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

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

In July of 1998, Duke, along with other licensees, joined a collaborative effort with EPRI and NEI to publish a Technical Basis Report (TBR) to address the waterhammer issue as described by GL 96-06. These efforts were described in Duke letters to the NRC dated March 23, 1999 and December 15, 1999. The NRC allowed deferment of remaining actions to fully address issues raised in the GL, until the TBR was reviewed and accepted by the NRC.

The culmination of the EPRI/NEI effort was the release of the EPRI Report TR-113594, "Resolution of Generic Letter 96-06 Waterhammer Issues," Volumes 1 and 2. In a letter dated April 3, 2002 to Mr. Vaughn Wagoner, Chairman, EPRI Waterhammer Project Utility Advisory Group, the NRC issued a safety evaluation report (SER) that accepted the EPRI TBR report for evaluation of waterhammers described in the GL, subject to the limitations delineated in the EPRI report.

An NRC letter dated May 2, 2002 advised Duke that the TBR had been accepted subject to the limitations described above. The letter further requested that Duke complete actions

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This letter provides Duke's response to the NRC's May 2, 2002 letter. As a result of analyses described in Attachment 1, modifications are being planned to the Low Pressure Water System to address the waterhammers described in GL 96-06. The conceptual scope of the modifications is also described in Attachment 1. Duke is currently developing plans for the design and implementation schedule for these modifications. Duke will notify the Staff by October 1, 2003 of the implementation schedule for these modifications.

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

Very truly yours,

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Attachments

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Oconee Nuclear Station,
Units 1, 2 and 3

Attachment 1
Response to Generic Letter 96-06

Background

NRC Generic Letter 96-06, "Assurance of Equipment Operability and Containment Integrity During Design-Basis Accident Conditions", identified three areas of concern:

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 system design and operability requirements.
3. Thermally induced over-pressurization of isolated water-filled piping sections in containment could jeopardize the ability of accident-mitigating systems to perform their safety functions and could also lead to a breach of containment integrity via bypass leakage. Corrective actions may be needed to satisfy system operability requirements.

This submittal addresses the first issue concerning waterhammers that may occur during design basis events. The second issue, two-phase flow in cooling water systems during design basis events, was previously addressed by a letter to the NRC dated January 28, 1997. This letter explains that the LPSW system provides sufficient flow to the LPI coolers and Reactor Building Cooling Units (RBCUs) to satisfy heat transfer requirements following a design basis accident with a single active failure.

The third issue, thermal overpressurization of isolated water filled piping in containment, was previously addressed in letters to the NRC dated January 28, 1997, April, 15, 1997, June 30, 1997, and December 17, 1998. These letters describe containment penetrations that required the installation of thermal relief valves and leak-off lines with check valves to prevent over-pressurization. Other containment penetrations were cut, capped, and abandoned. Water filled lines that are isolated within containment required administrative control to partially drain those lines prior to power operations.

To further address the first issue, Duke and other licensees joined an effort with EPRI and NEI to publish a Technical Basis Report (TBR) for the waterhammers described by GL 96-06. The NRC allowed deferment of actions needed to fully address waterhammer issues raised in the GL until the TBR was reviewed and accepted by the NRC. The culmination of the EPRI/NEI effort was the release of the EPRI Report TR-113594, "Resolution of Generic Letter 96-06 Waterhammer Issues," Volumes 1 and 2. The NRC issued an SER on the TBR April 3, 2002. In the SER, the staff requested that licensees who choose to implement the methodology described in the TBR could do so by supplementing their response to the GL to include the following:

- Certification that the EPRI methodology, including clarifications, was properly applied, and that plant specific risk considerations are consistent with the risk perspective that was provided in the EPRI letter dated February 1, 2002. If the un-cushioned velocity and pressure are more than 40 percent greater than the cushioned values, also certify that the pipe failure probability assumption remain bounding. Any questions that were asked previously by the staff with respect to the GL 96-06 waterhammer issues should be disregarded.
- The additional information that was requested in RAIs that were issued by the NRC staff with respect to the GL 96-06 two-phase flow issue (as applicable).
- A brief summary of the results and conclusions that were reached with respect to the waterhammer and two-phase flow issues, including problems that were identified along with corrective actions that were taken. If corrective actions are planned but have not been completed, confirm that the affected systems remain operable and provide the schedule for completing any remaining corrective actions.

With regard to the two phase flow issue noted above, Duke has previously responded to the NRC. In the absence of RAIs from the NRC Staff, this issue is considered closed, and is therefore not addressed in this submittal.

This submittal provides the above requested supplementary information regarding GL 96-06 described waterhammers. It includes a description of the Oconee Low Pressure Service Water (LPSW) system, a description of the applicable design basis accidents, and the resultant waterhammers. Further, this submittal describes the testing and analyses that have been completed to support the current operating configuration. It confirms that the analyses completed are consistent with the methodologies presented in the TBR and describes conceptual modifications that are planned to address potential GL 96-06 waterhammers.

Description of Low Pressure Service Water System

The Oconee LPSW system is an open raw water support system that takes suction from the Condenser Circulating Water (CCW) System. The CCW system withdraws aerated water directly from Lake Keowee, which has a temperature range of 40 °F to 90 °F. The LPSW system provides cooling to safety and non-safety components in the Turbine Building, Auxiliary Building, and Reactor Building.

Units 1 and 2 share three 15,000 gpm LPSW pumps. The LPSW pumps take suction from the 42 inch crossover line between the condenser inlet headers. Two separate 24 inch headers provide LPSW flow to the Unit 1 and 2 Auxiliary Building and Reactor Building components. These two supply headers are further divided into four separate supply headers, two supplying the Unit 1 components and two supplying the Unit 2 components. Unit 3 has two 15,000 gpm pumps. The two Unit 3 pumps provide cooling water via separate supply headers, similar to Units 1 and 2.

The LPSW system serves eleven principal components inside the Reactor Building of each Unit. These are the A, B, and C Reactor Building Cooling Units (RBCU), the A, B, C, and D Reactor Building Auxiliary Cooling Units (RBACU), and the A1, A2, B1, B2 Reactor Coolant Pump (RCP) Bearing Oil and Motor Air Coolers (See Figure 1 for a Partial Schematic of the

LPSW system). Four supply headers branch from the two main supply lines in the Auxiliary Building. One header supplies the "A" RBCU, the second header supplies the "C" RBCU, the third header supplies both the "B" RBCU and the RBACUs, and the fourth header supplies the RCP Bearing Oil and Motor Air Coolers. Each unit's supply header contains an electric motor operated isolation valve (LPSW-6, 16, 19, and 22) which are located in the Auxiliary Building. Inside containment, a branch line off the "B" RBCU supply header provides flow to the RBACUs. Valves LPSW-565 and 566 provide isolation to the RBACUs and the "B" RBCU respectively.

Four discharge headers from the RBCUs and RCP Bearing Oil and Motor Oil Coolers rejoin into one discharge line in the Auxiliary Building. The discharge from the RBACUs rejoins the "B" RBCU discharge inside containment. Each of the four discharge header contains electric motor operated valves (LPSW-15, 18, 21 and 24) which are located in the Auxiliary Building. The valves LPSW- 18, 21, and 24 provide both isolation and flow control to the RBCUs and RBACUs. Valve LPSW-15 isolates the discharge of the RCP Bearing Oil and Motor Air Coolers. The discharge line empties into the CCW Discharge line which flows into Lake Keowee.

Description of Accident Scenarios

Loss of Offsite Power (LOOP)

During normal operations, the cooling requirements for each unit are supplied by one LPSW pump. For Units 1 and 2, two out of the three shared pumps would normally be operating. The cooling requirements post accident can also be supplied by one pump per unit. During a LOOP only event, loss of power to the LPSW pumps causes a rapid flow coast down. As a result of column separation, voids will form in portions of the piping in which the pressure drops below the saturation pressure of the fluid. Eventually, voiding will occur in piping that is more than approximately 34 feet above the lake level.

Following a LOOP only event, the normally operating LPSW pump(s) should restart on power restoration at less than or equal to 31 seconds. Should a previously running LPSW pump fail to restart, auto restart logic will start a standby pump in a maximum of 41 seconds (31 seconds restart time (maximum) + 10 second auto-start logic delay time).

On pump restart, the water column(s) will be accelerated by the pump to a flowrate based on the hydraulic losses in each LPSW flowpath. The backpressure in the high points of the LPSW system will initially be very low due to the vacuum condition. As the water column fills each voided pipe section, a column closure waterhammer (CCWH) will occur.

Loss of Coolant Accident (LOCA) and Main Steam Line Break (MSLB)

During a combined LOCA-LOOP or MSLB-LOOP event, a rapid increase in the Reactor Building temperature and pressure occurs. A significant amount of heat is added to the containment atmosphere. A portion of the heat is transferred to the RBCUs and RBACUs even though air flow across the cooler coils is reduced as the intake fans coast down. The bounding LOCA event is a double-ended guillotine break of the reactor coolant hot leg pipe. The bounding MSLB event is a double-ended guillotine break of a Main Steam line from the

Once Through Steam Generators (OTSGs). The combination of the decrease in the LPSW pressure due to the loss of the pump driving head and the temperature rise due to the heat transfer across the cooler coils causes boiling in the RBCUs and RBACUs during LOCA-LOOP or MSLB-LOOP transients. Boiling is predicted to occur when the saturation pressure of the water rises from the heat addition and exceeds the local system pressure determined from the elevation and hydraulic losses in the system. Steam generated in both the RBCUs and RBACUs will leave the affected cooler and feed into both the supply and return lines of each cooler. Condensation Induced Waterhammers (CIWHs) are expected to occur in the RBCU and RBACU supply and discharge piping. After power is restored, an Engineering Safeguard (ES) signal restarts all pumps within 31 seconds and the voided piping will begin to be refilled. The refilling water column will be accelerated by the pumps to a flow rate determined by the hydraulic losses in each LPSW flow path, including the back pressure resulting from heat transfer to the service water system. The piping voided regions will refill due to re-pressurization of the system and condensation of steam. As a result, CCWHs will occur.

Testing

In February 1997, during a unit outage, the Unit 3 LPSW system supply and return piping serving the containment coolers (RBCUs and RBACUs) was monitored during the performance of a simulated LOOP. The purpose of the test was to obtain flow and pressure data to correlate to the analytical predictions. The LPSW system was monitored at three locations listed below (See Figure 1 for a LPSW system drawing):

- Supply flow meter upstream of valve 3LPSW-19 (RBCU 3B inlet isolation valve)
- Discharge flow meter downstream of valve 3LPSW-21 (RBCU 3B outlet isolation and flow control valve)
- Discharge Pressure on common discharge line to CCW.

The test monitoring equipment consisted of five pressure transducers and the two flow meters noted above. All equipment was wired directly into a data acquisition computer. The inlet and outlet pressure transducers were attached to the existing flow meter pressure sensing lines on both the supply and return piping. The pressure transducers could sense the pressure in the line due to any waterhammer disturbances. Flow measurements were recorded with the flow meters. The following table provides a description and ranges of the data acquisition equipment:

Data Logger Points

Description	***Data Range***
RBCU B Inlet Flow	0 to 1600 gpm
RBCU B Outlet Flow	0 to 1600 gpm
RBCU B Inlet Impulse Pressure	0 to 1000 psig
RBCU B Outlet Impulse Pressure	0 to 1000 psig
LPSW Outlet Header Impulse Pressure	0 to 1000 psig
RBCU B Inlet Pressure	-12 to +80 psig
RBCU B Outlet Pressure	-12 to +80 psig

In addition to data acquisition, the test was monitored by six engineers stationed at strategic points in containment.

For the test, the LOOP only pump configuration was tested. In this arrangement one pump was operating at the start of the test. This pump was stopped to simulate a LOOP and the same pump restarted. The standby LPSW pump remained in standby throughout the test.

The test sequence is presented below. The pumps were manually stopped and started at the appropriate time as determined by a stop watch. Communications to the engineers in containment witnessing the test were provided by portable radios.

Test Sequence

Test Time (sec.)	*Data Time (sec.)*	*Event*
0		Start test
15	0	Start data acquisition units
30	15	Stop LPSW Pump
63	48	Start LPSW Pumps
135	120	Data acquisition units automatically stops

The test was run three times. The results of the tests provided repeatable evidence of CCWHs. The peak pressure recorded was approximately 132 psig. The engineers witnessing the test reported of pipe movement and successive bangs indicating the progression of the CCWHs. A survey of the affected piping and piping support/restraints after the test noted no damage.

<u>Evaluation of Current Operating Condition</u>

For waterhammers described by the GL, Duke retained ALTRAN Corp. to determine the thermal hydraulic conditions in the LPSW piping serving containment components for waterhammers described by GL 96-06. Waterhammer potential was investigated for a LOOP only event, a combination MSLB-LOOP event, and a combination LOCA-LOOP event. Single active failures of equipment were incorporated into the analysis and bounding scenarios were selected. Pressure magnitudes for each scenario were developed using the evolving EPRI Report TR-113594, "Resolution of Generic Letter 96-06 Waterhammer Issues," as a guide.

Condensation Induced Waterhammers

Condensation Induced Waterhammers (CIWHs) that could occur during the draining phase of the LOCA-LOOP and MSLB-LOOP scenarios were evaluated. An assessment of the potential valve positions and single failure considerations within the LPSW system was included in the analysis. The Method of Characteristics (MOC) was used to model waterhammer behavior. The evaluation was subdivided into six analyses:

1) The heat transfer model determined the heat input into the RBCUs and RBACUs as a function of time for both the LOCA-LOOP and MSLB-LOOP scenarios. A transient thermal model was created that equated the total energy input to the coolers as the

finite difference between the heat input to the coolers from the containment environment and the heat removed by the draining water in the system. The overall heat transfer across the tubes was dynamically modeled based on the water flow through the cooler tubes, the containment temperature and air/steam mass fraction, and the air flow during the fan coast-down. Design data from Aerofin Corporation was used to model the coolers.

2) The hydraulic model determined the pressures and flow rates in the system following LOCA-LOOP and MSLB-LOOP events. Component resistance coefficients were modeled using Crane. Pressures and flow rates were determined for each RBCU and each RBACU.
3) A MOC model incorporated the results of the heat transfer model and the hydraulic model to determine the void closure velocity. The heat transfer model provided the steam generation rates in the coolers. The hydraulic model provided pressures and flow rates for the draining water. Steam condensation rates were first determined for the pipe walls and the steam/water interface based on the steam and water temperatures. Void pressures were then determined. The void closure velocity was then calculated based on the difference between the steam and water pressure, subject to inertia and shear limits. The calculated void closure velocity was then used in Joukowski's equation to determine the pressure pulse magnitude.
4) The results of the MOC model were then used to create a transient waterhammer force time history (FTH). The inputs into the analysis include the appropriate sonic velocity, the rise time of the pressure pulse, the length of the piping segment(s), the waterhammer pressure magnitude, the segment flow area, and the pressure attenuation factor. Actual support and equipment stiffness were calculated and used to determine the amount of fluid structure interaction (FSI) based on methods contained in Moody's "Introduction to Unsteady Thermo-Fluid Mechanics." The waterhammer was then traced through the system from the initiation point, taking into account pulse attenuation, pulse amplification, and FSI. The results of this work were a set of three dimensional force time histories for each accident scenario.
5) The FTHs were then used as input to the lumped mass piping analysis program SUPERPIPE. The direct integration feature of SUPERPIPE was used. A time step of .0005 seconds was selected for output results. A damping of 2% of the critical damping was used per NRC Regulatory Guide 1.61, "Damping Values for Seismic Design of Nuclear Power Plants." Actual pipe support/restraint and equipment stiffness was used in the analysis to determine reactions.
6) The output from SUPERPIPE was then used to qualify piping and piping support/restraints using appropriate limit bases (ASME Appendix F & AISC), and equipment using appropriate vendor data.

The critical results from the analysis are as follows:

Unit	Max. Void Pressure (psia)	Max. Closure Pressure (psig)
1 & 2	8.38	314.0
3	9.71	402.2

Column Closure Waterhammers

Column Closure Waterhammers (CCWHs) that could occur during the refill phase of the LOOP only, LOCA-LOOP and MSLB-LOOP scenarios were evaluated. An assessment of the potential valve positions and single failure considerations within the LPSW system was included in the analysis. Potential for CCWHs in the LPSW piping serving the RCP Bearing Oil and Motor Air Coolers was also investigated. The Method of Characteristics (MOC) was used to model waterhammer behavior. The evaluation was subdivided into five analyses:

1) Calculations were first made to determine the system hydraulics and refill rates following pump restart. This process was accomplished in two steps. First, the steady state velocities and pressures were calculated using a hydraulic model. The hydraulic model used the LPSW pump curves, line losses, and elevations to determine the flows and pressure in the system. To use the model under voided conditions, the node at the voided location was assigned a fixed pressure corresponding to the saturation (void) pressure, typically about 1 psia. The void locations were based on the results of the hydraulic model of drainage completed for the CIWH analysis. Second, the results of the hydraulic model provided the conditions in the system at the instant of closure. This was based on quasi-steady state conditions in the system with negligible resistance in the voided region and normal resistance in the remainder of the piping system.
2) The fluid acceleration of the water mass into the void was accomplished by using the Method of Characteristics (MOC) approach published by E. B. Wylie and V.L. Streeter, "Fluid Transients in Systems". This method calculates the acceleration of a mass of fluid, using driving pressures obtained from the hydraulic model. The participating mass, defined as the fraction of the total flow entering the voided path was determined. This mass was dynamically accelerated into the void using the boundary conditions from the hydraulic model. Credit was taken for the presence of non-condensables by using a sonic velocity of 2300 ft/sec. At locations away from the initial closure, a sonic velocity of 4600 ft/sec was used.
3) The results of the previous step were then used to create a transient waterhammer FTH similar to those constructed for the CIWH analyses.
4) The FTHs were then used as input to the piping analysis program SUPERPIPE as was used for the CIWH analyses.
5) The output from SUPERPIPE was then used to qualify piping and piping support/restraints similar to that used for the CIWH analyses.

Critical results from the analysis are given in Tables 1, 2, & 3 for the respective units. Refer to Figure 2 for Unit 1 CCWH closure locations and Figure 3 for Units 2 and 3 CCWH closure locations.

The results of the piping and structural analyses supported the conclusion that the LPSW system remained operable. However, certain code allowables associated with the piping and support/restraints were not met.

Conceptual Modifications

The results of the CCWH analysis indicated that approximately seventy five percent of the approximately three hundred piping support/restraints per Unit would require changes in order to meet certain design basis code allowables. Such changes to the LPSW piping support system inside containment is not considered prudent. Instead, the philosophy at Oconee is to eliminate the source of waterhammers or significantly reduce the magnitude of waterhammers through modifications to the piping system or through procedure changes, whenever feasible, rather than modifying piping support/restraints to sustain the loads resulting from the waterhammer. Two modifications are planned that will effectively reduce the magnitudes of waterhammers described by GL 96-06 to levels that could be sustained within the design basis code allowables of the present piping support/restraint system.

For CCWHs to occur, drainage of the LPSW system during the accident scenarios and the resultant voiding must first occur. Thus any system modifications contemplated should prevent or mitigate the drainage. The two conceptual modifications described in this submittal will prevent significant drainage in the LPSW system and thus prevent or significantly reduce waterhammers described by GL 96-06. The first conceptual modification would prevent drainage of the RBCU and RCP Bearing Oil and Motor Air Coolers supply and discharge lines. The second conceptual modification would physically separate in containment the RBACU lines and coolers from the RBCU lines and coolers. A more detailed description of these conceptual modifications is given below:

LPSW Containment Drainage Prevention Modification

This modification involves the installation of two check valves, four vacuum breakers, and control circuitry on each unit (refer to Figure 4). A 14" check valve (A3, B3) is required in each RBCU/RCP LPSW supply header. Upstream and downstream 14" isolation valves (A1, A5, B1, and B5) will also be installed to allow online maintenance of the check valves. The check and isolation valves will be installed in the East Penetration Room in each vertical LPSW supply header. Drain valves (A2, A4, B2, and B4) are provided for reverse flow testing and drainage for maintenance.

Six (6) inch vacuum breakers (A8, A10, B8, B10) are required in the RBCU/RCP discharge piping at the maximum pipe elevation (Unit 1 - 831.5', Unit 2 - 831', Unit 3 - 833') (refer to Figure 5). The vacuum breakers will be either air operated or actuated with a solenoid. Figure 5 is drawn assuming air operated vacuum breakers. The vacuum breakers will be single failure proof to open to ensure no voids exist prior to LPSW pump restart. The vacuum breakers will also be single failure proof to close to 1) ensure design basis LPSW flows to the RBCU are maintained, and 2) prevent potential adverse vibrations from chug flow due to air entrainment. The resulting design is single failure proof to open and single failure proof to close. This design requires two trains with two vacuum breakers in each train. Isolation valves (A6, B6) are provided to allow online maintenance. Drain valves (A7, A9, B7, and B9) are also provided to allow water to be drained from the vent piping.

Each vacuum breaker valve train will be opened via a separate pressure switch that will sense low LPSW header pressure. Opening the vacuum breaker valves will draw outside air into the discharge line. This action will increase the discharge line pressure so that drainage of the LPSW discharge lines is prevented. At a certain time period, before the restart of the LPSW pumps, the vacuum breaker valves will close. This allows the design basis rejection of heat from containment during either LOCA-LOOP or MSLB-LOOP events.

RBACU Train Separation Modification

It is necessary to separate the RBACU trains from the RBCU trains due to the increased voiding that occurs in the RBACU trains during the LOCA-LOOP or MSLB-LOOP events that cannot be alleviated by the vacuum breakers proposed in the LPSW containment drainage prevention modification described above. This is because the RBACUs are at a higher elevation in the Reactor Building than the RBCUs. It is not necessary to separate the RCP Bearing Oil and Motor Air Coolers train from the RBCU trains since RCP Bearing Oil and Motor Air Coolers do not thermally communicate with the containment environment during LOCA-LOOP and MSLB-LOOP events. As such, an increase in voiding due to heat transfer that occurs across the RBACU coils does not affect the RCP Bearing Oil and Motor Air Coolers.

The proposed modification ties the RBACU trains to the RBCU trains outside of the Reactor Building. Connecting the RBACU trains to the RBCU trains outside of the reactor building enables the use of air operated valves (AOV) for containment isolation of the RBACU train piping. The new AOVs will fail closed on a loss of power or loss of air (See Figure 6 for schematic of the RBACU train separation modification). The existing valves xLPSW-565 and 566 that receive an ES signal from Channels 5 and 6 will be eliminated. The current ES channel 5 that feeds xLPSW-565 and 566 will be used with the new outside containment isolation valves (Labeled as C1 and D1 in Figure 6) for the new penetrations. The current ES channel 6 that feeds xLPSW-565 and 566 will be used with the second set of outside containment isolation valves (Labeled as C2 and D2 in Figure 6). Thermal relief valves will be installed to prevent thermal over-pressurization at the containment penetrations and between the new set of isolation valves. Block valves and test connections will be added for leak rate testing of the new isolation valves. Logic signals will be added to the new containment isolation valves to isolate in the event of a LOOP, LOCA-LOOP, or MSLB-LOOP. The isolation valves will be designed to be fast closing (<5 sec.) to prevent significant drainage. The isolation valves will remain closed upon restoration of power. The RBACUs are not credited for containment cooling during either a LOCA-LOOP or MSLB-LOOP.

Conformance of Analyses with EPRI TBR

The Oconee waterhammer analyses described generally conform to the methods outlined in the EPRI Report, TR-113594, "Resolution of Generic Letter 96-06 Waterhammer Issues" (TBR). The TBR describes a series of steps needed to construct a Rigid Body Model (RBM). The first of these steps is the gathering of specific plant data regarding the cooling system and the containment fan cooling units (FCU). This task includes determination of the piping geometry, obtaining LOCA and MSLB containment response data, fan cooler performance data, and the cooling system pump data. Further, the limiting plant configuration is considered. This includes determining the plant configuration that maximizes voiding in the system. The Oconee analyses appropriately considered all aspects of the specific system parameters and equipment data.

The second step is the formation of a hydraulic model of the cooling system. This step includes calculating flow rates, pressures and potential drainage paths. The heat transfer across the cooler coils along with the system drainage characteristics is used to determine potential voiding locations during the drainage phase of the accident. In addition, the flow rates and velocities, based on the cooling system pump curves and system resistance, is used to determine the potential closure locations for the refill phase of the accident. The Oconee analyses appropriately considered system hydraulics and heat transfer rates across the cooling coils to determine void locations and resultant closure locations.

Should voiding occur during the drainage phase of the accident, the third step of the TBR directs postulation of CIWHs in piping lines that are horizontal, and that have a length to diameter ratio (L/D) of at least 24. The analyses considered CIWHs for the drainage phase of the accident at locations consistent with those described in the TBR. The results showed the system steam pressure was less than 20 psig, verified that the cooling system water was not de-gassed, and showed by test and analysis that the system was operable for CCWHs that occur during LOOP, LOCA-LOOP, or MSLB-LOOP scenarios.

The fourth step directs the determination of potential closure locations for CCWHs. This includes the postulation of closed valves, dead legs, and the return side water column locations. The analyses evaluated all potential valve positions and single active failures in the determination of potential closure locations and used a hydraulic drainage model to predict return side water column locations.

The fifth step is the calculation of CCWH magnitudes and pulse characteristics. This step contains four separate tasks. The first of these is the determination of the closure velocity limited by the inertia of the system. That is, the closure velocity is limited by the available pump pressure and system frictional resistance. The analyses considered various pump combination and system configurations to determine the bounding pump pressure and system frictional resistance in determination of the closure velocity.

Next, the amount of non-condensables available to cushion the impact and the resulting cushioned velocity is determined. The TBR describes a RBM that incorporates the cushioning aspects at the closure locations. Further, the TBR concludes that 40% of the dissolved gas is evolved from the total mass of the water in the cooler and local cooling water system during the transient. In addition, the TBR states that as a result of the non-condensables in the system cooling water, the sonic velocity at the impact location will be reduced. However, the TBR does not describe a methodology for considering the reduced sonic velocity at the closure location. The Oconee analyses did not construct a RBM. A MOC model was constructed. The MOC model compensated for the presence of non-condensables by reducing the sonic velocity at the initial impact locations. Thereafter the sonic velocity for water without non-condensables was used at succeeding impact locations. A reduction of approximately 50% of the maximum sonic velocity was assumed for the initial impact locations. This reduction is larger than the 40% reduction of the un-cushioned closure velocity permitted by the TBR. This small difference in the velocity reduction is deemed acceptable for two reasons:

1) In the risk considerations for the TBR, an upper bound piping failure probability of 10^{-2} was selected based on the fact that several plants had conducted LOOP only tests. A lower bound piping failure probability of 10^{-4} was also suggested based on the probability

of the actual piping stress at the time of the waterhammer being greater than the actual strength of the carbon steel piping. Oconee conducted three simulated LOOP tests in 1997 and found no damage to the piping or piping support/restraints. These test results suggest that a failure probability is likely lower than the lower bound probability of 10^{-4}.

2) The Oconee analyses were performed to support continued plant operation. Conceptual modifications are planned to prevent or significantly reduce waterhammers described by GL 96-06. In the interim period before the modifications are implemented, the closure velocity reduction used in the Oconee analysis is acceptable.

The final CCWH task determined the waterhammer magnitude and pulse shape. This task uses the cushioned velocity as described above in the calculation of the pressure pulse using Joukowski's equation. In addition, the pulse shape of the waterhammer wave is described using the concepts of rise time of the wave, duration of the wave, and peak clipping based on reflection of the initial impact. The Oconee analyses incorporated these concepts consistent with the methods described in the TBR for description of the pulse shape.

The sixth step of the overall waterhammer evaluation determines the propagation of the pressure pulse and the resulting loading of the piping system. This step traces the waterhammer wave through the piping system and determines the piping load as the differential pressures acting on each end of particular piping segment subject to attenuation and amplification. The Oconee analyses included both the effects of attenuation, amplification, and fluid structure interaction (FSI). The progression of the pressure pulse was plotted versus the piping geometry. The pressure pulse was then amplified for enlargements in the flow area, and attenuated for reductions in the flow area. A FTH was then constructed. The Oconee analyses employed attenuation and amplification consistent with the TBR in formulating the FTHs.

The final step of the overall waterhammer evaluation determines the structural response of the piping system and supporting elements to the FTH. The Oconee analyses employed the piping analysis program SUPERPIPE to evaluate the piping response to the waterhammers. Appropriate methods were used to dynamically model the system. Resulting pipe stress and support loads were evaluated versus appropriate operability limits.

Conclusions

As discussed above, Oconee has completed a series of simulated LOOP tests that resulted in the imposition of CCWH loads on the LPSW system in containment. No damage was noted to the LPSW piping system or to system supports as a result of the tests. A comprehensive set of analyses have been completed that demonstrate that while certain code allowables were exceeded, the LPSW systems serving the containment coolers remain operable. The analyses completed generally conform to the methods outlined in the EPRI Report, TR-113594, "Resolution of Generic Letter 96-06 Waterhammer Issues" (TBR). As a result of these analyses two conceptual modifications (LPSW Containment Drainage Prevention and RBACU Train Separation) are planned which will eliminate or significantly reduce the waterhammers described by the GL.

References

1. EPRI Report TR-113594, "Resolution of Generic Letter 96-06 Waterhammer Issues," Volumes 1 & 2
2. Introduction to Unsteady Thermo-Fluid Mechanics, F.J. Moody, 1990 John Wiley
3. NRC Regulatory Guide 1.61, "Damping Values for Seismic Design of Nuclear Power Plants"
4. 1989 Edition of ASME Code
5. AISC Manual of Steel Construction, 5th Edition
6. NUREG/CR-5220, "Diagnosis of Condensation Waterhammers"
7. Fluid Transients in Systems, Wylie, E.B. and Streeter, V.L., Prentice Hall, 1993
8. Letter dated April 3, 2002, from the NRC to Mr. Vaughn Wagoner, Chairman, EPRI Waterhammer Project Utility Advisory Group, "NRC Acceptance of EPRI Report TR-113594, Resolution of Generic Letter 96-06 Waterhammer Issues, Volumes 1 and 2."
9. Letter dated February 1, 2002, from Vaughn Waggoner to Mr. Jim Tatum (NRC), "Response to ACRS Comments (letter dated 10/23/01) on the EPRI Report on Resolution of NRC GL 96-06 Waterhammer Issues."

**Figure 1:
Oconee Nuclear
Station Units 1, 2, & 3
Partial Schematic of
LPSW System
w/o Modifications**

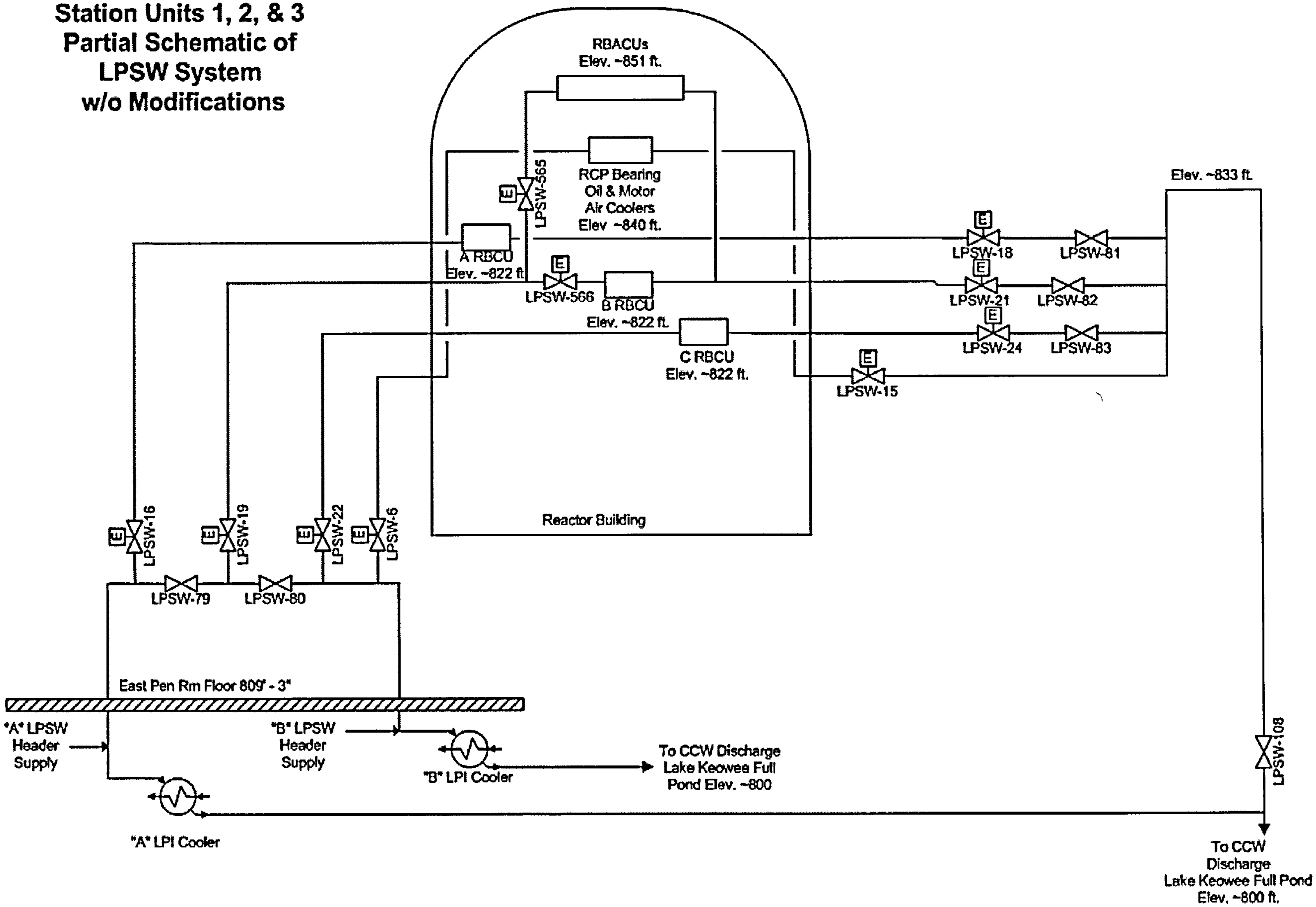

**Figure 2:
Oconee Nuclear
Station Unit 1 LPSW
System CCWH
Closure Locations**

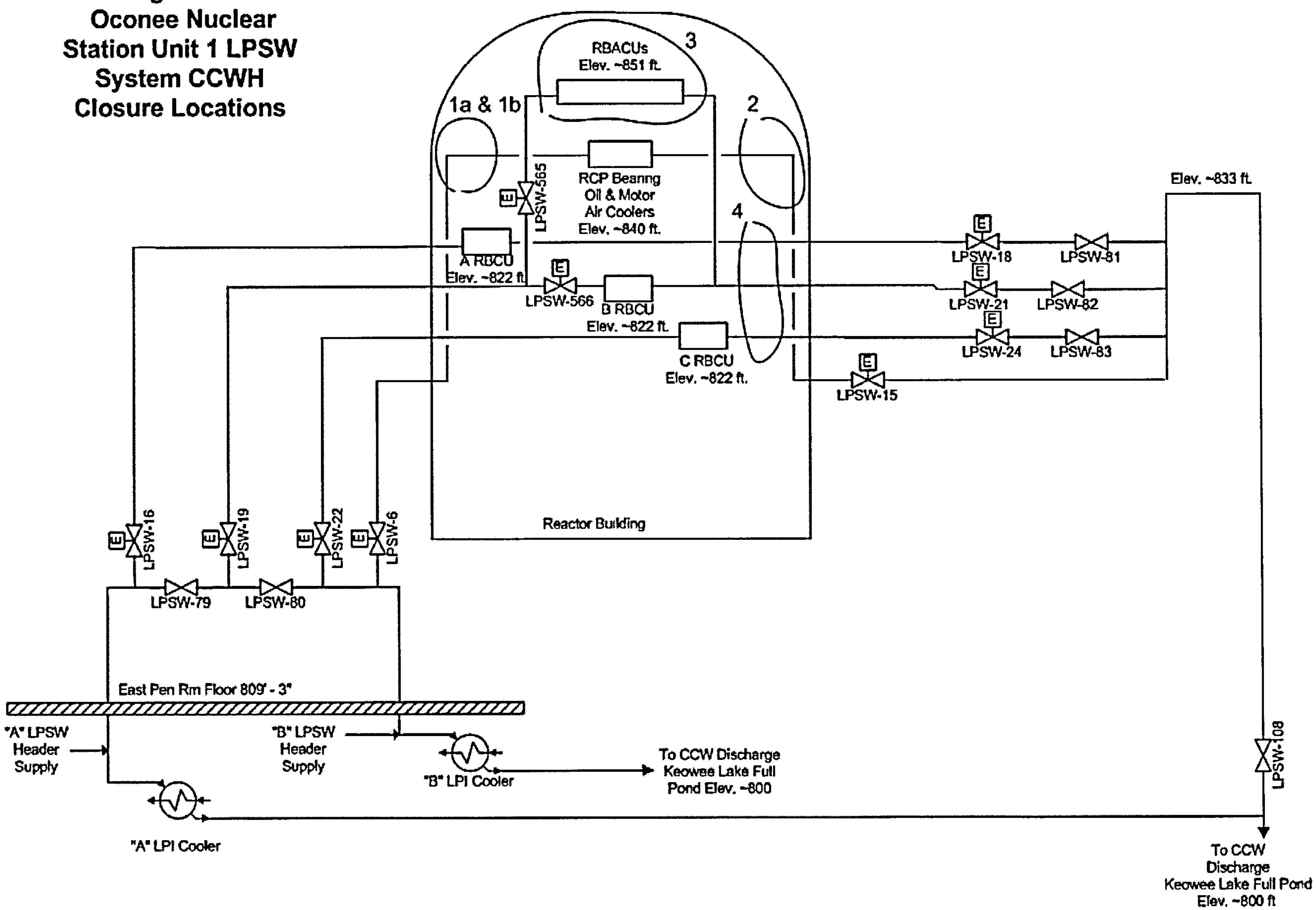

**Figure 3:
Oconee Nuclear
Station Units 2 & 3
LPSW System
CCWH Closure
Locations**

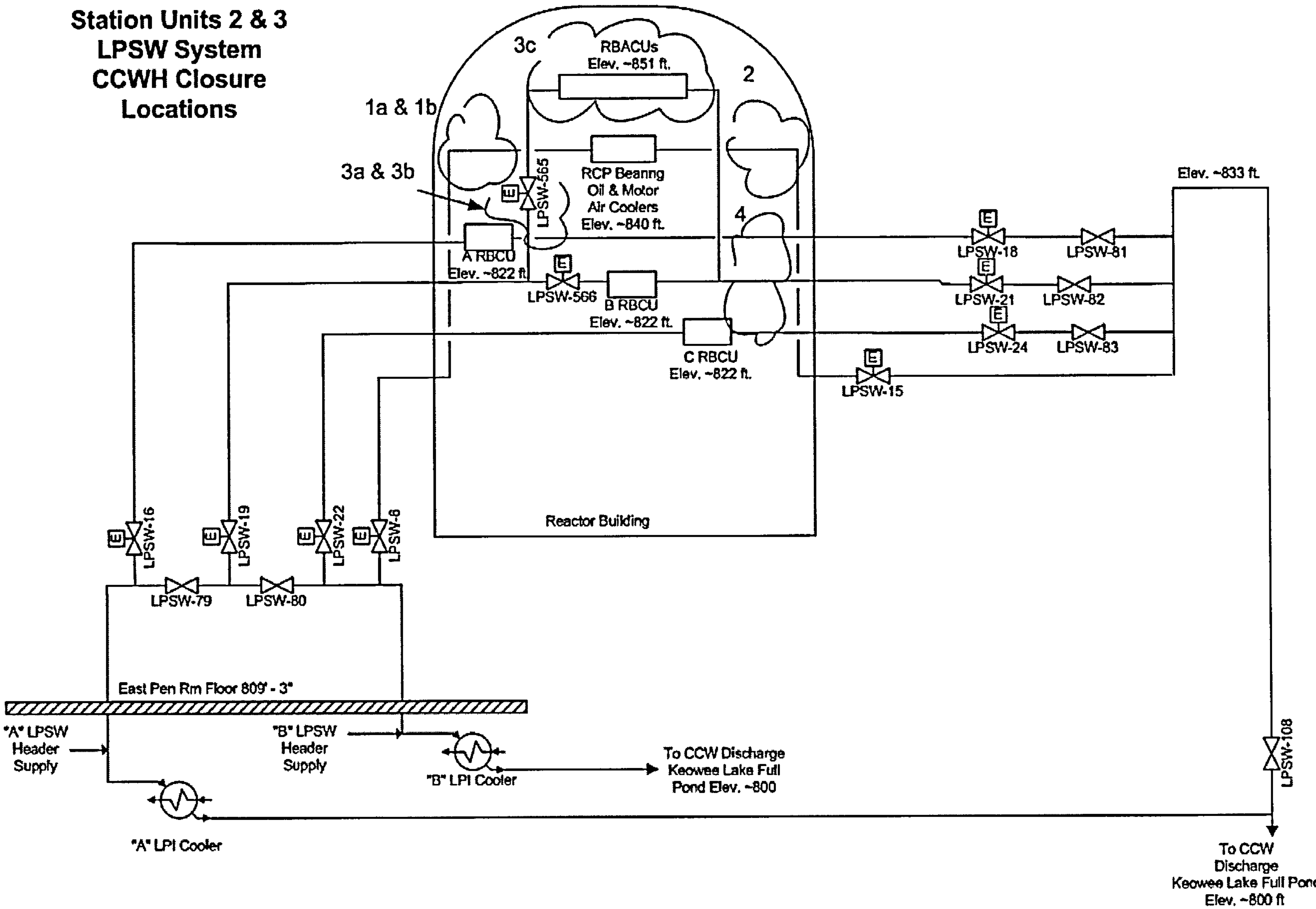

**Figure 4:
Oconee Nuclear Station
Units 1, 2, & 3
LPSW System w/
Drainage Prevention
Modification**

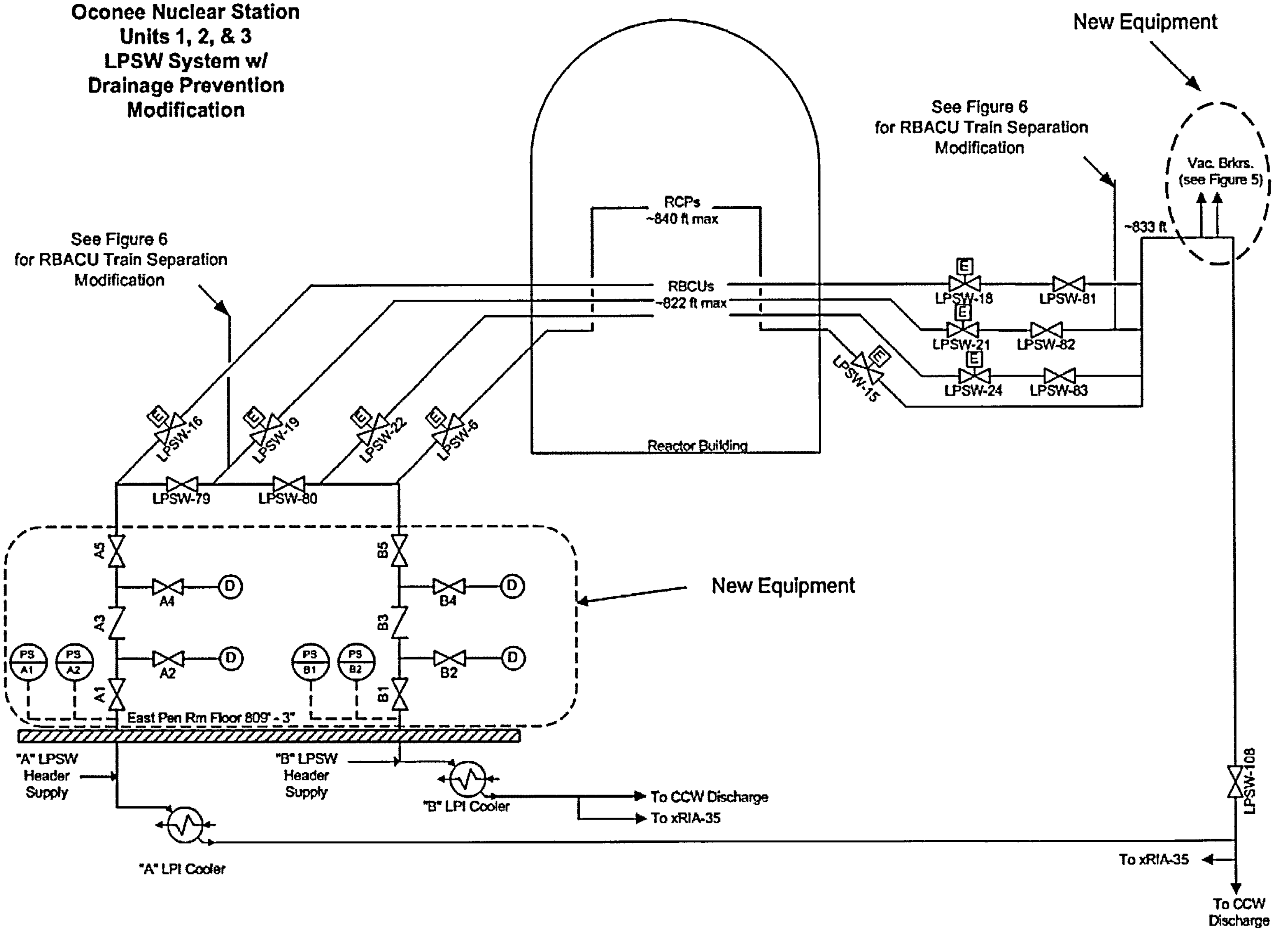

Figure 5
Oconee Nuclear Station
Units 1, 2, & 3
LPSW System w/
Drainage Prevention
Modification
Vacuum Breakers

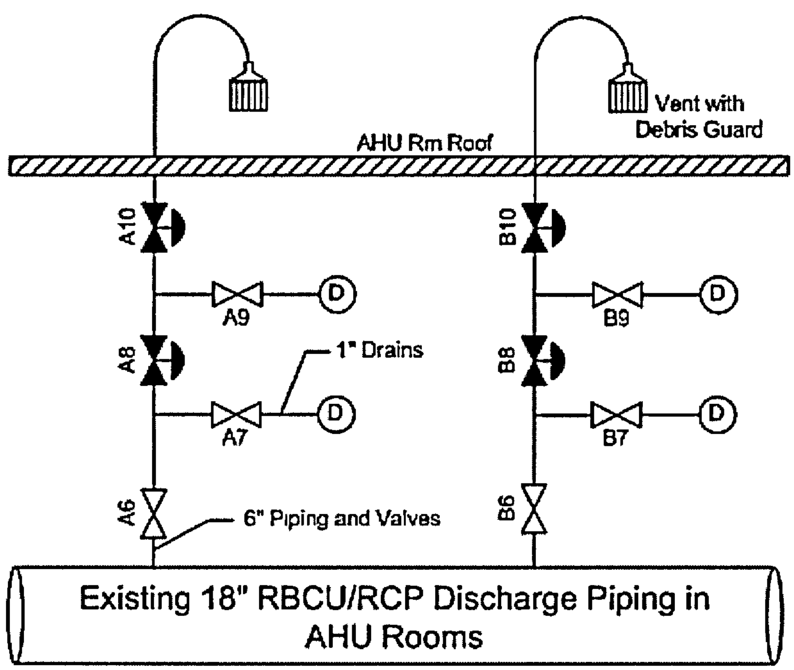

**Figure 6:
Oconee Nuclear
Station Units 1, 2, & 3
LPSW System
w/ RBACU
Separation
Modification**

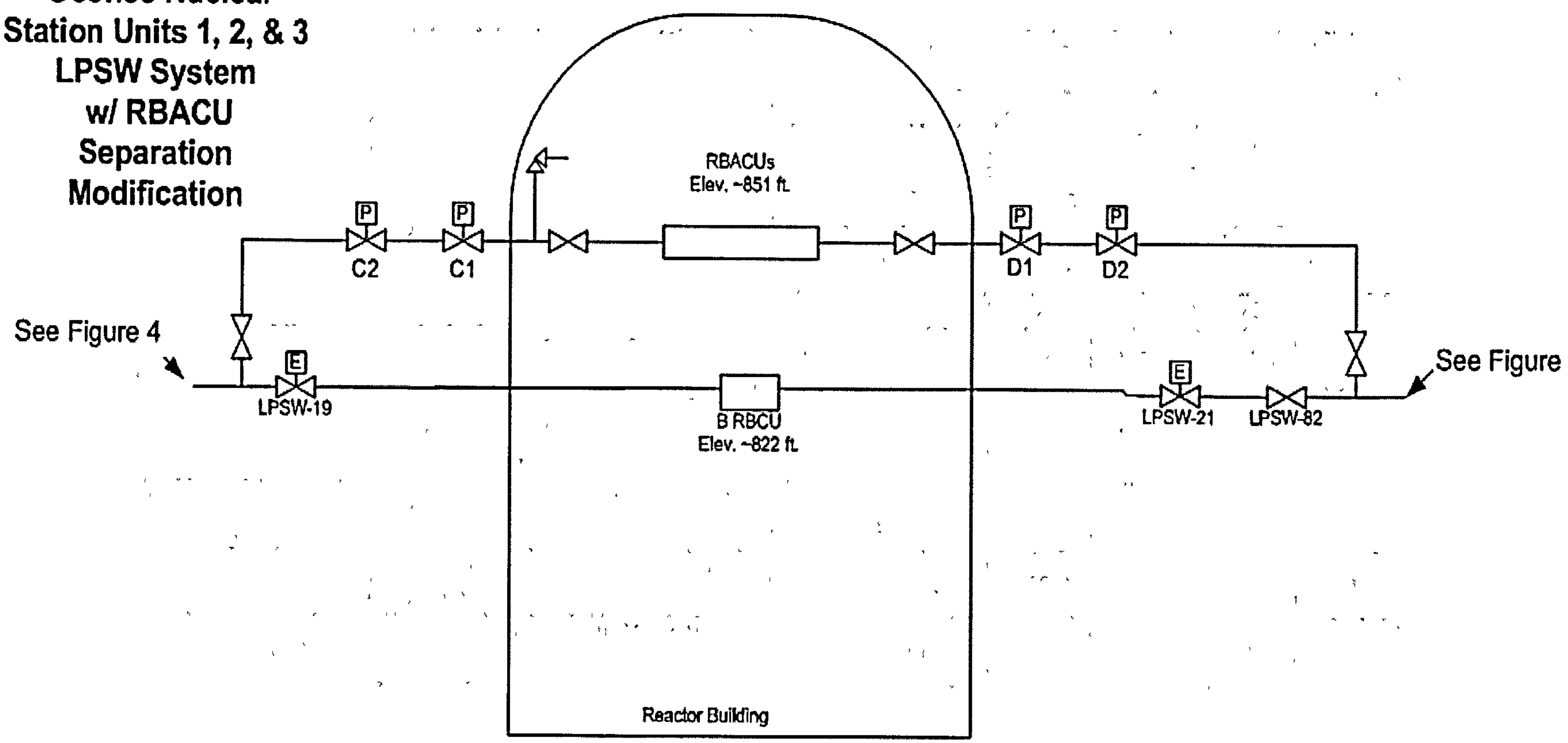

Table 2

Oconee Unit 2
CCWH Results

Voiding Region	ID	Closure Location	Waterhammer Pressure Magnitudes (psi)					
			Accident Case					
			LOOP		*LOOP*		*LOCA-LOOP*	
			Pump Operations					
			2 Pumps / 2 Units		*2 Pumps / 1 Unit*		*3 Pumps / 1 Unit*	
			Lake Elevation					
			778	*790*	*778*	*790*	*778*	*790*
6" RCP Supply before 840'	1a	*Vertical Piping between 840' to 827'*	250.0	259.0	219.0	226.0	220.0	226.0
	1b	*Vertical Piping between 840' to 827' w/ RCP Bearing Cooler and Motor Air Cooler Isolated.*	250.0	259.0	219.0	226.0	220.0	226.0
10" RCP Return After 840'	2	*Vertical Piping between 835'-5" and RB Penetrations*	178.0	184.0	168.0	174.0	169.0	175.0
8" Auxiliary Cooler Supply	3a	*On Closed Valve 2LPSW-565*	no w/h	no w/h	117.0	no w/h	124.0	no w/h
	3b	*On Closed Valve 2LPSW-565 with Valve 2LPSW-566 Closed*	no w/h	no w/h	120.0	no w/h	147.0	no w/h
	3c	*On Individual Closed RBACU Isolation Valves*	254.0	270.0	323.0	335.0	338.0	350.0
8" RBCU Return	4	*Piping at elevation 813'-815'*	no w/h	no w/h	no w/h	no w/h	225.0	234.0

Table 3

Oconee Unit 3
CCWH Results

Voiding Region	ID	Closure Location	Waterhammer Pressure Magnitudes (psi)					
			Accident Case					
			LOOP		*LOOP*		*LOCA-LOOP*	
			Pump Operation					
			1 Pump		*2 Pumps*		*2 Pumps*	
			Lake Elevation					
			778	*790*	*778*	*790*	*778*	*790*
6" RCP Supply before 840'	1a	*Vertical Piping between 840' to 827'*	356.0	376.0	381.0	400.0	381.0	400.0
	1b	*Vertical Piping between 840' to 827' w/ RCP Bearing Cooler and Motor Air Cooler Isolated.*	356.0	376.0	381.0	400.0	381.0	400.0
10" RCP Return After 840'	2	*Vertical Piping between 835'-5" and RB Penetrations*	216.0	228.0	230.0	241.0	230.0	241.0
8" Auxiliary Cooler Supply	3a	*On Closed Valve 3LPSW-565*	no w/h	no w/h	112.0	no w/h	353.0	368.0
	3b	*On Closed Valve 3LPSW-565 with Valve 3LPSW-566 Closed*	no w/h	no w/h	109.0	no w/h	395.0	409.0
	3c	*On Individual Closed RBACU Isolation Valves*	320.0	331.0	416.0	420.0	414.0	419.0
8" RBCU Return	4	*Piping at elevation 813'-815'*	no w/h	no w/h	no w/h	no w/h	260.0	287.0