December 1, 1982

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In the Matter of
SACRAMENTO MUNICIPAL UTILITY DISTRICT
(Rancho Seco Nuclear Generating Station)
Docket No. 50-312 (SP)

Dear Appeal Board Members:

Pursuant to the Appeal Board's Order of September 30, 1982, attached please find the following:

1) NUREG/CR-3013, entitled "Review Of The Rancho Seco Nuclear Generating Station Unit No. 1 Auxiliary Feedwater System Reliability Analysis," which report was previously provided to the Appeal Board and service list in final draft form on November 8, 1982; and

2) The "Affidavit Of Ernest D. Sylvester" together with an attached "Status Report, Rancho Seco - Auxiliary Feedwater System."

The undersigned Staff Counsel is advised that the Staff, based on its review to date, sees no reason to change its previous conclusion, contained in the Safety Evaluation Report transmitted to the licensee on June 27, 1979, as to the acceptability of the current AFWS until the upgraded AFWS is completed. The upgraded AFWS, which in the Staff's view provides a significant improvement over the present design, is scheduled to be completed during the refueling outage currently expected to begin in November of 1984. The safety grade automatic initiation and safety grade flow indication for the AFWS (NUREG-0737, Item II.E.1.2) is scheduled to be completed during the next refueling outage, starting in January of 1983. As Sections II.A.10 and II.B.5 of the attached Status Report indicate, the Staff's review of Item II.E.1.2 of NUREG-0737 has been completed. The Staff will be contacting the licensee regarding a schedule for the submittal of additional information required for completion of the Staff's review of the upgraded AFWS.

Sincerely,

Roy P. Lessy
Deputy Assistant Chief
Hearing Counsel

Enclosures: As Stated

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NUREG/CR-3013
BNL-NUREG-51620

REVIEW OF THE RANCHO SECO NUCLEAR GENERATING STATION UNIT NO. 1 AUXILIARY FEEDWATER SYSTEM RELIABILITY ANALYSIS

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ABSTRACT

This report presents the results of a review of the Auxiliary Feedwater System Upgrade Reliability Analysis for the Rancho Seco Nuclear Generating Station Unit No. 1. The objective of this report is to estimate the availability of the Auxiliary Feedwater System when required to perform its mission for each of three different initiators: (1) loss of main feedwater with offsite power available, (2) loss of offsite power, (3) loss of all 4160 VAC power. The scope, methodology, and failure data are prescribed by NUREG-0611, Appendix III. The results are compared with those obtained in NUREG-0611 for other plants.

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SUMMARY AND CONCLUSIONS

The probability of failure of the Rancho Seco Nuclear Generating Unit No. 1 Auxiliary Feedwater System on demand, under different loss of main feedwater conditions and different success criteria, has been evaluated using methodology and data put forth in NUREG-0611[1]. The results are as follows:

Initiator	Failure Probability to: Avoid Dryout	Failure Probability to: Supply AFW within 20 minutes
1. Loss of Main Feedwater(LMFW)	7.6×10^{-4}	2.6×10^{-4}(*)
2. Loss of Offsite Power(LOOP)	1.5×10^{-3}	5.3×10^{-4}
3. Loss of all AC(LOAC)	2.7×10^{-2}	1.3×10^{-2}

The column "Avoid Dryout" gives the probability per demand of Auxiliary Feedwater System failure when steam generator dryout is considered the undesired event, given each of the three initiators. These results have been obtained under the assumption that there is no time for any recovery action, and thus, the calculations do not include any credit for operator action to recover from malfunctions or maintenance errors. The probability of failure to deliver auxiliary feedwater within 20 minutes has also been calculated and is given in the second column of the Table for the various initiators. This mission success requirement is less restrictive as far as the available time for recovery is concerned and, therefore, credit has been given for operator actions.

(*)This value includes 2×10^{-4} contributed by common mode failures which may be beyond the scope of NUREG-0611. In that case, AFW failure probability will be 6×10^{-5}.

1. INTRODUCTION

The purposes of this study are: 1) to review and evaluate a Reliability Analysis[2] of the Auxiliary Feedwater System (AFW) of the Rancho Seco Nuclear Generating Station Unit No. 1 (RS-1) prepared by Babcock & Wilcox (BW) for Sacramento Municipal Utility District (SMUD) and submitted to the Nuclear Regulatory Commission (NRC); and 2) to perform an independent reliability analysis of the AFW system using methodology and data put forth in NUREG-0611[1].

After the accident at Three Mile Island, a study was performed of the Auxiliary Feedwater Systems (AFWS) of all then-operating plants. The results obtained for operating Westinghouse-designed plants were presented in NUREG-0611[1]. At that time, the objective was to compare Auxiliary Feedwater System (AFWS) designs; accordingly, generic failure probabilities were used in the analysis, rather than plant-specific data. Some of these generic data were presented in NUREG-0611. The probability that the AFWS would fail to perform its mission on demand was estimated for three initiating events: LMFW, LOOP, and LOAC.

Since then, each applicant for an operating license has been required (Ref. 3) to submit a reliability analysis of the plant's AFWS, carried out in a manner similar to that employed in the NUREG-0611 study.(*) Recently, a quantitative criterion for AFWS reliability has been defined by NRC[4] in the New Standard Review Plan (SRP - 10.4.9):

> "...An acceptable AFWS should have an unreliability in the range of 10^{-4} to 10^{-5} per demand based on an analysis using methods and data presented in NUREG-0611 and NUREG-0635. Compensating factors such as other methods of accomplishing the safety functions of the AFWS or other reliable methods for cooling the reactor core during abnormal conditions may be considered to justify a larger unavailability of the AFWS."

The objective of the study is, therefore, to analyze the reliability of the RS-1 AFWS, using methodology and data presented in NUREG-0611, in order to facilitate and supplement the qualitative review of the system design.

The report is organized as follows: Section 2 presents the scope of the present study. Section 3 discusses the mission success criteria for the AFWS and highlights the important differences between the definition of AFWS success for B & W plants and Westinghouse plants. The latter were the subject of the analysis in NUREG-0611. Section 4 describes the basic configuration and characteristics of the AFWS. Section 5 discusses the qualitative aspects of the reliability of the system and presents the dominant contribution to the unavailability. Section 6 presents the quantitative analysis and compares the results and approaches used in the SMUD study with those of this study. Finally, Section 7 summarizes the results and findings of the BNL study.

(*) In addition, some operating plants have also submitted reliability analyses of upgraded Auxiliary Feedwater Systems.

2. SCOPE

The scope of the reliability analysis of the AFWS is defined in APPENDIX III of NUREG-0611.

In the present study, the probability that the AFWS will not perform its mission on demand is calculated for two mission definitions and three types of demands. The two mission success definitions were necessary because of the substantial differences between the B & W plants and the Westinghouse plants. The success criteria stipulated by NUREG-0611 were based on the Westinghouse design. For the B & W plants the following two success criteria are considered:

1) Avoid dryout of the steam generators; and
2) Supply the steam generators with AFW within 20 minutes of the demand.

The failure to supply water to makeup for a loss of main feedwater, is estimated for different conditions, namely,

1) Loss of Main Feedwater without Loss of Offsite Power (LMFW).
2) Loss of Main Feedwater Associated with Loss of Offsite Power (LOOP).
3) Loss of Main Feedwater Associated with Loss of Offsite and Onsite AC (LOAC).

Since the purpose of this analysis is to assess the important characteristics of the AFWS design configuration, detailed modeling of support systems such as electrical power (both AC and DC), service water, instrument air, etc. was not performed. Such an undertaking is beyond the stated scope of the BNL reviews. The goal is a rudimentary understanding of the properties of the design of the AFWS. To this end, standardized data are used wherever they are available (emergency AC is schematically represented by the diesel generators) or assumed to be available (e.g., DC power is assumed available), although in some cases where such a system is seen to introduce a common cause mechanism, this is pointed out.

The quantity calculated here is the unavailability of the AFW system due to fluid system failures, maintenance acts, human errors, and failure to initiate, with mission success defined below (Section 3). "Unavailability" means (here as in NUREG-0611) "the probability per demand that the system will fail to perform its mission". The SMUD report deals with a number of additional failure modes, including steam generator overfill due to AFW control failures, spurious isolation of the steam generators, etc. These failures were reviewed on a qualitative basis (see comments in Sections 5.2 and 6). However, they lie beyond the scope of NUREG-0611.

3. MISSION AND SUCCESS CRITERIA

In the SMUD reliability study[2], "Mission success is defined as attainment of adequate flow from at least one pump to at least one steam generator." In the Revised System Description[10], the minimum acceptable flow is given as 760 gpm at a SG pressure of 1050 psig, and the maximum acceptable time for achievement of this flow is given as 50 seconds from the time an initiation signal is given.

There are two time scales to consider. One is a 20-minute deadline for AFWS initiation, which refers to a point up to which AFWS initiation can prevent core damage. According to NUREG-0667[5], "For plants with reactors designed by B&W, analyses prepared by B&W concluded that a period of approximately 20 minutes is available after loss of all feedwater for the operator to either (1) restore feedwater (either auxiliary or main), or (2) start the HPI pumps and enter into a "feed-and-bleed" method of core cooling. This available time is consistent with independent staff analyses" [page 5-32 of Ref. 5].

On the other hand, it is acknowledged that"...B&W-designed 177-Fa plants show some unique levels of sensitivity in their response and recovery from anticipated transients involving overcooling and undercooling events as well as small-break loss of coolant accidents. The recovery from such events has often led to undesirable challenges to engineered safety features (ESF) systems. This sensitivity stems mainly from the small heat sink resulting from the operation of the once-through steam generator (OTSG), which is an inherent design feature of the B&W reactor plants...[page 2-1 of Ref. 5]... B&W plants place a premium on the reliability with which the auxiliary feedwater starts are properly timed. The penalty for late starts is an increased likelihood of transient-induced LOCA [p. 7-8].

Therefore, for each initiator (LMFW, LOOP, and LOAC), failure proabilities are calculated for each of two mission success criteria:

1) Failure to deliver flow from at least one pump to at least one steam generator, with no credit for operator action;
2) Failure to deliver flow from at least one pump to at least one steam generator within 20 minutes, allowing credit for some operator actions within this time.

The failure criterion for NUREG-0611 purposes is steam generator dryout. For B&W plants, dryout occurs on a sufficiently short time scale that no credit for operator actions is warranted. Thus, for NUREG-0611 purposes, mission criterion 1) above is applied.

4. SYSTEM DESCRIPTION

RS-1's AFW system (Figure -1) consists of two pump trains. Each pump has a separate suction line originating from the Condensate Storage Tank. The two discharge lines to the two steam-generators are interconnected, allowing each train to supply AFW to either or both steam-generators (SG). AFW Train A pump (AFW-1) is a combination turbine-driven motor-driven pump with both the turbine and electric motor on a common shaft. The turbine drive is used as the primary motive source for this pump. The motor drive can be manually initiated. AFW Train B pump (AFW-2) is a motor driven pump which has the same rated capacity and recirculation flow as AFW-1. Both AFW pumps are self contained entities without dependences on secondary support systems for lubrication and for lube-oil cooling. The bearing on the turbine and both pumps are lubricated by slinging oil from reservoirs near the bearing. Lube oil cooling is accomplished by heat transfer to the pumped fluid.

The primary suction source is the condensate storage tank. The backup source is Folsom South Canal Pumps or On-Site Reservoir (by gravity). Switchover(to backup source) is manual.

The pumps discharge through check valves and locked open manual valves into cross-connected discharge lines. The cross-connection line contains two normally-open motor-operated valves. This cross-connect permits either pump to feed either or both of the SG's.

On each discharge line there are two flow control valves in parallel. They are all normally closed. Their control is pneumatic and is fail safe, i.e. fail open upon loss of air and half open upon loss of power (AC and DC). Downstream of the flow control valves are four motor-operated isolation valves (MOV's). They are installed in parallel, two on each discharge line. They are followed by check valves and locked-open manual valves.

The parallel arrangement of the flow control valves and MOV's on each discharge line may require isolation of the entire flow path to a steam generator each time any of these four valves in parallel requires maintenance action. In that case, both trains will be able to feed one SG only. However, in case of pump maintenance, the pump can be isolated by closing manual locked open valve in the suction line, and check valves isolate flow from the discharge and recirculation line side.

Pumps are assumed to be tested monthly. The test line recirculates water to the condenser via a normally closed air operated valve (FWS-X5). This valve fails safe upon loss of air to the closed position. It receives signals to close from both control channels A and B (EFIC -A and EFIC-B), whenever the AFW is initiated, to ensure its closed position and prevent flow diversion. The pump test verifies that the discharge line up to the cross-connect line and that the MOV's on this cross-connect are all open. It does not, however, check the conditions of the 8 valves in parallel on the discharge lines to both steam generators. The latter can be checked only during shutdown or emergency operation. Recirculation line for pump protection is provided through small lines to the condenser with normally locked open valves. It is not clear, however, whether there is always a redundant path arrangement or whether some lines are common to both pumps.

Steam to drive the turbine-driven pump is provided from the two steam generators. The steam is entering the turbine through a common supply line having a steam admission valve (V308C1). This valve has a DC operated motor and receives its control and initiation from Channel B.

Pumps P-318 and P-319 receive power for their motor drives from AC off-site and onsite through separate AC trains, each having one diesel.

The control system generates signals to automatically initiate the turbine to drive pump P-318 and the motor to drive pump P-319 upon sensing a number of initiating conditions (low SG level or pressure, loss of MFW etc). The turbine starts on a signal from channel B, and the motor on a signal from Channel A. The parallel flow control valves open, one on a signal from Channel A and the second in parallel from Channel B. These redundancies provide that no single failure of control system (Channel A or B failure) can fail AFW flow to any of the two SG's. The closure of valves FWS-X5 on the test line by two signals from both control channels serves the same purpose.

5. QUALITATIVE RELIABILITY ANALYSIS

There are two interconnected trains in the AFWS (see Figure 1). Each train consists of one pump and one discharge line having two control and isolation valves in parallel. A cross-connect links the two discharge lines, and permits each pump to supply AFW to one or two discharge lines. A common test line having the same diameter as the discharge line permits full flow test of both pumps. Mission success is defined as adequate flow from one pump to one SG within the appropriate time.

Failure of both trains = $[Q_1 + A * (B + C) + D]*[Q_2 + B* (A + C) + D] =$

$Q_1 Q_2 + Q_1AB + Q_1BC + Q_2AB + Q_2AC + AB + D$

where: Q_1 = inadequate flow out of FWS-047 (turbine train)

Q_2 = inadequate flow out of FWS-048 (EMD train)

A = flow path from FWS-047 to SGA blocked

B = flow path from FWS-048 to SGB blocked

C = cross-connect line blocked

D = test line valve - FWS-X5 failed open.

The dominant system cut sets are contained in Q_1Q_2. All of these events are double failures, products of large single contributors to Q_1 multiplying large single contributors to Q_2. These will be shown in Section 6. AB are not dominant because the important valves are redundant on each flow path. However, a common failure to A and B may become significant. Some potential common cause failures causing both A and B to fail were identified. They are discussed in Sections 5.1.2 and 5.2.2 below, and in Section 6.3.

Failures included in C are not significant contributors, and cut sets including C can be neglected. This is also because terms including C are triplets.

Event D is important because it is a single element term. Therefore, even low probability events or failure modes may become important. A single passive failure discussed in Section 5.1.1 below may be important. Thus, before neglecting D, potential low probability single failures should be investigated.

5.1 Fluid System Reliability

5.1.1 Single Point Failures

Event Q_1Q_2 does not contain any significant single failures. Likewise event A*B does not contain single failures. Event D includes the single test valve FWS-X5. A passive failure of this valve will open a flow path for both AFW trains which will bypass both steam generators. This path is 6" in diameter, the same diameter the discharge lines have. A passive failure with a failure rate of 10^{-7}/hr is assumed according to WASH-1400. It may yield a common mode failure probability of 10^{-4}, if special surveillance actions for this failure mode of the valve, are not taken during the period between regular maintenance schedules (assumed equal to 4.5 month per NUREG-0611).

If lack of recirculation can fail the AFW pumps, then this is another potential single failure. This is because in the "small lines" connecting the recirculation lines to the condenser, there may be some common lines with locked open valves. The SMUD report does not contain sufficient information to conclude whether such common valves do exist. If such valves exist then NUREG-0611 guides to use a flow blockage value of 1×10^{-4} for each valve even if it is locked open. While a value of 10^{-4} may be somewhat conservative for flow blockage, it is not considered to be overestimating the probability of leaving locked open valves closed following maintenance activites.

5.1.2 Common Mode Failures

Event Q_1Q_2 and AB both include some doubles such as two valves. Common mode failure of two check valves or locked open manual valves do not appear to be significant. Apart from this, the seeming redundancy of the flowpaths suggests that they contribute only to higher-order cut sets (2 or more failures). This is true only if there are no commonalities. There are examples in the LER files of events which bear on this question. At Arkansas Nuclear One, which has flowpath redundancy comparable to that of RS-1, a maintenance error disabled two flowpaths on one occasion (4/6/80), and on another occasion (5/22/79) the unexplained lifting of cable leads disabled two paths. Thus, system failures involving flow paths may not be wholly negligible, especially those involving coupled maintenance errors. However, they are unlikely to dominate the other system failures discussed here.

The four control valves depend on air, and are designed to fail open on loss of air. Valves in the same train are connected to different air sources. Thus, loss of one air train causes two valves to fail open. This does not prevent delivery of water to the steam generators, but leads in the direction of overcooling or overfilling.

5.2 Control System Reliability

5.2.1 Single Point Failures

The control system which provides actuation to initiate AFW flow has two separate channels: EFIC Channel A and EFIC Channel B. If these two channels fail they can cause AFW system failure in the following ways:

a) Isolating all four isolation valves on the two discharge lines to steam generator A and B.
b) Closing or not opening the four control valves on the same lines.
c) Not providing initiation of both AFW pump P-319 and steam admission valve to turbine driven pump P-318.

Our qualitative review of the fault trees supplied in SMUD report and the accompanying system description did not reveal any single point failure that can compromise both channels.

5.2.2 Double Point Failure

There are several double failures that can fail the AFW initiation. The most important hardware double appears to be the failure of both inverters TCAINZAM and TCBINZAM. This double is negligible according to SMUD analysis. However, NUREG-0611 guides to use for each control channel a value of 7×10^{-3}. Thus, the NUREG-0611 for independent failure of both channels become 5×10^{-5}. This means that using NUREG-0611 values and taking no credit for operator action, no AFWS can be better than 5×10^{-5} unless it has more than two separate independent control channels to initiate ArW.

5.2.3 Common Mode Failures

The SMUD report does not explicitly treat this subject. It is mentioned, however, that the fault trees were constructed to a level of detail that reveal dependencies if such exist. The fault trees of EFIC control, FOGG and overfill protection were not combined with the fault trees for AFW initiation. Thus, CMF within EFIC, FOGG and overfill protection were not revealed.

From our short review of the control system fault-tree provided by SMUD, we find that a repeated error by an operator miscalibrating the level setpoint of steam-generator level bistables can be a source of significant common mode failure which can fail AFW initiation by keeping the control or isolation valves on discharge lines in the closed position.

Two scenarios can each cause such an "AB event", i.e., closure of both paths of AFW flow to both SG's:

a) Overfill protection isolates all flow paths as a result of all four bistables miscalibrated - set too low (e.g. BIOFABMH, 81OFBBMLH etc.).
b) Four control valves (FV20527, FV20528, FUX1, FUX2) fail low due to miscalibration of the 2' setpoint - set too low in EFIC channels A and B.

In addition their may be also a few combinations of failures of FOGG and overfill protection, each isolating one steam generator.

NUREG-0611 provides data for scenarios such as the above. It provides a value of 5×10^{-3} for miscalibration of a setpoint which has an indication in control room, and for which a double check procedure exists. It also provides a value of 1×10^{-3} for miscalibration of more than one setpoint. SMUD assumes a similar value for miscalibration, i.e. 2.8×10^{-3} only a factor of two less than the NUREG value. However, SMUD did an independent tree analysis and did not take into account the higher probability of making, repeatedly, the same miscalibration error on the other actuation and control channels. If this CMF probability of 1/5 of the one channel miscalibrating failure rate (according to NUREG-0611) is taken into account, it can lead to a significant probability of AFW failure as further discussed in Section 6.3 below.

6. QUANTITATIVE RELIABILITY ANALYSIS

6.1 Limitations of the Reliability Analysis

The significance of the point estimates obtained in this review is best illuminated by the following quoation from NUREG-0611 (page III-19):

"The data was applied to the various identified faults in the fault logic structure and a point value estimate was determined for the top fault event (i.e., AFW System unavailability). Such an approach is considered adequate to gain those engineering and reliability based insights sought for this AFW System reassessment. As noted, no attempt was made to introduce the somewhat time consuming, calculational elegance, associated with the process of error propagation into this assessment (e.g., Monte Carlo). Prior experience with such a calculational process has revealed a somewhat predictable outcome that, even with the very redundant system, could be slightly higher than the point value solution (e.g., factor of approximately three times higher than the point value and usually less). Should there exist a clearly overwhelming fault in a systems design, then the process of error propagation would be expected to be merely one of higher elegance and it would yield no important change to the quantitative solution".

Clear cut dependencies or commonalities have been sought in the analysis, but parametric modeling of common cause failures (e.g., beta factor treatments) was beyond the scope of this review.

6.2 Approach of the SMUD Study vs. Approach of the BNL Review

Data Base: The SMUD study does not give details of basic event probabilities. According to Paragraph 2.3 of the study, generic data were obtained and then made plant-specific to RS-1 by incorporating RS-1 experience. The approach taken in the present analysis is to use data provided in NUREG-0611 and WASH-1400[6] wherever these exist.

Some of the data which apparently was used in SMUD study could be inferred from information supplied to BNL on some of the dominant cutsets derived for an AFWS reliability analysis of a similar plant. The similarity of the results for RS-1 and the other B&W plant indicates that plant specific data affected only a small part of the dominant sequences. The comparison of SMUD and BNL studies in Tables 6.1 and 6.2 is based on this inferred data rather than actual SMUD data. The results received for the "SMUD study" show slightly lower reliability which means that the inferred data is on the conservative side in most cases.

Unavailability for Different Initiators: The SMUD study does not present unavailability given LMFW, unavailability given LOOP, and unavailability given LOAC; it presents unavailability averaged over the initiators. In this review, unavailability is calculated for the three different initiators (see Table 7.1). Even though the SMUD report includes some information which allows for studying AFW availability in case of other transients (e.g. SG blowdown), this is not required by NUREG-0611 and was not studied.

Level of Detail in the Fault Tree: The SMUD fault trees go into considerable detail in treating the actuation and control logic. NUREG-0611, on the other hand, simply assigns 7×10^{-3} as the failure probability of each actuation and control channel. The AFW initiation fault-tree includes only actuation failures of channel A and B to initiate AFW. The fault-tree does not include control failures and spurious control faults which have the potential to isolate AFW discharge paths to either one or both SG's. These may have a significant effect if common mode failures are taken into account, as further remarked in Section 6.3 below.

Mission Success Criterion: The SMUD study provides conclusions for unavailability given no operator intervention for 20 minutes, and unavailability given credit for operator intervention. This is a useful distinction, which will be observed here (see Section 3).

Failure of Test Line: Failure of the test line valve is a potential single failure that can cause AFW flow diversion and consequently dryout of steam-generators. SMUD has made a considerable effort to remove the possibility of the valve being left open after test. By adding automatic closure of this valve upon automatic initiation of AFW using signals from both Channels A and B of EFIC, this mode of failure was practically eliminated. However, there is also a potential for failure of the valve to reset, or passive mechanical failure of the valve that allows gross leakage. It is difficult to prove that the probability of this failure mode is less than 10^{-5} per year. Thus, it becomes a significant contributor. BNL used a value of 10^{-4} for gross leakage from this single valve, i.e., 1/3 of the mechanical failure rate given by NUREG-0611 for air operated valves.

Manual Valves (Plugged): NUREG-0611 prescribes 1×10^{-4} for all manual valves and does not distinguish in this respect between locked or unlocked valves. Several events corresponding to blocked valves were added in BNL fault trees.

Control Failure of Pumps and Valves: In SMUD fault trees of AFW initiation, only actuation channel failures were considered. Failure of the local control circuit to a valve is considered by NUREG-0611. This was added on BNL fault trees, using the NUREG-0611 values for monthly testing. NUREG-0611 provides a value of 4×10^{-3} for local failure of a motor drive to an AFW pump. SMUD has included on the fault-tree the failure of the relay at the pump to close. SMUD quantified its failure rate as a 10^{-5} event. WASH-1440, which is apparently the basis for the NUREG-0611 4×10^{-3} value, used for this a value of 1×10^{-3}. Other local control failures which are part of the 4×10^{-3} and can be traced by review of the WASH-1400 fault tree were not included on SMUD fault tree for P-319 motor drive. In the BNL study, which used a value of 4×10^{-3}, it was added also to the P-318 motor drive. This added a small unavailability contribution in the case with credit to operator actions.

Valve Maintenance: NUREG-0611 indicates that valve maintenance should be assessed. In some studies, this has been done (notably the RSSMAP study[7] of Oconee). WASH-1400 indicates (Page III-40) that maintenance on valves should be assessed, but the only important contributor showing up in Table II 5-9 of WASH-1400 is maintenance on the steam admission valve. WASH-1400 acknowledges that maintenance is performed on the MOV's in the AFWS, but in that system the multiplicity of flow paths is such that these contributions to system unavailability are negligible. Here, the difficulty of isolating certain valves causes valve maintenance to contribute in spite of the seeming redundancy of flowpaths. Considering maintenance on control valve FV20527 (see Figure 1), it is necessary to close the locked open manual valve FWS-120. This is isolating steam generator A completely from both AFW pumps for the duration of the maintenance. The same will occur when valve FVX1 is maintained. Maintenance of the MOV's FV20577 or FVX3 will require, similarly, either to close valve FWS-120 or to disconnect the upstream control valves from their actuation system. Thus for the automatic initiation case (no credit to operator) steam generator A will again be unavailable for the duration of maintenance. The same situation occurs on the discharge line to steam generator B. The impact of this maintenance is not included in the SMUD report. In the BNL study this is included using NUREG-0611 data from page III-16. However, we assumed that maintenance of all four parallel valves will be completed in 7 hrs, the value used for one valve maintenance. The impact of this maintenance is small because it appears only in triplets (assuming that maintenance of both discharge lines A and B simultaneously is impossible). It may have some impact on the analysis of steam line or feedwater line break accidents. However, these are beyond the scope of this study.

The maintenance of the steam admission valve is not considered explicitly in SMUD analysis. It might be that it is a part of the turbine pump maintenance included in SMUD study. NUREG-0611 prescribes the use of both maintenance of turbine driven pump (19 hrs every 4.5 months) and the steam admission valve (7 hrs every 4.5 months).

6.3 Comparison of Estimated SMUD Failure Probabilities with Failure Probabilities used in the BNL Review

The SMUD study used plant-specific failure probabilities. A part of this data was made available(*) to BNL. This is tabulated, together with the values used in this review, in Tables 6.1, 6.2 and 6.3. The important differences are discussed here: Events which were included here but not by SMUD are flagged with asterisks in Tables 6.1, 6.2 and 6.3.

(*)See also Section 6.2 (Data Base) above.

Maintenance and Test Unavailability: NUREG-0611 effectively prescribes these numbers for pumps and valves. They have been assessed here wherever they can be assessed consistently with reasonable operating practice. (It has been assumed that certain maintenance acts which would completely disable automatic initiation will not be performed.) SMUD values for these unavailabilities are much lower.

Human Error Possibilities: NUREG-0611 gives substantial credit for valve position indication in the control room, which RS-1 has for many of the valves in the AFWS. Thus, the probability of leaving a suction valve in the wrong position after maintenance is 5×10^{-4} from Table III-2 of NUREG-0611. SMUD took no credit for position indication. Reckoning this way, one would obtain 5×10^{-3} from Table III-2, which is comparable to the 3.3×10^{-3} used in the SMUD study. Here, we have used 5×10^{-4}.

Failure to restore operability of steam to the turbine after maintenance was also included here (V30801LD). An event apparently of this type occurred at Farley on 3/25/78. Since valve V30801 is normally closed anyhow, credit for its position indication is superfluous; the value adopted here is that corresponding to failure to restore a suction valve without position indication.

This is not a substitute for a detailed human error analysis; it is simply an attempt to be consistent with the scope and methodology of the rest of the analysis without ignoring previously untabulated failure modes. It is not clear that this is a conservatism; several failures of the turbine pump have occurred at Arkansas Nuclear One which, though not precisely of this type, involve degradation of the steam supply because of maintenance errors.

Recovery Factors: Where recovery of a failure is practicable within 24 minutes, substantial credit for such recovery effectively removes that failure from the list of contributors. Example: 5×10^{-4} for an unrestored discharge valve drops to the 10^{-6} to 10^{-5} range when 20-minutes recovery is taken into account, which makes it relatively insignificant compared with other contributors to Q_{1H} and Q_{2H}, which are of order 10^{-2}. Substantial credit for recovery is appropriate on a 20-minute time scale. However, some events must be recovered much more quickly. For example, the pumps do not trip on loss of suction, and pump damage is expected within a few minutes if suction is lost. Restoration of suction at 19 minutes is therefore superfluous (the pumps are presumed damaged).

It should be borne in mind that the recovery factor being considered is not simply "failure to diagnose within 2 minutes and promptly correct a closed suction valve"; rather, it is this failure given that the other train of the AFWS has also failed, and that the initiating event might have been, for example, a loss of offsite power In other words, there are many claims on the operator's attention. Swain and Guttmann (NUREG/CR-1278, page 17-24)(8) suggest that for the first 5 minutes into a transient, it should be assumed that the operator is alone in the control room. Finally, given all this, stress is understandably moderate to high, so that even if the operator gets around to this particular problem, his error rate is somewhat elevated. For all these reasons, credit has not been given here for recovery of suction.

As a footnote to this discussion, observe that the SMUD Therp tree(*) for this recovery has the operator trip the pump in order to prevent damage while the auxiliary building operator finds and opens the valve, but the Therp tree does not then have the operator restart the pump.

Recovery of flow from the AFW turbine-driven pump after dryout is dubious, because it is not clear that there is enough steam in the system to start the turbine and operate it long enough to generate more steam. An analysis of this situation seems to be needed to determine how conservative is the assumption made here of 20-minutes initiation time for the case with operator credit.

Actuation Logic: NUREG-0611 prescribes 7×10^{-3} per channel for actuation logic failure probability. However, there are no entries in cut set tables available to BNL which can be compared with this value. These cut sets show the inverter in each channel to be the highest contributor with a failure rate of 1.2×10^{-4}. Other contributors are of the order of 10^{-5} only. We included the data derived from the cut sets for EFIC, FOGG and overfill protection fault-trees on the AFW initiation fault-tree. This gave only an unavailability of about 3×10^{-4} for each EFIC channel. It seems, therefore, that the value used for actuation logic failure in SMUD analysis is far lower than the value prescribed by NUREG-0611.

One should ask whether the assessment of 7×10^{-3} per channel is reasonable. In Westinghouse plants, this value tends not to overwhelm the system unavailability, because NUREG-0611 prescribes substantial credit for operator actuation within the "available" time. Here, for some purposes, we (and SMUD) are giving no credit for operator actions within the first few minutes, so that the conclusions are correspondingly sensitive to this parameter. For example, system failure by failure of both actuation channels without operator backup is $(7 \times 10^{-3})^2 = 4.9 \times 10^{-5}$, which virtually exhausts the unavailability contemplated by the new SRP for auxiliary feedwater systems. B&W plants arguably need, and may have, actuation systems which are more reliable than this. But SMUD has not explicitly documented this by providing failure data, and in any case, this level of detail is beyond the scope of this analysis.

The dominant contributors in the fault-trees for EFIC, FOGG and Overfill Protection were found by SMUD to be a miscalibration of level setpoints or level transmitter failures. These were given a probability of failure in the range of $2\text{-}3 \times 10^{-3}$. Two independent failures of these will cause one channel of the control to fail in a way that will isolate one of the parallel

(*)Therp tree - Technique for Human-Error Rate Prediction (see Ref. 8).

paths on each one of the discharge lines. Assuming independence, a value of 1×10^{-5} is obtained. However, there are several combinations of level setpoints that can lead to the isolation of these paths. This will increase the independent value for this to 1×10^{-4} per channel. This is not included in the AFW initiation fault-trees.

NUREG-0611 prescribes a failure probability for additional miscalibration of setpoints given the first setpoint was miscalibrated. This value is 0.2. If we would use this value to estimate the common mode probability we would arrive at a failure probability of 5×10^{-4} for miscalibration of two level setpoints. The multiplicity of setpoints would increase the probability of isolating two flow paths to the 10^{-3} region. If we would further assume that the setpoints for all EFIC channels are calibrated by the same operator in one operation, it would be possible to assume again a probability of 0.2 that the same miscalibration error will affect the other channels. The result of such a common-mode failure can be the isolation of all four flow paths controlled by EFIC A and B with a probability of 1×10^{-4} or more. A value of 1×10^{-4} was used in Table 6.1 for the term AxB to illustrate this potential common mode failure.

According to the Revised System Description[10] (p. 20), it is possible to place one channel of the Emergency Feedwater Initiation and Control Logic (EFIC) in "maintenance bypass". In another paragraph, it is stated that the maintenance bypass of the NI/RPS (from which the EFIC receives signals) is interlocked with the EFIC, so that automatic initiation of EFW is not prevented by the simultaneous disabling of one channel of EFIC and an opposing channel of NI/RPS; but it is further stated that <u>administrative procedures</u> should be written to prevent this. EFIC bypass events are absent from the SMUD fault trees. A failure rate of 5×10^{-4} per channel could have been used here for bypassing one EFIC channel and failing to realign after maintenance.

The above events were included essentially for completeness. They are beyond the scope of NUREG-0611 studies, which only require the use of 7×10^{-3} per channel. However, they may indicate that the 7×10^{-3} value may not be too conservative if common mode failures and maintenance detail are taken into account.

6.4 AFWS Dominant Failure Modes

The list of dominant cutsets for the different initiating events considered by NUREG-0611 are given in Appendix A, Tables A-1 to A-6. The most important cutsets out of those tables are given in the following subsections.

6.4.1 Loss of Main Feedwater (LMFW), With Credit for Operator Action

a) Miscalibration of all four steam generator level setpoints (same level)is a potential common mode failure. Its frequency depends on administrative procedures, and can be significant if procedures do not call for staggered calibration by different operators. BNL assumed here 10^{-4} to this common mode failure.

b) Leakage from test line valve FWS-X5 can divert AFW flow and potentially dry out the steam generators. BNL assumed that no special surveillance of this valve is performed between scheduled maintenance (4.5 month), which resulted in a failure probability of 10^{-4}. If surveillance is made more often or other effective measures are taken, this probability could be reduced.

c) A failure of the local control to the electric pump P-319 or a failure of this pump to start while the turbine pump P-318 is under maintenance is a major failure mode.

6.4.2 Loss of Main Feedwater (LMFW) With No Credit for Operator Action

a) Miscalibration and gross leakage described in (a),(b) above are important failure modes.

b) Failure of both actuation trains: EFIC A and EFIC-B is an important failure mode. It is assumed that the high value of $7x10^{-3}$ per channel prescribed by NUREG-0611 covers potential common mode failures.

c) One pump under maintenance and actuation failures of second pump.

d) Pump P-319 left disabled due to maintenance error while second pump (P-318) has an actuation failure.

e) (EFIC-B fails) or steam admission valve left disabled (Pump P-318) and electric pump P-319 has an actuation failure (EFIC-A fails).

6.4.3 Loss of Main Feedwater Due to and Loss of Offsite Power (LOOP), With Operator Corrective Action

a) Diesel generator A failure or being maintained while turbine driven pump is under maintenance is the most important failure mode. It should be noted that BNL assumed that while turbine drive is maintained, pump P-318 is maintained too.

b) Miscalibration and gross leakage discussed above in 6.4.1 (a),(b) are important failure modes.

c) Diesel generator A failure or being maintained while P-318 fail to start or to run.

d) A failure of the local control of pump P-319 or failure of the pump to start while the turbine pump P-318 is maintained (6.4.1 c).

6.4.4 Loss of Main Feedwater Due to and Loss of Offsite Power (LOOP) Without Credit for Operator Action

a) Diesel generator A failure or being maintained failing train P-319, with actuation failure (EFIC-B) to steam admission valve failing train P-318.

b) Same as 6.4.3 (a) above.

c) Diesel generator A failure or being maintained with steam admission valve left disabled after maintenance or being maintained.

d) Miscalibration and gross leakage discussed above in 6.4.1 (a), (b).

6.4.5 Loss of Main Feedwater and Loss of All Alternating Current Power (LOAC), With Credit for Operator Action

a) Turbine driven pump maintenance. In this case both turbine maintenance or pump P-318 maintenance or steam admission valve maintenance, all are dominant failure modes.
b) Failure of steam admission valve to open (local control failure, or mechanical failure of valve to open on demand).
c) Mechanical failure of the turbine drive.
d) Battery B failure.

6.4.6 Loss of Main Feedwater and Loss of All Alternating Current Power (LOAC), With No Credit for Operator Action

a) Failure of actuation channel B (EFIC-B).
b) Turbine pump P-318 train maintenance as 6.4.5 (a) above.
c) Failure of steam admission valve to open (6.4.5 (b) above).
d) Local control to steam admission valve failure.

6.4.7 Dominant Failure Mode of SMUD Study

The above failure modes are by large different from the dominant failure modes identified in SMUD study and listed in SMUD report. The SMUD dominant failures are:

a) The two trains unavailability is dominated by hardware failure of P-319, P-318, steam admission valve or diesel generator A, rather than pump maintenance as in BNL study (using NUREG-0611 values).
b) Inadvertent failure to reopen valve FWS-045 or FWS-046 following pump maintenance is more important in the SMD study than in the BNL study.
c) Failure of FWS-X5 to close while AFW pump is on test or after valve was left inadvertently open by operator . BNL study considers a passive failure of this valve a more significant failure mode.
d) Local controls to pumps and valves or actuation signal failures are not significant contributors in SMUD study.

6.5 Comparison of BNL probabilities for RS-1 AFW with NUREG-0611 Results

The results of the BNL study are shown in Table 7.1. Previous studies have been made by the NRC and others and were shown on a standard form table of AFW reliability. Such an analysis has been done also by B/W and was reported in BAW-1584[9]. In Table 7.2, the results of this study are put in the same form as that in which they are summarized in NUREG-0611 for other plants, to facilitate comparison. From the table, it is apparent that RS-1 AFW lies around the medium range of unavailabilities for all cases with operator action allowed. For cases where no credit is given to operator action, the RS-1 AFW ranks "low" for LOOP.

Table 6.1: Contributors to AFW Unavailability upon LMFW

Contributors to Q_{1H} (Inadequate flow out of turbine train - no test or maintenance)

Fault Identifier	BNL Value	Estimated SMUD Value(+)	Comments on BNL Values
P318ZZFS	$5x10^{-4}$	$5x10^{-4}$	Pump only (without electric or turbine drives)fails to start.
P318ZZFR	$2.4x10^{-4}$	$3.46x10^{-4}$	Pump and its drive fail to run an 8 hrs mission period.
[P318SDMF	$1x10^{-3}$	$5x10^{-3}$	Steam turbine drive fails to start.
P318MDOA]	$1x10^{-2}$	$1x10^{-2}$	Operator fails to start manually the electric motor drive within 20 minutes.
[V30801TO	$3.1x10^{-3}$	$3.9x10^{-3}$	Steam admission valve failure to operate ($1x10^{-3}$ mechanical, $2x10^{-3}$ control w/monthly testing, $1x10^{-4}$ flow blockage).
P318MDOA]	$1x10^{-2}$	$1x10^{-2}$	Operator fails to start manually within 20 minutes.
[EFIC-B	$7x10^{-3}$	$\sim 3x10^{-4}$	Actuation signal failure resulting in no automatic initiation of steam admission valve.
AFWTRPOP]	$1x10^{-2}$	$1x10^{-2}$	Operator fails to start manually the steam admission motor operated valve.
[V30801LD	$5x10^{-3}$	(*)	Steam admission valve left disabled after maintenance Control room status information assumed to be ineffective.
AFWTRPOP]	$1x10^{-2}$	(*)	Same as above.

(*) Event did not appear on SMUD fault trees.
(+) Estimated SMUD values based on some quantified cut-sets for a similar plant.

Table 6.1: Contributors to AFW Unavailability upon LMFW (Cont'd.)

Contributors to Q_{1H} (Inadequate flow out of turbine train - no test or maintenance)

Fault Identifier	BNL Value	Estimated SMUD Value(+)	Comments on BNL Values
FWS045LC	$5x10^{-4}$	$3.3x10^{-3}$	Valve FWS045 inadvertently left closed, with valve position indicated in control room
FWS045RE	1.0	$1.9x10^{-2}$	Assumed that pump damage may occur before operator action opens the valve.
FWS047FB	$1x10^{-4}$	$9.1x10^{-5}$	Flow blockage of check valve downstream from pump.
MCM057FB	$1x10^{-4}$	$9.1x10^{-5}$	Flow blockage of valve in suction line.
MCM060FB	$1x10^{-4}$	$9.1x10^{-5}$	Flow blockage of valve in suction line.
CSVSGARS and CSVSGBRS	$3.4x10^{-4}$	$3.4x10^{-4}$	Failure of safety relief valves on both steam generators resulting in loss of steam to turbine.

(*) Event did not appear on SMUD fault trees.
(+)Estimated SMUD values based on some quantified cut-sets for a similar plant.

Table 6.1: Contributors to AFW Unavailability upon LMFW (Cont'd.)

Contributors to Q_{2H} (Inadequate flow out of electric motor pump train - no test or maintenance)

Fault Identifier	BNL Value	Estimated SMUD Value(+)	Comments on BNL Values
P319ZZFS	$1x10^{-3}$	$5x10^{-4}$	Electric motor driven pump failure (no control) to start.
P319ZZFR	$2.4x10^{-4}$	$3.2x10^{-4}$	$3x10^{-5}$/hr *8hrs, pump failure to run.
P319CNZF	$4x10^{-3}$	(*)	$4x10^{-3}$,pump local control failure with monthly testing according to NUREG-0611 guidance.
[P319CNLD	$5x10^{-3}$	(*)	Control circuit to pump left disabled after maintenance.
[P319CNRE	$1x10^{-2}$	(*)	Recovery by operator: Failure probability of 10^{-2} to restart pump within 20 minutes.
[EFIC-A	$7x10^{-3}$	$\sim 3x10^{-4}$	Actuation signal failure, resulting in no automatic initiation of electric motor driven pump.
[AFWTRPOP	$1x10^{-2}$	$1x10^{-2}$	Operator fails to start manually the pump.
[FWS046LC	$5x10^{-4}$	$3.3x10^{-3}$	Valve FWS046 inadvertently left closed, with valve position indicated in control room.
[FWS046RE	1.0	$1.9x10^{-2}$	Assumed that pump damage may occur before operator action opens the valve.

(*) Event did not appear on SMUD fault trees.
(+)Estimated SMUD values based on some quantified cut-sets for a similar plant.

Table 6.1: Contributors to AFW Unavailability upon LMFW (Cont'd.)

Contributors to Q_{1H} (Inadequate flow out of electric motor pump train - no test or maintenance)

Fault Identifier	BNL Value	Estimated SMUD Value(+)	Comments on BNL Values
FWS048FB	$1x10^{-4}$	$9.1x10^{-5}$	Flow blockage of valve down stream from pump.
MCM058FB	$1x10^{-4}$	$9.1x10^{-5}$	Flow blockage of valve in suction line.
MCM060FB	$1x10^{-4}$	$9.1x10^{-5}$	Flow blockage of valve in suction line.

(*) Event did not appear on SMUD fault trees.

(+)Estimated SMUD values based on some quantified cut-sets for a similar plant.

Table 6.1: Contributors to AFW Unavailability upon LMFW (Cont'd.)

Contributors to Q_{1M} (Inadequate flow out of turbine train due-to test or maintenance)

Fault Identifier	BNL Value	Estimated SMUD Value(+)	Comments on BNL Values
P318ZZPM	5.8×10^{-3}	1.15×10^{-3}	Turbine pump maintenance According to NUREG-0611 guidance: $19 \text{ hrs} \times \frac{0.22 \text{ acts}}{\text{Month}} \times \frac{1 \text{ month}}{720 \text{ hrs.}} = 5.8 \times 10^{-3}$ This value may be conservative for the non-automatic case if steam turbine maintenance can be performed separately from pump (which have a motor drive too).
V30801PM	2.1×10^{-3}	(*)	Turbine steam admission valve maintenance: $7 \text{ hrs} \times 0.22/720 = 2.1 \times 10^{-3}$
P318MDOA	1×10^{-2}	(*)	Operator fails to initiate motor drive to pump P-318 within 20 minutes.

Contributors to Q_{2M} (Inadequate flow out of motor driven pump due to tests and maintenance)

Fault Identifier	BNL Value	Estimated SMUD Value(+)	Comments on BNL Values
P319ZZPM	5.8×10^{-3}	2.3×10^{-5}	Electric motor driven pump maintenance According to NUREG-0611 guidance: $19\times0.22/720 = 5.8 \times 10^{-3}$.

Contributors to A (Flow Path from FWS-047 to steam-geneator A is blocked).

Fault Identifier	BNL Value	Estimated SMUD Value(+)	Comments on BNL Values
PARVA1PM	2.1×10^{-3}	(*)	Four parallel valves are under maintenance. All valves assumed to be maintained by four teams at once to reduce unavailability of all AFW paths to SGA. According to NUREG-0611: $7 \times 0.22/720 = 2.1 \times 10^{-3}$

(*) Event did not appear on SMUD fault trees.
(+) Estimated SMUD values based on some quantified cut-sets for a similar plant.

Table 6.1: Contributors to AFW Unavailability upon LMFW (Cont'd.)

Fault Identifier	BNL Value	Estimated SMUD Value(+)	Comments on BNL Values
Contributors to B (Flow path from FWS-048 to steam generator B is blocked)			
PARVA2PM	2.1×10^{-3}	(*)	As above for flow path to steam generator B.
Contributors to A*B (No flow to both steam generators)			
EFIC-A and EFIC-B	4.9×10^{-5}.	(*)	Independent failure of both actuation channels to open control valves on all four parallel paths. According to NUREG-0611: $(7 \times 10^{-3}) \times (7 \times 10^{-3}) = 4.9 \times 10^{-5}$
Common Calibration Error	1×10^{-4}	(*)	Repeated miscalibration by the same operator of all SG level setpoints, resulting in isolation of all four flow paths (see Sec. 6.3)
Contributors to C (Cross-Connect line blocked)			
V31826PM	2.1×10^{-3}	(*)	MOV maintenance According to NUREG-0611.
V31827PM	2.1×10^{-3}	(*)	This contributors did not appear in any significant cutset.
Contributors to D (Test line valve FWS-X5, failed in the open position).			
FWSX5ZTC	2×10^{-4}	Similar Values	NUREG-0611 values for AOV's is 3×10^{-4} mechanical. and no control contribution. Here this 3×10^{-4} is split between FWSX5ZTC and FWSX5ZGL. SMUD report considers this a significant contributor. However, their values not known to us.
OPX5ZZDE	$\times10^{-3}$		

(*) Event did not appear on SMUD fault trees.
(+)Estimated SMUD values based on some quantified cut-sets for a similar plant.

Table 6.2 Additional Contributors to Loss of Offsite Power (LOOP)

Fault Identifier	BNL Value	Estimated SMUD Value(+)	Comments on BNL Values
Contributors to Q_1			
DGBZZZFS and P318SDMF or V30801TO	3.6×10^{-2} * 1×10^{-3} 3.1×10^{-3}	(*)	Highest additional term is $4.1\times10^{-3} \times 3.6\times10^{-2} = 1.5 \times 10^{-4}$. This is the effect of the dual-drive to pump P-318.
Contributors to Q_2			
DGAZZZFS	3.6×10^{-2}	1.93×10^{-2}	Failure of diesel generator A to start (3×10^{-2}) or diesel generator being in maintenance ($6\times10^{-3} = 21\times0.22/720$). According to NUREG-0611.
Contributors to A,B,C,D			
None Significant			

(*) Event did not appear on SMUD fault trees.
(+)Estimated SMUD values based on some quantified cut-sets for a similar plant.

Table 6.3 Additional Contributors to Loss of All AC Power (LOAC)

Fault Identifier	BNL Value	Estimated SMUD Value(+)	Comments on BNL Values
Contributors to Q_1			
P318MDOA = 1.0			Motor drive to plump P-318 is unavailable upon LOAC.
BATBZZAM	$1x10^{-3}$	$8x10^{-4}$	Failure of the battery will appear as a new cutset.
Contributors to Q_2			
This train is unavailable upon LOAC.			

(*) Event did not appear on SMUD fault trees.
(+)Estimated SMUD values based on some quantified cut-sets for a similar plant.

Table 6.4

	Q_1H	Q_1M	Q_2H	Q_2M	A*B	C	D
LMFW, Operator Credit	1.7×10^{-3}	5.8×10^{-3}	6.2×10^{-3}	5.8×10^{-3}	2.1×10^{-3} * 2.1×10^{-3} and 7×10^{-3} * 7×10^{-3} EFIC A and B failure and	No t significant	1×10^{-4}
LMFW, no operator Credit	1.8×10^{-2}	7.9×10^{-3}	1.8×10^{-2}	5.8×10^{-3}			
LOOP, operator Credit	1.9×10^{-3}	5.8×10^{-3}	4.2×10^{-2}	5.8×10^{-3}	Common mode failure in miscalibration of SG level setpoints (estimated to be $\sim10^{-4}$).		
LOOP, no operator Credit	1.8×10^{-2}	7.9×10^{-3}	5.4×10^{-2}	5.8×10^{-3}	All together: $\cong 1\times10^{-4}$		
LOAC Operator Credit	7.1×10^{-3}	5.8×10^{-3}	1.0				
LOAC no operator Credit	1.9×10^{-2}	7.9×10^{-3}	1.0				

7. RESULTS AND CONCLUSIONS

The results of BNL study are presented in Table 7.1. The detailed reasons for the differences between BNL results and SMUD results are clear from Table 6.1, 6.2 and 6.3 and from the discussions in Sections 6.2 and 6.3 above.

From Table 7.1 it can be seen that BNL and SMUD almost agree on the unavailability of the AFW upon loss of all AC power (LOAC).

In the case of loss of offsite power (LOOP) with no credit to operator error the results of BNL may be higher by a factor of 4, mainly due to:

- o Higher failure rate for the actuation system
- o Higher failure rate for diesel generators
- o Longer outage period for turbine driven pump maintenance
- o Inclusion of steam admission valve left disabled after maintenance or being under preventive maintenance.

All the above derive from the NUREG-0611 prescription.

In the case of loss of offsite power (LOOP) with credit given for operator action, and in the case of loss of main feedwater with no credit to operator action, the difference is by an order of magnitude. This is mainly due to:

- o Longer outage period for turbine driven pump maintenance
- o Higher failure rate for actuation system failure
- o Higher failure rate for diesel generators
- o Inclusion of the failure of local control to pump P-319
- o The two common mode failures assumed by BNL.

The first four differences follow from NUREG-0611 prescription.

In the case of loss of main feedwater while offsite power is available, and with credit to operator action, the BNL results differ even more than in the previous cases (by more than an order of magnitude). This is due mainly to the inclusion of two "common mode" failures:

- o Gross leakage from recirculation valve FWS-X5
- o Common mode miscalibration of all SG level setpoints.

For both of these failures, a value of 2×10^{-4} was assumed. It was partly based on WASH-1400 and on NUREG-0611 (see previous sections for detail). However, it may well be beyond the scope of the NUREG-0611 type treatment of AFW reliability analysis.

It should be noted that another potential source of common mode was not included. If there exists common valves on the recirculation lines before the condenser, a flow blockage probability of 10^{-4} should be assumed according to NUREG-0611.

Table 7.1 AFWS Unavailability

Values given here are calculated from

$$\bar{U} = Q_1 Q_2 + AB + D =$$

$$Q_{1_H} Q_{2_H} + Q_{1_H} Q_{2_M} + Q_{2_H} Q_{1M} + AB + D$$

where:

Q_1= Inadequate flow out of FWS-047 (Turbine train)

Q_2= Inadequate flow out of FWS-048 (Electric drive train)

A = Flow path from FWS-047 to SGA is blocked

B = Flow path from FWS-048 to SGB is blocked

D = Test line valve, FWS-X5 failed in the open position.

	This Work[c] $\bar{U}$	SMUD Report[c] $\bar{U}$
LMFW, Operator Credit	2.6×10^{-4}	1×10^{-5} [a]
LMFW, No Operator Credit (Dry out)	7.6×10^{-4}	1×10^{-4} [a]
LOOP, Operator Credit	5.3×10^{-4}	5×10^{-5} [b]
LOOP, No Operator Credit	1.5×10^{-3}	3.6×10^{-4} [b]
LOAC, Operator Credit	1.3×10^{-2}	1.3×10^{-2} [b]
LOAC, No Operator Credit	2.7×10^{-2}	1.6×10^{-2} [b]

(a) This value is given in SMUD report Table 3.1. Using the estimated data from Table 6.1 Column 3, and adding terms for loss of offsite power, we obtained the same value.

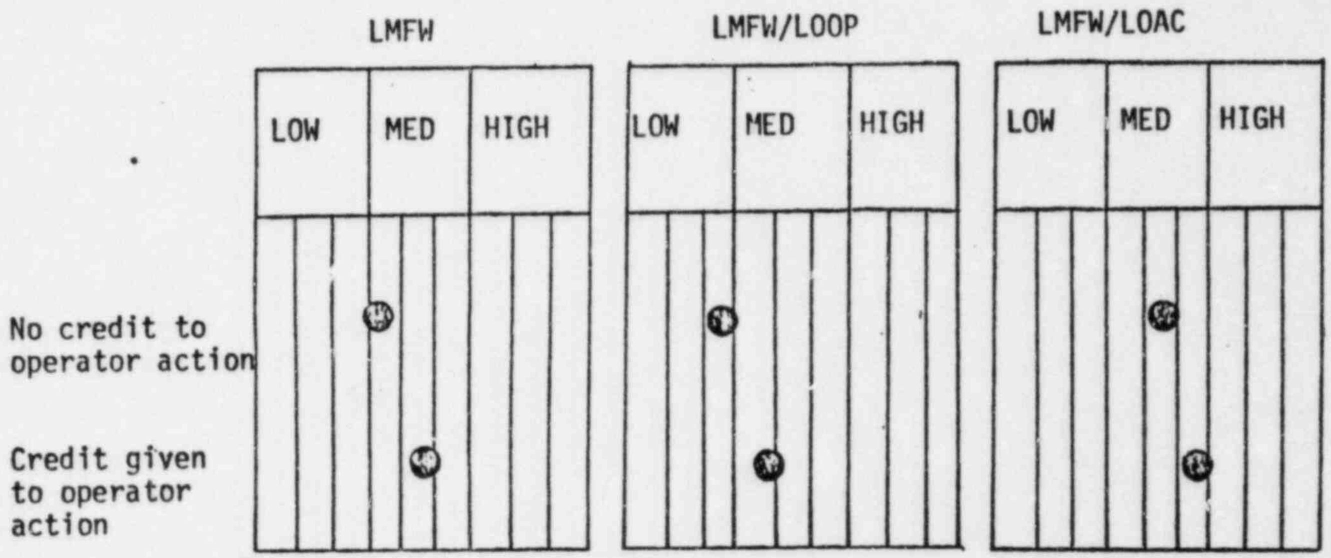
(b) This value does not appear in SMUD report. It is obtained by using the estimated SMUD data from Table 6.1 for the appropriate case.

(c) All these values were checked by computer runs of the fault trees using WAMCUT.

BNL conclusions are that the SMUD AFW unavailability is in the medium range of NUREG-0611 classification. This is for the case in which credit for operator action is given. In the case of automatic initiation, the unavailability is in the medium to low range. The latter is mainly because without operator action, the SMUD AFW corresponds to a two-train system. Using NUREG-0611 values, it is hardly possible to produce better results for a two-train AFW.

From the above one can conclude that the dual drive is an important feature of SMUD AFW reliability as long as sufficient time is available for operator recovery actions.

Table 7.2 BNL Results for Rancho Seco 1 in NUREG-0611 Format



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4. "Standard Review Plan 10.4.9: Auxiliary Feedwater Systems," NUREG-0800, U. S. Nuclear Regulatory Commission (July 1981).

5. "Transient Response of Babcock & Wilcox-Designed Reactors," NUREG-0667, U. S. Nuclear Regulatory Commission (May 1980).

6. "Reactor Safety Study, An Assessment of Accident Risks in U. S. Commercial Nuclear Power Plants, WASH-1400," NUREG-75(014), U. S. Nuclear Regulatory Commission (October 1975).

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8. "Handbook of Human Reliability Analysis with Emphasis on Nuclear Power Plant Applications," NUREG/CR-1278, U. S. Nuclear Regulatory Commission (October 1980).

9. "Auxiliary Feedwater Systems Reliability Analyses," BAW-1584, Babcock & Wilcox (December 1979).

10. "Revised System Description Auxiliary Feedwater System for Sacramento Municipal Utility District Rancho Seco," Submitted September 8, 1981 (received September 14, 1981) with a letter from John J. Mattimoe (SMUD) to John F. Stolz (NRC).

APPENDIX A

List of Cutsets from BNL Analysis

The following tables present the list of cutsets obtained for the different initiators considered by NUREG-0611.

The main purpose of these lists is to show the order of the main cutsets in each case, inorder to identify the dominant contributors.

Table A.1: Cutsets for LMFW - Credit Given to Operator Action

CUT SETS FOR GATE I1 ORDERED BY PROBABILITY

1.	1.00E-04	CAL8ZZCM		
~~2.~~	~~1.00E-04~~	~~FWSK5ZGL~~	(*)	
3.	3.36E-05	P318ZZPM	P319ZZPM	
~~4.~~	~~2.32E-05~~	~~P318ZZPM~~	~~P319CNZF~~	
5.	5.80E-06	P318ZZPM	P319ZZFS	
~~6.~~	~~4.41E-06~~	~~PARVA1PM~~	~~PARVA2PM~~ (*)	
7.	2.90E-06	P319ZZPM	FWS045LC	FWS045RE
~~8.~~	~~2.90E-06~~	~~P318ZZFS~~	~~P319ZZPM~~	
9.	2.90E-06	P318ZZPM	FWS046LC	FWS046RE
~~10.~~	~~2.00E-06~~	~~FWS045LC~~	~~FWS045RE~~	~~P319CNZF~~
11.	2.00E-06	P318ZZFS	P319CNZF	
~~12.~~	~~1.39E-06~~	~~P318ZZFR~~	~~P319ZZPM~~	
13.	1.39E-06	P318ZZPM	P319ZZFR	
~~14.~~	~~1.00E-06~~	~~FWSK5ZTG~~	~~OFK5ZZOE~~	
15.	9.60E-07	P318ZZFR	P319CNZF	
~~16.~~	~~5.80E-07~~	~~P318ZZPM~~	~~FWS048F3~~	
17.	5.80E-07	FWS047F3	P319ZZPM	
~~18.~~	~~5.80E-07~~	~~MCM057F3~~	~~P319ZZPM~~	
19.	5.80E-07	MCM059F3	P319ZZPM	
~~20.~~	~~5.80E-07~~	~~MCM058F3~~	~~P318ZZPM~~	
21.	5.80E-07	MCM060F3	P318ZZPM	
~~22.~~	~~5.00E-07~~	~~P319ZZFS~~	~~FWS045LC~~	~~FWS045RE~~
23.	5.00E-07	P318ZZFS	P319ZZFS	

CUT TOOK .346 SECS

(*) Assumed impossible.

CUT SETS FOR GATE I1 ORDERED BY PROBABILITY

1.	1.00E-04	CAL3ZZG4				
2.	1.00E-04	FWSX5ZGL				
3.	4.90E-05	P318MDOA	AFWTRPOP	TCBINZAM	TCAINZAM	
4.	4.06E-05	P319ZZPM	P318MDOA	AFWTRPOP	TCBINZAM	
5.	4.06E-05	P318ZZPM	AFWTRPOP	TCAINZAM		
6.	3.50E-05	P318MDOA	AFWTRPOP	TCBINZAM	P319CNLD	P319CNRE
7.	3.50E-05	P318MDOA	V30801LD	AFWTRPOP	TCAINZAM	
8.	3.36E-05	P318ZZPM	P319ZZPM(*)			
9.	2.90E-05	P319ZZPM	P318MDOA	V30801LD	AFWTRPOP	
10.	2.90E-05	P318ZZPM	P319CNLD	P319CNRE		
11.	2.80E-05	P318MDOA	AFWTRPOP	P319CNZF	TCBINZAM	
12.	2.80E-05	P318MDOA	AFWTRPOP	TCBINZAM	RY1P7ATC(*)	
13.	2.50E-05	P318MDOA	V30801LD	AFWTRPOP	P319CNLD	P319CNRE
14.	2.32E-05	P318ZZPM	P319CNZF			
15.	2.32E-05	P318ZZPM	AFWTRPOP	RY1P7ATC(*)		
16.	2.00E-05	P318MDOA	V30801LD	AFWTRPOP	P319CNZF	
17.	2.00E-05	P318MDOA	V30801LD	AFWTRPOP	RY1P7ATC(*)	
18.	1.47E-05	P318MDOA	AFWTRPOP	TCAINZAM	V30801PM	
19.	1.40E-05	P318MDOA	AFWTRPOP	TCAINZAM	CVY1RYTC	
20.	1.22E-05	P319ZZPM	P318MDOA	V30801PM		
21.	1.16E-05	P319ZZPM	P318MDOA	AFWTRPOP	CVY1RYTC	
22.	1.05E-05	P318MDOA	V30801PM	P319CNLD	P319CNRE	
23.	1.00E-05	P318MDOA	AFWTRPOP	CVY1RYTC	P319CNLD	P319CNRE
24.	8.40E-06	P318MDOA	P319CNZF	V30801PM		
25.	8.40E-06	P318MDOA	AFWTRPOP	V30801PM	RY1P7ATC(*)	
26.	8.00E-06	P318MDOA	AFWTRPOP	P319CNZF	CVY1RYTC	
27.	8.00E-06	P318MDOA	AFWTRPOP	CVY1RYTC	RY1P7ATC(*)	
28.	7.70E-06	P318MDOA	AFWTRPOP	TCAINZAM	V30801TO	
29.	7.00E-06	P318MDOA	P318SDMF	AFWTRPOP	TCAINZAM	
30.	7.00E-06	P319ZZFS	P318MDOA	AFWTRPOP	TCBINZAM	
31.	6.34E-06	P319ZZPM	P318MDOA	V30801TO		
32.	5.80E-06	P319ZZPM	P318MDOA	P318SDMF		
33.	5.80E-06	P318ZZPM	P319ZZFS			
34.	5.50E-06	P318MDOA	V30801TO	P319CNLD	P319CNRE	
35.	5.00E-06	P318MDOA	P318SDMF	P319CNLD	P319CNRE	
36.	5.00E-06	P319ZZFS	P318MDOA	V30801LD	AFWTRPOP	

(*) Ignored

CUT TOOK .452 SECS

Table A.2: Cutsets for LMFW, No Credit Given to Operator Action

CUT SETS FOR GATE I1 ORDERED BY PROBABILITY

1.	2.52E-04	P318MDOA	LOOP&ZZZ	DGAZZZFS	AFWTRPOP	TCBINZAM
2.	2.09E-04	P318ZZFM	LOOPZZZZ	DGAZZZFS		
3.	1.80E-04	P318MDOA	LOOPZZZZ	DGAZZZFS	V30801LD	AFWTRPOP
4.	1.00E-04	GAL3ZZCM				
5.	1.00E-04	FWSX5ZGL				
6.	7.56E-05	P318MDOA	LOOPZZZZ	DGAZZZFS	V30801PM	
7.	7.20E-05	P318MDOA	LOOPZZZZ	DGAZZZFS	AFWTRPOP	CVY1RYTC
8.	4.90E-05	P318MDOA	AFWTRPOP	TCBINZAM	TCAINZAM	
9.	4.06E-05	P319ZZPM	P318MDOA	AFWTRPOP	TCBINZAM	
10.	4.06E-05	P318ZZPM	AFWTRPOP	TCAINZAM		
11.	3.95E-05	P318MDOA	LOOPZZZZ	DGAZZZFS	V30801TO	
12.	3.60E-05	P318MDOA	P318SDMF	LOOPZZZZ	DGAZZZFS	
13.	3.50E-05	P318MDOA	AFWTRPOP	TCBINZAM	P319CNLD	P319CNRE
14.	3.50E-05	P318MDOA	V30801LD	AFWTRPOP	TCAINZAM	
15.	3.36E-05(*)	P318ZZFM	P319ZZPM			
16.	2.90E-05	P319ZZPM	P318MDOA	V30801LD	AFWTRPOP	
17.	2.90E-05	P318ZZPM	P319CNLD	P319CNRE		
18.	2.80E-05	P318MDOA	AFWTRPOP	P319CNZF	TCBINZAM	
19.	2.80E-05(*)	P318MDOA	AFWTRPOP	TCBINZAM	RY1P7ATC	
20.	2.50E-05	P318MDOA	V30801LD	AFWTRPOP	P319CNLD	P319CNRE
21.	2.32E-05	P318ZZPM	P319CNZF			
22.	2.32E-05(*)	P318ZZPM	AFWTRPOP	RY1P7ATC		
23.	2.00E-05	P318MDOA	V30801LD	AFWTRPOP	P319CNZF	
24.	2.00E-05(*)	P318MDOA	V30801LD	AFWTRPOP	RY1P7ATC	
25.	1.80E-05	FWS045LC	FWS045RE	LOOPZZZZ	DGAZZZFS	
26.	1.80E-05	P318ZZFS	LOOPZZZZ	DGAZZZFS		
27.	1.47E-05	P318MDOA	AFWTRPOP	TCAINZAM	V30801PM	
28.	1.40E-05	P318MDOA	AFWTRPOP	TCAINZAM	CVY1RYTC	
29.	1.22E-05	P318MDOA	LOOPZZZZ	DGAZZZFS	CSVSGARS	CSVSGBRS
30.	1.22E-05	P319ZZPM	P318MDOA	V30801PM		
31.	1.16E-05	P319ZZFM	P318MDOA	AFWTRPOP	CVY1RYTC	
32.	1.05E-05	P318MDOA	V30801PM	P319CNLD	P319CNRE	
33.	1.00E-05	P318MDOA	AFWTRPOP	CVY1RYTC	P319CNLD	P319CNRE

CUT TOOK .434 SECS

(*) Ignored

Table A.3: Cutsets for LOOP - No Operator Credit

CUT SETS FOR GATE I1 ORDERED BY PROBABILITY

1.	2.09E-04	P318ZZPM	LOOPZZZZ	DGAZZZFS	
2.	1.00E-04	GAL3ZZGM			
3.	1.00E-04	FWSX5ZGL			
4.	3.36E-05 (*)	P318ZZPM	P319ZZPM		
5.	2.32E-05	P318ZZFM	P319CNZF		
6.	1.80E-05	FWS045LC	FWS045RE	LOOPZZZZ	DGAZZZFS
7.	1.80E-05	P318ZZFS	LOOPZZZZ	DGAZZZFS	
8.	8.64E-06	P318ZZFR	LOOPZZZZ	DGAZZZFS	
9.	5.80E-06	P318ZZPM	P319ZZFS		
10.	4.41E-06 (*)	PARVA1PM	PARVA2PM		
11.	3.60E-06	FWS047F3	LOOPZZZZ	DGAZZZFS	
12.	3.60E-06	MCM057F3	LOOPZZZZ	DGAZZZFS	
13.	3.60E-06	MCM059F3	LOOPZZZZ	DGAZZZFS	
14.	2.90E-06	P319ZZFM	FWS045LC	FWS045RE	
15.	2.90E-06	P318ZZFS	P319ZZPM		
16.	2.90E-06	P318ZZPM	FWS046LC	FWS046RE	
17.	2.72E-06	LOOPZZZZ	DGAZZZFS	DGBZZZFS	V30801PM
18.	2.00E-06	FWS045LC	FWS045RE	P319CNZF	
19.	2.00E-06	P318ZZFS	P319CNZF		
20.	1.43E-06	LOOPZZZZ	DGAZZZFS	DGBZZZFS	V30801TO
21.	1.39E-06	P318ZZFR	P319ZZPM		
22.	1.39E-06	P318ZZPM	P319ZZFR		
23.	1.30E-06	P318SOMF	LOOPZZZZ	DGAZZZFS	DGBZZZFS
24.	1.10E-06	LOOPZZZZ	DGAZZZFS	DGBZZZFS	BATBZZAM
25.	1.00E-06	FWSX5ZTC	OPX5ZZOE		

CUT TOOK .382 SECS

(*) Ignored

Table A.4: Cutsets for LOOP - Credit Given to Operator Action

CUT SETS FOR GATE I1 ORDERED BY PROBABILITY

1.	7.00E-03	P318MDOA	LOOPZZZZ	DGAZZZFS	AFWTRPOP	TCBINZAM
2.	7.00E-03(*)	LOOPZZZZ	DGAZZZFS	DGBZZZFS	AFWTRPOP	TCBINZAM
3.	5.80E-03	P318ZZPM	LOOPZZZZ	DGAZZZFS		
4.	5.00E-03	P318MDOA	LOOPZZZZ	DGAZZZFS	V30801LD	AFWTRPOP
5.	5.00E-03(*)	LOOPZZZZ	DGAZZZFS	DGBZZZFS	V30801LD	AFWTRPOP
6.	2.10E-03	P318MDOA	LOOPZZZZ	DGAZZZFS	V30801PM	
7.	2.10E-03(*)	LOOPZZZZ	DGAZZZFS	DGBZZZFS	V30801PM	
8.	2.00E-03	P318MDOA	LOOPZZZZ	DGAZZZFS	AFWTRPOP	CVY1RYTC
9.	2.00E-03(*)	LOOPZZZZ	DGAZZZFS	DGBZZZFS	AFWTRPOP	CVY1RYTC
10.	1.10E-03	P318MDOA	LOOPZZZZ	DGAZZZFS	V30801TO	
11.	1.10E-03(*)	LOOPZZZZ	DGAZZZFS	DGBZZZFS	V30801TO	
12.	1.00E-03	P318MDOA	P318SDMF	LOOPZZZZ	DGAZZZFS	
13.	1.00E-03(*)	P318SDMF	LOOPZZZZ	DGAZZZFS	DGBZZZFS	
14.	8.46E-04	LOOPZZZZ	DGAZZZFS	DGBZZZFS	BATBZZAM	
15.	5.00E-04	FWS045LC	FWS045RE	LOOPZZZZ	DGAZZZFS	
16.	5.00E-04	P318ZZFS	LOOPZZZZ	DGAZZZFS		
17.	3.39E-04	P318MDOA	LOOPZZZZ	DGAZZZFS	CSVSGARS	CSVSGBRS
18.	3.39E-04(*)	LOOPZZZZ	DGAZZZFS	DGBZZZFS	CSVSGARS	CSVSGBRS
19.	2.40E-04	P318ZZFR	LOOPZZZZ	DGAZZZFS		
20.	1.00E-04	FWS047FB	LOOPZZZZ	DGAZZZFS		
21.	1.00E-04	MCM057FB	LOOPZZZZ	DGAZZZFS		
22.	1.00E-04	MCM059FB	LOOPZZZZ	DGAZZZFS		
23.	1.00E-04	CALBZZCM				
24.	1.00E-04	FWSX5ZGL				
25.	5.52E-05	P318MDOA	LOOPZZZZ	DGAZZZFS	CSVSGARS	V20596FC
26.	5.52E-05(*)	LOOPZZZZ	DGAZZZFS	DGBZZZFS	CSVSGARS	V20596FC
27.	5.52E-05	P318MDOA	LOOPZZZZ	DGAZZZFS	V20569FC	CSVSGBRS
28.	5.52E-05(*)	LOOPZZZZ	DGAZZZFS	DGBZZZFS	V20569FC	CSVSGBRS

CUT TOOK .384 SECS

(*) Ignored

Table A.5: Cutsets for LOAC - No Operator Credit

CUT SETS FOR GATE I1 ORDERED BY PROBABILITY

1.	5.80E-03	P318ZZFM	LOOPZZZZ	DGAZZZFS		
2.	2.10E-03	LOOPZZZZ	DGAZZZFS	DGBZZZFS	V30801PM	
3.	1.10E-03	LOOPZZZZ	DGAZZZFS	DGBZZZFS	V30801TO	
4.	1.00E-03	P318SDMF	LOOPZZZZ	DGAZZZFS	DGBZZZFS	
5.	8.46E-04	LOOPZZZZ	DGAZZZFS	DGBZZZFS	BATBZZAM	
6.	5.00E-04	FWS045LC	FWS045RE	LOOPZZZZ	DGAZZZFS	
7.	5.00E-04	P318ZZFS	LOOPZZZZ	DGAZZZFS		
8.	3.39E-04	LOOPZZZZ	DGAZZZFS	DGBZZZFS	CSVSGARS	CSVSGBRS
9.	2.40E-04	P318ZZFR	LOOPZZZZ	DGAZZZFS		
10.	1.00E-04	FWS047FB	LOOPZZZZ	DGAZZZFS		
11.	1.00E-04	HCM057FB	LOOPZZZZ	DGAZZZFS		
12.	1.00E-04	HCM059FB	LOOPZZZZ	DGAZZZFS		
13.	1.00E-04	CALBZZCM				
14.	1.00E-04	FWSX5ZGL				
15.	7.00E-05	LOOPZZZZ	DGAZZZFS	DGBZZZFS	AFWTRPOP	TCBINZAM
16.	5.52E-05	LOOPZZZZ	DGAZZZFS	DGBZZZFS	CSVSGARS	V20596FC
17.	5.52E-05	LOOPZZZZ	DGAZZZFS	DGBZZZFS	V20569FC	CSVSGBRS
18.	5.00E-05	LOOPZZZZ	DGAZZZFS	DGBZZZFS	V30801LD	AFWTRPOP
19.	3.36E-05	P318ZZPM	P319ZZPM(*)			
20.	2.32E-05	P318ZZFM	P319CNZF			
21.	2.10E-05	P318MDOA	LOOPZZZZ	DGAZZZFS	V30801PM	
22.	2.00E-05	LOOPZZZZ	DGAZZZFS	DGBZZZFS	AFWTRPOP	CVY1RYTC
23.	1.22E-05	P310ZZPM	LOOPZZZZ	DGBZZZFS	V30801PM	
24.	1.10E-05	P318MDOA	LOOPZZZZ	DGAZZZFS	V30801TO	
25.	1.00E-05	P318MDOA	P318SDMF	LOOPZZZZ	DGAZZZFS	
26.	1.00E-05	LOOPZZZZ	DGAZZZFS	DGBZZZFS	CNSTADZF	

CUT TOOK .374 SECS

(*) Ignored

Table A.6: Cutsets for LOAC - Credit Given to Operator Action

RANCHO SECO RELIABILITY ANALYSIS RUN # 3 BNL REPORT

INPUT COMPONENT LIST

(1) COMPONENT NUMBER
(2) COMPONENT NAME
(3) FIRST MOMENT OF COMPONENT UNAVAILABILITY
(4) SECOND MOMENT OF COMPONENT UNAVAILABILITY

(1)	(2)	(3)	(4)	
1	FWS061FB	1.0000E-04	-0.	check valve – discharge
2	PARVA1PM	2.1000E-03	-0.	Parallel Valves – "
3	FWS062FB	1.0000E-04	-0.	check valve – "
4	GAL3ZZCM	1.0000E-04	-0.	Miscalibration
5	PARVA2PM	2.1000E-03	-0.	
6	P318-319T	1.3000E-03	-0.	Pumps on test
7	FWSX5ZGL	1.0000E-04	-0.	Recirc Valve
8	FWSX5ZTC	2.0000E-04	-0.	" "
9	FWSX5CNF	1.0000E-05	-0.	" "
10	9PX5ZZOE	5.0000E-03	-0.	" " left open
11	V20527TO	3.0000E-04	-0.	Control valve – discharge
12	FVK3ZZFC	1.0000E-04	-0.	Isolation " – "
13	FVK1ZZTO	3.0000E-04	-0.	Control " – "
14	V20577FC	1.0000E-04	-0.	Isolation " – "
15	V31826MF	1.0000E-04	-0.	Cross connect MOV
16	V31827MF	1.0000E-04	-0.	" " "
17	CST358AM	3.6000E-07	-0.	Condensate Storage Tank
18	HCM059FB	1.0000E-04	-0.	Manual valve – suction
19	HCM057FB	1.0000E-04	-0.	" " "
20	V20528TO	3.0000E-04	-0.	Control valve – discharge
21	FVK4ZZFC	1.0000E-04	-0.	Isolation " – "
22	FVK2ZZTO	3.0000E-04	-0.	Control " – "
23	V20578FC	1.0000E-04	-0.	Isolation " – "
24	HCM060FB	1.0000E-04	-0.	Check valve – suction
25	HCM058FB	1.0000E-04	-0.	Manual valve – "
26	V31826PM	2.1000E-03	-0.	cross-connect MOV
27	V31827PM	2.1000E-03	-0.	" "
28	FWS047FB	1.0000E-04	-0.	check valve – discharge
29	P318ZZFR	2.4000E-04	-0.	Dual pump
30	P318ZZFS	5.0000E-04	-0.	" "
31	P318ZZPM	5.8000E-03	-0.	" "
32	BATAZZAM	8.4600E-04	-0.	Battery A failure
33	FWS048FB	1.0000E-04	-0.	check valve – discharge
34	P319ZZFR	2.4000E-04	-0.	Electric motor pump
35	P319ZZFS	1.0000E-03	-0.	" " "
36	P319ZZPM	5.8000E-03	-0.	" " "
37	EFICASCM	1.0000E-06	-0.	
38	FWS045LC	5.0000E-04	-0.	Manual valve
39	FWS045RE	1.0000E+00	-0.	" "
40	P318MDCF	4.0000E-03	-0.	Motor drive, pump 318
41	P318MDOA	1.0000E-02	-0.	" " , " "
42	P318MDMF	1.0000E-03	-0.	" " , " "
43	P318SDMF	1.0000E-03	-0.	Steam drive, " "
44	LOOPZZZZ	1.0000E-07	-0.	Loss of off site power
45	DGAZZZFS	3.6000E-02	-0.	Diesel generator A
46	FWS046LC	5.0000E-04	-0.	Manual valve
47	FWS046RE	1.0000E+00	-0.	" "

; FB = Failed blocked
; PM = Preventive Maintenance
; CM = Common Mode
; GL = Gross Leakage
; TC = Fail to close
; control failure
; TO = Fail to open
; FC = Failed closed
; MF = mechanical failure

FR = Fail to run
FS = " – start

LC = Left closed
RE = operator realign
CF = control failure
OA = operator fails to actuate

48	DGBZZZFS	3.6000E-02	-0.	Diesel Generator B	
49	V30801LD	5.6000E-03	-0.	Steam Admission valve	LD = left disabled
50	AFWTRPOP	1.0000E-02	-0.	Failure of operator to actuate.	
51	P319GNZF	4.0000E-03	-0.	Electric motor-pump	control failure
52	TCBMBRFO	1.0000E-05	-0.		
53	GNBRYATC	7.0000E-06	-0.		
54	GNBRYCTC	7.0000E-06	-0.		
55	TCBINZAM	7.0000E-03	-0.	EFIC-B failure	
56	RY1CAPTC	7.0000E-06	-0.		
57	RY2CAPTC	7.0000E-06	-0.		
58	INCAPZAM	1.2000E-04	-0.		
59	BRGAPZFO	1.0000E-04	-0.		
60	TCAMBRFO	1.0000E-04	-0.		
61	TCAINZAM	7.0000E-03	-0.	EFIC-A failure	
62	V30801TO	1.1000E-03	-0.	Steam Admission Valve	TO = Fail to open
63	GNSTAOZF	1.0000E-05	-0.		
64	V30801PM	2.1000E-03	-0.	" " "	
65	GVY1RYTC	2.0000E-03	-0.	Local control of steam	admission valve.
66	RY1P7ATC	4.0000E-03	-0.	" " " electric	pump (Ignored).
67	P319GNLD	5.0000E-03	-0.	Electric pump left disabled	
68	P319GNRE	1.0000E-02	-0.	Operator corrective action	failed.
69	BATBZZAM	8.4600E-04	-0.	Battery B failure	
70	REBRYASH	7.0000E-06	-0.		
71	BABRYAFO	1.0000E-05	-0.		
72	RYBRYATC	7.0000E-06	-0.		
73	REBRYBSH	7.0000E-06	-0.		
74	BABRYBFO	1.0000E-05	-0.		
75	RYBRYBTC	7.0000E-06	-0.		
76	REARYASH	7.0000E-06	-0.		
77	BAARYAFO	1.0000E-05	-0.		
78	RYARYATC	7.0000E-06	-0.		
79	REARYBSH	7.0000E-06	-0.		
80	BAARYBFO	1.0000E-05	-0.		
81	RYARYBTC	7.0000E-06	-0.		
82	MSS052FB	1.0000E-04	-0.	Check valve on Steam line	
83	V20569FC	3.0000E-03	-0.	MOV on steam line	
84	GSVSGARS	1.8400E-02	-0.	SGA relief valve failure	
85	MSS051FB	1.0000E-04	-0.	check valve on steam line	
86	V20596FC	3.0000E-03	-0.	MOV on steam line	
87	GSVSGBRS	1.8400E-02	-0.	SGB relief valve failure	
88	CHARGCAM	1.0000E-04	-0.		
89	CHARGDAM	1.0000E-04	-0.	charger failure	
90	CHARGAAM	1.0000E-04	-0.		
91	CHARGBAM	1.0000E-04	-0.		

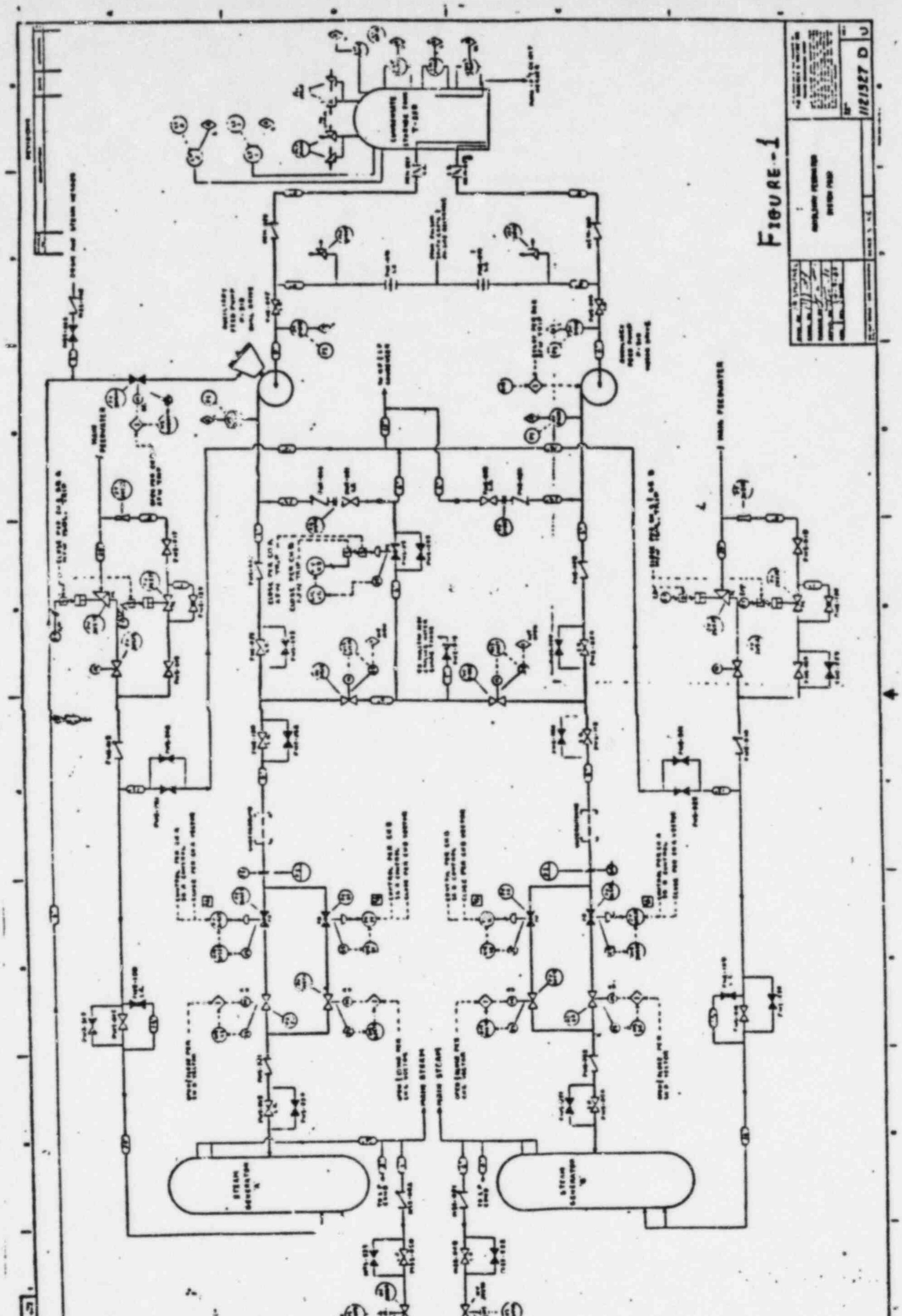
Figure-1
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