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Letter Report No. 240-6

Review Of St. Lucie (Units 1 and 2) Waterhammer And Two-Phase Flow Analysis

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Enclosure

1. INTRODUCTION

NRC Generic Letter 96-06 (GL 96-06) " Assurance of Equipment Operability and Containment Integrity During Design Basis Accident Conditions" [1] included a request for licensees to evaluate cooling water systems that serve containment air coolers to assure that they are not vulnerable to Water hammer and two-phase flow conditions. More specifically, the issues of concern are :[1]

"(1) Cooling water systems serving the containment air coolers may be exposed to the hydrodynamic effects of waterhammer during either a loss-of-coolant accident (LOCA) or a main steam line break (MSLB). These cooling water systems were not designed to withstand the hydrodynamic effects of Waterhammer and corrective actions may be needed to satisfy system design and operability requirements.

(2) Cooling water systems serving the containment air coolers may experience two-phase flow conditions during postulated LOCA and MSLB scenarios. The heat removal assumptions for design-basis accident scenarios were based on single-phase flow conditions. Corrective actions may be needed to satisfy design and operability requirements."

Florida Power and Light Company (FPL) provided its assessment for the St. Lucie, Units1 and 2 in a letter dated January 28, 1997. [2] Parts of the licensee's submittal addresses waterhammer and two-phase flow conditions. The licensee was requested to provide additional information in a letter dated July 28,1998.[3] The licensee's response was provided in a letter dated October 30,1998.[4] Further clarification on two-phase flow analysis was provided by the Licensee during a conference call with NRC on November 9, 1999.[5]

Scientech, Inc. was requested (NRC-03-95-026, Task Order No. 240) to assist the NRC staff in reviewing the waterhammer and two-phase flow analyses that have been completed by the licensee for the St. Lucie, Units1 and 2 in response to GL 96-06. The objective of the review was to determine whether or not the analyses are adequate and conservative in all respects.

This letter report summarizes the results of the review that was performed and conclusions that were reached. Section 2 provides background information regarding design characteristics of the St. Lucie component cooling water systems. The events considered for this evaluation are discussed in Section 3. Sections 4 and 5 provide the review results of the waterhammer and two-phase flow analyses, respectively. Section 6 provides a brief summary together with conclusions.

2. DESCRIPTION OF THE ST. LUCIE COMPONENT COOLING WATER SYSTEM

The component cooling water (CCW) system provides cooling water for the containment fan coolers (CFCs) at St. Lucie. The CCW systems for Units 1 and 2 are similar in layout and design. They are closed loop systems which provide cooling water flow to essential plant auxiliaries via two parallel safety related trains. The two essential trains are connected via return and supply headers with a non-essential train (N-header) arranged between them. During normal operation , all three trains are supplied with cooling water via two CCW pumps. A third pump functions as an installed spare. Automatic start of the spare pump is not a design feature.[4]

On a safety injection actuation signal (SIAS), the two essential trains are isolated from the N- headers by spring operated butterfly valves. Closure of these valves also serves to separate the essential trains into two redundant safety related A and B trains. The A and B trains serve essential services such as the containment coolers, shutdown heat exchangers, ECCS pump seals, and the control room air conditioners (Unit 2 only). The common atmospheric pressure surge tank for each unit is subdivided by a baffle and has an independent surge line serving each essential train. The surge tank low level alarm setpoint elevation is 75.67 feet in Unit 1 and 74.92 feet in Unit2.[4]

For both units, containment fan coolers HVS-1A and 1B are supplied from CCW Train A and HVS-1C and 1D are supplied from CCW Train B. In both units, the elevation of the top row of tubes in the HVS-1C cooler (72.3 ft and 71.4 ft, respectively) is higher than the other three coolers (which are approximately 17 to 21 feet lower).[4]

The CCW system is assumed to be operating in the normal configuration prior to the event with flow through both essential headers and the N-header. Within the design basis for each unit, water is always flowing to all four CFCs when the unit is on line. On a SIAS, the two essential trains ("A" and "B") are isolated from each other and from the non-essential header (N-header) by redundant, spring-to-close, fail-close butterfly valves. On a SIAS, a single spring-to-open, fail-open butterfly valve is opened within each essential train to provide flow to the shutdown heat exchangers. The transient hydraulic analysis considers these automatic valve position changes.

3. SEQUENCES OF EVENTS CONSIDERED FOR EVALUATION

A loss-of-offsite power (LOOP) with simultaneous initiation of a design basis accident (DBA) event was considered for this evaluation. The Updated Final Safety Analysis Report (UFSAR) containment analyses for LOCA and MSLB provided the maximum post DBA temperature profiles for use in the waterhammer and two-phase flow evaluations.

The licensee's evaluation included a review of single failures to determine the effect that potential component failures would have on the waterhammer and two-phase flow analyses.[4] This failure modes and effect analysis (FMEA) included all major components (including electrical and pneumatic failures) that could impact performance of the cooling water system. The licensee noted that the FMEA is documented and is available for review.

4. WATERHAMMER ANALYSIS

The initial licensee's response[2] concluded that no steam generation would occur within the bounding HVS-1C cooler for either Unit prior to the time (16 seconds) the CCW pumps restart and thus, the waterhammer and two-phase flow concerns were precluded. However, while developing a response to the NRC request for additional information (RAI), the licensee identified certain inputs to the original analysis that were non-conservative and would require changes. Specifically, the evaluation used a nominal value for emergency diesel generator (EDG) start time and CCW pump load block loading . This approach failed to consider time delays for the receipt of a safety injection actuation signal (SIAS) or an undervoltage (UV) signal, or tolerances in relay settings. The increase in the time duration for CCW system pressurization would result in additional heating prior to the increase in system pressure, and would exacerbate the potential for voiding and waterhammer.[4]

A subsequent evaluation was performed by the licensee to address the additional CCW pump coastdown and the time for EDG start/CCW system pressurization. The containment fan cooler waterhammer concerns were addressed by a combination of calculations. The Sargent & Lundy CFC program was used to determine the time-to-boil and the void size (if applicable) for each CFC for DBA/LOOP transients in the time period immediately following CCW pump trip.

The Sargent & Lundy CFC program treats the CFC fluid volume as a single node at a uniform temperature and pressure for any given time step.[4] Therefore, the localized boiling, which occurs before the bulk boiling of the entire CFC could not be observed. It is stated that the detailed analyses performed by Sargent & Lundy for other clients have shown that the duration of localized vapor voiding in the CFC tubes is short lived and significant vapor generation, leading to steam migration to the CCW system piping, does not occur until saturated bulk boiling begins in the CFC unit. However, no information about the methodology used for these analyses was provided. It should be noted that the CFC model neglects the heat capacity of the incoming water and thus any local boiling that would occur at the exit of the tubes would be conservatively applied to the entire mass of water in the CFC. Furthermore, the flushing of hot water from the CFC tubes was also conservatively neglected.[4]

A hydraulic transient analysis was performed to determine the CCW pump coastdown profile for input to time-to-boil and voiding analysis . A hydraulic transient analysis was also performed to determine the waterhammer forcing functions following CCW pump restart (if voids are present) for input into piping stress analysis. The Sargent & Lundy HYTRAN computer program was used to perform hydraulic analyses and waterhammer fluid analysis.

The HYTRAN program implements a fixed grid method of characteristic solution technique to calculate pressure and flow velocities in a network of pipes. These quantities are then used to calculate the time- varying forces on the pipe segments that comprise the network. No information about the assumptions inherent in the HYTRAN computer program, the treatment of vapor/liquid interfaces, and code validation was provided.

A HYTRAN analysis for Unit 1 CCW B train piping system was performed for a pump trip followed by restart after a coastdown interval of 18.5 seconds. The pressure and flow time histories generated for the HVS-1C and HVS-1D cooler outlets by this analysis were provided as an input to the CFC code for the time-to boil and voiding analysis, as previously discussed. This latter analysis determined the void size that occurs due to boiling in the CFCs, as well as the pressure time history during the boiling process. The pressure time history was provided as input into the HYTRAN analysis for the time period following pump restart. The resulting waterhammer force time history was then used as input for the piping stress analysis.[4]

The voiding analysis indicated that once boiling begins, the pressure in the CFC discharge nozzle ramps upward to about 30 psia (saturation pressure). This pressure remains constant throughout the entire event until the steam void collapses.[4] As the refill and the downstream columns of water compress the void, it is likely that any dissolved air coming out of solution during boiling will be compressed. This compressed air will cushion the steam bubble collapse and reduce the waterhammer loads. The HYTRAN analysis assumed that the pressure remains at the saturation value of 30 psia . The licensee stated that higher pressures (about 230 psi) occur just prior to void closure that would reduce waterhammer loads and in order to compensate for this neglect of the cushioning effect, a reduced sonic speed of 1000 ft/s was used in the pipe segments where boiling had occurred. Also, the void closure was assumed to take 60 milliseconds to complete.

The adjustments of sonic velocity and the pressure pulse duration were based (without any justification) on the RELAP work that Sargent and Lundy performed for Zion. However, in the absence of any specific benchmark calculations, and without quantification of the amount of air in the steam void, the validity of the HYTRAN results is questionable and may not be conservative.

The developed waterhammer force time histories were applied to the Sargent & Lundy dynamic piping analysis program, PIPSYS, to determine the effect of the loads on the piping and support structures. Waterhammer pipe stresses and support loads were calculated for Unit 1 CCW Train B, as the void sizes were largest for this train. The scope of piping modeled within the Unit 1B train for the waterhammer analysis included both supply piping for the HVC-1C and HVC-1D CFC inlet nozzles and the return piping for the HVC-1C and HVC-1D cooler outlet nozzles through the containment penetration to the 20-inch train B supply and return headers. Based on the results of these evaluations, the licensee concluded that the resulting system pressure, pipe stresses, and support loads can be accommodated under functionality rules established for the St.. Lucie Plant, but they may exceed design allowable limits.

5. TWO-PHASE FLOW ANALYSIS

The issue of two-phase flow in the containment air cooling system has also been evaluated for the St. Lucie Plant . The concern is related to a potential reduction in containment cooling capacity due to reduced flow, caused by the increased friction of two-phase flow.

Design flows are required to be established upon restarting of the CCW pumps to ensure design heat removal. If flashing occurs in the CCW system, flow may be reduced. Two - phase flow increases the frictional losses and provides the potential for choked flow conditions.

The licensee stated that analysis was performed to model the CCW system response in the time period immediately following pump restart (and void collapse, if voids were present) for the DBA/LOOP transient. Three aspects of system operation were examined in the calculation: (1) Heat removal from the containment atmosphere by the CFCs in the early time frame of the LOCA/MSLB transient and how it relates to that assumed in the design basis containment analysis, (2) Potential for sustained two-phase flow and associated two-phase frictional pressure drop in the discharge piping between the CFCs and the main CCW return header, and how this may affect CFC flow and system operation, and, (3) Transient NSPH margin at suction to the CCW pumps. Furthermore, it is stated that there is substantial margin in the system design to recover to design performance following pump restart and therefore, a simplified, bounding analysis was used. A composite CCW system using limiting inputs from either unit was analyzed as an enveloping case. Margin was included appropriately in the recovery analysis , both in use of conservative assumptions and design input. The details of the methodology for this bounding analysis were not provided for review. However, based on clarification provided by the licensee during a conference call [5], it was concluded that two-phase flow is not a concern for the St. Lucie fan cooler system.

6. SUMMARY AND CONCLUSIONS

The waterhammer and two-phase flow analysis that has been completed by the licensee for the St. Lucie (Units 1and 2) in response to GL96-06 was reviewed. The containment fan cooler water hammer concerns were addressed by a combination of calculations. The Sargent & Lundy CFC program was used to determine the time-to-boil and the void size (if applicable) for each CFC for DBA/LOOP transients in the time period immediately following CCW pump trip. A hydraulic transient analysis was performed to determine the CCW pump coastdown profile for input to time-to-boil and voiding analysis . A hydraulic transient analysis was also performed to determine the waterhammer forcing functions following CCW pump restart (if voids are present) for input into piping stress analysis. The Sargent & Lundy HYTRAN computer program was used to perform hydraulic analyses and waterhammer fluid analysis. In order to compensate for cushioning, a reduced sonic speed of 1000 ft/s was used in the pipe segments where boiling had occurred. Also, the void closure was assumed to take 60 milliseconds to complete. In the absence of any specific benchmark calculations, and without quantification of the amount of air in the steam void, the validity of the HYTRAN results is questionable and may not be conservative.

The developed waterhammer force time histories were applied to the Sargent & Lundy dynamic piping analysis program, PIPSYS, to determine the effect of the loads on the piping and support structures. Based on the results of these evaluations, the licensee has concluded that the resulting system pressure, pipe stresses, and support loads can be accommodated under functionality rules established for the St.. Lucie Plant, but they may exceed design allowable limits. It should be noted that the licensee has decided to join the group of utilities working with NEI and EPRI to develop a technical basis for resolution of GL 96-06 and, accordingly, will develop a plan for the resolution of this issue in the long-term based on the outcome and schedule developed for the work scope of this industry group.

The issue of two-phase flow in the containment air cooling system has also been evaluated. The licensee stated that there is substantial margin in the system design to recover to design performance following pump restart and therefore, a simplified, bounding analysis was used for this evaluation. The details of the methodology for this bounding analysis were not provided for review. However, based on clarification provided by the licensee during a conference call [5], it is agreed with the licensee's conclusion that two-phase flow is not a concern for the St. Lucie fan cooler system.

7. REFERENCES

1. Nuclear Regulatory Commission (NRC), " Assurance of Equipment Operability and Containment Integrity During Design-Basis Accident Conditions," NRC Generic Letter 96-06, 1996.

2. Florida Power and Light Company, "St. Lucie Units 1 and 2, 120-Day Response To Generic Letter 96-06," January 28, 1997.

3. Nuclear Regulatory Commission (NRC), " Request for Additional Information Regarding Generic Letter (GL) 96-06, Assurance of Equipment Operability and Containment Integrity During Design-Basis Accident Conditions, St. Lucie Plant, Units 1 and 2," Letter from William C. Gleaves to T. F. Plunkett, July 28,1998.

4. Florida Power and Light Company, "St. Lucie Units 1 and 2, Request for Additional Information, Generic Letter 96-06 Response", Letter from J. A. Stall, October 30, 1999.

5. Conference Call Between NRC Staff and The Licensee, November 9, 1999.

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