Enclosure

SAN ONOFRE NUCLEAR GENERATING STATION

UNITS 2 AND 3

AUXILIARY FEEDWATER SYSTEM AVAILABILITY

INCLUDING EFFECTS OF STEAM SUPPLY LINE RUPTURE

BECHTEL POWER CORPORATION

LOS ANGELES POWER DIVISION

DEC. 1982

TABLE OF CONTENTS

I. INTRODUCTION

The Auxiliary Feedwater System Design Review and Reliability Evaluation (Appendix A) determined that the auxiliary feedwater (AFW) system met Standard Review Plan 10.4.9 and Branch Technical Position ASB 10-1 criteria. The AFW system addressed in the evaluation was environmentally qualified to withstand the effects resulting from a postulated steam line break inside the AFW pump room. The AFW system was reported as environmentally qualified in the response to NUREG-0588 [1].

As a result of operating experience, the environmentally qualified electric-driven AFW pump motor bearings were replaced with babbitt bearings. The presently installed babbitt motor bearings are not environmentally qualified for the steam line break event and the response to NUREG-0588 has been updated accordingly. This analysis evaluates the contribution to AFW system unavailability resulting from the postulated steam line break event. This evaluation is performed using the Fault Tree type of probabilistic analysis.

Contributions to unavailability are lumped to two categories - those deriving from component failure and those deriving from environmental consequences of a steam line break in the AFW pump room. The first category was treated in the original study and is included in Appendix A. The results are unchanged and are used again here in combination with the second category.

Pipe break failure rates are taken from the literature generally cited for this purpose. These are used to provide conservative estimates of the addition to unavailability caused by the possible pipe break combined with coincident demand for the AFW system.

In response to San Onofre license condition 2.C(25), additional options designed to increase the AFW system reliability were examined. These options are: (1) addition of a forced lube oil cooling system to the electric-driven AFW pump motor bearings and (2) implementation of an enhanced steam piping inspection program. These two alternatives intended to mitigate the pipe break event are evaluated by similar probabababistic calculations. Neither of these affect the original component-failure unavailability and therefore they merely serve to reduce the magnitude of the pipe break component. The analysis presents the benefit contribution to system availability from each of the two options.

II. CONCLUSIONS

The conclusions of the analysis are:

1. The contribution of pipe break to the AFW system unavailability per demand is less than 10 percent of the system unavailability per demand from all other causes. These other causes for system unavilability are dominated by component failure.

2. The AFW system unavailability per demand, including effects resulting from a postulated steam line break event, meets Standard Review Plan 10.4.9 acceptance criteria.

In response to San Onofre license condition 2.C(25), the analysis concludes:

1. Addition of a forced lube oil cooling system to the electric-driven AFW pump motor bearings would, at best, improve AFW system reliability by the small amount (less than 10%) described above. Moreover, any system designed to mitigate the impact of pipe break on the AFW system will be subject to the same limitation.

2. Implementation of an enhanced steam pipe inspection program would significantly reduce the probability of the initiating pipe break event. Development of an initial inspection baseline would reduce the probability of pipe break by approximately a factor of 5. This would have the effect of reducing the contribution of pipe break to system unavailability from less than 10% to less than 2%. Implementation of a periodic inspection program on a regular basis would further reduce the pipe break probability, thus helping to eliminate the remaining 2% of unavailability resulting from pipe break.

III. EXISTING AUXILIARY FEEDWATER SYSTEM ANALYSIS

This section provides a description of the existing auxiliary feedwater (AFW) system. System unavailability is defined and the contributors to that unavailability are discussed. AFW system unavailability resulting from the postulated pipe break is then compared with system unavailability resulting from component failure rates.

A. System Description

The auxiliary feedwater (AFW) system is comprised of three redundant 100%-capacity auxiliary feedwater pumps, associated piping, controls, valves and instrumentation. The pumps are located in separate areas of the AFW pump room at elevation 28 ft. 0 in., in the tank building close to the condensate storage tanks. Two of the AFW pumps are driven by electric motors supplied from safety-related power sources. The third pump is driven by a steam turbine with steam supplied by the main steam system from upstream of the main steam isolation valves. Redundant channelized instrumentation which governs system actuation and operation is provided. A more detailed system description is provided in Section 1.4 of Appendix A.

B. System Design Review and Reliability Evaluation

Appendix A presented a comprehensive evaluation of the unavailability per demand for the San Onofre Units 2 and 3 Auxiliary Feedwater (AFW) system. The evaluation was conducted in response to requirements from the NRC office of Nuclear Reactor Regulation. Those requirements included development of an evaluation which shows that the AFW system meets each requirement in Standard Review Plan 10.4.9 and Branch Technical Position ASB 10-1.

The NRC reviewed the AFW system reliability evaluation in Safety Evaluation Report (SER), Supplement One, Section II.E.1.1, Item 3, paragraph (g), page 22-72. The review concluded that the San Onfore Units 2 and 3 AFW system will have a high reliability. The NRC further concluded that the San Onofre AFW system meets the requirements of NUREG-0660, NUREG-0737, the NRC's March 10, 1980 letter, and is acceptable.

The evaluation was conducted in a manner similar to the NRC evaluations of operating plant AFW systems reported in NUREG-0635. The evaluation consisted of a deterministic review of the system using current regulatory requirements and industry standards as well as an assessment of the relative overall reliability of the system as compared to the NUREG-0635 evaluations for operating plants.

The signficant conclusions of the evaluation are:

1. The AFW system adequately meets all the review requirements of Standard Review Plan 10.4.9 and Branch Technical Position ASB 10-1.

2. Using similar methods, the San Onofre AFW system, when compared with other previously evaluated systems, presents an overall high level of reliability.

3. The San Onofre AFW system design has incorporated all the applicable design recommendations.

Based upon Figure 3-2 of Appendix A, the AFW system unavailability resulting from component failure is estimated to be 3×10^{-5} per demand.* This AFW system unavailability meets the NRC acceptance criterion provided in Standard Review Plan 10.4.9.

C. System Unavailability Resulting From Pipe Break Events

The reliability evaluation included in Appendix A considered an AFW system design which was environmentally qualified for a steam line break event inside the pump room. For this event, environmental qualification of the electric-driven AFW pump motors met the requirements of NUREG-0588 with the installation of specially developed bearings in the pump motors. However, based upon operating experience, these qualified bearings had to be replaced with the original babbitt bearings. At the elevated temperatures achieved under steam line break conditions, the babbitt bearings in both electric-driven AFW pump motors are susceptible to eventual failure. Thus, in the current installation, the steam line break event contributes some factor to the overall AFW system unavailability per demand. This section provides a discussion of the initiating event and addresses the AFW system unavailability per demand resulting from various postulated steam piping failures occurring within the AFW pump room.

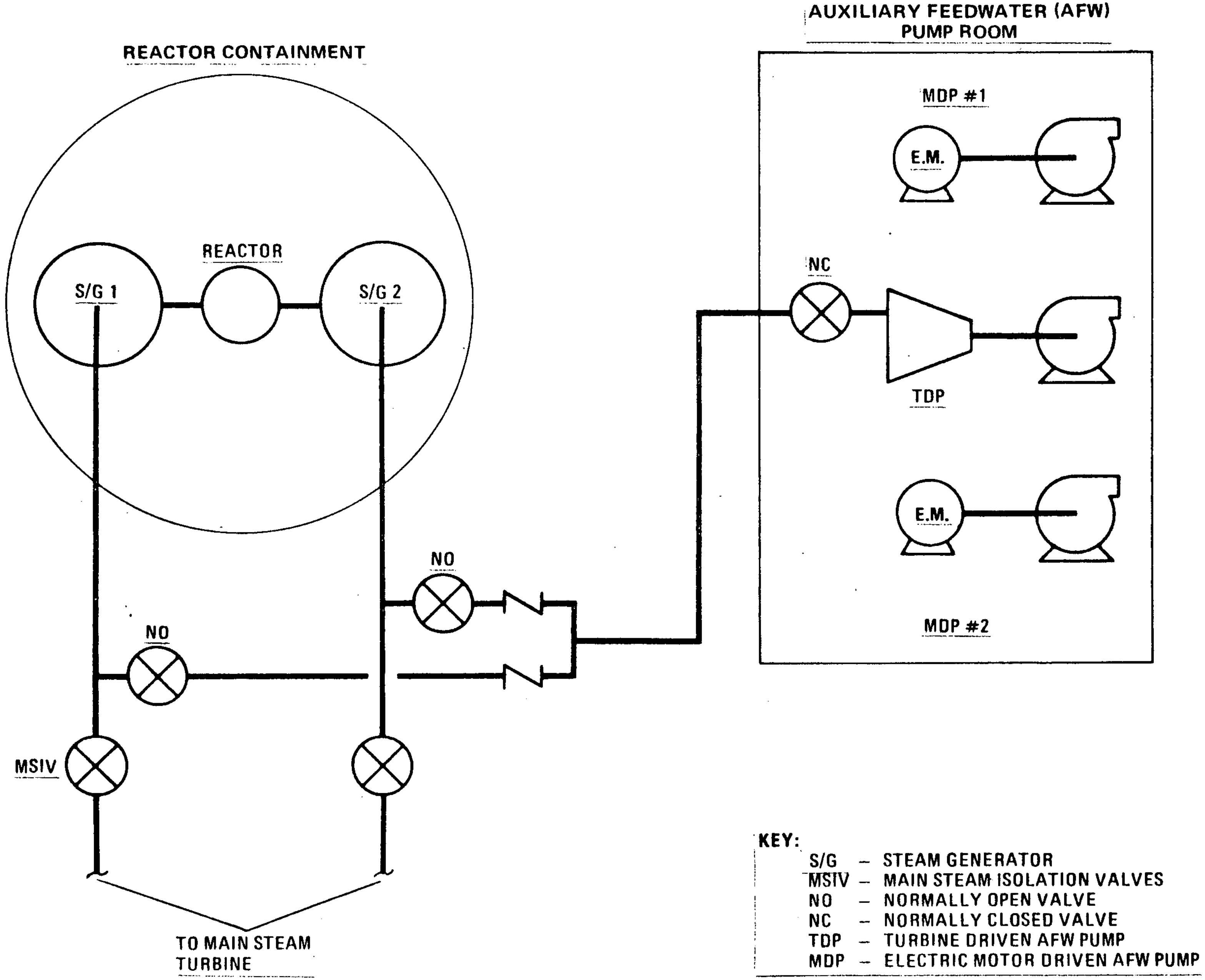
The piping supplying steam to the turbine-driven auxiliary feedwater (AFW) pump is shown schematically in Figure 1. A postulated failure of the piping supplying steam to the turbine driven AFW pump inside the pump room could generate a system unavailability with a subsequent system demand.

A break in the steam piping greater than one square inch could result in AFW pump room temperature achieving 300°F. At these elevated temperatures, the babbitt bearings in both electric-driven AFW pump motors would eventually fail.

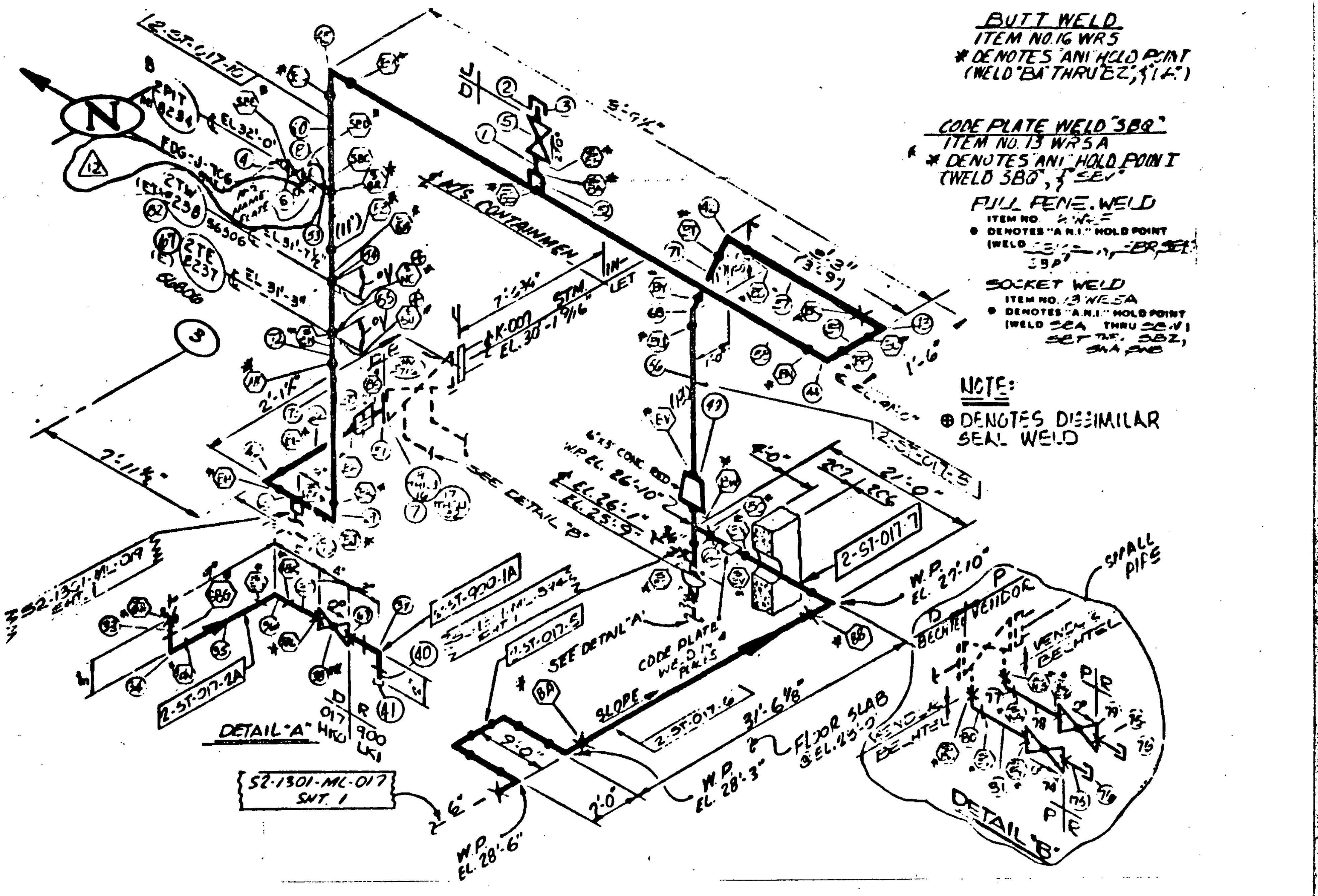
An isometric drawing of the steam supply piping to the turbine-driven AFW pump is show in Figure 2. There is approximately forty linear feet of piping inside the room. Approximately five feet of the pipe is six inch nominal pipe size; the remaining pipe is three inch nominal pipe size.

A postulated catastrophic failure in the six inch steam pipe would generate increased steam flow from the steam generators. This increase in steam flow would result in a corresponding increase in reactor power level. A comparison of this event with transients analyzed in FSAR Chapter 15 indicates that this event is comparable to inadvertent opening of an Atmospheric Dump Valve (ADV). Initiated at one hundred percent reactor power, this event creates a subsequent overshoot in reactor power level to approximately 113 percent of nominal power. The core protection calculator setpoints which

*Information was provided to supplement the Reference (A) submittal in a letter to NRC dated March 2, 1981. Additional quanitative information was supplied in a meeting with the NRC Reliability and Risk Assessment and Auxiliary Systems branches on March 3, 1981.



EXISTING DESIGN SCHEMATIC
FIGURE 1



STEAM SUPPLY LINE ISOMETRIC FOR TURBINE DRIVEN AFW PUMP
FIGURE 2

provide a reactor trip on high linear power level, are set at approximately 108 percent nominal reactor power level. By qualitative comparison, a catastrophic failure in the six inch AFW steam supply piping would be anticipated to create a subsequent reactor trip event. Conservatively, it is also assumed that a postulated catastrophic failure in the three inch steam piping would yield the same result.

A reactor and consequent turbine trip event from 100 percent reactor power creates a reduction in steam generator inventory. This reduction in inventory is sufficient to cause automatic actuation of the AFW system. Thus, the reactor trip event creates a system demand.

Based on the previous discussion, catastrophic failure in any section of the pipe is considered to result in a system unavailability with a coincident system demand. The fault tree representation in Figure 3 depicts this event in addition to the contribution to system unavailability resulting from component failure.

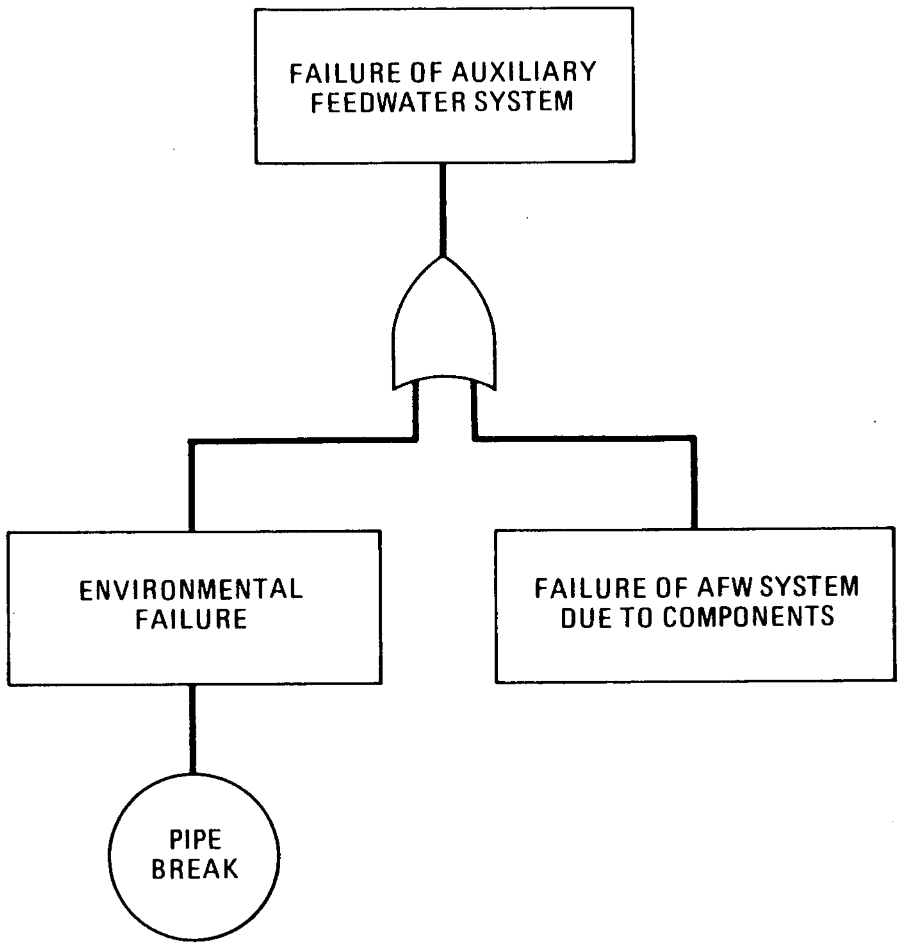
The probability of catastrophic pipe break is developed in section B.1 of Appendix B. The best estimate (median) value for the probability of occurance of this event is 9×10^{-6} per year. This value corresponds to an unavailability of approximately 0.3×10^{-5} per demand. The overall AFW system unavailability, including the effects resulting from rupture of the steam supply line to the turbine-driven AFW pump, is 3.3×10^{-5} per demand. Both values (with and without pipe break) for AFW system unavailability are within the NRC acceptance criterion of 10^{-5} to 10^{-4} per demand as set forth in Standard Review Plan 10.4.9. Thus, the existing system design, including the effects resulting from a pipe break event, currently meets the NRC acceptance criterion. Section B.2 of Appendix B provides a detailed discussion of this calculation.

Since the reliability of the existing design of the AFW system, including failure of the steam supply line to the turbine-driven AFW pump, is not significantly degraded by the pipe break event, no design change need be made. In addition, the existing design meets the NRC acceptance criteria.

D. Summary

The Auxiliary Feedwater System Design and Review and Reliability Evaluation (Appendix A) determined that the AFW system met Standard Review Plan 10.4.9 and Branch Technical Position ASB 10-1. The AFW system design addressed in the evaluation was environmentally qualified in accordance with NUREG-0588 requirements. Subsequent to this evaluation, the qualified motor bearings in the electric-driven AFW pumps were replaced with the original babbitt bearings. These babbitt bearings are susceptible to eventual failure under postulated steam line break conditions. Hence, the steam line break contributes some quantifiable factor to the overall system unavailability per demand with the babbitt bearings installed.

This analysis has developed the contributions to AFW system unavailability. The first contributor is system unavailability of the existing system from all causes except the postulated break. This unavailability per demand, developed from Appendix A, is approximately 3×10^{-5} and meets the NRC acceptance criterion of Standard Review Plan 10.4.9. The second contributor



EXISTING DESIGN FAULT TREE
FIGURE 3

to system unavailability is unavailability per demand resulting from the postulated pipe break event. This contributor was determined to be approximately 0.3×10^{-5} and was combined with the previous system unavailability per demand. The analysis demonstrates that the overall unavailability per demand for the existing AFW system with the babbitt bearings installed, is 3.3×10^{-5} and meets the NRC acceptance criteria. The existing AFW system therefore meets the intended safety goals.

IV. AUXILIARY FEEDWATER SYSTEM IMPROVEMENTS

A. General

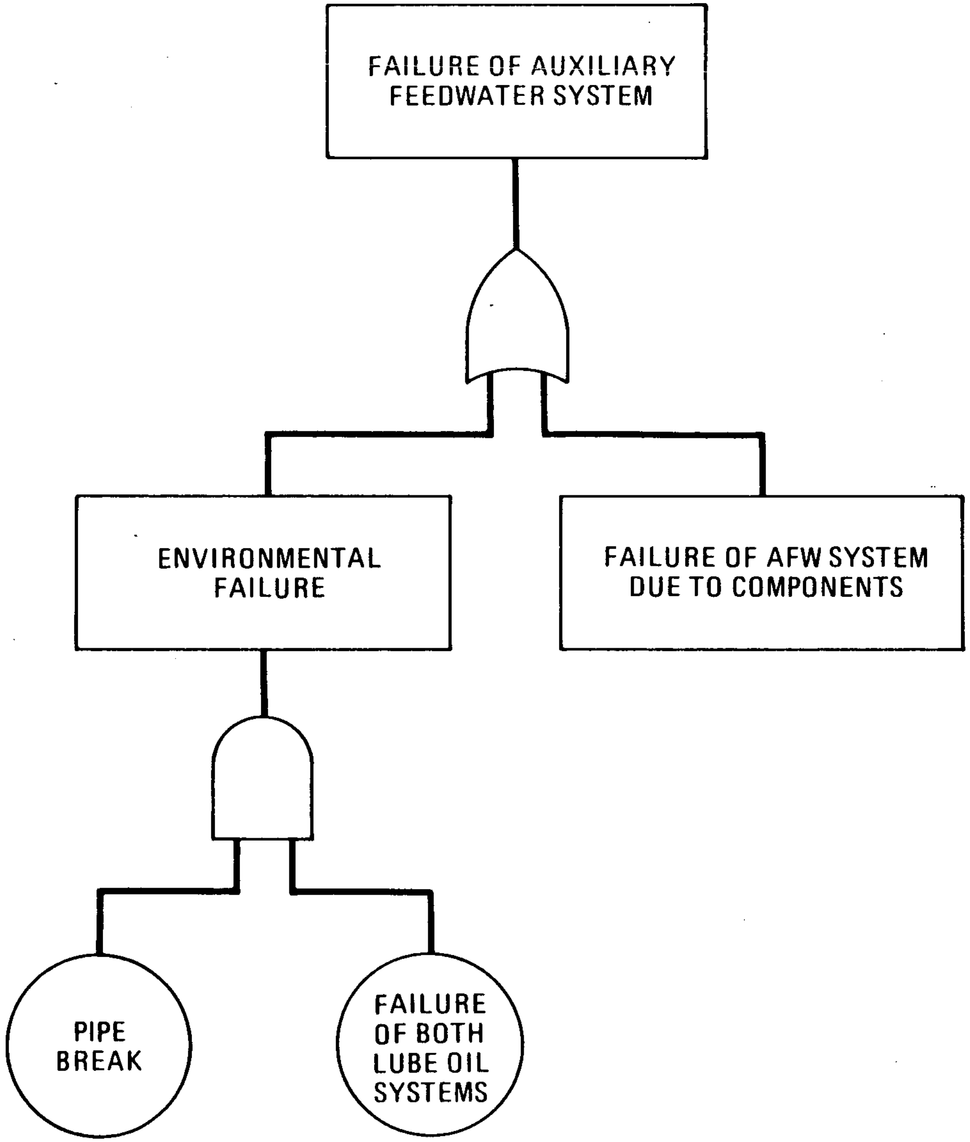
As demonstrated in the previous section, the existing AFW system reliability, including effects resulting from a postulated pipe break event, meets the NRC acceptance criterion. However, San Onofre license condition 2.C(25) requires submittal of a hardware modification to improve AFW system reliability in the event of a postulated break in the turbine-driven AFW pump steam supply line. In response to the license condition, two options to improve system reliability were pursued. These options are (1) addition of a forced lube oil cooling system to the electric-driven pump motor bearings and (2) implementation of an enhanced steam piping inspection program. This section provides a detailed description of each option as they would be implemented on the existing design. The benefit contribution to system availability derived from each option is then presented.

B. Lube Oil System Description

The first option to improve AFW system reliability requires addition of a forced lube oil cooling system to each electric-driven AFW pump motor. The lube oil system would supply additional, cooled oil to the babbitt bearings under steam line break conditions. The lube oil would be supplied at a rate such that heat is removed in a quantity sufficient to maintain acceptable bearing temperatures. The fault tree for this improvement is shown in Figure 4.

The forced lube oil cooling system would consist of a skid-mounted oil reservoir, filter, oil pump and a heat exchanger. There would be one skid for each of the two electric-driven AFW pumps. Both the pump and the heat exchanger (active components) would be located outside the AFW pump room with electric power supplied from a highly reliable source. Oil piping would run from the heat exchanger to the top of the electric-driven AFW pump motor bearings. A second oil line would emerge from the bearing sump and pass through a weir box such that excess oil would drain back to the oil reservoir. From the reservoir, the oil piping would run to the oil pump and on to the heat exchanger.

Loss of the lube oil system piping during normal operation would not affect AFW pump motor operability. The lube oil piping return line leaving the bearing pump would exit the sump at the same elevation as the normal oil level. In the event that the return oil line is lost, the oil would drain down to the normal oil level. Under these conditions, the oil rings would remain submerged and the bearings would be lubricated in the same manner as in the existing system design. Loss of the oil supply line to the bearings would result in a loss of oil reservoir level only, after which the lube oil pump would lose suction. This event would cause a loss of forced cooling but would not effect normal bearing lubrication.



AFW SYSTEM WITH
MOTOR LUBE OIL COOLER SYSTEM
FIGURE 4

C. Enhanced Inspection

The second option considered to improve AFW system reliability is the implementation of an enhanced steam pipe inspection program. This inspection program would reduce the probability of pipe break and thereby improve system reliability. The following paragraphs describe the development of an inspection program in terms of reducing the probability of the initiating pipe break event.

The pipe supplying steam to the turbine-driven AFW pump is shown in Figure 2. There are twenty-five circumferential and six small branch connection welds in the approximately forty feet of pipe inside the pump room. The installed steam piping is ASME Section III, Class 3 piping.

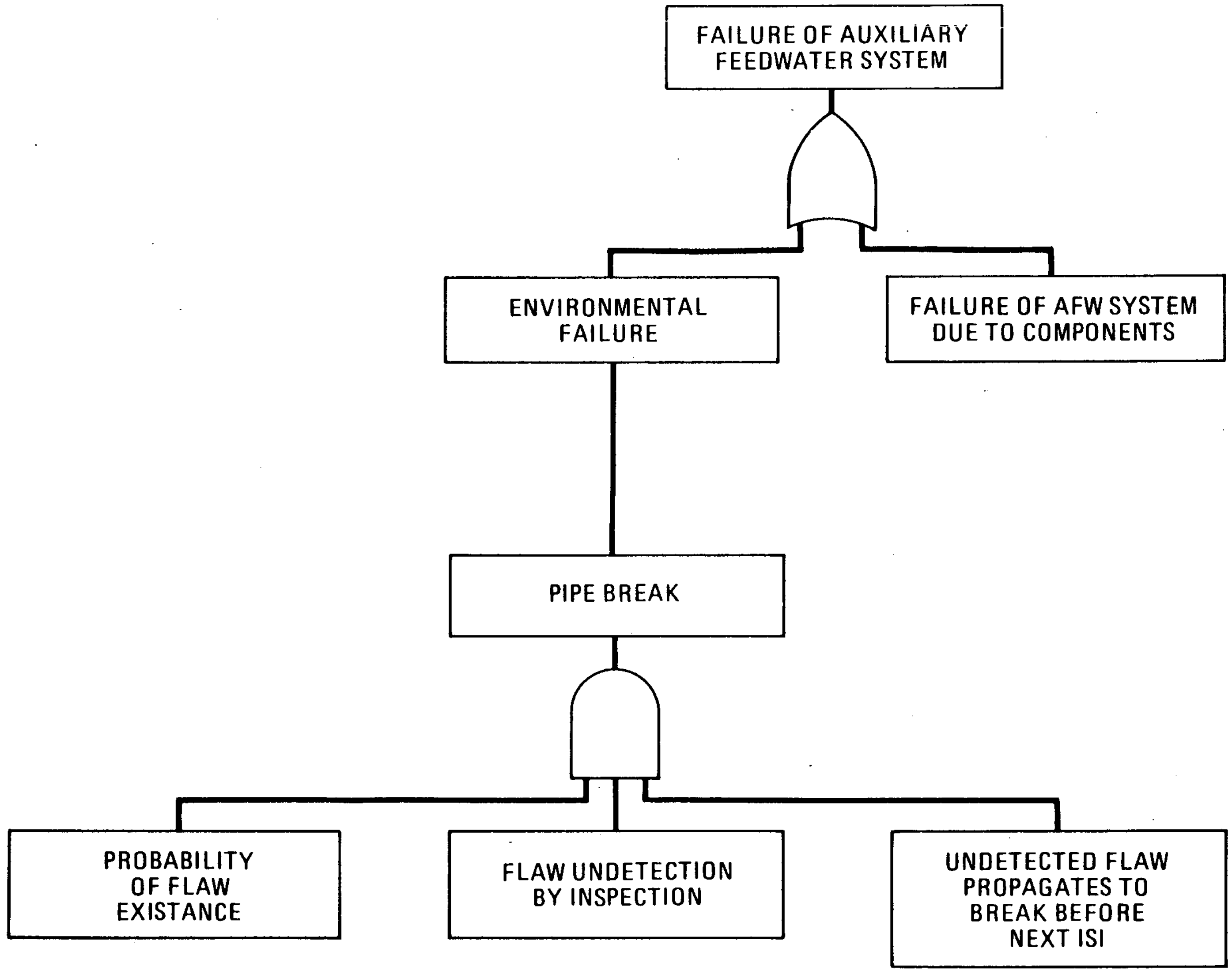
A probabilistic evaluation has been performed to determine the frequency of piping failure in the steam piping. The probability analysis assumed three requirements for a pipe break event to occur. These three elements are: (1) a flaw must exist in the pipe weld, (2) the flaw must be undetected by the examination technique used, and (3) the flaw must propagate into a break during the interval between examinations. The fault tree representing this improvement is provided in Figure 5.

ASME Section XI recognizes the ultrasonic test (UT) as a method to determine acceptable flaw sizes in piping welds. In order to establish a baseline for the existence of flaws, a UT inspection of all piping welds on the AFW steam supply line is necessary. The baseline information and the UT examinations thus form the basis for an enhanced piping inspection program.

ASME Section XI, 1980 edition, without addenda, Table IWC-2500, provides criteria for examination of pipe welds. Under ASME Section XI examination requirements, volumetric or surface examinations are not required for Class 3 pipe. ASME Section XI requires only visual examination of Class 3 pipe welds. For the purpose of performing volumetric examination and evaluating its results to establish baseline data, the installed piping is assumed to be ASME III, Class 2. Under these constraints, the UT examination of the twenty-five circumferential welds could be performed and evaluated.

Volumetric examination of the six small branch connection welds can not be performed because of the weld configurations. These welds are 1 inch and 3/4 inch nominal pipe size branch connections for two thermowells, one vent line, two drain connections and one pressure instrument tap. Failure of one or more of these lines could generate an unacceptable environmental profile within the room. However, since only surface examination of these welds is possible, volumetric baseline data cannot be obtained. Thus the reduction in postulated pipe failure frequency could not be applied to these six welds.

A detailed review of the piping arrangement has been made to fully assess the feasibility of conducting UT examinations on the circumferential welds. Eight of the existing twenty-five circumferential welds are either inaccessible or the fabrication geometry is such that the UT examination cannot be performed. Since, these eight welds are not fully examinable, baseline data cannot be



AFW SYSTEM WITH ENHANCED PIPE INSPECTION
FIGURE 5

developed. Thus, to develop an acceptable baseline for the inspection program, the steam supply piping inside the room must be rerouted to allow implementation of ultrasonic examination of all welds.

D. Benefits

As developed in the previous section, the existing AFW system meets the NRC acceptance criteria for unavailability per demand, including effects resulting from the postulated steam line break event. The contribution to AFW system unavailability from the pipe break event was quantified and shown to be less than 10 percent (Appendix B, page B-5) of the system unavailability per demand from all other causes. Hence, the benefits derived from implementation of any hardware modification would only be improving a statistically insignificant portion of the overall system reliability.

Installation of the forced lube oil cooling system would provide cooled lubrication to the pump motor bearings under steam line break conditions. Implementation of this system directly addresses the environmental qualification of the AFW pump motor bearings. Thus, the benefit derived from implementation of the lube oil system is restoration of the AFW system reliability to the level established in Appendix A, as shown in Appendix B, Section B.4.

Implementation of an enhanced steam piping inspection program would provide detection of flaws in piping welds. Weld flaws would be detected and corrective action taken prior to flaw propagation and development of leaks. Volumetric weld examination data thus provides a basis for reduction in the probability of an initiating pipe break event. The benefit derived from developing a satisfactory volumetric examination result would be a reduction in the probability of pipe break by approximately a factor of 5, [5]. This option would reduce the contribution of pipe break to system unavailability from less than 10% to less than 2%. Inspections conducted on more frequent intervals would further reduce the remaining 2% contribution of the pipe break event to system unavailability.

V. REFERENCES

1. NUREG-0588, Interim Staff Position on Environmental Qualification of Safety-Related Electrical Equipment, December, 1979.

2. "Auxiliary Feedwater System Evaluation," Combustion Engineering Inc., Revision 1, October 1980.

3. Loss of Off-Site Power at Nuclear Power Plants: Data and Analysis. EPRI NP-2301, Project 1322-1, Interim Report, March 1982, prepared by Science Application, Inc., Palo Alto, California.

4. Ten Year Review 1971-1980 Component Cause Code Report, Research Park, Turhune Road, Princeton, NJ 08540-3573.

5. Reactor Safety Study, WASH-1400, NUREG-75-014, October 1975.

AUXILIARY FEEDWATER SYSTEM
DESIGN REVIEW AND RELIABILITY EVALUATION
FOR
SAN ONOFRE NUCLEAR GENERATING STATION
UNITS 2 AND 3

September 4, 1980

REVISION 01 - 10/10/80

ABSTRACT

This report provides the results of a comprehensive evaluation of the San Onofre Nuclear Generating Station (SONGS) Units 2 and 3 Auxiliary Feedwater System (AFWS).

The AFWS as evaluated is described in Section 1.4 of this report. The significant conclusions of the evaluation are as follows:

1. The AFWS adequately meets all the review requirements of Standard Review Plan 10.4.9 and Branch Technical Position ASB 10-1.

2. Using methods similar to those described in Reference 1.3.3, the SONGS AFWS, when compared with other previously evaluated systems presents an overall high level of reliability.

3. The SONGS AFWS design has incorporated all the applicable design recommendations of Reference 1.3.3.

4. Overall system performance and reliability will be enhanced by incorporating the specific recommendations of Section 5.0.

Additionally, information requested by Reference 1.3.1 regarding the design basis for AFW system flow requirements is provided in Section 4.0.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

APPENDICIES

1.0 INTRODUCTION

1.1 Purpose

This report provides the results of a comprehensive evaluation of the San Onofre Nuclear Generating Station (SONGS) Units 2 and 3 Auxiliary Feedwater System (AFWS). The evaluation was conducted in response to requirements from the NRC office of Nuclear Reactor Regulation transmitted in Reference 1.3.1.Those requirements are as follows:

"With respect to operating license applications such as yours, we will require that you (a) provide an evaluation which shows how your AFW system meets each requirement in Standard Review Plan 10.4.9 and Branch Technical Position ASB 10-1, (b) perform a reliability evaluation similar in method to that described in Enclosure 1 that was performed for operating plants and submit it for staff review, (c) factor the recommendations of Enclosure 1 into your plant design, and (d) respond to Enclosure 2, which requests the information necessary to determine the design basis for your AFW system flow requirements and to verify that your AFW system will meet these requirements."

1.2 Scope

The SONGS Unit 2 and 3 AFWS as evaluated is described in Section 1.4 This is essentially the system presented in section 10.4.9, Amendment 13 of the Final Safety Analysis Report (reference 2) as modified by the addition of a third full capacity pump.

The evaluation was conducted in a manner similar to those evaluations of operating plant AFWS's reported in NUREG-0635 (reference 1.3.3). It consisted of a deterministic review of the system using current regulatory requirements and industry standards as well as an assessment of the relative overall reliability of the system as compared to the NUREG 0635 evaluations of operating plants. Additionally system design bases were thoroughly reviewed and documented in a format requested by the NRC (reference 1.3.1). As in the case of NUREG 0635

it was recognized that it would be very difficult and subject to large uncertainty if an attempt was made to quantify the enhanced reliability of the SONGS Unit AFWS. The overall assessment of reliability has been made on the semi quantitative, relative scale used in figure III-5 of NUREG 0635.

1.3 References

1. NRC letter from D. F. Ross, " All Pending Operating License Applicants of Nuclear Steam Supply Systems Designed By Westinghouse and Combustion Engineering, dated March 10, 1930.

2. Final Safety Analyses Report, San Onofre Nuclear Generating Station.

3. NUREG 0635, Generic Evaluation of Feedwater Transients and Small Break Loss of Coolant Accidents for C-E Designed Operating Plants.

4. NUREG 75/087 Standard Review Plan for the Review of Safety Analysis Reports for Nuclear Power Plants.

1.4 System Description

General Description

A flow diagram of the Auxiliary Feedwater System is provided in Appendix D. Major components of the auxiliary feedwater system include three 100% auxiliary feedwater pumps (two motor-driven and one driven by a steam turbine) and associated piping, valves, and instrumentation.

Component Description

Motor-Driven Pumps. Two of the three auxiliary feedwater pumps are driven by electric motors each supplied with power from a separate preferred AC power source. The horizontal centrifugal pumps have a capacity of 860 gal/min at a total developed head of 2842 feet. This figure includes a recirculated flow of 100 gal/min and a wear margin of 60 gal/min. The pumps take suction from condensate storage tank T-121 through independent suction lines. Each pump's discharge piping connects to one of the two main feedwater lines between the isolation valves and the steam generator nozzle, providing system separation.

Turbine-Driven Pump. A turbine-driven auxiliary feedwater pump, identical to the motor-driven pumps, provides overall system redundancy of auxiliary feedwater supply and diversity of motive pumping power. The pump is a horizontal, centrifugal unit with a capacity of 860 gal/min at a total developed head of 2842 feet. The pump takes suction from the condensate storage tank T-121 through a separate suction line, and its discharge is inter-connected through isolation valves and reverse flow check valves to the same piping used by the motor-driven auxiliary feedwater pumps. Steam supply piping to the turbine driver is taken from each of the two main steam lines between the containment penetrations and the main steam isolation valves. Each of the steam supply lines to the turbine driver is equipped with a check valve and also a pneumatic-actuated valve supplied with power from the emergency dc power source. The turbine driver can operate with steam inlet pressures ranging from 1210 to 65 psia. Exhaust steam from the turbine driver is vented to the atmosphere above the tank building roof. The auxiliary feedwater pumps are located in separate areas of the AFW pump room at elevation 28 ft 0 in in the tank building close to the condensate storage tanks.

Piping and Valves. Welded joints are used throughout the majority of the system. Flanged connections are provided at the suction and discharge of each pump, at the flow limiting venturis, and at the two tees where the turbine driven pump ties into the two auxiliary feedwater lines, each line dedicated to one steam generator. Each pump is equipped with manually operated isolation valves at the pump suction and discharge. These valves are used for maintenance only and are locked open during normal operation. Check valves are located close to each pump discharge to prevent backflow through a shutdown pump in the event of a loss-of-pump failure. The auxiliary feedwater lines are equipped with ac motor-operated and ac electro/hydraulic control valves in the motor-driven pump feed trains and dc motor-operated valves in the turbine-driven pump feed train. The lines that supply water to the auxiliary feedwater pumps from the condensate storage tank are equipped with manually-operated gate valves, at the storage tanks, which are normally locked open. Parallel isolation valves are provided in the auxiliary feedwater line to each steam generator outside the containment; one of each valve in parallel is ac-powered, the other is dc-powered.

System Operation

Plant Startup. During startup, the auxiliary feedwater pumps are used under manual control to supply feedwater from the condensate storage tank to the steam generators until sufficient steam is available to start the turbine-driven main feedwater pumps.

Normal Plant Operation. The auxiliary feedwater system is not required during normal power generation. The pumps are placed in the automatic mode, lined up with the condensate storage tank, and are available if needed.

For the hot standby mode of normal plant operation, it is assumed that four reactor coolant pumps will be in operation, and that a main feedwater pump will be used for the hour following departure from power. The auxiliary feedwater pumps will be manually started within approximately 10 minutes after shutdown. The capacity of the auxiliary feedwater pumps exceeds that required for this situation.

Normal Plant Cooldown. During cooldown, the auxiliary feedwater pumps are used under manual control to supply water from the condensate storage tank to the steam generators. Auxiliary feedwater flow to each steam generator is manually regulated by the remote-operated control valves or locally operated bypass valves. Steam generated during this mode of operation is bypassed to the main condenser. The auxiliary feedwater pumps are used until reactor coolant temperature drops to 350°F, at which

point the shutdown cooling system is placed in service for further cooldown of the reactor coolant system. To minimize thermal shock to the steam generators, the condensate storage tanks T-120 and T-121 are normally maintained above 70°F.

The minimum required pump capacity, 700 gal/min, is based on a 75°F per hour cooldown rate and always exceeds that required for this situation.

Emergency Operation. The auxiliary feedwater actuation system (AFAS) automatically actuates the auxiliary feedwater system by fully opening the isolation and control valves to deliver a minimum feedwater flowrate of 700 gal/min to the intact steam generator(s). The primary source of auxiliary feedwater is the 150,000 gallon, Seismic Category I, condensate storage tank. A 500,000 gallon, Seismic Category II, condensate storage tank serves as the primary backup supply of water. This is augmented by the fire protection system should the demand be in excess of that supplied by the other two tanks.

Heat is removed from the reactor by boiling the feedwater in the steam generators and venting steam to the atmosphere through the main steam safety relief valves until the operator actuates the atmospheric dump valves. If the main condenser is available, the steam may be relieved via a turbine bypass system. Controlled cooldown can be provided through the atmospheric dump valves if the main turbine bypass system is not available. When reactor coolant temperature drops to 350°F, cooldown is shifted to the shutdown cooling system.

An AFAS signal is required to automatically initiate the minimum auxiliary feedwater flowrate, 700 gal/min. Cavitating venturis at each pump discharge limit the discharge flow and thus prevent pump runout conditions.

Blackout Operation. The auxiliary feedwater actuation system (AFAS), automatically actuates the auxiliary feedwater system turbine, turbine controls, turbine-driven pump, including the dc-operated isolation and control valves, when required to ensure an adequate 700 gal/min feedwater supply to the steam generators during a blackout. The dc-operated control valves, which may be positioned by the operator, after overriding the AFAS,

are provided for each auxiliary feedwater line to control the auxiliary feedwater flow to each steam generator.

2.0 DETERMINISTIC REVIEW

Section 10.4.9 of reference 1.3.4 provides the NRC Standard Review Plan for Auxiliary Feedwater Systems as well as the Branch Technical Position regarding Auxiliary Feedwater System pump drive and power supply diversity. These documents provide basic acceptance criteria for the NRC's review of Auxiliary Feedwater Systems. Additional guidance regarding design criteria for AFW System is provided in ANSI/ANS 51.10 - 1979. The SONGS AFW system has been reviewed against all these criteria to ensure compliance. In cases where compliance with a specific criteria has been previously documented, that documentation (e.g. FSAR section) is referenced. The following subsections contain the results of that review on an item by item basis.

2.1 Standard Review Plan

Acceptance Criteria

Acceptability of the design of the auxiliary feedwater system, as described in the applicant's safety analysis report (SAR), is based on specific general design criteria and regulatory guides. Listed below are the specific criteria as they relate to the AFWS.

1. General Design Criterion 2, as related to structures housing the system and the system itself being capable of withstanding the effects of natural phenomena such as earthquakes, tornadoes, hurricanes, and floods.

   General Design Criterion 2 of Appendix A to 10CFR50, General Design Criteria for Nuclear Power Plants, and Appendix A to 10CFR100, Seismic and Geologic Siting Criteria for Nuclear Power Plants, require that nuclear power plant structures, components, and systems important to safety be designed to withstand the effects of earthquakes without loss of capability to perform their safety functions. The auxiliary feedwater system is designed to Seismic Category I requirements in accordance with Regulatory Guide 1.29 and remains functional following a design basis earthquake.

   All AFW components are located in Seismic Category I structures which are designed to withstand tornado pressure loadings and tornado-generated missiles. The design of all permanent non-Seismic Category I structures, systems, and components not designed for tornado loadings is analytically

checked to assure that (1) these structures, systems, and components cannot produce missiles, during a tornado, that have more severe effects than those tornado-generated missiles listed in FSAR table 3.5-1, and (2) their failure will not affect the integrity of adjacent Seismic Category I structures that house the AFWS. This design assures that Seismic Category I AFW system and components, required for safe shutdown after a tornado, will perform their intended functions.

The safety-related systems and components for which flood protection is provided are the same as those identified in Paragraph C.1 of Regulatory Guide 1.29.
As a Seismic Category I system, flood protection of AFW systems and components is provided for appropriate postulated flood levels and conditions described in FSAR Section 2.4.

Wind loadings for Seismic Category I AFWS structures were selected on the basis of ASCE Paper No. 3269, Wind Forces on Structures.

2. General Design Criterion 4, with respect to structures housing the system and the system itself being capable of withstanding the effects of external missiles and internally generated missiles, pipe whip, and jet impingement forces associated with pipe breaks.

Missile protection criteria conform to 10CFR50, General Design Criterion 4, Environmental and Missile Design Bases. Protection against the postulated missiles identified in FSAR subsection 3.5.1 is provided to fulfill the design criteria that a missile generated from a plant system, including the reactor coolant system, the main steam system, or main feedwater pump discharge lines, shall not cause loss of function to the AFWS as (1) a system required for safe shutdown of the reactor from the control room or (2) a system required to mitigate the consequences of a break in the RCPB or main steam and feedwater pump discharge pressure boundary.

The AFWS is protected against pipe whip as a result of pipe breaks, such that any unrestrained movement of the ruptured pipe cannot damage the AFWS to an unacceptable level. All essential AFW system components are protected by plant design features from the effects of jet impingement, such that impingement loads are insufficient to impair their safety functions. Analysis of pipe break effects is presented in FSAR Section 3.6.

3. General Design Criterion 5, as related to the capability of shared systems and components important to safety to perform required safety functions.

In accordance with General Design Criteria 5, the AFW systems and components are not shared between the two units. Make up for the condensate storage tank can be provided by interconnecting the condensate systems of Units 2 and 3 via the condensate transfer pumps, but failure of this system will not impair the AFWS capability to safely shutdown and cooldown either or both units.

4. General Design Criterion 19, as related to the design capability of system instrumentation and controls for prompt hot shutdown of the reactor and potential capability for subsequent cold shutdown.

The AFWS is a fully automatic system composed of three trains. The instrumentation and control of the components and equipment in each train are physically and electrically separate and independent of the instrumentation and controls of the components and equipment in other trains. Independence is adequate to retain the redundancy required to automatically actuate the Auxiliary Feedwater System, following those design basis accidents shown in FSAR Table 7.3-1 which require emergency feedwater.

The auxiliary feedwater system instrumentation and controls are designed for operation during all phases of plant operation. The system may be operated manually during transients such as shutdown, and hot standby. The safety-related display instrumentation for the auxiliary feedwater system, which provides the operator with sufficient information to monitor and perform the required safety functions, is described in Section 7.5 of the FSAR. Technical requirements for those portions of the Auxiliary Feedwater Actuation System (AFAS) required for safe shutdown are discussed in subsection 7.1.2 of the FSAR.

As shown in Appendix E the AFAS is initiated to Steam Generator 1 either by a low steam generator level coincident with no low pressure trip present on Steam Generator 1 or by a low steam generator level coincident with a differential pressure between the two steam generators with the higher pressure in Steam Generator 1. The two-out-of-four logic is provided independently for each steam generator. When steam generator water level returns to the reset point above the low level setpoint, the auxiliary feedwater system discharge valves will shut automatically to secure excess feedwater flow. The AFAS will continue to function as required to maintain steam generator water level while

the plant remains at hot standby or is brought to cold shutdown. The system is designed such that loss of electric power to two of the four like channels in the measurement channels or initiating logic or to the selective two-out-of-four actuating logic would actuate the auxiliary feedwater system. Automatic auxiliary feedwater actuation is initiated at the setpoints listed in Table 7.3-3 of the FSAR.

Should the control room become uninhabitable, sufficient AFWS instrumentation and controls are provided outside the control room on a Seismic Category I evacuation shutdown panel (L42) and other locations for the operation of the auxiliary feedwater pumps with controls available at the pump for the turbine-driven pump and at the switchgear for the motor-driven pump, and operation of the feedwater control valves by use of handwheels. Should the reactor be tripped and the control room evacuated, the auxiliary feedwater pumps can still supply feedwater to the steam generators for the removal of reactor decay heat and plant cooldown.

5. General Design Criteria 44, to assure:

a. The capability to transfer heat loads from the reactor system to a heat sink under both normal operating and accident conditions.

The Auxiliary Feedwater System contains three pumps each of which has sufficient capacity to transfer required heat loads from the reactor system to a heat sink under both normal operating and accident conditions. The nominal capacity characteristics for each pump are shown in Figures 2-1 and 2-2.

The auxiliary feedwater system is not required during normal power generation. For the hot standby, cooldown, and heatup modes of normal plant operation, heat loads consist of maximum core decay heat, 4 Reactor Coolant Pump (RCP) operation at hot standby and 2 RCP operation in conjunction with a 75°F/hr cooldown. Figures 2-3 and 2-4 show feedwater requirements during plant heatup and cooldown. Under emergency operation, the AFAS automatically actuates the auxiliary feedwater system by fully opening the isolation and control valves to deliver a minimum feedwater flowrate of 700 gpm to the intact steam generator. As indicated in Table 2.1, 700 gpm provides the minimum flow required for the Accident Analyses.

5. General Design Criterion 44, to assure:

b. Redundancy of components so that under accident conditions the safety function can be performed assuming a single active component failure. (This may be coincident with the loss of offsite power for certain events.)

System redundancy is provided by two independent motor-driven AC powered feedtrain, one dedicated to each SG, and a third turbine driven DC powered feedtrain capable of supplying either or both SGs. Each feedwater train has its separate suction line from the condensate storage tank. Both motor-driven trains have a AC powered control valve downstream of the pump and the turbine driven train has one DC powered control valve in each of the two branches downstream of the pump. Also, downstream of the interconnection between the motor-driven train and the turbine-driven train, parallel isolation valves are provided, one of each valve in parallel is AC powered and the other is DC powered. This valving arrangement provides redundant means for the system to remain functional in the event of loss of AC power. A Failure Modes and Effects Analysis is provided in Appendix C.

c. The capability to isolate components, subsystems, or piping if required so that the system safety function will be maintained.

The capability to isolate components, subsystems or piping is provided by reverse flow check valves, control valves and isolation valves for various flow paths. In the motor driven feedtrains, there is one reverse flow check valve and one control valve downstream of the pump and upstream of the interconnection with the turbine driven train. The same arrangement of valves is also provided in each of the cross-connections from the turbine driven feedtrain to the motor-driven train. Downstream of the interconnection between the motor-driven train and the turbine-driven train, there is isolation valve in each of the two redundant flow paths.

The capability to automatically isolate the AFWS from a ruptured SG is provided by the AFAS logic. The AFAS identifies a ruptured steam generator using the logic presented in Appendix E.

6. General Design Criterion 45, as related to design provisions made to permit periodic inservice inspection of system components and equipment.

The AFWS is designed so as to provide for inservice inspection and testing according to the requirements of ASME Boiler and Pressure Vessel Code Section XI. For test purposes, the pumps can be started manually. Water is drawn from the condensate storage tank and pumped back through the miniflow recirculation line while the control valves in the auxiliary feedwater lines may stay closed. The steam generators are supplied by the main feedwater pumps in the normal way during this regular test of the auxiliary feedwater pumps. The AFW pumps can also be operated in parallel with one main feed pump and flow monitored using the flow indicators. All power operated valves can be cycled to check operability without impairing system operation. All system components are accessable for inspection. Only the final downstream check valve is located inside containment. Test procedures are outlined under Criteria 7.

7. General Design Criterion 46, as related to design provisions made to permit appropriate functional testing of the system and components to assure structural integrity and leak-tightness, operability and performance of active components, and capability of integrated system to function as intended during normal, shutdown, and accident conditions.

Adequate system periodic testing is outlined in the surveillance requirement of the Technical Specifications as follows:

1. Each auxiliary feedwater pump shall be demonstrated OPERABLE:

A. At least once per 31 days by:
   1. Starting each pump from the control room.
   2. Verifying that:
      a. The motor driven pump develops a discharge pressure of at least 93% of the value indicated on the pump performance curve at the recirculation flowrate, and
      b. The steam turbine driven pump develops a discharge pressure of at least 93% of the value indicated on the pump performance curve at the recirculation flowrate.
   3. Verifying that each pump operates for at least 15 minutes.

4. Cycling each testable power-operated or automatic valve in the flow path through at least one complete cycle of full travel.
5. Verifying that each valve (manual, power-operated or automatic) in the flow path that is not locked, sealed, or otherwise secured in position, is in its correct position.
6. Verifying that each motor-driven pump is aligned to receive electrical power from its OPERABLE emergency bus.

B. At least once per 18 month during shutdown by:

1. Cycling each power-operated (excluding automatic) valve in the flow path that is not testable during plant operation, through at least one complete cycle of full travel.
2. Verifying that each automatic valve in the flow path actuates to its correct position on an auxiliary feedwater actuation signal (AFAS).
3. Verifying that each pump starts automatically upon receipt of an AFAS signal.

8. Regulatory Guide 1.26, as related to the quality group classification of system components.

Per FSAR Table 3.2-1, all AFW components and piping, from containment isolation valves to steam generator inlet, meet the ASME Code, Section III, Class II requirements. All other components and piping of the system meet the ASME Code, Section III, Class III requirements, except the chemical feed tank which is a non-nuclear component. The chemical feed tank connects to the AFWS with at least one normally closed isolation valve and its failure will not degrade AFWS performance.

9. Regulatory Guide 1.29 as related to the seismic design classification of system components.

The auxiliary feedwater system is designed in accordance with Seismic Category I requirements as specified in Section 3.2 of the FSAR. Any system, equipment, or structure that is not Seismic Category I, and whose collapse could result in loss of a required function of the auxiliary feedwater system through either impact or flooding, was analytically checked to determine that they will not collapse when subjected to seismic loading.

10. Regulatory Guide 1.62 as related to design provision made for manual initiation of each protective action.

The AFWS may be manually initiated on either a system level by manually initiating AFAS or a component level by controlling individual pumps and valves.

Display instrumentation is available to the operator allow him to adequately monitor the status of the AFW system. Information is provided to aid the operator in determining when manual actuation of an AFW system is required, and to aid in confirming proper system operation after system initiation. Switches for manual AFAS initiation are located on the main control board. Input parameters that initiate actuation are indicated on the control board along with positive indications that pumps and valves have actuated and that flows have been established. Manual control switches for the auxiliary feedwater pumps and valves are also provided in the control room. When the setpoints for automatic auxiliary feedwater actuation are reached, automatic actuation will take precedence over operator actions.

11. Regulatory Guide 1.102, as related to the protection of structures, systems, and components important to safety from the effects of flooding.

The safety-related systems and components for which flood protection is provided are the same as those identified in paragraph C.1 of Regulatory Guide 1.29, with clarifications and differences as specified in Appendix 3A. This includes the AFWS.

Flood protection of safety-related systems and components is provided for all postulated floor levels and conditions described in Section 2.4 of FSAR.

12. Regulator Guide 1.117, as related to the protection of structures, systems, and components important to safety from the effects of tornado missiles.

Protection against the postulated missiles identified in FSAR subsection 3.5.1 is provided to fulfill the design criteria that missiles generated by a tornado, which have velocities equal to or less than the design velocities, shall not cause loss of function of any system required for safe shutdown. That is, tornado-generated missiles are considered in design of all structures which contain AFWS components. The missiles considered in design of their characteristics are listed in FSAR table 3.5-8.

13. Branch Technical Positions ASB 3-1 and MEB 3-1, as related to breaks in high and moderate energy piping systems outside containment.

Branch Technical Position MEB 3-1 and ASB 3-1 address "Postulated Break and Leakage Locations in Fluid System Piping Outside Containment" and "Protection Against Postulated Piping Failures in Fluid Systems Outside Containment" respectively. FSAR Section 3.6 and Appendix 3.6A present the results of detailed pipe break analysis meeting the criteria of the positions regarding both the effect of AFWS pipe break on other systems and the effects of other system pipe breaks on the AFWS.

In addition to review of the above referenced analyses an independent review of the effects of AFWS pipe break on AFWS performance was conducted. This review was made in conjunction with the preparation of the Failure Modes and Effects Analysis of Appendix D and is reported in Section 2.2.

2.2 Branch Technical Position ASB 10-1

1. The auxiliary feedwater system should consist of at least two full capacity independent systems that include diverse power sources.

   System redundancy is provided by two independent motor-driven AC powered feedtrains, one dedicated to each steam generator; and a third turbine-driven DC powered feedtrain capable of supplying either steam generator. Each of the AC powered trains, utilizing diesel generators as a backup power source, includes a 100% full capacity motor-driven AFW pump. The pumps independently take suction from the condensate storage tank and each pump discharge is connected to an auxiliary feedwater line which discharges to a corresponding main feedwater line and steam generator. The third DC powered train includes a 100% full capacity steam-driven AFW pump, and thus provides system redundancy of auxiliary feedwater supply and diversity of motive pumping power. The pump takes suction from the condensate storage tank through a separate suction line, and its discharge is cross-connected through isolation valves to the same piping used by the motor-driven AFW pumps and is thereby capable of feeding either or both steam generators.

2. Other powered components of the auxiliary feedwater system should also use the concept of separate and multiple sources of motive energy. An example of the required diversity is two separte auxiliary feedwater trains, each capable of removing the afterheat load of the reactor system, having one separate train powered from either of two AC sources and the other train wholly powered by steam and DC electric power.

Each steam generator's AFW header has redundant AC and DC powered control and isolation valves that are operated by the AFAS to supply feedwater to their respective steam generators.

Also, downstream of the two junctions where the motor-driven train and the turbine-driven train are connected, there are redundant feed paths with an AC powered isolation valve in one path and a DC powered isolation valve in the other.

3. The piping arrangement, both intake and discharge, for each train should be designed to permit the pumps to supply feedwater to any combination of steam generators. This arrangement should take into account pipe failure, active component failure, power supply failure, or control system failure that could prevent system function. One acceptable arrangement is crossover piping containing valves that can be operated by remote manual control from the control room, using the power diversity principle for the valve operators and actuation systems.

   Each steam generator is capable of being supplied feedwater by either of two full capacity Auxiliary Feedwater pumps. The auxiliary feedwater lines are equipped with AC motor-operated and AC electro/hydraulic control valves in the motor-driven pump discharge and DC motor-operated valves in the turbine-driven pump discharge. The motor driven pumps take suction from condensate storage tank T-121 and their discharge pipings connect to each of the two main feedwater lines between the isolation valves and the steam generator nozzle such that each pump is aligned to one steam generator. The turbine-driven pump takes suction from the condensate storage tank T-121 through a separate suction line, and its discharge is inter-connected through isolation valves to the same piping usef by the motor driven auxiliary feedwater pump. The turbine driven pump is capable of being supplied steam from either of the two steam generators. Normally closed manual bypass valves allow both steam generators to be supplied from one motor driven AFW pump during startup.

4. The auxiliary feedwater system should be designed with suitable redundancy to offset the consequences of any single active component failure; however, each train need not contain redundant active components.

System redundancy is provided by three independently powered and operated feedtrains. The AC powered trains include two motor driven AFW pumps, with each motor driven AFW pump discharge connected to a separate MFW line between the MFW isolation valves and the steam generator nozzle. This arrangement provides system separation. The DC powered train, which includes the turbine driven pump, provides system redundancy of AFW supply and diversity of motive pumping power. This train has the pump discharge inter-connected through reverse flow check and isolation valves to the same piping used by each motor-driven AFW pump. Each AFW steam generator header has redundant AC and DC powered control and isolation valves that are operated by the AFAS to supply feedwater to their respective steam generators. A Failure Modes and Effects Analysis is presented in Appendix D.

5. When considering a high energy line break, the system should be so arranged as to assure the capability to supply necessary emergency feedwater to the steam generators despite the postulated rupture of any high energy section of the system, assuming a concurrent single active failure.

System redundancy and separation is provided by three independently powered feedtrains, a steam driven pump, and two motor driven pumps. Each of two AFWS header has redundant AC and DC powered control and isolation valves that are operated by the AFAS to supply feedwater to their respective steam generator. The review of the AFW design has indicated that postulated piping failures in the system piping will not cause a loss of the ability to deliver the required feedwater, taking into account the direct results of such failure and the further failure of any single active component.

In analyzing the effects of postulated piping failures, assumptions consistent with those of FSAR Section 3.6 are made with regard to the operability of systems and components. These are:

(1) Offsite power is assumed unavailable if a trip of the turbine-generator system or reactor protection system is a direct consequence of the postulated piping failure.
(2) A single active component failure is assumed to occur in addition to the postulated piping failure and any direct consequences of the piping failure, such as unit trip and loss of offsite power.
(3) Operator actions may be employed to mitigate the consequences of a postulated piping failure. The feasibility of carrying out operator actions should be judged on the basis of ample time and adequate access to equipment being available for the proposed actions.

Six locations of postulated piping failure were analyzed, and are shown in Figure 2.5. The worst case single active failure was found to be failure of the motor-driven pump in the separate symmetric side of the piping layout from the one of the postulated piping fracture. Results of the analysis are as follows:

(1) For break location 1 a large break could initially result in a total diversion of the turbine-driven flow to the break, and no AFW flow would be available to either steam generator. A cavitating venturi would prevent pump runout conditions. Such a situation would be identified from system flow indication and pump pressure indication. The operator would be required to isolate the turbine driven pump from the break by shutting the appropriate turbine pump control valve from the control room. Full required flow would now be delivered from the turbine pump to the unaffected AFWS header.

(2) For break location 2, breaks on the downstream side of the check valve will appear identical to break location 1. Again manual isolation using the turbine control valve will insure full turbine pump flow to the opposite S.G. After the exact location is determined, the motor driven pump control valve may be shut to isolate the break and allow aligning the turbine driven pump to both steam generators. For breaks upstream of the check valve the turbine driven pump will supply the required feedwater to both steam generators.

(3) For break location 3, breaks on the downstream side of the check valve again appear to the operator to be identical to break location 1. Consistently, the required operator action is the closure of the turbine driven pump control valve (HV-4706). This action now allows the available motor driven pump to deliver the required auxiliary feedwater flow to its respective steam generator. For break up steam of the check valve only the turbine driven pump will deliver to the break, the available motor driven pump supplying the required feedwater to its respective steam generator.

(4) For break location 4, the turbine pump will be unavailable for feedwater delivery. The available motor driven pump will supply the required feedwater to its respective steam generator. Closure of steam isolation valves allow isolation of the break.

(5) For break location 5, the turbine driven pump will be supplied steam from the unaffected steam generator and will supply the required feedwater to the unaffected steam generator. For breaks downstream of the isolation valve (HV 8200) the break will be isolated and the required feedwater delivered to both steam generators.

/jcp

Figure 2-1

TURBINE DRIVEN PUMP EQUILIBRIUM FLOW RATES: NO VENTURIES, CONTROL VALVE 100% OPEN

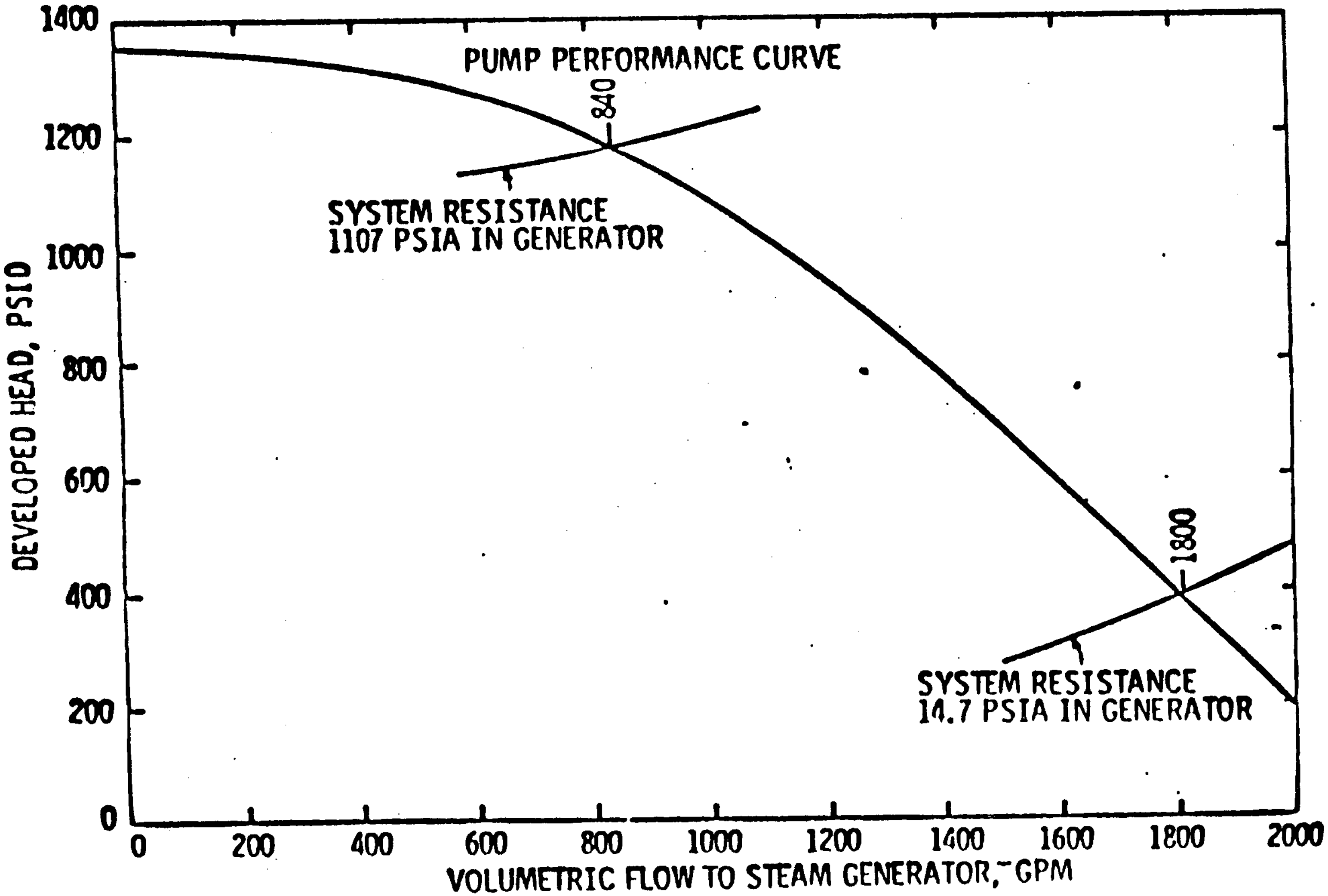


Figure 2-2

MOTOR DRIVEN PUMP EQUILIBRIUM FLOW RATE; NO VENTURIES, CONTROL VALVE 100% OPEN

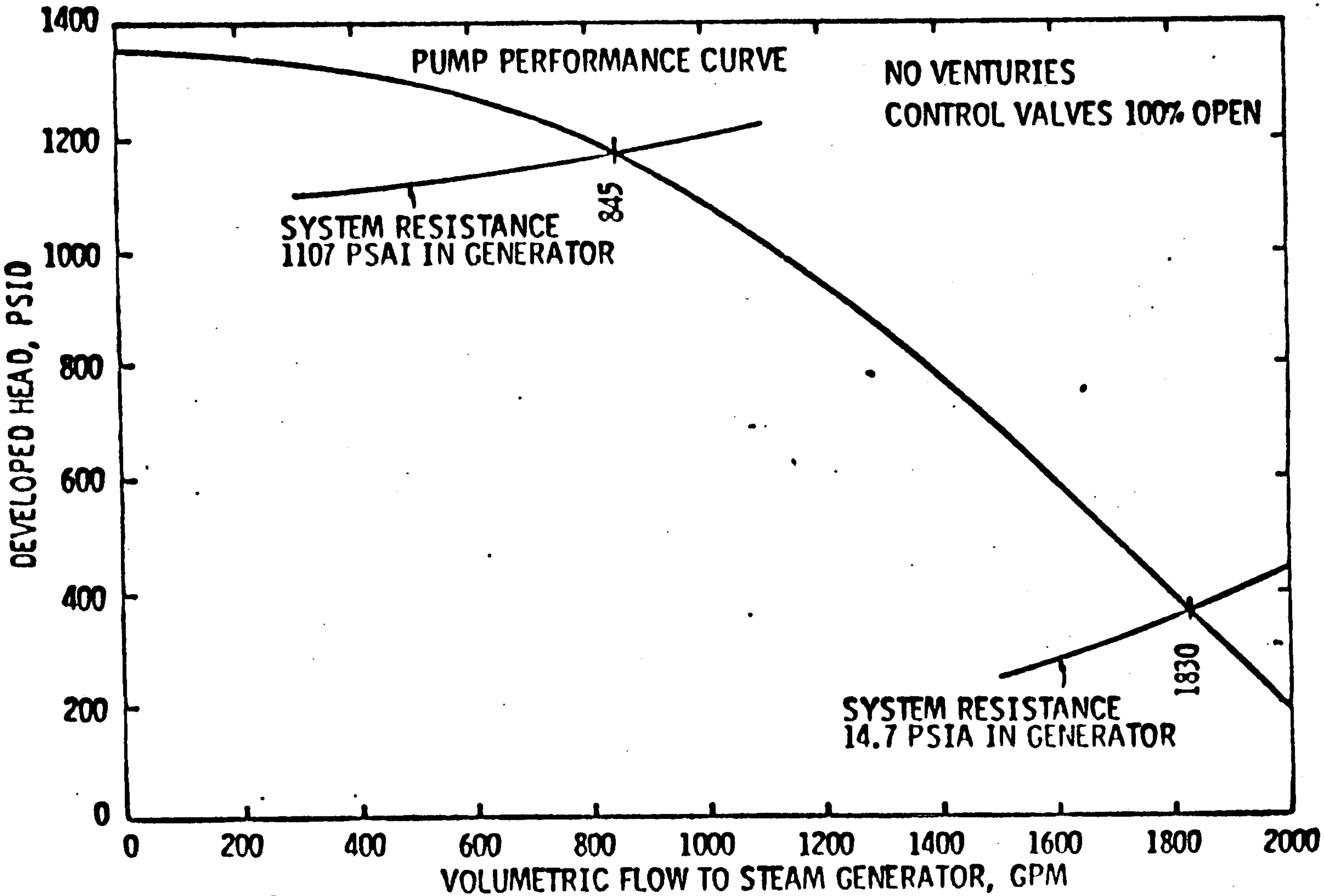


Figure 2-3

TYPICAL, HEATUP

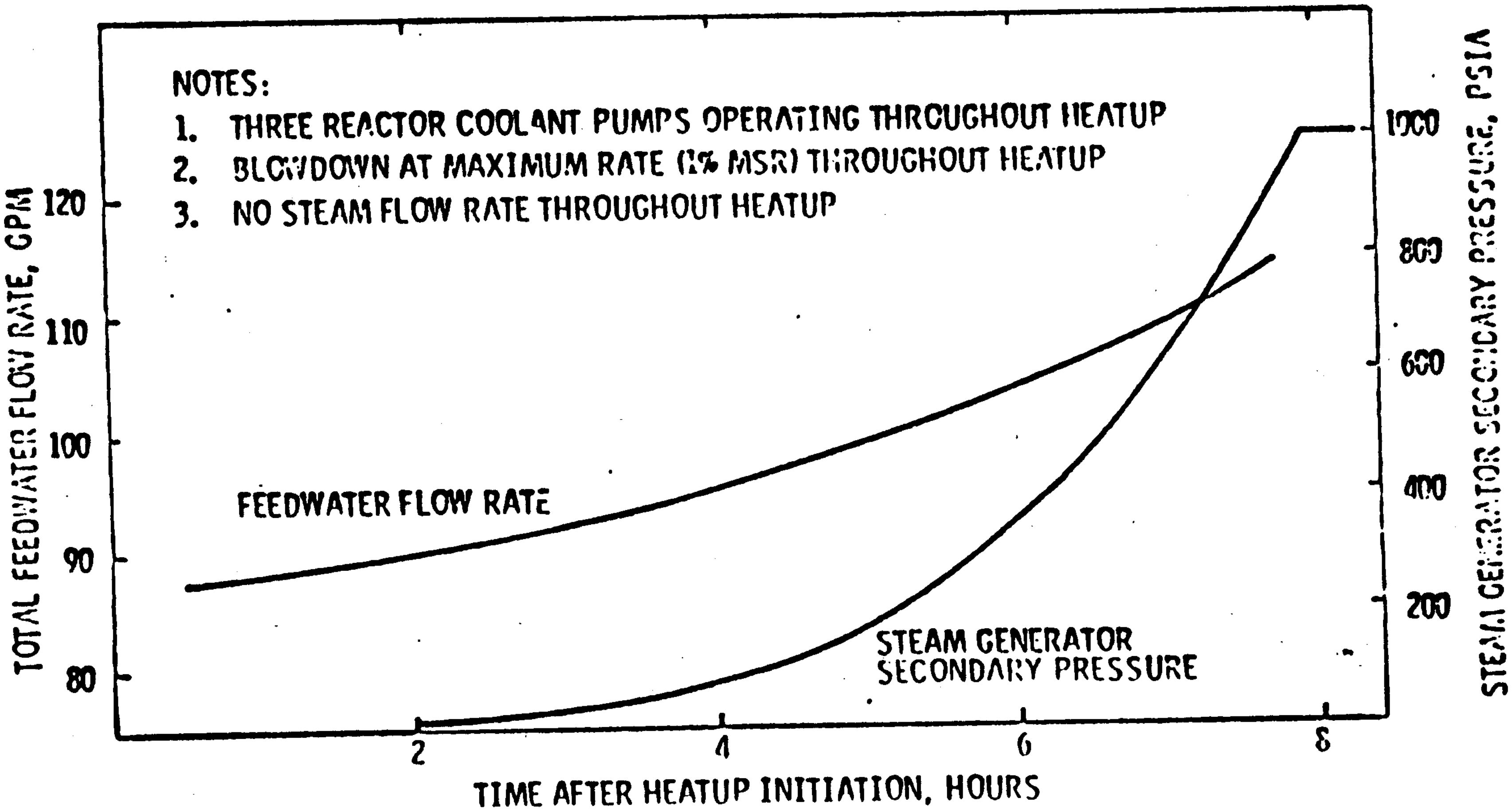
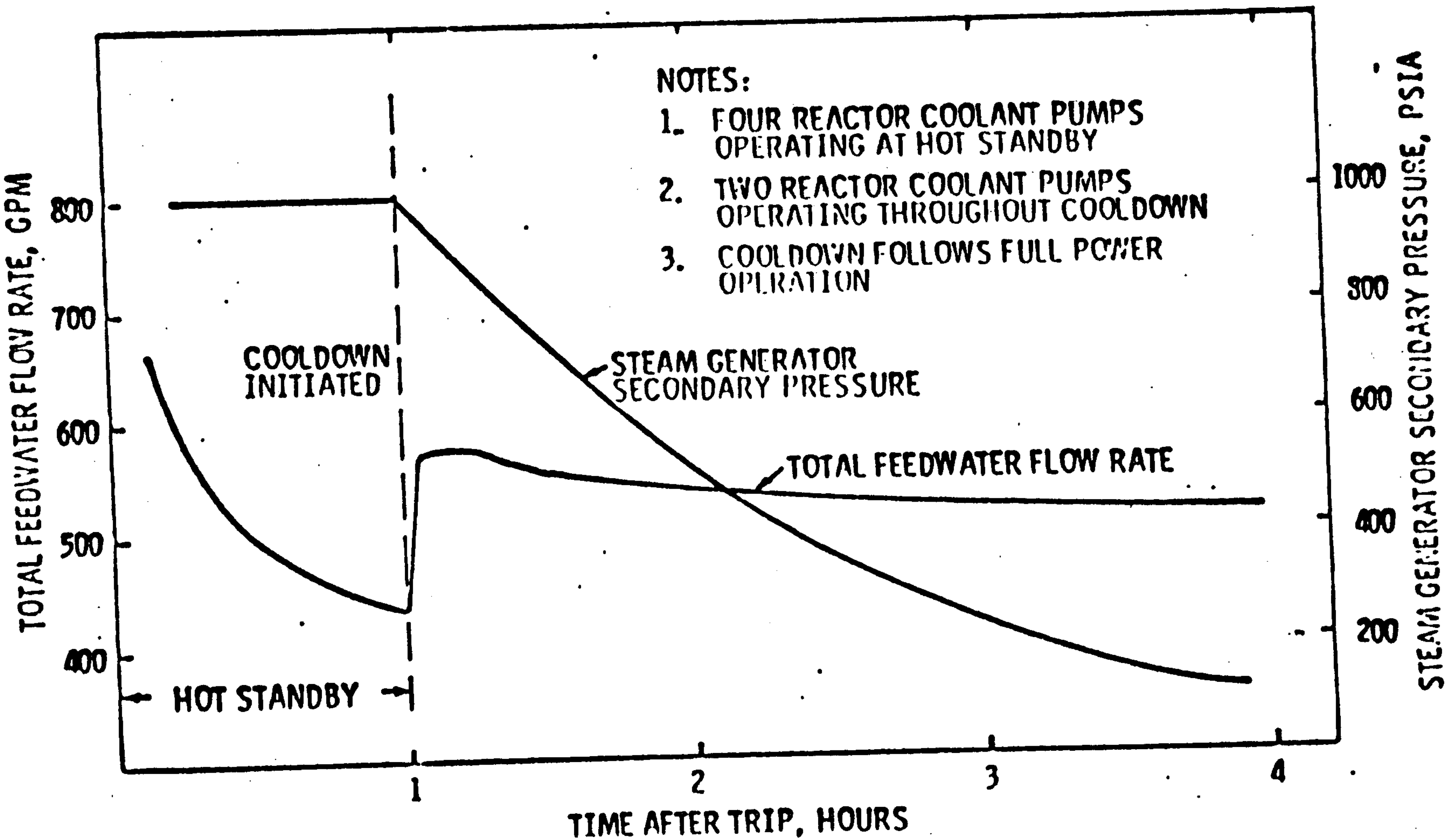
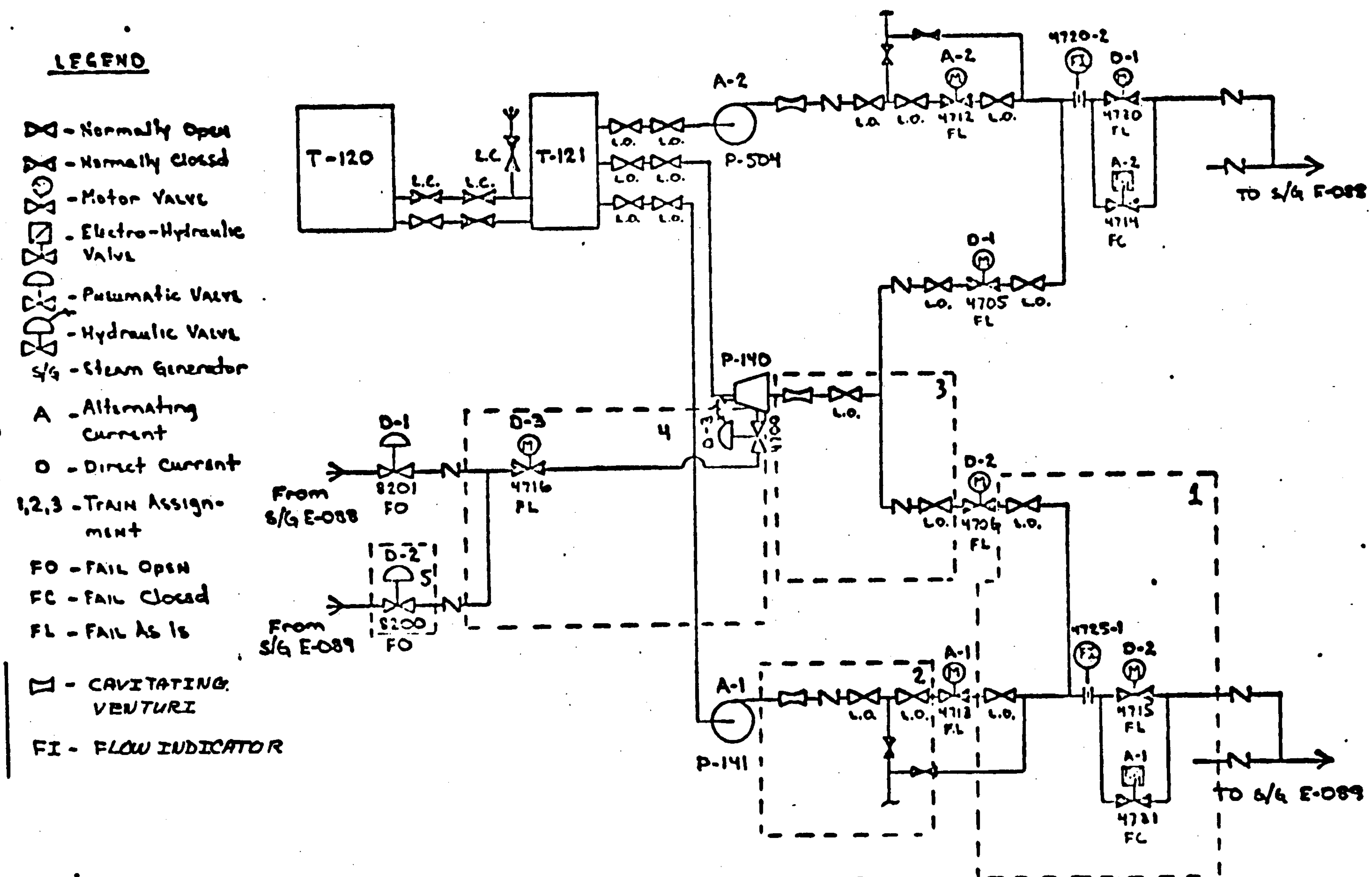


Figure 2-4
TYPICAL COOLDOWN





AUXILIARY FEEDWATER SYSTEM

SONGS 2 & 3

FIGURE 2-5

TABLE 2.1

ACCIDENT ANALYSES ASSUMING AUXILIARY FEEDWATER SYSTEM INITIATION

Event	Minimum AFW Flow Rate Assumed Available	Steam Generator Pressure Range for First 1800 Seconds (psia)	Time After AFW Initiation Signal that AFW Assumed At The Steam Generator
Increased Main Steam Flow (15.1.1.3)	700	1070 - 666	42 seconds
Inadvertent Opening of a Steam Generator Dump Valve (15.1.1.4) [1]	700	1033 - 903.5	42 seconds
Increased Main Steam Flow with Concurrent Single Failure of an Active Component (15.1.2.3) [1]	700	1139 - 828	53 seconds
Inadvertent Opening of a Steam Generator Atmospheric Dump Valve with a Concurrent Single Failure of an Active Component (15.1.2.4) [1]	700	1033 - 903.5	53 seconds
Steam System Piping Failures (15.1.3.1)	700	1155 - 600	53 seconds
Loss of Normal AC Power	700	1150 - 1050	53 seconds

TABLE 2.1 -- continued

Event	Minimum AFW Flow Rate Assumed Available	Steam Generator Pressure Range for First 1800 Seconds (psia)	Time After AFW Initiation Signal that AFW Assumed At The Steam Generator
Loss of Normal Feedwater Flow (15.2.2.5)	700	1154 - 950	43 seconds
Feedwater System Pipe Breaks (15.2.3.1)	700	1155 - <600	53 seconds
Loss of Normal Feedwater with an Active Failure in the Turbine Steam Bypass System (15.2.3.2)	700	1060 - 643	43 seconds
Control Element Assembly (CEA) Ejection (15.4.3.2)	700	1150 - 900	43 seconds
Steam Generator Tube Rupture with Concurrent Loss of Normal AC Power (15.6.3.2.2)	700	1139 - 900	60 seconds
Small Break LOCA	700	1150	60 seconds

TABLE 2.1 -- continued

NOTES:

1. These events would initiate AFW but no credit is taken for AFW in the analyses.

2. An Auxiliary Feedwater Actuation Signal is assumed initiated to a steam generator either by

   (A) no low pressure in the steam generator (i.e., steam generator pressure greater than 700 psia) or,

   (B) a differential pressure between the two steam generators greater than 100 psid (the higher pressure generator receiving flow).

   coincident with a low steam generator level (10% of tap to tap span).

3.0 RELIABILITY EVALUATION

The following sections contain the results of a comparative reliability evaluation of the SONGS Units 2 & 3 Auxiliary Feedwater System (AFWS) with respect to the AFWS of a previously evaluated reference plant. Arkansas Nuclear One Unit 2 (ANO-2) was chosen as the reference plant due to several design aspects similar to SONGS and also based on ANO 2's AFWS being characterized as having a higher reliability relative to other CE operating units in NUREG 0635, (Reference 1.3.3).

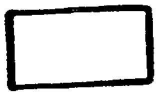
The results and conclusions contained herein are based solely on this comparative study which utilized the methodology and intent of NUREG 0635. The system reliability is assessed under various loss of feedwater transients and postulated potential failure conditions by determining the susceptability for AFW system failure due to common mode failures, single point failures, or any dominant causes of system unreliability particularly as a result of human error.

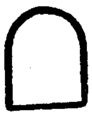
For the purposes of this study an AFW system schematic Figure 3-1 and simplified fault tree, Appendix B, for the reference plant were prepared and are contained herein. A more detailed description of the reference plant may be found in Enclosure 1 to NUREG 0635. The general format of the plant specific AFWS reliability study of NUREG 0635 has been followed here for SONGS 2 & 3 for purposes of standardization and completeness.

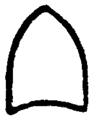
The fault tree diagrams of Appendices A and B are constructed for the case of insufficient flow of AFW to one S/G, that is, the AFWS being incapable of delivering a minimum AFW flowrate of 700 GPM to the intact S/G(s).

Since the purpose of the enclosed fault trees is to perform a qualitative comparative study rather than generate a quantitative probabilistic result, the simplified methodology utilized in constructing the fault tree diagrams serves as a useful tool in highlighting specific system design faults, existing common mode failures, and possible weaknesses in system arrangement or design that might result in relying on operator action to maintain system operability in cases where possible single failures exist.

The following symbols and assumptions were used in generating the fault trees of Appendices A & B.

 - The rectangle defines an event that results from the logical operation of two or more input events. It may also define a basic fault event that requires no further development.

 - The AND gate describes an operation that requires the coexistence of all events leading to it to provide the output event.

 - The OR gate describes an operation that requires only one of several inputs to produce the output event.

 - Transfer symbol.

Assumptions:

1. Maintenance/test failures include operator error (i.e. manual valve out of position) in addition to the system or component being unavailable due to routine maintenance and testing.

2. Check valve failures were not included as part of the fault tree diagrams due to the relative low probability of failure, and the desire to maintain a relatively simplified fault tree diagram.

3. A loss of AFAS is not considered a single failure event due to its 2 out of 4 logic to generate the signal. However, for simplicity and ease in highlighting common mode failures, the loss of AFAS gate is shown as a basic fault event.

3.1 SONGS 2 & 3 COMPARATIVE SYSTEM DESCRIPTION

Configuration - Overall Design

The AFWS as shown in Appendix D consists of a primary and secondary source of auxiliary feedwater along with three auxiliary feedwater pumps (2 motor driven, 1 steam driven) and associated valving arrangement to supply either/both steam generators (S/G). The primary source of AFW is a Seismic Category I condensate storage tank with a capacity of 150,000 gallons. An additional 500,000 gallon, Seismic Category II, condensate storage tank serves as the primary backup supply of water. The system is further supplemented by the fire protection system, makeup from the demineralizer, and the feasibility to interconnect the condensate systems of Units 2 & 3 via the condensate transfer pump

The three AFW pumps take suction from the primary water source via three independent suction lines each containing two locked-open manual isolation

valves. The two motor driven pumps are totally independent, each supplying one steam generator. The steam turbine driven pump can supply either/both steam generators. Each pump has a 100% capacity and is designed to deliver 860 gal/min at a 2842 ft. head. A flow limiting venturi is also provided in the discharge line of each AFW pump to limit pump runout flow in case of an AFW line break, thereby protecting the pump from possible damage due to effects of cavitation.

Component Design Classification

The AFWS including pumps, valves and piping is safety grade, Seismic Category I inclusive of condensate storage tank T-121 which serves as the primary source of auxiliary feedwater. A backup condensate storage tank T-120 is Seismic Category II. Cooling water from the steam driven AFW pump is supplied by the pump itself.

Power Sources

The AFW motor driven pumps are powered from independent AC power trains supplied by two separate emergency diesel generators when the preferred (offsite) power source is unavailable. The steam supply to the turbine driven AFW pump is routed from the main steam line of each S/G upstream of the main steam isolation valves (MSIVs). Each S/G steam supply line contains a pneumatic actuated fail open isolation valve. A motor driven steam isolation valve is also provided on the common steam supply line to the steam driven pump. Power to these valves is supplied by independent DC control power sources.

The AFW pump discharge lines are equipped with AC motor driven control valves at the motor driven pump discharge and DC motor driven control valves at the steam driven pump discharge. Parallel isolation valves are provided in the lines to each S/G with both a DC motor driven and AC electro/hydraulic driven valve provided in each line.

Instrumentation and Controls

Controls

An Auxiliary Feedwater Actuation Signal (AFAS) automatically actuates the auxiliary feedwater system by starting the AFW pumps, determining which S/G is intact, and fully opening the isolation and control valves to the unaffected steam generator(s). When the S/G water level returns to above the low level setpoint the AFW pump discharge valves will shut automatically. Manual control of the AFW pumps and control valves is also possible from the control room.

Information Available to Operator

Indication is provided in the control room and in the auxiliary feedwater pump area for the following parameters:

a) Auxiliary feedwater flowrate
b) Auxiliary feedwater pump discharge pressure.
c) Turbine driven steam inlet pressure:

Indication is provided in the control room only for the following parameters:

a) Steam generator water level.
b) Main feedwater pressure.
c) Steam generator pressure.
d) Motor running/stopped.
e) Condensate storage tank T-121 and T-120 level.

Alarms are provided in the control room for the following:

a) Condensate storage tank T-121 level.

Initiating Signals for Automatic Operation

The Engineered Safety Feature Actuation System (ESFAS) will generate an AFAS to either steam generator by one of the following conditions:

a) A low S/G level coincident with no low pressure trip present for that S/G.
b) A low S/G level coincident with a pre-set differential pressure present between the two S/Gs with the higher pressure associated with the S/G to be fed.

A two-out-of-four logic is required for generating an AFAS to a particular S/G.

Testing

Each month the AFW pumps are started from the control room and operated for at least 15 minutes in recirculation for discharge pressure verification. Each testable power-operated or automatic valve is cycled; electrical power alignment from an operable emergency bus to the motor driven pumps is verified; and non-locked or sealed valves are checked for proper positioning.

Technical Specifications

The following are existing technical specifications for SONGS 2 & 3 AFWS. Suggested modifications due to addition of a third AFW pump are marked as: (____________).

16.3.7.1.2.1 Limiting Condition for Operation. At least (three) independent steam generator auxiliary feedwater pumps and associated flow paths shall be OPERABLE with:

- (Two) auxiliary feedwater pumps capable of being powered from an OPERABLE emergency bus, and
- One auxiliary feedwater pump capable of being powered from an OPERABLE steam supply system.

A. Applicability: MODES 1, 2 and 3.

B. Action: With one auxiliary feedwater pump inoperable, restore at least (three) auxiliary feedwater pumps to OPERABLE status within 72 hours or be in HOT SHUTDOWN within the next 12 hours.

16.4.7.1.2.1 Surveillance Requirements. Each auxiliary feedwater pump shall be demonstrated OPERABLE.

A. At least once per 31 days by:

1. Starting each pump from the control room.
2. Verifying that:
   a. The motor driven pump develops a discharge pressure of at least 93% of the value indicated on the pump performance curve at the recirculation flowrate, and
   b. The steam turbine driven pump develops a discharge pressure of at least 93% of the value indicated on the pump performance curve at the recirculation flowrate.
3. Verifying that each pump operates for at least 15 minutes.
4. Cycling each testable power-operated or automatic valve in the flow path through at least one complete cycle of full travel.
5. Verifying that each valve (manual, power-operated or automatic) in the flow path that is not locked, sealed, or otherwise secured in position, is in its correct position.
6. Verifying that each motor-driven pump is aligned to receive electrical power from an OPERABLE emergency bus.

b. At least once per 18 months during shutdown by:

1. Cycling each power-operated (excluding automatic) valve in the flow path that is not testable during plant operation, through at least one complete cycle of full travel.
2. Verifying that each automatic valve in the flow path actuates to its correct position on an auxiliary feedwater actuation signal (AFAS).
3. Verifying that each pump starts automatically upon receipt of an AFAS signal.

16.3/4.7.1.3 Condensate Storage Tank

(later)

3.2 RELIABILITY ASSESSMENT

Dominant Failure Modes

Failure modes for the SONGS AFWS were assessed for the three initiating loss of feedwater transients outlined in NUREG 0635. The dominant failure modes for these events are discussed below.

Loss of Feedwater with Offsite Power Available

In analyzing the SONGS AFWS fault tree of Appendix A, it can be clearly seen that there are no potential single point failures existing which would result in a total loss of AFW to both steam generators. Furthermore this assessment also holds true for a loss of AFW to one steam generator. Since the system is automatically actuated, operator action is not a primary cause of system failure.

Therefore the dominant failure mode for a total loss of AFW would be the result of a combination of three separate failures (omitting line breaks at this time), each failure being associated with a different AFW pump or suction path (i.e. pump outage due to maintenance, manual valves mispositioned, etc.).

Loss of Feedwater With Loss of Offsite AC Power

This transient is similar in nature to the event described above. Since the AFWS is automatically transferred to onsite AC with a loss of offsite power, operator action is similarly not required for initiating flow. The dominant cause of system failure is basically identical to that which exists with offsite power available.

Loss of Feedwater With Only DC Power Available

The steam driven AFW pump and its associated steam supply and discharge flow paths are actuated automatically by onsite DC power. With AC power unavailable resulting in the loss of the two motor driven pumps, a single failure in the steam AFW pump train will result in total loss of AFW. As shown in Appendix A, examples of such failures are pump outage due to maintenance/test, mechanical failure, or loss of steam supply. However, only a failure occurring in that portion of the system between the pump turbine stop valve and the manual locked open pump suction and discharge valves will result in a loss of AFW flow.

Potential Interactions

No significant potential interactions exist in the AFWS other than those outlined for the above loss of feedwater cases.

In postulating system operation with an AFW line break in addition to a single failure occurring in the system, operator action may be required to isolate a break by either manual valve closure or securing one of two or more operating AFW pumps.

For example:

1. DELETED.

2. With the system operating in hot standby, a line break occurs in the AFWS between a motor pump discharge valve and its corresponding steam generator check valve along with a single failure of the second motor AFW pump. Upon receipt of an AFAS, operator action will be required to divert AFW from the break to the intact S/G by closing the steam driven AFW pump discharge valve V4706 or V4705 to the ruptured AFW header thereby assuring the turbine pump discharge flows to the intact AFW header and corresponding S/G only.

A Failure Modes and Effects Analysis, including line breaks, is shown in Appendix C.

Justification of SONGS 2 and 3 AFWS Reliability Characterization with Respect to Reference Plant.

Figure 3.3 represents a reliability characterization chart as appears in NUREG 0635 for AFWS designs in plants using the CE NSSS. An additional proposed reliabili*y characterization for SONGS 2 and 3 Units has been added to Figure 3-2 based on the results of the evaluation herein with respect to the reference plant.

In characterizing the reliability of AFW systems NUREG 0635 generally implies that the following traits exist for specific reliability ratings:

1. Loss of Main Feedwater (SONGS - High Reliability Characterization)

Low Reliability	Medium Reliability	High Reliability
a. Manual System Actuation	a. Auto actuation with manual backup	a. Auto actuation with manual backup.
b. Two-pump system.	b. Single point vulnerabilities may be present.	b. No single point vulnerabilities present.
c. Single point vulnerabilities present.	c. Technical specifications permit unlimited outage time	c. High system redundancy.
d. Technical Specifications permit unlimited outage time for system maintenance, test, etc.		d. Low reliance on operator action (human error)

The reference plant used in this study is classified in the medium reliability range for this transient. Generally, the system consists of two AFW pumps (one motor and one steam) and is actuated automatically when required. The system is susceptable to failure, however, if certain AFW line breaks occur concurrently with specific single failures. In analyzing a simplified AFWS fault tree for the reference plant (See Appendix B), it can also be seen that certain double failures which would secure flow to one steam generator are common mode occurrences in that an interruption of flow to the second steam generator may also result.

The SONGS AFWS with the added redundancy of a third AFW pump along with a corresponding independent parallel valve arrangement negates the possibility of a double failure terminating flow to both steam generators.
With the AFW system actuating automatically, the need for operator action, hence the probability of human error, is minimized.

Loss of Main Feedwater with Loss of Offsite Power
(SONGS - High Reliability Characterization)

The reliability classification of a specific plant under this transient is basically the same as for the previous LOFW event. The major difference being that onsite AC power sources are now accounted for and the system evaluated for the possible degradation of onsite AC power (i.e. loss of one of two diesel generators).

In the reference plant (characterized as medium reliability) a loss of the diesel supplying the motor driven pump might leave the system vulnerable to failure if an additional single failure were to occur. This can be averted, however, through operator action to manually close a series of breakers to align the pump to the alternate diesel generator.

With the three pump SONGS design, failure of one diesel will not leave the system vulnerable if an additional single failure occurs. The system has sufficient redundancy remaining to provide for two separate flow paths, one to each S/G. Should a single failure occur it would not be of a common mode nature resulting in loss of AFW to both S/G's.

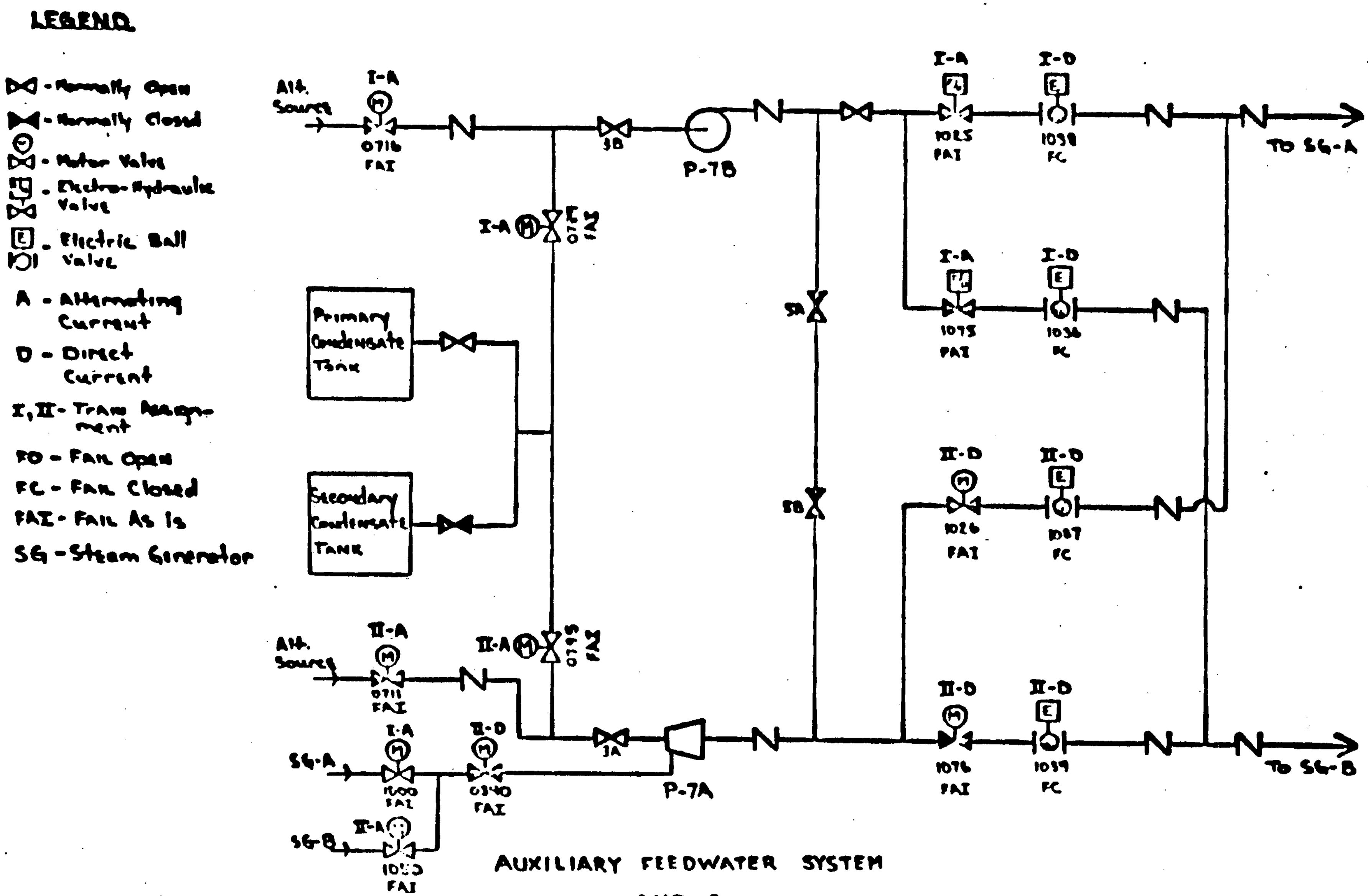
Loss of Main Feedwater with Loss of All AC Power
SONGS - High Reliability Characterization)

Low and medium reliability classifications under this event are generally due to systems having strong AC power dependencies in the steam turbine driven pump train. Such dependencies include lube oil cooling, power to steam turbine admission valves, or AC operated valves which fail closed on loss of air. Those systems characterized as having a relatively high reliability generally are auto actuated and have no potentially degrading AC power dependencies.

In comparing SONGS AFWS to the reference plant which has a high reliability characterization, the SONGS design has a similar reliability in that the turbine pump train has no AC dependencies in order to function normally. Slight AC dependency does exist in the reference system design where the steam generator steam isolation valves to the turbine driven pump are

controlled by AC power although they are classified as " fail-as-is"
Both systems are automatically actuated in this mode.

Overall, additional credence for a high reliability of SONGS AFWS is found in the tech. spec. requirements for periodic testing of the AFWS. Every 31 days both the steam and motor pumps must be operated for at least 15 minutes verifying satisfactory discharge pressure during the run, each testable power operated valve in the flowpath shall be cycled, and each motor driven pump shall be verified to be aligned to an OPERABLE emergency bus.



AUXILIARY FEEDWATER SYSTEM

ANO-2

FIGURE 3-1

Transient Events	LMFW									LMFW/LOOP									LMFW/Loss of All AC								
Plants	Low			Med.			High			Low			Med.			High			Low			Med.			High		
Combustion Engr.																											
Calvert Cliffs			●									●									●						
Palisades			●									●									●						
Maine Yankee			●									●									●						
Millstone			●									●											●				
St. Lucie			●									●											●				
* Ark. Nuc. #2					●								●												●		
Ft. Calhoun					●								●												●		
SONGS #2 & 3								●									●								●		

* reference plant.

FIGURE 3-2

Reliability Characterizations for AFWS Designs in Plants Using the C-E NSSS

4.0 REQUESTED INFORMATION REGARDING DESIGN BASE TRANSIENTS AND ACCIDENT CONDITIONS.

The following information is provided in accordance with the NRC request of Reference 1 for additional information regarding Auxiliary Feedwater System flow requirements.

1.a. Identify the plant transient and accident conditions considered in establishing AFWS flow requirements.

1) Loss of Main Feedwater (LMFW)

The loss of Main Feedwater is the primary design base event for the Auxiliary Feedwater System. As such the Auxiliary Feedwater pumps were each sized to equal the steam flow necessary for heat removal under the following assumptions.

a. Maximum decay heat at 5 minutes following reactor trip.
b. Four RCPs operating.
c. Maximum Auxiliary Feedwater temperature.
d. Steam generator pressure equal to lowest secondary safety valve set point.

For heat loads greater than this (i.e. first five minutes following reactor trip) steam generator initial inventory in conjunction with the automatic delivery of auxiliary feedwater maintains the steam generator as an acceptable heat sink. For heat loads less than that assumed, steam generator inventory will accumulate until manual control reduces the required flow rate or until feed flow is automatically terminated on high level.

As a design basis transient for sizing the AFW pumps, the analysis of FSAR Section 15.2.2.5 demonstrates that the capacity of the AFW system is sufficient to maintain the secondary heat sink.

2) LMFW with loss of offsite AC power.

This transient was analyzed but not presented in the FSAR. A LMFW with a failure of the Turbine Steam Bypass System open is presented and shown to produce the minimum steam generator inventory in the shortest time. The analysis of FSAR Section 15.2.3.2 demonstrates that the capacity of the AFW system is sufficient to maintain the secondary heat sink.

3) LMFW with loss of onsite and offsite AC power.

Although not a design base event for determining AFW pump capacity, the required flow rate is the same as that for a LMFW with loss of offsite AC power. In the remote case of failure of normal, perferred and emergency electrical power, the required flow is delivered by the turbine driven AFW pump.

4) Plant Cooldown

As a design base event for sizing the AFW pumps, each AFW pump has sufficient capacity to ensure adequate flow to maintain steam generator water level when either steam generator is being used to remove reactor decay heat, RCP heat, and primary and secondary system water and metal sensible heat. These requirements are shown in Figure 4.1.

5) Turbine Trip With and Without Bypass.

A Turbine Trip with or without Bypass would produce effects no more adverse than those of a Loss of Condenser Vacuum (which is essentially a Turbine Trip without Bypass). Although not a design basis transient for sizing the AFW pumps, the analysis of the Loss of Condenser Vacuum in FSAR Section 15.2.1.3 demonstrates that the capacity of the AFW system is sufficient to maintain the secondary heat sink.

6) Main Steam Isolation Valve Closure.

This transient is similar to and produces effects no more adverse than the Loss of Condenser Vacuum as discussed in 5) above.

7) Main Feedline Break

Although not a design basis accident for sizing the AFW pumps, the cases analyzed in FSAR Section 15.2.3.1 demonstrate that the capacity of the AFW system is sufficient to maintain the secondary heat sink.

8) Main Steam Line Break

The Main Steam Line Break (MSLB) accidents are analyzed in FSAR Section 15.1.3.1. Rapid depressurization of the affected steam generator results in a steam generator low pressure trip signal. This signal generates a MSIS which closes the main steam isolation valves (7.2 seconds after event) and main feedwater isolation valves (22.2 seconds after event), effectively preserving the unaffected steam generator's capability as a heat sink. A steam generator low water level signal is generated in the affected steam generator (it empties), however, the AFAS logic determines from the presence of the low pressure signal that a rupture exists at that steam generator and auxiliary feedwater should not be actuated. Thus the

AFW system is not automatically actuated within the 30 minutes prior to possible operator manual intervention. If the operator does not take manual control of the event, pressure in the unaffected steam generator would rise to the safety valve setpoint and begin to blowdown. AFAS logic would eventually detect the inventory loss by a low water level signal and the AFW system would be actuated to preserve the secondary heat sink.

9) Small Break LOCA.

Small Break LOCA are analyzed in FSAR Sections 15.6.3.3 and 6.3.3.3. Early isolation of the steam generators prevents significant loss of inventory and this precludes the necessity of early AFW actuation during the 30 minutes prior to possible operator manual actuation in the post-reflood cooldown phase. If the operator did not take manual control of the transient, the pressure in the steam generators would rise to the safety valve setpoint and the inventories would decrease through blowdown. AFAS logic would eventually detect this by low water level signals and the AFW system would be actuated to preserve the secondary heat sink.

10) Other transient or accident conditions not listed above.

a) Plant Startup

AFW flow requirement is less than that required for plant cooldown.

b) Hot standby and hot shutdown.

Although not a design base event for determining AFW pump capacity, the AFW system is placed in operation to maintain steam generator water level. Pump flow requirement is less than that required for plant cooldown.

1.b. Describe the plant protection acceptance criteria and corresponding technical bases used for each initiating event identified above. The acceptance criteria should address plant limits such as:

- Maximum RCS pressure (PORV or safety valve actuation).
- Fuel temperature or damage limits (DNB, PCT, maximum fuel central temperature).
- RCS cooling rate limit to avoid excessive coolant shrinkage.
- Minimum steam generator level to assure sufficient steam generator heat transfer surface to remove decay heat and/or cool down the primary system.

RCS Pressure

The Reactor Coolant Pressure Boundary (RCPB) is designed to accommodate the system pressures and temperatures attained under all expected modes of unit operation, including all anticipated transients, and to maintain the stresses within applicable limits. The design meets the requirements of the ASME Code, Section III, Division 1. The following specific criteria evolve from the ASME Code requirements:

Level B - Emergency Condition - The maximum pressure will not exceed 120% of the design value.

Level C - Upset Condition - The maximum pressure will not exceed 110% of the design value.

Also, FSAR Section 16.2.1.2.2 states that whenever the RCS pressure has exceeded 2750 lb/in^{2}a (110% of design), be in Hot Standby with the RCS pressure within its limits within one hour.

For the events discussed in 1a, above, in all cases except the Main Feed Line Break the maximum RCS pressure remains below the Level C limit. For the MFLB the maximum RCS pressure, 2870 lb/in^{2}a, is below the Level B limit and the analysis shows that the system is brought to Hot Standby within 30 minutes.

Fuel Temperature or Damage Limits

DNBR (Departure from Nucleate Boiling Ratio)

The CE-1 correlation in conjunction with the TORC code gives a DNBR minimum value of 1.19. This value provides, at minimum, a 95% probability with 95% confidence that departure from nucleate boiling does not occur on a fuel rod during steady state operation or anticipated operational occurrences. This value is used as the low DNBR trip setpoint for all the design transient analyses discussed in 1a, above. In all cases the DNBR remains above this minimum value.

Maximum Linear Heat Generation Rate (LHGR)

The peak LHGR is the value above which some centerline fuel melting could occur. The maximum allowable steady state LHGR for SONGS 2 and 3 is 12.5 KW/ft. For the design transient events discussed in 1a, above, at no time is the peak linear heat rate exceeded.

PCT (Peak Cladding Temperature)

By remaining in the nucleate boiling regime maximum cladding temperature will be only a few degrees higher than the coolant saturation temperature. This regime is maintained by assuming that the DNBR for any event remains above the minimum DNBR. The discussion of DNBR above indicates that this is true for the design transient events of 1a.

It can be seen from the above discussions of DNBR, PCT, and Peak Linear Heat Rate that fuel rod integrity is maintained for the design transient events of 1a.

RCS Cooling Rate Limit

The RCS is designed to withstand the cyclic loads generated by the pressure and temperature transients of normal starting and shutdown. The design is based on a rate of 100°F/hr. This is reflected in FSAR Section 16.3.4.9.1.1, Technical Specifications.

Steam Generator Water Level

Steam generator water level is not an explicit acceptance criterion. However, analyses shows that sufficient steam generator water level is maintained in either steam generator until the RCS temperature is reduced to 350°F and shutdown cooling is initiated.

2. Describe the analyses and assumptions and corresponding technical justification used with plant condition considered in 1.a. above including:

a. Maximum reactor power (including instrument error allowance) at the time of the initiating transient or accident.

The reactor power, including instrument error for the LMFW at the time of the initiating event is conservatively assumed to be 3478 MWt, which is 102 percent of licensed core power.

b. Time delay from initiating event to reactor trip.

The time delay from the initiating event to the reactor trip for the LMFW is 47.5 seconds. This represents the time until the CEAs begin to drop into the core.

c. Plant parameter(s) which initiates AFWS flow and time delay between initiating event and introduction of AFWS flow into steam generator(s).

Steam generator low water level is the only parameter which automatically initiates AFW flow into the steam generator(s). For the LMFW the AFAS receives a steam generator low water level signal 46.8 seconds after the initiating event. AFW flow reaches the steam generators at 89.5 seconds.

d. Minimum steam generator water level when initiating event occurs.

The initial primary pressure is set low to insure a reactor trip on steam generator low water level. The initial steam generator water level is set to the high level set point. This insures the maximum primary transient prior to the reactor trip. The reactor trip on steam generator low level insures minimum steam generator inventory when the cooldown phase beings.

e. Initial steam generator water inventory and depletion rate before and after AFWS flow commences - identify reactor decay heat rate used.

The initial steam generator inventories have important impact in two ways: 1) assuming the most limiting RCS transient prior to reactor trip, and (2) assuming the worst case secondary heat sink for subsequent cooldown. Since initial conditions for the LMFW transient are set such that the reactor trip occurs on steam generator low water level these points are assumed (see item d, above). The inventory depletion rate becomes immaterial since the water level must reach the low level setpoint before a reactor trip can occur. Once the AFW flow reaches the steam generators, sufficient AFW pump capacity exists to remove decay heat and maintain an appropriate steam generator water level.

f. Maximum pressure at which steam is released from generator(s) against which the AFW pump must develop sufficient head.

The maximum steam generator pressures are 1154 psia during safety valve operation. When the AFW flow reaches the steam generators the pressures have reduced significantly. However, the AFW system is designed to supply the necessary flow against the higher pressure.

g. Minimum number of steam generators that must receive AFW flow; e.g. 1 out of 2?, 2 out of 4?

Only one steam generator is required to assume that sensible and decay heat are removed during all operational transients and accidents.

h. RC flow condition - continued operation of RC pumps or natural circulation.

For the LMFW transient the reactor coolant pumps are assumed to continue operating unless normal offsite AC power is unavailable. The same assumption is true for Plant Cooldown.

i. Maximum AFW inlet temperature.

The maximum AFW inlet temperature is 100°F.

j. Following a postulated steam or feed line break, time delay assumed to isolate break and direct AFW flow to intact steam generator(s). AFW pump flow capacity allowance to accommodate the time delay and maintain minimum steam generator water level. Also identify credit taken for primary system heat removal due to blowdown.

Although not a design basis event, the feed line break was analyzed in FSAR Section 15.2.3.1. Water level setpoints in the affected steam generator are not used to avoid any uncertainties of level prediction. A low water level trip in the unaffected steam generator which actuates the AFW system occurs about 43 seconds after initiation of the event. AFW flow arrives at the unaffected steam generator at about 96 seconds (flow to the affected unit does not reach the steam generator, instead exiting at the break). At 188 seconds into the transient a low pressure trip occurs in the affected steam generator. This generates a MSIS, which isolates the steam generators. The AFAS receives the low pressure trip signal by which it determines the unaffected steam generator. The AFAS then terminates AFW flow to the affected steam generator.

k. Volume and maximum temperature of water in main feed lines between steam generator(s) and AFWS connection to main feed line.

The initial main feedwater temperature is assumed to be 323°F, which corresponds to full load plant conditions. For the feedwater line break case, main feedwater flow is assumed to be immediately terminated to both steam generators. When AFW flow is assumed to enter the steam generator no credit is taken for the volume of feedwater that would normally be available in the feed line between the steam generator and the AFW system connection.

l. Operating condition of steam generator normal blowdown following initiating event.

Steam generator normal blowdown is not considered in the LMFW analysis. It is isolated on receipt of the main steam isolation signal (MSIS) and is normally only 1% or less of normal steam flow.

m. Primary and secondary system water and metal sensible heat used for cooldown and AFW flow sizing.

1.67×10^6 Btu/°F.

n. Time at hot standby and time to cooldown RCS to RHR system cut in temperature to size AFW water source inventory.

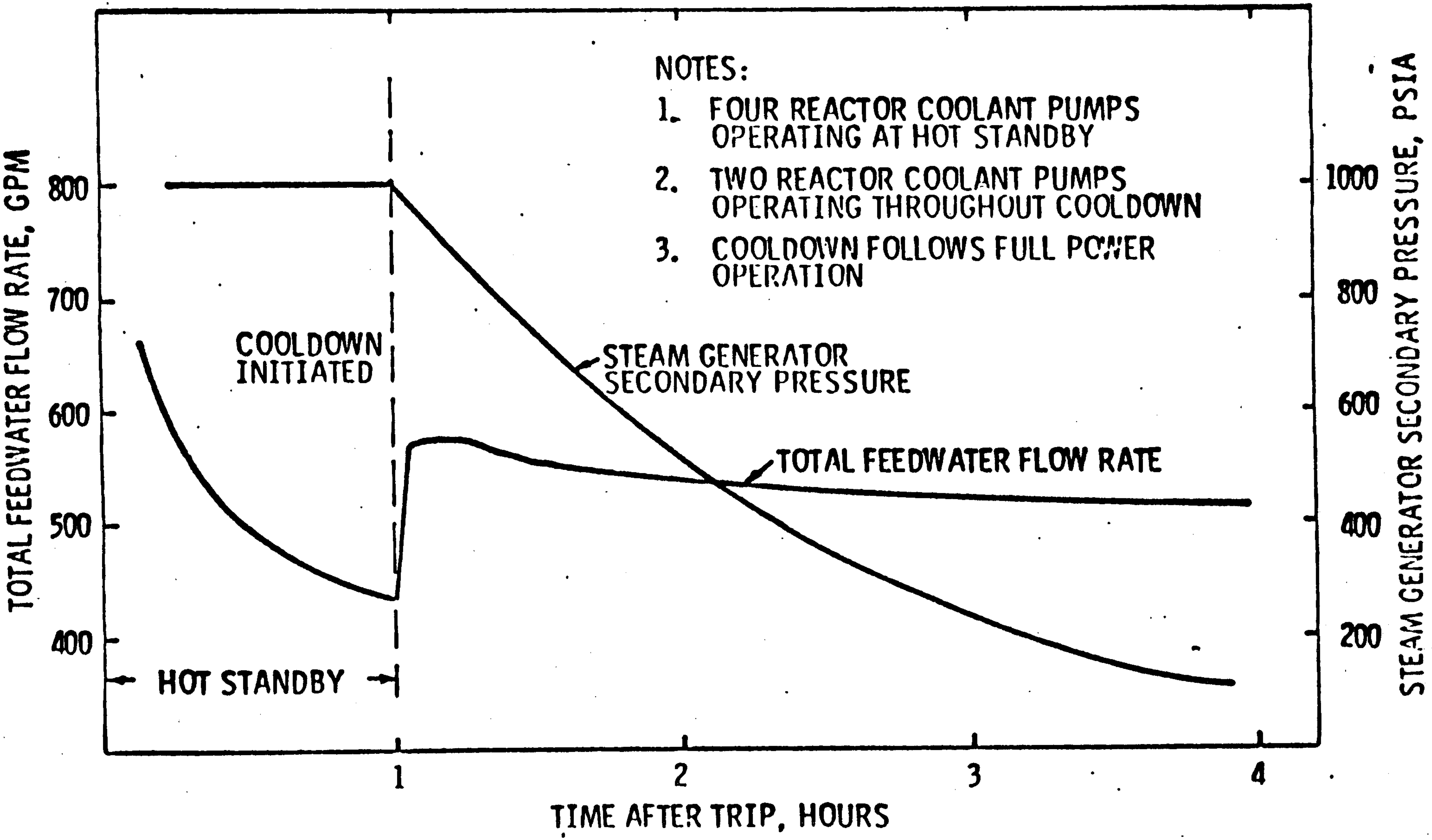
The design capability of the CST is discussed in the response to NRC Question 010.33 to the SONGS 2 and 3 FSAR.

3. Verify that the AFW pumps in your plant will supply the necessary flow to the steam generator(s) as determined by items 1 and 2 above considering a single failure. Identify the margin in sizing the pump flow to allow for pump recirculation flow, seal leakage and pump wear.

The AFW system will supply the necessary flow to the steam generators to maintain the secondary heat sink with the occurrance of a single failure (see FMEA, of Appendix C). Each AFW pump is capable of supplying the design bases flow requirements. A loss of all offsite and onsite AC power would result in the loss of both motor driven pumps. The turbine driven pump with DC power operated valves and controls meets the flow requirements. All other single failures result in two pumps being unavailable to fulfill requirements. Each AFW pump has a design allowance for recirculated flow of 100 gpm and a wear margin of 60 gpm.

Figure 4-1

TYPICAL · : COOLDOWN



5.0 RECOMMENDATIONS

The following items are recommendations, based on NUREG 0635, which pertain to the SCE AFW System, in particular to Technical Specifications and Emergency Procedures, and whose implementation will serve to improve and justify the performance and reliability of the SCE AFWS. A comparison of the SONGS 2 and 3 AFWS characteristics to the generic long and short term recommendations is provided in Table 5.1.

5.1 Technical Specifications

5.1.1 All locked opened manual valves in the AFWS should be verified to be in their proper position during monthly inspection of the system. This requirement should be included in the technical specification surveillance requirements.

5.1.2 Following an extended cold shutdown, a flow test of the AFWS should be performed to verify normal flow path from the primary water source to the steam generators with AFWS valves in their normal alignment. This requirement should also be included in the technical specification surveillance requirements.

5.2 Emergency/Operating Procedures

5.2.1 Procedures should be available to plant operators for transferring to/from alternate sources of AFW and to inform operators when and in what order the transfer should take place.

5.2.2 Procedures should be available which require that after an AFWS outage due to maintenance or periodic test, an operator shall determine that the AFWS valves are properly aligned and a second operator shall verify the same.

5.2.3 Maintenance and/or test procedures that result in the temporary degradation of the AFWS should have sufficient "CAUTION" statements included to ensure that no remaining portion of the system be isolated which would render AFW flow to the steam generator unavailable.

5.3 Design Recommendations

5.3.1 Redundant AFW primary water supply level indication and low level alarms should exist in the control room and whose low level setpoint should allow at least 20 minutes for operator action.

5.3.2 DELETED.

5.4 Miscellaneous Recommendations

5.4.1 A 48 hour endurance test on all AFW pumps should be performed if such a continuous period of operation has not been accomplished to date. Following the 48 hour run, the pumps should be cooled down and restarted for an additional one hour run. Test acceptance criteria should include demonstrating that the pumps' bearing/bearing oil temperatures and vibration remain within design limits and that pump room ambient conditions (temperature/humidity) do not exceed environmental qualification limits for safety-related equipment in the room.

PLANT	GS-1 Tech Spec LCO Train Outage Time Limit	GS-2 Tech Spec Single Flow Path Manual Valves	GS-3 AFWS Flow Throttling Water Hammer	GS-4 Emergency Procedure Backup Water Supplies	GS-5 Emergency Procedure AC Power Blackout	GS-6 Flow Path Verification	GS-7 Non-Safety Grade AFWS Automatic Start Signals	GS-8 Automatic Actuation of AFWS	GL-1 Automatic Actuation of AFWS	GL-2 Single Flow Path Manual Valves	GL-3 Eliminate AC Power Dependency of One Train	GL-4 Multiple Pump Damage Protection Natural Phenomena	GL-5 Non-Safety Grade AFWS Automatic Start Signals
	SHORT TERM								LONG TERM				
Arkansas 2 1 - elect. pump 1 - turbine pump Automatic Initiation						X	X						X
SONGS 2 & 3 2 - elect. pump 1 - turbine pump Automatic Initiation				X		X				X			

GENERIC RECOMMENDATIONS (columns above)

PLANT SPECIFIC RECOMMENDATIONS

ANO-2

- Propose technical specification revision to provide pressure/flow criteria for electric pump periodic tests.
- Evaluate postulated break in AFW discharge lines concurrent with a single active failure to 1) determine necessary change in AFWS design or procedures or 2) describe how plant can be safely shut down by use of other available systems.
- Evaluate capability to isolate a break downstream of turbine pump steam admission valve concurrent with single active failure of D-C emergency Division II bus.

SONGS 2 & 3

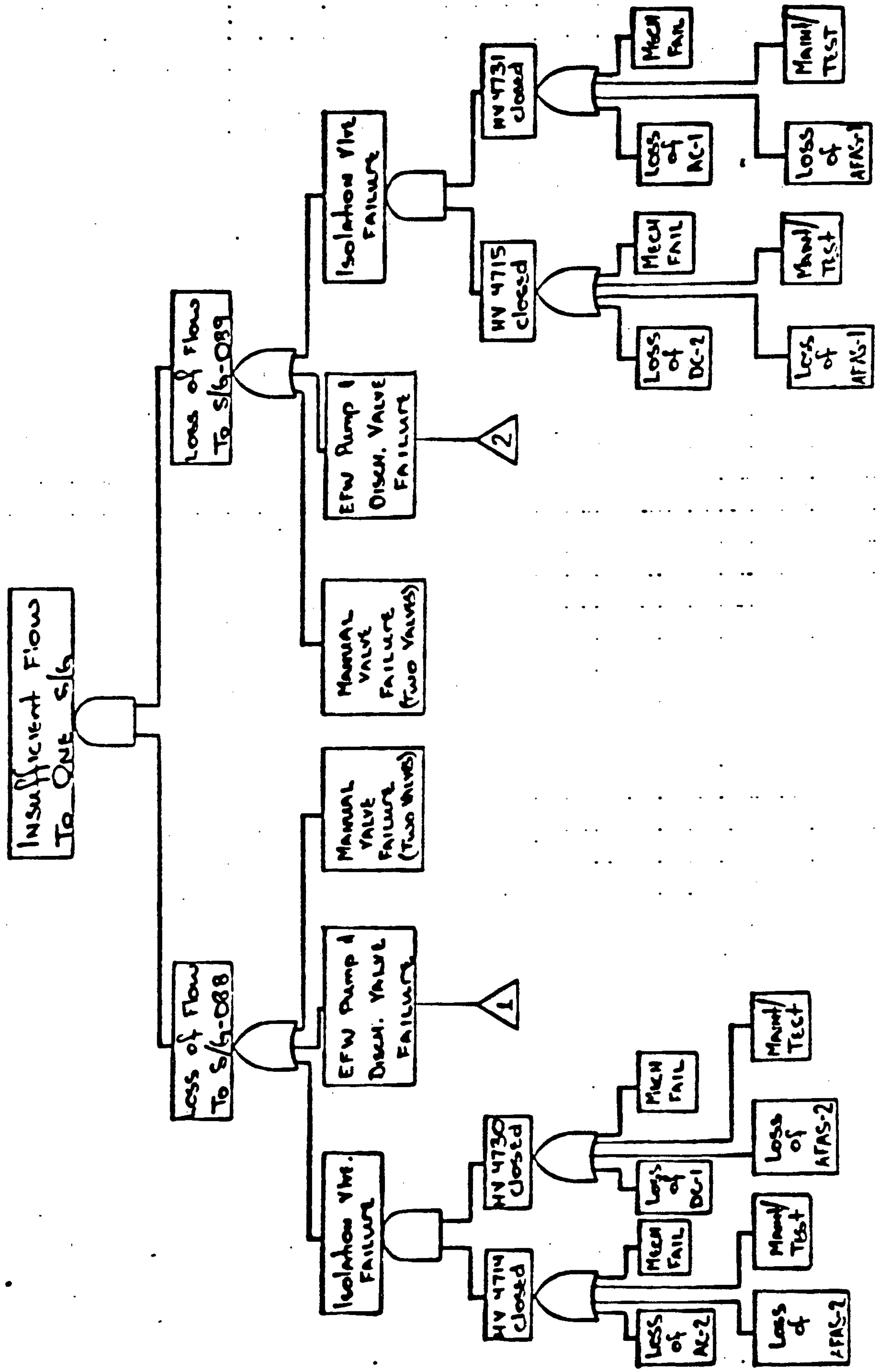
- Evaluate capability to isolate ruptured S/G with single active failure of DC power supply Train B (A) with turbine pump feeding ruptured unit.
- Evaluate capability to isolate a break downstream of turbine pump discharge valve concurrent with a single active failure of motor AFW pump opposite to break and supply AFW to at least one S/G.

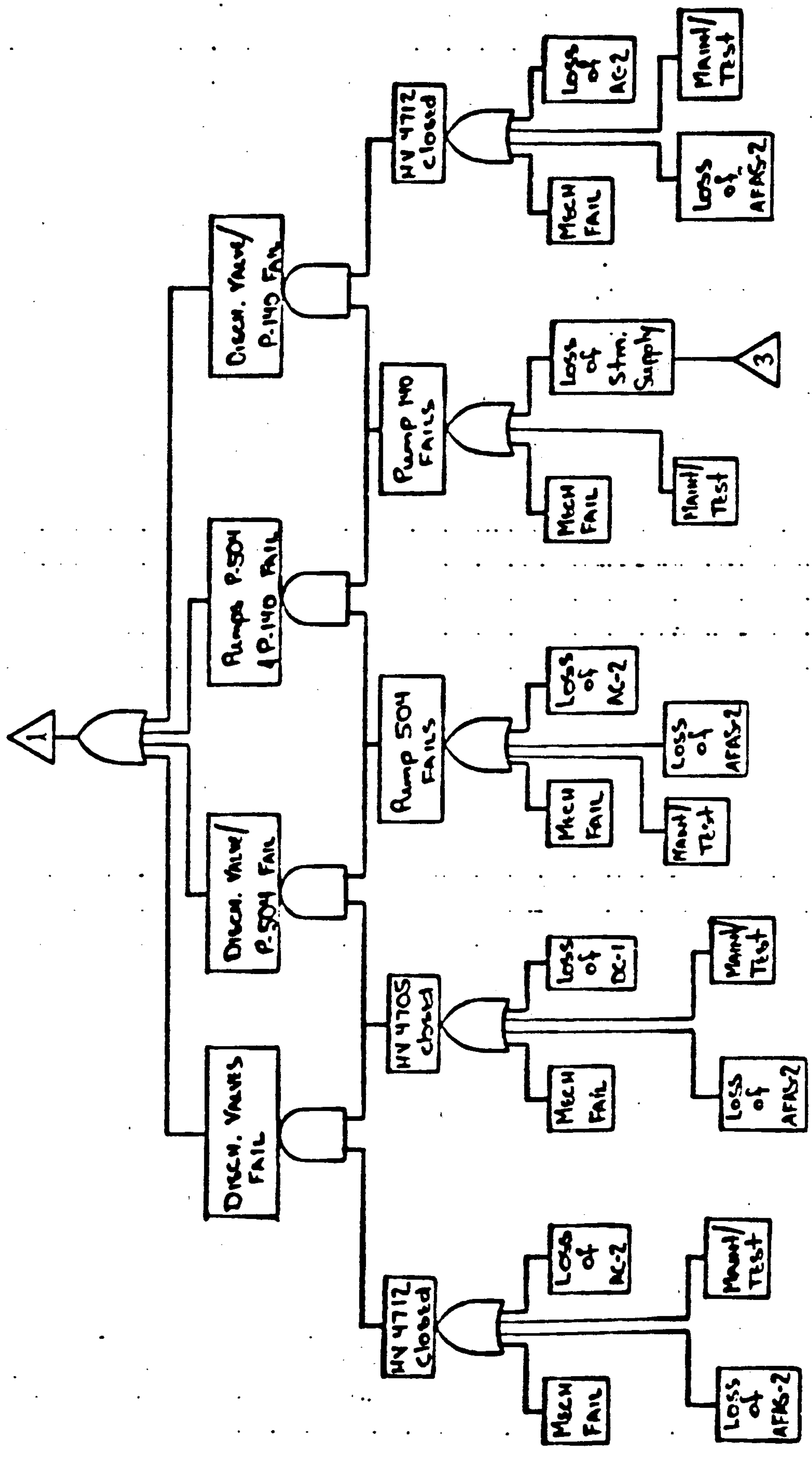
TABLE 5.1

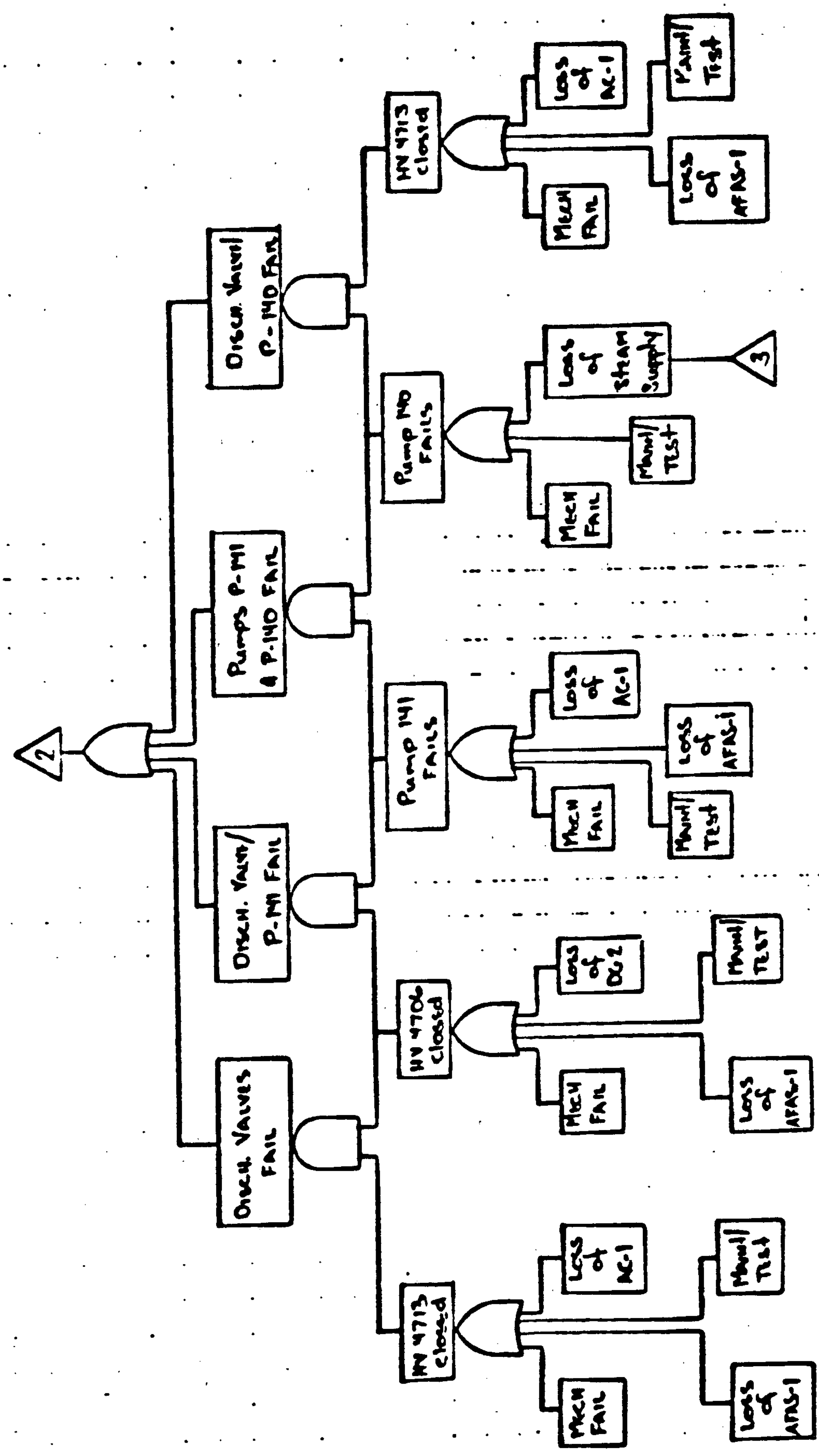
APPENDIX A

SONGS #2 & 3 AFWS

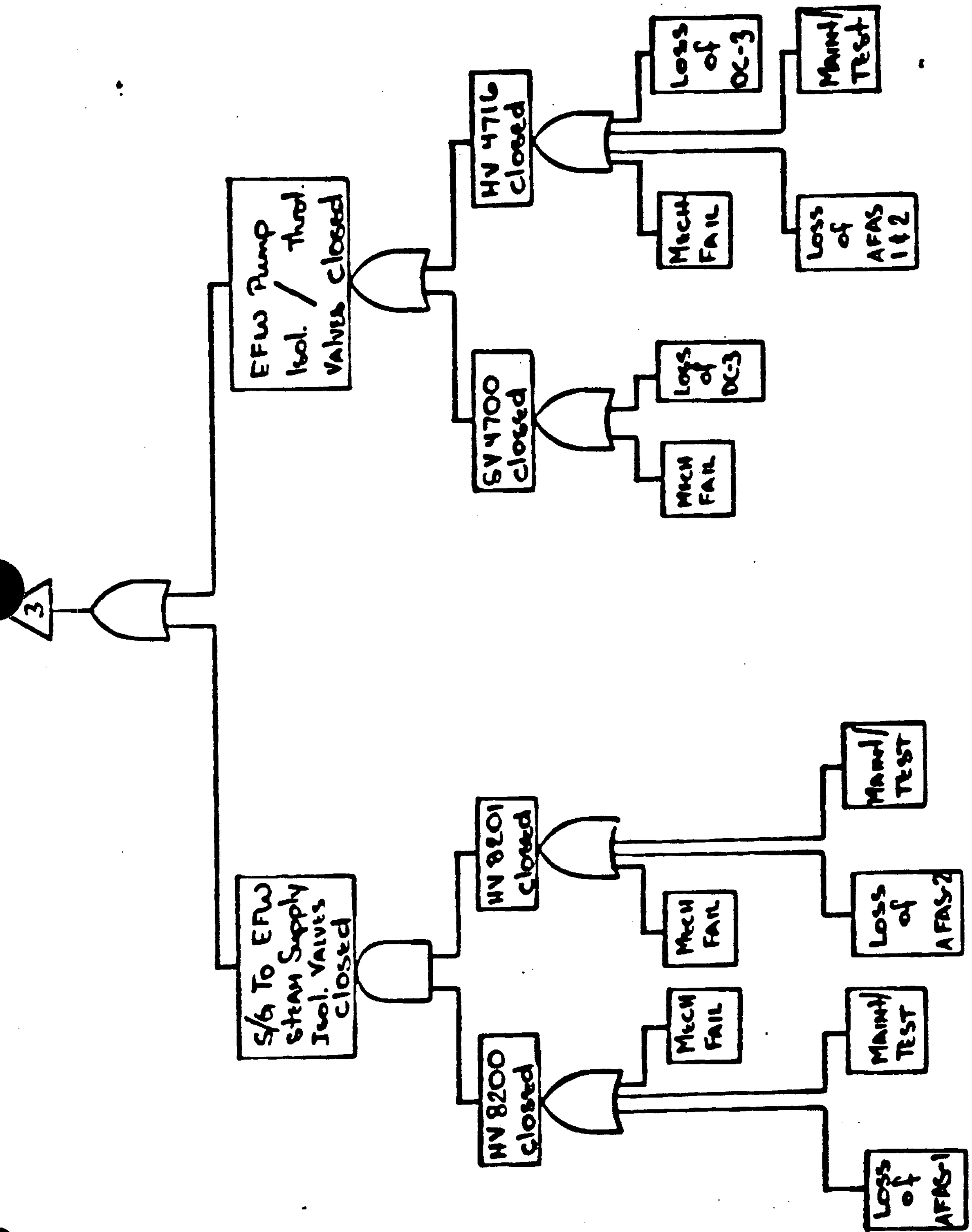
FAULT TREE


Insufficient Flow To One S/G
Loss of Flow To S/G-089
Isolation Vlve Failure
HV 4731 closed
Mech Fail
Maint/Test
Loss of AC-1
Loss of AFAS-1
HV 4715 closed
Mech Fail
Maint/Test
Loss of DC-2
Loss of AFAS-1
EFW Pump 1 Disch. Valve Failure
2
Manual Valve Failure (Two Valves)
Manual Valve Failure (Two Valves)
Loss of Flow To S/G-088
EFW Pump 1 Disch. Valve Failure
1
Isolation Vlve. Failure
HV 4730 closed
Mech Fail
Maint/Test
Loss of AFAS-2
Loss of DC-1
HV 4714 closed
Mech Fail
Maint/Test
Loss of AC-2
Loss of AFAS-2


1
DISCH. VALVE/ P-140 FAIL
PUMP P-504 & P-140 FAIL
DISCH. VALVE/ P-504 FAIL
DISCH. VALVES FAIL
HV 4712 closed
MECH FAIL
Loss of AC-2
Loss of AFAS-2
MAINT/ TEST
PUMP 140 FAILS
MECH FAIL
Loss of Stm. Supply
3
MAINT/ TEST
PUMP 504 FAILS
MECH FAIL
Loss of AC-2
Loss of AFAS-2
MAINT/ TEST
HV 4705 closed
MECH FAIL
Loss of DC-1
Loss of AFAS-2
MAINT/ TEST
HV 4712 closed
MECH FAIL
Loss of AC-2
Loss of AFAS-2
MAINT/ TEST



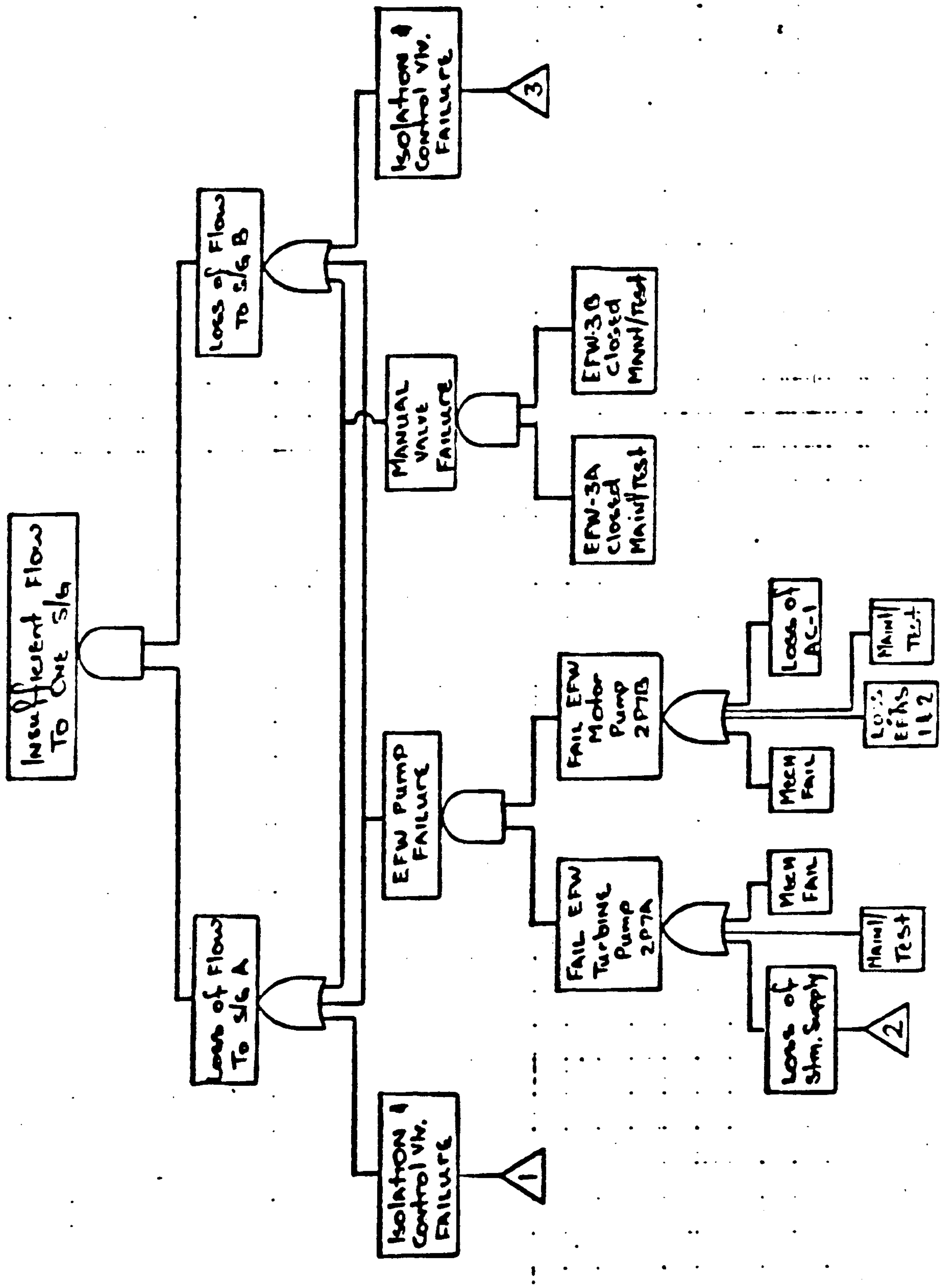
2
Disch. Valves Fail
Disch. Valve/P-141 Fail
Pumps P-141 & P-140 Fail
Disch. Valve P-140 Fail
HV 4713 closed
HV 4706 closed
Pump 141 Fails
Pump 140 Fails
HV 4713 closed
Mech Fail
Loss of AC-1
Maint/Test
Loss of AFAS-1
Mech Fail
Loss of DC-2
Maint/Test
Loss of AFAS-1
Mech Fail
Loss of AC-1
Loss of AFAS-1
Maint/Test
Mech Fail
Maint/Test
Loss of Steam Supply
3
Mech Fail
Loss of AC-1
Maint/Test
Loss of AFAS-1

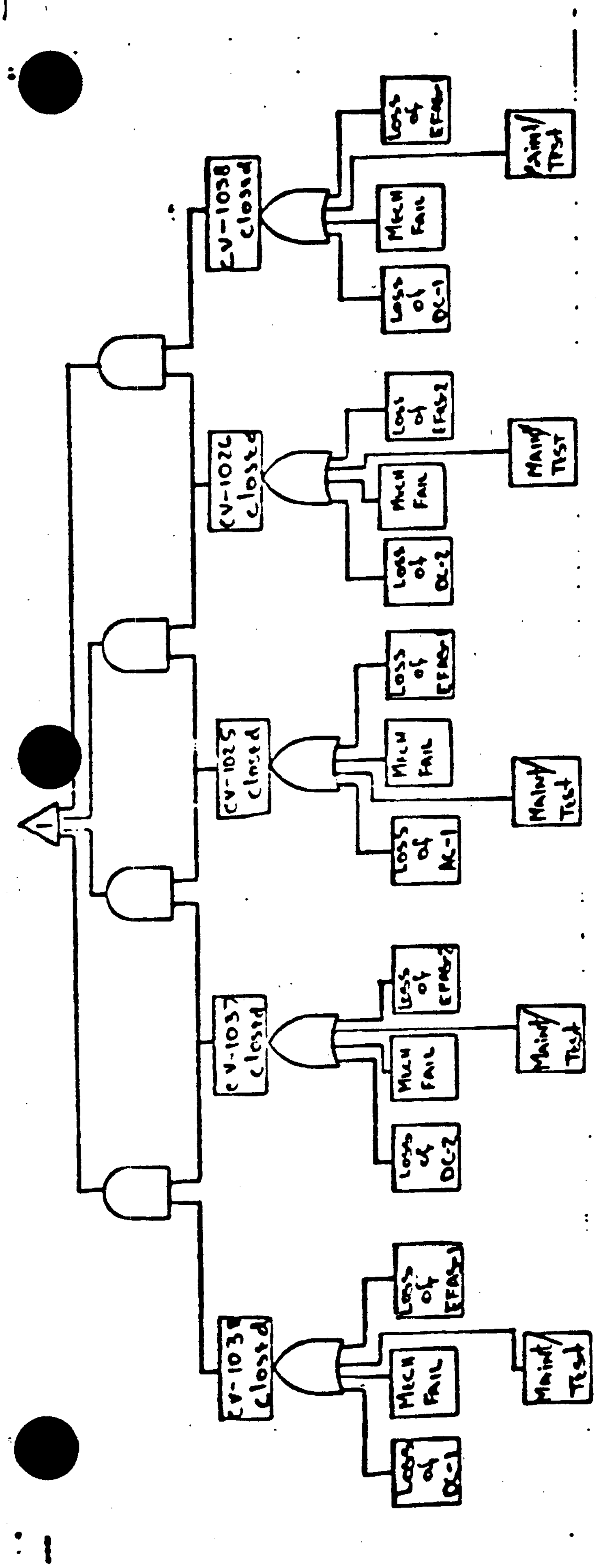

3
EFW Pump Isol. / Throt. Valves Closed
SV 4700 closed
Mech Fail
Loss of DC-3
HV 4716 closed
Mech Fail
Loss of AFAS 1 & 2
Maint/Test
Loss of DC-3
S/G To EFW Steam Supply Isol. Valves Closed
HV 8200 closed
Loss of AFAS-1
Maint/Test
Mech Fail
HV 8201 closed
Mech Fail
Loss of AFAS-2
Maint/Test

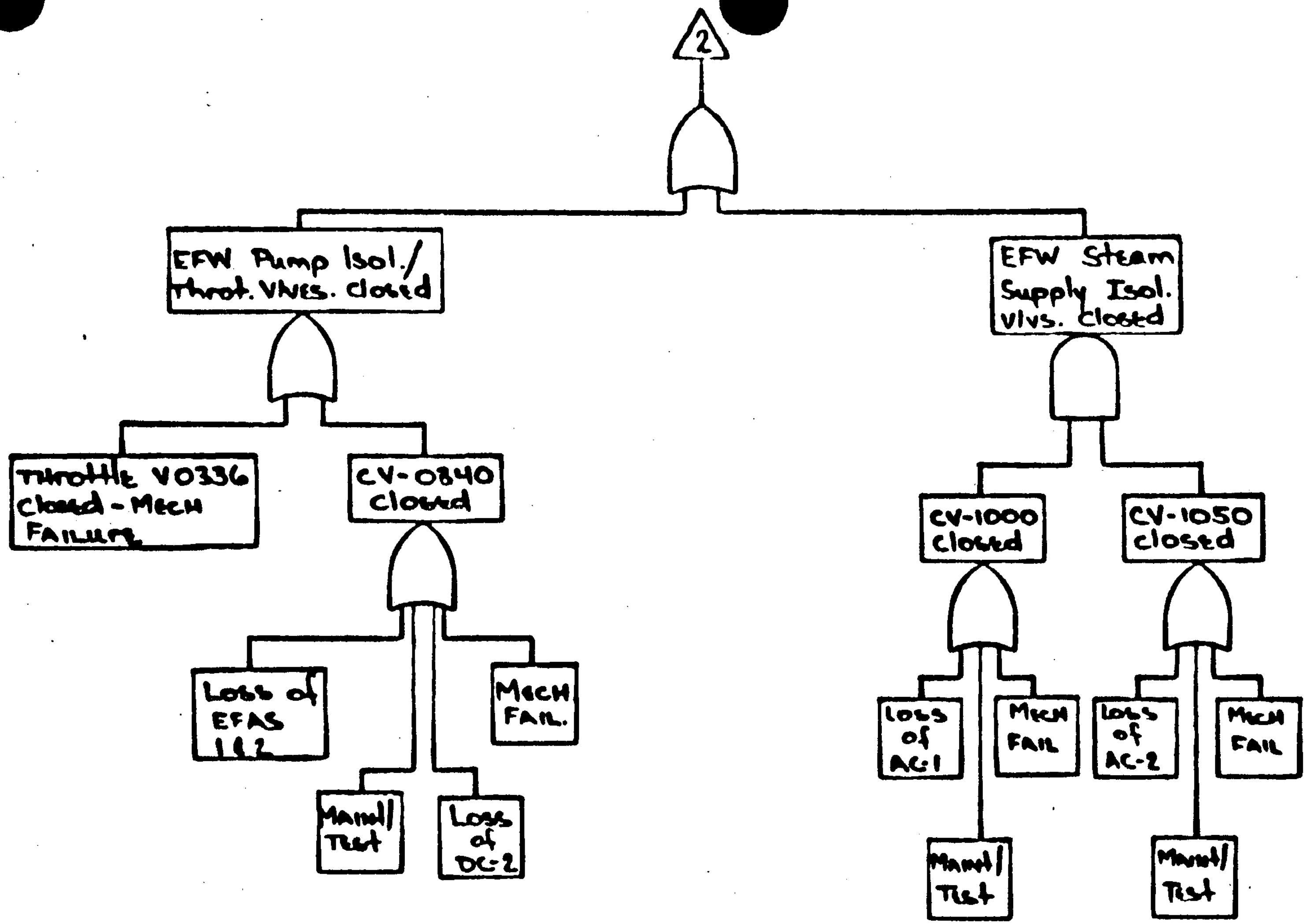
APPENDIX B

REFERENCE PLANT (ANO2)

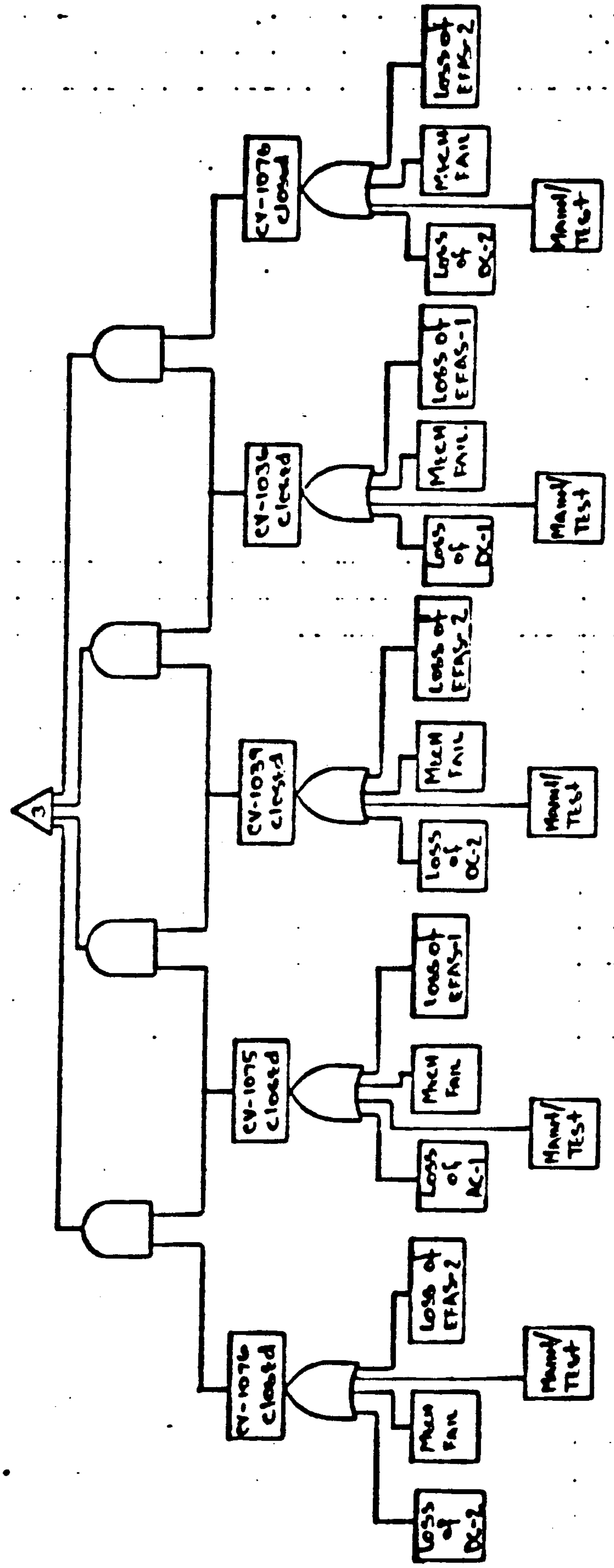
AFWS FAULT TREE


Insufficient Flow To One S/G
Loss of Flow To S/G B
Loss of Flow To S/G A
Isolation & Control Vlv. Failure
Isolation & Control Vlv. Failure
3
1
Manual Valve Failure
EFW-3B Closed Maint/Test
EFW-3A Closed Maint/Test
EFW Pump Failure
Fail EFW Motor Pump 2P7B
Fail EFW Turbine Pump 2P7A
Loss of AC-1
Maint/ Test
Loss EFAS 1 & 2
Mech Fail
Mech Fail
Maint/ Test
Loss of Stm. Supply
2


1
CV-1038 closed
Loss of EFAS-1
Maint/Test
Mech Fail
Loss of DC-1
CV-1026 closed
Loss of EFAS-2
Maint Test
Mech Fail
Loss of DC-2
CV-1025 closed
Loss of EFAS-1
Mech Fail
Maint Test
Loss of AC-1
CV-1037 closed
Loss of EFAS-2
Maint/Test
Mech Fail
Loss of DC-2
closed
Loss of EFAS-1
Maint/Test
Mech Fail
Loss of DC-1



2
EFW Pump Isol./ Throt. Vlvs. closed
Throttle V0336 Closed - Mech Failure
CV-0840 Closed
Loss of EFAS 1&2
Maint/ Test
Loss of DC-2
Mech Fail.
EFW Steam Supply Isol. Vlvs. Closed
CV-1000 Closed
CV-1050 closed
Loss of AC-1
Mech Fail
Maint/ Test
Loss of AC-2
Mech Fail
Maint/ Test



CV-1076 closed
Loss of EFAS-2
Mech Fail
Manual/ Test
Loss of DC-2
CV-1036 closed
Loss of EFAS-1
Mech Fail.
Manual/ Test
Loss of DC-1
CV-1039 closed
Loss of EFAS-2
Mech Fail
Manual/ Test
Loss of DC-2
CV-1075 closed
Loss of EFAS-1
Mech Fail
Manual/ Test
Loss of DC-1
CV-1076 closed
Loss of EFAS-2
Manual/ Test
Mech Fail
Loss of DC-2

APPENDIX C

SONGS 2 & 3 AFWS

FAILURE MODES AND EFFECTS

ANALYSIS

TABLE 1 - SONGS AFWS FAILURE MODES AND EFFECTS ANALYSIS

COMPONENT	FUNCTION (OPERATING MODE)	FAILURE MODE	FAILURE MECHANISM	EFFECT ON SYSTEM	METHOD OF FAILURE DETECTION
Motor-Driven Auxiliary feedwater pump (P-141)	Supplies feed-water for shut-down cooling.	Fails to start on AFAS	Malfunction of pump or motor; loss of power	None: due to redundant motor driven & steam turbine driven auxiliary feedwater pumps.	Disch. pressure indication in control room; periodic test; indicating lights in control room.
Motor-driven auxiliary feedwater pump (P-504)	Same as above.	Same as above.	Same as above.	Same as above.	Same as above.
Steam turbine driven auxiliary feedwater pump (P-140)	Supplies feed-water for shut-down cooling.	Fails to start on AFAS	Malfunction of turbine or pump; malfunction of steam inlet valve	None: due to redundant motor driven auxiliary feedwater pumps.	Disch. pressure indication in control room; periodic test.
Turbine driven pump steam inlet isolation valve from main steam lines (HV-8200 or HV-8201)	Admits driving steam to turbine	Fails closed (one of two valves)	Malfunction of valve.	None: due to redundant valve from second main steam line; two motor driven auxiliary feedwater pumps are also available.	Valve position indication in control room.
Steam driven auxiliary feedwater pump turbine stop valve (HV-4716)	Admits driving steam to turbine	Fails to open on AFAS	Loss of power or valve malfunction.	None: due to redundant motor driven auxiliary feedwater pumps.	Valve position indication in control room.
Pump discharge control valve (HV-4705, 4706, 4712, 4713)	Admits feed-water to steam generators.	Fails to open on AFAS (one of four valves)	Loss of power or valve malfunction.	None: due to parallel flow paths from auxiliary feedwater pumps to both steam generators.	Valve position indication in control room.
	Auxiliary feed-water isolation	Fails to close on MSIS or on removal of AFAS.	Maulfunction of valve: loss of power.	None: due to closure of pump discharge isolation valves (HV-4714, 4715, 4730, 4731)	Valve position indication in control room.

TABLE 1 - SONGS AFWS FAILURE MODES AND EFFECTS ANALYSIS -- continued

COMPONENT	FUNCTION (OPERATING MODE)	FAILURE MODE	FAILURE MECHANISM	EFFECT ON SYSTEM	METHOD OF FAILURE DETECTION
Containment isolation valve (HV-4714, 4715, 4730, 4731)	Auxiliary feedwater isolation	Fails to close on MSIS or on removal of AFAS	Malfunction of valve; loss of power.	None: due to redundant series valves.	Valve position indication in control room.
	Admits feedwater to steam generators.	Fails closed on AFAS (one of four valves)	Malfunction of valve; loss of power.	None: due to redundant parallel valve.	Valve position indication in control room.
Alternating Current Train 1	Supplies motive power to AFW pump-141 and valves in corresponding flow train.	Fails to supply AC power.	Electrical malfunction (i.e. bus breaker open)	None: due to availability of redundant motor and steam driven AFW pumps and associated valves supplied by independent AC & DC power trains.	Pump indicating lights in control room, various control room alarms if due to diesel generator trip.
Alternating Current Train 2	Supplies motive power to AFW pump-504 and valves in corresponding flow train.	Fails to supply AC power	Electrical malfunction (i.e. bus breaker open)	None: due to availability of redundant motor and steam driven AFW pumps and associated valves supplied by independent AC & DC power trains.	Pump indicating light in control room, various control room alarms if due to diesel generator trip.
Direct Current Trains 1, 2, 3	Supplies power to valves associated with steam driven AFW pump-141 flow train.	Fails to supply DC power.	Electrical malfunction (i.e. bus breaker open)	None: due to availability of redundant motor driven AFW pumps and associated valves supplied by independent AC power trains.	Valve position indication in control room, various DC voltage, current, and breaker alarms.

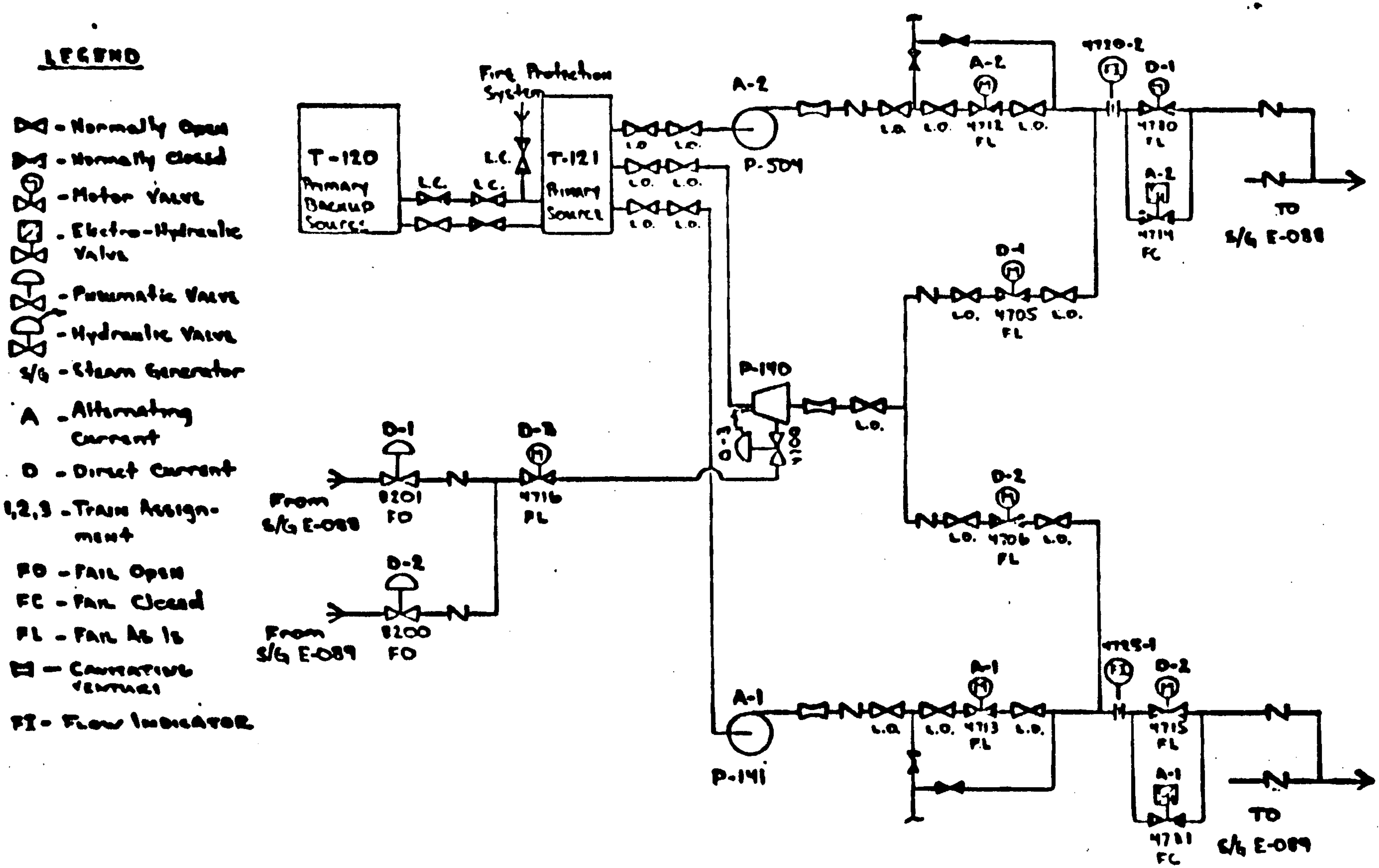
TABLE 1A - SONGS AFWS FAILURE MODES AND EFFECTS ANALYSIS WITH LINE BREAK

COMPONENT	FAILURE MODE	LIMITING LINE BREAK LOCATION	EFFECT ON SYSTEM	ACTION REQUIRED	METHOD OF FAILURE DETECTION
Motor driven auxiliary feedwater pump (P-141)	Fails to start	Upstream to V4730	Available flow from P-504 and P-140 diverted to break.	Valves V4712 and V4705 are closed to isolate break. P-140 available to feed S/G-089.	S/G-088 low level indication, AFWP flow indication, pump discharge pressure indication, pump indicating light.
Motor driven auxiliary feedwater pump (P-504)	Fails to start	Upstream of V4715	Available flow from P-141 and P-140 diverted to break.	Valves V4713 and V4706 are closed to isolate break. P-140 available to feed S/G-088.	S/G-089 low level indication, AFWP flow indication pump discharge pressure indication.
Steam turbine driven auxiliary feedwater pump (P-141) (1)	Fails to operate	Upstream of V4730	Flow from P-504 diverted to break P-141 continues to feed S/G-089	Valve V4712 is closed to isolate break. P-141 available to feed S/G 089.	S/G-088 low level indication, AFWP flow indication pump discharge pressure indication.
Turbine driven pump steam supply and stop valves (HV-8200, -8201, -4716)(1)	Closed	Upstream of V4730	Flow from P-504 diverted to break; P-141 continues to feed S/G-089.	Valve V4712 is closed to isolate break. P-141 available to feed S/G 089.	Valve position indication in control room.
Pump discharge control valve HV-4712 (HV-4713)(1)	Fails to open	Upstream of V4715	Available flow from P-140 and P-141 diverted to break.	Valves V4706 and V4713 are closed to isolate break. P-140 available to feed S/G E-088.	Valve position indication in control room.
Pump discharge control valve HV-4705 (HV-4706)(1)	Fails to open	Upstream of V4715	Flow from P-140 and P-141 diverted to break; P-504 continues to feed S/G E-088.	Valves V4706 and V4713 are closed to isolate break. P-504 available to feed S/G E-088.	Valve position indication in control room.
(1) Similar scenario exists for opposite feed train.					

APPENDIX D

SONGS 2 & 3 AFWS

FLOW DIAGRAM



AUXILIARY FEEDWATER SYSTEM

SONGS 2 & 3

APPENDIX B

PIPE BREAK ANALYSIS AND AFW SYSTEM RELIABILITY

This appendix provides pipe break probability data and evaluates the impact of pipe break on auxiliary feedwater (AFW) system availability.

B.1 Pipe Failure Probability

There has been considerable effort made by various industries to quantify the probability of pipe failure for various sizes, applications and service conditions. Of particular relevance to this analysis is the catastrophic failure probability of steam piping of 3" to 6" diameter, operating at less that 600°F.

One of the most significant factors relative to pipe break failures is that about 95% [1-3] of all failures result in system leaks rather than catastrophic failures. Catastrophic pipe failure is defined as the break size that results in the harsh environment and the demand for the AFWS.

The pipe break probability used in this report has been adjusted for the leak-before-break factor. Small breaks do not cause AFW demand and the probability of coincidental demand before detection of such breaks is considered negligibly small.

In general, the pipe failure data from the various sources varied considerably. Table B-1 shows pipe failure rates from different sources. From these data lower and upper 90% confidence bounds of pipe failure are determined as follows:

$$1.6 \times 10^{-5} \text{ to } 9 \times 10^{-7} \text{ /ft yr}$$

Table B-2 shows the proportion of catastrophic or near catastrophic failure from all pipe failure.

Combining the data of Tables B-1 and B-2, the lower and upper 90% confidence bound for catastrophic pipe failure is:

$$9.9 \times 10^{-7} \text{ to } 5.3 \times 10^{-8}\text{/ft yr}$$

The length of steam pipe in the room is 40 ft, so using these data the failure rate of this line per year is in the range.

$$4.0 \times 10^{-5} \text{ to } 2.1 \times 10^{-6}$$

Assuming a lognormal distribution, the median value is:

$$9.1 \times 10^{-6} \text{ per year}$$

TABLE B-1

PIPE BREAK FAILURE RATES (ALL TYPES)

Source		Failure Rate/ft-year
Wash 1400, Table III 3-3	Ref [1]	9×10^{-6}
Hall (Brookhaven National Laboratory)	Ref [4]	9×10^{-7}
Bush	Ref [5]	1.6×10^{-5}

TABLE B-2

PROPORTION OF FAILURES OCCURRING WITHOUT LEAKAGE

BEFORE BREAK

Source		Percentage
Wash 1400, p III-77	Ref [1]	6.0%
EPRI NP-438 (p 8)	Ref [2]	6.2%
H. M. Thomas	Ref [3]	5.85%

B.2 Pipe Break Effect on AFWS Reliability

Unavailability of AFWS depends on probability of failure to respond to a demand signal and the failure to sustain operation. Because failure to sustain operation is a relatively small contributor only failure to respond to demand is considered.

Under these circumstances the unavailability of the AFWS, U, is the probability of failure per demand. The relationship between the unavailability U and the probability of failure per year is:

$$P = U \times n \qquad (1)$$

Where n is the frequency of demands per year.

If we have N demand modes then the probability of failure per year can be found by:

$$P = \sum_{i=1}^{N} U_i \times n_i \qquad (2)$$

Where U_i and n_i are unavailabilities and demand frequencies for the ith mode.

Total unavailability of the AFWS with N demand modes is:

$$U = \frac{P}{N} \equiv \frac{\sum_{i=1}^{N} U_i n_i}{\sum_{i=1}^{N} n_i} \qquad (3)$$

It is desired to calculate the impact of an additional unavailability mode on a system (such as AFWS) which has previously calculated the unavailability neglecting this mode. This is in effect evaluating the same system with different number of demand modes. The previous calculation has unavailability U_o and number of modes N_o. The new calculation has the same modes with the same unavailabilities as the old one plus a new mode. The total unavailability of new calculation is U and number of demand modes is N.

The unavailability formulas for the two cases are:

$$U_o = \frac{\sum_{i=1}^{No} U_i n_i}{\sum_{i=1}^{No} n_i} \qquad (4)$$

And

$$U = \frac{\sum_{i=1}^{N} U_i \, n_i}{\sum_{i=1}^{N} n_i} \tag{5}$$

Formula (5) can be rewritten as:

$$U = \frac{\sum_{i=1}^{N_o} U_i \, n_i + \sum_{i=N_o+1}^{N} U_i \, n_i}{\sum_{i=1}^{N_o} n_i + \sum_{i=N_o+1}^{N} n_i} \tag{6}$$

Denoting

$$n_o = \sum_{i=1}^{N_o} n_i \tag{7}$$

$$i = \sum_{i\,=\,N_o+1}^{N} n_i = \Delta n$$

$$i = \sum_{i\,=\,N_o+1}^{N} U_i n_i = \Delta P$$

and taking into account formula (5) we get:

$$U = \frac{U_o + \frac{\Delta P}{n_o}}{1 + \frac{\Delta n}{n_o}} \tag{10}$$

The ratio of unavailability for the two calculations is given by:

$$\frac{U}{U_o} = \frac{1 + \frac{1}{no} \frac{\Delta P}{uo}}{1 + \frac{\Delta n}{n_o}} \tag{11}$$

In our case the previous calculation (Appendix A) considered three demand modes:

1. loss of main feedwater

2. loss of main feedwater plus offsite power

3. loss of main feedwater plus all AC power

The frequency of demands from NUREG 0635 [7] and the corresponding AFWS unavailability are:

$n_1 = 3$ per year $\qquad U_1 = 2.2 \times 10^{-5}$ per demand

$n_2 = 0.25$ per year $\qquad U_2 = 3.8 \times 10^{-5}$ per demand

$n_3 = 10^{-3}$ per year $\qquad U_3 = 2 \times 10^{-2}$ per demand

Therefore, $n_o \cong 3.25$ per year and the total unavailability of the system is $U_o = 3 \times 10^{-5}$ per demand (1×10^{-4} per year).

The new calculation identifies the additional mode of demand; namely, catastrophic pipe break. The catastrophic pipe break of a steam line in the feedwater pump room can create demand of the AFWS. Because the pump trains are located in the same pump room, the AFWS fails to respond on demand. Thus, the unavailability $U_4 = 1$ and frequency of demands per year is equal to the probability of catastrophic break per year:

$$\Delta n \equiv n_4 = 9 \times 10^{-6} \text{ demands per year}$$

$$\Delta P \equiv n_4 \cdot u_4 = 9 \times 10^{-6} \text{ failures per year}$$

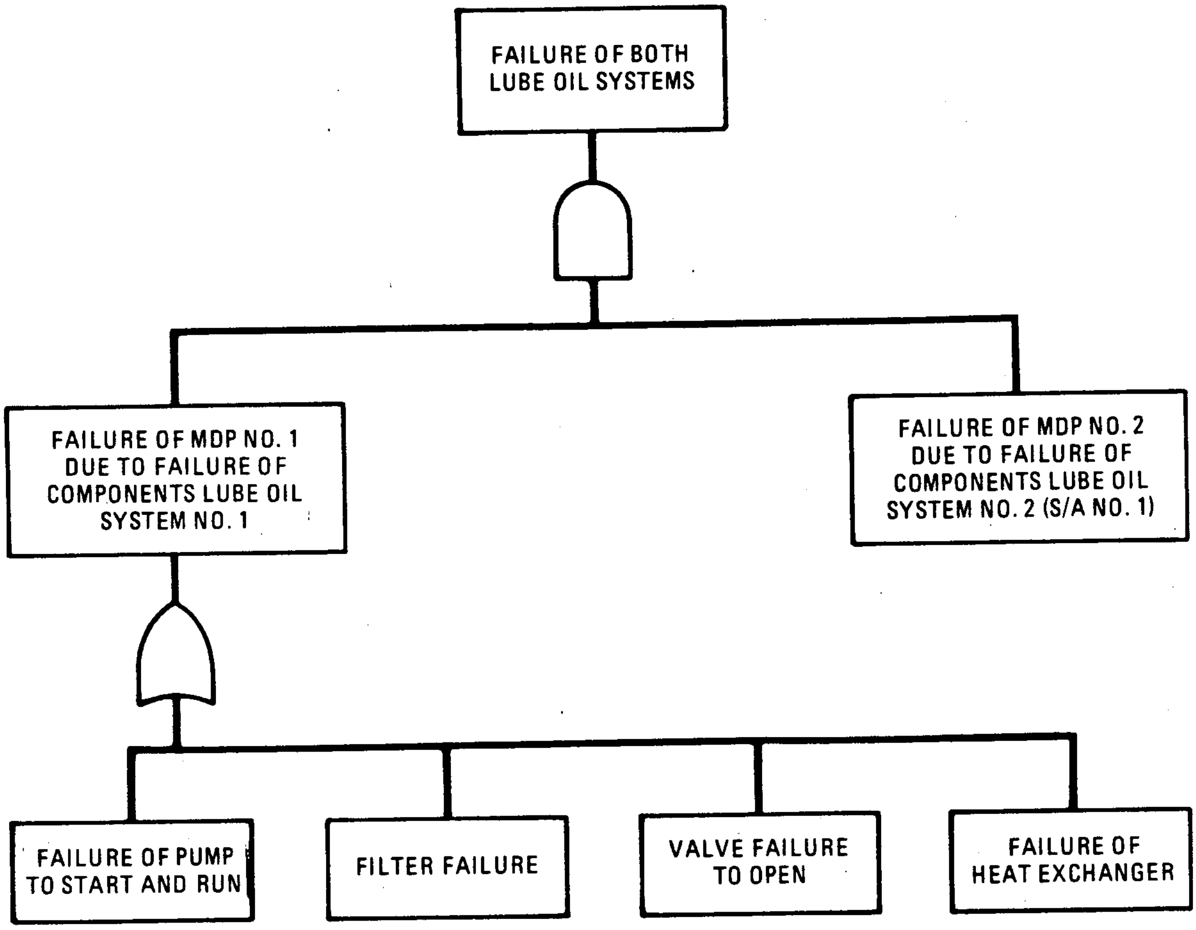
$$\frac{U}{U_o} = 1.09 \qquad (12)$$

Thus, the unavailability will increase by 9% to $U = 3.3 \times 10^{-5}$ per demand (1.1×10^{-4} per year). This is an acceptably small change. Moreover it can be shown that the addition of this HELBA mode has the effect of reducing the confidence in the previous upper and lower limits from 90% to 89.9%.

B.3 The Probability of Failure Motor Lube Oil System

Motor Lube Oil System consists of a pump, valve, heat exchanger and filter. Failure of Lube System depends on failure of components of this system. Figure B-1 is a fault tree which represents this system. From reference [8] the failure rate of a pump per demand is in the range

$$3 \times 10^{-3} - 3 \times 10^{-4}$$



MOTOR LUBE OIL SYSTEM
FIGURE B-1.

Failure rate of the manual valve per demand is in the range $3 \times 10^{-4} - 3 \times 10^{-5}$. The failure rate of a filters, heat exchanger, pipes and other components are negligible relatively to these major contributors. From this data, the probability of failure of one Lube Oil System is in the range

$$3.15 \times 10^{-3} - 3.70 \times 10^{-4} ,$$

with median value 1.08×10^{-3} per year .

The probability of failure both Lube Oil Systems is in the range

$$8.51 \times 10^{-5} - 9.99 \times 10^{-6} ,$$

with median value 2.91×10^{-5} per year.

For calculation of this probability, a common cause failure β factor of 0.027 was used.

B.4 AFWS Reliability with Motor Lube Oil System

The probability of failure AFW system due to failure components and environmental failure is in the range

$$3.24 \times 10^{-4} - 3.24 \times 10^{-5},$$

with median value 1×10^{-4} per year.

Comparing these values with the case without pipe break, it is seen that addition of the lube oil cooling system restores the AFW system reliability to that developed in Appendix A.

REFERENCES

1. WASH-1400 (NUREG-75/014) Reactor Safety Study, United States Nuclear Regulatory Commission, October 1975

2. Characteristics of Pipe System Failures in Light Water Reactor, EPRI NP 438 (Research Project 705-1), August 1977

3. H. M. Thomas, "Pipe and Vessel Failure Probability," Reliability Engineering, an International Journal, Volume 2, No. 2, April - June 1981

4. R. E. Hall, A. Coppola, S. P. Mitia, "Large Bore Pipe Rupture Probabilities as applied to a Steam Line Break," Brookhaven National Laboratory Associated Universities, Inc., Upton, New York 11973

5. Bush, S. H. "Reliability of Piping in Light Water Reactors." Nuclear Safety, Volume 17, No. 5, 568-569, (September - October 1976).

6. "Auxiliary Feedwater System Evaluation," Combustion Engineering, Inc., September 4, 1980

7. NUREG 0635, "Generic Evaluation of Feedwater Transients and Small Break Loss-of-Coolant Accidents in Combustion Engineering Designed Operating Plants," January 1980

8. Ten Year Review, 1971-1980, Component Cause Code Report, National Electric Reliability Council, Generating Availability Data System, Research Park, Terhune Road, Princeton, NJ 08540-3573.