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September 29, 2003

U. S. Nuclear Regulatory Commission
Attention: Document Control Desk
Washington, DC 20555

Subject: **Docket Nos. 50-361 and 50-362,**
Supplemental Response to Generic Letter 96-06 "Assurance of Equipment Operability and Containment Integrity During Design-Basis Accident Conditions,"
San Onofre Nuclear Generating Station, Units 2 and 3
(TAC Nos. M96862 and M96863)

References:
1. Letter from A. E. Scherer (SCE) to the Document Control Desk (NRC) dated November 26, 2002; Subject: Docket Nos. 50-361 and 50-362, Supplemental Response to Generic Letter 96-06 "Assurance of Equipment Operability and Containment Integrity During Design-Basis Accident Conditions," San Onofre Nuclear Generating Station, Units 2 and 3, (TAC Nos. M96862 and M96863)

2. EPRI Report 1006456: Generic Letter 96-06 Waterhammer Issues Resolution - User's Manual, April 2002

3. EPRI Report 1003098: Generic Letter 96-06 Waterhammer Issues Resolution - Technical Basis Report, April 2002

Dear Sir or Madam:

Southern California Edison (SCE) informed the NRC in Reference 1 that additional Generic Letter 96-06 type analysis will be performed at the San Onofre Nuclear Generating Station (SONGS) 2 and 3 to determine the potential for boiling in the Containment Emergency Air Coolers and evaluate the associated Waterhammer issues. This work has been completed in concert with the effort performed by EPRI at the industry level (References 2 and 3). EPRI methodology provided in Reference 2 was applied in the Waterhammer analyses.

The attached Summary Report documents the additional work performed in accordance with Section 3.3 of the NRC Safety Evaluation Report in Appendix B of Reference 2.

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This Summary Report shows that the SONGS Units 2 and 3 emergency cooling units and the associated Component Cooling Water System are capable of performing their intended Safety functions, as related to GL 96-06. No plant modifications are required and this report does not make any new commitments.

If you have any questions, please contact Mr. Jack Rainsberry at (949) 368-7420.

Sincerely

cc: T. P. Gwynn, Acting Regional Administrator, NRC Region IV
B. M. Pham, NRC Project Manager, San Onofre Units 2, and 3
C. C. Osterholtz, NRC Senior Resident Inspector, San Onofre Units 2 & 3

San Onofre Nuclear Generating Station's Final Summary Report to Generic Letter 96-06

1. Background

Generic Letter (GL) 96-06, identified a potential for boiling and resultant Waterhammer in the containment emergency cooling units (ECUs) following a Loss of Coolant Accident (LOCA) or a Main Steam Line Break (MSLB) with a concurrent Loss of Off-site Power (LOOP). The original GL 96-06 analysis for the San Onofre Nuclear Generating Station (SONGS) ECUs was performed in 1997 using the American Air Filter (AAF) "COOLNUC" computer code. It concluded that boiling in the ECUs will not take place during the transient. During the period between the initial Southern California Edison (SCE) response and now, a more rigorous approach has been developed by the industry and the Electric Power Research Institute (EPRI) to address the issues raised by GL 96-06. The EPRI methodology is conservative compared to the COOLNUC Code.

San Onofre Nuclear Generating Station (SONGS) has elected to re-perform the GL 96-06 Waterhammer analyses utilizing the methodology developed by EPRI (Reference 6.5). The EPRI methodology was applied with specific plant data from SONGS in a manner that is consistent with the requirements specified by the NRC staff as outlined in the Safety Evaluation Report (SER) in Appendix B of Reference 6.5.

The following tasks were performed to evaluate the Waterhammer issue at SONGS:

- System Design Data: Assembled / developed plant information including Piping and Instrument Diagrams (P & ID's), pipe geometry, LOCA and MSLB event parameters, ECU data, component cooling water (CCW) pump data, and design basis documents.

- Failure Modes and Effects Analysis (FMEA): Determined the bounding, worst accident scenario from a Waterhammer point of view with a single active failure, developed an event time line, and provided a risk perspective.

- Heat Transfer Analysis: Evaluated heat transfer conditions at the ECUs after various design events and accidents and determined the time-to-boil for the bounding scenario.

- Hydraulic Analysis: Developed a Hydraulic System Transient Analysis (HSTA) system model, performed a drain-down analysis to determine the void size and the location, performed the re-fill analysis to derive the column closure velocity and associated water hammer (CCWH) forcing functions, and evaluated the condensation induced Waterhammer (CIWH) and the two-phase flow issues.

- Structural / Stress Evaluation: Evaluated the CCW piping system's response to Waterhammer forces to ensure that the pressure boundary of the piping and containment integrity are not compromised. Qualified pipe supports to ensure structural integrity of the piping system.

1. Background – Continued

Piping and support configurations for SONGS Unit 2 and Unit 3 are basically a mirror image arrangement, and any deviations are within the analysis margin. Therefore, Unit 2 was chosen as the representative unit for this evaluation.

2. Conclusions

SONGS applied the EPRI methodology (Reference 6.5) in the evaluation for addressing the GL 96-06 Waterhammer issue. A brief summary of the results and conclusions of the evaluation is provided below.

As concluded in the FMEA, a large break LOCA with a subsequent LOOP is bounding over a MSLB/LOOP and other events as the worst-case scenario in terms of potential Waterhammer implications. A LOCA/LOOP event will result in a higher heat transfer rate to the ECU tube wall.

The heat transfer analysis (Reference 6.18.1) concluded that boiling will occur inside the ECU tubes at 11.75 seconds after a postulated LOCA. The CCW pump restarts at 30.9 seconds after a LOCA.

Single failures were examined from the standpoint of maximizing the Waterhammer impact (GL 96-06) on the pressure boundary of each CCW train, resulting in the following two bounding cases:

- Case A includes a single active failure rendering one CCW train inoperable. The resulting Waterhammer stresses in the remaining operable CCW train piping and supports met the Code allowables, and the resulting equipment nozzle loads met the vendor's allowables.
- Case B includes both trains as functional, but the CCW isolation valve at the shutdown cooling heat exchanger (SDCHX) in one train fails to open due to a single active failure. As the design SDCHX flowrate is 3 times larger than the design ECU flowrate, the failed-closed valve at the SDCHX will result in a substantially increased flow of cold water to the voided coolers and thus result in increased Waterhammer forces as compared to Case A. While only the integrity of containment penetrations would need to be evaluated for the affected train due to the full availability of the other train for cooling, SCE evaluated the integrity of the whole affected CCW train in addition to the penetrations. The penetrations, the system piping, and the supports met the design faulted allowables, and the resulting equipment nozzle loads met the vendor's allowable loads.

2. <u>Conclusions</u> - Continued

The Waterhammer forces were modeled using two hydraulic calculations (Reference 6.18.4 and 6.18.5). A HSTA computer program (Reference 6.8) was used to perform the draindown and refill analyses, and to generate the Waterhammer forcing functions.

Sensitivity analyses were performed to determine the bounding case with varied combinations of void size, vapor pressure, CCW pump start time, and the isolation of CCW flow to selected equipment. The bounding closure velocity was calculated as 8.9 ft/sec. Gas and steam cushioning effects were derived using EPRI methodology and resulted in 11% force reductions which were credited in followup stress calculations.

The hydraulic calculations evaluated the transient events that are associated with a CCWH and addressed the comparison with CIWH. The review determined that the CCWH effects bound the CIWH effects, which is consistent with EPRI findings (Reference 6.5). Therefore, an explicit calculation of forces based on CIWH was not performed. Additionally, an evaluation of potential two-phase flow concluded that a 30 psi CCW pressure margin to saturation precludes the two phase flow regime in the SONGS Unit 2 and Unit 3 CCW systems.

Computer code ME101 (Reference 6.9) was used to perform the time history analysis of the CCW piping systems using the forcing functions generated by HSTA. Twelve (12) stress calculations (Reference 6.19) for 12 piping sections were performed. The dynamic stresses resulting from Waterhammer loads were compared to the stresses due to design basis earthquake (DBE) inertia loads, and the larger of these two components was included in the faulted condition stress check. In all cases, all piping stresses met American Society Mechanical Engineers (ASME) Code faulted condition level D allowables (Reference 6.7). The ECUs nozzle loads due to piping reaction forces met the vendor's allowable loads. A comparison of the new reaction loads to the original vendor's design loads demonstrated the integrity of the containment penetrations. The reaction loads from piping at the pipe supports were generated, and they were used to check the pipe supports. The affected supports were evaluated by computer codes ME150 (Reference 6.10) and ME035 (Reference 6.11). No physical modifications are required as a result of the analysis (Reference 6.20).

Based on the above results, SCE concluded that the ECU, the associated CCW piping components, and the containment penetrations at SONGS Units 2 and 3 are capable of performing their intended safety functions as required by GL 96-06.

3. System Design

3.1 System Description

3.1.1 Containment Emergency Cooling System

The containment emergency fan cooler system, along with the containment spray system (CSS), is designed to remove heat from the containment atmosphere subsequent to the postulated design basis accident (LOCA or MSLB) inside the containment. The containment emergency fan cooler system is separated into two trains (A and B), each consisting of two fan cooler units. The two trains are serviced from separate (redundant) component cooling water trains and separate (redundant) Class 1E power buses. The failure of any components in one train will not affect the operability of the other train. The containment emergency cooler system is an Engineered Safety Feature (ESF) system that is not normally in use during plant operation but may be running prior to the postulated accident. The system operation is initiated automatically upon sensing high containment pressure or low pressurizer pressure. A Containment Cooling Actuation Signal (CCAS) will open the CCW valve(s) at the ECUs if one or both are closed and start the fans. The ECU fan starts 5 seconds after the associated CCW pump starts. The containment emergency fan cooler system will be fully operational within 49 seconds (Reference 6.13) from the start of the postulated accident.

3.1.2 Component Cooling Water System

The CCW system, that provides cooling water to the ECUs, is a closed pressurized system with two redundant, full-capacity, critical cooling loops and one common non-critical cooling loop that is connected to the critical cooling loops via safety-related isolation valves. These valves isolate the non-critical CCW loop from the critical loops post-accident. Each train of the CCW system includes a pressurized surge tank, which accommodates the system inventory volume changes and ensures that all portions of the CCW system remain pressurized at all times.

The heat from the CCW system is transferred to the ultimate heat sink (the Pacific ocean) by the saltwater cooling system. Each critical loop of the CCW system provides cooling to two containment emergency coolers (in addition to other safety-related heat exchangers), which together are capable of removing 50% of the total atmospheric heat load post LOCA. The other 50% of the atmospheric heat load is removed by the CSS. A CCAS opens the CCW supply and return valves of the four containment emergency cooling units. The ECU fans are interlocked to the CCW pumps to ensure both the fans and the pumps are running during an accident. The Containment Spray Actuation Signal (CSAS) also opens the isolation valves at the SDCHXs to provide heat removal capacity for the CSS.

3.1.2 Component Cooling Water System - Continued

The two 100% redundant CCW trains (Trains A and B) ensure that the full heat-removal capacity required for accident mitigation is available after a single failure of any active component.

3.2 Emergency Fan Cooler Configuration (Ref. 6.15) and Design Data

Train A of the emergency fan cooling system includes the following ECUs:

S2 (3) 1501ME399, S2 (3) 1501ME401,

Train B of the emergency fan cooling system includes the following ECUs:

S2 (3) 1501ME400, S2 (3) 1501ME402,

Each train of the emergency fan cooling system along with the CSS is capable of providing 100% of the total required heat removal rate. Thus, both trains from either the emergency fan cooling system or the CSS alone, or one train from each system acting together are required for pressure/temperature transients associated with a design basis accident event.

Each ECU consists of a vaneaxial fan, a fan motor, copper-alloy cooling coils with copper fins, a carbon steel housing, and a discharge duct. Each ECU consists of 10 sets of American Air Filter Coils Model AAF 16-54-4W5-6C with two passes of 32 tubes. The tube is made of copper ASME SB-75, Alloy 122 material and has a nominal 5/8" OD and 0.049" minimum wall thickness. The coil module length is 54".

At the supply and return terminals of each coil set, a 3" pipe manifold is provided to connect the coils to the 10" vertical supply and return headers.

The emergency fan cooler units are located on the operation deck at elevation 63' inside containment, and they are designed for the following conditions:

Containment (Accident) Design Temperature	=	300 °F	
Containment Design Pressure	=	60 psig	
Design Heat Removal Rate	=	70×10^6 Btu / hr	(each ECU)
Fan Flowrate	=	31,000 ft^3 / min	
Cooling Water (CCW) Flowrate	=	2,000 gpm	
Maximum CCW Inlet Temperature	=	105 °F	
Maximum CCW Outlet Temperature	=	177 °F	

In the heat transfer calculation (Reference 6.18.1), the initial CCW water temperature, at stagnant conditions prior to the LOCA, was conservatively assumed to equal the containment (normal) design temperature of 120 °F to minimize the "time-to-boil" at the ECUs after a LOCA.

3.3 Piping System Configuration

The CCW piping for each ECU passes through its supply containment isolation valve, runs up and around the periphery near the containment wall, through the ECU cooling coils, and exits along the periphery near the containment wall, out through its return containment isolation valve to the CCW system.

A simplified diagram of the affected systems, showing major components, relative elevations, critical piping runs and flow restrictions, is provided in Figure 1 below for illustration (Train A is shown, Train B is similar). The routing detail for each ECU CCW piping is depicted on the respective piping fabrication isometrics (Reference 6.21).

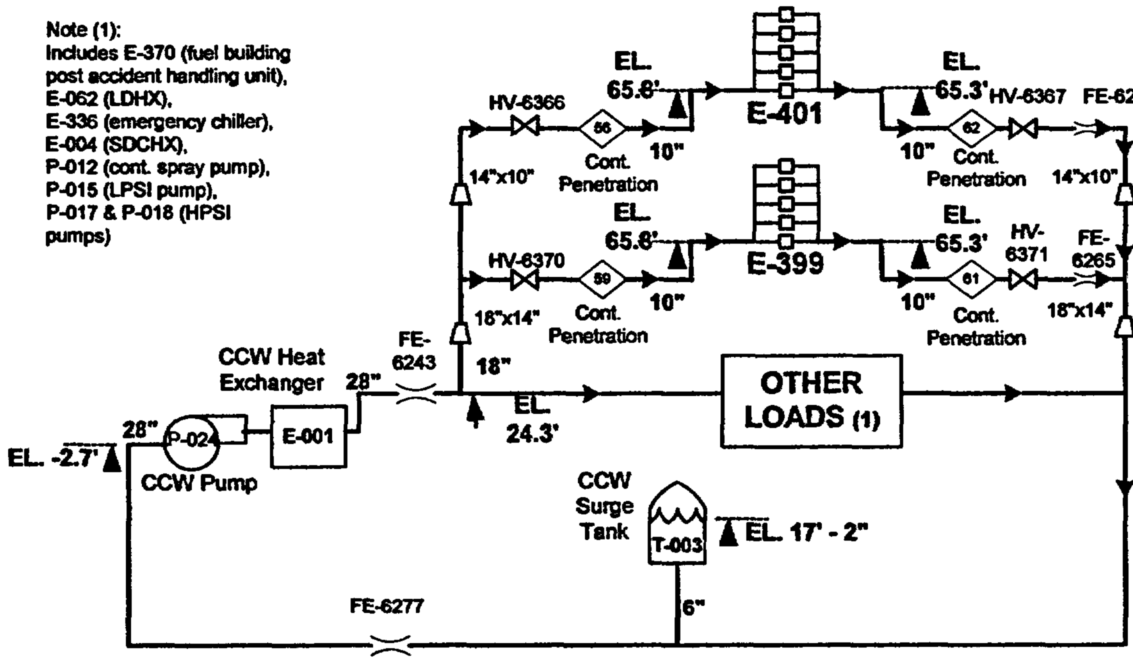

Figure 1: CCW Train A Closed Loop System

LDHX:	Letdown Cooling Heat Exchanger
SDCHX:	Shutdown Cooling Heat Exchange
LPSI:	Low Pressure Safety Injection
HPSI:	High Pressure Safety Injection

4. Failure Modes and Effects Analysis (FMEA)

4.1 Worst Case Scenario

For a potential Waterhammer at SONGS, the worst case scenario is a large break LOCA with a coincident (subsequent) LOOP, taking into consideration a range of event possibilities, system configuration, parameters, and potential component failures. This conclusion was drawn from the following assessment.

For the closed loop CCW system at SONGS, a LOOP transient alone is not expected to create voids at system high points and thus no Waterhammer transient is expected.

The large break LOCA bounds the smaller break LOCA, including the pressurizer surge line break, which is associated with a reduction in CCW system pressure. The latter would have a smaller rate of heat release to the containment, resulting in a lower containment temperature to which the containment air cooling coils would be exposed.

The heat transfer analysis performed for the LOCA/LOOP sequence determined that a MSLB inside containment is less limiting than a large LOCA with regard to potential vaporization of CCW in the containment air cooling coils. The LOCA and MSLB inside containment are the two design basis accidents which involve the highest heat release inside containment. Other events are less relevant to the GL 96-06 issues.

The LOCA bounds the MSLB case for the following reasons:

- Condensation heat transfer coefficients are significantly greater than the sensible heat convective heat transfer coefficients for superheated vapor. The saturation temperatures for the MSLB are much lower than the containment temperatures. Thus, the steam in the MSLB event is significantly superheated. Hence, for steam to begin condensing over the ECU tubes, it has to first pass over successively cooler tubes to cool down to the saturation temperature and lose the superheat by convection. This results in a reduced heat transfer rate to the tube wall.
- The steam saturation temperatures for the LOCA case are very close to the containment temperatures which means that the steam is not superheated. Therefore, the steam will condense over the cooler tubes that it contacts first.

For the potential vaporization sequence, it is the time interval between LOCA and CCW pump restart that is of interest. The time interval is the same regardless of whether one or both emergency diesel generators (EDG) start. A CCW pump failure to start is no worse than a diesel failure to start with respect to the sequence of interest. Thus, from the standpoint of potential vaporization in the ECU tubes, the CCW system alignment or initial alignment of the ECUs is irrelevant as the heat transfer analysis assumes the coils are exposed to steam-laden containment air post-LOCA.

4.2 Event Timeline

The sequence is based on the bounding scenario for the worst case, LOCA/LOOP.

t =	0	second	LOCA occurs
t =	3	seconds	LOOP occurs, SIAS signal is initiated and EDG start signal generated.
t =	11.75	seconds	Boiling starts in the ECU tubes (calculated in Reference 6.18.1)
t =	30.5	seconds	CCW pump motor breaker coils energized
t =	30.9	seconds	CCW pump starts

4.3 Single Active Failure

The single failure susceptibilities of the emergency fan cooling system, assuming the occurrence of a LOOP as included in the FMEA in the Updated Final Safety Analysis Report (Reference 6.13), Table 6.2-8, have been evaluated. The evaluation is documented in the applicable design basis document (Reference 6.17), demonstrating the adequacy of the emergency fan cooling system capability to perform its safety functions.

The evaluation of the Single Failure/Common Mode Failure for the CCW system is documented in the CCW system design basis document (Reference 6.16), demonstrating the adequacy of the CCW system capability to perform its safety functions.

Single failures were examined from the viewpoint of Waterhammer impact (GL 96-06) on the pressure boundary of a specific train in the following two bounding cases:

Case A includes a single failure of one complete CCW train. For worst-case considerations, to maximize the CCW flow through the ECUs, the CCW system alignments include the following:

1) CCW water to the Emergency Chiller being supplied from the other SONGS unit.
2) CCW water to the Letdown Heat Exchanger being supplied from the second CCW train (other than the evaluated train).
3) CCW water to the swing High Pressure Safety Injection Pump being supplied from the second CCW train (other than the evaluated train).

Case B includes both CCW trains functional, but the CCW isolation valve at the SDCHX in one train fails to open due to a single active failure. This would result in an increased CCW flow to the voided coolers which can result in increased Waterhammer forces as compared to Case A forces. The CCW water isolation at the three other components as described above in Case A are also considered in this case for conservatism. While only the integrity of the containment would need to be evaluated for this case due to the availability of the other CCW train for cooling, SCE evaluated both the containment penetrations and the system piping.

4.4 Risk Perspective

Appendix C of Reference 6.5 includes an EPRI letter to the NRC dated February 1, 2002. This letter provides a discussion of the risk considerations of the occurrences of a LOCA or MSLB in combination with LOOP and the likelihood of a resulting unacceptable event (piping pressure boundary failure). In addition, Appendix B of Reference 6.5 includes the NRC evaluation of the EPRI report TR-113594 and the acceptance of the EPRI risk evaluation approach. The intent of this risk evaluation is to show that the EPRI methodology does not significantly increase the risk of an unacceptable plant event, therefore, the use of the EPRI methodology can be done safely without compromising the integrity or safety of the evaluated systems beyond the derived risk factors.

4.4.1 Frequency of the Combined Events

Occurrence of a LOCA or MSLB
- mean frequency of occurrence per NUREG/CR-5750:

1)	Large LOCA	=	5E-6 / yr
2)	Medium LOCA	=	4E-5 / yr
3)	MSLB	=	1E-3 / yr

Occurrence of a LOOP following a LOCA or MSLB - mean frequency of occurrence per NUREG/CR-6538: 1.4E-2 / yr

The above values are listed here for reference and comparison with the SONGS-specific values.

Occurrence of a LOCA or MSLB - SONGS-specific values:

•	Large LOCA (> 6")	=	6.5E-5 / yr	(Reference 6.23.1)
•	Medium LOCA (2" - 6")	=	7.1E-5 / yr	(Reference 6.23.1)
•	MSLB	=	5.4E-4 / yr	(Reference 6.23.2)

Occurrence of a LOOP following a LOCA or MSLB - mean frequency of occurrence, SONGS-specific value: 5.4E-2 / yr (Reference 6.23.3)

Occurrence of a Simultaneous LOOP/LOCA or MSLB Event - mean frequency of the occurrence of one combined event at SONGS is:

•	Large LOCA / LOOP	=	(6.5E-5) * (5.4E-2) = 3.51E-6 / yr
•	Medium LOCA / LOOP	=	(7.1E-5) * (5.4E-2) = 3.83E-6 / yr
•	MSLB / LOOP	=	(5.4E-4) * (5.4E-2) = 2.92E-5 / yr

The total frequency of these three events for SONGS:

0.351E-5 + 0.383E-5 + 2.92E-5 = 3.65E-5 / yr

The probability of a pipe failure for SONGS:

Based on the actual margins that are available in the ASME Code, EPRI conservatively estimated that the probability of pipe failure is on the order of 1E-2 / yr (Appendix C of Reference 6.5)

The probability of an unacceptable event for SONGS:

(3.65E-5) * (1E-2) = 3.65E-7 / yr

The above value of the probability of a piping pressure boundary failure at SONGS due to the evaluated GL96-06 type event is considered to be below the threshold for significant risk and is comparable to the generic value derived by EPRI of 1E-7 / yr (Appendix C of Reference 6.5).

4.4.2 Failure Mechanisms Considered

Two failure mechanisms are evaluated for the effects of Waterhammer loads. The capability of the pipe to withstand the over pressure spike produced by the Waterhammer event, and the capability of the pipe and supports to withstand the dynamic effects induced by the traveling shock waves or the water hammer forces.

Pipe Overpressurization

Significant margin exists in the capacity of pipes to withstand pressure greater than the design pressure of the system. The burst pressure for 10" standard wall CCW pipe (SA106 Gr B) and 5/8" nominal wall ECU tube (SB 75, Alloy 122) are calculated as follows:

SA106 Gr B - $P_{burst} = (S_U \cdot 2t) / D_O$ = (60,000 * 0.75) / 10.75 = 4,186 psi

SB75, Alloy 122 - $P_{burst} = (S_U \cdot 2t) / D_O$ = (30,000 * 0.098) / 0.625 = 4,704 psi

The burst capacity of both the carbon steel pipe and copper tube are significantly greater than the calculated peak pressures of less than 350 psi. The Waterhammer pressure derived by HSTA was verified by the Joukowski equation in hydraulic calculations (References 6.18.4 and 6.18.5). Based on the above, the failure of the pressure boundary due to overpressure is not expected.

Dynamic Effects from Wave Propagation

Structural response to the Waterhammer effects on the CCW piping and supports are evaluated using linear elastic computer programs (ME101, ME150, and ME035) without considering the energy absorption characteristic in the piping and support system. The analyses have concluded that the Waterhammer event will not challenge the integrity or function of the ECUs or associated CCW piping and supports, nor pose a challenge to the containment integrity.

5. Method of Analysis

5.1 Heat Transfer Analysis

A Heat transfer calculation (Reference 6.18.1) documents the transient analysis, based on first heat transfer principles, that determined the time to start bulk boiling of water in the ECU tubes due to LOCA and LOOP. The analysis was performed on a representative model of the ECU tubing. It was demonstrated that the large break LOCA case bounds the MSLB case.

Conservative design inputs and assumptions, consistent with the EPRI methodology and SONGS licensing basis were used to minimize the uncertainties. For example, the CCW surge tank pressure was set at the lower tolerance limit of 32 psig and the water level was held at the low elevation of 17.2 ft. The pressure and temperature time histories of the containment atmosphere were taken for the bounding large break LOCA event (double ended hot leg slot break- Case 7) from the design basis calculation (Reference 6.18.7). The condensation heat transfer coefficients were taken from Reference 6.18.7 and multiplied by appropriate factors that are recommended by Standard Review Plan (SRP) Section 6.2.1.5.

A series of heat transfer calculations was performed in this analysis, starting with a calculation of condensation heat transfer from the containment environment to the cooler tube wall and followed by a calculation of convective heat transfer from the inside of the tube to the liquid. When the excess temperature (defined as the temperature difference between the tube wall and the saturated water temperature) reached 10 °F, the nucleate boiling heat transfer equation was used to calculate the heat flux between the tube wall and the water. The water temperature change was calculated at every 0.25 second time step until the saturation temperature was reached. At 6.25 seconds the excess temperature would reach 10 °F and the heat transfer between the tube wall and the water would switch from convection to boiling. At 11.75 seconds post LOCA the bulk temperature in the ECU tubes reaches the saturation point (230 F) and the formation of steam begins. After this time, the ECUs are voided within the next 5 seconds due to the system hydraulics, as shown in the drain-down analyses (References 6.18.4 and 6.18.5). Thus, the ECUs are voided well within 20 seconds following a LOCA, which is well ahead of the postulated CCW pump re-start time at 30.9 seconds.

5.2 Hydraulic Transient Analysis

5.2.1 HSTA Model

The input data to the HSTA computer program were documented in two calculations for Train A and Train B (References 6.18.2 and 6.18.3). The design data are taken from design basis documents (References 6.16 and 6.17); the pipe data are from the Mechanical Consolidated Data Base (MCDB, Reference 6.12); piping geometries and properties were taken from the piping fabrication isometrics (Reference 6.21) and the Crane handbook (Reference 6.22). The CCW piping systems were represented by a series of links (pipes of constant cross-sectional area), which are sub-divided into nodes where the computations are performed. Pipe/node data included pipe diameters, pipe lengths, pipe elevations, external and internal boundary conditions (e.g., reservoir data, valve data, etc.), flow rates, friction/equipment losses, speed of sound, etc.

The CCW surge tank was conservatively modeled as an infinite reservoir at a constant pressure of 32 psig throughout the modeled refilling transient. The heat exchangers were modeled as a lumped tubes model with their resistances treated appropriately. The vapor pressure in the vapor region is conservatively used in the HSTA model.

The calculations mentioned above include piping system schematics marked with links and pipe segment identifications. Tables containing pertinent links and pipe segments data are also included to be used as input for the HSTA model in the hydraulic transient calculations as described in Section 5.2.2.

5.2.2 Hydraulic Transient Calculation

The hydraulic calculations (References 6.18.4 and 6.18.5) provide the analysis performed on the CCW Train A and Train B piping systems for the voiding and refilling sequence taking place in the ECUs. The Bechtel computer program HSTA (Reference 6.8) was used to generate the Waterhammer forcing functions to be used as inputs to the structural evaluations (Section 5.3) after the application of the EPRI methodology to allow for the cushioning effects of the non-condensibles.

HSTA is a generalized transient program based on the Method of Characteristics (MOC) numerical scheme. It solves the equations of conservation of mass and momentum to obtain the values of head and velocity at every node of the fluid network. The pressure and velocity at each node are then used internally by the code to calculate a forcing function for each pipe segment. HSTA has the ability to perform water column separation and rejoining calculations using both the traditional approach with vapor bubbles forming/staying at each node, and the line filling approach in which a discrete vapor pocket is defined by a water/vapor interface at its beginning and a vapor/water interface at its end. This type of vapor pocket allows for its transport along the pipe and leads to more accurate calculations for bubbles which are longer than a nodal distance. Essential steps of the hydraulic transient analysis are highlighted below. The EPRI methodology and the SONGS licensing basis design inputs were utilized in the analysis.

5.2.2.1 Draindown Methodology and Results

The draindown was calculated using the HSTA code, accounting for the dynamics of the hydraulic system based on the developed CCW system model. The sizes of the vapor pockets inside the cooler area were successively calculated until the CCW pump restart. Maximum and minimum vapor sizes were obtained and then conservatively used in the subsequent calculation for the column rejoining phase of the transient.

The draindown analysis results indicated that the tube region would be occupied by steam within 5 seconds after the time bulk boiling begins. The time to boil was about 11.75 seconds after the postulated LOCA. In less than 20 seconds after the initiation of the LOCA, all the tubes in the ECUs were expected to be voided. Since the pump restarts after 30.9 seconds following the LOCA, the steam bubble, that covers the entire tube region within 20 seconds, will expand to a maximum value and will then contract because no additional steam will be produced. The size of the steam bubble would then oscillate. Therefore, the maximum bubble size was chosen conservatively to occur when the water flow velocity due to the expanding bubble reduces to zero before the column rejoining phase began. The column rejoining begins when the CCW pump is re-started. The steam bubble size is assumed to be at least equal to the total ECU tube volume in the refill sensitivity analyses.

5.2.2.2 Refill and Column Closure Methodology and Results

The results of the draindown analyses were used in developing the initial conditions for the refill transients. Similar to the draindown analyses, the computer code HSTA was used in analyzing the refill transients. The solutions to the liquid velocity and pressure head at known grid locations were used by HSTA to generate the dynamic forcing functions on specified pipe segments to be utilized as an input in the structural computer code ME101.

Various scenarios were modeled in the refill analyses to account for possible operating modes and single failures. Where the effects were not obvious, specific HSTA runs were made to determine the worst case. Runs were also made as part of a sensitivity analysis to determine the worst case effects of tolerances when applied to the startup timing of the CCW pump, the size of the draindown bubble, the range of void pressure resulting from elevation differences and/or a sensitivity pressure band, and the effects of isolation of CCW flow to selected equipment. The effects of CCW flow isolation to selected heat transfer equipment based on the plant operating procedures were evaluated with the intent to identify the worst-case loading condition. The effects of gas/steam cushioning on the HSTA-calculated void closure velocities were evaluated per EPRI methodology and were credited in the structural analyses.

5.2.2.2 Refill and Column Closure Methodology and Results - Continued

The single failures were examined from the viewpoint of Waterhammer effects on the pressure boundary of the train under consideration, as explained in section 4.0.

For the containment emergency air cooler piping loops, the final void closure was predicted by the HSTA code to take place in the piping downstream of the cooler when faster moving water from the CCW pump impacted the slower moving water in the cooler return line. The impact was calculated to have an uncushioned velocity of 8.9 ft/sec or less.

5.2.2.3 Comparison with EPRI Methodology

This analysis follows the basic EPRI guidance outlined in Sections 2.2 and 7.3 of the EPRI report (Reference 6.5). The computer code HSTA is used as the tool in implementing the hydraulic portion of the EPRI methodology. The EPRI methodology steps outlined in Sections 7.3 and 7.5 of Reference 6.5 are discussed below as applied to SONGS.

a) Initial Closure Velocity

Applicable portions of the CCW system are modeled in the HSTA code, including pump curves and pertinent flow coefficients. The HSTA code is capable of solving the flow balance equations. Additionally, it is capable of accounting for inertia effects and tracking the locations / velocities of the water / vapor interfaces bounding the voids. Therefore, HSTA is well suited to calculate the initial closure velocity. The calculation of the initial closure velocity is based on a constant void pressure and dissimilar flows into and out of the void. The void closure velocity is the relative velocity of the impacting interfaces and is calculated to be 8.9 ft/sec or less from the HSTA analysis.

b) Accelerating Column and Void Lengths

The length of the accelerating water column and gas volume are calculated from the draindown analysis results for use in selecting the appropriate gas/steam cushioning charts from Appendix A of Reference 6.5.

c) Mass of Gas

The mass of gas evolved and concentrated in the void during the void phase of the transient is calculated by assuming that the water that has experienced boiling releases its dissolved gas at surge tank pressure as described in Section 5 of Reference 6.5.

5.2.2.3 Comparison with EPRI Methodology – Continued

d) Cushioned Velocity

The cushioned velocity reduction is calculated per the EPRI methodology (gas/steam cushioning charts in Appendix A of Reference 6.5). Figure A-43 of Reference 6.5 was used in the determination of the cushioned velocity, resulting in an 11% velocity reduction. The gas/steam cushioning factor (0.89) is credited in producing the Waterhammer forcing functions in the stress analyses.

e) Sonic Velocity

The sonic velocity is manually calculated per Section 5.2.4 of Reference 6.5 for solid water without any gas bubbles.

f) Peak Pulse with No Clipping

The peak Waterhammer pressure pulse is calculated by the HSTA code based on the uncushioned velocity and the sonic velocity. The peak pressure (or head) is calculated as a solution to the fundamental continuity and momentum equations, which is equivalent to using the Joukowski equation from Reference 6.5. (Note that the Joukowsi equation is also derived from the fundamental flow equations.) In the HSTA model used in our analysis, we chose not to use the HSTA option of calculating the effects of gas/steam cushioning nor the rise time attributable to pressure pulse shape. Since HSTA allows for pressure reflections from boundaries such as throttle valves, dead ends, etc., our HSTA calculated results include the effects of pressure clipping for un-cushioned column closure. Therefore, the effect of pressure clipping for a cushioned column closure is not included in the HSTA analysis. The HSTA code tracks the propagation of pressure pulses through rigid piping and calculates the forcing functions (force time histories) on the various piping segments.

g) Rise Time

As mentioned in sub-section f) above, the HSTA option of non-condensibles was not used in our analysis. Therefore, the rise time effect due to the presence of non-condensibles is not included in the HSTA computations. The pressure increase at the column collapse location is therefore instantaneous. The rise time effects along with the gas/steam cushioning effects are credited by making appropriate adjustments when calculating the structural loading on the piping system. The rise time effects are based on the linear increase in pressure during the rise time as per the EPRI methodology.

5.2.2.3 Comparison with EPRI Methodology – Continued

h) Transmission Coefficients

The HSTA code is capable of directly solving the fundamental continuity and momentum equations at flow area change locations in the piping, which is equivalent to using the transmission and reflection coefficients described in Section 5.3.6 of Reference 6.5. Thus, the transmission / reflection coefficients are included in the HSTA results.

i) Duration

The HSTA code is capable of tracking reflections from the initial pressure pulse and calculating the pressure pulse accordingly. Therefore, the pressure pulse duration is inherently calculated by the computer code. As previously stated, rise time due to gas/steam cushioning is not computed by the HSTA code, as this option is not used in our HSTA model.

j) Peak Pressure Clipping

The HSTA model used by SONGS did not account for the rise time due to the presence of gas / steam. Based on that, the SCE HSTA results do not account for pressure clipping for a cushioned column closure.

k) Pressure Pulse Shape

The HSTA code generates a pressure pulse that is essentially a square wave for an instantaneous vapor collapse without the presence of non-condensibles. However, as stated previously, the conservative rise time adjustments are applied to the structural loading of the piping in a manner consistent with the linear increase in pressure during the rise time as per the EPRI methodology.

l) Flow Area Attenuation

The HSTA code inherently calculates the attenuation/amplification of the pressure pulse as it travels through the system. Fluid structure interaction (FSI) effects are conservatively ignored in the SONGS analyses, as suggested by the EPRI methodology. See above discussion h) for "Transmission Coefficients."

5.2.2.4 Condensation Induced Waterhammer Consideration

Based on the characteristics of the containment atmosphere following a design basis LOCA, the CCW temperature in the tubes of the containment air coolers is limited to about 230 °F. The corresponding saturation pressure is about 20 psia (about 5 psig). After the CCW pump starts, the void is refilled in short horizontal pipe headers or in a vertical header, which precludes CIWH conditions.

Based on the above, and using the guidance in Section 4.2 of Reference 6.5, SCE concluded that any CIWH that may occur are limited in magnitude such that it is not a threat to the pressure boundary integrity. The effects of any CIWH will be less than the effects of CCWH. The SONGS CCW system has been shown to be capable of withstanding CCWH by analysis for conditions of LOOP/LOCA. Therefore, an explicit calculation of CIWH was not performed.

5.2.2.5 Two-Phase Flow Evaluation

The GL 96-06 two phase flow issue was addressed from two perspectives:

a) The same perspective that was applied to the Waterhammer issue, i.e., MSLB or LOCA coincident with LOOP. This event results in steam generation during the period when the CCW pumps are not running and the containment emergency air coolers are draining; hence, both steam and water phases are present in the CCW system. However, the two-phase regimes are stagnant until the CCW pump is started. In this case the movement and the subsequent collapse of the steam void is calculated by the HSTA code.

b) The possibility of two-phase flow occurring during MSLB/LOCA with offsite power available and the CCW pumps operating. This possibility has been addressed in the design analyses of the CCW system as the SONGS design basis for the CCW system includes the requirement of no boiling (flashing) in the containment emergency air coolers or in the return piping from the containment during accident conditions. This requirement assumes that one CCW pump is operating in the train under consideration. A mechanical calculation (Reference 6.18.9) was performed to confirm that this requirement is met, and the results showed that there is a conservative pressure margin in excess of 30 psi above the required liquid vapor pressure at the ECU locations.

The basic methodology used in the two-phase flow evaluation is to calculate the CCW pressures at various critical locations (such as in the containment air coolers and the associated outlet piping). These pressures are then compared to the vapor pressure associated with the peak CCW fluid temperature. The locations examined include the farthermost piping downstream heat transfer equipment prior to mixing with cooler CCW return flow from other loads. The CCW pressures in

5.2.2.5 Two-Phase Flow Evaluation – Continued

the regions of interest were calculated using computer models of the CCW system in mechanical calculations (References 6.18.8 and 6.18.9).

The two-phase flow evaluation is based on the maximum CCW temperature of 177 °F (Reference 6.13, Section 6.2). The saturated pressure corresponding to the above stated 177 °F is approximately 7 psia. The analysis of the CCW system pressures at flowing conditions (Reference 6.18.9) shows the lowest pressure in the CCW system to be 37.5 psia (22.8 psig) with the associated saturated temperature 263 °F. Thus, the SONGS CCW system has at least a 30 psi margin to prevent flashing and an associated two-phase flow regime in the system. Therefore, boiling or flashing in the containment air coolers and in the associated outlet piping does not occur and two-phase flow does not exist. Consequently, the assumption of single phase flow for heat transfer and pressure drop calculations is appropriate.

5.3 Structural/Stress Evaluation

With the forcing functions generated by the HSTA, computer program ME101 (Reference 6.9) was used to perform the time history analysis to evaluate the structural integrity of the CCW piping systems in response to the Waterhammer event. ME101 is a well established and widely used finite element computer program that is capable of performing linear elastic response of piping systems under static and dynamic loading conditions.

5.3.1 Scope

The scope of the stress analysis produced twelve (12) stress calculations (Reference 6.19) that include the following:

Train A -	Supply & Return Piping of Cooler 1501ME399	(inside containment)
	Supply & Return Piping of Cooler 1501ME401	(inside containment)
	Combined Supply Header	(outside containment)
	Combined Return Header	(outside containment)
Train B -	Supply & Return Piping of Cooler 1501ME400	(inside containment)
	Supply & Return Piping of Cooler 1501ME402	(inside containment)
	Combined Supply Header	(outside containment)
	Combined Return Header	(outside containment)

The evaluation boundaries end at the anchors on the supply and the return headers outside containment where the Waterhammer effects are judged to have diminished due to attenuation from changes of flow direction and the resulting piping movement and energy dissipation. The following items were evaluated to determine piping system acceptability:

5.3.1 Scope - Continued

- Piping Stresses
- Equipment Nozzle Loads
- Containment Penetration Loads
- Integral Welded Attachments
- Pipe Support Loads

5.3.2 Methodology and Results

5.3.2.1 Forcing Function Modeling

The HSTA code generates a pressure pulse that is essentially a square wave. In reality, the pressure pulse acts more closely like a trapezoidal or triangular shape which has a finite rise time. The rise time is particularly important to the structural loading of the piping, since loads are dependent on the slope of the rise. The rise time is calculated in accordance with the EPRI methodology outlined in Section 5.3.4 of Reference 6.5.

Since a typical CCW pipe segment length is much shorter than the length of the rising pressure wave, the unbalanced force acting on each pipe segment was adjusted by the factor of elbow-to-elbow travel time versus rise time and the adjustment was applied at each change of direction.

5.3.2.2 Damping

Two percent (2%) structural damping was used in the Waterhammer time history analysis, consistent with the existing licensing basis at SONGS (Section 3.7B.1.1.4 of Reference 6.13) used to evaluate design basis events.

5.3.2.3 Time Step and Modes

To ensure a high level of accuracy, the time history analysis was based on a) a small time step of 0.0005 of a second in order to capture all of the peaks of the forcing functions and b) a small minimum period of 0.001 of a second to include a sufficiently large number of vibration modes.

5.3.2.4 Piping Stresses

The piping stresses were checked in accordance with ASME Code, Section III, Subsection NC-3600 (Reference 6.7). The resultant stresses from Waterhammer loads were compared to DBE inertia stresses, and the larger stresses were included in the faulted condition stresses and evaluated against Code Level D allowables. All piping components were shown generally to be about 50% below the code allowable stress.

5.3.2.5 Equipment Nozzle Loads

Piping resultant loads acting on the inlet and the outlet manifold flanges of the coolers were evaluated against the vendor allowables (Reference 6.15.4) and were found to be within the allowable loads. This also considered the acceptability of the coolers under the Waterhammer transient.

5.3.2.6 Containment Penetration Loads

The piping reaction loads resulting from the upstream and the downstream sides of the penetration were combined at the penetration head and were found to be within the vendor allowable loads. The evaluation was made for the two cases mentioned previously in Section 4.3.

5.3.2.7 Integral Welded Attachments

Local stresses imposed on piping due to integral welded attachments were calculated by computer program ME101LS (Reference 6.9), which is based on Welding Research Council Bulletin 107. The local stress intensities were then combined with nominal piping stresses and evaluated per ASME Code, Section III, Subsection NC-3200 (Reference 6.7). All integral welded attachments met the Code allowable stress requirements.

5.3.2.8 Pipe Support Evaluation

All affected pipe supports were evaluated by manual calculation or by computer code ME150 (Reference 6.10). Resulting stresses were compared to the allowable stresses based on the ASME Code, Section III, Appendix F (Reference 6.7). The evaluation covered standard components, structural members, insert plates, anchor bolts, and welds. Although Appendix F indicates an allowable stress factor of 1.88 for a faulted condition check, a factor equal to 1.5 was conservatively chosen for additional margin (ASME Code, Section III, Appendix F, Paragraph F-1334).

6. References

6.1 NRC Generic Letter 96-06: Assurance of Equipment Operability and Containment Integrity during Design-Basis Accident Conditions, September 10, 1996

6.2 NRC Generic Letter 96-06, Supplement 1: Assurance of Equipment Operability and Containment Integrity during Design-Basis Accident Conditions, November 13, 1997

6.3 SCE Letter to NRC, dated November 26, 2002, Subject: Docket Nos. 56-361 and 50-362, Supplemental Response to Generic Letter GL 96-06 " Assurance of equipment Operability and Containment Integrity During Design-Basis Accident Conditions, " San Onofre Nuclear Generating Station, Units 2 and 3 (TAC Nos. M96862 and M96863)

6.4 NUREG/CR-5220: Diagnosis of Condensation Induced Waterhammer, August 1988

6.5 EPRI Report 1006456: Generic Letter 96-06 Waterhammer Issues Resolution - User's Manual, April 2002

6.6 EPRI Report 1003098: Generic Letter 96-06 Waterhammer Issues Resolution - Technical Basis Report, April 2002

6.7 ASME III Code, 1974 Edition, up to 1974 Summer Addenda

6.8 Hydraulic System Transient Analysis (HSTA) Computer Program, Version 5C, October 1999

6.9 Linear Elastic Analysis of Piping Computer Program - ME101, Version N7, September 2002 including subprogram ME101LS

6.10 Frame Analysis Program for Pipe Supports (FAPPS) - ME150, Version 17, September 2002

6.11 Base Plate Analysis Program for Pipe Supports - ME035, Version 15, July 2002

6.12 90001, Mechanical Consolidated Data Base (MCDB), Rev. 48

6.13 San Onofre 2&3 Updated Final Safety Analysis Report

6. References - Continued

6.14 P & ID's:
- 40114B, Rev. 17
- 40123B, Rev. 33
- 40127A, Rev. 27
- 40127B, Rev. 32
- 40127C, Rev. 38
- 40127D, Rev. 14
- 40127E, Rev. 12
- 40172A, Rev. 12
- 40172B, Rev. 13
- 40177A, Rev. 20
- 40179A, Rev. 28
- 40180A, Rev. 27

6.15 Emergency Cooling Unit Documents

.1 SO23-410-1-23, Rev. 5: ECU Housing Assembly
.2 SO23-410-1-24, Rev. 9: ECU Header Piping Arrangement
.3 SO23-410-1-136, Rev. 2: ECU Coil Design Data
.4 SO23-410-1-349, Rev. 7: ECU Seismic Analysis Report

6.16 DBD-SO23-400, Rev. 8: Component Cooling Water System

6.17 DBD-SO23-770, Rev. 2: Containment HVAC and Combustible Gas Control

6.18 Mechanical Calculations

.1 M-DSC-387, Rev. 0: GL 96-06 ECU Heat Transfer Analysis
.2 M-0027-030, Rev. 0: Input Data for HSTA CCW Model Train A
.3 M-0027-031, Rev. 0: Input Data for HSTA CCW Model Train B
.4 M-0027-032, Rev. 0: GL 96-06 CCW System Evaluation - Train A
.5 M-0027-033, Rev. 0: GL 96-06 CCW System Evaluation - Train B
.6 M-0026-003, Rev. 2: CCW Surge Tank Pressure
.7 N-4080-026, Rev. 1: Containment P/T Analysis for Design Basis LOCA
.8 M-0026-010, Rev. 0: Component Cooling Water System Hydraulic Transient Analysis
.9 M-0026-011, Rev. 1: Component Cooling Water System Flow Pressure Distribution Analysis
.10 M-0027-025, Rev. 0: Component Cooling Water Flow Analysis

6. References - Continued

6.19 Stress Calculations

M-1203-210-05A,	Rev. 6, CCN N-3:	Train A Return Header
M-1203-244-AA,	Rev. 1, CCN N-2:	Train A Supply Header
M-1203-266-04A,	Rev. 3, CCN N-1:	Train B Return Header
M-1203-273-AA,	Rev. 1, CCN N-2:	Train B Supply to E402
M-1203-275-AA,	Rev. 3, CCN N-2:	Train B Return from E402
M-1203-277-AA,	Rev. 3, CCN N-2:	Train A Supply to E399
M-1203-279-AA,	Rev. 4, CCN N-2:	Train A Return from E399
M-1203-281-AA,	Rev. 3, CCN N-2:	Train A Supply to E401
M-1203-283-AA,	Rev. 4, CCN N-2:	Train A Return from E401
M-1203-285-AA,	Rev. 4, CCN N-2:	Train B Supply to E400
M-1203-287-AA,	Rev. 5, CCN N-2:	Train B Return from E400
M-1203-292-AA,	Rev. 1, CCN N-2:	Train B Supply Header

6.20 Pipe Support Calculations

P-450-1.012, Rev, 10, CCN N-8
P-450-1.063, Rev. 3, CCN N-3
P-450-1.112, Rev. 5, CCN N-4
P-450-1.163, Rev. 1, CCN N-2

6.21 Piping Fabrication Isometrics (latest revision with outstanding DCN's & ECN's) Unit 2's are listed, Unit 3's are mirror image

S2-1203-ML-093, Sheet 1
S2-1203-ML-094, Sheets 1 through 3
S2-1203-ML-095, Sheets 1 & 2
S2-1203-ML-099, Sheet 1
S2-1203-ML-100, Sheet 1
S2-1203-ML-202, Sheet 1
S2-1203-ML-203, Sheet 1
S2-1203-ML-204, Sheet 1
S2-1203-ML-205, Sheet 1
S2-1203-ML-210, Sheets 1 through 3
S2-1203-ML-211, Sheet 1
S2-1203-ML-213, Sheet 1
S2-1203-ML-215, Sheet 1
S2-1203-ML-216, Sheet 1
S2-1203-ML-243, Sheets 1 through 3
S2-1203-ML-244, Sheet 1
S2-1203-ML-265, Sheets 1 through 3
S2-1203-ML-266, Sheets 1 through 4
S2-1203-ML-273, Sheets 1 through 4
S2-1203-ML-275, Sheets 1 through 4
S2-1203-ML-277, Sheets 1 through 4
S2-1203-ML-279, Sheets 1 through 3
S2-1203-ML-281, Sheets 1 through 5
S2-1203-ML-283, Sheets 1 through 4
S2-1203-ML-285, Sheet 1 & 2
S2-1203-ML-287, Sheet 1 & 2
S2-1203-ML-292, Sheets 1 through 3

6. References - Continued

6.22 Crane Technical Paper No. 410: Flow of Fluids, 1988 issue

6.23 PRA Documents

.1 IPE-BE-IE-004: Loss of Coolant Accidents Initiating Event Frequencies
.2 CEOG PSAWG Technical Position Paper, Jan. 1997
.3 IPE-BE-IE-001: Loss of Offsite Power (Plant-Centered vs Grid/Weather-Related)

7. Nomenclature

AAF	American Air Filter Co
CCAS	Containment Cooling Actuation Signal
CCW	Component Cooling Water
CCWH	Column Closure Waterhammer
CIWH	Condensation Induced Waterhammer
CSS	Containment Spray System
DBD	Design Basis Document
DBE	Design Basis Earthquake
ECU	Emergency Cooling Unit
EDG	Emergency Diesel Generator
EPRI	Electric Power Research Institute
ESF	Engineered Safety Features
FMEA	Failure Modes and Effects Analysis
FSI	Fluid Structural Interaction
HPSI	High Pressure Safety Injection
HSTA	Hydraulic System Transient Analysis
LDHX	Letdown Heat Exchanger
LOCA	Loss of Coolant Accident
LOOP	Loss of Offsite Power
LPSI	Low Pressure Safety Injection
MCDB	Mechanical Consolidated Design Base
MOC	Method of Characteristics
MSLB	Main Steam Line Break
NPSH	Net Positive Suction Head
P/A CL-UP	Post-Accident Cleanup
RCS	Reactor Coolant System
SDCHX	Shutdown Cooling Heat Exchanger
SER	Safety Evaluation Report
SIAS	Safety Injection Actuation Signal
SONGS	San Onofre Nuclear Generating Station
SRP	Standard Review Plan