# EMERGENCY FEEDWATER SYSTEM
# RELIABILITY ANALYSIS
# FOR THE
# ARKANSAS NUCLEAR ONE NUCLEAR GENERATING STATION
# UNIT NO. 1

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Revision 1 - December 1979

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# EXECUTIVE SUMMARY

The NRC has requested all operating plants with Babcock & Wilcox (B&W) designed reactors to consider means for upgrading the reliability of their Emergency Feedwater Systems (EFWS). As a part of the response to this request, AP&L and the other B&W Owners Group utilities have requested B&W to perform a simplified reliability analysis of existing emergency feedwater systems. This draft report presents the results of that reliability study for the ANO-1 EFWS.

The primary objective of this study was to evaluate ANO-1 EFWS reliability (defined as "point unavailability") using an approach which would produce results comparable to those obtained by NRC staff analyses for Westinghouse and Combustion Engineering Plants. Another objective was to identify dominant failure contributors affecting system reliability.

EFWS reliability was assessed for three cases: Loss of Main Feedwater (LMFW) with reactor trip, LMFW with Loss of Offsite Power (LMFW/LOOP) and LMFW with Loss of all AC power (LMFW/LOAC). System reliability was assessed by the construction and analysis of fault trees.

The results of this study are on the following page. These results indicate the ANO-1 EFWS reliability, based on the reliabilities obtained by the NRC for Westinghouse plants, is low to medium for all cases.

Dominant failure contributors which were identified in this study include: 1) system unavailability resulting from preventive maintenance activities, 2) failures of EFWS initiation and control components, resulting in failure to obtain actuation for either EFWS train, 3) AC dependence of all valves needed to obtain EFW flow during LMFW/LOAC.

A similar study will be performed for each Owners Group utility and additional plant specific draft reports will be prepared. At the conclusion of the program, information contained in the plant specific reports will be collected and used to generate an EFWS reliability report comparing all B&W operating plants.

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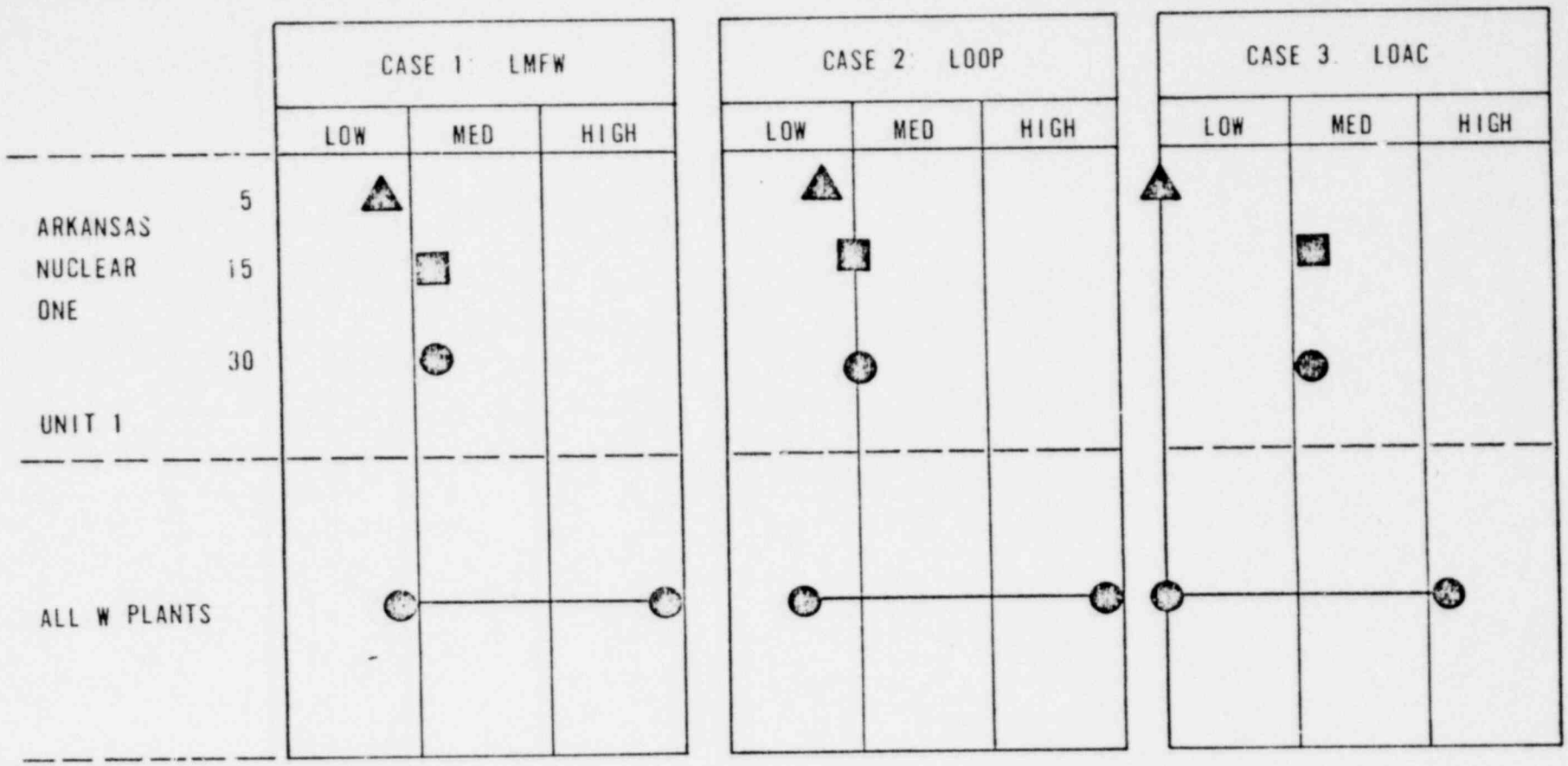


COMPARISON OF ANO-1 EFWS RELIABILITY WITH NRC RESULTS FOR W PLANTS

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# 1.0 Introduction

## 1.1 Background

This report presents the results of a reliability study for the Arkansas Nuclear One Unit 1 (ANO-1) Emergency Feedwater System (EFWS). The NRC is conducting similar analyses for Westinghouse and Combustion Engineering plants. Preliminary results of the NRC study are available (Reference 1) and have been included in this report for comparison with the ANO-1 EFWS reliability. The approach employed in this study has been developed in close coordination with the NRC and is therefore expected to yield comparable results.

## 1.2 Objectives

The objectives of this study are:

- To perform a simplified analysis to assess the relative reliability of the ANO-1 EFWS. It is intended that the results of this analysis be directly comparable to those obtained by the NRC for Westinghouse and Combustion Engineering plants. This is assured by the use of the same evaluative technique, event scenarios, assumptions and reliability data used by the NRC.
- To identify, through the development of reliability-based insight, dominant failure contributors to the ANO-1 EFWS unreliability.

## 1.3 Scope

Three event scenarios were analyzed:

- Case 1 - Loss of Main Feedwater with Reactor Trip (LMFW).
- Case 2 - LMFW coincident with Loss of Offsite Power (LMFW/LOOP).
- Case 3 - LMFW coincident with Loss of all AC Power (LMFW/LOAC).

These event scenarios were taken as given; that is, postulated causes for these scenarios and the associated probabilities of their occurrence were not considered. Additionally, external common mode events (earthquakes, fires, etc.) and their effects were excluded from consideration.

For each of the three cases, system reliability as a function of time was evaluated.



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## 1.4 Analysis Technique

The evaluation of reliability for the ANO-1 EFWS was based primarily on the construction and analysis of fault trees. This technique encourages the development of insights which permit identification of the primary contributors to system unreliability. Application of this technique is described in detail in Section 3.1.

## 1.5 Assumptions and Criteria

Assumptions and criteria were made in consultation with the NRC staff and were selected to assure that the ANO-1 reliability evaluation results will be comparable to those obtained by the NRC for the Westinghouse and Combustion Engineering analyses.

1) Criterion for Mission Success - In order to evaluate the overall reliability contribution of system components, it is necessary to establish whether or not failure of those components will prevent successful accomplishment of the EFWS mission. Thus, it is necessary to explicitly define the criterion for mission success. The criterion adopted for this study was the attainment of flow from at least one pump to at least one steam generator. Mission success can be alternatively defined as at least one running pump with suction to a source of water and an open flow path to at least one generator without flow diversion.

   System reliability was calculated at times of 5, 15, and 30 minutes to allow for a range of operator action. These times were specifically chosen because NRC-supplied operator reliability data for these times was available; however, these times are reasonable and consistent with LMFW mitigation for B&W plants. In their study, the NRC staff has used steam generator dryout time as a criterion for successful EFWS initiation, and the 5 minute case represents a comparable result for B&W plants since emergency feedwater delivery within 5 minutes will prevent steam generator dryout. However, steam generator dryout itself does not imply serious consequences; a more appropriate criteria is the maintenance of adequate core cooling. Recent ECCS analyses (Reference 2) have shown that adequate core cooling can be maintained for times in excess of 20 minutes without EFWS operation, providing that at least one High Pressure Injection Pump is operated.



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2) Power Availability - The following assumptions were made regarding power availability:

LMFW - All AC and DC power was assumed available with a probability of 1.0.

LMFW/LOOP - The most limiting diesel generator was unavailable with a probability of $10^{-2}$. The other generator was assumed available with a probability of 1.0. (The most limiting generator was DG-1 (see Figure 3) except for the case in which motor-driven EFWS pump P7B was in preventive maintenance.)

LMFW/LOAC - DC and battery-backed AC were assumed available with a probability of 1.0.

3) NRC-Supplied Data - NRC-supplied unreliability data for hardware, operator actions and preventive maintenance were assumed valid and directly applicable. These data are listed in Appendix B.

4) Coupled Manual Actions - Manual initiation of valves with identical function was considered coupled. Such valves were assumed to be both opened manually or both not opened. The case in which one valve was opened and the other valve was left closed was not considered.

5) Degraded Failures - Degraded failures were not considered; that is, components were assumed to operate properly or were treated as failed.

6) Integrated Control System Reliability - The degree of separation and redundancy of Integrated Control System circuits responsible for EFWS initiation and control for each EFWS train has not been fully evaluated. For the purpose of this study, the ICS was assumed to consist of only a single control device with signals to both EFWS trains and a combined failure probability of $7 \times 10^{-3}$ was assigned to the ICS functions of pump actuation and isolation valve opening.

7) Relief Valve Opening - Operation of the EFWS turbine steam inlet relief valves is unclear. For this study, it was assumed that both valves would open at least once in the course of turbine initiation and continued use.



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8) Flow Diversion - Lines on the order of 1-inch were ignored as possible flow diversion paths. It was assumed that inadvertent opening of recirculation valves FW11A or FW12A will defeat pump P7A; similarly, opening of FW11B or FW12B will defeat pump P7B. However, the effects of the 2-inch line containing interlocked valves CV2815 and CV2816 were ignored. (These effects could include flow degradation from the turbine driven pump if both the valves are incorrectly open or damage to the pump if either valve is incorrectly closed when increased recirculation is required.)

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## 2.0 System Description

### 2.1 Overall Configuration

A diagram of the ANO-1 EFWS is presented in Figure 1. The system consists of two interconnected trains, capable of supplying auxiliary feedwater to either or both steam generators under automatic or manual initiation and control.

#### 2.1.1 Suction

The primary water source for both EFWS trains is the condensate storage tank, T-41. This tank is required by technical specifications to contain a reserve of 107,000 gallons for EFWS use. The tank level is not indicated in the control room; however, there is a low level alarm in the control room which is battery-backed.

Water is supplied from this tank to a common suction header via a single 8-inch line containing normally open valve CS19 and check valves CS99 and CS98. There are other connections to this suction supply line including supply connections to the condensate transfer pumps and an interconnection with the unit 2 condensate storage tank, 2T-41. For this study, a penalty was taken for diverted suction flow to the transfer pumps. However, even though the unit 2 condensate storage tank will usually be available as an alternate water supply for the unit 1 EFWS, no credit was taken for this source because technical specifications do not make unit 1 operation contingent on the availability of water from unit 2.

An alternate EFWS suction source is available from the nuclear service water system. This source is described in detail in section 2.2. Suction may be manually transferred from the condensate storage tank to the nuclear service water system by means of AC motor-operated valve pairs CV2806/CV2802 and CV2803/CV2800. A common control switch for each pair causes the valves to assume opposite positions; that is, if one valve (e.g., CV2806) is open, then the other valve (CV2802) is closed and vice versa. Operators are alerted to perform this suction transfer by a low suction pressure alarm on the common suction header.



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### 2.1.2 Pumps and Discharge Cross-Tie

EFWS train A uses a turbine-driven pump, P7A, rated at 720 gpm at 1070 psig. This flow includes a normal recirculation flow of 15 gpm. The train B pump P7B, is motor-driven and is rated at 780 gpm at 1070 psig including a normal recirculation flow of 78 gpm.

The pumps discharge through check valves into a discharge cross-tie line containing two normally-open AC motor-operated valves (CV2813 and CV2814). This cross-tie permits either pump to feed either or both steam generators.

### 2.1.3 Steam Generator Isolation Vaives

The flow of emergency feedwater to each steam generator is controlled by normally-closed AC motor-operated "isolation valves" (CV2670 and CV2620). These fast-acting valves maintain steam generator water level to the desired setpoint. Control for these valves is obtained from the Integrated Control System (ICS) and is described in detail in Section 2.4.

The ICS-controlled valves are bypassed by two normally-closed AC motor-operated bypass valves (CV2627 and CV2626). These valves are under manual control only.

### 2.1.4 Steam Supply for the EFWS Turbine

Steam for the EFWS turbine is obtained from both steam generators via normally-closed AC motor-operated valves (CV2667 and CV2617). These valves are opened automatically by the ICS on EFWS initiation. They also may be opened by the Steam Line Break Instrumentation and Control System (SLBIC) or manually. A description of the ICS and SLBIC control for these valves is contained in Section 2.4. Valve CV2667 is bypassed by a normally-closed AC motor-operated valve (CV2666). This valve can be opened manually to admit steam from steam generator A to the EFWS turbine.

Steam from these valves passes into a common 4-inch line, through a restricting orifice to the turbine governor valve. A turbine overspeed trip valve is also provided to trip the turbine if turbine speed becomes excessive. Turbine trip is alarmed in the control room; the trip valve must be reset locally.



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Two overpressure relief valves (PSV6601 and PSV6602) are connected to the steam supply line upstream of the turbine governor. These valves are expected to open anytime there is insufficient steam flow to produce a significant pressure drop across the restricting orifice. These valves may briefly open upon turbine initiation, or whenever the ICS-controlled isolation valves (CV2670 and CV2620) and manual bypass valves (CV2627 and CV2626) are all closed.

Turbine exhaust is vented to the atmosphere.

2.1.5 Other Important System Features

Primary components for EFWS operation are described above. There are additional system features, however, which affect overall system reliability. These features are described below:

Recirculation and Test Lines - Recirculation and test lines are connected to the discharge piping of both pumps. Normal recirculation for pump protection is accomplished with normally open flow paths consisting of small lines, restricting orifices and needle valves as shown in Figure 1. Additionally, for the turbine driven pump, there are two AC motor-operated valves, CV2815 and CV2816, in an alternate path which are interlocked with the EFWS isolation and bypass valves (CV2627, CV2670, CV2620 and CV2626). If all isolation and bypass valves are blocking flow to both steam generators, CV2815 and CV2816 will open to increase recirculation flow for pump P7A. However, if any one of the four isolation or bypass valves is open, at least one of the valves, CV2815 or CV2816, will be closed.

Of significance to system reliability is the recirculation test line and its interconnected valves (FW11A, FW11B, FW12A and FW12B). These valves are used to perform full flow tests of the EFWS pumps by diverting flow to the condensor hotwell, the condensate storage tank or the cooling water discharge flume. For this study, it was assumed that, if either of the valves, FW11A or FW12A, is inadvertently left open, train A will be defeated. Similarly, inadvertent opening of FW11B or FW12B will defeat train B.

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SLBIC - The Steam Line Break Instrumentation and Control System isolates a steam generator in the event of a steam line or feedwater line rupture. The SLBIC closes main steam block valves CV2691 or CV2692 as well as main feedwater isolation valves not shown on Figure 1. The SLBIC also initiates the EFW turbine by opening steam supply valves CV2667 and CV2617.

### 2.1.6 Valve Indication and Operation

All motor-operated valves in the EFWS are AC powered. All fail "as is" on loss of AC and all are controllable and position indicated in the control room. The power for valve control and position indication for these valves is derived from the power source for the valve operator. For those valves which receive automatic signals from the ICS or SLBIC, manual override of the signal is possible at any time.

The atmospheric dump valves and the main steam block valves fail closed on loss of air. The dump valves fail to about 50% open on loss of control signal.

## 2.2 Supporting Systems and Backup Water Source

The EFWS pumps, pump motor and turbine are self-contained entities without dependencies on secondary support systems. The bearings on the turbine and both pumps are lubricated by slinging oil from reservoirs near the bearings. Cooling is accomplished by heat transfer to the surroundings.

The only support system of significance to the EFWS is the backup water supply source. This source is the service water system and those portions of this system pertinent to the EFWS are shown in Figure 2.

As shown in the figure, water is pumped from a reservoir by any or all of three service water pumps P4A, P4B or P4C which are on diesel generator-backed power. The discharge of these pumps passes through filters, check valves and normally-open manual valves (SW2A, 2B, 2C) to a system of normally-closed, cross-over valves. The purpose of these cross-over valves is to divert flow from the auxiliary cooling water system to one of the service water loops if required.

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During normal operation, two of the three pumps will be running, supplying water to one loop of the service water system and to the auxiliary cooling water system. An engineered safeguard signal caused the flow to the auxiliary cooling water system to be diverted to the other service water loop. This action can also be performed manually by setting the correct valve alignments.

In any event, manual action (opening of normally closed AC motor-operated valves CV3850 or CV3851) is required to obtain water from service water Loop I or Loop II for EFWS use.

The description of valve indication and operation contained in Section 2.1.6 is applicable to the service water valves shown in Figure 2.

## 2.3 Power Sources

A simplified diagram showing power distribution for EFWS and service water system components is shown in Figure 3. As indicated, AC power for all components needed to obtain emergency feedwater flow is derived from diesel generator-backed 4160 VAC busses.

Normally (Case 1), power for these busses is supplied from the switchyard. However, in the event of LMFW/LOOP (Case 2), the diesel generators are started automatically and all EFWS components will remain operable. (The motor-driven pump is automatically loaded on bus A3 after a 100-second delay.) No manual actions are required.

In the event of LMFW/LOAC (Case 3), the EFWS is initially unavailable because of the AC dependence of EFWS valves. Manual action to locally open a turbine steam supply valve and a steam generator isolation or bypass valve is required to obtain EFWS flow. Continued operation of the turbine-driven pump may require periodic manual opening and closing of the isolation or bypass valves and the recirculation valves CV2815 and CV2816.

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## 2.4 Instrumentation and Control

### 2.4.1 Initiation and Control

A logic diagram showing the means of EFWS initiation and control is provided in Figure 4. This simplified diagram is intended to show function only and does not show redundancies and protective interlocks which actually exist in the hardware.

EFWS initiation and control are performed primarily by the ICS, and each is essentially a separate function of the ICS. Logic for these functions is battery-backed.

EFWS initiation consists of pump actuation. As shown in Figure 4(A), low level in either steam generator, or a trip of all reactor coolant pumps, or a trip of both main feedwater pumps (if the reactor power was greater than 5% RTP 30 seconds earlier) will result in an ICS signal to start both EFWS pumps. The pumps can also be started manually and, in addition, the turbine pump can be started by a SLBIC signal.

EFWS flow is also controlled by the ICS. This is accomplished by opening and closing the steam generator isolation valves (CV2620 and CV2670) in a manner depicted in Figure 4(B). If both main feedwater pumps have tripped, the ICS will open or close the isolation valve for each steam generator to maintain the water level near a predetermined setpoint (10% on the startup instrumentation range). If all 4 RC pumps have tripped, the ICS will control the level to a higher setpoint (50% on the operate instrumentation range).

The isolation valve may also be opened or closed manually; but, in any case, the hand switch (ICS "Block Open" or "Block Close") shown in Figure 4(B) must not be set to block the desired operation.



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2.4.2 Instrumentation

The following instrumentation pertaining to the EFWS or supporting systems is provided in the control room.

| Instrumentation | Available in Case 1 | Case 2 | Case 3 |
|---|---|---|---|
| • Steam Generator Level for S/G A and S/G B | Yes | Yes | Yes |
| • Low EFW Pump Suction Pressure Alarm | Yes | Yes | No |
| • EFW Discharge Pressure Alarm and Indication | Yes | Yes | No |
| • EFW Turbine Inlet Steam Pressure | Yes | Yes | No |
| • Service Water Pressure for Loop I and Loop II | Yes | Yes | No |
| • EFW Flow to S/G A and S/G B | Yes | No | No |
| • CST Low Low Level Alarm | Yes | Yes | Yes |

2.5 Operator Actions

Assuming no component failures and correct system valve alignment, no operator actions are required for EFWS mission success for Cases 1 and 2.

For Case 3, operator action is required to open a turbine steam admission valve. Also, an operator must open a steam generator isolation valve in order to achieve EFWS flow. Continued system operation may also require periodic manual valve operation to control OTSG level, as well as operation fo the pump P7A recirculation valves (CV2815 and CV2816).

In all cases, if the condensate storage tank is depleted, manual action is required to switch EFWS pump suction to the service water system.

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## 2.6 Testing

The operability of both EFWS pumps is checked monthly by a test using the mini-flow recirculation lines. This test demonstrates that the pumps will start, operate for 5 minutes, and develop the correct discharge pressure.

During startup and after any changes in EFWS valve alignment, all manual EFWS valves are verified to be in the correct, locked position. In addition, all non-locked valves are checked monthly to assure that they are positioned correctly. Motor-operated valves are demonstrated to be operable by quarterly tests.

Every eighteen months, the entire EFWS is functionally tested including the automatic actuation of valves and pumps, verification that feedwater is delivered to the steam generators, and verification that the system can be operated manually.

## 2.7 Technical Specification Limitations

Technical Specifications require that both EFWS pumps be available anytime the reactor coolant temperature exceeds 280°F. If, however, the reactor is operating and one pump is determined to be inoperable, the reactor must be placed in hot shutdown within 36 hours.

Technical Specifications also require that 107,000 gallons of water be held in reserve in the condensate storage tank for EFWS use.

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## 3.0 Reliability Evaluation

### 3.1 Fault Tree Technique

The ANO-1 EFWS reliability was evaluated by constructing and analyzing a fault tree. The fault tree developed during this study is contained in Appendix A. The top level event in this tree is failure to achieve mission success; from this point, the tree branches downward to a level of detail corresponding to NRC-supplied data. This level is generally indicated by basic event circles.

For construction of the first tier of the tree (page A-1), the EFWS components in each train were grouped into three categories - Suction, Pump and Discharge. System failure can result from Suction 1 - Suction 2, Pump 1 - Pump 2, or Discharge 1 - Discharge 2 failures or from failures within one train when the other train is out of service for preventive maintenance. The fault tree also accounts for system failures resulting from combination failures such as Pump 1 - Discharge 2 with the appropriate discharge cross-connection unavailable. All combinations considered are indicated by the first tier.

The techniques used in fault-tree construction and the symbols shown in Appendix A are consistent with those used in WASH-1400 (Reference 3). Following completion of the tree, hand calculations were performed to obtain system unavailability for 5, 15 and 30 minutes for each of the three event scenario cases.

### 3.2 Comparative Reliability Results

The results of the analysis are presented in Figure 5. Indicated in this figure are the system reliability results for each of the three cases and for each time 5, 15 and 30 minutes. The basic format for this figure, including the characterization of Low, Medium, and High reliability, was adopted from information presented by the NRC in Reference 1. Because the NRC-supplied input data were often unverified estimates of component and human reliability, absolute values of calculated system reliability must be de-emphasized; results have significance only when used on a relative basis for purposes of comparison. Accordingly, the intent of Figure 5 is to show the relative reliability standing of the ANO-1 EFWS for each of the three cases and also to compare these results to the

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NRC results for Westinghouse plants. The Westinghouse results and numerical values permitting construction of Figure 5 were all obtained from Reference 1. It should be noted that there is a scale change for the Case 3 results; reliability results for Case 3 cannot be cross-compared with Cases 1 and 2.

As shown in Figure 5, relative to Westinghouse, ANO-1 has low to medium reliability for Cases 1 and 2; Case 3 has low reliability for success in 5 minutes, but medium reliability for success in 15-30 minutes. The underlying causes for these reliability results are described in Section 3.3.

Some general observations may be made regarding the results in Figure 5. As the time for operator action increases from 5 to 30 minutes, the probability of mission success usually improves. Most of the improvement occurs between 5 and 15 minutes, reflecting a significant difference in the NRC-supplied operator reliability data for these times. On the other hand, there was little difference in the operator reliability data between 15 and 30 minutes and this is reflected in the system unavailability results. The small difference in the results for Cases 1 and 2 indicates the relatively small effect associated with the improbable loss of one diesel generator. The Case 3 results stem from the AC dependence of all EFWS motor-operated valves.

## 3.3 Dominant Failure Contributors

### 3.3.1 Case 1 - LMFW

The dominant failure contributor for Case 1 is the unavailability of one EFWS train because of preventive maintenance activities. Outage for preventive maintenance reduces system redundancy, and, coupled with component or human failure affecting the other train, results in mission failure.

Another significant contributor is component failure within the ICS that results in failure to obtain system actuation. The ANO-1 EFWS relies on common components within the ICS for initiation and control of both EFWS trains. It is apparent that this lack of separation and independence is a significant factor affecting mission success.

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Other significant failure contributors for Case 1 are:

- o Flow diversion of either train because the full flow recirculation block valves FW11A, FW12A, FW11B or FW12B are inadvertently open.
- o Failure of the motor-driven pump caused by incorrect alignment or plugging of suction valves CV2803 and CV2800.
- o Failure to perform manual switchover to the service water system on depletion of the condensate storage tank.

3.3.2 Case 2 - LMFW/LOOP

Significant failure contributors for Case 2 are the same as for Case 1.

3.3.3 Case 3 - LMFW/LOAC

The dominant failure contributor for Case 3 is the AC dependence of all valves necessary to obtain steam for the EFW turbine and admit emergency feedwater to either steam generator. The system will be initially unavailable because of this AC dependence. Subsequent manual action, described in Section 2.5, will be required to operate these valves to both initiate the system and to support continued system operation.

Another significant failure contributor for Case 3 is inadequate steam supply to the EFW turbine caused by an overpressure relief valve failing to reseat after opening.

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## REFERENCES


1) "Auxiliary Feedwater Reliability Study", an NRC staff presentation to the ACRS at the ACRS meeting of July 26, 1979, 1717 "H" Street, Room 1046, Washington, D.C.

2) "Evaluation of Transient Behavior and Small Reactor Coolant System Breaks in the 177 Fuel Assembly Plant", May 7, 1979.

3) WASH-1400 (NUREG-75/014), "Reactor Safety Study (Appendix II)," USNRC, October 1975.


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FIGURE 1 ANO-1 EFWS

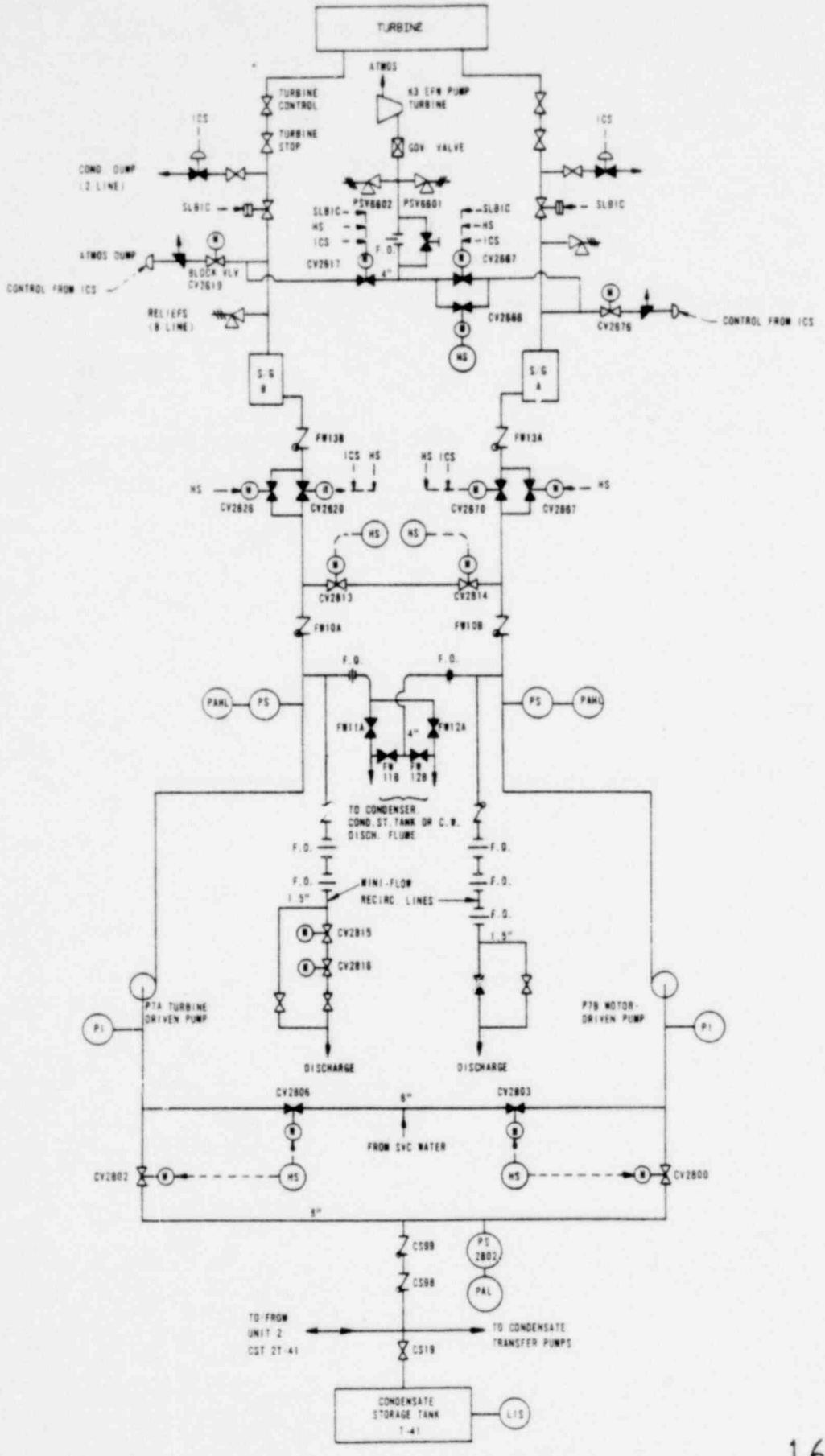


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FIG 2. SVC WATER SYSTEM - ALTERNATE EFW WATER SUPPLY - ANO-1

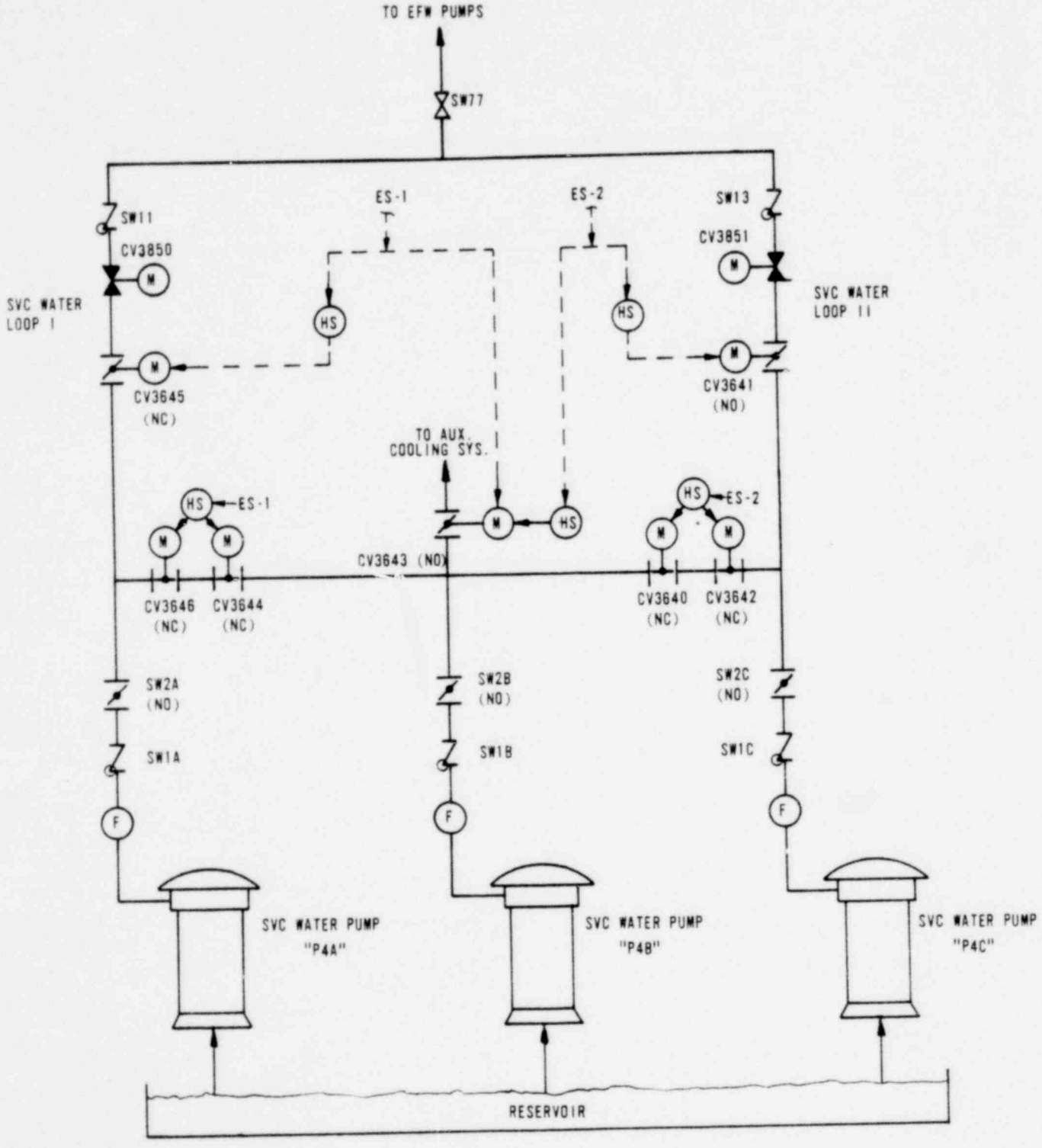


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FIG. 3 AC POWER DISTRIBUTION TO COMPONENTS IN EFWS & SVC WATER SYSTEM - ANO-1

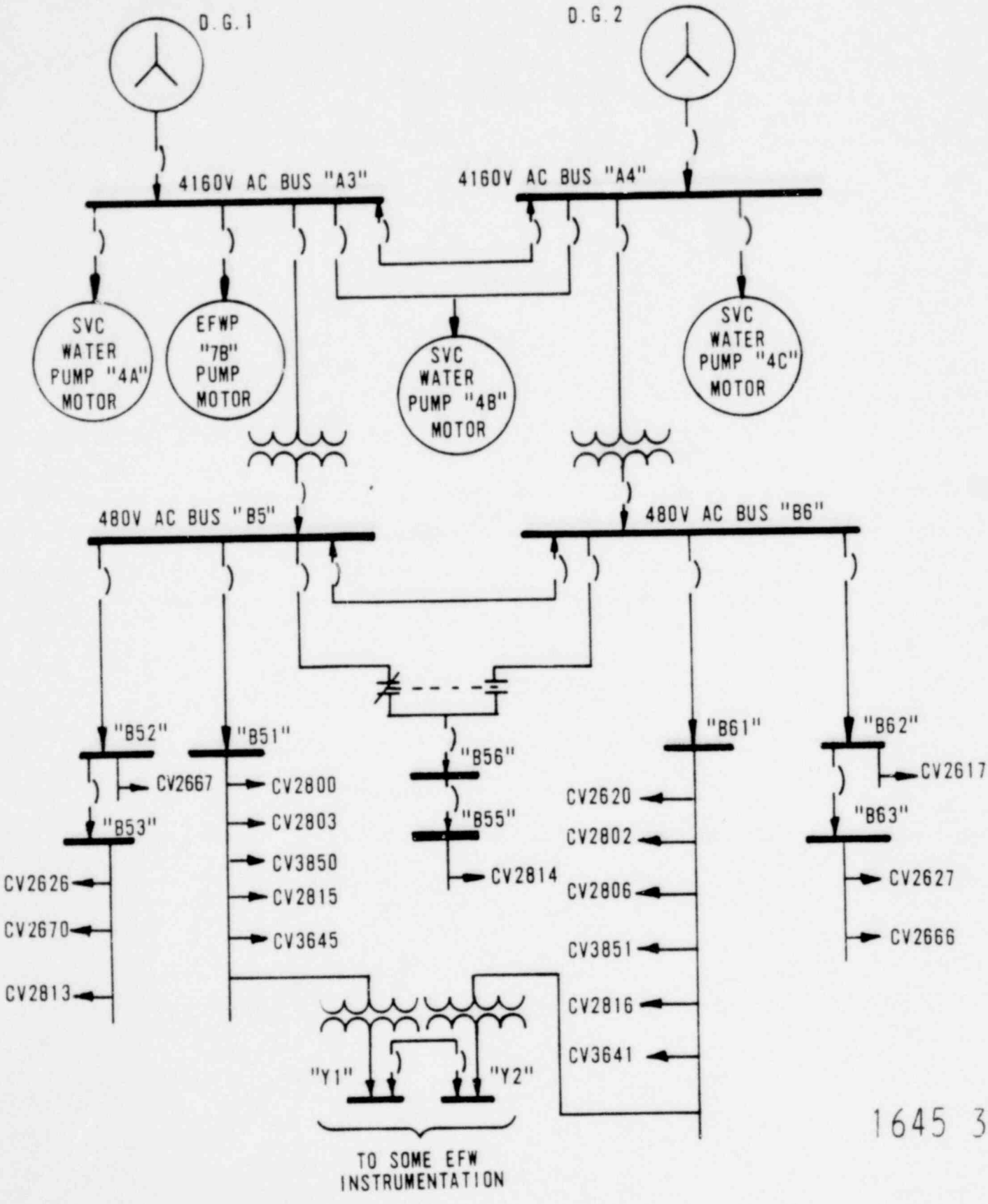


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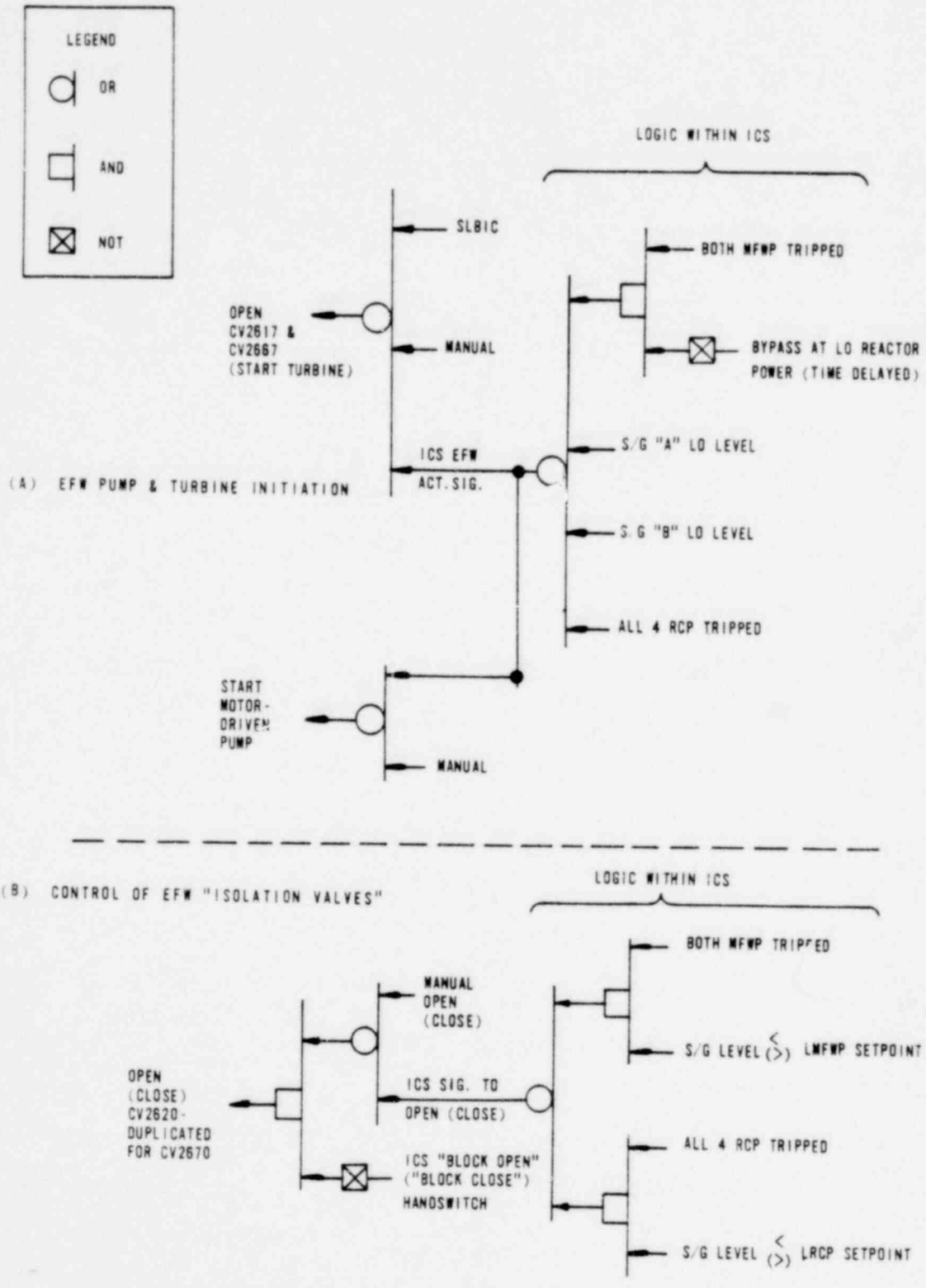
FIG. 4. ANO-1 EFW INITIATION & CONTROL FUNCTIONAL LOGIC DIAGRAM-SIMPLIFIED




NOTE. REDUNDANCIES & PROTECTIVE INTERLOCKS NOT SHOWN

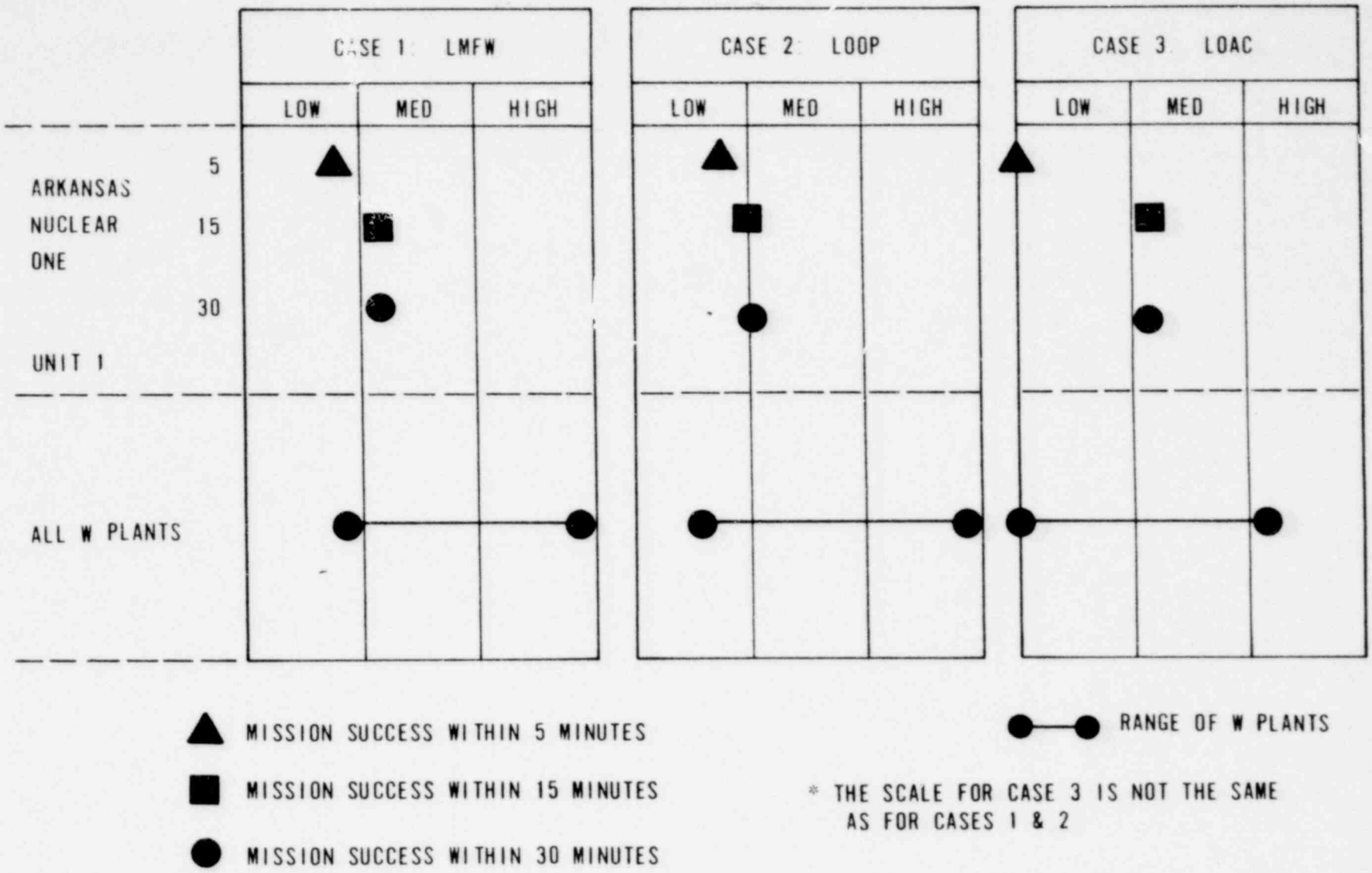



FIGURE 5 COMPARISON OF ANO-1 EFWS RELIABILITY WITH NRC RESULTS FOR W PLANTS

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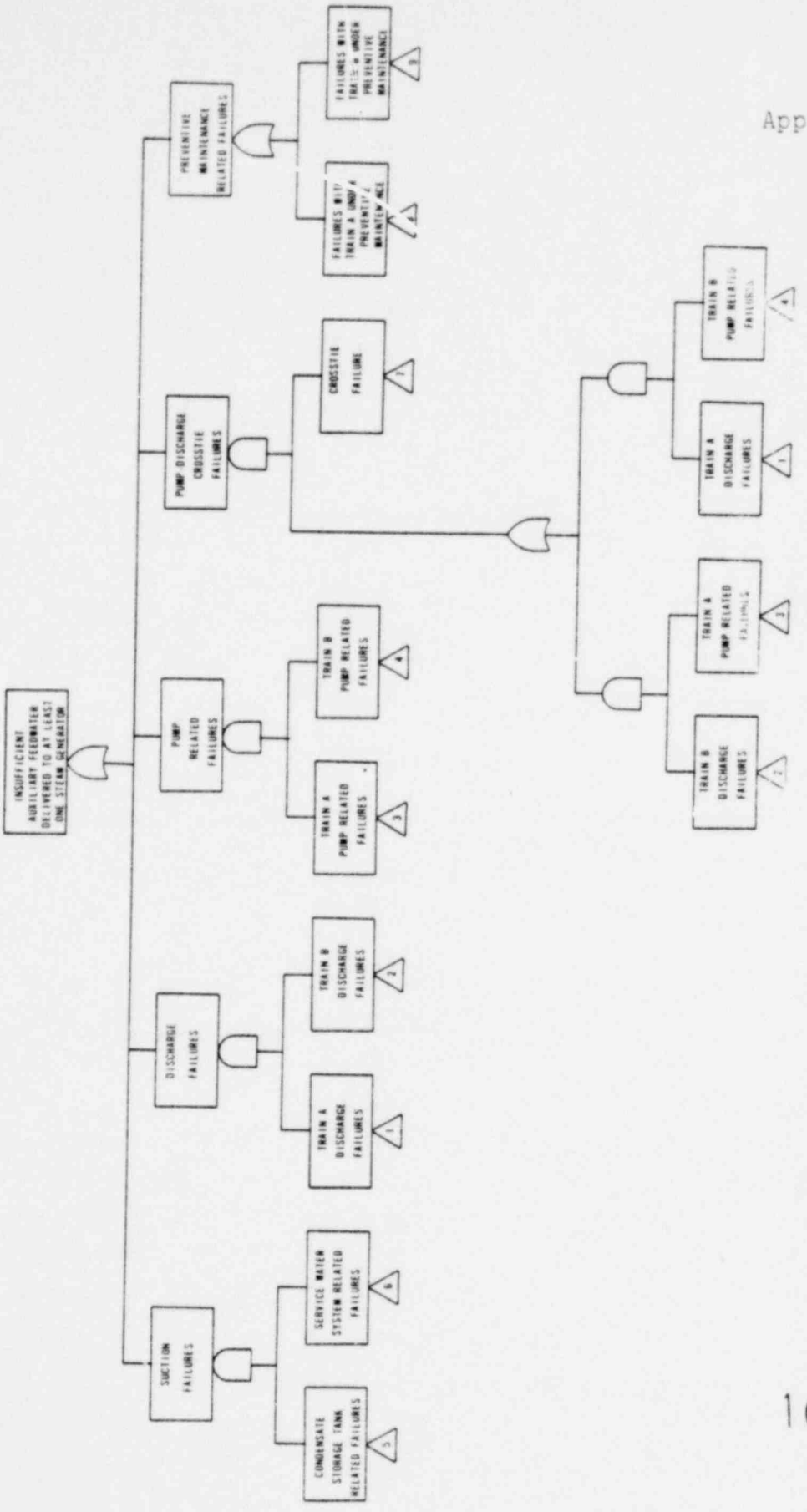
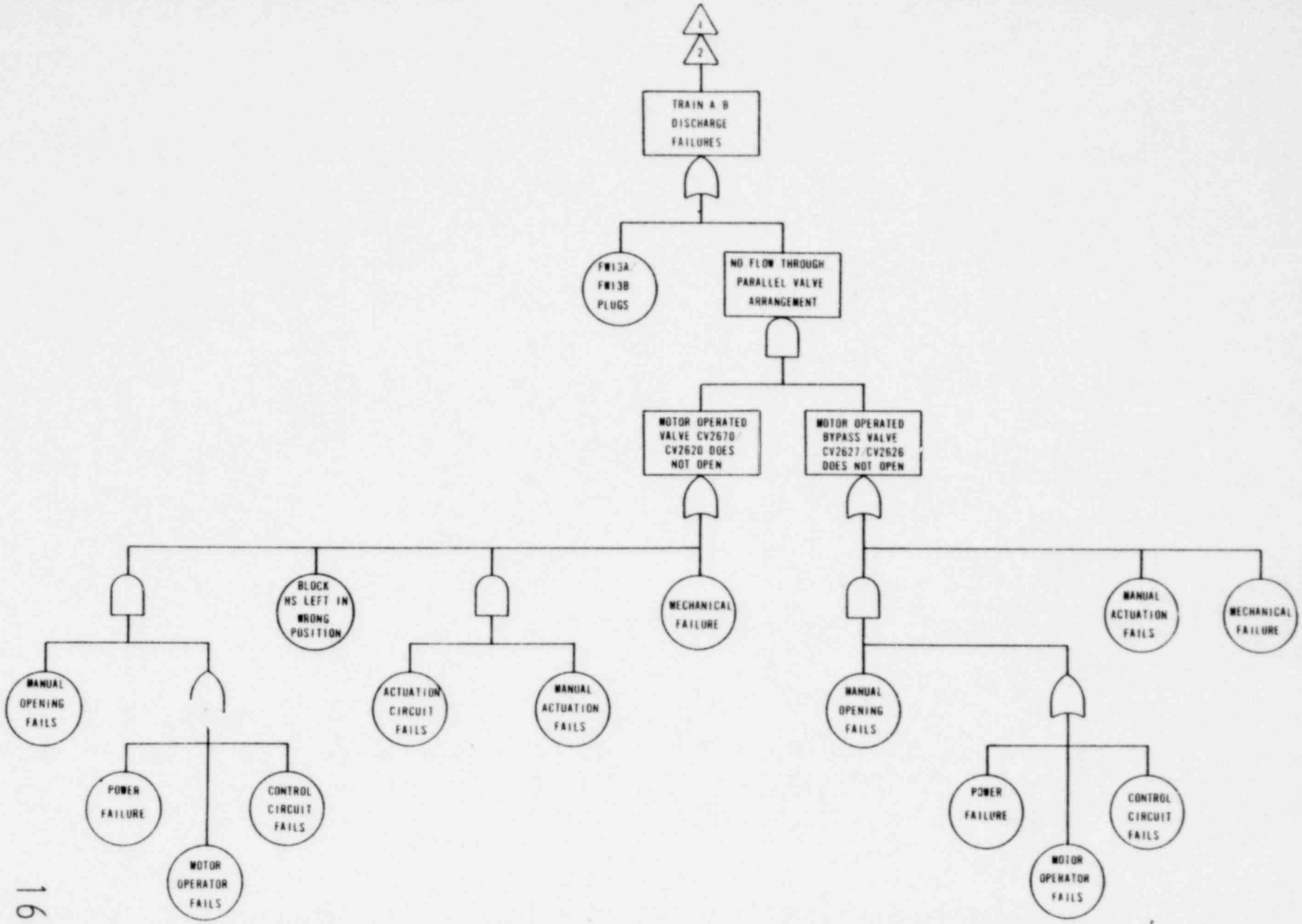
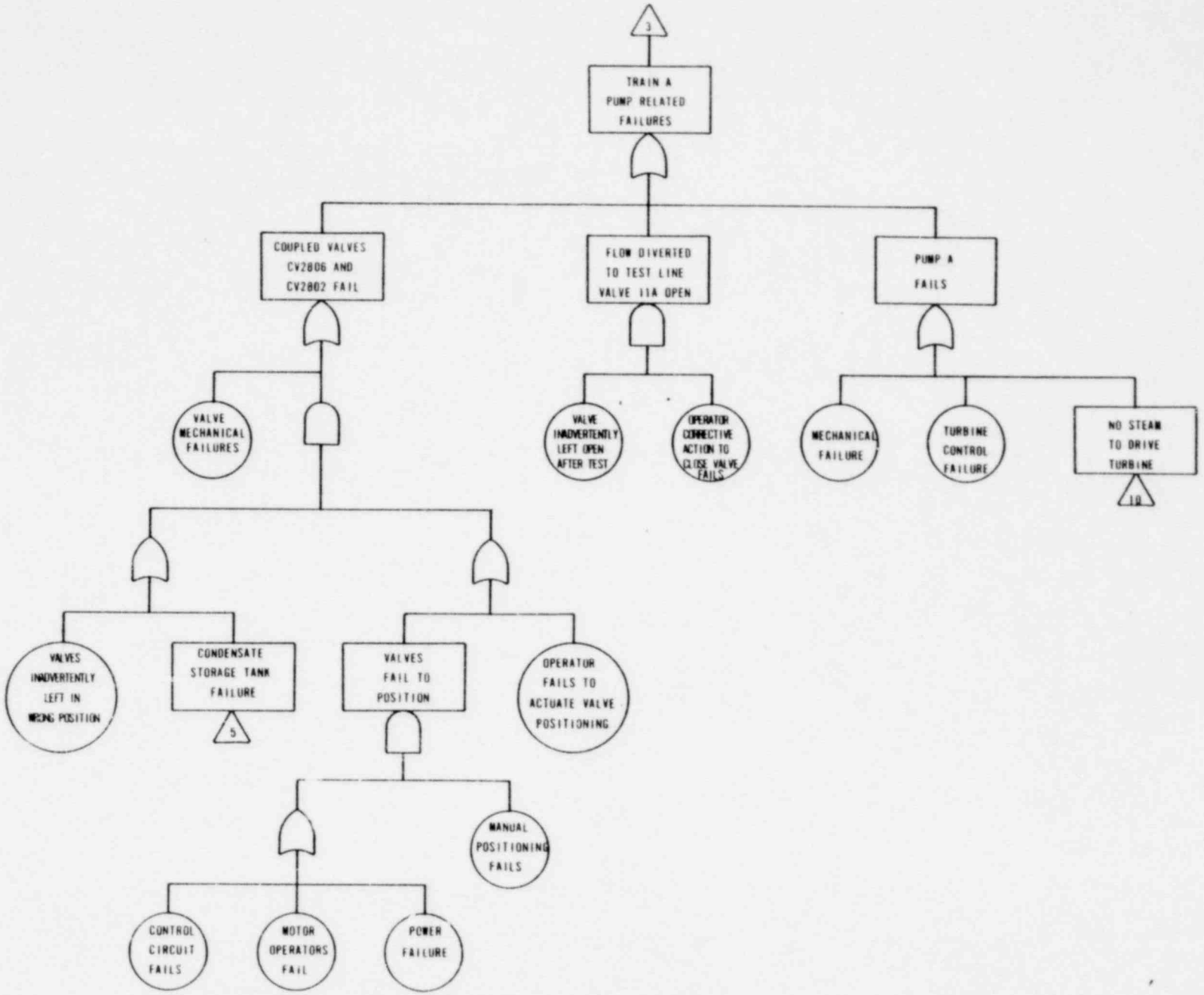

INSUFFICIENT AUXILIARY FEEDWATER DELIVERED TO AT LEAST ONE STEAM GENERATOR
PUMP RELATED FAILURES
TRAIN A PUMP RELATED FAILURES
3
TRAIN B PUMP RELATED FAILURES
4
PUMP DISCHARGE CROSSTIE FAILURES
CROSSTIE FAILURE
1
PREVENTIVE MAINTENANCE RELATED FAILURES
FAILURES WITH TRAIN A UNDER PREVENTIVE MAINTENANCE
FAILURES WITH TRAIN A UNDER PREVENTIVE MAINTENANCE
4
TRAIN A DISCHARGE FAILURES
TRAIN B DISCHARGE FAILURES
2
DISCHARGE FAILURES
TRAIN A DISCHARGE FAILURES
1
SUCTION FAILURES
SERVICE WATER SYSTEM RELATED FAILURES
6
CONDENSATE STORAGE TANK RELATED FAILURES
5
TRAIN A DISCHARGE FAILURES
1
TRAIN B DISCHARGE FAILURES
2
TRAIN A PUMP RELATED FAILURES
3
TRAIN B PUMP RELATED FAILURES
4

1645 321


1
2
TRAIN A B DISCHARGE FAILURES
FW13A/ FW13B PLUGS
NO FLOW THROUGH PARALLEL VALVE ARRANGEMENT
MOTOR OPERATED VALVE CV2670/ CV2620 DOES NOT OPEN
MOTOR OPERATED BYPASS VALVE CV2627/CV2626 DOES NOT OPEN
MANUAL OPENING FAILS
POWER FAILURE
MOTOR OPERATOR FAILS
CONTROL CIRCUIT FAILS
BLOCK HS LEFT IN WRONG POSITION
ACTUATION CIRCUIT FAILS
MANUAL ACTUATION FAILS
MECHANICAL FAILURE
MANUAL OPENING FAILS
POWER FAILURE
MOTOR OPERATOR FAILS
CONTROL CIRCUIT FAILS
MANUAL ACTUATION FAILS
MECHANICAL FAILURE

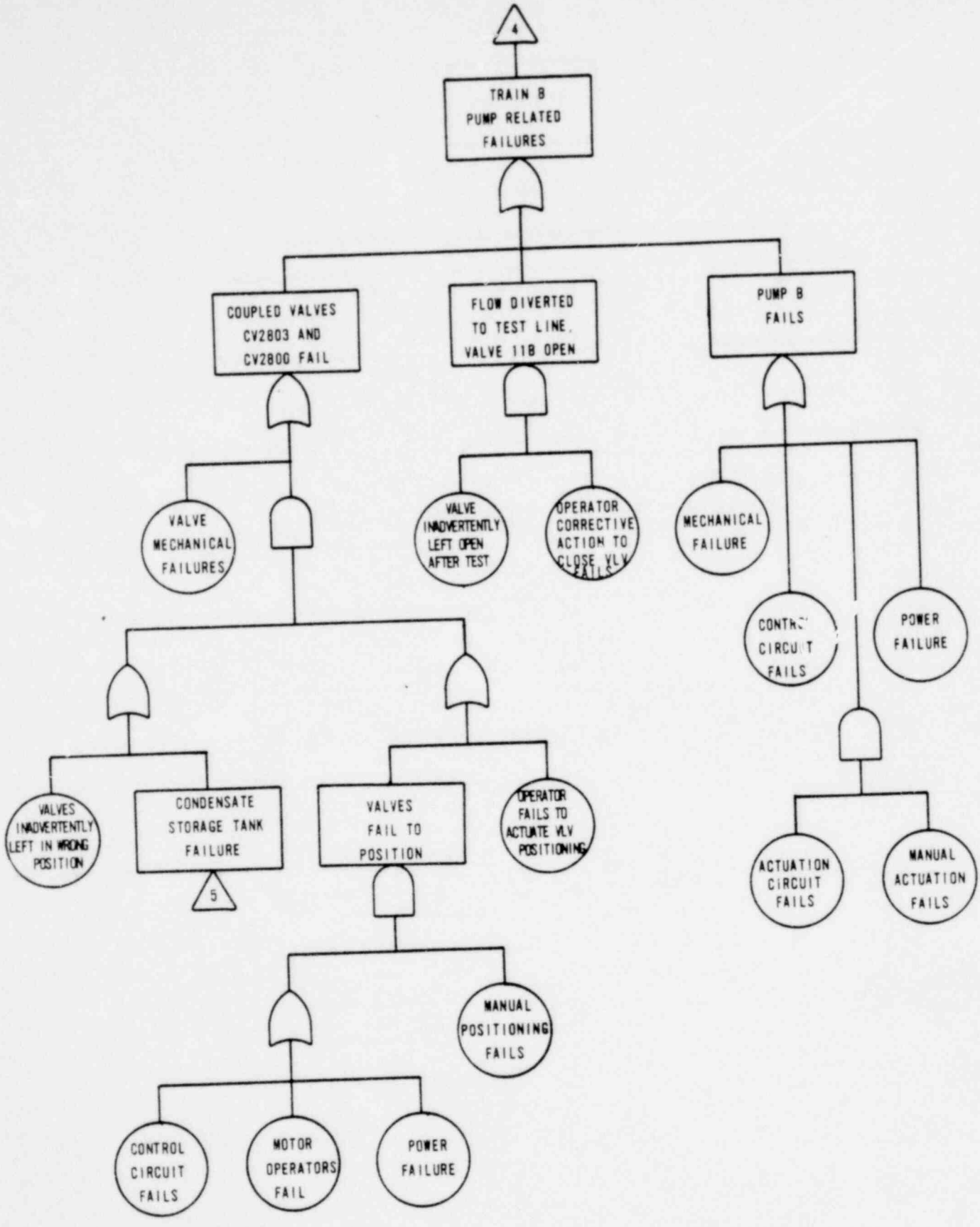


1645 322


3
TRAIN A PUMP RELATED FAILURES
COUPLED VALVES CV2806 AND CV2802 FAIL
FLOW DIVERTED TO TEST LINE VALVE 11A OPEN
PUMP A FAILS
VALVE MECHANICAL FAILURES
VALVE INADVERTENTLY LEFT OPEN AFTER TEST
OPERATOR CORRECTIVE ACTION TO CLOSE VALVE FAILS
MECHANICAL FAILURE
TURBINE CONTROL FAILURE
NO STEAM TO DRIVE TURBINE
10
VALVES INADVERTENTLY LEFT IN WRONG POSITION
CONDENSATE STORAGE TANK FAILURE
5
VALVES FAIL TO POSITION
OPERATOR FAILS TO ACTUATE VALVE POSITIONING
MANUAL POSITIONING FAILS
CONTROL CIRCUIT FAILS
MOTOR OPERATORS FAIL
POWER FAILURE

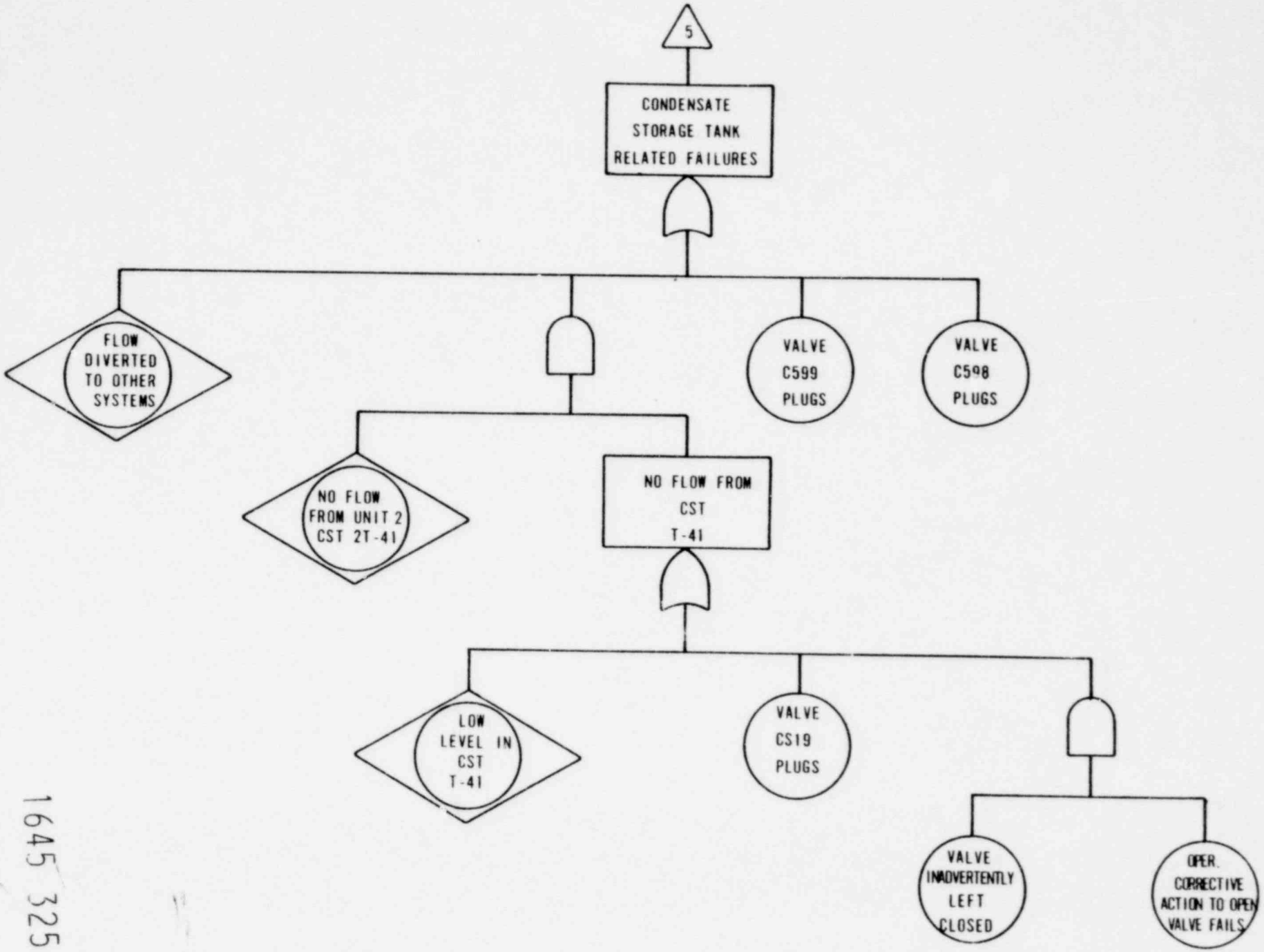


1645 323


4
TRAIN B PUMP RELATED FAILURES
COUPLED VALVES CV2803 AND CV2800 FAIL
FLOW DIVERTED TO TEST LINE, VALVE 118 OPEN
PUMP B FAILS
VALVE MECHANICAL FAILURES
VALVE INADVERTENTLY LEFT OPEN AFTER TEST
OPERATOR CORRECTIVE ACTION TO CLOSE VLV FAILS
MECHANICAL FAILURE
CONTROL CIRCUIT FAILS
POWER FAILURE
VALVES INADVERTENTLY LEFT IN WRONG POSITION
CONDENSATE STORAGE TANK FAILURE
5
VALVES FAIL TO POSITION
OPERATOR FAILS TO ACTUATE VLV POSITIONING
ACTUATION CIRCUIT FAILS
MANUAL ACTUATION FAILS
MANUAL POSITIONING FAILS
CONTROL CIRCUIT FAILS
MOTOR OPERATORS FAIL
POWER FAILURE



1645 324


5
CONDENSATE STORAGE TANK RELATED FAILURES
FLOW DIVERTED TO OTHER SYSTEMS
VALVE C599 PLUGS
VALVE C598 PLUGS
NO FLOW FROM UNIT 2 CST 2T-41
NO FLOW FROM CST T-41
LOW LEVEL IN CST T-41
VALVE CS19 PLUGS
VALVE INADVERTENTLY LEFT CLOSED
OPER. CORRECTIVE ACTION TO OPEN VALVE FAILS



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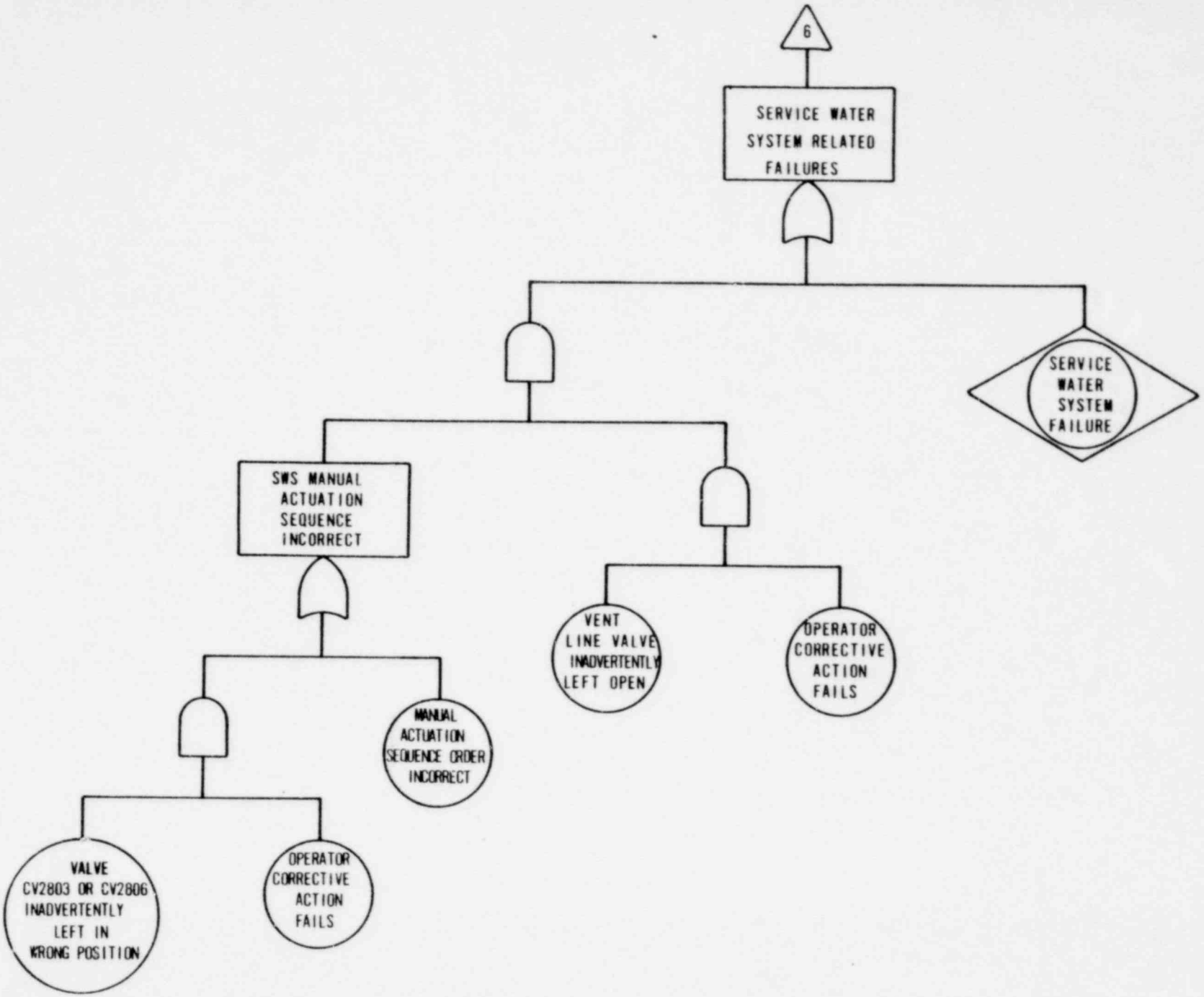
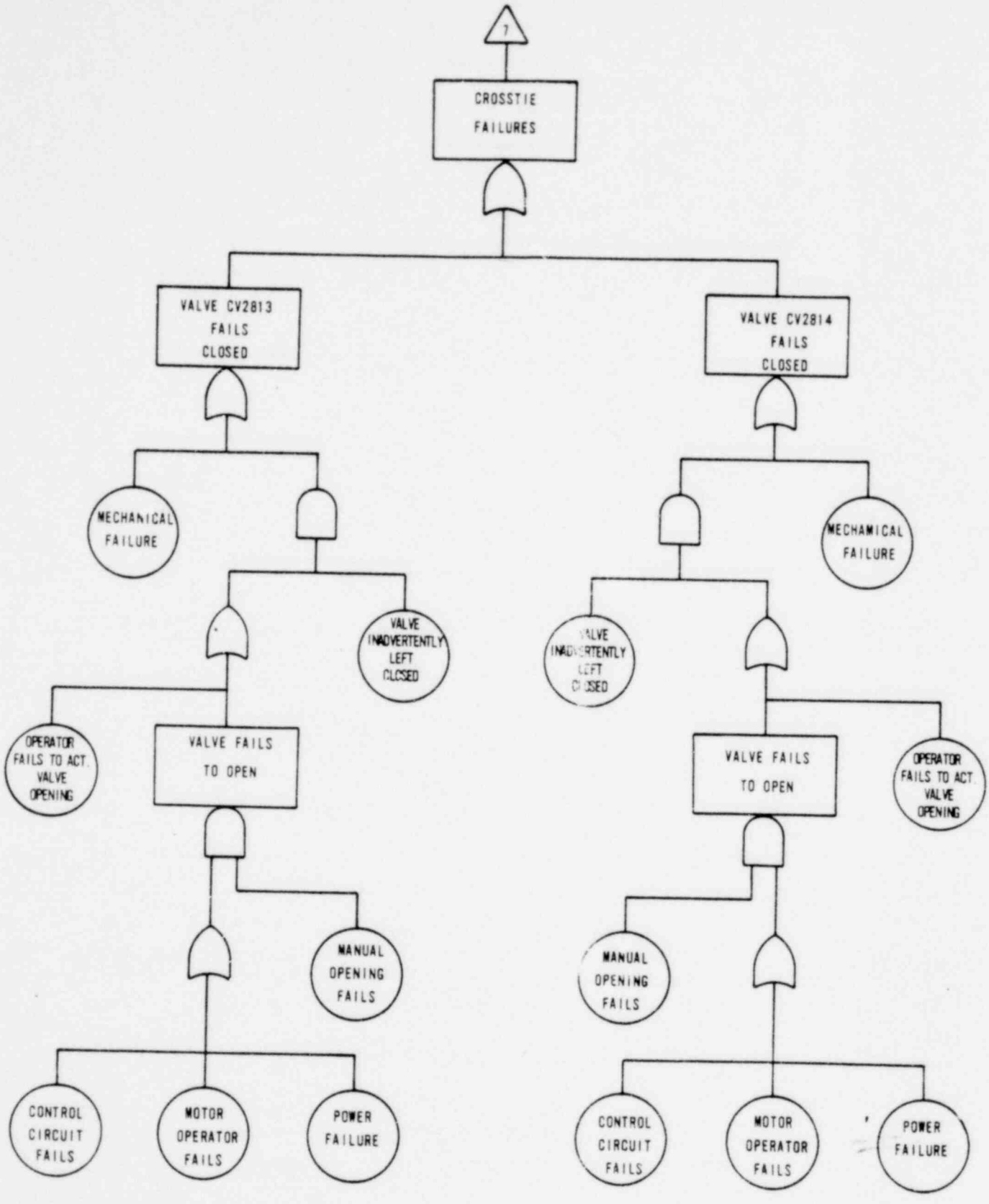
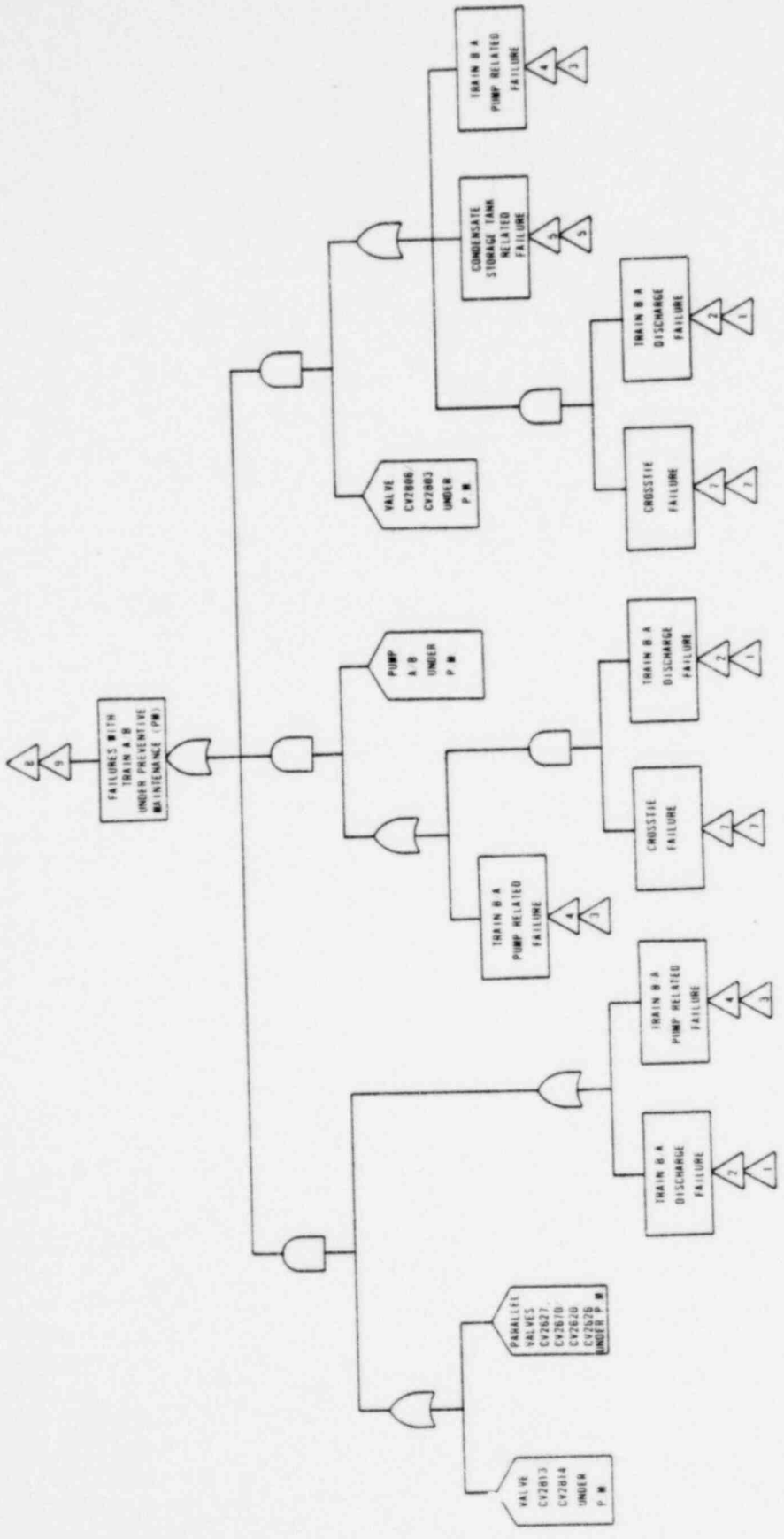
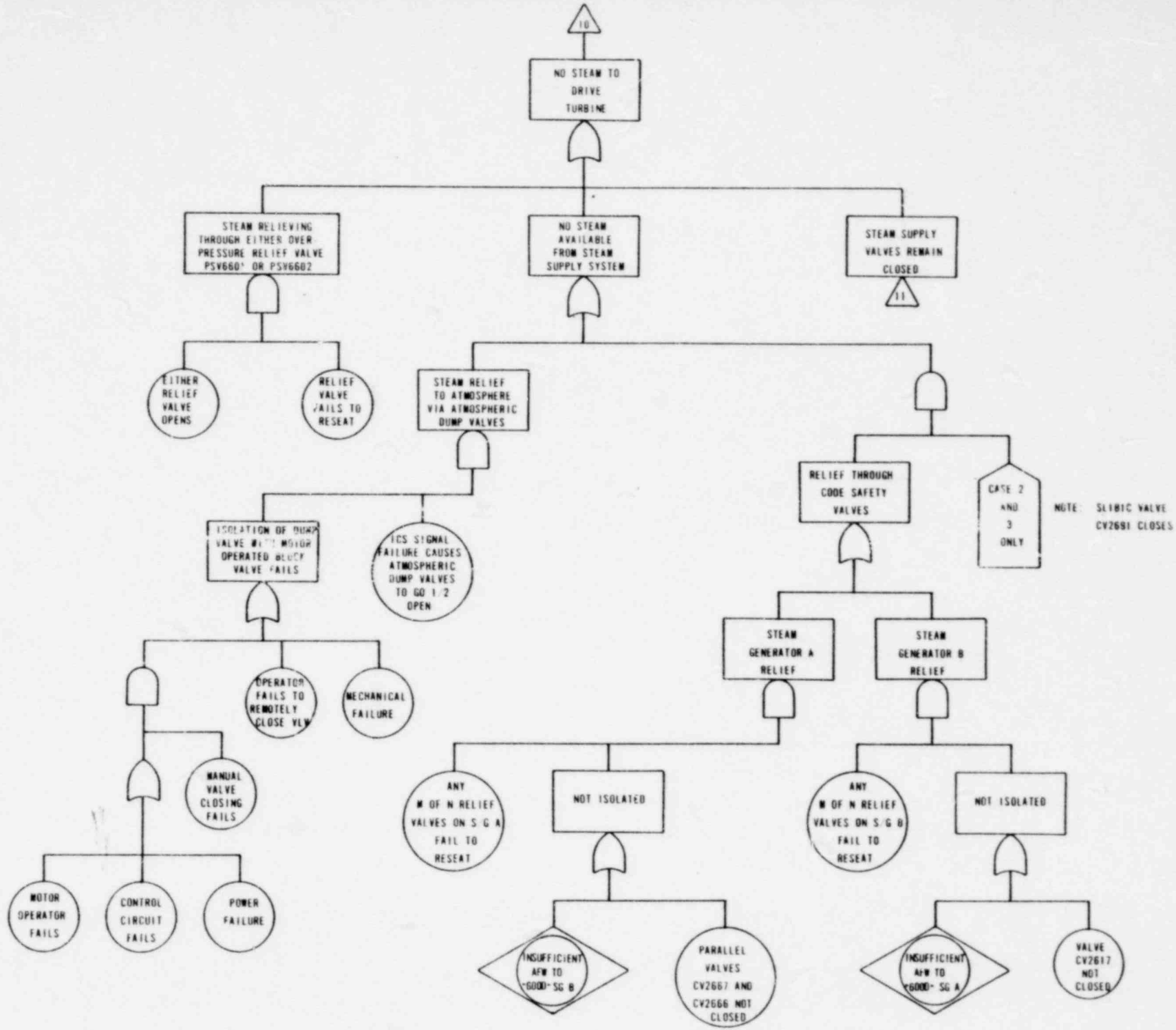

6
SERVICE WATER SYSTEM RELATED FAILURES
SERVICE WATER SYSTEM FAILURE
SWS MANUAL ACTUATION SEQUENCE INCORRECT
VENT LINE VALVE INADVERTENTLY LEFT OPEN
OPERATOR CORRECTIVE ACTION FAILS
MANUAL ACTUATION SEQUENCE ORDER INCORRECT
VALVE CV2803 OR CV2806 INADVERTENTLY LEFT IN WRONG POSITION
OPERATOR CORRECTIVE ACTION FAILS


7
CROSSTIE FAILURES
VALVE CV2813 FAILS CLOSED
VALVE CV2814 FAILS CLOSED
MECHANICAL FAILURE
VALVE INADVERTENTLY LEFT CLOSED
OPERATOR FAILS TO ACT. VALVE OPENING
VALVE FAILS TO OPEN
MANUAL OPENING FAILS
CONTROL CIRCUIT FAILS
MOTOR OPERATOR FAILS
POWER FAILURE
MECHAMICAL FAILURE
VALVE INADVERTENTLY LEFT CLOSED
VALVE FAILS TO OPEN
OPERATOR FAILS TO ACT. VALVE OPENING
MANUAL OPENING FAILS
CONTROL CIRCUIT FAILS
MOTOR OPERATOR FAILS
POWER FAILURE


FAILURES WITH TRAIN A B UNDER PREVENTIVE MAINTENANCE (PM)
PUMP A B UNDER P M
VALVE CV2806 CV2803 UNDER P M
TRAIN B A PUMP RELATED FAILURE
CONDENSATE STORAGE TANK RELATED FAILURE
TRAIN B A DISCHARGE FAILURE
CROSSTIE FAILURE
TRAIN B A PUMP RELATED FAILURE
CROSSTIE FAILURE
TRAIN B A DISCHARGE FAILURE
TRAIN B A PUMP RELATED FAILURE
TRAIN B A DISCHARGE FAILURE
PARALLEL VALVES CV2627 CV2670 CV2620 CV2626 UNDER P M
VALVE CV2813 CV2814 UNDER P M

1645 328


10
NO STEAM TO DRIVE TURBINE
STEAM RELIEVING THROUGH EITHER OVER PRESSURE RELIEF VALVE PSV660* OR PSV6602
NO STEAM AVAILABLE FROM STEAM SUPPLY SYSTEM
STEAM SUPPLY VALVES REMAIN CLOSED
11
EITHER RELIEF VALVE OPENS
RELIEF VALVE FAILS TO RESEAT
STEAM RELIEF TO ATMOSPHERE VIA ATMOSPHERIC DUMP VALVES
RELIEF THROUGH CODE SAFETY VALVES
CASE 2 AND 3 ONLY
NOTE: SLIBIC VALVE CV2691 CLOSES
ISOLATION OF DUMP VALVE #1 MOTOR OPERATED BLOCK VALVE FAILS
TCS SIGNAL FAILURE CAUSES ATMOSPHERIC DUMP VALVES TO GO 1/2 OPEN
OPERATOR FAILS TO REMOTELY CLOSE VLV
MECHANICAL FAILURE
MANUAL VALVE CLOSING FAILS
MOTOR OPERATOR FAILS
CONTROL CIRCUIT FAILS
POWER FAILURE
STEAM GENERATOR A RELIEF
STEAM GENERATOR B RELIEF
ANY M OF N RELIEF VALVES ON S/G A FAIL TO RESEAT
NOT ISOLATED
ANY M OF N RELIEF VALVES ON S/G B FAIL TO RESEAT
NOT ISOLATED
INSUFFICIENT AFW TO *6000* SG B
PARALLEL VALVES CV2667 AND CV2666 NOT CLOSED
INSUFFICIENT AFW TO *6000* SG A
VALVE CV2617 NOT CLOSED

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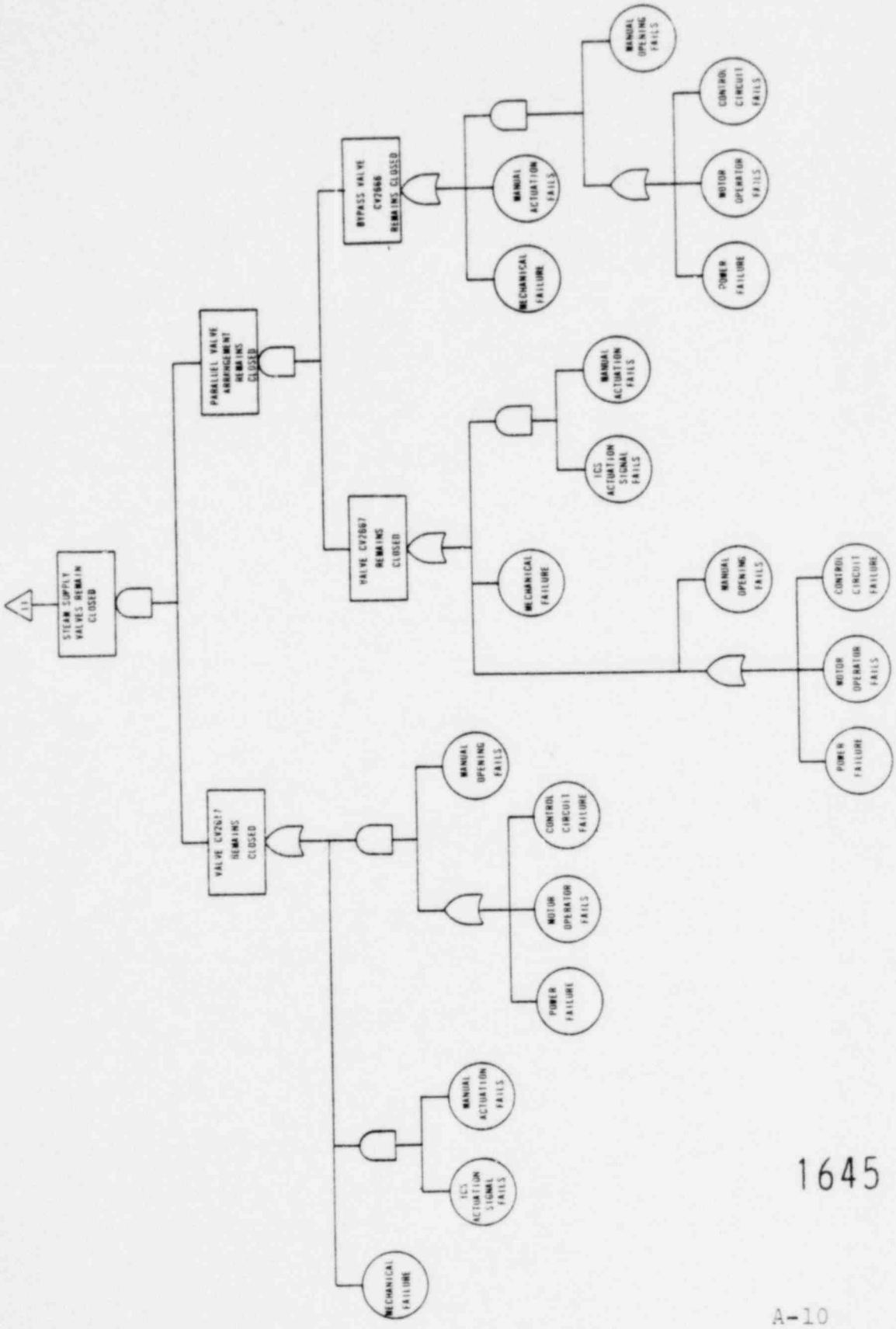
11
STEAM SUPPLY VALVES REMAIN CLOSED
PARALLEL VALVE ARRANGEMENT REMAINS CLOSED
VALVE CV2617 REMAINS CLOSED
BYPASS VALVE CV2666 REMAINS CLOSED
VALVE CV2667 REMAINS CLOSED
MANUAL OPENING FAILS
CONTROL CIRCUIT FAILURE
MOTOR OPERATION FAILS
POWER FAILURE
MANUAL ACTUATION FAILS
ICS ACTUATION SIGNAL FAILS
MECHANICAL FAILURE

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APPENDIX B

# NRC-SUPPLIED DATA USED FOR PURPOSES OF CONDUCTING A COMPARATIVE ASSESSMENT OF EXISTING AFWS DESIGNS & THEIR POTENTIAL RELIABILITIES

| | Point Value Estimate of Probability of* Failure on Demand |
|---|---|
| **I. Component (Hardware) Failure Data** | |
| a. Valves: | |
| Manual Valves (Plugged) | $\sim 1 \times 10^{-4}$ |
| Check Valves | $\sim 1 \times 10^{-4}$ |
| Motor Operated Valves | |
| • Mechanical Components | $\sim 1 \times 10^{-3}$ |
| • Plugging Contribution | $\sim 1 \times 10^{-4}$ |
| • Control Circuit (Local to Valve) | |
| w/Quarterly Tests | $\sim 6 \times 10^{-3}$ |
| w/Monthly Tests | $\sim 2 \times 10^{-3}$ |
| b. Pumps: (1 Pump) | |
| Mechanical Components | $\sim 1 \times 10^{-3}$ |
| Control Circuit | |
| • w/Quarterly Tests | $\sim 7 \times 10^{-3}$ |
| • w/Monthly Tests | $\sim 4 \times 10^{-3}$ |
| c. Actuation Logic | $\sim 7 \times 10^{-3}$ |

- - - - -

*Error factors of 3-10 (up and down) about such values are not unexpected for basic data uncertainties.



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II. Human Acts & Errors - Failure Data:

| | ← Estimated Human Error/Failure Probabilities → ← Modifying Factors & Situations → | | | | | |
|---|---|---|---|---|---|---|
| | With Valve Position Indication in Control Room | | With Local Walk-Around & Double Check Procedures | | w/o Either | |
| | Point Value Estimate | Est on Error Factor | Point Value Estimate | Est on Error Factor | Point Value Estimate | Est on Error Factor |
| A) Acts & Errors of a Pre-Accident Nature | | | | | | |
| 1. Valves mispositioned during test/maintenance. | | | | | | |
| a) Specific single valve wrongly selected out of a population of valves during conduct of a test or maintenance act ("X" no. of valves in population at choice). | $\frac{1}{20} \times 10^{-2} \times \frac{1}{X}$ | 20 | $\frac{1}{20} \times 10^{-2} \times \frac{1}{X}$ | 10 | $10^{-2} \times \frac{1}{X}$ | 10 |
| b) Inadvertently leaves correct valve in wrong position. | $\sim 5 \times 10^{-4}$ | 20 | $\sim 5 \times 10^{-3}$ | 10 | $\sim 10^{-2}$ | 10 |
| 2. More than one valve is affected (coupled errors). | $\sim 1 \times 10^{-4}$ | 20 | $\sim 1 \times 10^{-3}$ | 10 | $\sim 3 \times 10^{-3}$ | 10 |



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II. Human Acts & Errors - Failure Data (Cont'd):

← Estimated Human Error/Failure Probabilities →

| | Time Actuation Needed | Estimated Failure Prob. for Primary Operator to Actuate AFWS Components |
|---|---|---|
| B) Acts & Errors of a Post-Accident Nature | | |
| 1. Manual actuation of AFWS from Control Room. Considering "non-dedicated" operator to actuate AFWS and possible backup actuation of AFWS. | ~5 min.<br>~15 min.<br>~30 min. | $\sim 5 \times 10^{-2}$<br>$\sim 1 \times 10^{-2}$<br>$\sim 5 \times 10^{-3}$ |

III. Maintenance Outage Contribution

Maintenance outage for pumps and EMOVS:

$$Q_{Maintenance} \approx \frac{0.2 \text{ (\#hours/maintenance act)}}{720}$$

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