Letter Report No. 240-1

Review Of Callaway Waterhammer And Two-Phase Flow Analysis

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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."

Union Electric Company provided its assessment for the Callaway Plant, Unit 1, in a letter dated January 28, 1997. [2] Parts of licensee's submittal addresses waterhammer and two-phase flow conditions. The licensee was requested to provide additional information in a letter dated September 11,1997.[3] The licensee response was provided in a letter dated October 17,1997.[4]

Scientech, Inc. was requested (NRC-03-026,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 Callaway Plant 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 in Callaway Plant. The event considered for this evaluation is discussed in section 3. Section 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 CALLAWAY PLANT, UNIT 1

The containment air cooling system provides cooling by recirculation of the containment atmosphere across air -to-water heat exchangers[2]. There are four fan coolers (two coolers per train) at the Callaway Plant.

During normal operations, cooling water to the containment coolers is supplied by the non- safety- related Service Water (SW) system. During post- accident operations, the safety- related Essential Service Water (ESW) system provides flow to the coolers at a rate of approximately 4400 gpm. Two of the coolers are supplied by the "A" train of ESW and two are supplied by the "B" train. Each train is served by one safety grade pump.

Service water to the fan coolers is designed to flow in at 95 °F during a Loss of Coolant Accident (LOCA) at a flow rate of 2000 gpm to each cooler[5].

Following a MSLB or LOCA, each train of the ESW system is automatically isolated from the SW system by motor-operated butterfly valves. Both ESW pumps are started by the Emergency diesel load sequencer. Pump A starts 30 seconds after receipt of the Safety Injection (SI) signal or initiation of a Loss Of Offsite Power (LOOP) . Pump B starts 35 seconds after receipt of the SI signal or initiation of a LOOP.

Each ESW pump supplies the containment coolers through normally open motor - operated containment isolation valves. Cooling flow splits to supply the two coolers per train and rejoins prior to exiting containment. The coolers discharge through 10" lines that join in a 14" header with throttled butterfly valves prior to entering a 30" header. During normal operation, the 30" header discharges into the circulating water system return via the service water system. With ESW aligned, the system discharges to the Mechanical Draft Cooling Tower[5].

3. SEQUENCES OF EVENTS CONSIDERED FOR EVALUATION

A design basis LOCA with simultaneous initiation of a LOOP has been considered for this evaluation.

A LOCA provides higher heat transfer rate, from containment atmosphere to cooling coils, than 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 fans and the service water pumps would loose Power. The following expected key time parameters during the initial time period following the accident is from Reference 5.

Time	Description
0. sec	LOCA +LOOP
~2. sec	Interruption of cooling water (SW coast down to nominally 14 psig discharge pressure)
5 sec	Containment temperature at 250 °F
30 sec	"A" ESW pump starts Containment temperature at 260 °F
35 sec	"B" ESW pump starts Containment temperature at 270 °F

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), while the associated fans would coast down for a much longer time (approximately 45 seconds). Continuation of air flow over the coils would cause the water in the cooler tubes to boil until cooling flow resumes[2]. Since Callaway has an "open system" design for both the SWS and ESWS, the system will drain down from the containment coolers until the ESW pumps are able to repressurize the system . During this time, the system would be draining. Boiling would occur in the containment cooler coils until they are voided.

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).

Union Electric has evaluated these waterhammer issues for the Callaway Plant Unit 1 in response to GL96-06. The review results of waterhammer analyses are provided below for each of the two waterhammer mechanisms.

4.1 Column Closure Waterhammer

The Hydrodynamic loading due to water column rejoining during system refill has been evaluated in Altran Report (96225-TR-02)[5]. This report concluded that the column closure waterhammer that results from a LOOP without a LOCA is the limited case.

Appendix E to 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.

In the LOOP with LOCA case ,the sonic velocity at closure will be lower because the water is heated in the 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 can reduce the severity of the steam bubble collapse waterhammers.

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.

Union Electric contracted with ABB Impell in 1992 to evaluate waterhammer data taken at Wolf Creek during Engineered Safety Features Actuation Systems (ESFAS) testing , and to use this data to bound the LOOP waterhammer that Callaway would experience. ABB Impell , in a document entitled "Callaway Waterhammer Load Calculations" (0096-020-calc-01)[6], modified the pressure vs. time data from Wolf Creek waterhammer to account for differences in the test conditions and the Callaway design basis condition.

Since both Wolf Creek and Callaway are Standard Nuclear Unit Power Plant System (SNUPPS) plants, many similarities exist[6]. ABB Impell report compared the conditions which can affect the impact velocity and the amount of air in the system, and adjusted the slope of the pressure rise and the peak pressure from the Wolf Creek pressure trace in order to simulate the Callaway conditions.

Accurate calculation of the free air in the system is not possible and has not been attempted in ABB Impell calculations. Instead , the test results from Wolf Creek were adjusted to account for the possible differences between the two plants[6]. The adjustment is based on simple scaling which assumes that the amount of free air that forms a pocket between the separated columns is directly proportional to the volume of the void formed subsequent to the pump trip.

The factors which affect the magnitude of the peak pressure are defined 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

Expressing the peak pressure as a ratio,

$$\frac{(\Delta P)_{call}}{(\Delta P)_{wc}} = \frac{\rho_{call}}{\rho_{wc}} \frac{C_{call}}{C_{wc}} \frac{(V_{imp})_{call}}{(V_{imp})_{wc}} \qquad (2)$$

The pressure vs. time data from Wolf Creek waterhammer was taken on November 11,1991 when the incoming water was 40 °F. The incoming water temperature can be as high as 95 °F which is the most limiting for the amount of air dissolved in water.

The amount of air existing in the water as air bubbles affect sonic speed as provided by the following formula:

$$C = \sqrt{\frac{K/\rho}{1 + \frac{KD}{Ee} + \frac{mR_g KT}{P^2}}} \qquad (3)$$

Where K = volume modulus of water
D = pipe outer diameter
E = Young modulus
e = pipe thickness
m = mass of air per unit volume of mixture
T = temperature
P = absolute partial pressure of the air
R_g= gas constant

In equation (3), all terms except the mass of air per unit volume of mixture, m, are the same at Wolf Creek and Callaway. The solubility of air in water at 40 ^{0}F is 0.0288 air by volume at atmospheric pressure. The solubility of air in water at 95 ^{0}F is 0.016 air by volume at atmospheric pressure. Assuming that the ESW and SW are saturated with dissolved air and since 1+(KD/Ee) is much smaller that $(mR_gKT)/P^2$, the difference in air content resulted in:

$$\frac{C_{call}}{C_{wc}} = \sqrt{\frac{0.0288}{0.016}} = 1.34 \qquad (4)$$

The change in densities for the temperature ranges considered (32 ^{0}F- 95 ^{0}F) are small (less than 0.7%), therefore:

$$\frac{\rho_{call}}{\rho_{wc}} \approx 1. \qquad (5)$$

Based on review of system description, safety analysis report and load sequencing for both plants, ABB Impell report concluded that the ESW systems at both plants function in the same manner with the exception of the suction and discharge points. In addition the flows to containment coolers are different.

Hand calculations, using Bernoulli's Theorem, were performed to determine both plants impact velocities. Impact velocities of 12.24 ft/s and 12.22 ft/s were obtained for Callaway and Wolf Creek respectively. Therefore:

$$\frac{(V_{imp})_{call}}{(V_{imp})_{wc}} = \frac{12.24}{12.22} \approx 1. \qquad (6)$$

Using the peak pressure of 205 psig, obtained during waterhammer test at Wolf Creek, the peak pressure at Callaway was obtained by applying the equations (2)and (4)-(6) as:

$$P_{call} = 205psigX1.0X1.34 = 275psig \qquad (7)$$

The loads created in the piping segments when the pressure wave enters the segment increase proportionally with the pressure rise rate as the wave travels the length of the piping segment. A faster pressure rise rate would create a larger load in the piping segment.[6]

To determine the factors which would affect the rate of pressure rise , the following formulas were used:[6]

$$F = \frac{dP}{dS} l_s A_s \qquad (8)$$

where

F	= force in the piping segment
dP / dS	= slope of the pressure rise rate
l_s	= piping segment length
A_s	= piping segment area

$$\frac{dP}{dS} = \frac{dP}{dt}\frac{1}{C} \qquad (9)$$

where

dP / dt	= change in pressure vs. time $= \Delta P / \Delta t$
C	= sonic velocity of the pressure wave

$$\Delta t \propto \frac{L_{void}}{V_{imp}} \qquad (10)$$

where

L_{void}	= void length
V_{imp}	= impact velocity

Combining Joukowski equation (1) and equations (9)-(10),

$$\frac{dP}{dS} \propto \frac{\rho V_{imp}^2}{L_{void}} \qquad (11)$$

The piping at Callaway and Wolf Creek are identical in containment. Therefore for the force calculation:

$$\frac{F_{call}}{F_{wc}} = \left[\frac{(V_{imp})_{call}}{(V_{imp})_{wc}}\right]^2 \left[\frac{(L_{void})_{wc}}{(L_{void})_{call}}\right] \qquad (12)$$

A decrease in the length of the void will result in a decrease in the amount of air in the void and will serve to provide less of a cushion for the colliding columns and would result in a faster pressure rise rate.[6]

It was assumed that all the air existing in the void when the water columns rejoin comes from the dissolved air in the water in the piping which would become voided. When the pressure drops below vapor pressure, the water will release the air in solution. Therefore , the size of the void will affect the amount of air present when the water columns rejoin.

The elevation to which the columns of water will drain when the pump stops determines the location of the impact. The loads are at their peak values closest to the impact location and attenuate as they propagate through the system.[6] It should be noted that the analysis at Callway did not account for attenuation of the load, which is conservative.

The void heights difference between Wolf Creek and Callaway had an effect on the calculated loads because the void height difference changes the void size.

The slope of pressure rise (dp/ds) from Wolf Creek was adjusted for the void volume and temperature difference for Callaway.

$$(dP/dS)_{call} = (dP/dS)_{wc} \frac{v_{wc}}{v_{call}} \frac{(c_{air})_{wc}}{(c_{air})_{call}} \qquad (13)$$

Where v = void volume

c_{air} = concentration of air dissolved in water (by volume)

Hand calculation were performed by ABB Impell to determine both plants void volumes. Void volumes of 258.24 ft³ and 124.5 ft³ were obtained for Wolf Creek and Callaway respectively. Therefore:

$$\frac{v_{wc}}{v_{call}} = \frac{258.24}{124.5} = 2.07 \qquad (14)$$

Based on the solubility of air in water at 40 °F and 95 °F, discussed before,

$$\frac{(c_{air})_{wc}}{(c_{air})_{call}} = \frac{0.0288}{0.016} = 1.8 \qquad (15)$$

Using the most severe of all pressure traces recorded during Wolf Creek's ESFAS testing, the maximum value of dp/dt was calculated as 2625 psi/sec. The slope of pressure rise was then calculated based on equation (9) ,using sonic velocity of 4223 ft/sec (calculated by including the effect of pipe elasticity and neglecting the effect of air entrainment).

$$(dP/dS)_{wc} = \frac{2625 psi/\sec}{4223 ft/\sec} = .622 psi/ft \quad (16)$$

The slope of pressure rise for Callaway was then calculated using equations (13)-(16):

$$(dp/dS)_{call} = .622 X 2.07 X 1.8 = 2.32 psi/ft \quad (17)$$

In view of large uncertainties associated with the amount of the air in water both during the Wolf Creek waterhammer test and in actual Callaway SW system, the above methodology for extrapolating the results of Wolf Creek waterhammer test to Callaway plant is questionable and may not be conservative.

Applying Joukowski equation with the sonic velocity of 4500 ft/sec (as suggested in NUREG/CR-5220[7]for bounding calculation)and with the impact velocity of 12.24 ft/sec, the resulting pressure pulse for column closure induced waterhammer have a magnitude of 370.6 psig. Including only the effect of pipe elasticity (neglecting the air entrainment)would result in a sonic velocity of 4223 ft/sec (as calculated in ABB Impell Report, Page: 28) and a corresponding waterhammer pressure pulse of 347 psig, which is almost the same as the pressure pulse predicted for condensation induced waterhammer (346 psig). See Section 4.2 for an assessment of the pressure pulse.

4.2 Condensation Induced Waterhammer in Horizontal Lines

The potential for producing a stratified condition of steam and subcooled water in horizontal pipes and subsequent bubble collapse type condensation (condensation induced waterhammer) has also been 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 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 Callaway 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 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 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 [5].

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

(a) Near horizontal (i.e. vertical lines were neglected)
(b) Subcooling greater than 36 ° F (20 ° 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 evaluate subcooling margin. This conservatively ignored mixing in the headers.

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

$$\Delta P = 0.707C\sqrt{P_o \rho_l \frac{\alpha}{1-\alpha}} \qquad (18)$$

Where: C = sonic velocity
P_o = 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 higher than a typical exponent of 1.3 for steam but slightly (<10%) less than an isothermal process would predict. This is appropriate since pressure reduction due to condensing of the steam in the downstream water was neglected. An equation for the volumetric flow rate as a function of pressure in the cooler and the elevation of the column was derived for input into the spreadsheet program. Callaway KYPIPE model for "A" and "B" train was utilized to determine the overall system resistance coefficient for LOCA lineup .

A steam void to water ratio , $\alpha/(1-\alpha)$, of 0.35 was used in the analysis. This corresponds to void fraction (α) of 0.26 . The choice of this value for void fraction based on the expectation of low steam velocity with the isentropic steam expansion was considered to be conservative .

A sonic velocity of 2300 ft/sec was used in the calculations based on some experimental observations reported in NUREG/CR-6519 . Due to the presence of non- condensibles, Altran considered 2300 ft/sec for sonic velocity to be conservative. Altran has also provided some calculations (reported in Appendix G of their report[5]) to show the reduction in sonic velocity with temperature with an initial dissolved air concentration of 8 ppm. at 95° F). It should be noted that the air solubility data has incorrectly been implemented in the spreadsheet program provided in Appendix G 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 212° F. It should also be noted that 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."

In order to predict the most conservative waterhammer pressure pulses, two pressurization cases were run. A different system resistance coefficient was applied for each case:

Case 1 - LOCA lineup throughout transient. This case assumed that the system is configured for ESW flow with SW isolated. This provides the most system resistance since the flow path to the service water supply is isolated. This case will allow the pressure in the cooler to go the highest (since the cooler will take longer to drain) and will then result in the largest condensation induced waterhammer loads. This case resulted in a condensation induced waterhammer for the train "B" with a maximum pressure pulse of 346 psig. For the train "A", due to larger system resistance, the susceptible horizontal pipes were not reached during the drain down.

Case 2 - Normal lineup throughout transient. This case assumed that the system is configured for SW flow with discharge to the CW system and reverse flow through the SW supply (SW hydraulic discharge valves assumed to fail) . This case provides the least system resistance and the most conservative condensation induced waterhammer prediction (if piping prone to condensation induced waterhammer was not reached in case (1). This case does not take credit for valve realignments when the diesel loads and is therefore conservative. This case resulted in a maximum pressure pulse of 315 psig in the "A" train.

The potential for producing a stratified condition of steam and subcooled water in the horizontal pipes during the refill has also been 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 during refilling ,bubble collapse type waterhammer similar to those that occur during draining will not occur.

To determine the condensation induced waterhammer loads, the column closure waterhammer loads were multiplied by the ratio of the two pressure pulses:

$$F_{A-CIWH} = (\frac{315}{275})F_{A-CCWH} = 1.15F_{A-CCWH} \qquad (19)$$

$$F_{B-CIWH} = (\frac{346}{275})F_{B-CCWH} = 1.26F_{B-CCWH} \qquad (20)$$

Altran report, based on the argument that the pressure pulse period for a condensation induced waterhammer is much less than that of column closure waterhammer, concluded that the linearly increasing the column closure forces and stresses by these ratios is conservative.

The stresses from the LOOP pipe stress analysis performed on the ESW system were divided into 4 sections. They are the "A" train supply, "A" train return, "B"train supply and "B" train return. The highest stress points as a result of the waterhammer loading are shown in the table below (provided by licensee in a letter dated May 17, 1999[9]). For conservatism, the 26% maximum increase in the waterhammer load was applied to both trains "A" and "B". The loads were combined in the table below as required by the FSAR table 3.9(B)-2 for Faulted conditions (PO+DW+DF). The Dead Weight and Waterhammer stress were also increased by 0.75i(as required by ASME). These values were compared to the allowable stress for these conditions. In all cases , the condensation induced waterhammer load due to LOOP with LOCA resulted in stresses below the allowable stress limit[9].

Stress Run	Node with Max Stress	Pressure Stress (PO)	Dead Weight Stress (DW)	Water Hammer Stress (DF)	SIF (i)	PO+ 0.75i(DW+1.26DF)	Allowable (2.4Sh)
"A" Supply	6003	1718	181	4704	2.94	15186	36000
"A" Return	6003	1718	455	5220	2.94	17224	36000
"B" Supply	6008	1324	1300	4684	2.61	15422	36000
"B" Return	6004	1324	242	7116	2.61	19349	36000

It should be noted that in view of the high values for allowable stresses , the non-conservatism in predicting the peak pressure for condensation induced waterhammer (due to the assumption of 2300 ft/sec for sonic velocity) would not change the conclusion regarding the design and operability requirements.

5. TWO-PHASE FLOW ANALYSIS

The issue of two-phase flow in containment air cooling system has also been evaluated in 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.

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 condition was found.

While interruption of ESW flow to the coolers will cause some steam to form in the tubes, the Altran evaluation has 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 0.4 seconds (reported in Appendix F of Altran Report[5]),which is not significant.

Based on the evaluations discussed above, Union Electric has appropriately determined that Callaway does not have a problem with two-phase flow inhibiting full design heat removal capability of the containment coolers.[2]

6. SUMMARY AND CONCLUSIONS

The waterhammer and two-phase flow analysis that has been completed by the licensee for the Callaway Plant Unit1 in response to GL96-06 has been reviewed. The hydrodynamic loading due to column closure waterhammer has been evaluated using waterhammer data taken at Wolf Creek during ESFAS testing. In view of large uncertainties associated with the amount of the air in water both during the Wolf Creek waterhammer test and in actual Callaway SW system, the methodology used for extrapolating the results of the Wolf Creek test to the Callaway Plant is questionable and may not be conservative. However , it was found that any non-conservatism that may exist in predicting the peak pressure for column closure waterhammer would not change the conclusion regarding the design and operability requirements.

The potential for condensation induced waterhammer has also been evaluated. The use of Equation (18) ,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, a proper justification for including the effect of air entrainment in the water was not provided. In view of the high values for allowable stresses, the non-conservatism in predicting the peak pressure for condensation induced waterhammer (due to the assumption of 2300 ft/sec for sonic velocity) would not change the conclusion regarding the design and operability requirements. However, it is noted that no information about the effect of potential hydrodynamic loadings on the pipe support analysis for the piping associated with the fan coolers has been provided.

The issue of two-phase flow in 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(0.4 seconds) Based on these evaluations ,it is agreed with the licensee's determination that Callaway does not have a problem with two-phase flow inhibiting full design heat removal capability of the containment coolers.

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.

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3. Nuclear Regulatory Commission (NRC), " Request for Additional Information Pertaining to Generic Letter (GL) 96-06, Assurance of Equipment Operability and Containment Integrity During Design-Basis Accident Conditions," Letter from Barry C. Westreich to Garry L. Randolph, September 11,1997.

4. Union Electric Company, "Callaway Plant, Union Electric Response to Request for Additional Information- NRC Generic Letter 96-06", ULNRC-03667, October 17, 1997.

5. Altran Corporation, " Containment Fan Cooler Response to a Simultaneous LOCA & LOOP Event," Technical Report No. 96225-TR-02, Revision 0, January, 1997.

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8. Griffith, P. "Screening Reactor Steam/Water Piping Systems for Water Hammer" NUREG/CR-6519, September 1997.

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