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Subject: Oconee Nuclear Station
Docket Nos. 50-269, 50-270, 50-287
Supplemental Response to Generic Letter 96-06:
Assurance of Equipment Operability and Containment
Integrity During Design-Basis Conditions

Generic Letter (GL) 96-06, "Assurance of Equipment Operability and Containment Integrity During Design Basis Conditions", was issued on September 30, 1996. GL 96-06 requested licensees to determine if containment air cooler cooling water systems are susceptible to either waterhammer or two-phase flow conditions during postulated accident conditions and to determine if piping systems that penetrate containment are susceptible to thermal expansion of fluid that could lead to overpressurization of piping. Duke Energy Corporation (Duke) responded to the GL 96-06 in submittals to the NRC dated October 29, 1996, January 28, 1997, April 15, 1997, June 30, 1997, August 1, 1997, May 28, 1998, September 22, 1998, December 17, 1998, and September 30, 2002.

The NRC requested additional information concerning two-phase flow aspects of GL 96-06 as discussed by R. C. Douglas (Duke) and L. N. Olshan (NRC) on November 25, 2002. The responses to this request are provided by Enclosure A.

Enclosure B provides Duke's response to another request for information provided by Email from L. N. Olshan to R. C. Douglas dated January 14, 2003. As noted in the Email, the questions relate to those areas of Reactor Building Cooling Units' (RBCU) tubing that may experience steam formation or voiding.

Please address any questions to Robert Douglas at 864-885-3073.

Very truly yours,

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Enclosures

A072

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Enclosure A

Oconee Nuclear Station
Docket Nos. 50-269, 270 and 287

Response to Request for Additional Information Concerning Two-Phase Flow Aspects of GL 96-06

NRC Letter, dated April 3, 2002, "NRC Acceptance of EPRI Report TR-113549, "Resolution of Generic Letter 96-06 Waterhammer Issues, "Volumes 1 and 2," documented the NRC's acceptance and conditions for use of the methods and analyses proposed by EPRI. One of these conditions for use was that licensees provide the information related to two-phase flow aspects of the issue requested by NRC letter dated June 17, 1998. The following Duke Energy Corporation (Duke) responses address the two-phase flow aspects of the request as discussed by R. C. Douglas (Duke) and L. N. Olshan (NRC) on November 25, 2002. The water hammer aspects of the requests were addressed by Duke letters to the NRC dated January 28, April 15, June 30, August 1, 1997, and September 30, 2002.

The applicable portions of the NRC's request for information and the Duke response are provided below:

Request 1. a

Identify any computer codes that were used in the waterhammer and two-phase flow analyses; describe the methods used to benchmark the codes for the specific application and loading conditions involved (see Standard Review Plan 3.9.1)

<u>Response for Two-Phase Flow Analysis</u>

The RELAP5/MOD3.1 computer code is used in the two-phase flow analyses. The two-phase flow analyses are performed using unit-specific Low Pressure Service Water (LPSW) System models that are benchmarked to single-phase data obtained from LPSW System flow testing. The single-phase test data selected matches the flow configuration for the two-phase flow analyses of interest. Duke has not performed any two-phase flow benchmarking. The RELAP5 models related to two-phase flow are based on two-phase test data and have been benchmarked by the code developer as part of the code development process. The RELAP5 code complies with the 10 CFR 50, Appendix K requirement (I.C.2) for calculating pressure drops. The Colebrook correlation is used to calculate the friction factor. The HTFS-modified Baroczy correlation is used to calculate the two-phase multiplier. The RELAP5 code has been assessed versus a matrix of experimental data. The separate effects tests applicable to two-phase flow are the GE level swell tests, and the Dukler air-water flooding tests (refer to Volume III of the RELAP5/MOD3 Code Manual, NUREG/CR-5535). The modeling of the Reactor Building Cooling Units (RBCUs) uses the vendor design heat transfer capacity of 80E6 Btu/hr (1400 gpm flow at 75°F and 286°F containment temperature) as a point of reference. As long as the water in the RBCUs remains subcooled, the heat transfer capacity of the RBCU is not degraded by two-phase flow occurring downstream of the RBCU. The RELAP5 model captures any reduction in flow through the RBCUs due to two-phase conditions downstream. With this approach there is no need to benchmark the modeling of the RBCUs in the RELAP5 model. The RBCU heat transfer capacity is varied until the onset of two-phase conditions, and then that heat transfer capacity is compared to the value assumed in the UFSAR containment analyses. As long as the heat transfer capacity is less than that assumed in the UFSAR analyses, the effect of two-phase conditions in the LPSW piping downstream of the RBCUs is acceptable.

Request 1.b

Describe and justify all assumptions and input parameters (including those used in any computer codes) such as amplifications due to fluid structure interaction, cushioning, speed of sound, force reductions, and mesh sizes, and explain why the values selected give conservative results (e.g., explain why only horizontal nodes were considered, definition of significant voiding, Froude number criteria of less than 0.5). Also, provide justification for omitting any effects that may be relevant to the analysis (e.g., fluid structure interaction, pipe-wall temperature effects, steam transport and accumulation, flow induced vibration, erosion). Confirm that worst-case conditions were identified and used in the waterhammer and two-phase flow analyses that were performed.

Response for Two-Phase Flow Analysis

The RELAP5 hydraulic model of the LPSW System is a best-estimate steady-state model with conservative initial conditions. The conservative initial conditions consist of low lake level, high lake temperature, and minimum atmospheric pressure. These assumptions are conservative for maximizing the onset of two-phase flow in the LPSW System. The nodalization (mesh size) selected is sufficient for modeling the system configurations of interest, and the benchmarking to LPSW test data ensures that the model replicates the system. The use of this approach, as compared to use of an arbitrarily conservative model, is justified by the large margin in the results of the analyses. The cases analyzed assume worst-case configurations of the LPSW System. Ambient heat losses are not important to the analysis and are not modeled.

The steady-state analysis approach involves running a series of cases in which the RBCU heat load is reduced from the reference heat transfer capacity of 80E6 Btu/hr per RBCU in decrements of 5% until the fluid in the RBCUs remains single-phase. The LPSW flowrate changes as the RBCU heat transfer changes, due to changes in the pressure drop in the system and the change in pump performance. This establishes a maximum RBCU heat transfer capacity including the effects of two-phase conditions downstream of the RBCU.

The RBCU heat load assumptions from the Duke Power containment methodology for Oconee are less than 90% of the reference capacity of one RBCU. For example, 90% of one RBCU is equivalent to 2 RBCUs operating at 45% of capacity or 3 RBCUs operating at 30% of capacity. In each case evaluated in the two-phase flow analyses, the minimum heat transfer capacity is 200% of one RBCU. This heat load is significantly higher than the heat loads assumed in the containment response analyses. Therefore, the post-accident heat loads on the RBCUs are bounded by the heat transfer capacity of the RBCUs. The large margin between 90% RBCU capacity required and 200% available justifies the best-estimate hydraulic model with conservative initial conditions approach.

Request 1. c

Describe in detail the limitations and uncertainties associated with use of any computer code (e.g., RELAP5, GOTHIC) in analyzing waterhammer and two-phase flow in low pressure cooling water systems, and explain how these limitations and uncertainties were accounted for in the analysis to assure conservative results.

<u>Response for Two-Phase Flow Analyses</u>

The RELAP5/MOD3.1 code includes the constitutive models and steam tables required to simulate the thermal-hydraulics associated with the two-phase flow analyses. As with all digital computer codes, the flow regime maps and heat transfer correlations are approximations of the physical processes. The RELAP5/MOD3.1 code has been generically assessed by the international user community, and the code is considered by Duke to be acceptable for the simulation of the LPSW two-phase flow problem. Duke has not performed any additional assessment of RELAP5 for Generic Letter 96-06 issues.

For the two-phase flow analyses, the phenomena relating to wall friction, fluid properties, and heat transfer are most important. The uncertainty in single phase wall friction is addressed through the benchmarking of the LPSW fluid flow to plant data. The uncertainty associated with two-phase wall friction and phase separation modeling has not been evaluated specific to this application. The RELAP5 code has been assessed versus a matrix of phenomenological, separate-effects, and integral-effects problems which are described in the RELAP5 code manual (RELAP5/MOD3 Code Manual, NUREG/CR-5535). More recently, the results of the RELAP5/MOD3.1 assessment were published as Section 3 of NUREG/CR-5535/Rev. 1-Volume VII. One of the conclusions of this assessment was that the RELAP5/MOD3.1 calculated interphase drag is slightly overpredicted, although significantly improved from the previous formulation. A high interphase drag would tend to minimize the difference between the liquid and vapor phase velocities. The impact of this effect for the two-phase flow analyses, specifically the impact on the total mass flow through the RBCUs, has not been quantified. A high interphase drag would not impact the vapor generation or wall friction. The mass flow in an upward vertical direction would be expected to be slightly high, while the mass flow in a downward vertical direction would be slightly low. Both of these effects are present in the two-phase flow analyses. It is expected that the overall effect would be small, and would not significantly affect the results of the two-phase flow analyses. The generic assessment documentation does not indicate any known deficiencies associated with the two-phase wall friction model in RELAP5.

The uncertainty in the fluid properties is not considered to be significant. The uncertainty in the RELAP5 heat transfer correlations is not specifically addressed in this application. No specific limitations in the use of the RELAP5 code for modeling the two-phase flow in the LPSW System have been identified.

The uncertainties associated with the various elements of the code relative to this application have either been accounted for in the modeling approach, judged to be insignificant, or have not been specifically addressed. This issue of overall uncertainty can be sufficiently addressed by the large margin in the analysis results. The heat transfer capacity of the RBCUs including the effects of two-phase flow is more than twice what is assumed in the UFSAR containment analyses. That large margin offsets the net effect of uncertainties in the RELAP5 code and the LPSW model.

Request 1. d

Provide a detailed description of the worst-case scenarios for waterhammer and two-phase flow, taking into consideration the complete range of event possibilities, system configurations and parameters. For example, all waterhammer types and water slug scenarios should be considered, as well as temperatures, pressures, flow rates, load combinations, and potential component failures. Additional examples include:

- The effects of void fraction on flow balance and heat transfer;
- The consequences of steam formation, transport, and accumulation;
- Cavitation, resonance, and fatigue effects; and
- Erosion considerations

You may find NUREG/CR-6031, 'Cavitation Guide for Control Valves", helpful in addressing some aspects of the two-phase flow analyses. (Note: it is important to realize that in addition to heat transfer considerations, two-phase flow also involves structural and system integrity concerns that must be addressed).

Response for Two-Phase Flow Analyses

The single most important parameter in the two-phase flow analyses that determine the post-accident RBCU heat transfer capabilities is the local pressure in the RBCU discharge piping high point. To maximize this pressure and thus minimize the heat transfer capabilities, single failures that minimize flow but not heat transfer capacity were examined.

Two scenarios are considered in detail - the loss of an electrical bus, and the loss of a single LPSW pump. Each of these scenarios is discussed below. These scenarios are analyzed with a minimum lake level, minimum atmospheric pressure, and maximum lake temperature. A minimum lake level and atmospheric pressure are assumed to minimize the saturation temperature at which flashing will occur, and thereby maximize the two-phase friction losses. The maximum lake temperature serves to maximize the RBCU discharge temperature for a given heat load, thereby maximizing the local pressure in the RBCU discharge piping high point.

The loss of an electrical bus failure was the limiting scenario for total heat transfer capacity. In this scenario a single LPSW pump per unit is operating along with two RBCUs. For the two-phase flow analyses, the maximum heat transfer for the scenario is 2 x 100% = 200% (i.e. no degradation in the RBCU capacity due to two-phase effects) of the capacity of one RBCU. This heat transfer capacity was achieved in the analysis for all units. This heat transfer capacity is significantly higher than the 90% total RBCU capacity assumed in the UFSAR containment analysis.

The loss of an LPSW pump was the limiting scenario with regard to the per RBCU heat transfer capacity. In this scenario, a single LPSW pump per unit is operating along with three RBCUs. Following the final system alignment, assumed to occur nominally 30 minutes after the event initiation, the minimum RBCU heat transfer capacity was 3 x 90% = 270% of the capacity of one RBCU. Note that while the per RBCU heat transfer is less, the overall heat transfer capacity (270%) is quite a bit higher than the loss of an electrical bus failure scenario (200%).

Request 1. e

Confirm that the analyses include a complete failure modes and effects analysis (FMEA) for all components (including electrical and pneumatic failures) that could impact performance of the cooling water system and confirm that the FMEA is documented and available for review, or explain why a complete and fully documented FMEA was not performed.

Response for Two-Phase Flow Analyses

A complete FMEA was performed for the LPSW system relative to the RELAP5/MOD3.1 two-phase flow analyses.

Request 1. f

Explain and justify all uses of "engineering judgment".

Response for Two-Phase Flow Analyses

One engineering judgement is employed in the RELAP5 LPSW System two-phase flow analyses. As stated above, the uncertainties for some of the code and modeling aspects have not been quantified specifically for the purposes of this application of RELAP5. An engineering judgement is made that the total effect of the unquantified uncertainties is offset by the large margin in the results.

Request 2

Determine the uncertainty in the waterhammer and two-phase flow analyses, explain how the uncertainty was determined, and how it was accounted for in the analyses to ensure conservative results.

Response for Two-Phase Flow Analyses

The two-phase flow analyses do not specifically account for all of the uncertainties in the RELAP5 code and the LPSW System modeling. Uncertainty in the single-phase wall friction model was addressed by benchmarking to LPSW test data. Uncertainties for the two-phase flow aspects, heat transfer, pump model, and fluid properties were not quantified. The standard RELAP5 models for these elements of the two-phase flow analysis are widely used in the industry and are supported by a body of generic assessment studies. Engineering judgment is used to conclude that the net effect of the unquantified uncertainties is offset by the large margin in the analysis results. The results of the two-phase flow analyses indicate that the RBCU heat capacity including the effects of two-phase flow (200% of the capacity of one RBCU) is significantly higher than that assumed in the containment response analyses (90% of the capacity of one RBCU).

Request 3

Confirm that the waterhammer and two-phase flow loading conditions do not exceed any design specifications or recommended service conditions for the piping system and components, including those stated by equipment vendors; and confirm that the system will continue to perform its design basis functions as assumed in the safety analysis report for the facility and that the containment isolation valves will remain operable.

Response for Two-Phase Flow Analyses

During steady state conditions, the LPSW discharge lines outside containment at elevation 831'-0" will experience two-phase flow conditions. The conditions at this location are predicted to be approximately 255 degrees F and approximately 17.8 psig. The components in the LPSW system are designed for a pressure of 100 psig, well above the predicted two phase flow pressure. The present design temperature of the LPSW system is 193 degrees F. A 50% increase in thermal stress in the piping is predicted over the stress predicted at the present design temperature. It is well known that secondary stress, in absence of other type stress, does not cause piping failures. However, primary plus secondary stress may cause piping failures. In this case, the actual primary stress in the piping is low enough such that enough margin exists below the primary plus secondary allowable to accommodate the increase in the thermal stress. An increase in the piping temperature can also cause an increase in loads on system support/restraints. An evaluation was made on all affected support/restraints, and all were found to be acceptable versus faulted criteria.

Enclosure B

Oconee Nuclear Station
Docket Nos. 50-269, 270 and 287

Response to Requests for Information Concerning Steam Formation and Voiding In Reactor Building Cooling Units - GL 96-06

The following requests for information were received by Email from L. N. Olshan (NRC) to R. C. Douglas (Duke) dated January 14, 2003. As noted in the Email, the questions relate to those areas of Reactor Building Cooling Units' (RBCU) tubing that may experience steam formation or voiding.

Request 1

Identify any areas where steam and/or void formation may still occur after the modifications described in the September 30, 2002, submittal have been completed.

Response

The vacuum breaker / check valve modification described in our submittal dated September 30, 2002, involves placing two trains of redundant air operated valves on the LPSW discharge header outside of containment. Upon a LOOP the valves would open, allowing air to be drawn in and pressurize the piping to approximately 1 atmosphere at the 833' elevation. Two new check valves would be placed on the two LPSW supply headers outside containment, preventing drainage in the inlet and outlet piping between the check valves and the vacuum breaker valves. The addition of approximately 1 atmosphere pressure at the 833' elevation, together with the supply check valves to remove the reverse flow drainage path, keeps the Reactor Coolant Pump (RCP) lines from voiding. Also, since the heat exchangers on the RCPs do not communicate directly with containment, heat input to these lines is considered negligible. Thus neither Condensation Induced Waterhammers (CIWHs) nor Column Closure Waterhammers (CCWHs) occur.

The RBCUs are located at elevation 821'-0". The pressure provided by the vacuum breakers and the elevation difference between the RBCUs and the new vacuum breakers keeps the RBCUs from boiling during the LOCA transients. However, boiling is predicted to occur in the RBCUs at approximately 25 seconds into the Main Steam Line Break (MSLB)-LOOP transient. During the worst case scenario, the LPSW pumps restart at approximately 31 seconds, and full flow is restored in 33 seconds. The RBCUs at Oconee are situated below both the supply and discharge headers. The steam produced in the RBCU during the short duration between the onset of boiling and the full flow restoration will be condensed by the water remaining in the water-boxes and the inlet and outlet piping headers, thus preventing migration of the steam into horizontal sections of piping. The volume of water in both the water-boxes and the headers is sufficient to condense all the steam produced in the 7 seconds before the LPSW pumps restart.

The modification associated with the separation of the Reactor Building Auxiliary Cooler Unit (RBACU) trains from the RBCU trains and the provision of fast closing isolation valves minimize voiding in the RBACU trains. The isolation valves will remain closed after restoration of power since the RBACUs are not credited for containment cooling during either a LOCA-LOOP or MSLB-LOOP event.

Request 2

For these areas (where steam and/or void formation may still occur), describe the results of your waterhammer analysis, including generated forcing functions and structural analyses.

Response

As noted in the response to Request 1, after installation of the proposed modifications, boiling is predicted to occur in the RBCUs tubes during only the MSLB-LOOP event. The pressure of the steam generated during this event is predicted to be approximately 12.3 psig. The magnitudes of the CIWHs that could occur at this pressure are expected to be negligible based on conclusions reached in the EPRI Report 1003098 "Generic Letter 96-06 Waterhammer Issues Resolution." The report concludes that CIWH that may occur in low pressure service water systems are limited in magnitude and / or duration such that they are not a credible threat to pressure boundary integrity provided that:

- The system steam pressure at the time of the postulated CIWH is less than 20 psig.
- The system is not de-gassed.
- The piping has been shown by test or analysis to be capable of withstanding a CCWH following LOOP, LOCA-LOOP, or MSLB-LOOP.

The predicted steam pressure of 12.3 psig is less than the 20 psig threshold. The LPSW system at Oconee draws water from the Condenser Circulating Water (CCW) System. The CCW system draws water directly from Lake Keowee. Water in these systems is not degassed. In addition, several simulated LOOP only tests have demonstrated the structural integrity of the RBCU tubing for CCWHs that occurred during the test.

Upon restart of the LPSW pumps, the voids in the RBCU will be closed. Column closure waterhammers could occur. Calculations performed to support the conceptual modifications described indicate that pressure magnitudes of those waterhammers are not significant enough to challenge the integrity of the 5/8" OD .049" thick copper tubes, nor the outlet water boxes. As design input into the modification design process, waterhammer magnitudes will be limited to the pressure retaining capability of the Low Pressure Water Service Water (LPSW) System.

Request 3

Describe any deviations from the EPRI analytical methodology that was approved by the NRC for this limited-use application, and provide justification for these deviations that is at least equivalent to the justification that was provided by EPRI and relied upon by the NRC for demonstrating that use of the proposed EPRI methodology should be approved.

Response

Oconee has proposed a series of modifications that will limit the severity or eliminate waterhammers described in the GL. These modifications were determined after several years of study and participation in the EPRI waterhammer work. To support the current operating configuration (i.e. without the proposed modifications), a comprehensive operability evaluation was completed during the time in which the EPRI methodology was being originated. This operability evaluation incorporated as much of the EPRI methodology that was available. The operability evaluation utilized a Method of Characteristics (MOC) approach for prediction of waterhammer pressure magnitudes instead of the Rigid Body Model (RBM) described in the EPRI work. As noted in the EPRI work, the RBM was created as a simplified and conservative adaptation of a MOC model. The input into the MOC model created for the Oconee operability evaluation is the same input that would have been used for creation of a RBM. The RBM allows for the reduction in the waterhammer impact velocity based on the amount of air and steam released when the volume is displaced from the fan cooler unit (at Oconee, Reactor Building Cooling Unit, RBCU). The EPRI work predicts that a maximum of 40% of the volume of water evacuated from the cooler can be credited as releasing non-condensable gas. In the EPRI work, the amount of air and steam cushioning predicted is provided in nomographs. Inputs required for input into the nomographs are the initial closure velocity, the frictional flow loss coefficient between the pump and the void, the weight of the released non-condensable gas, the length of the void, and the length of the accelerating water column. This cushioned velocity was then substituted for ΔV in Joukowski's equation, using the maximum sonic velocity, C. Sample calculations using the RBM modeling techniques were made for the Oconee configuration for comparison purposes versus the MOC results. All of the thresholds for use of the RBM, i.e., the void temperature and the mass of non-condensable gas released met the limitations published in the EPRI report. The results of the sample calculations indicated that the RBM predicts a cushioning of 20% to 30% of the initial closure velocity.

The MOC model utilized for the Oconee operability work compensated for the release of non-condensable gas by assuming a reduction of approximately 50% of the maximum sonic velocity, C. This reduced sonic velocity was then used in Joukowski's equation to predict the pressure pulse magnitude using an un-cushioned closure velocity. Comparing the effect of the cushioned closure velocity on the pressure pulse magnitude calculated by Joukowski's equation with the maximum sonic velocity versus the effect of a reduced sonic velocity with an un-cushioned closure velocity, it is concluded that the MOC model utilized in the Oconee operability over predicts the amount of reduction in pressure magnitudes by 20 to 30% versus that of the RBM.

The EPRI work characterized the risk of the failure of service water piping during GL 96-06 described waterhammer events as less than 1.0E-7, based on the concurrent LOCA-LOOP or MSLB-LOOP probability of 1.0E-5, and the probability of pipe failure of 1.0E-2. The EPRI work noted that the failure probability of the piping was likely greater than 1.0E-2, given the number of LOOP only tests performed at a number of nuclear plants throughout the United States. Oconee has performed LOOP- only tests on a number of occasions and the results of the tests show that no damage occurred to the piping pressure boundary, or to the supporting elements of the piping system. This result indicates that the piping failure probability is probably less than 1.0E-2.

The EPRI work provided an alternative estimation of the piping failure probability based on the premise that the piping code stresses were exceeded by 40%, which coincides with the maximum reduction in the closure velocity due to the presence of non-condensable gas. The report further noted that, based on the actual margins available in the piping codes, the probability of failure is on the order of 1.0E-4 or even less. If the piping code stresses were exceeded by 50%, which coincides with the reduction in the maximum sonic velocity used in the Oconee operability analyses, the failure probability would not change appreciably from the 1.0E-4 figure.

This suggests then that the slight over prediction in the reduction of the pressure magnitudes concluded in the Oconee MOC work, versus the results of a RBM are insignificant, when viewed against the conservatism inherent in the failure probability calculations and the fact that Oconee has conducted several LOOP-only tests with no structural damage. Further, it is noted that the MOC work supported the current operating configuration, and not the future planned configuration. Oconee is confident that the results of the operability evaluation completed to support the current operating configuration are accurate, and in the example given above compare favorably with results from a RBM evaluation. The modifications described in our submittal dated 9/30/02, and repeated here, will address the waterhammer issues described in GL 96-06.