November 20, 2003

Mr. Lew W. Myers
Chief Operating Officer
FirstEnergy Nuclear Operating Company
Davis-Besse Nuclear Power Station
5501 North State Route 2
Oak Harbor, OH 43449-9760

SUBJECT: DAVIS-BESSE NUCLEAR POWER STATION, UNIT 1 GENERIC LETTER 96-06, "ASSURANCE OF EQUIPMENT OPERABILITY AND CONTAINMENT INTEGRITY DURING DESIGN-BASIS ACCIDENT CONDITIONS" (TAC NO. M96803)

Dear Mr. Myers:

Generic Letter (GL) 96-06, "Assurance of Equipment Operability and Containment Integrity During Design-Basis Accident Conditions," was issued by the Nuclear Regulatory Commission (NRC) on September 30, 1996. GL 96-06 requested licensees evaluate cooling water systems that serve containment air coolers to assure that they are not vulnerable to waterhammer and two-phase flow conditions.

You responded to GL 96-06 by letter dated January 28, 1997, as supplemented February 28, July 28, and September 30, 1997, and April 7, 1999. An NRC contractor, Information Systems Laboratories, Inc. (ISL), evaluated the information provided and has documented its review in Letter Report No. 240-11 (enclosed). With regard to the information that was submitted, ISL made the following observations:

- The condensate-induced waterhammer (CIW) evaluation for the drain down phase was based on qualitative discussions and some small scale experiments, and the evaluation incorrectly assumes that fully developed flow during the drain down phase will prevent the occurrence of CIW.

- The column closure waterhammer (CCW) evaluation relies on several user specified empirically derived model parameters. No scaling rationale for the as-built piping configuration or for the actual accident time sequence was provided to address biases that might exist due to scale distortion.

- Scaling and piping configuration effects on the minimum void fraction that was selected for calculating the two-phase sonic velocity were not addressed.

Based on its review of the ISL report, the NRC staff agrees with the above observations and requests additional information be submitted to address them. Additionally, the NRC staff is aware that you have modified the cooling water piping to the containment air coolers and requests that you review your responses to GL 96–06 and supplement them where appropriate.

The NRC staff, with input from its consultant, concluded that your response to the two-phase flow issue was acceptable; however, due to your recent piping modifications, the staff requests that you either affirm that your responses are still valid in this area or supplement your responses for two-phase flow. The GL 96-06 issue concerning thermal overpressurization is being reviewed separately and is not included in this review.

The NRC staff requests that you respond within 45 days of the date of this letter with your schedule for response. The enclosed report was provided to your staff on November 7, 2003.

Sincerely,

/RA/

Jon B. Hopkins, Senior Project Manager, Section 2
Project Directorate III
Division of Licensing Project Management
Office of Nuclear Reactor Regulation

Docket No. 50-346

Enclosure: As stated

cc w/encl: See next page

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Letter Report No. 240-11

Review Of Davis-Besse Nuclear Power Station, Unit 1 Waterhammer And Two-Phase Flow Analysis

Hossein P. Nourbakhsh
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December 2000

Prepared for:
U.S. Nuclear Regulatory Commission
Office of Nuclear Reactor Regulation

Under Consultant Agreement No. 5401-240
From Information Systems Laboratories, INC.
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Suite 500
Rockville, MD 20852

Contract N0. NRC-03-95-026, Task 240,
TAC M96803

Attachment

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."

Toledo Edison Company provided its assessment for the Davis-Besse Nuclear Power Station in letters dated January 28, 1997 [2], February 28, 1997 [3], July 28, 1997 [4], and September 30, 1997 [5]. Parts of the licensee's submittal address waterhammer and two-phase flow conditions. The licensee was requested to provide additional information in a letter dated April15, 1998.[6] The licensee's response was provided in a letter dated April 7, 1999.[7]

Information Systems Laboratories (ISL), 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 has been completed by the licensee for the Davis-Besse Nuclear Power Station 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 the design characteristics of the Containment Air Cooler (CAC) cooling water systems at Davis-Besse Nuclear Power Station. The event considered for this evaluation is 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 CONTAINMENT AIR COOLER COOLING WATER SYSTEM AT DAVIS-BESSE NUCLEAR POWER STATION

The Davis-Besse Nuclear Power Station Unit 1, containment air cooler cooling water system consists of three essential powered, safety related CACs. One of the CACs is an installed spare, while each of the others is aligned to one of the two open loop, safety- related Service Water (SW) trains. The same coolers are used for both normal and post accident cooling loads. For normal operation, the CAC fans run in high speed ($\approx$1200 rpm). The fans are automatically switched /started to low speed ($\approx$600 rpm) for specific accident conditions to allow for increased containment atmosphere density.[3]

All three CACs (including the one spare in standby) are located next to each other on the 585' elevation in containment. The cooling water for the CACs is supplied by an open loop system using Lake Erie as its source. Supply and return piping for each CAC train is routed similar to that of the redundant trains. High points on the supply and return piping reach the 614' elevation inside containment.[3]

3. SEQUENCES OF EVENTS CONSIDERED FOR EVALUATION

A Large Break Loss of Coolant Accident (LBLOCA) with simultaneous initiation of a Loss Of Offsite Power (LOOP) has been considered for this evaluation. The LBLOCA vapor containment heat profile bounds the MSLB profile, in part due to the limited inventory available in once-through-steam generators. Therefore, the selection of LBLOCA/LOOP (rather than MSLB/LOOP) as a bounding scenario for evaluating the responses of the containment cooling system is appropriate.

On a LBLOCA/LOOP scenario, the fans and the service water pumps would loose Power. The following assumed key time parameters during the initial time period following the accident is from Reference 3.

Time	Description
0. sec	LBLOCA +LOOP
5 sec	Interruption of cooling water (pump coast down)
30. sec	Service Water (SW) pumps restart

A failure modes and effect analysis (FMEA) was not performed. However, to assure a worst case scenario within the plant design basis, the detailed thermal hydraulic analyses, including sensitivity analyses, used conservative assumptions and design basis accident conditions to maximize void formation.

4. WATERHAMMER ANALYSIS

LOCA concurrent with a LOOP causes interruption of cooling water flow soon after initiation of the event, while the associated fans would coast down for a much longer time. Continuation of air flow over the coils would cause the water in the cooler tubes to boil until cooling flow resumes. Since Davis- Besse Nuclear Power Station, Unit 1, has an "open system" design for the service water system, water will drain down from the containment coolers until the service water pumps are able to repressurize the system.

The uncovering of horizontal runs of pipe during the drain down creates the potential for condensation induced waterhammer (subcooled water slugs). As horizontal section of lines are exposed, steam will enter the space formed at the top of the pipe. The space between the top of the pipe and the exposed water can allow condensation of steam and trapping of steam bubbles. The rapid condensation of the trapped steam and the subsequent closing of the void by water causes a condensation induced waterhammer pressure pulse.

During the refill of the containment coolers, hydrodynamic loads could be experienced due to column closure (water column rejoining) waterhammer. There is also a potential for producing a stratified condition of steam and subcooled water in the horizontal pipes and subsequent bubble collapse type waterhammer (condensation induced waterhammer).

The licensee performed a detailed review of service water system piping geometry in conjunction with the fluid state in the piping system prior to pump restart to determine the likelihood of various types of waterhammer events occurring in the Davis-Besse service water piping.

The methodology used to evaluate waterhammer issues for the Davis-Besse Plant Unit 1 in response to GL96-06 consisted of two parts. First, experimental and theoretical investigations were performed to investigate the dominant containment fan cooler waterhammer phenomena. Second, detailed computer modeling of the affected portions of the service water system was performed to determine the transient thermal hydraulic response of the service water system and the forcing functions resulting from the waterhammer events.

Waterhammer calculations were performed with TREMOLO 1.0, a proprietary code developed by Fauske & Associates, Inc. (FAI). TREMOLO is a node and junction code which is designed to perform transient analyses of single and two-phase flow conditions in nuclear power plant piping systems. The TREMOLO Revision 1 model uses separate mass and energy conservation equations for each of the two fluid phases and a single momentum equation to describe the fluid mixture. To provide closure to this system of equations, fluid transport between phases is defined and an equation of state is used. An essential part of the equation of state is the retention of a residual void following the large scale void collapse. TREMOLO Revision 1 also provides a calculation of the reaction force resulting from fluid flow across the upstream and downstream boundaries of the modeled pipe circuit.

Long horizontal runs of pipe exist in the Davis-Besse service water system near the inlet and outlet of the air coolers. These piping sections were predicted by the licensee to contain significant steam voids under the postulated accident conditions prior to the service water pump restart. However the licensee concluded that the specific accident conditions would not be conducive to the formation of subcooled water slugs and condensation induced waterhammer. This conclusion was based on some qualitative discussions and small scale experiments described in a Fauske & Associates document[8]. This document stresses the importance and impact of the thermal boundary layer and the presence and influence of residual gas bubbles in the fluid following void collapse. It was also stated that since during the draindown phase of the accident and prior to pump restart, the flow rates of water spilling down the downcomer pipes are expected to be high enough to allow the horizontal pipes at the lower elevations to run full of water, therefor, stratified flow patterns would not develop in the horizontal piping segments. However, it should be noted that the condensation induced waterhammer pressures are independent of the draining flow rate of water or Froude number.

The potential for producing a stratified condition of steam and subcooled water in the horizontal pipes during the refill has also been evaluated by the licensee. Using a critical Froude number (Fr) of 1 (suggested in NUREG/CR-5220[9]), the licensee concluded that the piping refill velocities are sufficient to ensure that the horizontal lines run full during refill. Therefore during refilling,a bubble collapse type waterhammer similar to those that occur during draining will not occur.

The licensee also evaluated the hydrodynamic loading due to water column rejoining (trapped void collapse) during system refill. This particular type of waterhammer event is most like the waterhammer events modeled by TREMOLO. The TREMOLO code was run with Davis-Besse specific plant models for the three separate CAC piping circuits. The plant model also incorporated sequence specific assumptions, initial conditions and boundary conditions. The TREMOLO code also requires several user specified empirically derived model parameters. Engineering judgment and experimental observations were used to quantify these model parameters.

The TREMOLO code models non-condensible gas coming out of solution. This model is based on an assumed initial non-condensible gas partial pressure.[7] The gas then comes out of solution as the total fluid pressure approaches (but while it is still typically a few percent higher than) the initial gas partial pressure. Based on experiments performed by Fauske & Associates, Inc. on room temperature water that was initially saturated with air at one atmosphere, gas was observed to come out of solution when the fluid pressure was decreased to 6 psia or less. Consistent with experimental observations, the initial nitrogen partial pressure for the Davis Besse analysis was assumed to be slightly less than 5 psia. However, no scaling rational to as built piping configuration and actual time sequences of the Davis -Besse accident conditions was provided. Without quantifying the biases due to scale distortion or due to non-prototypical conditions of these tests, the above modeling assumption is questionable and may not be conservative.

In TREMOLO, to account for dissolved gas coming out of solution plus residual vapor bubbles that remain after the large scale void collapse has occurred, a user specified minimum void fraction is retained once the void in a fluid node exceeds the specified minimum void fraction.[7] The void fraction is used to calculate the two-phase sonic velocity and hence the node pressure. A value of 0.005 for the minimum void fraction, based on the benchmark calculations to validate the results of TREMOLO with the data of G. Cerne, et. al [10], was used in the analysis. No discussion on how this data applies to Davis -Besse plant specific situation was provided. Scaling effects and piping configuration could introduce uncertainties that need to be addressed.

Reaction forces calculated by TREMOLO were used as input to piping stress Structurally, the housing, frame and mounting of the CACs have been evaluated for waterhmmer induced loading. Based on these evaluations, the licensee has concluded that the structural loads associated with the subject transient are within existing design basis events. It should be noted that a detailed review of the structural dynamic analysis is beyond the scope of this evaluation and will be considered separately by the NRC staff.

5. TWO-PHASE FLOW ANALYSIS

The issue of two-phase flow in containment air cooling system has also been evaluated by the licensee. 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, and accelerated wear and system failure is also of concern.

The licensee stated that following a design basis accident, the SW pumps will be capable of suppressing further boiling and sweeping any voids out of the CACs. Because the CAC effectiveness is low early in the transient compared to other heat removal mechanism and the CACs are not credited in the containment analysis for 45 seconds, any reduction in initial effectiveness is inconsequential.

During normal operation, discharge valves in the CAC outlet lines may be throttled if desired for containment temperature control. However, accidents which involve significant containment heating, such as steam leaks or LOCAs, will result in automatic opening of the outlet throttle valves. Therefore, when significant containment heatup has occurred, no throttling points exist in the CAC system where prolonged flashing can occur. Therefore, the licensee’s conclusion that the two-phase flow is not a concern for the Davis -Besse CACs was found to be justified and acceptable.

6. SUMMARY AND CONCLUSIONS

The waterhammer and two-phase flow analysis that has been completed by the licensee for the Davis -Besse, Unit 1, in response to GL96-06, was reviewed. The licensee performed a detailed review of the service water system piping geometry in conjunction with the fluid state in the piping system prior to pump restart to determine the likelihood of various types of waterhammer events occurring in the Davis-Besse service water piping. The waterhammer and two-phase flow calculations were performed with TREMOLO 1.0, a proprietary code developed by Fauske & Associates, Inc. (FAI).

The licensee concluded that the specific accident conditions would not be conducive to the formation of subcooled water slugs and condensation induced waterhammer during the draindown phase of the accident. This conclusion was based on qualitative discussions and small scale experiments described in a Fauske & Associates document[8]. This document stresses the importance and impact of the thermal boundary layer and the presence and influence of residual gas bubbles in the fluid following void collapse. It was also stated that since during the draindown phase of the accident and prior to pump restart, the flow rates of water spilling down the downcomer pipes are expected to be high enough to allow the horizontal pipes at the lower elevations to run full of water. Therefor, stratified flow patterns would not develop in the horizontal piping segments. However, it should be noted that the condensation induced waterhammer pressures are independent of draining flow rate of water or Froude number. Further justification is needed to conclude that the condensation induced waterhammer during draining is not a concern for Davis-Besse.

The potential for producing a stratified condition of steam and subcooled water in the horizontal pipes during the refill phase has also been evaluated by the licensee. Using a critical Froude number (Fr) of 1 (suggested in NUREG/CR-5220[9]), the licensee concluded that the piping refill velocities are sufficient to ensure that the horizontal lines run full during refill. Therefore the licesee's conclusion that the condensation induced waterhammer during refilling is not a concern for Davis -Besse was found to be justified and acceptable.

The licensee also evaluated the hydrodynamic loading due to water column rejoining (trapped void collapse) during system refill. This particular type of waterhammer event is most like the waterhammer events modeled by TREMOLO. The code input, such as sequence specific assumptions, initial conditions and boundary conditions, were deliberately adjusted to achieve conservative results. The TREMOLO code also requires several user specified empirically derived model parameters such as initial non-condensible gas partial pressure and minimum void fraction to model the non-condensible gas coming out of solution. Engineering judgment, separate effect experimental observations and benchmark calculations to validate the results of TREMOLO with the experimental data were used to quantify these model parameters. No scaling rational for these experiments was provided. However, without quantifying the biases due to scale distortion or due to any non-prototypical conditions of these tests, these modeling assumptions are questionable and may not be conservative.

The issue of two-phase flow in the containment air cooling system has also been evaluated by the licensee. The licensee's conclusion that two-phase flow is not a concern for the Davis - Besse CACs was found to be justified and acceptable.

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. Centerior Energy, "Interim Response to NRC Generic Letter 96-06: Assurance of Equipment Operability and Containment Integrity During Design- Basis Accident Conditions," Letter from John K. Wood to U.S. NRC, January 28, 1997.

3. Centerior Energy, "Response to NRC Generic Letter 96-06: Assurance of Equipment Operability and Containment Integrity During Design- Basis Accident Conditions," Letter from John K. Wood to U.S. NRC, February 28, 1997.

4. Centerior Energy, "Response to NRC Generic Letter 96-06: Assurance of Equipment Operability and Containment Integrity During Design- Basis Accident Conditions," Letter from John K. Wood to U.S. NRC, July 28, 1997.

5. Centerior Energy, "Response to NRC Generic Letter 96-06: Assurance of Equipment Operability and Containment Integrity During Design- Basis Accident Conditions,"Letter from John K. Wood to U.S. NRC, September 30, 1997.

6. Nuclear Regulatory Commission (NRC), "Davis-Besse Nuclear Power Station, Unit 1- Supplemental Request for Additional Information Pertaining To Generic Letter 96-06, " Assurance of Equipment Operability and Containment Integrity During Design- Basis Accident Conditions," Letter from Allen G. Hansen to John K. Wood, April 15,1998.

7. First Energy, "Response to NRC Request for Additional Information Pertaining to Generic Letter 96-06: Assurance of Equipment Operability and Containment Integrity During Design- Basis Accident Conditions," Letter from Guy G. Cambell to U.S. NRC, April 7, 1999.

8. Fauske & Associates, Inc. "Waterhammer Phenomena in Containment Air Cooler Service Water Systems", Client: Toledo Edison, Project: Davis Besse, FAI/98-126, December, 1998.

9. Izenson, M.G.,P.H. Rothe and G.B. Wallis, "Diagnosis of Condensation- Induced Waterhammer," NUREG/CR-5220, October 1998.

10. Cerne, G., Tiselj, I., and Petelin, S. (Jozef Stefan Ints., Slovania), "Modeling of Water Hammer with Column Separation" Transaction of the American Nuclear Society, PP 387-388, 1996.