U.S. NUCLEAR REGULATORY COMMISSION STAFF REVIEW

OF THE DOCUMENTATION PROVIDED BY

DUKE ENERGY CAROLINAS, LLC

FOR THE OCONEE NUCLEAR STATION UNITS 1, 2, AND 3

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 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).

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

After the NRC staff evaluation of licensees’ 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 functions 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 Vortexing
- 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-focused. The Commission issued a Staff Requirements Memorandum on December 14, 2012 (ADAMS Accession No. ML12349A378), approving all three options for closure of GSI-191.

By letter dated May 15, 2013 (ADAMS Accession No. ML13137A047), 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 Oconee Nuclear Station, Units 1, 2, and 3 (ONS).

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

DOCUMENT DATE	ADAMS ACCESSION NUMBER
March 1, 2005	ML050670465
September 1, 2005	ML052500399
February 9, 2006 (NRC RAI)	ML060380002
February 29, 2008	ML080710159
February 27, 2014	ML14065A040

The NRC staff reviewed the responses to the February 29, 2008 RAIs, and by letter dated July 1, 2008 (ADAMS Accession No. ML081750635), concluded that the NRC staff had no further questions regarding the licensee's completion of corrective actions for GL 2004-02, with the exception of the demonstration that in-vessel downstream effects issues are resolved. The NRC staff's conclusion is based on the very low debris loading at ONS, as discussed in the licensee's February 29, 2008 RAI response.

2.0 DOWNSTREAM EFFECTS - FUEL AND VESSEL

The objective of the downstream effects review, 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 NRC staff review is based on documentation provided by the licensee through February 29, 2008.

By letter dated February 29, 2008, the licensee submitted a supplemental response to GL 2004-02. In the submittal, the licensee stated that it performed an evaluation of the effects of ECCS sump strainer bypassed debris on post-LOCA long-term core cooling at ONS using the guidance in WCAP-16793-NP, Revision 0. The evaluation showed that long-term core cooling can be achieved and the maximum fuel clad temperature, after the initial core quench, can be maintained below 800 ºF. However, the licensee acknowledged that the NRC staff had not

issued a final SE on WCAP-16793-NP, Revision 0, and, therefore, committed to submitting a final response within 90 days of receipt of the final NRC SE.

By letter July 1, 2008 the NRC staff expressed reasonable assurance that the likelihood of unacceptable in-vessel debris impact for ONS is very low because of the low debris loading at ONS. However, because the GL 2004-02 response referred to and relied on a topical report for which the NRC had not yet issued an SE, the NRC deferred issuance of a closure letter to ONS for GL 2004-02 until uncertainties regarding the issues with WCAP-16793-NP were reduced. Further, the NRC stated that the licensee could wait for the issues to be resolved through the WCAP process or could demonstrate that in-vessel downstream effects issues were resolved for ONS by demonstrating, without reference to WCAP-16793 or the NRC staff SE, that in-vessel downstream effects were addressed for Oconee.

FINAL NRC STAFF REVIEW:

By letter dated February 27, 2014, the licensee submitted a revised GL 2004-02 in-vessel downstream effects resolution for ONS. The final NRC staff review is based on the licensee's February 27, 2014 letter.

Evaluation Criteria:

On April 8, 2013, the NRC staff issued an SE (ML13084A154) on Topical Report (TR) WCAP-16793-NP, Revision 2, finding the TR an acceptable model for assessing the effects 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, the TR, the limitations and conditions section of the NRC SE of the TR, and the GL 2004-02 response to the content guide (ML073110278) require certain actions of the licensee. These requirements and the licensee's actions for meeting these requirements are described herein.

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

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

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

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

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

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

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

By letter dated February 27, 2014, the licensee stated that ONS meets the requirements of 10 CFR 50.46, "Acceptance criteria for emergency core cooling systems for light-water nuclear power reactors," based on approved models for analyses, strainer head loss testing, and its analysis of in-vessel downstream effects. As the WCAP-16793-NP, Revision 2 methodology represents an NRC-approved model, successful completion of the in-vessel downstream effects analysis in accordance with the WCAP and associated SE shows compliance with 10 CFR 50.46 as it relates to in-vessel downstream effects, and resolves this final outstanding item for ONS.

The licensee determined the amount of fiber that could bypass their ECCS strainer using the methods allowed in the NRC Staff SE for WCAP-16793, Rev. 2. The SE allows licensees to determine the quantity of strainer bypass for their strainer by using the results of strainer testing conducted on a strainer of the same manufacture and same perforation size as the plant strainer. If necessary, the results are to be prorated to the plant's strainer area, approach velocity, debris types, and debris quantities. In the February 27, 2014 letter, the licensee provided a comparison of the ONS strainer design parameters to the Salem Nuclear Generating Station, Units 1 and 2, strainer design parameters to demonstrate that the bypass testing conducted for Salem could be applied to the ONS strainer installations to determine the ONS strainer bypass quantities. The NRC staff has reviewed and accepted the Salem bypass evaluation as documented in the GL 2004-02 Salem plant closure documentation (ADAMS Accession No. ML14113A221).

The licensee performed a critical parameter review that compared the Salem ECCS strainer design and operating conditions to those at ONS. The licensee stated that the Salem strainer and the ONS strainer were both manufactured by Control Components Incorporated and both have 1/12-inch diameter perforations. The NRC staff performed a GL 2004-02 audit at both Salem and ONS and examined the strainer designs and layouts and reviewed their operating conditions. The NRC staff concluded that the designs and operating conditions for the strainers are similar and that bypass testing for one strainer can be applied to the other, if properly scaled.

The licensee compared the strainer areas of the strainers installed in the two Salem units and the three ONS units. The ONS strainers are slightly larger than the Salem strainers, but are sufficiently similar. The effective surface areas of the Salem strainers are 4656 square feet (ft^2) for Unit 1 and 4854 ft^2 for Unit 2. The three ONS strainers range in area from 4867 ft^2 to 5191 ft^2. Because testing was conducted in a reduced scale facility and the results scaled up to the plant strainer area, the difference in strainer sizes between the plants is not significant to the evaluation of debris bypass. The NRC staff concluded that scaling of the test results adequately addresses the difference in sizes between the Salem and ONS strainers.

The licensee compared the strainer flow rates at Salem to those at ONS. The licensee stated that for Salem, the maximum strainer flow rate is 8850 gallons per minute (gpm), and the

maximum ONS strainer flow rate is 7400 gpm. The submittal stated that higher flow rates were shown to result in higher amounts of debris bypass. The NRC staff agrees that the Salem tests, and similar industry testing, show that higher flow velocities result in larger amounts of bypass. The velocity at the strainer (approach velocity) is determined by the flow rate through the strainer and the strainer surface area. Since the ONS flow rate is lower than that at Salem and the strainer areas at ONS are larger than at Salem, the velocity through the ONS strainer is lower than at Salem. Therefore, using Salem bypass values for ONS is conservative when considering the strainer approach velocity. The NRC staff also noted that the velocity through the ONS strainer would be significantly more uniform than that through the Salem strainer before debris is deposited on the strainer. This simplifies applying the module test results to a larger plant strainer. The NRC staff reviewed the evaluations and concluded that the velocities used in the Salem bypass testing are conservative with respect to the ONS strainer for the purpose of determining debris bypass amounts.

The licensee compared the amount of fibrous debris used in the Salem tests with that which comprises the ONS design basis. The Salem test that contained the smallest amount of fiber considered only the latent debris term at Salem. Salem's latent fibrous debris is assumed to be 30 pounds mass (lbm) and this value was used to determine the amount of debris that should be included in the test. The total ONS fibrous debris term is 18.18 lbm. Because the amount of fiber in the ONS design basis is lower than the smallest amount of fiber tested for Salem, and because the testing determined that the amount of bypass is a function of strainer area and not the amount of fiber arriving at the strainer, the results of the Salem tests adequately represent the amount of bypass that would be expected at ONS. The ONS submittal also stated that their evaluation of bypass was based on a test that had higher quantities of fiber than the latent debris-only test. The staff also considered that the Salem testing was conducted by adding the debris to the test slowly so that a thick debris bed that could prevent higher quantities of fiber bypass would not form quickly on the strainer.

The licensee's submittal discussed the test conditions that were used during the Salem testing. The NRC staff has evaluated the test conditions as discussed in the GL 2004-02 Salem plant closure document referenced above. The NRC staff's evaluation and acceptance of the test conditions can be found in that document. For ONS, the NRC staff found that the licensee adequately demonstrated the similarity of the ONS and Salem strainer designs and operating conditions and demonstrated that the Salem test conditions are similar to or bound the ONS plant conditions. Further, the NRC staff finds the licensee's extrapolation of the Salem test results to the ONS plant conditions acceptable. These actions meet the staff guidance provided in the staff SE for WCAP-16793, Rev. 2. Therefore, the NRC staff concludes that the licensee's evaluation of strainer bypass is technically adequate. The bypass amount of 11.3 grams per fuel assembly was determined in accordance with NRC staff guidance and is therefore acceptable.

The licensee performed a plant-specific evaluation of the maximum fuel clad temperature and deposit thickness for ONS using WCAP-16793-NP, Revision 2, and the associated NRC SE for that document. The evaluation results are:

1. The maximum calculated cladding temperature is 331 degrees Fahrenheit (°F). This is less than the WCAP-recommended maximum cladding temperature of 800 °F.

2. The total deposition thickness is 0.0238 inch (23.8 mils). This is less than the WCAP recommended total debris deposition thickness of 0.050 inch.

Also, in the letter dated February 27, 2014, the licensee satisfactorily demonstrated compliance with the 14 L&Cs of the NRC SE for WCAP-16793-NP-A, Revision 2.

Based on the above information, the licensee has documented that ONS Units 1, 2 and 3 meet the requirements specified in WCAP-16793-NP, Revision 2, and the specifications, limitations, and conditions listed in the associated NRC SE.

NRC STAFF FINAL CONCLUSION:

The NRC staff reviewed the description of the analyses, strainer bypass testing, and compliance with the L&Cs of the SE, as described in the licensee's GL 2004-02 response to Item (n) and finds that the licensee's response addressing in-vessel downstream effects for Oconee Nuclear Station Units 1, 2, and 3 satisfies the requirements stated in TR WCAP-16793-NP-A, Revision 2 and the NRC SE for that document. Therefore, the NRC staff concludes that the licensee has adequately addressed the potential effects of ECCS sump strainer bypassed debris on core cooling at ONS. The NRC staff considers this item closed for GL 2004-02.

3.0 CONCLUSION

The NRC staff has performed a thorough review of all of the licensee's responses and RAI supplements to GL 2004-02. The NRC staff conclusions associated with in-vessel downstream effects are documented above. Based on the above evaluation, and the NRC July 1, 2008, letter 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 for debris to adversely affect long-term core cooling. The NRC staff finds the information provided by the licensee demonstrates that debris will not inhibit the ECCS or CSS from performing their intended functions 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 Oconee Nuclear Station, Units 1, 2, and 3.