AUXILIARY FEEDWATER SYSTEM RELIABILITY ANALYSIS FOR CRYSTAL RIVER UNIT NO. 3

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October 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 Auxiliary Feedwater Systems (AFWS). As a part of the response to this request, Florida Power Corporation and the other B&W Owners Group utilities have requested B&W to perform a simplified reliability analysis of existing auxiliary feedwater systems. This draft report presents the results of that reliability study for the Crystal River 3 AFWS.

The primary objective of this study was to evaluate the Crystal River 3 AFWS 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.

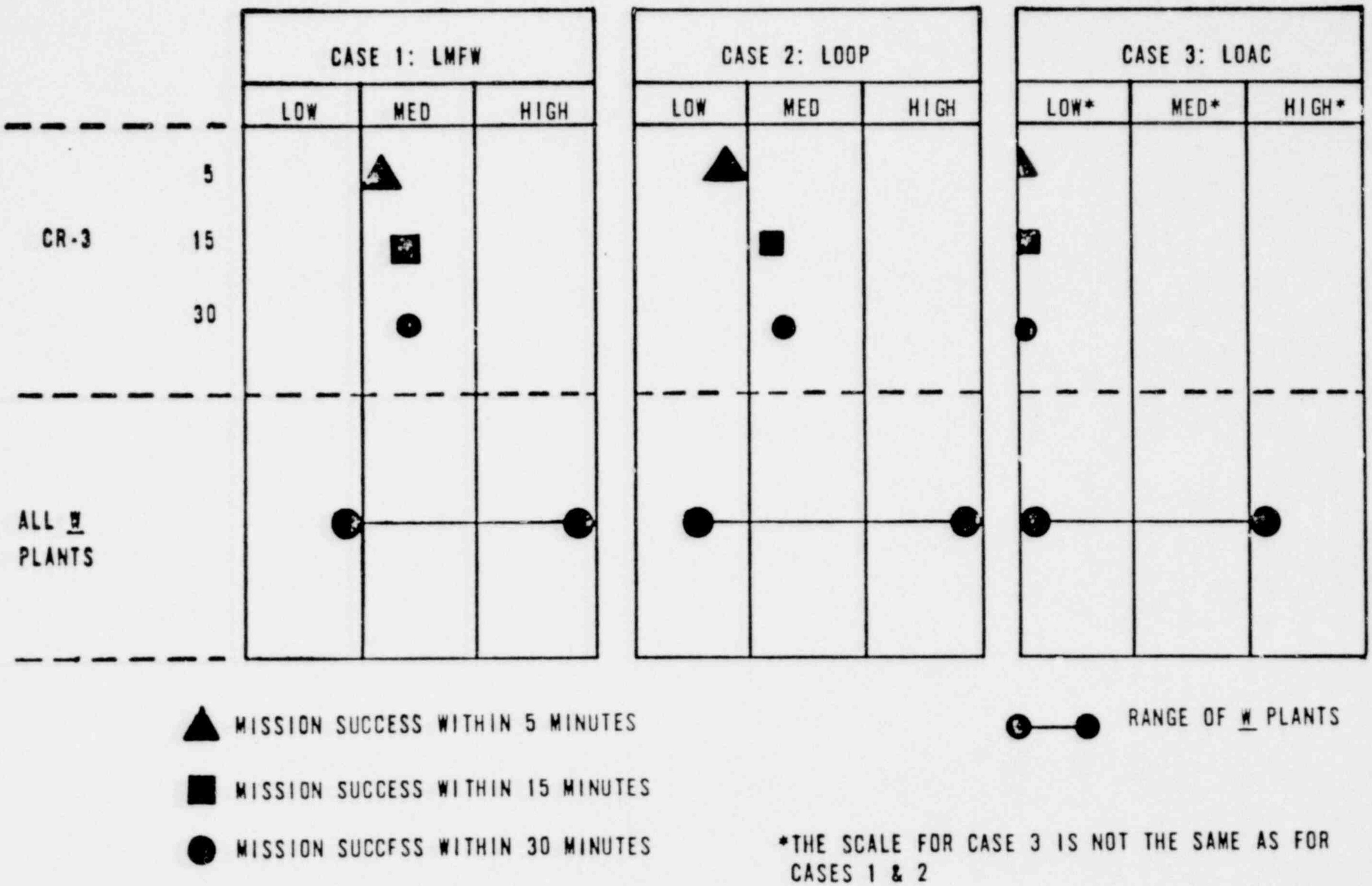
AFWS reliability was assessed for three cases: Loss of Main Feedwater (LMFW) with reactor trip, LMFW with Loss of Offsite Power (LMFW/LOOP) and LMFW with Loss of all AC power (LMFW/LOAC). System reliability was assessed by the construction and analysis of fault trees.

The results of this study are on the following page. These results indicate the Crystal River 3 AFWS reliability, based on the reliabilities obtained by the NRC for Westinghouse plants, is medium for LMFW, low to medium for LMFW/LOOP, and low for LMFW/LOAC. The LOOP case is low for 5 minutes because the operator must manually load the motor-driven auxiliary feedwater pump on the diesel generator. AFWS probability of failure for the LMFW/LOAC case is 1.0, accounting for the major AC dependency of pump cooling water..

Dominant failure contributors which were identified in this study include 1) dependency on external AC-powered cooling water pumps, and 2) system unavailability resulting from outages for preventive maintenance.

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 AFWS reliability report comparing all B&W operating plants.

COMPARISON OF CRYSTAL RIVER AFWS 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 Crystal River 3 Auxiliary Feedwater System (AFWS). 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 Crystal River 3 AFWS reliability. The approach employed in this study for Crystal River 3 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 Crystal River 3 AFWS. 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 Crystal River 3 AFWS unreliability.

1.3 Scope

The Crystal River 3 AFWS was analyzed as it existed on August 1, 1979. 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 Crystal River 3 AFWS 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 Crystal River 3 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 AFWS 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 AFWS initiation, and the 5 minute case represents a comparable result for B&W plants since auxiliary 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 AFWS 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-3A (see Figure 2) which, in Case 2, provides power to ES bus 3A which supplies the motor-driven EFW pump.)

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) Small Lines Ignored - Lines on the order of 1-inch were ignored as possible flow diversion paths.

5) 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.

6) Degraded Failures - Degraded failures were not considered; that is, components were assumed to operate properly or were treated as failed. The only exception to this assumption was the Electric/Pneumatic signal converters which result in a 50% flow control valve position on loss of power; this position was considered as not failed closed and, therefore, capable of passing adequate flow.

7) Condensate Storage Tank - The Condensate Storage Tank is a Seismic Category I structure and a failure probability of 5×10^{-6} was assigned to this tank.

8) ICS Reliability - Although separate control circuits are provided within the Integrated Control System (ICS) to control the flow of AFW to either of the steam generators, the ICS was assumed to consist of only a single control device with signals to both AFWS trains and a failure probability of 7×10^{-3} was assigned to ICS operation.

9) <u>Alternate Steam Source</u> - Although steam is alternately available to the turbine-driven auxiliary feedwater pump from the fossil-powered Units 1 and 2, this was not considered in the reliability study. Use of this steam required operation of manual valves in Unit 3 and Unit 1 or 2.

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2.0 System Description

2.1 Overall Configuration

A diagram of the Crystal River Unit 3 AFWS is presented in Figure 1. The system consists of two interconnected trains, each 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 trains of the Crystal River AFWS is the Seismic Category 1 Condensate Storage Tank, CDT-1. Separate six-inch lines with normally open AC-powered valves draw suction through a common eight-inch line with a locked-open manual valve.

A reserve of 150,000 gallons is maintained within the tank and is verified by control room indication of level, control room annunciation on low level, and Technical Specification requirements.

An alternate, non-seismic source of water is available for AFWS use from the main condenser hotwell. Separate eight-inch lines with normally-closed DC-powered valves can draw suction through a common eight-inch line with a normally-open manual valve. The DC-powered valves are interlocked such that they can be opened only if at least one of two DC-powered vacuum breaker valves is open.

2.1.2 Pumps and Discharge Cross-Tie

The pumps in both trains are each rated at 740 gpm with a design recirculation flowrate of 20 gpm. Thus each pump is capable of delivering 720 gpm against maximum OTSG pressure to the discharge piping supplying both steam generators.

The Train A pump (EFP-2) is a turbine-driven pump, capable of receiving motive steam from either OTSG or from the auxiliary steam supply from fossil-powered Units 1 and 2. The Train B pump (EFP-1) is a motor-driven pump powered from diesel-backed ES bus 3A.

The pumps are interconnected at their discharge by separate cross-ties, each containing a normally-open DC-powered valve and a check valve. In addition, there is another cross-tie containing two normally-closed manual valves.

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2.1.3 Flow Control Valves

The flow of auxiliary feedwater to each s[illegible] generator is controlled by pneumatic valves FWV-39 and FWV-40. During [illegible] AFWS initiation and control these valves are under control of the Integrated Control System (ICS) via electric to pneumatic converters. Control for these valves, including manual control, will be described in greater [illegible] Section 2.4.

Valves FW-39 and 40 function both as the auxiliary feedwater flow control valves and as the startup feedwater flow control valves. During low power operation, flow from the main feedwater pump passes through FWV-41 (FWV-42), is controlled by FWV-40 (FWV-39), and returns to the main feedwater header through FWV-36 (FWV-33); FWV-35 (FWV-34) is closed to prevent this flow from entering the auxiliary feedwater nozzles.

2.1.4 Steam Supply for EFP-2

Steam for the turbine-driven pump (EFP-2) is extracted immediately downstream of both steam generators. This steam must pass through a normally-open DC-operated stop-check valve (MS-55 or 56) a check valve (MS-186 or 187) and a normally-closed DC-operated stop valve (ASV-5). Initiation of the turbine-driven pump is accomplished by opening this stop valve. Initiation signals are described in Section 2.4.

In addition, an alternate source of steam is available from fossil-powered Units 1 and 2 and taps in immediately upstream of ASV-5. Lineup of this source required local, manual operation of valves at both Unit 3 and either Unit 1 or 2; therefore, this feature was not included in the reliability study.

2.1.5 Other Important System Features

The primary components for AFWS operation following LMFW are described above. There are additional system features, however, which affect overall system reliability. These features are described below:

Steam Line Rupture Matrix: This feature is a redundant, Class IE logic matrix that senses low steam generator pressure and isolates the generator with low pressure by closing main steam isolation valves, main feedwater isolation valves, and auxiliary feedwater isolation valves (FWV-33,34, 35,36,161,162).

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Remote Manual Bypass Valves: Two remote-manual, normally-open, DC-powered bypass valves (FWV-161,162) are provided, one in each AFWS supply line to the steam generators. These valves provide a back-up means of controlling AFWS flow should the ICS-controlled valves (FWV-39, 40) fail for any reason. They are pre-throttled to provide ≈ 550 gpm to each steam generator at design pressure.

2.1.6 Valve Indications and Operability

All AC-and DC-powered valves fail "as is" on the loss of electric power. All such valves shown on Figure 1 are controllable from the control room and their position is indicated in the control room. Power for the indication and control of these valves is derived from the power source for the respective valve motors. Only four valves (EFV-3,4,7, and 8) are AC-powered (non-vital) and they are normally open.

The penumatic flow control valves (FWV-39,40) will fail "as is" on loss of supply air pressure. An air lock is provided that senses. low air pressure and de-energizes a solenoid valve to lock the existing air pressures across the control valve piston. An air reservoir is provided for each valve which allows remote-manual opening of the control valve when normal supply air is lost. This is accomplished using DC-powered solenoid valves to direct air from the reservoir to the underside of the control valve piston while venting the top of the piston. Loss of power to the electric/pneumatic converters will result in the valves assuming a position of approximately 50% open.

In addition to the backup air supply, further reliability is achieved by the provision of remote-manual DC-powered valves (FWV-161,162).

2.2 Supporting Systems

The only supporting systems required for successful operation of the AFWS is cooling water for the pumps. Pump cooling water is supplied by the Nuclear Services Closed Cycle Cooling System. The two EFW pumps are supplied in parallel from a common header. Five cooling water pumps are provided, two of which receive diesel-backed power. The cooling system is Seismic Class I. All valves in the loop supplying the EFW pumps are normally open manual valves.

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Lubricating oil is an integral system powered by the pump shaft, and requires no electrical input.

2.3 Power Sources

Simplified diagrams showing power distribution for the AFWS are shown in Figures 2-4. The motor-driven auxiliary feedwater pump (EFP-1) and two Nuclear Services Closed Cycle Cooling Water pumps (NSCCCW-3A & 3B) are AC-powered components backed by diesel generators as shown in Figure 2. DC-powered AFWS valves are powered as shown in Figure 3. AC-powered valves (EPV-3,4,7, & 8) are not diesel backed and are powered as shown in Figure 4; these valves are normally open and fail "as is" on loss of power. Flow paths from each pump to both steam generators are available without any valve repositioning.

In the event of Case 2 (LMFW/LOOP), the diesel generators are started automatically and the cooling water pumps (one on each ES bus) are automatically loaded on their respective diesels. However, the motor-driven AFWS pump (EFP-1) will not start automatically; it must be manually loaded on the diesel. Case 2 will also result in a loss of normal air supplies but adequate backup is available as described in Section 2.1.6; the followup action in the plant operating procedure for LOOP requires manual loading of air compressors on the diesels.

In the event of Case 3 (LMFW/LOAC) the AFWS flow will still be initiated through the DC-powered steam supply valve and the turbine-driven pump. However, power will not be available for the Nuclear Service Closed Cycle Cooling pumps and the turbine-driven pump can operate for only a short period of time (estimated at thirty minutes) without cooling water.

2.4 Instrumentation and Control

2.4.1 Initiation Logic

A simplified diagram of AFWS initiation is shown in Figure 5. This diagram is functional in nature and does not represent actual hardware. The actual logic is contained in relay racks and the individual component controllers.

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Automatic initiation will occur whenever one of two conditions exist: loss of both main feedwater pumps or low level in both steam generators. The logic in the relay cabinets de-energizes a relay to initiate the AFWS, thus a loss of the vital 120VAC source will also cause initiation. The automatic initiation will open ASV-5 and MSV-55 (MSV-55 and 56 are normally open) to start the turbine-driven pump. The initiation signal also closes the circuit breaker to start the motor-driven pump provided the two interlocks described below are satisfied. Once a pump is started, AFWS flow will occur since the flowpaths, including the discharge cross-connects, are normally open.

DC power is required to open ASV-5 and to close the breaker for the motor-driven pump; this power dependency is shown in Figure 5. In addition, the motor-driven pump is interlocked to prevent automatic start unless offsite power is available on the ES bus and one of the suction valves (EFV-2 or 3) is open.

A key-operated bypass is provided to prevent inadvertent initiation of the AFWS when the main feedwater pumps are secured during normal startups and shutdowns. This bypass feature does not have automatic removal but it is under administrative control. Initiation on low steam generator level is provided as a backup means of ensuring AFW initiation and this actuation is not bypassed.

2.4.2 Flow Control

Normal control for AFWS flow is achieved with flow control valves FWV-39 and 40. The ICS senses the loss of main feed pumps or low level in the steam generators and opens the AFWS Block Valves (FWV-34 and 35) and closes the Main Feedwater Connections (FWV-33 and 36). This directs AFWS flow through FWV-39 and 40 to the upper nozzles in the steam generators.

FWV-39 and 40 are pneumatic-operated valves and are normally controlled by the ICS via electric/pneumatic converters. The ICS adjusts these valves to attain and maintain one of two level setpoints, depending on RC pump status. A loss of the ICS control signal will result in the valve failing to a position approximately 50% open. On loss of supply air pressure, the valve will fail "as is", which, depending on SG level at the time of failure, could be the closed position.

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In addition to the backup provisions for FWV-39 and 40, DC-powered bypass valves (FWV-161 and FWV-162) are provided. These valves are pre-throttled to allow a flowrate of approximately 550 gpm to each steam generator, to ensure flow is established should FWV-34,35, 39 or 40 fail. Once AFWS initiation occurs, the operator will verify proper operation of the normal flow control path and then close FWV-161 and 162.

2.4.3 Instrumentation

Instrumentation provided in the control room and availability during the three cases (i.e., power source dependency) is:

	Available		
Indication	Case 1	Case 2	Case 3
CDT-1 level	Yes	No	No
CDT-1 level alarms	Yes	Yes	Yes
EFW flow	Yes	Yes	Yes
Valve positions	Yes	Yes*	Yes*
OTSG level	Yes	Yes	Yes
OTSG level alarms	Yes	Yes	Yes

* for all except AC-powered valves EFW-3,4,7, and 8

2.4.4 Steam Line Rupture Matrix (Figure 6)

Operation of the AFWS can be affected by the steam line rupture matrix (SLRM); therefore, it is described here and included in the fault tree analysis.

The SLRM detects low steam pressure in either steam generator and will isolate a generator if a low pressure condition exists; low pressure must be detected by two pressure switches, one set at 725 psig, the other at 600 psig (See Figure 6). The isolation signal will cause closure of the main steam isolation valves, main feedwater isolation valves, and auxiliary feedwater isolation valves for the affected steam generator.

The SLRM is a safety-grade system provided with battery-backed power and coincidence logic in the actuation circuitry. Inadvertent actuation of the SLRM could cause isolation of one steam generator; therefore, this possibility is included in the fault tree.

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2.5 Operator Actions

For Case 1, no operator action is required to establish AFWS flow. The operator will verify proper flow control and adjust FWV-161 and 162 as required. Certain failures, as shown in the fault trees, can be corrected by operator action and this probability is included for three times following initiation; 5 minutes, 15 minutes, and 30 minutes. All components of the AFWS are operable from the control room.

The only significant differences for Case 2 are as follows:

a) The motor-driven pump must be manually loaded onto the ES bus (from the control room).

b) Failures involving AC-powered valves EFW-3,4,7, or 8 would require local manual correction.

For Case 3, the turbine-driven pump would start automatically and all the DC-powered valves would be operable from the control room. Because cooling water for the turbine-driven pump requires AC power, the pump would eventually overheat; no mitigative operator action was identified.

2.6 Testing

Automatic initiation and full flow testing is accomplished during every cold shutdown if at least three months has expired since the last test, or if the shutdown is planned to exceed 48 hours in duration.

AFWS valves are cycled once each quarter. After cycling they are verified to be in the correct position by two independent valve lineup checks.

Monthly operability checks of both pumps are performed using the normal recirculation flow paths. These checks confirm the pump and pump drive capability to operate and produce the required pump discharge pressure. These checks require closure of the associated stop-check valve (EFV-7 or EFV-8). Following the tests, proper valve lineup is ensured by two independent checks.

2.7 Technical Specification Limitations

The limiting condition for operation for the AFWS requires two independent auxiliary feedwater pumps and associated flow paths be operable with:

a) One auxiliary feedwater pump capable of being powered from an operable steam supply system.

b) One auxiliary feedwater pump capable of being powered from an operable steam supply system.

If one auxiliary feedwater system becomes inoperable, it must be restored to an operable condition within 72 hours or the plant must be placed in hot shutdown within the next 12 hours.

Technical Specifications also require the availability of 150,000 gallons of water in the condensate storage tank (CDT-1) for AFWS use.

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3.0 Reliability Evaluation

3.1 Fault Tree Technique

The Crystal River 3 AFWS 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 AFWS components in each train were grouped into three categories - Suction, Pump and Discharge. The suction cross-tie interconnects the trains between the categories Suction and Pump, and the discharge cross-tie interconnects the trains between categories Pump and Discharge. System failure can result from Suction-Suction, Pump-Pump and Discharge-Discharge failures or from failure combinations such as Pump(A)-Discharge(B) with the discharge cross-tie inoperable. The tree on page A-1 indicates all the combinations which were considered.

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 7 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 7 is

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to show the relative reliability standing of the Crystal River 3 AFWS for each of the three cases and also to compare these results to the NRC results for Westinghouse plants. The Westinghouse results and numerical values permitting construction of Figure 7 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 indicated in Figure 7 relative to Westinghouse, Crystal River 3 has medium reliability for Case 1, low to medium reliablity for Case 2, and low reliability for Case 3.

As the time for operator action increases from 5 to 30 minutes, the probability of mission success 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 primary reason for the lower reliability of Case 2 at 5 minutes is the requirement for manual loading of the pump onto the diesel; although inclusion of a failure probability for the limiting diesel also contributes to the overall change from Case 1 to Case 2.

The low Case 3 result reflects the AC dependency of pump cooling water.

3.3 Dominant Failure Contributors

3.3.1 Case 1 - LMFW

A major contributor for this case involves the cooling water system for the AFWS pumps. Although redundant, ES-backed cooling water pumps are provided, both AFWS pumps are supplied by a common header with a single common supply valve and a single common return valve. These valves are normally open and manually operated locally. They are not routinely cycled and their position is verified by monthly surveillance checks. However, plugging of either valve would result in loss of cooling water flow, and eventual bearing failure, for both AFWS pumps.

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Other major contributors for Case 1 include preventive maintenance taking one AFWS pump out of service, and pump failures. Major pump failure contributors include mechanical failures and failure of ASV-5 to open for the turbine-driven pump.

3.3.2 Case 2 - LMFW/LOOP

The major contributors for Case 1 apply as well to Case 2. However, there is an added contributor which accounts for the major portion of the difference in the overall system reliability between Case 1 and Case 2 as shown in Figure 7. This additional contributor is the requirement for manual loading of the motor-driven pump onto the ES bus. This action is included in the procedure for station blackout (LOOP).

3.3.3 Case 3 - LMFW/LOAC

As stated previously, even with total loss of AC power (other than that supplied by battery-backed inverters) AFWS flow will be initiated and can be controlled using DC powered valves. However, the ES busses supplying power to the cooling water pumps are lost in Case 3 and this will result in eventual overheating and bearing failure of the turbine-driven pump. For this reason, credit was not taken for the initial flow and an overall probability of failure of 1.0 was assigned. This contributor was the only major AC dependency identified in the Crystal River 3 AFWS.

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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)," US NRC, October 1975.

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Figure 1

CRYSTAL RIVER UNIT 3-AFWS

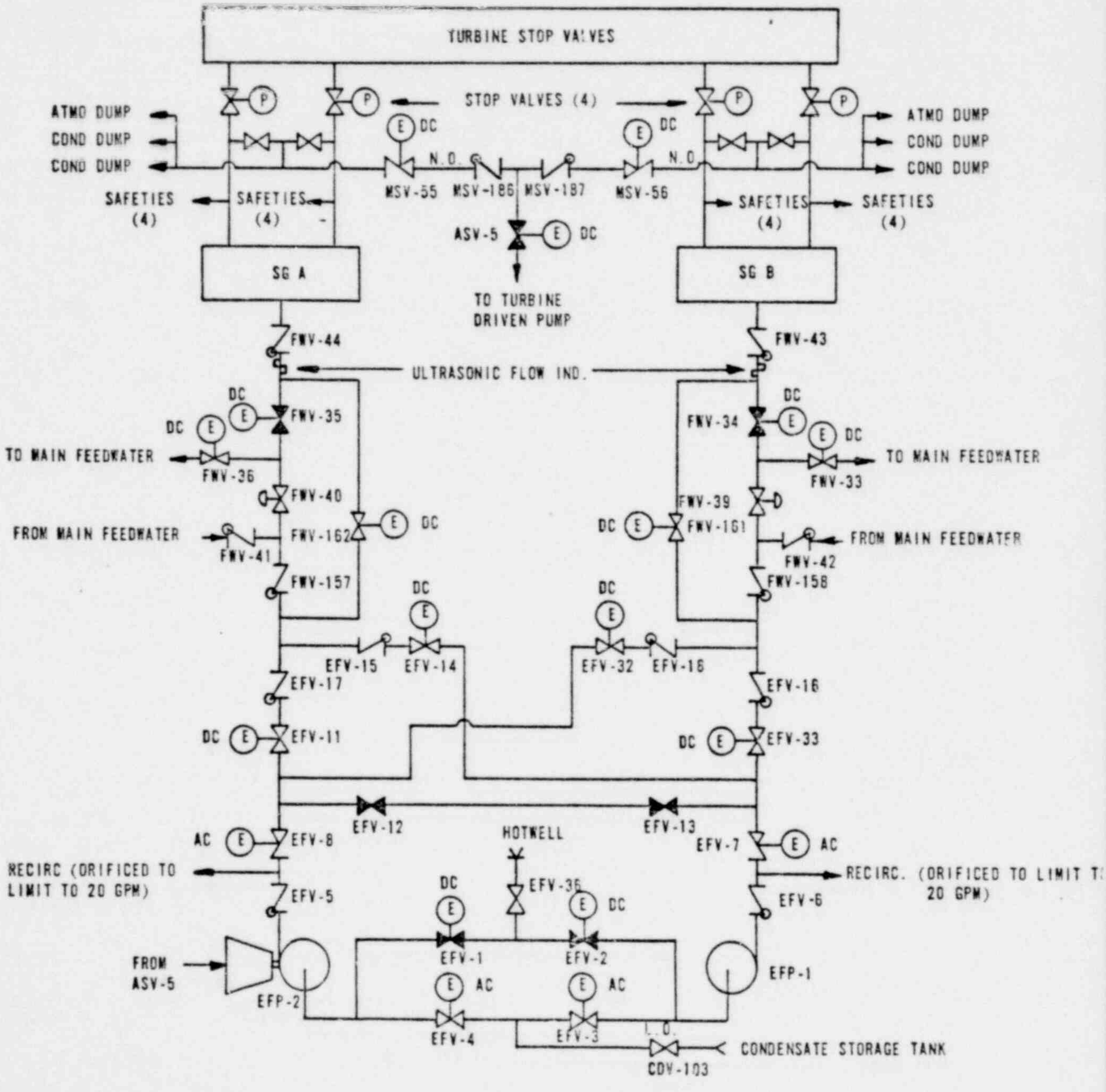
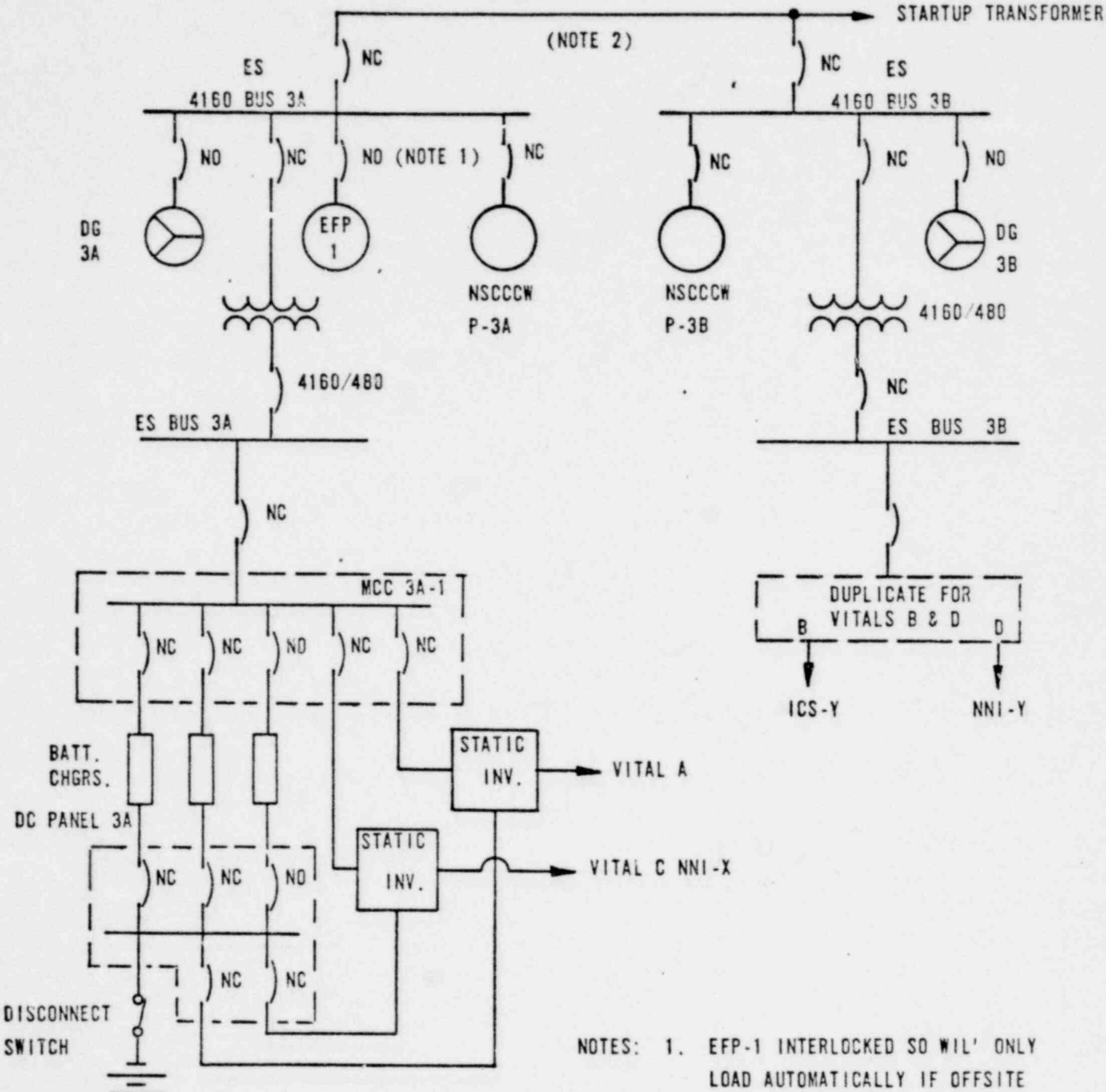


Figure 2

CRYSTAL RIVER UNIT 3

SIMPLIFIED POWER SOURCE DIAGRAM



NOTES:

1. EFP-1 INTERLOCKED SO WIL' ONLY LOAD AUTOMATICALLY IF OFFSITE POWER ON BUS 3A.
2. TWO ALTERNATE SOURCES AVAILABLE MANUALLY; UNIT 1/2 STARTUP XFMR WITHIN MINUTES AND UNIT 3 AUX. XFMR WITHIN EIGHT HOURS.

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Figure 3

CRYSTAL RIVER UNIT 3
SIMPLIFIED POWER SOURCE DIAGRAM
DC LOADS

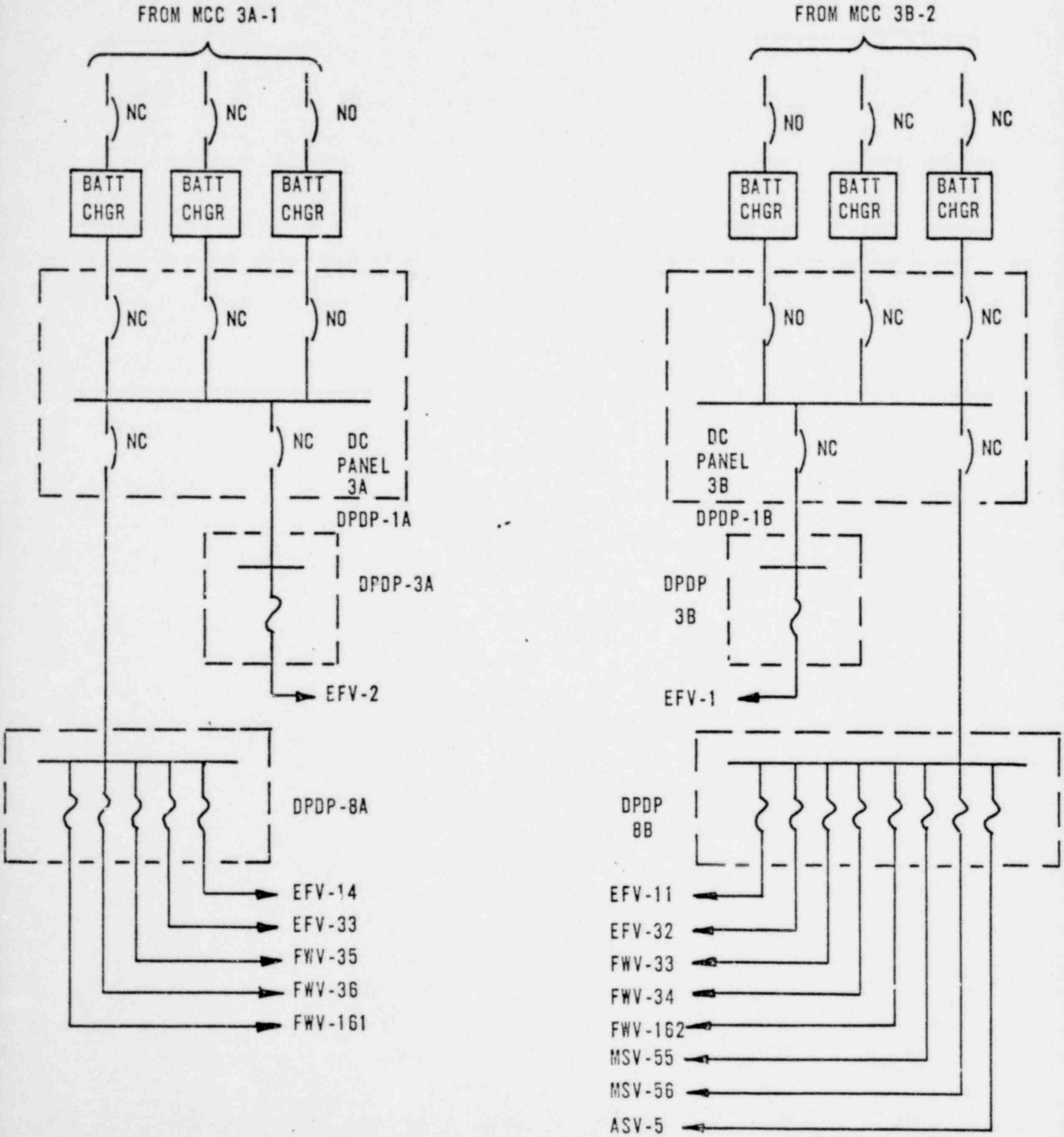

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Figure 4

CRYSTAL RIVER UNIT 3
SIMPLIFIED POWER SOURCE DIAGRAM
AC VALVES

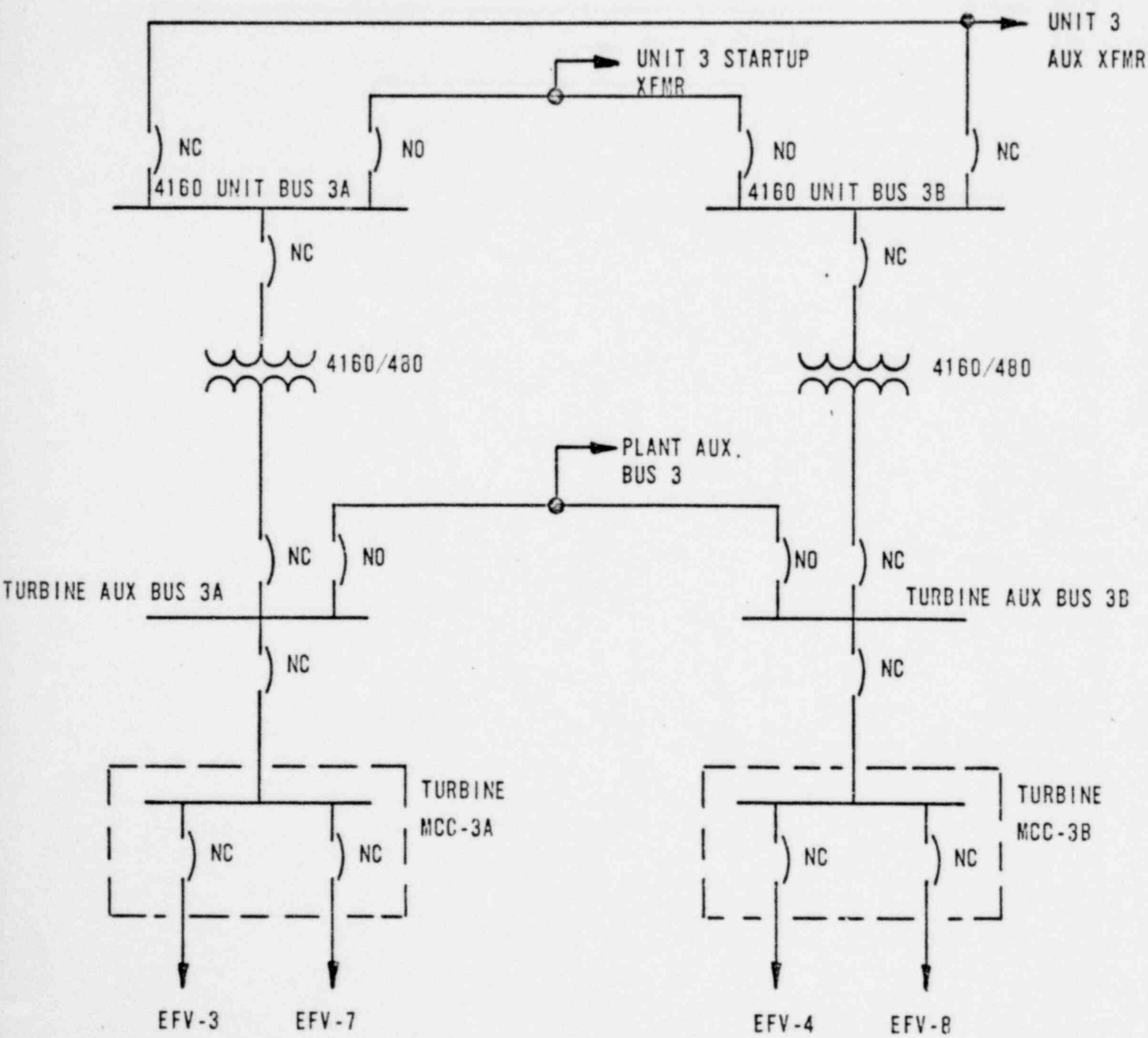

Figure 5

CRYSTAL RIVER UNIT 3
PUMP START LOGIC

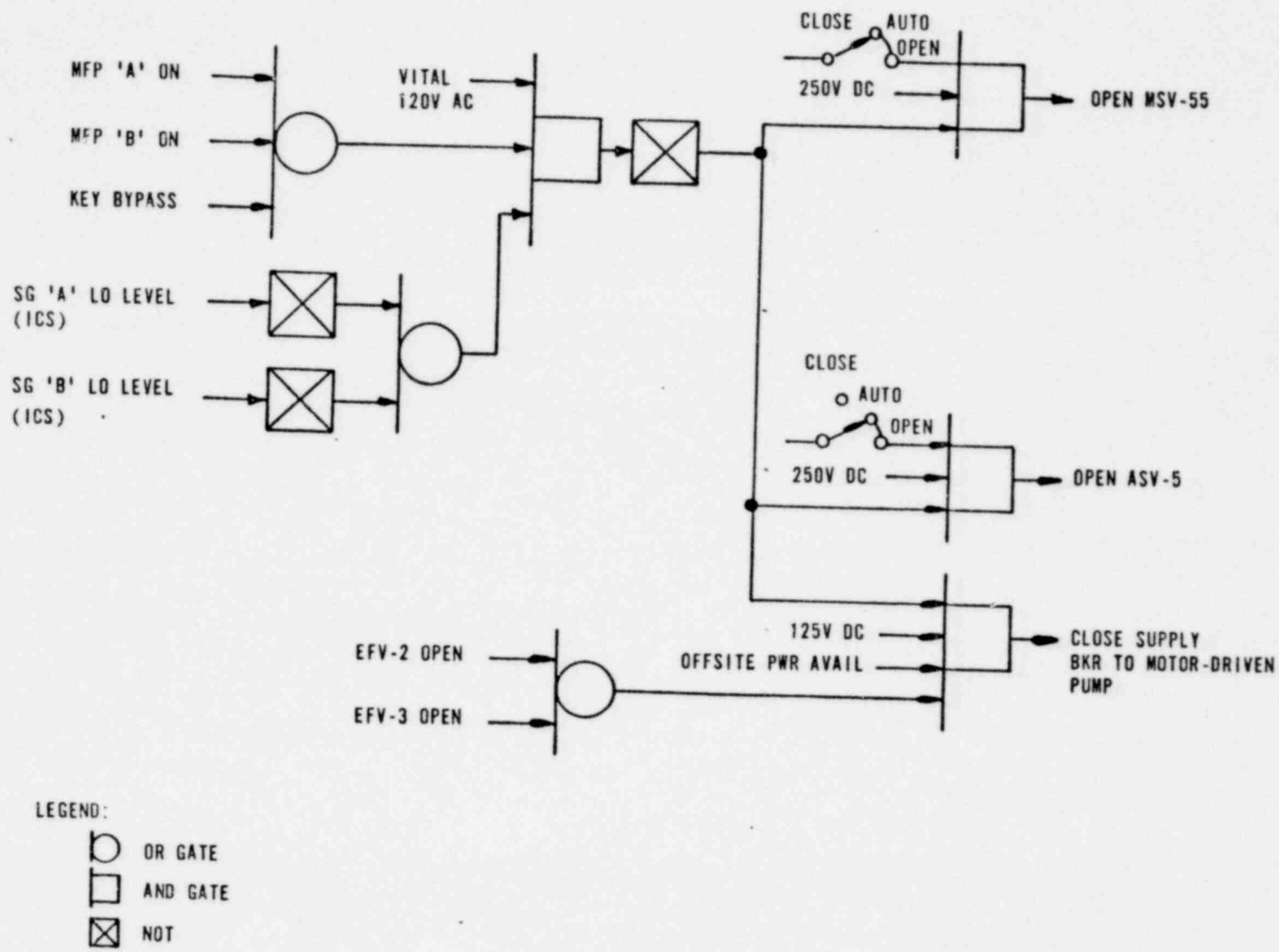

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Figure 6

CRYSTAL RIVER UNIT 3
SLRM LOGIC
("A" CIRCUIT SHOWN)

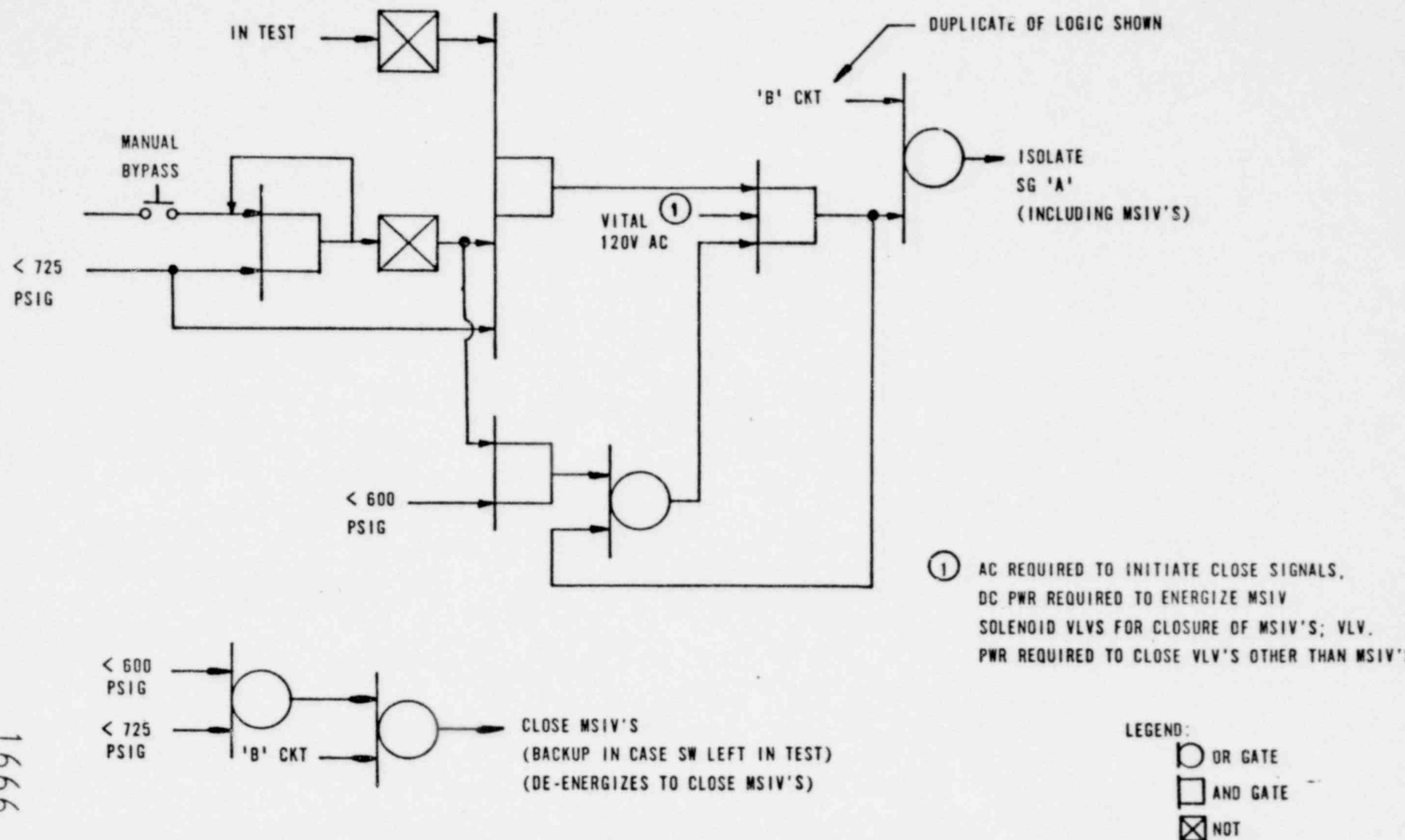

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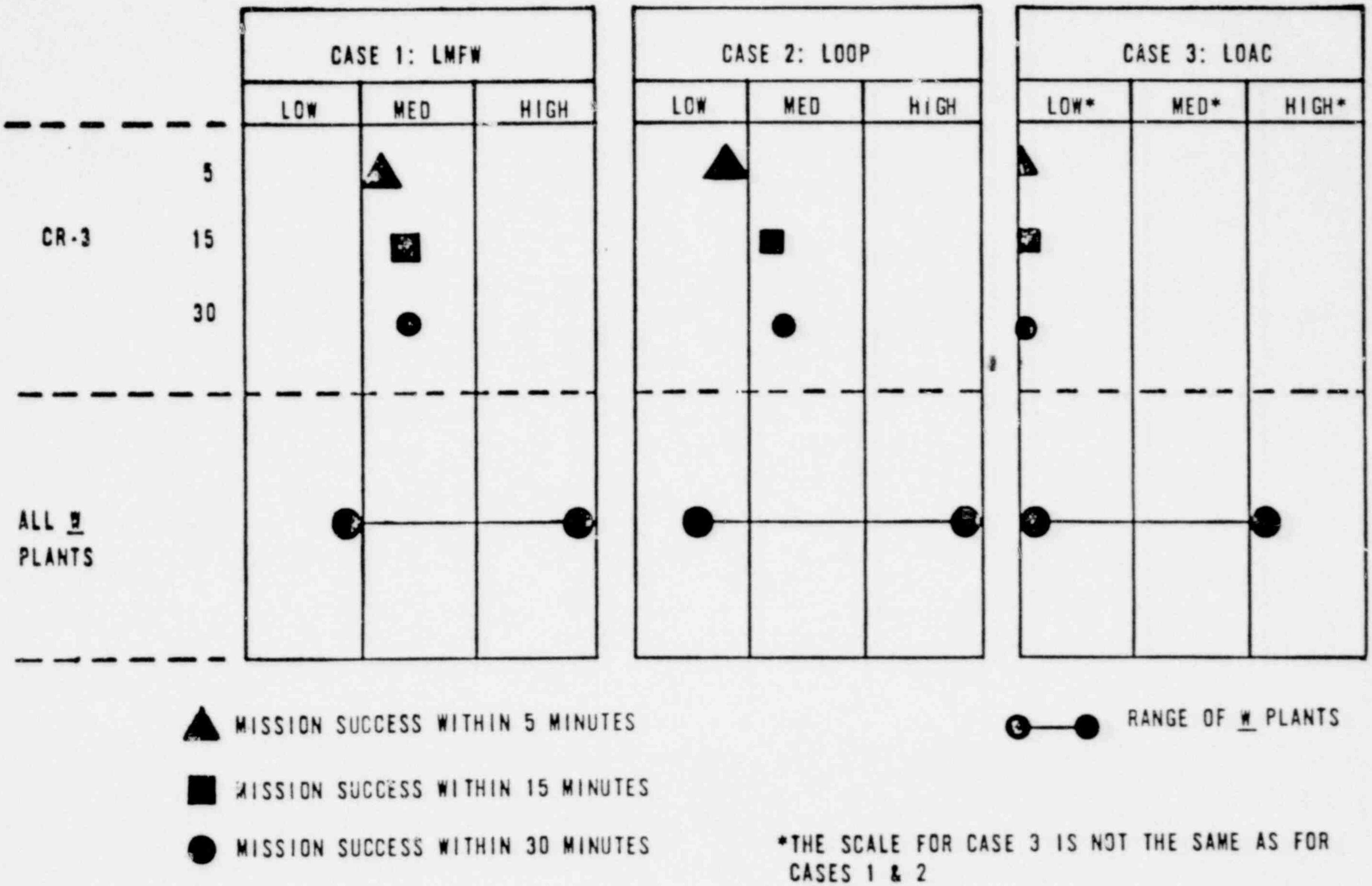
Figure 7

COMPARISON OF CRYSTAL RIVER AFWS RELIABILITY WITH NRC RESULTS FOR W PLANTS



*THE SCALE FOR CASE 3 IS NOT THE SAME AS FOR CASES 1 & 2

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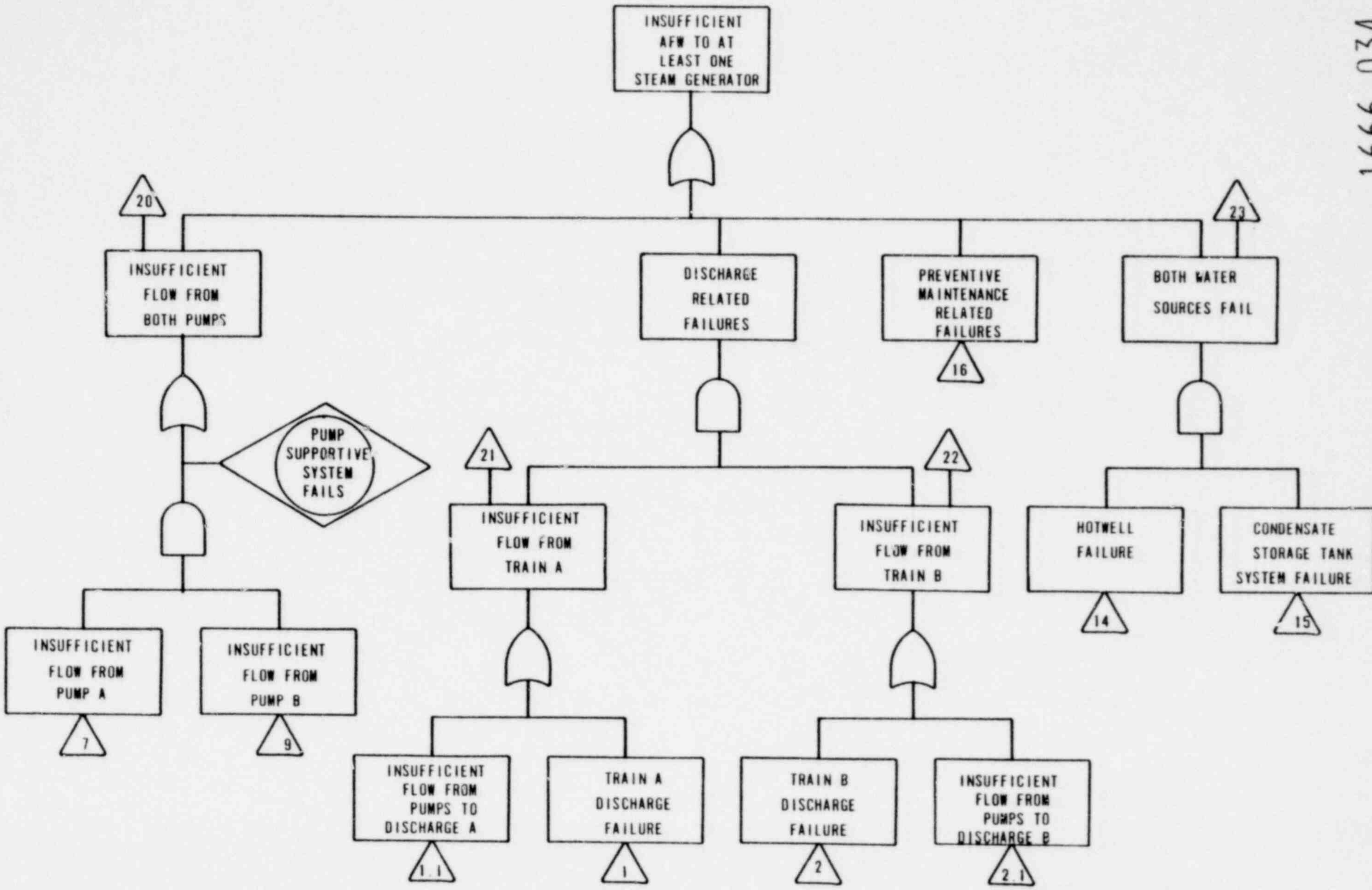
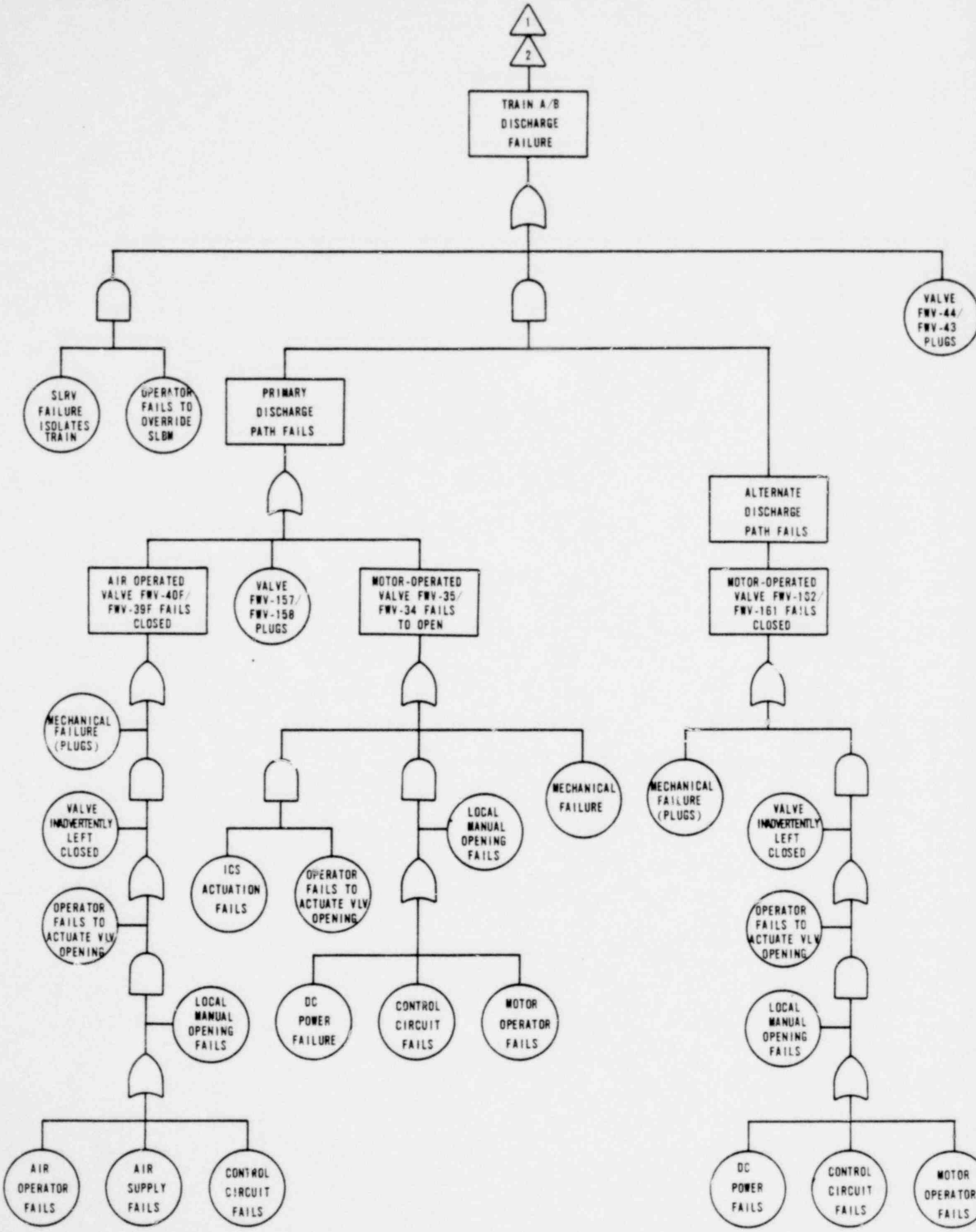
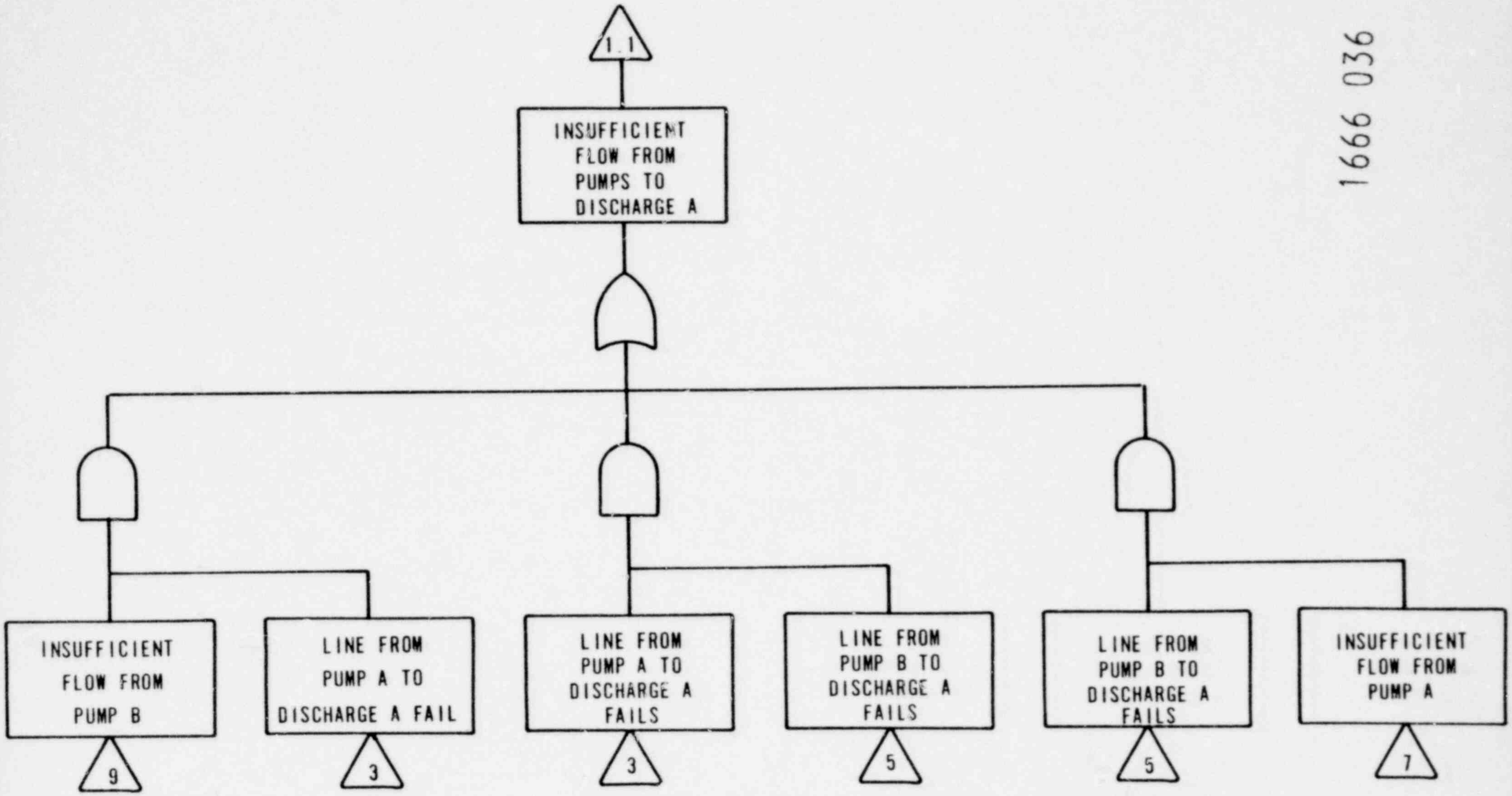

INSUFFICIENT AFW TO AT LEAST ONE STEAM GENERATOR
20
INSUFFICIENT FLOW FROM BOTH PUMPS
DISCHARGE RELATED FAILURES
PREVENTIVE MAINTENANCE RELATED FAILURES
16
23
BOTH WATER SOURCES FAIL
PUMP SUPPORTIVE SYSTEM FAILS
21
INSUFFICIENT FLOW FROM TRAIN A
22
INSUFFICIENT FLOW FROM TRAIN B
HOTWELL FAILURE
14
CONDENSATE STORAGE TANK SYSTEM FAILURE
15
INSUFFICIENT FLOW FROM PUMP A
7
INSUFFICIENT FLOW FROM PUMP B
9
INSUFFICIENT FLOW FROM PUMPS TO DISCHARGE A
1.1
TRAIN A DISCHARGE FAILURE
1
TRAIN B DISCHARGE FAILURE
2
INSUFFICIENT FLOW FROM PUMPS TO DISCHARGE B
2.1

1666 034

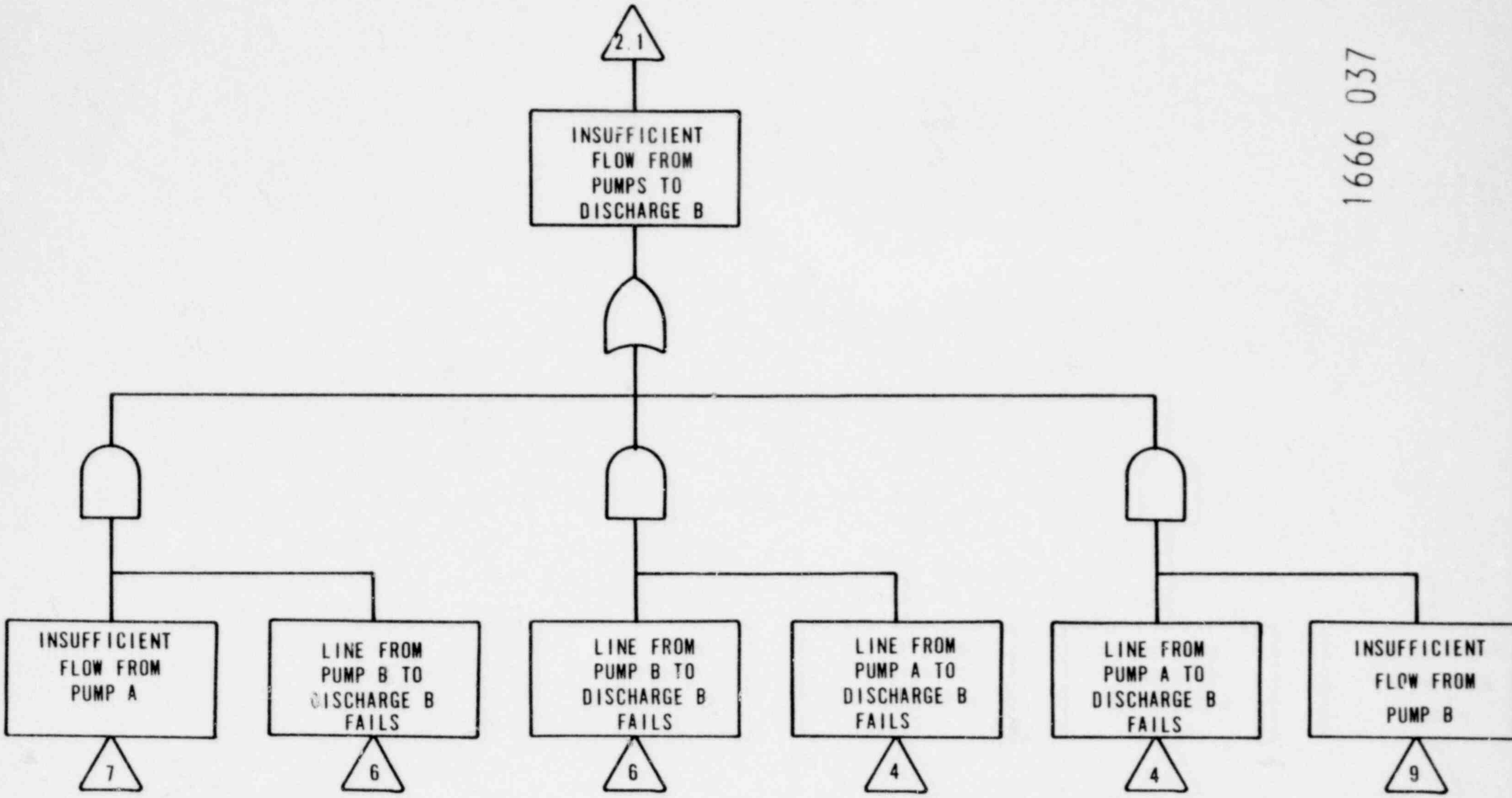


1
2
TRAIN A/B DISCHARGE FAILURE
SLRV FAILURE ISOLATES TRAIN
OPERATOR FAILS TO OVERRIDE SLBM
PRIMARY DISCHARGE PATH FAILS
VALVE FWV-44/ FWV-43 PLUGS
ALTERNATE DISCHARGE PATH FAILS
AIR OPERATED VALVE FWV-40F/ FWV-39F FAILS CLOSED
VALVE FWV-157/ FWV-158 PLUGS
MOTOR-OPERATED VALVE FWV-35/ FWV-34 FAILS TO OPEN
MOTOR-OPERATED VALVE FWV-162/ FWV-161 FAILS CLOSED
MECHANICAL FAILURE (PLUGS)
VALVE INADVERTENTLY LEFT CLOSED
OPERATOR FAILS TO ACTUATE VLV OPENING
LOCAL MANUAL OPENING FAILS
AIR OPERATOR FAILS
AIR SUPPLY FAILS
CONTROL CIRCUIT FAILS
ICS ACTUATION FAILS
OPERATOR FAILS TO ACTUATE VLV OPENING
LOCAL MANUAL OPENING FAILS
MECHANICAL FAILURE
DC POWER FAILURE
CONTROL CIRCUIT FAILS
MOTOR OPERATOR FAILS
MECHANICAL FAILURE (PLUGS)
VALVE INADVERTENTLY LEFT CLOSED
OPERATOR FAILS TO ACTUATE VLV OPENING
LOCAL MANUAL OPENING FAILS
DC POWER FAILS
CONTROL CIRCUIT FAILS
MOTOR OPERATOR FAILS

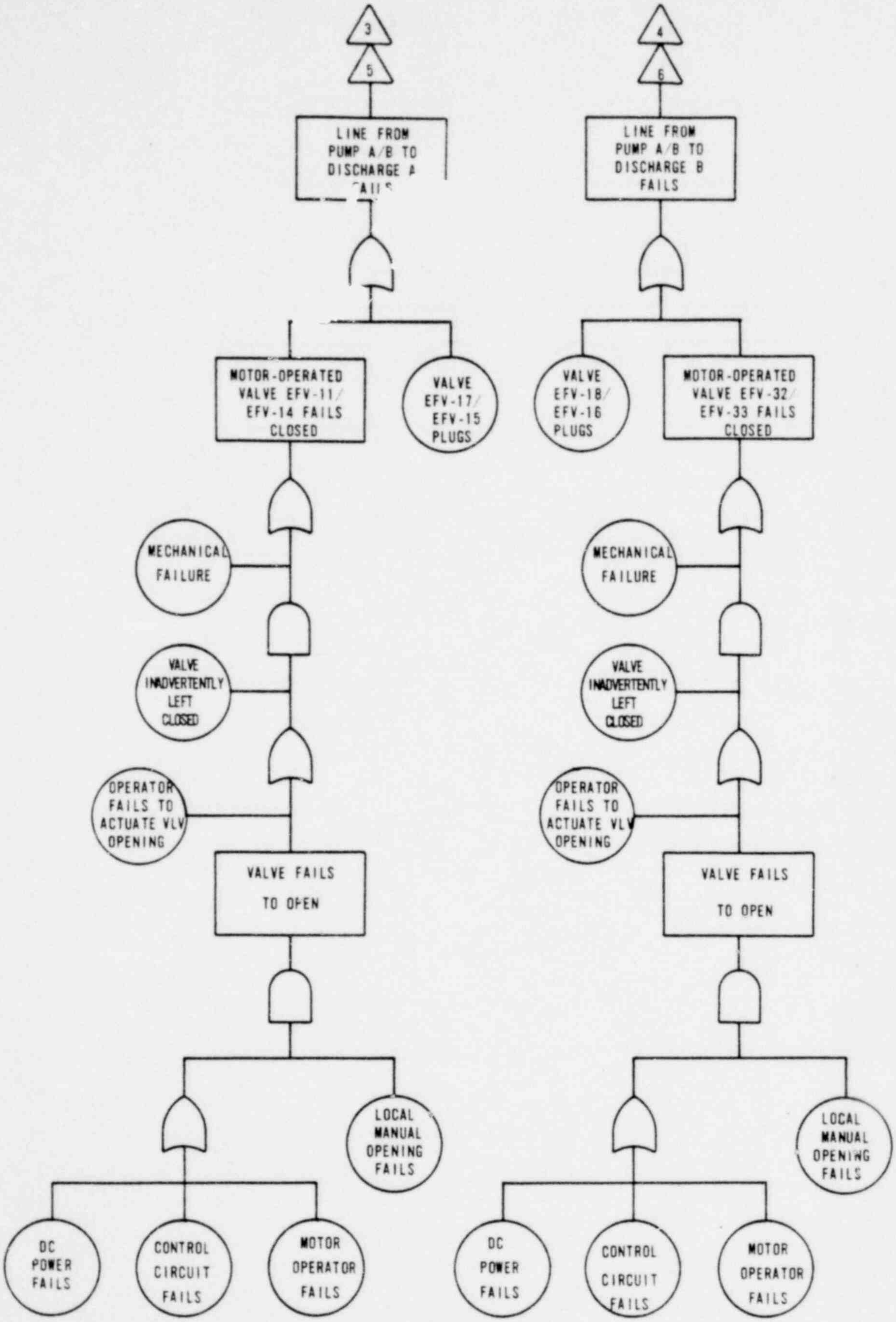
1666 035


1.1
INSUFFICIENT FLOW FROM PUMPS TO DISCHARGE A
INSUFFICIENT FLOW FROM PUMP B
9
LINE FROM PUMP A TO DISCHARGE A FAIL
3
LINE FROM PUMP A TO DISCHARGE A FAILS
3
LINE FROM PUMP B TO DISCHARGE A FAILS
5
LINE FROM PUMP B TO DISCHARGE A FAILS
5
INSUFFICIENT FLOW FROM PUMP A
7

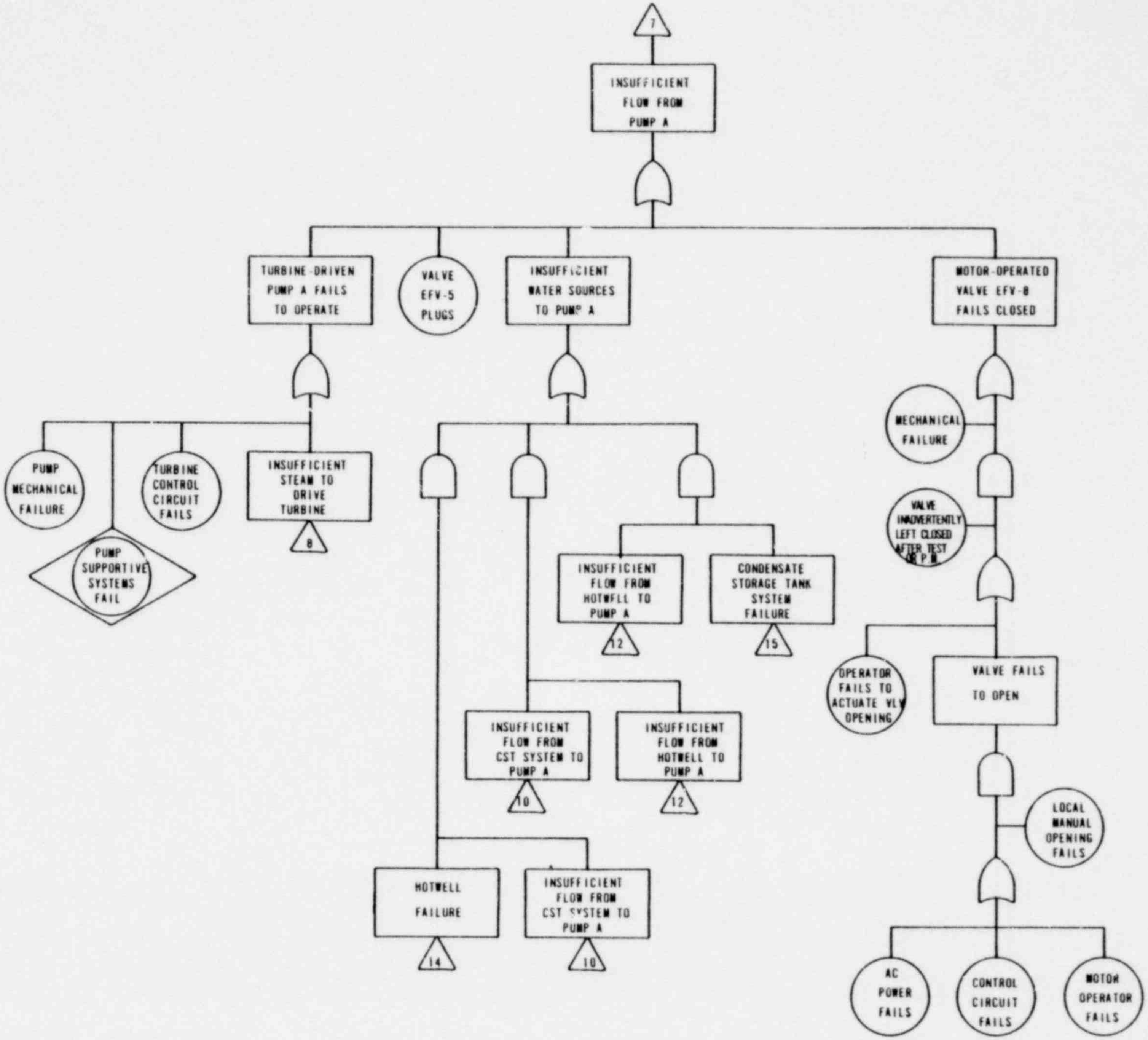
1666 036


2.1
INSUFFICIENT FLOW FROM PUMPS TO DISCHARGE B
INSUFFICIENT FLOW FROM PUMP A
7
LINE FROM PUMP B TO DISCHARGE B FAILS
6
LINE FROM PUMP B TO DISCHARGE B FAILS
6
LINE FROM PUMP A TO DISCHARGE B FAILS
4
LINE FROM PUMP A TO DISCHARGE B FAILS
4
INSUFFICIENT FLOW FROM PUMP B
9

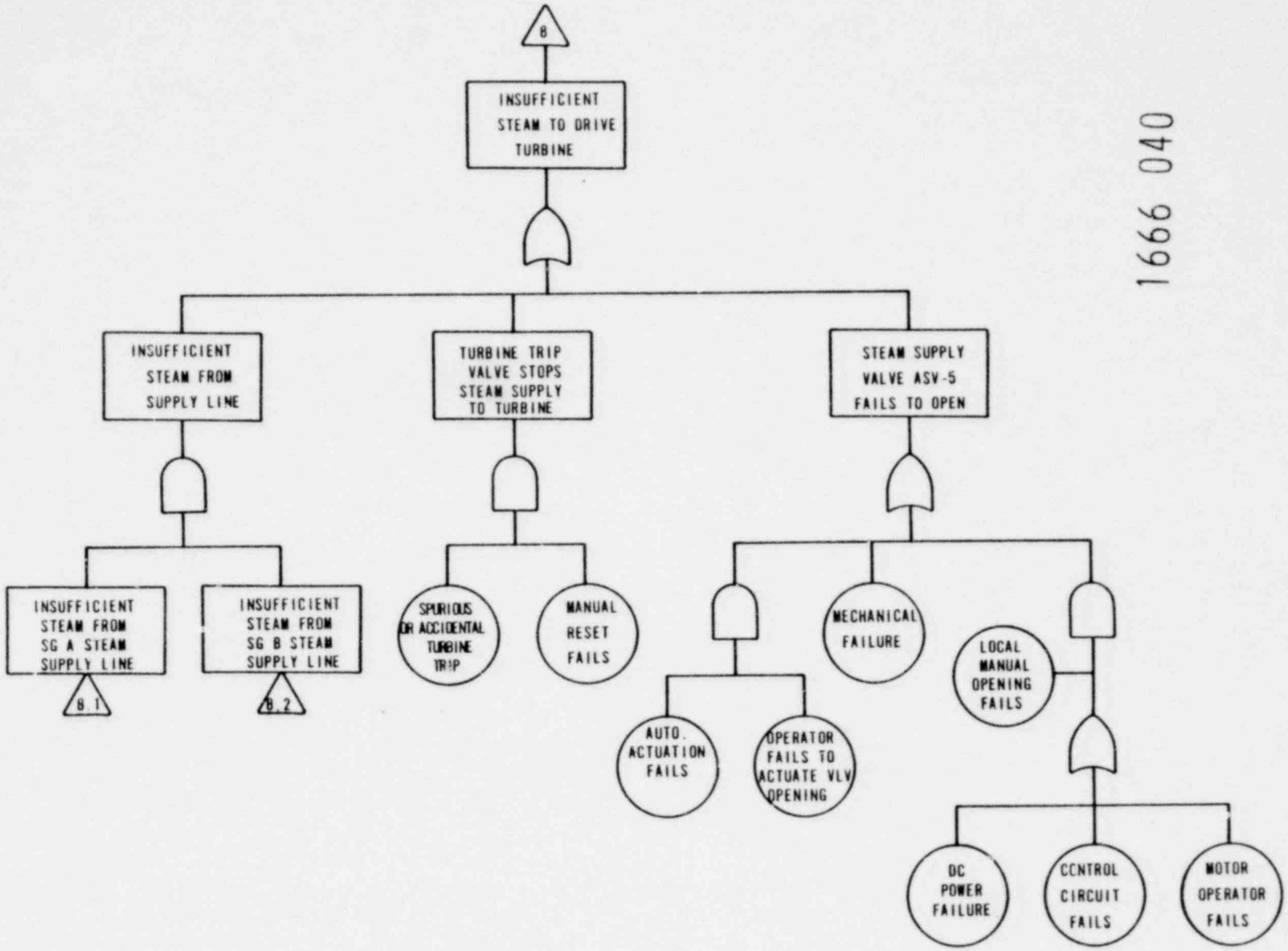
1666 037


3
5
LINE FROM PUMP A/B TO DISCHARGE A FAILS
MOTOR-OPERATED VALVE EFV-11/ EFV-14 FAILS CLOSED
VALVE EFV-17/ EFV-15 PLUGS
MECHANICAL FAILURE
VALVE INADVERTENTLY LEFT CLOSED
OPERATOR FAILS TO ACTUATE VLV OPENING
VALVE FAILS TO OPEN
LOCAL MANUAL OPENING FAILS
DC POWER FAILS
CONTROL CIRCUIT FAILS
MOTOR OPERATOR FAILS
4
6
LINE FROM PUMP A/B TO DISCHARGE B FAILS
VALVE EFV-18/ EFV-16 PLUGS
MOTOR-OPERATED VALVE EFV-32/ EFV-33 FAILS CLOSED
MECHANICAL FAILURE
VALVE INADVERTENTLY LEFT CLOSED
OPERATOR FAILS TO ACTUATE VLV OPENING
VALVE FAILS TO OPEN
LOCAL MANUAL OPENING FAILS
DC POWER FAILS
CONTROL CIRCUIT FAILS
MOTOR OPERATOR FAILS

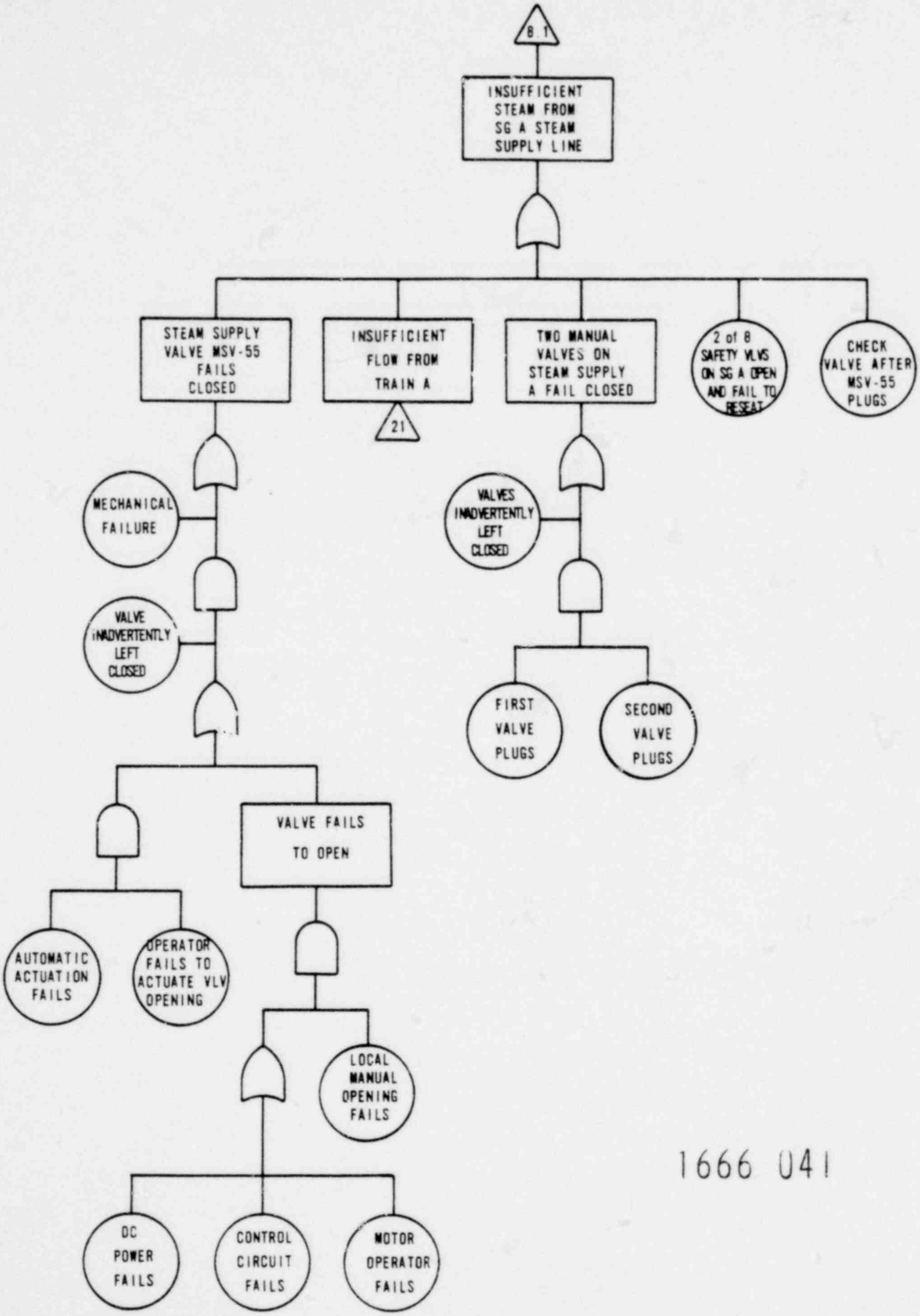
1666 038


7
INSUFFICIENT FLOW FROM PUMP A
TURBINE-DRIVEN PUMP A FAILS TO OPERATE
VALVE EFV-5 PLUGS
INSUFFICIENT WATER SOURCES TO PUMP A
MOTOR-OPERATED VALVE EFV-8 FAILS CLOSED
PUMP MECHANICAL FAILURE
PUMP SUPPORTIVE SYSTEMS FAIL
TURBINE CONTROL CIRCUIT FAILS
INSUFFICIENT STEAM TO DRIVE TURBINE
8
INSUFFICIENT FLOW FROM HOTWELL TO PUMP A
12
CONDENSATE STORAGE TANK SYSTEM FAILURE
15
INSUFFICIENT FLOW FROM CST SYSTEM TO PUMP A
10
INSUFFICIENT FLOW FROM HOTWELL TO PUMP A
12
HOTWELL FAILURE
14
INSUFFICIENT FLOW FROM CST SYSTEM TO PUMP A
10
MECHANICAL FAILURE
VALVE INADVERTENTLY LEFT CLOSED AFTER TEST
OPERATOR FAILS TO ACTUATE VLV OPENING
VALVE FAILS TO OPEN
LOCAL MANUAL OPENING FAILS
AC POWER FAILS
CONTROL CIRCUIT FAILS
MOTOR OPERATOR FAILS

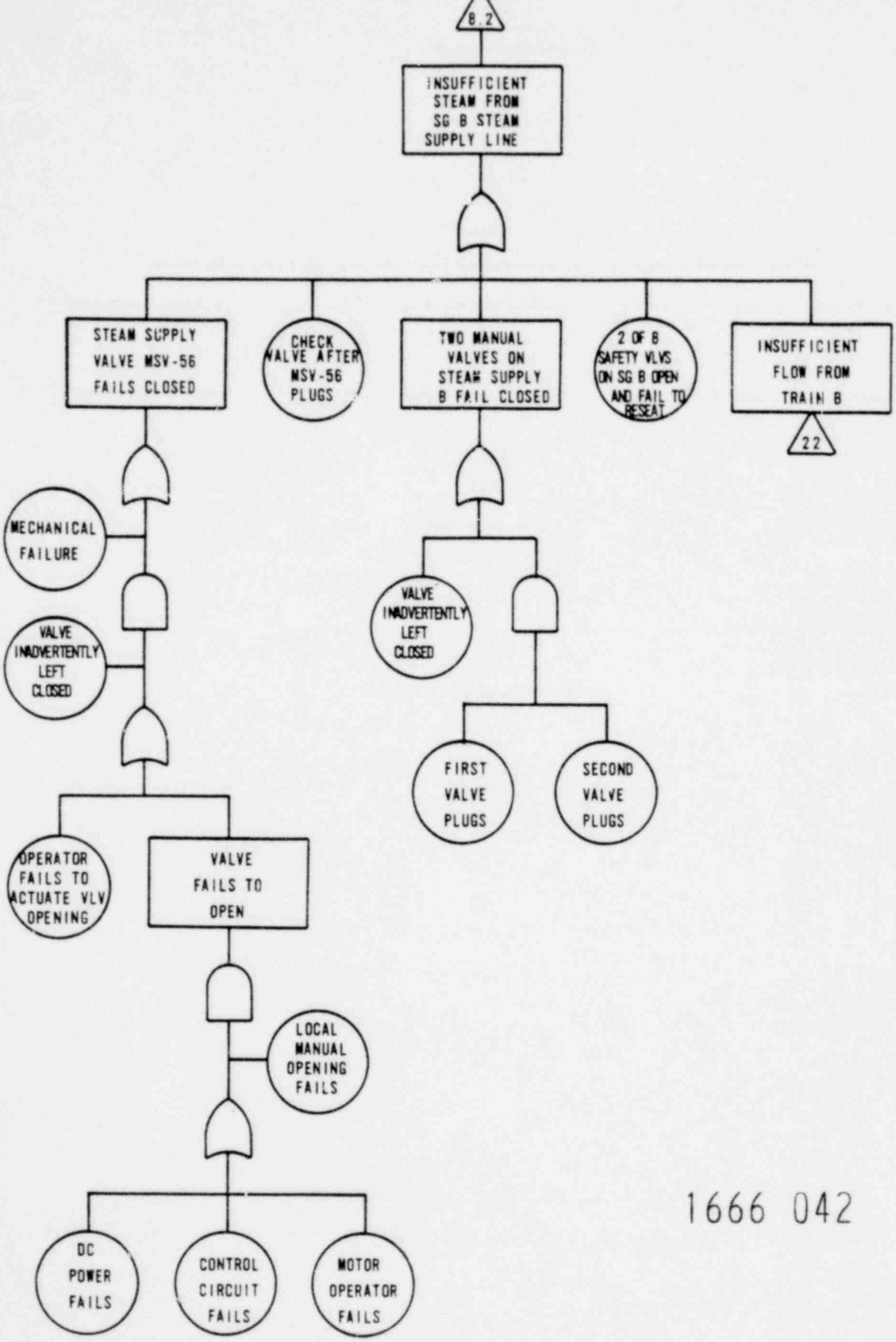
1666 039


B
INSUFFICIENT STEAM TO DRIVE TURBINE
INSUFFICIENT STEAM FROM SUPPLY LINE
TURBINE TRIP VALVE STOPS STEAM SUPPLY TO TURBINE
STEAM SUPPLY VALVE ASV-5 FAILS TO OPEN
INSUFFICIENT STEAM FROM SG A STEAM SUPPLY LINE
B.1
INSUFFICIENT STEAM FROM SG B STEAM SUPPLY LINE
B.2
SPURIOUS OR ACCIDENTAL TURBINE TRIP
MANUAL RESET FAILS
MECHANICAL FAILURE
LOCAL MANUAL OPENING FAILS
AUTO. ACTUATION FAILS
OPERATOR FAILS TO ACTUATE VLV OPENING
DC POWER FAILURE
CCNTROL CIRCUIT FAILS
MOTOR OPERATOR FAILS

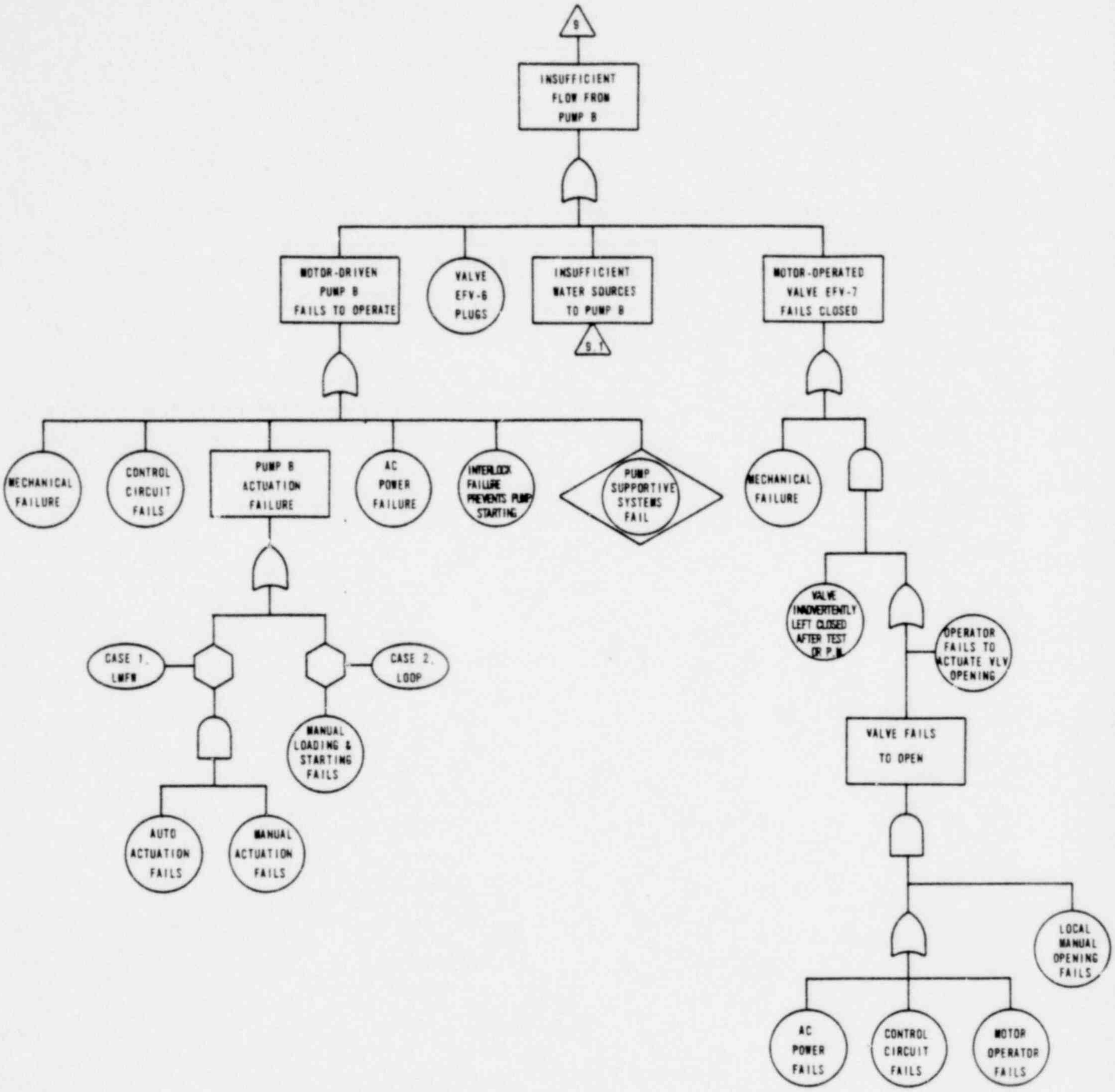
1666 040


8.1
INSUFFICIENT STEAM FROM SG A STEAM SUPPLY LINE
STEAM SUPPLY VALVE MSV-55 FAILS CLOSED
INSUFFICIENT FLOW FROM TRAIN A
21
TWO MANUAL VALVES ON STEAM SUPPLY A FAIL CLOSED
2 of 8 SAFETY VLVS ON SG A OPEN AND FAIL TO RESEAT
CHECK VALVE AFTER MSV-55 PLUGS
MECHANICAL FAILURE
VALVES INADVERTENTLY LEFT CLOSED
VALVE INADVERTENTLY LEFT CLOSED
FIRST VALVE PLUGS
SECOND VALVE PLUGS
VALVE FAILS TO OPEN
AUTOMATIC ACTUATION FAILS
OPERATOR FAILS TO ACTUATE VLV OPENING
LOCAL MANUAL OPENING FAILS
DC POWER FAILS
CONTROL CIRCUIT FAILS
MOTOR OPERATOR FAILS

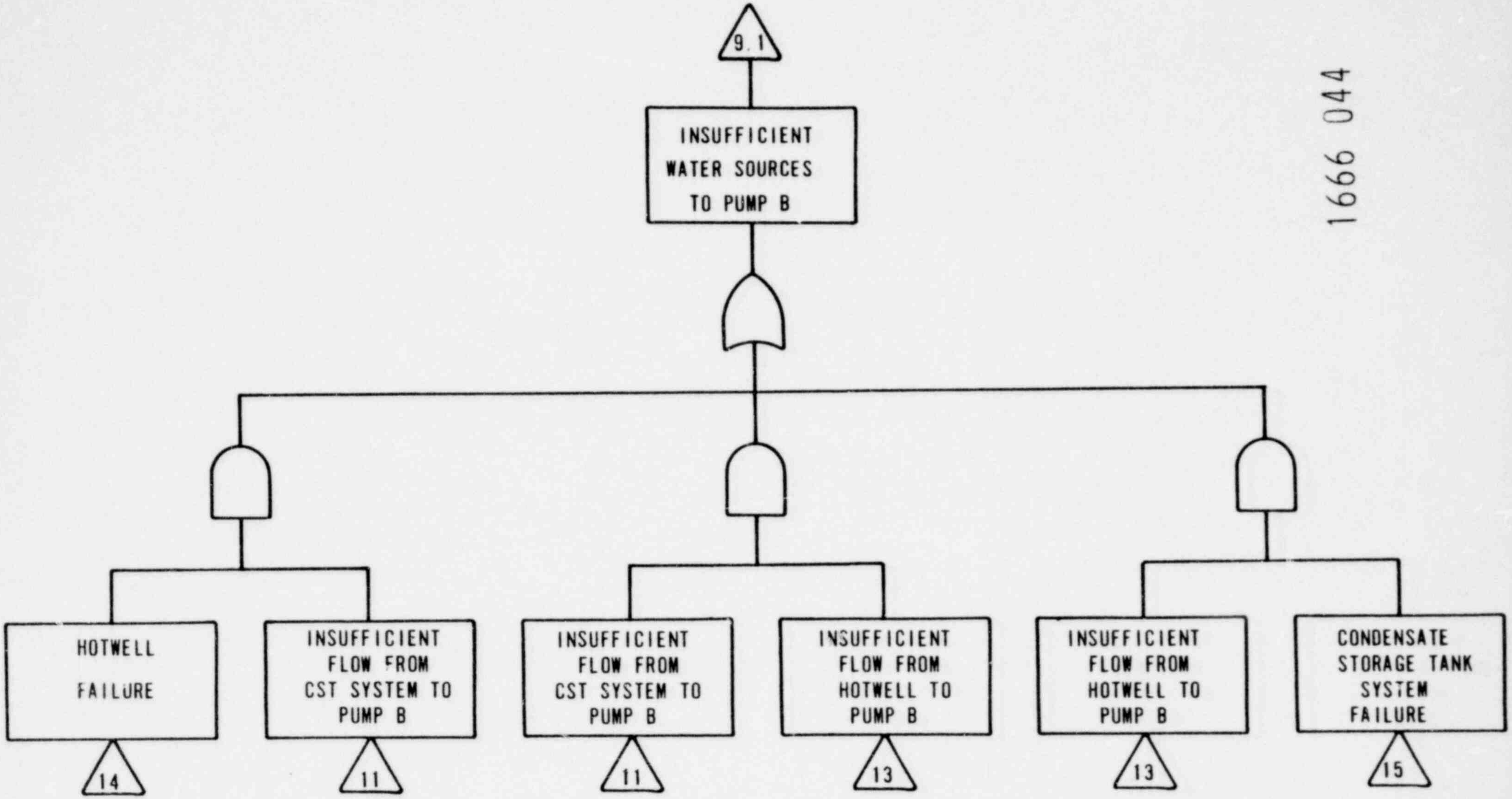
1666 041


8.2
INSUFFICIENT STEAM FROM SG B STEAM SUPPLY LINE
STEAM SUPPLY VALVE MSV-56 FAILS CLOSED
CHECK VALVE AFTER MSV-56 PLUGS
TWO MANUAL VALVES ON STEAM SUPPLY B FAIL CLOSED
2 OF 8 SAFETY VLVS ON SG B OPEN AND FAIL TO RESEAT
INSUFFICIENT FLOW FROM TRAIN B
22
MECHANICAL FAILURE
VALVE INADVERTENTLY LEFT CLOSED
VALVE INADVERTENTLY LEFT CLOSED
FIRST VALVE PLUGS
SECOND VALVE PLUGS
OPERATOR FAILS TO ACTUATE VLV OPENING
VALVE FAILS TO OPEN
LOCAL MANUAL OPENING FAILS
DC POWER FAILS
CONTROL CIRCUIT FAILS
MOTOR OPERATOR FAILS

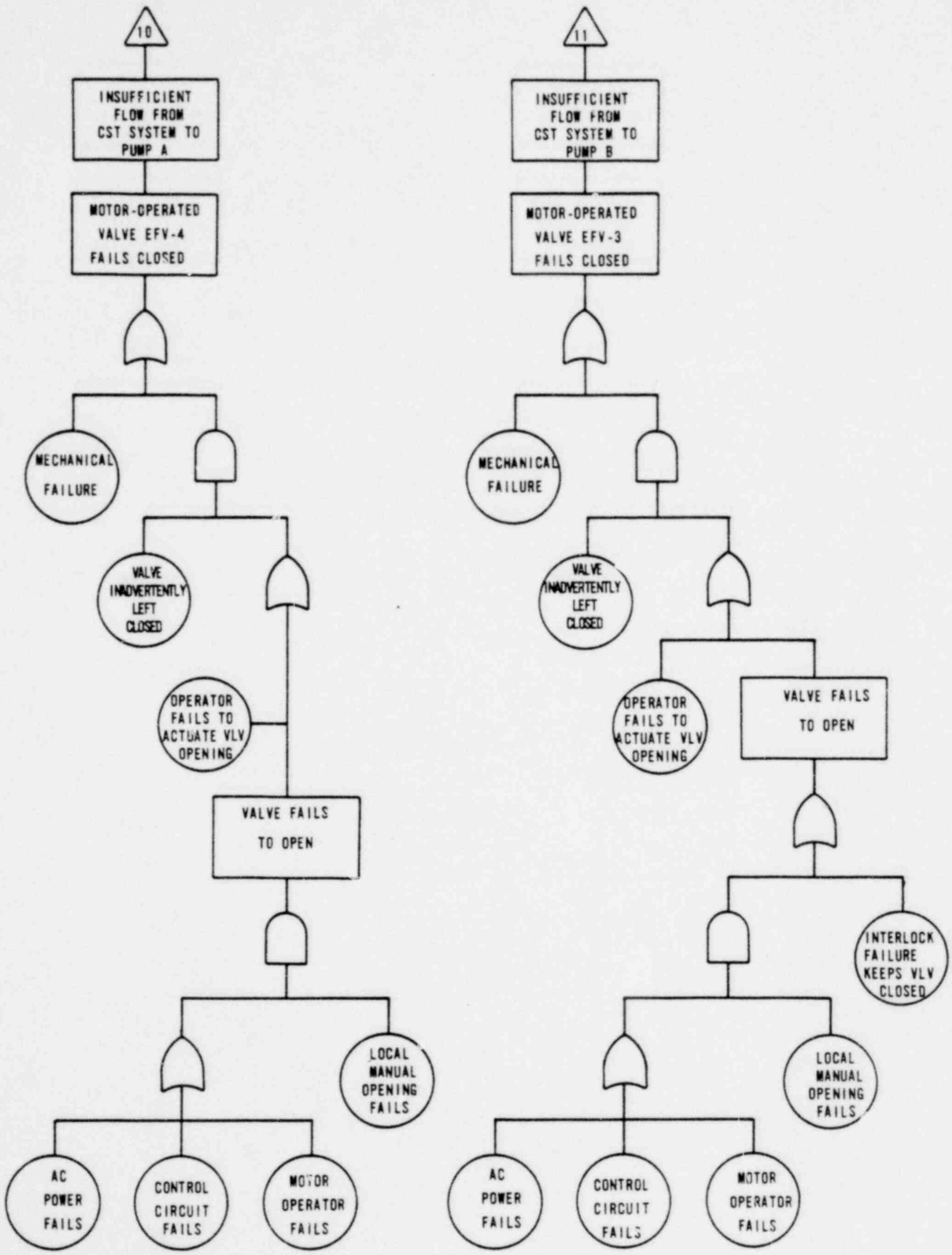
1666 042


9
INSUFFICIENT FLOW FROM PUMP B
MOTOR-DRIVEN PUMP B FAILS TO OPERATE
VALVE EFV-6 PLUGS
INSUFFICIENT WATER SOURCES TO PUMP B
9.1
MOTOR-OPERATED VALVE EFV-7 FAILS CLOSED
MECHANICAL FAILURE
CONTROL CIRCUIT FAILS
PUMP B ACTUATION FAILURE
AC POWER FAILURE
INTERLOCK FAILURE PREVENTS PUMP STARTING
PUMP SUPPORTIVE SYSTEMS FAIL
MECHANICAL FAILURE
CASE 1, LMFW
CASE 2, LOOP
MANUAL LOADING & STARTING FAILS
AUTO ACTUATION FAILS
MANUAL ACTUATION FAILS
VALVE INADVERTENTLY LEFT CLOSED AFTER TEST OR P.M.
OPERATOR FAILS TO ACTUATE VLV OPENING
VALVE FAILS TO OPEN
LOCAL MANUAL OPENING FAILS
AC POWER FAILS
CONTROL CIRCUIT FAILS
MOTOR OPERATOR FAILS

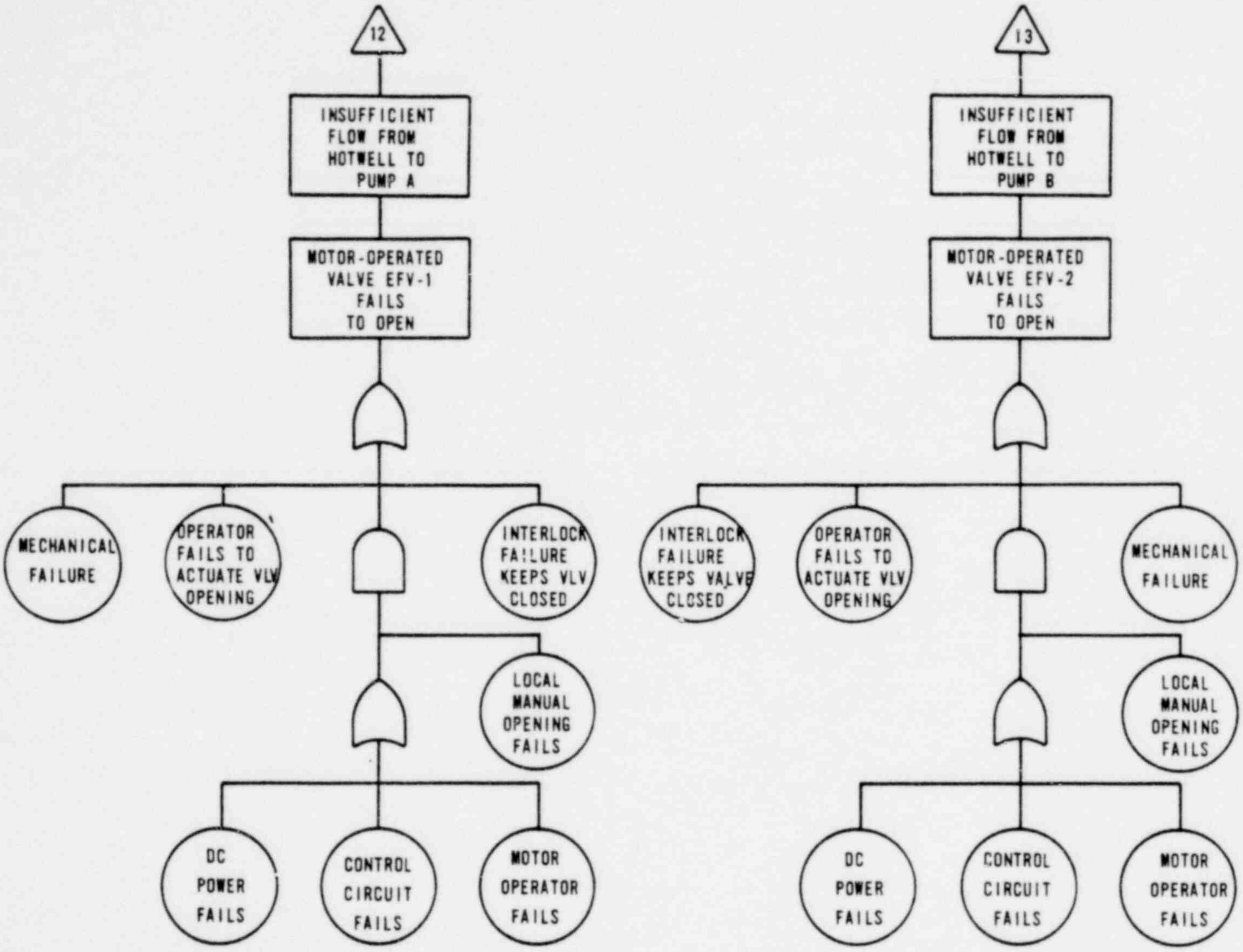
1666 043


9.1
INSUFFICIENT WATER SOURCES TO PUMP B
HOTWELL FAILURE
14
INSUFFICIENT FLOW FROM CST SYSTEM TO PUMP B
11
INSUFFICIENT FLOW FROM CST SYSTEM TO PUMP B
11
INSUFFICIENT FLOW FROM HOTWELL TO PUMP B
13
INSUFFICIENT FLOW FROM HOTWELL TO PUMP B
13
CONDENSATE STORAGE TANK SYSTEM FAILURE
15

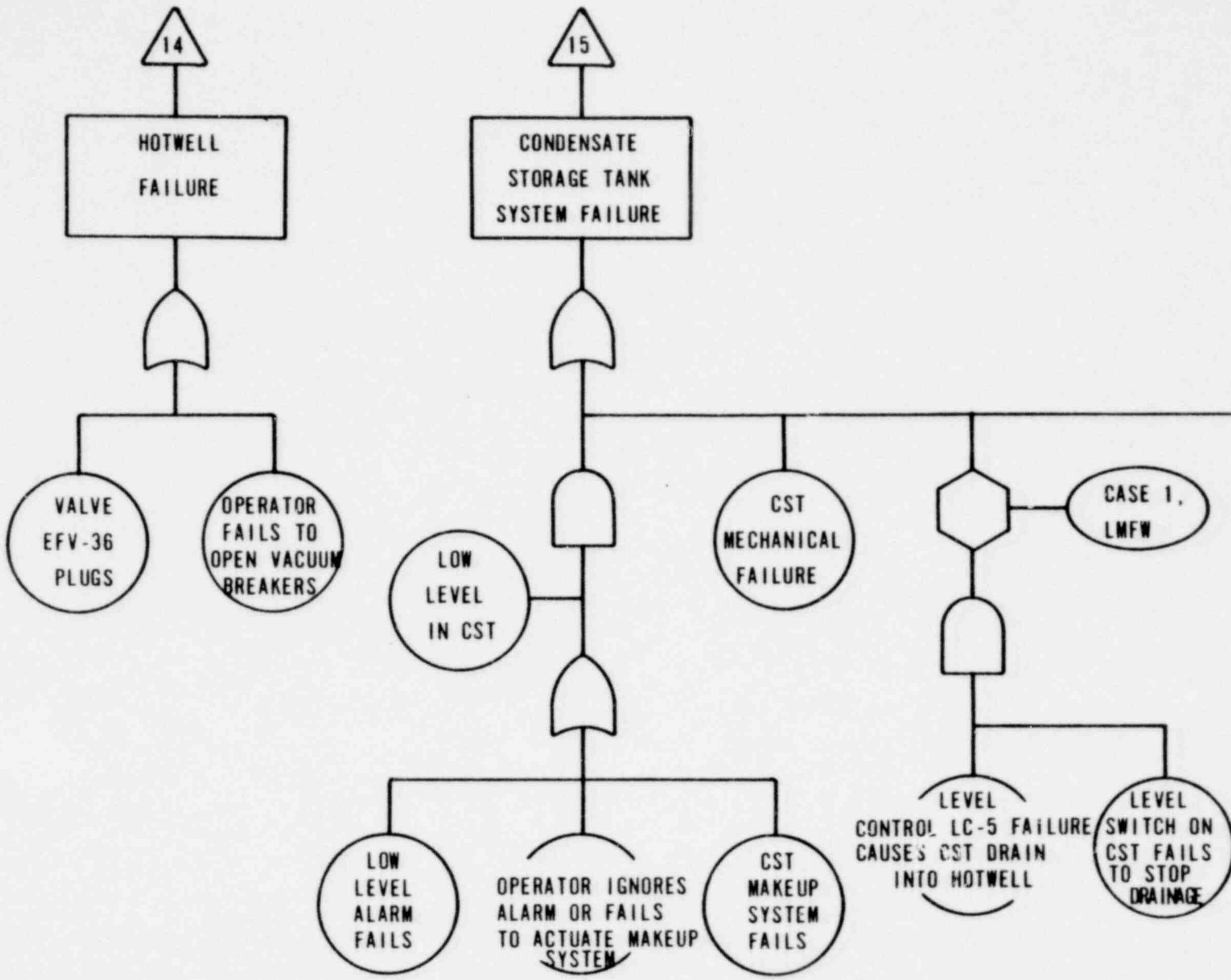
1666 044


10
INSUFFICIENT FLOW FROM CST SYSTEM TO PUMP A
MOTOR-OPERATED VALVE EFV-4 FAILS CLOSED
MECHANICAL FAILURE
VALVE INADVERTENTLY LEFT CLOSED
OPERATOR FAILS TO ACTUATE VLV OPENING
VALVE FAILS TO OPEN
LOCAL MANUAL OPENING FAILS
AC POWER FAILS
CONTROL CIRCUIT FAILS
MOTOR OPERATOR FAILS
11
INSUFFICIENT FLOW FROM CST SYSTEM TO PUMP B
MOTOR-OPERATED VALVE EFV-3 FAILS CLOSED
MECHANICAL FAILURE
VALVE INADVERTENTLY LEFT CLOSED
OPERATOR FAILS TO ACTUATE VLV OPENING
VALVE FAILS TO OPEN
INTERLOCK FAILURE KEEPS VLV CLOSED
LOCAL MANUAL OPENING FAILS
AC POWER FAILS
CONTROL CIRCUIT FAILS
MOTOR OPERATOR FAILS

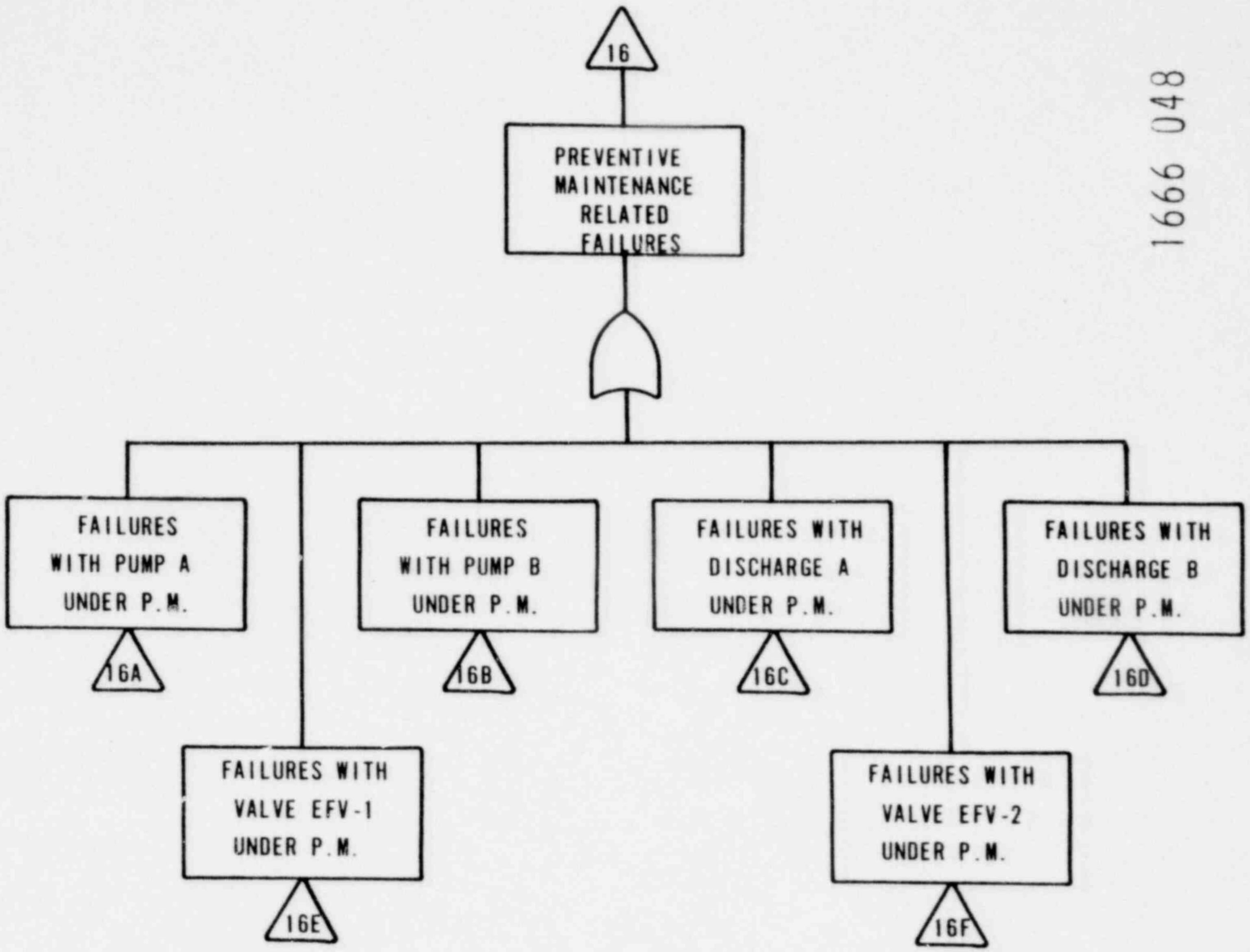
1666 045


12
INSUFFICIENT FLOW FROM HOTWELL TO PUMP A
MOTOR-OPERATED VALVE EFV-1 FAILS TO OPEN
MECHANICAL FAILURE
OPERATOR FAILS TO ACTUATE VLV OPENING
INTERLOCK FAILURE KEEPS VLV CLOSED
LOCAL MANUAL OPENING FAILS
DC POWER FAILS
CONTROL CIRCUIT FAILS
MOTOR OPERATOR FAILS
13
INSUFFICIENT FLOW FROM HOTWELL TO PUMP B
MOTOR-OPERATED VALVE EFV-2 FAILS TO OPEN
INTERLOCK FAILURE KEEPS VALVE CLOSED
OPERATOR FAILS TO ACTUATE VLV OPENING
MECHANICAL FAILURE
LOCAL MANUAL OPENING FAILS
DC POWER FAILS
CONTROL CIRCUIT FAILS
MOTOR OPERATOR FAILS

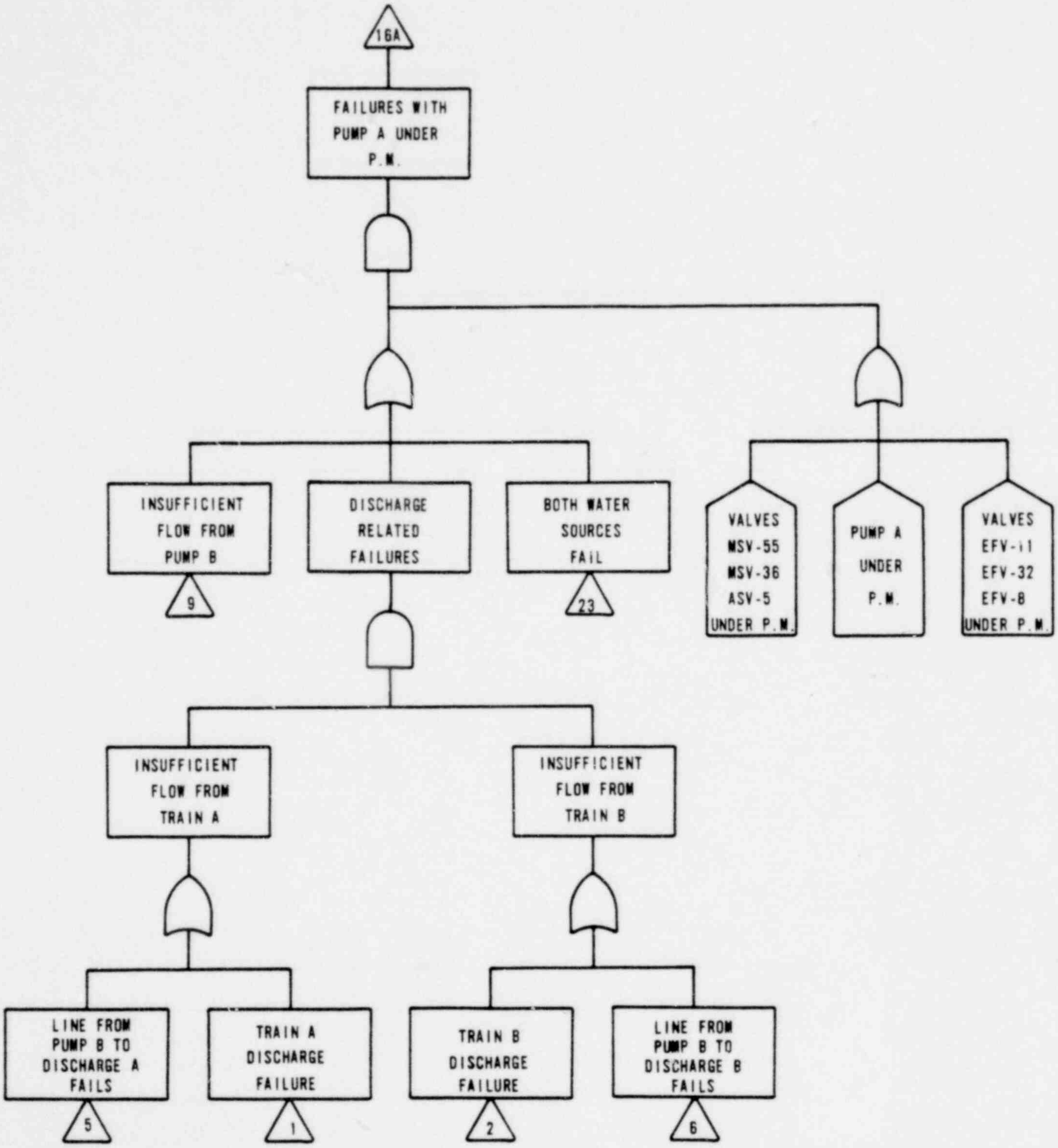
1666 046


14
HOTWELL FAILURE
VALVE EFV-36 PLUGS
OPERATOR FAILS TO OPEN VACUUM BREAKERS
15
CONDENSATE STORAGE TANK SYSTEM FAILURE
LOW LEVEL IN CST
CST MECHANICAL FAILURE
CASE 1, LMFW
VALVE EFV-103 PLUGS
LOW LEVEL ALARM FAILS
OPERATOR IGNORES ALARM OR FAILS TO ACTUATE MAKEUP SYSTEM
CST MAKEUP SYSTEM FAILS
LEVEL CONTROL LC-5 FAILURE CAUSES CST DRAIN INTO HOTWELL
LEVEL SWITCH ON CST FAILS TO STOP DRAINAGE

1666 047

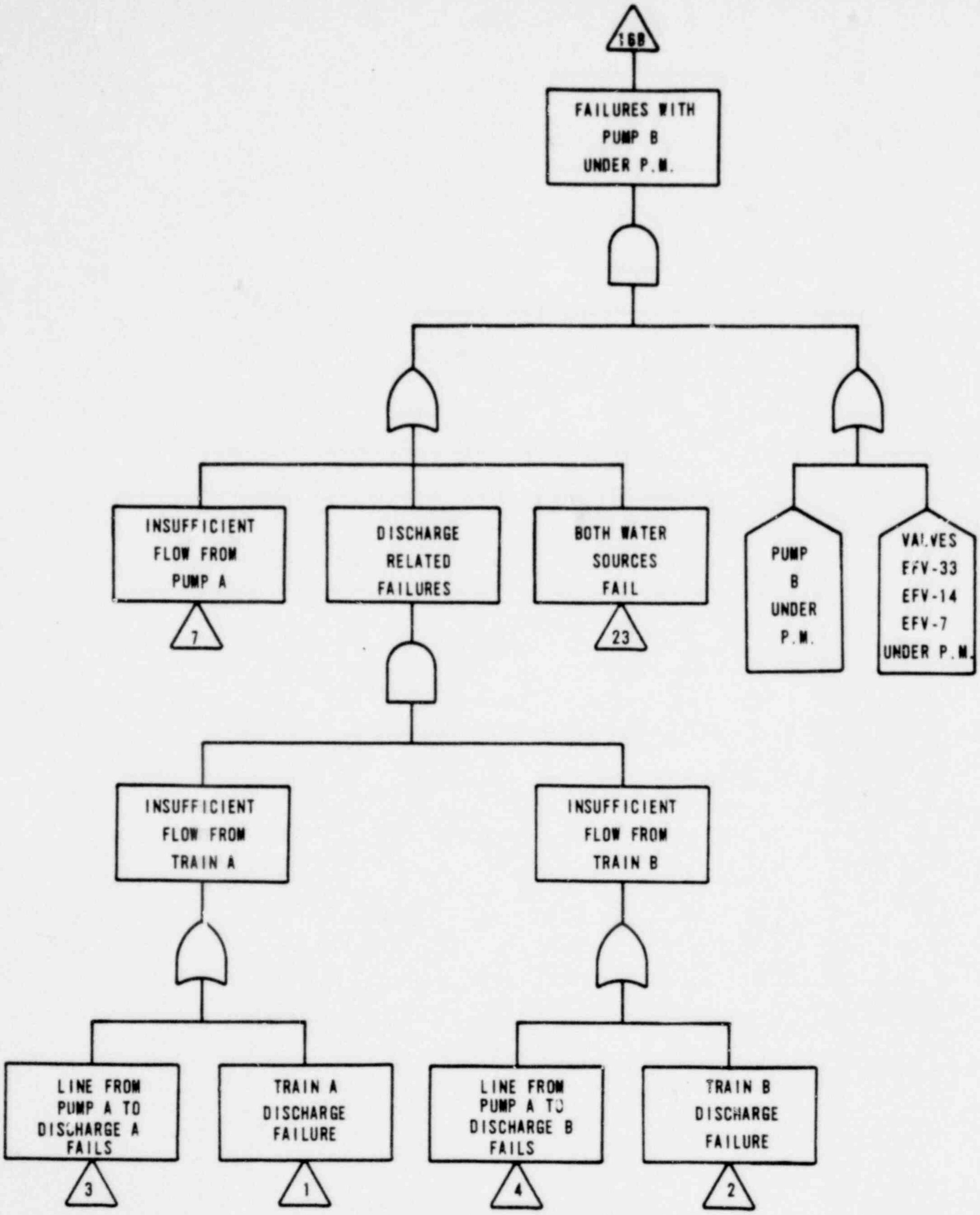

16
PREVENTIVE MAINTENANCE RELATED FAILURES
FAILURES WITH PUMP A UNDER P.M.
16A
FAILURES WITH PUMP B UNDER P.M.
16B
FAILURES WITH DISCHARGE A UNDER P.M.
16C
FAILURES WITH DISCHARGE B UNDER P.M.
16D
FAILURES WITH VALVE EFV-1 UNDER P.M.
16E
FAILURES WITH VALVE EFV-2 UNDER P.M.
16F

1666 048

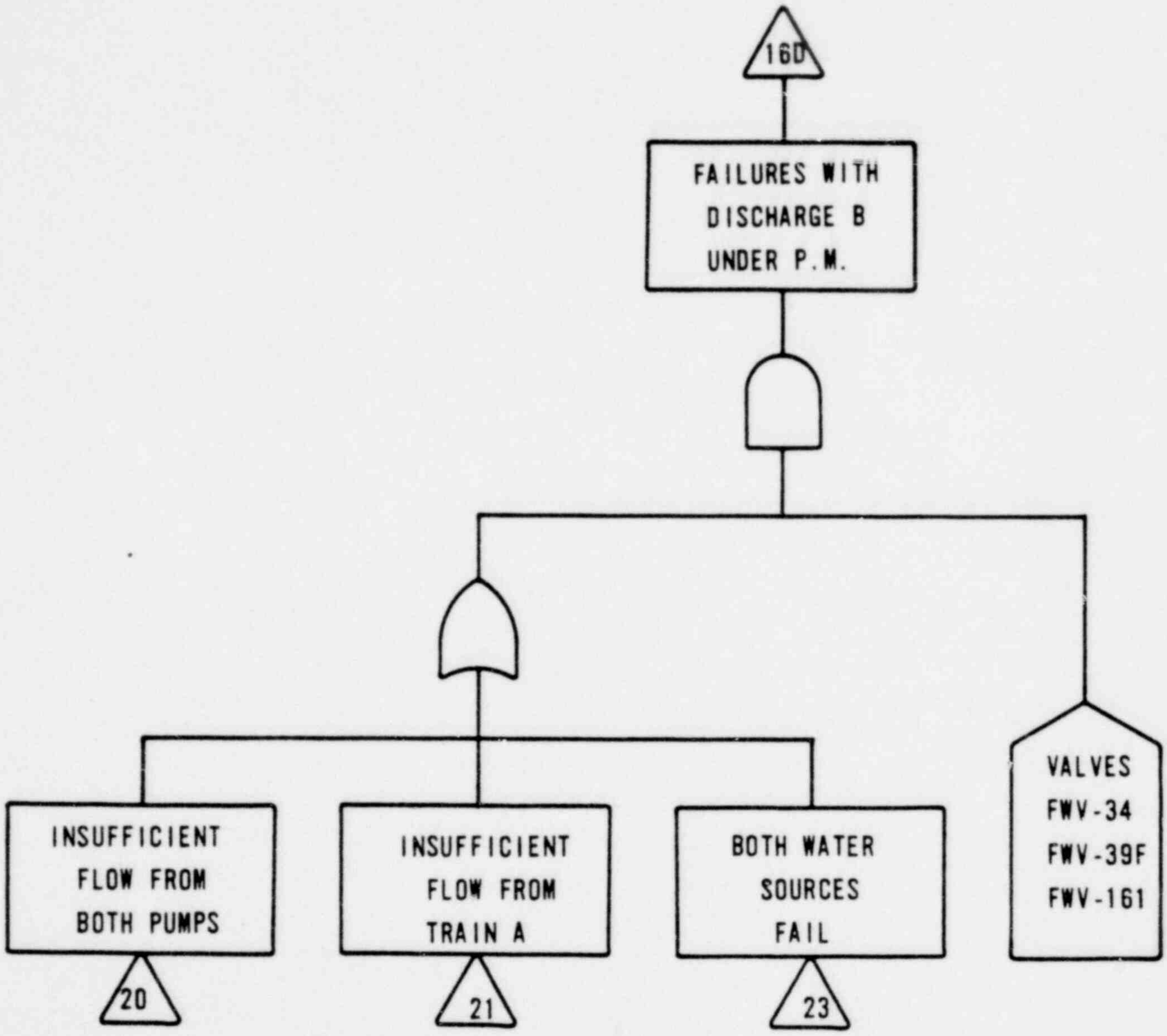


16A
FAILURES WITH PUMP A UNDER P.M.
INSUFFICIENT FLOW FROM PUMP B
9
DISCHARGE RELATED FAILURES
BOTH WATER SOURCES FAIL
23
VALVES MSV-55 MSV-36 ASV-5 UNDER P.M.
PUMP A UNDER P.M.
VALVES EFV-11 EFV-32 EFV-8 UNDER P.M.
INSUFFICIENT FLOW FROM TRAIN A
INSUFFICIENT FLOW FROM TRAIN B
LINE FROM PUMP B TO DISCHARGE A FAILS
5
TRAIN A DISCHARGE FAILURE
1
TRAIN B DISCHARGE FAILURE
2
LINE FROM PUMP B TO DISCHARGE B FAILS
6

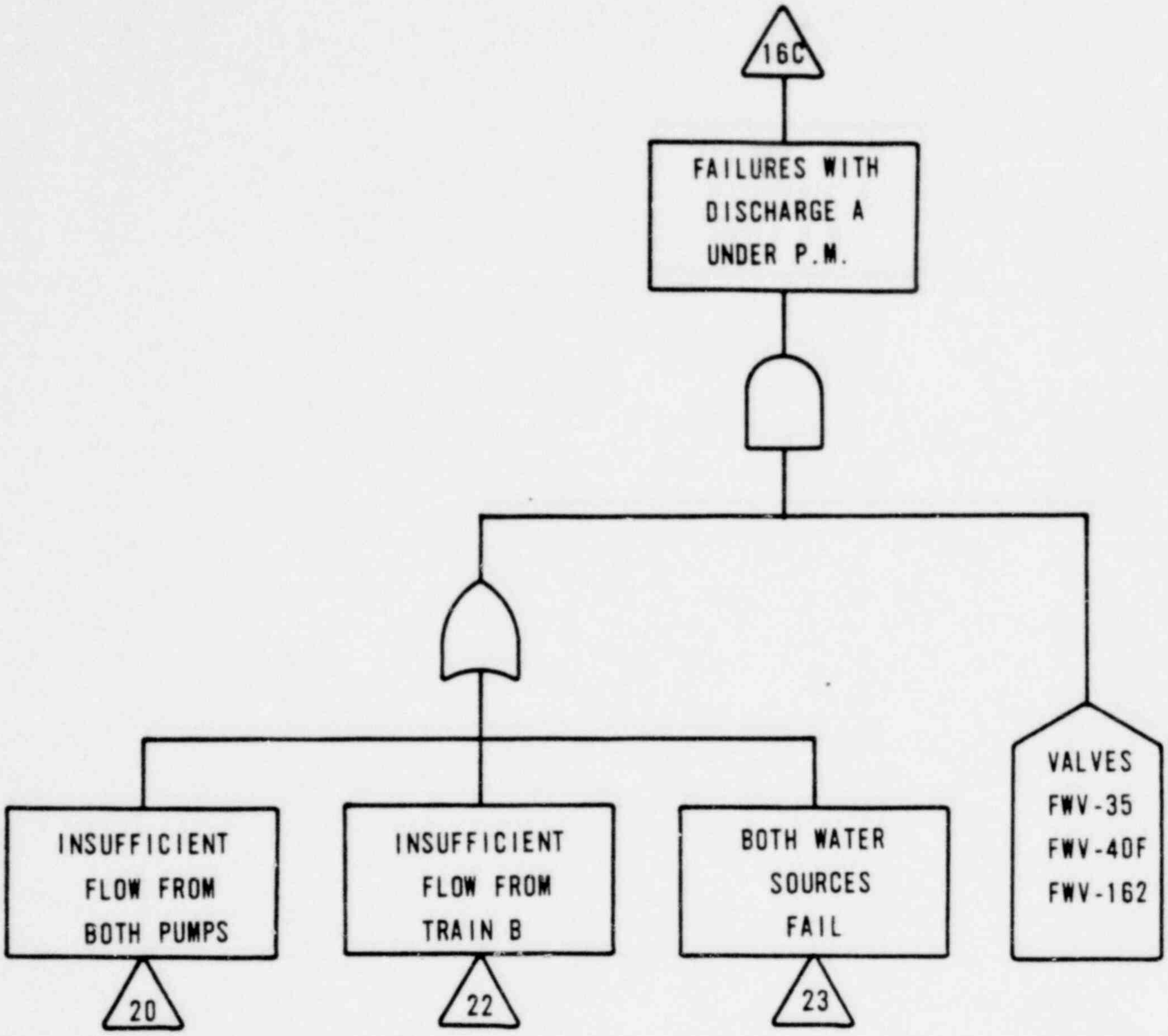
1666 049


16B
FAILURES WITH PUMP B UNDER P.M.
INSUFFICIENT FLOW FROM PUMP A
7
DISCHARGE RELATED FAILURES
BOTH WATER SOURCES FAIL
23
PUMP B UNDER P.M.
VALVES EFV-33 EFV-14 EFV-7 UNDER P.M.
INSUFFICIENT FLOW FROM TRAIN A
INSUFFICIENT FLOW FROM TRAIN B
LINE FROM PUMP A TO DISCHARGE A FAILS
3
TRAIN A DISCHARGE FAILURE
1
LINE FROM PUMP A TO DISCHARGE B FAILS
4
TRAIN B DISCHARGE FAILURE
2

1666 050

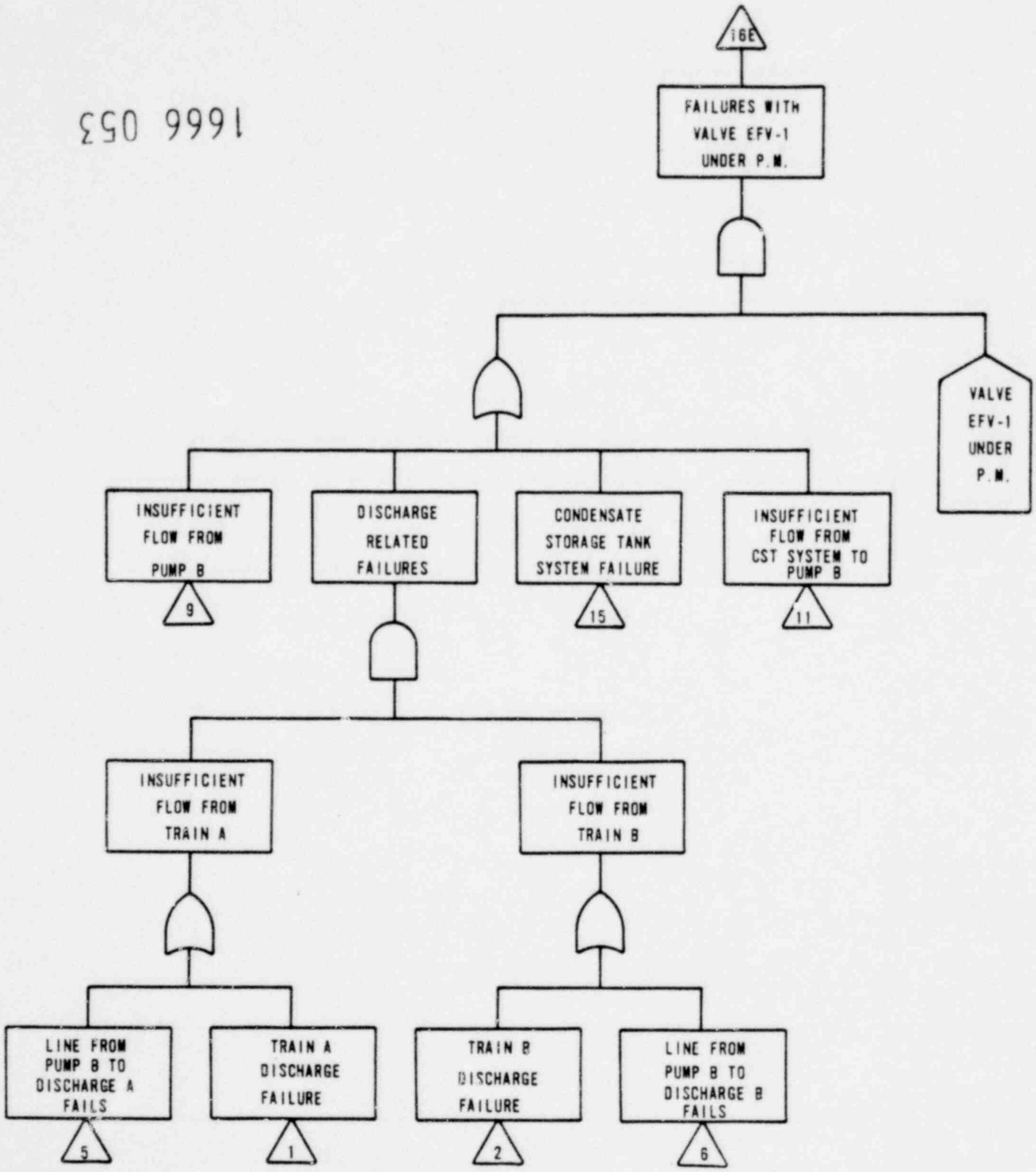

16D
FAILURES WITH
DISCHARGE B
UNDER P.M.
INSUFFICIENT
FLOW FROM
BOTH PUMPS
20
INSUFFICIENT
FLOW FROM
TRAIN A
21
BOTH WATER
SOURCES
FAIL
23
VALVES
FWV-34
FWV-39F
FWV-161

1666 051

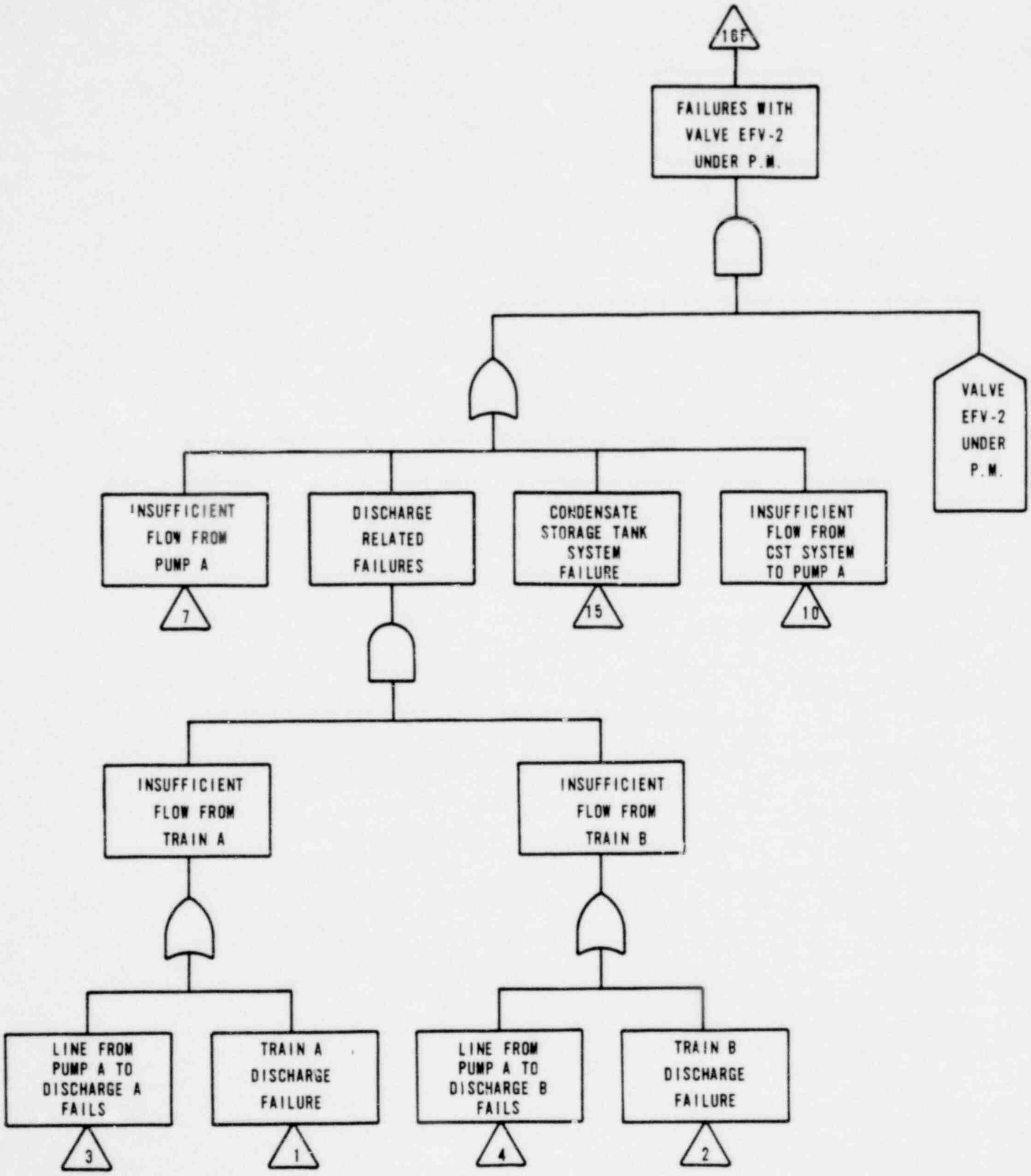

16C
FAILURES WITH DISCHARGE A UNDER P.M.
INSUFFICIENT FLOW FROM BOTH PUMPS
20
INSUFFICIENT FLOW FROM TRAIN B
22
BOTH WATER SOURCES FAIL
23
VALVES FWV-35 FWV-40F FWV-162

1666 052

1666 053



16E
FAILURES WITH VALVE EFV-1 UNDER P.M.
VALVE EFV-1 UNDER P.M.
INSUFFICIENT FLOW FROM PUMP B
9
DISCHARGE RELATED FAILURES
CONDENSATE STORAGE TANK SYSTEM FAILURE
15
INSUFFICIENT FLOW FROM CST SYSTEM TO PUMP B
11
INSUFFICIENT FLOW FROM TRAIN A
INSUFFICIENT FLOW FROM TRAIN B
LINE FROM PUMP B TO DISCHARGE A FAILS
5
TRAIN A DISCHARGE FAILURE
1
TRAIN B DISCHARGE FAILURE
2
LINE FROM PUMP B TO DISCHARGE B FAILS
6


16F
FAILURES WITH VALVE EFV-2 UNDER P.M.
VALVE EFV-2 UNDER P.M.
INSUFFICIENT FLOW FROM PUMP A
7
DISCHARGE RELATED FAILURES
CONDENSATE STORAGE TANK SYSTEM FAILURE
15
INSUFFICIENT FLOW FROM CST SYSTEM TO PUMP A
10
INSUFFICIENT FLOW FROM TRAIN A
INSUFFICIENT FLOW FROM TRAIN B
LINE FROM PUMP A TO DISCHARGE A FAILS
3
TRAIN A DISCHARGE FAILURE
1
LINE FROM PUMP A TO DISCHARGE B FAILS
4
TRAIN B DISCHARGE FAILURE
2

1666 054

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.

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

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. ∿15 min. ∿30 min.	$\sim 5 \times 10^{-2}$ $\sim 1 \times 10^{-2}$ $\sim 5 \times 10^{-3}$

III. Maintenance Outage Contribution

Maintenance outage for pumps and EMOVS:

$$Q_{Maintenance} \approx \frac{0.22\ (\#hours/maintenance\ act)}{720}$$

1666 057