U.S. NUCLEAR REGULATORY COMMISSION STAFF REVIEW

OF THE DOCUMENTATION PROVIDED BY

DUKE ENERGY CAROLINAS, LLC

FOR THE CATAWBA NUCLEAR 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 coolant system (RCS) piping to ensure 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. 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 pressurized water reactors (PWRs) once the primary water source has been depleted.

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 and the reactor core, 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. This could result in reduce core cooling and potential core damage. If the ECCS strainer were to remain functional, even with core cooling reduced, containment cooling would be maintained and the containment function would not be adversely affected.

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, 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 research findings prompted the U.S. Nuclear Regulatory Commission (NRC) to open Generic Safety Issue (GSI)-191, "Assessment of Debris Accumulation on PWR Sump Performance," in 1996. This resulted in new research for PWRs in the late 1990s. GSI-191 focuses on reasonable assurance that the provisions of Title 10 of the *Code of Federal Regulations* (10 CFR) Section 50.46(b)(5) are met. This rule, which is deterministic, requires maintaining 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 and 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 concluded that debris clogging of sump strainers could lead to recirculation system ineffectiveness as a result of a loss of net positive suction head (NPSH) for the ECCS and CSS recirculation pumps. 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.

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), on June 9, 2003. 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 emergent issues discussed in Bulletin 03-01, the NRC staff requested an expedited response from PWR licensees on the status of their compliance of regulatory requirements concerning the ECCS and CSS recirculation functions based on a mechanistic analysis. The NRC staff asked licensees, who chose not to confirm regulatory compliance, to describe any interim compensatory measures that they had implemented or will implement to reduce risk until the analysis could be completed. All PWR licensees responded to Bulletin 03-01. The NRC staff reviewed all licensees Bulletin 03-01 responses and found them acceptable.

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, that information was not requested in the Bulletin 03-01, but licensees were informed that the NRC staff was preparing a generic letter (GL) that would request this information. 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 Bulletin 03-01. This document set the expectations for resolution of PWR sump performance issues identified in GSI-191, to ensure the reliability of the ECCS and CSS at PWRs. NRR requested and obtained the review and endorsement of the GL from the CRGR (ADAMS Accession No. ML040840034).

The 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 are requested to submit the information specified in this letter to the NRC. This request is based on the identified potential susceptibility of PWR recirculation sump screens to debris blockage during design basis accidents requiring recirculation operation of ECCS or CSS and on the potential for additional adverse effects due to debris blockage of flowpaths necessary for ECCS and CSS recirculation and containment drainage. The GL 2004-02 required addressees to provide the NRC a written response in accordance with 10 CFR 50.54(f).

By letter dated May 28, 2004 (ADAMS Accession No. ML041550279), the Nuclear Energy Institute (NEI) submitted s a report describing a methodology for use by PWRs in the evaluation of containment sump performance. 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 starts with a conservative baseline evaluation. The baseline evaluation 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 adverse containment sump blockage for a given plant design. The baseline evaluation also facilitates the evaluation of potential modifications that can enhance the capability of the design to address sump debris blockage concerns and uncertainties and supports resolution of GSI-191. The report offers additional guidance that can be used to modify the conservative baseline evaluation results through revision to analytical methods or through modification to the plant design or operation.

By letter dated December 6, 2004 (ADAMS Package Accession No. ML043280641), the NRC issued an evaluation of the NEI methodology. The NRC staff concluded that the methodology, as approved in accordance with the NRC staff safety evaluation (SE), provides an acceptable overall guidance methodology for the plant-specific evaluation of the ECCS or CSS sump performance following postulated design basis accidents.

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 (ADAMS Accession No. ML081000027), 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," issued March 2008 (ADAMS Accession No. ML081150379) was submitted by the PWROG to provide a consistent approach for plants to evaluate the chemical effects which may occur post-accident in containment sump fluids. The NRC staff reviewed WCAP-16530 and issued an SE that concluded the WCAP, as modified by the NRC staff's limitations and conditions (L&C), which provides an acceptable technical justification for the evaluation of plant specific chemical effects related to GSI-191.

- TR-WCAP 16793 NP-A, "Evaluation of Long-Term Cooling Considering Particulate, Fibrous and Chemical Debris in the Recirculating Fluid," Revision 2 (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 L&C stated in the respective SEs). A more detailed evaluation of how the TRs were used by the licensee is contained in the evaluations below.

After the NRC staff evaluation of licensee's responses to GL-2004-02, the NRC staff found that there was a misunderstanding between the industry and the NRC on the level of detail necessary to respond to GL 2004-02. The NRC staff in concert with stakeholders developed a content guide for responding to requests for additional information (RAIs) concerning GL 2004-02. By letter dated August 15, 2007 (ADAMS Accession No. ML071060091), the NRC issued the content guide describing the necessary information 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 their intended function following any design basis accident. 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:

- Corrective Actions for GL 2004-02
- Break Selection
- Debris Characteristics
- Latent Debris
- Debris Transport
- Head Loss and Vortexting
- ECCS and CSS 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, the NRC staff in 2012 developed three options that will 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 would require licensees to demonstrate compliance with 10 CFR 50.46, "Acceptance criteria for emergency core cooling systems for light-water nuclear power reactors," through approved models and test methods. These will be low fiber plants with less than 15 grams of fiber per fuel assembly

- Option 2 requires implementation of additional mitigative measures and allows additional time for licensees to resolve issues through further industry testing or use of a risk informed approach.

    - Option 2 Deterministic: Industry to perform more testing and analysis and submit TR WCAP for NRC review and approval (in-vessel only).

    - Option 2 Risk Informed: South Texas Project pilot currently under review with NRR staff.

- Option 3 involves separating the regulatory treatment of the sump strainer and in-vessel effects.

The options allowed industry alternative approaches for resolving GSI-191. The options are innovative and creative, as well as risk informed and safety conscious. 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 13, 2013 (ADAMS Accession No. ML13134A264), Duke Energy Carolinas, LLC (the licensee) stated that they will pursue Option 1 for the closure of GSI-191 and GL 2004-02 for the Catawba Nuclear Station Units 1 and 2 (Catawba 1 and 2).

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

RESPONSES TO GL 2004-02		
DOCUMENT DATE	ACCESSION NUMBER	
March 1, 2005	ML050670465	
September 1, 2005	ML052500399	
June 28, 2006	ML061870061	
1st NRC RAI February 9, 2006 Accession No. ML060370347		
Licensee Responses to RAIs		
February 29, 2008	ML080650559	
April 30, 2008	ML081270091	
2nd NRC RAI November 21, 2008 Accession No. ML083080373		
Licensee Response to RAIs		
September 30, 2010	ML102870100	
August 13, 2012	ML12229A512	
July 31, 2013	ML13213A284	

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. RAI Nos. referenced in the following evaluations correspond to the NRC RAIs, dated November 21, 2008.

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 Catawba 1 and 2 in support of the resolution of GL 2004-02:

- Evaluation using the guidance of NEI 04-07, completed by Enercon Services, Inc. COMPLETE.

- Downstream effects evaluation using the TR-WCAP-16406-P-A, Revision 1 methodology. Containment walkdowns using the guidance of NEI 02-01, "Condition Assessment Guidelines: Debris Sources Inside PWR Containments," April 19, 2002 (ADAMS Accession No. ML021490212). COMPLETE.

- The modification process and the plant labeling process have been enhanced relative to GL 2004-02 controls. COMPLETE.

- Replacement of the Microtherm® insulation, previously installed on portions of the reactor vessel heads, with reflective metal insulation (RMI). COMPLETE.

- Installation of a new ECCS sump strainer in Units 1 and 2 (≈2000 square feet). COMPLETE.

- Replacement of the fiberglass blankets (Nukon) insulation on the bottom bowls of the Unit 1 steam generators (SGs) with RMI. This replacement removed approximately 400 cubic feet of fibrous insulation of which approximately 280 cubic feet are below the maximum flood level in containment. Unit 2 does not require a similar modification since RMI insulation is already installed on the bottom SG bowls. COMPLETE.

- Replacement of the existing orifice plates with smaller diameter orifice plates to allow the ECCS throttle valves to be opened greater than currently allowed for flow balancing. Initial orifice plate sizing modification was not successful in allowing the throttle valves to be opened the proper amount in order to meet the requirements for the TR-WCAP-16406-P, Revision 1 downstream effects analysis. COMPLETE.

- Integrated Prototype Test (IPT)/chemical effects test. COMPLETE.

- The licensee stated that the Catawba ECCS sump strainer was initially sized using Enercon baseline analyses in an attempt to install as large a strainer area as possible in each containment. Refined analyses were then performed along with testing to validate the final design. COMPLETE.

- The licensee has replaced a significant amount of low density fiberglass (LDFG) insulation on the Catawba 1 SGs with RMI. Catawba 2 SGs were previously insulated with RMI and remains bounded by the overall insulation quantities contained in Catawba 1. Catawba analyses are based on the Catawba 1 insulation amounts. COMPLETE.

- The licensee submitted a license amendment request (LAR) dated September 2, 2008 (ADAMS Accession No. ML082490094), to the NRC for ECCS water management modifications. This LAR reduces the number of required ECCS trains from four to three (two trains of residual heat removal (RHR) and one of containment spray (CS), referred to as “three-train flow” throughout this submittal). The effect of these changes include revisions to post-accident response that reduce recirculation flow rates through the ECCS sump strainers, increases post-accident sump pool volume and decreases the predicted volume of transported sump pool debris. This license amendment was approved by the NRC on June 28, 2010 (ADAMS Accession No. ML092530088), and the modifications are complete for Catawba 1 and 2. COMPLETE.

- ECCS sump strainer performance for Catawba was confirmed in 2011 by performing a prototype chemical precipitates head loss test. COMPLETE.

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 size and location that present the greatest challenge to post-accident sump performance.

INITIAL NRC STAFF REVIEW:

The initial staff review is based on documentation provided by the licensee through April 30, 2008.

The licensee used a discrete approach to determine the break locations to analyze rather than the NRC staff approved methodology contained in the NEI 04-07 guidance report and the associated NRC staff SE (GR/SE) suggested evaluation at 5 feet intervals along the primary coolant loop and other piping being evaluated for potential break locations. The licensee’s original assumed zone of influence (ZOI) of 17 diameters (D) for jacketed Nukon, jacketed Thermal-Wrap, and jacketed Knauf insulation was large enough to encompass the entire SG compartments and the judgment based discrete approach was reasonable as nearly any break location in a piping run would affect nearly all the insulation in the steam generator compartment. However, the licensee refined the ZOI for these insulation types to 7D. The licensee stated in their supplemental dated February 29, 2008, that review of the break locations determined assuming a 17D ZOI for these insulation types shows the limiting break location (“B” loop hot leg) for debris generation remains bounding when the 7D ZOI is applied. The licensee’s RAI response dated April 30, 2008, stated that the change from the 17D to 7D ZOI moved the limiting break from the “B” loop hot leg to the “B” loop crossover leg. This might suggest that the licensee appropriately revisited the break location determination for the reduced ZOI and not just recalculated the debris totals for the break locations selected considering the larger 17D ZOI. However, it might also mean that debris generation was recalculated for the previously determined break locations and the limiting break location moved from one previously determined point to another based on those results.

The licensee indicated that secondary line breaks would not introduce different debris types to the pool, would involve jets at lower pressure and thus would be bounded by primary line breaks and were not considered. The NRC staff review of the licensee's Updated Final Safety Analysis Report (UFSAR) contents makes no mention of recirculation being needed or assumed available for secondary (main steam or feedwater) line break accidents, so, consideration of those breaks would not be needed for evaluating sump strainer adequacy.

RAI 1:

> Please state whether or not the break location selection was revisited when the Zone of Influence (ZOI) for fibrous insulation was changed from 17D to 7D. If break selections were not revisited, please provide the rationale for not doing so. If the break selections were revisited, please provide the top four breaks in terms of debris generation for the 7D ZOI. (The supplemental response sent by letter dated February 29, 2008, indicates only that the break locations already identified for a 17D ZOI were reassessed for debris quantity generation and confirmed not to have changed relative ranking.)

<u>FINAL NRC STAFF REVIEW</u>:

Based on the licensee's August 13 2012, RAI response.

The RAI requested that the licensee state whether the break selection process was revisited following the decision to increase the ZOI for fibrous insulation from 7D to 17D. This RAI is intended to ensure that the licensee used current information when performing the break selection evaluation.

<u>Licensee Response Summary for RAI 1</u>:

The licensee stated that a large scale reduction of fibrous insulation was performed in Catawba 1 and that the amount of fibrous debris in Catawba 1 is significantly greater than that in Catawba 2. Therefore, the licensee revisited the break selection process using the updated fibrous insulation locations in Catawba 1 and a 17D ZOI. The licensee also provided details on the relative amounts of fibrous debris generated by breaks in various locations. The 1B loop hot leg break adjacent to the SG was identified as the limiting break location for fibrous debris generation.

<u>Acceptability of Response and Basis for RAI 1</u>:

The NRC staff considers the response to the RAI to be acceptable, because the licensee used the current as-built insulation configuration and the NRC staff approved ZOI for fibrous insulation to determine the limiting break location.

<u>FINAL NRC STAFF CONCLUSION</u>:

For this review area, the licensee has provided sufficient information such that the NRC staff has reasonable assurance that the subject review area has overall been addressed conservatively or prototypically. The NRC staff had previously determined that the licensee had used approved methodology for conducting its break selection evaluation. Because the licensee had changed its ZOI size used to determine the amount of fibrous debris that could be generated by a break, the NRC staff concluded that the limiting break location could change.

The NRC staff requested clarification that the licensee had re-performed the break selection process using the approved ZOI. The licensee verified that the break selection evaluation considered the approved ZOI. Since the NRC staff found the licensee's break selection methodology adequate and the evaluation was redone using the approved ZOI, the NRC staff concludes that the break selection evaluation for Catawba 1 and 2 is acceptable. Based on the information provided by the licensee, the NRC staff considers this item closed for GL 2004-02.

4.0 DEBRIS GENERATION/ZONE OF INFLUENCE (EXCLUDING COATINGS)

INITIAL NRC STAFF REVIEW:

The initial staff review is based on documentation provided by the licensee through April 30, 2008.

The licensee used the NEI 04-07, Section 4.2.2.1.1 ZOI refinement of debris-specific spherical ZOIs. The licensee's RAI responses dated February 29, and April 30, 2008, indicated that the licensee assumed the NEI 04-07 default ZOI of 28.6D for their mirror RMI. The licensee indicated that they were using a refined 7D ZOI for their jacketed Nukon rather than the GR/SE default ZOI of 17D. The licensee referred to TR-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," dated October 2007, as providing justification for using a ZOI of 7D for their jacketed insulation. The licensee stated that the WCAP methodology in this report was evaluated and determined to apply to Catawba, and as such, was implemented. The licensee also assumed a 7D ZOI for their jacketed Thermal-Wrap and jacketed Knauf fiber insulation. The licensee stated that the design and properties of jacketed Thermal-Wrap, jacketed Knauf, and jacketed Nukon insulation are sufficiently similar such that this refined ZOI can be applied to all three. The licensee's RAI response dated February 29, 2008, provides tables showing the initial and refined insulation debris quantities and the reduction in ZOI from 17D to 7D results in a substantial reduction in fibrous debris.

RAI 2:

> Please state whether the testing identified in the test report WCAP-16710-P, "Jet Impingement Testing to Determine the Zone of Influence of Min-K and Nukon® Insulation for Wolf Creek and Callaway Nuclear Operating Plants," was specific to the Catawba Nuclear Station, Units 1 and 2 (Catawba), insulation systems. If not, please provide information that compares the Catawba encapsulation and jacketing systems structures with the systems that were used in the testing, showing that the testing conservatively or prototypically bounded potential damage to the insulation materials.

RAI 3:

> Considering that the Catawba debris generation analysis diverged from the approved guidance in NEI 04-07, "Pressurized Water Reactor Sump Performance Evaluation Methodology," Revision 0, please provide details on the testing conducted that justified the ZOI reductions for jacketed Nukon®. The information should include the jacket materials used in the testing, geometries and sizes of the targets and jet nozzle, and materials used for jackets installed in

the plant. Please provide information that compares the mechanical configuration and sizes of the test targets and jets versus the potential targets and two-phase jets in the plant. Please evaluate how any differences in jet/target sizing and jet impingement angle affect the ability of the insulation system to resist damage from jet impingement. Please state whether the testing described in test report WCAP-16710-P was bounding for the Catawba insulation systems. If not, please provide information that compares the Catawba encapsulation and jacketing systems structure with the system that was used in the testing, showing that the testing conservatively or prototypically bounded potential damage to the insulation materials.

RAI 4:

The NRC staff is not convinced that Catawba's currently postulated limiting break, that results in no fine fibrous debris, but does result in 195 ft^3 of small pieces and 130 ft^3 of large pieces, is truly the limiting break from a final head loss perspective. Please provide the fibrous size distribution (including debris amounts determined) for the debris generation calculation based on the 7D ZOI. Please provide the basis for the determination that no fine fibrous debris would be generated by the limiting break. (The NRC staff considers the assumption of no fine fibrous debris to be non-conservative and inconsistent with previous industry and NRC insulation destruction test data that indicates that a fraction of the debris formed within a 7D ZOI would be destroyed into fines. The NRC staff guidance for break selection (NEI Guidance Report and NRC staff Safety Evaluation) requires that "pipe breaks shall be postulated with the goal of creating the largest quantity of debris and/or the worst-case combination of debris types at the sump screen." Fine fiber is a basic constituent of a limiting debris bed. If a different break location would result in the generation of fine fibrous debris, even if the total debris amount is less than the currently postulated Catawba limiting break, that different break may actually be the limiting break. The licensee should evaluate each potential break location from debris generation to transport (including erosion and ensuing transport) to head loss to determine which break is actually limiting.)

RAI: 5

Industry debris destruction testing was used as a basis to revise assumptions concerning the ZOIs and debris size distributions for Nukon®, Knauf, and Thermal Wrap low-density fiberglass insulations. Please describe the jacketing, banding and latching mechanisms, and cloth covers of these three types of insulation installed at Catawba and compare them to the insulation for which destruction testing was performed in order to demonstrate the applicability of the industry destruction tests results to Catawba.

FINAL NRC STAFF REVIEW:

Based on the licensee's August 13, 2012, RAI response.

Summary for RAI 2:

The RAI requested that the licensee state whether industry debris generation testing referenced by Catawba in a previous submittal was conducted specifically on the applicable Catawba insulation systems, and if not, to provide justification that the testing was representative of the Catawba insulation system performance under jet impingement conditions.

Licensee Response Summary for RAI 2:

The licensee stated that the debris generation evaluation for Catawba is based on NRC staff approved guidance for ZOIs and that the testing in question is no longer used as a basis for their debris generation evaluation.

Acceptability of Response and Basis for RAI 2:

The NRC staff finds the licensee response acceptable because the use of potentially non-conservative test results was abandoned and replaced with the use of NRC staff approved ZOI guidance.

Summary for RAI 3:

RAI 3 requested that the licensee provide details on the testing used to justify reductions in ZOI volumes compared to those approved by the NRC staff.

Licensee Response Summary for RAI 3:

The licensee stated that the testing in question is no longer used as justification for reduced ZOI volumes and that NRC staff approved ZOI sizes were used to determine the debris generation values for Catawba.

Acceptability of Response and Basis for RAI 3:

The NRC staff finds the response to RAI 3 acceptable because the licensee decided that use of the smaller ZOI sizes based on industry testing would not be used and they reverted to NRC staff approved guidance for ZOI sizes.

Summary for RAI 4:

RAI 4 requested that the licensee provide additional details regarding the debris size distribution from a break that was postulated to result in a significant amount of small and large fibrous debris, but no fine debris. The NRC staff had concluded that such a debris size distribution was very unlikely and likely non-conservative because no fine debris was assumed to be generated.

Licensee Response Summary for RAI 4:

The licensee stated that the debris generation evaluation was re-performed. The updated evaluation used an NRC staff approved ZOI. The response to RAI 4 provided details on the assumed debris size distribution within the approved ZOI. A table in the RAI response provides the debris size distribution assumed in the evaluation for insulation located different distances from the postulated break. The RAI response also includes a table that provides the total amount of debris generated, the size breakdown of the debris, and the amount of debris in each size category that is estimated to transport to the strainer.

Acceptability of Response and Basis for RAI 4:

The size distribution used in the updated evaluation is consistent with NRC staff guidance. Therefore, the response to the RAI is acceptable.

Summary for RAI 5:

RAI 5 requested that the licensee provide additional information regarding the construction of the target insulation systems used in industry jet impingement testing and how the construction of these systems compares to the insulation systems installed at Catawba for which the industry testing was credited.

Licensee Response Summary for RAI 5:

The licensee stated that credit for smaller ZOIs based on industry testing was no longer required for the Catawba debris generation evaluation. The Catawba debris generation evaluation was completed using NRC staff accepted ZOI values.

Acceptability of Response and Basis for RAI 5:

Because the licensee used NRC staff approved guidance to determine the debris generation values in their final analysis, the NRC staff concluded that the information requested in the RAI was no longer required. Therefore, the response to the RAI is acceptable.

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 been addressed conservatively or prototypically. The NRC staff had previously determined that the licensee had used approved methodology for conducting its debris generation evaluation with the exception of crediting ZOIs smaller than those approved by the NRC staff and the claim that an analyzed break would result in no fine fibrous debris. The licensee has changed its ZOI size used to determine the amount of fibrous debris that could be generated by a break to a NRC staff approved value.

Additionally, the licensee re-evaluated the amount of fine debris that could be generated by the break in question using a methodology previously evaluated and considered acceptable by the NRC staff. Other aspects of the debris generation evaluation had previously been found to be acceptable by the NRC staff. Therefore, the NRC staff concludes that the debris generation evaluation for Catawba is acceptable. The NRC staff considers this item closed for GL 2004-02.

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 initial NRC staff review is based on documentation provided by the licensee through April 30, 2008.

The licensee provided the information requested in the content guide. However, the information presented in the supplement appears to be associated with the 17D ZOI for fiberglass, which was used for the original non-chemical array testing that the licensee is no longer planning to credit. No characteristics information appears to be provided for the new 7D ZOI for fiberglass that is being used for the chemical head loss testing and will actually be relied upon to qualify the replacement strainer.

The licensee stated that the debris at Catawba includes fibrous insulation and RMI debris, failed coatings, and latent debris. For fibrous insulation (Nukon, Knauf, and Thermal-Wrap low-density fiberglass) the licensee provided debris size information consistent with the GR/SE baseline values of 60 percent small fines / 40 percent large pieces. The licensee provided additional information that a methodology similar to that from Appendix II to the SE on NEI 04-07 was used in a revised analysis. However, this revised analysis is clearly associated with the 17D ZOI and not the new 7D ZOI. No information was provided in the February 29, 2008, supplement on the debris characteristics assumed for the reduced size 7D ZOI. The licensee assumes a size distribution of 60 percent small pieces and 40 percent large pieces within a 7D ZOI for low-density fiberglass. Zero percent fines were assumed to be generated. The NRC staff considers this size distribution to be significantly non-conservative in comparison to existing jet testing data that supports a percentage of fines in the range of 20–25 percent within a 7D ZOI. Catawba's assumption of zero, on the other hand, does not appear to be supported by valid data and is considered unacceptable by the NRC staff.

One aspect of the licensee's characteristics assumptions for fiberglass that is unorthodox is the assumption that large pieces are 6 inches in size; whereas, the guidance considers large pieces to be larger than 4 inches in size. Therefore, the licensee's assumption is non-conservative. However, large pieces are less significant from a head loss standpoint and the licensee assumption that small pieces are all sized at 1 inch is conservative. Because the sizing of small pieces is more important to the overall Catawba evaluation, the NRC staff does not consider the licensee's assumption concerning the size of large debris pieces to be a significant concern. The RMI size distribution was based on the NRC SE approving NEI 04-07. This size distribution appears acceptable but is not expected to be important since RMI was not even included in the head loss testing.

The density and characteristic size information provided for all debris is reasonable and consistent with guidance.

For foreign materials, the licensee conservatively assumed a fairly large quantity of debris. The assumption is 586 square feet. The licensee took 75 percent of this surface as sacrificial strainer area, which is consistent with approved NRC SE guidance.

Coatings are reviewed separately.

RAI:

See RAI 4 above.

FINAL NRC STAFF REVIEW:

The licensee revised its debris generation calculation to use methodology consistent with staff accepted guidance. This issue is addressed in RAI 4 in Section 4 of this document. The resolution of the debris size distribution issue closed the only NRC staff identified error in the debris characteristics area.

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 conservatively or prototypically. The NRC staff had previously determined that the licensee had used approved methodology for conducting its debris characteristics evaluation with the exception of the assumption that no fine fiber would be created within a ZOI. The licensee re-evaluated the amount of fine debris that could be generated by the break in question using a methodology previously evaluated and considered acceptable by the NRC staff. Other aspects of the debris characteristics evaluation had previously been found to be acceptable by the NRC staff. Therefore, the NRC staff concludes that the debris characteristics evaluation for Catawba is acceptable. The NRC staff considers this item closed for GL 2004-02.

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 initial staff review is based on documentation provided by the licensee through April 30, 2008.

The licensee presented the results of its latent debris analyses. Walkdowns to evaluate the existence of latent debris in Catawba 1 and 2 were conducted. Walkdown observations were used to estimate total area of each latent material by containment area. Generic sampling data (mass densities) from other plants were used to determine latent debris mass by containment area. The total latent debris in Catawba 1 and 2 were estimated to be 100 pounds mass (lbm) and 113 lbm, respectively.

The latent debris properties and characteristics were assumed based upon the guidance in NEI-04-07, as modified by the NRC SE (i.e., 15 percent fiber and 85 percent particulate). A bounding value for the latent debris source term for the analyses was assumed by the licensee to be 200 pounds.

Sacrificial Screen Area:

The amount of miscellaneous material (signs, placards, tags, etc.) was estimated to be 586 square feet. Accounting for overlap, the total sacrificial screen area becomes 440 square feet. No discussion of the methodology for this result was presented by the licensee.

Latent Debris Fiber and Particulate:

The latent debris sampling methodology was not clearly defined and is possible the method used deviates from the industry guidance.

Catawba containment foreign material walkdowns were conducted using NEI 02-01 guidance for both units. As a part of these walkdowns, the existence of latent debris was evaluated. The walkdown results were tabulated using walkdown notes and photographs. Only materials that were expected to remain in containment after an outage were included in the inventories.

Subsequent to these walkdowns, a tag and label reduction evaluation was performed to analytically reduce the amount of stickers, labels, and tags that could fail in a postulated LOCA and transport to the ECCS sump pool, using current equipment qualifications and engineering judgment.

An additional 20 percent was then added to take into account the potential for missed materials, areas of low photograph-to-area size ratios, and areas not accessible due to limited space, outage activities, and high radiation. The latent debris tabulations were intended by the licensee to develop a reasonable but conservative total square footage where each material could reside by containment area. Generic sampling data (mass densities) from other plants, combined with subjective walkdown observations as to plant cleanliness, were also used to make quantitative estimates of latent debris by containment area.

The following discussion provides the assumptions and their bases regarding the treatment of latent debris inside the Catawba containments:

- Penetration sealant is assumed to fail only in the break ZOI. Foam sealants are identified only in the upper containment and lower containment outside of the crane wall. There are no breaks postulated in upper containment.

- The walkdown report identifies flexible connections in various areas of containment as miscellaneous debris. It is assumed that only the flexible connections within the ZOI will be destroyed. Since these flexible connections are also identified as a type of fabric, the debris is assumed to be a fibrous type. It is reasonable to assume that flexible connections that are outside a break ZOI will not spontaneously fail.

- In accordance with NEI 04-07, the fiber content of the latent dust and dirt debris is assumed to be 15 percent by mass. With the assumption of 200 pounds of latent debris, 30 pounds of the debris is considered to be latent fibers. The NRC SE for NEI 04-07 further assumes that the latent fiber bulk density is assumed to be the same as low density fiberglass material (2.4 pounds per cubic feet). This results in 12.5 cubic feet of latent fibrous debris. NEI 04-07 and the NRC SE Method 2 provide a conservative estimate of the latent fibers and particulate densities (94 pounds per cubic feet and 169 pounds per cubic feet, respectively). To be consistent for the Catawba head loss analysis, the microscopic density of the latent fiber material was assumed to be equivalent to Nukon® fiberglass (175 pounds per cubic feet). The NRC SE also states that the particulate size can be estimated by using NUREG/CR-6224 "Parametric Study of the Potential for BWR ECCS Strainer Blockage Due to LOCA Generated Debris" October 31, 1995 (ADAMS Accession No. ML083290498), for head loss data for typical mixtures of latent particulate debris. The latent particulate debris size using this methodology is 17.3 microns.

- Additionally, the NRC SE states that the latent fiber sizing for head loss purposes are assumed to be the same as reported in NUREG/CR-6224 for commercial fiberglass (approximately 7 microns).

- All tags and labels that detach from their affixed positions are assumed to fall straight down when in the presence of containment spray only (i.e., no submergence and no jet impingement). The same assumption applies when containment spray is not present, such as in the accumulator and fan rooms above the maximum flood level.

- A large portion of the tags and labels inside the crane wall in lower containment will be in the break's ZOI and will fail. It is not possible to conservatively estimate the percentage of tag and label surface area that is in the ZOI; therefore, all tags and labels inside the crane wall in lower containment will be assumed to fail.

- Plastic tags outside the ZOI are assumed to stay intact. While there may be some deformation due to the LOCA environment, they are assumed to not become overly pliable (i.e., they will not deform to pass through an obstruction that has a smaller dimension than the tag).

- The miscellaneous latent debris total area contribution to sump strainer blockage at Catawba is 586 square feet. NEI 04-07 guidance recommends that 75 percent of the total miscellaneous latent debris transporting to the ECCS sump pool be allotted to sump strainer blockage.

RAI 6:

Please specify whether latent debris samples were collected as part of the containment walkdowns performed described in the supplemental response sent by letter dated April 30, 2008, and describe how these samples were used to estimate the latent debris quantities for both units. In addition, if samples were not collected, please justify how the use of photographs and walkdown notes of the Catawba containments, as described in the response, provide assurance that the 200 lbm of latent debris assumed for the supporting calculations is bounding.

RAI 7:

> Please describe the analytical method used to extrapolate the total amount of latent debris in containment. If a statistical method was used, please provide the confidence level of the results.

RAI 8:

> Please provide the details of the methodology used for the tag and label refinement evaluation. Please provide details of the equipment qualifications and engineering judgments used as basis for reduction of tag and label quantities assumed to fail and reach the sump.

RAI 10:

> Please provide details of the tags and labels equipment qualifications and engineering judgments used as the basis for reduction of tags and label quantities which are assumed to fail and reach the sump. Specifically, please justify the application of Institute of Electrical and Electronics Engineers (IEEE) Standard 323-1974, "IEEE Standard for Qualifying Class 1 E Equipment for Nuclear Power Generating Stations," in qualifying Electromark® labels for a post-loss-of-coolant-accident (post-LOCA) environment with respect to non-debris transport to the sump strainer.

FINAL NRC STAFF REVIEW:

The final NRC staff review is based on the licensee's August 13, 2012, RAI responses.

Summary for RAI 6:

RAI 6 requested that the license provide details regarding the methods used to estimate latent debris amounts within the containments. The RAI asked whether samples were taken, and if so, how they were used to estimate the amount of latent debris, and requested that the licensee's assumption of 200 pounds of latent debris be justified. The intent of the RAI was to ensure that the basis for the licensee's assumptions regarding the amount of latent is valid.

Licensee Response Summary for RAI 6:

The licensee responded that guidance from NEI 02-01 and NEI 04-07 (including the staff SE) was used to estimate the amount of latent debris within the Catawba containments. Catawba 2 latent debris calculations were used to estimate the amounts for both units since the containments are almost identical in layout, and maintenance and cleaning practices are the same for both units. The licensee performed a small scale comparison of debris concentration between the units by sampling to validate the assumption that the Catawba 2 estimate could be applied to both units. The licensee categorized surface types within containment and sampled representative areas from each category. The mass of debris collected was determined by weighing. The licensee statistically evaluated the weights of debris collected in each surface category and extrapolated the results in order to estimate the total latent debris source term in containment. The licensee used a 95 percent confidence interval to develop an estimate of

113 pounds of latent debris per containment. The licensee also stated that using a simple arithmetic mean of sample weights, as allowed by NRC staff guidance, results in an estimate of about 70 pounds of latent debris per containment. Additionally, the licensee adopted the NRC staff baseline guidance amount of latent debris (200 pounds) as its licensing basis source term. The licensee assumed that 15 percent of the latent debris is fibrous.

Acceptability of Response and Basis for RAI 6:

Based on the use of approved guidance to determine the amount of latent debris in the containment, the NRC staff finds the response to RAI 6 acceptable. Additionally, the NRC staff notes that the licensee added conservatism to the design basis latent debris source term assumption by using the NRC staff guidance value of 200 pounds even though the calculated value was significantly lower. This provides some margin and ability to evaluate the discovery of unanticipated debris within containment.

Summary for RAI 7:

RAI 7 requested that the licensee describe the analytical method used to extrapolate the latent debris sample results to estimate the total latent debris source term and also requested the confidence level attained in the extrapolation. The purpose of the RAI was to understand the licensee's calculational methodology for determining the amount of latent debris in containment.

Licensee Response Summary for RAI 7:

The licensee referred to the response to RAI 6.

Acceptability of Response and Basis for RAI 7:

The response to RAI 7 provided the requested information including the confidence interval, which was stated to be 95 percent. Because the licensee used methodology approved by the NRC staff and included conservatism, the NRC staff finds the response to RAI 7 acceptable.

Summary for RAIs 8 and 10:

RAIs 8 and 10 requested that the licensee provide the details of the methodology used for the tag and label refinement evaluation.

Licensee Response Summary for RAIs 8 and 10:

The licensee referred to the response to RAI 10 to address RAI 8. The response to RAI 10 stated that only one refinement was made to the estimate of miscellaneous debris that could block strainer area. This refinement credited qualified tags such that they would not contribute to strainer area blockage. Some qualified tags are metal tags with stainless steel braided connections and were assumed to either not fail or not transport to the strainer. Plastic tags, not directly within a break ZOI were assumed to either fail or not based on the conditions expected in the area of the tags. Some of these tags were assumed to transport to the strainers and others that would be held up by some structure or grating, or trapped within a room were assumed not to transport. The licensee described the qualification program used to qualify the tags and labels for LOCA environments and stated that the program was conducted under the general guidance recommended in IEEE 323-1974, "IEEE Standard for Qualifying Class IE Equipment for Nuclear Power Generating Stations."

Acceptability of Response and Basis for RAIs 8 and 10:

The NRC staff reviewed the assumptions used by the licensee in its tag and label refinement evaluation and found them to be appropriated and in many cases conservative. The use of the IEEE standard methodology to qualify tags and labels is a good practice. Therefore, the response to these RAIs is acceptable.

FINAL NRC STAFF CONCLUSION:

For this review area, the licensee has provided information such that there is reasonable assurance that the subject review area has overall been addressed conservatively or prototypically. The licensee had previously addressed all issues, with the exception of those in RAIs 6, 7, 8, and 10 within the latent debris area adequately. Since the two issues have been adequately addressed by the RAI responses, the NRC staff considers the latent debris area to be adequately evaluated by the licensee. Therefore, the NRC staff considers this item closed for GL 2004-02.

7.0 DEBRIS TRANSPORT

The objective of the debris transport evaluation process is to estimate the fraction of debris that would be transported from debris sources within containment to the sump suction strainers.

INITIAL NRC STAFF REVIEW:

The initial NRC staff review is based on documentation provided by the licensee through April 30, 2008.

The licensee provided the information requested in the content guide. There was a problem, though, in that the transport results presented by the licensee because they were associated with the old 17D ZOI for fiberglass, which was used for the original non-chemical array testing that the licensee is no longer planning to credit. However, by letter dated April 30, 2008, the licensee updated the transport results to account for the new 7D ZOI for fiberglass that is being used for the chemical head loss testing that will actually be relied upon to qualify the replacement strainer.

The licensee stated that the methodology used in the debris transport analysis is based on the NEI 04-07 guidance and refinements and the NRC staff SE, including Appendices III, IV, and VI. Logic trees were used to quantify the analysis. Computational fluid dynamics (CFD) was used to calculate containment pool flows during recirculation, and a 4-category debris size distribution for fiberglass was stated to have been used to provide a more refined size distribution to complement the CFD analysis. The licensee assumed that the recirculation transport fractions calculated for Loop B of the RCS can be applied for all breaks because Loop B is closest to the ECCS strainer.

The licensee has not credited the retention of debris in upper containment. The licensee, although discussing Stokes' Law for the settling of fine debris, ultimately has not taken credit the settling of fines. The licensee has not taken credit for hold up of debris in inactive containment pool volumes.

The licensee did not describe any debris interceptors, but stated that debris would have to pass through either crane wall penetrations (varying in size with a diameter of up to 12 inches). The Catawba strainer is completely outside the crane wall.

The licensee assumed 10-percent erosion of the fiberglass debris settled in the containment pool but provided no justification for this assumption, such as testing.

A change to the CFD model resulted in a reduction in debris transport for small pieces of LDFG from 70 percent to 45 percent. The NRC staff has had concerns with the existing modeling used by Alion and other vendors for spray drainage and other sources of kinetic energy into the containment pool. The licensee should explain the basis for the revised kinetic energy modeling at the crane wall exits so that the staff can verify prototypicality.

<u>INITIAL NRC STAFF CONCLUSION</u>:

The size of the fibrous debris used for the strainer qualification head loss testing was non-prototypically large (whereas the transport calculation predicts mostly fines) and this resulted in debris settling in the test tank in the vicinity of the strainer, as well as other concerns with the uniformity of the accumulation on the strainer, etc.

The flow pattern in the test tank was non-prototypical and appeared to artificially prevent the formation of a uniform bed. The design of the test tank resulted in the flow in the flume being directed predominately toward the inside of the top hat module. Although some Alion array tests of top hats have shown thin beds in the range of .25 to .375 inches, Catawba tested with a debris bed of 1.75 inches and still did not come close to covering the strainer module. Particularly on the inside of the top hat, the channeled incoming flow cleaned off most of the interior of the top hat and compressed the debris near the bottom of the top hat. The licensee's discussion of this topic includes some incorrect theoretical reasoning for thin beds being unable to form on complex strainers, but the evidence suggests issues with the test protocol and tank geometry for the Catawba testing. The issue regarding the transport of debris during strainer testing is addressed in the Head Loss Section (Section 8) of this document.

RAI 9:

> Please provide the technical basis for the assumption of 10-percent erosion of fibrous debris in the containment pool. If testing was performed to support this assumption, please demonstrate the similarity of the flow conditions, chemical conditions, and fiberglass material present in the test versus the conditions expected in the Catawba containment pool.

<u>FINAL NRC STAFF REVIEW</u>:

The NRC final staff review is based on the licensee's April 13, 2012, RAI responses.

The RAI 9 requested that the licensee provide the technical basis for the assumption of 10-percent erosion of fibrous debris in the containment pool.

Licensee Response Summary for RAI 9:

The licensee provided a description of a test program designed to evaluate the amount of erosion that could occur to fibrous debris over the strainer mission time. The licensee discussed a vendor's program that was designed to estimate the erosion of fibrous debris. The erosion test found that between 3 and 7 percent of the small and large pieces eroded on average over a 30-day period. The test also found that the erosion tended to be greatest in the early part of the test and subsequently subsided. The response noted that the test program was reviewed by the NRC and found to provide acceptable justification that the erosion of fibrous debris in the containment pool would be conservatively bounded by the use of the 10-percent assumption.

Acceptability of Response and Basis for RAI 9:

The NRC staff considers the response to RAI 9 to be acceptable because the test program referenced by the licensee was reviewed by the NRC staff and found to be acceptable as a basis for assigning an erosion value to Nukon (and similar) insulation.

FINAL NRC STAFF CONCLUSION:

For this review area, the licensee has adequate provided information such that the reviewer has reasonable assurance that the subject review area has overall been addressed conservatively or prototypically. The NRC staff had previously determined that the licensee had used approved methodologies for conducting its transport analysis. The only outstanding issue associated with the transport analysis was the assumption of 10 percent erosion of fibrous debris in the sump pool. Since the licensee provided an acceptable justification for the 10-percent erosion assumption for damaged fiberglass in the sump pool, the NRC staff concludes that the transport analysis for Catawba is acceptable. Therefore, the NRC staff considers this item closed for GL 2004-02

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.

INITIAL NRC STAFF REVIEW:

The initial staff review is based on documentation provided by the licensee through April 30, 2008.

The licensee's approach to reducing strainer head loss was to install an array of Enercon top hat strainer modules in place of the original sump strainer. Scaled testing of the strainer modules was conducted both at Alion and at Wyle Laboratories. The Alion testing utilized a 3x2 array and did not include chemical effects, but concentrated on fibrous and particulate debris predicted to reach the strainer following a postulated LOCA. The Wyle testing termed, IPT, was designed to measure the effects of chemicals on head loss. The strainer area is moderate in comparison to other PWRs at about 2000 square feet. All evaluated breaks initially generated substantial amounts of fibrous debris including significant fine fibrous debris.

However, later debris generation calculations resulted in reductions in the amounts of debris including zero fine fibrous debris. This is significant and was not adequately justified by the licensee. The licensee assumed that there would be 200 pounds of latent material within containment of which 30 pounds would be fine fibers. The licensee assumes 586 square feet of labels, tape, and other miscellaneous debris. This corresponds to 440 square feet of sacrificial strainer area.

The Enercon strainer design incorporates internal debris bypass eliminator mesh to reduce strainer bypass. The top hat design has resulted in a somewhat non-uniform debris bed formation during testing. However, testing may have been non-prototypical due to debris sizing and debris introduction issues.

The NRC staff has witnessed several tests at the Alion laboratory, and also witnessed part of the IPT at Wyle laboratory. Based on these tests, the NRC staff had several concerns with the test methods used to determine the head loss of the Catawba strainer array.

The Catawba evaluation of head loss across the strainer combined an evaluation of clean strainer head loss along with the Alion array test and the Wyle IPT. There were no test results provided by the licensee. In addition, it was not described how the results of the array test and IPT were combined to arrive at a final head loss value. The NRC staff had several concerns with the test methods used for the IPT. These concerns were not addressed by the licensee. The concerns with the IPT concentrated on the flow pattern in the test tank and the debris generation and introduction techniques. Similar issues have been noted at Alion tests.

The strainer is submerged by at least 3.75 inches during a small break LOCA (SBLOCA) at the onset of recirculation. For a large break LOCA (LBLOCA), submergence was not provided; however, it would be greater due to ice melt and additional refueling water storage tank (RWST) inventory added to the sump. The strainer is fully submerged and is not vented.

Limiting clean strainer head loss (calculated) is 3.63 feet for Catawba 2.

Flow through the strainer is predicted to be a maximum of 16,000 gallons per minute resulting in a strainer approach velocity of 0.0178 feet per second (ft/sec) (with no sacrificial area subtracted). Circumscribed velocity is about 0.045 ft/sec. The maximum predicted approach velocity (at locations close to the pump suction) is 0.035 ft/sec (double the nominal; however the licensee provided no basis for this number).

For this review area the licensee has not provided information such that the NRC staff has reasonable assurance that the subject review area has overall been addressed conservatively or prototypically.

<u>RAIs 11 - 24</u>:

RAI 11:

> Please provide the results of the array testing conducted at Alion Science and Technology Corporation and the Integrated Prototype Test (IPT) testing conducted at Wyle Laboratories. For the IPT testing, in addition to head loss values, please provide the results as a function of time. Please provide a

thorough description of the methodology used to combine the two test results to determine the final head loss for the strainer debris bed. If a correlation was developed to determine head loss, please provide the correlation along with the assumptions and bases used in the development of the correlation.

RAI 12:

Please provide information that establishes that vortex testing was conducted at less than or equal to the expected 3.75-inch minimum strainer submergence. The licensee's response to RAI question 38 in Enclosure 1 to the supplemental response sent by letter dated February 28, 2008, and Enclosure 2 of this supplemental response, Section 3(f)(2), state that the strainer modules are submerged by 3.75 inches under limiting sump level conditions. The licensee's response to RAI question 38 states that testing was conducted at a submergence of 3 inches. Enclosure 2, Section 3(f)(3), states that the testing was conducted with a "few inches" of water coverage above the strainer modules. Separately, Enclosure 2, Section 3(f)(3), states that approach velocities for testing were between 0.01 ft/sec and 0.09 ft/sec, while the expected maximum approach velocity for the plant strainer is 0.045 ft/sec. In order to clarify the conditions under which vortex testing was conducted, please provide the following information:

a. Please provide the basis for the maximum approach velocity value of 0.045 ft/sec.

b. Please discuss how flume velocity was controlled during vortex testing.

c. Please provide a quantitative value for the approach velocity during which any vortices were observed to form.

d. Please provide a quantitative value for the vortex suppressor grating submergence.

e. Please verify that all vortex testing was conducted at less than or equal to 3.75 inches of strainer submergence, with or without a vortex suppressor grating.

f. Please state whether vortex formation occurred during testing and what conditions were present at such times (submergence level, approach velocity and grating installation).

RAI 13:

Please provide a response to the question from the NRC Content Guide sent by letter dated November 21, 2007, relating to Enclosure 2 of the supplemental response sent by letter dated February 29, 2008, Section 3(f)(5), regarding the ability of the strainer to accommodate the maximum potential debris volume. This response should apply specifically to the Catawba strainer and not be a generic answer.

RAI 14:

Please provide information that verifies that the debris preparation and introduction methods used during the array test and IPT were prototypical or conservative with respect to the transport evaluation for the plant. In general, protocols for fibrous debris preparation result in debris that is coarser than predicted by the plant-specific transport calculation. In addition, the NRC staff has noted that debris introduction frequently results in agglomeration of debris such that it may not transport to the strainer prototypically or create a prototypical debris bed. Both of these issues can result in non-conservative head loss values during testing.

RAI 15:

Please provide information on the flow fields in the array test. The NRC staff is concerned that non-prototypical debris distribution may have occurred during testing as a result of stirring of the tank. Stirring can result in the transport of debris that would otherwise not transport, or result in debris being washed from the strainer screen surfaces. Either of these phenomena can result in reduced (non-conservative) head loss values during testing.

RAI 16:

Please provide information that verifies that the debris preparation and introduction methods used during the thin bed testing for the top hat strainer design were prototypical with respect to the plant-specific debris generation and transport evaluation for Catawba. Note that for thin bed testing, the NRC staff considers it prototypical or conservative for fine fiber to arrive at the strainer prior to less transportable debris. Overly coarse debris preparation or non-prototypical introduction to the flume may non-conservatively affect the potential for thin bed formation.

RAI 17:

Please provide the criteria used to judge that differential pressure-induced effects (e.g., boreholes) did not occur during testing. The existence of pressure-induced effects could invalidate the application of temperature scaling. Please state whether pressure-induced effects were identified and, if so, the resultant effect on the application of temperature scaling.

RAI 18:

Please provide the scaling parameters used for calculation of debris quantities and strainer approach velocities used during testing. Please state whether the scaling accounted for strainer areas blocked by miscellaneous debris such as labels and tape.

RAI 19:

Please discuss the NRC staff's observation that in the IPT the flow was non-prototypically directed at the top hat strainer in a direction parallel to the top hat long axis. Please address whether this non-prototypical flow direction could result in a non-prototypical formation of debris on the top hat strainer.

RAI 20:

Please provide the clean strainer head loss for Catawba Unit 1 (only the clean strainer head loss for Catawba Unit 2 was provided).

RAI 21:

Please provide the time-dependent results and calculation methodology for determining net positive suction head (NPSH) margin throughout the 30-day mission time.

RAI 22:

Please provide the basis for the debris introduction information that indicates that no fine fibrous debris would be generated during a loss-of-coolant accident (LOCA). If the assumption of zero fibrous debris generation is in error please provide the amount of fibrous debris generated by the limiting break and justify why, in such a case, the head loss test results would remain valid.

RAI 23:

Please provide the types and amounts of debris added to each test (Array and IPT) and include information on introduction sequence. Please provide relevant test parameters such as temperature, debris introduction times, and flow rate for the Array and IPT tests.

RAI 24:

Please provide information on the amounts of debris that settled during testing for each test (IPT, Array, and Thin Bed). Note that Enclosure 1 of supplemental response dated February 29, 2008, stated that near-field settling was not credited during testing. However, the NRC staff observed significant settling during the IPT. Please provide a quantitative evaluation of how this settling affected head losses for each test. Please state whether this settling is prototypical of plant conditions and provide a basis for the conclusion.

FINAL NRC STAFF REVIEW:

The NRC final staff review is based on the licensee's August 13, 2012, RAI response.

Summary for RAI 11:

RAI 11 requested that the licensee provide the results of two different test programs that were combined to develop an estimated strainer head loss that included both non-chemical and chemical debris. The RAI also requested that the methodology used to combine the test results be provided.

Licensee Response Summary for RAI 11:

The licensee stated that the RAI as posed by the NRC staff is no longer applicable because Catawba performed additional testing which superseded the previous tests. The new test program was implemented so that the issues identified in RAI 11 were addressed by using test methods accepted by the NRC staff. The head loss results were not attained by combining two test results, but from a single test that included both non-chemical and chemical debris. The licensee provided the results of the strainer head loss test as a function of strainer mission time. The head loss evaluation assumes that chemicals do not precipitate until the pool temperature decreases below 165 degrees Fahrenheit ($^{\circ}$F). The evaluation also corrects the head loss results to account for varying sump fluid temperatures.

Acceptability of Response and Basis for RAI 11:

The NRC staff reviewed the licensee's test methods by traveling to the test site. Through these interactions and based on information submitted by the licensee, the NRC staff determined that the final test results were acceptable because the tests of record were performed in accordance with NRC staff guidance for strainer head loss testing. Both the temperature dependent precipitation assumption and the temperature correction for fluid temperature are methods that have been approved by the NRC staff. Therefore, the response to RAI 11 is acceptable.

Summary for RAI 12:

RAI 12 requested that the licensee provide additional information and justification for conditions under which vortex testing of the strainer was conducted. Important variables during the test are approach velocity and strainer submergence level, so these were the areas concentrated on by the RAI. The intent of the RAI is to ensure that the testing was conducted under the most limiting conditions that could realistically occur at Catawba.

Licensee Response Summary for RAI 12:

The licensee provided information regarding the test methodology, the approach velocities used during testing, the strainer submergence, and the bases for these values. The licensee provided information that indicates that both the approach velocity and the submergence used during vortex testing was significantly conservative with respect to expected post-LOCA conditions.

Acceptability of Response and Basis for RAI 12:

The NRC staff concluded that the licensee showed that the test conditions were conservative when compared to the design basis plant conditions. Testing showed that vortex formation would not occur under conditions conservative with respect to the plant. Therefore, the response to RAI 12 is acceptable.

Summary for RAI 13:

RAI 13 requested that the licensee provide information that shows that the strainer array installed at Catawba can accommodate the maximum potential debris volume that may transport to the strainer. The RAI is intended to insure that the strainer array will not be completely engulfed with debris or that testing adequately modeled such a condition.

Licensee Response Summary for RAI 13:

The licensee stated that significant amounts of fibrous debris have been removed from the Catawba containment and stated that the bounding amount of fiber that could transport to the strainer is about 55 cubic feet. Catawba also provided the design basis volumes of other materials which could become damaged and transport to the strainer. The total volume of debris predicted to reach the strainer is about 72.25 cubic feet and the interstitial volume of the strainer was reported as about 513 cubic feet for the limiting (smaller) strainer (Catawba 2). The licensee noted that the debris will collect non-uniformly on the strainer and is not of sufficient volume to fill the strainer interstitial volume. Therefore, the licensee concluded that the analyzed flow velocities remain bounding.

Acceptability of Response and Basis for RAI 13:

The NRC staff concluded that the response to RAI 13 is acceptable, because the limiting amount of debris that could reach the strainer is significantly less than the interstitial volume of the strainer. The NRC staff also noted that the density (as-manufactured) used to determine the fibrous debris volume is likely significantly lower than the density of the fiber once it collects on the strainer so the volume assumed in the evaluation is conservative. Therefore, the strainer will not become engulfed with debris and the testing performed to evaluate the strainer is valid.

Summary for RAI 14:

RAI 14 requested that the licensee verify that the debris preparation and introduction methods used during head loss testing were prototypical or conservative with respect to the expected plant condition following a LOCA. The RAI concerns the fact that some strainer tests were conducted with fiber not prepared as finely as the plant evaluation predicts. This could cause non-conservative head loss results.

Licensee Response Summary for RAI 14:

The licensee stated that the concerns regarding debris preparation and introduction were based on early testing and that these concerns required additional testing to be completed. The RAI response stated that debris preparation and introduction methods for newer testing were based on NRC staff guidance on head loss testing and also on discussions with the staff. For the more recent testing, the debris was well diluted and inspected to ensure that it met the desired size distribution. The licensee stated that shakedown tests were conducted to ensure that agglomeration would not occur and that the majority of the fiber would transport to the strainer.

<u>Acceptability of Response and Basis for RAI 14</u>:

Based on the licensee description of the debris preparation, inspection, and introduction methodology, the NRC staff was able to conclude that the Catawba testing was conducted using methods accepted by the NRC staff. Therefore, the response to RAI 14 is acceptable.

<u>Summary for RAI 15</u>:

RAI 15 requested that the licensee provide information regarding the flow fields present during the array testing because there was concern that non-prototypical and potentially non-conservative debris distribution over the strainer may have occurred during the testing due to stirring in the tank.

<u>Licensee Response Summary for RAI 15</u>:

The licensee stated that the test facility was designed to prevent non-prototypical debris bed formation by maintaining adequate separation between agitators designed to maintain debris in suspension and the strainers.

<u>Acceptability of Response and Basis for RAI 15</u>:

The fact that the agitators were placed so that they could not affect the morphology of the debris bed, the NRC staff finds the response to RAI 15 is acceptable.

<u>Summary for RAI 16</u>:

RAI 16 requested that the licensee provide information that verified that the debris preparation and introduction practices used during thin bed testing were prototypical with respect to the sites debris generation and transport evaluation, and that the debris addition order was in accordance with NRC staff accepted guidance. The RAI is intended to ensure that the debris met accepted criteria for fine sizing and that the fine debris was added first since it is the most likely to transport.

<u>Licensee Response Summary for RAI 16</u>:

The licensee stated that additional testing was performed after the NRC staff developed the RAI. Some of the newer tests were specifically designed to determine whether the Catawba strainers were susceptible to high head losses from a thin, relatively low porosity debris bed. The testing included both testing that added all particulate first followed by incremental batches of fiber and testing that added small batches of particulate and fibrous debris simultaneously. The licensee noted that the thin bed test protocol, or particulate debris followed by incremental fiber additions resulted in higher head losses. However, the thin bed testing did not ultimately result in the highest head losses for the Catawba strainer. The debris preparation was noted as being described in RAI 14. Debris introduction was noted as being described in RAI 15.

Acceptability of Response and Basis for RAI 16:

The two methods described in the response to RAI 16 are both NRC staff accepted thin bed methodologies. The fact that the licensee used both methodologies and chose the limiting method ensures conservatism in the strainer head loss evaluation. Based on the use of NRC staff approved methodologies, the response to RAI 16 is acceptable.

Summary for RAI 17:

RAI 17 requested that the licensee explain how it was determined that pressure induced effects did not occur during testing. This RAI is intended to ensure that any viscosity based temperature scaling performed is conservative.

Licensee Response Summary for RAI 17:

The licensee stated that all tests included flow sweeps, as recommended by NRC staff guidance, to ensure that temperature scaling of the head loss tests was conducted correctly and that pressure driven debris bed breakdown did not limit the head loss. The results of the flow sweeps were used to scale the head loss test results to various temperatures predicted to occur at different times after a postulated LOCA. The temperature scaling was discussed further in the response to RAI 11.

Acceptability of Response and Basis for RAI 17:

NRC Staff guidance is that flow sweeps should be conducted to determine whether head loss across the debris bed responds relatively linearly to flow changes before scaling the test results for temperature driven viscosity changes. Instead of applying a direct viscosity correction, the licensee based the scaling on the results of the flow sweeps for the tests of record. This methodology is acceptable to the NRC staff since it applies less credit than a straight viscosity correction and is therefore more conservative. Therefore, the response to RAI 17 is acceptable.

Summary for RAI 18:

RAI 18 requested that the licensee provide the scaling parameters used to calculate the amount of debris added to the strainer head loss tests and the flow velocities used during testing. The purpose of this RAI is to ensure that the important test parameters were scaled properly with respect to the plant.

Licensee Response Summary for RAI 18:

The licensee stated that the scaling was based on the ratio of the smaller of the two units' surface areas (Unit 2) minus an area penalty for tags and labels that could block some of the strainer surface to the area of the test strainer. This scaling ratio was used for both the debris and velocity scaling for the test. The licensee also stated that the velocity scaling was based on ECCS water management flows.

Acceptability of Response and Basis for RAI 18:

The scaling was performed in accordance with accepted NRC staff guidance. The use of ECCS water management flows is acceptable to run only a single train of containment spray instead of the original design which started two trains of spray. The NRC approved a license amendment to allow Catawba to run a single train of containment spray following a LOCA. Therefore, the response to RAI 18 is acceptable.

Summary for RAI 19:

RAI 19 requested that the licensee provide additional information regarding the flow patterns that occurred during the early testing that may have resulted in a non-conservative debris bed distribution on the strainer.

Licensee Response Summary for RAI 19:

The licensee stated that the results of the earlier testing were not used for the strainer design basis head loss. Later testing was conducted per NRC staff guidance with the debris preparation and introduction described in RAIs 4 and 5.

Acceptability of Response and Basis for RAI 19:

The debris introduction and preparation for more recent testing has been accepted in RAIs 14 and 15. The results of the test in question were not used for the strainer design basis. The response to RAI 19 is acceptable based on the acceptable methodologies used for the most recent testing.

Summary for RAI 20:

RAI 20 requested that the licensee provide the clean strainer head loss value for the Catawba 2 strainer because it had not previously been provided.

Licensee Response Summary for RAI 20:

The licensee provided Catawba 1 and 2 clean strainer head loss values. Catawba 1 value is slightly greater than Catawba 2 value (2.94 feet vs. 2.78 feet). The clean strainer head loss values were reduced from the one originally supplied because of the flow reductions obtained through the water management LAR.

Acceptability of Response and Basis for RAI 20:

The NRC staff finds that it is acceptable to base the clean strainer head loss values on water management flow rates since these are the design basis flow rates for the strainer. Because the licensee provided the requested information, the response to RAI 20 is acceptable.

Summary for RAI 21:

RAI 21 requested that the licensee provide the time dependent test results and methodology for determining the NPSH margin throughout the strainer mission time. This RAI concentrated on the issues arising from combining test results to derive this information.

Licensee Response Summary for RAI 21:

The licensee stated that the original test program was abandoned and a new test program undertaken to determine the strainer head losses to be applied to the NPSH calculations. The licensee referenced the response to RAI 25 under the NPSH section of the RAI responses.

Acceptability of Response and Basis for RAI 21:

Based on the updated testing and evaluation conducted by the licensee, which was conducted using NRC staff accepted guidance, the response to RAI 21 is acceptable. The NRC staff also considered responses to several other RAIs in this section, especially RAI 11, along with a review of RAI 25.

Summary for RAI 22:

RAI 22 requested that the licensee provide the basis for the assertion that no fine debris would be generated during a LOCA and how this assumption could affect the head loss test results. This RAI is focused on ensuring that testing was conducted with conservative debris sizes.

Licensee Response Summary for RAI 22:

The licensee stated that the response to RAI 14 should be referenced.

Acceptability of Response and Basis for RAI 22:

The NRC staff reviewed RAI 14 and determined that the proper debris size distribution was used as an input to the licensee's most recent test program. Therefore, the response to RAI 22 is acceptable.

Summary for RAI 23:

RAI 23 requested that the licensee provide the amounts of debris added, flow rates, and temperatures for the early strainer head loss tests. This RAI is intended to gain information to understand how the tests were conducted to ensure that they were performed in a realistic or conservative manner and to determine whether the licensee's methodology of combining test results was justified.

Licensee Response Summary for RAI 23:

The licensee provided the debris amounts, debris introduction procedures, the temperatures, and the flow rate used in the more recent testing that was conducted using NRC staff approved guidance. The RAI response noted that the scaling for testing was discussed in the response to RAI 18.

Acceptability of Response and Basis for RAI 23:

Because the licensee conducted updated testing that was performed using NRC staff approved guidance, the issue identified by the RAI was resolved by the new testing. Therefore, the response to RAI 23 is satisfactory.

Summary for RAI 24:

RAI 24 requested that the licensee provide estimates of the amounts of debris that settled during head loss testing. This RAI is intended to ensure that excessive settling of debris did not occur during testing resulting in non-conservative head loss results and was based on NRC staff observations of early Catawba strainer testing.

The licensee stated that near field settling was not credited in the evaluation of the Catawba sump strainers. The licensee noted that updated testing was completed and that RAI 15 discussed the methods used to ensure that the majority of debris transported to the test strainer.

Acceptability of Response and Basis for RAI 24:

Based on the updated testing conducted by the licensee and the response to RAI 15, the NRC staff concluded that excessive settling of debris did not occur during the testing of Catawba's strainer. Therefore, the response to RAI 24 is acceptable.

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 conservatively or prototypically. The NRC staff had previously determined that the licensee had used approved methodology for conducting its strainer head loss and vortexing evaluation in all areas except those addressed by RAIs 11 through 24. It should be noted that the issues described in the RAIs are significant and these issues led the licensee to abandon their early test program, make significant changes to the test and evaluation program, and reperform testing. Because the licensee re-performed its head loss testing and evaluations using procedures acceptable to the NRC staff, the NRC staff finds that the testing and evaluation are acceptable and result in a design basis head loss that will reasonably bound any potential head loss that may occur across the strainer following a LOCA. Therefore, the NRC staff concludes that the head loss and vortexing evaluation for Catawba is acceptable. The NRC staff considers this item closed for GL 2004-02.

9.0 NET POSITIVE SUCTION HEAD

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.

INITIAL NRC STAFF REVIEW:

The initial NRC staff review is based on documentation provided by the licensee through April 30, 2008.

The licensee provided the content guide specified information but with a minimum of explanatory or supporting detail. The RHR and containment spray (CS) pump flows at available NPSH and at required NPSH were provided as representative pump flow rates along with a maximum analyzed recirculation (sump) flow rate of 16,000 gallons per minute (from both the RHR and CS pumps in hot leg injection). The licensee's February 29, 2008, supplemental response, Table 3G1-1, shows pump flows at available NPSH is less than flow at required NPSH, and the licensee's supplemental response dated April 30, 2008, Tables 12-2/3/4/5 show the total sump flow. Individual pump flow rates at this maximum calculated sump flow rate were not provided, but the supplemental response indicates that this total sump flow reflects pump operation in excess of that possible with corresponding system flow resistance. The supplemental response indicated that the limiting NPSH available would occur early in the accident due to the lower vapor pressure due to high sump temperatures. The vapor pressure decrease throughout the accident more than compensates for the increased head loss due to higher viscosity water which increased strainer head loss. The reduction in vapor pressure also helps to compensate for chemical effect head loss, which is assumed to occur once the pool temperature drops below 165 °F pool temperature, at the beginning of ECCS sump pool recirculation was identified as being 190 °F. This temperature was used in determining minimum NPSH available and NPSH margin. The supplemental response describes the minimum containment water level as being 33 inches above the containment/sump floor, which is 3.75 inches above the top of the highest point of perforated plate strainer surface, as occurring during a SBLOCA where CS is not actuated and there is no contribution from melting of the ice.

The licensee describes the assumptions used for determining the pump flow rates, the total recirculation sump flow rate, sump temperature(s), and minimum containment water level as follows:

- Accident containment overpressure is not credited for NPSH available.
- The containment ECCS sump pool temperature is 190 °F.
- Available NPSH determination assumes a pool water level of 552 foot elevation, or 33 inches above the containment/sump floor.
- RHR/CS pump required NPSH is taken from the pump curves at a flow rate above that achievable based on downstream flow path (system) resistance.
- All RHR/CS pumps have similar hydraulic capabilities.

Overall system configurations/flow resistance and thus flow rates are similar, with the exception of the 1B RHR pump discharge orifice having a higher resistance than that of 2B. The 2B RHR pump orifice resistance is used in the hydraulic model for the calculation of flow. Pump suction piping from the ECCS sump have similar configurations and flow resistances.

Minimum pool water level determination assumes a small break of indeterminate size which fills up the incore instrumentation room (located below the reactor vessel), but has insufficient energy to cause the CSS to actuate, the ice condenser doors to open, or result in a RCS pressure drop to that of the accumulators. For larger break sizes these additional water sources would result in a higher pool level. For the minimum pool water level determination, no ice melting contributes to the pool inventory. Pool water inventory contributions include the technical specification (TS) minimum inventory from the RWST down to the RWST low-low level setpoint which is conservatively error-adjusted upward to minimize the usable RWST volume. The following ECCS sump inventory penalties (lost water sources) are applied in the small break minimum pool level analysis:

- Reactor coolant system shrinkage
- Incore instrumentation room diversion
- Volume control tank diversion
- Pressurizer relief tank diversion
- Lower containment ventilation system condensation diversion (loss of lower containment condensate through drain pans and drain lines)

For larger break sizes the upper containment holdup volumes that come into play and are accounted for by including the refueling canal, refueling deck (3-inch curb), CS piping volume, airborne droplets, and water draining down vertical surfaces.

The licensee indicated that the required NPSH values were taken from the pump head curves. The supplemental response did not identify if the three percent head drop criterion was applied in the development of the NPSH required curves, but it would be reasonable to assume this common industry practice applied.

The licensee indicated that for the ECCS/CSS piping, hydraulic models were generated using standard methodologies which apply appropriate resistance coefficients and friction factors. No specific methodology or source reference was provided, which is similar detail to the licensee's original UFSAR discussion on this topic.

The licensee provided the limiting NPSH margin for the CS pumps as being 4.6 feet of water and the margin for RHR pumps as being 11.6 feet. These limiting margins were stated as occurring at or very near the start of sump recirculation flow when strainer debris loaded head loss is predicted to be 5.4 feet of water and pool temperature is assumed to be 190 $^{\circ}$F. The supplemental response states that strainer differential pressure losses are time dependent and are largely offset by vapor pressure reduction and sump pool level increase during the accident period.

The supplemental response does not identify the exact methodology or source for resistance coefficients and friction factors. However, the Catawba UFSAR lists the "Handbook of Hydraulic Resistance" by I.E. Idelchik, as a general reference where similar hydraulic design/modeling has been done although not in the particular section describing the ECCS Sump and RHR/CS system design and operation.

RAI 25:

> The supplemental response stated that the head loss across the Catawba Emergency Core Cooling System Sump strainer (clean strainer head loss plus debris bed head loss) is conservatively predicted to be 5.4 feet at switchover to sump recirculation. However, no explanation was provided as to how this value

> was derived. It appears that credit was taken for time-dependency in head loss, since the 30-day value is 8.2 feet. Please provide the time-dependent results and calculation methodology for determining NPSH margin throughout the 30-day mission time.

FINAL NRC STAFF REVIEW:

The NRC final staff review is based on the licensee's August 13, 2012, RAI responses.

RAI 25 requested that the licensee provide the time dependent results and the calculational methodology for determining the NPSH margin throughout the 30 day mission time. The RAI is intended to ensure that the NPSH margin was accurately determined over the full mission time.

Licensee Response Summary for RAI 25:

The licensee stated that because of concerns with early strainer head loss testing that additional testing was required and that the RAI response was based on the results of the updated tests. The response stated that the updated testing used results of single tests rather than attempting to combine tests to obtain a result that included both non-chemical and chemical precipitate head loss. The licensee referred to RAI 11 which provided the test results and methodology for extrapolating the results over the mission time, including scaling for temperature related viscosity effects. The RAI response also included a table which provided both NPSH and strainer structural margins calculated at various times throughout the postulated event. The table illustrated that the NPSH margin is limiting when the sump fluid temperature is hot, but structural margin becomes more limiting later in the event as the fluid cools. The RAI response also included the methodology used to determine the margins. The RAI response also provided the NPSH required for the CS and RHR pumps as well as the structural limit for the strainer.

Acceptability of Response and Basis for RAI 25:

The methodology used to calculate the time and temperature dependent strainer head loss is consistent with NRC staff guidance. The NRC staff considers the response to RAI 25 to be acceptable because the licensee used methods acceptable to the NRC staff. The review of RAI 11 is applicable to this RAI and that response was found to be satisfactory.

FINAL NRC STAFF CONCLUSION:

For this review area, the licensee has provided information such that the reviewer has reasonable assurance that the subject review area has overall been addressed conservatively or prototypically. The NRC staff had previously determined that the licensee had used approved methodology for conducting its NPSH evaluation in all areas except as it was affected by the strainer head loss evaluation. Because the licensee re-performed its head loss testing and evaluations using procedures acceptable to the NRC staff, the NRC staff finds that its use as an input to the NPSH calculations result in conservative NPSH and strainer structural margins. Therefore, the NRC staff concludes that the NPSH evaluation for Catawba is acceptable. The NRC staff considers this item closed for GL 2004-02.

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 30, 2008.

The break zone ZOI used for calculating amount of qualified epoxy coating debris was 5D which is acceptable by WCAP-16568-P-A. 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 to NEI 04-07. Debris transport assumed that 100 percent of the coating debris particulate would transport to the sump and was used in head loss testing which is acceptable by the NRC SE 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 NRC staff since the licensee's assessment is conducted during each refueling outage, is conducted by qualified personnel, and if degraded coatings are identified, these areas are documented and additional tests and remediation may be performed.

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 conservatively or prototypically. Therefore, the NRC staff concludes that the coatings evaluation for Catawba is acceptable. The NRC staff considers this item closed for GL 2004-02.

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.

INITIAL NRC STAFF REVIEW:

The initial staff review is based on documentation provided by the licensee through April 30, 2008.

The licensee provided a high level description of the programmatic controls that will ensure that potential sources of debris introduced into containment (e.g., insulations, signs, coatings, and foreign materials) will be assessed for potential adverse effects on the ECCS and CSS recirculation functions. The licensee referenced in its response the actions taken to address

Bulletin 03-01. It is not clear to the NRC staff if the containment cleaning practices mentioned in the response are controlled administratively or if these are permanent activities in Catawba.

The licensee's August 7, 2003 (ADAMS Accession No. ML032260651), response to Bulletin 03-01, described planned actions regarding containment cleanliness. These actions have been implemented and provide for containment cleaning and visual inspections.

Containment cleaning is conducted prior to entering Mode 4.

Extensive containment cleaning is conducted using water spray. In general, washdowns are limited to the space in lower containment that would be submerged under LBLOCA conditions. Accessible floor and wall surfaces and mechanical equipment are washed down. Localized washdowns are performed as directed by radiation protection personnel. Visual inspections are performed on remaining areas of containment. Identified potential debris is cleaned or removed, as necessary.

As part of the housekeeping/material condition programmatic controls, containment cleanliness at Catawba is verified prior to entry into Mode 4 by an inspection controlled by procedure. This cleanliness inspection ensures that the ECCS sump area is free of debris. Containment foreign material exclusion (FME) controls and inspection activities are implemented during Modes 1 through 4. Catawba FME control practices and inspection activities assuring containment cleanliness during Modes 1 through 4 are described as follows:

- Containment entries during normal power operations are controlled by an administrative procedure. Increased material accountability control at Catawba is achieved by requiring material accountability logs be kept for items carried into and out of containment during normal power operations (Modes 1 through 4).

- The licensee's modification process currently includes an administrative procedure that directs the design and implementation of engineering changes in the plant. This procedure directs that engineering changes be evaluated for system interactions. As part of this evaluation, there is direction to include consideration of any potential adverse effect with regard to debris sources and/or debris transport paths associated with the containment sump.

Modify Existing Insulation:

The licensee stated that Microtherm® insulation installed on the Catawba 1 and 2 reactor vessel heads was removed and replaced with RMI. Additionally, fiberglass blankets (Nukon®) insulation on the bottom bowls of the Catawba 1 SGs was replaced with RMI. This replacement removed approximately 400 cubic feet of fibrous insulation of which approximately 280 cubic feet are below the maximum flood level in containment. Catawba 2 does not require a similar modification since RMI insulation is already installed on the SG bottom bowls.

Modify Other Equipment or Systems:

The licensee stated that Electromark® labels have been qualified to IEEE Standard 323-1974. Subsequently, they have been removed from the debris generation quantification for all areas of containment except inside the crane wall in lower containment, since much of the area inside the crane wall is within the zone of influence (ZOI) and all labels and tags are assumed to fail.

Modify or Improve Coatings Program:

The licensee stated that a primary containment coatings condition assessment is conducted during each refueling outage or any other extended outage. The primary containment coating condition assessment protocol consists of a visual inspection of all readily accessible coated areas by qualified personnel. When degraded coatings are visually identified, the affected areas are documented in accordance with plant procedures. Additional non-destructive and/or destructive examinations are conducted as appropriate to define the extent of the degraded coatings and to enable disposition of the coating deficiency. The guidance contained in Electric Power Research Institute (EPRI) TR-109937, "Plant Support Engineering: Guideline on Nuclear Safety-Related Coatings," Revision 2, dated December 23, 2009, is used as appropriate to disposition areas of degraded coatings when discovered. If degraded qualified/acceptable coatings will be left in place during plant operation, the degraded qualified/acceptable coatings are assumed to fail and to be available for transport to the ECCS sump. After each containment coatings condition assessment, the quantity listing of degraded coatings is updated, and the revised quantity of degraded coatings is verified to meet the acceptance limit in the ECCS debris source term analysis.

RAI 26:

> Please state whether the containment cleaning actions described in Duke's response to Bulletin 2003-01, sent by letter dated August 7, 2003, will remain in effect at Catawba (in order to assure that debris source assumptions made as part of the GL 2004-02 resolution remain valid). Specifically, please identify the procedures which control the cleanliness actions for containment and any commitments regarding the long-term applicability of these procedures.

FINAL NRC STAFF REVIEW:

The NRC final staff review is based on the licensee's August 13, 2012, RAI response.

Summary for RAI 26:

RAI 26 requested that the licensee state whether the containment cleaning actions described in the plant response to Bulletin 2003-01 will remain in effect at Catawba. The purpose of the RAI was to ensure that programs are in place that will maintain the containment cleanliness at the level assumed in the current licensee evaluations.

Licensee Response Summary for RAI 26:

The licensee stated that they have instituted programmatic controls to ensure that potential sources of debris that may enter containment will be assessed to determine if they could adversely affect the recirculation functions. The licensee stated that these controls had been identified in their supplemental response dated February 29, 2008.

The programmatic controls include the following:

- Prior to Mode 4 restart water spray is used to clean lower containment. Accessible floor and wall areas as well as mechanical equipment are washed down. The containment cleanliness is verified prior to entry into Mode 4 by operating procedures for unit startup.

- The licensee performs visual inspections of the ECCS strainer to evaluate sump availability, cleanliness, and structural soundness.

- Refueling canal cleanliness is verified prior to entering Mode 5.

- A quarterly inspection verifies that the upper containment and refueling canal are free from debris that could clog the refueling canal drains.

- Material accountability controls track items taken into and out of containment in Modes 1 through 4.

- After containment integrity is established, a visual inspection is conducted to identify and remove loose debris inside containment.

The procedures and programs used to control these evolutions are included in the licensee's response to RAI 26. These procedures implement the licensee's commitments made in response to Bulletin 2003-01 and GL 2004-02.

Acceptability of Response and Basis for RAI 26:

The licensee has implemented controls intended to maintain containment cleanliness and ensure that foreign materials do not adversely affect the operation of the recirculation functions for ECCS and CS. The controls are those typically used throughout industry and have been generally effective in limiting undesirable materials to an acceptable level. Therefore, the response to RAI 26 is acceptable.

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 conservatively or prototypically. The licensee has provided information necessary for the NRC staff to conclude that the debris source term is controlled to an acceptable level such that the recirculation function will not be adversely affected. Therefore, the NRC staff concludes that the debris source term evaluation for Catawba is acceptable. The NRC staff considers this item closed for GL 2004-02.

12.0 SCREEN MODIFICATION PACKAGE

NRC STAFF REVIEW:

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

The NRC staff review is based on documentation provided by the licensee through April 30, 2008.

The licensee provided a basic description of the major features of the sump screen modification, in addition to a listing rerouting of piping and other components modifications necessitated by the sump strainer modification. A summary of the modifications to the ECCS sump strainer installations appears below:

- The modified ECCS sump strainer assembly design for Catawba removed the original ECCS sump structure and replaces it with strainer assemblies consisting of a series of stainless steel tubular modules (top-hats) connected by a plenum to water boxes. The top-hats are constructed from two concentric, rolled perforated plates. The openings in the perforated plate are 3/32 inch diameter nominal. Sandwiched between the concentric tubes of each top-hat module is a bypass eliminator, fabricated from fine knitted wire. This component is designed to further filter fine entrained debris that has already penetrated the perforated top-hat exterior. The RHR/CSS recirculation lines are connected to the main plenum of the strainer assembly using 18-inch piping. Horizontal vortex suppressors are installed above the top-hat strainer assemblies.

- The modified Catawba strainer is installed entirely in the pipe-chase outside the polar crane wall. There are no pipe whips or water/steam jet loads projected to occur within the Catawba pipe-chase. The modified sump structures are nuclear safety-related assemblies designed to withstand safe shutdown earthquake loadings and protected from tornado missiles by virtue of being located within the containment building which is, in turn, protected by the seismically designed reactor building. These structures are passive assemblies qualified for all design environmental conditions in the sump.

The objective of the new strainer design is to provide acceptable flow with minimal head loss at the specified debris loads and to ensure adequate NPSH to the RHR/CSS pumps during the post-LOCA recirculation phase. The new strainer offers approximately 2000 square feet of surface area versus the original 135 square feet total for the original sump screens.

<u>FINAL NRC STAFF CONCLUSION</u>:

The licensee has provided information necessary for the NRC staff review. Based on its review the NRC staff finds the licensee has provided sufficient information as required by GL 2004-02, and considers this item closed for 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.

<u>INITIAL NRC STAFF REVIEW</u>:

The initial staff review is based on documentation provided by the licensee through April 30, 2008.

The NRC staff review of Sump Structural Analysis*,* has led to the conclusion that the licensee did not adequately addressed the information requested by the revised content guide for GL 2004-02 Item 2(d)(vii). Specifically, the licensee has not provided a summary of the structural qualification design margins for the various components of the sump strainer structural assembly. This information is explicitly requested by the second bullet of the Sump Structural Analysis Section of the revised content guide. The remainder of the evaluation is relatively well-documented and complete; however, without conveyance of the existing margins between actual stress and allowable stress, it was not possible for the NRC staff to evaluate the extent of the conservatism inherent to the design.

The licensee's submittal stated that structural analyses were performed for the various replacement sump strainer components. The analytical models were subjected to load combinations associated with dead load, operating loads, differential pressure loads, seismic loads (including hydrodynamic mass), and thermal loads. These individual loads are consistent with the guidance of NEI 04-07 and the NRC staff's corresponding SE. The maximum stresses, which were calculated for the analytical models were then compared with the appropriate allowable stresses from the American Institute of Steel Construction (AISC)Manual (AISC 9th Edition) and the American Society of Mechanical Engineers (ASME) Section IIII, Division 1, NF-3324.6 for stainless steel studs/bolts. The welds associated with the stainless steel assembly were qualified from the American Welding Society (AWS) D1.6 guidance. The licensee stated that all design aspects of the replacement sump structure met AISC, AWS, and ASME Code allowable stresses.

With regard to potential loadings associated with an HELB, the licensee stated that the entire replacement sump strainer assembly is located within the pipechase area. There are no pipe whips or water/steam jet loads projected to occur within the Catawba pipechase. For this reason, there are no dynamic loads associated with a HELB on the replacement strainers.

The licensee's submittal stated that backflushing was not considered feasible for the replacement sump strainer.

The information provided by the licensee shows that the sump structural evaluation contains inherent conservatism by complying with the AISC 9th Edition, ASME Boiler and Pressure Vessel Code, and AWS Welding Code. The licensee did not, however, transmit the interaction ratios or design margins associated with the structural analysis to the staff (see RAI section below). The design inputs, which were tabulated in the submittal, appear reasonable, but without the interaction ratios or design margins, it is not possible for the staff to comment on the level of significance of the conservatism which has been employed.

The licensee's submittal contained a blanket statement that all components associated with the new strainer assembly meet the applicable AISC, AWS, and ASME Code allowable stresses. The NRC staff proposed an RAI for completeness and comparison to the degree of rigor, which was employed.

RAI 27:

> The revised "Content Guide for Generic Letter 2004-02 Supplemental Responses," sent by letter dated November 21, 2007, Section 3k, requests a summary of structural qualification design margins for the various components of

the sump strainer structural assembly. This summary should include interaction ratios and/or design margins for structural members, welds, concrete anchorages, and connection bolts as applicable. Please provide this information.

FINAL NRC STAFF REVIEW:

The NRC final staff review is based on the licensee's August 13, 2012, RAI response.

RAI 27 requested the licensee to provide the design margins for the strainer components, which were analyzed for structural adequacy in support of the Catawba GL 2004-02 resolution. The response to this RAI is documented in the licensee's August 13, 2012, submittal. A figure of the modified sump strainer assembly at Catawba is provided to assist in visualizing the components included in the structural analysis. Additionally, the licensee provided a table summarizing the design inputs and loads used in the structural qualification of the Catawba sump strainer assemblies. The results of the structural analysis performed for the Catawba 1 and 2 sump strainer assemblies, including interaction ratios and design margins, are documented in Tables 27S-2 through 27S-9. The maximum stresses and loads which were calculated for these components are compared with the appropriate allowable stresses from the AISC 9th Edition and the ASME Section IIII, Division 1, NF-3324.6 for stainless steel studs/bolts. The welds associated with the stainless steel assembly were qualified based on the guidance in AWS D1.6.

FINAL NRC STAFF CONCLUSION:

The NRC staff has reviewed the licensee's response to RAI 27 and considers the response to be acceptable. This acceptance is based on the fact that the licensee has presented a detailed set of results for the structural qualification of the components, which make up the Catawba 1 and 2 sump strainer assemblies. Based on these results, the licensee was able to demonstrate that all applicable design code requirements were satisfied by maintaining interaction ratios, stresses and loads less than allowable values. This provides the NRC staff with reasonable assurance that the sump strainer assemblies will remain structurally adequate under normal and abnormal loading conditions such that the assemblies will be able to perform their intended design functions. The NRC staff considers this item 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 the sump.

INITIAL NRC STAFF REVIEW:

The initial staff review is based on documentation provided by the licensee through April 30, 2008.
The evaluation of post-accident ECCS sump inventory holdup in the Catawba containments includes physical diversions (e.g., curbs and filled CS piping) as well as potential debris blockage. The minimum ECCS sump pool level to ensure strainer submergence for SBLOCA events is discussed in the licensee response, including the assumptions for lost inventory due to physical diversions. The potential loss of ECCS sump inventory due to debris blockage is addressed below.

The evaluation of post-accident ECCS sump inventory holdup in the Catawba containments includes physical diversions as well as potential debris blockage. The minimum ECCS sump pool level evaluation to ensure strainer submergence in the limiting SBLOCA scenario is discussed below, including the assumptions for lost inventory due to physical diversions. For a larger break that would cause the CSS to actuate, there would be additional inventory not available for the ECCS sump (e.g., due to curbs in upper containment and filled CS piping). This inventory loss would be offset by ice melt contributions, since a break size that would actuate CS would also lead to the opening of the ice condenser lower inlet doors.

The evaluation does not addressed nor does it provide the basis for the assumption, which there is no potential blockage of the refueling canal drains by debris that may be blown upward in containment and fall in the vicinity of the drains or debris that may be transported by CS in the accident scenarios where the CSS is necessary.

The limiting analytical case for minimum ECCS sump level at Catawba can be characterized as a SBLOCA during which the CSS does not actuate and there is no water source contribution from ice melt. In addition, this containment analysis conservatively accounts for potentially diverted ECCS injection inventory.

The analysis assumes a small break of indeterminate size, which fills up the incore instrumentation room (located below the reactor vessel), but has insufficient energy to cause the containment spray system to actuate. No ice melt is credited in this analysis. Credited water for this specific accident includes the TS minimum inventory from the RWST, and the RWST low-low level setpoint is conservatively error adjusted upward to minimize the usable RWST volume. The following ECCS sump inventory penalties (lost water sources) are applied in this analysis:

- Reactor Coolant System shrinkage
- Incore instrumentation room diversion
- Volume Control Tank diversion
- Pressurizer Relief Tank diversion
- Lower containment ventilation system condensation diversion (loss of lower containment condensate through drain pans and drain lines)

The lower containment at Catawba is basically made up of two compartments - the area inside the crane wall and the pipe-chase. The ECCS strainer is located in the pipe chase. These two areas are connected at lower elevations by a number of crane wall penetrations on each unit, ranging in diameter up to 12 inches. The majority of these penetrations are centered at least 3 feet above the floor. Although it is possible for some of these penetrations to clog with debris, it is unlikely that a sufficient number of the penetrations would become clogged sufficiently to create a situation where the ECCS sump could be starved. The CFD model used for the evaluation of debris transport provides the basis for this conclusion.

Other potential choke points include the ice condenser drains and the refueling canal drains. Catawba has a total of twenty 12-inch ice condenser drains for draining the melting ice. If one of these drains were to become clogged, the water would flow to the other drains. The licensee stated that it is not likely that all 20 drains would become sufficiently clogged with debris to keep the water from flowing to the containment sump pool. The refueling canal in each unit has six 8-inch drains that are open during operation. Four of the drains discharge inside the crane wall, and the other two discharge into the pipe chase. The plant was designed so that the majority of the upper containment spray water flows to lower containment through these six drains. Given the size of these drains and the debris postulated to be washed down with the sprays (latent debris, paint chips and/or particulate, and possibly a small quantity of LOCA generated fines blown past the ice baskets) these drains are not likely to become clogged. Finally, the Catawba debris generation calculation does not postulate significant amounts of debris being generated in upper containment, since this area is outside the limiting break ZOI.

Catawba TS Surveillance Requirement 3.5.2.8 requires that the ECCS sump be visually inspected to verify there are no restrictions as a result of debris, and no evidence of structural distress or abnormal corrosion present prior to declaring the ECCS sump operable. A visual inspection of containment is performed to ensure no loose material is present, which could be transported to the containment sump and cause restriction of the ECCS pump suction during accident conditions prior to the transition from Mode 5 to Mode 4 operations. When these inspections are performed, major outage work is complete, and any remaining loose material in containment must be logged and tracked in accordance with station procedures for control and accountability. If any debris, damage, or deficiency were to be discovered during the inspection, station procedures would require entry into the corrective action program, with the requisite investigation and implementation of appropriate corrective action prior to the transition from Mode 5 to Mode 4. Catawba TS 3.6.15 applies to the ice condenser drains and the refueling canal drains. An inspection of the refueling canal drain is required to ensure that each canal drain valve is locked open and each drain is not obstructed by debris prior to entering Mode 4 from Mode 5 after partial/complete fill of the canal. A visual inspection is performed every 92 days to verify that no debris is present in the upper compartment or refueling canal that could obstruct the refueling canal drains. Lastly, each ice condenser floor drain valve is visually inspected and physically tested every 18 months to ensure it is not impaired by ice, frost, or debris, the valve seat shows no evidence of damage, the valve opening force is not excessive, and the drain from the ice condenser floor to the lower compartment is unrestricted.

RAI 28:

> Describe the basis in order to conclude that there is no potential of debris blockage at the choke points identified in the Upstream Effects evaluation (ice condenser drains and refueling canal drains) for accident scenarios where containment spray is necessary.

Summary for RAI 28:

The RAI requested that the licensee provide the basis for the conclusion that there is not a potential for debris blockage at the ice condenser and refueling canal drains for accidents when containment spray is necessary. The concern is that water could be prevented from reaching the containment sump which could challenge the operation of the strainer and the pumps taking suction from the sump.

Licensee Response Summary for RAI 28:

The licensee provided information regarding the inspections performed to ensure that the ice condenser is free of debris and that the ice condenser floor drains are operable. The ice condenser is inspected and debris removed or evaluated prior to the transition from Mode 4 to Mode 5. Additionally, every 18 months the ice condenser drain valves and drain lines are inspected to ensure that they will function. During an accident the ice condenser drains are designed with a check valve that is held closed by the blowdown pressure. These valves prevent debris from entering the drain lines. If some debris were to be carried up to the ice beds and become trapped, it would have a torturous path to exit the basket array to reach the ice condenser floor drains. If a drain or even multiple drains were to become blocked, there are other floor drains and alternate paths which would allow the water to reach the containment sump.

The licensee stated that debris created during an accident could not reach the refueling canal unless it was carried up through the spaces around the pressurizer, SGs, and reactor nozzles, then passed through the ice condenser lower plenum and through the baskets to reach upper containment. Only from upper containment is there potential for blocking the refueling canal drains. The licensee considers this to be a scenario that is not credible.

The licensee stated that programmatic controls prevent blockage of the ice condenser and refueling canal drains prior to an accident.

Acceptability of Response and Basis for RAI 28:

The licensee instituted controls to ensure that the ice condenser drain lines and refueling canal drain lines are operational and that debris could block them is not present in containment when the drains are required to be operational. These controls are sufficient to ensure that the drains will function to allow spray water to reach the containment sump and that pre-existing debris will not create blockages of the drains. Because any LOCA-generated debris would have to travel a torturous path to reach the refueling canal drain lines, the NRC staff concluded that it is not credible for debris large enough to block the drains to reach them. Although some debris may be blown into the ice condensers and eventually be released to the drain lines, it is not likely it would block an ice condenser drain. If an ice condenser drain becomes blocked there are multiple parallel drain lines and other flow paths, which would allow the water to reach the containment sump. Therefore, the NRC staff finds the response to RAI 28 to be acceptable.

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 conservatively or prototypically. With the exception of the potential for the blockage of the drains described in RAI 28, the licensee had previously provided adequate information to show that water will drain to the sump and not be held up to the extent that the function of the ECCS strainer and pumps would be compromised. Since the licensee has shown that the drainage paths from the ice condensers and refueling canal cannot credibly become blocked the NRC staff concluded that the upstream effects area has been adequately addressed by the licensee. The NRC staff considers this item closed for GL 2004-02.

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.

NRC STAFF REVIEW:

The NRC staff review is based on documentation provided by the licensee through April 30, 2008.

Initially, the licensee evaluated the downstream effects of sump debris on Catawba components and systems in accordance with TR-WCAP-16406-P, Revision 0, dated June 2005 that was superseded by Revision 1 of TR-WCAP-16406-P and the NRC SE for that WCAP. The licensee stated that a comparative evaluation would be performed to address any differences extended by TR-WCAP-16406-P, Revision 1. The licensee stated that the conclusions of the evaluations, based on the original TR-WCAP-16406-P, Revision 0, were considered conservative.

In the April 30, 2008, supplement, the licensee submitted the results of the re-evaluation of downstream effects using the methods and acceptance criteria described in TR-WCAP-16406-P, Revision 1, and the associated NRC SE. The licensee stated that the re-evaluation determined that all affected single and multistage pumps, heat exchangers, instrument tubing, valves, spray nozzles and orifices are not expected to fail or become blocked during the 30-day mission time following a LOCA event. The wear evaluation of all ECCS and CSS piping containing recirculated containment sump pool fluid during and after an accident determined that system piping is not expected to fail. The licensee stated that consistent with the GL 2004-02 supplemental response dated February 28, 2008, the results of the Catawba downstream debris effects evaluations on the critical ECCS/CSS components, performed in accordance with TR-WCAP-1 6406-P, Revision 1 criteria and the associated NRC SE, demonstrate that the currently installed components are acceptable for the expected ECCS mission time. No design or operational changes are required.

FINAL NRC STAFF REVIEW:

The NRC staff reviewed the evaluation results presented in the licensee’s GL 2004-02 response. The licensee performed ex-vessel downstream effects calculations and analyses in accordance with the NRC recognized methods prescribed in TR-WCAP-16406-P-A, Revision 1 and the associated NRC SE, including L&C. Therefore, the NRC staff concludes that the downstream effects of debris laden recirculated sump fluid on ex-vessel downstream components and systems have been adequately addressed at Catawba Nuclear Station, Units 1 and 2. The NRC staff considers this item closed for GL 2004-02

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 long term core cooling.

INITIAL NRC STAFF REVIEW:

The initial staff review is based on documentation provided by the licensee through April 30, 2008.

The licensee evaluated the in-vessel downstream effects of sump debris on Catawba components and systems in accordance with TR-WCAP-16406-P, Revision 0, dated June 2005 that is superseded by Revision 1 of TR-WCAP-16406-P and the NRC SE for that WCAP. The licensee also cited the analyses contained in TR-WCAP-16793-NP as being applicable to Catawba. The licensee stated that it is aware that the NRC is still evaluating the industry guidance provided by TR-WCAP-16793-NP, and will monitor the status of this evaluation. Based on the results of the plant specific downstream fiber and particulate debris effects evaluations performed, the licensee does not expect that significant changes to their assessment will be required as a result of the guidance in the final TR-WCAP-16793-NP.

The licensee performed an evaluation of the downstream effects of post-accident containment sump pool debris on the Catawba ECCS/CS systems. The evaluation considered the effect of debris ingested through the containment sump strainer on ECCS/CS components that are required to operate in the ECCS recirculation mode. The evaluation is based on the methodology developed and documented in Section 9 of TR-WCAP-16406-P, Revision 0, which the NRC did not accept for in-vessel evaluations. The licensee's evaluation of the Catawba reactor vessel internals showed that blockage in the vessel would not occur because the smallest flow clearance in the Catawba reactor vessel internals was much larger than the strainer opening size (2.24 inch flow passage vs 0.09375 inch strainer holes size). Using sump strainer fiber bypass test data, the licensee performed a preliminarily evaluation of the potential for blockage of the nuclear fuel assemblies during containment sump recirculation. The licensee evaluation stated that because the Catawba ECCS strainer top-hat design features a debris bypass eliminator, designed to reduce both the fibrous debris size and quantity that could potentially enter the core, the majority of the fiber bypass (over 98 percent) through the debris bypass eliminator would not build a fiber bed below or above the nuclear reactor core. Therefore, per the Westinghouse evaluation, sufficient open flow paths would exist to allow cooling of the nuclear fuel assemblies.

The licensee stated that the plant-specific fibrous debris bypass evaluations performed for Catawba are bounded by the evaluations described by TR-WCAP-16793-NP. Further, the licensee stated that it is aware that NRC staff is still evaluating the industry guidance provided by TR-WCAP-16793-NP, and will monitor the status of this evaluation. Based on the results of the licensee's specific downstream fiber and particulate debris effects evaluations performed, significant changes to the current assessment of the Catawba ECCS are not expected.

In the April 30, 2008, supplement, the licensee re-affirmed that the previous acceptable downstream effects evaluations addressing the nuclear fuel and reactor internals were determined to still be bounding with respect to the new requirements of TR-WCAP-16406-P, Revision 1.

The licensee's GL 2004-02 supplemental response for Catawba Units 1 and 2 does not contain sufficient information regarding the size and quantity of bypassed debris to permit a comprehensive evaluation, nor does it specifically address the evaluation guidelines in WCAP 16793-NP.

RAI 29:

The NRC staff considers in-vessel downstream effects to not be fully addressed at Catawba, as well as at other pressurized-water reactors. The supplemental response for Catawba refers to the evaluation methods of Section 9 of Topical Report (TR) WCAP-16406-P, Revision 1, "Evaluation of Downstream Sump Debris Effects in Support of GS-191," for in-vessel downstream evaluations and makes reference to a comparison of plant-specific parameters to those evaluated in TR WCAP-16793-NP, Revision 0, "Evaluation of Long-Term Cooling Considering Particulate, Fibrous, and Chemical Debris in the Recirculating Fluid." The NRC staff has not issued a final SE for TR WCAP-16793-NP. The licensee may demonstrate that in-vessel downstream effects issues are resolved for Catawba by showing that the licensee's plant conditions are bounded by the final TR WCAP-16793-NP and the conditions and limitations identified in the final NRC staff's SE. The licensee may also resolve this item by demonstrating without reference to TR WCAP-16793 or the NRC staff's SE that in-vessel downstream effects have been addressed at Catawba. 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's SE on TR WCAP-16793 .

FINAL NRC STAFF REVIEW:

The final NRC staff review is based on the licensee's July 31, 2013 letter.

On April 8, 2013 (ADAMS Accession No. ML13084A152), the NRC staff issued a SE on 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. 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 to NRC staff, the TR, the limitations and conditions section of the NRC SE of the TR and GL 2004-02 response content guide equire certain actions of the licensees.

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 safety evaluation on that document. Also, the response should briefly summarize the application of the WCAP evaluation methods and include the following information:

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

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

- The results of the peak clad temperature and clad deposit thickness (LOCADM) calculation,

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

- 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.

The L&C 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. 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.

In the licensee's July 31, 2013, response to NRC staff RAI regarding in-vessel downstream effects, the licensee provided the following information:

- The strainers are of the "top hat" design, consisting of two concentric cylinders having 0.09375 of an inch perforations and stainless steel knitted wire mesh located in the annular space between the two cylinders, functioning as a debris bypass eliminator. Strainer bypass-testing performed by Alion Science and Technology yielded a bounding fiber bypass quantity of 6.9 grams per fuel assembly—well below the 15 gram per fuel assembly limit qualified by TR-WCAP-16793-NP-A, Revision 2.

- The calculated maximum fuel clad temperature (after the initial quench) is 350 °F and the maximum calculated deposit thickness on the fuel rods is 12.2 thousandths of an inch (mils) well below the WCAP limits of 800 °F and 50 mils thickness.

- In the July 31, 2013, letter, the licensee satisfactorily demonstrated compliance with the 14 L&C of the NRC SE of TR-WCAP-16793-NP-A, Revision 2.

<u>FINAL NRC STAFF CONCLUSION</u>:

NRC staff reviewed the description of the analyses, strainer bypass testing, and compliance with the L&C of the SE, as described in the Licensee's GL-2004-02 response to Item (n) and find that the licensee response addressing in-vessel downstream-effects for Catawba 1 and 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 long term core cooling at Catawba 1 and 2. The NRC staff considers this item closed for GL 2004-02.

17.0 CHEMICAL EFFECTS

The objective of the chemical effects section is to evaluate the effect that chemical precipitates have on head loss and core cooling.

INITIAL NRC STAFF REVIEW:

The initial staff review is based on documentation provided by the licensee through April 30, 2008.

The licensee performed bench testing to evaluate aluminum corrosion rates in representative post-LOCA sump pool environments. The NRC staff reviewed the bench tests results (for information only outside the GL supplement review) and concluded the tests were well conceived and executed. The licensee used these test results to establish a licensee specific aluminum release rate algorithm. Since the licensee's aluminum release is different and slightly greater than that calculated using the WCAP-16530-NP Equation, the licensee used their own aluminum release rate calculations.

The licensee also performed 14 vertical loop head loss tests to evaluate sensitivities for potential chemical effects. Since the licensee is relying on the IPT, details of the vertical loop head loss tests were not provided in the licensee submittal.

The licensee performed a 30 day IPT that involved adding non-chemical debris such as fiberglass to a test tank containing heated borated water with sodium tetraborate added to reach a plant specific potential of Hydrogen (pH). Dissolved aluminum, in the form of aluminum nitrate, was metered into the tank over the course of the test. Aluminum concentrations were intended to match the aluminum concentration predicted by the release rate calculations. The test fluid was heated and the tank temperature was highest at the start of the test and allowed to cool during the test to simulate the post-LOCA cooling profile.

IPT used maximum temperature profile for the beginning of the test and the minimum temperature profile at the end of the test to promote dissolution and subsequent precipitation. A bounding amount of aluminum was used for the submerged and sprayed surface areas.

Due to the tank/pipe/strainer physical arrangement, the plant debris would not transport to the top-hat strainer using the normal test flow. Therefore, a reduced water volume, more turbulent flow was used during debris addition in an attempt to transport the debris to the strainer. Video of the debris addition to the test tank showed significant debris agglomeration (e.g., clumps of debris dropping from the bucket into the tank). Following the test, the NRC staff observed that a significant amount of fibrous debris settled at the entrance to the pipe section, upstream of the test strainer.

The NRC staff was concerned that the debris bed that formed on the test strainer, and the amount of bare strainer area, is not representative of what may occur with the plant configuration. Dissolved aluminum in the licensee's 30 IPT decreased over time, which may indicate a precipitation process. NRC sponsored tests (at higher pH) indicated that aluminum based precipitate formation in a sodium tetraborate environment most probably occurs in a delayed time frame rather than immediately.

INITIAL NRC STAFF CONCLUSION:

For this review area the licensee has not provided information such that the NRC staff has reasonable assurance that the subject review area has overall been addressed conservatively or prototypically. Provide a summary-level basis for this overall conclusion.

Although the licensee's integrated head loss testing (i.e., IPT) indicated that the pressure drop across the strainer was acceptable), NRC staff observations of the test and video review of debris addition has caused the staff to question whether this test was representative of the plant. Fibrous debris was agglomerated when added to the test tank and flow to a single 36-inch long Enercon top-hat strainer was intentionally turbulent in an attempt to transport the fiber. This flow during debris addition was not prototypical of the plant and therefore, the debris bed on the top-hat strainer may not have been prototypical. At the completion of the test, approximately 10 inches at the top of the strainer were bare, so any impact from chemical precipitate was not necessarily measured since precipitate tends to pass through bare strainer.

RAI 30:

> Please discuss why the Integrated Prototype Test (IPT) provided a representative debris bed on the top-hat strainer module for filtering chemical precipitates. The NRC staff observed the debris addition video and concluded that the fibrous debris introduced into the test tank was more agglomerated than what may arrive at the strainer under post-LOCA flow conditions in the plant. Is the amount of bare strainer area observed in the test representative of what is expected to occur with the plant strainer array if a large break LOCA were to occur? The use of chemical effects test results derived from a test which formed a non-prototypically partially clean screen fiber bed would not be appropriate.

The NRC staff asked this RAI because the previous strainer head loss test performed by the licensee at Wyle Laboratory that evaluated chemical effects had issues with debris preparation, debris agglomeration, and debris transport to the test strainer. Therefore, the NRC staff questioned whether the licensee had an adequate test for chemical effects since the staff concluded that the amount of bare strainer area in the test may have been non-conservative. There also is a link between this RAI and RAIs 11, 21, and 25 in that the time-dependent head loss is provided and compared to the NPSH margin. This review would cover the chemical effects part of those RAIs as well. The licensee calculated total head loss by adding the chemical effects head loss to the particulate and fibrous debris head loss at an assumed temperature of approximately 165 °F.

FINAL NRC STAFF EVALUATION:

The Final NRC staff review is based on the licensee's August 13, 2012, RAI response.

NRC Staff Evaluation of RAI 30 Response:

As stated in the licensee's August 13, 2012, response, the RAI based on the licensee's February 29, 2008, response (and supplemented with a April 30, 2008, response), no longer applies in the same manner as written since the licensee redesigned the test facility and performed additional testing in response to the RAI. Nevertheless, the broad intent of the question that related to the licensee demonstrating an adequate chemical effects evaluation remained valid.

The licensee calculated total head loss by adding the chemical head loss to the head loss from other (non-chemical) debris from a strainer test performed at Wyle Laboratory. Chemical effects were simulated by adding WCAP-16530-NP-A precipitate, assuming a delay in the precipitate formation until the post-LOCA pool temperature cools to approximately 165 °F. This temperature would be reached between 50 minutes (170 °F) and 1.2 days (160 °F) following swap-over to sump recirculation phase.

The NRC staff evaluated the licensee's response on delayed precipitation based on plant specific pH, temperature, and calculated aluminum concentration in the post-LOCA sump pool. In the licensee's February 29, 2008, supplement, it stated that Catawba uses sodium tetraborate to buffer the post-LOCA pool pH. The Catawba pH is calculated to be in the approximate range of 7.8 to 8.0. The licensee's aluminum concentration provided in the same submittal is approximately 11 parts per million. Using this information, the NRC staff calculated the solubility of aluminum using the referenced Argonne National Laboratory (ANL) Technical Letter Report "Aluminum Solubility in Boron Containing Solutions as a Function of pH and Temperature," September 19, 2008 (ADAMS Accession No. ML091610696), Equation 4 and confirmed that the licensee's dissolved aluminum concentration is well below the amount predicted to result in precipitation at the 165 °F temperature of interest. In addition, though not all test parameters were identical, the aluminum solubility observed in Intergrated Chemical Effects Test 5 also supports the NRC staff judgment that the Catawba assumption on precipitation temperature is conservative. These tests were conducted and reported in NUREG/CR-6914, "Integrated Chemical Effects Test Project," December 2006. Therefore, the licensee's overall evaluation is acceptable to the NRC staff since the use of chemical precipitate formed per the TR-WCAP-16530-NP-A in strainer head loss testing is acceptable and the delay in applying the chemical induced head loss according to the Catawba evaluation also, is acceptable.

<u>FINAL NRC STAFF CONCLUSION</u>:

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 conservatively or prototypically. The licensee has provided information such that the reviewer has high confidence in the adequacy of the licensee's test and evaluation methods in this subject area.

The licensee performed sump strainer testing and simulated chemical effects by adding pre-mixed precipitate formed with the TR-WCAP-16530-NP-A method. This is acceptable to the NRC staff since the NRC staff reviewed and approved this WCAP method for evaluating chemical effects. Since the plant specific approach credited short term solubility of aluminum based precipitates, the staff performed an independent calculation of aluminum solubility using Equation 4 in the referenced ANL Technical Letter Report. The NRC staff calculation showed the licensee assumption about precipitation temperature to be conservative and therefore, acceptable to the NRC staff. Based on the above NRC staff review, the NRC staff concludes that the Catawba chemical effects evaluation is acceptable. Therefore, the NRC staff considers this item closed for GL 2004-02.

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 the changes associated with GL 2004-02.

In supplemented response letter dated February 29, 2008, the licensee committed to change the UFSAR in accordance with 10 CFR 50.71(e) to reflect the changes to the plant in support of the resolution to GL 2004-02. In addition, the licensee stated that changes would be made to the UFSAR describing the new licensing basis to reflect the revised debris loading as it effects ECCS sump strainer performance and in-vessel effects, including the following:

- Break Selection
- Debris Generation
- Latent Debris
- Debris Transport
- Head Loss
- Additional Design Considerations

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 conservatively or prototypically. Based on the licensee's commitment, the NRC has confidence that the licensee will affect the appropriate changes to the Catawba Unit 1 and 2 UFSAR, in accordance with 10 CFR 50.71(e), that will 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 10 CFR 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 foe 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 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-2004-04 are adequate and considers GL-2004-02 closed for the Catawba Nuclear Station Units 1 and 2.