April 23, 2014

Ms. Lesa Hill, Chairman
Boiling Water Reactor Owner's Group
Southern Nuclear Operating Company
PO Box 1295 Bin B048
Birmingham, AL 35201-1295

SUBJECT: FEEDBACK ON BOILING WATER REACTOR OWNER'S GROUP REPORT BWROG-ECCS-WP-3/11-1, SUMMARY OF MEMBER RESPONSES TO BWROG SURVEY ON STRAINER HEAD LOSS AND NEAR-FIELD EFFECTS

Dear Ms. Hill:

The U.S. Nuclear Regulatory Commission (NRC) staff has reviewed the Boiling Water Reactor (BWR) Owner's Group (BWROG) report BWROG-ECCS-WP-3/11-1, "Summary of Member Responses to BWROG Survey on Strainer Head Loss and Near-Field Effects," and offers the following feedback:

The NRC staff understands that the survey responses are being used to address BWROG Issues 3 and 11, Debris Head Loss and Near-Field Effects and Scaling. However, the report did not attempt to provide final closure to these issues. The NRC staff has developed comments which should be considered by the BWROG during resolution of Issues 3 and 11.

Issues 3 and 11 are summarized below based on minutes of meetings between the BWROG and the NRC.

Issue 3, Debris Head Loss, was identified because semi-empirical head loss correlations that were used to evaluate BWR strainer performance may not have accurately predicted head losses for some conditions that may occur in the plant. The most significant aspects of this issue are the concerns that correlations:

1) may not accurately predict thin bed head losses,
2) may not account for types of debris that were not tested (including problematic debris types like calcium silicate or other microporous insulation types),
3) may not have tested an adequate range of conditions to ensure accurate prediction of head loss for the range of potential plant conditions,
4) may have been based on testing conducted with non-conservative debris surrogates including fibrous debris that did not include an adequate amount of fine debris (related to Issue 10, Debris Characteristics), and
5) may not adequately model non-homogenous debris beds.

Issue 11, Near-Field Effects and Scaling, was identified because adequate information was not available to determine whether the testing used to qualify BWR strainers adequately insured that the debris intended to reach the strainer actually did so.

The issue also identified that the extrapolation of head loss results to plant conditions different from tested conditions may not have been performed conservatively. The most significant aspects of this part of the issue relate to:

1) scaling the test results to higher temperatures,
2) extrapolating the test results to the strainer mission time, and
3) extrapolating the results to debris bed conditions not within the test scope (circumscribed debris beds).

It is not clear that the information provided in the report, in conjunction with the process provided for plants to assess their plant head loss evaluation in Appendix A, will ensure that the issues are addressed. Issue 10, Debris Characteristics, may have to be resolved in conjunction with Issues 3 and 11. Areas that may require additional information or revised methodology are discussed below.

In several places, the report implies that BWR implementation methodology should be reviewed against guidance in the Utility Resolution Guide (URG). The 12 BWR issues were developed because there are concerns that the URG methodology may contain some non-conservative guidance based on lessons learned since the guidance was developed. Therefore, verifying that methodologies used by BWRs comply with URG guidance may not adequately assure that the issues have been addressed.

Although the report discussed some areas in more than one location, the NRC staff comments will be focused on Sections 6 and 7 of the report.

Section 6.1.2 of the report discusses problematic debris and coatings. It was not clear that all problematic debris sources were considered or that the lessons learned during pressurized water reactor (PWR) strainer test programs were fully considered in the report. The report indicates that most plants had small amounts of problematic debris, but did not address plants that had larger amounts of the debris or provide a threshold or basis for amounts that could be considered negligible. Although some PWR tests with very small amounts of problematic materials did not result in significantly increased head loss, some tests with relatively small amounts of these materials did result in higher than expected head losses. The BWROG may be able to develop an amount of problematic debris below which their effects can be considered negligible. A basis for the threshold amount should be provided.

Section 6.1.2 of the report did not discuss Koolphen insulation which was included in the air jet testing of insulation. Based on the information in the URG on air jet tests, Koolphen forms a cloud of dust when exposed to a jet. This behavior is similar to microporous insulations. The staff has not received any head loss test reports for tests that included Koolphen and therefore does not know how it behaves in a debris bed. Licensees should consider the potential for Koolphen to behave as microporous debris or perform testing to determine its head loss characteristics.

The report discusses debris settling (or transport) and time dependence of debris arrival at the strainer in Sections 6.1.3, 6.1.4, and 6.3.10. Sections 6.1.3 and 6.1.4 consider settling that was credited in the transport evaluation.

Some licensees calculated these parameters using the BLOCKAGE code. It was not clear whether the implementation of the BLOCKAGE code for each plant resulted in an equivalent debris transport to that provided in the URG and approved by the staff safety evaluation (SE). Although information regarding the transport of debris in the plant is included in the report, it is beyond the scope of Issues 3 and 11 which deal with testing. The NRC staff has concluded that it is unlikely that fine fibrous debris would settle in the suppression pool before it reaches the strainer. The NRC staff also noted that NUREG/CR-6224 states that most fibrous debris in the suppression pool would be reduced to relatively fine fibers during the blowdown and chugging phases of the loss-of coolant-accident (LOCA). The NUREG also cautions that the settling information for fibrous debris is only applicable to encapsulated Nukon. It is not clear that the delay in debris arrival credited by the vendors was justified. However, it is unlikely that assuming that the full amount of debris does not reach the strainer for a short period of time after a LOCA would add significant non-conservatism to the head loss evaluation. The debris is likely to be very well mixed in the suppression pool and reach the strainer over time as the water is pumped through the emergency core cooling system (ECCS). Any significant delay credited for debris arrival times should be evaluated to ensure that net positive suction head (NPSH) margins are not challenged early in the event. Timing of debris arrival may be more critical for strainer bypass and in-vessel evaluations. Section 6.3.10 is addressed later in this review.

In Section 6.1.5, the report discusses debris mixtures. This section states that one plant considered other operating modes of the residual heat removal (RHR) system (other than the maximum fiber case of one pump running). The report states that with more pumps running, the debris load is decreased but the flow velocity through the strainer may be increased. It is not clear which condition results in the maximum head loss or whether other plants considered other pump alignments. The most limiting pump alignment that is within plants' design bases should be considered by each plant.

Section 6.1.5 also states that a plant discovered additional sources of problematic debris after performing head loss tests and increased the debris head loss by 20 percent to account for the debris. It was not clear to the staff whether the problematic debris could have resulted in a significant head loss increase or how it was determined that a 20 percent increase in head loss adequately accounted for the additional debris. A more detailed basis should be developed for the 20 percent factor.

The debris mixtures section also states that one plant had Min-K insulation installed inside welded steel cassettes and that this potential debris source was treated as Nukon for the testing. Although the Zone of Influence (ZOI) for welded steel cassettes may be smaller than that for typical Nukon installations it is not clear to the staff that the licensee's approach was realistic or conservative. A determination of potential Min-K debris generation should be conducted to determine whether this is a significant issue.

Thin beds are discussed in Sections 6.1.6 and 6.3.14 of the report. The report states that alternate geometry strainers did not produce higher head losses when tested with less fiber debris than with the maximum amount of fiber for the tested debris loads. The report references the URG and the associated staff SE. The SE states that small fiber loads combined with large amounts of sludge do not result in very high head losses so that medium breaks are bounded by larger breaks. This does not directly address whether the thin bed effect was considered in the test programs.

The URG is lacking in detail, and its conclusions do not match observations made during some PWR testing. The results of the URG testing may have been affected by debris surrogate characteristics. The BWROG has stated that thin-bed head losses will be addressed by a test program. The test program, if conducted adequately, should be able to disposition this issue.

Section 6.2 discusses head loss correlations. The NRC staff has determined that the use of correlations for predicting ECCS strainer head loss may result in significant inaccuracy. The major issues with correlations are that they:

1) may not accurately predict thin bed head losses,
2) may not adequately account for types of debris or debris mixes that were not tested (including problematic debris types like calcium silicate or other microporous insulation types or different fibrous debris types),
3) may not have tested an adequate range of conditions to ensure accurate prediction of head loss for the range of potential plant conditions,
4) may have been based on testing conducted with non-conservative debris surrogates including fibrous debris that did not include an adequate amount of fine debris (related to Issue 10, Debris Characteristics), and
5) may not adequately model non-homogenous debris beds.

Section 6.2.7 discusses problematic debris as it relates to correlations. The report states that some correlations model problematic debris based on its physical characteristics similar to the methodology used in the NUREG/CR-6224 correlation for the determination of head loss. The NRC staff has determined that physical characteristics (especially characteristics like specific surface area or Sv) are not reliable predictors of head loss as used in correlations, and that some head losses, including those due to problematic debris, may be significantly underestimated by the use of physical characteristics.

One correlation was developed using sludge, fiber, and RMI debris. This correlation also includes a miscellaneous bump up factor to account for some materials like paint, rust, dust, and calcium silicate. Additional debris-specific bump up factors for this correlation were developed from gravity head loss testing. It was not clear how the miscellaneous bump up factor was developed, whether there was a technical basis for the factor, or how it was included in the final head loss. The gravity head loss testing bump up factors may not be valid unless the debris beds in the testing had similar morphologies to the beds that the bump up factors are applied to. Additionally, to ensure validity, the gravity testing should have been developed under flow and differential pressure conditions similar to those in the plant. It was also unclear how the gravity bump up factors were applied. A clear basis for the development and application of these factors should be established including the concerns noted above.

The correlation section discusses temperature scaling in Section 6.2.8. Temperature scaling is also discussed in Section 6.3.12. The NRC staff has concluded that temperature scaling to higher temperatures is appropriate if testing has demonstrated that the head loss responds relatively linearly to flow changes. Testing should include flow sweeps that verify this behavior if temperature scaling is credited in the strainer evaluation.

The NRC staff concluded that correlations should not be used for strainer qualification unless they are based on an experimental program that includes appropriate debris surrogates, and

ranges of conditions that provide reasonable assurance that a maximum head loss for potential plant specific conditions has been determined, considering the concerns listed above.

Section 6.3 discusses generic and specific head loss tests. General staff concerns for strainer testing are listed below:

1) thin bed head loss was not evaluated in all test programs,
2) testing or evaluations should account for all types of debris that may be present at the strainer (including problematic debris types like calcium silicate or other microporous insulation types and varying types of fibrous debris if significantly different from those tested),
3) tests should include an adequate range of conditions to ensure accurate or conservative prediction of head loss for the range of potential plant conditions, and
4) debris preparation and introduction should ensure realistic or conservative test results; that is, debris surrogates should be verified to be realistic or conservative, including that fine fibrous debris was adequately represented in the testing based on both the amount and characteristics of the fiber (related to Issue 10, Debris Characteristics) and that unrealistic agglomeration of the debris did not occur during testing.

The report discusses debris characteristics in Section 6.3.9. The report indicates that, in general, the fibrous debris surrogates were similar to fibrous debris that has been shredded once in a leaf shredder. During PWR testing it was determined that leaf shredded fiber does not meet the requirements for fine fiber. NUREG/CR-6224 indicates that most debris in the suppression pool would be classes 1, 2, and 3 following the chugging phase of the LOCA (see the NUREG for fiber classifications). Additionally, the URG states that a significant portion of the debris that transports to the suppression pool will be fines. The testing performed both for correlation development and for strainer qualification appears to have used fiber pieces larger than those predicted by NUREG/CR-6224 to arrive at the strainers. This can have a non-conservative effect on debris head loss during testing. The effect of use of leaf shredded fiber in head loss testing should be evaluated and corrective actions taken, if necessary.

For the ENERCON strainer testing, Section 6.3.9 states that the debris was prepared to simulate LOCA debris properties. There is inadequate information in this statement for the staff to determine whether the debris was prepared properly. There is inadequate information about the properties of debris surrogates used in the ABB testing for the staff to determine its adequacy. Considering the discussion above the debris characteristics for all BWR tests should be evaluated and corrective actions taken as necessary.

The report discusses the near-field effect, or debris settling during testing in Section 6.3.10. The report states that vendors typically took measures to prevent debris settlement during testing. The exception was that testing for ENERCON strainers was designed to simulate suppression pool conditions in the Mark III containments where they are installed.

During PWR testing it was determined that simulating velocities in a test strainer near field may result in significantly lower turbulence than would actually occur in the plant. This was generally due to test facilities being smaller in scale than the plant. Low turbulence could result in non-conservative amounts of debris settling during testing. The ENERCON strainer test program

should be reviewed to ensure that turbulence and velocity levels were realistic or conservative during testing. Additionally, when considering the near field effect, the debris surrogates are an important consideration. For example, fiber prepared in large pieces would be more likely to settle than finer fiber. Therefore, debris surrogates should be ensured to transport similarly to those in the plant. Although not discussed, one other concern with agitation is that it should not disturb the debris bed in an unrealistic manner.

In Section 6.3.11, the report discusses test termination criteria. The termination criteria for one vendor's strainer testing were stated to be less than a 5 percent increase in pressure drop during 30 minutes. Other termination criteria were stated to be steady state pressure differential. The termination criteria for one strainer vendor's testing were not known. During PWR strainer testing it was determined that although head loss may appear to be stable after all debris has been added to the test, head loss may slowly increase over time. The head loss behavior during testing was dependent on strainer design and debris load. For example, for some PWR debris loads and strainer designs, head loss would begin to decrease shortly after all debris had reached the strainer. For other tests, head loss would remain stable, and for some, it would slowly increase. To allow a 5 percent increase over 30 minutes appears to be non-conservative and possibly highly non-conservative. The strainer mission times are on the order of days, not minutes. Even a seemingly small increase rate can be significant over the strainer mission time. The test results should be further evaluated to determine whether increasing, steady state, or decreasing head loss trends existed at termination. For tests that had increasing head loss and for those tests for which the trend is indeterminate, the potential effects of head loss increase over the mission time of the strainers should be evaluated and corrective actions taken, as necessary. PWR test vendors used various methods to evaluate the need to extrapolate head loss test results to strainer mission times, and to perform the extrapolation if necessary.

The report provides conclusions regarding the head loss surveys in Section 7.0. Some of the conclusions from the report are discussed in more detail in the sections below.

Section 7.1 of the report discusses near field effects. The NRC staff agrees that plants that have ENERCON strainers should review the approach velocities used during testing to ensure that they are realistic or conservative. The staff also concluded that turbulence levels should be evaluated and ensured to be realistic or conservative. As noted above, test debris surrogate characteristics can affect transport during testing. Surrogate characteristics should also be evaluated as part of the near field effect evaluation.

Section 7.2 of the report discusses debris settling which was credited in the transport evaluation. The report concludes that the BLOCKAGE and STRAIN codes should be evaluated to determine whether they are consistent with the latest BWROG guidance and references Issue 9. The NRC staff agrees that the portions of these codes that address settling can be evaluated within Issue 9.

The report, in Section 7.3, discusses the use of the NUREG/CR-6224 correlation for determination of head loss. The report states that plants with Performance Contracting, Inc. (PCI) strainers that have problematic debris should review their head loss evaluations to ensure that the assumed debris characteristics are consistent with latest industry practices for the use of the correlation. The NRC staff agrees with this recommendation, but also believes it should extend to all plants that used correlations. Plants that used this or another correlation should

address the generic issues that the use of correlations present, as discussed above, including how problematic debris was assessed.

Section 7.4 of the report discusses epoxy coatings characteristics and states that this issue will be evaluated as part of Issue 10, debris characteristics. The NRC staff agrees that the coatings characteristics can be evaluated within Issue 10, but notes that it may not be realistic or conservative to treat unqualified epoxy coatings as chips.

Section 7.5 of the report discusses the thin bed effect and states that most plants do not have large quantities of microporous debris within a ZOI. The report also states that the BWROG is planning a series of tests with potential debris mixtures containing problematic debris to determine whether the thin bed effect can occur on BWR strainers. The staff agrees that the test program is a method that may determine if thin beds can occur. However, during PWR testing, thin beds were observed in debris beds composed of fiber and non-problematic particulate debris. The apparent assumption that thin beds only occur when problematic debris is present should be evaluated and revised or justified.

The report, Section 7.6, discusses debris and surrogate materials and their introduction into a test facility. Using material surrogates that are sized based on realistic plant or accepted test data is appropriate. The report states that although the size distributions may differ from the size distributions used in PWR testing they are considered acceptable for the BWR tests which were maximum thickness tests. The NRC staff has concluded that the fiber size distribution can affect debris bed head loss for all debris bed thicknesses and therefore disagrees with the BWROG assertion that the fiber size distributions used in the thick bed tests is acceptable. The use of leaf shredded fiber may have been non-conservative. The fiber size distributions listed in the URG appendices regarding testing are larger than those used during PWR testing and significantly larger than the fiber sizes estimated by NUREG/CR-6224 as expected to be at the strainer. The report did not provide information on how the debris was handled after it was prepared. The handling of debris can result in unintended consequences either by loss of fine debris or agglomeration. The NRC staff could not find significant information in the URG on debris handling. The prevention of unrealistic agglomeration during debris introduction is an important factor during head loss testing.

Section 8 of the report discusses a flow chart that may be used for assessment of BWR head loss evaluations. The report references BWROG guidelines, some of which have not yet been developed. Because the guidelines are not available for staff review, a determination of the adequacy of the process described in the flowchart cannot be completed at this time. The chart appears to provide an overall process that will assist the plants in assessing their strainer evaluations. In some cases the flowchart references URG guidance which may not be acceptable. It was not clear that the referenced URG guidance is “updated” in several instances.

It is not clear to the staff how using updated debris characteristics will allow licensees that used correlations to determine an appropriate head loss considering the issues noted with correlations elsewhere in this review. Some of the wording in the flowchart was unclear. For example, one box in the flowchart is a comparison of pump NPSH and the debris head loss. There are other factors that affect NPSH besides debris head loss. These should be considered in an NPSH margin comparison. The chart should be reviewed to ensure that it clearly provides the desired direction.

If you have any questions regarding the above staff feedback, please contact Joseph Golla at 301-415-1002 or via e-mail at Joe.Golla@nrc.gov.

Sincerely,

***/RA/***

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