**Jeffrey B. Archie**
*Vice President, Nuclear Operations*
803.345.4214

SCE&G®
A SCANA COMPANY

December 12, 2005
RC-05-0204

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

ATTN: Mr. R. E. Martin

Dear Sir / Madam:

Subject: VIRGIL C. SUMMER NUCLEAR STATION (VCSNS)
DOCKET NO. 50/395
OPERATING LICENSE NO. NPF-12
RESPONSE TO NRC QUESTIONS REGARDING
RESPONSE TO GENERIC LETTER 96-06
(TAC NO. M96872)

References:
1) Stephen A. Byrne letter to Document Control Desk, RC-04-0018, January 20, 2004 (ADAMS Accession Number ML040220466)
2) K. R. Cotton (NRC) Electronic Letter to R. Sweet (SCE&G), "GL 96-06 Questions" dated October 14, 2004
3) Stephen A. Byrne letter to Document Control Desk, RC-04-0111, August 4, 2004 (ADAMS Accession Number ML042220080)
4) J. Turkett (SCE&G) Electronic Letter to K. R. Cotton (NRC), 2005 Draft Response to NRC Questions Regarding SCE&G Response to Generic Letter 96-06 (TAC NO. M96872), April 15, 2005
5) R. E. Martin (NRC) Electronic Letter (FAX) to R. Sweet (SCE&G), "The NRC Staff reviewed SCE&G's draft response and additional information is needed...", June 29, 2005

On October 14, 2004, South Carolina Electric & Gas Company (SCE&G) received an electronic communication (Reference 2) presenting an NRC request for additional information (RAI) regarding the VCSNS response to Generic Letter (GL) 96-06 submitted August 4, 2004 (Reference 3). SCE&G reviewed these questions in consideration of the activities conducted to address the GL 96-06 issues. On January 13, 2005, a telephone conference between SCE&G, the NRC, and the technical reviewers for the NRC was held to discuss the questions of the RAI and explain the SCE&G position regarding the responses developed for VCSNS. SCE&G provided Reference 4 based on an understanding reached with the reviewers during the referenced telephone conference. On June 29, 2005, the NRC responded with a series of questions (Reference 5) addressing additional information needed.

SCE&G is providing the attached response to address questions presented in Reference 2 and Reference 5.

A072

<u>Summary of Commitments</u>

SCE&G makes the following commitments as further discussed in the attachment to this letter:

> VCSNS has initiated a plant modification that will accomplish three changes to the current plant configuration for Service Water (SW) discharge from the Reactor Building Cooling Units (RBCUs). First, this modification will delay the opening of gate valves 3107A/B upon start up of SW booster pump (SWBP) A/B. This delay will allow the SWBPs to build up fluid momentum and full fluid flow prior to the opening of these valves preventing gravity drain-down of fluid to the SW pond thereby preventing the creation of a vacuum void. Second, the modification will install vacuum relief valves downstream of valves 3107A/B to replace with air any vacuum developed in the downstream piping during normal operations and eliminate the need for manual action to "vent" the piping. The air in lieu of vacuum will tend to cushion the water column impact as the SWBPs are energized after a station blackout. Third, SCE&G will replace valve 3107A/B with fast closing butterfly valves that close in seven seconds upon de-energizing of SWBP A/B. The fast valve closure will trap water in the high points above the valve and prevent void formation from gravity drain-down of the water to the SW pond. SCE&G is confident that the combined affects of these modifications will reduce the waterhammer loads in the piping to very low levels.

These changes are not required to address any deficiencies in the ability of the plant to meet its current design and licensing basis, but they will reduce operator burden and increase design margins. These changes are currently scheduled for completion in RF-16 (October 2006).

If you have any questions or require additional information, please contact Mr. Robert Sweet at (803) 345-4080.

I certify under penalty of perjury that the information contained herein is true and correct.

12/12/05
Executed on

Jeffrey B. Archie

JT/JBA/dr
Attachment

c: N. O. Lorick
S. A. Byrne
N. S. Carns
G. S. Champion (w/o Attachment)
R. J. White
W. D. Travers
NRC Resident Inspector
K. M. Sutton
NSRC
RTS (C-02-3455)
File (815.14)
DMS (RC-05-0204)

**South Carolina Electric & Gas Company (SCE&G)**
**Virgil C. Summer Nuclear Station (VCSNS)**
**Response to NRC Request for Additional Information (RAI)**
**Regarding SCE&G Response to Generic Letter (GL) 96-06**

**Review of GL 96-06 waterhammer condition as it applies to V. C. Summer Nuclear Station**

Refer to Figure 1 on page 19 of this attachment.

There are two system alignments for the cooling of the Reactor Building Cooling Units (RBCUs), via the non-safety Industrial Cooling (IC) System or via the safety related Service Water (SW) system. Cooling via the IC system is the normal plant operation alignment. Cooling is automatically transferred to the SW system after an Engineered Safeguards Features Actuation Signal (ESFAS). With the RBCUs aligned for normal plant operations (aligned to the IC system), a void as noted in Figure 1 is present in the piping downstream of valve 3107A/B (this void will be referred to as the first void). This first void is formed by gravity drain-down of fluid in the RBCU return piping to the SW pond upon realignment of the RBCU from the SW system to the IC system. During this realignment, valve 3107A/B is closed and the gravity drain-down occurs. This void contributes to the waterhammer event as will be explained later. Analysis has shown that if the void contains air in lieu of a vacuum, the affects of the waterhammer are greatly reduced, i.e., the air in the void tends to cushion the impact of the two columns of water as the void collapses versus no cushion with a vacuum in the void. Therefore, plant operating procedures have been revised to include venting of the piping to replace the vacuum void with air. This venting is performed per procedure immediately after the realignment of RBCU cooling from the SW system to the IC system. During normal plant operation the venting process is only required after quarterly system testing (SW supplied in lieu of IC).

The waterhammer condition postulated in GL 96-06 is caused by the coincident initiating occurrences of a Main Steam Line Break (MSLB) or Loss of Coolant Accident (LOCA) and a Loss of Offsite Power (LOOP).

Note: For piping loads only, the loads from a seismic event are conservatively combined with those caused by a LOCA event. Refer to the Response for the RAI Question regarding load determination methodology on page 9 of this attachment for further details.

It is assumed that prior to these events the RBCUs are operating in their normal lineup such that they are being cooled by the non-safety IC System. The initiation of a MSLB/LOCA would cause the temperature in the Reactor Building (RB) to begin to rise. After approximately 20 seconds, the temperature in the containment would reach 260 degrees Fahrenheit (°F). A concurrent LOOP would cause the IC flow to the RBCUs to stop due to the loss of the system pumps. From the time of the LOOP, it would take approximately 41.5 seconds for the emergency diesel generators (EDGs) to start and load sequencing by the ESFAS to be completed. After 41.5 seconds, the SW booster pumps (SWBPs) are re-energized and the alignment of RBCU cooling to SW begins. Therefore, the stagnant cooling water in the RBCUs could be exposed to a 260 °F temperature for aproximately 41.5 seconds. Heat transfer from containment to the RBCU cooling coils could

produce steam voids in the SW pipe. However, It should be understood that until valve 3107A/B begins to stroke open simultaneously with SWBP A/B startup (41.5 seconds following LOCA/LOOP) there is no possibility of steam generation in the RBCUs because fluid pressure in the RBCUs remains above the corresponding saturation pressure for the FSAR peak containment temperatures for LOCA or MSLB. The analysis of the waterhammer condition in VCSNS considered that a steam void did not develop in the RBCUs due to the heat transfer from containment. (It is noted that this is conservative as compared to the consideration of steam void formation. This will be explained in detail in the Questions and Responses that follow.). Upon re-energizing SWBP A/B and initiation of the transfer to SW system for RBCU cooling, valve 3107A/B (a gate valve under current plant configuration) begins to open. The characteristics of a gate valve are such that a signficant amount of flow occurs in the early stages of valve opening. Contrary to this, it takes several seconds for SWBP A/B to build up fluid momentum and commence full fluid flow. Due to these discrepancies, the fliud flows rapidly through valve 3107A/B to the SW pond and creates a vacuum void. This is the second void as described in the Figure 1. Collapse of the first air void and the second void occur when the SWBPs achieve operating speeds at full flow parameters.

Note: A waterhammer will not occur upstream of the RBCUs because there are two check valves near the containment penetration that trap the water above the RBCUs upon loss of flow and thus prevent voiding.

<u>Application of the EPRI Methodology at VCS</u>

The occurrence of multiple independent column-closure waterhammer sites separated in time by up to ten seconds, the complicating effects of containment isolation valves stroking open slowly at different rates, and the presence of a large static air volume in the RBCU return piping take the VCSNS transient outside the realm of the approved EPRI GL 96-06 methodology. Significant effort was expended to apply the EPRI methodology to VCSNS. However, the calculations required so many simplifying assumptions to the transient scenario that the EPRI GL 96-06 methodology was not considered an adequate evaluation tool for the VCSNS configuration. This conclusion was validated during verification by an outside consultant with considerable experience in fluid hydraulic analysis.

<u>Questions and Responses</u>

**Question:**

**RELAP5 is a computer code with a largely empirical basis for its closure relations. Therefore, RELAP5 must be assessed against experimental data that is applicable to the present analysis. Please provide the RELAP5 assessment that was performed that qualifies it for the present application. Describe how the range of conditions in the experiments correspond to the waterhammer conditions that might occur at Virgil Summer Nuclear Station during an accident with LOOP. Consider both thermal/hydraulic as well as geometrical considerations.**

**Response:**

SCE&G has very high confidence that the support loads and pipe stresses calculated through the meticulous application of the RELAP5/MOD3 and PIPESTRESS computer codes bound the conditions that would be experienced in the plant should a GL 96-06 waterhammer event occur. References 1 and 2 (pp.20 through 23 and pp.24 through 30 respectively of this attachment) are engineering papers showing that RELAP5/MOD3 can be successfully applied to conservatively calculate hydrodynamic forces resulting from both two-phase and single-phase waterhammer events. The RELAP5 modeling techniques used in the fluid transient analyses performed for VCSNS for GL 96-06 are similar to those applied in References 1 and 2. Furthermore, the cold column-closure waterhammer event on the RBCU discharge piping that has been identified as the bounding VCSNS waterhammer transient for GL 96-06 is almost identical to the normal transient which occurs during SWBP quarterly testing and RBCU cooling supply transfer from IC to SW cooling. Despite the relative frequency of this transient, no related damage to SW piping or supports has ever been reported.

Reference 1 is a recent engineering paper presenting analysis results directly applicable to the use of RELAP5/MOD3 for calculation of waterhammer loads for GL 96-06. The calculations were based on piping loads calculated using the EPRI methodology (References 3 and 4) and RELAP5 (Reference 5) to simulate the hydraulic behavior of the system. The RELAP5 generated loads were compared to loads calculated using the EPRI GL 96-06 methodology. This evaluation was based on a pressurized water reactor's Reactor Containment Fan Cooler (RCFC) coils thermal hydraulic behavior during a LOOP and a LOCA. The paper concludes that the EPRI methodology and the RELAP5 calculations can be used to generate hydraulic loads for the RCFC system. The RELAP5 calculated hydraulic loads for this analysis produced larger loads than the loads developed using the EPRI methodology.

Reference 2 is a 1994 engineering paper documenting the acceptability of the default two-velocity momentum equation option in the RELAP5/MOD3 computer program for the estimation of hydrodynamic loads associated with steam safety relief valve discharge. A RELAP5 analysis of the EPRI/Combustion Engineering Safety Valve Test Loop Facility was performed and time-dependent hydrodynamic forcing functions for the four pipe segments of the Combustion Engineering (CE) Test Facility were developed. These forcing functions were subsequently used in an elastic piping analysis model to estimate the resultant structural responses. The calculated loads were then compared to the values from the original 1981 Test data (Dresser safety valve Test 1017 with cold water loop seal). The results verify that RELAP5/MOD3 and the REFORC post-processor can be used with confidence to calculate hydrodynamic forces for use in pipe stress and support analysis. While the Safety Relief Valve (SRV) test cases were conducted at significantly higher pressures than would occur for the GL 96-06 waterhammer scenarios, the CE 1017 test scenario is a cold water slug propelled down an empty 12-inch diameter discharge pipe. Because of relief valve chatter the water slug is released incrementally and does not remain intact. The hydrodynamic conditions are similar to the GL 96-06 waterhammer scenario at VCSNS in which a cold water column is released into a voided (air-filled) 16-inch diameter RBCU return pipe when containment isolation valve 3107A/B opens slowly over a 30 seconds stroke period. An important conclusion from this study is that the RELAP5-computed forces become significantly more conservative (by factors of 1.5 to 2.0) compared to the test data as the water slug is accelerated down successive pipe segments. The Reference 2 analysis methodology is very similar to the RELAP5-based waterhammer analyses performed for VCSNS for GL 96-06.

Dynamic net axial forces were computed by calculating the total wave (momentum) force in each pipe segment during each RELAP5 time step (maximum 0.0002 second). The net forces were written to the RELAP5 restart-plot file every 0.002 second after being processed through a lag filter control function with a 0.002 second time constant. Because the VCSNS RBCU piping lengths are much longer than the CE SRV test facility pipe segments, and because approximately the same node length/diameter ratio is used for the VCSNS GL 96-06 analyses as was used for the Reference 2 RELAP5 model, it is anticipated that the RELAP5-calculated forces for GL 96-06 have significant conservatism compared to forces that would be experienced in the actual plant piping during GL 96-06 transient scenarios. The VCSNS RELAP5 model for GL 96-06 contains approximately 476 volumes for each RBCU train.

The bounding waterhammer scenario for GL 96-06 at VCSNS occurs as follows. The inside containment RBCU cooling loops between containment isolation valves 3106A/B (RBCU supply) and 3107A/B (RBCU return) is pressurized and filled with cold water from the IC System, the normal cooling water supply for the RBCUs. The IC system contains a large accumulator tank that passively maintains system pressure even when the IC pumps are unpowered following a LOOP[1]. The piping immediately downstream of valve 3107A/B is manually filled with air at atmospheric pressure. The air vent is accomplished by procedure whenever the SW supply to the RBCUs is secured. Following a LOCA with coincident LOOP the Emergency Diesel Generators (EDGs) start 11.5 seconds after LOCA/LOOP. The SW pumps (SWPs) start and containment isolation valves 3111A/B and 3112A/B begin stroking closed over a 60 seconds stroke time to isolate the non-safety IC system from the safety-related SW supply to the RBCUs. At 41.5 seconds after LOOP, SWBP A/B starts and containment isolation valves 3106A/B and 3107A/B begin to stroke open. Valve 3107A/B opens in approximately 30 seconds and 3106A/B opens in approximately 45 seconds.

Because gate valve 3107A/B in the RBCU return line has flow at a relatively high capacity early in its opening stroke, the drain flow rate from the RBCU header temporarily exceeds the fill rate from SWBP A/B (which is conservatively modeled to ramp to full flow over a period of 5 seconds.) The drain flow causes vapor voids[2] to develop in the 10-inch piping downstream of the RBCUs. No attempt to credit steam cushioning is taken because, per References 3 and 4, the cold water column collapse (LOOP only) scenario has been shown to bound the LOCA scenarios with steam generation in the RBCUs[3]. The RELAP5 analysis predicts that moderate waterhammer forces due to void collapse occur in the two 10-inch piping segments downstream of the RBCUs as the SWBP refills the header inside containment. Meanwhile containment isolation valves 3106A/B and 3107A/B continue to stroke open and a third column-closure waterhammer occurs in the 16-inch RBCU return piping outside containment. The severity of this column-closure event is mitigated by the presence of the large air volume between the incident water column from valve 3107A/B and the standing water column near orifice 99A/B and the 412-ft elevation floor penetration. The incident water column is also broken up by flow element 4468/4498 and orifice 29A/B.

[1] No credit for the IC accumulator tank maintaining pressure is taken in the RELAP5 analysis.

[2] Void formation is exacerbated in the RELAP5 analysis because the fill/pressurization benefits of the IC system are not included.

[3] It should be understood that until valve 3107A/B begins to stroke open simultaneously with SWBP A/B startup 41.5 seconds following LOCA/LOOP there is no possibility of steam generation in the RBCUs. Fluid pressure in the RBCUs remains above the corresponding saturation pressure for the UFSAR peak containment temperatures for LOCA or MSLB.

**Question:**

**Identify any valves that are credited for preventingdrain-down or backflow in the system in order to minimize the void size and to the extent this is applicable, discuss the specific seat leakage assumptions that are credited in the analysis and describe periodic testing that is performed in accordance with the IST program to assure that the seat leakage assumptions remain valid.**

**Response:**

On the discharge side of the RBCUs, following shutdown of SWBP A/B and transfer to IC, a vacuum void downstream of valve 3107A/B is manually filled with air. This was noted in a previous response and will be discussed further in the following responses. Once the vacuum is replaced with air, no additional vacuum void formation or air in-leakage is expected as long as valve 3107A/B remains closed. The fluid and air will remain stable in equilibrium at a pressure of 1 atmosphere. When aligned with IC, the fluid pressure and volume upstream of valve 3107A/B is maintained via a surge tank. Due to pressure differentials across the valve and the very small leak path for the development of buoyant forces, any fluid leakage past valve 3107A/B will flow into the void. In order to maintain equilibrium, this leakage will essentially flow through the void to the SW pond and not affect the air void, and is therefore acceptable.

On the supply side of the RBCUs, it has been proposed that during a LOOP or LOCA scenario, voids could form in the piping as a result of water column drain back into the main SW system header through two check valves (3137A/B and 3135A/B) and a normally closed butterfly valve (3106A/B). The RBCUs are normally aligned to the IC system such that valve 3106A/B is closed. Another proposed drain back path is to the closed-loop IC via the two check valves (3136A/B and 3137A/B).

To create a void in the RBCU inlet piping, it is necessary to remove enough cooling water to drain the RBCUs and several segments of the 10" piping at the RBCU inlet. The RBCU cooling coil volume is approximately 132 gallons. Considering the hypothetical case in which two pipe segments adjacent to the RBCU inlet are voided due to drain back, the volume of the two pipe segments is approximately 13 gallons and their lengths are 1.77 feet and 2.02 feet., respectively. Conservatively assuming that only 50% of the RBCU volume needs to be drained before the inlet piping begins to uncover, the total back-leakage through the check valves must approach (50%)(132 gal) + 13 gal = <u>79 gallons</u> over the time period for which back leakage would be a concern.

The time period over which back-leakage may occur is a very important factor. The valve and pump timing following LOOP (or LOOP/LOCA) is as follows.

| | |
|---|---|
| 0.0 sec | Event Initiation, SWPs tripped due to assumed loss of offsite power. |
| 1.5 sec | ES actuation |
| 11.5 sec | EDG started and running, ready to accept loads from ES Sequencer. SWPs and essential motor-operated valves (MOVs) are powered back up at this time. Safety-related MOVs begin moving as necessary to safety positions, which is "closed" for butterfly valve 3106A/B. |
| 41.5 sec | SWBP A/B starts. Simultaneously, valve 3106A/B begins to open. |

From the above time sequence we can easily conclude that the available time window for drain-back is 41.5 seconds or less. The required leakage rate through the check valves and valve 3106A/B is (79 gal/41.5 seconds) 114.2 gpm, a very large and *substantial* leak rate. When the SWBP is not running, the pressure at the SWBP outlet is approximately 60 psig when the SWPs are running. The elevation difference between the RBCUs and SWBPs is 107.6 feet, and the associated water column head is 46.5 psi at 66°F. Thus, SWP pressure is more than sufficient (with a 10+ psi margin) to keep the RBCUs filled and prevent back-leakage into the SW header. The SWPs restart in the LOOP scenario at 11.5 seconds. Plant data traces from Emergency Safeguards surveillance testing show that the SW header pressure is restored almost instantly upon SWPs startup. Therefore, the time window for back-leakage through the SW system is not 41.5 seconds, but is actually only 11.5 seconds or less (depending on SWP coast down pressure decay following LOOP). The required leakage rate to void the two pipe segments of interest over 11.5 seconds is <u>412 gpm</u>, a rate which is so large as to be considered clearly incredible through two check valves in series and a normally closed butterfly valve. And if a leak path that large did exist, the void would refill at low pressure from the SWPs before the SWBP starts at 41.5 seconds. Therefore, void formation in the RBCU inlet piping due to back-leakage into the SW system is not a viable concern for GL 96-06 at VCSNS.

If the leakage path is into the closed-loop IC system, we have to postulate a 114.2 gpm leak rate into the system over 41.5 seconds to void the RBCU inlet piping. However, the IC system is a closed-loop system with a pressurized surge tank. For back-leakage to occur from the RBCU piping it is necessary to postulate rapid net leakage out of the IC system. The cover pressure in the surge tank will resist transient inflow from RBCU drainage. Review of monthly plant chemistry data reveals that the average maximum leak rate from the IC system is only 0.06 gpm. Thus, it is impossible to achieve the required 114 gpm back-leakage into the IC system required to void even a small portion of the RBCU inlet piping.

**Question:**

**For the valves that are credited for preventing drain-down or backflow in the system as identified in the draft response, discuss the specific seat leakage assumptions that are credited in the analysis and describe periodic testing that will be performed in accordance with IST requirements to assure that the seat leakage assumptions will remain valid over time (see the Southern Nuclear Operating Company response for the Vogtle plant dated November 5, 2004, for an example).**

**Response:**

As justified in the previous response, seat leakage is not considered in the analysis for the valves credited for preventing RBCU drain-down or backflow.

Valves 3137A/B, RB Cooling Unit Supply Header Valves perform an active safety function in the OPEN position. These valves are normally open to allow IC flow to the RBCUs. During an accident, the flow is automatically transferred to safety-related SW for cooling flow. These valves open to supply flow from either source. Full flow ASME Code check valve testing is performed

quarterly under STP-223.002A at a post accident minimum design basis flow of 2000 gpm. These normally open valves are closed tested in accordance with ASME Code check valve testing requirements each refueling outage under STP-230.006G.

Valves 3135A/B, Service Water Booster Pump Discharge Check Valves, are normally closed valves that perform an active safety function in the OPEN position. These valves must open to allow SW flow to the RBCUs. During an accident, the flow is automatically transferred to safety-related SW for cooling flow, by SWBP auto start, discharge valve opening and isolation of IC flow. Full flow ASME Code check valve testing is performed quarterly under STP-223.002A at a post accident minimum design basis flow of 2000 gpm. The valves are provided with an adjustable dashpot which controls the opening and closing speed of the disc for prevention of waterhammer. In the closed position, the valve prevents the diversion of IC into the SW system. This is an operational function, since IC is not a safety-related system. These normally closed valves are closed tested quarterly in accordance with ASME Code check valve testing requirements under STP-223.002A.

**Question:**

**It is stated that in the future the severity of postulated waterhammer events will be reduced by the injection of air into the service water piping and that system operating procedures have been revised to require air injection after system realignment. Please provide the following information concerning the air injection system:**

**a. Provide drawings of the service water system showing the location of the injected air pocket relative to the location of the postulated waterhammer. Demonstrate the injected air will flow into any steam space caused by LOOP, LOOP/MSLB or LOOP/LOCA.**

**Response:**

Figure 1 (p.19 of this attachment) shows the locations of the voids and the predicted waterhammer sites for RBCU Train A. Steam voiding in the VCSNS RBCUs does not occur for GL 96-06 scenarios because the fluid pressure in the RBCU coils remains above the saturation pressure corresponding to LOCA peak containment temperature until after SWBP startup.

Following shutdown of SWBP A/B and realignment to IC, a vacuum void forms due to fluid column gravity drainage downstream of valve 3107A/B, the containment isolation valve on the RBCU return piping to the SW pond. Compressed air is injected into the vacuum void by the Operations staff in accordance with plant procedures such that the void is filled with air at a pressure of approximately 1 atmosphere. The air is supplied via a plant air hose (connected only during the fill procedure) and remains trapped between valve 3107A/B and the downstream standing water column until the next time SWBP A/B is started and the associated RBCUs are placed on SW cooling. This relatively large air volume (extending for approximately 119 feet of the 12-inch diameter pipe) cushions the column collapse waterhammer event that analysis predicts could occur following SWBP A/B startup and opening of valve 3107A/B. The waterhammer is projected to occur when the incident water flow from valve 3107A/B reaches the standing water column near flow orifice 99A/B. Figure 1 shows the location of the air volume and column collapse waterhammer locations predicted by analysis.

Regarding the potential for steam formation in the RBCUs from LOCA/MSLB coincident with a LOOP, the normal RBCU cooling water supply is via the IC system. The IC system is a closed loop design with a pressurized expansion tank and relief valves. Valves 3106A/B and 3107A/B are normally closed, isolating the SW cooling supply to the RBCUs. The VCSNS design basis does not require the consideration of the seismic event occurring coincident with any other transient, such as the LOCA/MSLB. Therefore, the passive function (structural integrity) of the IC system outside containment can be relied upon after the occurrence of the LOCA/MSLB. The LOCA peak containment temperature of approximately 260 °F (Reference: VCSNS FSAR) corresponds to a saturation pressure ($P_{sat}$) of only 20 psig in the RBCU coils. This pressure is well below the nominal RBCU internal fluid pressure of approximately 50 psig when aligned to the IC system and is far below the RBCU thermal relief valve opening set points. Heat transfer to the RBCU coils will stop when the coils reach 260 °F, and boiling/steam formation cannot occur if the fluid pressure in the coils remains above 20 psig. Following a LOOP/LOCA and EDG startup, the containment isolation valves for the IC cooling water supply to the RBCUs (valves 3110A/B, 3111A/B, and 3112A/B) begin to close at a rate of approximately 60 seconds for full stroke. During the 41.5-seconds period between LOOP/LOCA and SWBP startup the expansion tank for the IC system passively maintains fluid inventory and pressure in the RBCU coils well above 20 psig. Therefore, steam formation in the RBCU coils is not expected to occur. If for whatever reason the coil pressure does drop below 20 psig, the volume of steam that can be generated is very small because any steam expansion in a closed loop system will quickly drive the pressure back to equilibrium $P_{sat}$ with the containment temperature.

**Question:**

b. **We understand that following a LOCA or MSLB with LOOP, the service water pumps will be automatically loaded onto emergency power. During this time, a steam void might have formed within the service water system which might cause waterhammer when the service water pumps are restarted. Please discuss the means by which air injection will be assured before the service water pumps are restarted. If the air is injected at an earlier time, please discuss the means which will assure that the air remains present and in the proper location.**

**Response:**

The air injection is only required upon restoration of the RBCU cooling to the IC system, the alignment for normal plant operations. Plant operating procedures have been revised to require this injection during this restoration. After this restoration, additional air injection is not required during normal operations. The injected air will remain in place due to the make up of differential pressures between that inside the pipe and the ambient pressures outside the pipe.

As noted in the previous response, following shutdown of SWBP A/B and transfer to IC, a vacuum void forms due to fluid column gravity drainage downstream of valve 3107A/B. Immediately after this transfer, compressed air is then injected into the vacuum void by the Operations staff in accordance with plant procedures such that the void is filled with air. The air is supplied via a plant air hose (connected only during the fill procedure). The air remains trapped between valve

3107A/B and the downstream standing water column until the next time SWBP A/B is started and the associated RBCUs are placed on SW cooling. The "injection" of air is merely for the convenience of the Operation staff. Initially, VCSNS Engineering had specified the "venting" of the piping to fill the vacuum with air. However, based on the size of the tubing to be used for this "venting", Operations staff concluded that an unreasonably long time would be required to assure the system was completely filled with air. Therefore, a means to "inject" air into the piping to speed up the process was developed and incorporated into plant procedures. Once the vacuum is replaced with air, no additional vacuum void formation or air in leakage is expected as long as valve 3107A/B remains closed. The fluid and air will remain stable in equilibrium at a pressure of approximately 1 atmosphere. Any fluid leakage past valve 3107A/B will drain through the void to the SW pond and not affect the air void.

VCSNS is in process of developing a modification that will install vacuum relief valves downstream of 3107A/B to eliminate the need for manual action to "vent" the piping.

**Question:**

**Describe the methodology by which structural piping and support loads were determined, including a description of the load combinations that were applied.**

**Response:**

Using the force time histories developed by the RELAP fluid hydraulic analysis as inputs, a classical time history piping analysis was performed using the computer program PIPESTRESS to determine pipe stress and pipe support loads.

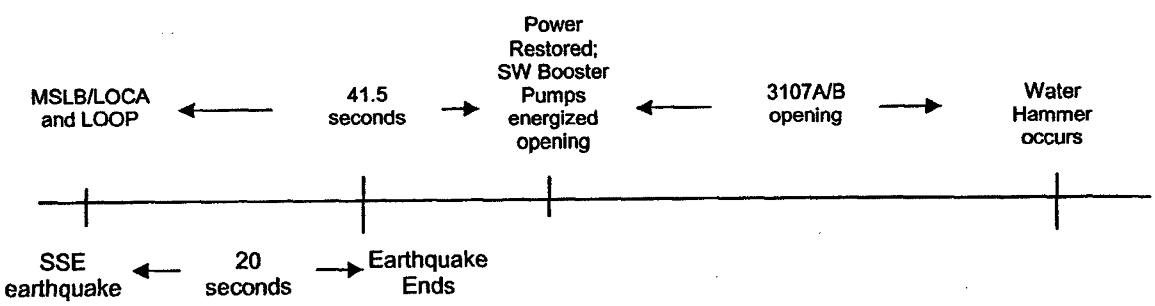
VCSNS considers this waterhammer to be an upset event that does not require the inclusion of a seismic event. VCSNS has applied the ASME Code, Section III, NC-3652 (1971 Edition through Summer 1973 Addenda) stress limits for an upset condition to the piping and pipe support qualifications. The following load combinations were used:

Pipe stress: 9U - Pressure + Deadweight + Waterhammer < 1.2 $S_H$

Pipe Support loads: Deadweight + Thermal Expansion + Waterhammer

Regulatory Guide 1.48 (Reference 6), with similar discussion in the VCSNS FSAR, states that for piping the code limits for the faulted condition shall not be exceeded when piping is subjected to concurrent loadings associated with the normal plant condition, the vibratory motion of the safe shutdown earthquake (SSE) and the dynamic system loadings associated with the faulted plant condition. Regulatory Guide 1.48 defines "the dynamic system loadings associated with the faulted plant condition" as those dynamic loadings which result from the occurrence of a postulated rupture (e.g., complete severance or equivalent longitudinal break area) of any reactor coolant pressure boundary piping or of any other piping not a part of the reactor coolant pressure boundary. Therefore, in terms of piping, the "LOCA" event to be combined with seismic is an event associated only with the dynamic structural consequences of a pipe break. The waterhammer loads in the SW piping need not be combined with the seismic loads if there is reasonable assurance that the two events would not occur concurrently.

An initiating event occurs which includes a LOCA or MSLB inside containment and a LOOP happening concurrently which initalizes the ESFAS. For loads on piping systems, the earthquake loads are combined with those from a LOCA. (Note: The VCSNS design basis does not require the consideration of the seismic event occurring coincident with any other transient, such as a LOCA. However, for conservatism, the loads on a structural piping system from a seismic event are combined with the loads from a LOCA event.) After the intiating events, the EDGs are energized and load sequencing is initialized which includes the transfer of RBCU cooling from the IC system to the SW system. VCSNS design basis defines the duration of an SSE to be 20 seconds. Therefore, 20 seconds after the intiating event, the earhquake ceases. 41.5 seconds after the initiating event, the SWBP A/B becomes energized and valve 3107A/B open restoring cooling flow through the RBCUs. This would cause a collapse of the void in the SW pipe and the consequential waterhammer as described in the above responses. This is depicted on the following timeline:




Therefore, the waterhammer loads do not need to be considered concurrent with the loads from LOCA/MSLB plus earthquake in the piping analysis. VCSNS considers this waterhammer event to be a separate event by itself that will always occur 41.5 seconds after an event causing the plant to enter into the SI mode, or during switch over of RBCU cooling from the IC system to the SW system which is permitted during normal operations and during surveillance testing. (Note: VCSNS design basis does not require an earthquake to be considered concurrent with these transfers in which the system is in limited operation.)

Conclusion

VCSNS believes that the current analysis as described above adequately qualifies the as built piping and pipe supports of the RBCU discharge piping for the loads associated with the waterhammer conditions described in GL 96-06. It is noted that the VCSNS as-built SW piping has experienced the GL 96-06 waterhammer event discussed herein many times over the twenty three years of plant operation. During this time, no damage to the SW piping or pipe supports has ever been reported.

Planned Modifications

VCSNS has initiated a plant modification that will significantly improve, if not eliminate, the waterhammer condition associated with the GL 96-06 concerns. These changes are not required to address any deficiencies in the ability of the plant to meet its current design and licensing bases, but they will reduce operator burden and increase design margins. VCSNS is utilizing

structural piping analysis that uses bounding fluid hydraulic force time histories developed by RELAP5 in the development of this modification. These changes are currently scheduled for completion in RF-16 (October 2006). This modification will accomplish two changes to the current plant configuration for SW discharge from the RBCUs. First, this modification will delay the opening of valve 3107A/B upon start up of the SWBP A/B. This delay will allow SWBP A/B to build up fluid momentum and full fluid flow prior to the opening of valves 3107A/B. This will prevent the gravity drain-down of fluid to the SW pond thereby preventing the creation of a vacuum void, i.e., the second void on Figure 1 will not develop. Preventing creation of this void reduces piping and support loads. Second, the modification will install vacuum relief valves downstream of valves 3107A/B which will automatically fill with air any void formed at this location due to gravity drain-down to the SW pond (first void on Figure 1). These vacuum relief valves will preclude the requirement to manually fill the vacuum void with air whenever the SW supply to the RBCUs is secured. They will provide assurance that air will always be present in the void. The combined affects of these two modifications will reduce the waterhammer loads in the piping to very low levels.

**Question:**

**Confirm that the proposed plant modifications for resolving the GL 96-06 waterhammer issue will satisfy all applicable criteria that have been established for safety-related applications (e.g., seismic, single failure, environmental qualification, power supplies) and that the requirements of 10 CFR 50, Appendix B are fully applicable. Also, describe Technical Specification Requirements that will be established to assure operability.**

**Response:**

Station Administrative Procedure SAP-133, "Design Control/Implementation and Interface", controls plant modifications implemented at VCSNS. This procedure is governed by 10CFR50, Appendix B. Design input considerations are evaluated for Appendix B requirements, FSAR Section 17.2 (Quality Assurance) commitments, and Technical Specifications, Section 6.5 (Technical Review and Control). The VCSNS Modification Program also satisfies ANSI N45.2.11-1974, "Quality Assurance Requirements for the Design of Nuclear Power Plants". Engineering Services procedure ES-455, "Design Control: Plant Modification" and procedure ES-454, "Design Control: Plant Enhancement" address initiation, design considerations, design reviews, implementation, and documentation of VCSNS plant modifications. SAP-107, "10CFR50.59 Review Process" additionally controls plant changes, where applicable.

There are existing Technical Specification surveillance requirements on the RBCUs and the plant systems, structures, and components that interface with the RBCUs. SCE&G considers these existing requirements sufficient based on our plant design and, therefore, plans no additional Technical Specification requirements.

**Question:**

**Establish a regulatory commitment to complete any actions that remain, such as plant modifications and TS changes, along with the scheduled completion dates.**

The planned modifications will be implemented during VCSNS refueling outage RF-16 and are projected to be complete by December 31, 2006. No other actions are identified for this issue.

**Question:**

**As requested in Section 3.3 of the staff's safety evaluation dated April 3, 2002, that approved the use of the proposed methodology in EPRI Technical Reports 1003098 and 1006456 for resolving the GL 96-06 waterhammer issue, please provide certification that plant-specific considerations are consistent with the risk perspective that was provided by EPRI in a letter dated February 1, 2002, and included as an enclosure to these technical reports.**

**Response:**

Assuming that the planned system modifications have been made, the following is an assessment of the risk to the plant of the application of RELAP5/MOD3 using as a basis the assessment provided by EPRI in a letter dated February 1, 2002 (hereinafter referred to as Reference 7). A review of the "progression" of events that could lead to an unacceptable condition is listed. For the purposes of this evaluation, the "unacceptable condition" following a LOOP/LOCA event will be defined as a breach of the service water system pressure boundary. The events are as follows.

1. Occurrence of a LOCA or MSLB - Discussion same as that noted in Reference 7.
2. Occurrence of a LOOP following a LOCA or MSLB - Discussion same as that noted in Reference 7.
3. Occurrence of a Simultaneous LOCA/LOOP Event - Discussion same as that noted in Reference 7.
4. Void Formation - A void will form in the SW return piping outside containment due to fluid gravity drain. This void is air-filled (because of the new vacuum breaker), is the normal configuration, and exists whenever the upstream containment isolation valve (3107A or 3107B) is closed. No significant voiding will occur in the RBCU piping upstream of 3107A/B.
5. Pump Restart - The pumps will restart with certainty and the velocity of the fluid in the pipe, immediately prior to closing the void, is defined by the dynamic pressure in the void, the piping geometry (losses from wall friction and fittings such as valves, elbows, tees, and orifices) and the pump characteristics. This un-cushioned[4] closure velocity has been

[4] Meaning the assumed amount of entrained air in the flow from the SWBP is so small as to be insignificant. The sonic velocity is approximately 5000 feet per second for the subcooled upstream water column.

calculated by RELAP5/MOD3. As noted in responses to other NRC questions, the RELAP5-based closure velocities and associated segment forces are considered conservative because they are substantially higher than what was experienced in the plant for one of the analyzed transient scenarios (see response to previous question). The liquid flow velocity downstream of valve 3107A/B, when the pipe is running full, peaks at about 5.25 feet per second. Because of the 30 seconds opening time of valve 3107A/B, and the flow orifice 29A/B immediately downstream, the incident water column is disorganized (mixed) as it encounters the air mass between valve 3107A/B and the standing water column. Because the standing water column is receding (draining) while the vacuum breaker is open, the effective relative velocity between the incident water column and the receding column is quite small.

6. Column-closure - Discussion same as that noted in Reference 7.

7. Maximum Waterhammer Pressure - Application of the Joukowski correlation to the incident water columns downstream of valve 3107A/B results in very low calculated pressures (typically 25 psi or less increase) because the mixture density is low, the sonic velocity is very low because of the two-phase conditions, and because the slow valve opening time of approximately 30 seconds causes the velocity differentials to be comparatively low. It should be noted, however, that the calculated segment forces were computed not on the analyzed pressure rise, but on the net segment wave force from the total momentum equation. The transient force in each pipe segment is the sum of the liquid total mass-acceleration and vapor mass-acceleration over each 0.0002 second time step. In RELAP5, the mass-acceleration force is computed from the rate of change of the mass rates for each volume. Where the liquid mass rate for a volume is:

   ***The time-derivative (differend) of the quantity: liquid density (rhof) x volume liquid velocity (velf) x liquid fraction (voidf) x volume size (vvol).***

   The same computation is performed for the vapor phase, for all volumes in each (straight) pipe segment. The computation is performed for each RELAP5 time step, and then smoothed using a lag function with a 0.002 second time constant to ensure that no numerical force peaks are clipped or lost between the 0.002 second minor-edit write intervals required for the piping analysis.

   It is this conservative approach that helps ensure the design-basis RELAP5 force-time history data bounds what is experienced in the actual plant during safeguards testing.

8. Cushioned Waterhammer – No credit was taken for cushioning effects[5] due to air entrained in solution with the SW source water. In the RELAP5 analysis only a trace amount of non-condensable air was added to the SW supply, to facilitate phase calculation stability when the incident subcooled water encounters the large air volume from the vacuum breaker. The non-condensable quality of the SW supply in the RELAP5 model is 1.0E-8 at 95°F. The resulting code-calculated sonic velocity in the liquid-filled pipe sections was approximately 5000 feet per second.

[5] Note that "Cushioned Waterhammer" as used in the EPRI methodology refers to a reduction in the waterhammer pressure rise when non-condensable gas is dissolved in solution in the SW supply. The pressure reduction is due principally to the decrease in sonic velocity because of the presence of dissolved gas. Cushioning in the EPRI methodology is not the force-reduction effect that occurs when a large air volume is trapped between the incident water columns.

9. Likelihood of an Unacceptable Event - Discussion same as that noted in Reference 7 except the use of RELAP5/MOD3 replaces the use of the EPRI User's Manual and the Technical Basis Report. The discussion therefore reads: Given the low probability ($10^{-5}$/year) of the initiating events and the low probability ($10^{-2}$) of piping failure, the use of the methodology using RELAP5/MOD3 will lead to a likelihood of an unacceptable event that is on the order of $10^{-7}$. Again, for the purposes of this evaluation, the "unacceptable event" following a LOOP/LOCA event is taken as a breach of the SW system pressure boundary. The probability of $10^{-7}$ for this event is below the threshold for significant risk to the plant. Use of the methods employing RELAP5/MOD3, therefore, will not compromise the safety of the plant for the systems within the bound provided by the RELAP5/MOD3 analysis. The methodology should be accepted as recommended.

The change in risk introduced by the use of RELAP5/MOD3 and the method employed is not significant and the methods do not lead to an unacceptable plant risk following a LOOP/LOCA event. Hence, from a risk-informed perspective, the methods proposed are adequate for the plant-specific application for resolution of the GL 96-06 issues.

**Additional Discussion Pertaining to VCSNS System Performance**

Other Waterhammer Condition in SW piping not directly related to the GL 96-06 waterhammer condition:

As noted previously, it is assumed that the GL 96-06 waterhammer condition occurs when the plant is operating in its normal alignment with the RBCUs aligned with the IC system for cooling. During the effort to address the GL 96-06 waterhammer, another waterhammer scenario was identified. This waterhammer is postulated to occur during the time that the RBCUs are aligned with the SW system and a LOOP occurs. This alignment of the RBCUs is not a normal alignment. The RBCUs are aligned to the SW system only during quarterly testing, IC system maintenance and during refueling outages. In addition, this waterhammer condition is simulated in the plant every outage during safeguards testing. No anomalies of the piping or supports have ever been observed due to this waterhammer. However, SCE&G has incorporated the piping loads of this waterhammer into the plant design basis and has performed an analysis of the condition. Even though the actual waterhammer results in no anomalies of the pipe supports, this analysis predicted the presence of very high loads on pipe supports. SCE&G has developed interim measures and has scheduled the implementation of a plant modification to reduce these loads to levels that are analytically acceptable. This waterhammer condition, the interim measures and the plant modification for mitigation are at issue in the following RAIs.

**Question:**

**Explain why the scenario with the safety-related service water system aligned to provide cooling for the RBCUs at the onset of the postulated accident does not result in a more severe waterhammer event, or otherwise establish appropriate restrictions in the Technical Specifications on use of the service water system for RBCU cooling during normal plant operation.**

**Response:**

The scenario with the safety-related SW system aligned to provide cooling for the RBCUs at the onset of the postulated accident does result in a more severe waterhammer event than the waterhammer resulting from the GL 96-06 scenario described in the preceding review discussion. The RBCUs are typically aligned with the SW system during quarterly surveillance tests, IC system maintenance and during plant outages. If a LOOP were to occur during this alignment, as noted in the review discussion (page 1 of 34), from the time of LOOP, it will take approximately 41.5 seconds for the EDGs to start and the ESFAS sequencing to complete. After which the SWBPs will energize.During this 41.5 seconds, the column of fluid in the piping downstream of the RBCUs will gravity drain-down to the SW pond (Refer to Figure 2, p.33 of this attachment). This will form a large void in the piping. Upon SWBP re-start and the commencing of fluid flow, the void will rapidly collapse creating a significant waterhammer. Comparative analysis using RELAP5/MOD3 has shown that the waterhammer event from this scenario to be of greater severity by several magnitudes than that of the GL 96-06 scenario previously described.

In order to mitigate the affects of this waterhammer on the piping system, VCSNS has adopted a two-phase approach. The first is an interim phase that provides adminitrative and procedural controls over the use of the SW system for cooling to the RBCUs. The second is a modification to change valve closing and opening times and their coresponding initiating logic to permanently eliminate the waterhammer concerns. This modification is scheduled for implementation during RF16 in the fall of 2006. These two phases are discussed in detail in the following paragraphs.

In the first phase until the plant modification is implemented, the procedure for SW system operation, SOP-117, "Service Water System", has been revised to include a special set of initial conditions prior to aligning the system to the RBCUs. These conditions are intended to minimize the risk for a LOOP during the SW alignment, minimize the time duration the RBCUs are aligned to the SW system and to remind operations of the potential for a waterhammer in the event of a LOOP. These intial conditions are summarized as follows:

- In Modes 1 through 4, SW shall only be supplied to the RBCUs, when one or more of the following conditions are met:
    a. Post Accident or High Containment Pressure Conditions.
    b. Loss of Non-ESF power.
    c. Loss of IC.
    d. During testing.

- In Modes 1 through 4, when SW is being supplied to the RBCUs, all the following conditions shall be met:
    a. No planned work is allowed in the switchyard.
    b. The dispatcher confirms that no transmission system work is planned that would decrease the reliability of the off site power supplies.
    c. There is no severe weather predicted in South Carolina for the expected duration of the testing.
    d. If for surveillance testing or post maintenance testing, the testing has been approved as if it were a (Yellow) MODERATE Risk Activity.
    e. If for any other reason, the testing has been approved as if it were an (Orange) ELEVATED Risk Activity.

The second phase requires the implementation of a plant modification in the fall of 2006. This modification will include (Refer to Figure 3, p.34 of this attachment):

- The replacement of gate valve 3107A/B with a fast closing butterfly valve that closes in seven seconds upon de-energizing of SWBP A/B. The fast valve closure will trap water in the high points above the valve and prevent void formation from gravity drain-down of the water to the SW pond. This will prevent any waterhammer event that would have occurred upon re-energizing the SWBPs and a consequential rapid collapse of the void.

- The addition of vacuum relief valves downstream of valve 3107A/B. These valves will replace with air any vacuum void downstream of closed valve 3107A/B that may be formed due to gravity drain-down of water to the SW pond. Upon the opening of valve 3107A/B and the re-start of SWBP A/B, the air in the piping will act as a cushion to minimize any waterhammer affects that could occur at that time. In addition, these relief valves will eliminate the need for operations to manually vent the piping downstream of valve 3107A/B immediately after the transfer of RBCU cooling from the SW system alignment to the IC system as noted in the preceding review discussion and discussed in following question responses.

- The opening logic of valve 3107A/B will be modified to have a 5 seconds delayed opening after SWBP A/B start. The delayed start of the valve opening will assure that additional void formation in the RBCU piping inside containment will not occur upon re-energizing the SWBP.

NOTE: The addition of vacuum relief valves and the delayed opening time at the valve 3107A/B location also help to mitigate the GL 96-06 waterhammer condition and are taken credit for as such.

Fluid hydraulic analysis using RELAP5/MOD3 and pipe stress analysis using the computer program PIPESTRESS have concluded that these modifications will largely eliminate the potential for waterhammer in the RBCU piping. The analysis concludes that the post modification waterhammer loads on the piping develop stresses in the piping that are well below the ASME Code allowables.

**Question:**

**Assuming that the planned system modifications have been made, describe the results of a comparative analysis using analytical methods that have been approved by the NRC for this purpose (i.e., EPRI methodology or NUREG/CR-5220) that demonstrates that the RELAP results are conservative for the worst-case waterhammer location that was identified by the RELAP analysis.**

**Response:**

VCSNS Technical Specification surveillance requirement 4.8.1.1.2.g.4 states: "Each EDG shall be demonstrated operable at least once every 18 months by simulating a loss of offsite power by itself..." VCSNS surveillance test procedure STP-125.017, "Diesel Generator 'A' Loss of Offsite Power Test", contains the operating instructions that are conducted to demonstrate compliance with this requirement. These instructions, performed each refueling outage, have as an initiating condition the alignment of the SW system to the RBCUs followed by a simulated LOOP. Therefore, this test simulates exactly the waterhammer condition described in Figure 2. Since initial plant operations, at least ten of these surveillance tests have been conducted. This means that the piping and pipe supports have been subjected to these waterhammer loads at least ten times. Waterhammer within the SW piping during these tests have been reported. However, the severity of the actual waterhammer has not been of the magnitude to cause any concern. This past refueling outage (May 2005) a walk down of the SW piping and pipe supports downstream of the RBCUs was conducted. The intent was to provide assurance that no damage existed in the piping or pipe support components. During this walk down, particular attention was drawn to welded attachments, support rods and support pins for any signs of deformation. In addition, observations were made at pipe welds and fittings for any indications of cracked or flaking paint and at pipe supports for paint rubbed off piping indicating recent pipe motion. No visible anomalies were found. This provided assurance that the actual waterhammer event occurring during each surveillance test was developing acceptable loads within the piping. However, the RELAP5/MOD3 fluid hydraulic analysis (for the Figure 2 scenario) has predicted very high waterhammer loads, loads that would create forces on pipe supports that would easily create deformation in many pipe support components. Therefore, the surveillance tests have provided empirical evidence that the waterhammer loads developed by the RELAP5/MOD3 analysis are very conservative and demonstrate that RELAP5/MOD3 is the appropriate tool to be used in predicting the waterhammer loads for the design of the structural piping system.

Response References

1. Engineering paper ICONE12-49214 Calculation of Forces on Reactor Containment Fan Cooler Piping, by Joseph S. Miller/EDA, Inc. and Kevin Ramsden/Exelon Nuclear, Proceedings of 12th International Conference on Nuclear Engineering, Arlington, Virginia, April 25-29, 2004.
2. Engineering paper Qualification of RELAP5/MOD3 for Safety Relief Valve Hydrodynamic Load Analysis: A Comparison Against EPRI/CE SRV Test 1017, by P. R. Boylan (Touch Base Computing, Inc.), and D.W. Peltola (Vectra Technologies), Presented at the 1994 International RELAP5 Conference, Baltimore, Md.
3. "Generic Letter 96-06 Waterhammer Issues", Technical Report and User's Manual, 1006456, EPRI Project Manager - A. Singh, (April 2002).
4. "Generic Letter 96-06 Waterhammer Issues" - Technical Basis Report, EPRI # 1003098, (April 2002).
5. NUREG/CR-5535/Rev1, RELAP5/MOD3.3 VOLUMES 1 through 8, Prepared by Information Systems Laboratories, Inc., Idaho Falls, ID for Division of Systems Research, NRC, Washington, DC 20555. December 2001.

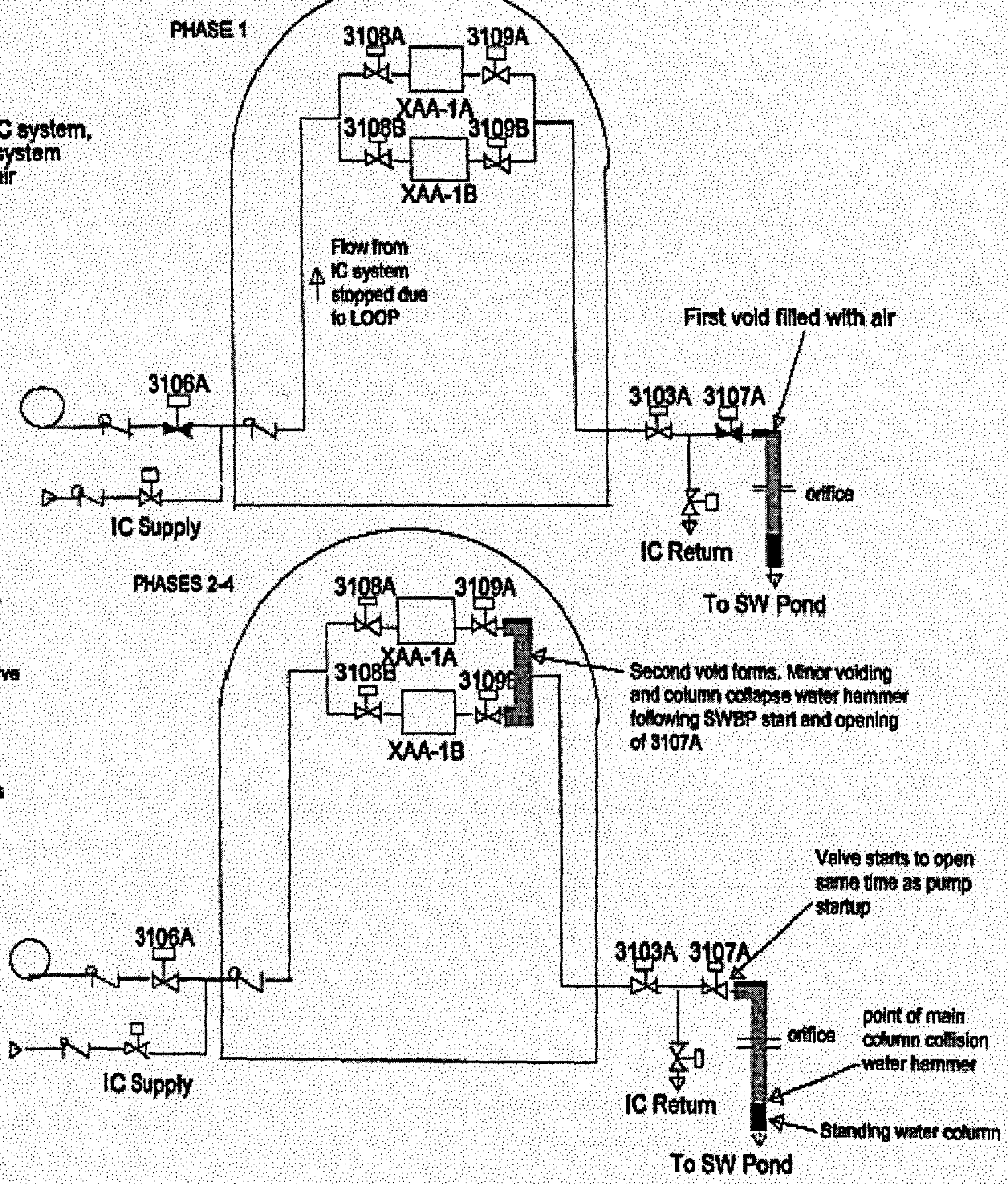
6. NRC Regulatory Guide 1.48, "Design Limits and Loading Combinations for Seismic Category I Fluid System Components".
7. EPRI Letter to Document Control Desk, U.S. Nuclear Regulatory Commission (Attn: Mr. Jim Tatum), dated 1/1/202, Subject"Response to ACRS Comments (letter dated 10/23/01) on EPRI Report on Resolution of NRC GL96-06 Waterhammer Issues".

# FIGURE 1

Initial Condition -System aligned with IC system, void downstream of 3107A vented by system operating procedures to be filled with air

Initiating Event - LOCA/MSLB + LOOP

PHASE 1 - First void formed downstream of 3107A due to drain down of fluid to SW pond filled with air.
PHASE 2 - 41.5 seconds after LOOP, 3107A begins to open simultaneous with SW booster pump startup. 3107A is a gate valve which allows significant flow immediately after the start to open. Flow from pump can not keep up with gravity drain down through valve resulting in a second vacuum void formation.
PHASE 3 - full flow of pump start causes collapse of second void in RB causing water hammer events in two 10" pipe
Phase 4 - Void downstream of 3107A collapses causing second water hammer in 16" pipe



Proceedings of 12th International Conference on Nuclear Engineering
"Nuclear Energy - Powering the Future"
Hyatt Regency Crystal City
Arlington, Virginia (Washington, D.C.), USA
April 25-29, 2004

ICONE12-49214

# Calculation of Forces on Reactor Containment Fan Cooler Piping

Joseph S. Miller/EDA, Inc.
*6397 True Lane*
*Springfield, VA 22150*
Phone: 703 597-2459, Fax: 703 313-9138
e-mail: JoeMiller@edasolutions.com

Kevin Ramsden/Exelon Nuclear
Mechanical Engineering, LLC
4300 Winfield Road
Warrenville, IL 60555
Phone: 630 657-3892, Fax: 630 657-4328
e-mail: Kevin.ramsden@exeloncorp.com

## ABSTRACT

The purpose of this paper is to present the results of the Reactor Containment Fan Cooler (RCFC) system piping load calculations. These calculations are based on piping loads calculated using the EPRI methodology (Refs. 1 & 2) and RELAP5 (Ref. 3) to simulate the hydraulic behavior of the system. The RELAP5 generated loads were compared to loads calculated using the EPRI GL 96-06 methodology. This evaluation was based on a pressurized water reactor's RCFC coils thermal hydraulic behavior during a Loss of Offsite Power (LOOP) and a loss of coolant accident (LOCA). The RCFC consist of two banks of service water and chill water coils. There are 5 SX and 5 chill water coils per bank. Therefore, there are 4 RCFC units in the containment with 2 banks of coils per RCFC. Two Service water pumps provide coolant for the 4 RCFC units (8 banks total, 2 banks per RCFC unit and 2 RCFC units per pump).

Following a LOOP/LOCA condition, the RCFC fans would coast down and upon being reenergized, would shift to low-speed operation. The fan coast down is anticipated to occur very rapidly due to the closure of the exhaust damper as a result of LOCA pressurization effects. The service water flow would also coast down and be restarted in approximately 43 seconds after the initiation of the event. The service water would drain from the RCFC coils during the pump shutdown and once the pumps restart, water is quickly forced into the RCFC coils causing hydraulic loading on the piping. Because of this scenario and the potential for over stressing the piping, an evaluation was performed by the utility using RELAP5 to assess the piping loads. Subsequent to the hydraulic loads being analyzed using RELAP5, EPRI through GL 96-06 provided another methodology to assess loads on the RCFC piping system. This paper presents the results of using the EPRI methodology and RELAP5 to perform thermal hydraulic load calculations and compares them.

## NOMENCLATURE

EPRI – Electric Power Research Institute
CIWH - Condensation Induced Waterhammer
LOCA - Loss of Coolant Accident
MSLB – main Steam Line Break
RCFCs – Reactor Containment Fan Coolers
SX - Emergency Service Water System

## INTRODUCTION

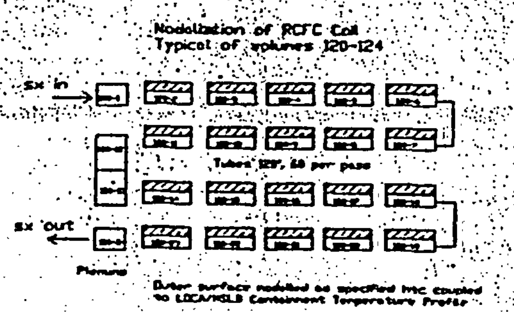
Following either a Loss of Coolant Accident (LOCA) or a Main Steam Line Break (MSLB) concurrent with a Loss of Offsite Power (LOOP), pumps that supply cooling water to reactor containment fan coolers (RCFCs) and fans that supply air to RCFCs will temporarily lose power. Cooling water flow will stop due to the loss of pump head. Boiling may occur in RCFC tubes, causing steam bubbles to form in RCFCs and pass into the attached piping, creating steam voids. As service water pumps restart, accumulated steam in the fan cooler tubes and piping will condense and the pumped water can produce a waterhammer when the void closes. Hydrodynamic loads introduced by such a waterhammer event could potentially challenge the integrity and function of RCFCs and associated cooling water system components. The U.S. Nuclear Regulatory Commission (NRC) Generic Letter 96-06 identified potential issues for waterhammer effects during postulated events that can cause potential damage to service water systems. In response to GL 96-06, the Electric Power Research Institute (EPRI) and the nuclear power plant owners developed methodologies to evaluate these events. The EPRI methodologies are presented in References 1 and 2.

Another methodology used by the utility was to calculate the hydraulic loads using RELAP5 (Ref. 3). RELAP5/MOD3 is a "best estimate" system code suitable for the analysis of all transients and postulated accidents in Light Water Reactor (LWR) systems, as well as the full range of operational

transients. RELAP5 can also be used to model piping systems that contain two-phase and sub cooled liquid. The one dimensional RELAP5/MOD3 code is based on a non-homogeneous and non-equilibrium model for the two-phase system that is solved by a fast, partially implicit numerical scheme to permit economical calculation of system transients.

The RCFC system was modeled using RELAP5 and hydraulic forcing functions were developed from these analyses. The RELAP5 model was initialized using option 4 to include a small amount of air in the fluid. The fraction was kept as small as possible, typically less than 25% of what could be dissolved in the fluid. The main reason for the air was not to get cushioning effects, but rather to prevent negative pressures from terminating the computer run during spiking behavior. Draindown of the RCFC system was determined dynamically by modeling the boundary conditions of pump coast down simultaneous with LOCA temperatures and heat transfer effects on the fan coolers using RELAP5. The boundary conditions and modeling assumptions were selected to maximize the void creation and maximize the potential for dynamic effects on SX pump restart. A postprocessor was developed and used to calculate the forces from RELAP5 generated pressure, densities, fluid velocity and user provided areas. The RELAP5 nodal diagram for the RCFC is shown in Figure 1.

**Figure 1 RELAP5 Nodal Diagram**



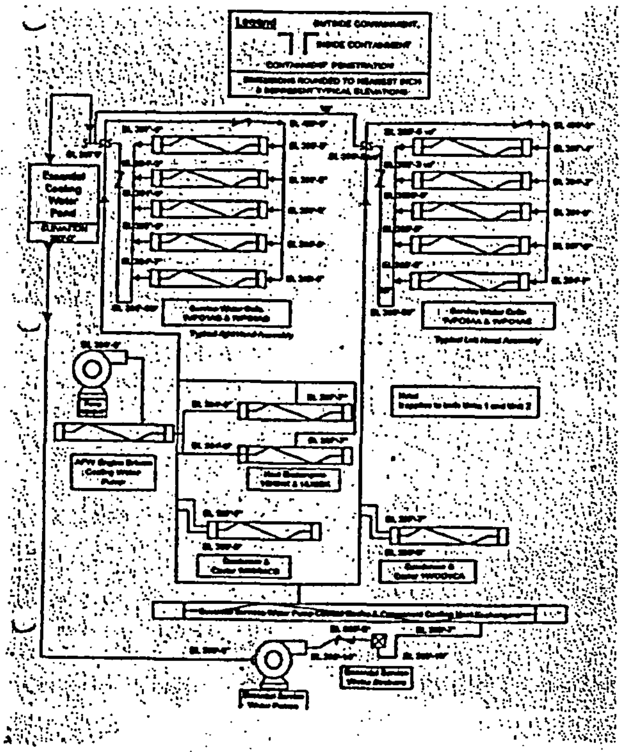

## DISCUSSION

The purpose of this paper is to provide a comparison of thermal hydraulic load calculations based on using EPRI methodology (Ref. 1 & 2) and using RELAP5 simulator to determine the hydraulic loads of the RCFC system subsequent to a LOOP and a LOCA. This paper discusses the results of the evaluation of Reactor Containment Fan Cooler (RCFC) coils thermal hydraulic behavior during a LOOP/LOCA using the EPRI GL 96-06 methodology and RELAP5.

A diagram of the RCFC system is shown in Figure 2. The RCFC consist of two banks of service water and chill water coils. There are 5 SX and 5 chill water coils per bank. Therefore, there are 4 RCFC units in the containment with 2 banks of coils per RCFC. Two Service water pumps provide coolant for the 4 RCFC units (8 banks total, 2 banks per RCFC unit and 2 RCFC units per pump). In normal operation, both sets of coils have a flow, and the RCFC fan is operating in a high speed mode. Following a LOOP/LOCA condition, the fans would coast down and upon being reenergized, would shift to low-speed operation. The fan coast down is anticipated to occur very rapidly due to the closure of the exhaust damper as a result of LOCA pressurization effects. The exhaust dampers would also have the effect of trapping air, creating a low flow, or an upswept zone around the coils that would not favor condensation. The SX flow would also coast down and be restarted in approximately 43 seconds after the initiation of the event. The chill water would not be restarted in a typical design basis accident scenario.

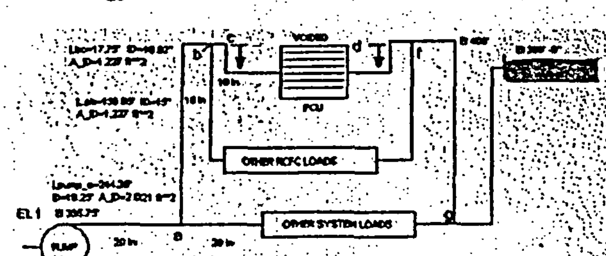
The schematic of the RCFC/SX system is shown in Figure 3. The designation on Figure 3 refers to the same designation presented in Ref. 1 for an open loop system (See Figure 7-1 of Ref. 1). The designation of c represents the front edge of the void and d represents the back edge of the void. The void is contained in the volume of the fan cooler unit (fcu) and the attached piping including the 10" riser. The fcu is represented in this case as 5 coils (1/2 of 1 RCFC unit). The flow path is as follows: Water leaves SX pump and branches from a 36" header pipe into a 20", which is designated as the pump location. From the 36 x 20 tee, the flow travels 244.35' to a 20" x 16", which is designated as point a. From point a, the flow travels through a 16" pipe for 138.85' to the first flow split into a 10" riser going to the 5 fcu coils. At this point, which is designated as point b, the flow is split by ¼ to ¾, with ¼ of the flow going down the 10" riser and feeding the 5 coils and the remaining ¾ flow steam proceeding to the other half of the RCFC 2D and to RCFC 2B. The point designated as c is located in the 10 " riser at 17.75' below the 16" x 10" split designated as point b. The 10" riser evenly distributes the flow through the 5 coils through 4" pipes that tee from the 10" riser. These 4" pipes run in parallel and are reduced to 3" pipes, which go into a coil. The point designated as c is the front edge of the void.

**Figure 2 RCFC SYSTEM**



The steps that are specified by the EPRI methodology are: 1) Evaluate the System, 2) Model System Hydraulics, 3) Determine Condensation Induced Waterhammer (CIWH) magnitude, 4) Determine Potential Closure Locations, and 5) Determine Column Closure Waterhammer (CCWH) Magnitude and Pulse Characteristics.

**Figure 3 Schematic of RCFC According to EPRI Methodology**



The most significant aspect of the calculation using the EPRI methodology was determining the peak pressure pulse. The peak pressure pulse is affected by pressure reflections from other obstruction downstream from the initial pressure pulse. During a column closure event, the pressure rises as the void closes. This rising pressure travels upstream and downstream from the closure location. As the pressure pulse encounters area changes, a portion of the original pressure wave is reflected back toward the closure location. The reflected pressure wave will add to the pressure it encounters in a positive or negative manner. If the reflection comes from an expansion, then it will have a negative magnitude and cause the oncoming pressure to be reduced. The peak pressure will be "clipped" if the reflection reaches the closure location before the pressure peaks. In the case of the RCFC pressure pulse evaluated in this paper, the distance from the pressure pulse to the expansion at point "b" is only 17.75', therefore pressure clipping is expected. Ref. 1 has provided guidance for determining pressure clipping. Since References 1 and 2 are proprietary documents, only the final results will be presented here.

The peak pressure is checked for "clipping" using Table 5-3 of Reference 1. Point "a" is checked (See Figure 3). The primary factors used to calculate the peak pressure are: length of void ($L_{cd}$), release of non-condensables to calculate the cushioned velocity, determine the pressure pulse shape, determine the pressure pulse magnitude, rise time and peak pressure duration, and determine reflective pressure wave. From these elements, the clipped peak pressure can be determined. The pressure reflection from the first major expansion in the piping system will cause the initial pressure wave created from the water hammer to be clipped (i.e., reduced) based on the speed of the refection wave to and from the major expansion and the degree of expansion. In addition, the pressure pulse is cushioned by the non-condensables in the water.

The unclipped pressure is 126 psi and the clipped pressure pulse is 64 psi. The system pressure is added to this value. The resultant pressure pulses using the EPRI mythology with cushioning and non-cushion effects considered are presented in Figure 4.

RELAP5 was used to simulate the LOOP/LOCA event. The pressure pulse calculated from the RELAP5 simulation is shown in Figure 5. As you can see from Figure 5, the pressure pulse from the RELAP5 calculation is slightly larger than the pressure pulses calculated using the EPRI methodology.

To evaluate the loads on the piping system, it was assumed that PA represented the force on the piping system. Figure 6 shows that hydraulic load of the RELAP5 pulse is greater than the hydraulic load of the EPRI pulses.

**Figure 4 Pressure Pulse Using EPRI Methodology**

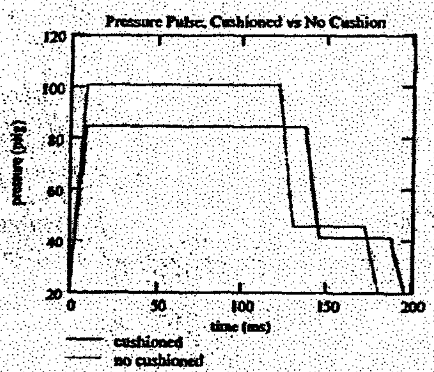
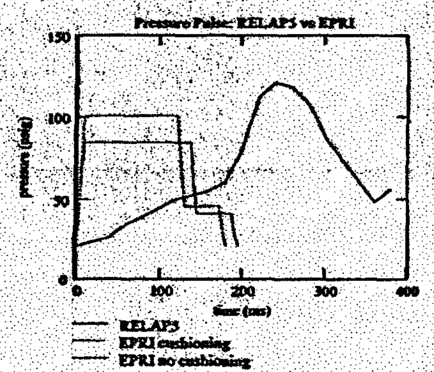
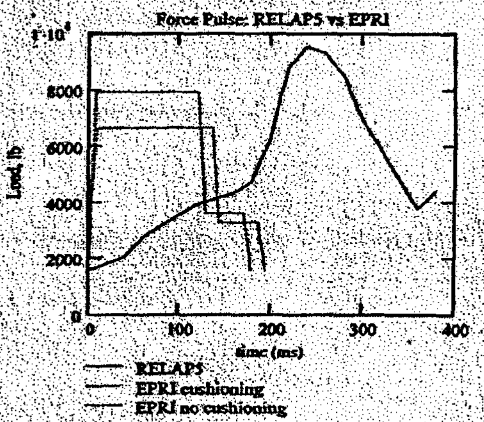



**Figure 5 RELAP5 and EPRI Methodology Pressure Pulses**




In conclusion, it was determined that the EPRI methodology and the RELAP5 calculations can be used to generate hydraulic loads for the RCFC system. The RELAP5 calculated hydraulic loads for this analysis produced larger loads than the loads developed using the EPRI methodology. The reason that RELAP5 results produced a larger load was due to the

**Figure 6 Force Pulse Comparison Using RELAP5 and EPRI**




conservative modeling assumptions used in RELAP5. These assumptions were as follows. The SX pump start was assumed to occur in 1 second. The HEM choking model was used sparingly, only enabled at the coil exits and at the transitions from inlet headers to the large bore piping. Only a very small quantity of air was introduced.

## ACKNOWLEDGMENTS

We would like to thank Jeff Drowley and Exelon Nuclear for supporting this work.

## REFERENCES

1) "Generic Letter 96-06 Waterhammer Issues", Technical Report and User's Manual, 1006456, EPRI Project Manager - A. Singh, (April 2002)

2) "Generic Letter 96-06 Waterhammer Issues - Technical Basis Report, EPRI # 1003098, (April 2002).

3) NUREG/CR-5535/Rev1, RELAP5/MOD3.3 VOLUMES 1 through 8, Prepared by Information Systems Laboratories, Inc., Idaho Falls, ID for Division of Systems Research, NRC, Washington, DC 20555, December 2001.

# QUALIFICATION OF RELAP5/MOD3 FOR SAFETY RELIEF VALVE HYDRODYNAMIC LOAD ANALYSIS: A COMPARISON AGAINST EPRI/CE SRV TEST 1017

by
**Philip R. Boylan**
**Touch Base Computing, Inc., Rome Ga.**
**David W. Peltola, PE**
**Vectra Technologies, Inc., Norcross, Ga.**
**Kirk L. Beck, PE**
**Duluth, Ga.**

## Abstract

This paper documents the acceptability of the default two-velocity momentum equation option in the RELAP5/MOD3 computer program for the estimation of hydrodynamic loads associated with steam safety relief valve discharge. A RELAP5 analysis of the EPRI/Combustion Engineering Safety Valve Test Loop Facility was performed. Time-dependent hydrodynamic forcing functions for the four pipe segments of the Combustion Engineering Test Facility were developed. These forcing functions were subsequently used in an elastic piping analysis model to estimate the resultant structural responses. The calculated loads were then compared to the values from the original 1981 Test data (Dresser safety valve Test 1017 with cold water loop seal). The results verify that RELAP5/MOD3 and the REFORC post-processor can be used with confidence to calculate hydrodynamic forces for use in pipe stress and support analysis.

## Introduction

The release of RELAP5/MOD1in the early 1980's coincided with a need within the nuclear industry to perform detailed analysis of Safety Relief Valve (SRV) hydrodynamic loads. RELAP5 (Reactor Excursion and Leak Analysis Program) was developed for best-estimate transient simulation of light water reactor coolant systems during a severe accident. RELAP5's ability to model complex steam-water interactions and maintain separate fluid phases made it a promising candidate for application to SRV analysis. The Electric Power Research Institute (EPRI) and Intermountain Technologies, Inc. showed (Ref. 2) that if specific modeling rules were followed, reasonably good results could be achieved. The use of RELAP5 for steam-water hammer analysis generated significant controversy among code users and developers because the code numerics were designed primarily for efficient simulation of reactor coolant system transients. Computation of water hammer effects in relatively small piping was considered outside the code's approved application. The controversy continues to the present. Opinions of code developers and analysts at EG&G Idaho, Inc. range from not using the code at all for these types of problems, to using it with qualifications (Ref. 5).

The current release of the code is RELAP5/MOD3. A number of improvements have been made since the initial MOD1 release. Significant for hydrodynamic load analysis was the implementation of separate vapor and liquid junction calculations. RELAP5/MOD1 used a combined velocity for both phases. The single velocity calculation produces larger hydrodynamic loads and remains an input option in RELAP5/MOD3. The work documented by this paper shows that RELAP5/MOD3, properly applied, can provide conservative hydrodynamic loads for input into "real-world" piping support design.

## Application of RELAP5/MOD3 To S/RV Hydrodynamic Load Analysis

### Objectives and Concerns

The RELAP5 modeling guidelines recommended by Reference 2 sometimes require unacceptable compromises when analyzing typical SRV configurations in U.S. pressurized water reactors (PWRs). For example, the recommendation that cold water loop seals be initialized immediately downstream of the safety valve simply cannot be reasonably applied to some configurations, particularly those with long loop seals and vertical elbows located near valve outlets. Placing the loop seal downstream also creates a problem in calculating loop-seal related loads for the Class 1 piping upstream of the SRV. A third consideration is that RELAP5/MOD1 analyses of complex multiple SRV systems with long discharge piping runs have often produced extraordinarily high loads in pipe segments far removed from the SRVs. The CE test data indicate that loop seal breakup occurred after the second elbow. The recommended RELAP5 modeling techniques tended to preserve the water slug, resulting in ultra-conservative design for downstream piping supports.

The objectives of this study were to (1) establish successful benchmarks against the CE test data with the loop seal initialized in its rightful place upstream of the SRV, and (2) investigate new modeling techniques, specifically use of the two-velocity option, which could potentially reduce downstream loads while still maintaining adequate design conservatism.

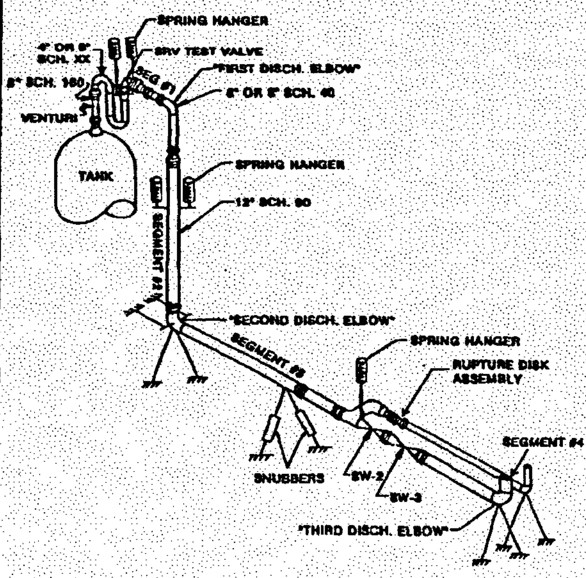



**Figure 1**
**CE SRV Test Facility Layout**
**(Courtesy Electric Power Research Institute)**

## RELAP5/MOD3 Model of CE Test Facility for Dresser SRV Test 1017

Data from CE Test 1017 for a Dresser model 31709 safety valve were selected for the benchmark. The Dresser valve test was selected because (1) the data obtained from this particular test was well documented, and (2) the flow capacity of this valve was similar to that of a Copes-Vulcan Power Operated Relief Valve (PORV). Since the results from this study would be used to provide technical support for a "production" plant-specific PORV discharge analysis, matching the flow rates was particularly important.

## Revised Modeling Techniques

Key to achieving a successful benchmark against CE Test 1017 was detailed dynamic modeling of the SRV stem position in accordance with the test data (see Figure 2). Full open stem position is 0.53 inches. The Dresser SRV was simulated using the true throat area, a trial-run-derived valve coefficient (Cv = 48) so that the full open steam flow matched EPRI test results, and the RELAP5 smooth area change model was specified. This is in contrast to simpler previous models which used the abrupt area change option with the valve area adjusted downward to achieve the target flow rate.

The RELAP5 nodalization downstream of the SRV was similar to the nodalization used by EPRI in Reference 2. Additional detail was added in the region of the 6x12 diffuser in segment #2, and the SW-2 and SW-3 valves used for the Dresser tests were added to segment #3. The CE test loop used two pressurized tanks to simulate the nuclear pressurizer. A RELAP5 time-dependent volume simulated the tank pressure boundary condition on the SRV inlet piping. Particular attention was devoted to the SRV loop seal dimensions and initial temperature (100°F).

RELAP5 volume lengths were established so as to maintain a length to pipe diameter ratio of approximately 1:1. This fine nodalization is required to maintain the compactness of the water slug. It also helps prevent rapid attenuation of acoustic wave fronts. The fine nodalization required an equally fine time step of 2x10-4 seconds to stay within the courant limit. The minimum courant time step calculated during the analysis was 4x10-4 seconds.

Figure 3 shows a comparison of the calculated SRV outlet pressure versus test data from instrument PT-08. Except for the 580 psia peak, the timing, shape, and magnitude of the calculated pressure are quite similar to the test results. Pressure instrument PT-09 was installed at the same location as PT-08, but PT-09 data (not shown, see Reference 7) has spikes to 800 psia. The calculated pressure therefore appears to be a good compromise between the data sets.

Numerous runs were made in order to determine which input options had a critical effect on the benchmark results. It was confirmed that preservation of the loop seal water slug in the first two pipe segments is critical to reproducing the measured forces on these segments. The 6x12 diffuser in segment #2 of the CE test rig has traditionally been a source of modeling difficulty. Thermal hydraulic codes naturally have trouble (related in part to numerical smearing) in maintaining the compactness of the water slug as it passes through a large diffuser at high velocity. If the slug is dispersed, the peak force at the downstream elbow can be greatly diminished.

Trial runs showed that the default two-velocity (non-homogeneous) junction control option which allows vapor and liquid to move at separate velocities tends to exacerbate slug dispersal. Dispersal can be reduced if the single velocity (homogeneous) junction option is specified. For the homogeneous option, vapor and liquid move at the same velocity, interphase mixing is reduced, and the slug mass flux remains more concentrated. Figures 4 through 7 show the effects of varying the junction control options on the calculated hydraulic forces. Force peaks for segments #1, #3, and #4 are noticeably lower when the two-velocity option is used. The segment #2 positive force peak in Figure 5 is higher for the two-velocity option, and the negative peaks are about equal. Despite Figure 5, the authors have observed in comparisons against other S/RV test data that the single velocity option <u>generally</u> results in higher forces for segment #2 also.

In production analyses, budget and schedule usually do not permit the effort necessary to model the thermal energy loss from the fluid to the pipe walls. Decoupling of the thermal hydraulic and structural analysis prohibits accounting for fluid energy expended in the displacement of the structure. Both effects are "non-conservative" if included in the analysis because they reduce calculated fluid forces. The calculated forces thus tend to become more conservative as one moves further downstream. This is born out in the test data. The SRV test data show reduced loads in segment #3 compared to segment #2. This suggests that significant fluid energy was expended in segment #2, and/or the effect of the diffuser combined with a direction change through the downstream elbow was sufficient to disperse the slug and remove energy from the fluid.

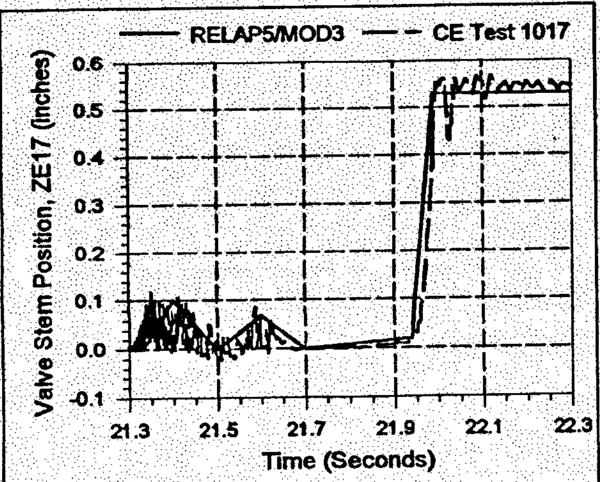



Figure 2 - Modeling Valve Stem Dynamics

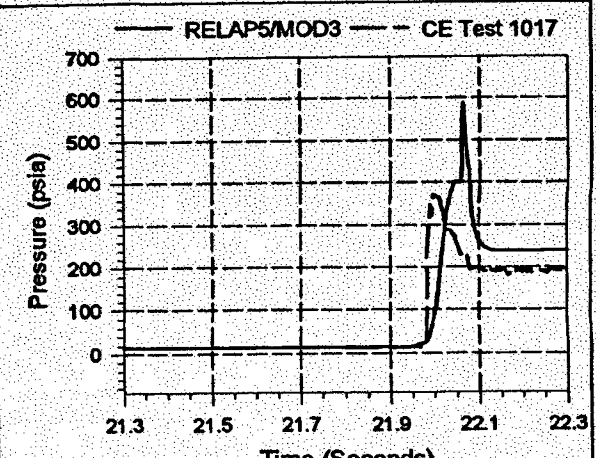



Figure 3 - SRV Outlet Pressure (PT-08)

Production analysis experience has shown that if the homogeneous single velocity junction option is used for all downstream piping junctions, the forces may be significantly over-predicted for segments well away from the SRV. Benchmark results for segments #3 and #4 (Figures 6 and 7) show that judicious use of the two-velocity option can significantly reduce the calculated forces in downstream piping away from the SRV. The following rule for applying RELAP5/MOD3 for SRV loop seal hydrodynamic load analysis was developed to help reduce the level of excess conservatism in downstream piping loads:

- *Use the homogeneous junction control option for all junctions upstream of the first elbow following the first diffuser in the SRV outlet piping. Use the non-homogeneous option (at analyst's discretion) for the remaining downstream junctions.*

## PREPREF and REFORC Post-Processors (by Vectra Technologies)

PREPREF ver. 3A and REFORC ver. 3A are post-processing programs which are used to develop time-dependent fluid forces from the RELAP5 thermal-hydraulic data.

EPRPREF ("PREParation for REFORC") reads the RELAP5 original output print file and extracts the problem geometry, sequentially renumbering the RELAP5 junctions and volumes. PREPREF then reads the RELAP5 restart-plot file and extracts the time-dependent hydrodynamic data for each volume and junction. PREPREF processes this data and arranges it in a form suitable for use by REFORC.

REFORC ("RELAP5 FORCES") allows the analyst to define regions of the RELAP5 model over which force-time histories are to be calculated. For the analysis of the CE SRV test loop model, wave (mass times acceleration) forces were calculated for each of the four pipe segments. These provided the net axial fluid force applied to each segment.

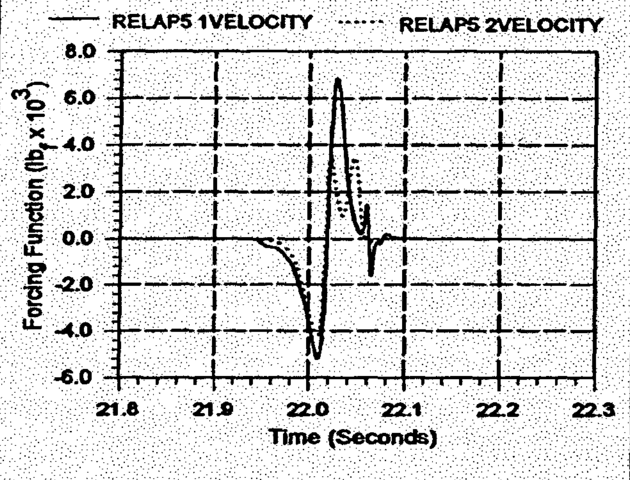



**Figure 4 - Segment #1 Calculated Force**

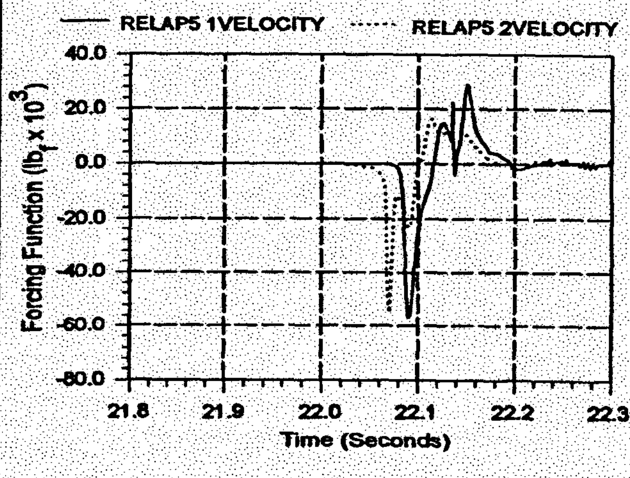



**Figure 6 - Segment #3 Calculated Force**

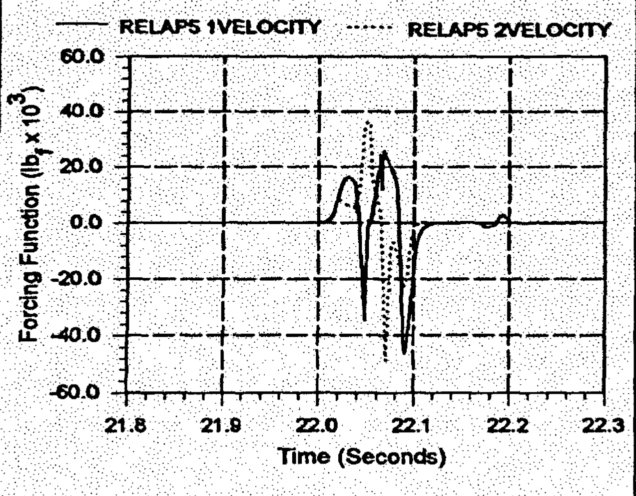



**Figure 5 - Segment #2 Calculated Force**

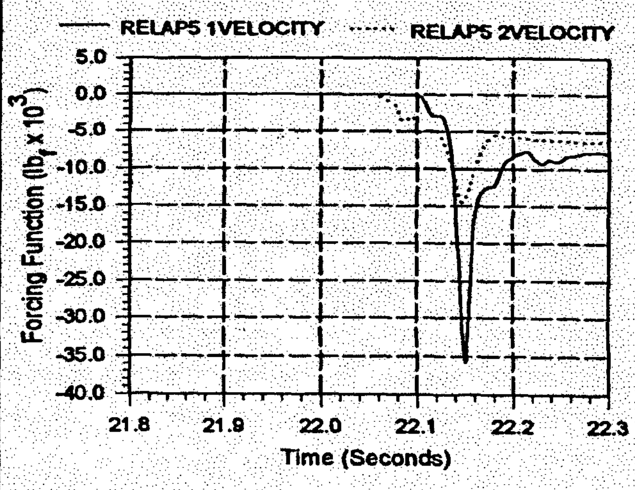



**Figure 7 - Segment #4 Calculated Force**

## Elastic Piping Analysis Computer Program

For this evaluation, a linear elastic piping analysis computer program was required. Due to ease of accessibility and minimal cost to the authors, the SUPERPIPE Computer Program was selected. SUPERPIPE is a comprehensive computer program for the elastic structural analysis and code compliance verification of piping systems. It places particular emphasis on nuclear power piping designed to meet the requirements of the ASME Boiler and Pressure Vessel Code, Section III, for Class 1, 2 or 3 nuclear piping systems. The program used in this evaluation has the following major features:

- *Specification and plot of system geometry, dynamic properties, and Time-History analysis in individual or single computer runs.*
- *Determination of Dynamic Properties, including automatic generation of supplemental mass points for required dynamic characteristics.*
- *Both Modal Superposition and Direct Integration Force Time-History Analysis.*
- *Pipe support loads and displacement summaries, including time dependent reactions as a function of time.*

More details of this specific computer program are available in Reference 1.

## Elastic Piping Model of CE Test Facility

The CE Test Facility model as documented in Reference 2 is used for the structural model. The moderately simple structural model is based on actual piping sections, distributed and concentrated masses due to flanges and valves, actual support orientations and realistic support stiffness values (shown in Table 1 below from Reference 3). No attempt was made to duplicate the complex, non-linear structural models used in References 2 or 3.

| Table 1 - Analyzed Support Stiffness (lb/in) | | |
|---|---|---|
| Pipe Segment Number | Support Direction | Support Stiffness |
| 1 | X | 6.00e+07 |
| 2 | INCL Y | 1.50e+06 (ea.) |
| 3 | X | 7.50e+05 |
| 3 | Y* | 10.00e+04 |
| 4 | INCL Y | 5.00e+05 (ea.) |

* Intermediate Y support only, no detailed loads were evaluated.

The individual spool piece drawings (Figures A-1 through A-17 of Reference 2 and Figure 2-3 of Reference 3) were nodalized and connected to match the 1017 test series geometry, with the global X axis in the direction of valve discharge, the global Y axis vertically upward, and the global Z axis defined by the right hand rule. For simplicity the model was anchored at the Safety Relief Valve inlet, with a support stiffness representative of the structure in the X direction, and "rigid" (1.0E+13 lb/in) Y and Z stiffness in the other two global directions.

Both supports on the vertical Segment 2 run were modeled as shown on Figure 3-7 of Reference 2 (in the Y-Z plane). The pair of axial (X-direction) supports for Segment 3 were modeled as a single support along the pipe centerline, with twice the stiffness of the individual supports. The single intermediate vertical support on Segment 3 was located per Figure 2-3 of Reference 3. The two vertical supports for Segment 4 were modeled as shown on Figure 3-8 of Reference 2 (in the Y-Z plane). The stiffness values of Table 1 were used for all supports.

The Safety Relief Valve mass was 900 lbs, with a center of gravity assumed 12" above the valve inlet, and valves SW-2 and SW-3 at 3450 lbs each along the centerline of the pipe, per Reference 3. Estimated masses associated with the graylock fittings were input per the model geometry at their individual node points.

## Analysis Methods

Two Dynamic evaluations were performed for this analysis. The Direct Integration Force Time History (DITH) method was used as the benchmark method of analysis. For comparison purposes, a Mode-by-Mode Force Time History (MMTH) method was also performed. A discussion of the two methods is presented in the following paragraphs.

## Mode-by-Mode Analysis Technique

For the MMTH option, the analysis is carried out using the mode shapes and frequencies determined in the dynamic properties phase. Because only a limited number of modes are considered (up to 250 Hz), high frequency responses were included by specifying intermediate node locations so that up to 250 Hz pipe bending modes would be resolved. This nodalization was used to insure an accurate evaluation of these high frequency valve discharge loads. In addition structural damping (as a percent of critical) may be input on an individual mode basis.

A 0.001 second integration time step was used, which matched the time step contained in the RELAP5/MOD3 time history file. This forcing function file contained force-time history pairs from 0.0 to 1.0 seconds. All modes within a single run had identical damping values of 1% or 10% (.01 & .10) of critical damping. This resulted in a constant, flat damping curve over the entire frequency range of interest.

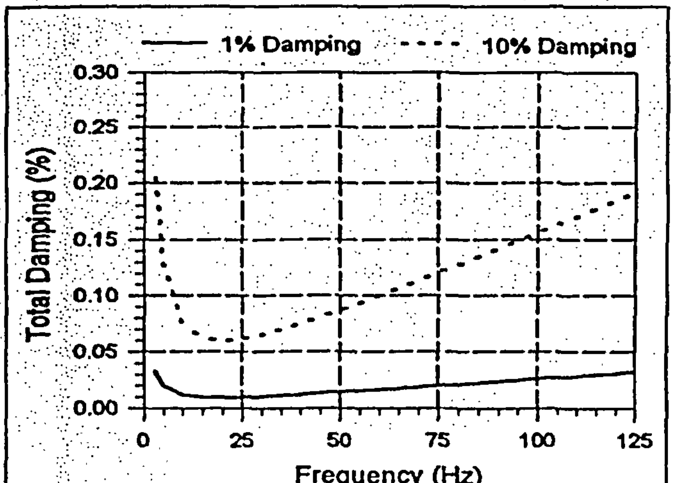



Figure 8 - DITH Damping

### Direct Integration Analysis Technique

For the DITH method, the integration is carried out directly on the coupled equations of dynamic equilibrium without uncoupling into normal modes. This, theoretically, will not truncate the high frequency effects. However, with this option, there is less freedom in specifying damping ratios, which are based on the sum of the mass (alpha) and stiffness (beta) proportional damping values. This total damping curve results in a concave shape, which yields different damping values for different modal frequencies. Figure 8 shows the frequency dependent damping curves used in the DITH analyses.

The DITH method also uses a .001 second integration time step. Damping curves were generated that did not overly damp the high and low frequency range or under estimate the damping in the middle frequency range. The damping values are input into SUPERPIPE as Damping Value 1 at Frequency 1 and Damping Value 2 at Frequency 2. The values used are given in Table 2.

| Table 2 - DITH Damping | | | | |
|---|---|---|---|---|
| Case | Damping 1 | Freq 1 | Damping 2 | Freq 2 |
| 1% Min. | 0.02 | 5 | 0.03 | 100 |
| 10% Avg. | 0.06 | 20 | 0.1 | 60 |

Required damping values for use in evaluating hydrodynamic loadings are not well defined. Conservatively, the recommendations of Reference 4 are used as a lower bound.

The first set of values represents this lower bound damping case, matching the range of values of Reference 4. Here, the curve lower bound value is 1%, and the 3-100 Hz average (over the range of significant modes) is 1.6%.

The second damping set represents the high damping case. Page 212 of Reference 2 indicates that "The structure generally displayed a damping of about 10%." Therefore, the high damping case values identified above result in a lower bound value of 6% and the 3-100 Hz average at 9.8%. This high damping case is used as an upper bound parametric evaluation to determine higher critical damping effects on the support loads.

## Analysis Results: Test Data vs. RELAP5/MOD3 and Elastic Piping Analysis Combination

Three DITH and three MMTH evaluations were performed as summarized in Table 3. Table 1 values of support stiffness were used for all but Case 3, where one-half the Table 1 values were used.

Table 4 provides a tabulation of the maximum support loads for the analysis described above. For comparison purposes, the CE 1017 Test results (Reference 3) and the detailed Non-linear DAGS 1017 Test results (Reference 2) are also given.

In all but the first segment, the calculated loads are between a factor of 1.5 to 2.0 more conservative than the CE 1017 reported test values. Even for segment 1, depending on the support stiffness assumed, the DITH values are no less than 15% lower, or more than 30% higher than the CE 1017 Test values.

| Table 3 Summary of Analyses Performed | | | |
|---|---|---|---|
| Analysis Case | Method | Damping | Dynamic Properties |
| 1 | DITH | 1% Min. | N/A |
| 2 | DITH | 10% Avg. | N/A |
| 3 | DITH | 1% Min. | N/A |
| 4 | MMTH | 0.01 | 250 Hz |
| 5 | MMTH | 0.01 | 150 Hz |
| 6 | MMTH | 0.1 | 250 Hz |

The agreement is similar for the Segment 2 through 4 DAGS results. The Segment 2 loads, are within 30%. The Segment 3 and 4 loads are overestimated by about a factor of 2. The Segment 1 elastic results are however, a factor of 1.9 lower than the non-linear DAGS results, primarily due to the over-conservative DAGS results for this segment.

| Table 4 - Analysis Results Summary | | | | |
|---|---|---|---|---|
| Analysis Case | Seg. #1 Max Load (Kips) | Seg. #2 Max Load (Kips) | Seg. #3 Max Load (Kips) | Seg. #4 Max Load (Kips) |
| 1 | 8.1 | 64.2 | 72.9 | 19.4 |
| 2 | 7.9 | 64.4 | 68.3 | 17.7 |
| 3 | 12.1 | 79.7 | 77.4 | 19.5 |
| 4 | 8.2 | 67 | 73.2 | 22.2 |
| 5 | 7.7 | 66.2 | 72.2 | 20.5 |
| 6 | 7.6 | 68.5 | 65.2 | 17.5 |
| CE-1017 | 9.3 | 41 | 23.6 | 8.1 |
| DAGS | 15.5 | 50 | 30.5 | 10.7 |

The MMTH analysis results show similar trends and values, thus validating the nodalization and dynamic properties used during the comparative MMTH evaluation.

As expected, the damping had little effect on the magnitude of the maximum forces, but as shown on the following figures, has a great influence on the long term response of the piping segment. In particular compare Figures 11 and 15 for the Segment 3 loads.

The time histories of the support reactions for each segment are reported in Figures 9 through 16 on the following pages for two of the analyzed load cases. Figures 9 through 12 are for Analysis Case 1, and detail the Segment 1, 2, 3 and 4 load histories, respectively. The second set (Figures 13 through 16) is for Analysis Case 2, also for Segments 1, 2, 3 and 4 respectively. The shapes of the curves are remarkably similar, given the simplified detail of the structural model used in this evaluation. Both cases utilized the RELAP5 single velocity option for junctions upstream of the second elbow downstream of the SRV. The default two-velocity option was used for segments #3 and #4.

## Conclusions

A RELAP5/MOD3 analysis of the Combustion Engineering Safety Valve Test Loop Facility (for Test 1017) was performed. This evaluation used the default two-velocity momentum equation option of the RELAP5/MOD3 program to develop time-dependent hydrodynamic forcing functions for the four segments of the piping of the CE SRV Test Facility. These forcing functions were subsequently used in an elastic piping analysis model to estimate the resultant structural responses. These calculated loads were then compared to the values from the original 1981 CE 1017 Test.

The piping model used simple, single stiffness elastic supporting structures without gap or inelastic modeling effects. The model generally predicted conservative maximum loads (by a factor of 2) with the exception of the first segment, where differences of -15% to +30% of the CE 1017 Test result loads were calculated. A comparison of these results to the detailed, non-linear DAGS results showed similar correlations. Although overpredicting the actual magnitudes, the structural reaction shapes were very similar to both the CE Test Facility and DAGS Test 1017 results.

**The results verify that RELAP5/MOD3 can be used in concert with a suitable post-processor (such as PREPREF/REFORC) and a dynamic structural analysis code capable of accepting force-time history input (such as SUPERPIPE) to economically develop bounding support load and stress profiles for typical power plant high energy piping configurations.**

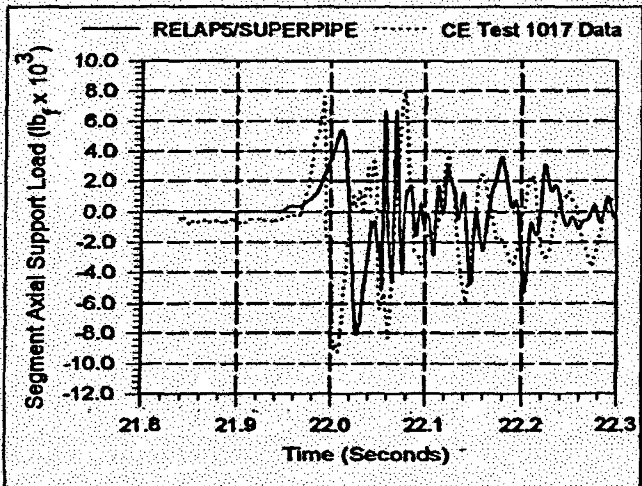



**Figure 9 - Segment #1 Load, 1% Damping**

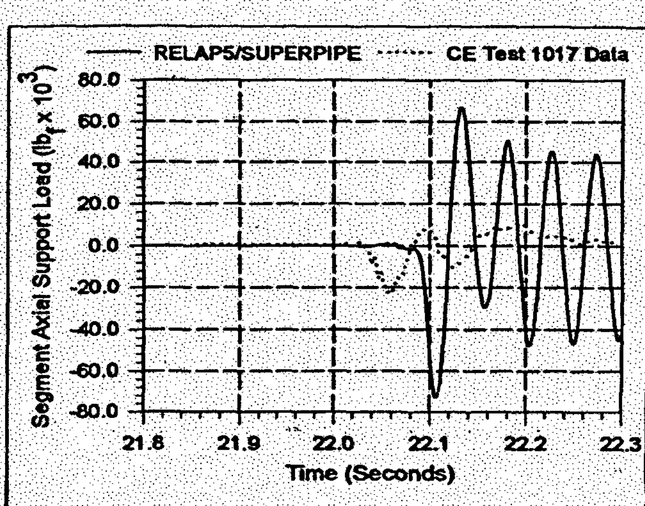



**Figure 11 - Segment #3 Load, 1% Damping**

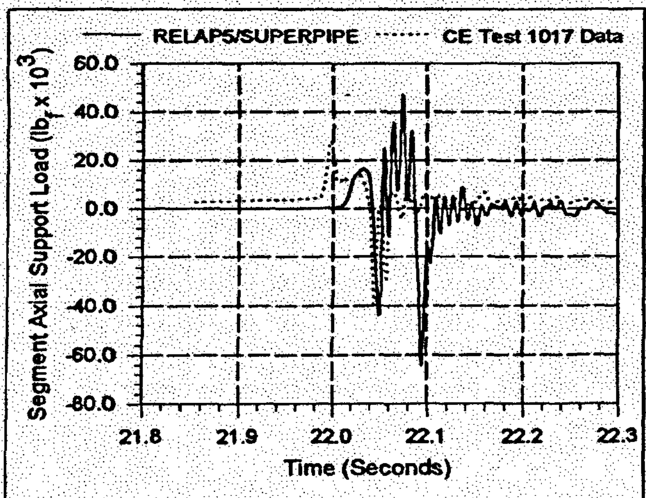



**Figure 10 - Segment #2 Load, 1% Damping**

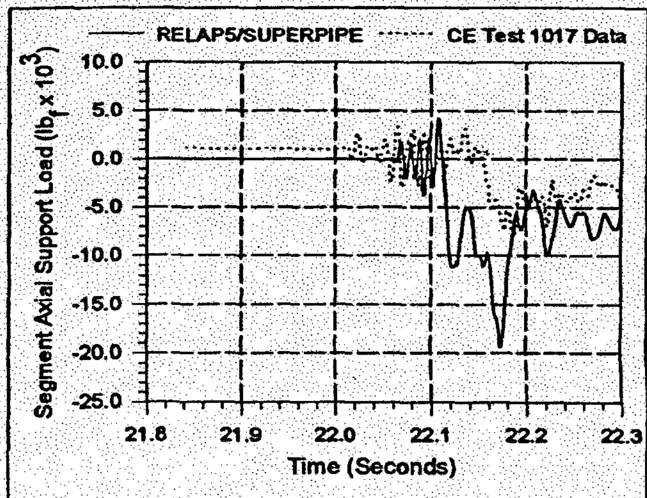



**Figure 12 - Segment #4 Load, 1% Damping**

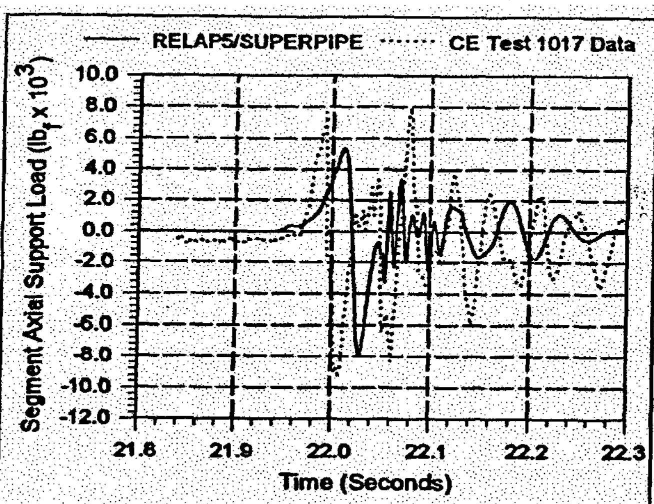



**Figure 13 - Segment #1 Load, 10% Damping**

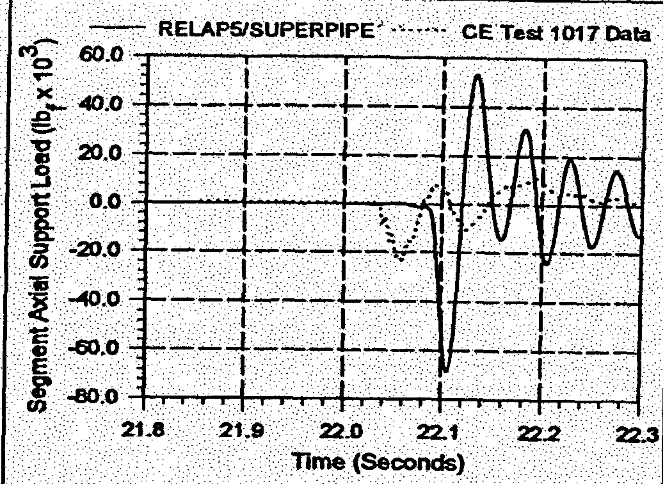



**Figure 15 - Segment #3 Load, 10% Damping**

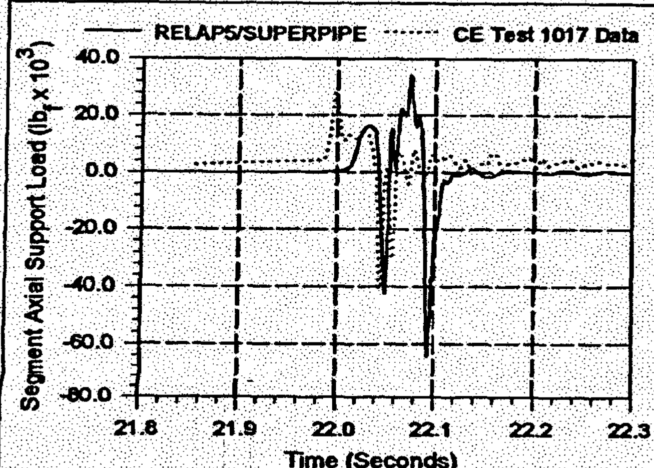



**Figure 14 - Segment #2 Load, 10% Damping**

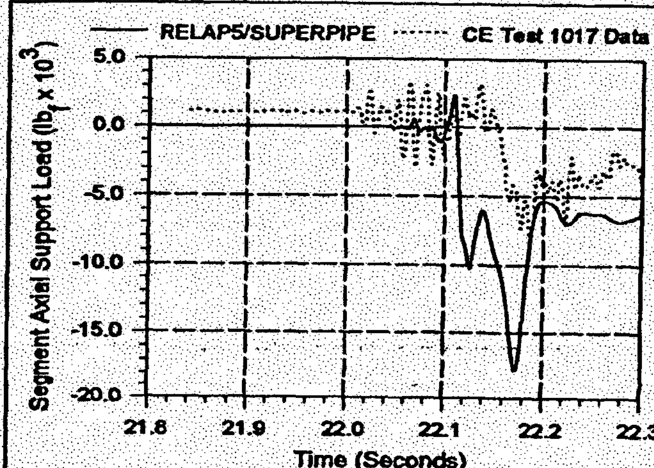
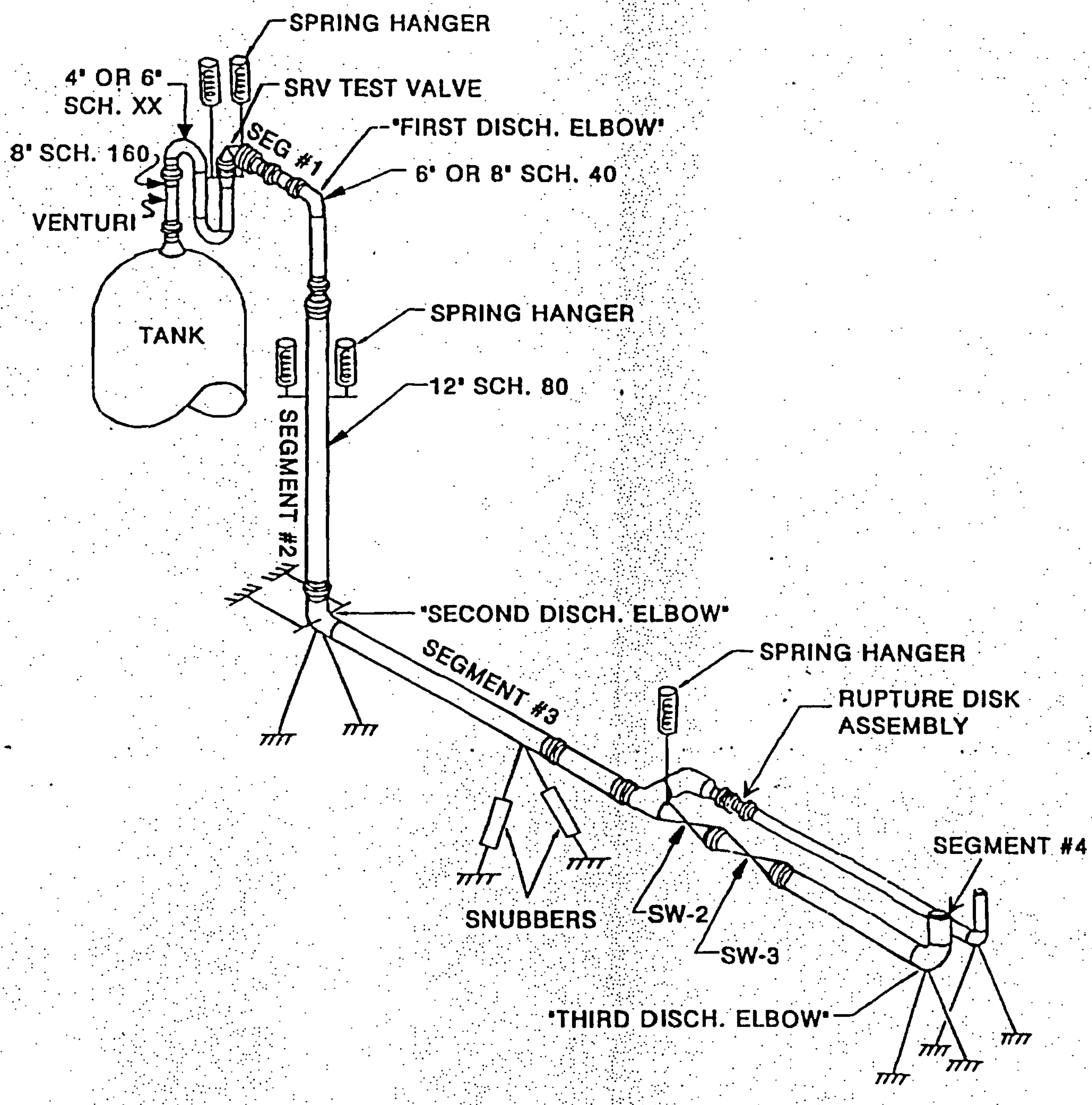



**Figure 16 - Segment #4 Load, 10% Damping**

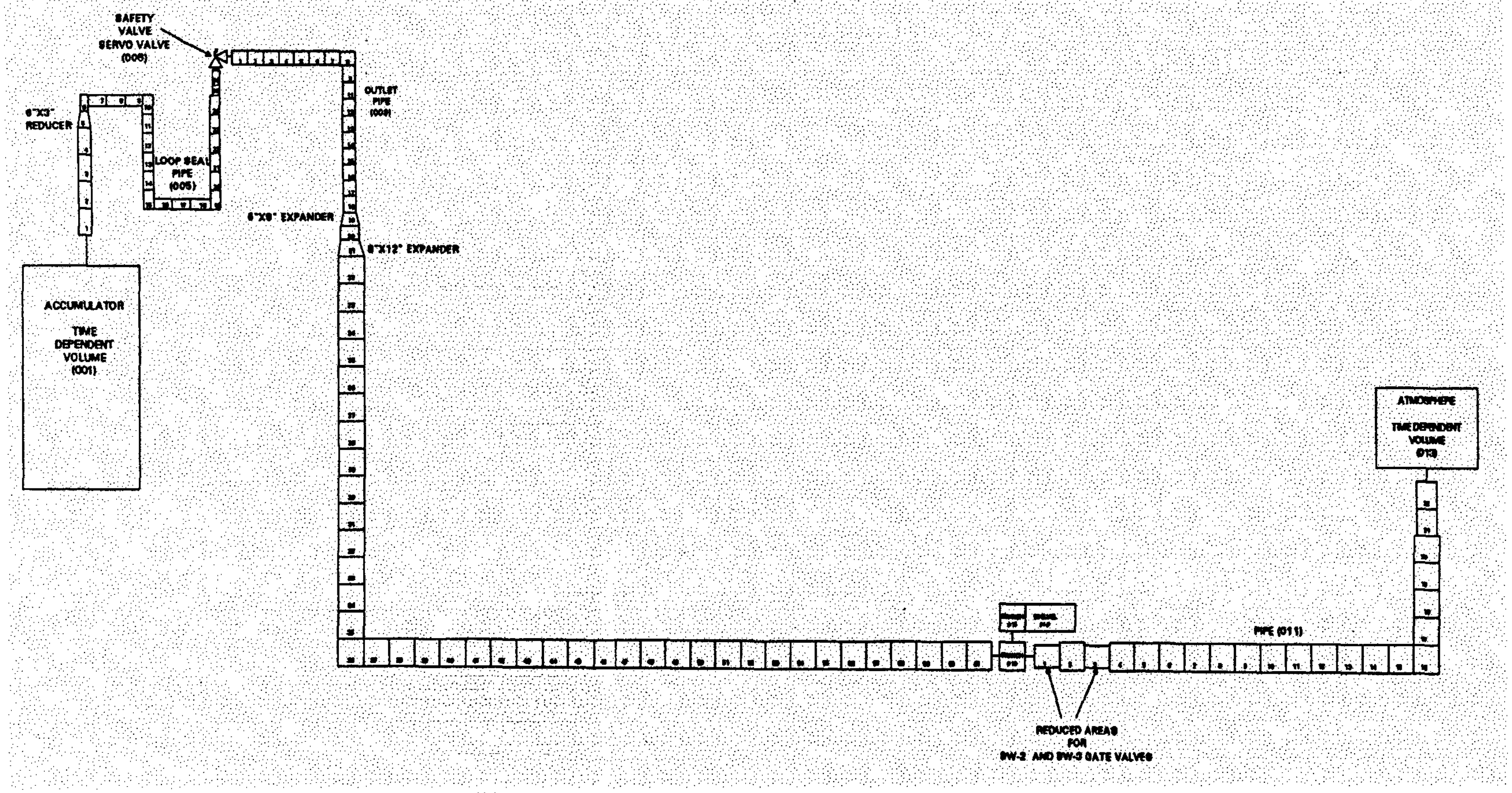
## References

This paper documents the acceptability of the use of the two-velocity momentum equation option in RELAP5/MOD3 for hydrodynamic evaluations applicable to safety relief discharge loadings.

1. SUPERPIPE Users Manual Revision 7, SUPERPIPE VAX/IBM Version 22E, dated 5/31/90.
2. EPRI NP 2479 (Research Project V102-28), "Application of RELAP5/MOD1 for Calculation of Safety and Relief Valve Discharge Piping Hydrodynamic Loads", Final Report, December 1982
3. EPRI NP-2770-LD, "Volume 3: Test Results for Dresser Safety Valve Model 31739A", Interim Report, February 1983.
4. Regulatory Guide 1.61, "Damping Values for Seismic Design of Nuclear Power Plants", October 1973.
5. NUREG/CR-5535, Vol. 5, "RELAP/MOD3 Code Manual, User's Guidelines", R4, January, 1992.
6. EPRI NP-2770-LD, "Volume 10: Structural Results for Dresser Safety Valve Model 31739A, Interim Report", March 1983.




# CE SRV Test Facility Layout


SAFETY
VALVE
SERVO VALVE
(006)
6"X3"
REDUCER
LOOP SEAL
PIPE
(005)
OUTLET
PIPE
(008)
6"X8" EXPANDER
8"X12" EXPANDER
ACCUMULATOR
TIME
DEPENDENT
VOLUME
(001)
ATMOSPHERE
TIME DEPENDENT
VOLUME
(013)
PIPE (011)
REDUCED AREAS
FOR
SW-2 AND SW-3 GATE VALVES

Inital Configuration - System aligned with SW system

Water Hammer Condition - Occurs after LOOP event when SW booster pumps are re-started.

PHASE 1 - LOOP occurs causing SW booster pumps to de-energize.
PHASE 2 - Column of fluid gravity drains down to SW pond causing vacuum void formation
PHASE 3 - After 41.5 seconds, SW booster pumps re-energized causing vacuum void to collapse and resulting water hammer

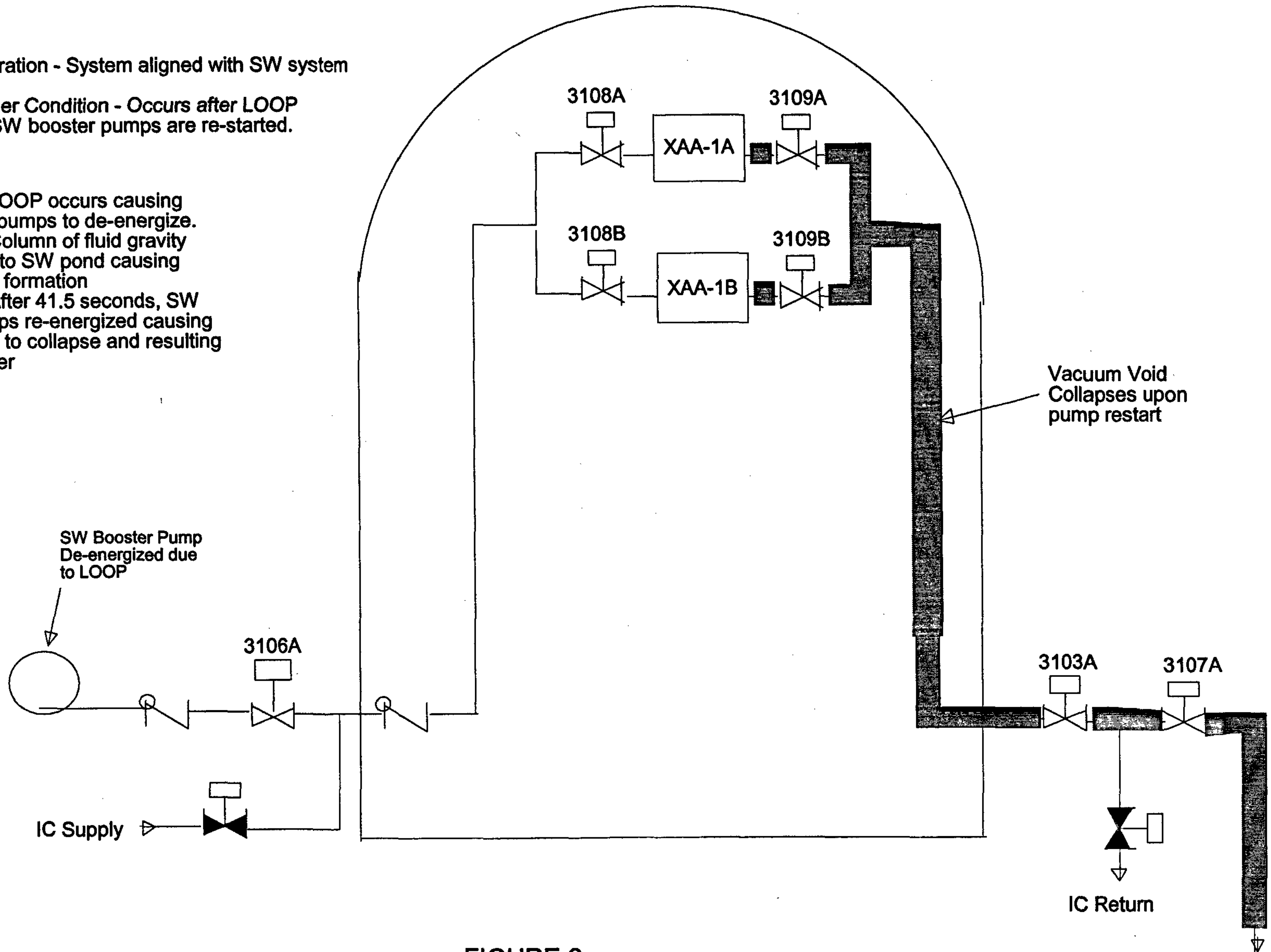



FIGURE 2

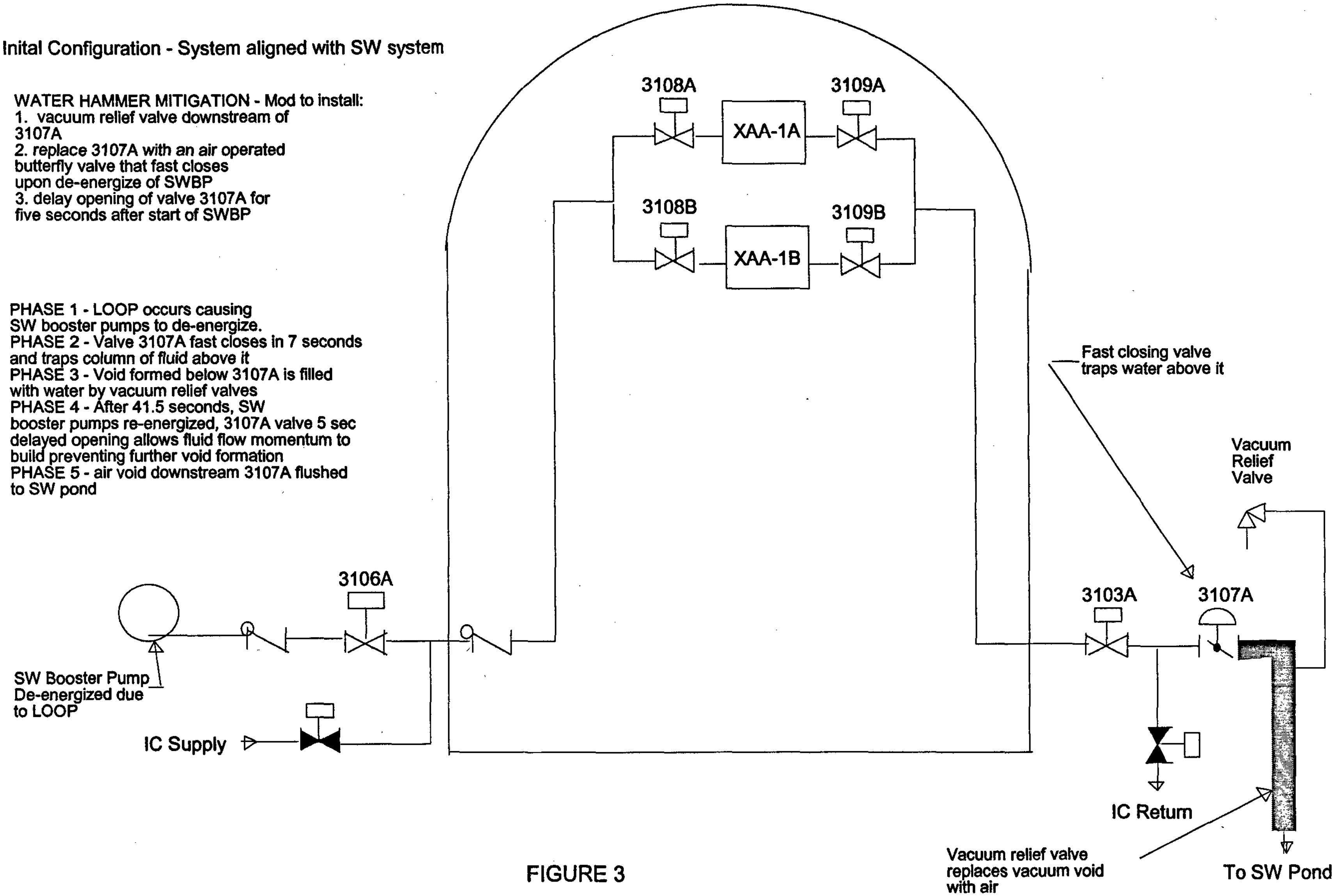

Inital Configuration - System aligned with SW system
WATER HAMMER MITIGATION - Mod to install:
1. vacuum relief valve downstream of 3107A
2. replace 3107A with an air operated butterfly valve that fast closes upon de-energize of SWBP
3. delay opening of valve 3107A for five seconds after start of SWBP
PHASE 1 - LOOP occurs causing SW booster pumps to de-energize.
PHASE 2 - Valve 3107A fast closes in 7 seconds and traps column of fluid above it
PHASE 3 - Void formed below 3107A is filled with water by vacuum relief valves
PHASE 4 - After 41.5 seconds, SW booster pumps re-energized, 3107A valve 5 sec delayed opening allows fluid flow momentum to build preventing further void formation
PHASE 5 - air void downstream 3107A flushed to SW pond
3108A
3109A
XAA-1A
3108B
3109B
XAA-1B
Fast closing valve traps water above it
Vacuum Relief Valve
3106A
3103A
3107A
SW Booster Pump De-energized due to LOOP
IC Supply
IC Return
Vacuum relief valve replaces vacuum void with air
To SW Pond

FIGURE 3