

The licensee’s coating assessment program is acceptable to the staff since the assessment is conducted during each refueling outage, conducted by qualified personnel, and if degraded coatings are identified, these areas are documented and remediation may be performed.

11.0 DEBRIS SOURCE TERM

The objective of the debris source term section is to identify any significant design and operational measures taken to control or reduce the plant debris source term to prevent potential adverse effects on the ECCS and CSS recirculation functions.

NRC STAFF INITIAL REVIEW

This area was closed based on the first licensee supplemental response. The licensee listed and described a robust program of existing procedures to control debris inside containment. In addition, debris reduction, specifically for fiber, has been performed through equipment modifications and insulation change-outs in order to minimize debris burden on the screen. The new coatings program follows updated guidance and is controlled by existing procedures, which the licensee listed and described.

PSEG has existing programmatic controls to ensure that potential sources of debris are not introduced into containment. PSEG has already implemented controls for the procurement, application, and maintenance of Service Level I protective coatings used in containment that is consistent with the licensing basis and regulatory requirements applicable to Salem as stated in PSEG letter dated November 12, 1998 (NRC Legacy Library No. 9811240021); Response to Generic Letter 98-04, "Potential for Degradation of the Emergency Core Cooling System and the Containment Spray System after a Loss-of-Cooling Accident Because of Construction and Protective Coating Deficiencies and Foreign Material in Containment," dated July 14, 1998 (ADAMS Accession No. ML031110081).

Plant modifications are controlled through design change process procedures that ensure that the plant modifications do not create a negative impact on the existing plant components. As part of the newly installed containment sump strainers, Salem has provided additional programmatic control procedures to ensure that potential sources of debris are assessed for adverse effects on the ECCS and CSS recirculation functions. These programmatic controls include requirements related to coatings, insulation, containment housekeeping, material condition, temporary changes, and modifications.

Prior to entering Mode 4 from a refueling outage, a formal containment closeout procedure is performed to ensure that loose materials are removed. The closeout procedure requires a check for foreign materials such as tape, equipment labels, construction and maintenance debris (e.g., rags, plastic bags, packaging, sawdust, etc.), and temporary equipment (e.g., scaffolding, ladders, insulation material, etc). Additionally, the walkdown requires operations personnel to check for dirt, dust, lint, paint chip buildup, and loose paint/coatings on surfaces such as walls or floors in containment.

As part of containment closeout, the ECCS containment sump and sump screens are inspected for damage and debris, as directed by procedure. Refueling canal drains are verified to be unobstructed and it is verified that there are no potential debris sources in the refueling canal area that could obstruct the drains.

Salem has procedures in place to control the introduction of foreign material inside containment, which provide overall necessary requirements and guidance to prevent and control introduction of foreign materials into structures, systems, and components. This procedure also controls investigation and recovery actions when foreign material exclusion (FME) integrity is lost or unexpected foreign material is discovered. All containment entries during Modes 1 through 4 are done in accordance with a procedure, which requires that all material taken into containment is either installed or removed upon exit. The final disposition of the material is documented in the FME area accountability log. Due to the possibility of an emergency evacuation of containment, the procedure requires minimizing the material left unsecured and unattended, while working in the containment building.

NRC STAFF FINAL REVIEW

The NRC staff reviewed Salem's final supplemental response to determine if changes had been made to the response that was accepted during the first round review. There were no significant changes between the licensee's first and final submittals. Therefore, the conclusions reached by the initial review remain valid. Salem has robust programmatic controls to minimize the potential for the introduction or generation of debris from unevaluated sources, to verify that the strainer is in good physical condition, and to verify that significant drainage paths are open and unlikely to be blocked by debris. Therefore, the debris source term area has been addressed adequately by the licensee.

12.0 SCREEN MODIFICATION PACKAGE

The objective of the screen modification package section is to provide a basic description of the sump screen modification.

INITIAL NRC STAFF REVIEW:

The initial NRC staff review is based on documentation provided by the licensee through March 31, 2009.

By letters dated February 29, 2008 (ADAMS Accession No. ML080800469), and March 31, 2009 (ADAMS Accession No. ML091000557), PSEG submitted and subsequently updated the supplemental response to GL 2004-02 for Salem, Units 1 and 2. The NRC staff reviewed the initial and updated response and found the updated response to adequately describe the modification made to Salem, Units 1 and 2, to resolve the issues identified in GL 2004-02. The following is a summary of the staff initial review:

The licensee stated that it performed the physical changes necessary to bring Salem, Unit 1 and 2, into full resolution with GL 2004-02. This involved removing the ECCS containment sump outer cage and inner screen and installing new ECCS containment sump strainer modules in each unit. The sumps are located in the outer annulus area on elevation 78 foot of the Salem, Unit 1 and 2, Containment Buildings. Each sump is surrounded by a concrete curb with the top of the curb at elevation 78 foot-9 inches. The inside of the sump is partitioned into two sides: the non-safety side that collects water from the trenches around the biological shield wall, and the ECCS side that takes water from the floor at elevation 78 foot to supply the RHR pumps following a LOCA.

The new strainer in each unit consists of a series of strainer modules installed along the outer containment wall between the existing containment sump and the pressure relief tank. The strainer modules are passive strainers that were engineered, qualified, and manufactured by CCI. In order to maximize the surface area in a small footprint, each strainer module has pockets attached to the front and back of the module with a flow channel in the center. The modules are either 10-pocket modules or 15-pocket modules. The 10-pocket modules are 10 pockets wide and 7 pockets high, whereas the 15-pocket modules are 15 pockets wide and 7 pockets high. The pockets are made of stainless steel plate with 1/12-inch diameter holes.

The ECCS side of the sump is covered with a stainless steel enclosure made of 6-mm thick solid plate. The enclosure has an access panel that allows entry into the sump for maintenance and inspection. Inside the sump enclosure is a diffuser at the water inlet to help reduce turbulence.

There are two level transmitters located in each sump with a span of 204 inches. These level transmitters are three-stage transmitters such that the bottom stage is fully submerged in the sump, the top stage is completely outside the sump, and the middle stage overlaps the two. Therefore, the top of the sump enclosure has sealing plates that fit around the level transmitters and/or conduit. The 1/8-inch mesh partition between the two sides of the sump was sealed with a solid plate to prevent communication between the two sides. This forces water from the non-safety side of the sump back up through the trenches, onto the floor at elevation 78 foot and through the new strainer modules. This tortuous path helps to allow debris to settle, limiting the amount transported to the sump.

The strainer modules are connected end-to-end and attached to the sump enclosure through a connection duct. The connection duct has internal vanes to reduce turbulence through the duct. The final result is a train of strainer modules that extends approximately a quarter of the way around the outer annulus and allows flow of water to the sump and the RHR pumps.

A 9-inch tall debris interceptor is bolted to the front feet of the strainer modules to prevent large debris from reaching the strainer pockets. The debris interceptor is made of grating with bearing bars on 15/16-inch centers and cross bars on 4-inch centers. Attached to the back of the grating is a perforated plate with 1/8-inch diameter perforations. The top of the debris interceptor has an overhanging lip that keeps larger debris from lifting off the floor and flowing over the trash rack. At the end of the strainer train, the debris interceptor wraps around the side and extends to the containment liner to limit debris transport to the back of the strainers.

Other modifications include modifying three out of the four biological shield wall doors to prevent blockage of the flowpath and replacing portions of calcium silicate, Min-K and NUKON® insulation with RMI.

FINAL NRC STAFF REVIEW

Although the description of the screen modifications was accepted by the NRC staff, the licensee resubmitted its GL 2004-02 response on April 27, 2012 (ADAMS Accession Nos. ML12129A388, ML12129A389, and ML12129A390). The Screen Modification Package section of the resubmitted response is nearly identical to the previous submittal, with no technical changes.

NRC STAFF FINAL CONCLUSION

The NRC staff reviewed the strainer modifications, as described in the licensee's GL-2004-02 response to Item (3j) in letters dated February 29, 2008, March 31, 2009, and April 27, 2012, (ADAMS Accession Nos. ML080800469, ML091000557, and ML12129A388, respectively) and concludes that the sump strainer modifications at Salem, Units 1 and 2, are adequate to address the issues identified in GL 2004-02.

13.0 SUMP STRUCTURAL ANALYSIS

The objective of the sump structural analysis section is to verify the structural adequacy of the sump strainer including seismic loads and loads due to differential pressure, missiles, and jet forces.

INITIAL NRC STAFF REVIEW

The initial staff review is based on documentation provided by the licensee through February 29, 2008.

The NRC staff review of the information provided by the licensee documented in the NRC's Final Audit Report for Salem, Units 1 and 2, led to the conclusion that the licensee has not adequately addressed the information requested by the Revised Content Guide for GL 2004-02 Item 2(d)(vii). Specifically, the NRC staff's audit report included an Open Item (5.1-1) pertaining to the head loss testing, which was to verify the assumptions relied upon in the structural qualification of the replacement sump strainers. This item was not addressed by the licensee and remained open.

The evaluation performed by the licensee for the replacement sump strainer structure demonstrated compliance with the appropriate requirements of the American Institute of Steel Construction (AISC), Manual of Steel Construction, 6th Edition, the American Society of Mechanical Engineers Boiler and Pressure Vessel Code (ASME B&PV Code), Section NF, and ASME B31.1, Power Piping. The NRC staff's audit report for Salem confirmed this fact and stated that all stresses were below code-allowable limits.

Utilizing ANSYS structural analysis software, finite element analyses were performed by the licensee on the replacement sump strainers and supports. The analyses subjected the structural models to loading combinations associated with differential pressure, self-weight, debris weight, live loads, and seismic loads (including hydrodynamic mass). These loads are consistent with the instructions given in NEI 04-07. The stresses induced in the structure were then compared to the allowable values given in the aforementioned Code documents. As confirmed by the NRC staff's evaluation in the audit report, all stresses were shown to be below the code allowable limits.

To address potential dynamic effects associated with a high-energy line break (HELB) on the replacement sump strainers, the licensee stated that the strainers are protected from HELB of the coolant loop piping by the bio-shield wall and refueling floor. The remaining high-energy sources were determined to be at an appropriate distance to preclude structural damage to the strainers. This conclusion was confirmed in the NRC staff's Audit Report.

The information provided by the licensee shows that the sump structural evaluation contains inherent conservatism by complying with the accepted design codes (e.g., ASME B&PV Code, AISC 6th Edition, etc.). All provided interaction ratios were within the allowable limits (e.g., less than 1.0) with the maximum value being 0.992. A thorough review of pertinent calculations and submittals was performed during the audit of Salem's proposed solution to GL 2004-02. In all reviewed areas associated with structural qualification, the NRC staff concluded that the licensee had provided reasonable assurance that the strainers were adequate to perform the intended design function without compromise. However; in the Salem audit report, the NRC staff noted that the qualification of the strainer module was acceptable, subject to the outcome of the strainer head loss and chemical effects testing. This fact was stated in Open Item 5.1-1 of the audit report. The information provided by the licensee did not address the testing or its impact on the assumptions of the structural qualification. For this reason, the NRC could not make a final conclusion on the structural qualification of the new Salem, Units 1 and 2 strainers.

RAI-19:

Please address Open Item 5.1-1 in the NRC's GL 2004-02 audit report for Salem which stated:

> Open Item 5.1-1: Based on strainer head loss and chemical effects testing, confirm that the head loss values used in the strainer module structural evaluation are conservative or revise the strainer module structural evaluation to reflect the maximum expected pressure drop across the strainer. Provide a summary of the results to NRC staff for review.

FINAL NRC STAFF REVIEW:

The NRC final staff review is based on the licensee's RAI response dated April 27, 2012.

The NRC staff considers the licensee's response to RAI 19 acceptable. This RAI referenced Audit Open Item 5.1-1, which requested that the licensee confirm that sufficient conservatism was employed with regards to the head loss (pressure drop) values used in the structural analyses of the replacement strainers. The licensee summarized the updated NPSH calculations and provided additional detail regarding the relationship between the structural margin and NPSH values. Based on the licensee's strainer head loss calculations found in Section 3f.10 of Attachment 1 to the April 12, 2012, response, the maximum strainer head loss was 12.87 ft.(for Unit 2 two-pump operation). The licensee indicated that the maximum pressure difference used in the original structural analyses of the strainer components was 5.8 psi (head loss of 13.12 ft) and that a subsequent structural analysis established the structural limit of thee strainer as 16.94 ft. Given the fact that the structural limit of 16.94 ft. bounds the maximum strainer head loss values, the NRC staff concludes that the licensee has employed a sufficient amount of conservatism with respect to the pressure differences used in the structural analyses of the strainers. The NRC staff considers this area closed for GL 2004-02.

14.0 UPSTREAM EFFECTS

The objective of the upstream effects assessment is to evaluate the flowpaths upstream of the containment sump for holdup of inventory which could reduce flow to and possibly starve the sump.

INITIAL NRC STAFF REVIEW:

Sources of water for the Salem sump include the RWST, the accumulators, and the RCS. The volumes of these sources are presented in the licensee's submittal. One of the holdup mechanisms is holdup of spray water in the refueling cavity. Section 3.g.8 of the submittal states that containment spray water is trapped in the refueling cavity. Attachment 3 states that a break that would generate debris that could block the refueling cavity drain would not "result in immediate filling of the reactor cavity," and a break that would fill the reactor cavity would not lead to blockage of the refueling canal drain lines. As a result, the licensee used the reactor cavity, the larger of the two volumes, for the limiting case for holdup. The NRC staff reviewed these arguments during the GSI-191 audit for Salem, and accepted the licensee conclusions.

As part of the minimum flood level and debris transport calculations, flowpaths were identified for returning water to the recirculation sump strainer and possible holdup locations were considered. The flowpaths were modeled in a CFD analysis as part of the transport calculation.

A break in the RCS piping at the SGs could generate debris that could block the reactor cavity drain. However, this break will not result in immediate filling of the reactor cavity. To block the reactor cavity drain, a piece of debris could be blown up between an SG and its enclosure wall. This debris could land on the refueling cavity drain on elevation 130'. With the drain blocked, any of the containment spray discharge falling into the refueling cavity would be held up and not be available for the recirculation pool inventory. Conversely, a break at the reactor nozzle that leads to direct filling of the reactor cavity will not generate the amount of debris needed to block the refueling cavity drain. Therefore, the concurrent use of both of these hold up volumes for determining minimum flood level for switchover to recirculation operation is not credible at Salem, Unit 1 or 2. Because the reactor cavity has the largest volume, the reactor cavity is considered the limiting case for ECCS inventory hold up for both Salem units.

The sump pit is surrounded by a 9-inch high curb. Neither the debris interceptor nor the sump curb creates holdup volumes, as they are located in the outer annulus area of the containment. At switchover to recirculation operation, all curbs and debris interceptors in the annulus area are fully submerged in the sump pool. Since the curbs and interceptors have already been fully submerged, water flows over them and is not held up.

Water on the containment floor will not flow into the reactor cavity prior to switchover because the curb around the cavity is above the minimum flood level. The minimum flood level calculation conservatively assumes that the reactor cavity fills at the start of the LOCA before water begins spilling onto the containment floor. As discussed above, this holdup volume is assumed to be filled prior to the swapover to recirculation. With this assumption, there is still adequate water to cover the strainers to its minimum design submergence.

Flowpaths from the inner annulus to the outer annulus (where the strainers are located) have been modified to remove potential obstructions that could collect debris and block flow.

Based upon the information that has been reviewed and summarized in the audit report and the Supplemental Response, the NRC staff concluded that water drainage in the Salem containments would not be susceptible to being trapped other than in the analyzed hold up locations. Therefore, the upstream effects area has been adequately addressed.

NRC STAFF FINAL REVIEW

There were no significant changes made in the final Salem supplemental response in the area of upstream effects. Therefore, the conclusions drawn by the NRC staff during previous reviews remain valid. The upstream effects area has been adequately addressed.

15.0 DOWNSTREAM EFFECTS - COMPONENTS AND SYSTEMS

The objective of the downstream effects, components and systems section is to evaluate the effects of debris carried downstream of the containment sump screen on the function of the ECCS and CSS in terms of potential wear of components and blockage of flow streams.

INITIAL NRC STAFF REVIEW:

The initial NRC staff review is based on documentation provided by the licensee through March 31, 2009.

By letters dated February 29, 2008, and March 31, 2009, (ADAMS Accession Nos. ML080800469 and ML091000557, respectively), PSEG submitted and subsequently updated the supplemental response to GL 2004-02 for Salem, Units 1 and 2. The NRC staff reviewed the initial and updated response and found the updated response to adequately address the effects of ECCS sump strainer bypassed debris on downstream components and systems external to the RPV. The following is a summary of the staff initial review:

The licensee's supplemental response contained the information requested in the revised content guide. The licensee stated that it evaluated the downstream effects of debris ingested into the ECCS during containment sump recirculation operation using the methods described in Revision 1 of TR-WCAP-16406-P, including the limitations and conditions contained in the associated NRC SE. The evaluation addressed the effect of debris ingestion on equipment in the ECCS and CSS, including valves, pumps, heat exchangers, orifices, spray nozzles, and instrumentation. The equipment evaluations included erosive wear, abrasion, and potential blockage of flow paths and used plant-specific depletion coefficients based on flow rates, volumes and settling velocities. These depletion coefficients also credited filtration of particulates, as well as fibers on the sump screen where such filtration is supported by plant-specific testing. The evaluations show that the ECCS equipment at Salem will remain capable of passing sufficient flow to the reactor to adequately cool the core during the recirculation phase of a postulated LOCA.

Because the licensee demonstrated that the ECCS equipment downstream of the ECCS sump strainers can perform their safety-related functions to mitigate the consequences of a HELB or LOCA using analytical methods prescribed in TR-WCAP-16406-P, Rev 1 and the associated NRC SE (including limitations and conditions), the NRC staff concluded that the downstream effects of debris-laden recirculated sump fluid on ex-vessel downstream components and systems had been adequately addressed at Salem, Units 1 and 2.

FINAL NRC STAFF REVIEW:

Although the downstream-effects evaluation was accepted by the NRC staff, the licensee submitted an updated GL 2004-02 response on April 27, 2012 (ADAMS Accession Nos. ML12129A388, ML12129A389, and ML12129A390). The ex-vessel downstream effects evaluation section of the update is identical to the previous submittal, except as follows:

In its letter dated April 27, 2012, the licensee modified the wear evaluation results for the safety injection (SI) pumps. The licensee stated that in-service testing of the SI pumps indicated some wear due to normal operation. During every refueling outage, the SI pumps are tested to ensure that they provide the required flow rate. This information is used to ensure that the SI pumps will perform their intended function during their 2-day mission time after a postulated LOCA when debris-laden fluid passes through them. The licensee stated that the evaluation shows that the SI pumps will perform their intended function during the recirculation phase of a LOCA. The licensee stated that any degrading trends noted during in-service testing that could potentially impact the availability of the SI pumps for the remaining life of the plant will be entered into PSEG's corrective action program to evaluate and resolve the concern.

The licensee stated that based on the evaluation performed by NRC staff (Memorandum from Ervin Geiger (NRC) to Michael. Scott (NRC); Subject: Basis for Excluding Chemical-Effects Phenomenon from WCAP-16406-P Ex-Vessel Downstream Evaluations, dated January 21, 2010 (ADAMS Accession No. ML093160100)), the effects of chemical precipitates that could form in a PWR post-LOCA environment on the safety-related functions of ECCS and CSS components had not been further evaluated.

In the letter dated April 27, 2012, the licensee concluded that the Salem ECCS components and systems that are required to operate and pass debris-laden fluid during the recirculation phase of recovery from a postulated LOCA will remain capable of passing sufficient flow to the reactor to adequately cool the core.

NRC STAFF FINAL CONCLUSION

The NRC staff reviewed the description of the analyses as described in the licensee's GL 2004-02 response to Item (m) in letters dated February 29, 2008, March 31, 2009, and April 27, 2012 (ADAMS Accession Nos. ML080800469, ML091000557, ML12129A388, respectively). Because the licensee demonstrated that the ECCS equipment downstream of the ECCS sump strainers can perform their safety-related functions to mitigate the consequences of a HELB or LOCA using analytical methods prescribed in TR-WCAP-16406-P, Rev 1 and the associated NRC SE (including limitations and conditions), the NRC staff concludes that the downstream effects of debris-laden recirculated sump fluid on ex-vessel downstream components and systems had been adequately addressed at Salem, Units 1 and 2.

16.0 DOWNSTREAM EFFECTS - FUEL AND VESSEL

The objective of the downstream effects, fuel and vessel section is to evaluate the effects that debris carried downstream of the containment sump screen and into the reactor vessel has on core cooling.

INITIAL NRC STAFF REVIEW

The initial staff review is based on documentation provided by the licensee through April 27, 2012.

By letter dated February 29, 2008 (ADAMS Accession No. ML080800469), PSEG submitted a supplemental response to GL 2004-02. This submittal stated that PSEG was in the process of completing an in-vessel downstream effects evaluation that would be included in a future supplement. In response to this submittal, the NRC staff generated the following RAI (RAI-21) regarding the Salem in-vessel downstream-effects evaluation.

> The NRC staff considers in-vessel downstream effects to not be fully addressed at Salem, as well as at other pressurized water reactors. PSEG's submittal refers to Revision 0 of the Pressurized-Water Reactor Owners Group (PWROG) topical report WCAP-16793-NP, "Evaluation of Long-Term Cooling Considering Particulate, Fibrous, and Chemical Debris in the Recirculating Fluid." At this time, the NRC staff has not issued a final safety evaluation (SE) for this topical report since the PWROG intends to submit Revision 1 to address several issues identified by the Advisory Committee on Reactor Safeguards and the NRC staff. The licensee may demonstrate that in-vessel downstream effects issues are resolved for Salem by showing that the Salem plant conditions are bounded by the revised version of WCAP-16793 and the corresponding final NRC staff SE, and by addressing the conditions and limitations in the final SE. The licensee may also resolve this item by demonstrating, without reference to WCAP-16793 or the staff SE, that in-vessel downstream effects have been addressed at Salem. In any event, the licensee should report how it has addressed the in-vessel downstream effects issue within 90 days of issuance of the final NRC staff SE on WCAP-16793. The NRC staff is developing a Regulatory Issue Summary to inform the industry of the staff's expectations and plans regarding resolution of this remaining aspect of Generic Safety Issue 191.

By letter dated March 31, 2009 (ADAMS Accession No. ML091000557), the licensee re-stated that the in-vessel downstream effects analysis was not yet complete. The licensee stated that it would provide a response to RAI 21 within 90 days of the issuance of the final NRC SE on WCAP-16793-NP. However, the licensee completed an in-vessel chemical effects analysis for Salem based on guidance from the "Draft NRC Staff Review Guidance for Evaluation of Downstream Effects of Debris Ingress into the PWR RCS on Long Term Core Cooling Following a LOCA," WCAP-16793-NP, and Option 2 of the additional guidance for modeling post-LOCA core deposition, which is contained in the enclosure to PWROG letter OG-07-534. The licensee stated that it would provide a final response within 90 days of the issuance of the final NRC SE on WCAP-16793-NP.

By letter dated April 27, 2012, the licensee submitted a final supplemental response to GL 2004-02. In the supplement, the licensee stated that the in-vessel downstream- effects analysis for Salem utilizes the WCAP-16793-NP, Revision 2, methodology and addresses both material deposition on the fuel rods and core blockage due to fibrous debris which could bypass the containment sump strainer. Because the NRC had not yet issued an SE for WCAP-16793-NP, the in-vessel downstream effects evaluation may require revision after the SE is issued.

NRC staff did not perform an evaluation of the licensee's submittal for Salem in this area as the NRC SE on WCAP-16793-NP, Revision 2 had not been completed at the time of the submittal.

<u>FINAL NRC STAFF REVIEW</u>

By letter dated July 11, 2013, (ADAMS Accession No. ML13192A417) the licensee submitted the GL 2004-02 in-vessel downstream-effects resolution for Salem, Units 1 and 2. The final NRC staff review is based on the licensee's July 11, 2013, letter.

Evaluation criteria

On April 8, 2013, the NRC staff issued an SE for TR-WCAP-16793-NP, Revision 2, finding it an acceptable model for assessing the effect of sump strainer bypassed fibrous, particulate, and chemical debris on core cooling in PWRs (ADAMS Accession No. ML13084A154). The TR guidance and acceptance bases were developed through analyses and flow testing using representative fuel assemblies and ECCS flow rates. In order to demonstrate adequate core cooling capability, the limitations and conditions section of the NRC SE of the TR, and GL 2004-02 response content guide (ADAMS Accession No. ML073110278) require certain actions of the licensees. These requirements and the licensee's actions for meeting these requirements are described herein.

The GL 2004-02 response content guide required the response to item n, "Downstream Effects - Fuel and Vessel," to confirm that the licensee's evaluation is consistent with, or bounded by, the industry generic guidance contained in TR-WCAP-16793-NP, Revision 2, as modified by the NRC staff's conditions and limitations stated in the NRC SE on that document. Also, the response shall briefly summarize the application of the WCAP evaluation methods and include the following information:

a) The available driving head and ECCS flow rate used in the evaluation of the hot-leg break LOCA scenario,

b) The type(s) of fuel and inlet filters installed in the plant,

c) The results of the LOCADM calculation, including the predicted peak clad temperature,

d) The amount of fiber (in grams per fuel assembly) that is assumed to reach the core inlet after a LOCA and,

e) The method(s) used to estimate the quantity and size distribution of the fibrous debris that would pass through the ECCS sump strainer and reach the core inlet during a LOCA.

   (Note: The Limitations and Conditions Section of the NRC SE of WCAP-16793-NP, Revision 2, states that licensees may determine the quantity of debris that passes through their strainers by: (1) performing strainer bypass testing using the plant strainer design, plant-specific debris loads, and plant-specific flow velocities; (2) relying on strainer bypass values developed through strainer bypass testing of the same vendor and same perforation size, prorated to the licensee's plant-specific strainer area; approach velocity; debris types, and debris quantities; or (3) assuming that the entire quantity of fiber transported to the sump strainer passes through the sump strainer. Further, NRC staff review of the Nuclear Energy Institute document, "Clean Plant Acceptance Criteria for Emergency Core Cooling Systems," as documented in a letter from dated May 2, 2012 (ADAMS Accession No. ML120730181), allows an assumption of 75 percent transport and 45 percent fiber pass-through for a typical perforated strainer if a plant can demonstrate that the total in-containment latent fiber plus fibrous insulation located within the zone-of-influence is less than 20 lbm.

   When applying the above criteria, the licensee shall ensure that the width of any gaps in the strainer assembly does not exceed the diameter of the strainer perforations and the total area of the gaps does not exceed 1 percent of the total strainer perforation area.

f) A description of any deviations from, or exceptions to the WCAP or the NRC SE of the WCAP.

In the PSEG letter to NRC dated July 11, 2013, [responding to Request for Additional Information #21 regarding in-vessel downstream effects], PSEG provided the following information:

PSEG performed a plant-specific evaluation for Salem using WCAP-16793-NP, Revision 2, and the associated NRC SE of that document. The evaluation results are:

1. The maximum calculated cladding temperature is 384 °F. This is less than the WCAP-recommended maximum cladding temperature of 800 °F.

2. The total deposition thickness is 0.0284 inch (28.4 mils). This is less than the recommended total debris deposition thickness of 0.050 inch.

3. Based on Salem-specific strainer bypass testing, the fiber calculated to bypass the strainers and reach the fuel assembly is 10.6 grams per fuel assembly. This quantity is less than the WCAP-16793-NP acceptance criteria of 15 grams per fuel assembly.

Also, in the letter dated July 11, 2013, the licensee satisfactorily demonstrated compliance with the 14 Limitations and Conditions of the NRC SE of WCAP-16793-NP-A, Revision 2.

Based on the above information, the licensee concluded that Salem, Units 1 and 2, meet the requirements specified in WCAP-16793-NP, Revision 2, and the specifications, limitations, and conditions listed in the associated NRC SE. Therefore, Salem, Units 1 and 2, are in compliance with the requirements of GL 2004-02.

NRC STAFF FINAL CONCLUSION

The NRC staff reviewed the description of the analyses, strainer bypass testing, and compliance with the Limitations and Conditions of the SE, as described in the licensee's GL 2004-02 response to Item (n) and find that the PSEG response addressing in-vessel downstream-effects for Salem, Units 1 and Unit 2, satisfies the requirements stated in TR-WCAP-16793-NP-A, Revision 2, and the NRC SE of that document. Therefore, the NRC staff concludes that the licensee has adequately addressed the potential effects of ECCS sump strainer-bypassed debris on core cooling at Salem, Units 1 and 2. The NRC staff considers this item closed for GL 2004-02.

17.0 CHEMICAL EFFECTS

The objective of the chemical effects review is to evaluate the potential for chemical reactions within the sump pool and to determine the potential effects of chemical products on head loss across the strainer debris bed and any debris that collects within the reactor.

Salem's initial chemical effects evaluation was impacted by subsequent changes to the plant-specific debris generation calculation. Salem re-evaluated their debris generation and transport evaluations to account for a change in the NUKON® insulation zone of influence (ZOI) from the assumed 7D ZOI to a 17D ZOI. The revised debris generation evaluation determined that additional debris would be created and that this debris would increase the calculated amount of chemical precipitates that are present in the post-LOCA sump. The Salem, Unit 2 design-basis head loss test included the quantity of chemical precipitates that accounts for the full amount predicted using the larger ZOI value. Since the Unit 2 design-basis test was performed using the WCAP-16530-NP-A protocol that has been previously accepted by the NRC, the staff finds the Salem, Unit 2 chemical effects evaluation acceptable. The Salem, Unit 1 design-basis head loss test did not, however, include chemical precipitate amounts that would fully represent the revised amounts of chemical debris predicted using the WCAP-16530-NP-A methodology. The amount of WCAP-16530-NP-A precipitates added to the Salem, Unit 1 design-basis test amounted to approximately 70 percent of the amount predicted by that methodology with the larger 17D ZOI value for NUKON®.

Although the Salem design-basis test of record did not include the entire chemical load predicted by the WCAP-16530-NP-A methodology, the NRC staff concludes the design-basis test is acceptable for a number of reasons. As has been observed by NRC staff at other plant strainer head loss tests, the Salem design-basis tests results showed that the addition of chemical effects, past a point, did not result in additional head loss. For the design-basis tests for Units 1 and 2, the peak head loss value occurred before 30 percent of the total chemical precipitate was added to the test loop. In each case, after an initial peak head loss value created by precipitate addition is reached, the strainer bed is unable to maintain its structure and bed shifting causes a significant head loss decrease. These bed shifts were observed by the NRC staff during a trip to observe the Salem head loss testing and also during review of test photographs. Although subsequent chemical precipitate additions increased the head loss in some cases, the head loss values never approaches the initial peak head value used by the licensee and the overall head loss trend is stable at the conclusion of the test. This supports the NRC staff conclusion that an additional batch of WCAP-16530-NP-A precipitate addition (to reach 100 percent of the predicted amount for the Unit 1 test) would not have resulted in a head loss greater than the value used by the licensee.

In addition to the two design-basis tests with WCAP-16530-NP-A precipitates, Salem provided the inputs and results from two earlier tests that used a different technique to simulate chemical effects. These tests were run to assess the performance of the strainers at an earlier stage of the design process and are not intended to be tests of record. Nevertheless, the head loss results are informative in that precipitates were generated by injecting chemicals into the loop over time to cause precipitation instead of adding pre-mixed precipitates. The NRC staff reviewed the debris loads that were used for each test based on the staff audit report of Salem and the GL 2004-02 submittals. The staff noted that the non-chemical debris loads were very similar. The head loss response to chemical precipitation resulting from chemical injection is similar with significant increases in head loss followed by decreases due to debris bed shifting. In contrast to the tests with pre-mixed precipitates, however, the head loss slowly increases and stabilizes at the highest level after all chemical precipitates were formed in-situ from chemical injection. For Unit 1, the total chemical injection represents an amount representative of the calculated amount with the17D ZOI for NUKON®. Although the earlier head loss tests with chemical injection were not used, it is important to note that the actual Salem design-basis test for Unit 1 (with pre-mixed WCAP-16530-NP-A precipitates) resulted in an approximately 2X higher head loss. Although not a test of record, the NRC staff considered the earlier test to be informative since: (1) it showed similar evidence of debris bed shifting though not to the same degree as the design-basis test that had greater head loss; and (2) even with the calculated formation of a full chemical precipitate load and the a stable peak head loss occurring later in the test after all precipitate was formed, the peak head loss obtained from this test is bounded by the design-basis test.

The NRC staff considered one additional item when evaluating the Salem, Unit 1 design-basis test that did not use the full chemical precipitate load calculated by the WCAP-16530-NP-A methodology. The licensee's chemical effects analysis assumes the 30 day chemical load once the sump pool temperature has cooled to 160 ^{0}F temperature. Using the Salem plant-specific inputs to the Argonne National Laboratory Equation 4 for aluminum solubility (ADAMS Accession No. ML091610696), the NRC staff determined that the licensee precipitation assumption is conservative since significant aluminum solubility is predicted for a pH of 8.4 and a 160 ^{0}F pool temperature. In other words, the WCAP-16530-NP-A methodology calculation that assumes all dissolved aluminum precipitates contains significant margin for the Salem plant-specific conditions.

The NRC staff concludes that Salem chemical effects test program adequately evaluates precipitates effects on strainer head loss. The Unit 2 evaluation is acceptable based on using the WCAP-16530-NP-A methodology previously approved by the NRC staff. The Unit 1 design-basis strainer test, that used only about 70 percent of the chemical precipitate quantity predicted by the WCAP-16530-NP-A methodology, is also acceptable to the staff since: (1) the peak head loss in this test occurred before 30 percent of the total precipitate quantity was added; (2) head loss in other plant tests that added a full chemical load, but injected chemicals to form precipitates in the test loop, were bounded by the design-basis test; (3) the Salem plant specific conditions at the point where the full precipitate load is assumed contains some significant margin due to aluminum solubility.

18.0 LICENSING BASIS

The objective of the licensing basis section is to provide information regarding any changes to the plant licensing basis due to changes associated with GL 2004-02.

In its supplemental response letter dated April 27, 2012, the licensee stated that changes to the Salem UFSAR were approved and incorporated in support of implementation of the physical plant modifications associated with the containment sump upgrades in accordance with 10 CFR 50.71(e). These changes included:

- a revised description of containment sump strainer and debris interceptor design
- revised NSPHa values for ECCS pumps and recirculation containment spray using RHR pumps.
- changes for consistency with the debris generation and debris transport calculations changes related to the containment sump level instrumentation.

FINAL NRC STAFF CONCLUSION

For this review area, the licensee has provided information, such that the NRC staff has reasonable assurance that the subject review area has overall been addressed appropriately. Based on the information provided by the licensee, the NRC has confidence that the licensee affected the appropriate changes to the Salem, Units 1 and 2 UFSAR, in accordance with 10 CFR 50.71(e), that reflect the changes to the licensing basis as a result of corrective actions made to address GL 2004-02. Therefore, the NRC considers this item closed for GL 2004-02.

19.0 CONCLUSION

The NRC staff has performed a thorough review of all licensee's responses and RAI supplements to GL 2004-02. The NRC staff conclusions are documented above. Based on the above evaluations the NRC staff finds the licensee has provided adequate information as requested by GL 2004-02.

The stated purpose of GL 2004-02 was focused on demonstrating compliance with Part 50 Section 50.46. Specifically the GL requested addressees to perform an evaluation of the ECCS and CSS recirculation and, if necessary take additional action to ensure system function, in light the potential for debris to adversely affect long term core cooling. The NRC staff finds the information provided by the licensee demonstrates that debris will not inhibit the ECCS or CSS performance of its intended function in accordance with 10 CFR 50.46 to assure adequate long term core cooling following a design-basis accident.

Therefore the NRC staff finds the licensee's responses to GL-2004-02 are adequate and considers GL-2004-02 closed for the Salem Nuclear Generating Station, Units 1 and 2.