July 9, 2001

Mr. Otto L. Maynard
President and Chief Executive Officer
Wolf Creek Nuclear Operating Corporation
Post Office Box 411
Burlington, KS 66839

SUBJECT: CLOSEOUT OF RESPONSES TO GENERIC LETTER 96-06 CONCERNING WATERHAMMER AND TWO-PHASE FLOW FOR WOLF CREEK GENERATING STATION (TAC NO. M96887)

Dear Mr. Maynard:

The Nuclear Regulatory Commission (NRC) staff issued Generic Letter (GL) 96-06, "Assurance of Equipment Operability and Containment Integrity During Design-basis Accident Conditions," on September 30, 1996. In the GL, the NRC staff requested that you determine, for postulated accident conditions at Wolf Creek Generating Station (WCGS), if (1) containment air cooler cooling water systems are susceptible to either waterhammer or two-phase flow conditions, and (2) piping systems that penetrate containment are susceptible to thermal expansion of fluid so that overpressurization of piping could occur. You responded in letters of October 25, 1996 (ET 96-0083), January 29, 1997 (ET 97-0004), July 1, 1997 (ET 97-0059), September 28, 1998 (WM 98-0100), June 29, 1999 (WM 99-0042), February 29, 2000 (ET 00-0010), and February 12, 2001 (ET 01-0006).

This letter concerns the staff's review of your responses related to an assessment of containment cooling water systems to ensure that these systems are not vulnerable to waterhammer and two-phase flow conditions. You provided an assessment of these systems for Wolf Creek Generating Station in your letters of January 29, 1997, September 28, 1998, June 29, 1999, February 29, 2000, and February 12, 2001.

In the enclosed safety evaluation, the staff concludes that the occurrence of a waterhammer event under the conditions postulated in the GL, such as would affect plant safety, would be very unlikely at WCGS. Furthermore, the staff concludes that you have provided the required evaluations and have adequately addressed the issues raised in GL 96-06 regarding waterhammer and two-phase flow. Included with the safety evaluation is a copy of our consultant's preliminary evaluation in a letter report dated November 2000. The additional information identified in the letter report was provided in your letter of February 12, 2001. As discussed in the enclosed safety evaluation, all necessary analyses and modifications for the GL have been completed.

This closes out the staff's review of your responses to the waterhammer and two-phase flow aspects of the GL. Our evaluation of your responses to the thermal overpressurization aspects of the GL will be addressed at a later date.

Sincerely,

/RA/

Jack Donohew, Senior Project Manager, Section 2
Project Directorate IV
Division of Licensing Project Management
Office of Nuclear Reactor Regulation

Docket No. 50-482

Enclosure: Safety Evaluation

cc w/encl: See next page

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SAFETY EVALUATION BY THE OFFICE OF NUCLEAR REACTOR REGULATION

RELATED TO GENERIC LETTER 96-06, "ASSURANCE OF EQUIPMENT OPERABILITY

AND CONTAINMENT INTEGRITY DURING DESIGN-BASIS ACCIDENT CONDITIONS"

WATERHAMMER AND TWO PHASE FLOW ASPECTS

WOLF CREEK NUCLEAR OPERATING CORPORATION

WOLF CREEK GENERATING STATION

DOCKET NO. 50-482

1.0 INTRODUCTION

Generic Letter (GL) 96-06, "Assurance of Equipment Operability and Containment Integrity During Design-basis Accident Conditions," dated September 30, 1996, requires that licensees determine for postulated accident conditions of their licensed nuclear power plants, if (1) containment air cooling water systems are susceptible to either waterhammer or two-phase flow conditions, and (2) piping systems that penetrate containment are susceptible to thermal expansion of fluid so that overpressurization of piping could occur. If systems are found to be susceptible to these conditions, licensees are expected to assess the operability of affected systems and take corrective action as appropriate.

This evaluation deals with the waterhammer and two-phase flow evaluation requirements of GL 96-06 for the Wolf Creek Generating Station (WCGS). Wolf Creek Nuclear Operating Corporation (the licensee) provided the required evaluations for WCGS described in the following discussions in its letters dated January 29, 1997, September 28, 1998, June 29, 1999, February 29, 2000, and February 12, 2001.

An NRR consultant performed a preliminary evaluation dated November 2000, which is attached as Letter Report (LR) No. 240-3. The LR concluded that the licensee’s evaluations are conservative, but with the qualification that additional justifications needed to be provided. The appropriate information was provided in the licensee’s submittal of February 12, 2001. The staff’s evaluation of the waterhammer and two-phase flow aspects of WCGS is based in part on the attached LR.

2.0 EVALUATION

The containment air cooling at WCGS is accomplished by four safety-related fan cooler units in two trains. These units are designed to maintain the containment building within its design pressure and temperature following design basis events. The fan cooler units are supplied with cooling water by the essential service water system (ESWS). During normal operation the ESWS may be cross connected with the service water system (SWS). The service water system is not safety related. Following loss of offsite power (LOOP), the non-safety related SWS is isolated from the ESWS. Cooling water to the containment fan cooler units will then be supplied by the ESWS pumps. These pumps can be powered by the station emergency diesel generators which automatically start following a LOOP event.

Loss of offsite power will cause the ESWS pumps to stop and be automatically loaded on the emergency diesel generators. During the period between when pumping pressure is lost and when pumping power is restored by the emergency diesel generators, the ESWS can drain leaving voids of water vapor within the system high points. As draining occurs in horizontal pipes, cooler water surfaces may become uncovered as horizontal sections of the pipe are voided, thereby causing condensation induced water hammer (CIWH) to occur. After the ESWS pumps are re-supplied with power from the emergency diesel generators (EDGs), column closure waterhammer (CCWH) may occur as the returning water causes void collapse within the system.

Following loss of pumping power, the pressure within the fan coolers will decrease to the saturation pressure of the water within the fan cooler coils. In the absence of accident conditions which would cause the containment atmosphere to transmit heat to the fan cooler units, this pressure would be very low. As the pressure drops to the saturation pressure, the water within the fan coolers will flash and release both steam and some of the air dissolved in the water. The licensee calculates that gravity draining of the fan coolers will cause a gas space 101 feet long in the piping on each side of a fan cooler unit. This void space would be filled with low pressure steam and a small amount of air that was dissolved in the service water.

CIWH Evaluation

The licensee evaluated the potential for CIWH that might result during a draining of the horizontal system piping runs. The maximum pressure pulse was calculated to be 178 psi using the Joukowski equation as recommended in NUREG/CR-05220 (Reference 1). The principal input variables in the Joukowski equation are the closure velocity and the speed of sound in the water. The closure velocity is a function of the difference between the steam driving pressure and the steam pressure within the collapsing void. To evaluate the worst case condition, the licensee evaluated the maximum pressure that could occur within the voided fan coolers under accident conditions. The occurrence of a loss of coolant accident (LOCA) or main steam line break concurrent with the LOOP will maximize the driving pressure for the CIWH. To maximize the calculated driving pressure, the licensee used (1) maximum heat transfer coefficients to the steam within the fan cooler units from the heated containment atmosphere, and (2) minimum heat transfer from the steam to the water within the piping. The NRC staff believes the licensee calculated the steam driving pressure in a conservative manner.

For the steam pressure within the collapsing void, for analysis of CIWH, the licensee used the vapor pressure corresponding to the average temperature for the draining water. Use of the average temperature might not be conservative for water stratified in the horizontal pipe section since cooler water surfaces might become uncovered. The use of the average temperature introduces a possible non-conservatism in the licensee's calculation of CIWH.

The licensee used a speed of sound in water of 2300 ft/sec. This value would be appropriate if the water contained small amounts of suspended air bubbles. The speed of sound in unaerated cold water has a maximum value of approximately 4800 ft/sec. For actual piping systems for which the walls of the pipe can expand, a lower value (approximately 4500 ft/sec) is appropriate. A sudden pressure decrease such as would occur during system draining following a LOOP occurrence would cause air bubble formation. The effect of entrained air bubbles in water is to produce a dramatic reduction in the speed of sound (Reference 2). Air bubbles have been found to quickly form within liquid water that experiences a sudden decrease in pressure (Reference 3). Experiments at MIT determined the effective sonic speed to be 2000 ft/sec for CIWH (Reference 4).

During the decompression and draining process that would occur within the fan coolers and associated piping following a LOOP occurrence, low pressure would cause steam formation as well as gas formation within the service water as it drains. The actual hydrodynamic conditions within the piping are not well understood, and there are uncertainties regarding condensation rates and sonic speed. The staff performed bounding calculations taking into account the uncertainties in assumptions for collapsing void pressure and speed of sound. The licensee's structural evaluations have shown a large margin to exist between the calculated and maximum allowable loads for piping or penetration failure. In view of the calculated margin, the staff concludes that WCGS is protected from CIWH and the licensee's conclusions regarding CIWH are acceptable.

CCWH Evaluation

The licensee evaluated the pressure pulse that would occur from closure of the water columns after restart of the ESW pumps. The licensee believes that the case of LOOP without a concurrent LOCA or main steam line break to be the worst case for CCWH. This is because heating of the steam within the fan cooler units from heat transfer with the containment atmosphere would act to pressurize the steam void. This pressure would act to retard the velocity of the converging water columns. For LOOP without LOCA or main steam line break, the licensee calculated that the returning water would converge with a velocity of 14.477 ft/sec. The licensee then calculated the pressure pulse that would occur using the Joukowski equation recommended in Reference 1 and calculated a peak pressure of 225 psi. In performing the calculation, the licensee used a speed of sound of 2300 ft/sec. This sonic velocity would result from the depressurization and the resulting air bubbles which would form in the water. The air bubbles should still be present in the time required for the emergency diesel generators to start and restore flow through the fan cooler units. Calculation of piping and penetration loads by the licensee have shown a large margin to failure and the margin exceeds the effect of any uncertainty in the speed of sound. Therefore, the staff concludes that ESWS loads will remain below those for which failure could occur.

In November of 1991, the licensee conducted CCWH tests on the actual ESWS at WCGS. The test was representative of a LOOP event with subsequent restart of the ESWS pumps. A peak pressure pulse of 205 psig was measured. This result approximates the licensee's calculations and gives additional assurance that ESWS loads from CCWH will remain below those for which failure would occur.

Two Phase Flow Evaluation

Design flows are required to be established upon starting of the ESWS pumps to ensure design heat removal. If flashing occurs in the ESWS system, flow may be reduced. Two-phase flow increases the frictional losses and provides the potential for choked flow conditions. The concern is related to a potential reduction in containment cooling capacity due to reduced ESWS flow caused by the increased friction of two-phase flow.

While interruption of ESWS flow to the coolers will cause some steam to form in the tubes, the licensee’s evaluation determined that the steam will be quickly passed from the cooler and condensed. The difference in system refill time due to the presence of steam was calculated to be 0.7 seconds, which is not significant. Erosion, cavitation, and fatigue/vibration are not of concern since two-phase flow conditions will not occur upstream or downstream of the containment air coolers following pump restart.

3.0 CONCLUSION

Based on the foregoing considerations, the NRC staff concludes that the occurrence of a waterhammer event such as that which will affect plant safety as postulated in GL 96-06 is highly unlikely at WCGS. Furthermore, the staff concludes that the licensee has provided the required evaluations and has adequately addressed the issues raised in GL 96-06 regarding the potential for waterhammer and two-phase flow.

In two e-mails to the NRC (ADAMS Accession No. ML 011650501) on the licensee’s implementation of the GL, the licensee stated that all analyses for the GL were completed prior to refueling outage 10 in the spring of 1999, and all necessary modifications were installed during that refueling outage. However, as a result of staff questions on the analysis for the waterhammer issue submitted in the letter of June 29, 1999, the licensee revised the analysis and provided the revised results in its letter of February 12, 2001. The licensee stated that no further modifications to WCGS were needed as a result of the revised analysis.

4.0 REFERENCES

1. M. G. Izenson, P. H. Rothe and, G. B. Wallis, "Diagnosis of Condensation-Induced Waterhammer," NUREG/CR-5220 Vol. 1, October 1988.

2. J. Paul Tullis, "Pumps, Valves, Cavitation, Transients," John Wiley & Sons, New York, 1989.

3. W. Zielke, H-D Perko and A. Keller, "Gas Release in Transient Pipe Flow," Proc. 6th International Conference on Pressure Surges, BHRA, Cambridge, England October 4-6, 1989.

4. P. Griffith, "Screening Reactor Steam/Water Piping Systems for Water Hammer," NUREG/CR-6519, Massachusetts Institute of Technology, September 1997.

Attachment: Letter Report No. 240-3

Principal Contributors: Charles Hammer
Walton Jensen

Date: July 9, 2001

Letter Report No. 240-3

Review Of Wolf Creek Waterhammer And Two-Phase Flow Analysis

Hossein P. Nourbakhsh
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November 2000

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

Under Consultant Agreement No. 5401-240
From Information Systems Laboratories, Inc.
11140 Rockville Pike
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Rockville, MD 20852

Contract N0. NRC-03-95-026, Task 240,
TAC M96887

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."

The Wolf Creek Nuclear Operating Corporation (WCNOC) provided its assessment for the Wolf Creek Generating Station (WCGS), in a letter dated January 29, 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 21,1998.[3] The licensee's response was provided in a letter dated September 28,1998.[4]

Information System Laboratories, Inc. was requested (Task Order No. 240, NRC-03-95-026) to assist the NRC staff in reviewing the waterhammer and two-phase flow analyses that has been completed by the licensee for the WCGS 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 cooling water systems at WCGS. 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 AIR COOLING SYSTEM IN WOLF CREEK GENERATING STATION

The containment air cooling system provides cooling by recirculation of the containment atmosphere across air -to-water heat exchangers. There are four fan coolers (two coolers per train) at the WCGS.

The heat sink for Wolf Creek is a man-made lake. A portion of the lake has a seismically qualified partial height dam that serves as the Essential Service Water (ESW) Ultimate Heat Sink (UHS) in the event of a LOCA. The two ESW trains are independent. Flow for each train is provided by a single ESW pump or by the Service Water (SW) system. Discharge can be either to the SW system return header or to the ESW system return header. The SW system return header releases into the Circulating Water (CW) system discharge tunnel and the ESW system return header releases to the UHS. During normal operation, discharge is to both the CW system and UHS[5].

Service water to the fan coolers is designed to flow in at 95 ^{o}F during a LOCA at a flow rate of 1000 gpm to each cooler[5].

The ESW and SW pumps are equipped with discharge check valves. A single 14" pipe branches to two10" pipes inside containment to supply the two coolers on a train. The discharge rejoins in a common 14" pipe before exiting containment. Flow and back pressure to the coolers are controlled with a butterfly valve and orifice on each train located outside containment[5] .

3. SEQUENCES OF EVENTS CONSIDERED FOR EVALUATION

A design basis LOCA with simultaneous initiation of a loss- of- offsite- power (LOOP) has been considered for this evaluation.

A LOCA provides a higher heat transfer rate from the containment atmosphere to the cooling coils than a MSLB. Therefore, a LOCA with a LOOP is a bounding scenario, and its selection for evaluating the responses of the containment air coolers is appropriate.`

On a LOCA/LOOP scenario, the pumps, fans, and valves lose power until the Diesel Generators are started. The following key time parameters during the initial time period following the accident is from Reference 5:

Time	Description
0 sec	LOCA +LOOP SW Pumps, ESW pumps, Fans, and Valves loose Power
12 sec	D/G's start SW supply and return isolation valves begin stroking closed ESW return valves to UHS begin stroking open
18 sec	"A" train ESW return valve to UHS full open
25.5 sec	"B" train ESW return valve to UHS full open
32 sec	"A" ESW pump starts
37 sec	"B" ESW pump starts
42 sec	SW supply and return isolation valves full closed

4. WATERHAMMER ANALYSIS

A LOCA concurrent with a LOOP causes interruption of cooling water flow soon after initiation of the event (within approximately 2 seconds). Continuation of air flow over the coils would cause the water in the cooler tubes to boil until cooling flow resumes. Since Wolf Creek has an "open system" design for both the SWS and ESWS, water will drain from the containment coolers until the ESW pumps are able to repressurize the system. Boiling will occur in the containment cooler coils until they are voided.

During 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 has evaluated these waterhammer issues for WCGS in response to GL 96-06. The review results of waterhammer analyses are provided below for each of the two waterhammer mechanisms.

4.1 Column Closure Waterhammer

When the ESW pump starts, the water advances towards the cooler from the normal supply side and at a lesser rate from the normal discharge side. The advancing water columns will eventually meet in the discharge piping and a column closure waterhammer will occur.[5] The velocity of the closing water column will affect the magnitude of the waterhammer induced pressure pulse.

The hydrodynamic loading due to water column rejoining during system refill has been evaluated in Altran Report (96227-TR-01)[5]. This report concluded that the column closure waterhammer that results from a LOOP without a LOCA is the limitting case.

Section 5.6 of the Altran Report[5] has determined properly, based on a comparison of system resistances, that the LOOP without LOCA column closure impact velocity is greater than the LOOP with LOCA impact velocity. It has also been argued that in the LOOP with LOCA case, the sonic velocity at closure will be lower because the water is heated in the containment cooler, releasing free air in the water prior to closure. In addition, the steam void has a higher concentration of air in the LOOP with LOCA case than the LOOP without LOCA case[5] . The additional air causes a cushioning affect which will reduce the severity of the steam bubble collapse waterhammer.

Based on the above discussions, the magnitude of the column closure pressure pulse will be lower for the LOOP with a LOCA, and the selection of LOOP without LOCA as the limiting column closure waterhammer is appropriate. However, it should be noted that there is a good deal of uncertainty as to the precise amount of air dissolved in the water at the time of accident initiation and, in view of the relatively large time scale for the evolution of dissolved air, the amount of air released during these short transient events may not be significant.

In order to evaluate the worst case scenario for column closure waterhammer, Altran made the following assumptions:

- The check valve from the service water supply was assumed to fail open during the draining transient to maximize the void size,and the valve was assumed to be closed during the refill to maximize velocity.

- The circulating water/service water return path was assumed to be fully open during the draining transient to maximize the void size, and the path was assumed to be isolated during refill to maximize velocity.

The potential pressure load due to water column rejoining during system refill was calculated by the Joukowski equation:

$$\Delta P = k\rho C V_{imp} \qquad (1)$$

where ΔP = waterhammer induced pressure pulse
k = a factor that reflects the compressibility of impacted surface (k=1 where moving water column is stagnated on a perfectly rigid surface, k=0.5 for situations where moving column is stagnated by impacting another water column)
ρ = water density

C =sonic velocity
V_{imp} = impact velocity

A value of k equal to 0.5, a water density of 62.5 lbm/ft^3, and the speed of sound in water of 2300 ft/sec were used in the analysis. For the B train, column closure waterhammer will occur in the 10" discharge piping with an impact velocity of 12.42 ft/sec. The impact velocity of 12.42 ft/sec has been determined appropriately by hand calculations, using Bernoulli's Theorem, reported in Reference 6 (the actual velocity reported in Reference 6 is 12.22 ft/sec). The A train column closure waterhammer will occur in the 14" discharge piping which is common to both the A and C coolers. An impact velocity of 14.477 ft/sec was obtained for the fourteen inch piping. The resultant column closure waterhammer pressure pulses were calculated as 193 psig and 225 psig for train B and train A respectively.

While most of the values used in the column closure waterhammer load calculations are typical for the physical configuration, the assumption of the speed of sound in water of 2300 ft/sec is less than the value of 4500 ft/sec suggested in NUREG/CR-5220[7] for performing bounding calculations. This sonic velocity adjustment was made to account for the waterhammer load reduction due to the presence of air (non-condensable gas) in the water, compliance of piping and hangers, and others. However, neither detailed calculations to include the effects of the pipe elasticity nor quantification of the amount of air entrainment in the water was provided.

It should be noted that during LOCA sequencing and other testing at Wolf Creek, column closure waterhammers have occurred. The data obtained during a test, conducted in November 1991, provides a simulation of the LOOP with an SI signal generated during a LOCA. This test most closely represents the system configuration for which this analysis was performed. This representative test resulted in a peak pressure pulse of approximately 205 psig for column closure waterhammer. This is in agreement with the predicted column closure waterhammer pulses of 193 psig and 225 psig for the "B" and "A" trains respectively. However, the uncertainty in measuring the pressure pulses during these tests was not quantified.

4.2 Condensation Induced Waterhammer in Horizontal Lines

The potential for producing a condensation induced waterhammer was also evaluated in Altran report (96225-TR-02)[5].

Following initiation of a LOOP with LOCA , while the pump is coasting down, the water in the containment cooler tubes will be heated. The heating soon causes boiling in the tubes as the saturation pressure is reached. The boiling creates a steam void in the cooler. Steaming does not continue in the cooler because the piping configuration at Wolf Creek allows draindown of the coolers.

The steam in the coolers quickly reaches a superheated condition as the containment temperature continues to rise. The behavior of the steam in the piping adjacent to the coolers is governed by the expanding void space in the piping system. The uncovering of horizontal runs of pipe during the draindown creates the potential for condensation induced waterhammer. As horizontal sections 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 surface 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.

Altran used the following criteria (suggested in NUREG/CR-6519 [8]) to determine what piping is susceptible to condensation induced waterhammer:

(a) Near horizontal (i.e. vertical lines were neglected)
(b) Subcooling greater than 36 ^{o} F (20 ^{o} F).
(c) L/D > 24

It was assumed that during draindown horizontal pipes do not run full. This assumption is appropriate and may even be conservative. The difference in temperature between the coldest water in the header and the hottest steam was used to determine the subcooling margin. This conservatively ignored mixing in the headers.

Altran used the following equation, which is derived from the Joukowski equation and an energy balance, to calculate the pressure pulse that would result from the waterhammer:

$$\Delta P = 0.707 C \sqrt{P_{\circ} \rho_l \frac{\alpha}{1-\alpha}} \qquad (2)$$

Where: C = sonic velocity

$P_{\circ}$ = system pressure

ρ_l = water density

α =void fraction

The system pressure when the pipe is first uncovered was conservatively used in the analysis for the initial system pressure, P_o. A spreadsheet program (using Quattro Pro) was developed by Altran to model the pressure transient in the SW piping following a LOOP concurrent with a LOCA. The pressure in the cooler while it is draining was conservatively assumed to follow the saturation pressure corresponding to the containment temperature. An isentropic expansion of the steam following draining of the cooler was assumed. An isentropic exponent of 1.13 was used in the analysis. This provides pressures higher than a typical exponent of 1.3 for steam, but slightly less than an isothermal process would predict. This is acceptable since pressure reduction due to condensing of the steam in the downstream water was neglected.

A steam void to water ratio, $\alpha/(1-\alpha)$, of 0.35 was used in the analysis. This corresponds to a void fraction (α) of 0.26. The choice of this value for void fraction was considered to be conservative because the condensation of steam on the water interface and the resultant pressure moderation was not modeled. Additionally, the 0.35 volume ratio was justified due to the limited potential to develop waves and trap steam bubbles above a volume ratio of 0.35. However, no quantitative evaluation (based on experimental data or deterministic calculations) was provided to justify the volume ratio that was used. It should also be noted that a maximum volume ratio of 0.28 was used in the waterhammer load analysis for the "A" train, and no explanation was given.

Altran used a sonic velocity of 2300 ft/sec in the calculations based on some experimental observations reported in NUREG/CR-6519 related to the presence of non-condensables. The assumption of the speed of sound in water of 2300 ft/sec is less than the value of 4500 ft/sec suggested in NUREG/CR-5220[7] for performing bounding calculations. Altran has also provided some calculations (reported in Figure 6 and Appendix C of their report[5]) to show the reduction in sonic velocity with temperature with an initial dissolved air concentration of 8 ppm at 95 ^oF. It should be noted that the air solubility data has incorrectly been implemented in the spreadsheet program provided in Appendix C of the Altran report. Using the correct interpolation of the air solubility data, the sonic velocity would not have changed significantly by increasing the temperature to more than 200 ^oF. As it was noted earlier in section 4.1, there is a large uncertainty associated with the amount of air in water and as it is suggested in NUREG/CR-6519, "for practical calculation, treating the sonic velocity as a parameter which has an uncertainty range makes the most sense."

The most conservative condensation induced waterhammer magnitude corresponds to a slow drainage rate. Altran used the following conservative assumptions for the condensation induced waterhammer calculation:

- No reverse flow was considered through the normal service water supply path.

- Although several valves should be stroking closed during the transient, the Circulating Water/Service Water flow path was assumed to be isolated.

The resultant condensation induced waterhammer pressure pulses were calculated as 216 psig and 270.4 psig for the A and B trains respectively.

The potential for producing a stratified condition of steam and subcooled water in the horizontal pipes during system refill was also evaluated in the Altran report[5]. Using a critical Froude (Fr) number of 1 suggested in NUREG/CR-5220, it was concluded that the piping refill velocities are sufficient to ensure that the horizontal lines run full during refill. Therefore, a bubble collapse type waterhammer (similar to those that occur during draining) will not occur during refill.

4.3 Structural Dynamic Analysis

A structural analysis of the Reactor Building Train "A" and Train "B" containment cooling system Return and Supply lines has been performed by Altran[9]. The hydrodynamic loading due to waterhammer results in a transient pressure wave which travels through the system. Altran has performed a structural assessment of these cooling water lines to determine if the piping system (pipe, supports, equipment nozzles, and penetrations) could withstand such loadings, maintain the integrity of the pressure boundary, and ensure the piping will continue to pass flow.

Fluid structural interaction was not credited as a method for reducing either column closure or condensation induced waterhammer pulse magnitude as it travels through the system.

The licensee has also asserted that experimental fluid structure interaction results, which show potential amplification of long duration pressure pulses in minimally restrained piping, are not applicable to the piping at Wolf Creek.[4] The waterhammer pressure pulses are short duration and the containment cooler piping system at Wolf Creek is restrained to withstand significant seismic events.

Several commercial software packages were used for stress analysis in the affected components. ADLPIPE, a general purpose piping analysis code, was used to analyze piping stress. PD STRUDL, a structural analysis software package, was used to analyze piping supports for the waterhammer loading. ALTRALUG , a vendor developed software tool, was used to analyze integral welded lug attachments to the piping. All waterhammer loads were evaluated in accordance with the design criteria specified in the Wolf Creek Updated Safety

Analysis Report (USAR). It should be noted the detail review of structural analysis was beyond the scope of this evaluation.

5. TWO-PHASE FLOW ANALYSIS

The issue of two-phase flow in containment air cooling system has also been evaluated in the Altran Report [5]. 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.

Design flows are required to be established upon starting of the ESW pumps to ensure design heat removal. If flashing occurs in the ESW system, flow may be reduced. Two -phase flow increases the frictional losses and provides the potential for choked flow conditions [5]. Altran has evaluated the potential for flow limitation at (1) restrictions upstream of coolers, (2)the coolers themselves, (3)restrictions downstream of coolers, and (4) restrictions in the 30" return header. Hand calculations were performed for these evaluations. For all cases evaluated, no flow limiting conditions were found.

While interruption of ESW flow to the coolers will cause some steam to form in the tubes, the Altran evaluation concluded that this steam will be quickly pushed from the cooler tubes and condensed[5] . The difference in system refill time due to the presence of steam was found to be 0.7 seconds (reported in section 5.7 of Altran Report[5]), which is not significant.

During normal design operation, the cooling water system at Wolf Creek has a margin to boiling of at least 10 psia at all locations. Using hand calculations, Altran determined that the system will be at design conditions within 65.2 seconds following a LOCA plus LOOP event. The safety analyses at Wolf Creek do not take credit for containment coolers removing heat from the containment until 70 seconds following an event.

Erosion, cavitation, and fatigue/vibration issues were considered not to be a concern since two-phase flow conditions would not occur upstream or downstream of the containment air coolers following pump restart.

Based on the evaluations discussed above, the licensee's conclusion that two-phase flow is not a concern for the Wolf Creek fan cooler system was found to be adequately justified.

6. SUMMARY AND CONCLUSIONS

The waterhammer and two-phase flow analysis that has been completed by the licensee for the Wolf Creek Generating Station in response to GL96-06 has been reviewed. The hydrodynamic loading due to column closure (water column rejoining) waterhammer has been evaluated using the Joukowski equation with a sonic velocity adjustment to account for the waterhammer load reduction due to presence of air (non-condensable gas) in the water, compliance of piping and hangers, and others. However, neither detailed calculations to include the effects of the pipe elasticity, nor justification for any amount of air entrainment in the water, has been provided.

The potential for condensation induced waterhammer has also been evaluated. The use of Equation (2) ,which is derived from The Joukowski equation and an energy balance, for a conservative estimate of potential condensation induced waterhammer loads during the draindown is appropriate. However, appropriate justification for including the effects of air entrainment has not been provided. Additionally, a quantitative evaluation (based on experimental data or deterministic calculations) was not provided to justify use of the 0.35 volume ratio that was used in the analysis.

It should be noted that the above concerns were discussed with the licensee. The licensee indicated that their responses to GL 96-06 would be supplemented to address these concerns.

The issue of two-phase flow in the containment air cooling system has also been evaluated. While interruption of ESW flow to the coolers will cause some steam to form in the tubes, it has been concluded that this steam will be quickly pushed from the cooler tubes and condensed. The difference in system refill time due to presence of steam was found to be insignificant (0.7 seconds). Based on these evaluations ,the licensee’s conclusion that two-phase flow is not a concern for the Wolf Creek Generating Station fan cooler system was found to be 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. Wolf Creek Nuclear Operating Corporation, "Final Response to Generic Letter 96-06, Assurance of Equipment Operability and Containment Integrity During Design-Basis Accident Conditions," Letter from Richard A. Muench to U. S. Nuclear Regulatory Commission, ET 97-0004, Docket No. 50-482, January 29, 1997.

3. Nuclear Regulatory Commission (NRC), " Request for Additional Information Related to GL 96-06-Wolf Creek Nuclear Operating Corporation-Wolf Creek Nuclear Generating Station, Unit 1," Letter from Kristine M. Thomas to Otto L. Maynard, July 21, 1998.

4. Wolf Creek Nuclear Operating Corporation, "Response to Request for Additional Information Related to Generic Letter 96-06," Letter from Otto L. Maynard to U. S. Nuclear Regulatory Commission, WM 98-0100, September 28, 1998.

5. Altran Corporation, " Containment Fan Cooler Response to a Simultaneous LOCA & LOOP Event," Technical Report No. 96227-TR-01, Revision 3, March, 1998.

6. ABB Impell Corporation, " Callaway Waterhammer Load Calculation," 0096-020-CALC-01 , Rev.0, dated 6/29/92.

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9. Altran Corporation, "Structural Dynamic Analysis of Containment Cooling System Reactor Building Train "A" and Train "B" Supply and Return Piping," Technical Report No. 96227-TR-03, Revision 0, February, 1998.