SAFETY INJECTION SYSTEM MODIFICATION

SAN ONOFRE NUCLEAR GENERATING STATION

UNIT 1

OCTOBER, 1981

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SECTION 1

INTRODUCTION

On September 3, 1981, San Onofre Unit 1 experienced a partial loss of instrumentation due to a voltage regulator failure. The reactor was manually tripped by the Control Room Operator for the following reasons:

1. Erratic feedwater control,

2. Many unrelated alarms, and

3. Uncertainty of plant conditions due to erractic and conflicting indicators.

During the ensuing transient, Reactor Coolant System pressure dropped below that necessary to actuate safety injection. During operator surveillance of the safety injection actuation sequence, it was observed that neither feedwater pump safety injection discharge valve (HV-851A and HV-851B) opened. The feedwater pumps were then secured. As the pressure upstream of HV-851A and HV-851B decreased, the valves opened. Safety injection was not actually needed for this transient, and would not have actually occurred until Reactor Coolant System pressure decreased below the discharge pressure of the feedwater pumps (i.e., approximately 1200 psi). Reactor Coolant System pressure reached a minimum of approximately 1700 psi and was shortly restored to normal. Following a plant shutdown, a program was initiated to investigate and evaluate the failure of HV-851A and HV-851B to open.

On September 15 and 30, 1981, we met with representatives of the Regulatory staff to discuss the results of our investigation and evaluation of the failure of HV-851A and HV-851B to open. The information presented at the meetings is contained in Sections 2 through 8 of this report. Information is also contained herein which was prepared subsequent to the meetings to describe (1) changes in the valve sequencing, (2) drilling a hole in the feedwater pumps discharge check valves, and (3) changes in the preoperational and periodic surveillance testing. This information was discussed with the Regulatory staff via telephone on October 9, 1981.

The configuration and operation of the Safety Injection System is discussed in Section 2. The results of our investigation and evaluation to determine the cause of HV-851A and HV-851B not opening are discussed in Section 3. The results of our evaluation of other Safety Injection System valves are discussed in Section 4. The alternatives considered and the alternative selected to assure that HV-851A and HV-851B open are discussed in Section 5. The analyses of the selected alternatives are discussed in Section 6. The testing of the selected alternative is discussed in Section 7. The future plans and commitments are discussed in Section 8.

SECTION 2

SAFETY INJECTION SYSTEM CONFIGURATION AND OPERATION

The configuration of the Safety Injection System (SIS) is shown in Figure 1 of this report. During normal plant operation, both feedwater pumps are running and are taking suction from the condensate heater train through HV-854A and HV-854B and discharging to the feedwater heater train and steam generators through HV-852A and HV-852B. During normal operation, the safety injection pumps are not running and are isolated by HV-853A and HV-853B. The safety injection lines downstream of the feedwater pumps are isolated by HV-851A and HV-851B and the reactor coolant Loops are isolated by MOV-850A, MOV-850B and MOV-850C.

Following a safety injection actuation signal with offsite power available, the SIS is realigned from its normal operating configuration as follows:

1. Both feedwater pumps remain running while HV-852A, HV-852B, HV-854A and HV-854B are closing (within five seconds),

2. At the same time, HV-853A, HV-853B, MOV-850A, MOV-850B and MOV-850C are opening (HV-853A and HV-853B within five seconds and MOV-850A, MOV-850B and MOV-850C within 10 seconds) and the safety injection pumps are started, and

3. Until HV-854A and HV-854B are closed, an interlock prevents HV-851A and HV-851B from opening. When HV-854A and B are closed, HV-851A and B are opening (within five seconds).

With a loss of offsite power, the SIS is aligned as discussed above with the exception that there is an additional eleven second delay for the diesel generators to come up to speed and accept loading. In addition, both feedwater pumps are tripped and are restarted following diesel generator startup and loading.

The sequences discussed above are shown in Figure 2 of this report. Figure 3 of this report shows the resequencing of the SIS which has been implemented following our determination of the failure mechanism of HV-851A and HV-851B as discussed in Section 3 of this report. The details of the resequencing of the SIS are discussed in Subsection 5.2 of this report.

SECTION 3

INVESTIGATION AND EVALUATION TO DETERMINE CAUSE OF SAFETY INJECTION VALVES NOT OPENING

As discussed in Section 1 of this report, a plant shutdown was initiated on September 3, 1981, following the observation that HV-851A and HV-851B had not opened. During the plant shutdown, a program was undertaken to investigate and evaluate the failure of HV-851A and HV-851B to open. This program included the following:

1. A review of the operation and maintenance history of the valves,

2. A test program to evaluate operability of the valves, and

3. A study of the design of the valves, including system operating parameters.

Appendix 1 of this report summarizes the historical information concerning the operation and maintenance of the valves. Based on the information, no major problems have occurred since the valves were installed during the 1976-1977 refueling outage. However, it should be noted that the surveillance testing of the valves was performed with zero differential pressure across the valves in accordance with the technical specifications. As discussed below, the high differential pressure across the valves experienced on September 3, 1981 has been identified as a contributing factor to the failure of the valves to open.

Appendix 2 of this report summarizes the testing which was performed in an attempt to determine the cause of the valves not opening. In conjunction with the performance of the test program, an independent consultant (Kalsi Engineering, Inc.) was requested to review the design of the valves to determine the failures mode. Based on this review, the failure of HV-851A and HV-851B to open is attributed to galling of the valve seats, double-disc drag and insufficient margin on the coefficient of friction used to size the valve actuator. Each of these contributing factors is discussed below:

1. Galling of the valve seats occurred during valve cycling because of an excessive average contact stress (i.e., approximately 32,000 psi) on the valve seat face due to a high differential pressure (i.e., 1,500 psi) across the valve disc during opening. An average contact stress of 10,000 psi is appropriate for gate valves using stellite overlaid seats and gate faces to eliminate galling. Galling increases the coefficient of friction significantly, and therefore, a much higher than design actuator force would be required. Galling is technically defined as that material transfer due to adhesive wear, and once galling is initiated and surface movement is repeated under high loads, the process continues (i.e., smearing and scoffing both the surfaces). The surface gets progressively worse until seizing by welding occurs.

2. Inspection of the valve disc intervals indicated that both valve discs were generating a resulting friction force during opening. The valve actuators are sized to overcome the friction force of only one disc.

3. The coefficient of friction used to size the actuator should have included margin for long term effects. Coefficient of friction for stellite to stellite surfaces range from 0.119 to 0.4 depending upon operating conditions with the maximum value measured after long term set effects not exceeding 0.4. Under clean, water immersion gate valve tests performed in the laboratory, the coefficient of friction values ranged from 0.15 to 0.25 for undamaged seat faces (i.e., by heavy wear or galling) and seat contact stresses below 10,000 psi. Therefore, a 0.4 coefficient of friction should have been used rather than the 0.2 value originally used.

Appendix 3 of this report summarizes the findings of the independent consultant and the proposed solutions to assure that the valves have sufficient actuator force to open under operating conditions. In order to maintain the average contact stress at the valve seat face to less than 10,000 psi, the differential pressure across the valve discs during opening should not exceed 450 psi. As discussed in Section 5 of this report, modifications are required to assure that the differential pressure does not exceed 450 psi during opening. In order to assure an additional margin, the maximum differential pressure under operating conditions will be limited to 350 psi.

SECTION 4

EVALUATION OF OTHER SAFETY INJECTION VALVES

In addition to the evaluation discussed in Section 3 of this report, the other Safety Injection System hydraulically actuated valves were examined to assure that the valves have sufficient actuator force to open under their respective operating conditions. Appendix 4 of this report provides the design maximum actuator thrust and the maximum actuator thrust required assuming the differential pressure is that following the implementation of the modifications discussed in Section 5 of this report for each valve. In each case, there is sufficient actuator force to open the valves under their respective operating conditions.

For the motor-operated valves MOV-850A, MOV-850B and MOV-850C, an evaluation is underway to determine the average contact stress across the valve seat face due to the expected differential pressure across the valve disc. Since these valves have a wider seating surface than the hydraulically actuated valves, the evaluation is expected to indicate that the stress is below that required to cause galling (i.e., 10,000 psi) as discussed in Section 3 of this report. In addition, the manufacturer (i.e., Limatorque) of the valve motor generator has provided written confirmation that the operator can generate sufficient thrust to open the valves under the maximum expected differential pressure (i.e., 1685 psi). The evaluation will be completed by October 23, 1981. If the evaluation indicates that the average contact stress is above the 10,000 psi galling threshold, we will advise the NRC concerning any required corrective actions.

SECTION 5

IMPLEMENTATION OF CORRECTIVE ACTIONS

5.1 Alternatives Considered

As discussed in Section 3 of this report, the failure of HV-851A and B to open is attributed to galling of the valve seats and insufficient margin on the coefficient of friction used to size the valve actuator. In order to assure that the valves have sufficient actuator force to open under operating conditions and to maintain the average contact stress at the valve seat faces to below the galling threshold of 10,000 psi, modifications are required as follows:

1. Provisions to lower Δp across HV-851A and B when required to open on SIS and SISLOP signals, and

2. Installation of valve body vents on HV-851A and B and HV-853A and B to preclude double-disc drag on these valves.

Based on our review of the required modifications, the alternatives which were considered to achieve the desired objectives were as follows:

1. Valve and operator replacement,

2. Operator replacement,

3. Valve bypass installation with valve body cavity vents, and

4. Valve and feedwater pump stop/start resequence and valve body cavity vents.

Following a review of the design basis for the SIS, it was concluded that the valve and feedwater pump stop/start resequence was the same condition as exists for SISLOP with the existing system and could be implemented in a relatively short time. In addition, the other alternatives considered either could not be shown to be bounded by any existing system considerations or could not be implemented as quickly as the valve and feedwater pump stop/start resequence. The details of the valve and feedwater pump stop/start resequence and valve body cavity vents are discussed in Subsection 5.2 of this report.

5.2 Selected Alternative

The modifications to the SIS described below assure that the hydraulically actuated valves have sufficient actuator force to open under operating conditions.

1. Resequence of Safety Injection System Components

The changes to the SIS sequence are shown in Figure 3* of this report. For the SIS actuation signal with offsite power available, the only changes are to trip the feedwater pump at t=0 and restart them in 11 seconds and to delay the opening of MOV-850 A, B and C. Tripping the feedwater pump will reduce the pressure acting on the upstream disc of HV-851A and B to 350 psi or less, thus reducing sufficiently the force required to ensure opening and eliminate the potential for galling of the valves. The stroke times of HV-854A and B, HV-852A and B and HV-851A and B will be adjusted during testing as discussed in the notes to Figure 3 of this report. As discussed with the Regulatory staff via telephone on October 9, 1981, this adjustment will ensure a sufficient time for the feedwater pumps to rundown to the required 350 psi pressure and to allow the pressure downstream of the feedwater check valves to decay. The delayed opening of MOV-850A, B and C by 11 seconds will mitigate the effects of back pressure on HV-851A and B which potentially could exist due to a leak in the reactor coolant boundary check valves downstream of MOV-850A, B and C. The changes have been implemented as follows:

a. The feedwater pumps are tripped by a signal from a t=0 contact (SIS) from the sequencer. This initiates timing of an 11 second time delay restart of the feedwater pumps by means of an agastat relay, and

b. MOV-850A, B and C are opened from 11 to 21 seconds by means of a signal at t=0 (SIS) from the sequencer to an 11 second time delay agastat relay.

For the case of a SIS actuation signal with loss of offsite (SISLOP) power, the feedwater pumps and MOV-850A, B and C are sequenced in the same manner described above. However, HV-852A and B, HV-853A and B, and HV-854A and B now receive a signal to actuate at t=0 seconds. The interlock will remain such that HV-851A and B does not start to open until HV-854A and B are fully closed. The purpose of this change is to allow HV-851A and B to open under a reduced differential pressure after the feedwater pump has coasted down with the valve stroke time adjustments discussed above.

The significant things to note from the above described changes in evaluating the impact on SIS performance are as follows:

a. Tripping the feedwater pumps on SIS and restarting them in 11 seconds is the same condition as exists for SISLOP with the existing system, and

*The times discussed in this Subsection reflect nominal times while those shown in Figure 3 reflect maximum times demonstrated to be acceptable by accident analyses as discussed in Subsection 6.4 of this report.

b. HV-851A and B, HV-852A and B, HV-853A and B and HV-854A and B are aligned to their safety injection positions sooner for a SISLOP than the previous design.

2. Valve Body Cavity Vents on HV-851A and B and HV-853A and B

In order to eliminate the potential for double-disc-drag due to a higher pressure between the discs than the upstream and downstream piping pressure equalization has been provided across one disc. As indicated in Appendix 3 of the report, the independent consultant indicated that this condition could cause too high a drag force which could prevent the valves from opening. The equalization is accomplished by providing an equalizing line between the valve body cavities and the upstream or downstream piping.

The equalizing line for HV-851A and B is shown in Figure 4 of this report. The installation was accomplished by drilling a hole in the side of the body of the valve and installing a piping connection to the upstream piping. A solenoid valve is provided in this equalizing line to maintain the containment isolation capability in conjunction with the upstream disc of HV-851A and B. The solenoid valve is normally closed and is opened on SIS or SISLOP to equalize pressure between the body cavity and the feedwater pump discharge pressure during coastdown. Following safety injection, HV-851A and B and the corresponding solenoid valves can close when required for containment isolation. The solenoid valves can be remote manually actuated from the control room.

The equalizing line for HV-853A and B is shown in Figure 5 of this report. This line was installed by drilling a hole in the side of the body of the valve and installing a piping connection to the downstream piping. A normally open block valve is provided in the equalizing line for maintenance purposes during plant shutdown. This block valve will be administratively controlled to assure its open position during plant operation.

3. Feedwater Pump Discharge Check Valve Notch and Hole

As can be seen in Figure 1 of this report, the potential exists for a higher pressure on the upstream disc of HV-851A and B than the feedwater pump discharge should the feedwater pump check valve be leak tight. This condition could defeat the depressurization at the HV-851A and B inlet following a feedwater pump trip. In order to ensure than the pressure at the feedwater pump discharge nozzle is equalized with the inlet of HV-851A and B, a small notch has been cut and a small hole has been drilled in the check valve discs.

As discussed at the September 15 and 30, 1981 meetings, it was anticipated that only a small notch in the disc would be required to assure an adequate pressure decay. However, during testing, it was discovered that additional relief capacity was required; therefore, a small hole has also been drilled in the discs to provide the additional relief capacity. The hole has been sized to provide sufficient relief capacity assuming a failure of a check valve which isolates the line from the steam generator back pressure. Under this condition, there would be no pressure decay downstream of the feedwater pump check valves until HV-852A and B are fully closed. At this point, the volume between HV-851A and B, HV-852A and B and the check valves will depressurize, to the decayed feedwater pump discharge pressure. The closing time of HV-852A and B will be adjusted during testing as discussed in 1 above to ensure sufficient time (i.e., greater than 0.5 seconds) to allow this decay prior to opening HV-851A and B.

4. Administrative Control of Pressure Downstream of HV-851A and B

As can be seen in Figure 1 of this report, there is a normally isolated volume of liquid between HV-851A and B and MOV-850A, B and C. This volume could be pressurized to 700 psig (spring loaded check valve setpoint) from leakage of HV-851A and B or from MOV-850A, B and C. In order to ensure a maximum differential pressure of 350 psi across HV-851A and B, the pressure in this volume will be administratively controlled to a maximum of 350 psig. An existing alarm in the control room will be reset to this value and venting required if the alarm is activated.

SECTION 6

ANALYSES OF SELECTED ALTERNATIVE

6.1 Reliability

A reliability study was performed on three of the alternatives considered as discussed in Subsection 5.1 as follows:

1. Option 1 - Eliminate high ΔP on the hydraulically operated valves: main feedwater pump trip; body equalization of the normally closed HV-851A and B and HV-853A and B; and a small notch and hole in the disc on the main feedwater pump check valve,

2. Option 2 - Eliminate high ΔP on the hydraulically operated valves: bypass and body equalization on HV-851A and B and HV-853A and B, and

3. Option 3 - Change the hydraulically operated HV-851A and B to motor-operated valves qualified to open under full system ΔP.

The reliability study developed a system fault tree which was quantified for each of the three options. Test and maintenance contributions were considered as well as random and common cause hardware failures. Generic data which included plant-to-plant variability was obtained from NUREG/CR-1205, NUREG/CR-1363, IEEE Std. 500-1977, and WASH-1400 (NUREG-75/014). A limited amount of plant specific data was obtained and used to update the generic data using Bayes' theorem for three components. The methods of analysis are fully documented in Section 0, Methodology, of the "Zion Station Probabilistic Safety Study," submitted to the USNRC by Commonwealth Edison Company, September 1981.

The system was analyzed under large LOCA conditions as specified in the FSA: success required flow from the RWST via either pump train into either one of two intact reactor coolant loops within about 25 seconds and continuing for 1 hour. The possibility of operator response to recover from hardware failures was not considered.

The following conclusions were obtained from the analysis:

1. All three options compare favorably with the injection systems analyzed in WASH-1400. No active single point failures were identified. The only single point failures, piping failure or failure of the refueling water storage tank, do not affect the results of this analysis.

2. On the basis of reliability, there is little to recommend one option over the others. The hydraulic operators used in Options 1 and 2 will only work if these options sufficiently unload the valve differential pressure. Therefore, prestartup testing at expected

operating conditions is crucial if Option 1 or 2 is selected. Option 3 offers valve operators that are slightly less reliable under unloaded valve conditions, but which are much more capable of opening the valves if high differential pressure exists.

Additional details can be found in "Reliability Analysis of Safety Injection System Modification, San Onofre Nuclear Generating Station, Unit 1," included as Appendix 5 of this report.

6.2 Hydraulic

The hydraulic transient effects due to the modified valve and pump stop/start resequence have been evaluated and it has been shown to be bounded by the original analysis. This result was expected because the revised sequence represents a slower startup due to the feedwater pump starting up in conjunction with MOV-850A, B and C opening in 10 seconds. The previous condition analyzed assumed the feedwater pump was running at shutoff head against HV-851A and B which opened in 5 seconds. The details of the analysis assumptions, methods and results are provided in Appendix 6 of this report.

In addition to the hydraulic transient effects discussed above, the feedwater pump performance was evaluated with respect to the new valve and pump stop/start resequence. It has been concluded that the revised sequence, as far as the feedwater pump performance, is the same condition as existed for the original design for a SISLOP condition. This condition is a pump trip at t=0 and restart at t=11 seconds. In addition, the runout characteristics for the revised sequence is slower due to a slower opening discharge valve on pump restart.

Previous test results for which the pump was qualified were reviewed and found to show completely the adequacy of the feedwater pump/motor assembly to operate under the most severe conditions. These tests were run satisfactorily. The test agenda is provided in Appendix 7 of this report. In addition, the new valve and pump stop/start resequence was reviewed with the pump manufacturer and a letter is provided in Appendix 8 of this report which further substantiates the previous test results.

6.3 Electric

The capabilities of the auxiliary and onsite power systems for providing sufficient torque for motor acceleration has been analyzed. The results of this analysis are provided in Appendix 9 of this report. Based on the results, the effects due to the modified valve and pump stop/start has been shown to be bounded by the original analysis.

6.4 Accident

The effect of the modifications on accidents which have been analyzed in the FSA has been assessed as discussed below:

1. Loss of Coolant Accident

   For the limiting case loss of coolant accident (LOCA) with coincident loss of offsite power, the total delay time from initiation of a safety injection signal to effective full flow to the reactor vessel used in previous analyses was 26.7 seconds. The delay time previously used was allocated as follows:

   a. 10 seconds for diesel generator startup,

   b. 10 seconds for operation of all valves, and

   c. 6.7 seconds to establish effective full flow to the reactor vessel inlet nozzles.

   As a result of the modifications to the SIS discussed in Subsection 5.2 of this report, the total delay time was re-evaluated. The delay times associated with major equipment sequencing for a SIS actuation signal concurrent with a loss of offsite power and with offsite power available are shown in Figure 3 of this report for the modified Safety Injection System. Effective full flow to the reactor vessel was conservatively evaluated to occur at 24.2 seconds following initiation of a SIS actuation signal. The delay time associated with the modified system is allocated as follows:

   a. 1.0 second for signal transmission,

   b. 12.0 seconds for time delay following feedwater pump trip. Startup of diesel generators and complete operation of valves which realign the feedwater pump trains in the safety injection mode are also accomplished during this time period, and 11.0 seconds for startup of feedwater pumps and opening of safety injection valves.

   c. 0.2 seconds for safety injection flow transit time to vessel.

   The safety injection flow transit time from the point of safety injection to the reactor vessel nozzles was re-evaluated taking credit for flow to the vessel during feedwater pump startup and during the opening of MOV-850A, B and C. The evaluation used the startup characteristics of the feedwater pump and the opening characteristics of the valves to determine the effective full flow time to the reactor vessel. An effective full flow time of less than 11.2 seconds was calculated. Thus, an additional allowance of 0.2 seconds is necessary to account for safety injection flow transit time.

The total delay time of 24.2 seconds is applicable for the case of LOCA with offsite power available and for the limiting case LOCA with loss of offsite power as the time delay for startup of the diesel generators is concurrent with the feedwater pump trip time delay. Since the total delay time for the modified system is less than that used in previous LOCA analyses, the previous LOCA analyses remain valid.

2. Main Steam Line Break

For the limiting case main steam line break (MSLB) with offsite power available, the total delay time from initiation of a safety injection actuation signal to full flow to the reactor coolant system used in previous analyses was 10 seconds for startup of safety injection pumps and realignment of all valves. The safety injection actuation signal occurred at 15.5 seconds so that the SIS was capable of delivering water to the reactor coolant system at 25.5 seconds. However, safety injection flow was not initiated until reactor coolant system pressure decreased to the shutoff head of the feedwater pumps which occurred at 28.5 seconds.

As a result of the modifications, the total delay time from initiation of a safety injection actuation signal to full flow to the reactor coolant system is increased to 17 seconds, 12 seconds for the time delay before restart of the feedwater pump and opening of the MOV-850A, B and C, and 5 seconds for startup of the feedwater pumps and 50% opening of the MOV-850A, B and C. Hence, safety injection flow to the reactor coolant system would commence at 32.5 seconds, or 4 seconds later than the time at which the reactor coolant system pressure decreases to the shutoff head of the feedwater pumps. The 4 second time delay has been evaluated to show that the safety criteria of DNBR $>$ 1.30 will not be invalidated due to the additional reactivity inserted.

SECTION 7

TESTING OF SELECTED ALTERNATIVE

As previously discussed, modifications have been made to the SIS with the objective of ensuring that hydraulically actuated valves HV-851A and B and HV-853A and B have sufficient actuator force to open under their respective operating conditions. The design approach to accomplishing this objective relies upon limiting the maximum differential pressures, and therefore, the loads developed on valve seating surfaces when the valves are required to open such that (1) the force required to open each valve is less than the available actuator force, and (2) the potential for galling of valve seating surfaces is eliminated.

The preoperational and surveillance testing programs which follow were formulated to (1) verify that the above modifications are properly installed and perform their intended functions, and (2) provide assurance that the design approach as implemented accomplishes the stated overall objective.

7.1 Preoperational Testing

The preoperational test program consists of two categories of tests as follows: (1) prerequisite tests to verify that design modifications are properly installed and ready for functional testing, and (2) functional tests to demonstrate the performance capability of modifications at both the component and system levels.

A list of tests to be performed within each category is given below and is followed by summary level descriptions of these tests in Appendix 10 of this report. In addition, a functional test matrix which summarizes the test sequence and test conditions imposed on each valve is provided in Appendix 10 of this report.

1. Prerequisite Tests

    a. Hydrostatic test of HV-851A and B and HV-853A and B valve body vent welded piping,

    b. Leak test of HV-851A and B valve body vent solenoids, SV-2900 and SV-3900,

    c. Electrical test and checkout of modified electrical circuitry, and

    d. Calibration and electrical checkout of SIS header pressure alarm bistable.

2. Functional Tests

   a. Differential Pressure Stroke Test of HV-853A and B,

   b. Differential Pressure Stroke Test of MOV 850 A, B and C,

   c. Force Test of HV-851 A and B,

   d. Differential Pressure Stroke Test of HV-851 A and B,

   e. Hot Force Test of HV-851 A and B,

   f. Cold zero Δp/No-Flow Sequencing Test of HV-851, 852, 853, 854 (trains A and B) and MOV-850 A, B and C,

   g. Cold Δp/Flow Test of Safety Injection System Pumps and HV 851, 852, 853 and 854 (both trains),

   h. Valve Internals Inspection of HV-851 A and B, and

   i. Hot Safety Injection System Test.

With regard to functional testing, the number and type of component and/or system level tests which are specified are intended to demonstrate both the operability and repeatability of operation of the modified system and equipment under simulated operating conditions. Test conditions are established to assure required performance under actual operating conditions.

In the event that negative results are encountered during preoperational testing, such results will be reported to the NRC along with an assessment of their significance and impact on the SIS modification effort and plans for recovery as appropriate.

With the successful implementation of the preoperational test program, the underlying assumptions of the system reliability analysis previously discussed are confirmed. With such confirmation, system reliability as determined by analysis is assessed to be such that system modifications can be implemented without risk to the public health and safety. The continuing operable status of the modified SIS is verified by periodic surveillance testing as discussed in Subsection 7.2 of this report.

7.2 Surveillance Testing

An interim surveillance testing program will be conducted throughout the remainder of the current fuel cycle and to conclude at the next refueling outage. At that time, the interim program will be supplanted by a long term surveillance testing program. It is intended that this long term program will be developed and submitted to the NRC for approval prior to the next refueling outage.

The interim surveillance program has as its paramount objective the periodic demonstration of SIS operability. This objective will be accomplished through a series of cold and hot SIS functional tests as follows:

1. Not less than two weeks nor more than five weeks following return to power at the conclusion of the current outage, the unit will be brought to a hot shutdown condition and a hot test performed. This test will essentially correspond to the hot SIS test performed during unit start-up this outage and will be performed so as to demonstrate the operable status of the SIS at hot shutdown conditions. This test will include a determination of the force required to open HV-851A and B and the margin to available actuation force.

    a. If no significant reduction in available margin is observed, the unit may be returned to power operation.

    b. If a significant reduction in margin is observed compared to that observed during preoperational testing during the current outage, the hot SIS test will be repeated to again determine required opening force and available margin.

        1) If significantly reduced margin is observed in the second test, indicating that such reduction is not necessarily attributable to "setting" of valve seating surfaces, this result will be reported to the NRC along with an assessment of its significance and corrective actions deemed appropriate as a consequence thereof.

        2) If (a) margin comparable to that observed during preoperational testing is restored in the second test, indicating that margin reduction is attributable to "setting" of valve seating surfaces, and (b) margin observed in each test is found to be adequate, then the unit may be returned to power operation.

2. Every three, plus or minus one, months following return to power at the conclusion of the current outage and throughout the remainder of the current fuel cycle, the unit will be placed in a cold shutdown condition and a cold Δp/Flow Sequencing SIS Test performed.

3. Commencing with the second shutdown and during every other subsequent shutdown in accordance with 2 above, the unit will be placed in a hot shutdown condition and a hot SIS functional test performed in accordance with the criteria in 1. above.

4. If the acceptance criteria of a surveillance test are not met, test results will be reported to the NRC along with proposed corrective actions and NRC approval obtained prior to returning the unit to service.

SECTION 8

FUTURE PLANS AND COMMITMENTS

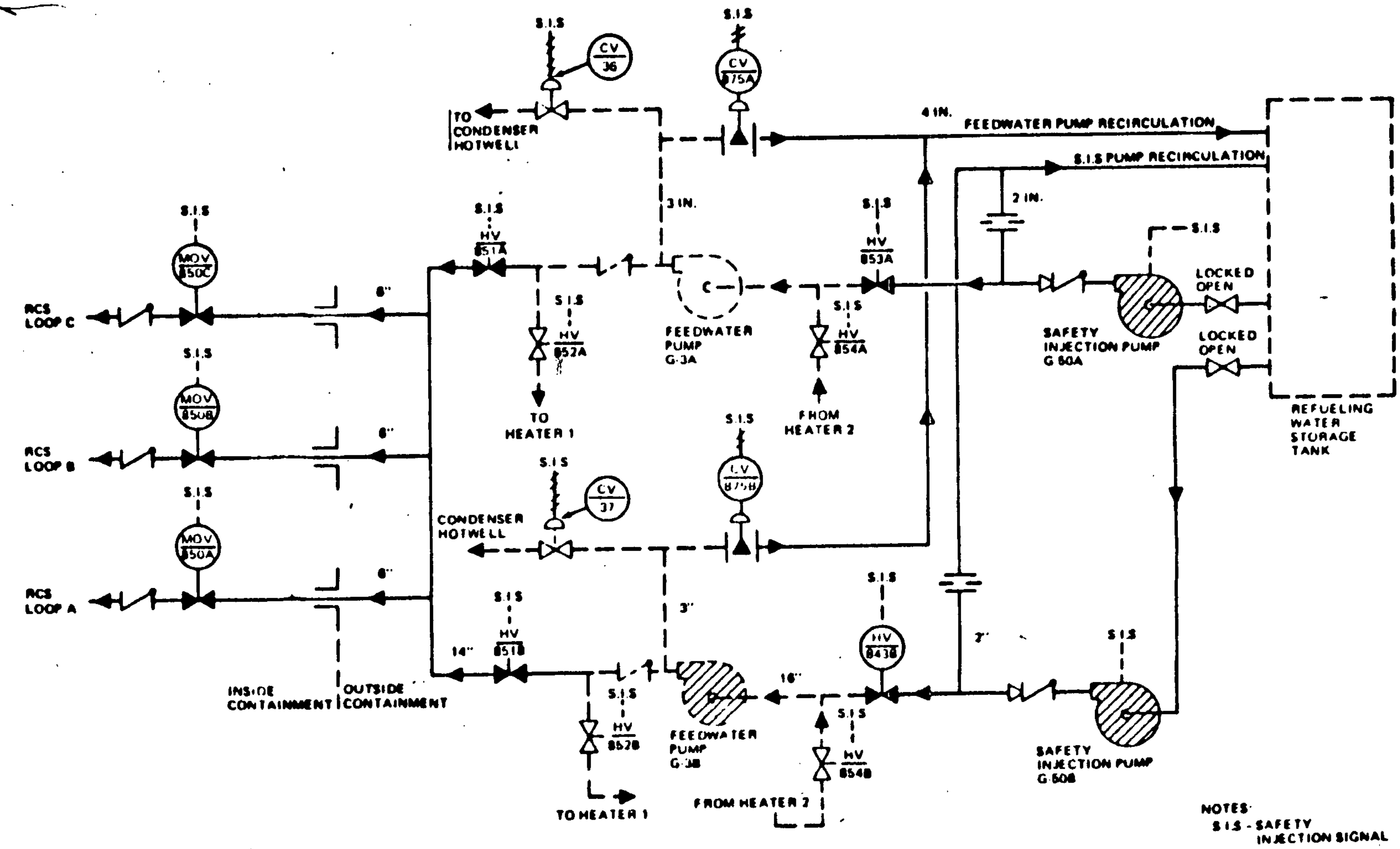
8.1 Evaluation of Valve Replacement

In order to eliminate the need to trip the feedwater pump and vent the valve body cavities, an evaluation will be initiated to replace the hydraulically operated valves HV-851A and B, HV-852A and B, HV-853A and B and HV-854A and B. By December 1, 1981, we will provide the NRC a schedule for replacement of these valves. This schedule will include design and engineering time, procurement time and construction time such that we can optimize the valve design and capabilities.

8.2 Study of Safety Injection System Design and Performance

Since San Onofre Unit 1 has a unique SIS that requires the normal feedwater pumps to realign to the safety injection mode, the design and performance of the SIS will be studied to determine if major redesign is warranted. By December 1, 1981, we will provide the NRC a schedule for submittal of the study.

FIGURE 1

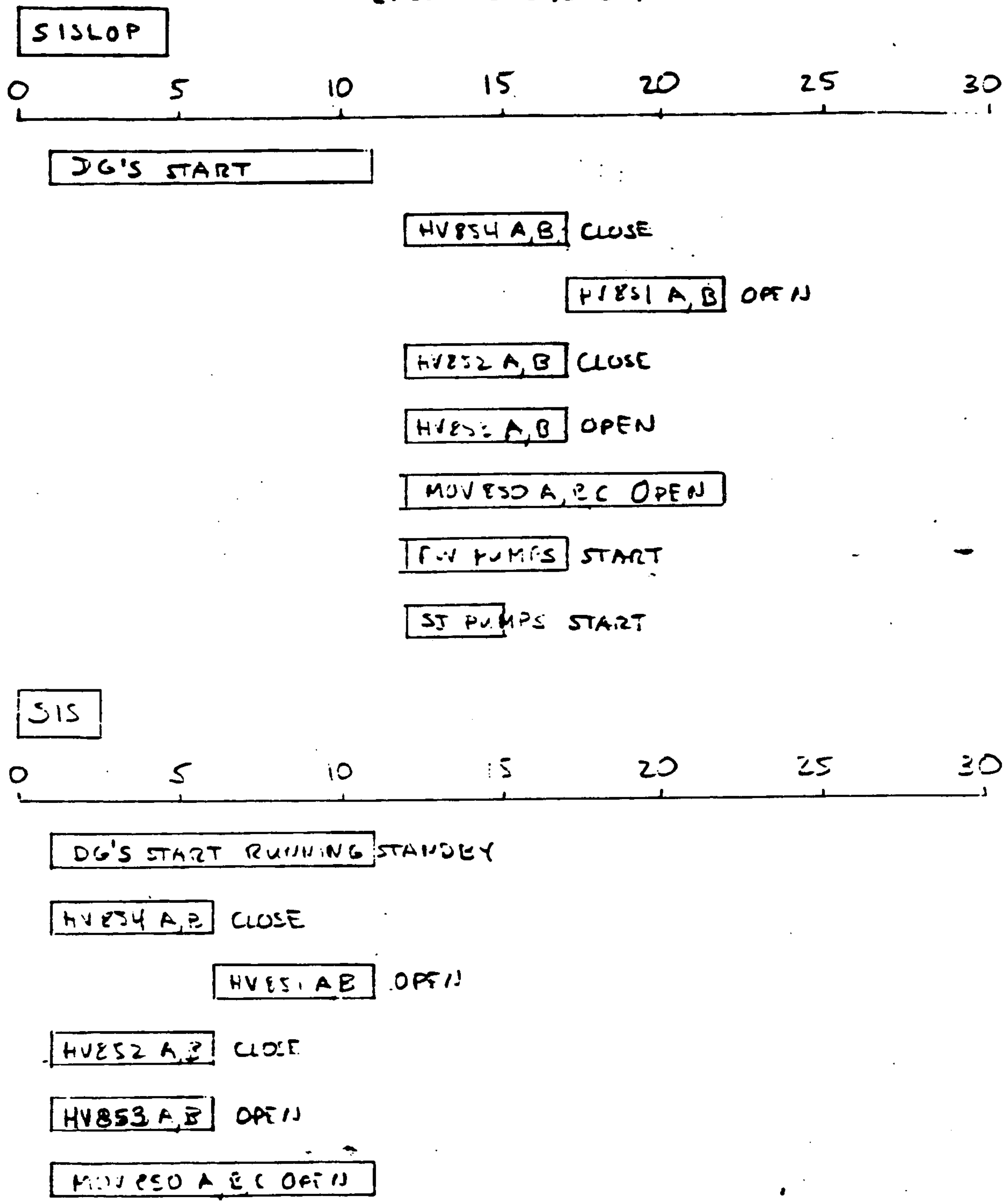


SIMPLIFIED SCHEMATIC OF SONGS-1 SAFETY INJECTION SYSTEM

FIGURE 2

SAFETY INJECTION DELAY TIME (SECONDS)

EXISTING SYSTEM



FW Pumps Running

FIGURE 3

SAFETY INJECTION DELAY TIME (SECONDS)

FOR MODIFIED SIS

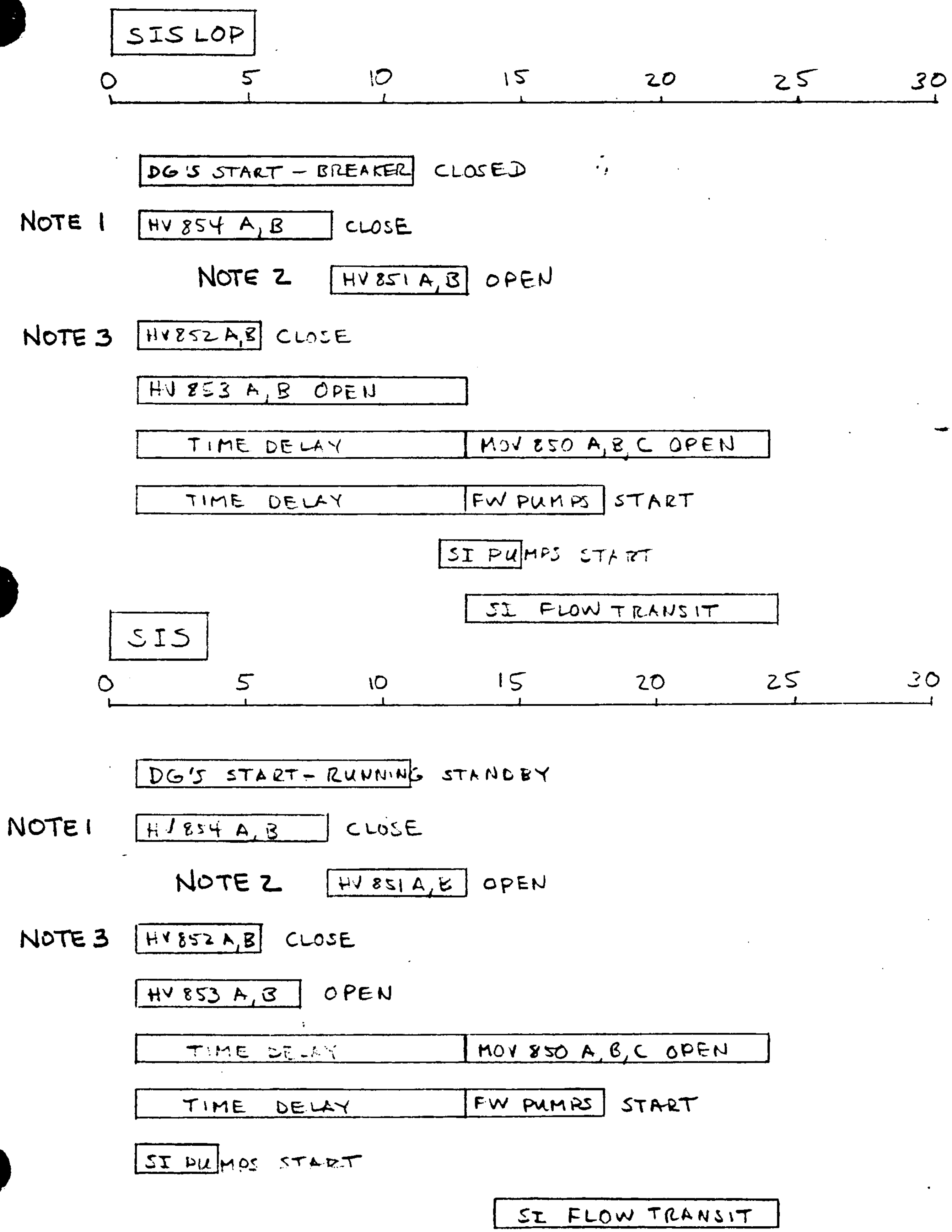


FIGURE 3 (Continued)

NOTES:

1. HV-854 A, B closing time will be adjusted during testing to ensure that HV-851 A, B, which are interlocked with HV-854 A, B, receive signal to open after Δp across valve seating surfaces has decayed to value less than 350 psi;

2. HV-851 A, B are timed to open such that the overall sequence of HV-854 A, B closing and HV-851 A, B opening is 13 seconds or less.

3. HV-852 A, B closing times will be adjusted during testing to ensure pressure relief through feedwater pump discharge check valve such that Δp across HV-851 A, B is less than 350 psi at the time the valve receives a signal to open.

FIGURE 4

HV 851A, B BODY VENT

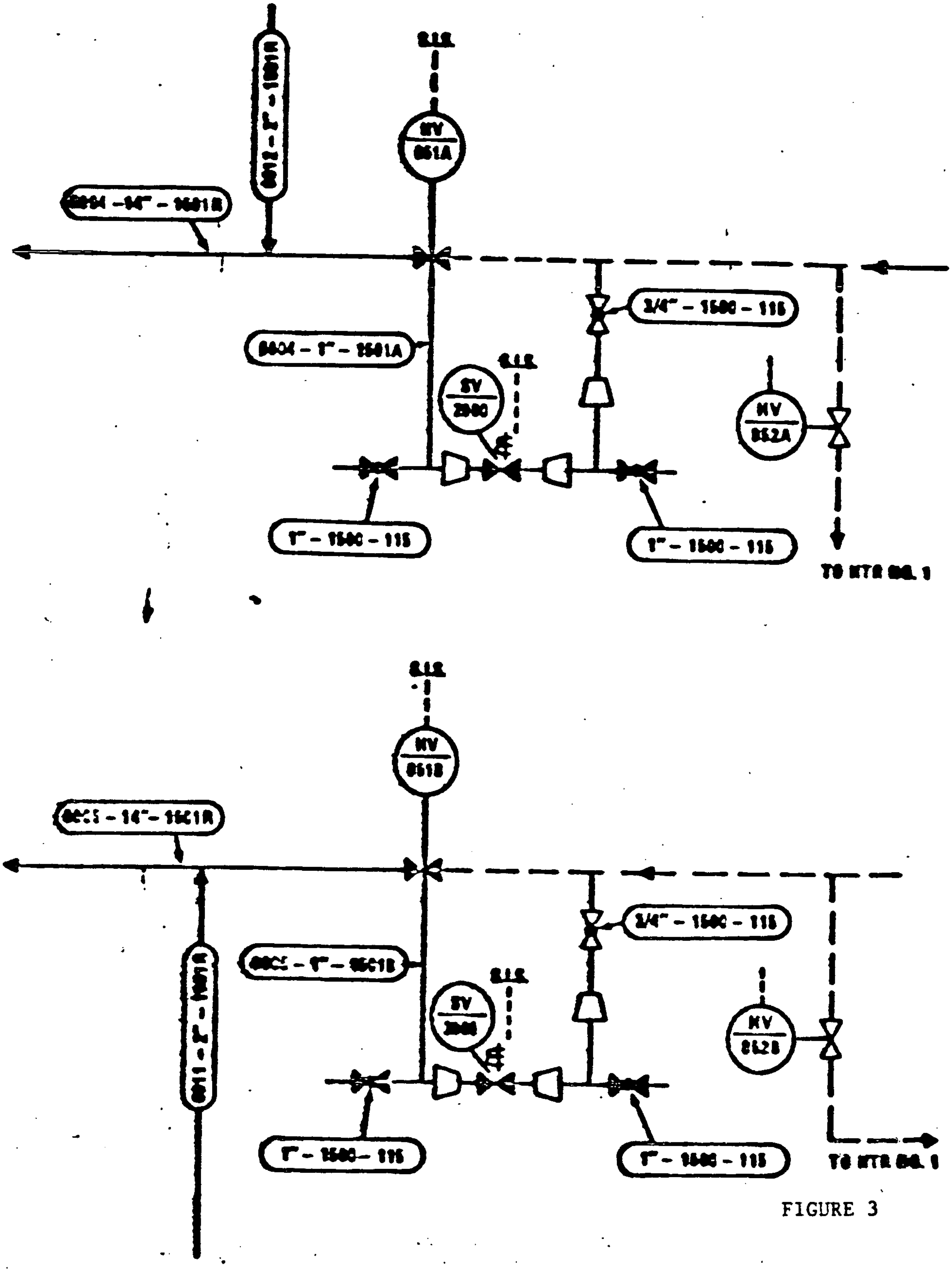


FIGURE 3

FIGURE 5

HV 853A, B BODY VENT

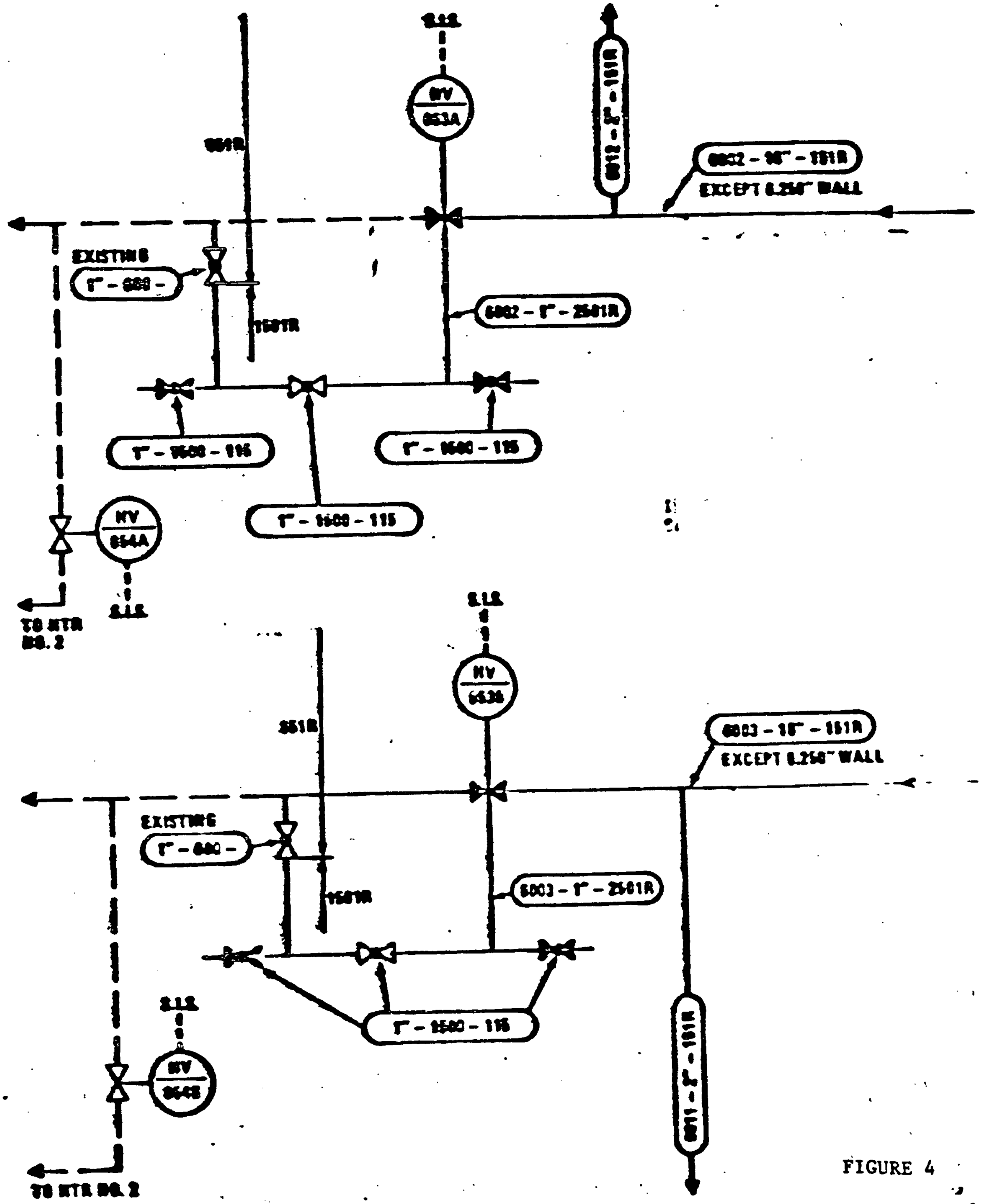


FIGURE 4

APPENDIX 1

OPERATION AND MAINTENANCE HISTORY

1. SAFETY INJECTION SYSTEM OPERATION

   - o Between 1977 (Startup) and September 3, 1981 no S.I.S. challenge occurred

   - o Cold shutdown S.I.S. Testing was peformed after each cold shutdown during this period

     - Timing (5 seconds) Test

     - No Valve Differential Pressure

2. SAFETY INJECTION SYSTEM MAINTENANCE

   - o Actuator work performed in 1980 to replace (as specified by vendor) elastomeric components

   - o Minor maintenance occurred for such items as broken gauges, etc., on a breakdown basis

   - o No major valve maintenance (removal, etc.) was performed during this period

APPENDIX 2

TESTING AND INSPECTION

1. Testing - A test procedure was prepared and tests were performed with valve conditions duplicating the system conditions at the time of failure. Signals were given to the HV851A and B valves. Neither valve operated until the packing was released. After releasing the packing HV851A operated with 5 seconds for one cycle. Both valves operated with a reduced differential pressure condition.

2. Disassembly Inspection - Upon completion of the initial test program both valves were disassembled to evaluate internal valve conditions. The inspection revealed no abnormal conditions. The vendor representative described the valve disc and seats as having normal wear minor scratches on downstream discs and seats. No galling was observed. The discs and seats were lapped, the valve was reassembled and packed. The operator was tested and found to provide design force.

3. Testing - Again after the previous reassembly both HV851A and B were tested using system conditions duplicating the plant at the time of failure. HV851B was stroked open 18 times with the first 16 within 5 seconds and the 2 remaining cycles out of the specified 5 second minimum. HV851A was stroked open 3 times under the defined system conditions before the failure to cycle with only the first within the 5 second minimum.

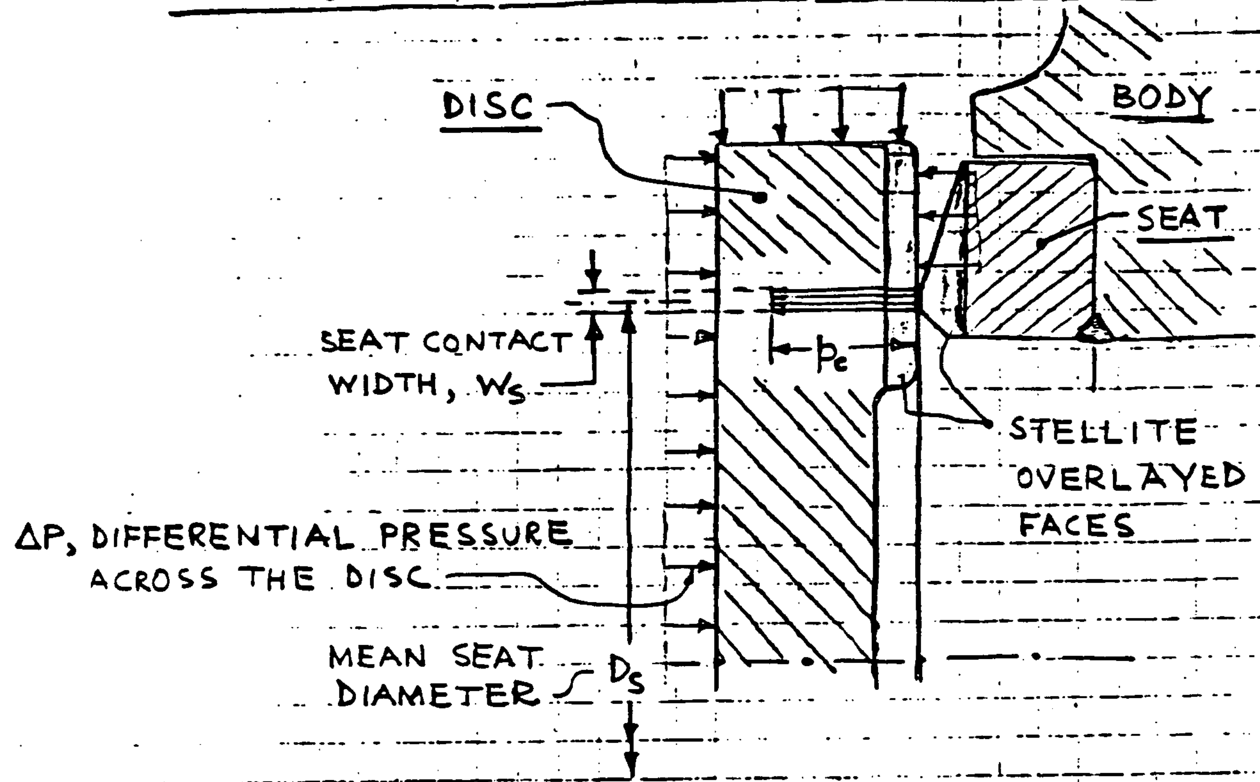
4. Diassembly/Inspection (2) - After the previously described testing both of the HV851A and B valves were disassembled and downstream discs and seats were found to be galled.

APPENDIX 3

KALSI ENGINEERING, INC.
DESIGN & ANALYSIS CONSULTANTS

CUSTOMER/PROJECT SOUTHERN CALIFORNIA EDISON/SONGS-1 PAGE NO.
DATE 9/14/81
SUBJECT SIS GATE VALVES # 851 A&B BY KALSI

SEAT CONTACT PRESSURE FOR S.I.S. VALVES 851 A&B



AVERAGE CONTACT PRESSURE

AT THE SEAT FACE, $$p_c = \frac{\frac{\pi}{4} \times D_s^2 \times \Delta P}{\pi \times D_s \times W_s}$$

$$p_c = \frac{D_s \times \Delta P}{4 \times W_s}$$

For 851 A&B, $D_s = 10.8125''$ & $W_s = 0.125''$ (ANCHOR/DARLING REPORT)

For $\Delta P = 1500$ (psi) design pressure,

$$p_{c_{ave}} = \frac{10.8125 \times 1500}{4 \times 0.125} = 32,437 \text{ psi}$$

This is too high for a sliding surface! This average stress is further accentuated by the non-flatness caused by elastic deformations, resulting in values that exceed threshold of galling stress.

CUSTOMER/PROJECT SOUTHERN CALIFORNIA EDISON
PAGE NO.
DATE KALSI 9/14/81
BY
SUBJECT SIS VALVES - (SONGS-1)

1. VALVE DESIGN REVIEWED IN DETAIL FROM AN OPERABILITY STANDPOINT

2. TWO PROBLEM AREAS FOUND :

(1) NOT ENOUGH MARGIN OF THE COEFFICIENT OF FRICTION - CONSIDERING LONG TERM INCREASES

(2) HIGH AVERAGE CONTACT STRESS AT SEAT FACES (FOR A SLIDING SURFACE) — EXCEEDING THRESHOLD OF GALLING.

3. PROPOSED SOLUTIONS :

(1) DECREASE SEAT CONTACT STRESS BY LOWERING ΔP — ASSURING MARGIN BELOW THRESHOLD OF GALLING.

(2) USE HIGHER COEFF OF FRICTION IN SIZING ACTUATORS — TO ACCOUNT FOR LONG TERM EFFECT

(3) RELIEVE BODY CAVITY PRESSURE TO UPSTREAM PIPING — TO PRECLUDE THE POSSIBILITY OF 'DOUBLE DISC DRAG'. WITH LOWER UPSTREAM PRESSURE.

(4) LOWER (ΔP) WILL REDUCE REQD. OPENING FORCE

APPENDIX 4

SAN ONOFRE NUCLEAR GENERATING STATION

UNIT 1

SIS VALVE ACTUATOR EVALUATION

	Δp		ACTUATOR THRUST	
Valve (Position for SIS)	Design (PSI)	Post 9/81 Design (PSI)	Design (LB)	Load Design Post 9/81 (LB)
HV-851 A & B (Open)	1500	350	33,160	21,646
HV-852 A & B (Close)	1500	22	44,942	6,336
HV-853 A & B (Open)	350	171	13,130	10,825
HV-854 A & B (Close)	350	174	10,269	2,807

APPENDIX 5

APPENDIX 6

SAN ONOFRE NUCLEAR

GENERATING STATION

UNIT 1

SAFETY INJECTION SYSTEM MODIFICATION

HYDRAULIC TRANSIENT STUDY

FEEDWATER PUMP TRIP SCHEME

1. INTRODUCTION

The purpose of the hydraulic and stress analysis described in this report was to evaluate the effects of hydraulic transient events on modified Safety Injection System. The hydraulic event was described in ref. 1 and figure 1. The SIS modification includes the following three changes to the existing operating sequence.

- Feedwater pump (G3A & G3B): Upon receiving either a SIS or SISLOP signal, trip both pumps instantly; and 11 seconds later restart these pumps. In the existing system, the F. W. pumps continue operation upon receiving a SIS signal and restart after the diesel generator starts upon receiving a SISLOP signal.

- MOV's 850A, 850B & 850C: Upon receiving either a SIS or SISLOP signal, delay 11 seconds before opening these three valves. In the existing system, the MOV's open immediately upon receiving the SIS signal.

- Control valves HV 854 A & B, HV 853 A & B, HV 852 A & B, HV 851 (A & B): Upon receiving either a SIS or SISLOP signal, these valves react instantaneously. In the existing system, a 10 second delay was designed prior to the reaction to the signals. The existing interlock between HV 854 A & B and HV 851 A & B will not be changed so that HV 851 A & B will not start to open until HV 854 A & B are closed.

The scope of this analysis is limited to the transients caused by the above changes. In addition to the three flow conditions analyzed in the previous report (Ref. 2), one more condition was added. These four cases are:

Case	
1A	Two safety injection trains, three safety injection lines with one spilling.
2A	Two safety injection trains, three safety injection lines and nonspilling.
3A	Two safety injection trains, two safety injection lines and the third injection line isolated.
4	Restart the feedwater pump with all valves wide open. (2 trains, 3 injection lines and nonspilling)

The calculated data history of pressure was plotted (See Fig 3). The data of rate of change of pressure for the original case and alternative 1 were tabulated (See table 1).

2. METHOD OF ANALYSIS

The Bechtel program, "Hydraulic Transient Analysis", was developed to simulate the transient response in a generalized hydraulic system in accordance with the procedures described by Streeter and Wylie (Reference No. 3). The controlling one-dimensional unsteady flow equations of continuity and momentum in a closed conduit including the elastic effect of the liquid and the pipe wall are partial differential equations of hyperbolic type. These partial differential equations may be transformed into particular total differential equations by the use of the method of characteristics. A first order finite difference scheme is then used to place the total differential equation in a form suitable for numerical solution on a digital computer.

The transient conditions in each pipeline in the system are related in accordance with the above description. Boundary conditions are used to transfer the effect of one pipeline to another and to introduce the effect of hydraulic components such as pumps, valves, etc. In each boundary condition, it is assumed that flow continuity holds at the boundary and that the wave travel effect within the boundary can be neglected. One characteristic equation for each pipeline connecting to the boundary, in addition to the pertinent dynamic hydraulic equations of the boundary itself, provides enough conditions for the solution of the unknown variables within the boundary.

In a typical computer analysis, an initial steady state operating condition is imposed upon the system; then a numerical solution is obtained at finite points throughout the entire system at finite time increments during the life of the transient.

The program implements mainly the characteristics method of solution to compute the transient response of a piping system. The method of characteristics is able to provide a stable and accurate solution. However, for stability reasons, the method requires that the computational time increment be restricted to the reach length (ΔX) divided by the corresponding wave speed.

The equation to calculate pressure wave speed(s) is described in Appendix A.

An internal boundary condition that allows a vapor cavity to form is provided whenever the pressure in a section is indicated at or below vapor pressure. During existence of the cavity, the pressure remains at vapor pressure. The growth and subsequent decay of the cavity for each time increment is calculated by accumulating the net flow into the section containing the cavity. At the time the cavity solume vanishes, the head rise due to the contract of the two liquid columns is obtained by $H = a\Delta V/2g$, where a and ΔV are, respectively, the pressure wave speed and the relative velocity of the two liquid columns. The head at time of impact is

$Hv + \Delta H$, where Hv is the vapor head. Then rate of change in pressure $\Delta p/\Delta t$ can be calculated at each Station number as described in the schematic layout of the Safety Injection System (Fig 2). The formulas to calculate rate of change in pressure and unbalanced force on the pipe is described in the Appendix A.

3. SUMMARY OF RESULTS AND CONCLUSIONS

Based on the data described above, four selected transient conditions were analyzed and the results are summarized in Table 1. The results show that the hydraulic transient effects for the revised operating sequence are less severe than the original analysis. Table 1 shows the station number, positive and negative maximum pressure gradient ($\Delta p/\Delta t$) for cases 1A to 3A. Also maximum positive and negative pressure gradient data were selected out of three cases for each station number and summarized in Table 1. Since the transients for case 4 are much slower than for the other cases, the results of Case 4 are not included herein. - For the original analysis, the maximum positive and negative pressure gradient data were obtained from Ref. 2. These data were tabulated in Table 2. Table 2 presents the rates of change of pressure caused due to alternative 1 modification of the SIS and also those used in the original stress analysis (March 1976). A comparison of the two values at the specified stations were made and the ratios "Alternative 1/original value" is presented in the same table. This comparison indicates that the rates of change of pressure caused in the alternative 1 analysis are lower than those used in the original analysis. Hence, unbalance forces on the system will be lower in alternative 1 than original analysis (see equation 3 in Appendix). Since the original analysis met the requirements of the ASME Code, Section III, Division 1, 1974 it is concluded that the modifications made in SIS in accordance with the alternative 1 will also meet the same code requirements and that no modification of the supports will be necessary.

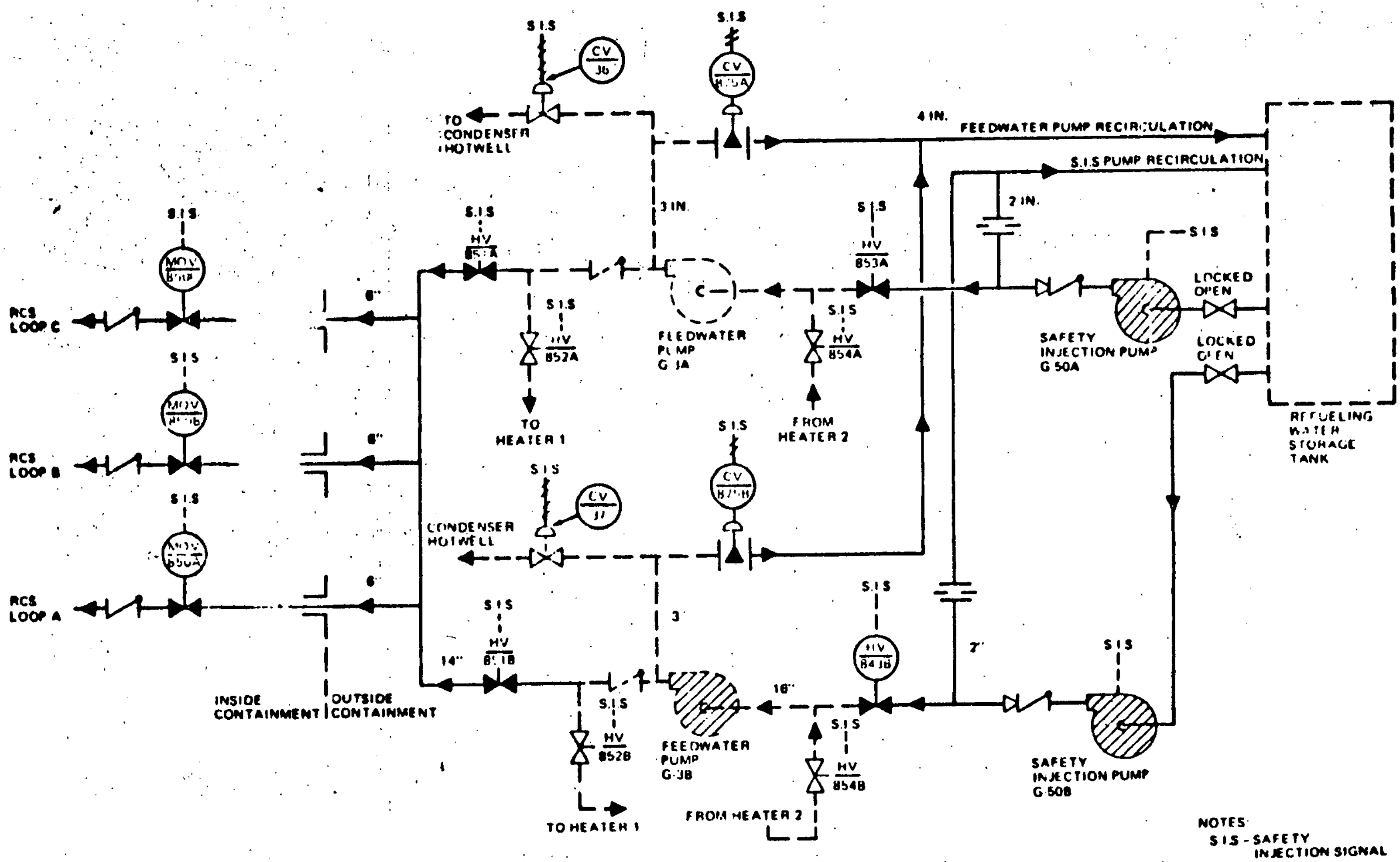
Also, it was concluded that transients results are very sensitive to the valve data for the first 5% of valve opening. Also, from the study, it was concluded that the maximum transient pressure caused by the modified SIS operating sequence (alternative 1) will be within maximum allowable limit of 1500 psig.

REFERENCES

1. "Design Criteria for Safety Injection System Modification - Song 1", September 10, 1981, by Bechtel Power Corporation L.A. Division

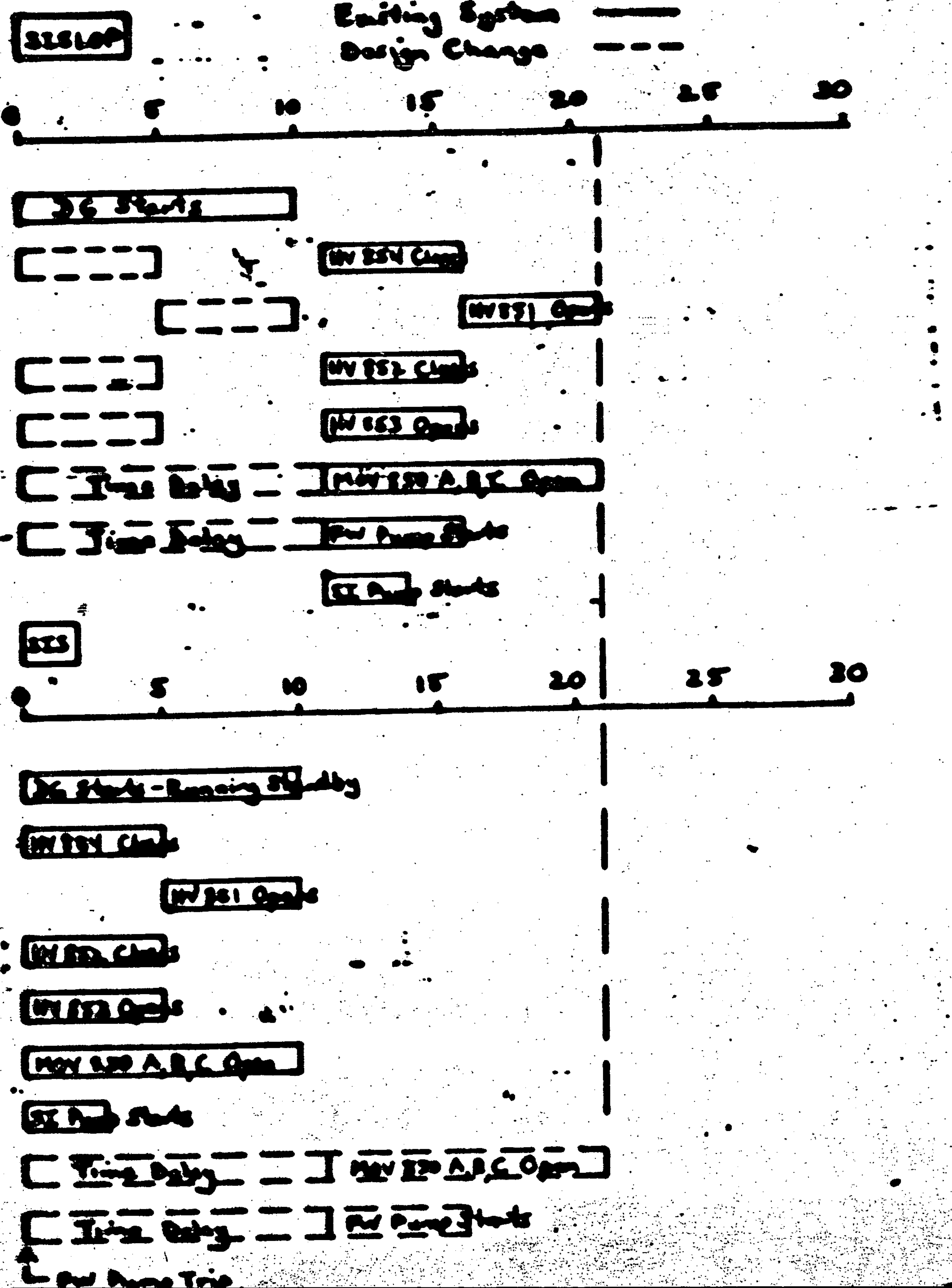
2. "Hydraulic Transient Analysis of the Safety Injection System - Song 1", December 1975, by Geotechnical Services, H&CF, Bechtel.

3. "Hydraulic Transients" McGraw Hill Book Company, 1967, by Streeter, V. L. and Wylie, E. B.



SIMPLIFIED SCHEMATIC OF SONGS-1 SAFETY INJECTION SYSTEM

SI DELAY TIME



SONGI — LPSIS MODIFICATION DESIGN TRANSIENT STUDY

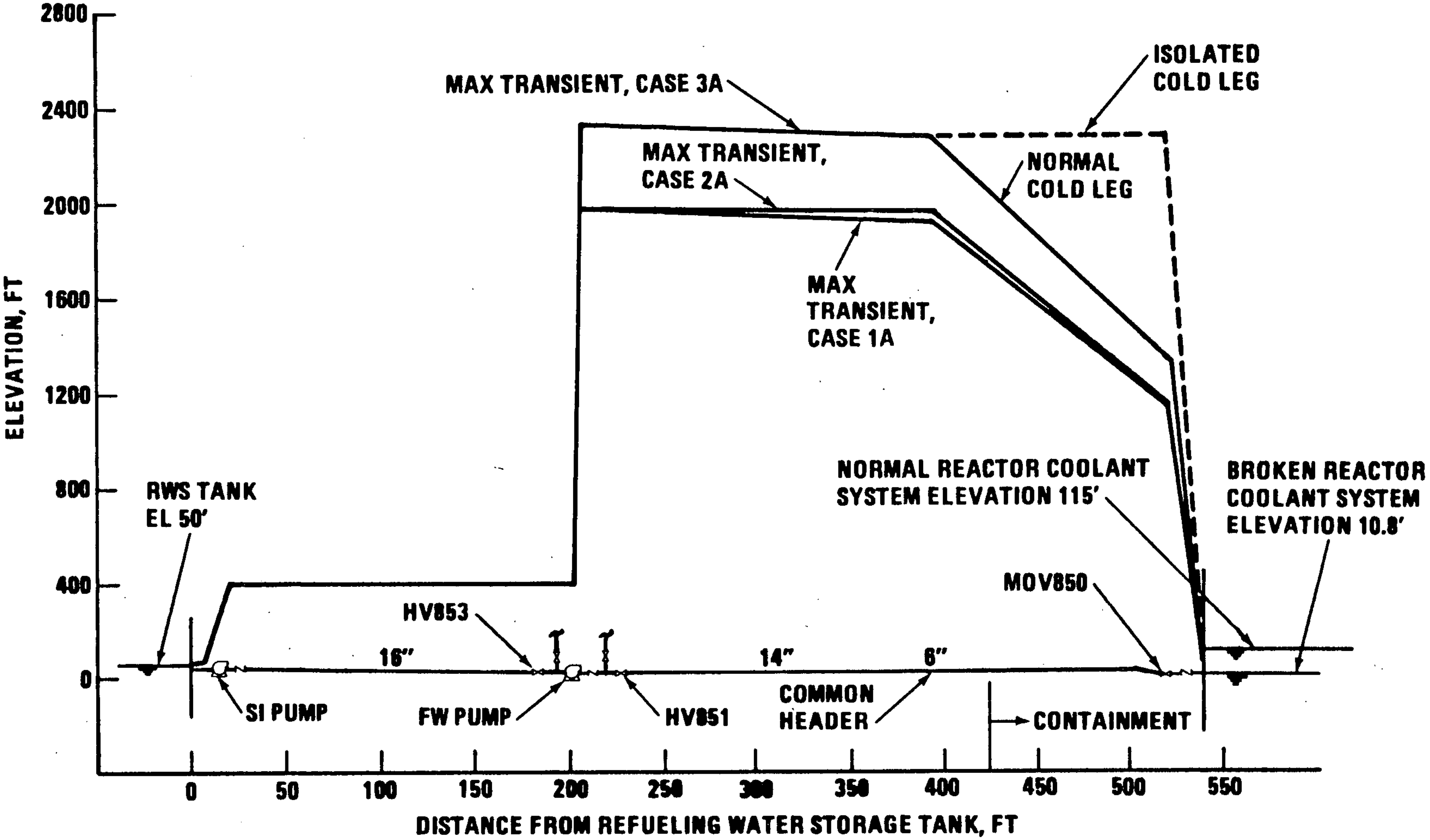


TABLE 2 — COMPARISON OF RATE OF CHANGE OF PRESSURE DATA

STATION NUMBER	ORIGINAL ΔP/Δt		MODIFICATION ΔP/Δt		RATIO	
	+	–	+	–	+	–
5	7000	3352	834	817	0.12	0.24
8	2929	5462	800	860	0.27	0.16
13	4199	9265	1000	1000	0.24	0.11
16	7184	5993	1244	950	0.17	0.16
17	7184	5993	1300	750	0.18	0.13
18	6755	4676	1443	700	0.21	0.15
19	10220	5456	1635	1090	0.16	0.20
22	8574	4676	1365	1165	0.16	0.25
24	9266	4070	992	1180	0.11	0.29
26	9960	4416	704	1304	0.07	0.30

ORIGINAL: ORIGINAL ANALYSIS
MODIFICATION: ANALYSIS WITH RESEQUENCING OF VALVES & FW PUMP
RATIO: MODIFICATION/ORIGINAL

TABLE 2 — COMPARISON OF RATE OF CHANGE OF PRESSURE DATA (CONT)

STATION NUMBER	ORIGINAL ΔP/Δt		MODIFICATION ΔP/Δt		RATIO	
	+	−	+	−	+	−
30	3614	4212	775	1017	0.21	0.24
32	3614	4212	780	1000	0.22	0.24
33	3826	3062	886	975	0.23	0.32
35	4714	4126	950	1017	0.20	0.25
36	4714	4126	950	1017	0.20	0.25
37	4503	5110	1191	1090	0.26	0.21
38	5110	5283	1191	1090	0.23	0.21
40	9872	4156	861	852	0.09	0.21
42	9093	4156	900	1217	0.1	0.29
47	12928	5197	1051	3130	0.08	0.60

ORIGINAL: ORIGINAL ANALYSIS
MODIFICATION: ANALYSIS WITH RESEQUENCING OF VALVES & FW PUMP DATED SEPT., 81
RATIO: MODIFICATION/ORIGINAL

TABLE 2 — COMPARISON OF RATE OF CHANGE OF PRESSURE DATA (CONT)

STATION NUMBER	ORIGINAL ΔP/Δt		MODIFICATION ΔP/Δt		RATIO	
	+	−	+	−	+	−
48	13124	7917	1182	3150	0.09	0.40
49	13124	7917	1739	3165	0.13	0.40
55	12928	5197	920	3130	0.07	0.60
56	13124	7917	1113	3150	0.09	0.40
57	13124	7917	1166	3165	0.09	0.40
64	12928	5197	1391	3574	0.11	0.69
65	13124	7917	1209	3574	0.09	0.45

ORIGINAL: ORIGINAL ANALYSIS
MODIFICATION: ANALYSIS WITH RESEQUENCING OF VALVES & FW PUMP DATED SEPT., 81
RATIO: MODIFICATION/ORIGINAL

E. APPENDIX

Equation to calculate pressure wave speed(s)

$$S = \left[\frac{g}{w} \frac{EE'}{\left(E' + \frac{ED}{T}\right)} \right]^{1/2} \quad — \quad (1)$$

Where g = Gravitational constant, 32.2 ft/sec^2

E = Bulk modulus of fluid, psi

E^1 = Young's modulus of elasticity, psi

d = Inside diaemeter of pipe, in

T = Thickness of pipe, in

Equation to calculate rate of change in pressure $\Delta p/\Delta t$

$$\Delta p/\Delta t = \frac{\gamma}{144} \times \frac{h_2 - h_1}{t_2 - t_1} \text{ psi/sec} \quad — \quad (2)$$

Where h_2 = pressure head at time t_2, ft.

h_1 = pressure head at time t_1, ft.

γ = density of fluid, lb/ft.^{3}

The time interval $(t_2 - t_1)$ should be approximately equal to to the time taken for pressure wave to travel over the length 'L' of pipe between two consecutive bends. For large values of 'L' the drop rate $(t_2 - t_1)$ should be calculated with a value equal to L/S

Equation to calculate the unbalance force (F) on pipe resulting from hyraulic transient

$$F = \left(\frac{\Delta p}{\Delta t}\right) X (A) X \left(\frac{L}{S}\right) \text{lbs} \qquad -(3)$$

Where $\Delta p / \Delta t$ = rate of change in pressure, psi/sec

A = flow area, in^2

L = length of pipe, ft.

S = speed of pressure wave, ft/sec.

APPENDIX 7

11 November 1965

TEST AGENDA

Bechtel Corporation

BJ Job 723305-306
10 x 10 x 17 2 stage DVMX

PURPOSE:

The purpose of this agenda is to describe the intended procedures to be followed in the performance of the required tests.

BLOCKED SUCTION TEST (CLOSED SUCTION VALVE):

A test to determine the pump characteristics when the pump suction is completely blocked will be performed in the following manner: While the pump is running at reduced flow, the suction valve will be completely closed until the pump evacuates itself, and still remain closed until a time lapse of 10 seconds after power input is near Zero is noted. The suction valve will then be reopened until the pump has recovered full head and flow.

THERMAL SHOCK TEST:

The pump will be run at full design speed with the discharge valve closed and minimum flow valve set for minimum flow at which temperature control can be achieved. The suction pressure control valve will be full open. The pump will be taking suction from a high pressure inspection pump. The temperature inside the test pump will be allowed to rise 300° above ambient (approximately 380°F.). When this temperature is achieved the hot water in the loop will be replaced by cold water in required quantities to drop the loop temperature 300°F. in 10 seconds.

POST TEST INSPECTION:

The pump will be completely inspected for evidence of malfunction, after the Thermal Shock Test and before proceding with the balance of the test program.

PERFORMANCE TEST (COLD):

A full range performance test will be run at the final wear ring clearances. The test will be run at ambient temperature. The pump will be directly coupled to a customer's 3500 hp, 2 pole motor. Flow will be measured by a Herschel type Venturi meter in conjunction with a mercury manometer. Discharge and suction pressure will be read with laboratory type Bourdon tube pressure guages. Power will be read with a polyphase wattmeter. Speed will be read with a strobotac reading slip from synchronous speed. The test will be run in an open loop.

(Continued . . . .

CAVITATION TEST (COLD):

A test to determine cavitation characteristics of the pump will be performed in the same open loop utilizing the same instrumentation as the performance tests, and at the same temperature. Characteristics of cavitation will be demonstrated by slowly varying the suction head while holding a constant discharge flow. When the required NPSH is reached data will be recorded. The discharge flow control valve will then be gradually opened until there is a decrease in head with no increase in flow. This will be considered the unstable head condition.

OPEN VALVE TEST:

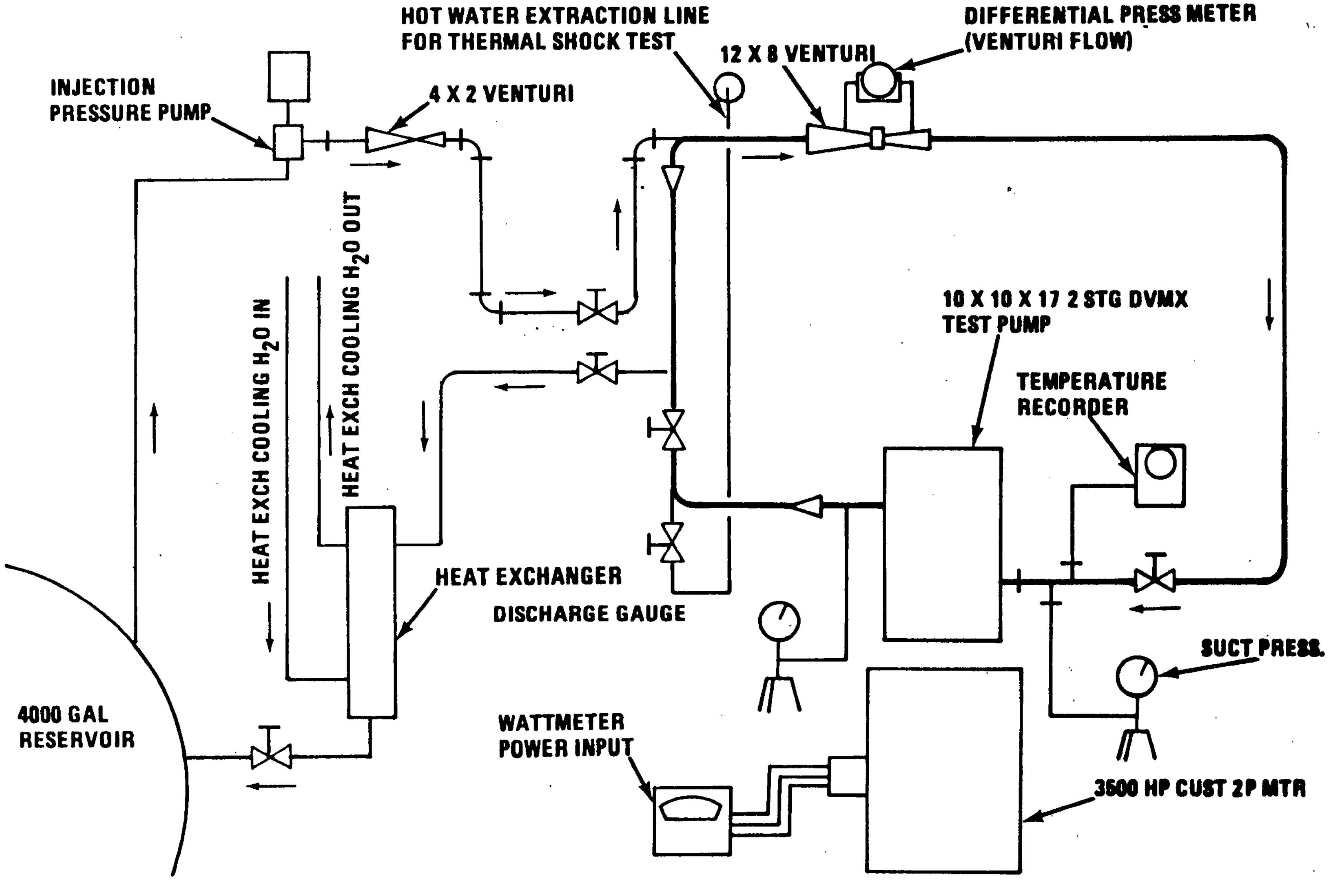
A test to demonstrate the ability of the motor to bring the pump up to full speed with an open discharge valve within 30 seconds will be run. Ample NPSH will be provided.

Byron Jackson Pumps, Inc.
BORG-WARNER CORPORATION

E. A. Dovidio
Supervisor Test Facility

EAD:mq

PERFORMANCE AND THERMAL SHOCK TEST STAND



APPENDIX 8

Byron Jackson Pump Division

P.O. BOX 2017 TERMINAL ANNEX, LOS ANGELES, CALIFORNIA 90051 • 213/587-6171

23 September 1981

Bechtel Power Corp.
P.O. Box 60860 - Terminal Annex
Los Angeles, Calif. 90860

Attention: Mr. Art Sanders
Project Engineer

Subject: Feed Pumps BJPD S/N 723305/6
Completeness Requirements for
Reliability Analysis of Corrective
Actions Proposed by Licensees as a
Result of 9/3/81 Feedwater Transient
at San Onofre Unit 1

Gentlemen:

We understand from the meeting of today that the transient conditions to which these pumps might be subjected are as follows:

1. From normal operation at 350°F. a pump might be tripped and restarted. It would immediately be pumping 3% boric acid solution at ambient temperature.

2. The pump might also be subject to operation with inadequate suction conditions until safety injection flow is established. The duration will be in the order of seconds rather than minutes.

3. The pump might be started against either a closed or open discharge valve.

During tests made at our facilities in Los Angeles in 1965 and 1966, the above conditions were simulated. For reference please see our letter dated 21 January 1966 to J.R. McEntee. The pumps, including one actual driver, satisfied all test requirements and remained operational without any sign of distress. We have since that time designed and tested other pumps to meet similar requirements. These tests, with subsequent disassembly and component inspection, have satisfied us that there were no inherent flaws in our design or manufacturing procedures.

We, therefore, conclude that our pumps were designed and tested to successfully perform through and after the described transients.

Should you have need for further discussion, please contact us.

Very truly,

BYRON JACKSON PUMP DIVISION
BORG-WARNER CORPORATION

E.B. Fiske

E.B. Fiske
Director of Engineering, LAO

EBF/mw

APPENDIX 9

SAN ONOFRE NUCLEAR
GENERATING STATION
UNIT 1

SAFETY INJECTION SYSTEM MODIFICATION
ELECTRIC ANALYSIS

Introduction: The Safety Injection System, SIS, modifications causes the feedwater pump motor breakers to trip on initiation of SIS or SISLOP from its respective sequencer. The trip signal is cleared following on eleven second time delay (via Agastat Series 7000 time delay relays) and the breakers are signaled to close. The trip of the feedwater pumps with off-site power available and eleven second time delay for a motor start imposes a different demand on the auxiliary power system than the present design.

In addition, the fixed time delay of eleven seconds on initiation of a SISLOP may create a different loading sequence than previously analyzed for the diesel generators (on-site power system). Analysis of the capabilities of the auxiliary and on-site power systems for providing sufficient torque for motor acceleration is analyzed below.

Motor Starting Characteristics:

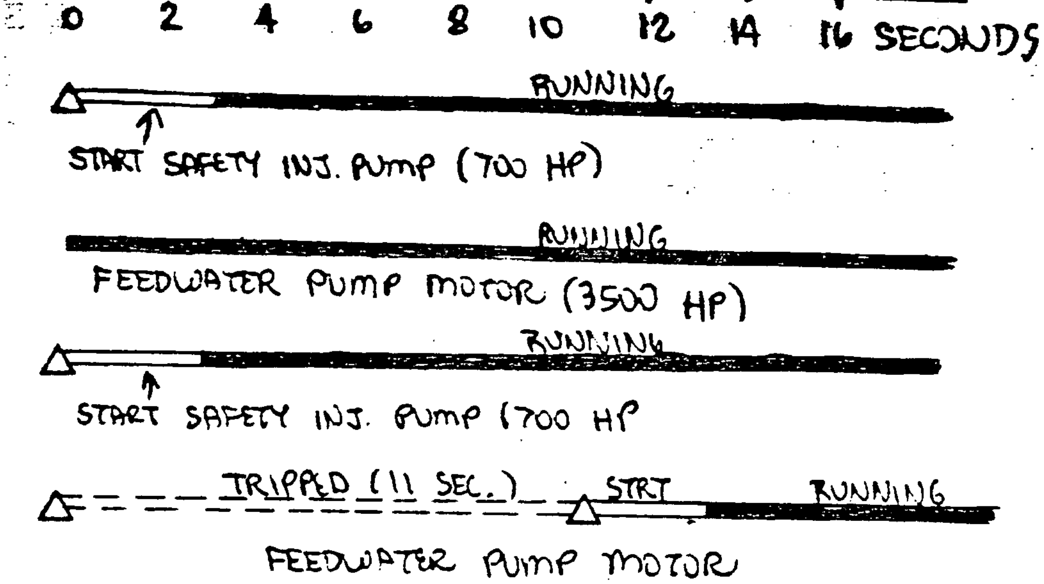
In order to determine what constitutes allowable voltage drop to the feedwater pump motor terminals, motor torque vs. percent synchronous RPM for various voltage levels was ploted against the "Open Valve" and "Closed Valve" load torque vs. percent sychronous RPM curves (see Figure I). Although the "Open Valve" torque curve is more severe than the actual load curves for the SIS modifications which have been proposed, it is the most severe case and is used for analysis herein. From Figure I, it can be determined that as long as the feedwater pump motor terminal voltage is maintained in excess of 85% of rated motor voltage, (4160 Volts), a "Motor Stall" cannot occur. Computer runs indicate that at 80% of rated motor terminal voltage, (3328 Volts), the motor would cease to accelerate at 75% of synchronous speed, (2700 RPM), in 8.97 seconds. A "Motor Stall" speed would result in a maintained overcurrent condition on the motor (approximately 1500 amps @ 0.8 PU Volts) eventually resulting in a motor winding short circuit. At 85% of rated motor terminal voltage, (3536 Volts), the motor would successfully accelerate its load to approximately 3550 RPM in 12.7 seconds (8.61 sec. to 90% of synchronous RPM).

SIS With Offsite Power Available:

The existing design calls for the Safety Injection Pump (700 HP) of each loadgroup to start on receipt of a SIS with the feedwater pumps running. The SIS modification trips the feedwater pump at SIS and allows a restart in 11 seconds.

Existing Design:

Proposed Design:



Each feedwater pump and safety injection pump motor derive power from offsite (see Figure II) via Auxiliary Transformer "C" (30 MVA 230-4.36 kV/4.36 kV) and 4.16KV Switchgear buses 1C and 2C. Each switchgear derives power from one of two secondary windings rated 15 MVA each, (one winding is dedicated per loadgroup). The safety injection pumps for the proposed design have a higher terminal voltage as they are now started without the additional 409 amps of full load current for each feedwater pump which caused greater voltage drop to each switchgear bus.

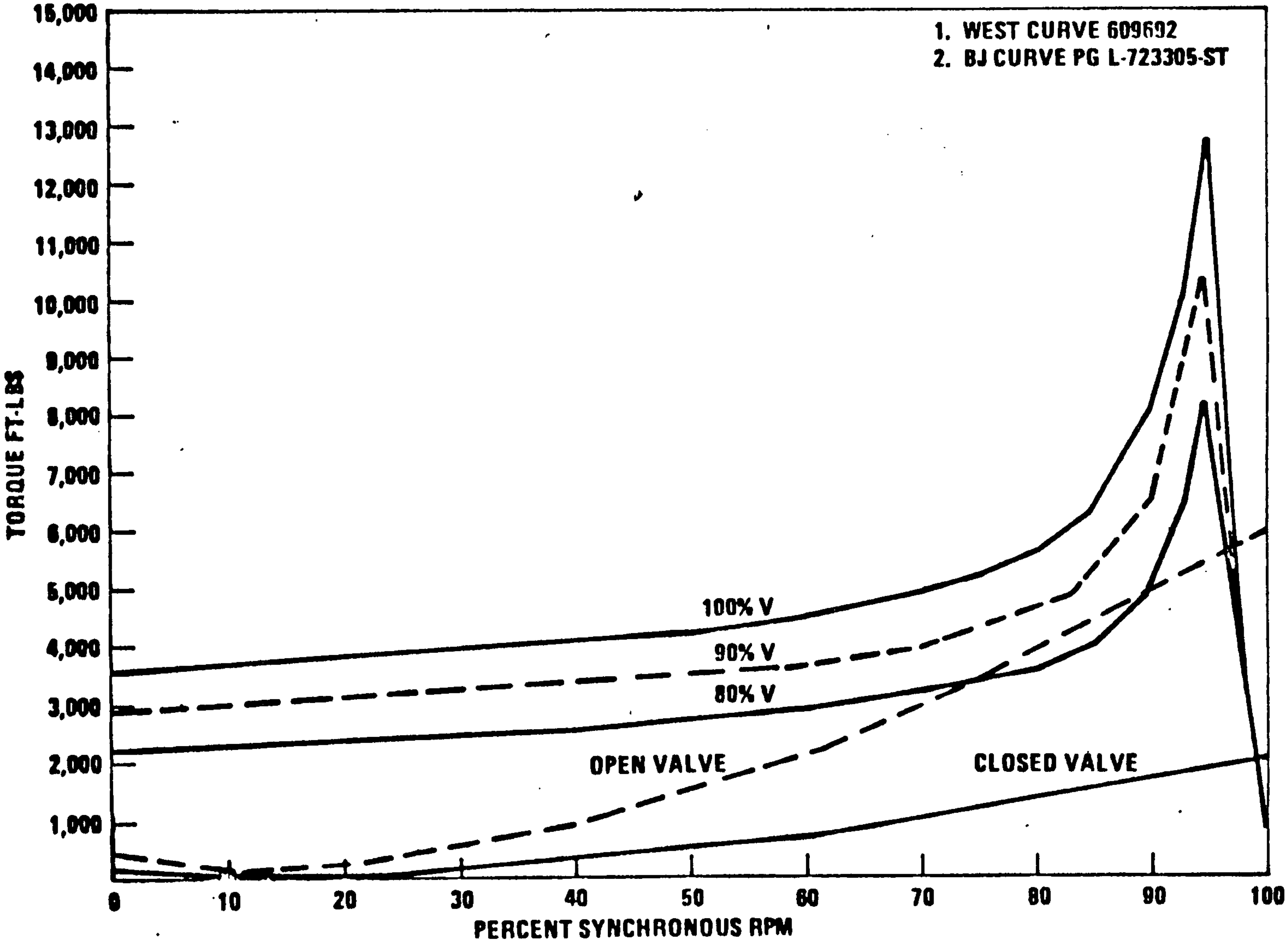
An inrush current of 2,318 amps @ 4.16 kV will be imposed on the auxiliary power system (per load group) with running loads including the safety injection pumps. The auxiliary power system has been analyzed for the worst case of the safety injection pumps and feedwater pumps starting at the same time (SIS) for a minimum grid voltage of 217.8 kV (0.95 P.U. Volts). The calculated feedwater pump motor terminal voltage for this configuration is 0.89 P.U. (=3700 Volts). The proposed design is therefore less severe for starting the safety injection pump motors when compared with the existing design. The design is also acceptable for starting the feedwater pump motors at 11 seconds inthat the voltage drop calculation yields acceptable motor terminal voltages for a"worst case" load torque given a more severe analytical model.

Notes: 1) Other loads and bus tie lines on switchgear 1C and 2C are not shown.

Malfunction of a starting feedwater pump motor will not cause a failure of the safety injection system. A locked rotor of either G3A or G3B will not prevent the accelerating motor from reaching full load speed. If the overcurrent does not clear, a motor winding fault would cause tripping of the faulty motor, (overcurrent tripping is bypassed on SIS) clearing the fault.

Loss of Transformer "C" would result in restoration of power to each switchgear bus via the diesel generators. Load shed and re-sequencing would follow via the SISLOP signal.

MOTOR TORQUE AND LOAD TORQUE VS SYNCH. SPEED CURVE



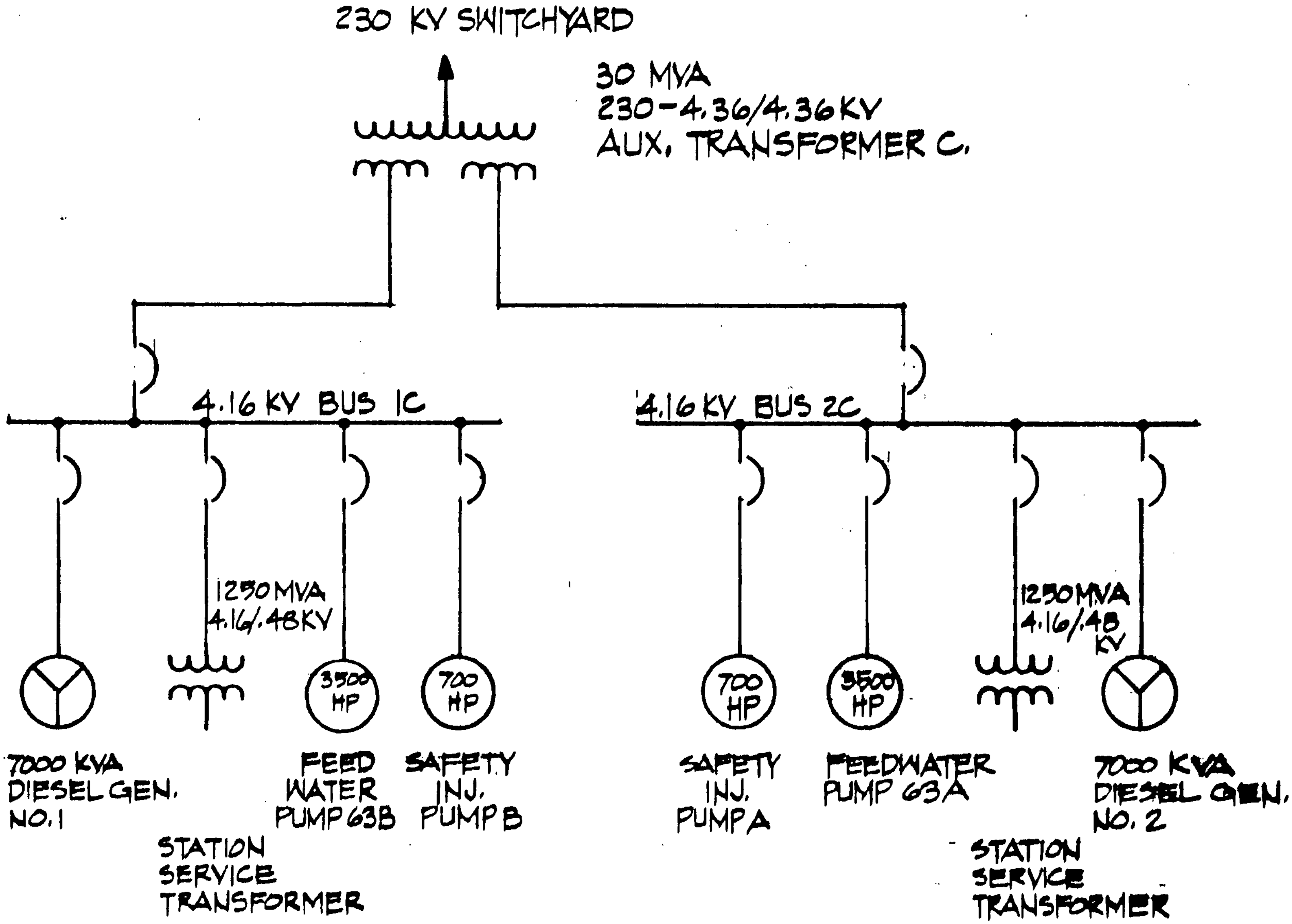
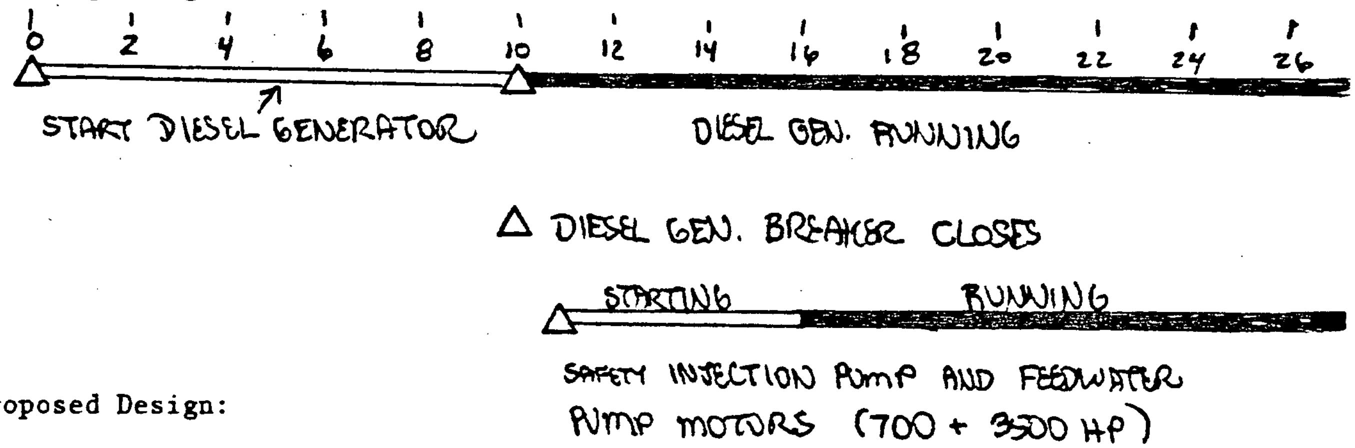

230 KV SWITCHYARD
30 MVA
230-4.36/4.36 KV
AUX. TRANSFORMER C.
4.16 KV BUS 1C
4.16 KV BUS 2C
1250 MVA
4.16/.48 KV
3500 HP
700 HP
700 HP
3500 HP
1250 MVA
4.16/.48 KV
7000 KVA
DIESEL GEN.
NO. 1
STATION
SERVICE
TRANSFORMER
FEED
WATER
PUMP 63B
SAFETY
INJ.
PUMP B
SAFETY
INJ.
PUMP A
FEEDWATER
PUMP 63A
7000 KVA
DIESEL GEN.
NO. 2
STATION
SERVICE
TRANSFORMER

FIGURE II

SIS With Loss of Power Signal:

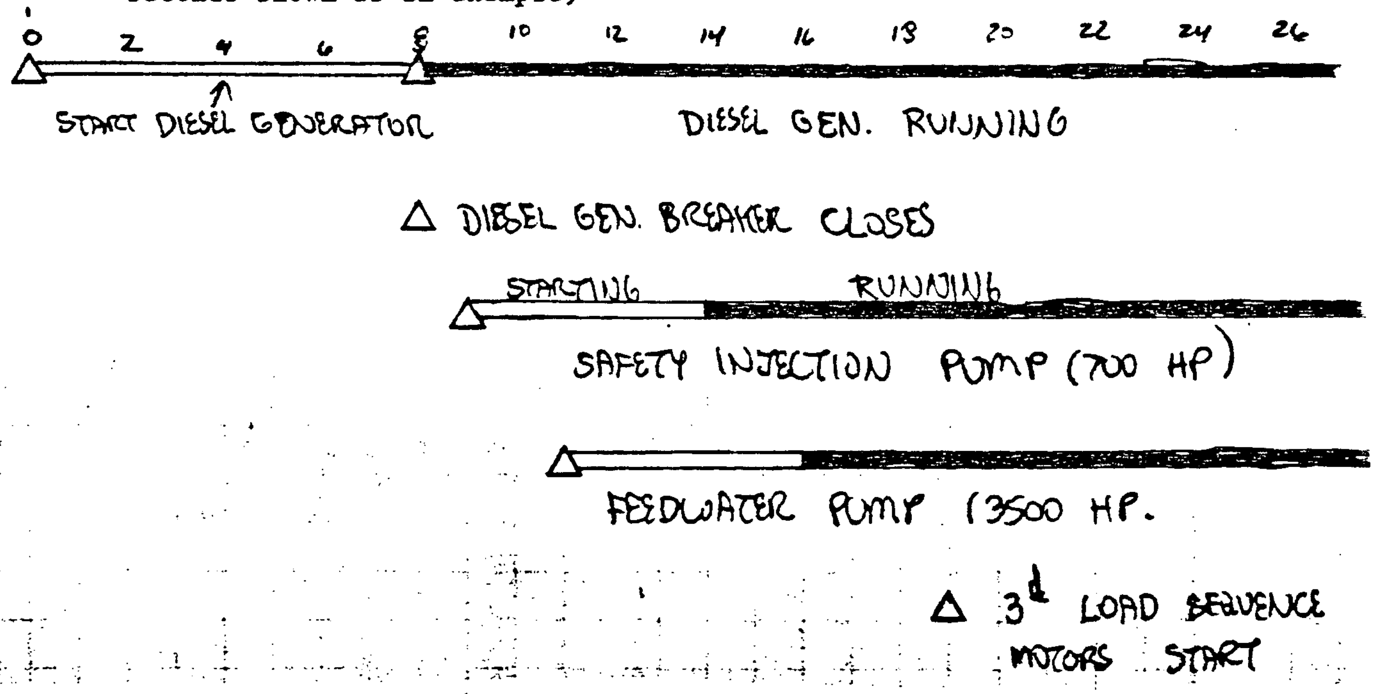
The existing design calls for diesel generator start and a load shed signals to selected loads on a SISLOP signal. When the diesel generator is at rated frequency and voltage, its associated switchgear supply breaker closes, re-establishing power. Certain loads are not tripped and on closure of the diesel generator breaker are energized. These loads include inductive transformer magnetization current inrush to each load groups 4.16/0.48 kV station service transformer, and approximately 560 KW of connected motor loads. One second after the closure of the breaker, the feedwater pump motor and safety injection pump with miscellaneous MOV's and small loads are signalled to start. The next load sequence occurs ten seconds latter. The SIS modification is similar to the existing design, but allows for the feedwater pump motor to start at eleven seconds from a SISLOP, independent of the time the diesel generator breaker closes.

Existing Design:



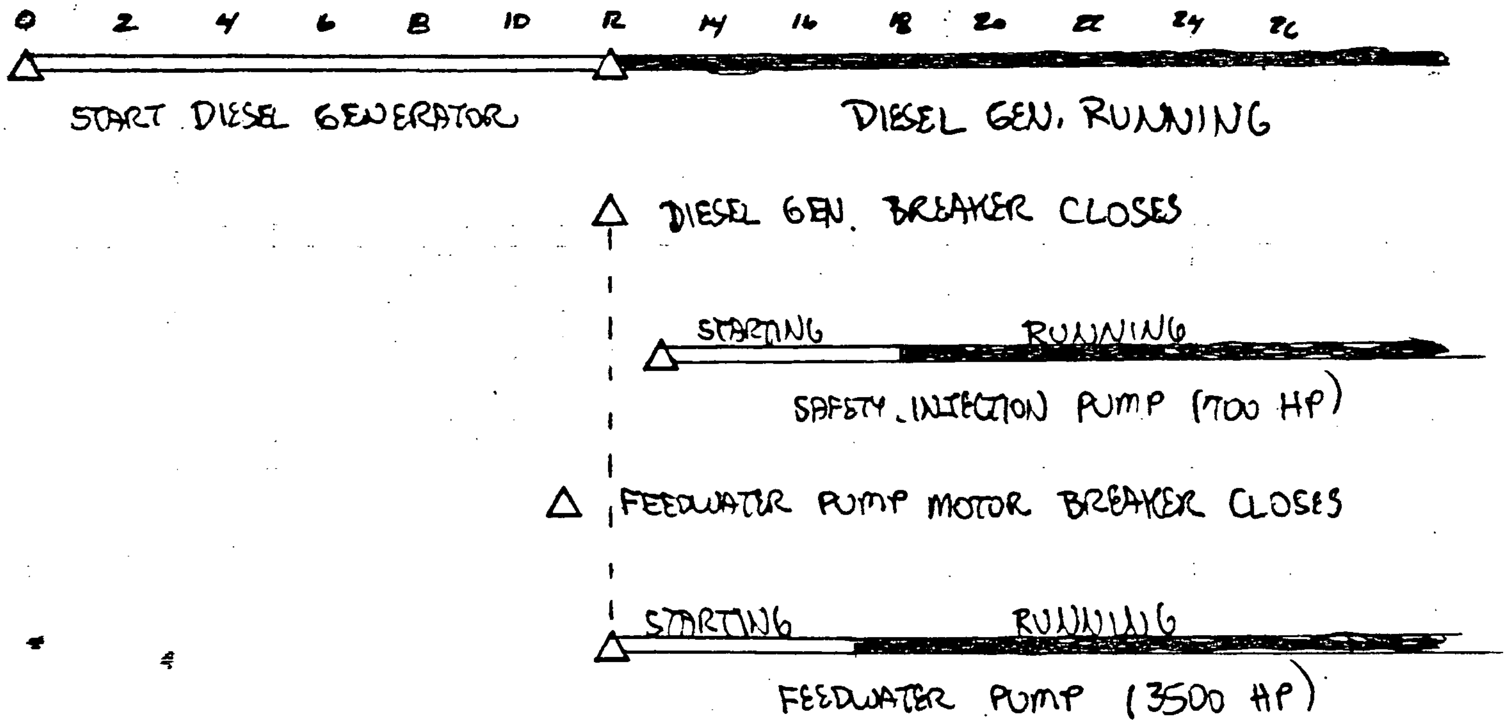
Proposed Design:

Case I - Diesel Gen. Breaker Closure Prior to or at 10 Seconds, (8 seconds shown as an example)



Note: The diesel generator normal will start before 10 Seconds. The ECCS analysis assumes breaker closure at 10 Seconds for conservatism.

Case II - Out of Spec. Diesel Generator Breaker Closure at or later than 11 Seconds (12 Seconds shown as an example).



The proposed design results in a less severe loading condition on the diesel generator as can be seen for Case I. For diesel generator breaker closure at or before 10 seconds, the safety injection pump motor terminal voltage is higher than the existing design because the start of the feedwater pump is delayed until 11 seconds (a 2 second margin for the example). When the feedwater pump motor is actuated to start, the total inrush current demand on the automatic voltage regulator of the generator is reduced allowing for a more rapid re-establishment of voltage at the generator terminals, and subsequently higher voltage (and motor torque) available for the feedwater pump motor.

For a late diesel generator start (Case II), the feedwater pump motor would be started when the diesel generator breaker closes. The inrush current to the motor is then added to the magnetization inrush current to the 416/0.48 kV station service transformer and 560 KW of connected motor load inrush current. Factory tests were conducted February 13, 1976 in which 4300 HP of motor load at 4.16 kV nameplate and 3750 KW of resistive load were connected in one step to the diesel generator, resulting in a voltage dip to 3325 volts and a frequency dip to 57.5 Hz, (from 4360 kv and 60 Hz initial conditions).

The total inrush current for an 11-12 second diesel generator breaker closure is calcultated to be approximately 3232 amps @ 79.7° and 4.16 kV base at the motor terminals and transformer primary. The inrush current for the factory tests was approximately 3695 amps @ 71.3° and 4.16 kV base at the motor terminals (data has been compared at 4.16 kV by analytically adjusting test data). During the factory test, the automatic voltage regulator was able to restore generator terminal voltage to 3924 volts in approximately 0.42 seconds.

It can be concluded that the Case II event discussed above for the design modifications proposed is less severe than factory testing which resulted in satisfactory voltage levels for the feedwater pump motor start for a worst case "Open Valve" load torque mode. It should also be noted that transformer magnetization current inrush transients are usually substantially reduced in magnitude within 0.5 seconds.

<u>Summary</u>

I. For the SIS mode of operation, the auxiliary power system is capable of providing sufficiently large motor terminal voltages for the feedwater pump motors to start and accelerate load for a worst case "Open Valve" system. The auxiliary power system was analyzed for all feedwater pump and safety injection pump motors starting at the same time for an off-site grid voltage of 0.95 PU. (230 kV base).

II. For the SISLOP modes, it is concluded that the system is adequate to power all connected motors for diesel generator breaker closures before 10 seconds and as late as 12. The diesel generator automatic voltage regulation is capable of supplying expected inrush current and restoring voltage to 3924 volts minimum in approximately 0.42 seconds for the "late start", (Case II), event described.

APPENDIX 10

PREREQUISITE TESTING

SAFETY INJECTION SYSTEM MODIFICATIONS

SAN ONOFRE NUCLEAR GENERATING SYSTEM

UNIT 1

A.1 Hydrostatic Test of HV-851A and B and HV-853 A and B valve body vent welded piping

a. Objective

To demonstrate the new piping and connection to valve body are leak tight.

b. Prerequisites

1) Construction installation completed.

2) Non-destructive examination complete.

c. Test Method

Piping and valve body are pressurized to test pressure required by ASME XI by closing isolation valve and pressurizing through test connections as shown on Figure 2.

d. Acceptance Criteria

No visible leakage.

A.2. Leak Test of Solenoid Valves 2900, 3900

a. Objective

1) To demonstrate that valves are leak tight at system hydro pressure

2) To demonstrate that valves are leak tight for containment isolation

b. Prerequisite

Piping Hydrostatic Test complete

c. Method

1) Pressurize the valve upstream seat to hydro pressure -1690 psi

2) Pressurize the valve upstream seat to 100 psi

d. Acceptance Criteria

Per manufacturer's instructions,

1) Leak rate of $\leq$1.5 cc/hr at hydro pressure

2) Leak rate of $\leq$7.5 cc/hr at 100 psi

A.3. ELECTRICAL PREREQUISITE TESTING

a. Objective

To verify that the modified electrical circuitry is per the elementary disgrams and wiring diagrams

b. Prerequisites

1) Construction complete

c. Test Method

1) Testing to be conducted per test procedure to verify the following:

a) Contact configuration
b) Pickup and dropout voltages of AC & DC relays
c) Setting of time delay relays
d) Indicating lights operate per applicable elementary diagrams
e) Fuse sizes and current rating are per applicable drawing and fuses are intact
f) Resistors and adjustments agree with drawings
g) Circuit insulation test
h) Circuit terminations are tight and connected per applicable wiring diagrams and elementary diagrams

d. Acceptance Criteria

1) Circuit integrity is as reflected on the elementary diagrams.

2) As specified in test procedure.

A.4 SIS Header pressure alarm bistable calibration and loop check

a. Objective

1) Recalibrate SIS header pressure alarm bistable to new setpoint

2) Verify instrument loop integrity

b. Prequisite - N/A

c. Test Method

1) Recalibrate alarm set point per standard pressure switch calibration procedures.

2) Verify loop integrity per test procedure

d. Acceptance Criteria

1. Alarm set point adjusted to 350 psig.

FUNCTIONAL TESTS

PREOPERATIONAL TEST PROGRAM

SAFETY INJECTION SYSTEM MODIFICATIONS

SAN ONOFRE NUCLEAR GENERATING STATION

UNIT 1

B.1 Differential Pressure Stroke Test of HV's-853 A and B

a. Objective

Demonstrate that HV-853A and B actuators will open valve in required time against a static differential pressure greater than or equal to operational differential pressure.

b. Prerequisite

1) Piping hydrostatic test complete

2) SIS pumps and valves in test mode.

c. Method

1) Referring to Figure 1, pressurize HV's-853 A and B from upstream side (Safety Injection pump side) using hydrotest pump.

2) Recirculation lines to refueling water storage tank are blind flanged closed.

3) Valves are given open signal and timed out using limit switches.

4) Test is performed 3 times on each valve to demonstrate and verify operability and repeatability.

d. Acceptance Criteria

With Δp of 175 psi, valve travels to full open position in 5 seconds or less.

B.2 Differential Pressure Stroke Test of MOV's 850 A, B, and C

a. Objective

Demonstrate the MOV's-850 A, B, and C will each open in the required time against a statically applied differential pressure greater than or equal to the operational differential pressure.

b. Prerequisites

1) Mechanical modifications to safety injection system complete

2) Pressurize level at mid-range

3) SIS filled and vented

4) Hydrotest pump supply water boron concentration 3750-4300 ppm.

5) SIS pumps and valves in test mode

c. Test Method

1) Referring to Figure 1, the safety injection system header is pressurized to 1250 psig using a high capacity hydro test pump.

2) Electrically stroke open and close MOV's 850 A, B, and C one at a time.

3) Valve stroke time is determined based on MOV limit switch closure.

d. Acceptance Criteria

With 1250 psi across valve,valve travels to full open position within 10 seconds.

B.3 Force Test of HV's 851-A and B

a. Objective

Determine by test the breakaway force required to open the valve when subjected to statically applied differential pressures of 350 psi and 0 psi.

b. Prerequisite

1) Mechanical modifcations to safety injection system complete.

2) SIS pumps and valves in test mode.

c. Method

1) Each valve is tested individually with the opposite train valve maintained closed.

2) With 0 Δp across the valve, actuator force applied to valve stem is gradually increased until breakaway occurs at which time the actuator force is recorded. This step is performed 3 times before proceeding to next step to assure repeatability of results.

3) Step 2 above is repeated except with a Δp of 350 psi across the valve which is applied by pressurizing the safety injection header using the hydro-test pump.

4) Step 2 is again repeated at 0 Δp to determine whether seating surfaces are measurably altered after stroking with applied ΔP of 350 psi

d. Acceptance Criteria

The forces required to open the valves are less than 21,646 lbs. Forces are computed based on recorded actuator parameters.

B.4 Hot Opening Force Test of HV-851-A

a. Objective

Determine characteristic change in opening force due to temperature.

b. Prerequisite

1) Mechanical modifications to safety injection system are complete.

2) SIS pumps and valves in test mode.

c. Method

1) HV-851A is heated such that fluid temperature in the valve body is approximately 200° F.

2) Safety injection system header is pressurized to 350 psig using the hydro-test pump.

3) Valve is stroked by gradually increasing actuator force until breakaway condition is achieved. Actuator parameters are recorded at this condition such that breakaway force can be computed.

4) Test is performed 3 times.

d. Acceptance Criteria

Calculated breakaway force based on recorded test parameters is less than 21,646 lbs.

B.5 Differential Pressure Stroke Test of HV's-851 A & B

a. Objective

Demonstrate that HV's-851 A and B will reliably open in the required time against a statically applied differential pressure greater than that experienced under operating conditions.

b. Prerequisites

1) Mechanical modifications to the safety injection system are complete.

2) Safety injection system pumps and valves in test mode.

3) SIS header filled and vented

c. Test Method

1) Referring to Figure 1, the safety injection system header is pressurized to 350 psig using a high capacity hydro-test pump.

2) Referring to Figure 2, body relief solenoid valves and associated manual valves are opened such that there is positive assurance of 350 psi Δp across valve upstream disc/seat.

3) Valve actuator is given open signal and travel time to full open position is recorded based on limit switch actuation.

4) Each valve is stroked individually, 10 times each to assure repeatability.

d. Acceptance Criteria

With 350 psi statically applied across the valve, valve achieves full open condition within 5 seconds of receipt of open signal.

B.6 Cold Zero Δ P/No-Flow Valve Sequencing Test

a. Objective

1) To demonstrate that the valves and pump control circuits sequence per the design modification. Testing is performed under no-flow, zero differential pressure conditions.

2) To demonstrate proper train alignment

b. Prerequisites

1) Mechanical and electrical modifications are complete including satisfactory completion of prerequisite tests A.1, A.2 and A.3.

2) SIS System filled and vented.

3) Calibrated test instrumentation installed and powered from an uninterruptable power source.

c. Method

1) With SIS System Pumps in test (i.e. control power only), simulate SIS and record pump stop and start signals and valve stroke timing. Use existing station cold SIS test modified such that only one train is actuated at a time.

2) Repeat using SISLOP initiation signal.

d. Acceptance Criteria

1) Sequence and stroking times are in accordance with the design modification and consistent with safety analysis.

2) Proper train alignment.

B.7 Cold ΔP/Flow Sequencing Test

a. Objective

1) Verify that the switchover from feedwater/condensate system to SIS sequences per the design modification and that system pressures are consistent with design assumptions.

2) Simulate system operation upon receipt of SIS and SISLOP actuation signals with feedwater and condensate pumps running to demonstrate system function.

b. Prerequisites

1) Prerequisite testing satisfactorily completed.

2) Functional testing satisfactorily completed through cold zero ΔP/No-Flow testing.

3) Refueling water storage tank water chemistry within limits.

4) MOV's 850 A, B and C maintained closed in test positions.

c. Method

1) Run feed pump on condensate recirculation, MOV-850 A, B, and C and HV-851A and B positively blocked closed. Provide SIS signal. Record pumps stops and starts, valve stroke times and sequence, and pump pressure decay. Perform three times with actuation on SIS signal.

2) Line up the feedwater pump to recirculate to the refueling water storage tank with HV-853A and B blocked open. Simulate SIAS and record data. Perform 9 times on SIS signal and once on SISLOP.

d. Acceptance Criteria

1) System sequential operation, valve stroke timing and system pressures are as per the design modification.

B.8 Valve Inspection

a. Objective

To determine the condition of the HV-851 A & B seating surfaces after 10 or more cycles with design Δp.

b. Prerequisite

1) HV-851 A & B have been operational 10 or more times against the feed pump decay pressure or greater.

c. Method

1) Remove valve internals and inspect

d. Acceptance Criteria

1) No evidence of galling on the seat or disc seating surfaces.

B.9 Cold ΔP/Flow Sequencing Test

a. Objective

1) Simulate system operation upon receipt of SIS actuation signal with feedwater pump running on refueling water tank recirculation to demonstrate system function following reassembly of HV-851A and B.

b. Prerequisites

1) Prerequisite testing satisfactorily completed.

2) Functional testing satisfactorily completed through HV-851A, B disassembly, inspection and reassembly.

3) Refueling water storage tank water chemistry within limits.

4) MOV's 850 A, B and C maintained closed in test positions.

c. Method

1) Line up the feedwater pump to recirculate to the refueling water storage tank with HV-853A and B blocked open. Simulate SIAS and record data. Perform once on SIS signal.

d. Acceptance Criteria

1) System sequential operation, valve stroke timing and system pressures are as per the design modification for the given valve line-up.

B.10 Hot Functional Test of Safety Injection System

a. Objective

Demonstrate capability of SIS to perform upon receipt of SIS signal when the plant is at hot shutdown.

b. Prerequisites

1) Plant in hot shutdown condition with primary system at pressure between 1700 psig and 2050 psig and at 535°F.

2) All SIS modification functional tests are successfully completed.

3) SIS operable.

c. Method

1) Manually initiate safety injection.

2) All SIS components addressed by modification are permitted to operate per design.

3) Verify operation by means of event recorders and personal observation.

4) NOTE: Because SIS pressure is well below RCS pressure, injection into the RCS will not occur.

d. Acceptance Criteria

Sequencing/timing are per design modifications.

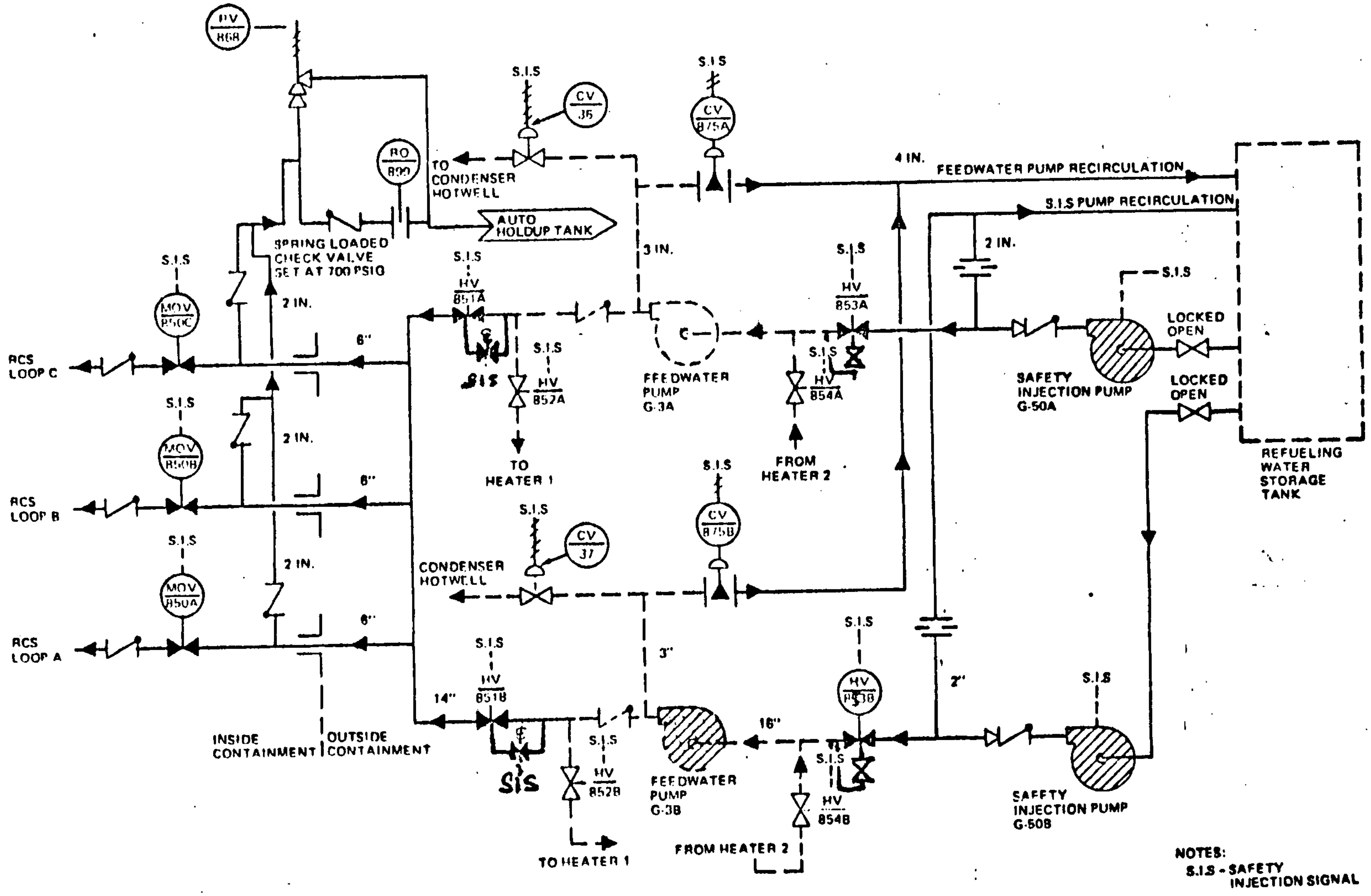


FIGURE B-1 SIMPLIFIED SCHEMATIC OF SONGS-1 SAFETY INJECTION SYSTEM

S.I.S. MECHANICAL MODIFICATIONS

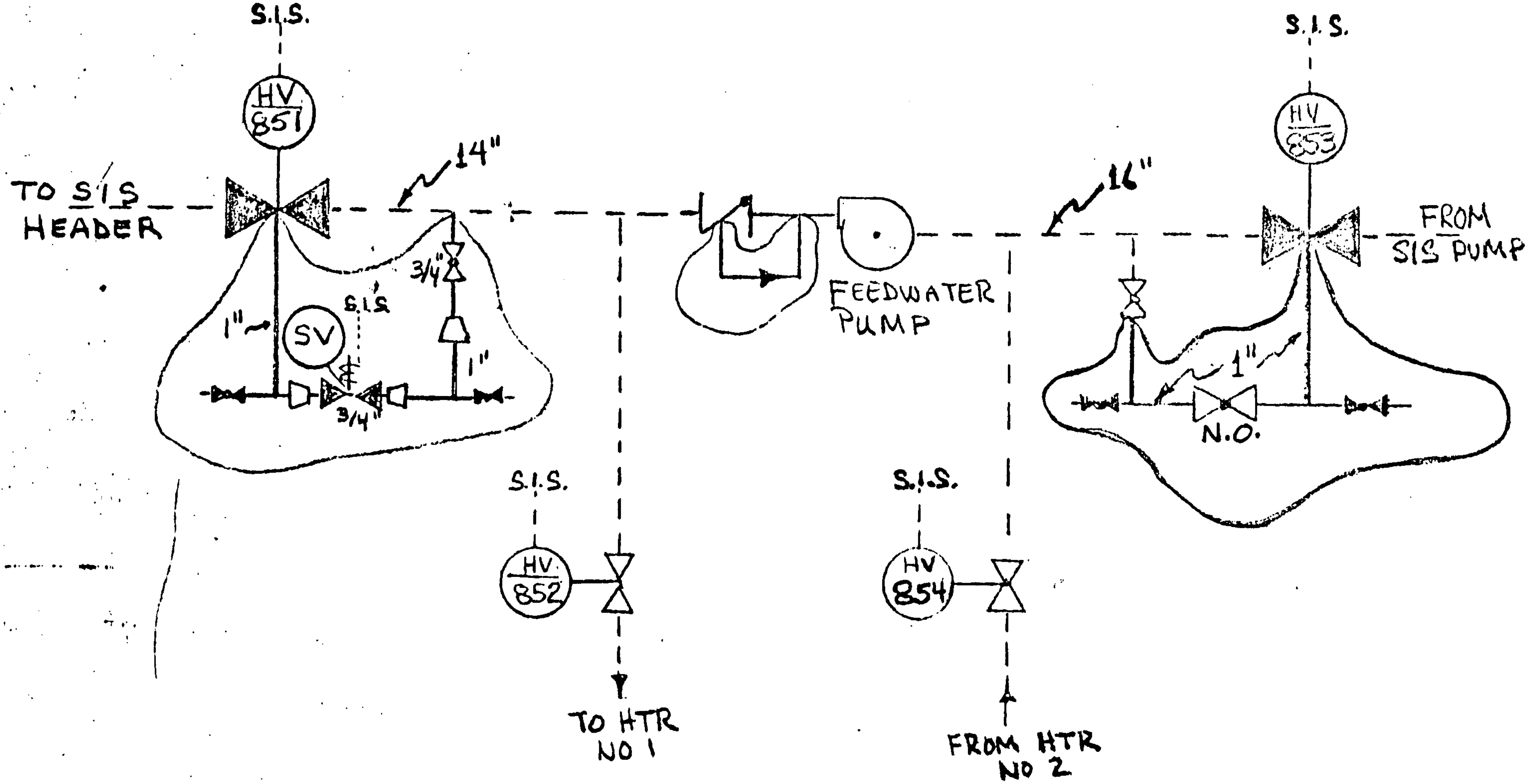


FIGURE B.2

SAN ONOFRE NUCLEAR [illegible]ERATING STATION UNIT 1
SAFETY INJECTION VALVES MODIFICATIONS
PREOPERATIONAL FUNCTIONAL TEST MATRIX

TEST (IN SEQUENCE)	MOV 850 A, B, C	HV-851 A, B	HV-852 A, B	HV-853 A, B	HV-854 A, B	SV 2900 SV 3900
ΔP STROKE	ΔP = 1250 CYC's = 1	NA	NA	ΔP = 175 CYC's = 3	NA	NA
OPENING FORCE	NA	ΔP = 0/350/0 CYC's = 3/3/3	NA	NA	NA	Maintained Open
*HOT OPENING FORCE (851A only)	NA	ΔP = 350 *CYC's = 3	NA	NA	NA	Maintained Open
ΔP STROKE	NA	ΔP = 350 CYC's = 10	NA	NA	NA	Maintained Open
COLD NO-FLOW SEQUENCING 1-SIS 1-SISLOP	ΔP = 0 CYC's = 2	ΔP = 0 CYC's = 2	ΔP = 0 CYC's = 2	ΔP = 0 CYC's = 2	ΔP = 0 CYC's = 2	ΔP = 0 CYC's = 2
COLD FLOW/ΔP SEQUENCING 3-SIS	Maintained Closed	Maintained Closed	ΔP = Pump Decay CYC's = 3	ΔP = Pump Decay CYC's = 3	ΔP = Pump Decay CYC's = 3	Maintained Closed
COLD FLOW/ΔP SEQUENCING 9-SIS 1-SISLOP	Maintained Closed	ΔP = Pump Decay CYC's = 10	ΔP = Pump Decay CYC's = 10	Maintained Open	ΔP = Pump Decay CYC's = 10	ΔP = Pump Decay CYC's = 10
VALVE INTERNALS INSPECTION	NA	HV-851A, B Only	NA	NA	NA	NA
COLD FLOW/ΔP SEQUENCING 1-SIS	Maintained Closed	ΔP = Pump Decay CYC's = 1	ΔP = Pump Decay CYC's = 1	Maintained Open	ΔP = Pump Decay CYC's = 1	ΔP = Pump Decay CYC's = 1
HOT SIS 1-SIS	ΔP = Pump Start CYC = 1	ΔP = Pump Decay CYC's = 1	ΔP = Pump Decay CYC's = 1	ΔP = Pump Decay CYC's = 1	ΔP = Pump Decay CYC's = 1	ΔP = Pump Decay CYC's = 1
TOTAL CYCLES, EACH VALVE, AT 0 ΔP	2	8	2	2	2	2
TOTAL CYCLES, EACH VALVE AT ΔP > 0	2	*HV-851A - 28 HV-851B - 25	15	7	15	15

APPENDIX 5