PLG-0147

MIDLAND PLANT AUXILIARY FEEDWATER SYSTEM RELIABILITY ANALYSIS

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ACKNOWLEDGEMENTS

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The authors are especially grateful to Dennis Budzik of CPCo who provided strong overall direction to the project. John Kindinger of CPCo provided frequent guidance and technical information throughout the study. At Midland Plant, Jim Alderink coordinated our plant visit, provided important information about the actual field installation, and reviewed our early work. Many others gave significant help at key points in the study.

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1. STATEMENT OF PURPOSE

A study was made of the reliability of the Midland Auxiliary Feedwater System for Consumers Power Company (CPCo) of Jackson, Michigan. The purpose of the study was to

- Provide a thorough and comprehendible assessment of the overall reliability of the system.
- Identify important contributors to unreliability.
- Compare three alternative pump configuration designs.

A principal aim of the study was to use the most applicable data in the analysis with due regard for the true range of uncertainty in this information. In addition, to make comparisons with NRC analyses more directly visible, calculations using the standard NRC data base have been included.

2. SUMMARY

The emergency function of the Auxiliary Feedwater System (AFWS) is to provide heat removal for the primary system when the main feedwater system is not available. A conceptual block diagram of the AFWS is shown in Figure 1. Water is supplied through two pumps to each of two steam generators. The AFWS must provide this function during small Loss of Coolant Accidents (LOCA) as well as following transients that lead to a loss of main feedwater. The AFWS provides initial cooling to prevent overpressurization of the primary system and has sufficient preferred water supply to maintain hot standby conditions for 4 hours followed by a cooldown to 320°F. The system is also used during normal plant startup, shutdown, and hot standby conditions. Requirements for success under emergency conditions are that flow from a least one pump be delivered to at least one steam generator immediately following initial demand.

The fault tree analysis determines the system hardware minimal cutsets, i.e., the smallest groups of combined component failure modes that lead to system failure. It further catalogs the causes for specific component failure modes and evaluates their likelihood of occurrence. The causes considered include:

- Random independent failures
- Test and maintenance
- Human error
- Common cause failures

Two sets of data are used in separate quantifications. The NRC point estimate data from NUREG-0611[1] is identified here as NRC Data. Data most applicable to the Midland AFWS that includes uncertainty has been identified as Plant-Specific Data. The three specific cases described in NUREG-0611 are analyzed:

1. LMFW - transient initiated by interruption of the main feedwater system (reactor trip occurs) and offsite AC power remains available.
2. LMFW/LOOP - transient initiated by loss of offsite AC power and reactor trip occurs (main feedwater system is interrupted by the loss of offsite power). Onsite emergency AC power sources are treated probabilistically.
3. LMFW/only DC power available - transient is initiated as in item 2 above, but onsite emergency AC power sources are unavailable.

Note that these cases lead to conditional unavailability calculations that are coupled with specific states of electric power. Results are displayed in Table 1 for each of the three cases and each data set.

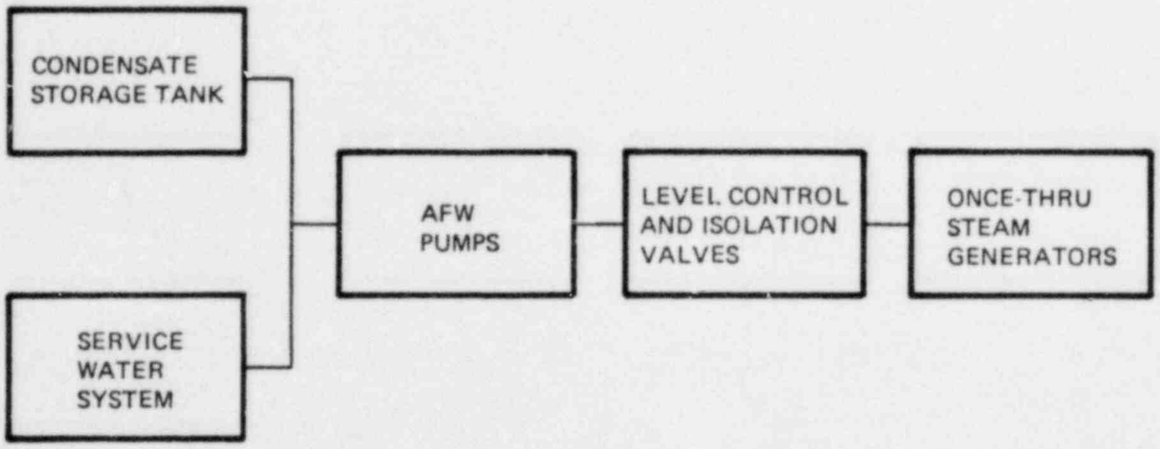


FIGURE 1. AUXILIARY FEEDWATER SYSTEM
CONCEPTUAL BLOCK DIAGRAM

TABLE 1. SUMMARY OF RESULTS
CONDITIONAL* UNAVAILABILITIES** OF THE MIDLAND AFWS

Contributors to Unavailability	Loss of Main Feedwater		Loss of Main Feedwater Due to Loss of Offsite Power		Loss of Main Feedwater and Loss of All AC Power	
	Double Crossover (Plant Specific Data)	Double Crossover (NRC Data)	Double Crossover (Plant Specific Data)	Double Crossover (NRC Data)	Double Crossover (Plant Specific Data)	Double Crossover (NRC Data)
Random failures	7.0 E-5+ (1.1 E-8)	3.5 E-5	6.6 E-4 (8.4 E-6)	2.5 E-4	1.7 E-2 (5.3 E-4)	6.4 E-3
Test and maintenance and random system failures	1.2 E-4 (3.9 E-8)	6.9 E-5	3.4 E-4 (6.5 E-7)	2.8 E-4	5.9 E-3 (1.9 E-4)	5.9 E-3
Human error (test--failure to close full flow test valve)	6.3 E-6 (1.1 E-10)	3.7 E-6	1.8 E-5 (2.0 E-9)	1.5 E-5	3.1 E-4 (5.3 E-7)	3.1 E-4
Common cause (full flow test valve open after test)	8.4 E-6 (5.9 E-10)	8.4 E-6	8.4 E-6 (5.9 E-10)	8.4 E-6	8.4 E-6 (5.9 E-10)	8.4 E-6
Other	ε	ε	ε	ε	ε	ε
System Total						
Mean	2.0 E-4		1.0 E-3		2.3 E-2	
Variance	4.7 E-8		6.0 E-6		6.7 E-4	
5th	3.4 E-5		4.1 E-5		3.5 E-3	
95th	5.8 E-4		3.8 E-3		6.8 E-2	
Median	1.4 E-4	1.2 E-4	4.0 E-4	5.5 E-4	1.6 E-2	1.3 E-2

*The total unavailabilities as well as the individual contributions given in this table are not actual system unavailabilities but are system characteristics conditional on specific states of electric power as follows:
LMFW: Offsite AC power is continuously available.
LMFW/LOOP: Offsite AC power is unavailable--diesel generators may or may not accept load.
LMFW/Loss of All AC: All AC power is unavailable; DC power is available.

**Unavailability is the fraction of times the system will not perform its function when required.

+7.0 E-5 read 7.0 × 10^{-5}.

( ) Variance - describes the spread of the results about the mean.

Results using the NRC Data for each of the three cases are plotted in Figure 2 along with similar results[2] for other Babcock and Wilcox (B&W) plants. Midland appears to be one of the better performing (B&W) auxiliary feedwater systems.

Three alternative pump configuration designs are analyzed. Their block diagrams are shown in Figure 3:

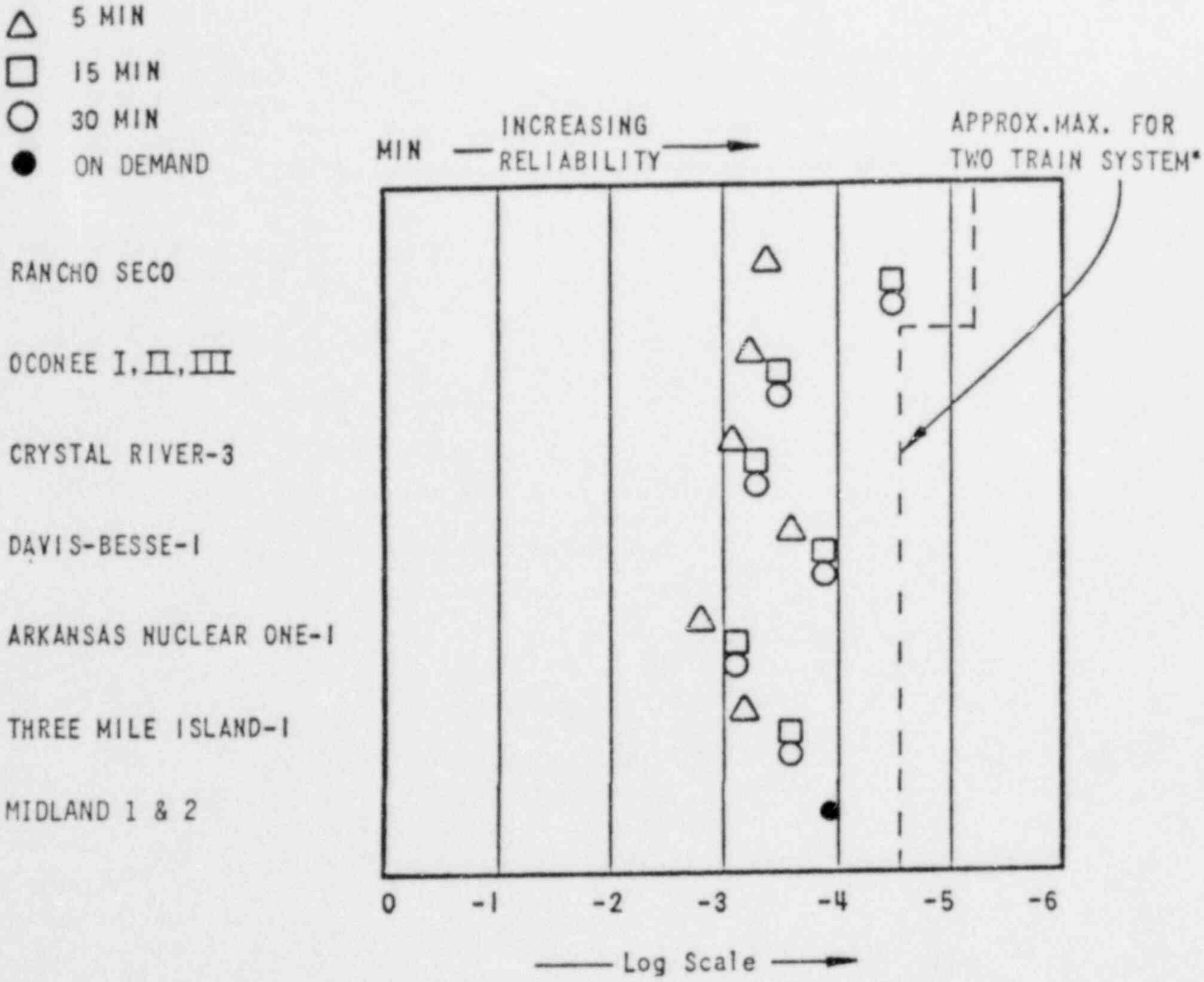
3a. Double Crossover (DCO) - one 100% motor-driven pump and one 100% turbine-driven pump. This option has been selected by CPCo for installation at Midland. It permits each pump to supply either or both steam generators. Each crossover path is controlled by the same electrical supply as the associated pump.

3b. Base Case - one 100% motor-driven pump and one 100% turbine-driven pump. This option was the original Midland design. It permits each pump to supply either or both steam generators.

3c. Three Pump - two 50% motor-driven pumps and one 100% turbine-driven pump. This design is similar to that used at some other (B&W) plants and is included for comparison purposes only.

NRC data was used only in the DCO analysis (Table 1). Tables 2 and 3 present the results using plant-specific data for comparisons of the Base Case and the Three Pump designs against the DCO. The Base Case and the DCO have nearly identical reliability results. The DCO is clearly better than the Three Pump design analyzed.

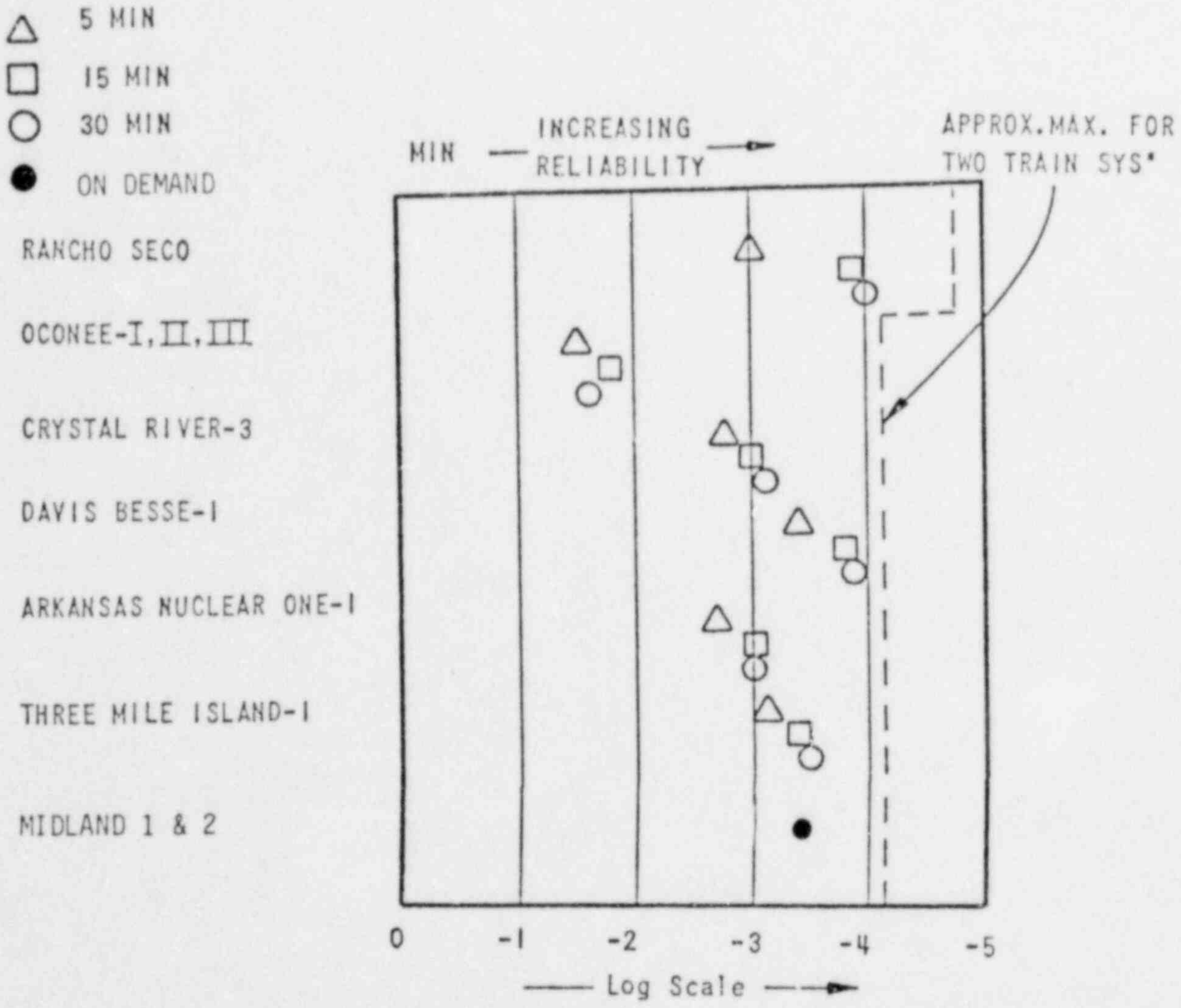
It is possible to imagine modifications in hardware and procedures that have potential to reduce the impact of the dominant contributors. Some examples are given in Chapter 6. However, the system is already very reliable, i.e., no serious deficiencies have been identified. No changes should be made without a careful evaluation of all costs and benefits including the chance that a change aimed at improving reliability could actually degrade it.



*UPPER LIMIT IS DIFFERENT FOR RANCHO SECO BECAUSE OF THE MULTI-DRIVE PUMP.

FIGURE 2. COMPARISON OF RELIABILITY (NRC DATA) OF AFWAS DESIGNS IN PLANTS USING THE B&W NSSS
(This figure, except for Midland, was taken from Reference 2.)

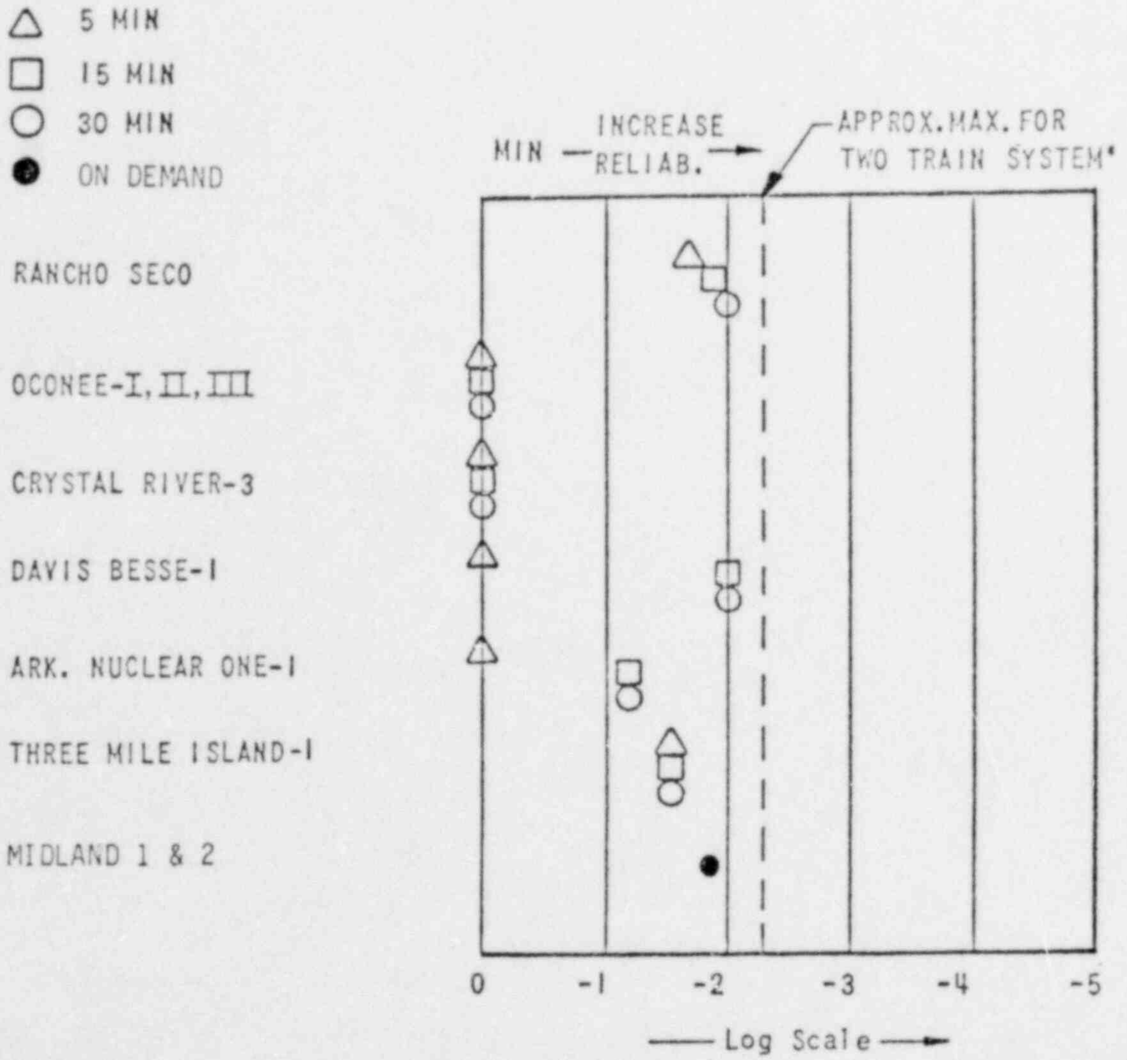
Figure 2(a): LMFW



*WHERE ONE TRAIN IS ELECTRIC POWERED FROM A DIESEL GENERATOR (IE., EXCLUDING DAVIS-BESSE-1). LIMIT IS DIFFERENT FOR RANCHO SECO BECAUSE OF THE MULTI-DRIVE PUMP.

FIGURE 2. COMPARISON OF RELIABILITY (NRC DATA) OF AFWAS DESIGNS IN PLANTS USING THE B&W NSSS
(This figure, except for Midland, was taken from Reference 2.)

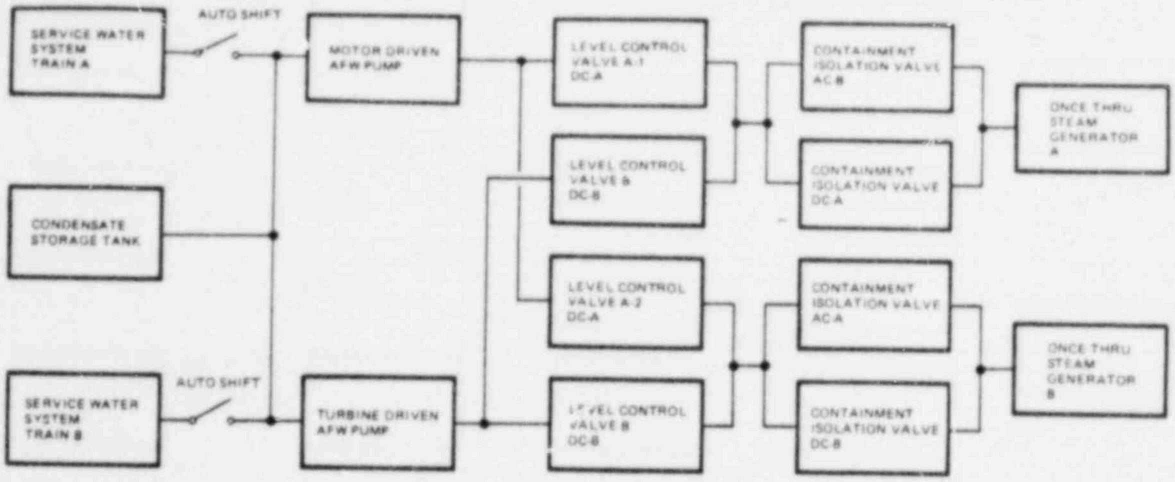
FIGURE 2(b): LMFW/LOOP



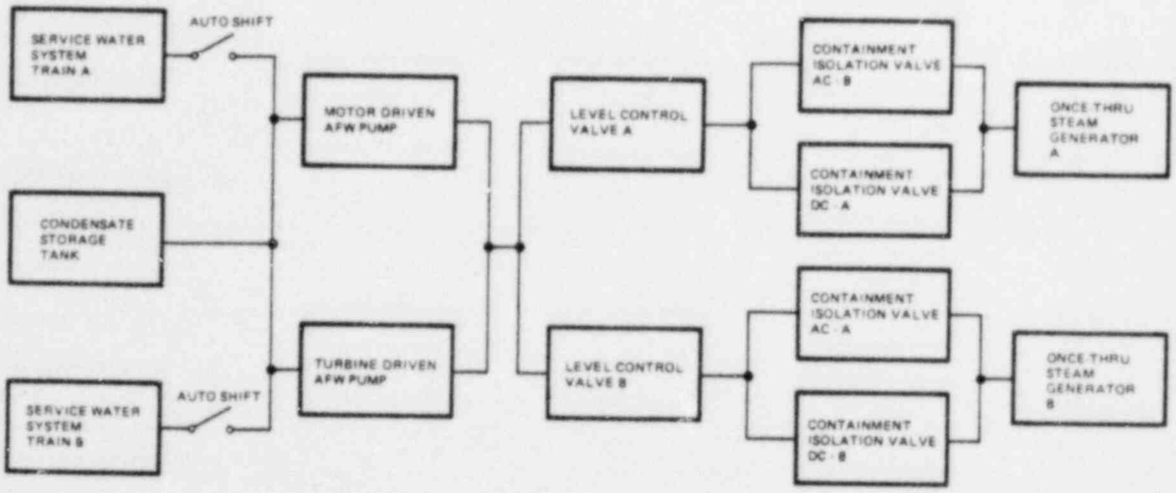
*WHERE ONE TRAIN IS ELECTRIC POWERED FROM A DIESEL GENERATOR (IE., EXCLUDING DAVIS BESSE-I)

FIGURE 2. COMPARISON OF RELIABILITY (NRC DATA) OF AFWAS DESIGNS IN PLANTS USING THE B&W NSSS
(This figure, except for Midland, was taken from Reference 2.)

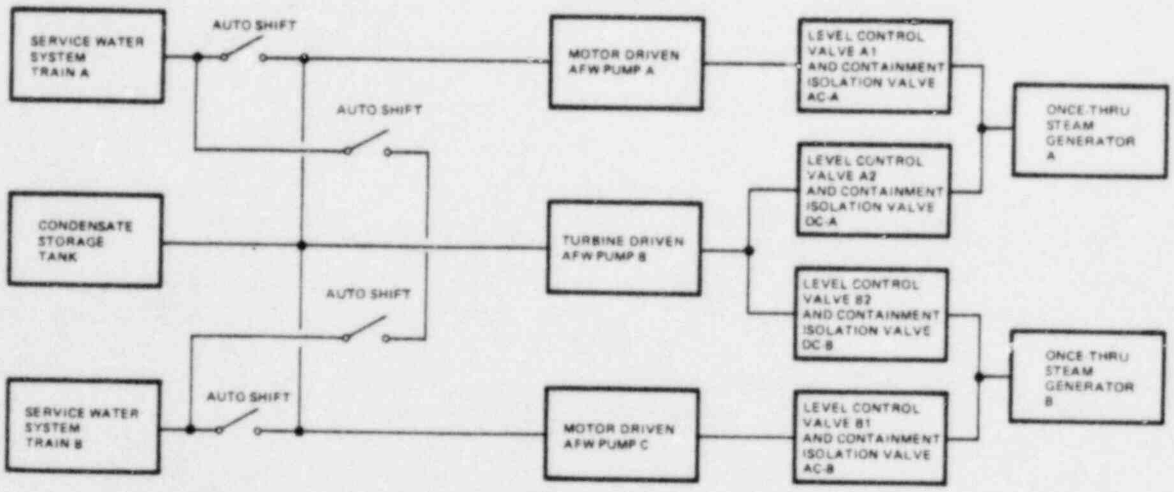
FIGURE 2(c): LMFW/LOAC



a. Double Crossover



b. Base Case



c. Three Pump

FIGURE 3. BLOCK DIAGRAMS OF THREE ALTERNATIVE PUMP CONFIGURATION DESIGNS FOR THE MIDLAND PLANT AFW SYSTEM

TABLE 2. SUMMARY OF RESULTS
CONDITIONAL* UNAVAILABILITIES** OF THE MIDLAND AFWS
(Plant Specific Data)

Contributors to Unavailability	Loss of Main Feedwater		Loss of Main Feedwater Due to Loss of Offsite Power		Loss of Main Feedwater and Loss of All AC Power	
	Double Crossover	Base Case	Double Crossover	Base Case	Double Crossover	Base Case
Random failures	7.0 E-5⁺ (3.1 E-8)	7.3 E-5 (1.9 E-8)	6.6 E-4 (8.4 E-6)	6.6 E-4 (3.3 E-6)	1.7 E-2 (5.3 E-4)	1.6 E-2 (7.5 E-3)
Test and maintenance and random system failures	1.2 E-4 (3.9 E-8)	1.2 E-4 (1.2 E-7)	3.4 E-4 (6.5 E-7)	3.4 E-4 (3.2 E-7)	5.9 E-3 (1.9 E-4)	5.9 E-3 (1.9 E-4)
Human error (test--failure to close full flow test valve)	6.3 E-6 (1.1 E-10)	6.4 E-6 (3.4 E-10)	1.8 E-5 (2.0 E-9)	1.8 E-5 (9.2 E-10)	3.1 E-4 (5.3 E-7)	3.1 E-4 (5.3 E-6)
Common cause (full flow test valve open after test)	8.4 E-6 (5.9 E-10)	8.4 E-6 (5.9 E-10)	8.4 E-6 (5.9 E-10)	8.4 E-6 (5.9 E-10)	8.4 E-6 (5.9 E-10)	8.4 E-6 (5.9 E-10)
Other	ε	ε	ε	ε	ε	ε
System Total						
Mean	2.0 E-4	2.1 E-4	1.0 E-3	1.0 E-3	2.3 E-2	2.2 E-2
Variance	4.7 E-8	1.1 E-7	6.0 E-6	2.9 E-6	6.7 E-4	8.8 E-4
5th	3.4 E-5	1.7 E-5	4.1 E-5	7.9 E-5	3.5 E-3	2.5 E-3
95th	5.8 E-4	7.0 E-4	3.8 E-3	3.5 E-3	6.8 E-2	7.0 E-2
Median	1.4 E-4	1.1 E-4	4.0 E-4	5.3 E-4	1.6 E-2	1.3 E-2

*The total unavailabilities as well as the individual contributions given in this table are not actual system unavailabilities but are system characteristics conditional on specific states of electric power as follows:

LMFW: Offsite AC power is continuously available.
LMFW/LOOP: Offsite AC power is unavailable--diesel generators may or may not accept load.
LMFW/Loss of All AC: All AC power is unavailable; DC power is available.

**Unavailability is the fraction of times the system will not perform its function when required.

⁺7.0 E-5 read 7.0 x 10^{-5}.

( ) Variance - describes the spread of the results about the mean.

TABLE 3. SUMMARY OF RESULTS
CONDITIONAL* UNAVAILABILITIES** OF THE MIDLAND AFWS
(Plant Specific Data)

Contributors to Unavailability	Loss of Main Feedwater		Loss of Main Feedwater Due to Loss of Offsite Power		Loss of Main Feedwater and Loss of All AC Power	
	Double Crossover	Three Pump	Double Crossover	Three Pump	Double Crossover	Three Pump
Random failures	7.0 E-5⁺ (1.1 E-8)	8.1 E-4 (1.4 E-6)	6.6 E-4 (8.4 E-6)	2.0 E-3 (1.1 E-5)	1.7 E-2 (5.3 E-4)	1.7 E-2 (3.6 E-5)
Test and maintenance and random system failures	1.2 E-4 (3.9 E-8)	4.9 E-4 (1.0 E-7)	3.4 E-4 (6.5 E-7)	9.2 E-4 (2.9 E-6)	5.9 E-3 (1.9 E-4)	5.9 E-3 (1.9 E-4)
Human error (test--failure to close full flow test valve)	6.3 E-6 (1.1 E-10)	2.6 E-5 (2.0 E-9)	1.8 E-5 (2.0 E-9)	4.9 E-5 (8.8 E-9)	3.1 E-4 (5.3 E-7)	3.1 E-4 (5.3 E-7)
Common cause (full flow test valve open after test)	8.4 E-6 (5.9 E-10)	8.4 E-6 (5.9 E-10)	8.4 E-6 (5.9 E-10)	8.4 E-6 (5.9 E-10)	8.4 E-6 (5.9 E-10)	8.4 E-6 (5.9 E-10)
Other	ε	ε	ε	ε	ε	ε
System Total						
Mean	2.0 E-4	1.3 E-3	1.0 E-3	3.0 E-3	2.3 E-2	2.3 E-2
Variance	4.7 E-8	2.0 E-6	6.0 E-6	1.3 E-5	6.7 E-4	2.0 E-4
5th	3.4 E-5	2.2 E-4	4.1 E-5	4.0 E-4	3.5 E-3	8.0 E-3
95th	5.8 E-4	3.8 E-3	3.8 E-3	9.0 E-3	6.8 E-2	5.0 E-2
Median	1.4 E-4	9.2 E-4	4.0 E-4	1.9 E-3	1.6 E-2	2.0 E-2

*The total unavailabilities as well as the individual contributions given in this table are not actual system unavailabilities but are system characteristics conditional on specific states of electric power as follows:

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LMFW/Loss of All AC: All AC power is unavailable; DC power is available.

**Unavailability is the fraction of times the system will not perform its function when required.

⁺7.0 E-5 read 7.0 x 10^{-5}.

( ) Variance - describes the spread of the results about the mean.

3. INTRODUCTION AND SCOPE

3.1 BACKGROUND

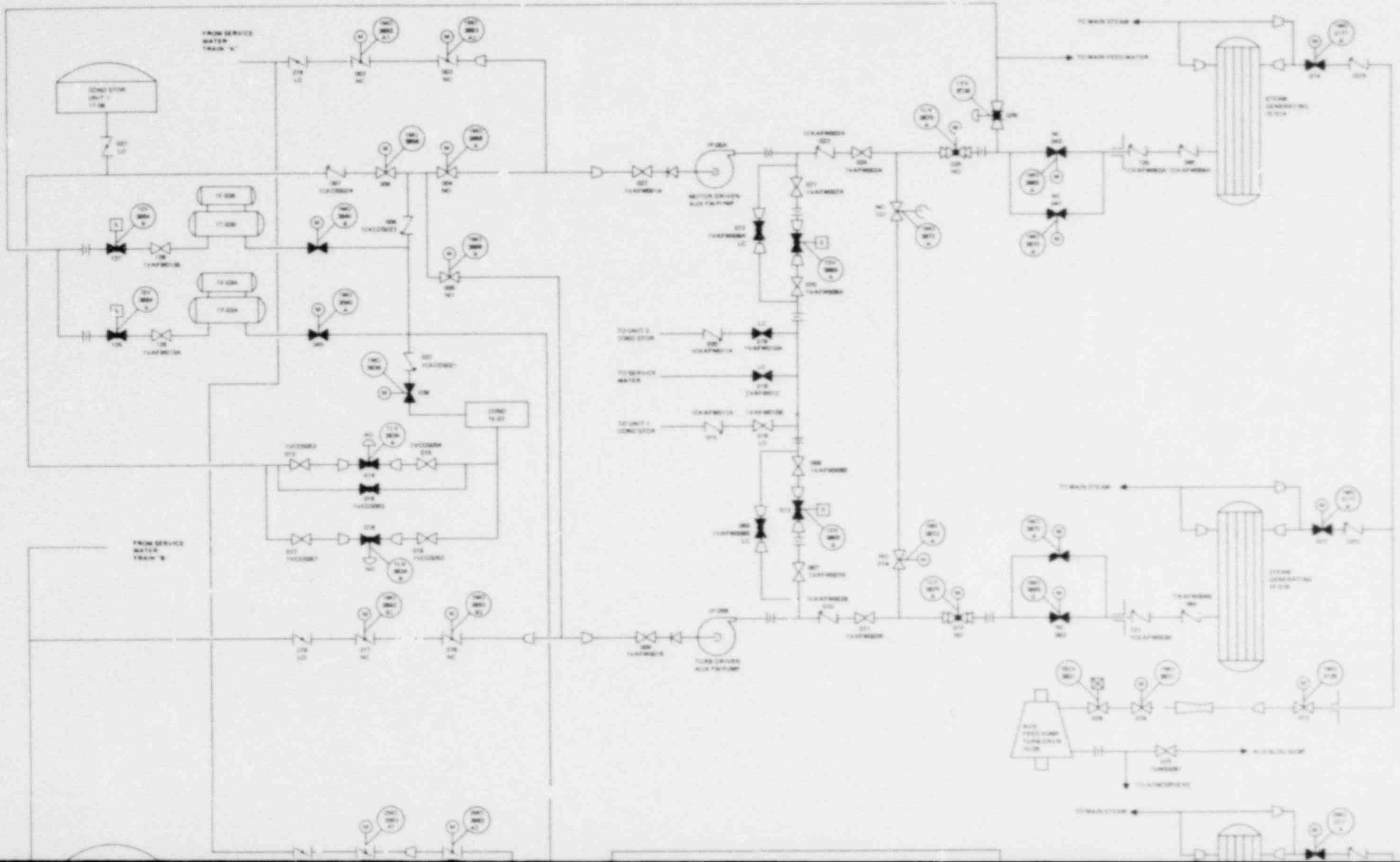
The purpose of this study is to analyze the reliability of three alternative Auxiliary Feedwater System (AFWS) designs for the Midland Nuclear Station. A diagram of each alternative system design is drawn and is presented here as Base Case, Figure 4; Double Crossover, Figure 5; and Three Pump, Figure 6. The auxiliary feedwater system supplies feedwater to the steam generators during normal plant startup, shutdown, and hot standby conditions. It also serves an important emergency function by providing cooling water to remove decay heat from the core. To place the AFWS emergency function in perspective, we consider what options for cooling are available to a core following extended high power operations. The simplified core cooling event tree of Figure 7 provides a framework for discussion. Following an initiating event that could lead to loss of main feedwater (turbine trip, reactor trip, LOCA, etc.), core heat can be removed via the primary coolant system in two ways: through the steam generators (steam production in the secondary side) or directly by reactor coolant blowing down through a valve or rupture. If a LOCA is large enough to remove the decay heat, sufficient makeup flow must be delivered to the reactor to avoid core uncovery. The design mode of heat removal is by steam generator cooling (steam reliefs or power operated atmospheric vents). For continued success of this mode, feedwater must be supplied by the AFWS or by restoring main feedwater. Even if all feedwater supplies fail, successful core cooling can be provided by primary bleed and feed. Recent analyses show that high pressure injection combined with the opening of power operated relief valves can supply sufficient bleed and feed cooling to prevent core damage.[3] For cases that involve loss of all AC power, only the feed systems can provide cooling since the makeup pumps cannot run. In this report we address only the reliability of the AFWS.

The fault tree analysis determines the system hardware minimal cutsets, i.e., the smallest groups of combined component failure modes that lead to system failure. We further catalog the causes for specific component failure modes and evaluate their likelihood of occurrence. The causes considered include:

- Random independent failures
- Test and maintenance
- Human error
- Common cause failures

Results are quantified using plant specific data for each case analyzed, and once using NRC generic point value data taken from NUREG-0611[1] as applied to the double crossover design.

POOR ORIGINAL



POOR ORIGINAL

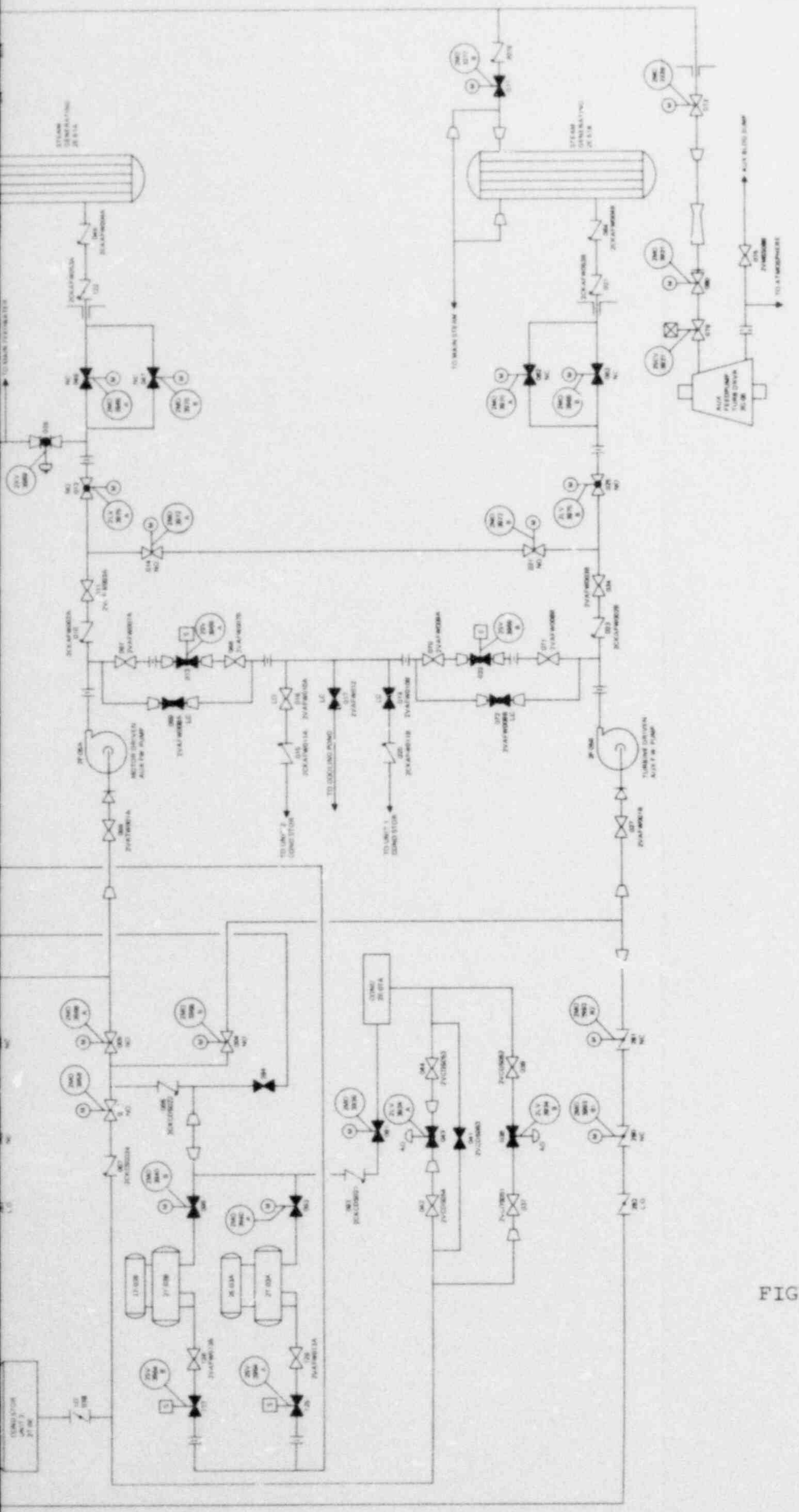
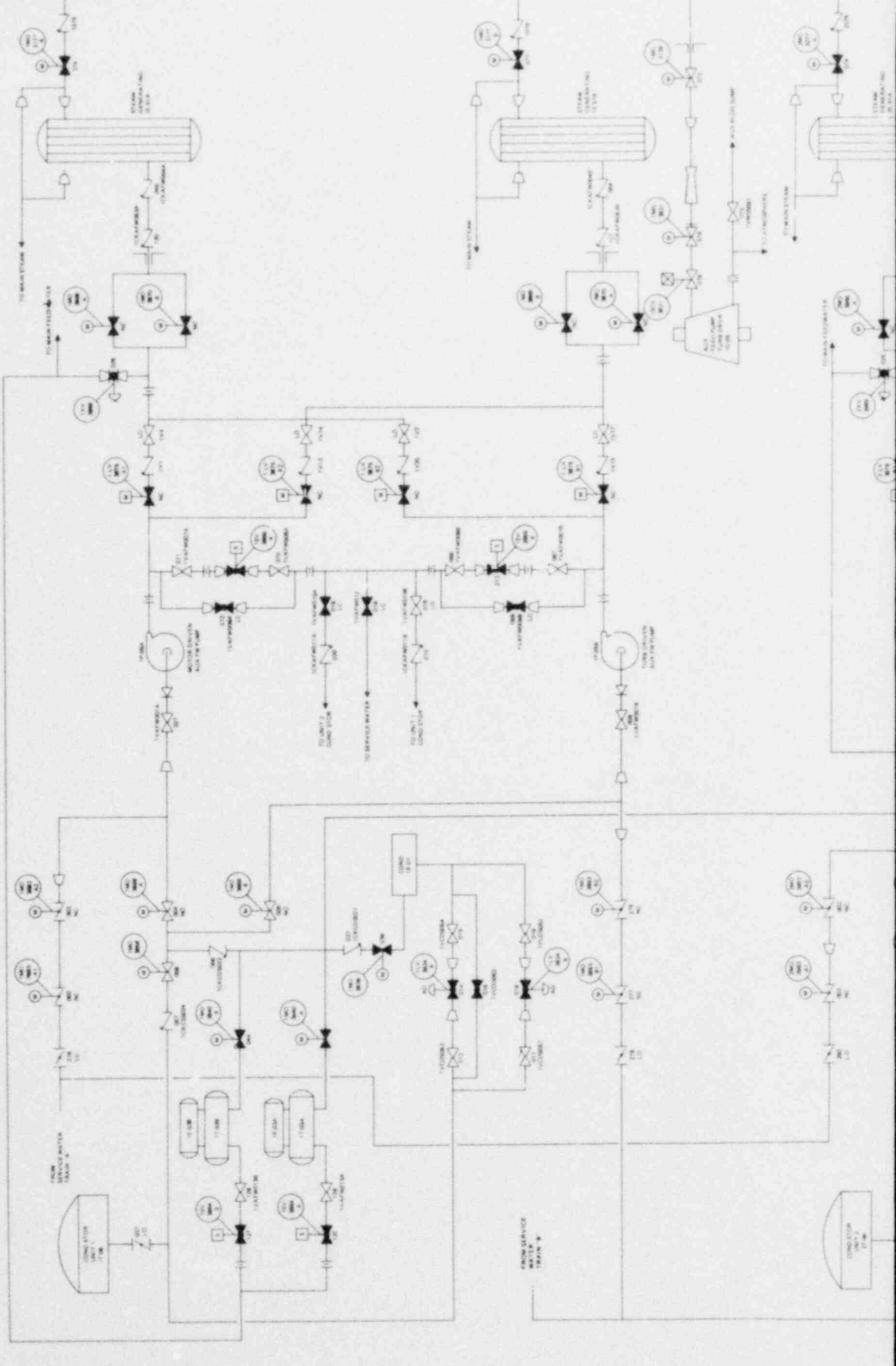


FIGURE 4. MIDLAND AUXILIARY FEEDWATER SYSTEM - BASE CASE

POOR ORIGINAL



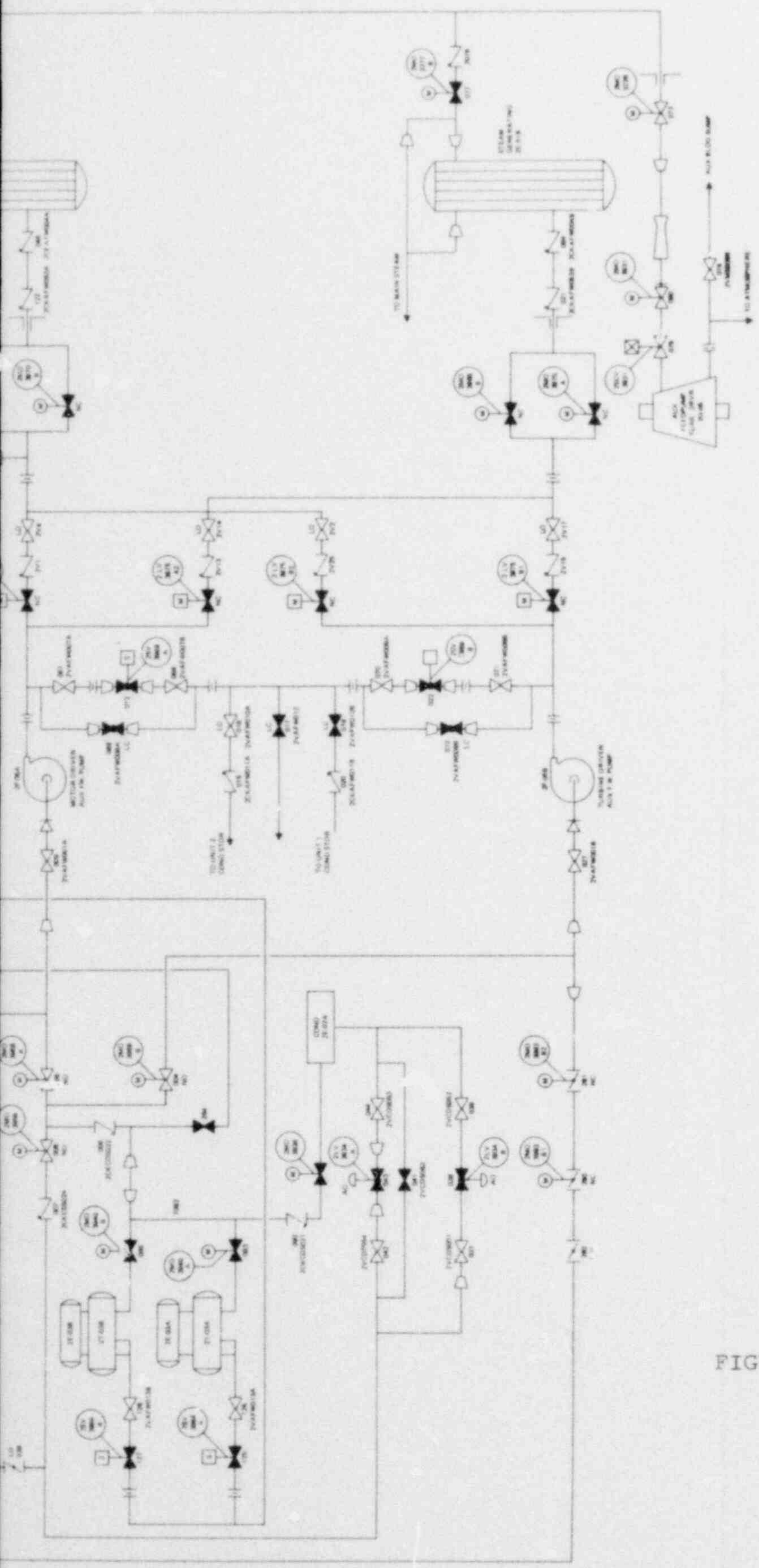


FIGURE 5. MIDLAND AUXILIARY FEEDWATER SYSTEM - DOUBLE CROSSOVER

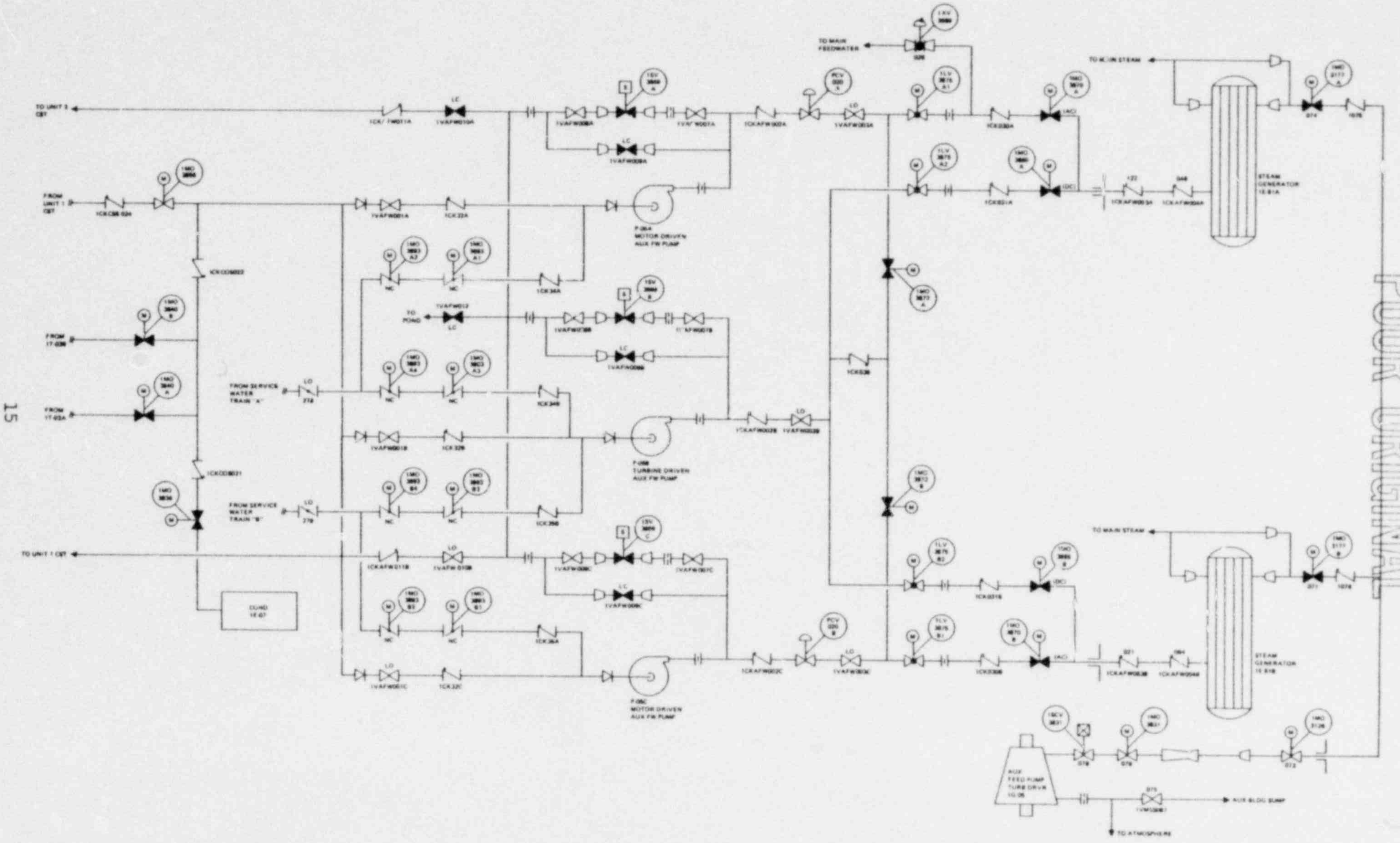
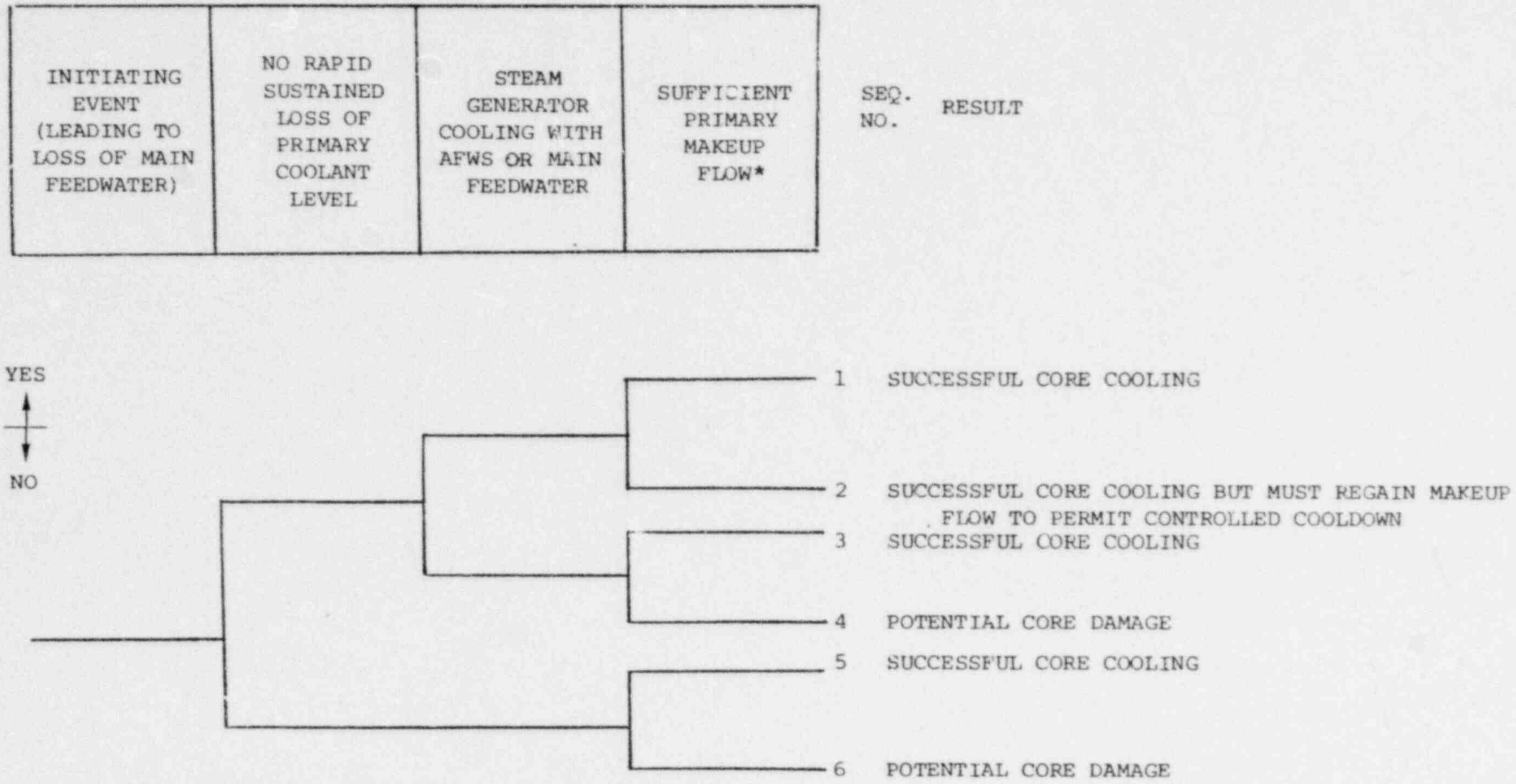


FIGURE 6. MIDLAND AUXILIARY FEEDWATER SYSTEM - THREE PUMP



*INCLUDES SUCCESSFUL OPENING OF PORVs IF REQUIRED FOR FEED AND BLEED COOLING.

FIGURE 7. SIMPLIFIED CORE COOLING EVENT TREE

In the report, conditional unavailability is evaluated for the three specific electric power conditions considered by the NRC in NUREG-0611:

- Offsite AC available
- No offsite AC available
- No AC available.

Note that these cases lead to conditional unavailability calculations that are coupled with specific states of electric power.

3.2 AUXILIARY FEEDWATER SYSTEM DESCRIPTION

3.2.1 System Function

The auxiliary feedwater (AFW) system[4-10] supplies feedwater to the steam generators during normal plant startup, shutdown, and hot standby operations when the main feedwater system is unavailable for service. The AFW system is also designed to respond automatically to emergency conditions, to supply feedwater to the steam generators (SGs) in order to remove reactor decay heat, assist in establishing natural circulation, and to cool down the reactor coolant system to the point at which the plant decay heat removal system may be placed into operation.

The AFW system must fulfill certain plant safety design bases, therefore, care is taken in selection and design of the interfaces for motive power to the AFW system. Electric power demands of the AFW system are met by taking the load from the vital plant buses that are powered by the onsite emergency diesel generators. A redundant and diverse source of motive power is the steam from either of the two SGs. If a demand occurs on the system, then it is highly likely that steam is available to drive the turbine for the AFW system pump. Valves and controls for the turbine-powered AFW system loop receive power from DC power systems which are battery supported.

Three alternative designs are considered for the Midland AFW system. Although distinct differences exist between the alternatives, the essential elements, water sources, pumping sections, flow control, and isolation remain the same.

In the following paragraphs, the basic system is described using the AFW system as described in the Final Safety Analysis Report (FSAR). The differences between the alternative designs are then presented.

3.2.2 Basic AFW System

The Base Case AFW design consists of two AFW pumps, a level control arrangement, AFW to SG feed lines, steam supply to the turbine-driven pump, and a water supply arrangement.

Three sources of water are supplied for the auxiliary feedwater system:

- The condensate storage tank (CST) serves as a backup source of water during normal system operations (startup, hot standby, and cooldown) and as the primary source of water during plant emergency conditions.

- The condensate system is used for plant startup, hot standby, or cooldown operations.

- The service water system serves as a safety-grade backup system to the CST during plant emergency conditions.

The CST is the source of makeup water to the plant condensate system and the AFW system during normal operations. The CST is always aligned to supply water to the AFW system during plant operation through a normally open motor-operated valve (MOV). This MOV receives an open signal from the auxiliary feedwater actuation system (AFWAS) during plant emergency conditions.

The condensate system is used to supply the AFW system during normal plant startup, shutdown, and cooldown operations. Three separate condensate system sources--either of two deaerating storage tanks or the condenser hotwell--are available to the AFW pumps. MOVs in each separate supply line receive an automatic close signal from the AFWAS system in the event of a plant emergency which requires AFW.

The service water system provides a safety-grade backup to the CST. Two MOVs in series supply each AFW pump. The "A" service water train supplies the "A" AFW pump and the "B" service water train supplies the "B" AFW pump. These motor-operated valves open automatically upon receipt of an AFWAS signal in conjunction with a two-out-of-four low suction pressure condition at the associated AFW pump. The low suction pressure trip also closes the associated normal suction valve from the CST.

Redundant auxiliary feedwater pumps are provided. The motive power for the auxiliary feedwater pumps is diverse and independent; using steam generated in either or both SGs to drive a turbine-powered pump, or vital 4160VAC electric power to the motor-driven pump. The motor breaker is DC controlled to close and trip. The motor breaker trips on bus undervoltage, phase overcurrent, ground fault, and high-high SG level. The motor-driven AFW pump restarts automatically when SG level is restored to normal. The valves associated with steam supply to the turbine-driven pump are DC motor-operated. The turbine controls are supplied power from the same DC source. The pumps and drives are located in separate rooms in the Auxiliary Building. Each room contains a fan cooler unit that is started when the associated pump starts. Cooling water for the fan cooler unit is supplied from the plant service water system.

Each pump has a recirculation line to remove pump heat during low flow conditions. Flow through the recirculation line is controlled by a solenoid valve that opens in response to pump flow. AFW pump recirculation is normally directed to the condensate storage tank supplying the AFW pump.

In addition to the recirculation line, each pump has a full flow test line that bypasses the recirculation solenoid. This line is used for the pump flow testing that is required by plant technical specifications. The full flow test valve is normally locked closed and has a remote position indication in the Main Control Room.

Each pump has a manual suction and discharge isolation valve used for isolation of the associated pump for maintenance. Each pump also has a discharge check valve to protect the pump from back flow.

The motor-driven AFW pump discharge line contains the auxiliary feedwater to main feedwater cross-connect valve. The motor-driven AFW pump supplies flow to the SGs through the main feedwater system piping during startup, hot standby, and cooldown operations. This valve is hydraulically operated to open and fails closed upon loss of power. This valve also receives a close signal from the AFWAS.

The steam for the turbine-driven pump is supplied from either or both SGs through normally closed motor operated isolation valves. These valves receive an open signal from the AFWAS. The supply from each SG ties into a common supply line inside the Reactor Containment Building. There is a normally open steam header isolation valve outside the building. Should this valve be closed, an AFWAS signal is sent to open the valve.

The turbine is supplied with a trip throttle valve and a turbine governor valve. The trip throttle valve is a motor-open, trip close valve which trips closed on turbine overspeed. Once tripped, the valve motor must be energized, and the valve shut to reset the trip. When the valve motor has been driven to the shut condition, the overspeed trip is reset, and the valve is reopened. The turbine governor valve is an electro-hydraulically operated valve which maintains turbine speed at the required value after the turbine is started. Hydraulic pressure for valve operation is supplied by a lube oil pump attached to the turbine shaft. This pump also supplies lubrication for the turbine journal and thrust bearings. When the turbine is shut down, the governor valve is wide open. As the turbine increases in speed after the admission of steam, the governor valve closes to limit possible overspeed of the turbine and to control final turbine speed. In addition to overspeed, the turbine trips on high-high SG level. When SG level is restored, the pump automatically restarts.

The AFW pumps are cross-connected after the pump discharge valve through two normally open MOVs. These cross-connect valves close automatically on high-high SG water level in either SG and must be manually reopened after the high-high level condition has been corrected. These valves do not receive an open signal from the AFWAS.

Each SG AFW line contains a normally open, motor-operated level control valve. These valves operate to maintain a programmed water level in the associated SG. Base Case control circuit design requires that two channels of SG level indication require valve movement before the level control valve will change position. Failure of either level channel results in no valve movement under automatic control or manual control. In addition, these valves can only operate for fifteen minutes out of every hour.*

The supply line to each SG passes through a parallel Reactor Containment Building AFW isolation valve arrangement. These isolation valves are normally closed and receive an open signal from the AFWAS. In the line to each SG there is one DC and one AC operated valve, which provides diversity of power supply for these valves.

Two check valves in series in the AFW line to each SG prevent blowing down an intact SG through the AFW lines to a leaking or ruptured SG.

Turbine exhaust steam passes up through the exhaust line to the roof of the Auxiliary Building where the steam is exhausted to the atmosphere. There are no isolation valves in the turbine exhaust line.

In addition to the AFWAS signal required to start the AFW system, the AFW feedwater isolation valves and the steam supply valves to the turbine-driven pump receive a Main Steam Line Isolation System (MSLIS) signal through a Feed-Only-Good-Generator (FOGG) logic network. This FOGG signal is designed to prevent the addition of feedwater to a ruptured SG and is used as an interlock or blocking signal rather than a direct signal such as the AFWAS signal (i.e., the FOGG signal being present prevents valve movement but does not cause valve movement).

The AFW system is normally in a standby status with the valves lined up as indicated in Figure 4. Upon receipt of an AFWAS signal, the following events occur: The motor-driven and turbine-driven AFW pumps receive a start signal; the turbine steam supply valves from the SGs open; the AFW isolation valves to the SGs open; if closed, the CST isolation valve opens; the DAST and condenser isolation valves close; and the main feedwater cross-connect valve closes. Within 40 seconds they will be supplying both SGs.

In the event of a loss of suction to the AFW pumps, after a time delay of 4 seconds, the service water valves will open and the CST outlet valve will close.

After the SG levels have been restored, the level control valves will throttle closed to maintain SG level. In the event of a high-high SG level, the associated AFW pump will trip off and the discharge cross-connect valve will close. With an AFWAS signal still present, the associated AFW pump will automatically restart upon the clearing of the SG

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*The design of these valves has been changed to allow continuous operation.

high level alarm. The discharge cross-connect valve must be reopened by the operator after the SG high level alarm has reset.

3.2.3 Double Crossover Design

The double crossover design shown in Figure 5 represents the present design of the AFW system. The differences between the basic design (Base Case) and the double crossover are as follows:

- Improved Feed-Only-Good-Generator logic and system interaction.
- Two level control valves per SG, one supplied from each of the AFW pumps.
- Improved level control system for the SGs.

The improved FOGG logic continously monitors differential pressure between the SGs and automatically isolates AFW flow to the lower pressure SG whenever the differential pressure exceeds a predetermined value. This allows the FOGG logic to be independent of the MSLIS signal and to perform a direct function (i.e., close valves) rather than a blocking or interlock function. In addition, FOGG signals are channelized and are sent to the SG level control valves, thus preventing a single failure from disabling the FOGG function. Presented below are the new relationships between FOGG channels and the actuated valves and the AFWAS channels and actuated equipment.

FOGG/ACTUATED EQUIPMENT RELATIONSHIP

Actuated Equipment	FOGG Channel	AFWAS Channel	Electric Power	
			AC	DC
1P-05A	NA	1A	1A05	1D11
1P-05B	NA	1B	NA	1D21
1MO3865A	1C	1A	NA	1D11
1MO3870B	1C	1A	1B56	NA
1MO3865B	1D	1B	NA	1D21
1MO3870A	1D	1B	1B55	NA
1LV3875A1	1A	1A	1Y11	NA
1LV3875A2	1A	1A	1Y12	NA
1LV3875B1	1B	1B	1Y13	NA
1LV3875B2	1B	1B	1Y14	NA
1MO3177A	1B	1B	NA	1D21
1MO3177B	1B	1B	NA	1D21

The level control valve arrangement for the double crossover design was shown in Figure 5. Each AFW pump discharges to two electro-hydraulically operated level control valves, one valve for each SG. These level control valves are 120 VAC motor-operated and fail open upon loss of AC power. The AC power for the level control valves associated with one AFW pump comes through an inverter network from the same DC load group as the pump's DC control power.

The level control system for each level control valve now relies upon a single level signal rather than two level signals, which was the requirement in the Base Case design. A single level channel failure will not cause either underfeeding or overfeeding of the SG.

System operation remains the same for the double crossover design as was discussed for the base case design.

3.2.4 Three Pump Design

The three pump design shown in Figure 6 is similar to the design of the auxiliary feedwater system used in Bellefonte Nuclear Power Station. In this design, either both motor-driven pumps or one turbine-driven pump is required to operate in order for the AFW system to satisfactorily perform its safety functions.

For the purposes of this analysis, it is assumed that the power supplies to the AFW feedwater isolation valves would be the same as the base case, that the motor-driven pumps discharge through the two AC-powered valves, and that the turbine-driven pump discharges through the two DC-powered valves. In addition, the control circuit for the level control valves was assumed to be modified such that a single channel of SG level could only affect one level control valve rather than both. These assumptions assure a system design that is similar to Midland.

Further assumptions were required concerning DC power to the turbine controls. DC power to the turbine-driven pump was assumed to be available from either DC bus. Preliminary analysis indicated a single failure of DC bus 1D21 would cause system failure due to the loss of the turbine-driven pump and the failure to start of the second motor-driven AFW pump. An alternative assumption to power the second motor-driven pump from the same AC source as the first motor-driven pump produced the same results as the alternate DC power supplies to the turbine-driven pump. These assumptions allow the most flexibility for the AFW three pump design.

Assumptions concerning the service water modifications were made to maintain the same double isolation valve and independence of service water trains as are present in the current Midland design.

3.2.5 Electric Power and Other Babcock and Wilcox Designs

The AFW system dependence on electric power is analyzed to the bus that powers the equipment. The power supply interface used in the analysis is given in Table 4.

A comparison of the Midland double crossover design with other operating B&W plant AFWS designs is given in Table 5.

3.3 SCOPE

The three Midland alternative auxiliary feedwater system designs are analyzed as presently designed (with the assumptions noted above) and as expected to be maintained and operated. Two sets of data are used in separate quantifications. The NRC point estimate data from NUREG-0611 is identified here as NRC DATA. Data most applicable to the Midland AFWS, including uncertainty has been identified as Plant-Specific Data. The three specific cases described in NUREG-0611 are analyzed:

1. LMFW - transient initiated by interruption of the main feedwater system (reactor trip occurs) and offsite AC power remains available.

2. LMFW/LOOP - transient initiated by loss of offsite AC power and reactor trip occurs (main feedwater system is interrupted by the loss of offsite power). Onsite emergency AC power sources (diesel generators) are treated probabilistically.

3. LMFW/only DC power available - transient is initiated as in item 2 above, but onsite emergency AC power sources are unavailable.

The boundary of the analysis is pictured in Figure 8. The turbine steam supply from the SGs and all of the auxiliary feedwater system components are included directly in the analysis. The water supplies themselves are not analyzed in detail. However, the piping systems and valves that deliver water to the auxiliary feedwater system are included. Electrical power supplies are outside the boundary of the analysis and are considered as discussed in Cases 1, 2, and 3 above. The AFWS actuation signal is outside the boundary of the analysis. The analysis is conducted conditional on the presence of an AFWS actuation signal. Finally, some human interactions are included within the analysis and some are outside the boundary. Within the boundaries the human interaction through test and maintenance as well as operator response to system failure on demand are considered.

An event tree model of AFW system operation is developed in order to address detailed system concerns such as overcooling and undercooling, reliability of continued operation, discrimination among "Bad SG" conditions, and consequences of feeding the "Bad SG."

TABLE 4. AFW POWER SUPPLIES

Base Case Alternative

	Component	Power Supply
1.	Motor-driven AFW pump P05A	4160V AC bus 1A05
	control power	125 VDC panel 1D11
2.	Turbine-driven AFW pump P05B control power	125V DC panel 1D21
3.	Level control valve, LV3875A	480V MCC 1B55
4.	Level control valve, LV3875B	480V MCC 1B56
5.	OTSG A steam supply to turbine MO3177A	125V DC panel 1D21
6.	OTSG B steam supply to turbine MO3126	125V DC panel 1D21
7.	Steam supply isolation valve MO3126	480V MCC 1B56
8.	Turbine throttle valve MO3831	125V DC panel 1D21
9.	Feedwater isolation to SG A (AC), MO3870A	480V MCC 1B55
10.	Feedwater isolation to SG A (DC), MO3865A	125V DC panel 1D11
11.	Feedwater isolation to SG B (AC), MO3870B	480V MCC 1B56
12.	Feedwater isolation to SG B (DC), MO3865B	125V DC panel 1D21
13.	AFW discharge crossover, MO3872A	480V MCC 1B55
14.	AFW discharge crossover, MO3872B	480V MCC 1B56
15.	CST isolation, MO3856	480V power panel 1BP03
16.	AFW suction cross-connect, MO3868A	480V power panel 1BP03
17.	AFW suction cross-connect, MO3868B	480V power panel 1BP04
18.	Train A service water to P05A, MO3893A1	480V power panel 1BP03
19.	Train A service water to P05A, MO3893A2	480V power panel 1BP03
20.	Train B service water to P05B, MO3893B1	480V power panel 1BP04
21.	Train B service water to P05B, MO3893B2	480V power panel 1BP04
22.	DAST A outlet valve, MO3840A	480V power panel B31
23.	DAST B outlet valve, MO3840B	480V power panel B32
24.	Condenser outlet valve, MO3836	480V power panel B31

TABLE 4 (continued)

Double Crossover Alternative

	Component	Power Supply
1.	Level control valve, LV3875A1	120VAC Panel 1Y11
2.	Level control valve, LV3875B1	120VAC Panel 1Y12
3.	Level control valve, LV3875A2	120VAC Panel 1Y13
4.	Level control valve, LV3875B2	120VAC Panel 1Y14

Three Pump Alternative

	Component	Power Supply
1.	Motor-driven AFW pump P05C control power	4160V bus 1A06 125V DC panel 1D21
2.	Turbine-driven AFW pump P05B control room	125V DC panel 1D21 or 1D11
3.	Train A service water to P05B, MO3893A3	480V power panel 1BP03
4.	Train A service water to P05B, MO3893A4	480V power panel 1BP03
5.	Train B service water to P05B, MO3893B3	480V power panel 1BP04
6.	Train B service water to P05B, MO3893B4	480V power panel 1BP04
	All other components same as Base Case	

Note: All power supplies for Three Pump Designs are assumed.

TABLE 5. SUMMARY OF MAJOR CHARACTERISTICS OF B&W OPERATING PLANT AFW SYSTEMS

PLANT		Rancho Seco	Oconee-I,II,III	Crystal River-3	Davis-Besse-1	Arkansas Nuclear One-1	Three Mile Island-1	Midland 1 & 2
Pumps		1 turbine/motor driven 1 motor driven	1 turbine driven 2-1/2 capacity motor driven	1 turbine driven 1 motor driven	2 turbine driven	1 turbine driven 1 motor driven	1 turbine driven 2-1/2 capacity motor driven	1 turbine driven 1 motor driven (full capacity)
Primary Suction Source		250,000 g. CST	50,000 g. USTA+B for TDP UST+100,000 g. condensor hotwell for MDP	150,000 g. CST	2 CSTs each 250,000 g.	107,000 g. CST	2 CSTs each 150,000 g.	2 CSTs, 300,000 g. each
Alternate Suction Source		Canal and reservoir connector	Condensor hotwell	Condensor hotwell	2 service water trains	Nuclear service water	River water system	1st - Service water 2nd - Condensor hotwell (for startup, shutdown)
Switchover to Alternate Suction		Manual	Manual for TDP	Manual	Automatic	Manual	Manual	Automatic
Discharge Crosstie		Yes, with normally open valves	No (normally closed paths not considered) Each MDP feeds 1 SG TDP feeds both	Yes, two with check valves	Yes, with normally closed valves SFRCS/manual control	Yes, with normally open valves	Yes, any pump feeds any SG	Yes, each pump feeds each SG through a different LCV (4)
Backup Power		2 diesel generators	Keowee hydro generators	2 diesel generators	2 diesel generators	2 diesel generators	2 diesel generators	4 diesel generators (2 per plant)
Common Steam Supply Header Fed from both SG		Yes	Yes	Yes	No, separate steam supply lines with cross-over connections under SFRCS control	Yes	Yes	Yes
Pump Initiation	TDP	ESFAS, 4 RCP trip, 2 MFWP trip	2 MFWP lo discharge pressure 2 MFWP trip	2 MFWP trip 2 SG lo level	1 MFW valve hi reverse ΔP 1 SG lo level, 4 RCP trip	2 MFWP trip, 1 SG lo level 4 RCP trip	2 MFWP lo ΔP, 2 MFWP trip 4 RCP trip	ECCAS, RCP trip main feedwater trip, RB pressure high. Class IE bus UV, SG level low, SG press low.
	MDP	Same minus ESFAS	Same	Same	N/A	Same	Same minus 2 MFWP trip	Same
	Location	External to ICS	External to ICS	External to ICS	SFRCS	All within ICS	External to ICS	External to ICS
AFW Control and Valves		ICS control for flow Control valves SPs for loss of 4 RCP, 2 MFWP	SG level control circuits for each SG flow control valves	ICS control for flow control valves	Turbine speed control, speed-control valves, SFRCS isolation valves All control separate from ICS	ICS control for flow control valves SPs for loss of 4 RCP, 2 MFWP	ICS control for flow control valves SPs for loss of 4 RCP, 2 MFWP	SG level control circuits for each SG flow control valves
Operator Actions for Sustained AFW Flow	Case 1	None required	None required	None required	None required	None required	None required (open 6" steam supply)	None required
	Case 2	Manual load of MDP on diesel generator (if TDP fails)	Open TDP cooling water valve, restore load shed PWR	Manual load of MDP (if TDP fails)	None required	None required	None required (open 6" steam supply)	None required
	Case 3	None required	None available	None available	Manual open AC valves	Manual open AC valves	None required (open 6" steam supply)	None required

Note: For details, refer to plant specific draft reports (Reference 2)

TDP - Turbine Driven Pump
MDP - Motor Driven Pump
CST - Condensate Storage Tank
UST - Upper Surge Tank
RCP - Reactor Coolant Pump
MFWP - Main Feedwater Pump
SG - Steam Generator
SP - Set Point
ICS - Integrated Control System

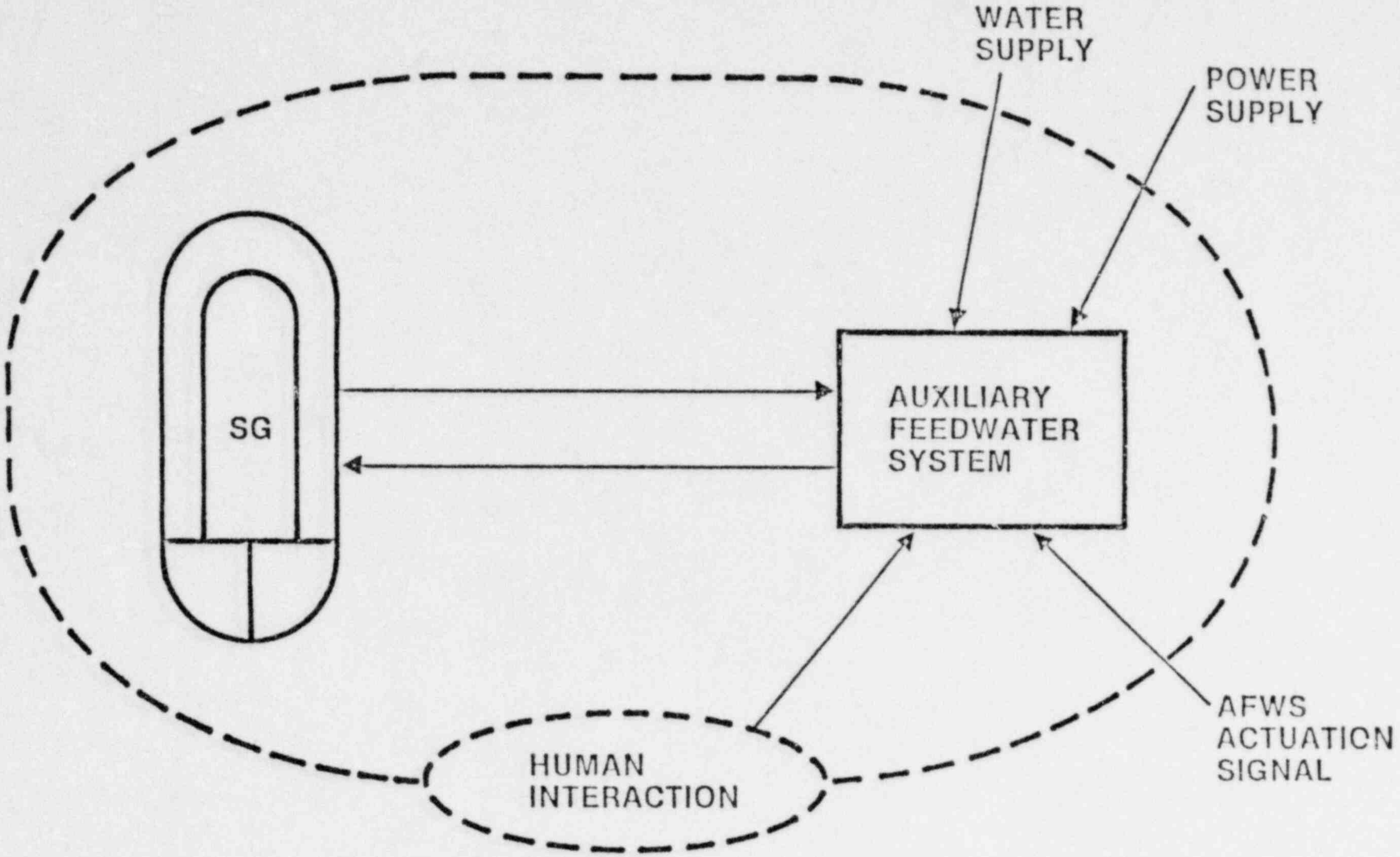


FIGURE 8. BOUNDARY OF ANALYSIS

4. METHODOLOGY

The approach taken in this study is to separate the reliability problem into two logically distinct modules--determination of minimal cutsets of equipment failure modes and determination of cause sets, i.e., causes that can bring about failures of the equipment cutsets.

The first step is to develop a detailed fault tree of the system. That tree is developed down to the level of basic component failure modes, such as "valve MOV-3870A fails to open." Thus when the minimal cutsets of this fault tree are determined, they represent groups of equipment functional failure modes that must occur together if the system is to fail. Those cutsets are characteristic of the system hardware alone.

A simplified fault tree for the Midland AFWS is shown in Figure 9. The TOP event, "No Or Insufficient Flow (NOIF) To Both Steam Generators," can only occur if there is NOIF from the motor pump section AND from the turbine pump section. NOIF from a pump section can only occur on NOIF from all water sources or failures within the pump sections. The detailed fault trees are shown in Appendixes A, B, and C for the base case, double crossover, and three pump, respectively.

The second step is to tabulate the possible causes for each failure mode. A single equipment functional failure mode may be caused by random independent faults, test and maintenance, common or independent human interactions, common environmental conditions such as high temperature or flooding, aging, etc. Entire cutsets may fail due to any single cause or coincident combinations of causes.

The cause tree for the Midland AFWS, Figure 10, lays out the overall solution approach of this report. NOIF to both steam generators can only occur if one or more failure mode cutsets are failed. Such failures must be caused by

Random Independent Failures

OR

Independent Human Errors

OR

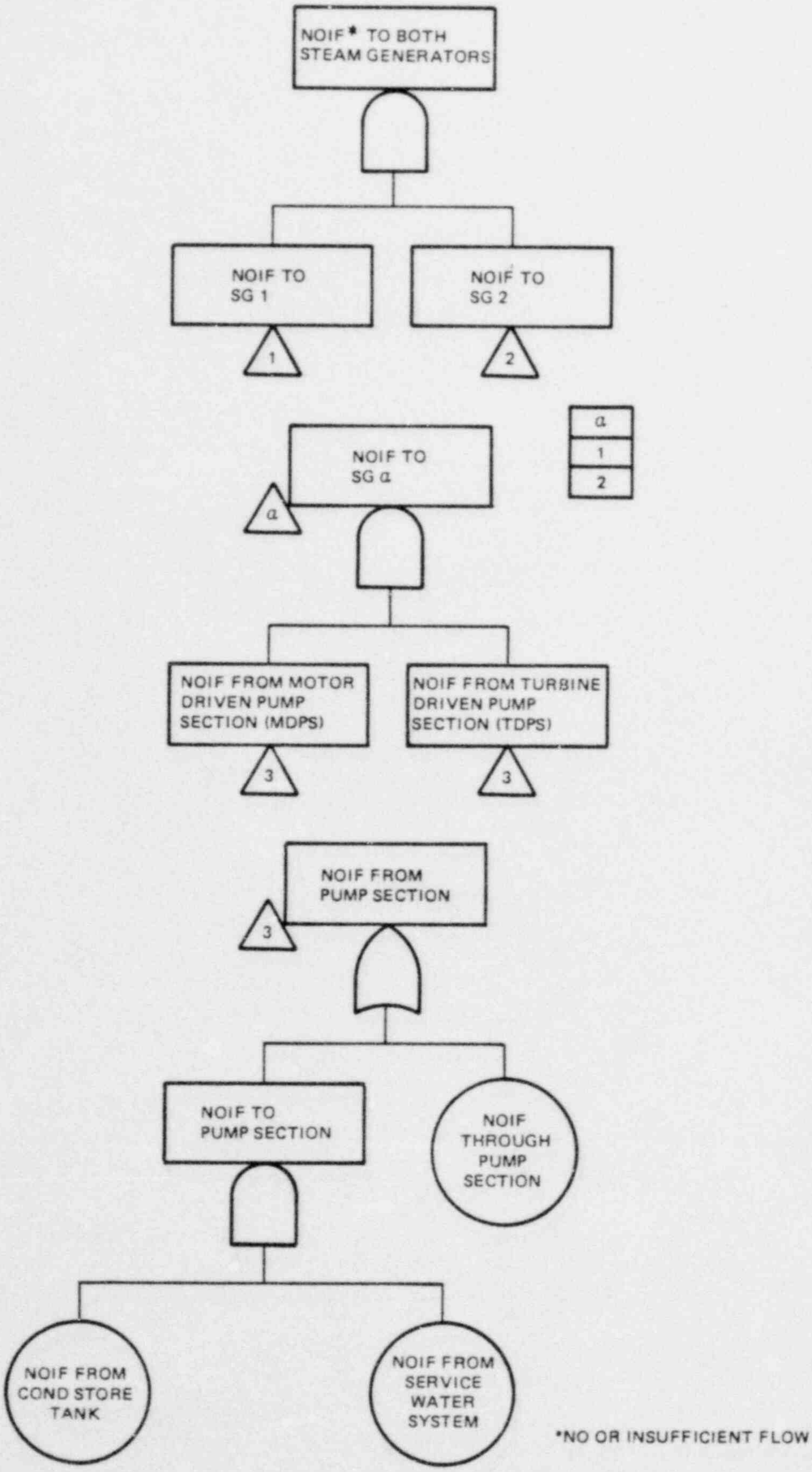
Test and Maintenance in Conjunction With Other Causes

OR

Common Cause Failures

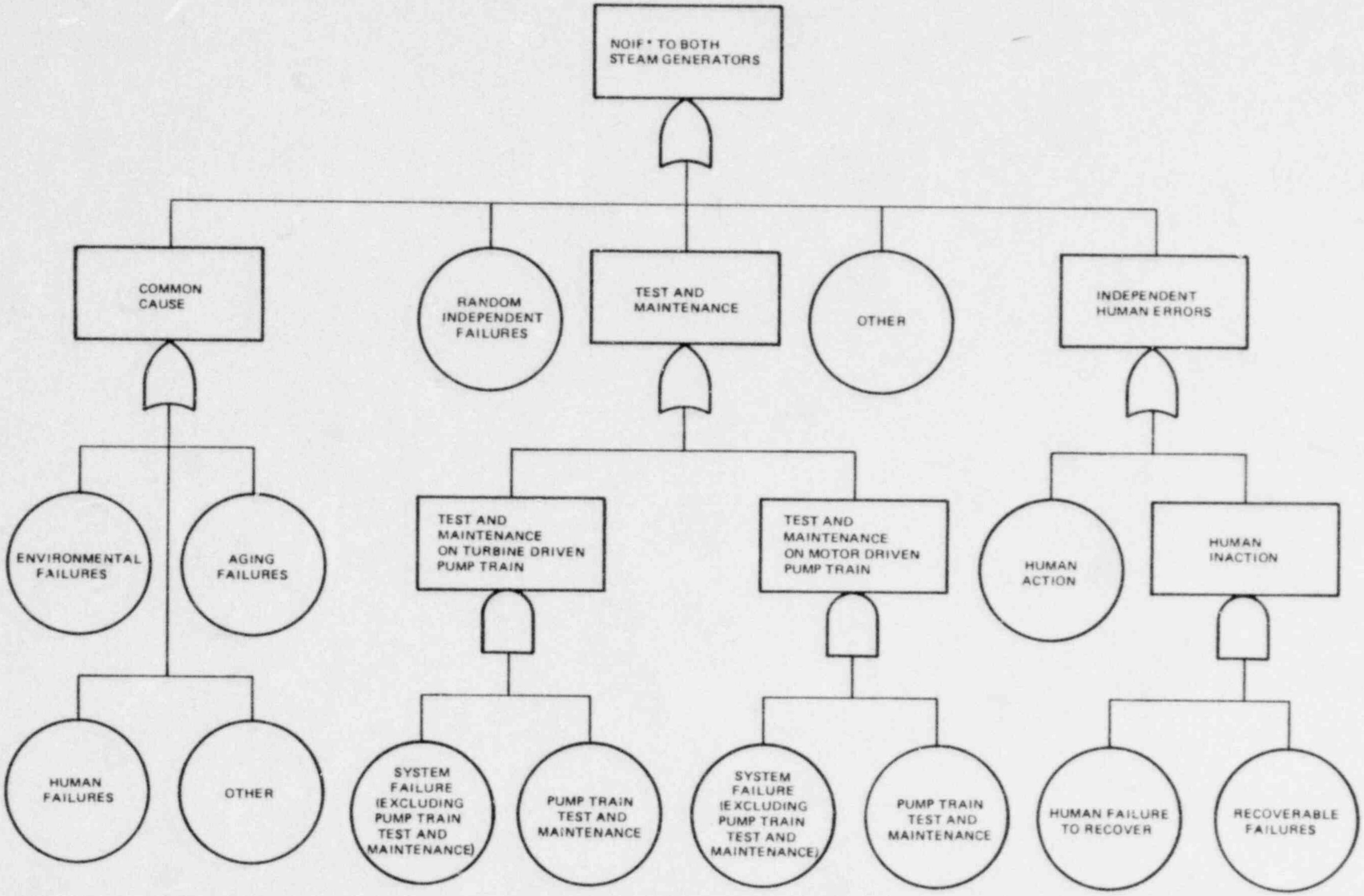
OR

Other Failure Causes.



*NO OR INSUFFICIENT FLOW

FIGURE 9. SIMPLIFIED FAULT TREE



*NO OR INSUFFICIENT FLOW

FIGURE 10. CAUSE TREE FOR THE MIDLAND AUXILIARY FEEDWATER SYSTEM

If time is available to recover from system failure, then recoverable random failures only lead to system failure when combined with human inaction--human failure to recover. Such cases were not considered in this analysis because, based on available information, system success requires immediate operation.

5. SYSTEM ANALYSIS

5.1 SYSTEM MODELS

5.1.1 System Fault Tree

The fault tree models the failures that must occur to prevent successful system operation. The TOP event is defined as "No Or Insufficient Flow To Both Steam Generators." Success is defined as the flow from at least one pump train delivered to at least one steam generator. The simplified fault tree of Figure 9 (Section 4) shows that for the system to fail we must fail to deliver sufficient flow to both steam generators. In each case this requires that there is no or insufficient flow through the steam generator inlet valve section or that there is no or insufficient flow delivered to that section. Secondly, we must have no or insufficient flow from the motor driven pump (either must fail in the three pump alternative) and no or insufficient flow from the turbine driven pump. Finally, there is no water from any of the potential water sources. The complete fault tree models are presented in Appendixes A, B, and C for the base case, double crossover, and three pump alternatives respectively, where the system is modeled to the level of major components. Included are the pumps, valves, electrical supply, motor operators, and turbine and control mechanisms. Not modeled are drain lines, drain valves, piping, and connected lines which are small in size, i.e., system components whose failure rates are very low compared to the ones included in the model. The AFWS flowpath is modeled from the water sources to the steam generators. Electrically, the system is modeled from the bus to the system. (Note that for the case No Offsite Power Available, the diesel generators are treated probabilistically.)

Variations on the main models were made depending upon the initial conditions of the scenario. These variations were made at the basic event level and consisted of changes to the failure probability for the basic event. As examples, consider the following: to run the model for the case "Loss of Offsite Power," the failure probabilities for the AC buses were increased to the value of the probability of failure of a diesel generator to start; to simulate the condition of maintenance on a pump train, the pump failure probability was changed to one (which indicates a failed component) which resulted in a new listing of minimum cutsets for system failure. In this manner, the basic tree developed for a particular system design can correctly evaluate system failure for varying initial conditions.

5.1.2 Computer Programs

The computer programs that are used by Pickard, Lowe and Garrick, Inc., to process information in system reliability analyses are in the public domain and are available through the Argonne Code Center. The codes are the most current versions of computer packages that have been in use for many years. Most of the computer programs were used in support of the Reactor Safety Study, WASH-1400, and have been modified as developments are made to reduce computer cost or improve output presentations. The computer programs used on this project are RAS[11], COMCANII-A[12], and MOCARS[13].

5.1.2.1 RAS. Reliability analysis system, RAS, is a combination of codes that do qualitative and quantitative fault tree analysis. FATRAM (method of obtaining cutsets) KITT (kinetic tree theory), and COMCAN (commom cause failure analysis) are the core elements for RAS. FATRAM is known as a "top down" method for determining cutsets or pathsets for a fault tree. The tree top is developed for its inputs until it is resolved to the basic events in the model. The super sets are then eliminated leaving the minimal cutsets. Kinetic tree theory is the methodology used next to predict the system reliability characterisitics (quantitatively) from the cutsets developed by FATRAM. These codes use the rare event approximation in quantifying reliability.

RAS also includes the COMCAN routines necessary to perform a common cause failure analysis on fault trees. This common cause analysis uses the minimal cutsets as input to the algorithm. Searches are then carried out through other libraries of information supplied to the routines by the user to identify those cutsets that have a single cause of failure for each component.

5.1.2.2 COMCANII-A. The II-A version of COMCAN presently stands separately from RAS. Incorporation is forthcoming. A principal advantage of COMCANII-A is that it allows the common cause analysis to be completed on a much larger tree without the need for "pruning" and analysis of each pruned branch.

5.1.2.3 MOCARS. The Monte Carlo sampling program, MOCARS, is a marked improvement over SAMPLE which was used in the *Reactor Safety Study*. MOCARS readily accepts the cutsets as they are prepared in RAS. A Monte Carlo routine is then used to determine the distribution for the reliability characteristic in question. Improvements in MOCARS make it readily usable for applications other than fault tree analysis.

5.1.3 Data

5.1.3.1 NRC Data. The data used for the point estimate quantification as requested by the NRC, is taken from Appendix III of NUREG-0611. The source for that data was primarily WASH-1400[14]. In some cases such generic data misrepresents equipment actually installed in a specific plant. Using point estimates masks the plant-to-plant variability as the primary source of uncertainty in the data as used in WASH-1400. A complete listing of this data source is provided in Table 6.

5.1.3.2 Generic and Plant-Specific Data. A plant specific data book for Midland is provided in Appendix D. Here the best available data to describe the specific equipment in place at Midland is presented. It is based upon generic data that includes a wide uncertainty band to account for plant-to-plant variability and where sufficient Midland specific data is available those generic distributions have been updated to account for the specific equipment and practices in place at Midland.

TABLE 6. NRC FAILURE DATA

Events	$(\times 10^{-6})$	MTTR	Q (Demand)	WASH-1400 Event
CST1GLOR	.0001	360	—	PTKCONDF
J001A05F	30.	8	—	JH00
J001BP3F	14.	8	—	JF00
J001BP4F	14.	8	—	JF00
J001B55F	14.	8	—	JF00
J001B56F	14.	8	—	JF00
J001D11F	1.2	2	—	JK00
J001D21F	1.2	2	—	JK00
PCV0001D	—	—	1×10^{-4}	PCV0157C
PCV0013D	—	—	1×10^{-4}	PCV0157C
PCV0015D	—	—	1×10^{-4}	PCV0142C
PCV0025D	—	—	1×10^{-4}	PCV0142C
PCV024-D	—	—	1×10^{-4}	—
PCV075-D	—	—	1×10^{-4}	—
PCV076-D	—	—	1×10^{-4}	—
PCVU53AD	—	—	2×10^{-4}	PCV0133, 131C
PCVU53BD	—	—	2×10^{-4}	PCV0137, 138C
PLV75A1D	—	—	1.1×10^{-3}	—
PLV75A2D	—	—	1.1×10^{-3}	—
PLV75B1D	—	—	1.1×10^{-3}	—
PLV75B2D	—	—	1.1×10^{-3}	—
PM0105AA	—	—	4×10^{-3}	PST3ACNT
PM0177AA	—	—	6×10^{-3}	—
PM0177BA	—	—	6×10^{-3}	—
PM03126C	—	—	1×10^{-4}	PMVMS02C
PM075A1A	—	—	6×10^{-3}	—
PM075A2A	—	—	6×10^{-3}	—
PM075B1A	—	—	6×10^{-3}	—
PM075B2A	—	—	6×10^{-3}	—
PM08931A	—	—	6×10^{-3}	—
PM08932A	—	—	6×10^{-3}	—
PM08933A	—	—	6×10^{-3}	—
PM08934A	—	—	6×10^{-3}	—
PMV177AD	—	—	1.1×10^{-3}	—
PMV177BD	—	—	1.1×10^{-3}	—
PMV3856C	—	—	1×10^{-4}	—
PMV865AD	—	—	1.1×10^{-3}	—
PMV865BD	—	—	1.1×10^{-3}	—
PMV868AC	—	—	1×10^{-4}	—
PMV868BC	—	—	1×10^{-4}	—
PMV870AD	—	—	1.1×10^{-3}	—

TABLE 6. NRC FAILURE DATA (continued)

Events	$(\times 10^{-6})$	MTTR	Q (Demand)	WASH-1400 Event
PMV870BD	—	—	1.1×10^{-3}	—
PMV8931D	—	—	1.1×10^{-3}	—
PMV8932D	—	—	1.1×10^{-3}	—
PMV8933D	—	—	1.1×10^{-3}	—
PMV8934D	—	—	1.1×10^{-3}	—
PPM105AF	—	—	1×10^{-3}	PPMFW3AA
PPM105BF	—	—	1×10^{-3}	PPMTURBF
PREA109F	—	—	1×10^{-4}	—
PREA209F	—	—	1×10^{-4}	—
PREB109F	—	—	1×10^{-4}	—
PREB209F	—	—	1×10^{-4}	—
PRE1A03F	—	—	1×10^{-4}	—
PRE1A08F	—	—	1×10^{-4}	—
PRE1A11F	—	—	1×10^{-4}	—
PRE1A12F	—	—	1×10^{-4}	—
PRE1B03F	—	—	1×10^{-4}	—
PRE1B08F	—	—	1×10^{-4}	—
PRE1B11F	—	—	1×10^{-4}	—
PRE1B12F	—	—	1×10^{-4}	—
PRE1111F	—	—	1×10^{-4}	—
PRE1512X	—	—	1×10^{-4}	—
PRE1514X	—	—	1×10^{-4}	—
PRE1610F	—	—	1×10^{-4}	—
PRE1613F	—	—	1×10^{-4}	—
PSTMO0AF	—	—	6×10^{-3}	—
PSTMO0BF	—	—	6×10^{-3}	—
PSTMO5AF	—	—	6×10^{-3}	—
PSTMO5BF	—	—	6×10^{-3}	—
PTB1G05A	—	—	4×10^{-3}	—
PXV001AC	—	—	1×10^{-4}	PXV0168C
PXV001BC	—	—	1×10^{-4}	PXV0153C
PXV0002C	—	—	1×10^{-4}	—
PXV0004C	—	—	1×10^{-4}	—
PXV0014C	—	—	1×10^{-4}	—
PXV0017C	—	—	1×10^{-4}	—
PXV009AO	—	—	5×10^{-4}	PXVTESTY
PXV009BO	—	—	5×10^{-4}	PXVTESTY
PXV037-C	—	—	1×10^{-4}	—
PXV278-C	—	—	1×10^{-4}	—
PXV279-C	—	—	1×10^{-4}	—

Note: All other events were contained in the events listed above, therefore, no failure rates were assigned. All data taken from WASH-1400 or NUREG-0611.

5.2 RANDOM FAILURES

Random system failures reflect the system malfunctions that occur as a result of random component failures. The coincident failure of each component in an AFWS cutset results in a random system failure. This situation does not include, and should be differentiated from, test and maintenance, common cause, and independent human errors. The section on human interaction elaborates on the subject of recovery of the system by repair or operator action.

Table 7 lists all basic events (component failure modes) for the three designs analyzed. Table 8 presents the dominant cutsets and basic events for the double crossover design using NRC data and all three designs using plant specific data for each of the three states of electric power analyzed.

5.3 TEST AND MAINTENANCE

5.3.1 Testing

The Auxiliary Feedwater System (AFWS) and its supporting systems are tested periodically to satisfy plant technical specification requirements. This testing ensures that these systems will be operable when required by various plant conditions. The plant technical specifications also limit the time that systems, or portions of systems, may be out of service and identify special testing requirements necessary to ensure plant safety while these out-of-service systems or components are being repaired.

Plant procedures concerning this technical specification testing were not yet available for this analysis; therefore, slight differences between the actual test methods and the general methods discussed in this section may exist.

5.3.1.1 AFW Pumps. The auxiliary feedwater pumps are tested monthly on a staggered basis. This test requires that the AFW pump successfully pass 100% of the required flow through the pump test bypass line at the required pump discharge head. To develop the required pressure, the pumps were assumed to be isolated from the AFW system at the level control valves during this full flow testing. During the test, if the AFWS is required to operate, the operator at the test bypass valve must close this valve to allow AFW flow to feed the SGs.

Every 18 months, the auxiliary feedwater pumps are checked to ensure that they start upon receipt of an Auxiliary Feedwater Actuation Signal; and that the auxiliary feedwater pumps restart after tripping on high level in the steam generators when the steam generator water level is returned to the normal control band.

5.3.1.2 AFW Valves. All manual, power-operated, or automatic valves that are not locked, sealed, or otherwise secured in position are verified in the correct position monthly. This test is assumed to be a visual check rather than a valve cycling check.

TABLE 7a. FAULT TREE COMPONENT LIST AND FAILURE MODE
BASE CASE

Basic Event		Failure Mode	Description of Event	Failure Data Appendix D Page No.
1.	PPM105AF	Fail to operate	Pump P05A fails to deliver sufficient water (includes support equipment).	D-8
2.	PPM105BF	Fail to operate	Pump P05B fails to deliver sufficient water (includes support equipment).	D-8
3.	PTB1G05A	Fail to start	Turbine G05A fails to start (includes M03831 and turbine controls).	D-28
4.	J001A05F	No output	4,160 V switchgear bus 1A05 fails.	D-10
5.	J001B55F	No output	480 V MCC 1B55 fails.	D-10
6.	J001B56F	No output	480 V MCC 1B56 fails.	D-10
7.	J001D11F	No output	125 VDC panel 1D11 fails.	D-12
8.	J001D21F	No output	125 VDC panel 1D21 fails.	D-12
9.	J001BP4F	No output	480 V power panel 1BP04 fails.	D-10
10.	J001BP3F	No output	480 V power panel 1BP03 fails.	D-10
11.	J001Y13F	No output	120 V instrument panel 1Y13 fails.	D-10
12.	J001Y14F	No output	120 V instrument panel 1Y14 fails.	D-10
13.	J001Y31F	No output	120 V instrument panel 1Y31 fails.	D-10
14.	J001Y32F	No output	120 V instrument panel 1Y32 fails.	D-10
15.	CMUAF1TO	Flow lost	CST makeup flow lost to condenser hotwell (includes LV-3834A, LV-3834B, and ball valve V063).	D-5
16.	CST1GLOR	Rupture	Condensate storage tank ruptures.	D-27
17.	1RUPTLOF	Flow lost	AFW flow lost in main feed system.	D-27
18.	1PPSW-AF	No flow	No supply from service water train A.	D-11
19.	1PPSW-BF	No flow	No supply from service water train B.	D-11
20.	PLV875AC	Closed	Level control valve, LV3875A, fails closed.	D-5
21.	PLV875BC	Closed	Level control valve, LV3875B, fails closed.	D-5
22.	PCVU53AD	Closed	Check valves in OTSG A supply fail closed (includes CV004A and CV053A).	D-2
23.	PCVU53BD	Closed	Check valves in OTSG B supply fail closed (includes CV004B and CV053B).	D-2

TABLE 7a (continued)

Basic Event	Failure Mode	Description of Event	Failure Data Appendix D Page No.
24. PCV076-D	Closed	Check valve OTSG B to AFW turbine fails closed.	D-2
25. PCV075-D	Closed	Check valve OTSG A to AFW turbine fails closed.	D-2
26. PCV002AD	Closed	Check valve P05A discharge fails closed.	D-2
27. PCV002BD	Closed	Check valve P05B discharge fails closed.	D-2
28. PCV024-D	Closed	Check valve CST to AFW fails closed.	D-2
29. PMV8931D	Closed	Service water supply valve MO3893A1 fails closed.	D-3
30. PMV8932D	Closed	Service water supply valve MO3893A2 fails closed.	D-3
31. PMV8933D	Closed	Service water supply valve MO3893B1 fails closed.	D-3
32. PMV8934D	Closed	Service water supply valve MO3893B2 fails closed.	D-3
33. PMV868AC	Closed	Suction header cross-connect valve MO3868A transfers closed.	D-4
34. PMV868BC	Closed	Suction header cross-connect valve MO3868B transfers closed.	D-4
35. PMV177AD	Closed	OTSG A steam supply to AFW turbine MO3177A fails closed.	D-4
36. PMV177BD	Closed	OTSG B steam supply to AFW turbine MO3177B fails closed.	D-4
37. PMV872AC	Closed	AFW pump discharge cross-connect valve MO3872A transfers closed.	D-4
38. PMV872BC	Closed	AFW pump discharge cross-connect valve MO3872B transfers closed.	D-4
39. PMV870AD	Closed	Feedwater isolation valve MO3870A fails closed.	D-4
40. PMV870BD	Closed	Feedwater isolation valve MO3870B fails closed.	D-4
41. PMV865AD	Closed	Feedwater isolation valve MO3865A fails closed.	D-4
42. PMV865BD	Closed	Feedwater isolation valve MO3865B fails closed.	D-4
43. PXV037-C	Closed	CST isolation valve V037 transfers closed.	D-3
44. PXV278-C	Closed	Service water train A isolation valve, V278, transfers closed.	D-3
45. PXV279-C	Closed	Service water train B isolation valve, V279, transfers closed.	D-3
46. PXV001AC	Closed	P05A suction valve, V001A, transfers closed.	D-4
47. PXV001BC	Closed	P05B suction valve, V001B, transfers closed.	D-4
48. PXV003AC	Closed	P05A discharge valve, V003A, transfers closed.	D-4
49. PXV003BC	Closed	P05B discharge valve, V003B, transfers closed.	D-4
50. PXV009AO	Open	P05A full flow test valve, V009A, transfers open.	D-5

TABLE 7a (continued)

Basic Event	Failure Mode	Description of Event	Failure Data Appendix D Page No.
51. PXV009BO	Open	P05B full flow test valve, V009B, transfers open.	D-5
52. PHV889-O	Open	AFW - main feed cross-connect valve HV3889 transfers open.	D-5
53. PCN1C56O	Open	FOGG relay 95-1, channel 1C, contacts 5-6, fail open.	D-20
54. PCN1D12O	Open	FOGG relay 95-1, channel 1D, contacts 1-2, fail open.	D-20
55. PSTM00AF	Fail to operate	Valve MO3870A motor operator does not operate (includes: motor operator, master contactor, 95 relay, FOGG power fuse, and breaker).	D-25
56. PSTM00BF	Fail to operate	Valve MO3870B motor operator does not operate (includes: motor operator, master contactor, 95 relay, FOGG power fuse, and breaker).	D-25
57. PSTCC0AF	No signal	Valve MO3870A controls fail (includes opening circuit, closing circuit, and common circuit failures).	D-25
58. PSTCC0BF	No signal	Valve MO3870B controls fail (includes opening circuit, closing circuit, and common circuit failures).	D-25
59. PCB1526O	Open	Breaker 52-26 in MCC1B55 transfers open.	D-13
60. PCB1626O	Open	Breaker 52-26 in MCC1B56 transfers open.	D-13
61. PRE1A11F	Open	AFWAS relay K611, channel 1A, fails open.	D-18
62. PRE1B11F	Open	AFWAS relay K611, channel 1B, fails open.	D-18
63. PSTM05AF	Fail to operate	Valve 3865A motor operator does not operate (includes motor operator, master contactor, 95-1 relay, FOGG power fuse, and FOGG power breaker).	D-25
64. PSTM05BF	Fail to operate	Valve 3865B motor operator does not operate (includes, motor operator, master contactor, 95-1 relay, FOGG power fuse, and FOGG power breaker).	D-25
65. PSTCC5AF	No signal	Valve MO3865A controls fail (includes opening circuit, closing circuit, and common circuit).	D-26
66. PSTCC5BF	No signal	Valve MO3865B controls fail (includes opening circuit, closing circuit, and common circuit).	D-26
67. PCN1C12O	Open	FOGG relay 95-1, channel 1C, contacts 1-2 fail open.	D-20
68. PCN1D56O	Open	FOGG relay 95-1, channel 1D, contacts 5-6 fail open.	D-20
69. PRE1A12F	Open	AFWAS relay K612, channel 1A, fails open.	D-18

TABLE 7a (continued)

Basic Event	Failure Mode	Description of Event	Failure Data Appendix D Page No.
70. PRE1B12F	Open	AFWAS relay K612, channel 1B, fails open.	D-18
71. PCC1AC1E	False signal	Valve LV3875A closing circuit C1 fails energized.	D-25
72. PCC1AC2E	False signal	Valve LV3875A closing circuit C2 fails energized.	D-25
73. PCC1BC1E	False signal	Valve LV3875B closing circuit C1 fails energized.	D-25
74. PCC1BC2E	False signal	Valve LV3875B closing circuit C2 fails energized.	D-25
75. PSTSL1AF	False signal	Valve MO3872A closing circuit fails energized.	D-26
76. PSTSL1BF	False signal	Valve MO3872B closing circuit fails energized.	D-26
77. PRE1111F	Open	AFWAS relay K1111, channel 1A, fails open.	D-18
78. PMO105AA	Fail to start	PO5A motor fails to start.	D-9
79. PSTBR1AF	Fail to close	PO5A motor breaker does not close (includes control power and closing circuit failures).	D-25
80. PMO177AA	Fail to start	Valve MO3177A motor operator does not operate (includes motor operator and power fuses).	D-7
81. PMO177BA	Fail to start	Valve MO3177B motor operator does not operate (includes motor operator and power fuses).	D-7
82. PRE1512X	False signal	MSLIS relay K512, channel 1B, fails closed, false signal.	D-18
83. PRE1514X	False signal	MSLIS relay K514, channel 1B, fails closed, false signal.	D-18
84. PRE1610F	Open	AFWAS relay K610, channel 1B, fails open.	D-18
85. PRE1613F	Open	AFWAS relay K613, channel 1B, fails open.	D-18
86. PCB1714O	Open	1D21 circuit breaker 72-14 fails open.	D-15
87. PCB1715O	Open	1D21 circuit breaker 72-15 fails open.	D-15
88. PCC177AF	Fail to operate	Valve MO3177A control circuit fails (includes opening, circuit, closing circuit, and common circuit).	D-26
89. PCC177BF	Fail to operate	Valve MO3177B control circuit fails (includes opening circuit, closing circuit, and common circuit).	D-26
90. PMO3126C	Closed	Valve MO3126 transfers closed (includes control circuit and valve failure).	D-4
91. PSTCS1AC	False signal	Valve MO3868A controls provide close signal (includes false signal).	D-26
92. PSTCS1BC	False signal	Valve MO3868B controls provide close signal (includes false signal).	D-26

TABLE 7a (continued)

	Basic Event	Failure Mode	Description of Event	Failure Data Appendix D Page No.
93.	PMV3856C	Closed	Valve MO3856 fails closed (includes inadvertant close signal).	D-4
94.	PMO8934A	Fail to operate	Valve MO3893B2 motor operator fails to operate.	D-6
95.	PCB11O3O	Transfer open	Valve MO3893B2 circuit breaker opens.	D-13
96.	PRE1BO3F	Open	Valve MO3893B2 AFWAS relay fails open.	D-18
97.	PSTCCB2F	No signal	Valve MO3893B2 control circuit fails (includes open, close, and common circuits).	D-25
98.	PMO8933A	Fail to operate	Valve MO3893B1 motor operator fails to operate.	D-6
99.	PCB11O2O	Transfer open	Valve MO3893B1 circuit breaker opens.	D-13
100.	PRE1BO8F	Open	Valve MO3893B1 AFWAS relay fails open.	D-18
101.	PSTCCB1F	No signal	Valve MO3893B1 control circuit fails (includes open, close, and common circuits).	D-25
102.	PMO8932A	Fail to operate	Valve MO3893A2 motor operator fails to operate.	D-6
103.	PCB21O3O	Transfer open	Valve MO3893A2 circuit breaker opens.	D-13
104.	PRE1AO3F	Open	Valve MO3893A2 AFWAS relay fails open.	D-18
105.	PSTCCA2F	No signal	Valve MO3893A2 control circuit fails (includes open, close, and common circuits).	D-25
106.	PMO8931A	Fail to operate	Valve MO3893A1 motor operator fails to operate.	D-6
107.	PCB21O2O	Transfer open	Valve MO3893A1 circuit breaker opens.	D-13
108.	PRE1A08F	Open	Valve MO3893A1 AFWAS relay fails open.	D-18
109.	PSTCCA1F	No signal	Valve MO3893A1 control circuit fails (includes open, close, and common circuits).	D-25

TABLE 7b. FAULT TREE COMPONENT LIST AND FAILURE MODES DOUBLE CROSSOVER

Basic Event	Failure Mode	Description of Event	Failure Data Appendix D Page No.
1. PPM105AF	Fail to operate	Pump P05A fails to deliver sufficient water (includes support equipment).	D-8
2. PPM105BF	Fail to operate	Pump P05B fails to deliver sufficient water (includes support equipment).	D-8
3. PTB1G05A	Fail to start	Turbine G05A fails to start (includes M03831 and turbine controls).	D-28
4. J001A05F	No output	4,160 V switchgear bus 1A05 fails.	D-10
5. J001B55F	No output	480 V MCC 1B55 fails.	D-10
6. J001B56F	No output	480 V MCC 1B56 fails.	D-10
7. J001D11F	No output	125 VDC panel 1D11 fails.	D-12
8. J001D21F	No output	125 VDC panel 1D21 fails.	D-12
9. J001BP4F	No output	480 V power panel 1BP04 fails.	D-10
10. J001BP3F	No output	480 V power panel 1BP03 fails.	D-10
11. J001Y11F	No output	120 V instrument panel 1Y11 fails.	D-10
12. J001Y12F	No output	120 V instrument panel 1Y12 fails.	D-10
13. J001Y13F	No output	120 V instrument panel 1Y13 fails.	D-10
14. J001Y14F	No output	120 V instrument panel 1Y14 fails.	D-10
15. J001Y31F	No output	120 V instrument panel 1Y31 fails.	D-10
16. J001Y32F	No output	120 V instrument panel 1Y32 fails.	D-10
17. CMUAF1TO	Flow lost	CST makeup flow lost to condenser hotwell (includes LV-3834A, LV-3834B, and ball valve V063).	D-5
18. CST1GLOR	Rupture	Condensate storage tank ruptures.	D-27
19. 1RUPTLOF	Flow lost	AFW flow lost in main feed system.	D-27
20. 1PPSW-AF	No flow	No supply from service water train A.	D-11
21. 1PPSW-BF	No flow	No supply from service water train B.	D-11
22. PLV75A1D	Closed	Level control valve, LV3875A1, fails closed (mechanical failure).	D-5
23. PLV75A2D	Closed	Level control valve, LV3875A2, fails closed (mechanical failure).	D-5

TABLE 7b (continued)

Basic Event		Failure Mode	Description of Event	Failure Data Appendix D Page No.
24.	PLV75B1D	Closed	Level control valve, LV3875B1, fails closed (mechanical failure).	D-5
25.	PLV75B2D	Closed	Level control valve, LV3875B2, fails closed (mechanical failure).	D-5
26.	PCVU53AD	Closed	Check valves in OTSG A supply fail closed (includes CV004A and C[illegible]053A).	D-2
27.	PCVU53BD	Closed	Check valves in OTSG B supply fail closed (includes CV004B and CV053B).	D-2
28.	PCV076-D	Closed	Check valve, OTSG B to AFW turbine, fails closed.	D-2
29.	PCV075-D	Closed	Check valve, OTSG A to AFW turbine, fails closed.	D-2
30.	PCV0001D	Closed	Check valve, outlet of LV3875A1, fails closed.	D-2
31.	PCV0013D	Closed	Check valve, outlet of LV3875A2, fails closed.	D-2
32.	PCV0015D	Closed	Check valve, outlet of LV3875B1, fails closed.	D-2
33.	PCV0025D	Closed	Check valve, outlet of LV3875B2, fails closed.	D-2
34.	PCV024-D	Closed	Check valve, CST to AFW, fails closed.	D-2
35.	PMV8931D	Closed	Service water supply valve, MO3893A1, fails closed.	D-3
36.	PMV8932D	Closed	Service water supply valve, MO3893A2, fails closed.	D-3
37.	PMV8933D	Closed	Service water supply valve, MO3893B1, fails closed.	D-3
38.	PMV8934D	Closed	Service water supply valve, MO3893B2, fails closed.	D-3
39.	PMV868AC	Closed	Suction header cross-connect valve, MO3868A, transfers closed.	D-4
40.	PMV868BC	Closed	Suction header cross-connect valve, MO3868B, transfers closed.	D-4
41.	PMV177AD	Closed	OTSG A steam supply to AFW turbine, MO3177A, fails closed.	D-4
42.	PMV177BD	Closed	OTSG B steam supply to AFW turbine, MO3177B, fails closed.	D-4
43.	PMV870AD	Closed	Feedwater isolation valve. MO3870A, fails closed.	D-4
44.	PMV870BD	Closed	Feedwater isolation valve, MO3870B, fails closed.	D-4
45.	PMV865AD	Closed	Feedwater isolation valve, MO3865A, fails closed.	D-4
46.	PMV865BD	Closed	Feedwater isolation valve, MO3865B, fails closed.	D-4
47.	PXV037-C	Closed	CST isolation valve, V037, transfers closed.	D-3

TABLE 7b (continued)

Basic Event		Failure Mode	Description of Event	Failure Data Appendix D Page No.
48.	PXV278-C	Closed	Service water train A isolation valve, V278, transfers closed.	D-3
49.	PXV279-C	Closed	Service water train B isolation valve, V279, transfers closed.	D-3
50.	PXVOO1AC	Closed	PO5A suction valve, VOO1A, transfers closed.	D-4
51.	PXVOO1BC	Closed	PO5B suction valve, VOO1B, transfers closed.	D-4
52.	PXV0002C	Closed	Outlet valve, LV3875B2, transfers closed.	D-4
53.	PXV0004C	Closed	Outlet valve, LV3875A1, transfers closed.	D-4
54.	PXV0014C	Closed	Outlet valve, LV3875A2, transfers closed.	D-4
55.	PXV0017C	Closed	Outlet valve, LV3875B1, transfers closed.	D-4
56.	PXVOO9AO	Open	PO5A full flow test valve, VOO9A, transfers open.	D-5
57.	PXVOO9BO	Open	PO5B full flow test valve, VOO9B, transfers open.	D-5
58.	PHV889-O	Open	AFW - main feed cross-connect valve, HV3889, transfers open.	D-5
59.	PCN1C56O	Open	FOGG relay 95-1, channel 1C, contacts 5-6, fail open.	D-20
60.	PCN1D12O	Open	FOGG relay 95-1, channel 1D, contacts 1-2, fail open.	D-20
61.	PSTMOOAF	Fail to operate	Valve MO3870A motor operator does not operate (includes: motor operator, master contactor, 95 relay, FOGG power fuse, and breaker).	D-25
62.	PSTMOOBF	Fail to operate	Valve MO3870B motor operator does not operate (includes: motor operator, master contactor, 95 relay, FOGG power fuse, and breaker).	D-25
63.	PSTCCOAF	No signal	Valve MO3870A controls fail (includes opening circuit, closing circuit, and common circuit failures).	D-26
64.	PSTCCOBF	No signal	Valve MO3870B controls fail (includes opening circuit, closing circuit, and common circuit failures).	D-26
65.	PCB1526O	Open	Breaker 52-26 in MCC1B55 transfers open.	D-13
66.	PCB1626O	Open	Breaker 52-26 in MCC1B56 transfers open.	D-13
67.	PRE1A11F	Open	AFWAS relay K611, channel 1A, fails open.	D-18
68.	PRE1B11F	Open	AFWAS relay K611, channel 1B, fails open.	D-18

TABLE 7b (continued)

Basic Event	Failure Mode	Description of Event	Failure Data Appendix D Page No.
69. PSTMO5AF	Fail to operate	Valve 3865A motor operator does not operate (includes motor operator, master contactor, 95-1 relay, FOGG power fuse, and FOGG power breaker).	D-25
70. PSTMO5BF	Fail to operate	Valve 3865B motor operator does not operate (includes, motor operator, master contactor, 95-1 relay, FOGG power fuse, and FOGG power breaker).	D-25
71. PSTCC5AF	No signal	Valve MO3865A controls fail (includes opening circuit, closing circuit, and common circuit).	D-26
72. PSTCC5BF	No signal	Valve MO3865B controls fail (includes opening circuit, closing circuit, and common circuit).	D-26
73. PCN1C12O	Open	FOGG relay 95-1 channel 1C contacts 1-2 fail open.	D-20
74. PCN1D56O	Open	FOGG relay 95-1 channel 1D contacts 5-6 fail open.	D-20
75. PRE1A12F	Open	AFWAS relay, K612 channel 1A, fails open.	D-18
76. PRE1B12F	Open	AFWAS relay, K612 channel 1B, fails open.	D-18
77. PRE1111F	Open	AFWAS relay, K1111 channel 1A, fails open.	D-18
78. PMO105AA	Fail to start	PO5A motor fails to start.	D-9
79. PSTBR1AF	Fail to close	PO5A motor breaker does not close (includes control power and closing circuit failures).	D-25
80. PMO177AA	Fail to start	Valve MO3177A motor operator does not operate (includes motor operator and power fuses).	D-7
81. PMO177BA	Fail to start	Valve MO3177B motor operator does not operate (includes motor operator and power fuses).	D-7
82. PRE1512X	False signal	MSLIS relay K512, channel 1B, fails closed, false signal.	D-18
83. PRE1514X	False signal	MSLIS relay K514, channel 1B, fails closed, false signal.	D-18
84. PRE1610F	Open	AFWAS relay K610, channel 1B, fails open.	D-18
85. PRE1613F	Open	AFWAS relay K613, channel 1B, fails open.	D-18
86. PCB1714O	Open	1D21 circuit breaker 72-14 fails open.	D-15
87. PCB1715O	Open	1D21 circuit breaker 72-15 fails open.	D-15
88. PCC177AF	Fail to operate	Valve MO3177A control circuit fails (includes opening, circuit, closing circuit, and common circuit).	D-26
89. PCC177BF	Fail to operate	Valve MO3177B control circuit fails (includes opening circuit, closing circuit, and common circuit).	D-26

TABLE 7b (continued)

Basic Event		Failure Mode	Description of Event	Failure Data Appendix D Page No.
90.	PMO3126C	Closed	Valve MO3126 fails closed (includes control circuit and valve failure).	D-4
91.	PSTCS1AC	False signal	Valve MO3868A controls provide close signal (includes false signal).	D-26
92.	PSTCS1BC	False signal	Valve MO3868B controls provide close signal (includes false signal).	D-26
93.	PMV3856C	Closed	Valve MO3856 fails closed (includes inadvertent close signal).	D-4
94.	PMO8934A	Fail to operate	Valve MO3893B2 motor operator fails to operate.	D-6
95.	PCB1103O	Transfer open	Valve MO3893B2 circuit breaker opens.	D-13
96.	PRE1BO3F	Open	Valve MO3893B2 AFWAS relay fails open.	D-18
97.	PSTCCB2F	No signal	Valve MO3893B2 control circuit fails (includes open, close, and common circuits).	D-25
98.	PMO8933A	Fail to operate	Valve MO3893B1 motor operator fails to operate.	D-6
99.	PCB1102O	Transfer open	Valve MO3893B1 circuit breaker opens.	D-13
100.	PRE1BO8F	Open	Valve MO3893B1 AFWAS relay fails open.	D-18
101.	PSTCCB1F	No signal	Valve MO3893B1 control circuit fails (includes open, close, and common circuits).	D-25
102.	PMO8932A	Fail to operate	Valve MO3893A2 motor operator fails to operate.	D-6
103.	PCB2103O	Transfer open	Valve MO3893A2 circuit breaker opens.	D-13
104.	PRE1AO3F	Open	Valve MO3893A2 AFWAS relay fails open.	D-18
105.	PSTCCA2F	No signal	Valve MO3893A2 control circuit fails (includes open, close, and common circuits).	D-25
106.	PMO8931A	Fail to operate	Valve MO3893A1 motor operator fails to operate.	D-6
107.	PCB2102O	Transfer open	Valve MO3893A1 circuit breaker opens.	D-13
108.	PRE1A08F	Open	Valve MO3893A1 AFWAS relay fails open.	D-18
109.	PSTCCA1F	No signal	Valve MO3893A1 control circuit fails (includes open, close, and common circuits).	D-25
110.	POOCCA1X	No signal	Valve LV3875A1 control circuit fails (includes open, close, and common circuits).	D-25

TABLE 7b (continued)

Basic Event		Failure Mode	Description of Event	Failure Data Appendix D Page No.
111.	POOCCA2X	No signal	Valve LV3875A2 control circuit fails (includes open, close, and common circuits).	D-25
112.	POOCCB1X	No signal	Valve LV3875B1 control circuit fails (includes open, close, and common circuits).	D-25
113.	POOCCB2X	No signal	Valve LV3875B2 control circuit fails (includes open, close, and common circuits).	D-25
114.	PRE1A01F	Open	Valve LV3875A1 AFWAS relay fails open.	D-18
115.	PRE1A02F	Open	Valve LV3875A2 AFWAS relay fails open.	D-18
116.	PRE1B01F	Open	Valve LV3875B1 AFWAS relay fails open.	D-18
117.	PRE1B02F	Open	Valve LV3875B2 AFWAS relay fails open.	D-18
118.	PCB1620O	Open	Valve LV3875A1 circuit breaker opens.	D-13
119.	PCB1621O	Open	Valve LV3875A2 circuit breaker opens.	D-13
120.	PCB1720O	Open	Valve LV3875B1 circuit breaker opens.	D-13
121.	PCB1721O	Open	Valve LV3875B2 circuit breaker opens.	D-13

TABLE 7c. FAULT TREE EVENTS AND FAILURE MODES
THREE PUMP

Basic Event		Failure Mode	Description of Event	Failure Data Appendix D Page No.
1.	PPM105AF	Fail to operate	Pump P05A fails to deliver sufficient water (includes support equipment).	D-8
2.	PPM105BF	Fail to operate	Pump P05B fails to deliver sufficient water (includes support equipment).	D-8
3.	PPM105CF	Fail to operate	Pump P05C fails to deliver sufficient water (includes support equipment).	D-8
4.	PTB1G05A	Fail to start	Turbine G05A fails to start (includes M03831 and turbine controls).	D-28
5.	J001A05F	No output	4,160 V switchgear bus 1A05 fails.	D-10
6.	J001A06F	No output	4,160 V switchgear bus 1A06 fails.	D-10
7.	J001B55F	No output	480 V MCC 1B55 fails.	D-10
8.	J001B56F	No output	480 V MCC 1B56 fails.	D-10
9.	J001D11F	No output	125 VDC panel 1D11 fails.	D-12
10.	J001D21F	No output	125 VDC panel 1D21 fails.	D-12
11.	J001BP4F	No output	480 V power panel 1BP04 fails.	D-10
12.	J001BP3F	No output	480 V power panel 1BP03 fails.	D-10
13.	J001Y13F	No output	120 V instrument panel 1Y13 fails.	D-10
14.	J001Y14F	No output	120 V instrument panel 1Y14 fails.	D-10
15.	J001Y31F	No output	120 V instrument panel 1Y31 fails.	D-10
16.	J001Y32F	No output	120 V instrument panel 1Y32 fails.	D-10
17.	CMUAF1TO	Flow lost	CST makeup flow lost to condenser hotwell (includes LV-3834A, LV-3834B, and ball valve V063).	D-5
18.	CST1GLOR	Rupture	Condensate storage tank ruptures.	D-27
19.	1RUPTLOF	Flow lost	AFW flow lost in main feed system.	D-27
20.	1PPSW-AF	No flow	No supply from service water train A.	D-11
21.	1PPSW-BF	No flow	No supply from service water train B.	D-11
22.	PLV75A1C	Closed	Level control valve LV3875A1 fails closed.	D-5
23.	PLV75A2C	Closed	Level control valve LV3875A2 fails closed.	D-5

TABLE 7c (continued)

	Basic Event	Failure Mode	Description of Event	Failure Data Appendix D Page No.
24.	PLV75B1C	Closed	Level control valve LV3875B1 fails closed.	D-5
25.	PLV75B2C	Closed	Level control valve LV3875B2 fails closed.	D-5
26.	PCVU53AD	Closed	Check valves in OTSG A supply fail closed (includes CV004A and CV053A).	D-2
27.	PCVU53BD	Closed	Check valves in OTSG B supply fail closed (includes CV004B and CV053B).	D-2
28.	PCV076-D	Closed	Check valve OTSG B to AFW turbine fails closed.	D-2
29.	PCV075-D	Closed	Check valve OTSG A to AFW turbine fails closed.	D-2
30.	PCV002AD	Closed	Check valve P05A discharge fails closed.	D-2
31.	PCV002BD	Closed	Check valve P05B discharge fails closed.	D-2
32.	PCV002CD	Closed	Check valve P05C discharge fails closed.	D-2
33.	PCV030AD	Closed	Check valve LV3875A1 outlet to OTSG E51A fails closed.	D-2
34.	PCV030BD	Closed	Check valve LV3875B1 outlet to OTSG E51B fails closed.	D-2
35.	PCV031AD	Closed	Check valve LV3875A2 outlet to OTSG E51A fails closed.	D-2
36.	PCV031BD	Closed	Check valve LV3875B2 outlet to OTSG E51B fails closed.	D-2
37.	PCV032AD	Closed	Check valve condensate supply to P05A fails closed.	D-2
38.	PCV032BD	Closed	Check valve condensate supply to P05B fails closed.	D-2
39.	PCV032CD	Closed	Check valve condensate supply to P05C fails closed.	D-2
40.	PCV034AD	Closed	Check valve service water supply to P05A fails closed.	D-2
41.	PCV034BD	Closed	Check valve service water supply to P05B fails closed.	D-2
42.	PCV035AD	Closed	Check valve service water supply to P05C fails closed.	D-2
43.	PCV035BD	Closed	Check valve service water supply to P05B fails closed.	D-2
44.	PCV024-D	Closed	Check valve CST to AFW fails closed.	D-2
45.	PHV020AC	Closed	Pressure control valve, PCV020A, fails closed.	D-5
46.	PHV020BC	Closed	Pressure control valve, PCV020B, fails closed.	D-5
47.	PHV889-O	Open	AFW main feed cross-connect valve, HV3889, transfers open.	D-5
48.	PMV177AD	Closed	OTSG A steam supply to AFW turbine, MO3177A, fails closed.	D-4
49.	PMV177BD	Closed	OTSG B steam supply to AFW turbine, MO3177B, fails closed.	D-4
50.	PMV870AD	Closed	Feedwater isolation valve, MO3870A, fails closed.	D-4
51.	PMV870BD	Closed	Feedwater isolation valve, MO3870B, fails closed.	D-4
52.	PMV865AD	Closed	Feedwater isolation valve, MO3865A, fails closed.	D-4

TABLE 7c (continued)

Basic Event	Failure Mode	Description of Event	Failure Data Appendix D Page No.
53. PMV865BD	Closed	Feedwater isolation valve, MO3865B, fails closed.	D-4
54. PXV037-C	Closed	CST isolation valve, V037, transfers closed.	D-3
55. PXV278-C	Closed	Service water train A isolation valve, V278, transfers closed.	D-3
56. PXV279-C	Closed	Service water train B isolation valve, V279, transfers closed.	D-3
57. PXV001AC	Closed	PO5A suction valve, V001A, transfers closed.	D-4
58. PXV001BC	Closed	PO5B suction valve, V001B, transfers closed.	D-4
59. PXV001CC	Closed	PO5C suction valve, V001C, transfers closed.	D-4
60. PXV003AC	Closed	PO5A discharge valve, V003A, transfers closed.	D-4
61. PXV003BC	Closed	PO5B discharge valve, V003B, transfers closed.	D-4
62. PXV003CC	Closed	PO5C discharge valve, V003C, transfers closed.	D-4
63. PXV009AO	Open	PO5A full flow test valve, V009A, transfers open.	D-5
64. PXV009BO	Open	PO5B full flow test valve, V009B, transfers open.	D-5
65. PXV009CO	Open	PO5C full flow test valve, V009C, transfers open.	D-5
66. PMV93A1D	Closed	Service water supply valve, MO3893A1, fails closed.	D-3
67. PMV93A2D	Closed	Service water supply valve, MO3893A2, fails closed.	D-3
68. PMV93A3D	Closed	Service water supply valve, MO3893A3, fails closed.	D-3
69. PMV93A4D	Closed	Service water supply valve, MO3893A4, fails closed.	D-3
70. PMV93B1D	Closed	Service water supply valve, MO3893B1, fails closed.	D-3
71. PMV93B2D	Closed	Service water supply valve, MO3893B2, fails closed.	D-3
72. PMV93B3D	Closed	Service water supply valve, MO3893B3, fails closed.	D-3
73. PMV93B4D	Closed	Service water supply valve, MO3893B4, fails closed.	D-3
74. PCV024-D	Closed	Check valve CST to AFW fails closed.	D-3
75. PCN1C56O	Open	FOGG relay 95-1, channel 1C, contacts 5-6, fail open.	D-20
76. PCN1D12O	Open	FOGG relay 95-1, channel 1D, contacts 1-2, fail open.	D-20
77. PSTMOOAF	Fail to operate	Valve MO3870A motor operator does not operate (includes: motor operator, master contactor, 95 relay, FOGG power fuse, and breaker).	D-25
78. PSTMOOBF	Fail to operate	Valve MO3870B motor operator does not operate (includes: motor operator, master contactor, 95 relay, FOGG power fuse, and breaker).	D-25

TABLE 7c (continued)

Basic Event	Failure Mode	Description of Event	Failure Data Appendix D Page No.
79. PSTCCOAF	No signal	Valve MO3870A controls fail (includes opening circuit, closing circuit, and common circuit failures).	D-25
80. PSTCCOBF	No signal	Valve MO3870B controls fail (includes opening circuit, closing circuit, and common circuit failures).	D-25
81. PCB15260	Open	Breaker 52-26 in MCC1B55 transfers open.	D-13
82. PCB16260	Open	Breaker 52-26 in MCC1B56 transfers open.	D-13
83. PRE1A11F	Open	AFWAS relay K611, channel 1A, fails open.	D-18
84. PRE1B11F	Open	AFWAS relay K611, channel 1B, fails open.	D-18
85. PSTMO5AF	Fail to operate	Valve 3865A motor operator does not operate (includes motor operator, master contactor, 95-1 relay, FOGG power fuse, and FOGG power breaker).	D-25
86. PSTMO5BF	Fail to operate	Valve 3865B motor operator does not operate (includes, motor operator, master contactor, 95-1 relay, FOGG power fuse, and FOGG power breaker).	D-25
87. PSTCC5AF	No signal	Valve MO3865A controls fail (includes opening circuit, closing circuit, and common circuit).	D-26
88. PSTCC5BF	No signal	Valve MO3865B controls fail (includes opening circuit, closing circuit, and common circuit).	D-26
89. PCN1C12O	Open	FOGG relay 95-1, channel 1C, contacts 1-2 fail open.	D-20
90. PCN1D56O	Open	FOGG relay 95-1, channel 1D, contacts 5-6 fail open.	D-20
91. PRE1A12F	Open	AFWAS relay K612, channel 1A, fails open.	D-18
92. PRE1B12F	Open	AFWAS relay K612, channel 1B, fails open.	D-18
93. PRE1111F	Open	AFWAS relay K1111, channel 1A, fails open.	D-18
94. PRE1112F	Open	AFWAS relay K1112, channel 1B, fails open.	D-18
95. PMO105AA	Fail to start	PO5A motor fails to start.	D-9
96. PMO105CA	Fail to start	PO5C motor fails to start.	D-9
97. PSTBR1AF	Fail to close	PO5A motor breaker does not close (includes control power and closing circuit failures).	D-25
98. PSTBR1BF	Fail to close	PO5C motor breaker does not close (includes control power and closing circuit failures).	D-25

TABLE 7c (continued)

Basic Event	Failure Mode	Description of Event	Failure Data Appendix D Page No.
99. PMO177AA	Fail to start	Valve MO3177A motor operator does not operate (includes motor operator and power fuses).	D-7
100. PMO177BA	Fail to start	Valve MO3177B motor operator does not operate (includes motor operator and power fuses).	D-7
101. PRE1512X	False signal	MSLIS relay K512, channel 1A, fails closed, false signal.	D-18
102. PRE1514X	False signal	MSLIS relay K514, channel 1B, fails closed, false signal.	D-18
103. PRE1610F	Open	AFWAS relay K610, channel 1A, fails open.	D-18
104. PRE1613F	Open	AFWAS relay K613, channel 1B, fails open.	D-18
105. PCB1714O	Open	1D11 circuit breaker 72-14 fails open.	D-15
106. PCB1715O	Open	1D21 circuit breaker 72-15 fails open.	D-15
107. PCC177AF	Fail to operate	Valve MO3177A control circuit fails (includes opening, circuit, closing circuit, and common circuit).	D-26
108. PCC177BF	Fail to operate	Valve MO3177B control circuit fails (includes opening circuit, closing circuit, and common circuit).	D-26
109. PMO3126C	Closed	Valve MO3126 fails closed (includes control circuit and valve failure).	D-4
110. PMV3856C	Closed	Valve MO3856 fails closed (includes inadvertent close signal).	D-4
111. PMO93A1A	Fail to operate	Valve MO3893A1 motor operator fails to operate.	D-6
112. PMO93A2A	Fail to operate	Valve MO3893A2 motor operator fails to operate.	D-6
113. PMO93A3A	Fail to operate	Valve MO3893A3 motor operator fails to operate.	D-6
114. PMO93A4A	Fail to operate	Valve MO3893A4 motor operator fails to operate.	D-6
115. PMO93B1A	Fail to operate	Valve MO3893B1 motor operator fails to operate.	D-6
116. PMO93B2A	Fail to operate	Valve MO3893B2 motor operator fails to operate.	D-6
117. PMO93B3A	Fail to operate	Valve MO3893B3 motor operator fails to operate.	D-7
118. PMO93B4A	Fail to operate	Valve MO3893B4 motor operator fails to operate.	D-8
119. PCB93A1O	Transfer open	Valve MO3893A1 circuit breaker opens.	D-13
120. PCB93A2O	Transfer open	Valve MO3893A2 circuit breaker opens.	D-13
121. PCB93A3O	Transfer open	Valve MO3893A3 circuit breaker opens.	D-13
122. PCB93A4O	Transfer open	Valve MO3893A4 circuit breaker opens.	D-13
123. PCB93B1O	Transfer open	Valve MO3893B1 circuit breaker opens.	D-13

TABLE 7c (continued)

Basic Event		Failure Mode	Description of Event	Failure Data Appendix D Page No.
124.	PCB93B20	Transfer open	Valve MO3893B2 circuit breaker opens.	D-13
125.	PCB93B3O	Transfer open	Valve MO3893B3 circuit breaker opens.	D-13
126.	PCB93B4O	Transfer open	Valve MO3893B4 circuit breaker opens.	D-13
127.	PREA301F	Open	Valve MO3893A1 AFWAS relay fails open.	D-18
128.	PREA302F	Open	Valve MO3893A2 AFWAS relay fails open.	D-18
129.	PREA801F	Open	Valve MO3893A3 AFWAS relay fails open.	D-18
130.	PREA802F	Open	Valve MO3893A4 AFWAS relay fails open.	D-18
131.	PREB301F	Open	Valve MO3893B1 AFWAS relay fails open.	D-18
132.	PREB302F	Open	Valve MO3893B2 AFWAS relay fails open.	D-18
133.	PREB801F	Open	Valve MO3893B3 AFWAS relay fails open.	D-18
134.	PREB802F	Open	Valve MO3893B4 AFWAS relay fails open.	D-18
135.	PSTCCA1D	No signal	Valve MO3893A1 control circuit fails (includes open, close, and common circuits).	D-25
136.	PSTCCA2D	No signal	Valve MO3893A2 control circuit fails (includes open, close, and common circuits).	D-25
137.	PSTCCA3D	No signal	Valve MO3893A3 control circuit fails (includes open, close, and common circuits.	D-25
138.	PSTCCA4D	No signal	Valve MO3893A4 control circuit fails (includes open, close, and common circuits).	D-25
139.	PSTCCB1D	No signal	Valve MO3893B1 control circuit fails (includes open, close, and common circuits).	D-25
140.	PSTCCB2D	No signal	Valve MO3893B2 control circuit fails (includes open, close, and common circuits).	D-25
141.	PSTCCB3D	No signal	Valve MO3893B3 control circuit fails (includes open, close, and common circuits).	D-25
142.	PSTCCB4D	No signal	Valve MO3893B4 control circuit fails (includes open, close, and common circuits).	D-25
143.	POOCCA1X	False signal	Valve LV3875A1 transfers closed due to control faults.	D-25
144.	POOCCA2X	False signal	Valve LV3875A2 transfers closed due to control faults.	D-25
145.	POOCCB1X	False signal	Valve LV3875B1 transfers closed due to control faults.	D-25
146.	POOCCB2X	False signal	Valve LV3875B2 transfers closed due to control faults.	D-25

TABLE 8. DOMINANT RANDOM FAILURE CUTSETS

TABLE 8.A.1. Loss of Main Feedwater - Double Crossover (NRC Data) - Failure to Start on Demand

Rank	Cutsets	Unavailability	Cutset Importance	Cutset Cumulative Importance
1	PTB1G05A, PMO105AA	1.6×10^{-5}	45.6	45.6
2	PTB1G05A, PPM105AF	4.0×10^{-6}	11.4	57.0
3	PPM105BF, PMO105AA	4.0×10^{-6}	11.4	68.4
4	PXV009BO, PMO105AA	2.0×10^{-6}	5.7	74.2
5	PTB1G05A, PXV009AO	2.0×10^{-6}	5.7	79.8
6	PPM105BF, PPM105AF	1.0×10^{-6}	2.9	82.7
7	PTB1G05A, JO01A05F	9.6×10^{-7}	2.7	85.4
8	PXV009BO, PPM105AF	5.0×10^{-7}	1.4	86.8
9	PPM105BF, PXV009AO	5.0×10^{-7}	1.4	88.3
10	PXV001BC, PMO105AA	4.0×10^{-7}	1.1	89.4
11	PTB1G05A, PRE1111F	4.0×10^{-7}	1.1	90.5
12	PMO3126C, PMO105AA	4.0×10^{-7}	1.1	91.7

Basic Events

Rank	Basic Event	Description	Unavailability	Importance
1	PTB1G05A	Turbine G05A fails to start (and controls)	2.4×10^{-5}	68.5
2	PMO105AA	P05A motor fails to start	2.3×10^{-5}	66.4
3	PPM105BF	P05B fails to deliver sufficient water	6.0×10^{-6}	17.1
4	PPM105AF	P05A fails to deliver sufficient water	5.8×10^{-6}	16.6
5	PXV009BO	P05B full flow test valve transfers open	3.0×10^{-6}	8.6
6	PXV009AO	P05A full flow test valve transfers open	2.9×10^{-6}	8.3
7	JO01A05F	4,160V switchgear bus 1A05 fails	1.4×10^{-6}	4.0
8	PMO3126C	Valve MO3126 fails closed	6.0×10^{-7}	1.7
9	PXV001BC	P05B suction valve transfers closed	6.0×10^{-7}	1.7
10	PRE1111F	AFWAS relay K1111 fails open	5.8×10^{-7}	1.7

TABLE 8.A.2. Loss of Main Feedwater Due to Loss of Offsite Power - Double Crossover (NRC Data) - Failure to Start on Demand

Rank	Cutsets	Unavailability	Cutset Importance	Cutset Cumulative Importance
1	PTB1G05A, J001A05F	1.5×10^{-4}	58.8	58.8
2	PPM105BF, J001A05F	3.7×10^{-5}	14.7	73.5
3	PXV009BO, J001A05F	1.8×10^{-5}	7.3	80.8
4	PTB1G05A, PM0105AA	1.6×10^{-5}	6.4	87.2
5	PTB1G05A, PPM105AF	4.0×10^{-6}	1.6	88.8
6	PPM105BF, PM0105AA	4.0×10^{-6}	1.6	90.3

Basic Events

Rank	Basic Event	Description	Unavailability	Importance
1	J001A05F	4,160V switchgear bus 1A05 fails	2.2×10^{-4}	86.5
2	PTB1G05A	Turbine G05A fails to start (and controls)	1.7×10^{-4}	67.9
3	PPM105BF	P05B fails to deliver sufficient water	4.3×10^{-5}	17.0
4	PM0105AA	P05A motor fails to start	2.3×10^{-5}	9.2
5	PXV009BO	P05B full flow test valve transfers open	2.1×10^{-5}	8.5
6	PPM105AF	P05A fails to deliver sufficient water	5.8×10^{-6}	2.3

TABLE 8.A.3. Loss of All AC - Double Crossover (NRC Data) - Failure to Start on Demand

Rank	Cutsets	Unavailability	Cutset Importance	Cutset Cumulative Importance
1	PTB1G05A	4.0×10^{-3}	62.7	62.7
2	PPM105BF	1.0×10^{-3}	15.7	78.4
3	PXV009BO	5.0×10^{-4}	7.8	86.2
4	PXV001BC	1.0×10^{-4}	1.6	87.8
5	PMO3126C	1.0×10^{-4}	1.6	89.4
6	PMV868BC	1.0×10^{-4}	1.6	91.0
7	PMV3856C	1.0×10^{-4}	1.6	92.5
8	PXV037-C	1.0×10^{-4}	1.6	94.1
9	PCV024-D	1.0×10^{-4}	1.6	95.7

Basic Events

Rank	Basic Event	Description	Unavailability	Importance
1	PTB1G05A	Turbine G05A fails to start (and controls)	4.0×10^{-3}	62.7
2	PPM105BF	P05B fails to deliver sufficient water	1.0×10^{-3}	15.7
3	PXV009BO	P05B full flow test valve transfers open	5.0×10^{-4}	7.8
4	PMV868BC	Suction header cross-connect valve transfers closed	1.0×10^{-4}	1.6
5	PMO3126C	Valve MO3126 transfers closed	1.0×10^{-4}	1.6
6	PMV3856C	Valve MO3856 transfers closed	1.0×10^{-4}	1.6
7	PXV037-C	CST isolation valve transfers closed	1.0×10^{-4}	1.6
8	PCV024-D	CST check valve fails closed	1.0×10^{-4}	1.6
9	PXV001BC	P05B suction valve transfers closed	1.0×10^{-4}	1.6

TABLE 8.B.1. Loss of Main Feedwater - Double Crossover - Failure to Start on Demand

Rank	Cutsets	Unavailability	Cutset Importance	Cutset Cumulative Importance
1	PTB1G05A, PPM105AF	3.3×10^{-5}	46.5	46.5
2	PPM105BF, PPM105AF	1.5×10^{-5}	20.7	67.2
3	PTB1G05A, PM0105AA	5.8×10^{-6}	8.2	75.4
4	PTB1G05A, PSTBR1AF	3.5×10^{-6}	4.9	80.4
5	PPM105BF, PM0105AA	2.6×10^{-6}	3.7	84.0
6	PPM105BF, PSTBR1AF	1.6×10^{-6}	2.2	86.2
7	PTB1G05A, PRE1111F	1.5×10^{-6}	2.2	88.4
8	PTB1G05A, J001A05F	1.2×10^{-6}	1.7	90.1

Basic Events

Rank	Basic Event	Description	Unavailability	Importance
1	PPM105AF	P05A fails to deliver sufficient water	5.1×10^{-5}	69.4
2	PTB1G05A	Turbine G05A fails to start (and controls)	4.9×10^{-5}	66.6
3	PPM105BF	P05B fails to deliver sufficient water	2.2×10^{-5}	29.7
4	PM0105AA	P05A motor fails to start	9.0×10^{-6}	12.3
5	PSTBR1AF	P05A motor breaker does not close	5.4×10^{-6}	7.4
6	PRE1111F	AFWAS relay K1111 fails open	2.4×10^{-6}	3.2
7	J001A05F	4,160V bus 1A05 fails to supply power	1.9×10^{-6}	2.6

TABLE 8.B.2. Loss of Main Feedwater Due to Loss of Offsite Power - Double Crossover - Failure to Start on Demand

Rank	Cutsets	Unavailability	Cutset Importance	Cutset Cumulative Importance
1	PTB1G05A, J001A05F	3.9×10^{-4}	59.1	59.1
2	PPM105BF, J001A05F	1.8×10^{-4}	26.4	85.4
3	PTB1G05A, PPM105AF	3.3×10^{-5}	4.9	90.4

Basic Events

Rank	Basic Event	Description	Unavailability	Importance
1	J001A05F	4,160V switchgear bus 1A05 fails	6.3×10^{-4}	89.7
2	PTB1G05A	Turbine G05A fails to start (and controls)	4.4×10^{-4}	65.9
3	PPM105BF	P05B fails to deliver sufficient water	2.0×10^{-4}	29.4
4	PPM105AF	P05A fails to deliver sufficient water	5.1×10^{-5}	7.3

TABLE 8.B.3. Loss of Main Feedwater Due to Loss of All AC - Double Crossover - Failure to Start on Demand

Rank	Cutsets	Unavailability	Cutset Importance	Cutset Cumulative Importance
1	PTB1G05A	1.1×10^{-2}	63.4	63.4
2	PPM105BF	4.7×10^{-3}	28.3	91.7

Basic Events

Rank	Basic Event	Description	Unavailability	Importance
1	PTB1G05A	Turbine G05A fails to start (and controls)	1.1×10^{-2}	63.4
2	PPM105BF	P05B fails to deliver sufficient water	4.7×10^{-3}	28.3

TABLE 8.C.1. Loss of Main Feedwater - Base Case - Failure to Start on Demand

Rank	Cutsets	Unavailability	Cutset Importance	Cutset Cumulative Importance
1	PPM105AF, PTB1G05A	3.3×10^{-5}	44.8	44.8
2	PPM105AF, PPM105BF	1.5×10^{-5}	20.0	64.8
3	PMO105AA, PTB1G05A	5.8×10^{-6}	7.9	72.7
4	PSTBR1AF, PTB1G05A	3.5×10^{-6}	4.8	77.4
5	PMO105AA, PPM105BF	2.6×10^{-6}	3.5	81.0
6	PSTBR1AF, PPM105BF	1.6×10^{-6}	2.1	83.1
7	PRE1111F, PTB1G05A	1.5×10^{-6}	2.1	85.2
8	JOO1A05F, PTB1G05A	1.2×10^{-6}	1.7	86.9
9	PXV003AC, PTB1G05A	1.2×10^{-6}	1.6	88.5
10	PCV002AD, PTB1G05A	1.1×10^{-6}	1.5	89.9
11	PPM105AF, PXV003BC	8.9×10^{-7}	1.2	91.1

Basic Events

Rank	Basic Event	Description	Unavailability	Importance
1	PPM105AF	P05A fails to deliver sufficient water	4.9×10^{-5}	67.5
2	PTB1G05A	Turbine G05A fails to start (and controls)	4.8×10^{-5}	65.8
3	PPM105BF	P05B fails to deliver sufficient water	2.1×10^{-5}	29.4
4	PMO105AA	P05A motor fails to start	8.7×10^{-6}	12.0
5	PSTBR1AF	P05A motor breaker does not close	5.2×10^{-6}	7.2
6	PRE1111F	AFWAS relay K1111 fails open	2.3×10^{-6}	3.2
7	JOO1A05F	4,160V switchgear bus 1A05 fails	1.8×10^{-6}	2.5
8	PXV003AC	P05A discharge valve transfers closed	1.7×10^{-6}	2.4
9	PCV002AD	Check valve P05A discharge fails closed	1.6×10^{-6}	2.2
10	PXV003BC	P05B discharge valve trans-	1.3×10^{-6}	1.8

TABLE 8.C.2. Loss of Main Feedwater Due to Loss of Offsite Power - Base Case -Failure to Start on Demand

Rank	Cutsets	Unavailability	Cutset Importance	Cutset Cumulative Importance
1	J001A05F, PTB1G05A	3.9×10^{-4}	59.1	59.1
2	J001A05F, PPM105BF	1.7×10^{-4}	26.4	85.5
3	PPM105AF, PTB1G05A	3.3×10^{-5}	4.9	90.4
4	PPM105AF, PPM105BF	1.4×10^{-5}	2.2	92.6

Basic Events

Rank	Basic Event	Description	Unavailability	Importance
1	J001A05F	4,160V switchgear bus 1A05 fails	5.9×10^{-4}	89.2
2	PTB1G05A	Turbine G05A fails to start (and controls)	4.4×10^{-4}	66.1
3	PPM105BF	P05B fails to deliver sufficient water	1.9×10^{-4}	29.5
4	PPM105AF	P05A fails to deliver sufficient water	4.9×10^{-5}	7.4

TABLE 8.C.3. Loss of Main Feedwater Due to Loss of All of AC - Base Case - Failure to Start on Demand

Rank	Cutsets	Unavailability	Cutset Importance	Cutset Cumulative Importance
1	PTB1G05A	1.1×10^{-2}	64.7	64.7
2	PPM105BF	4.7×10^{-3}	28.8	93.5

Basic Events

Rank	Basic Event	Description	Unavailability	Importance
1	PTB1G05A	Turbine G05A fails to start (and controls)	1.1×10^{-2}	64.7
2	PPM105BF	P05B fails to deliver sufficient water	4.7×10^{-3}	28.8

TABLE 8.D.1. Loss of Main Feedwater - Three Pump - Failure to Start on Demand

Rank	Cutsets	Unavailability	Cutset Importance	Cutset Cumulative Importance
1	POOCCB1X, PTB1G05A	1.5×10^{-4}	19.1	19.1
2	POOCCB1X, PPM105BF	6.9×10^{-5}	8.5	27.6
3	POOCCA1X, PTB1G05A	5.9×10^{-5}	7.3	34.9
4	PHV020BC, PTB1G05A	5.8×10^{-5}	7.2	42.1
5	PHV020AC, PTB1G05A	5.8×10^{-5}	7.2	49.3
6	PSTMOOBF, PTB1G05A	3.7×10^{-5}	4.6	53.9
7	PSTMOOAF, PTB1G05A	3.7×10^{-5}	4.6	58.5
8	PPM105CF, PTB1G05A	3.3×10^{-5}	4.1	62.6
9	PPM105AF, PTB1G05A	3.3×10^{-5}	4.1	66.6
10	POOCCA1X, PPM105BF	2.6×10^{-5}	3.3	69.9
11	PHV020BC, PPM105BF	2.6×10^{-5}	3.2	73.1
12	PHV020AC, PPM105BF	2.6×10^{-5}	3.2	76.3
13	PSTMOOBF, PPM105BF	1.7×10^{-5}	2.1	78.4
14	PSTMOOAF, PPM105BF	1.7×10^{-5}	2.1	80.4
15	PPM105CF, PPM105BF	1.5×10^{-5}	1.8	82.2
16	PPM105AF, PPM105BF	1.5×10^{-5}	1.8	84.1
17	PLV75B1C, PTB1G05A	6.1×10^{-6}	0.8	84.8
18	PMO105CA, PTB1G05A	5.8×10^{-6}	0.7	85.5
19	PMO105AA, PTB1G05A	5.8×10^{-6}	0.7	86.3
20	POOCCB1X, PXV003BC	4.7×10^{-6}	0.5	86.8

Basic Events

Rank	Basic Event	Description	Unavailability	Importance
1	PTB1G05A	Turbine G05A fails to start (and controls)	5.3×10^{-4}	65.2
2	PPM105BF	Pump P05B fails to deliver sufficient water	2.3×10^{-4}	29.1
3	POOCCB1X	LV3875B1 transfers closed (controls)	2.3×10^{-4}	28.5
4	POOCCA1X	LV3875A1 transfers closed (controls)	8.8×10^{-5}	10.9
5	PHV020BC	Pressure control valve PCV020B fails closed	8.6×10^{-5}	10.7
6	PHV020AC	Pressure control valve PCV020A fails closed	8.6×10^{-5}	10.7
7	PSTMOOAF	MO3870A motor operator does not operate	5.6×10^{-5}	6.9
8	PSTMOOBF	MO3870BF motor operator does not operate	5.6×10^{-5}	6.9
9	PPM105CF	Pump P05C fails to deliver sufficient water	4.9×10^{-5}	6.0
10	PPM105AF	Pump P05A fails to deliver sufficient water	4.9×10^{-5}	6.0
11	PXV003BC	P05B discharge valve transfers closed	1.4×10^{-5}	1.8
12	PLV75B1C	Level control valve LV3875B1 fails closed	9.1×10^{-6}	1.1
13	PMO105CA	P05C motor fails to start	8.6×10^{-6}	1.1
14	PMO105AA	P05A motor fails to start	8.6×10^{-6}	1.1

TABLE 8.D.2. Loss of Main Feedwater Due to Loss of Offsite Power - Three Pump - Failure to Start on Demand

Rank	Cutsets	Unavailability	Cutset Importance	Cutset Cumulative Importance
1	PTB1G05A, JOO1A05F	3.9×10^{-4}	19.9	19.9
2	PTB1G05A, JOO1A06F	3.9×10^{-4}	19.7	39.7
3	PPM105BF, JOO1A05F	1.7×10^{-4}	8.9	48.6
4	PPM105BF, JOO1A06F	1.7×10^{-4}	8.9	57.5
5	POOCCB1X, PTB1G05A	1.5×10^{-4}	7.8	65.3
6	POOCCB1X, PPM105BF	6.9×10^{-5}	3.5	68.8
7	PTB1G05A, POOCCA1X	5.9×10^{-5}	3.0	71.8
8	PTB1G05A, PHV020BC	5.8×10^{-5}	2.9	74.7
9	PTB1G05A, PHV020AC	5.8×10^{-5}	2.9	77.6
10	PTB1G05A, PSTMOOBF	3.7×10^{-5}	1.9	79.5
11	PTB1G05A, PSTMOOAF	3.7×10^{-5}	1.9	81.4
12	PTB1G05A, PPM105CF	3.3×10^{-5}	1.6	83.1
13	PTB1G05A, PPM105AF	3.3×10^{-5}	1.6	84.7
14	PPM105BF, POOCCA1X	2.6×10^{-5}	1.3	86.1
15	PPM105BF, PHV020BC	2.6×10^{-5}	1.3	87.4
16	PPM105BF, PHV020AC	2.6×10^{-5}	1.3	88.7
17	PPM105BF, PSTMOOBF	1.7×10^{-5}	.8	89.5
18	PPM105BF, PSTMOOAF	1.7×10^{-5}	.8	90.4
19	PPM105BF, PPM105CF	1.5×10^{-5}	.7	91.1

Basic Events

Rank	Basic Event	Description	Unavailability	Importance
1	PTB1G05A	Turbine 1G05A fails to start (and controls)	1.3×10^{-3}	66.3
2	JOO1A05F	4,160V switchgear bus 1A05 fails	5.8×10^{-4}	29.6
3	JOO1A06F	4,160V switchgear bus 1A06 fails	5.8×10^{-4}	29.6
4	PPM105BF	P05B fails to deliver sufficient water	5.8×10^{-4}	29.6
5	POOCCB1X	Valve LV3875B1 transfers closed	2.3×10^{-4}	11.7
6	POOCC1X	Valve LV3875A1 transfers closed	8.8×10^{-5}	4.4
7	PHV020BC	Pressure control valve PCV020 fails closed	8.6×10^{-5}	4.4
8	PHV020AC	Pressure control valve PCV020A fails closed	8.6×10^{-5}	4.4
9	PSTMOOAF	MO3870A operator fails (and controls)	5.7×10^{-5}	2.9
10	PSTMOOBF	MO3870B operator fails (and controls)	5.7×10^{-5}	2.9
11	PPM105CF	P05C fails to deliver sufficient water	4.9×10^{-5}	2.5
12	PPM105AF	P05A fails to deliver sufficient water	4.9×10^{-5}	2.5

TABLE 8.D.3. Loss of Main Feedwater Due to Loss of All of AC - Three Pump - Failure to Start on Demand

Rank	Cutsets	Unavailability	Cutset Importance	Cutset Cumulative Importance
1	PTB1G05A	1.1×10^{-1}	62.5	62.5
2	PPM105BF	4.7×10^{-2}	27.9	90.3

Basic Events

Rank	Basic Event	Description	Unavailability	Importance
1	PTB1G05A	Turbine G05A fails to start (and controls)	1.1×10^{-1}	62.5
2	PPM105BF	P05B fails to deliver sufficient water	4.7×10^{-2}	27.9

Every 18 months each automatically operated valve is checked to ensure the valve cycles to the correct position upon receipt of an Auxiliary Feedwater Actuation Signal; the auxiliary feedwater steam generator level control valves are checked to ensure they maintain steam generator water level; and the feedwater stop valves are checked to ensure they cycle shut upon receipt of a high level in the associated steam generator.

5.3.1.3 Auxiliary Feedwater Actuation System. The Auxiliary Feedwater Actuation System (AFWAS) is functionally checked monthly. Channel checks are performed at least every 12 hours, and the instrumentation channels are calibrated at least every 18 months.

5.3.1.4 Condensate Storage Tank. Level in the Condensate Storage Tank is verified at least every 12 hours. With one of the two Condensate Storage Tanks inoperable, an auxiliary feedwater pump supply flowpath is demonstrated to be operable at least daily.

5.3.1.5 Service Water System. Service water valves (manual, automatic, or power-operated) which service safety-related equipment are verified to be in the correct position monthly if the valves are not locked, sealed, or otherwise secured in position.

Every 18 months each automatic valve is verified to actuate to its correct position upon receipt of an Essential Safeguards Features Actuation Signal (ESFAS) and each service water pump is verified to start on an ESFAS test signal.

5.3.2 Maintenance

All system components were reviewed for possible contribution to maintenance unavailability. Generic data was reviewed in conjunction with this component review to identify prevalent failure modes and the effect of the associated maintenance on system operation. The following is a brief discussion of the results of this review.

5.3.2.1 Hardware Failures (Mechanical Components). Packing replacement and adjustment is the dominant cause of maintenance on valves. In most cases, this maintenance can be performed with the valve in the correct position for system operation (fully open or fully closed). Valve repairs requiring disassembly of the valve, although not frequently occurring, may have a major impact on system availability due to system isolation requirements necessary to safely perform this maintenance. Those valves which require full AFWS shutdown in order for repair also require a plant shutdown (per technical specifications) and, therefore, do not contribute to the maintenance unavailability of the AFWS. Those valves requiring maintenance which only need a single AFW pump train to be shut down do contribute to maintenance unavailability of the AFWS. Valves which are periodically cycled, which have a throttling action, or which are in a high energy system are the dominant contributors to this unavailability. These valves are included in the pump train maintenance unavailability.

Pump maintenance consists of a range of actions from major disassembly to packing adjustment. For the AFW pumps, most maintenance performed requires isolation of the pump from the system and, therefore contributes to the maintenance unavailability of the pump train.

The maintenance on large motors range from inspection and cleaning to major disassembly. The prevalent failure mode is bearing failure which requires partial disassembly of the motor. All maintenance of the AFW pump motor contributes to maintenance unavailability and is included in the pump train maintenance unavailability.

Turbine maintenance can range from simple adjustments to major disassembly. A review of Licensee Event Reports from January 1972 to April 1978 revealed only one reported failure of a turbine in an AFWS. This failure was due to a casing steam leak discovered during startup after routine maintenance had been performed. Turbine failure is included in the maintenance contribution to unavailability of the turbine driven pump train.

5.3.2.2 Electrical Failures (Controls, etc.). Motor-operated valve (MOV, LCV) control circuit failures occur with moderate frequency. Repairs generally consist of troubleshooting and defective component replacement or repair. In some cases, the associated valve may be placed in the desired position prior to commencing repairs on the control circuit. The level control valves (two) for each pump train, and the SG AFW isolation valves (two per SG) were considered for their maintenance contribution to system unavailability; however, their individual contribution to maintenance unavailability is less than 1% of the contribution of the individual pump trains to maintenance unavailability.

The AFW pump motor breaker and control circuit requires periodic maintenance and repair. Because the 4160V breakers are interchangeable between 4160V cubicles, and spare breakers are available, major breaker repair is not included in the maintenance unavailability of the motor-driven pump train. All other control and breaker maintenance is included in the unavailability of the motor driven AFW pump train.

5.3.2.3 Data. Plant historical records for maintenance actions were available for this analysis; however, because the plant is not yet operating, this data was not used in determining the maintenance unavailability of the different pump trains, instead generic values from WASH-1400, the Reactor Safety Study, were used.

From WASH-1400, the expected frequency of pump maintenance is one act every 4.5 months. This maintenance is assumed to include the pump, the driver (turbine or motor), and associated control circuits. The maintenance duration ranged from a few minutes to several days. The plant technical specifications limit this maintenance duration to 72 hours. The lognormal mean maintenance act duration is 19 hours.

Based upon the preceding discussion, Table 9 presents the maintenance unavailability contributions for AFW pump trains.

TABLE 9. PUMP TRAIN UNAVAILABILITY DUE TO TEST AND MAINTENANCE

$$Q \text{ maintenance turbine} = \frac{1 \text{ actuation}}{4.5 \text{ months}} \times \frac{19 \text{ hours}}{\text{actuation}} \times \frac{\text{month}}{720 \text{ hours}} = 5.9 \times 10^{-3}$$

$$Q \text{ maintenance motor} = \frac{1 \text{ actuation}}{4.5 \text{ months}} \times \frac{19 \text{ hours}}{\text{actuation}} \times \frac{\text{month}}{720 \text{ hours}} = 5.9 \times 10^{-3}$$

$$\begin{array}{l} Q \text{ test turbine} \\ \text{(operator error)} \end{array} = \frac{15 \text{ minutes}}{\text{month}} \times \frac{\text{hour}}{60 \text{ minutes}} \times \frac{\text{month}}{720 \text{ hours}} \times 0.9 = 3.1 \times 10^{-4}$$

$$\begin{array}{l} Q \text{ test motor} \\ \text{(operator error)} \end{array} = \frac{15 \text{ minutes}}{\text{month}} \times \frac{\text{hour}}{60 \text{ minutes}} \times \frac{\text{month}}{720 \text{ hours}} \times 0.9 = 3.1 \times 10^{-4}$$

System Unavailability Due to Test and Maintenance

$$\begin{aligned} Q\ \text{system}_{T+M} = {} & (Q \text{ maintenance turbine} + Q \text{ test turbine}) \\ & (Q \text{ system with turbine pump down}) \\ + {} & (Q \text{ maintenance motor} + Q \text{ test motor}) \\ & (Q \text{ system with motor pump down}) \end{aligned}$$

5.4 HUMAN INTERACTION

5.4.1 Human Interaction/Recoverable Failures

For the purposes of this analysis, due to the short period of time between failure of the AFWS to start and loss of the SGs due to dryout, no operator action to recover the AFWS was considered. This conservatism could be eliminated if more definitive calculations for timing of AFWS starting are made.

There are some system failures from which the operator may recover. The most significant of these is a turbine-driven auxiliary feedwater pump trip.

The dominant contributor to turbine-driven auxiliary feedwater pumps failure to start on demand is a failure of the turbine controls; primarily due to turbine trip on overspeed during startup. The operator may manually reset the overspeed trip, or take control of the turbine-driven AFW pump if, during a demand, this pump did not operate. The probability of failure for the operator failing to take action within 30 minutes is P_f--0.044 mean with 0.005 variance.

Using this value, a point value estimate of the system unavailability (failure to start and no recovery) for the double crossover system design is 2.5×10^{-5}.

5.4.2 Human Error/Testing

During the monthly full flow testing of the AFW pumps, an operator is stationed at the full flow test bypass valve. After the pump is started, this operator throttles open the full flow test valve to achieve rated pump flow and discharge head. Should the AFWS be actuated by a plant transient, this operator must close the full flow test valve to allow the AFW pump to feed the SGs. The full flow test is assumed to last 15 minutes per month. Pump unavailability due to this test is equal to

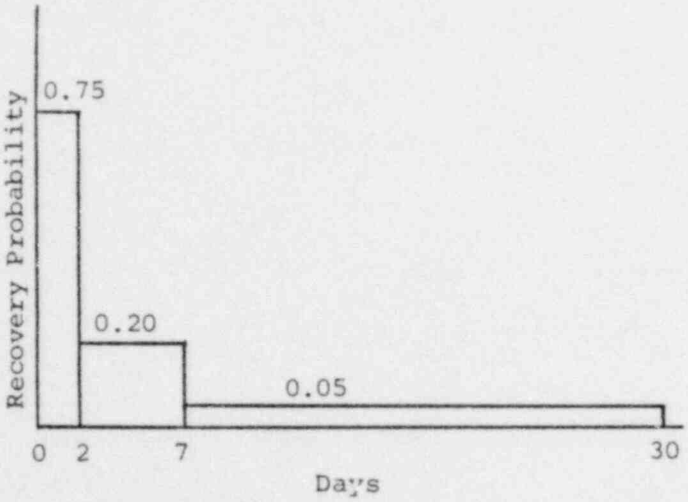
$$\frac{\text{15 minutes}}{\text{month}} \times \frac{\text{hour}}{\text{60 minutes}} \times \frac{\text{month}}{\text{720 hours}} = 3.5 \times 10^{-4}.$$

The operator error, failing to act correctly during the first 5 minutes after the onset of an extremely high stress situation is 0.9. The unavailability of a pump train on demand due to this failure is 3.1×10^{-4}.

5.4.3 Human Error--Common Cause

A common cause human error has been identified for the AFWS. The error can occur after the pump monthly flow testing. Essentially, after each pump test, the auxiliary plant operator must close the full flow test valve. The pumps themselves are controlled from the main control board, and position indication is available for the full flow test valve at the main control board. If the pumps are tested sequentially (i.e., one pump is tested and at the completion of this test the other pump is tested) common human error or combinations of errors is possible. These errors consist of: the auxiliary plant operator failing to close the full flow test valve for the first pump and failing to close the second pump's full flow test valve (close coupling is assumed); and the main control board operator failing to notice the valve position indication for the full flow test valves on the main control board (also close coupled if the first valve position indication is missed). The recovery time for this failure is based upon the probability of the improper valve position being discovered during shift change when the oncoming and offgoing operators "walk down" the main control boards from NUREG-0611, Table III-2, the point value estimate for this potential human error is 1×10^{-4} with an estimated error factor of 20.

Based upon discussions with the plant operators, the following recovery histogram was constructed.



The mean value from this histogram for recovery is 2.53 days and the variance is 13.7 days.

The probability for failure on demand for this common cause human error is then (if one assumes that the error has occurred)

$$Q_F = \frac{1 \text{ actuation}}{\text{month}} \times 10^{-4} \; P(f) \times 2.52 \text{ days} \times \frac{\text{month}}{30 \text{ days}}$$

$$Q_F = 8.4 \times 10^{-6} \text{ with a variance of } 6.7 \times 10^{-10}.$$

5.5 COMMON CAUSE ANALYSIS

The method used to perform the common cause failure analysis is based on the system logic model. Qualitative failure characteristics are identified for each basic event. A search is then performed to identify those combinations of basic events that result in system failure and share qualitative failure characteristics. Barriers between components, both physical and administrative, are considered in the analysis. The results of the common cause search are groups of cutsets identified by common failure characteristics and absence of barriers.

There is an extremely large array of failure causes that must be considered in a comprehensive common cause failure analysis. These failure causes have been grouped into two major categories and these two categories have been further subdivided. For each subdivision a generic cause of failure has been identified. The first division is made on the basis of barriers that can be erected to the cause of failure in order to prevent it from failing the entire system. The barriers that exist are of either procedural or physical. The failure causes, also called qualitative failure characteristics of the basic event or "susceptibilities" are categorized by criterion based on barriers to the failure cause.

The susceptibility codes for the causes of failure considered in this analysis are given in Table 10. Due to the limits of the available information, assumptions were made concerning maintenance actions, test procedures, and manufacturers. These links are assumed to be different for different generic components.

5.5.1 The First Criterion

A qualitative failure characteristic, or a susceptibility, is a common link when physical barriers cannot be erected to prevent the propagation of the failures, and procedural barriers must then be erected. Typical common links used in a common cause analysis are:

- Manufacturer
- Test/Maintenance
- Operator
- Motive Power
- Instrument Power
- Installation
- Calibration
- Similar Parts

The common links of manufacturer and similar parts were used in this analysis.

5.5.2 The Second Criterion

The coding of failure sensitivity to causes of failure are given for each generic component type in Table 11. The final information that needs to be coded for the auxiliary feedwater system common cause analysis is the physical location of the basic events. Table 12 is the reference used in location definition. The first part of the exhibit identifies the codes used with the basic events and the location in the plant that these codes represent. The second part of the exhibit identifies all basic events used in the analysis and the physical location for these basic events.

TABLE 10. SUSCEPTIBILITY CODES

First Criterion

Maintenance Action – MA MB MD M1 M2 M3 M4

Test Procedure – T1 T2 T3 T4 TD TE TF TG TI TJ TK TL TM TP TS TT TU TV TW

Manufacturer
- Anchor Darling – AD
- Byron Jackson – BG
- Control Component – CC
- Henry Pratt – HP
- Limitorque – LJ
- Terry Turbine – TT
- Unknown (Similar Components Grouped Together) – X1 X2 X3 X4 X5 X7 X8

Second Criterion

Impact – I

Vibration – V

Moisture – M

Grit – G

Stress – S

TABLE 11. GENERIC COMPONENTS AND THEIR SENSITIVITIES TO FAILURE

Component Type	Code	Special Condition	Susceptibility
Level Valve	LV	T M	I S
Manual Valve	XV	T M	I S
Pump	PM	T M	I V
Turbine (includes controls)	TB	T	I V M G
Contact	CN	T	I V M G
Circuit Breaker	CB	T	I V M G
Control Circuit	ST	T	I V M G
Power Bus	OO	T	I V M G
Control Circuit	CC	T M	I V M G
Motor Valve	MV	T M	I S
Relay	RE	T	I V M G
Check Valve	CV	T M	I
Motor	MO	T	I M G

TABLE 12. PHYSICAL BARRIER INFORMATION

Equipment Locations Used in the Midland AFW System Analysis

R15A
R15B - inside reactor building.
RSDC

PISO - auxilary building pipe chase.

CLCV - auxilary building outside AFW pump rooms.

MAAA - auxilary building motor driven pump room.

TBAA - auxilary building turbine driven pump room.

YARD - exterior of buildings.

SAAA - 4160VAC switchgear room A.
SABA - 480VAC switchgear room A.
SBBA - 480VAC switchgear room B.

BAAD - 125VDC battery room A, Panel 1D11.
BBAD - 125VDC battery room B, Panel 1D21.

PABA - service water pump room A.
PBBA - service water pump room B.

OCHA - ESF actuation - AFWAS channel A.
OCHB - ESF actuation - AFWAS channel B.

<u>Basic Events in Locations R15A, R15B, RSDC</u>

PMV177AD
PMV177BD
PCVU53AD
PCVU53BD
PM0177AA
PM0177BA

<u>Basic Events in Location PISO</u>

PMV870AD
PMV870BD
PMV865AD
PMV865BD
PM03126C

TABLE 12. PHYSICAL BARRIER INFORMATION (continued)

Basic Events in Location CLCV

PLV75A1D
PLV75A2D
PLV75B1D
PLV75B2D
PM075A1A
PM075A2A
PM075B1A
PM075B2A
PXV0002C
PXV0004C
PXV0014C
PXV278-C
PXV279-C
PMV868AC
PMV868BC
PMV3856C
PCV0001D
PCV0013D
PCV0015D
PCV0025D
PXV009AO
PMV8931D
PMV8932D
PMV8933D
PMV8934D
PM08931A
PM08932A
PM08933A
PM08934A

Basic Events in Location MAAA

PXV001AC
PPM105AF

Basic Events in Location TBAA

PXV001BC
PTB1G05A
PXV009BO
PPM105BF

Basic Event in Location YARD

PXV037-C

Basic Event i ation SAAA

PSTBR1AF

Basic Events in Location SABA

PCN1D120
PCB15260
PSTM00AF
PSTCS1AC
PSTCC0AF

TABLE 12. PHYSICAL BARRIER INFORMATION (continued)

Basic Events in Location SBBA

PCN1C560
PCB16260
PSTMOOBF
PSTCS1BC
PSTCCOBF

Basic Events in Location BAAD

PCN1C120
PCB16200
PCB16210
PSTCC5AF
POOCCA1X
POOCCA2X
PSTMO5AF

Basic Events in Location BBAD

PCN1D560
PCB17150
PCB17140
PSTMO5BF
PCC177BF
PCC177AF
PCB17200
PCB17210
PSTCC5BF
POOCCB1X
POOCCB2X

Basic Events in Location PABA

PCB21030
PRE1A03F
PCB21020
PRE1A08F
PSTCCA1F
PSTCCA2F

Basic Events in Location PBBA

PCB11030
PCB11020
PRE1B03F
PRE1B08F
PSTCCB1F
PSTCCB2F

Basic Events in Location OCHA

PRE1A11F
PRE1A12F
PRE1111F
PREA109F
PREA209F
PRE1A03F
PRE1A03F

Basic Events in Location OCHB

PRE1610F
PRE1B11F
PRE1B12F
PRE1613F
PRE1512X
PRE1514X
PREB109F
PREB209F
PRE1B03F
PRE1B08F

5.5.3 Results of Common Cause Analysis

All cutsets with common susceptibilities were in the same location, CLCV, the area of the auxiliary building outside the AFW pump rooms. Moisture, grit, and impact were found in this location. The number and order (number of basic events in the cutset) for each of these causes of failure are given in Table 13. Moisture was found to be a common susceptibility for the four level control valves and for four two-event cutsets in the pump suction lines (consisting of the pump suction MOVs and various combinations of the service water supply MOVs). The design of these valves protects the motor operators from high humidity and other minor sources of water. Flooding or pipe rupture could, however, prevent these valves from operating when demanded. The level control valves are the most susceptible to this cause because they must move from their normally closed position to permit AFW flow to the steam generators. The suction valves are only required to operate in the event of low pressure at the pump suction and a coincident AFWAS signal. From WASH-1400, the probability of a pipe rupture is 1×10^{-4} per reactor year of operation. However, this system is called upon to operate (and therefore pressurized) 16 times per year (six actuations and ten startup/shutdowns). The average run time is about two hours. The resulting probability of failure is 4×10^{-7} which is significantly less than the common cause human error identified in Section 5.4 but was found to be a common susceptibility for the same cutsets as moisture. Motor operated valve design protects the motor operators from the normal sources of airborne grit or dust during plant operation. During maintenance periods, the plant general maintenance procedures limit the sources of grit as a general housekeeping practice. This practice in conjunction with the safety system testing that occurs prior to plant operation results in a large reduction in the probability of failure due to grit because of maintenance. In addition, because failure due to grit is not an instantaneous failure, but rather a slow degradation in operation, any common cause failures will most likely be detected and corrected as a result of normal testing and preventive maintenance.

Because of the above reasons, the probability of system failure due to the common cause susceptibility--grit--is very much less than the common cause human error identified in Section 5.4.

Impact is identified as a common cause susceptibility for 51 three-event cutsets in the pump suction piping, 16 three-event cutsets in the pump discharge piping, and 451 four-event cutsets in the pump discharge piping. There is no high energy piping in the immediate vicinity of the pump suction piping, thus eliminating pipe whip as an impact source. The only other possible sources of impact in this area are due to external causes such as explosion. Plant procedures limit the amount and location of explosive materials (acetelyne, etc.) and thereby form an administrative barrier to explosion as a cause of impact.

The pump discharge piping is a high energy system when the AFW system is in operation and is the only high energy system in the vicinity. If one assumes that pipe rupture leads directly to pipe whip (a conservative

TABLE 13. COMMON CAUSE CANDIDATES IN PHYSICAL LOCATION CLCV

	Cutsets	
Susceptibility	Quantity	Basic Events
Moisture (suction)	4	2
(discharge)	1	4
Grit (suction)	4	2
(discharge)	1	4
Impact (suction)	51	3
(discharge)	16	3
(discharge)	451	4

assumption considering piping support design), impact as a source of common cause failure can be no more severe than moisture as a source which has been discussed above. Therefore, the probability of failure due to impact is less than 4×10^{-7}, which is significantly less than the common cause human error identified in Section 5.4.

Common links were found in 278 cutsets, identifying those cutsets as common cause candidates. The common links and manufacturer are identified following the groups of common cause candidates with those susceptibilities in Table 14. Since these components are tested regularly during surveillance tests and normal operations, and are maintained regularly, they should have shaken out most manufacturer-related problems. Furthermore, the components are located in different areas of the plant and are therefore subjected to different environments.

5.6 EVENT TREE ANALYSIS

Time sequential behavior, key system dependencies, and reduced system performance states can be modeled using event tree methods. The event tree of Figure 11 lays out such a model for the Midland Plant Auxiliary Feedwater System. Here, the initiating event is an auxiliary feedwater actuation signal. Next, the question of good and "bad" steam generators is addressed. We have defined a bad steam generator to be one with a steam break that has not been isolated. WASH-1400 gives the failure rate as 1×10^{-4} per for pipes. Further containment and steam generator analyses could lead to a revised definition.

Next in the tree come the questions concerning the availability of electric power. Without DC power, the entire system must fail. Without AC power, the turbine-driven pump train may still operate.

The next three events define successful start of the auxiliary feedwater system. Turbine train starts, turbine restarts after turbine trip, and motor train starts. Probabilities of successful starting will be derived from decompositions of the system fault tree. Without success in at least one start path, the system fails on demand. When some electric power is available we must now ask if the FOGG system operates. For cases with a single bad steam generator, FOGG must keep auxiliary feedwater isolated from that steam generator and must permit flow to a good steam generator. Lacking a final FOGG system design, we have assigned a reasonable unavailability of 10^{-4} per demand per train based on high quality actuation systems in WASH-1400. Given that the system has started, we next ask if the failure in the level control system leads to overcooling in either steam generator. Again lacking complete level control system information, we have assigned a probability of failure of 10^{-4} per demand. Finally, given a successful start, we ask if the system continues to run successfully for eight hours.

The event tree in Figure 11 has been simplified by showing repeated similar sequences coded A, B, and C. The full expansion of the complete tree is shown in Figure 12. Seven final system states have been identified on the tree. S stands for complete success. The system starts successfully, does not overcool, and continues to run for eight hours.

TABLE 14. COMMON CAUSE CANDIDATES

Cutset	Basic Events Commonalities				
1.	PPM105AF	PPM105BF		Common Link M4, TK	Manufacturer BG
2.	PXV001AC	PXV001BC		Common Link MB	Manufacturer X8
3.	PXV009AO	PXV009BO		Common Link TK, MB	Manufacturer X7
4.	PPM105AF	PXV009BO		Common Link TK	
5.	PXV009AO	PPM105BF			
6.	PCVU53BD	PCVU53AD		Common Link TI, M2	Manufacturer X1
7.	PXV001AC	PXV009BO		Common Link MB	
8.	PXV009AO	PXV001BC			
9.	PXV037-C	PXV278-C	PXV279-C	Common Link MA	Manufacturer HP
10.	PXV001AC	PXV0017C	PXV0002C	Common Link MB, TK	
11.	PXV001BC	PXV0014C	PXV0004C	Common Link MB, TK	

TABLE 14. COMMON CAUSE CANDIDATES (continued)

Cutset	Basic Events Commonalities		
12.	PXV009AO	PXV0017C	PXV0002C
13.	PXV009BO	PXV0014C	PXV0004C
	Common Link MB, TK		Manufacturer X7
14.	PCV0013D	PCV0015D	PCVU53AD
15.	PCV0001D	PCV0025D	PCVU53BD
	Common Link M2, TI		Manufacturer X1
16.	PREB209F	PRE1111F	PREA109F
17.	PRE1610F	PRE1613F	PRE1111F
	Common Link TV		Manufacturer X2
18.	PMV8931D	PXV279-C	PXV037-C
19.	PMV8932D	PXV279-C	PXV037-C
20.	PXV278-C	PXV8934D	PXV037-C
21.	PMV8931D	PMV8934D	PXV037-C
22.	PMV8932D	PMV8934D	PXV037-C
23.	PXV278-C	PMV8933D	PXV037-C
24.	PMV8931D	PMV8933D	PXV037-C
25.	PMV8932D	PMV8933D	PXV037-C
	Manufacturer HP		
26.	PM03126C	PM075A2A	PM075A1A
27.	PM08934A	PM08931A	PMV3856C
28.	PM08933A	PM08931A	PMV3856C
29.	PM08934A	PM08932A	PMV3856C
30.	PM08933A	PM08932A	PMV3856C
	Manufacturer LI		

TABLE 14. COMMON CAUSE CANDIDATES (continued)

Cutset	Basic Events Commonalities			
31.	PRE1514X	PRE1512X	PRE1111F	
32.	PRE1613F	PRE1512X	PRE1111F	
33.	PRE1514F	PRE1610F	PRE1111F	
	Manufacturer X2			
34.	PXV0017C	PXV0004C	PXV0002C	PXV0014C
	Common Link MB, TK		Manufacturer X7	
35.	PMV865BD	PMV865AD	PMV870BD	PMV870AD
	Common Link M1, TE		Manufacturer AD	
36.	PLV75A2D	PLV75B2D	PLV75A1D	PLV75B1D
	Common Link M3, TJ		Manufacturer CC	
37.	PCV075-D	PCV0013D	PCV075-D	PCV0001D
38.	PCV075-D	PCVU53BD	PCV0001D	PCV076-D
39.	PCV0013D	PCV0015D	PCV0001D	PCV0025D
40.	PCV075-D	PCV0013D	PCV076-D	PCVU53AD
	Common Link M2, TI		Manufacturer X1	
41.	POOCCA2X	POOCCB2X	POOCCA1X	POOCCB1X
	Common Link TM		Manufacturer X3	
42.	PSTCC5BF	PSTCC5AF	PSTCC0BF	PSTCC0AF
	Common Link TS		Manufacturer X3	
43.	PCB17140	PCB16200	PCB16210	PCB17150
44.	PCB16200	PCB16210	PCB17200	PCB17210
	Common Link TU		Manufacturer X3	

TABLE 14. COMMON CAUSE CANDIDATES (continued)

Cutset	Basic Events Commonalities			
45.	PCN1D560	PCN1C120	PCN1C560	PCN1D120
	Common Link TW		Manufacturer X5	
46.	PSTM05BF	PSTM05AF	PSTM00BF	PSTM00AF
	Common Link TI		Manufacturer LI	
47.	PRE1B12F	PRE1A12F	PRE1B11F	PRE1A11F
48.	PREA109F	PREB209F	PREA209F	PREB109F
49.	PRE1A12F	PRE1B11F	PREA209F	PREB109F
50.	PRE1A12F	PRE1B11F	PRE1111F	PREB109F
51.	PRE1B12F	PREA109F	PREB209F	PRE1A11F
52.	PRE1610F	PREA109F	PRE1613F	PREA209F
53.	PRE1B12F	PRE1111F	PREB209F	PRE1A11F
	Common Link TW		Manufacturer X2	
54.	PRE1613F	PREA109F	PRE1512X	PREA209F
55.	PRE1514X	PREA109F	PRE1512X	PREA209F
56.	PRE1514X	PREA109F	PRE1610F	PREA209F
	Common Manufacturer X2			
57.	PCB15260	PSTCC0BF	PSTCC5AF	PSTCC5BF
58.	PSTCC0AF	PCB16260	PSTCC5AF	PSTCC5BF
59.	PCB15260	PCB16260	PSTCC5AF	PSTCC5BF
60.	PSTCS1AC	PCB21030	P00CCB2X	P00CCB1X
61.	PSTCS1AC	PSTCCA2F	P00CCB2X	P00CCB1X
62.	PSTCS1AC	PCB21030	PCB17210	P00CCB1X
63.	PSTCS1AC	PSTCCA2F	PCB17210	P00CCB1X

TABLE 14. COMMON CAUSE CANDIDATES (continued)

Cutset	Basic Events Commonalities			
64.	PSTCS1AC	PCB21030	POOCCB2X	PCB17200
65.	PSTCS1AC	PSTCC[illegible]	POOCCB2X	PCB17200
66.	PSTCS1AC	PCB21030	PCB17210	PCB17200
67.	PSTCS1AC	PSTCCA2F	PCB17210	PCB17200
68.	PSTCS1AC	PCB21030	PSTCS1BC	PCB11020
69.	PSTCS1AC	PSTCCA2F	PSTCS1BC	PCB11020
70.	PSTCS1AC	PCB21030	PSTCS1BC	PSTCCB1F
71.	PSTCS1AC	PSTCCA2F	PSTCS1BC	PSTCCB1F
72.	PSTCS1AC	PCB21030	PCB17150	PCB17140
73.	PSTCS1AC	PSTCCA2F	PCB17150	PCB17140
74.	PSTCS1AC	PCB21030	PCC177BF	PCB17140
75.	PSTCS1AC	PSTCCA2F	PCC177BF	PCB17140
76.	PSTCS1AC	PCB21030	PCB17150	PCC177AF
77.	PSTCS1AC	PSTCCA2F	PCB17150	PCC177AF
78.	PSTCS1AC	PCB21030	PCC177BF	PCC177AF
79.	PSTCS1AC	PSTCCA2F	PCC177BF	PCC177AF
80.	PCB11030	PSTCS1AC	PCB21030	PSTCS1BC
81.	PSTCCB2F	PSTCS1AC	PCB21030	PSTCS1BC
82.	PCB11030	PSTCS1AC	PSTCCA2F	PSTCS1BC
83.	PSTCCB2F	PSTCS1AC	PSTCCA2F	PSTCS1BC
84.	PCB21020	PSTCS1AC	POOCCB2X	POOCCB1X
85.	PSTCCA1F	PSTCS1AC	POOCCB2X	POOCCB1X
86.	PCB21020	PSTCS1AC	PCB17210	POOCCB1X
87.	PSTCCA1F	PSTCS1AC	PCB17210	POOCCB1X
88.	PCB21020	PSTCS1AC	POOCCB2X	PCB17200
89.	PSTCCA1F	PSTCS1AC	POOCCB2X	PCB17200
90.	PCB21020	PSTCS1AC	PCB17210	PCB17200

TABLE 14. COMMON CAUSE CANDIDATES (continued)

Cutset	Basic Events Commonalities			
91.	PSTCCA1F	PSTCS1AC	PCB17210	PCB17200
92.	PCB21020	PSTCS1AC	PSTCS1BC	PCB11020
93.	PSTCCA1F	PSTCS1AC	PSTCS1BC	PCB11020
94.	PCB21020	PSTCS1AC	PSTCS1BC	PSTCCB1F
95.	PSTCCA1F	PSTCS1AC	PSTCS1BC	PSTCCB1F
96.	PCB21020	PSTCS1AC	PCB17150	PCB17140
97.	PSTCCA1F	PSTCS1AC	PCB17150	PCB17140
98.	PCB21020	PSTCS1AC	PCC177BF	PCB17140
99.	PSTCCA1F	PSTCS1AC	PCC177BF	PCB17140
100.	PCB21020	PSTCS1AC	PCB17150	PCC177AF
101.	PSTCCA1F	PSTCS1AC	PCB17150	PCC177AF
102.	PCB21020	PSTCS1AC	PCC177BF	PCC177AF
103.	PSTCCA1F	PSTCS1AC	PCC177BF	PCC177AF
104.	PCB11030	PCB21020	PSTCS1AC	PSTCS1BC
105.	PSTCCB2F	PCB21020	PSTCS1AC	PSTCS1BC
106.	PCB11030	PSTCCA1F	PSTCS1AC	PSTCS1BC
107.	PSTCCB2F	PSTCCA1F	PSTCS1AC	PSTCS1BC
108.	PSTCC0AF	POOCCA1X	POOCCB2X	PSTCC5BF
109.	PCB15260	POOCCA1X	POOCCB2X	PSTCC5BF
110.	PSTCC0AF	PCB16200	POOCCB2X	PSTCC5BF
111.	PCB15260	PCB16200	POOCCB2X	PSTCC5BF
112.	PSTCC0AF	POOCCA1X	PBC17210	PSTCC5BF
113.	PCB15260	POOCCA1X	PCB17210	PSTCC5BF
114.	PSTCC0AF	PCB16200	PCB17210	PSTCC5BF
115.	PCB15260	PCB16200	PCB17210	PSTCC5BF
116.	PCB16200	POOCCB2X	POOCCA2X	POOCCB1X
117.	POOCCA1X	PCB17210	POOCCA2X	POOCCB1X
118.	PCB16200	PCB17210	POOCCA2X	POOCCB1X

TABLE 14. COMMON CAUSE CANDIDATES (continued)

Cutset	Basic Events Commonalities			
119.	POOCCA1X	POOCCB2X	PCB16210	POOCCB1X
120.	PCB16200	POOCCB2X	PCB16210	POOCCB1X
121.	POOCCA1X	PCB17210	PCB16210	POOCCB1X
122.	PCB16200	PCB17210	PCB16210	POOCCB1X
123.	POOCCA1X	POOCCB2X	POOCCA2X	PCB17200
124.	PCB16200	POOCCB2X	POOCCA2X	PCB17200
125.	POOCCA1X	PCB17210	POOCCA2X	PCB17200
126.	PCB16200	PCB17210	POOCCA2X	PCB17200
127.	POOCCA1X	POOCCB2X	PCB16210	PCB17200
128.	PCB16200	POOCCB2X	PCB16210	PCB17200
129.	POOCCA1X	PCB17210	PCB16210	PCB17200
130.	POOCCA1X	PSTCS1BC	PCB11020	POOCCA2X
131.	PCB16200	PSTCS1BC	PCB11020	POOCCA2X
132.	POOCCA1X	PSTCS1BC	PSTCCB1F	POOCCA2X
133.	PCB16200	PSTCS1BC	PSTCCB1F	POOCCA2X
134.	POOCCA1X	PSTCS1BC	PCB11020	PCB16210
135.	PCB16200	PSTCS1BC	PCB11020	PCB16210
136.	POOCCA1X	PSTCS1BC	PSTCCB1F	PCB16210
137.	PCB16200	PSTCS1BC	PSTCCB1F	PCB16210
138.	POOCCA1X	PCB17150	PCB17140	POOCCA2X
139.	PCB16200	PCB17150	PCB17140	POOCCA2X
140.	POOCCA1X	PCC177BF	PCB17140	POOCCA2X
141.	PCB16200	PCC177BF	PCB17140	POOCCA2X
142.	POOCCA1X	PCB17150	PCC177AF	POOCCA2X
143.	PCB16200	PCB17150	PCC177AF	POOCCA2X
144.	POOCCA1X	PCC177BF	PCC177AF	POOCCA2X
145.	PCB16200	PCC177BF	PCC177AF	POOCCA2X
146.	POOCCA1X	PCB17150	PCB17140	PCB16210

TABLE 14. COMMON CAUSE CANDIDATES (continued)

Cutset	Basic Events Commonalities				
147.	POOCCA1X	PCC177BF	PCB17140	PCB16210	
148.	PCB16200	PCC177BF	PCB17140	PCB16210	
149.	POOCCA1X	PCB17150	PCC177AF	PCB16210	
150.	PCB16200	PCB17150	PCC177AF	PCB16210	
151.	POOCCA1X	PCC177BF	PCC177AF	PCB16210	
152.	PCB16200	PCC177BF	PCC177AF	PCB16210	
153.	PCB11030	POOCCA1X	PSTCS1BC	POOCCA2X	
154.	PSTCCB2F	POOCCA1X	PSTCS1BC	POOCCA2X	
155.	PCB11030	PCB16200	PSTCS1BC	POOCCA2X	
156.	PSTCCB2F	PCB16200	PSTCS1BC	POOCCA2X	
157.	PCB11030	POOCCA1X	PSTCS1BC	PCB16210	
158.	PSTCCB2F	POOCCA1X	PSTCS1BC	PCB16210	
159.	PCB11030	PCB16200	PSTCS1BC	PCB16210	
160.	PSTCCB2F	PCB16200	PSTCS1BC	PCB16210	
161.	PSTCC0BF	PSTCC5AF	POOCCA2X	POOCCB1X	
162.	PCB16260	PSTCC5AF	POOCCA2X	POOCCB1X	
163.	PSTCC0BF	PSTCC5AF	PCB16210	PCOCCB1X	
164.	PCB16260	PSTCC5AF	PCB16210	POOCCB1X	
165.	PSTCC0BF	PSTCC5AF	POOCCA2X	PCB17200	
166.	PCB16260	PSTCC5AF	POOCCA2X	PCB17200	
167.	PSTCC0BF	PSTCC5AF	PCB16210	PCB17200	
168.	PCB16260	PSTCC5AF	PCB16210	PCB17200	
		Common Manufacturer X2			
169.	PRE1B12F	PRE1610F	PREA109F	PRE1613F	PRE1A11F
170.	PRE1A12F	PRE1B11F	PREA209F	PRE1610F	PRE1613F
		Common Link TV		Manufacturer X2	

TABLE 14. COMMON CAUSE CANDIDATES (continued)

Cutset	Basic Events Commonalities				
171.	PRE1B12F	PRE1514X	PREA109F	PRE1512X	PRE1A11F
172.	PRE1B12F	PRE1613F	PREA109F	PRE1512X	PRE1A11F
173.	PRE1B12F	PRE1514X	PREA109F	PRE1610F	PRE1A11F
174.	PRE1A12F	PRE1B11F	PREA209F	PRE1514X	PRE1512X
175.	PRE1A12F	PRE1B11F	PREA209F	PRE1613F	PRE1512X
176.	PRE1A12F	PRE1B11F	PREA209F	PRE1514X	PRE1610F
		Common Manufacturer X2			
177.	PSTCC0AF	PCB11030	P00CCA1X	PSTCS1BC	PSTCC5BF
178.	PCB15260	PCB11030	P00CCA1X	PSTCS1BC	PSTCC5BF
179.	PSTCC0AF	PSTCCB2F	P00CCA1X	PSTCS1BC	PSTCC5BF
180.	PCB15260	PSTCCB2F	P00CCA1X	PSTCS1BC	PSTCC5BF
181.	PSTCC0AF	PCB11030	PCB16200	PSTCS1BC	PSTCC5BF
182.	PCB15260	PCB11030	PCB16200	PSTCS1BC	PSTCC5BF
183.	PSTCC0AF	PSTCCB2F	PCB16200	PSTCS1BC	PSTCC5BF
184.	PCB15260	PSTCCB2F	PCB16200	PSTCS1BC	PSTCC5BF
185.	PSTCC0AF	PSTCS1AC	PCB21030	P00CCB2X	PSTCC5BF
186.	PCB15260	PSTCS1AC	PCB21030	P00CCB2X	PSTCC5BF
187.	PSTCC0AF	PSTCS1AC	PSTCCA2F	P00CCB2X	PSTCC5BF
188.	PCB15260	PSTCS1AC	PSTCCA2F	P00CCB2X	PSTCC5BF
189.	PSTCC0AF	PSTCS1AC	PCB21030	PCB17210	PSTCC5BF
190	PCB15260	PSTCS1AC	PCB21030	PCB17210	PSTCC5BF
191	PSTCC0AF	PSTCS1AC	PSTCCA2F	PCB17210	PSTCC5BF
192.	PCB15260	PSTCS1AC	PSTCCA2F	PCB17210	PSTCC5BF
193.	PSTCC0AF	PCB21020	PSTCS1AC	P00CCB2X	PSTCC5BF
194.	PCB15260	PCB21020	PSTCS1AC	P00CCB2X	PSTCC5BF
195.	PSTCC0AF	PSTCCA1F	PSTCS1AC	P00CCB2X	PSTCC5BF
196.	PCB15260	PSTCCA1F	PSTCS1AC	P00CCB2X	PSTCC5BF
197.	PSTCC0AF	PCB21020	PSTCS1AC	PCB17210	PSTCC5BF
198.	PCB15260	PCB21020	PSTCS1AC	PCB17210	PSTCC5BF

TABLE 14. COMMON CAUSE CANDIDATES (continued)

Cutset	Basic Events Commonalities				
199.	PSTCC0AF	PSTCCA1F	PSTCS1AC	PCB17210	PSTCC5BF
200.	PCB15260	PSTCCA1F	PSTCS1AC	PCB17210	PSTCC5BF
201.	PSTCC0AF	POOCCA1X	PCB17150	PCB17140	PSTCC5BF
202.	PCB15260	POOCCA1X	PCB17150	PCB17140	PSTCC5BF
203.	PSTCC0AF	PCB16200	PCB17150	PCB17140	PSTCC5BF
204.	PCB15260	PCB16200	PCB17150	PCB17140	PSTCC5BF
205.	PSTCC0AF	POOCCA1X	PCC177BF	PCB17140	PSTCC5BF
206.	PCB15260	POOCCA1X	PCC177BF	PCB17140	PSTCC5BF
207.	PSTCC0AF	PCB16200	PCC177BF	PCB17140	PSTCC5BF
208.	PCB15260	PCB16200	PCC177BF	PCB17140	PSTCC5BF
209.	PSTCC0AF	POOCCA1X	PCB17150	PCC177AF	PSTCC5BF
210.	PCB15260	POOCCA1X	PCB17150	PCC177AF	PSTCC5BF
211.	PSTCC0AF	PCB16200	PCB17150	PCC177AF	PSTCC5BF
212.	PCB15260	PCB16200	PCB17150	PCC177AF	PSTCC5BF
213.	PSTCC0AF	POOCCA1X	PCC177BF	PCC177AF	PSTCC5BF
214.	PCB15260	POOCCA1X	PCC177BF	PCC177AF	PSTCC5BF
215.	PSTCC0AF	PCB16200	PCC177BF	PCC177AF	PSTCC5BF
216.	PCB15260	PCB16200	PCC177BF	PCC177AF	PSTCC5BF
217.	PSTCC0AF	POOCCA1X	PSTCS1BC	PCB11020	PSTCC5BF
218.	PCB15260	POOCCA1X	PSTCS1BC	PCB11020	PSTCC5BF
219.	PSTCC0AF	PCB16200	PSTCS1BC	PCB11020	PSTCC5BF
220.	PCB15260	PCB16200	PSTCS1BC	PCB11020	PSTCC5BF
221.	PSTCC0AF	POOCCA1X	PSTCS1BC	PSTCCB1F	PSTCC5BF
222.	PCB15260	POOCCA1X	PSTCS1BC	PSTCCB1F	PSTCC5BF
223.	PSTCC0AF	PCB16200	PSTCS1BC	PSTCCB1F	PSTCC5BF
224.	PCB15260	PCB16200	PSTCS1BC	PSTCCB1F	PSTCC5BF
225.	PSTCC0BF	PSTCC5AF	POOCCA2X	PCB11030	PSTCS1BC
226.	PCB16260	PSTCC5AF	POOCCA2X	PCB11030	PSTCS1BC

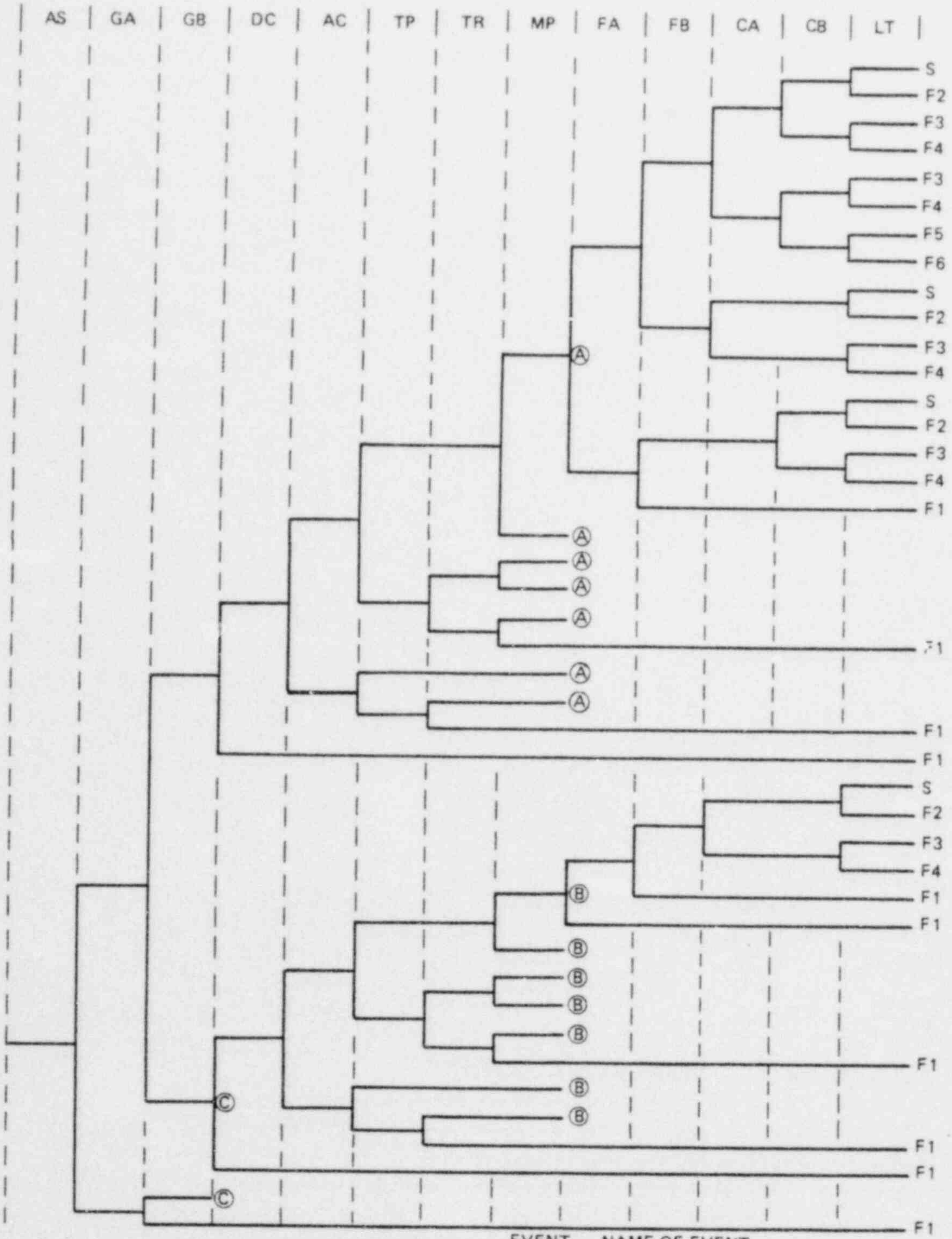
TABLE 14. COMMON CAUSE CANDIDATES (continued)

Cutset	Basic Events Commonalities				
227.	PSTCC0BF	PSTCC5AF	PCB16210	PCB11030	PSTCS1BC
228.	PCB16260	PSTCC5AF	PCB16210	PCB11030	PSTCS1BC
229.	PSTCC0BF	PSTCC5AF	P00CCA2X	PSTCCB2F	PSTCS1BC
230.	PCB16260	PSTCC5AF	P00CCA2X	PSTCCB2F	PSTCS1BD
231.	PSTCC0BF	PSTCC5AF	PCB16210	PSTCCB2F	PSTCS1BC
232.	PCB16260	PSTCC5AF	PCB16210	PSTCCB2F	PSTCS1BC
233.	PSTCC0BF	PSTCC5AF	P00CCB1X	PCB21020	PSTCS1AC
234.	PCB16260	PSTCC5AF	P00CCB1X	PCB21020	PSTCS1AC
235.	PSTCC0BF	PSTCC5AF	PCB17200	PCB21020	PSTCS1AC
236.	PCB16260	PSTCC5AF	PCB17200	PCB21020	PSTCS1AC
237.	PSTCC0BF	PSTCC5AF	P00CCB1X	PSTCCA1F	PSTCS1AC
238.	PCB16260	PSTCC5AF	P00CCB1X	PSTCCA1F	PSTCS1AC
239.	PSTCC0BF	PSTCC5AF	PCB17200	PSTCCA1F	PSTCS1AC
240.	PCB16260	PSTCC5AF	PCB17200	PSTCCA1F	PSTCS1AC
241.	PSTCC0BF	PSTCC5AF	P00CCB1X	PSTCS1AC	PCB21030
242.	PCB16260	PSTCC5AF	P00CCB1X	PSTCS1AC	PCB21030
243.	PSTCC0BF	PSTCC5AF	PCB17200	PSTCS1AC	PCB21030
244.	PCB16260	PSTCC5AF	PCB17200	PSTCS1AC	PCB21030
245.	PSTCC0BF	PSTCC5AF	P00CCB1X	PSTCS1AC	PSTCCA2F
246.	PCB16260	PSTCC5AF	P00CCB1X	PSTCS1AC	PSTCCA2F
247.	PSTCC0BF	PSTCC5AF	PCB17200	PSTCS1AC	PSTCCA2F
248.	PCB16260	PSTCC5AF	PCB17200	PSTCS1AC	PSTCCA2F
249.	PSTCC0BF	PSTCC5AF	P00CCA2X	PCB17150	PCB17140
250.	PCB16260	PSTCC5AF	P00CCA2X	PCB17150	PCB17140
251.	PSTCC0BF	PSTCC5AF	PCB16210	PCB17150	PCB17140
252.	PCB16260	PSTCC5AF	PCB16210	PCB17150	PCB17140
253.	PSTCC0BF	PSTCC5AF	P00CCA2X	PCC177BF	PCB17140
254.	PCB16260	PSTCC5AF	P00CCA2X	PCC177BF	PCB17140

TABLE 14. COMMON CAUSE CANDIDATES (continued)

Cutset	Basic Events Commonalities				
255.	PSTCC0BF	PSTCC5AF	PCB16210	PCC177BF	PCB17140
256.	PCB16260	PSTCC5AF	PCB16210	PCC177BF	PCB17140
257.	PSTCC0BF	PSTCC5AF	POOCCA2X	PCB17150	PCC177AF
258.	PCB16260	PSTCC5AF	POOCCA2X	PCB17150	PCC177AF
259.	PSTCC0BF	PSTCC5AF	PCB16210	PCB17150	PCC177AF
260.	PCB16260	PSTCC5AF	PCB16210	PCB17150	PCC177AF
261.	PSTCC0BF	PSTCC5AF	POOCCA2X	PCC177BF	PCC177AF
262.	PCB16260	PSTCC5AF	POOCCA2X	PCC177BF	PCC177AF
263.	PSTCC0BF	PSTCC5AF	PCB16210	PCC177BF	PCC177AF
264.	PCB16260	PSTCC5AF	PCB16210	PCC177BF	PCC177AF
265.	PSTCC0BF	PSTCC5AF	POOCCA2X	PSTCS1BC	PCB11020
266.	PCB16260	PSTCC5AF	POOCCA2X	PSTCS1BC	PCB11020
267.	PSTCC0BF	PSTCC5AF	PCB16210	PSTCS1BC	PCB11020
268.	PCB16260	PSTCC5AF	PCB16210	PSTCS1BC	PCB11020
269.	PSTCC0BF	PSTCC5AF	POOCCA2X	PSTCS1BC	PSTCCB1F
270.	PCB16260	PSTCC5AF	POOCCA2X	PSTCS1BC	PSTCCB1F
271.	PSTCC0BF	PSTCC5AF	PCB16210	PSTCS1BC	PSTCCB1F
272.	PCB16260	PSTCC5AF	PCB16210	PSTCS1BC	PSTCCB1F

Common Manufacturer X3



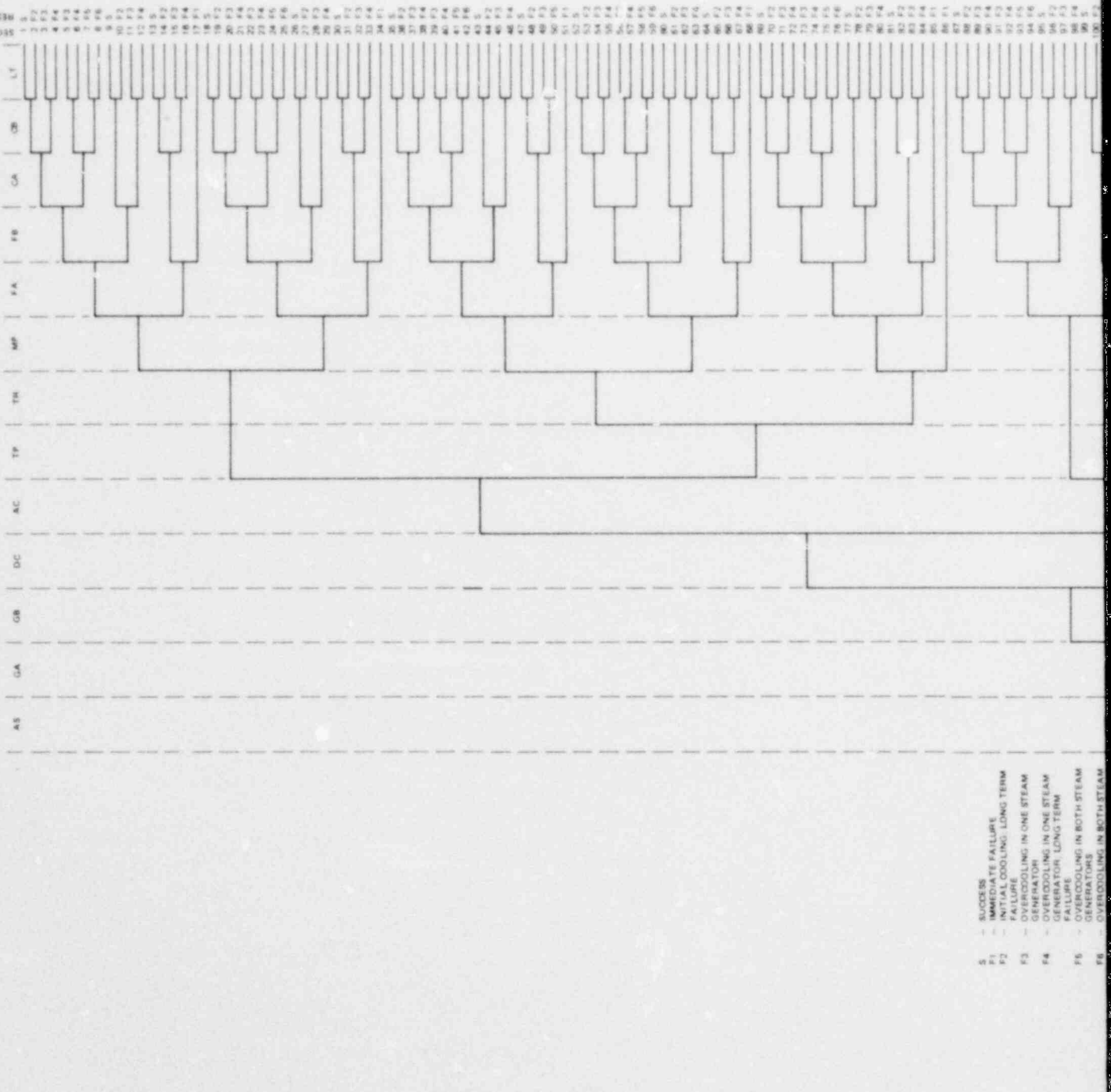
S – SUCCESS
F1 – IMMEDIATE FAILURE
F2 – INITIAL COOLING; LONG TERM FAILURE
F3 – OVERCOOLING IN ONE STEAM GENERATOR
F4 – OVERCOOLING IN ONE STEAM GENERATOR; LONG TERM FAILURE
F5 – OVERCOOLING IN BOTH STEAM GENERATORS
F6 – OVERCOOLING IN BOTH STEAM GENERATORS; LONG TERM FAILURE

EVENT	NAME OF EVENT
AS	AFW ACTUATION SIGNAL
GA	OTSG-A NO UNISOLABLE STEAM BREAK
GB	OTSG-B NO UNISOLABLE STEAM BREAK
DC	DC POWER
AC	AC POWER
TP	TURBINE TRAIN
TR	TURBINE RESTART
MP	MOTOR TRAIN
FA	FOGG SIGNAL OTSG-A
FB	FOGG SIGNAL OTSG-B
CA	NO OVERCOOLING OTSG A
CB	NO OVERCOOLING OTSG B
LT	LONG TERM COOLING

FIGURE 11. ABBREVIATED VERSION OF MIDLAND AUXILIARY FEEDWATER EVENT TREE GIVEN AN ACTUATION SIGNAL

F1 is immediate failure; the system does not start on demand. F2 is initial cooling; the system starts successfully but long-term failure and no overcooling. F3 is overcooling in one steam generator; the system starts and continues to run successfully but level control malfunction leads to overcooling in one steam generator. F4 is early overcooling in one steam generator; the system starts successfully but fails to run for eight hours and level control malfunction leads to overcooling in one steam generator. F5 is over cooling in both steam generators; the system starts successfully and continues to run for eight hours but overcools both steam generators, and F6 is overcooling in both steam generators and failure to run for eight hours; the system successfully starts but fails to run for eight hours and level control malfunctions lead to overcooling in both steam generators.

POOR ORIGINAL



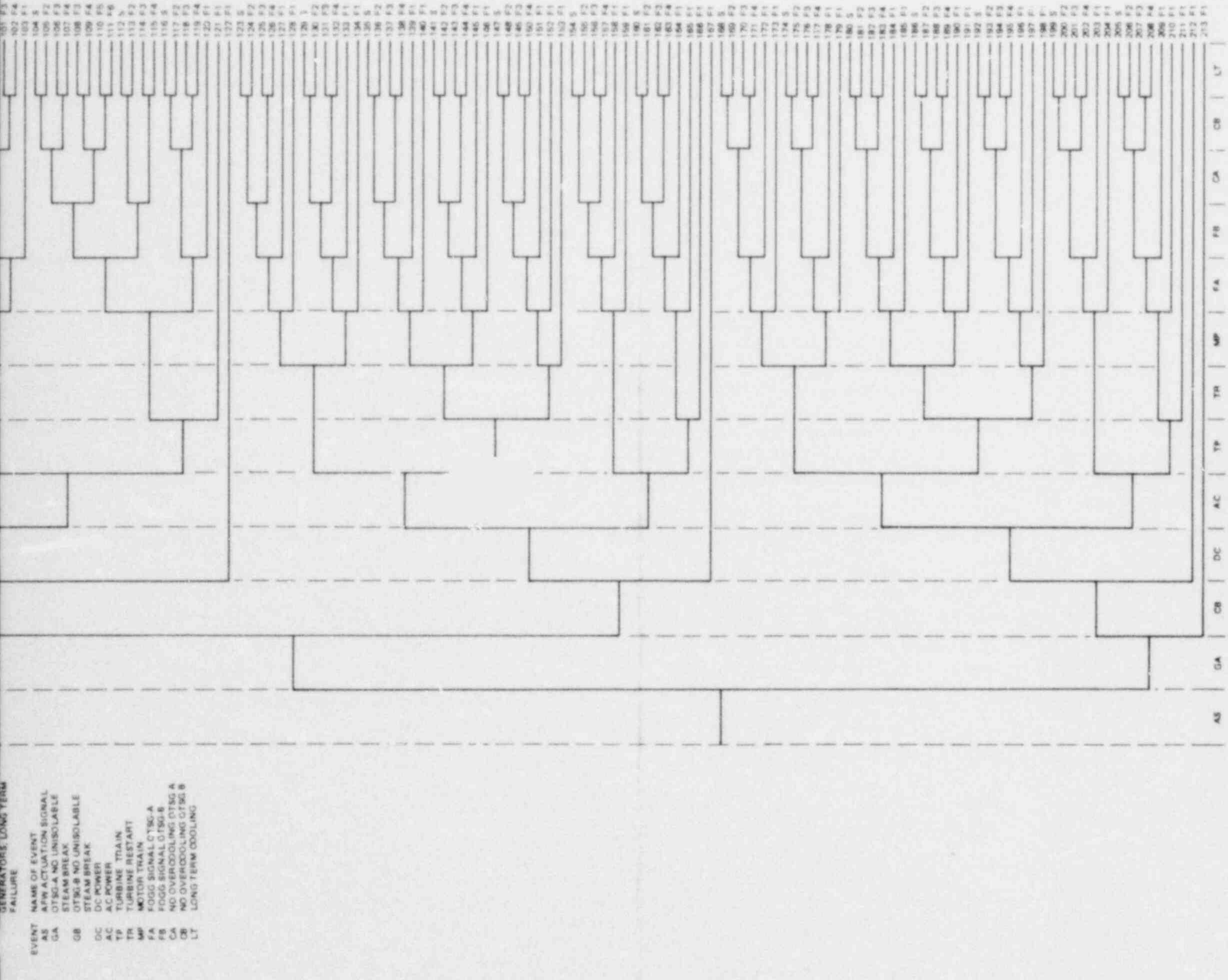


FIGURE 12. MIDLAND AUXILIARY FEEDWATER EVENT TREE GIVEN AN ACTUATION SIGNAL

6. RESULTS

The results presented in this section show that in the emergency mode the Midland Plant Auxiliary Feedwater System is very reliable. Redundancy, separation, and availability during testing are applied in combinations that make the system quite sound. The results presented here follow from the detailed fault trees given in Appendixes A, B, and C, the data given in Appendix D, and the analysis described in Section 5. They are based on failure of the auxiliary feedwater system to deliver sufficient flow immediately upon demand to at least one SG; therefore, human intervention to recover from some system failures is not considered. If further analyses of the B&W nuclear plant demonstrate that a time window exists during which actuation of the auxiliary feedwater system can provide adequate core cooling, then the effects of operator intervention to restore system function should improve the system reliability. Such considerations will require reviewing emergency procedures to determine the likelihood of successful operator action.

6.1 RESULTS OF SYSTEM ANALYSIS

The results for all three initiating event cases from NUREG-0611 are given in Tables 15, 16, and 17. In Table 15, the point values based on NUREG-0611 data are tabulated along with means and variances based on plant-specific data for the double crossover design. The distributions obtained by propagating discrete probability distributions for the three alternative designs - loss of main feedwater case are shown in Figure 13 to help picture the uncertainty bands and distribution shapes. Similar shapes apply to the other cases. In Table 16, means and variances based on plant-specific data are provided for the double crossover and the base case designs. In Table 17, means and variances based on plant-specific data are provided for the double crossover and the three pump designs.

Test and maintenance in combination with random system failures are the dominant contributors to unavailability. They are followed by random failures alone, human error, and common human error in importance. For the three pump design and in all cases given a loss of all AC power, random independent failures are the dominant contributors. The dominant random independent failure contributions are associated with the pumps: either the pumps themselves, their prime movers--motors or turbines, and the power supply to the motor-driven pumps. Dominant human errors are associated with failure of the operator to close the full flow recirculation test valve either during a test when the system is demanded to function, or following a test in which the valve is left in the wrong position. Tables 18 through 29 describe the dominant contributions to conditional unavailability for each of the four situations described in Tables 15, 16, and 17.

The dominant contributors for the double crossover design system using NRC data are given in Tables 18, 19, and 20 for the three cases of NUREG-0611. In each case, maintenance on the turbine-driven auxiliary feedwater pump combined with random failures in the motor pump train is

TABLE 15. SUMMARY OF RESULTS
CONDITIONAL* UNAVAILABILITIES** OF THE MIDLAND AFWS

Contributors to Unavailability	Loss of Main Feedwater		Loss of Main Feedwater Due to Loss of Offsite Power		Loss of Main Feedwater and Loss of All AC Power	
	Double Crossover (Plant Specific Data)	Double Crossover (NRC Data)	Double Crossover (Plant Specific Data)	Double Crossover (NRC Data)	Double Crossover (Plant Specific Data)	Double Crossover (NRC Data)
Random failures	7.0 E-5[+] (1.1 E-8)	3.5 E-5	6.6 E-4 (8.4 E-6)	2.5 E-4	1.7 E-2 (5.3 E-4)	6.4 E-3
Test and maintenance and random system failures	1.2 E-4 (3.9 E-8)	6.9 E-5	3.4 E-4 (6.5 E-7)	2.8 E-4	5.9 E-3 (1.9 E-4)	5.9 E-3
Human error (test--failure to close full flow test valve)	6.3 E-6 (1.1 E-10)	3.7 E-6	1.8 E-5 (2.0 E-9)	1.5 E-5	3.1 E-4 (5.3 E-7)	3.1 E-4
Common cause (full flow test valve open after test)	8.4 E-6 (5.9 E-10)	8.4 E-6	8.4 E-6 (5.9 E-10)	8.4 E-6	8.4 E-6 (5.9 E-10)	8.4 E-6
Other	ε	ε	ε	ε	ε	ε
System Total						
Mean	2.0 E-4		1.0 E-3		2.3 E-2	
Variance	4.7 E-8		6.0 E-6		6.7 E-4	
5th	3.4 E-5		4.1 E-5		3.5 E-3	
95th	5.8 E-4		3.8 E-3		6.8 E-2	
Median	1.4 E-4	1.2 E-4	4.0 E-4	5.5 E-4	1.6 E-2	1.3 E-2

*The total unavailabilities as well as the individual contributions given in this table are not actual system unavailabilities but are system characteristics conditional on specific states of electric power as follows:

LMFW: Offsite AC power is continuously available.
LMFW/LOOP: Offsite AC power is unavailable--diesel generators may or may not accept load.
LMFW/Loss of All AC: All AC power is unavailable; DC power is available.

**Unavailability is the fraction of times the system will not perform its function when required.

[+] 7.0 E-5 read 7.0 × 10^{-5}.

( ) Variance - describes the spread of the results about the mean.

TABLE 16. SUMMARY OF RESULTS CONDITIONAL* UNAVAILABILITIES** OF THE MIDLAND AFWS (Plant Specific Data)

Contributors to Unavailability	Loss of Main Feedwater		Loss of Main Feedwater Due to Loss of Offsite Power		Loss of Main Feedwater and Loss of All AC Power	
	Double Crossover	Base Case	Double Crossover	Base Case	Double Crossover	Base Case
Random failures	7.0 E-5⁺ (1.1 E-8)	7.3 E-5 (1.9 E-8)	6.6 E-4 (8.4 E-6)	6.6 E-4 (3.3 E-6)	1.7 E-2 (5.3 E-4)	1.6 E-2 (7.5 E-3)
Test and maintenance and random system failures	1.2 E-4 (3.9 E-8)	1.2 E-4 (1.2 E-7)	3.4 E-4 (6.5 E-7)	3.4 E-4 (3.2 E-7)	5.9 E-3 (1.9 E-4)	5.9 E-3 (1.9 E-4)
Human error (test--failure to close full flow test valve)	6.3 E-6 (1.1 E-10)	6.4 E-6 (3.4 E-10)	1.8 E-5 (2.0 E-9)	1.8 E-5 (9.2 E-10)	3.1 E-4 (5.3 E-7)	3.1 E-4 (5.3 E-6)
Common cause (full flow test valve open after test)	8.4 E-6 (5.9 E-10)	8.4 E-6 (5.9 E-10)	8.4 E-6 (5.9 E-10)	8.4 E-6 (5.9 E-10)	8.4 E-6 (5.9 E-10)	8.4 E-6 (5.9 E-10)
Other	ε	ε	ε	ε	ε	ε
System Total						
Mean	2.0 E-4	2.1 E-4	1.0 E-3	1.0 E-3	2.3 E-2	2.2 E-2
Variance	4.7 E-8	1.1 E-7	6.0 E-6	2.9 E-6	6.7 E-4	8.8 E-4
5th	3.4 E-5	1.7 E-5	4.1 E-5	7.9 E-5	3.5 E-3	2.5 E-3
95th	5.8 E-4	7.0 E-4	3.8 E-3	3.5 E-3	6.8 E-2	7.0 E-2
Median	1.4 E-4	1.1 E-4	4.0 E-4	5.3 E-4	1.6 E-2	1.3 E-2

*The total unavailabilities as well as the individual contributions given in this table are not actual system unavailabilities but are system characteristics conditional on specific states of electric power as follows:

LMFW: Offsite AC power is continuously available.
LMFW/LOOP: Offsite AC power is unavailable--diesel generators may or may not accept load.
LMFW/Loss of All AC: All AC power is unavailable; DC power is available.

**Unavailability is the fraction of times the system will not perform its function when required.

⁺7.0 E-5 read 7.0 x 10^{-5}.

( ) Variance - describes the spread of the results about the mean.

TABLE 17. SUMMARY OF RESULTS
CONDITIONAL* UNAVAILABILITIES** OF THE MIDLAND AFWS
(Plant Specific Data)

Contributors to Unavailability	Loss of Main Feedwater		Loss of Main Feedwater Due to Loss of Offsite Power		Loss of Main Feedwater and Loss of All AC Power	
	Double Crossover	Three Pump	Double Crossover	Three Pump	Double Crossover	Three Pump
Random failures	7.0 E-5[+] (1.1 E-8)	8.1 E-4 (1.4 E-6)	6.6 E-4 (8.4 E-6)	2.0 E-3 (1.1 E-5)	1.7 E-2 (5.3 E-4)	1.7 E-2 (3.6 E-5)
Test and maintenance and random system failures	1.2 E-4 (3.9 E-8)	4.9 E-4 (1.0 E-7)	3.4 E-4 (6.5 E-7)	9.2 E-4 (2.9 E-6)	5.9 E-3 (1.9 E-4)	5.9 E-3 (1.9 E-4)
Human error (test--failure to close full flow test valve)	6.3 E-6 (1.1 E-10)	2.6 E-5 (2.0 E-9)	1.8 E-5 (2.0 E-9)	4.9 E-5 (8.8 E-9)	3.1 E-4 (5.3 E-7)	3.1 E-4 (5.3 E-7)
Common cause (full flow test valve open after test)	8.4 E-6 (5.9 E-10)	8.4 E-6 (5.9 E-10)	8.4 E-6 (5.9 E-10)	8.4 E-6 (5.9 E-10)	8.4 E-6 (5.9 E-10)	8.4 E-6 (5.9 E-10)
Other	ε	ε	ε	ε	ε	ε
System Total						
Mean	2.0 E-4	1.3 E-3	1.0 E-3	3.0 E-3	2.3 E-2	2.3 E-2
Variance	4.7 E-8	2.0 E-6	6.0 E-6	1.3 E-5	6.7 E-4	2.0 E-4
5th	3.4 E-5	2.2 E-4	4.1 E-5	4.0 E-4	3.5 E-3	8.0 E-3
95th	5.8 E-4	3.8 E-3	3.8 E-3	9.0 e-3	6.8 E-2	5.0 E-2
Median	1.4 E-4	9.2 E-4	4.0 E-4	1.9 E-3	1.6 E-2	2.0 E-2

*The total unavailabilities as well as the individual contributions given in this table are not actual system unavailabilities but are system characteristics conditional on specific states of electric power as follows:

LMFW: Offsite AC power is continuously available.
LMFW/LOOP: Offsite AC power is unavailable--diesel generators may or may not accept load.
LMFW/Loss of All AC: All AC power is unavailable; DC power is available.

**Unavailability is the fraction of times the system will not perform its function when required.

[+] 7.0 E-5 read 7.0×10^{-5}.

( ) Variance - describes the spread of the results about the mean.

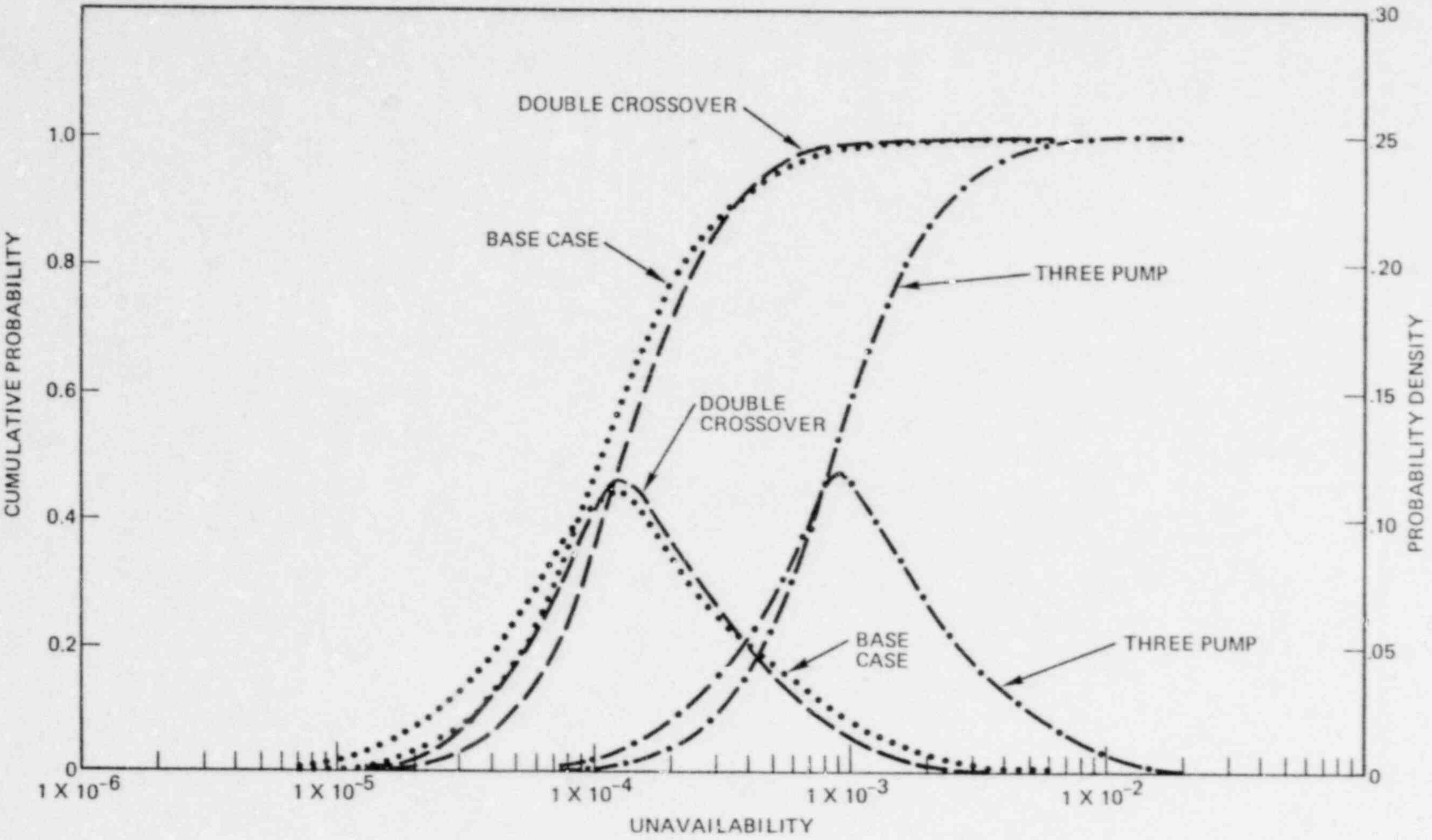


FIGURE 13. CONDITIONAL UNAVAILABILITY OF THE MIDLAND PLANT AFWS - THREE ALTERNATIVE DESIGNS, PLANT-SPECIFIC DATA - LOSS OF MAIN FEEDWATER

TABLE 18. DOMINANT CONTRIBUTORS TO CONDITIONAL UNAVAILABILITY

LOSS OF MAIN FEEDWATER

Double Crossover (NRC Data)

Rank	Event Description	Unavailability
1	Maintenance of turbine-driven AFWP an system failure on demand without this pump.	3.5×10^{-5}
2	Maintenance of motor-driven AFWP and system failure on demand without this pump.	3.4×10^{-5}
3	Turbine or turbine controls fail and P05A motor fails to start.	1.6×10^{-5}
4	Common cause--human error--full flow test valves open after test.	8.4×10^{-6}
5	Turbine or turbine controls fail and P05A fails to deliver sufficient water.	4.0×10^{-6}
6	P05B fails to deliver sufficient water and P05A motor fails to start.	4.0×10^{-6}
7	P05B test valve is open and P05A motor fails to start.	2.0×10^{-6}
8	Turbine or turbine controls fail and P05B test valve is open.	2.0×10^{-6}
9	P05B in test (operator error) and system failure on demand without this pump.	1.9×10^{-6}
10	P05A in test (operator error) and system failure on demand without this pump.	1.8×10^{-6}

TABLE 19. DOMINANT CONTRIBUTORS TO CONDITIONAL UNAVAILABILITY

LOSS OF MAIN FEEDWATER DUE TO LOSS OF OFFSITE POWER

Double Crossover (NRC Data)

Rank	Event Description	Unavailability
1	Maintenance of turbine-driven AFWP and system failure on demand without this pump.	2.5×10^{-4}
2	Turbine or turbine controls fail and 4,160V bus 1A05 fails to supply power.	1.5×10^{-4}
3	P05B fails to deliver sufficient water and 4,160V bus 1A05 fails to supply power.	3.7×10^{-5}
4	Maintenance of motor-driven AFWP and system failure on demand without this pump.	3.4×10^{-5}
5	P05B test valve open and 4,160V bus 1A05 fails to supply power.	1.8×10^{-5}
6	Turbine or turbine controls fail and P05A motor fails to start.	1.6×10^{-5}
7	P05B in test (operator error) and system failure on demand without this pump.	1.3×10^{-5}
8	Common cause--human error--full flow test valves open after test.	8.4×10^{-6}
9	Turbine or turbine controls fail and P05A fails to deliver sufficient water.	4.0×10^{-6}
10	P05B fails to supply sufficient water and P05A motor fails to start.	4.0×10^{-6}
11	P05A in test (operator error) and system failure on demand without this pump.	1.8×10^{-6}

TABLE 20. DOMINANT CONTRIBUTORS TO CONDITIONAL UNAVAILABILITY

LOSS OF ALL AC

Double Crossover (NRC Data)

Rank	Event Description	Unavailability
1	Maintenance of turbine-driven AFWP.	5.9×10^{-3}
2	Turbine or turbine controls fail.	4.0×10^{-3}
3	P05B fails to deliver sufficient water.	1.0×10^{-3}
4	P05B in test (operator error).	3.1×10^{-4}
5	P05B test valve open.	1.0×10^{-4}
6	P05B suction valve transfers closed.	1.0×10^{-4}
7	Valve MO3126 transfers closed.	1.0×10^{-4}
8	Suction header cross-connect valve MO868B transfers closed.	1.0×10^{-4}
9	Valve MO3856 transfers closed.	1.0×10^{-4}
10	CST isolation valve 037 transfers closed.	1.0×10^{-4}
11	CST outlet check valve 024 fails closed.	1.0×10^{-4}
12	Common cause--human error--full flow test valves open after test.	8.4×10^{-6}

TABLE 21. DOMINANT CONTRIBUTORS TO CONDITIONAL UNAVAILABILITY

LOSS OF MAIN FEEDWATER

Double Crossover (Plant-Specific Data)

Rank	Event Description	Unavailability
1	Maintenance of motor-driven AFWP and system failure on demand without this pump.	9.3×10^{-5}
2	Turbine or turbine controls fail and P05A fails to deliver sufficient water.	3.3×10^{-5}
3	Maintenance of turbine-driven AFWP and system failure on demand without this pump.	2.6×10^{-5}
4	P05B fails to deliver sufficient water and fails to deliver sufficient water.	1.5×10^{-5}
5	Common cause--human error--full flow test valves open after test.	8.4×10^{-6}
6	Turbine or turbine controls fail and P05A motor fails to start.	5.8×10^{-6}
7	P05A in test (operator error) and system failure on demand without this pump.	4.9×10^{-6}
8	Turbine or turbine controls fail and P05A motor breaker does not close.	3.5×10^{-6}
9	P05B fails to deliver sufficient water and P05A motor fails to start.	2.6×10^{-6}
10	P05B fails to deliver sufficient water and P05A motor breaker does not close.	1.6×10^{-6}
11	Turbine or turbine controls fail and AFWP relay K1111 (P05A) fails open.	1.5×10^{-6}
12	P05B in test (operator error) and system failure on demand without this pump.	1.4×10^{-6}

TABLE 22. DOMINANT CONTRIBUTORS TO CONDITIONAL UNAVAILABILITY

LOSS OF MAIN FEEDWATER DUE TO LOSS OF OFFSITE POWER

Double Crossover (Plant-Specific Data)

Rank	Event Description	Unavailability
1	Turbine or turbine controls fail and 4,160V bus 1A05 fails to supply power.	3.9×10^{-4}
2	Maintenance of turbine-driven AFWP and system failure on demand without this pump.	2.4×10^{-4}
3	P05B fails to deliver sufficient water and 4,160V bus 1A05 fails to supply power.	1.8×10^{-4}
4	Maintenance of motor-driven AFWP and system failure on demand without this pump.	9.3×10^{-5}
5	Turbine or turbine controls fail and P05A fails to deliver sufficient water.	3.3×10^{-5}
6	P05B in test (operator error) and system failure on demand without this pump.	1.3×10^{-5}
7	Common cause--human error--full flow test valves open after test.	8.4×10^{-6}
8	P05A in test (operator error) and system failure on demand without this pump.	4.9×10^{-6}

TABLE 23. DOMINANT CONTRIBUTORS TO CONDITIONAL UNAVAILABILITY

LOSS OF ALL AC

Double Crossover (Plant-Specific Data)

Rank	Event Description	Unavailability
1	Turbine or turbine controls fail.	1.1×10^{-2}
2	Maintenance of turbine-driven AFWP.	5.9×10^{-3}
3	P05B fails to deliver sufficient water.	4.7×10^{-3}
4	P05B in test (operator error).	3.1×10^{-4}
5	Common cause--human error--full flow test valves open after test.	8.4×10^{-6}

TABLE 24. DOMINANT CONTRIBUTORS TO CONDITIONAL UNAVAILABILITY

LOSS OF MAIN FEEDWATER

Base Case (Plant-Specific Data)

Rank	Event Description	Unavailability
1	Maintenance of motor-driven AFWP and system failure on demand without this pump.	9.4×10^{-5}
2	P05A fails to deliver sufficient water and turbine or turbine controls fail.	3.3×10^{-5}
3	Maintenance of turbine-driven AFWP and system failure on demand without this pump.	2.6×10^{-5}
4	P05A fails to deliver sufficient water and P05B fails to deliver sufficient water.	1.5×10^{-5}
5	Common cause--human error--full flow test valves open after test.	8.4×10^{-6}
6	P05A motor fails to start and turbine or turbine controls fail.	5.8×10^{-6}
7	P05A in test (operator error) and system failure on demand without this pump.	5.0×10^{-6}
8	P05A motor breaker does not close and turbine or turbine controls fail.	3.5×10^{-6}
9	P05A motor fails to start and P05B fails to deliver sufficient water.	2.6×10^{-6}
10	P05A motor breaker does not close and P05B fails to deliver sufficient water.	1.6×10^{-6}
11	AFWS relay K1111 (P05A) fails open and turbine or turbine controls fail.	1.5×10^{-6}
12	P05B in test (operator error) and system failure on demand without this pump.	1.4×10^{-6}

TABLE 25. DOMINANT CONTRIBUTORS TO CONDITIONAL UNAVAILABILITY

LOSS OF MAIN FEEDWATER DUE TO LOSS OF OFFSITE POWER

Base Case (Plant-Specific Data)

Rank	Event Description	Unavailability
1	Turbine or turbine controls fail and 4,160V bus 1A05 fails to supply power.	3.9×10^{-4}
2	Maintenance of turbine-driven AFWP and system failure on demand without this pump.	2.4×10^{-4}
3	P05B fails to deliver sufficient water and 4,160V bus 1A05 fails to supply power.	1.7×10^{-4}
4	Maintenance of motor-driven AFWP and system failure on demand without this pump.	9.4×10^{-5}
5	Turbine or turbine controls fail and P05A fails to deliver sufficient water.	3.3×10^{-5}
6	P05B fails to deliver sufficient water and P05A fails to deliver sufficient water.	1.4×10^{-5}
7	P05B in test (operator error) and system failure on demand without this pump.	1.3×10^{-5}
8	Common cause--human error--full flow test valves open after test.	8.4×10^{-6}
9	P05A in test (operator error) and system failure on demand without this pump.	5.0×10^{-6}

TABLE 26. DOMINANT CONTRIBUTORS TO CONDITIONAL UNAVAILABILITY

LOSS OF ALL AC

Base Case (Plant-Specific Data)

Rank	Event Description	Unavailability
1	Turbine or turbine controls fail.	1.1×10^{-2}
2	Maintenance of turbine-driven AFWP.	5.9×10^{-3}
3	P05B fails to deliver sufficient water.	4.7×10^{-3}
4	P05B in test (operator error).	3.1×10^{-4}
5	Common cause--human error--full flow test valves open after test.	8.4×10^{-6}

TABLE 27. DOMINANT CONTRIBUTORS TO CONDITIONAL UNAVAILABILITY

LOSS OF MAIN FEEDWATER

Three Pump (Plant-Specific Data)

Rank	Event Description	Unavailability
1	Maintenance of turbine-driven AFWP and system failure on demand without this pump.	2.9×10^{-4}
2	Turbine or turbine controls fail and LV3875B1 transfers closed (controls).	1.5×10^{-4}
3	Maintenance on motor-driven AFWP (P05A) and system failure on demand without this pump.	9.8×10^{-5}
4	Maintenance on motor-driven AFWP (P05C) and system failure on demand without this pump.	9.8×10^{-5}
5	P05B fails to deliver sufficient water and LV3875B1 transfers closed (controls).	6.9×10^{-5}
6	Turbine or turbine controls fail and LV3875A1 transfers closed (controls).	5.9×10^{-5}
7	Turbine or turbine controls fail and pressure control valve 020B fails closed.	5.8×10^{-5}
8	Turbine or turbine control fail and pressure control valve 020A fails closed.	5.8×10^{-5}
9	Turbine or turbine controls fail and MO3870B motor operator fails.	3.7×10^{-5}
10	Turbine or turbine controls fail and MO3870A motor operator fails.	3.7×10^{-5}
11	Turbine or turbine controls fail and P05C fails to deliver sufficient water.	3.3×10^{-5}
12	Turbine or turbine controls fail and P05A fails to deliver sufficient water.	3.3×10^{-5}
13	P05B fails to deliver sufficient water and LV3875A1 transfers closed (controls).	2.6×10^{-5}
14	P05B fails to deliver sufficient water and pressure control valve 020B fails closed.	2.6×10^{-5}
15	P05B fails to deliver sufficient water and pressure control valve 020A fails closed.	2.6×10^{-5}
16	P05B fails to deliver sufficient water and MO3870B motor operator fails.	1.7×10^{-5}
17	P05B fails to deliver sufficient water and MO3870A motor operator fails.	1.7×10^{-5}
18	P05B in test (operator error) and system failure on demand without this pump.	1.6×10^{-5}
19	P05B fails to deliver sufficient water and P05C fails to deliver sufficient water.	1.5×10^{-5}

TABLE 27. DOMINANT CONTRIBUTORS TO CONDITIONAL UNAVAILABILITY (continued)

LOSS OF MAIN FEEDWATER

Three Pump (Plant-Specific Data)

Rank	Event Description	Unavailability
20	P05B fails to deliver sufficient water and P05A fails to deliver sufficient water.	1.5×10^{-5}
21	Common cause--human error--full flow test valves open after test.	8.4×10^{-6}
22	Turbine or turbine controls fail and level control valve LV3875B1 fails closed.	6.1×10^{-6}
23	Turbine or turbine controls fail and P05C motor fails to start.	5.8×10^{-6}
24	Turbine or turbine controls fail and P05A motor fails to start.	5.8×10^{-6}
25	P05A in test (operator error) and system failure on demand without this pump.	5.3×10^{-6}
26	P05C in test (operator error) and system failure on demand without this pump.	5.3×10^{-6}

TABLE 28. DOMINANT CONTRIBUTORS TO CONDITIONAL UNAVAILABILITY

LOSS OF MAIN FEEDWATER DUE TO LOSS OF OFFSITE POWER

Three Pump (Plant-Specific Data)

Rank	Event Description	Unavailability
1	Maintenance of turbine-driven AFWP and system failure on demand without this pump.	7.2×10^{-4}
2	Turbine or turbine controls fail and 4,160V bus 1A05 fails to supply power.	3.9×10^{-4}
3	Turbine or turbine controls fail and 4,160V bus 1A06 fails to supply power.	3.9×10^{-4}
4	P05B fails to deliver sufficient water and 4,160V bus 1A05 fails to supply power.	1.7×10^{-4}
5	P05B fails to deliver sufficient water and 4,160V bus 1A06 fails to supply power.	$1.7 \times 10_{-4}$
6	Turbine or turbine controls fail and LV3875BA transfers closed.	1.5×10^{-4}
7	Maintenance on motor-driven AFWP (P05A) and system failure on demand without this pump.	9.8×10^{-5}
8	Maintenance on motor-driven AFWP (P05C) and system failure on demand without this pump.	9.8×10^{-5}
9	P05A fails to deliver sufficient water and LV3875B1 transfers closed.	6.9×10^{-5}
10	Turbine or turbine controls fail and LV3875A1 transfers closed.	5.9×10^{-5}
11	Turbine or turbine controls fail and pressure control valve 020B fails closed.	5.8×10^{-5}
12	Turbine or turbine controls fail and pressure control valve 020A fails closed.	5.8×10^{-5}
13	P05B in test (operator error) and system failure on demand without this pump.	3.8×10^{-5}
14	Turbine or turbine controls fail and MO3870B motor operator fails (and controls).	3.7×10^{-5}
15	Turbine or turbine controls fail and MO3870A motor operator fails (and controls).	3.7×10^{-5}
16	Turbine or turbine controls fail and P05C fails to deliver sufficient water.	3.3×10^{-5}
17	Turbine or turbine controls fail and P05A fails to deliver sufficient water.	3.3×10^{-5}
18	P05B fails to deliver sufficient water and LV3875A1 transfers closed.	2.6×10^{-5}
19	P05B fails to deliver sufficient water and pressure control valve 020B fails closed.	2.6×10^{-5}

TABLE 28. DOMINANT CONTRIBUTORS TO CONDITIONAL UNAVAILABILITY (continued)

LOSS OF MAIN FEEDWATER DUE TO LOSS OF OFFSITE POWER

Three Pump (Plant-Specific Data)

Rank	Event Description	Unavailability
20	P05B fails to deliver sufficient water and pressure control valve 020A fails closed.	2.6×10^{-5}
21	P05B fails to deliver sufficient water and MO3870B operator fails (and controls).	1.7×10^{-5}
22	P05B fails to deliver sufficient water and MO3870A operator fails (and controls).	1.7×10^{-5}
23	P05B fails to deliver sufficient water and P05C fails to delver sufficient water.	1.5×10^{-5}
24	Common cause--human error--full flow test valves open after test.	8.4×10^{-6}
25	P05A in test (operator error) and system failure on demand without this pump.	5.2×10^{-6}
26	P05C in test (operator error) and system failure on demand without this pump.	5.2×10^{-6}

TABLE 29. DOMINANT CONTRIBUTORS TO CONDITIONAL UNAVAILABILITY

LOSS OF ALL AC

Three Pump (Plant-Specific Data)

Rank	Event Description	Unavailability
1	Turbine or turbine controls fail.	1.1×10^{-2}
2	Maintenance of turbine-driven AFWP.	5.9×10^{-3}
3	P05B fails to deliver sufficient water.	4.7×10^{-3}
4	P05B in test (operator error).	3.1×10^{-4}
5	P05B discharge valve transfers closed.	2.9×10^{-4}
6	LV3875B2 transfers closed (controls) and LV3875A2 transfers closed (controls).	2.2×10^{-4}
7	LV3875AS transfers closed (controls) and MO3870B fails closed.	2.1×10^{-4}
8	LV3875B2 transfers closed (controls) and MO3870A fails closed.	2.1×10^{-4}
9	Common cause--human error--full flow test valves open after test.	8.4×10^{-6}

the dominant contributor. For the loss of main feedwater case, maintenance on the motor-driven auxiliary feedwater pump combined with random failures in the turbine train ranks second. In the other two cases, this failure mode is not as important because of the reduced availability of AC electrical power. Next in all cases is turbine or turbine control failure coupled with failure of the motor-driven pump motor. Using plant-specific data for the double crossover system, Tables 21, 22, and 23 show the same dominant contributors appear with some changes in ordering.

Dominant contributors for the base case design using plant-specific data are presented in Tables 24, 25, and 26. These results are very similar to the double crossover case using plant-specific data both in the rank order of the individual contributors and in the quantification. Tables 27, 28, and 29 present the dominant contributors for the three pump design using plant-specific data. The overall results of this design are not as good as for the double crossover or base case designs. Although there are three pumps, success requires either the turbine pump operating or both 50% motor pumps operating. The leading contributor for the cases when AC power may be available is maintenance of the turbine-driven auxiliary feedwater pump combined with random failures in the motor-driven pump trains. However, the large number of fairly important contributors due to random failures throughout the system leads to the overall effect that combined random failures provide the dominant contribution to system unavailability. Such random failures include failure of the turbine or turbine controls combined with single motor pump train level control valve failing, failure of the turbine-driven pump combined with failure of power to either electrically driven pump, turbine or turbine control failure and a single pressure control valve in a motordriven pump train failing, and failure of the turbine-driven pump combined with failure of a motor-operated valve in either motor-driven pump train. This design suffers from the fact that success, given a failure in a turbine pump train, requires that two complete trains of motor-driven pumps operate.

The selected design, the double crossover system, has very low unavailability. Nevertheless, it is instructive to list possible system modifications that have potential to further reduce that unavailability. To improve unavailability, the modifications must attack dominant contributors of Tables 18 through 23. For example, consider the following dominant contributors and the possible modifications that might address them.

- Maintenance of the turbine-driven auxiliary feed pump and system failure on demand without this pump--reduce the frequency of pump maintenance by carefully eliminating any nonessential maintenance, consolidating maintenance, etc., and reduce the duration of pump maintenance outages through additional preplanning, training, etc.

- Maintenance of the motor-driven auxiliary feedwater pump and random failures in the turbine-driven pump train--same as for turbine maintenance.

- Turbine or turbine controls fail combined with random failures in the motor-driven pump train--modifications to improve reliability of turbine controls, perhaps provisions for preheating control fluid and positive identification that the turbine trip is reset.
- Human errors associated with the full recirculation flow valve during and following pump test--carefully written test procedures to ensure the valves are reclosed, staggered testing to avoid sequential highly coupled human failures, automatic closing of these test valves when an AFWAS is present.

These contributors are responsible for approximately 80% of the total unavailability of the auxiliary feedwater system. Thus, improvements could have a substantial effect on the overall unavailability. However, a word of warning is appropriate. It is possible that some of these changes could create more problems than they solve. For example, a redesigned turbine control system might not perform better than the one already installed. Also, for any of these options aimed at the single cause of failure, accomplishment of any one enormously decreases the value of those remaining. Finally, the system is already very reliable and no serious deficiencies have been identified. Any changes considered should only be made after a careful evaluation of all costs and benefits including the chance that a change aimed at improving reliability could actually degrade it.

6.2 RESULTS OF EVENT TREE ANALYSIS

The event tree analysis described in Section 5 has been performed for the double crossover system (see Figures 11 and 12). A decomposition of the double crossover system event tree and time dependent reliability calculations have been used to quantify the system event tree. Probabilities have been calculated for each path and each sequence number in Figure 12. We have summarized those calculations in the following brief table.

System State	Relative Frequency Following Demand
1. Immediate failure	4×10^{-5}
2. Initial cooling, long-term failure	1×10^{-5}
3. Successful operation but overcooling in at least one SG	2×10^{-4}
4. Initial overcooling and long-term failure	2×10^{-9}

State 3, overcooling, may not be a serious contributor to public risk. Recent calculations show that natural circulation cooling can be effective even with two phase conditions in the primary as long as the core remains covered. Overcooling cannot shrink the primary coolant enough to uncover the core. States 2 and 4--initial cooling but long-term failure--are much less serious than State 1--immediate failure. They have removed initial decay heat, permitted some cooldown, and have allowed power to decay. Much more time is available for recovery.

The event tree developed in this study can provide a basis for revised analyses in the future. As more details on FOGG and the level control system become available, they can be easily included. Also, additional thinking on good and bad SGs can be incorporated.

7. REFERENCES

1. USNRC, "Generic Evaluation of Feedwater Transients and Small Break Loss of Coolant Accidents in Westinghouse Designed Operating Plants," NUREG-0611, January 1980.

2. Weaver, W. W., R. W. Dorman, R. S. Enzinna, "Auxiliary Feedwater Systems Reliability Analyses: A Generic Report for Babcock and Wilcox-Designed Plants," BAW-1584, December 1979.

3. U.S. Nuclear Regulatory Commission, "Transient Response of Babcock and Wilcox-Designed Reactors," NUREG-0667, May 1980.

4. Midland FSAR, Chapters 8 and 9.

5. Midland P&IDs for Auxiliary Feedwater, Main Steam, Condensate and Feedwater, and Service Water Systems.

6. Midland Schematics for AFW pumps and motor-operated valves.

7. Midland Technical Specifications for Auxiliary Feedwater, Condensate Storage Tank, Electric Power, Service Water, and Instrumentation Systems.

8. AFW System Operating, Emergency and Surveillance Procedures.

9. Discussions with members of the Midland Plant Staff in the Operations, Maintenance, Startup, and Technical Groups.

10. Sullivan, T. S., J. P. Kindinger, "AFW System Configuration and Control Task Recommendation," Consumers Power Company Internal Correspondence, Kind 5-80, April 9, 1980

11. Users Guide for the Reliability Analysis System (RAS) Computer Code, TREE-1168, developed by EG&G, IDAHO, Inc., at the Idaho National Engineering Laboratory (INEL), September 1977.

12. COMCAN II-A, A Computer Program for Automated Common Cause Failure Analysis, TREE-1361, developed by EG&G, IDAHO, Inc., at the Idaho National Engineering Laboratory (INEL), May 1979.

13. MOCARS: A Monte Carlo Code for Determining the Distribution and Simulation Limits, Scott D. Mathews, developed by EG&G, IDAHO, Inc., July 1977.

14. U.S. Nuclear Regulatory Commission, "Reactor Safety Study: An Assessment of Accident Risks in U.S. Commercial Nuclear Power Plants," WASH-1400, 1975.

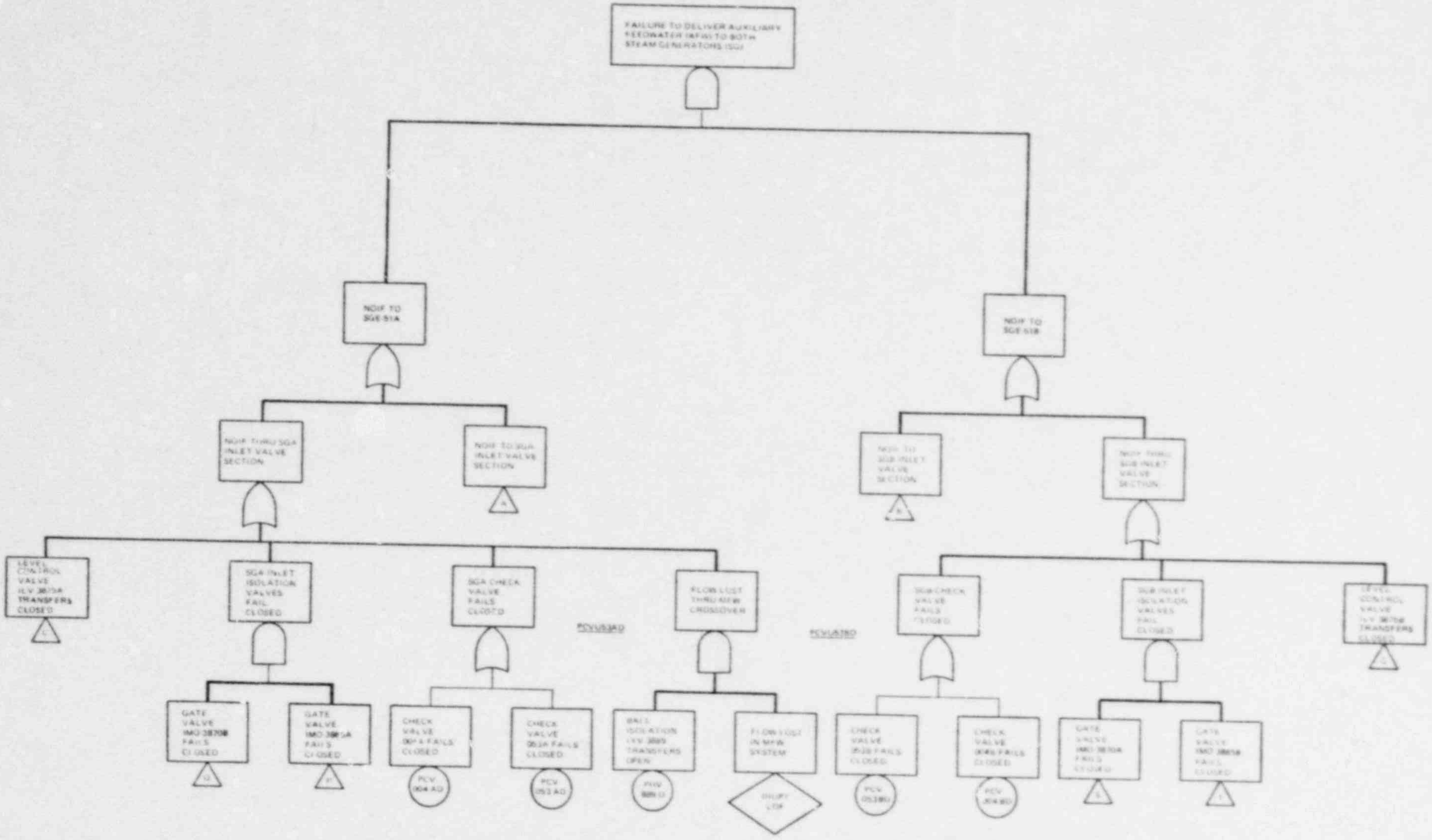
15. U.S. Nuclear Regulatory Commission, "Staff Report on the Generic Assessment of Feedwater Transients in Pressurized Water Reactors Designed by the Babcock and Wilcox Company," NUREG-0560, May 1979.

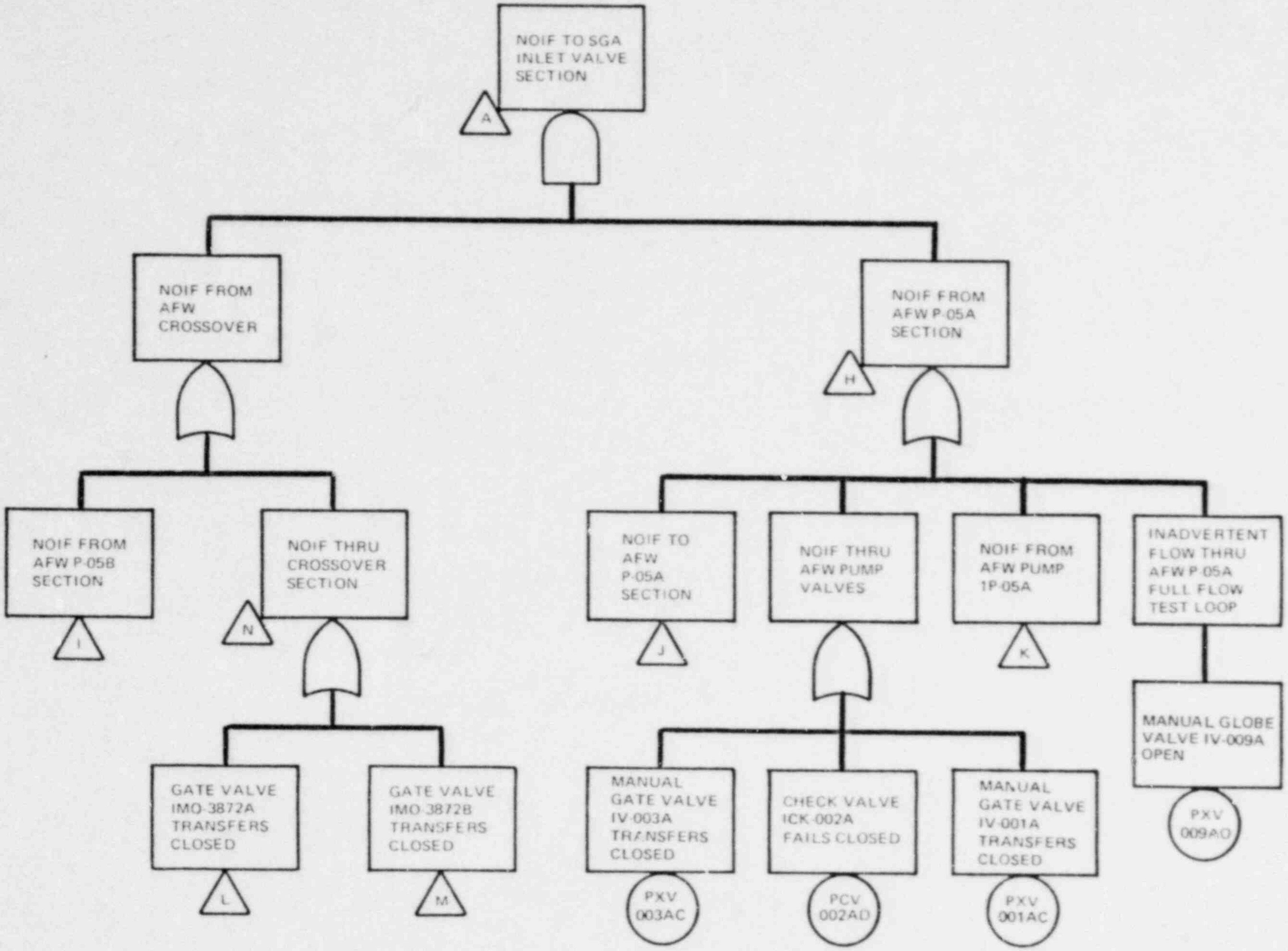
APPENDIX A

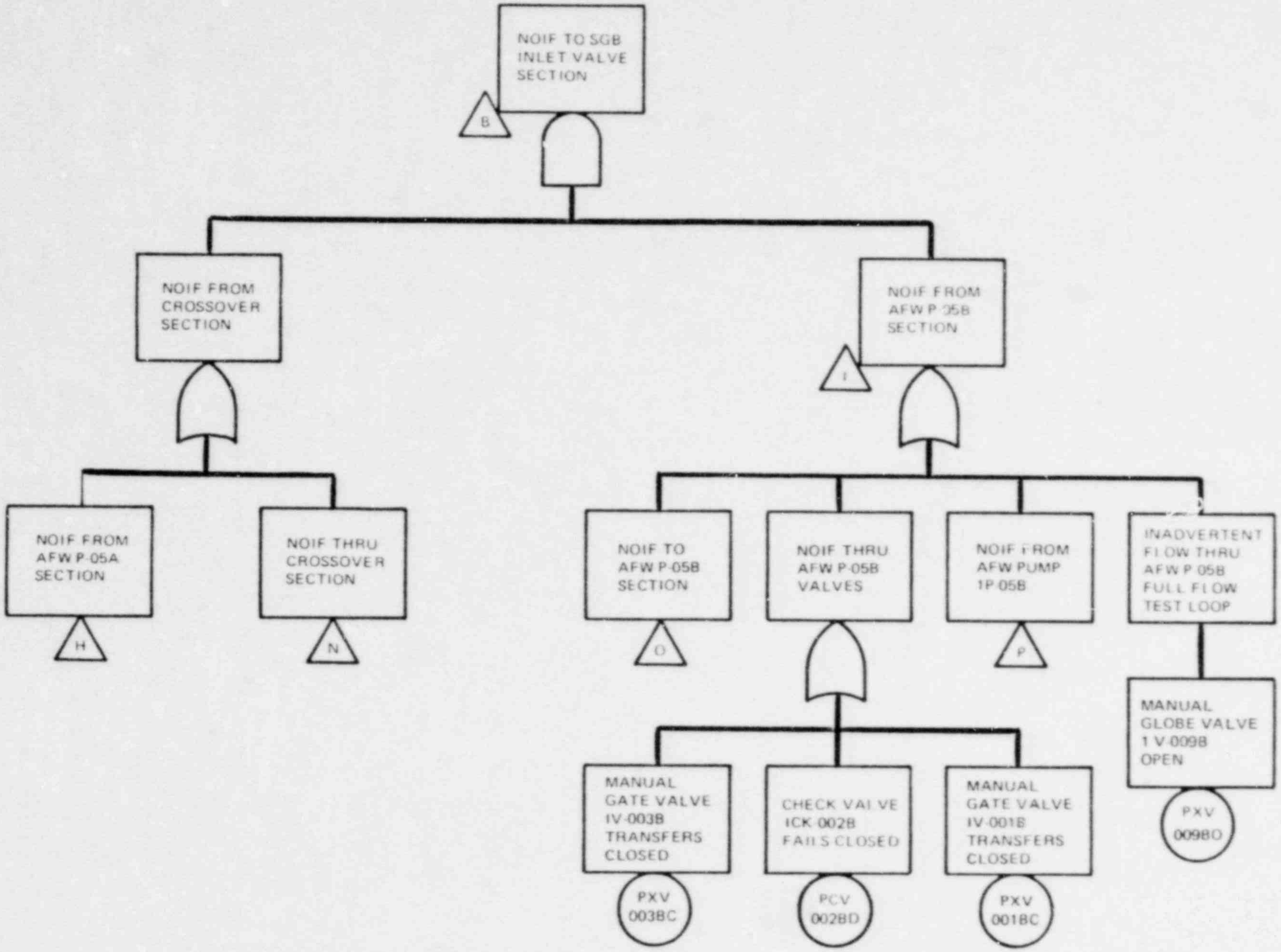
MIDLAND AUXILIARY FEEDWATER SYSTEM FAULT TREE

BASE CASE DESIGN

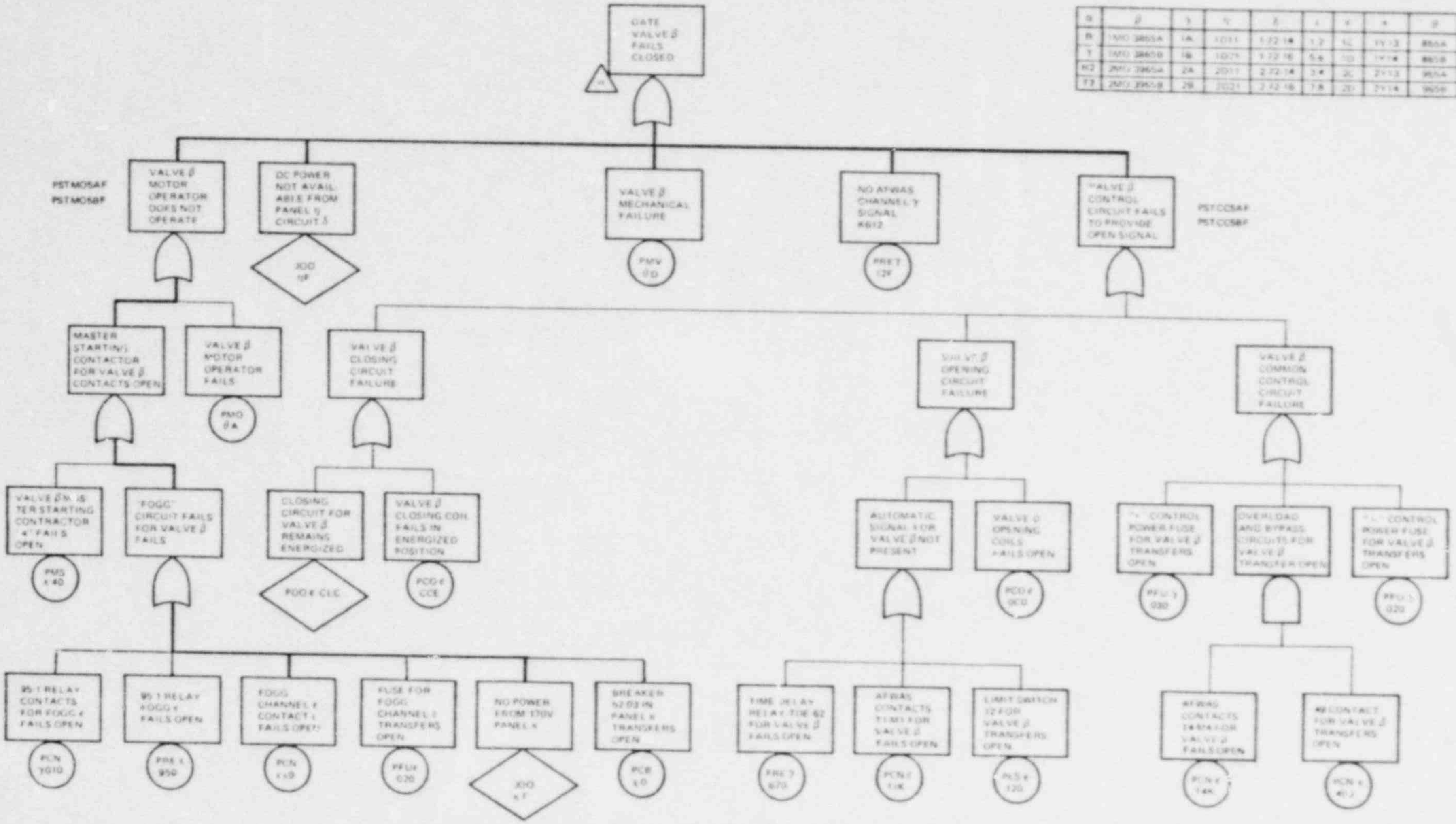
This appendix presents the fault tree model constructed to represent the original AFWS design at Midland. The tree logic defines the component failure modes necessary to fail the system. The fault trees have been heavy lined to show the level to which the quantification was performed. Quantification was performed to the level at which the most applicable data was available. The detailed fault trees were constructed to ensure that all components which could possibly affect the system performance were included in our analysis.


FAILURE TO DELIVER AUXILIARY FEEDWATER (AFW) TO BOTH STEAM GENERATORS (SG)
NOIF TO SGE-51A
NOIF TO SGE-51B
NOIF THRU SGA INLET VALVE SECTION
NOIF TO SGA INLET VALVE SECTION
A
NOIF TO SGB INLET VALVE SECTION
B
NOIF THRU SGB INLET VALVE SECTION
LEVEL CONTROL VALVE ILV 3875A TRANSFERS CLOSED
C
SGA INLET ISOLATION VALVES FAIL CLOSED
GATE VALVE IMO 3870B FAILS CLOSED
GATE VALVE IMO 3885A FAILS CLOSED
SGA CHECK VALVE FAILS CLOSED
CHECK VALVE 004A FAILS CLOSED
PCV 004AD
CHECK VALVE 053A FAILS CLOSED
PCV 053AD
PCVU53AD
FLOW LOST THRU AFW CROSSOVER
BAIS ISOLATION LCV 3889 TRANSFERS OPEN
PHV 889D
FLOW LOST IN MFW SYSTEM
PCVU04BD
SGB CHECK VALVE FAILS CLOSED
CHECK VALVE 053B FAILS CLOSED
PCV 053BD
CHECK VALVE 004B FAILS CLOSED
PCV 004BD
SGB INLET ISOLATION VALVES FAIL CLOSED
GATE VALVE IMO 3870A FAILS CLOSED
GATE VALVE IMO 3885B FAILS CLOSED
LEVEL CONTROL VALVE ILV 3875B TRANSFERS CLOSED

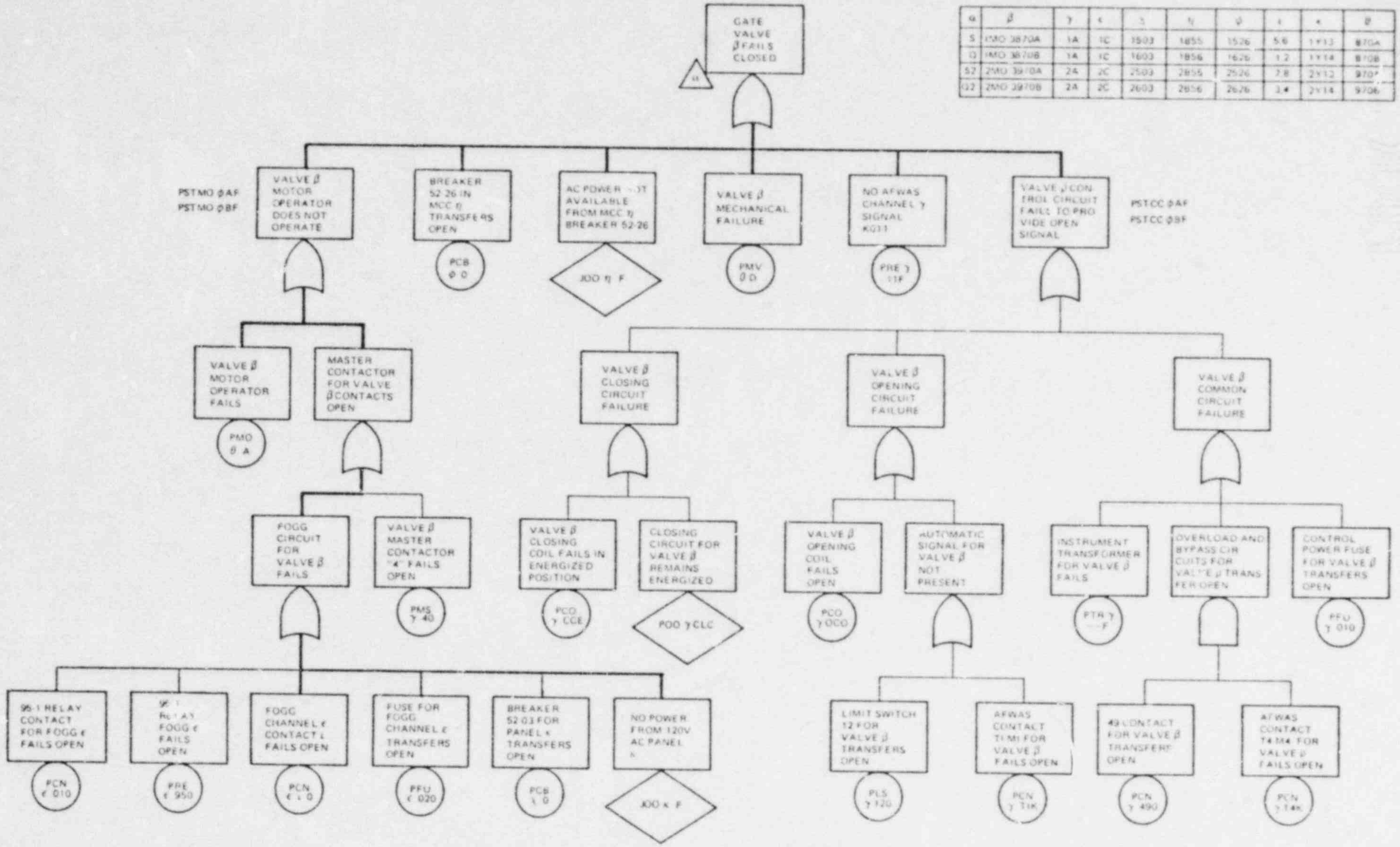

NOIF TO SGA INLET VALVE SECTION
A
NOIF FROM AFW CROSSOVER
NOIF FROM AFW P-05A SECTION
H
NOIF FROM AFW P-05B SECTION
I
NOIF THRU CROSSOVER SECTION
N
NOIF TO AFW P-05A SECTION
J
NOIF THRU AFW PUMP VALVES
NOIF FROM AFW PUMP 1P-05A
K
INADVERTENT FLOW THRU AFW P-05A FULL FLOW TEST LOOP
GATE VALVE IMO-3872A TRANSFERS CLOSED
L
GATE VALVE IMO-3872B TRANSFERS CLOSED
M
MANUAL GATE VALVE IV-003A TRANSFERS CLOSED
PXV 003AC
CHECK VALVE ICK-002A FAILS CLOSED
PCV 002AD
MANUAL GATE VALVE IV-001A TRANSFERS CLOSED
PXV 001AC
MANUAL GLOBE VALVE IV-009A OPEN
PXV 009AO


NOIF TO SGB INLET VALVE SECTION
B
NOIF FROM CROSSOVER SECTION
NOIF FROM AFW P-05B SECTION
I
NOIF FROM AFW P-05A SECTION
H
NOIF THRU CROSSOVER SECTION
N
NOIF TO AFW P-05B SECTION
O
NOIF THRU AFW P-05B VALVES
NOIF FROM AFW PUMP 1P-05B
P
INADVERTENT FLOW THRU AFW P-05B FULL FLOW TEST LOOP
MANUAL GATE VALVE IV-003B TRANSFERS CLOSED
PXV 003BC
CHECK VALVE ICK-002B FAILS CLOSED
PCV 002BD
MANUAL GATE VALVE IV-001B TRANSFERS CLOSED
PXV 001BC
MANUAL GLOBE VALVE 1V-009B OPEN
PXV 009BO

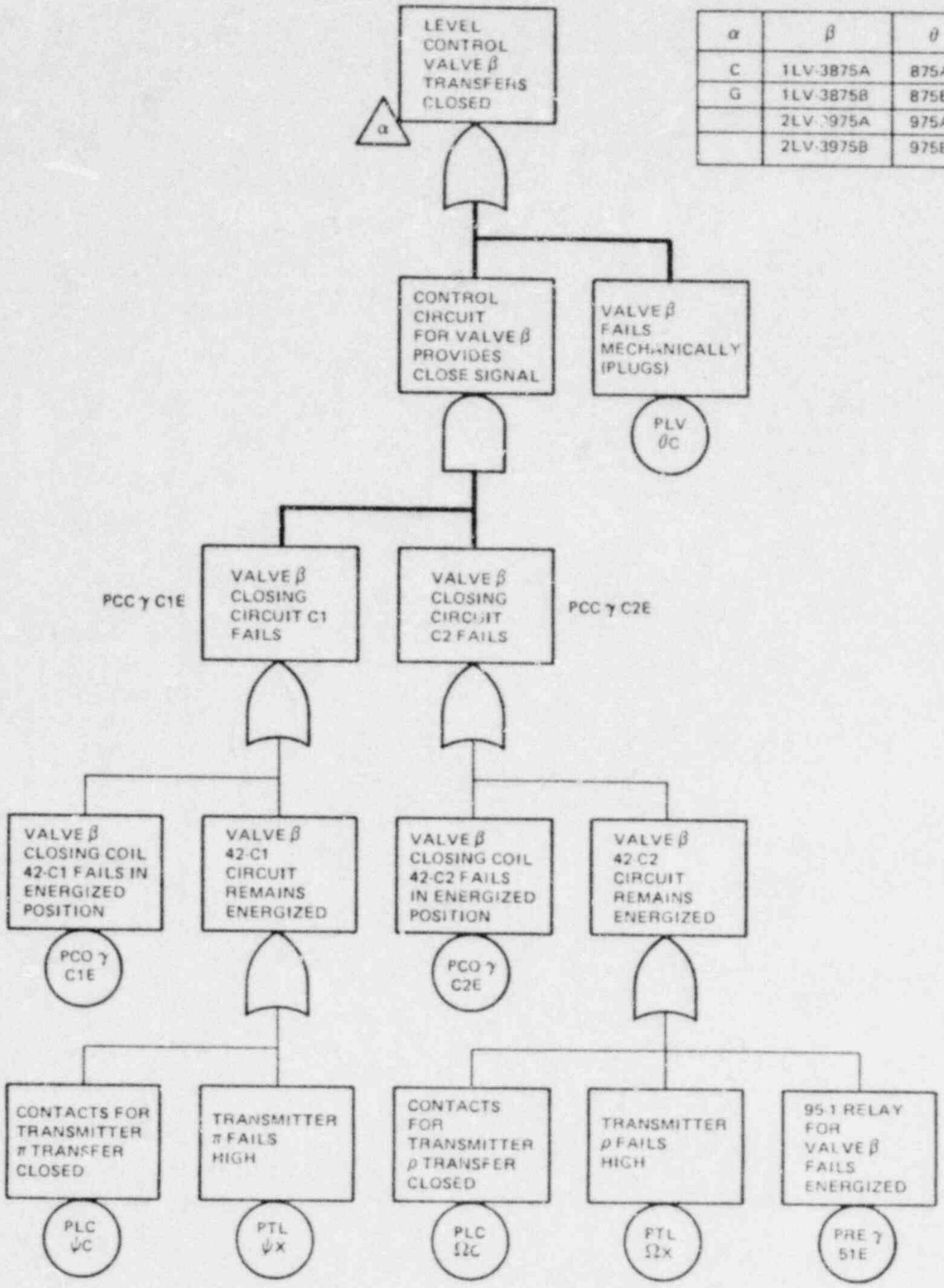
α	β	γ	η	δ	ε	κ	λ	θ	ψ
B	1MO 3865A	1A	1D11	1-72-14	1-2	1C	1Y13	865A	1503
T	1MO 3865B	1B	1D21	1-72-16	5-6	1D	1Y14	865B	1603
K2	2MO 3965A	2A	2D11	2-72-14	3-4	2C	2Y13	965A	2503
T2	2MO 3965B	2B	2D21	2-72-16	7-8	2D	2Y14	965B	2603



POOR ORIGINAL



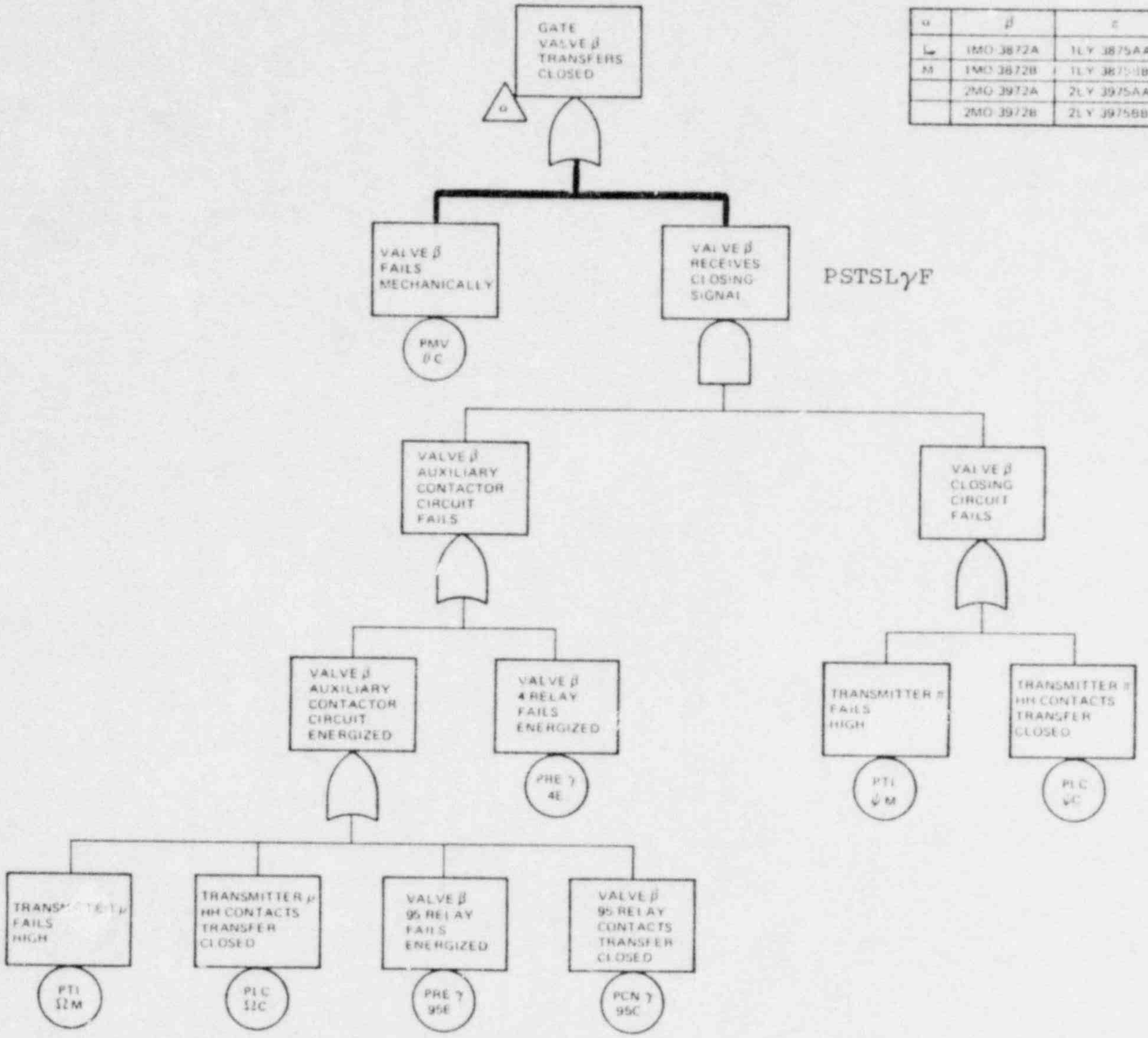
α	β	γ	ε	ζ	η	ψ	ι	κ	θ
S	1MO 3870A	1A	1C	1503	1855	1526	5.6	1Y13	870A
Q	1MO 3870B	1A	1C	1603	1856	1626	1.2	1Y14	870B
S2	2MO 3970A	2A	2C	2503	2855	2526	7.8	2Y13	970A
Q2	2MO 3970B	2A	2C	2603	2856	2626	3.4	2Y14	970B



α	β	θ	γ	π	ψ	ρ	Ω
C	1LV-3875A	875A	1A	1LY-3875AB	38AB	1LY-3875AD	38AD
G	1LV-3875B	875B	1B	1LY-3875BA	38BA	1LY-3875BC	38BC
	2LV-3975A	975A	2A	2LY-3975AB	39AB	2LY-3975AD	39AD
	2LV-3975B	975B	2B	2LY-3975BA	39BA	2LY-3975BC	39BC

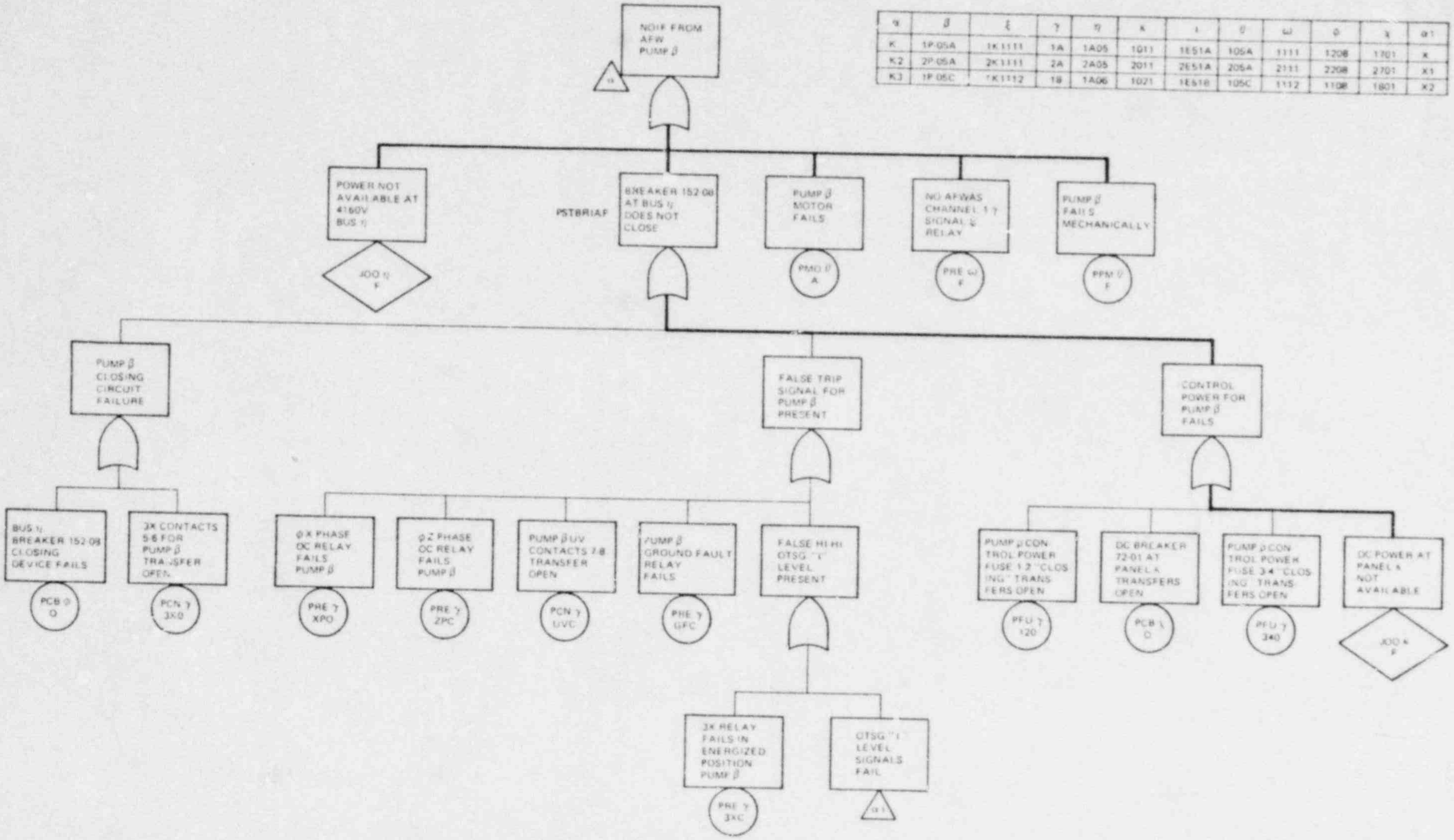
α	β	ε	μ	Ω	ψ	γ	δ
L	1MO 3872A	1LY 3875AA	1LY 3875AC	38AC	38AA	1A	872A
M	1MO 3872B	1LY 3875BB	1LY 3875BD	38BD	38BB	1B	872B
	2MO 3972A	2LY 3975AA	2LY 3975AC	39AC	39AA	2A	972A
	2MO 3972B	2LY 3975BB	2LY 3975BD	39BC	39BB	2B	972B

PSTSLγF



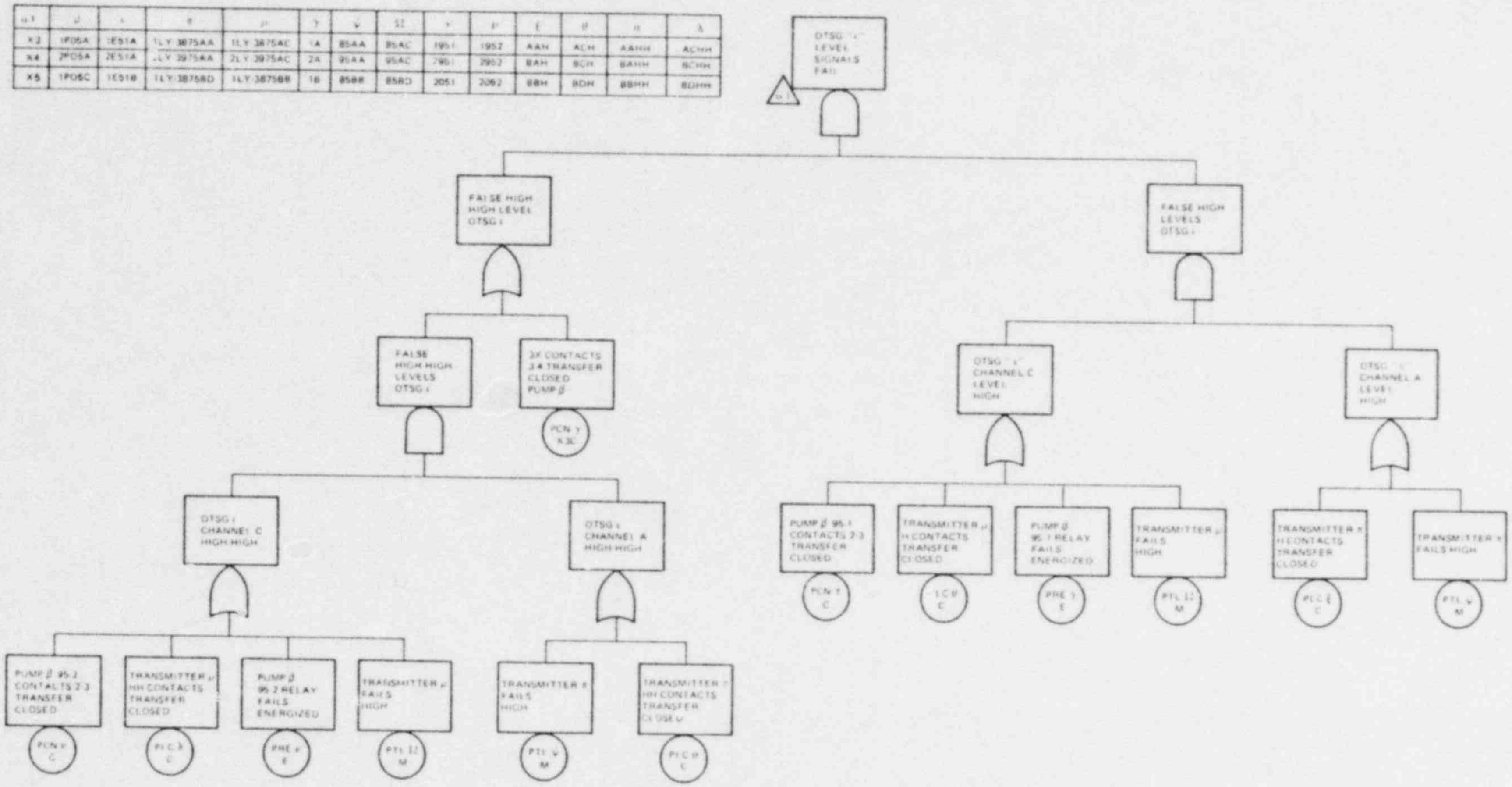
POOR ORIGINAL

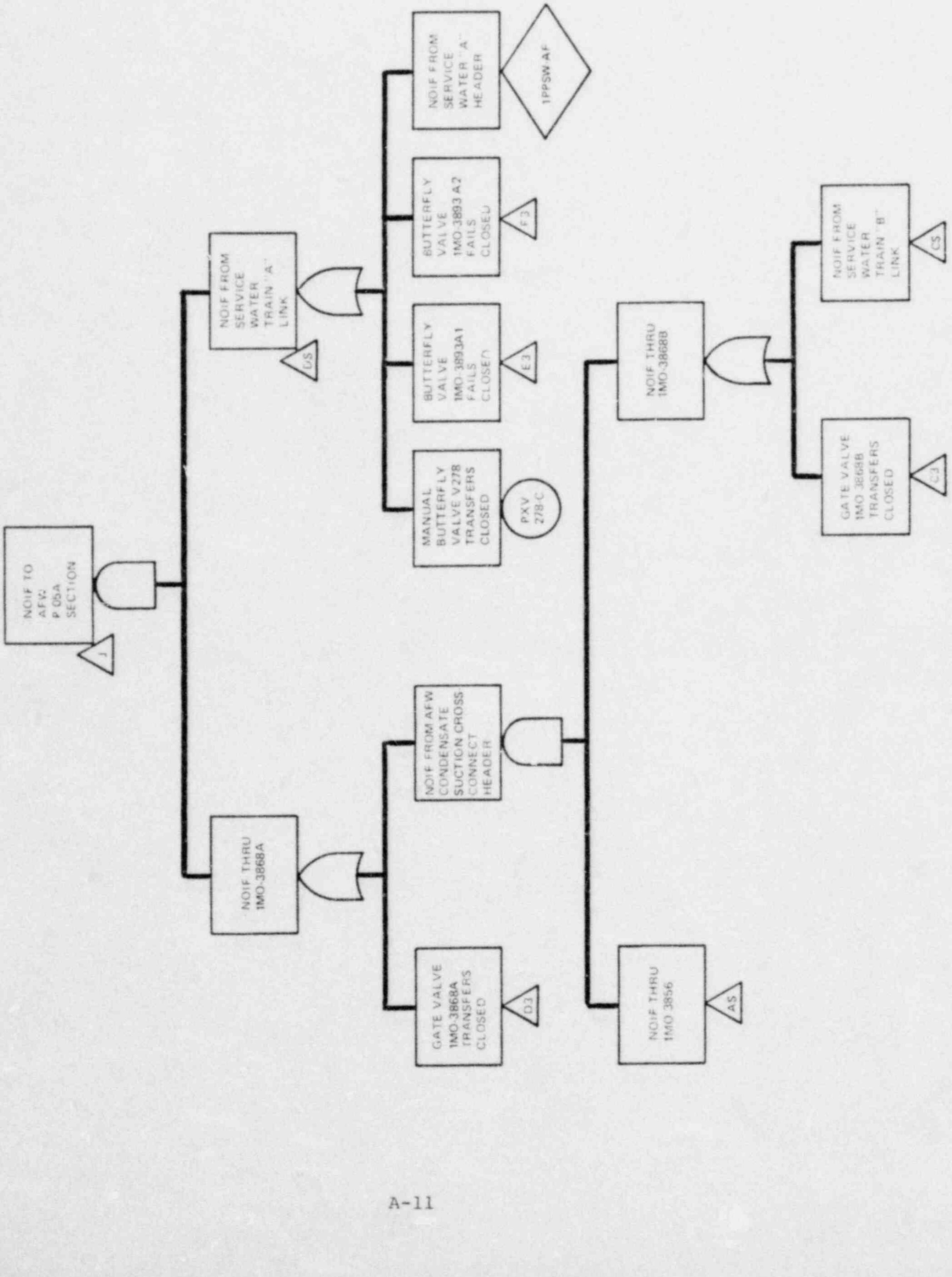
α	β	ξ	γ	η	κ	ι	θ	ω	φ	χ	α1
K	1P-05A	1K1111	1A	1A05	1011	1E51A	105A	1111	1208	1701	K
K2	2P-05A	2K1111	2A	2A05	2011	2E51A	205A	2111	2208	2701	X1
K3	1P-05C	1K1112	1B	1A06	1021	1E51B	105C	1112	1108	1801	X2

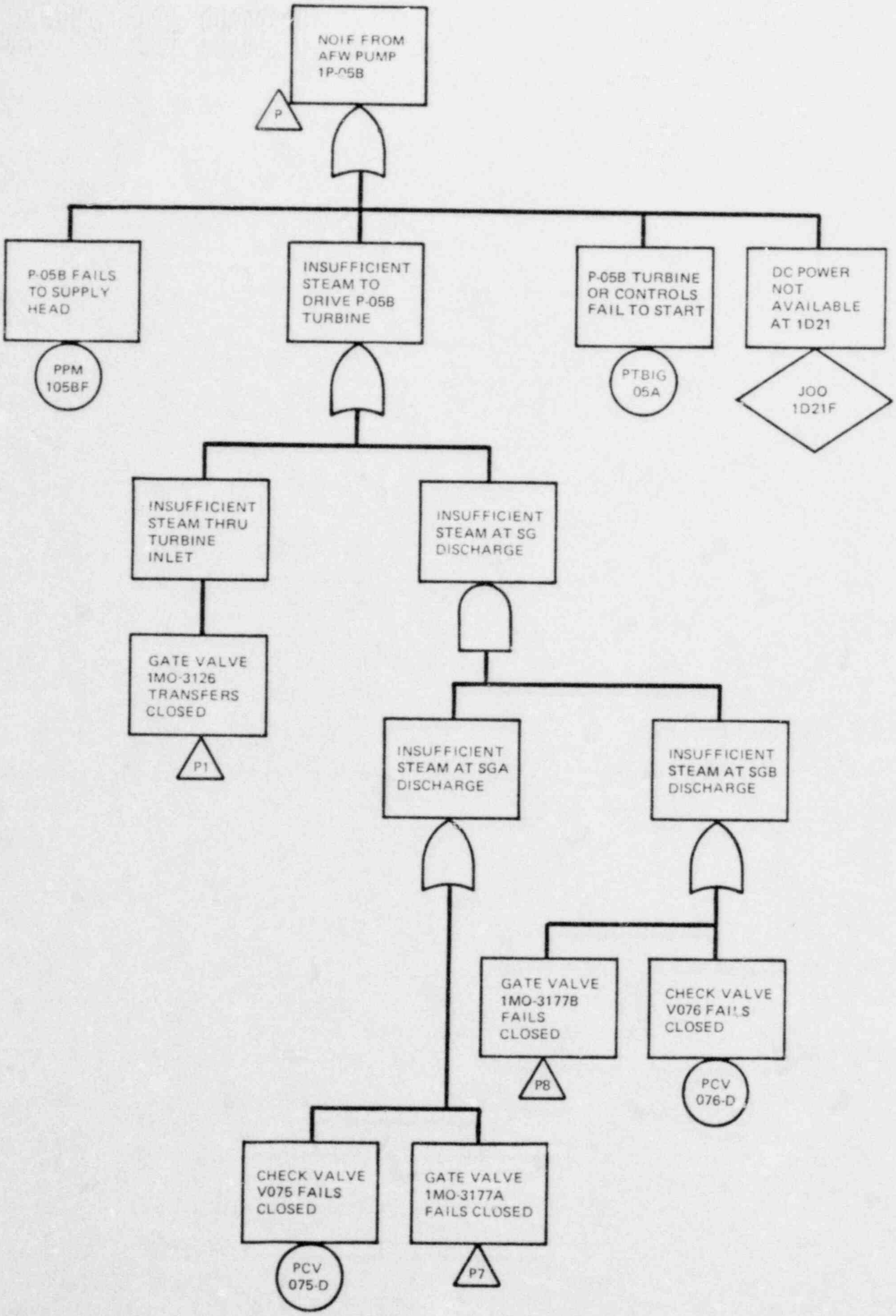


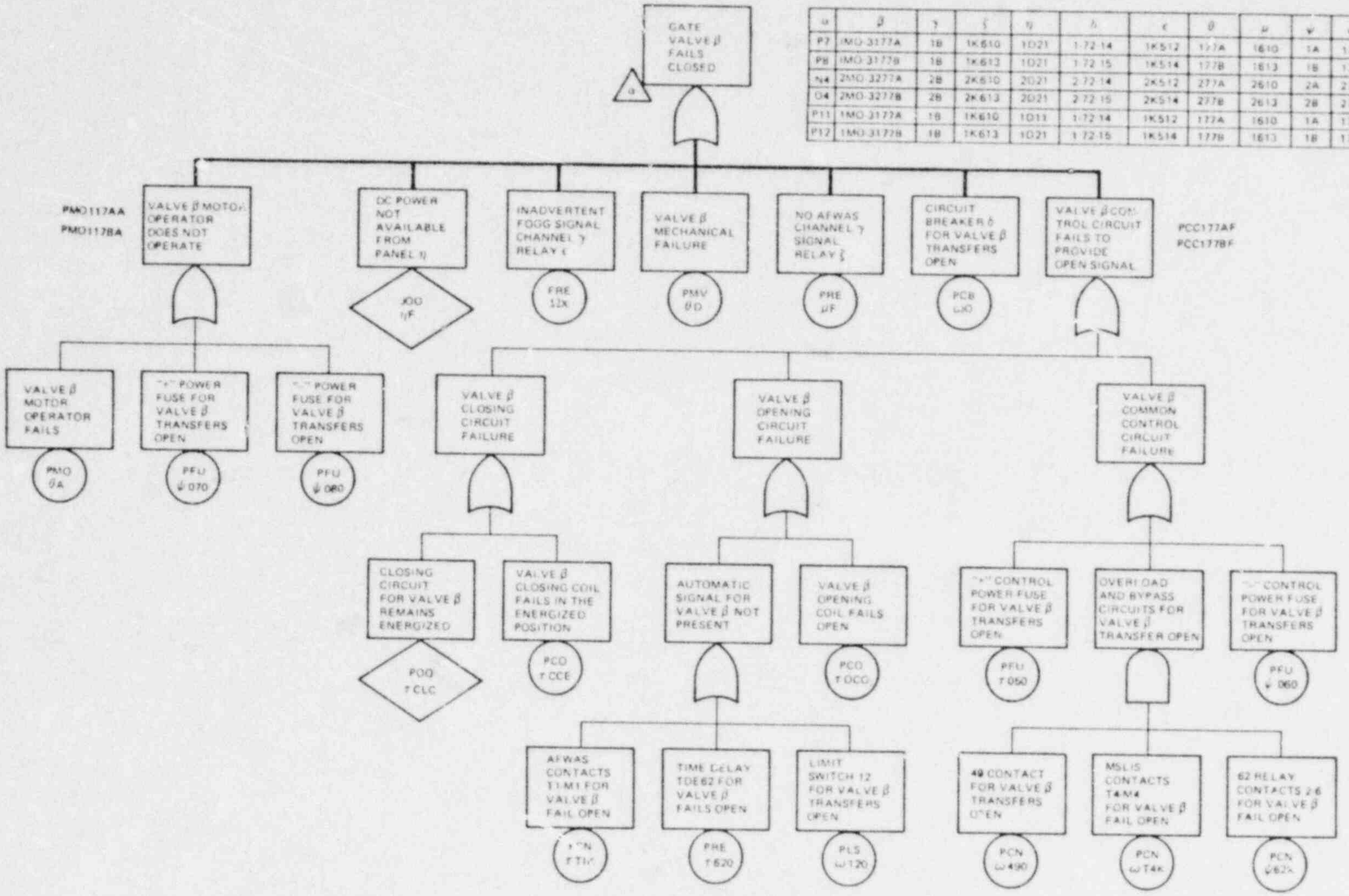
POOR ORIGINAL

α1	μ	ι	θ	ρ	γ	ψ	Ω	τ	φ	ξ	β	η	λ
X2	1P05A	1E51A	1LY 3875AA	1LY 3875AC	1A	85AA	85AC	1951	1952	AAH	ACH	AAHH	ACHH
X4	2P05A	2E51A	2LY 3975AA	2LY 3975AC	2A	95AA	95AC	2951	2952	BAH	BCH	BAHH	BCHH
X5	1P05C	1E51B	1LY 3875BD	1LY 3875BB	1B	85BB	85BD	2051	2062	BBH	BDH	BBHH	BDHH



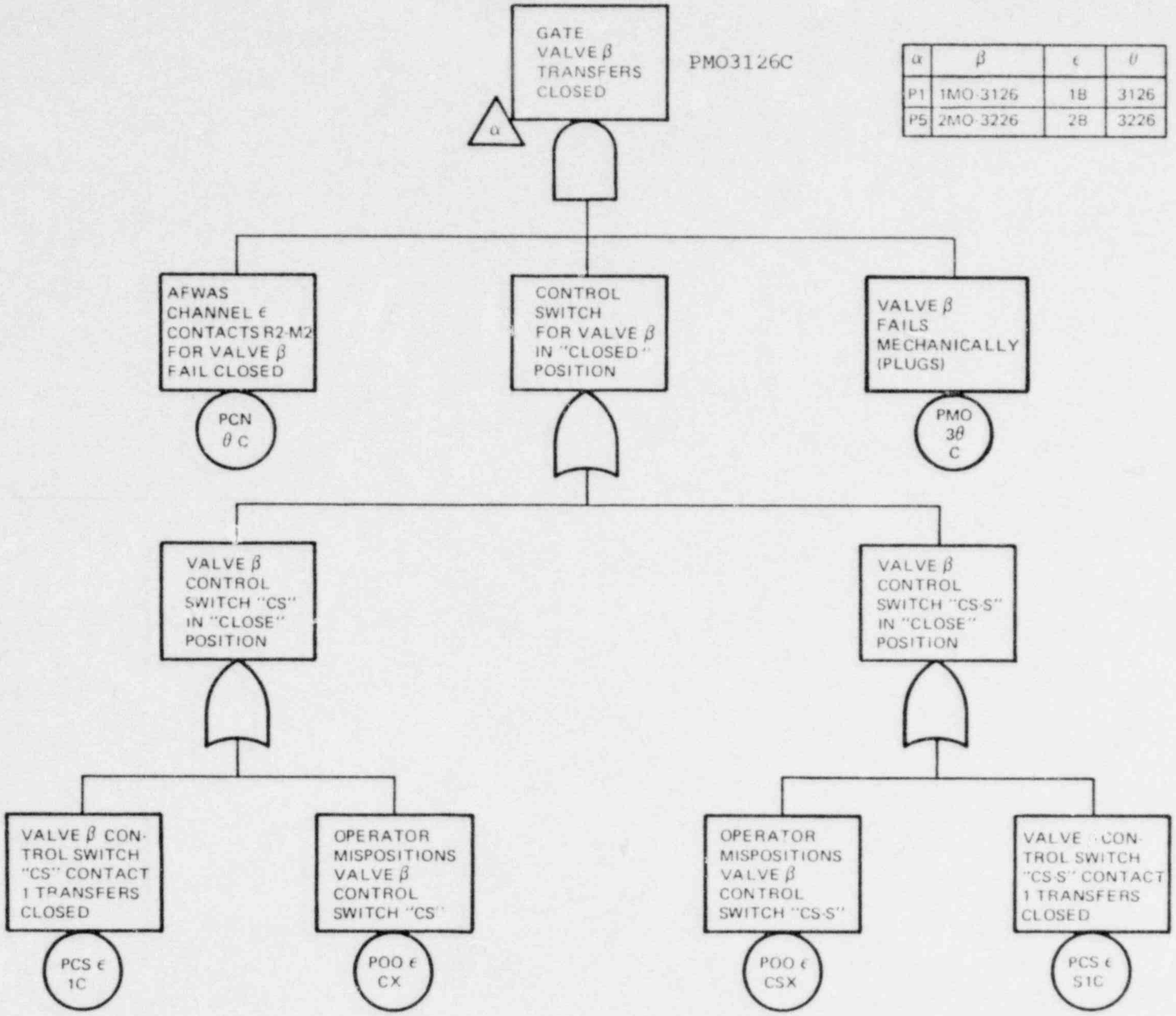

NOIF TO AFW P 05A SECTION
J
NOIF FROM SERVICE WATER TRAIN "A" LINK
D5
NOIF THRU 1MO-3868A
MANUAL BUTTERFLY VALVE V278 TRANSFERS CLOSED
PXV 278-C
BUTTERFLY VALVE 1MO-3893A1 FAILS CLOSED
E3
BUTTERFLY VALVE 1MO-3893 A2 FAILS CLOSED
F3
NOIF FROM SERVICE WATER "A" HEADER
1PPSW AF
NOIF FROM AFW CONDENSATE SUCTION CROSS CONNECT HEADER
GATE VALVE 1MO-3868A TRANSFERS CLOSED
D3
NOIF THRU 1MO-3868B
NOIF THRU 1MO 3856
A5
GATE VALVE 1MO 3868B TRANSFERS CLOSED
C3
NOIF FROM SERVICE WATER TRAIN "B" LINK
C5


NOIF FROM AFW PUMP 1P-05B
P
P-05B FAILS TO SUPPLY HEAD
PPM 105BF
INSUFFICIENT STEAM TO DRIVE P-05B TURBINE
P-05B TURBINE OR CONTROLS FAIL TO START
PTBIG 05A
DC POWER NOT AVAILABLE AT 1D21
JOO 1D21F
INSUFFICIENT STEAM THRU TURBINE INLET
GATE VALVE 1MO-3126 TRANSFERS CLOSED
P1
INSUFFICIENT STEAM AT SG DISCHARGE
INSUFFICIENT STEAM AT SGA DISCHARGE
INSUFFICIENT STEAM AT SGB DISCHARGE
GATE VALVE 1MO-3177B FAILS CLOSED
P8
CHECK VALVE V076 FAILS CLOSED
PCV 076-D
CHECK VALVE V075 FAILS CLOSED
PCV 075-D
GATE VALVE 1MO-3177A FAILS CLOSED
P7

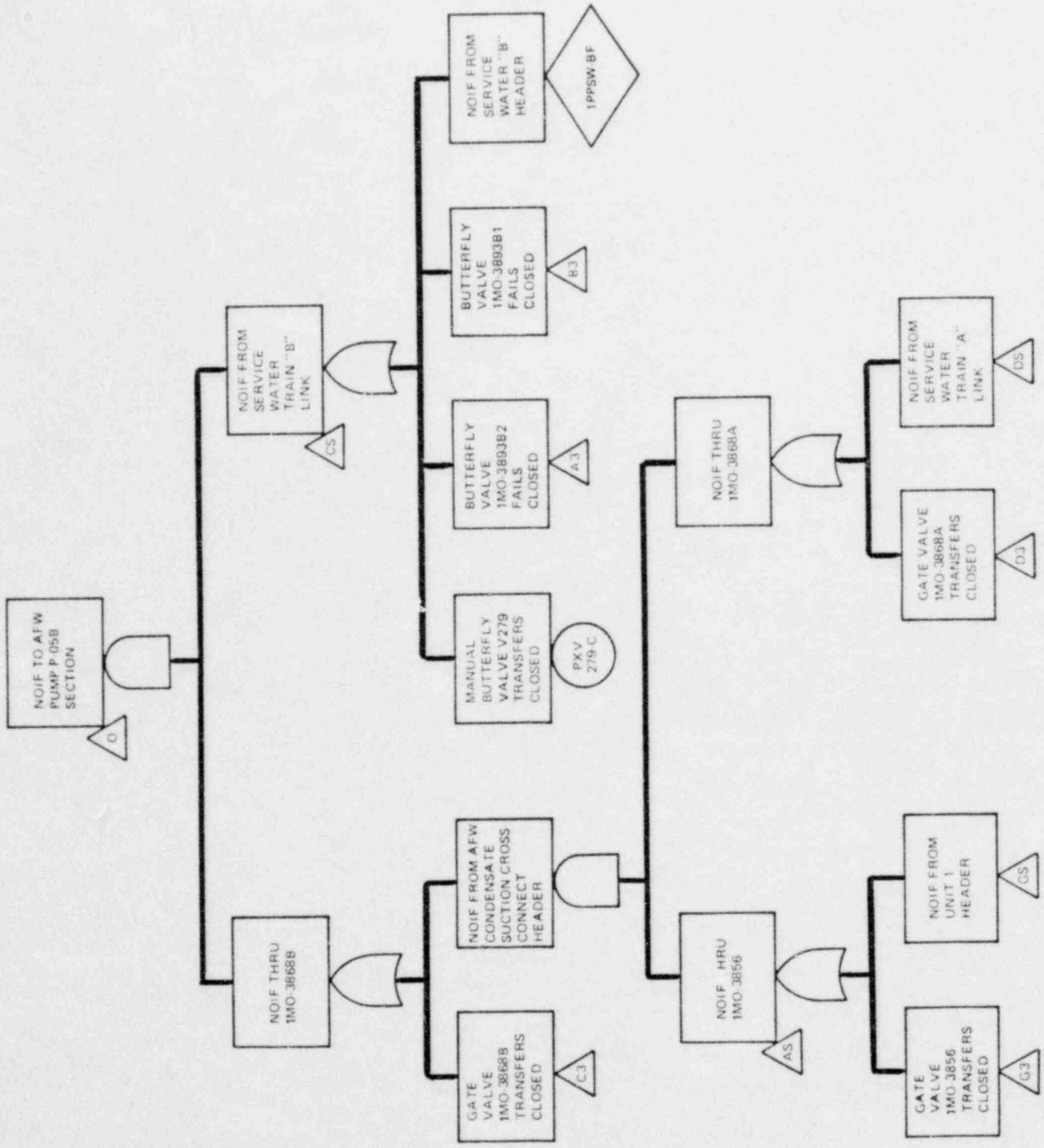


α	β	γ	ζ	η	δ	ε	θ	μ	ψ	ω	Ω	τ
P7	1MO-3177A	1B	1K610	1D21	1-72-14	1K512	177A	1610	1A	1714	1512	1E
P8	1MO-3177B	1B	1K613	1D21	1-72-15	1K514	177B	1613	1B	1715	1514	1F
N4	2MO-3277A	2B	2K610	2D21	2-72-14	2K512	277A	2610	2A	2714	2512	2E
O4	2MO-3277B	2B	2K613	2D21	2-72-15	2K514	277B	2613	2B	2715	2514	2F
P11	1MO-3177A	1B	1K610	1D11	1-72-14	1K512	177A	1610	1A	1714	1512	1E
P12	1MO-3177B	1B	1K613	1D21	1-72-15	1K514	177B	1613	1B	1715	1514	1F

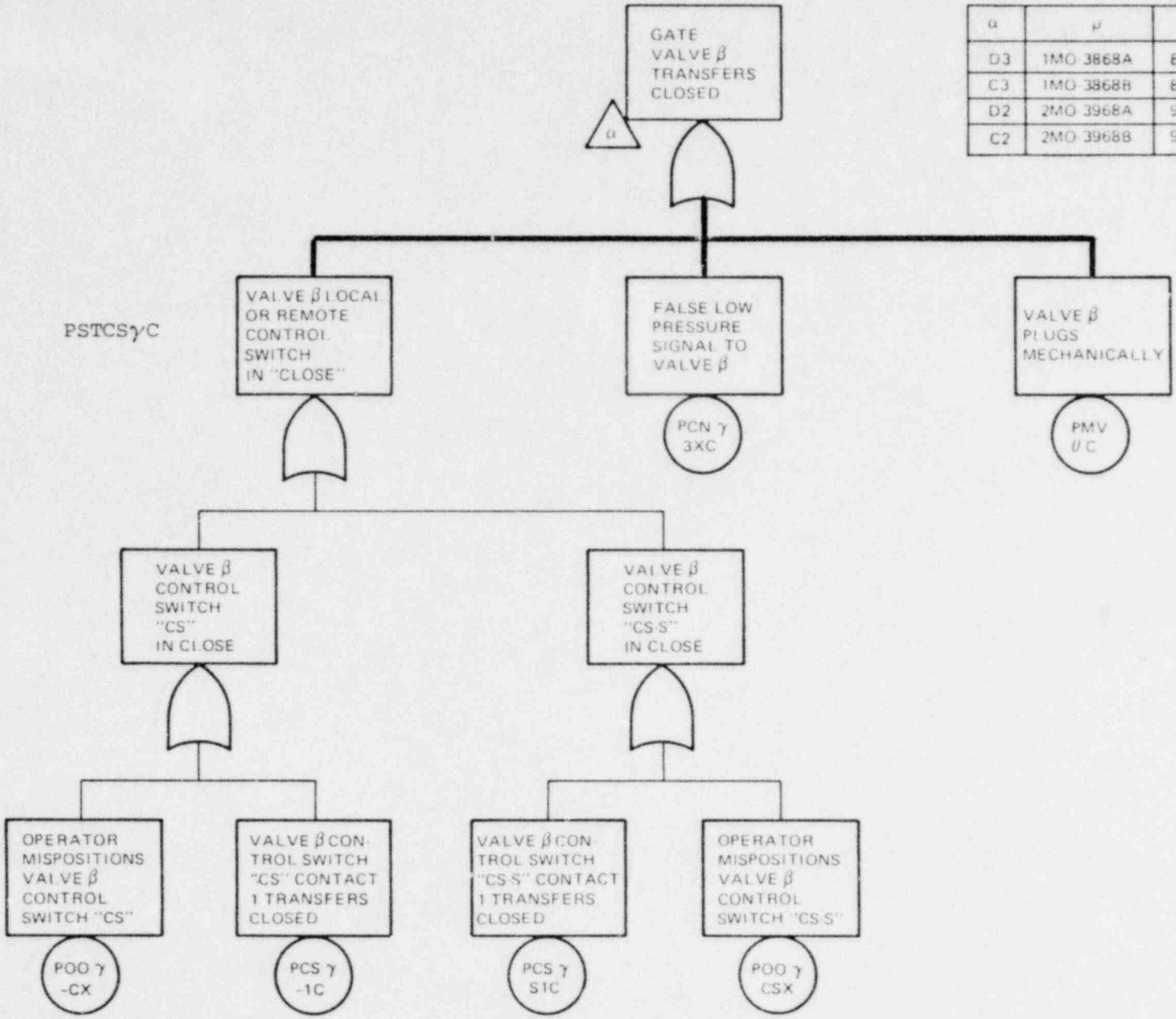
POOR ORIGINAL



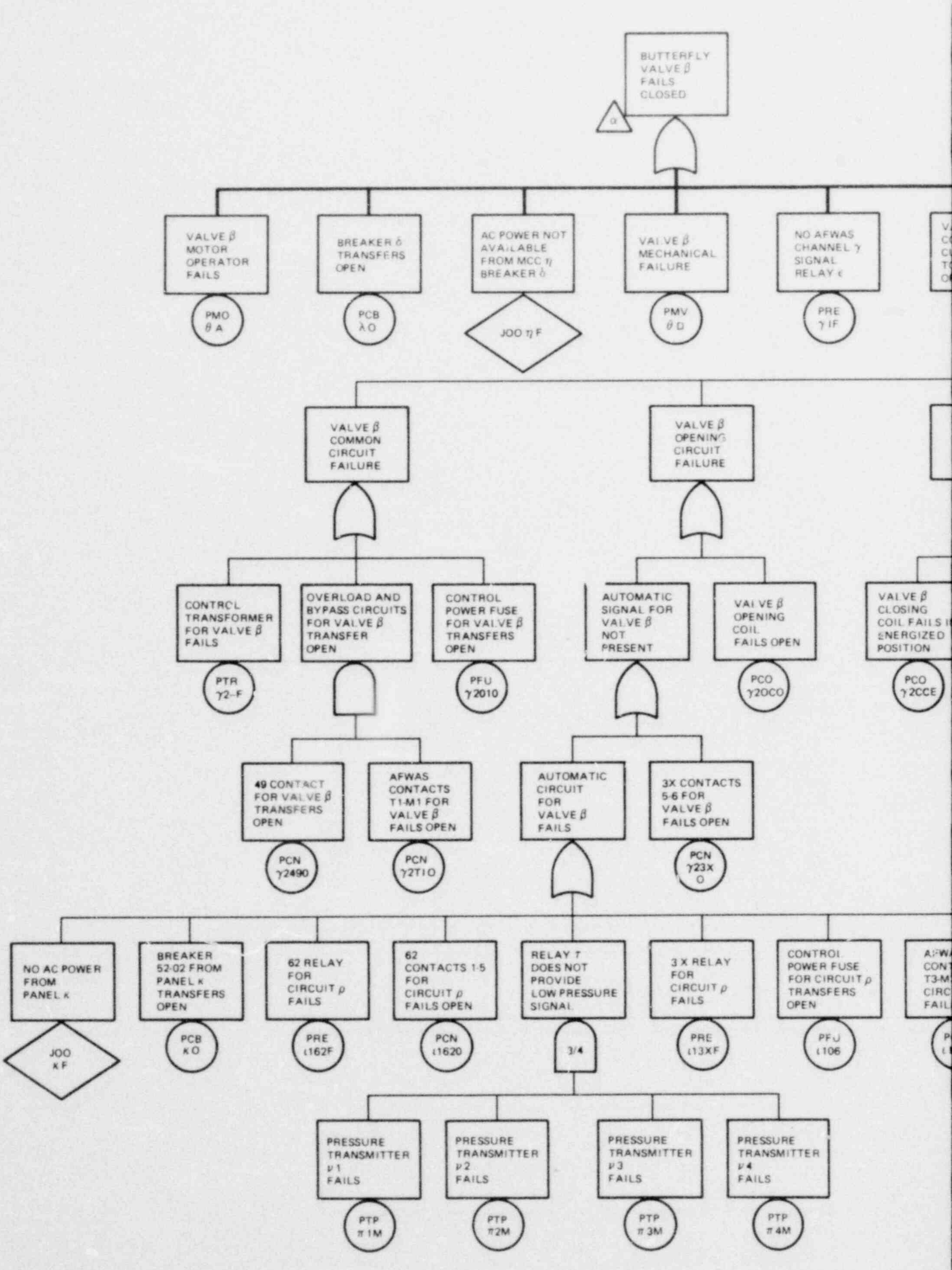
α	β	ϵ	θ
P1	1MO-3126	1B	3126
P5	2MO-3226	2B	3226


NOIF TO AFW PUMP P-05B SECTION
D
NOIF FROM SERVICE WATER TRAIN "B" LINK
C5
NOIF THRU 1MO-3868B
MANUAL BUTTERFLY VALVE V279 TRANSFERS CLOSED
PXV 279-C
BUTTERFLY VALVE 1MO-3893B2 FAILS CLOSED
A3
BUTTERFLY VALVE 1MO-3893B1 FAILS CLOSED
B3
NOIF FROM SERVICE WATER "B" HEADER
1PPSW-BF
NOIF FROM AFW CONDENSATE SUCTION CROSS CONNECT HEADER
GATE VALVE 1MO-3868B TRANSFERS CLOSED
C3
NOIF THRU 1MO-3868A
NOIF HRU 1MO-3856
A5
GATE VALVE 1MO-3868A TRANSFERS CLOSED
D3
NOIF FROM SERVICE WATER TRAIN "A" LINK
D5
NOIF FROM UNIT 1 HEADER
G5
GATE VALVE 1MO-3856 TRANSFERS CLOSED
G3

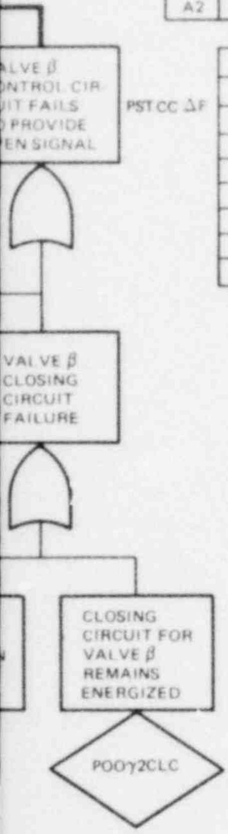
PSTCSγC



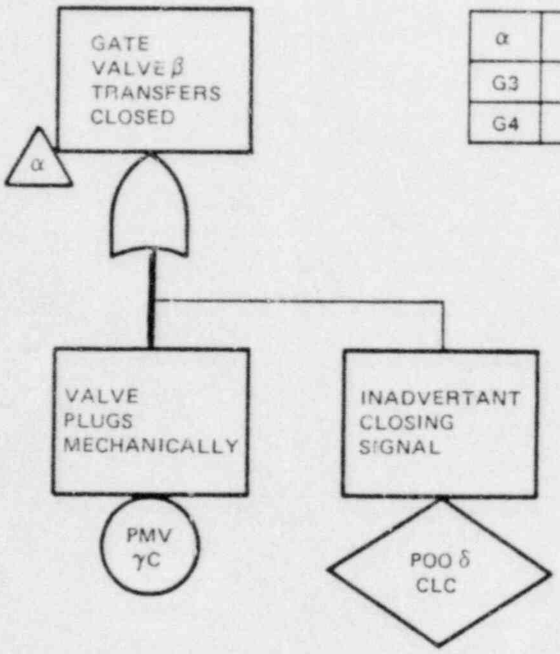
α	β	θ	γ
D3	1MO-3868A	868A	1A
C3	1MO-3868B	868B	1B
D2	2MO-3968A	968A	2A
C2	2MO-3968B	968B	2B


BUTTERFLY VALVE β FAILS CLOSED
α
VALVE β MOTOR OPERATOR FAILS
PMO θ A
BREAKER δ TRANSFERS OPEN
PCB λ O
AC POWER NOT AVAILABLE FROM MCC η BREAKER δ
JOO η F
VALVE β MECHANICAL FAILURE
PMV θ D
NO AFWAS CHANNEL γ SIGNAL RELAY ϵ
PRE γ IF
VALVE β COMMON CIRCUIT FAILURE
VALVE β OPENING CIRCUIT FAILURE
CONTROL TRANSFORMER FOR VALVE β FAILS
PTR γ2–F
OVERLOAD AND BYPASS CIRCUITS FOR VALVE β TRANSFER OPEN
CONTROL POWER FUSE FOR VALVE β TRANSFERS OPEN
PFU γ2010
AUTOMATIC SIGNAL FOR VALVE β NOT PRESENT
VALVE β OPENING COIL FAILS OPEN
PCO γ2OCO
VALVE β CLOSING COIL FAILS I ENERGIZED POSITION
PCO γ2CCE
49 CONTACT FOR VALVE β TRANSFERS OPEN
PCN γ2490
AFWAS CONTACTS T1-M1 FOR VALVE β FAILS OPEN
PCN γ2T1O
AUTOMATIC CIRCUIT FOR VALVE β FAILS
3X CONTACTS 5-6 FOR VALVE β FAILS OPEN
PCN γ23X O
NO AC POWER FROM PANEL κ
JOO κF
BREAKER 52-02 FROM PANEL κ TRANSFERS OPEN
PCB κO
62 RELAY FOR CIRCUIT ρ FAILS
PRE ι162F
62 CONTACTS 1-5 FOR CIRCUIT ρ FAILS OPEN
PCN ι1620
RELAY τ DOES NOT PROVIDE LOW PRESSURE SIGNAL
3/4
3 X RELAY FOR CIRCUIT ρ FAILS
PRE ι13XF
CONTROL POWER FUSE FOR CIRCUIT ρ TRANSFERS OPEN
PFU ι106
AFWA CONT T3-M CIRC FAIL
PRESSURE TRANSMITTER ν1 FAILS
PTP π1M
PRESSURE TRANSMITTER ν2 FAILS
PTP π2M
PRESSURE TRANSMITTER ν3 FAILS
PTP π3M
PRESSURE TRANSMITTER ν4 FAILS
PTP π4M

α	β	γ	ε	η	δ	θ	ν1	ν2	ν3	ν4	ρ	κ	τ
E3	1MO-3893A1	1A	1B-K608	1BP3	II-1-52-02	8931	1PT-38000A1	1PT-38000A2	1PT-38000A3	1PT-38000A4	1AI055	1Y31	1KY-38000A
F3	1MO-3893A2	1A	1B-K603	1BP3	II-1-52-03	8932	1PT-38000A1	1PT-38000A2	1PT-38000A3	1PT-38000A4	1AI055	1Y31	1KY-38000A
B3	1MO-3893B1	1B	1A-K608	1BP4	I-1-52-03	8933	1PT-38000B1	1PT-38000B2	1PT-38000B3	1PT-38000B4	1BI055	1Y32	1KY-38000B
A3	1MO-3893B2	1B	1A-K603	1BP4	I-1-52-03	8934	1PT-38000B1	1PT-38000B2	1PT-38000B3	1PT-38000B4	1BI055	1Y32	1KY-38000B
E2	2MO-3993A1	2A	2B-K608	2BP3	II-2-52-02	9931	2PT-39000A1	2PT-39000A2	2PT-39000A3	2PT-39000A4	2AI055	2Y31	2KY-39000A
F2	2MO-3993A2	2A	2B-K603	2BP3	II-2-52-03	9932	2PT-39000A1	2PT-39000A2	2PT-39000A3	2PT-39000A4	2AI055	2Y31	2KY-39000A
B2	2MO-3993B1	2B	2A-K608	2BP4	I-2-52-02	9933	2PT-39000B1	2PT-39000B2	2PT-39000B3	2PT-39000B4	2BI055	2Y32	2KY-39000B
A2	2MO-3993B2	2B	2A-K603	2BP4	I-2-52-03	9934	2PT-39000B1	2PT-39000B2	2PT-39000B3	2PT-39000B4	2BI055	2Y32	2KY-39000B

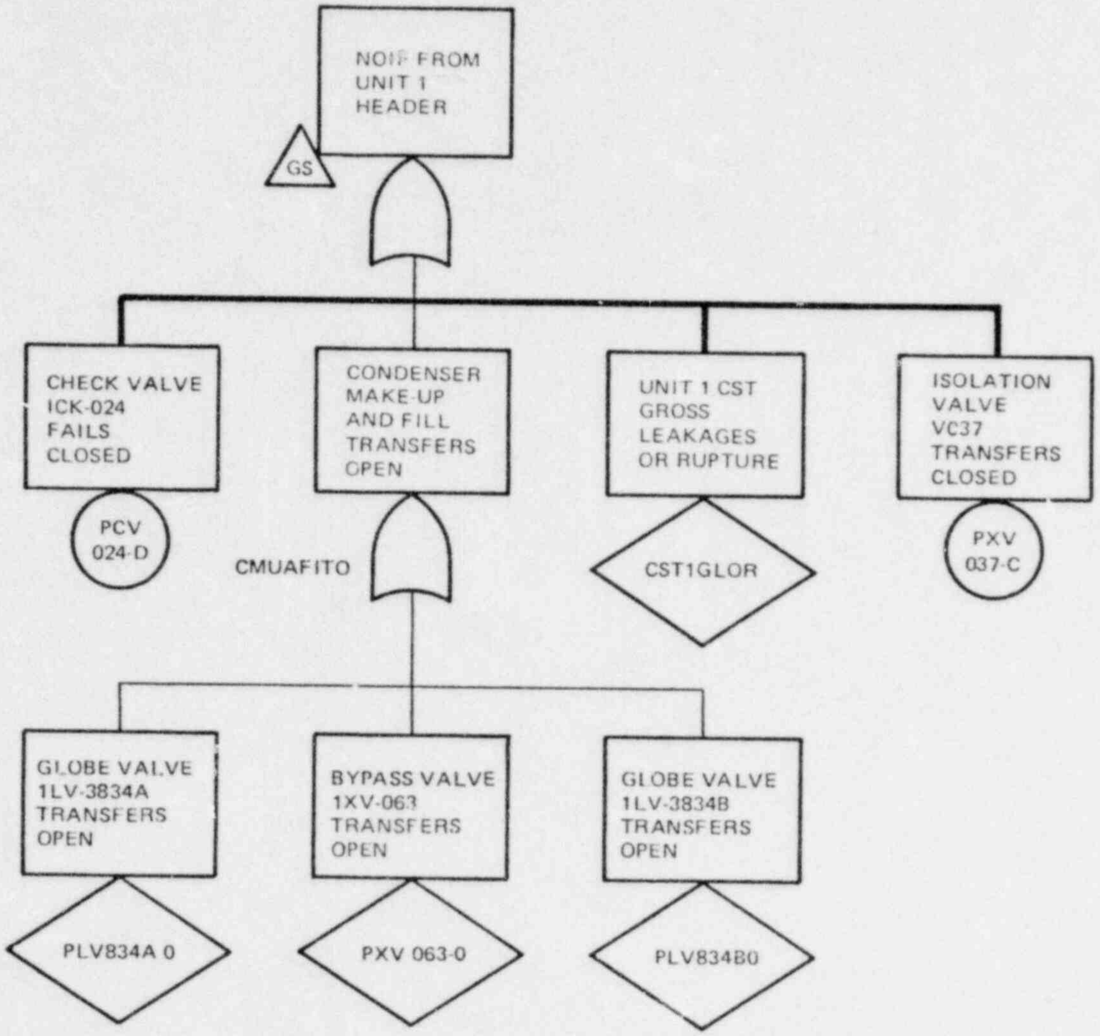


γ1	γ2	ξ	λ	ι1	π1	π2	π3	π4	Δ
1B08	1G	1P03	2102	1L	38A1	38A2	38A3	38A4	A1
1B03	1H	1P03	2103	1L	38A1	38A2	38A3	38A4	A2
1A08	1J	1P04	1102	1M	38B1	38B2	38B3	38B4	B1
1A03	1K	1P04	1103	1M	38B1	38B2	38B3	38B4	B2
2B08	2G	2P03	2202	2L	39A1	39A2	39A3	39A4	A3
2B03	2H	2P03	2203	2L	39A1	39A2	39A3	39A4	A4
2A08	2J	2P04	1202	2M	39B1	39B2	39B3	39B4	B3
2A03	2K	2P04	1203	2M	39B1	39B2	39B3	39B4	B4



PMV3856C

α	β	γ	δ
G3	1 MO-3856	3856	1L
G4	2 MO-3956	3956	2L

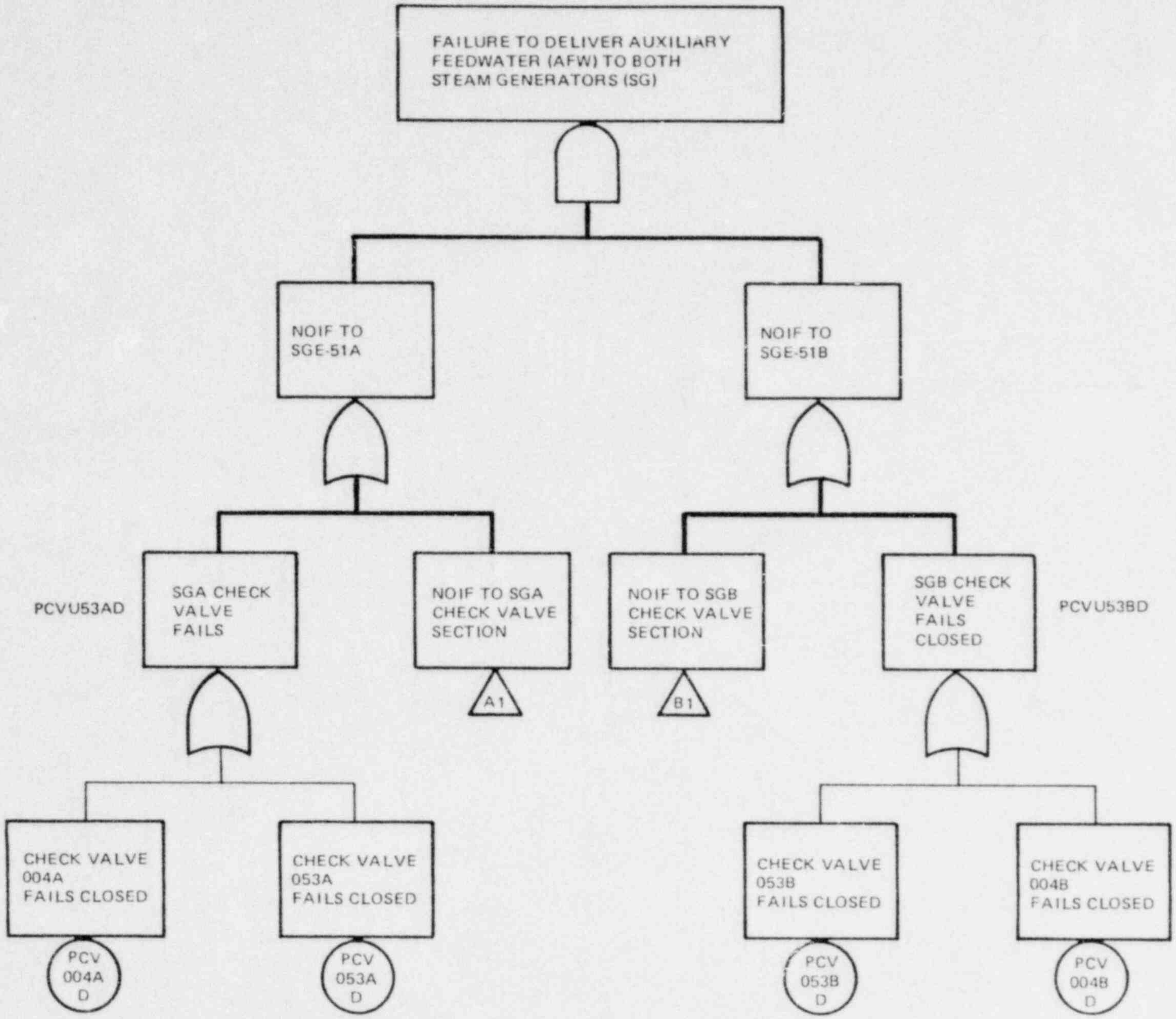

NOIF FROM UNIT 1 HEADER
GS
CHECK VALVE ICK-024 FAILS CLOSED
PCV 024-D
CONDENSER MAKE-UP AND FILL TRANSFERS OPEN
CMUAFITO
UNIT 1 CST GROSS LEAKAGES OR RUPTURE
CST1GLOR
ISOLATION VALVE VC37 TRANSFERS CLOSED
PXV 037-C
GLOBE VALVE 1LV-3834A TRANSFERS OPEN
PLV834A 0
BYPASS VALVE 1XV-063 TRANSFERS OPEN
PXV 063-0
GLOBE VALVE 1LV-3834B TRANSFERS OPEN
PLV834B0

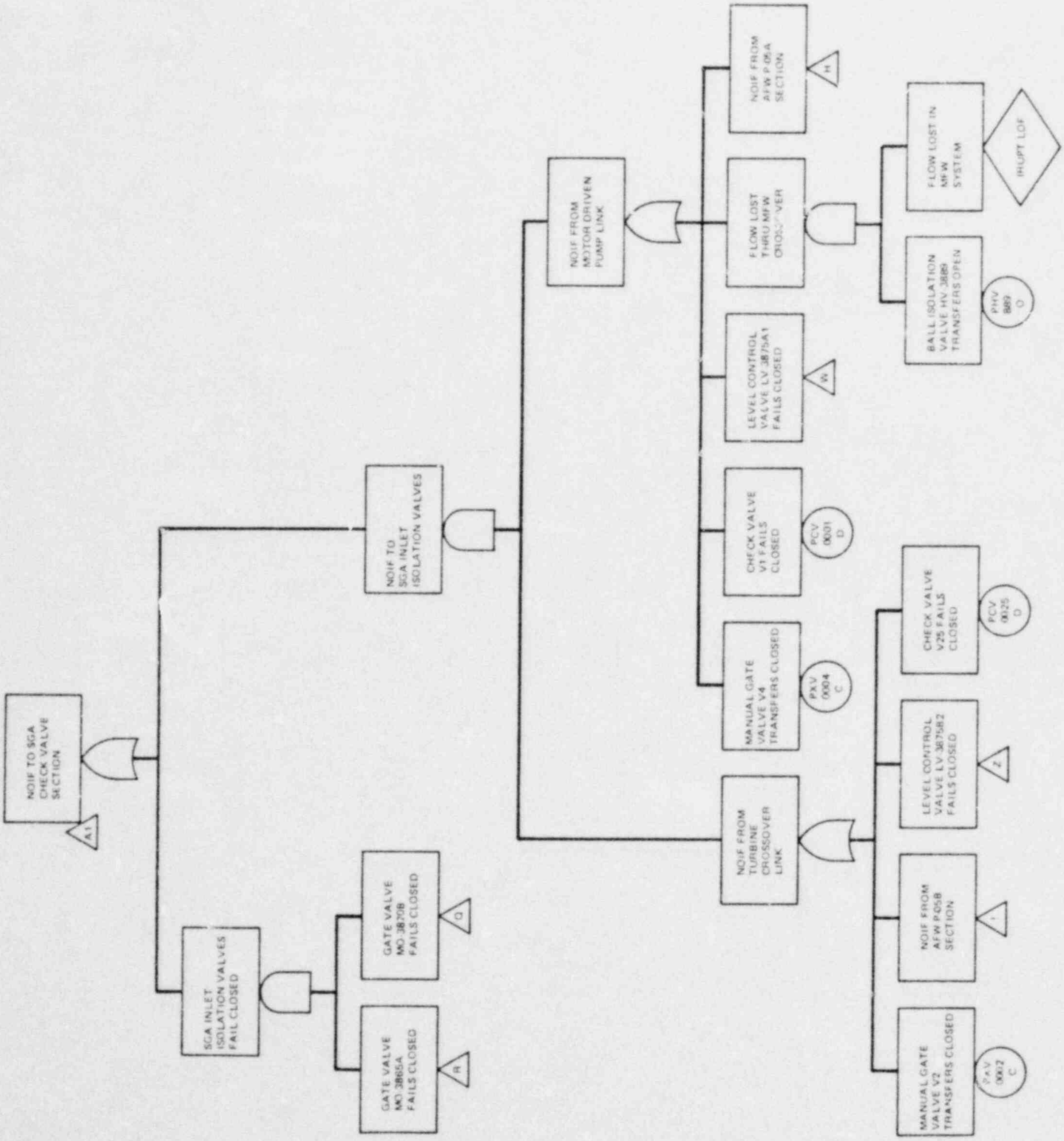
APPENDIX B

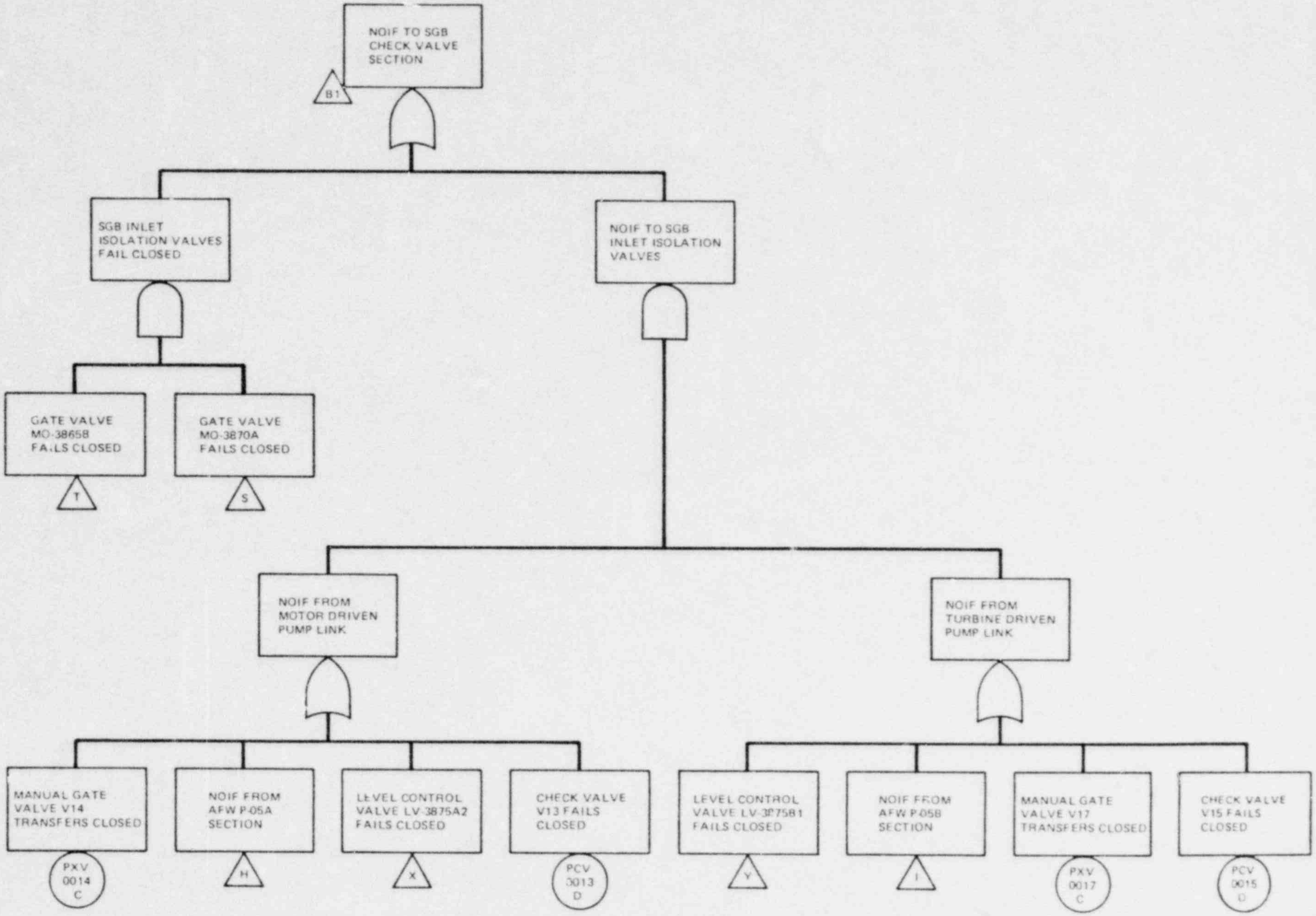
MIDLAND AUXILIARY FEEDWATER SYSTEM FAULT TREE

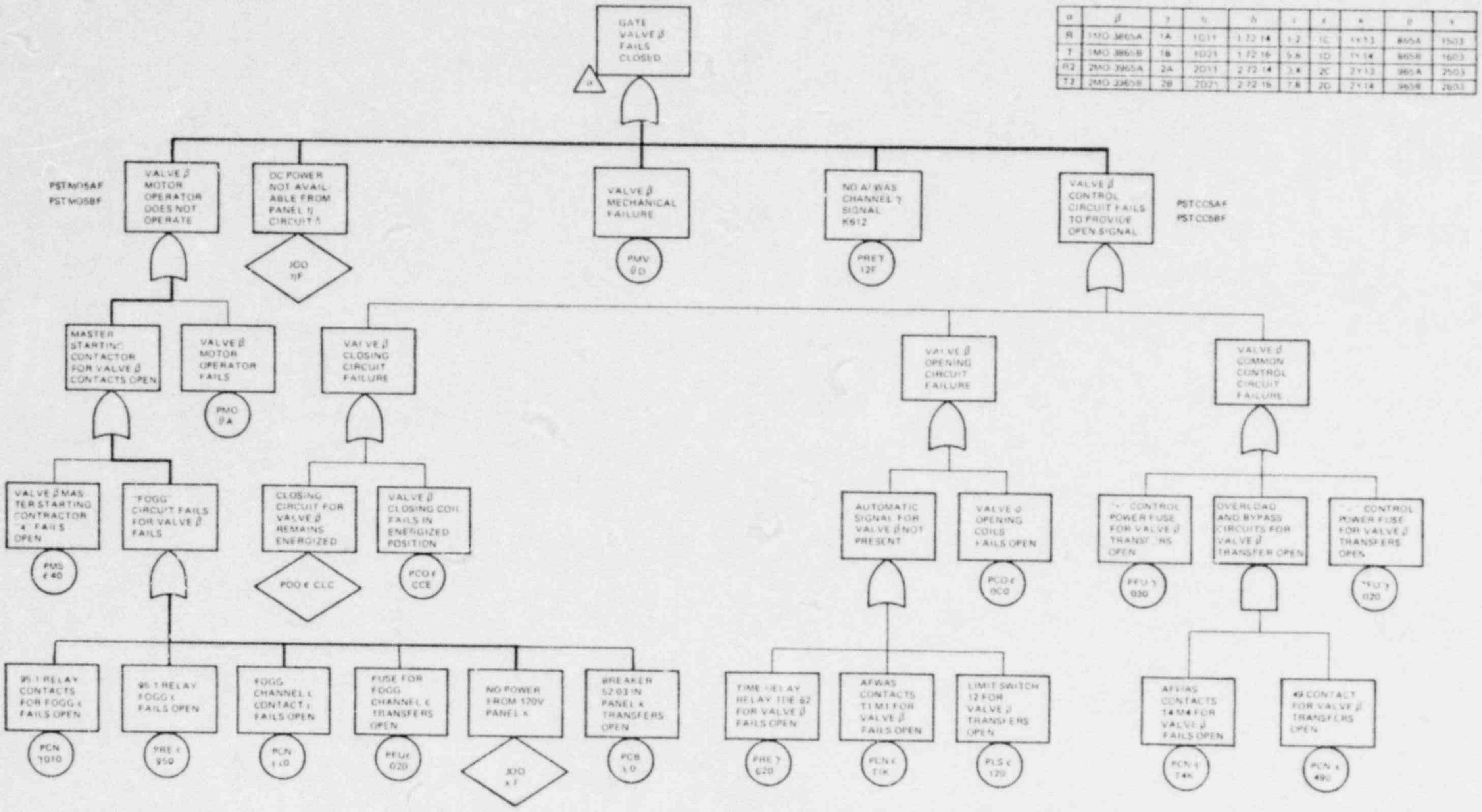
DOUBLE CROSSOVER DESIGN

This appendix presents the fault tree model constructed to represent the AFWS as it is presently designed at Midland. The tree logic defines the component failure modes necessary to fail the system. The fault trees have been heavy lined to show the level to which the quantification was performed. Quantification was performed to the level at which the most applicable data was available. The detailed fault trees were constructed to ensure that all components which could possibly affect the system performance were included in our analysis.

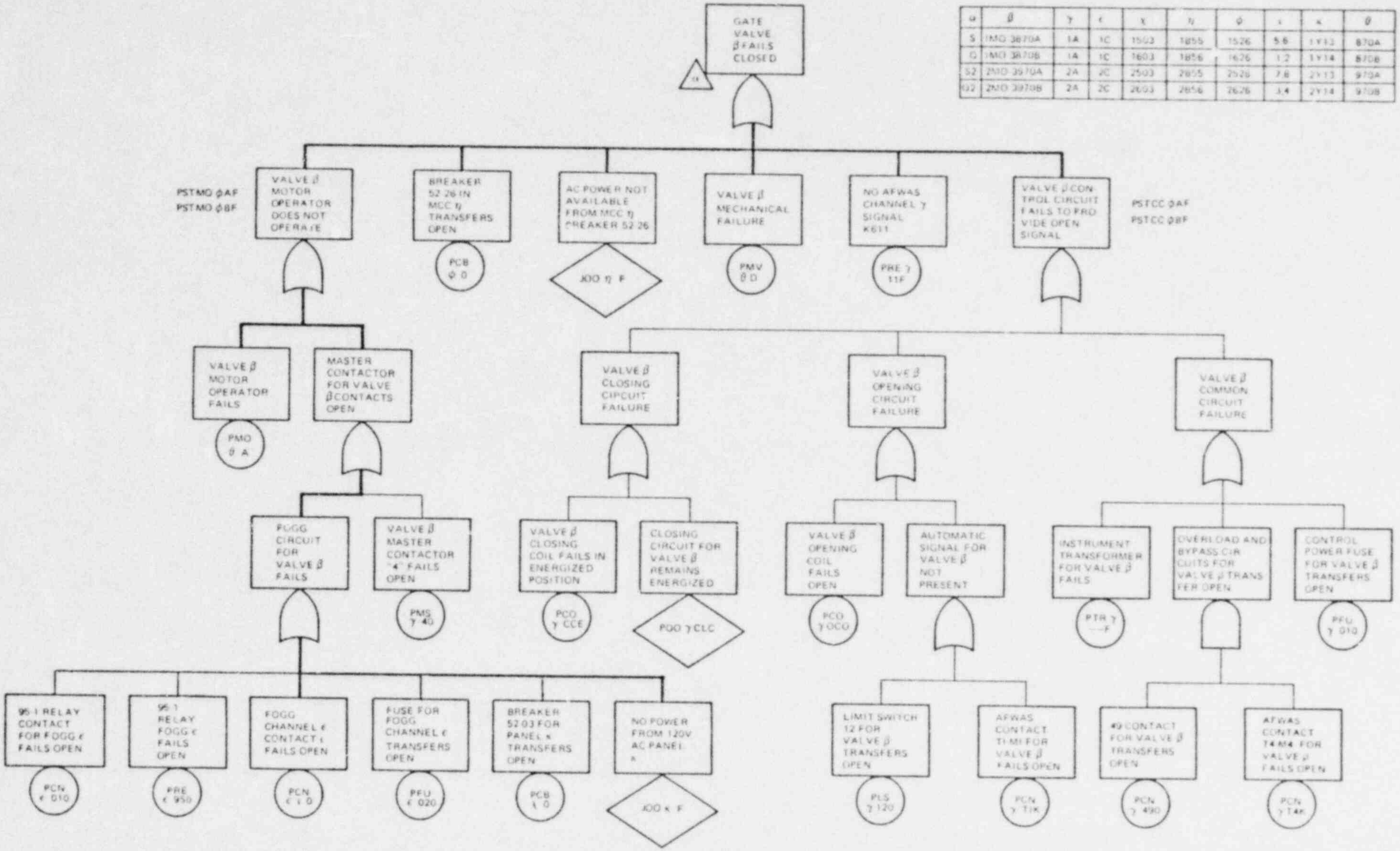

FAILURE TO DELIVER AUXILIARY FEEDWATER (AFW) TO BOTH STEAM GENERATORS (SG)
NOIF TO SGE-51A
NOIF TO SGE-51B
PCVU53AD
SGA CHECK VALVE FAILS
NOIF TO SGA CHECK VALVE SECTION
A1
NOIF TO SGB CHECK VALVE SECTION
B1
SGB CHECK VALVE FAILS CLOSED
PCVU53BD
CHECK VALVE 004A FAILS CLOSED
PCV 004A D
CHECK VALVE 053A FAILS CLOSED
PCV 053A D
CHECK VALVE 053B FAILS CLOSED
PCV 053B D
CHECK VALVE 004B FAILS CLOSED
PCV 004B D


NOIF TO SGA CHECK VALVE SECTION
A1
SGA INLET ISOLATION VALVES FAIL CLOSED
GATE VALVE MO 3865A FAILS CLOSED
R
GATE VALVE MO 3870B FAILS CLOSED
Q
NOIF TO SGA INLET ISOLATION VALVES
NOIF FROM MOTOR DRIVEN PUMP LINK
MANUAL GATE VALVE V4 TRANSFERS CLOSED
PXV 0004 C
CHECK VALVE V1 FAILS CLOSED
PCV 0001 D
LEVEL CONTROL VALVE LV 3875A1 FAILS CLOSED
W
FLOW LOST THRU MFW CROSSOVER
NOIF FROM AFW P-05A SECTION
H
BALL ISOLATION VALVE HV 3889 TRANSFERS OPEN
PHV 889 O
FLOW LOST IN MFW SYSTEM
INPUT LOF
NOIF FROM TURBINE CROSSOVER LINK
MANUAL GATE VALVE V2 TRANSFERS CLOSED
PXV 0002 C
NOIF FROM AFW P-05B SECTION
I
LEVEL CONTROL VALVE LV-3875B2 FAILS CLOSED
Z
CHECK VALVE V25 FAILS CLOSED
PCV 0025 D

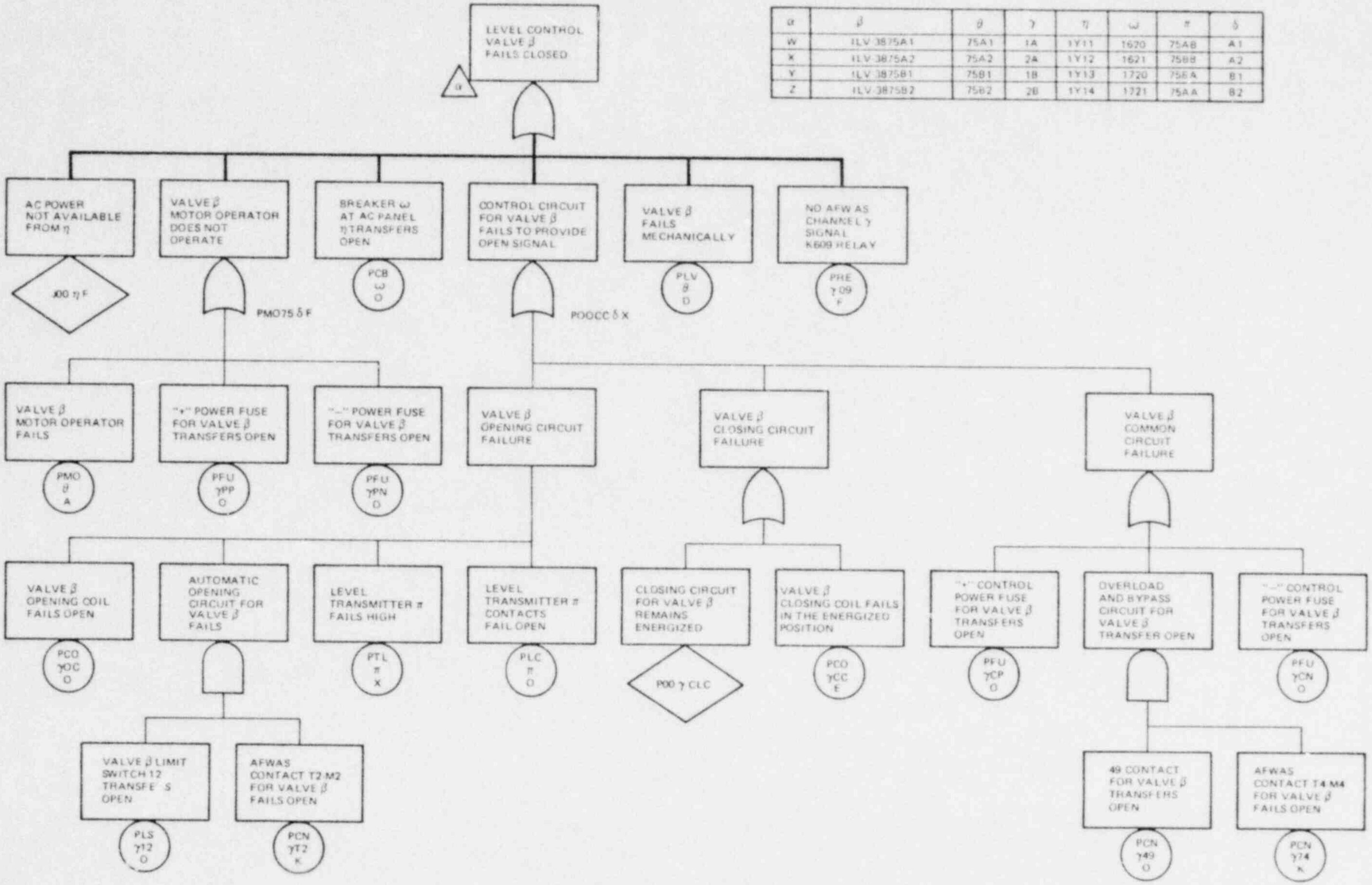

NOIF TO SGB CHECK VALVE SECTION
B1
SGB INLET ISOLATION VALVES FAIL CLOSED
NOIF TO SGB INLET ISOLATION VALVES
GATE VALVE MO-3865B FAILS CLOSED
T
GATE VALVE MO-3870A FAILS CLOSED
S
NOIF FROM MOTOR DRIVEN PUMP LINK
NOIF FROM TURBINE DRIVEN PUMP LINK
MANUAL GATE VALVE V14 TRANSFERS CLOSED
PXV 0014 C
NOIF FROM AFW P-05A SECTION
H
LEVEL CONTROL VALVE LV-3875A2 FAILS CLOSED
X
CHECK VALVE V13 FAILS CLOSED
PCV 0013 D
LEVEL CONTROL VALVE LV-3875B1 FAILS CLOSED
Y
NOIF FROM AFW P-05B SECTION
I
MANUAL GATE VALVE V17 TRANSFERS CLOSED
PXV 0017 C
CHECK VALVE V15 FAILS CLOSED
PCV 0015 D



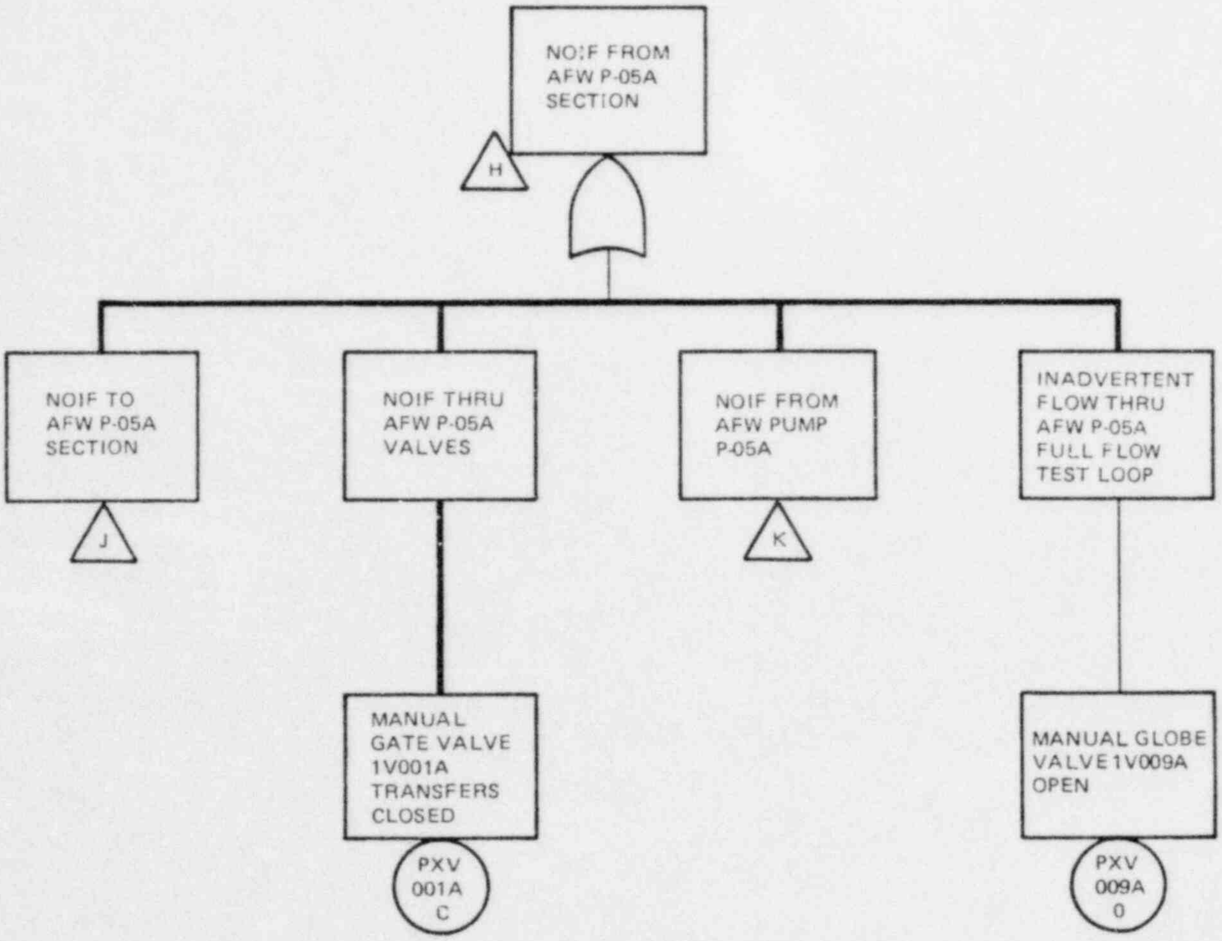
α	β	γ	η	δ	ι	ε	κ	θ	χ
R	1MO 3865A	1A	1D11	1 72 14	1 2	1C	1Y13	865A	1503
T	1MO 3865B	1B	1D21	1 72 16	5 6	1D	1Y14	865B	1603
R2	2MO 3965A	2A	2D11	2 72 14	3 4	2C	2Y13	965A	2503
T2	2MO 3965B	2B	2D21	2 72 16	7 8	2D	2Y14	965B	2603



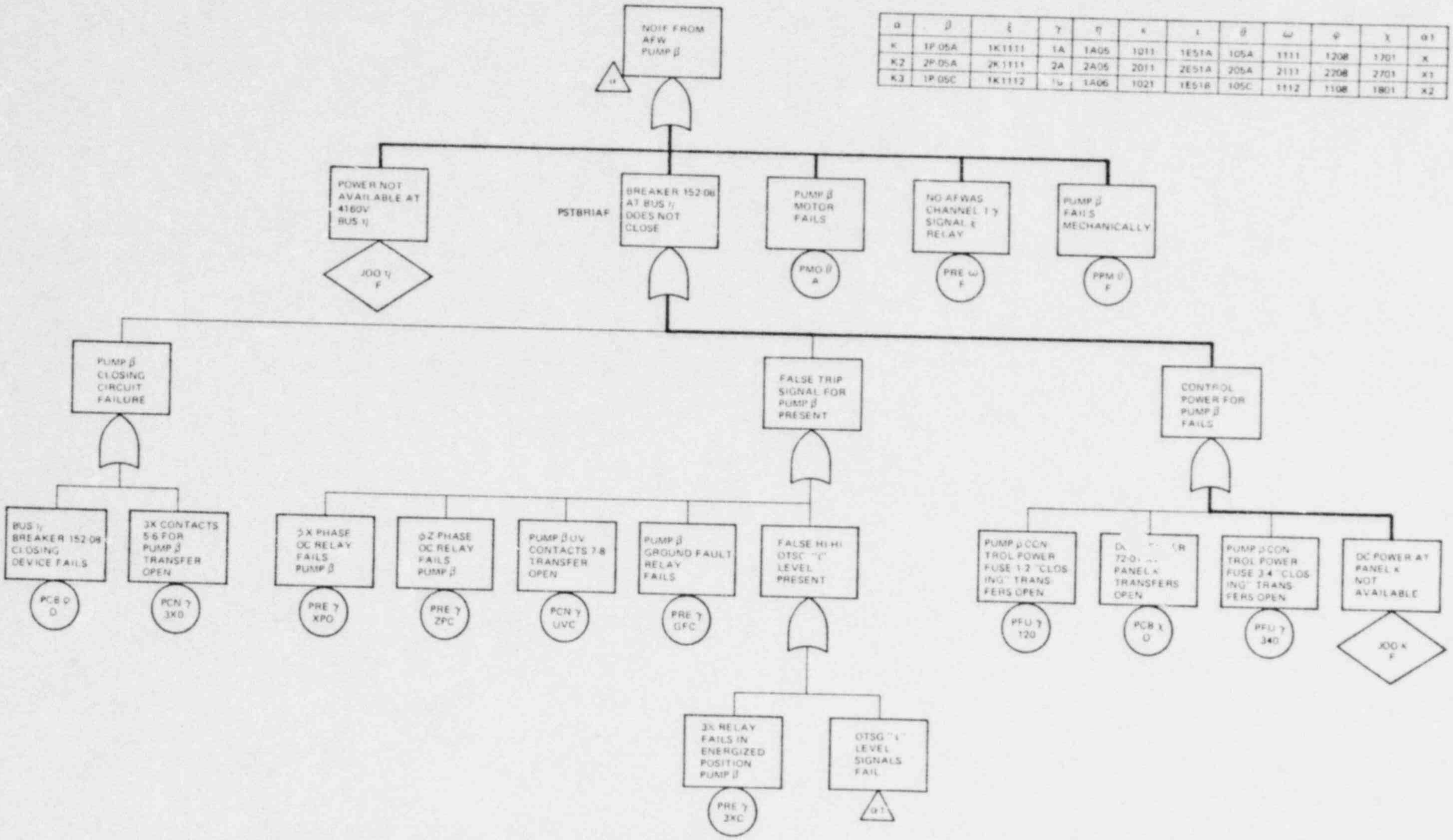
α	β	γ	ε	χ	η	φ	ι	κ	θ
S	1MO 3870A	1A	1C	1503	1855	1526	5.6	1Y13	870A
Q	1MO 3870B	1A	1C	1603	1856	1626	1.2	1Y14	870B
S2	2MO 3970A	2A	2C	2503	2855	2526	7.8	2Y13	970A
Q2	2MO 3970B	2A	2C	2603	2856	2626	3.4	2Y14	970B

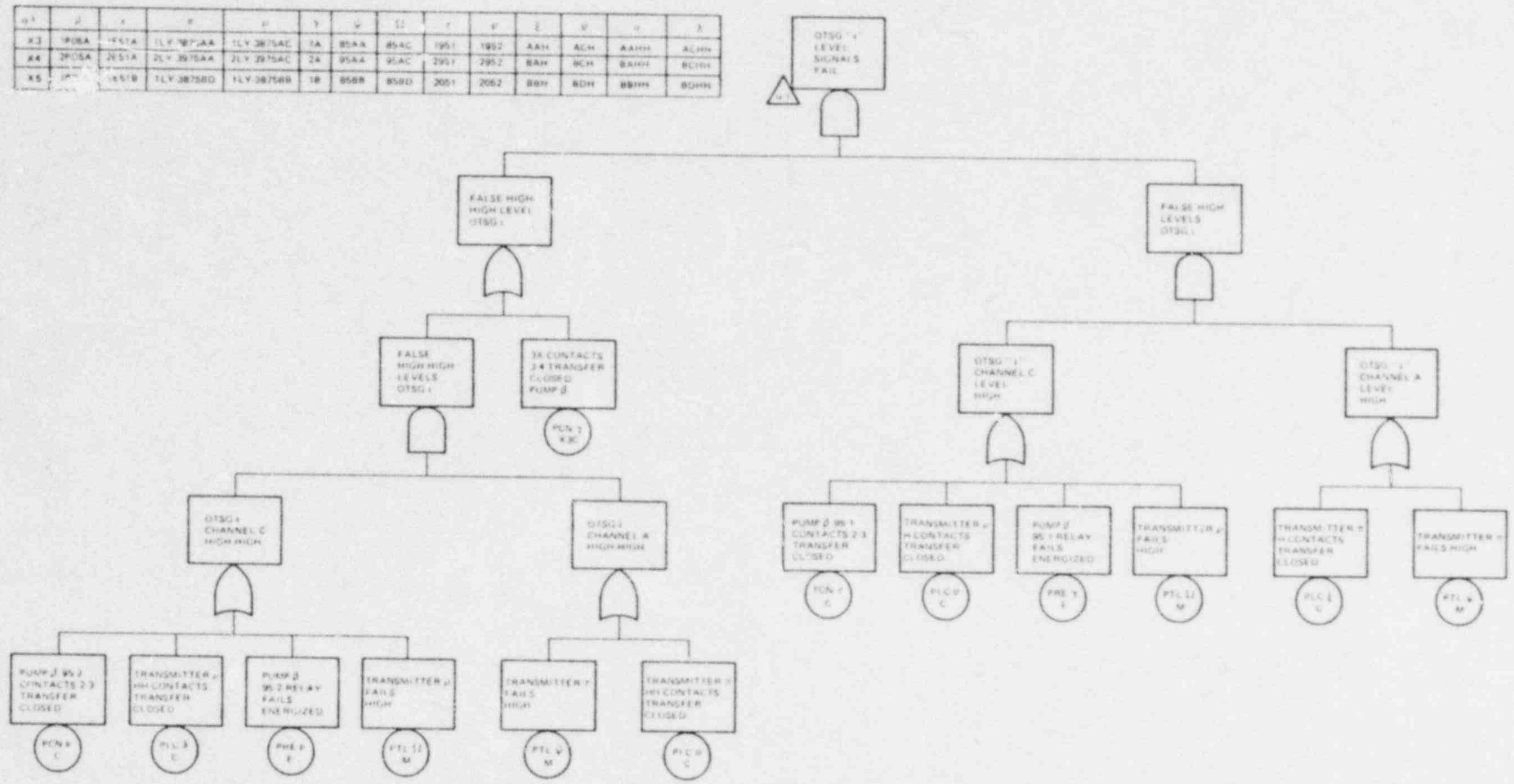


α	β	θ	γ	η	ω	π	δ
W	ILV-3875A1	75A1	1A	1Y11	1620	75AB	A1
X	ILV-3875A2	75A2	2A	1Y12	1621	75BB	A2
Y	ILV-3875B1	75B1	1B	1Y13	1720	75BA	B1
Z	ILV-3875B2	75B2	2B	1Y14	1721	75AA	B2

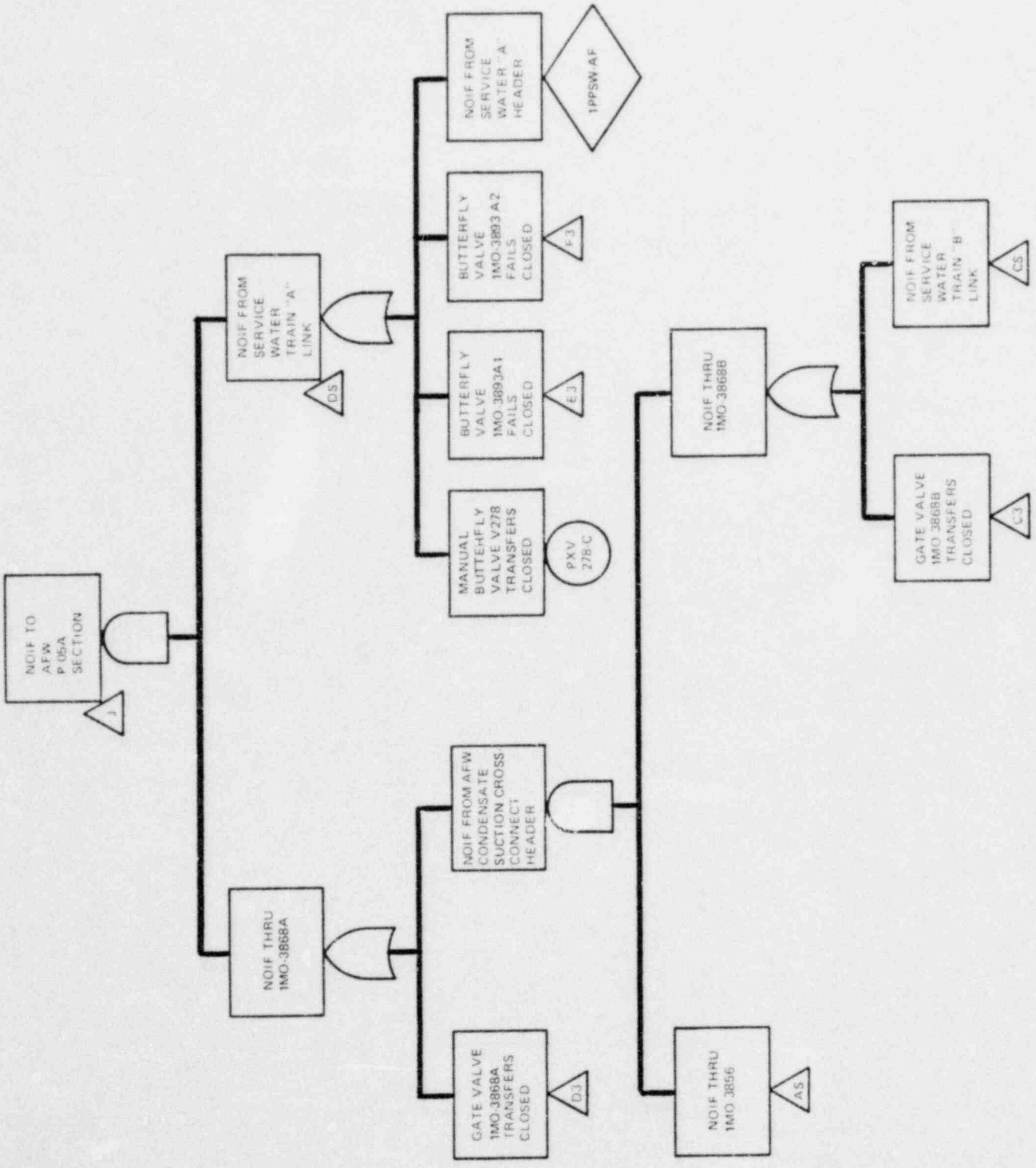

NOIF FROM AFW P-05A SECTION
H
NOIF TO AFW P-05A SECTION
J
NOIF THRU AFW P-05A VALVES
NOIF FROM AFW PUMP P-05A
K
INADVERTENT FLOW THRU AFW P-05A FULL FLOW TEST LOOP
MANUAL GATE VALVE 1V001A TRANSFERS CLOSED
PXV 001A C
MANUAL GLOBE VALVE 1V009A OPEN
PXV 009A 0

α	β	ξ	γ	η	κ	ι	θ	ω	φ	χ	α1
K	1P 05A	1K1111	1A	1A05	1011	1E51A	105A	1111	1208	1701	X
K2	2P 05A	2K1111	2A	2A05	2011	2E51A	205A	2111	2208	2701	X1
K3	1P 05C	1K1112	1C	1A06	1021	1E51B	105C	1112	1108	1801	X2





α^1	β	κ	π	ρ	γ	ψ	Ω	τ	υ	ξ	ν	η	λ
X3	1P08A	1E51A	1LY 3875AA	1LY 3875AC	1A	85AA	854C	1951	1952	AAH	ACH	AAHH	ACHH
X4	2P05A	2E51A	2LY 3975AA	2LY 3975AC	2A	95AA	95AC	2951	2952	BAH	BCH	BAHH	BCHH
X5	1P[illegible]	1E51B	1LY 3875BD	1LY 3875BB	1B	85BB	85BD	2051	2052	BBH	BDH	BBHH	BDHH


NOIF TO AFW P 05A SECTION
J
NOIF FROM SERVICE WATER TRAIN "A" LINK
D5
MANUAL BUTTEHFLY VALVE V278 TRANSFERS CLOSED
PXV 278-C
BUTTERFLY VALVE 1MO-3893A1 FAILS CLOSED
E3
BUTTERFLY VALVE 1MO-3893 A2 FAILS CLOSED
F3
NOIF FROM SERVICE WATER "A" HEADER
1PPSW-AF
NOIF THRU 1MO-3868A
GATE VALVE 1MO-3868A TRANSFERS CLOSED
D3
NOIF FROM AFW CONDENSATE SUCTION CROSS CONNECT HEADER
NOIF THRU 1MO 3856
A5
NOIF THRU 1MO 3868B
GATE VALVE 1MO 3868B TRANSFERS CLOSED
C3
NOIF FROM SERVICE WATER TRAIN "B" LINK
C5

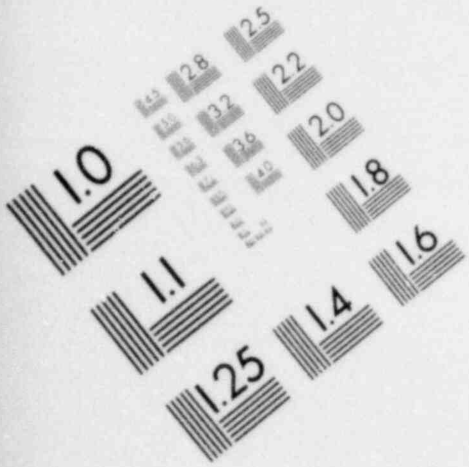
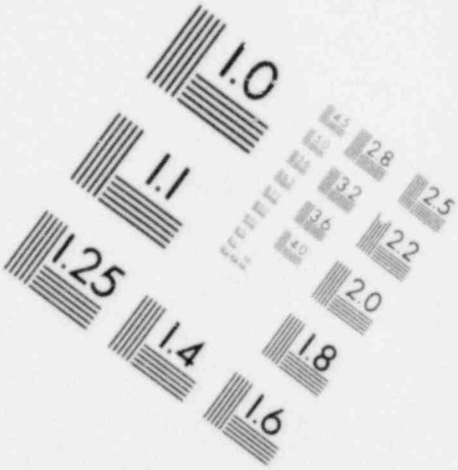
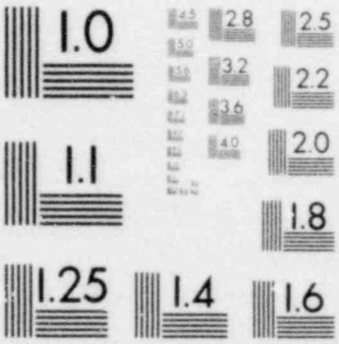
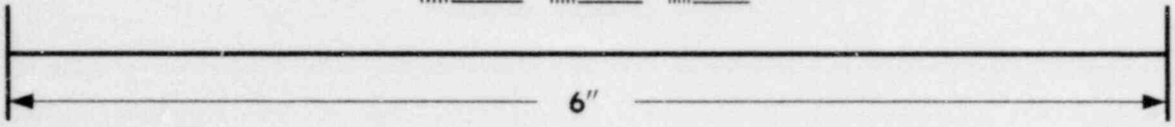
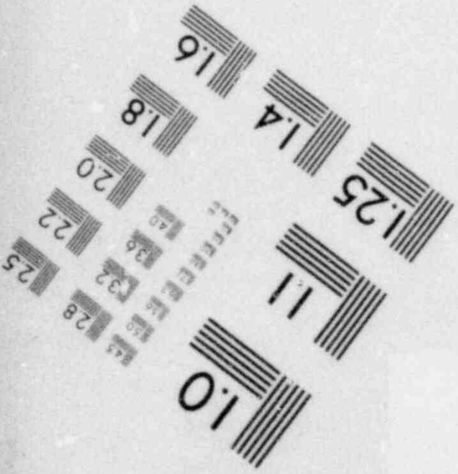
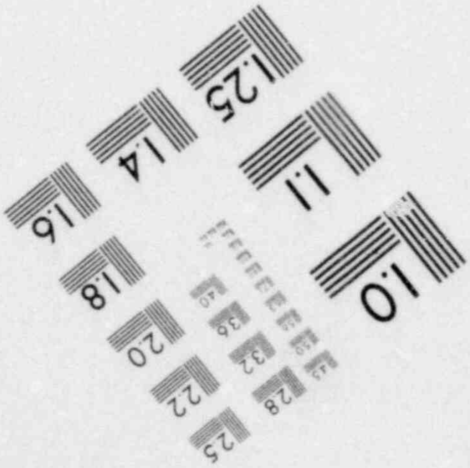
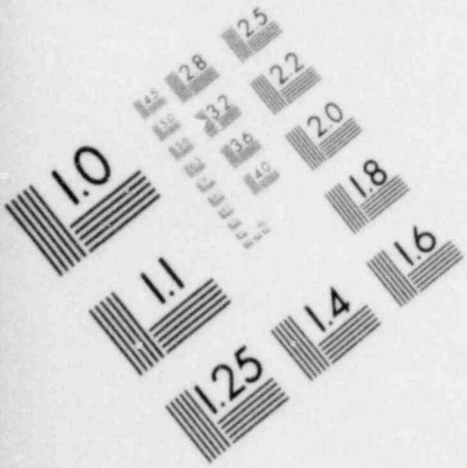



IMAGE EVALUATION TEST TARGET (MT-3)







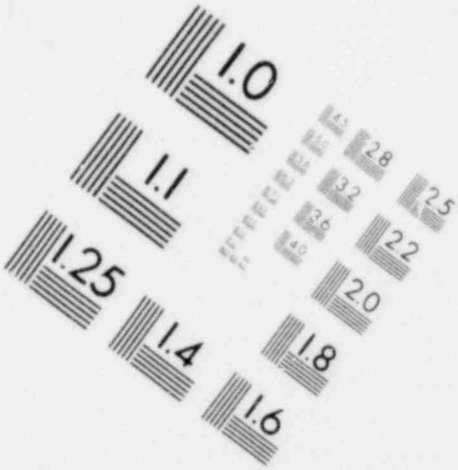
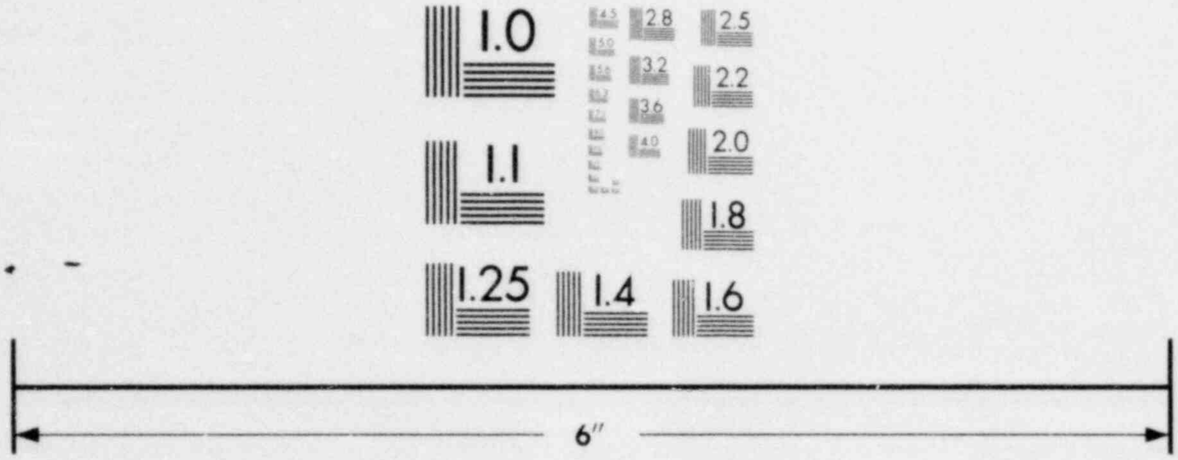
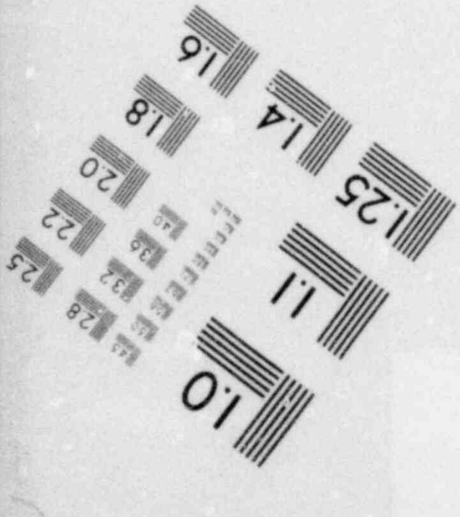
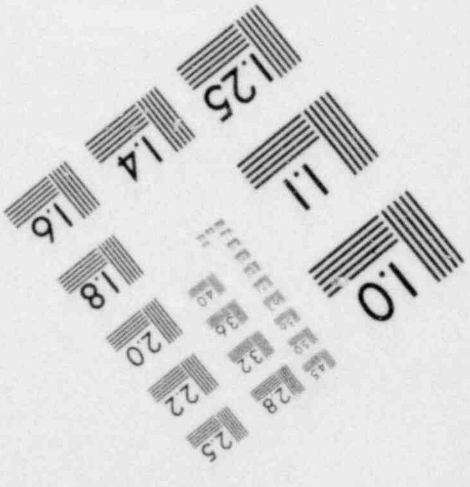
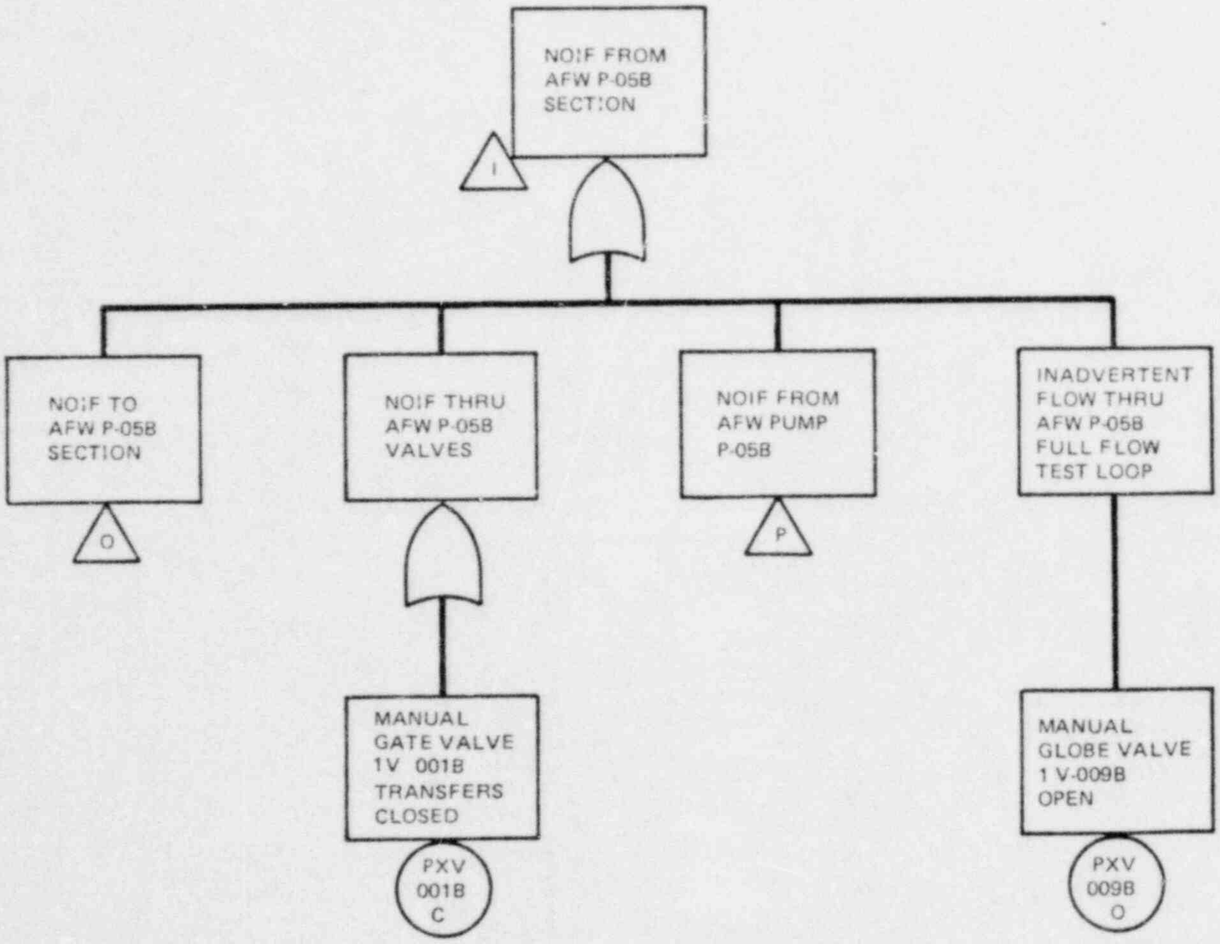


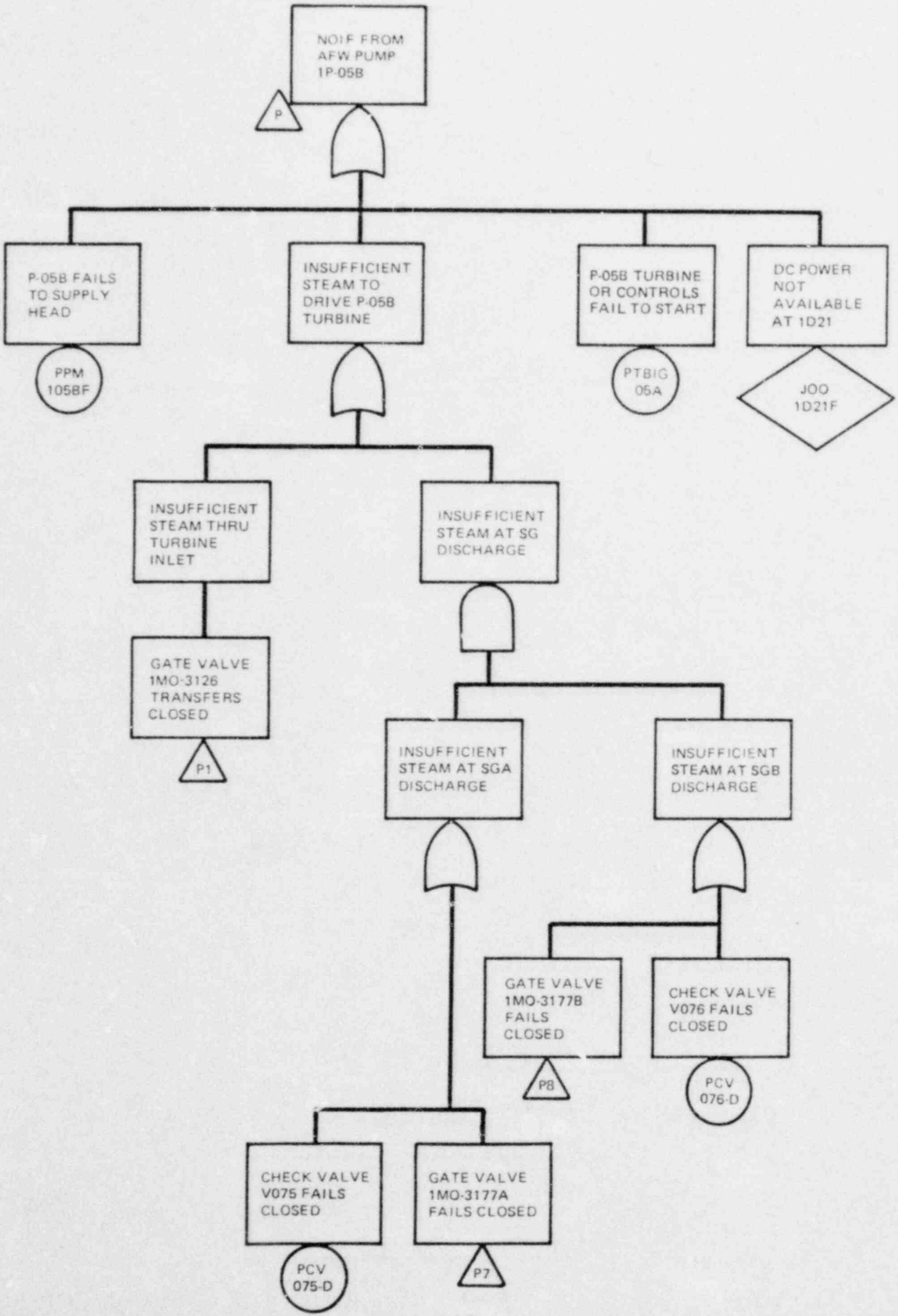
IMAGE EVALUATION TEST TARGET (MT-3)

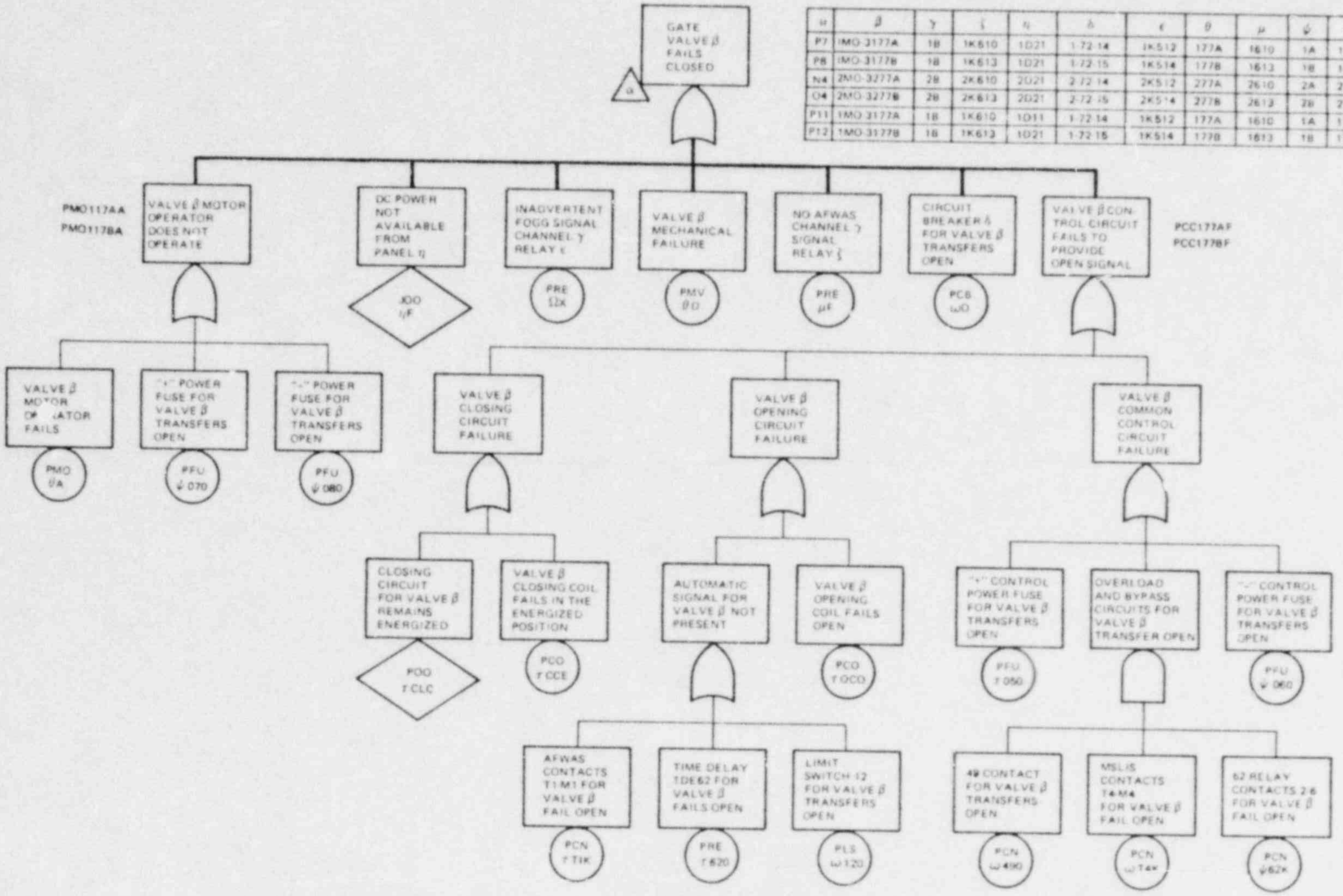




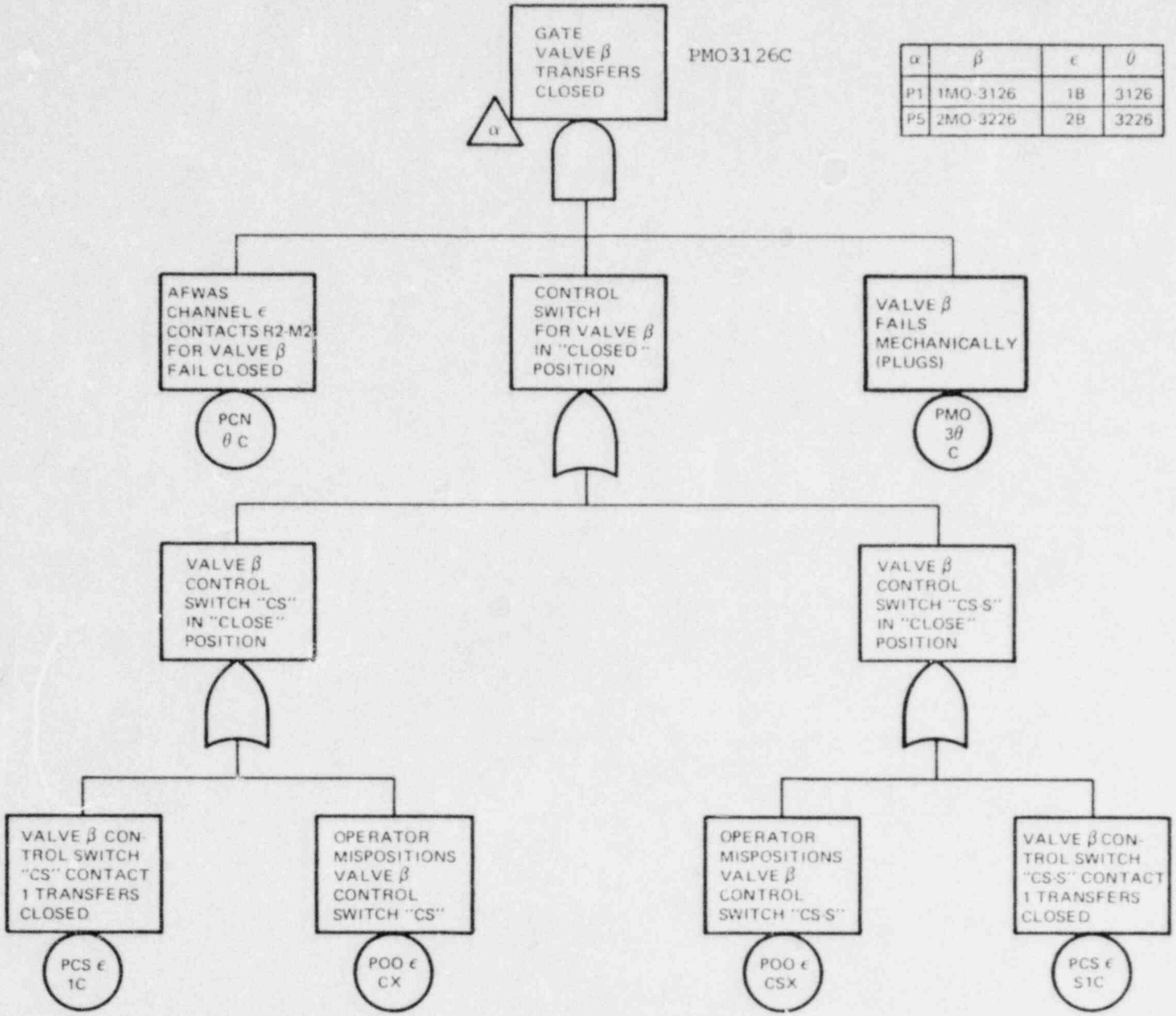



NOIF FROM AFW P-05B SECTION
I
NOIF TO AFW P-05B SECTION
O
NOIF THRU AFW P-05B VALVES
NOIF FROM AFW PUMP P-05B
P
INADVERTENT FLOW THRU AFW P-05B FULL FLOW TEST LOOP
MANUAL GATE VALVE 1V 001B TRANSFERS CLOSED
PXV 001B C
MANUAL GLOBE VALVE 1 V-009B OPEN
PXV 009B O

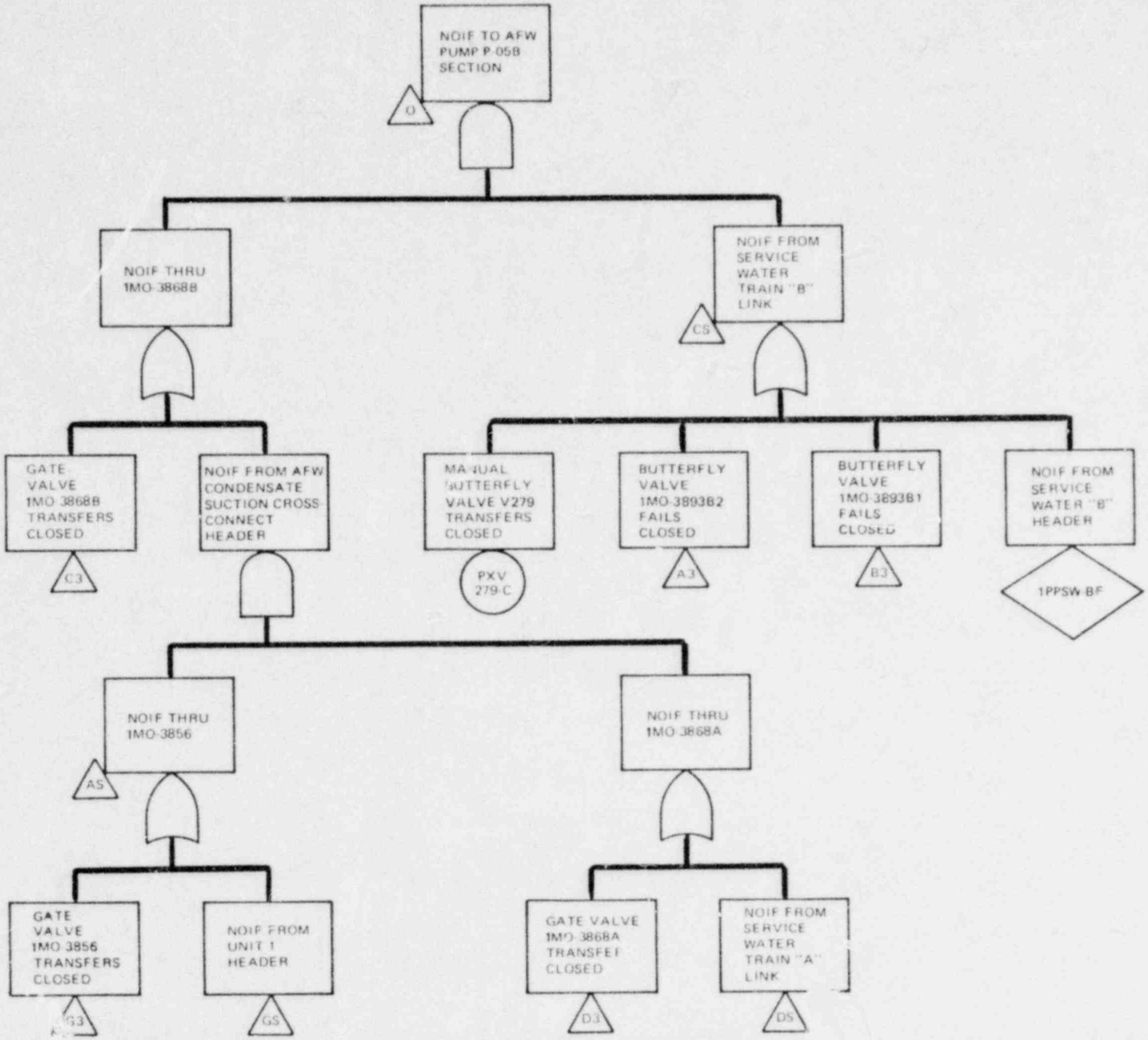

NOIF FROM AFW PUMP 1P-05B
P
P-05B FAILS TO SUPPLY HEAD
PPM 105BF
INSUFFICIENT STEAM TO DRIVE P-05B TURBINE
P-05B TURBINE OR CONTROLS FAIL TO START
PTBIG 05A
DC POWER NOT AVAILABLE AT 1D21
JOO 1D21F
INSUFFICIENT STEAM THRU TURBINE INLET
INSUFFICIENT STEAM AT SG DISCHARGE
GATE VALVE 1MO-3126 TRANSFERS CLOSED
P1
INSUFFICIENT STEAM AT SGA DISCHARGE
INSUFFICIENT STEAM AT SGB DISCHARGE
GATE VALVE 1MO-3177B FAILS CLOSED
P8
CHECK VALVE V076 FAILS CLOSED
PCV 076-D
CHECK VALVE V075 FAILS CLOSED
PCV 075-D
GATE VALVE 1MO-3177A FAILS CLOSED
P7

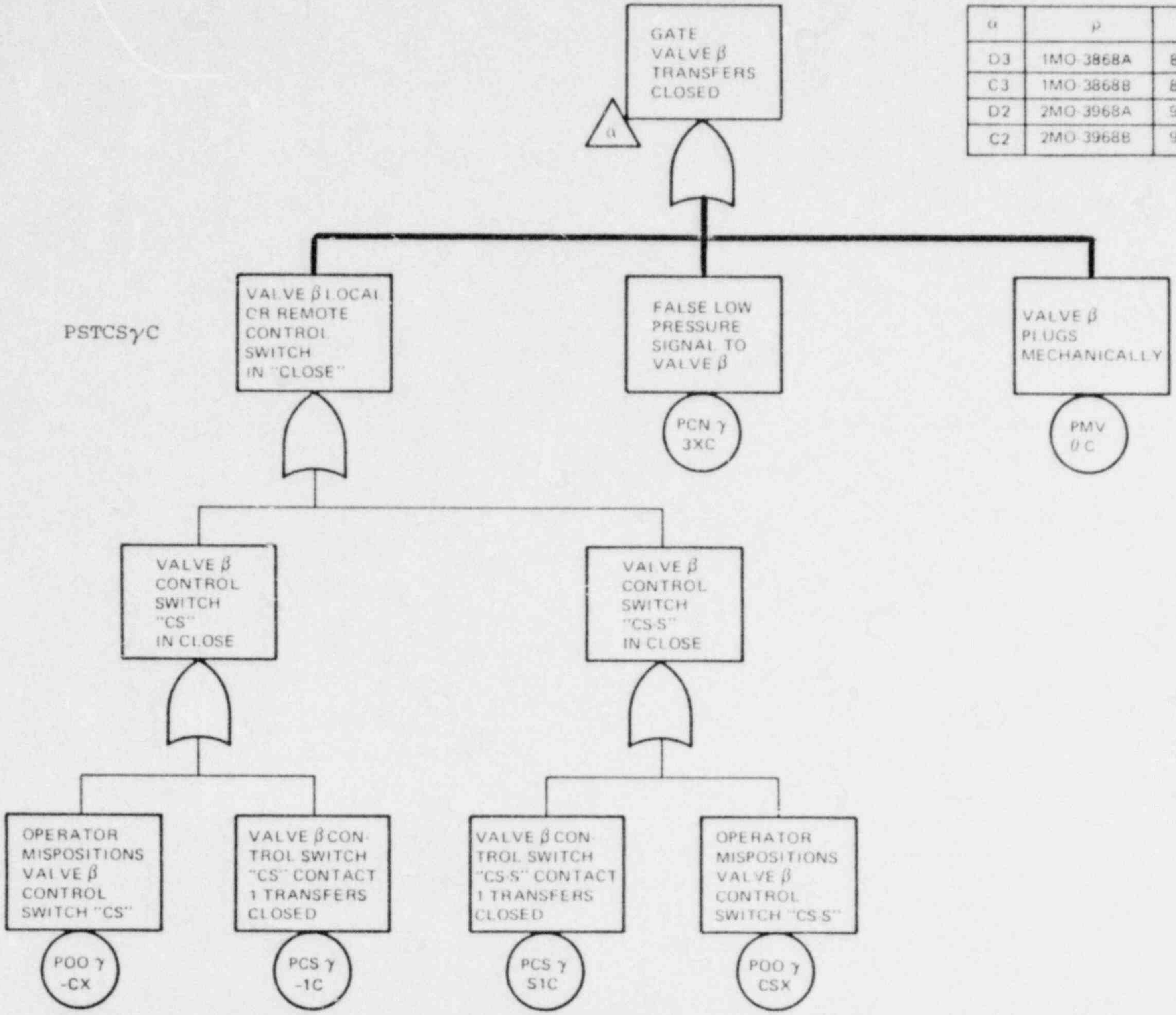


α	β	γ	ζ	η	δ	ε	θ	μ	ψ	ω	Ω	τ
P7	IMO-3177A	1B	1K610	1D21	1-72-14	1K512	177A	1610	1A	1714	1512	1E
P8	IMO-3177B	1B	1K613	1D21	1-72-15	1K514	177B	1613	1B	1715	1514	1F
N4	2MO-3277A	2B	2K610	2D21	2-72-14	2K512	277A	2610	2A	2714	2512	2E
O4	2MO-3277B	2B	2K613	2D21	2-72-15	2K514	277B	2613	2B	2715	2614	2F
P11	1MO-3177A	1B	1K610	1D11	1-72-14	1K512	177A	1610	1A	1714	1512	1E
P12	1MO-3177B	1B	1K613	1D21	1-72-15	1K514	177B	1613	1B	1715	1514	1F

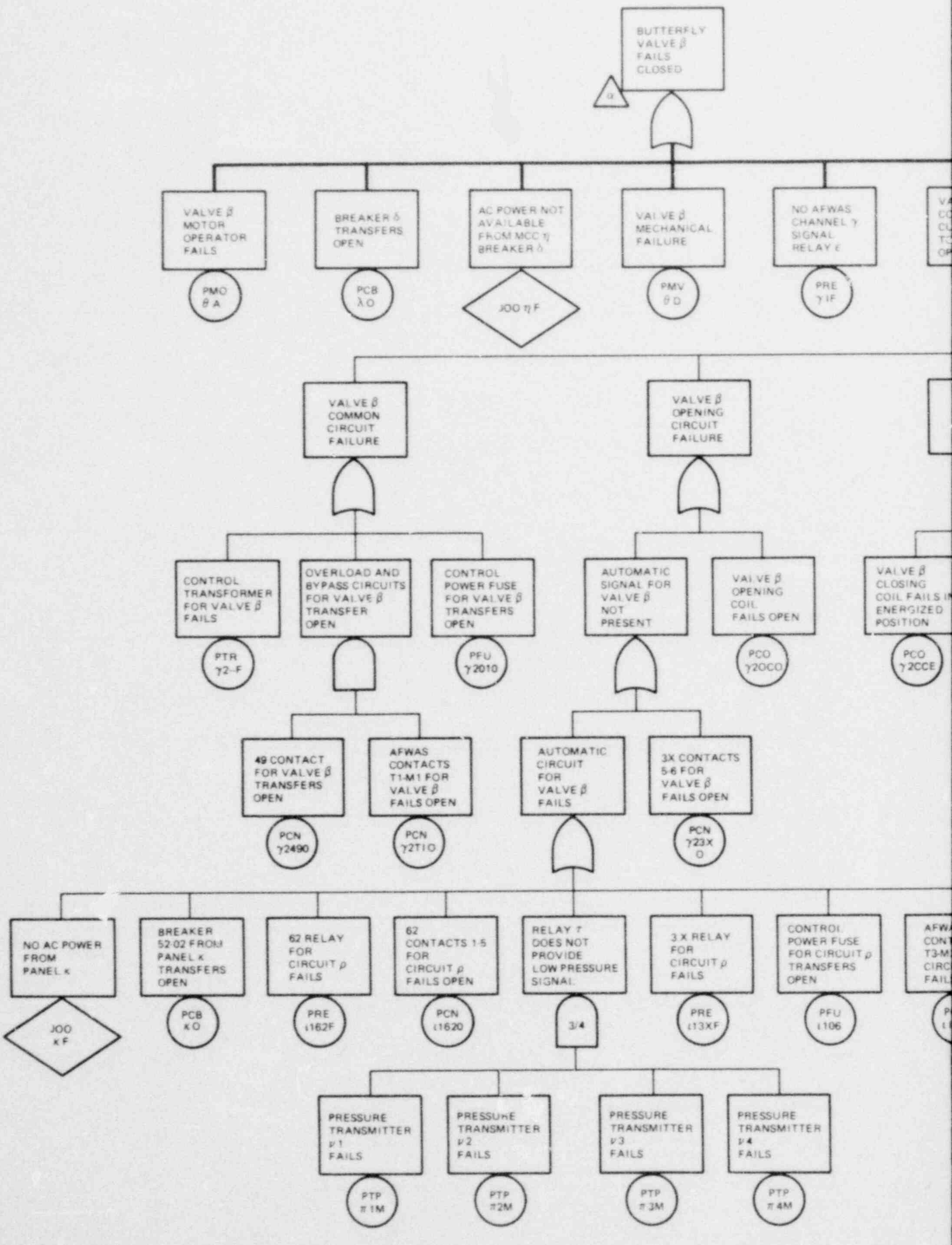


α	β	ϵ	θ
P1	1MO-3126	1B	3126
P5	2MO-3226	2B	3226


NOIF TO AFW PUMP P-05B SECTION
O
NOIF THRU 1MO-3868B
NOIF FROM SERVICE WATER TRAIN "B" LINK
CS
GATE VALVE 1MO-3868B TRANSFERS CLOSED
C3
NOIF FROM AFW CONDENSATE SUCTION CROSS-CONNECT HEADER
MANUAL BUTTERFLY VALVE V279 TRANSFERS CLOSED
PXV 279-C
BUTTERFLY VALVE 1MO-3893B2 FAILS CLOSED
A3
BUTTERFLY VALVE 1MO-3893B1 FAILS CLOSED
B3
NOIF FROM SERVICE WATER "B" HEADER
1PPSW-BF
NOIF THRU 1MO-3856
AS
NOIF THRU 1MO-3868A
GATE VALVE 1MO-3856 TRANSFERS CLOSED
G3
NOIF FROM UNIT 1 HEADER
GS
GATE VALVE 1MO-3868A TRANSFERS CLOSED
D3
NOIF FROM SERVICE WATER TRAIN "A" LINK
DS



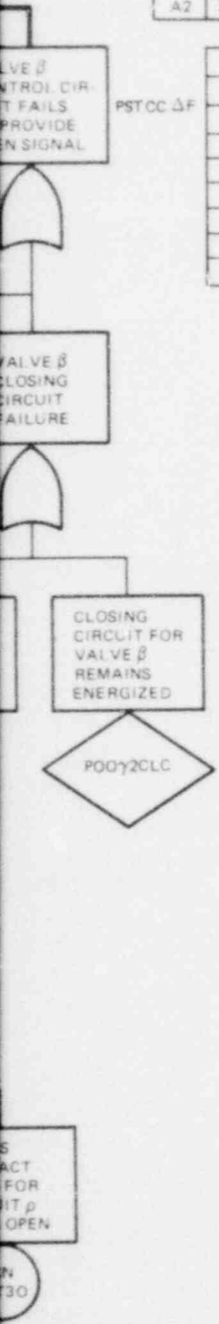
α	β	θ	γ
D3	1MO-3868A	868A	1A
C3	1MO-3868B	868B	1B
D2	2MO-3968A	968A	2A
C2	2MO-3968B	968B	2B

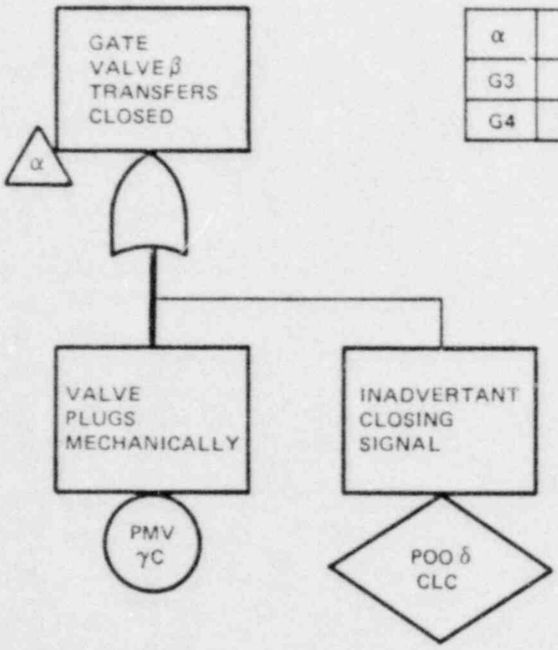

BUTTERFLY VALVE β FAILS CLOSED
α
VALVE β MOTOR OPERATOR FAILS
PMO θA
BREAKER δ TRANSFERS OPEN
PCB λO
AC POWER NOT AVAILABLE FROM MCC η BREAKER δ
JOO η F
VALVE β MECHANICAL FAILURE
PMV θD
NO AFWAS CHANNEL γ SIGNAL RELAY ε
PRE γIF
VALVE β COMMON CIRCUIT FAILURE
VALVE β OPENING CIRCUIT FAILURE
CONTROL TRANSFORMER FOR VALVE β FAILS
PTR γ2--F
OVERLOAD AND BYPASS CIRCUITS FOR VALVE β TRANSFER OPEN
CONTROL POWER FUSE FOR VALVE β TRANSFERS OPEN
PFU γ2010
AUTOMATIC SIGNAL FOR VALVE β NOT PRESENT
VALVE β OPENING COIL FAILS OPEN
PCO γ2OCO
VALVE β CLOSING COIL FAILS I ENERGIZED POSITION
PCO γ2CCE
49 CONTACT FOR VALVE β TRANSFERS OPEN
PCN γ2490
AFWAS CONTACTS T1-M1 FOR VALVE β FAILS OPEN
PCN γ2T1O
AUTOMATIC CIRCUIT FOR VALVE β FAILS
3X CONTACTS 5-6 FOR VALVE β FAILS OPEN
PCN γ23X O
NO AC POWER FROM PANEL κ
JOO κF
BREAKER 52-02 FROM PANEL κ TRANSFERS OPEN
PCB κO
62 RELAY FOR CIRCUIT ρ FAILS
PRE ι162F
62 CONTACTS 1-5 FOR CIRCUIT ρ FAILS OPEN
PCN ι1620
RELAY τ DOES NOT PROVIDE LOW PRESSURE SIGNAL
3/4
3 X RELAY FOR CIRCUIT ρ FAILS
PRE ι13XF
CONTROL POWER FUSE FOR CIRCUIT ρ TRANSFERS OPEN
PFU ι106
PRESSURE TRANSMITTER ν1 FAILS
PTP π1M
PRESSURE TRANSMITTER ν2 FAILS
PTP π2M
PRESSURE TRANSMITTER ν3 FAILS
PTP π3M
PRESSURE TRANSMITTER ν4 FAILS
PTP π4M

α	β	γ	ε	η	δ	υ	ν1	ν2	ν3	ν4	ρ	κ	τ
E3	1MO-3893A1	1A	1B-K608	1BP3	II-1-52-02	8931	1PT-38000A1	1PT-38000A2	1PT-38000A3	1PT-38000A4	1A1055	1Y31	1KY38000A
F3	1MO-3893A2	1A	1B-K603	1BP3	II-1-52-03	8932	1PT-38000A1	1PT-38000A2	1PT-38000A3	1PT-38000A4	1A1055	1Y31	1KY38000A
B3	1MO-3893B1	1B	1A-K608	1BP4	I-1-52-03	8933	1PT-38000B1	1PT-38000B2	1PT-38000B3	1PT-38000B4	1B1055	1Y32	1KY38000B
A3	1MO-3893B2	1B	1A-K603	1BP4	I-1-52-03	8934	1PT-38000B1	1PT-38000B2	1PT-38000B3	1PT-38000B4	1B1055	1Y32	1KY38000B
E2	2MO-3993A1	2A	2B-K608	2BP3	II-2-52-02	9931	2PT-39000A1	2PT-39000A2	2PT-39000A3	2PT-39000A4	2A1055	2Y31	2KY39000A
F2	2MO-3993A2	2A	2B-K603	2BP3	II-2-52-03	9932	2PT-39000A1	2PT-39000A2	2PT-39000A3	2PT-39000A4	2A1055	2Y31	2KY39000A
B2	2MO-3993B1	2B	2A-K608	2BP4	I-2-52-02	9933	2PT-39000B1	2PT-39000B2	2PT-39000B3	2PT-39000B4	2B1055	2Y32	2KY39000B
A2	2MO-3993B2	2B	2A-K603	2BP4	I-2-52-03	9934	2PT-39000B1	2PT-32000B2	2PT-39000B3	2PT-39000B4	2B1055	2Y32	2KY39000B

PST CC ΔF

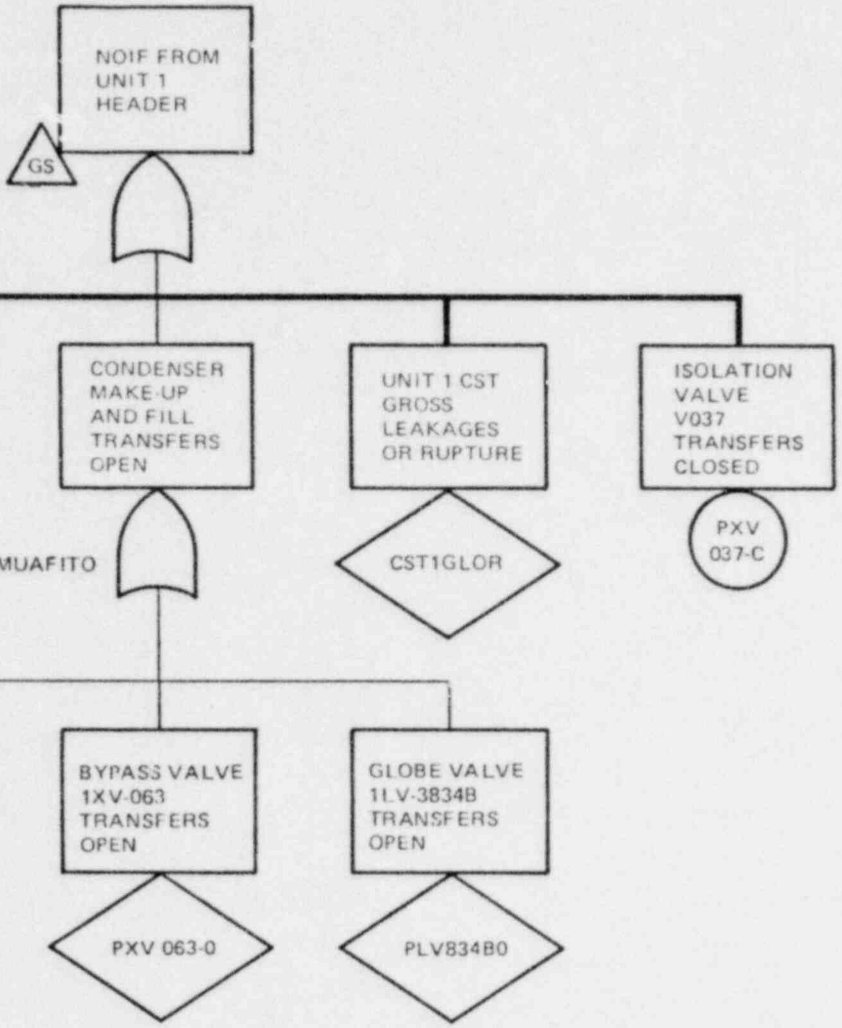
γ1	γ2	ξ	λ	ι1	π1	π2	π3	π4	Δ
1B08	1G	1P03	2102	1L	38A1	38A2	38A3	38A4	A1
1B03	1H	1P03	2103	1L	38A1	38A2	38A3	38A4	A2
1A08	1J	1P04	1102	1M	38B1	38B2	38B3	38B4	B1
1A03	1K	1P04	1103	1M	38B1	38B2	38B3	38B4	B2
2B08	2G	2P03	2202	2L	39A1	39A2	39A3	39A4	A3
2B03	2H	2P03	2203	2L	39A1	39A2	39A3	39A4	A4
2A08	2J	2P04	1202	2M	39B1	39B2	39B3	39B4	B3
2A03	2K	2P04	1203	2M	39B1	39B2	39B3	39B4	B4





PMV3856C

α	β	γ	δ
G3	1 MO-3856	3856	1L
G4	2 MO-3956	3956	2L

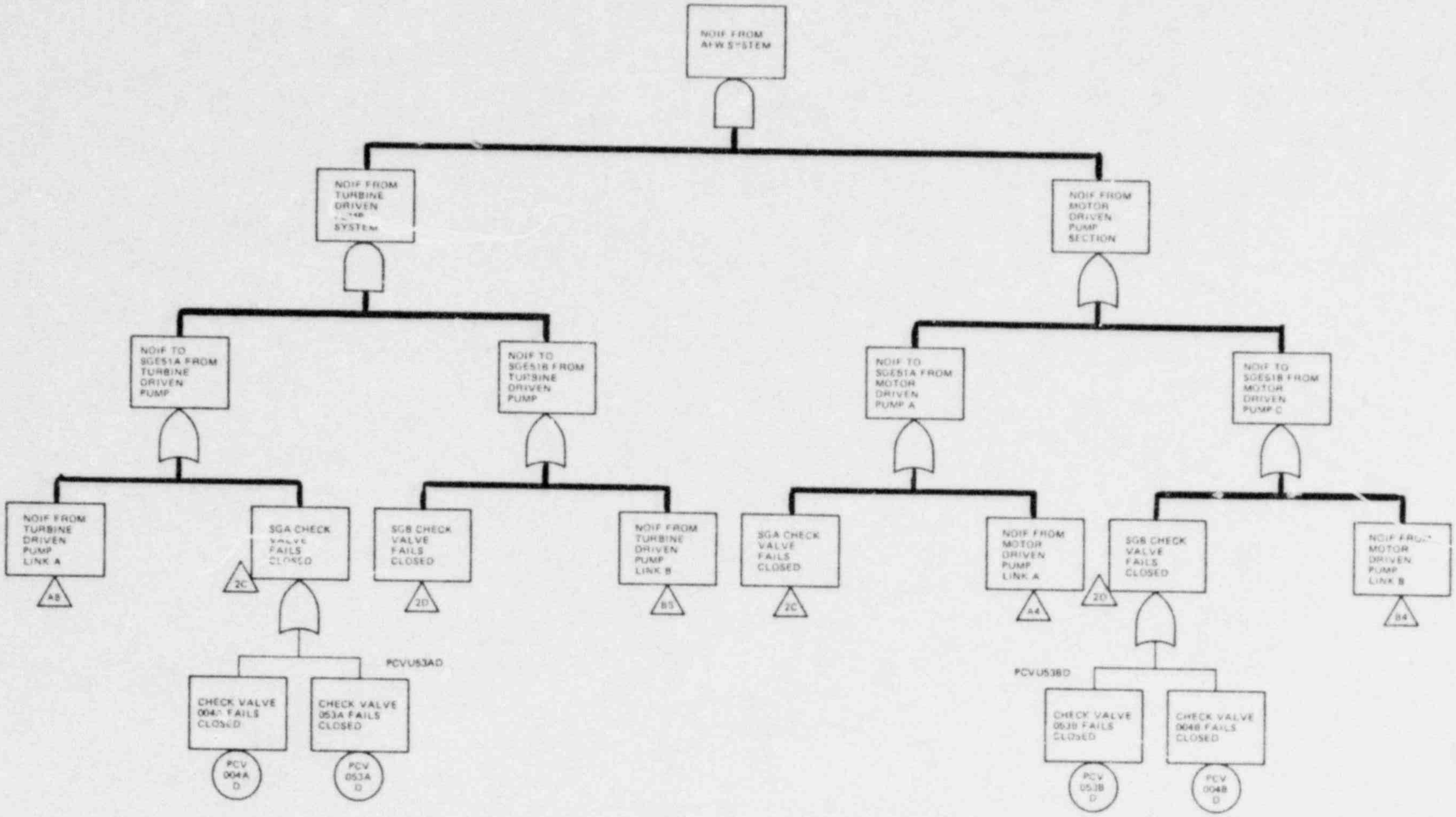

NOIF FROM UNIT 1 HEADER
GS
CHECK VALVE ICK-024 FAILS CLOSED
PCV 024-D
CONDENSER MAKE-UP AND FILL TRANSFERS OPEN
CMUAFITO
UNIT 1 CST GROSS LEAKAGES OR RUPTURE
CST1GLOR
ISOLATION VALVE V037 TRANSFERS CLOSED
PXV 037-C
GLOBE VALVE 1LV-3834A TRANSFERS OPEN
PLV834A 0
BYPASS VALVE 1XV-063 TRANSFERS OPEN
PXV 063-0
GLOBE VALVE 1LV-3834B TRANSFERS OPEN
PLV834B0

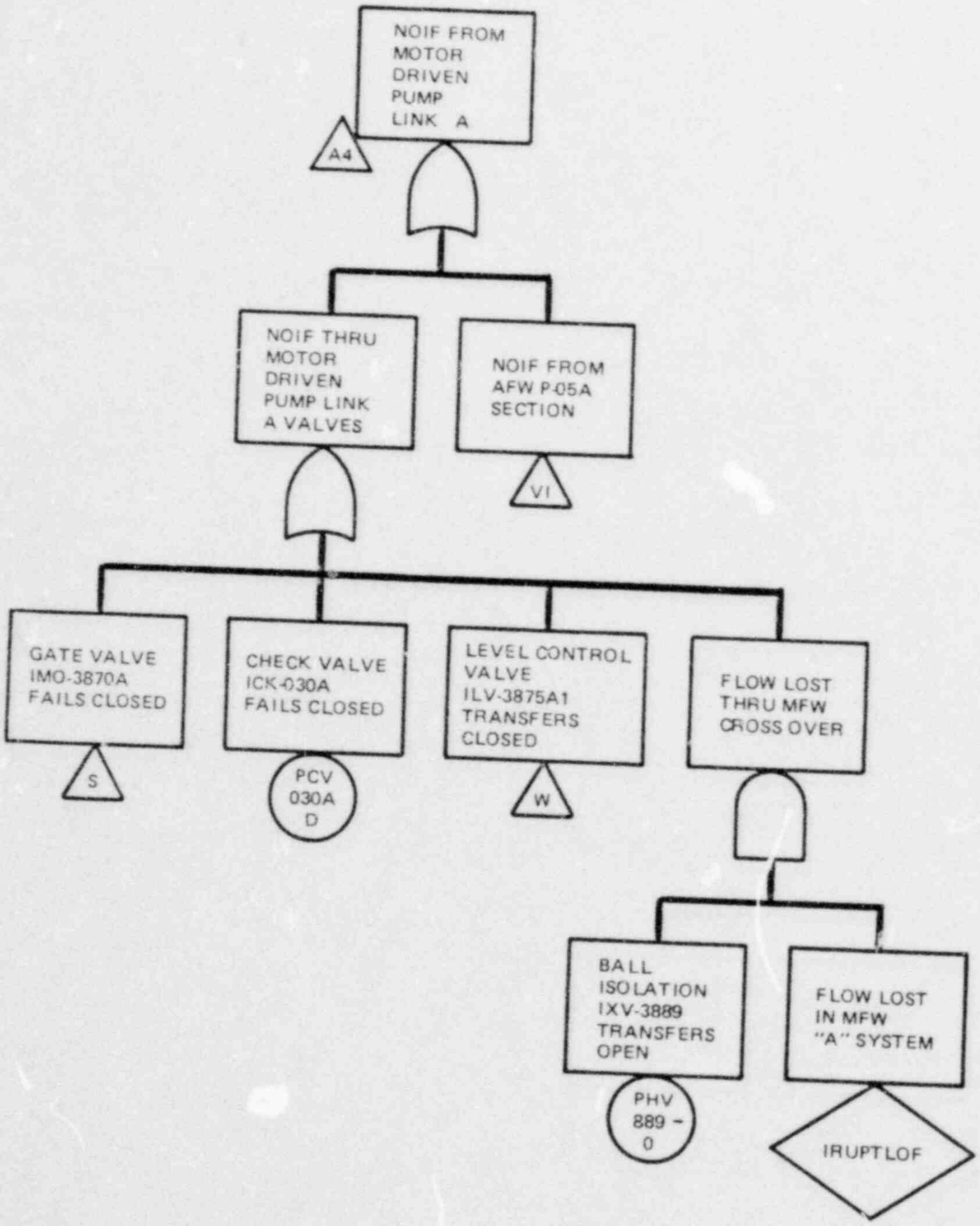
APPENDIX C

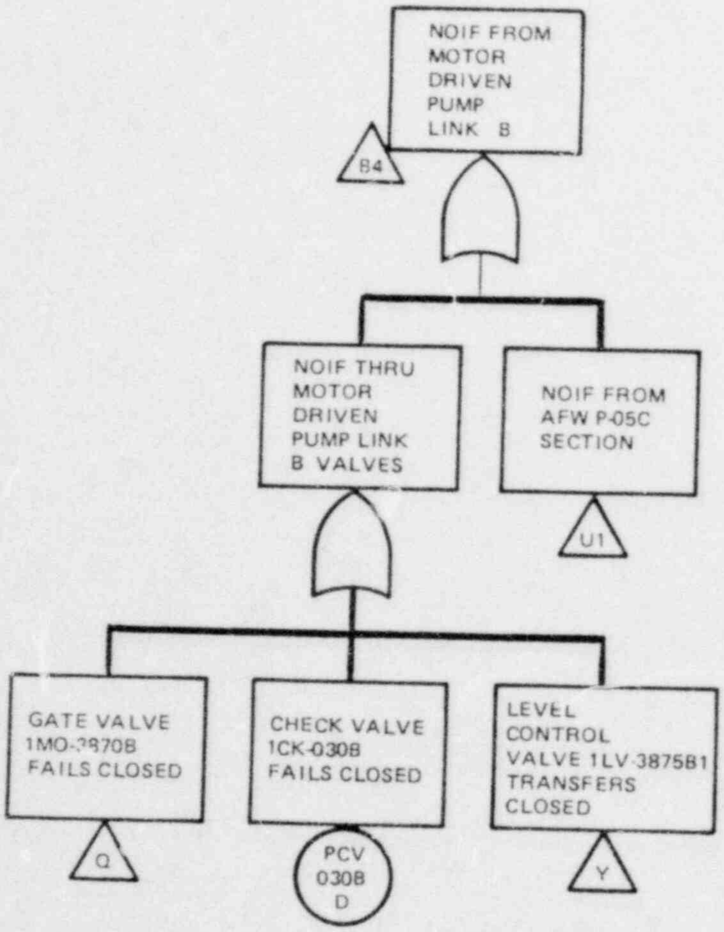
MIDLAND AUXILIARY FEEDWATER SYSTEM FAULT TREE

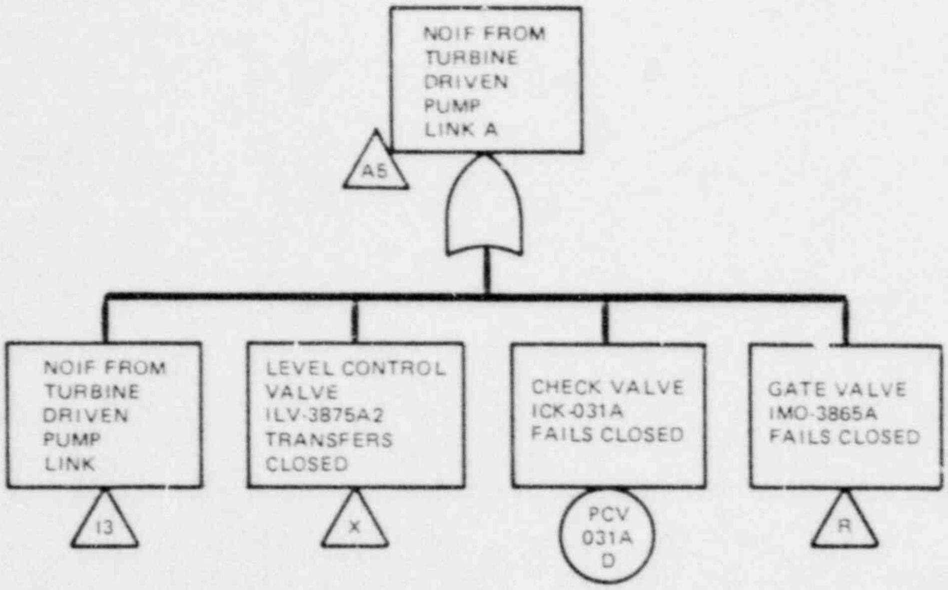
THREE PUMP DESIGN

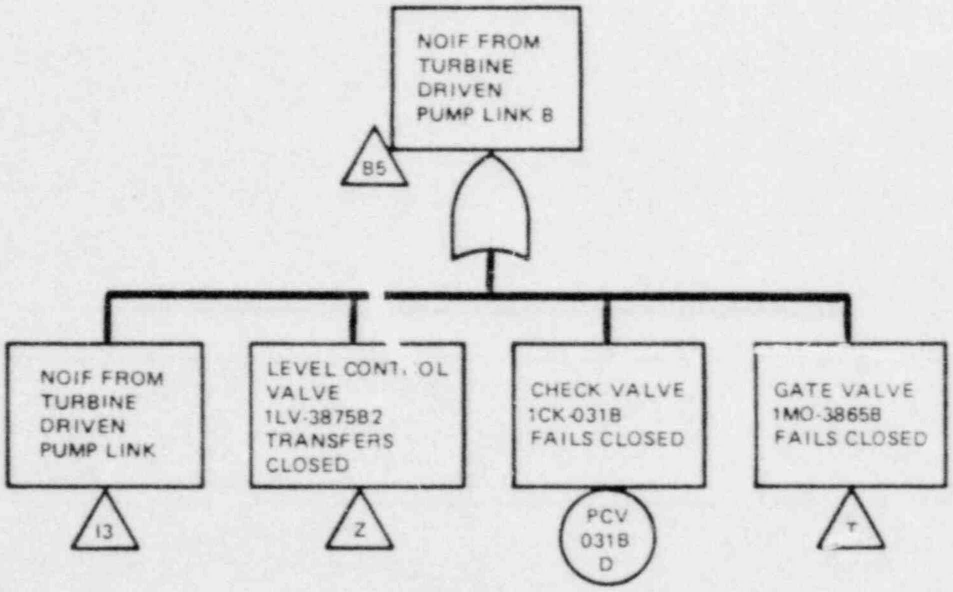
This appendix presents the fault tree model constructed to represent an alternate design of the AFWS. The basic system modeled was similar to the AFWS installed at some other B&W nuclear plants. The tree logic defines the component failure modes necessary to fail the system. The fault trees have been heavy lined to show the level to which the quantification was performed. Quantification was performed to the level at which the most applicable data was available. The detailed fault trees were constructed to ensure that all components which could possibly affect the system performance were included in our analysis.


NOIF FROM AFW SYSTEM
NOIF FROM TURBINE DRIVEN PUMP SYSTEM
NOIF FROM MOTOR DRIVEN PUMP SECTION
NOIF TO SGES1A FROM TURBINE DRIVEN PUMP
NOIF TO SGES1B FROM TURBINE DRIVEN PUMP
NOIF TO SGES1A FROM MOTOR DRIVEN PUMP A
NOIF TO SGES1B FROM MOTOR DRIVEN PUMP C
NOIF FROM TURBINE DRIVEN PUMP LINK A
A8
SGA CHECK VALVE FAILS CLOSED
2C
SGB CHECK VALVE FAILS CLOSED
2D
NOIF FROM TURBINE DRIVEN PUMP LINK B
B5
SGA CHECK VALVE FAILS CLOSED
2C
NOIF FROM MOTOR DRIVEN PUMP LINK A
A4
SGB CHECK VALVE FAILS CLOSED
2D
NOIF FROM MOTOR DRIVEN PUMP LINK B
B4
PCVU53AD
CHECK VALVE 004A FAILS CLOSED
PCV 004A D
CHECK VALVE 053A FAILS CLOSED
PCV 053A D
PCVU53BD
CHECK VALVE 053B FAILS CLOSED
PCV 053B D
CHECK VALVE 004B FAILS CLOSED
PCV 004B D

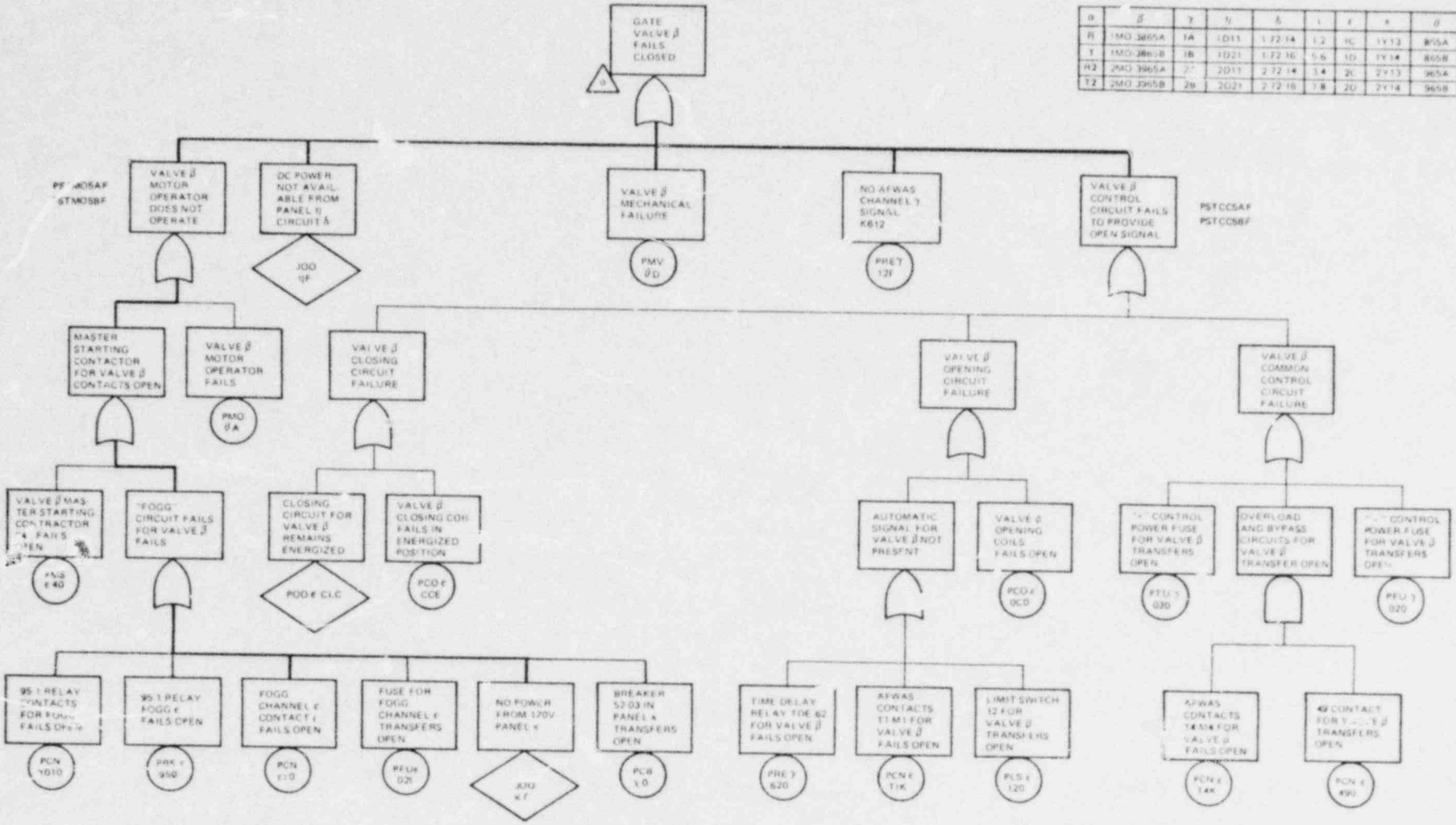

NOIF FROM MOTOR DRIVEN PUMP LINK A
A4
NOIF THRU MOTOR DRIVEN PUMP LINK A VALVES
NOIF FROM AFW P-05A SECTION
VI
GATE VALVE IMO-3870A FAILS CLOSED
S
CHECK VALVE ICK-030A FAILS CLOSED
PCV 030A D
LEVEL CONTROL VALVE ILV-3875A1 TRANSFERS CLOSED
W
FLOW LOST THRU MFW CROSS OVER
BALL ISOLATION IXV-3889 TRANSFERS OPEN
PHV 889 - 0
FLOW LOST IN MFW "A" SYSTEM
IRUPTLOF


NOIF FROM MOTOR DRIVEN PUMP LINK B
B4
NOIF THRU MOTOR DRIVEN PUMP LINK B VALVES
NOIF FROM AFW P-05C SECTION
U1
GATE VALVE 1MO-3870B FAILS CLOSED
Q
CHECK VALVE 1CK-030B FAILS CLOSED
PCV 030B D
LEVEL CONTROL VALVE 1LV-3875B1 TRANSFERS CLOSED
Y

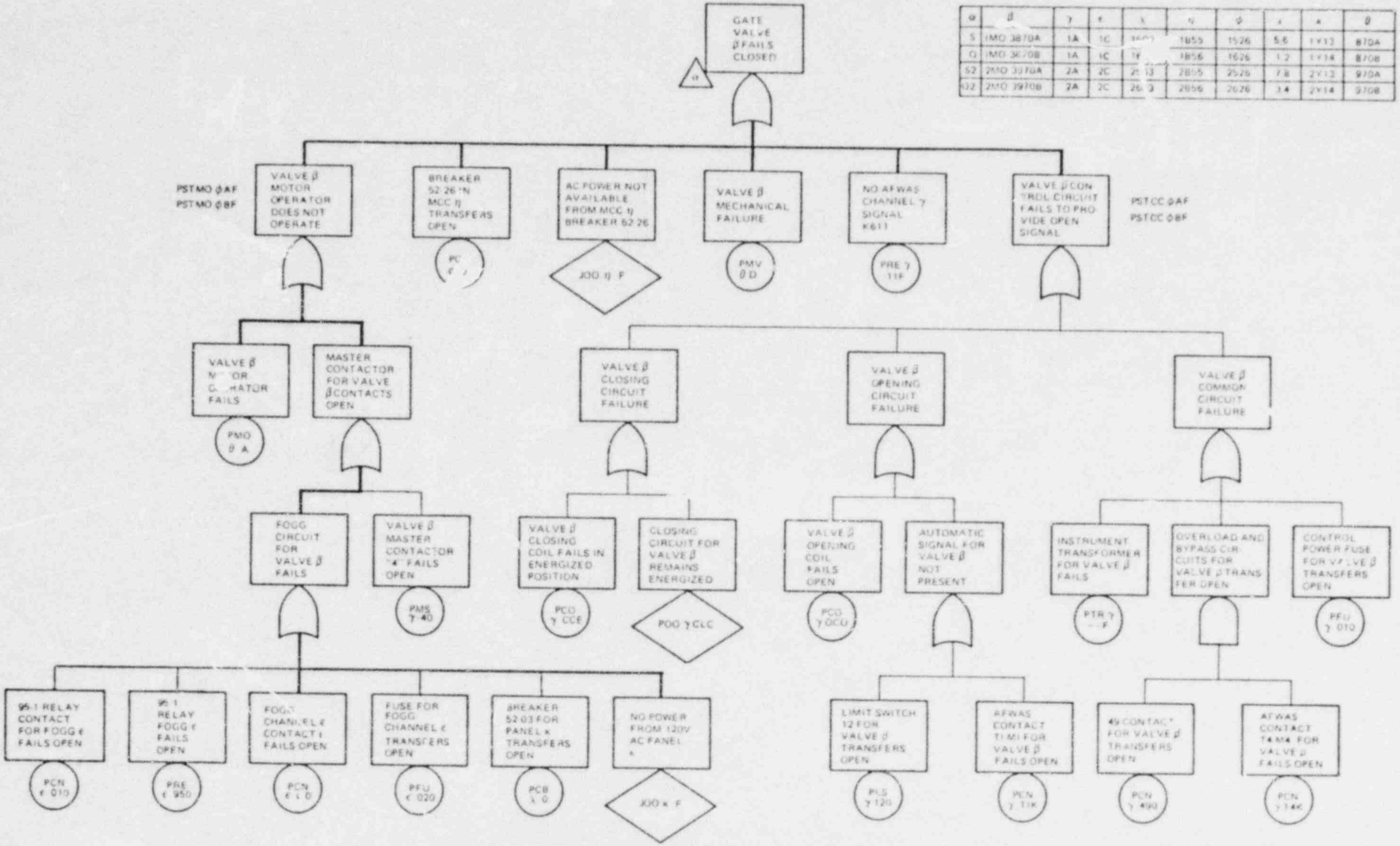

NOIF FROM TURBINE DRIVEN PUMP LINK A
A5
NOIF FROM TURBINE DRIVEN PUMP LINK
I3
LEVEL CONTROL VALVE 1LV-3875A2 TRANSFERS CLOSED
X
CHECK VALVE 1CK-031A FAILS CLOSED
PCV 031A D
GATE VALVE 1MO-3865A FAILS CLOSED
R

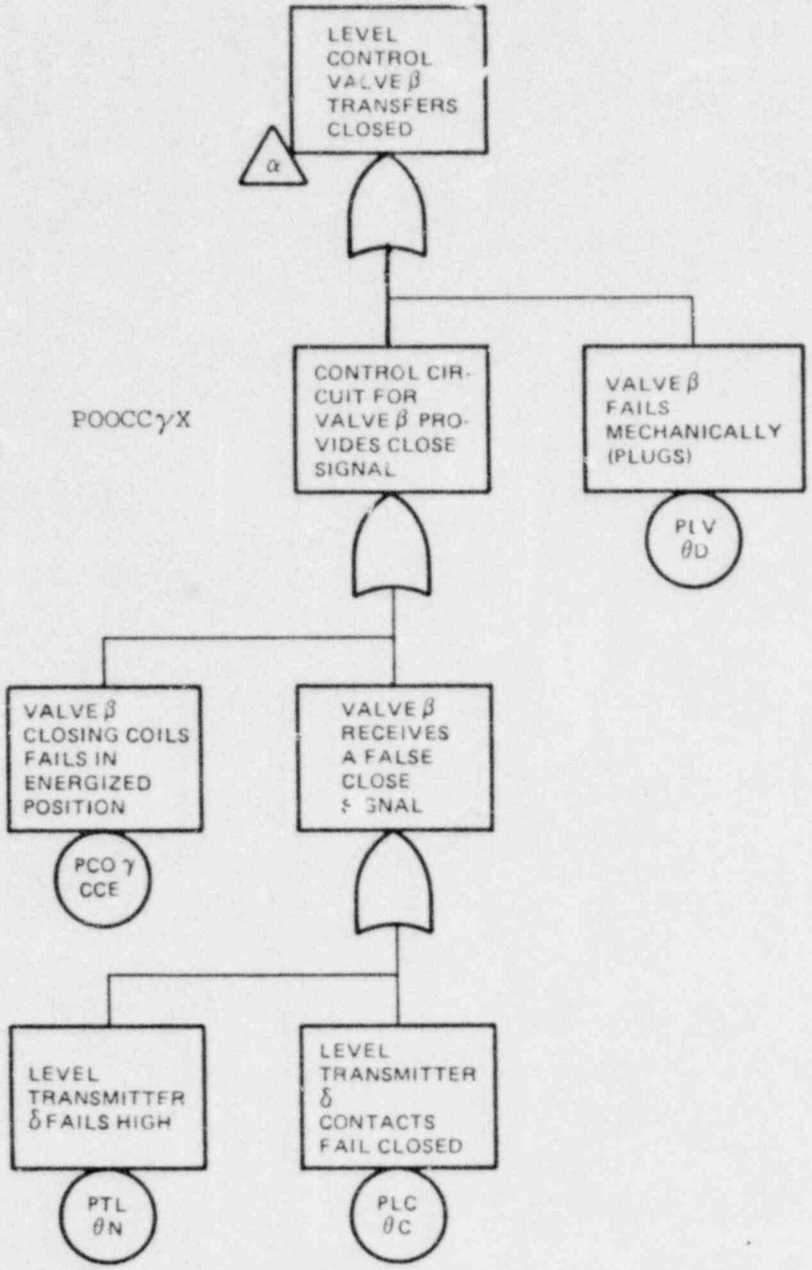

NOIF FROM TURBINE DRIVEN PUMP LINK B
B5
NOIF FROM TURBINE DRIVEN PUMP LINK
I3
LEVEL CONTROL VALVE 1LV-3875B2 TRANSFERS CLOSED
Z
CHECK VALVE 1CK-031B FAILS CLOSED
PCV 031B D
GATE VALVE 1MO-3865B FAILS CLOSED
T

α	β	γ	η	δ	ι	ε	κ	θ	λ
R	1MO 3865A	1A	1D11	1-72-14	1-2	1C	1Y13	855A	1503
T	1MO 3865B	1B	1D21	1-72-16	5-6	1D	1Y14	865B	1603
R2	2MO 3965A	[illegible]	2D11	2-72-14	3-4	2C	2Y13	965A	2503
T2	2MO 3965B	2B	2D21	2-72-16	7-8	2D	2Y14	965B	2603

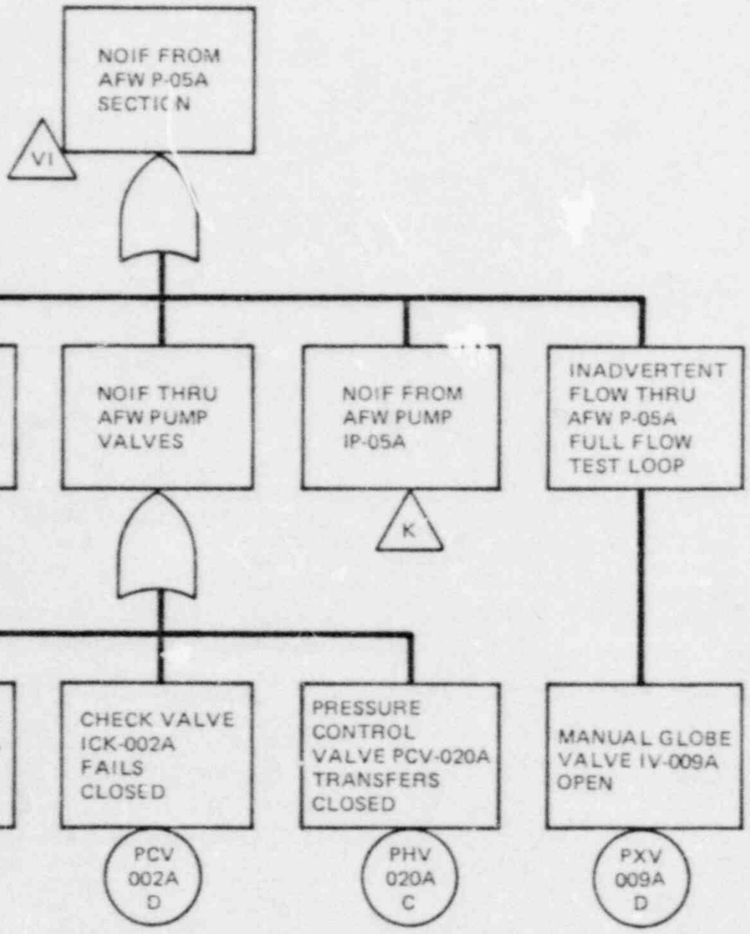


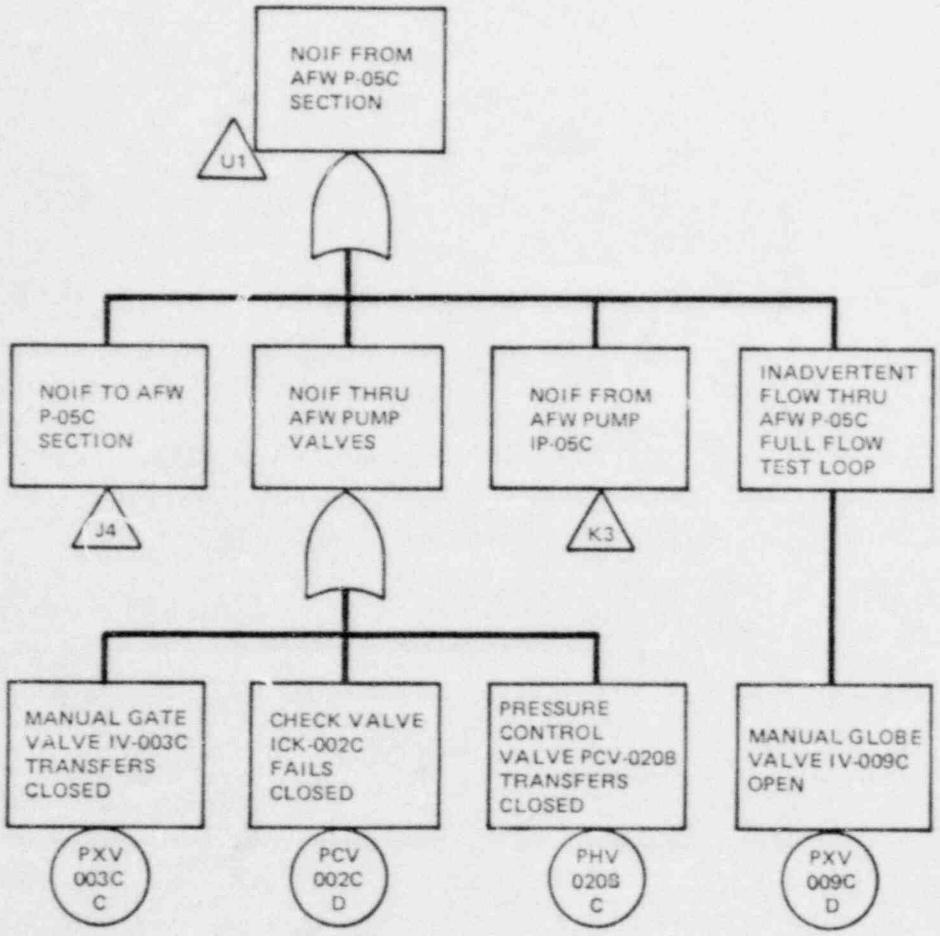
α	β	γ	ε	λ	η	φ	ι	κ	θ
S	IMO 3870A	1A	1C	[illegible]	1855	1526	5.6	1Y13	870A
Q	IMO 3870B	1A	1C	[illegible]	1856	1626	1.2	1Y14	870B
S2	2MO 3970A	2A	2C	[illegible]	2855	2526	7.8	2Y13	970A
Q2	2MO 3970B	2A	2C	[illegible]	2856	2626	3.4	2Y14	970B

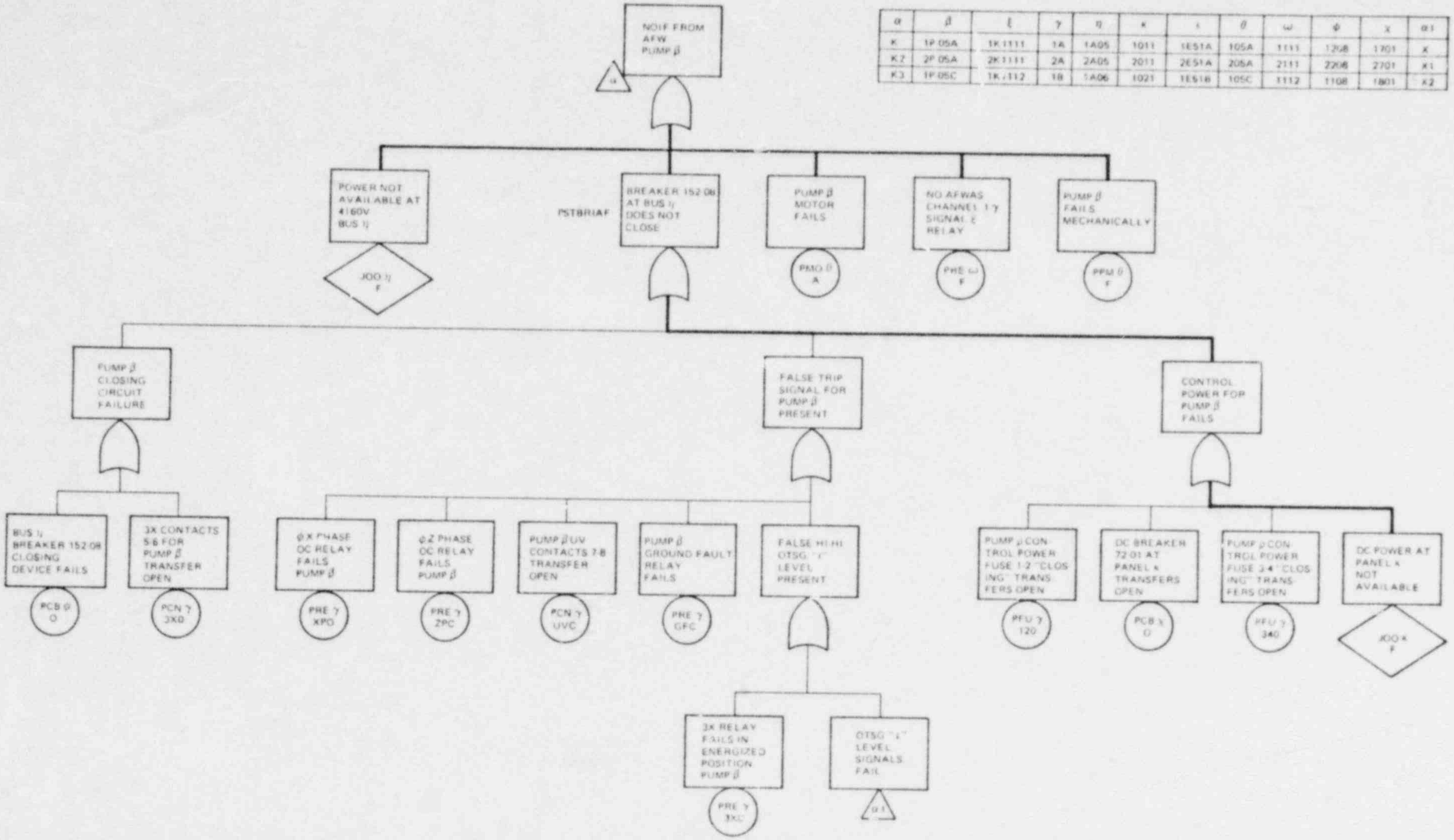




α	β	θ	γ	δ
W2	2LV-3975A1	75A1	A1	LYS-3875BA
Y2	2LV-3975A2	75A2	A2	LYS-[illegible]75AB
X2	2LV-3975B1	75B1	B1	LYS-3875BC
Z2	2LV-3975B2	75B2	B2	LYS-3875-AD
W	1LV-3875A1	75A1	A1	LYS-3875AA
X	1LV-3875A2	75A2	A2	LYS-3875AB
Y	1LV-3875B1	75B1	B1	LYS-3875BA
Z	1LV-3875B2	75B2	B2	LYS-3875BB

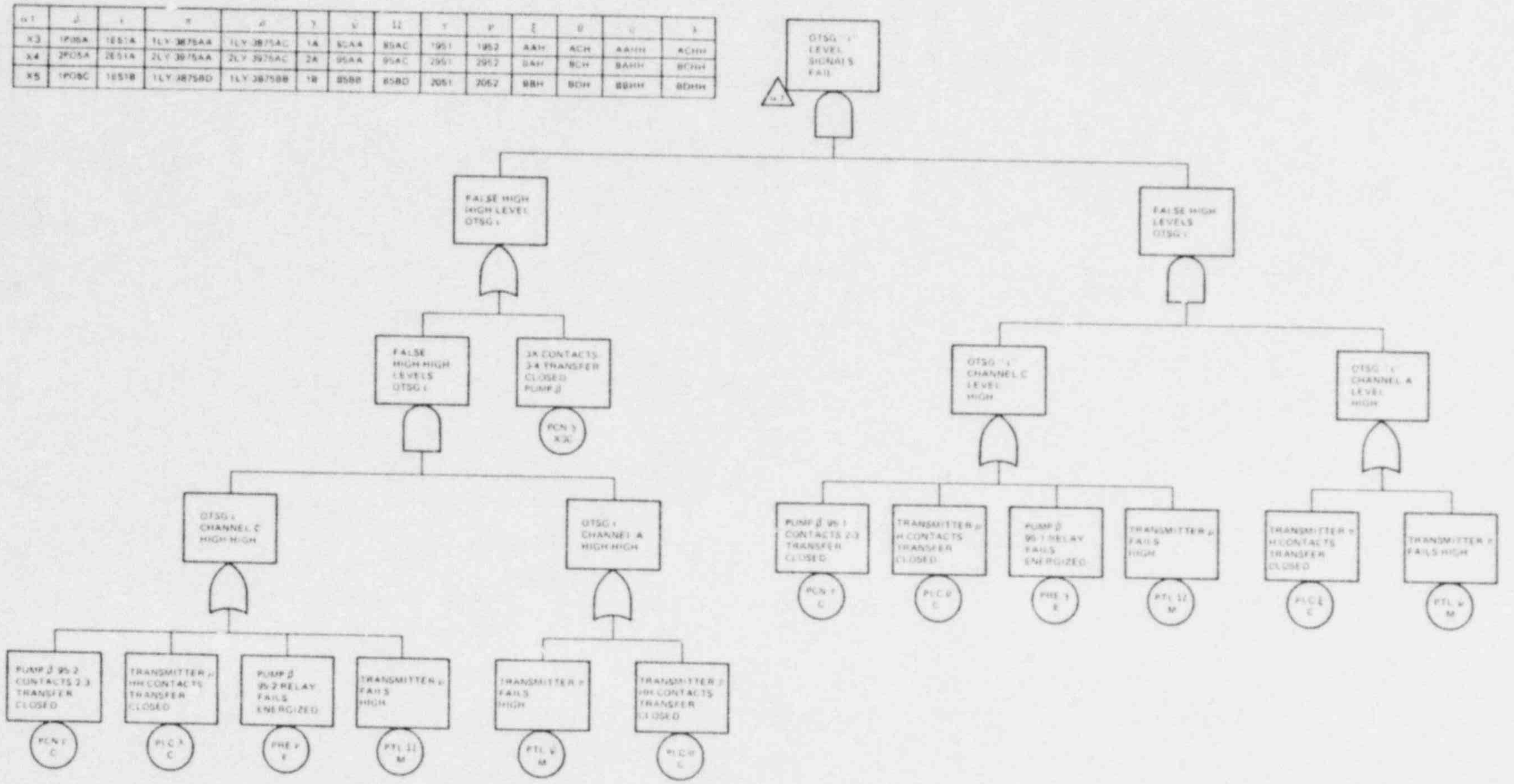

NOIF FROM AFW P-05A SECTION
VI
NOIF TO AFW P-05A SECTION
J3
NOIF THRU AFW PUMP VALVES
NOIF FROM AFW PUMP IP-05A
K
INADVERTENT FLOW THRU AFW P-05A FULL FLOW TEST LOOP
MANUAL GATE VALVE IV-003A TRANSFERS CLOSED
PXV 003A C
CHECK VALVE ICK-002A FAILS CLOSED
PCV 002A D
PRESSURE CONTROL VALVE PCV-020A TRANSFERS CLOSED
PHV 020A C
MANUAL GLOBE VALVE IV-009A OPEN
PXV 009A D

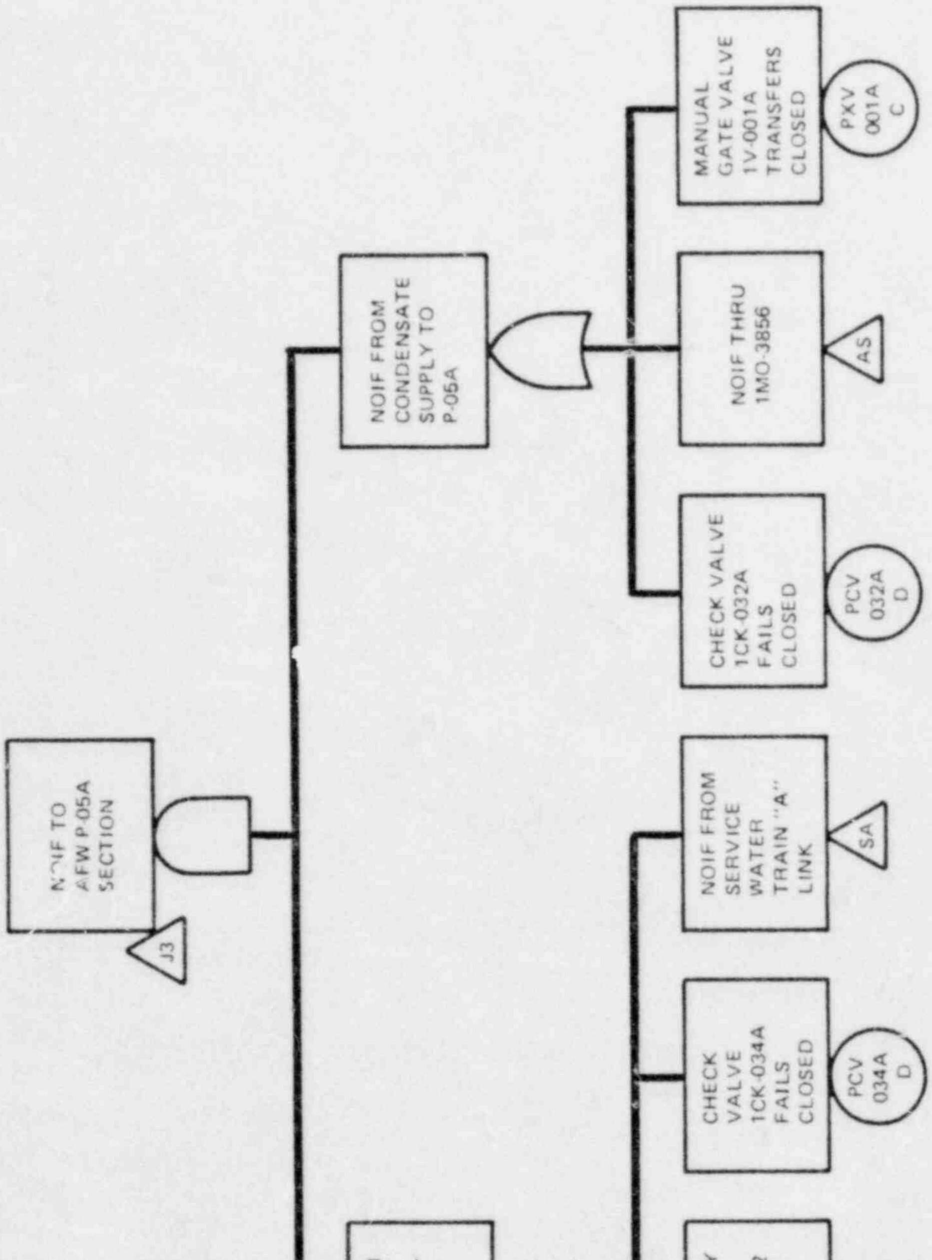

NOIF FROM AFW P-05C SECTION
U1
NOIF TO AFW P-05C SECTION
J4
NOIF THRU AFW PUMP VALVES
NOIF FROM AFW PUMP IP-05C
K3
INADVERTENT FLOW THRU AFW P-05C FULL FLOW TEST LOOP
MANUAL GATE VALVE IV-003C TRANSFERS CLOSED
PXV 003C C
CHECK VALVE ICK-002C FAILS CLOSED
PCV 002C D
PRESSURE CONTROL VALVE PCV-0208 TRANSFERS CLOSED
PHV 0208 C
MANUAL GLOBE VALVE IV-009C OPEN
PXV 009C D

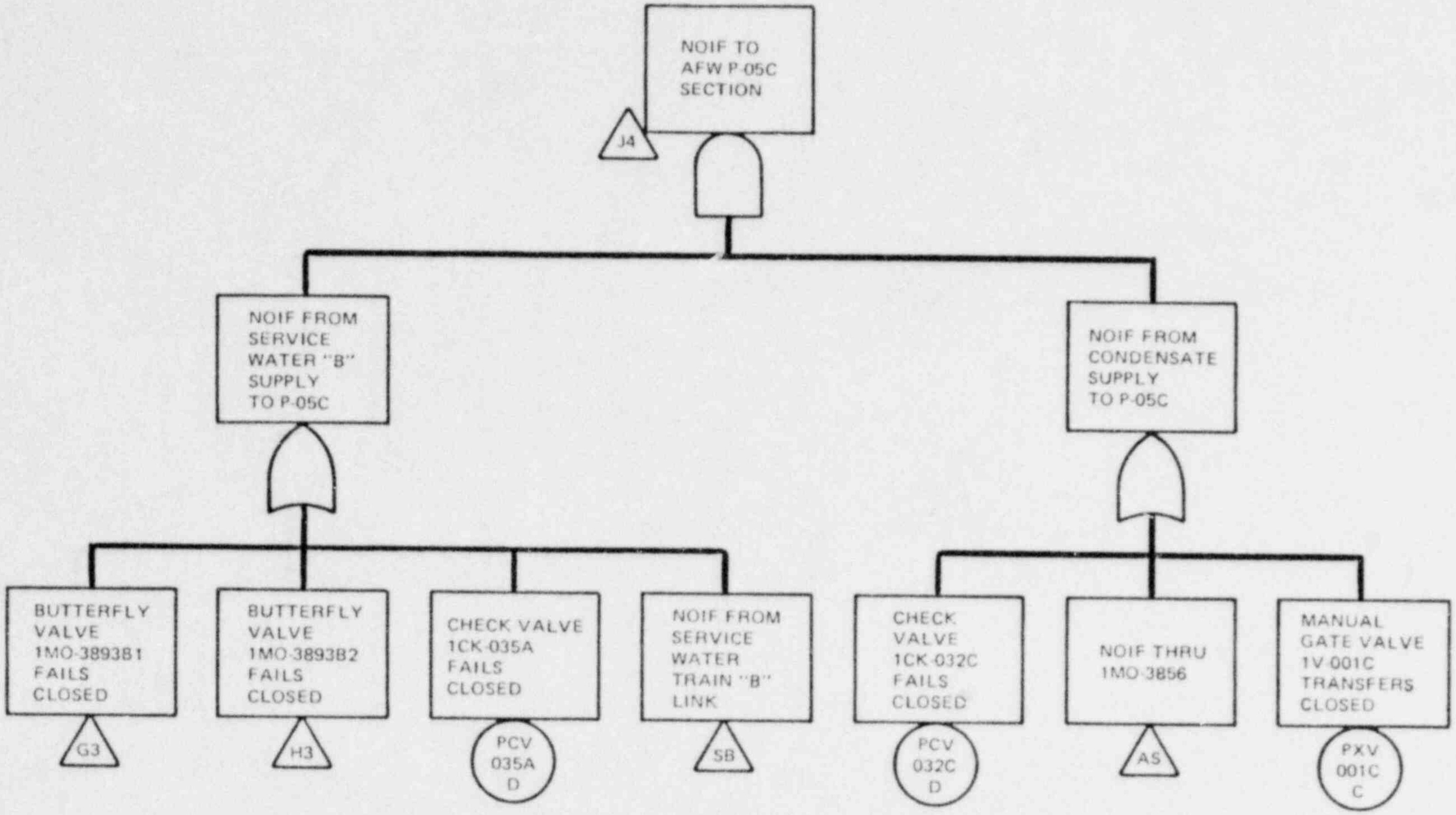


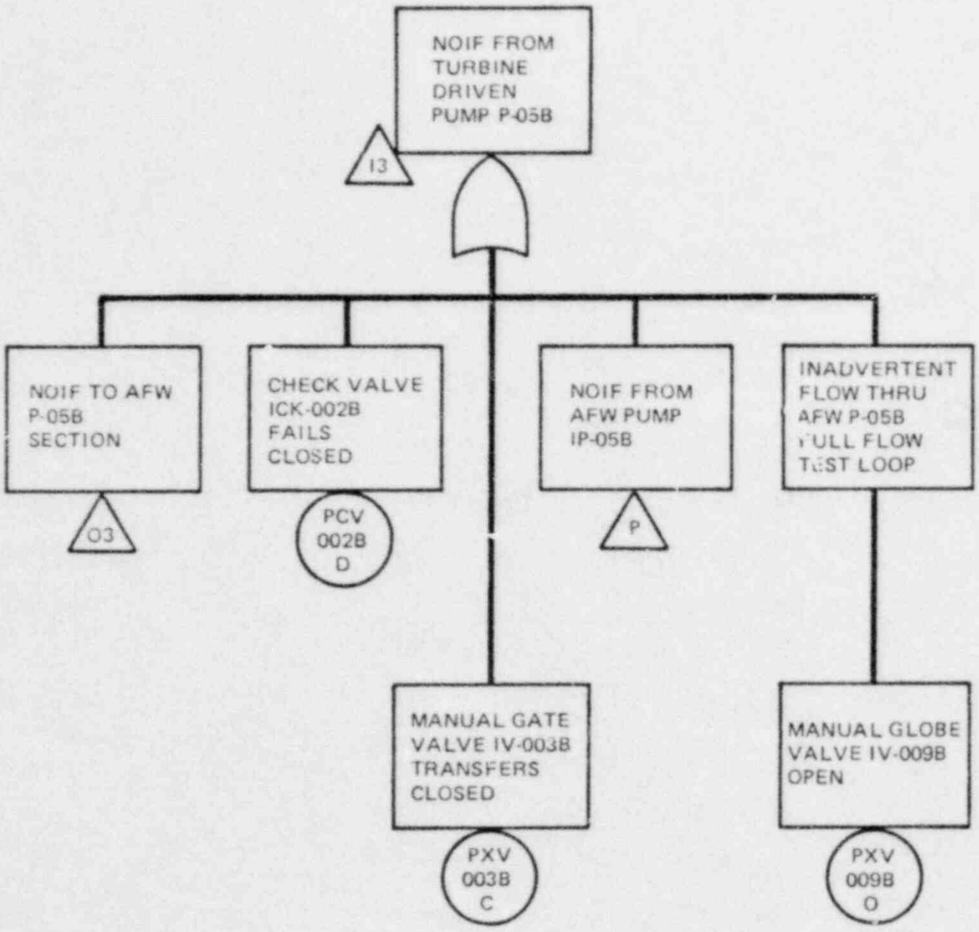
α	β	ξ	γ	η	κ	ι	θ	ω	φ	χ	α1
K	1P 05A	1K1111	1A	1A05	1011	1E51A	105A	1111	1208	1701	X
K2	2P 05A	2K1111	2A	2A05	2011	2E51A	205A	2111	2208	2701	X1
K3	1P 05C	1K/112	1B	1A06	1021	1E51B	105C	1112	1108	1801	X2

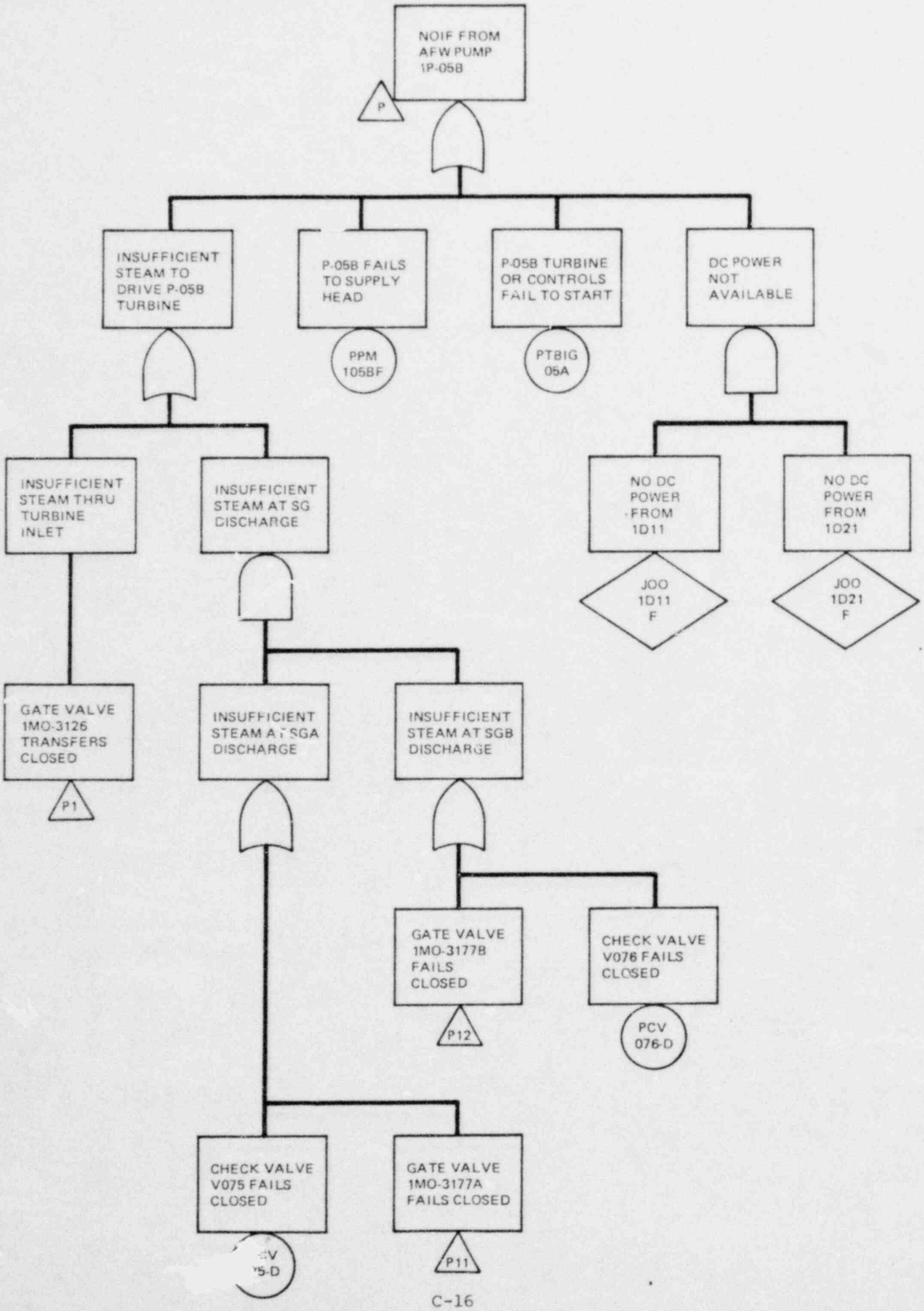
α↑	β	ι	π	ρ	γ	ν	Ω	τ	μ	ξ	θ	υ	λ
X3	1P05A	1E51A	1LY-3875AA	1LY-3875AC	1A	85AA	85AC	1951	1952	AAH	ACH	AAHH	ACHH
X4	2P05A	2E51A	2LY-3975AA	2LY-3975AC	2A	95AA	95AC	2951	2952	BAH	BCH	BAHH	BCHH
X5	1P08C	1E51B	1LY-3875BD	1LY-3875BB	1B	85BB	85BD	2051	2052	BBH	BDH	BBHH	BDHH

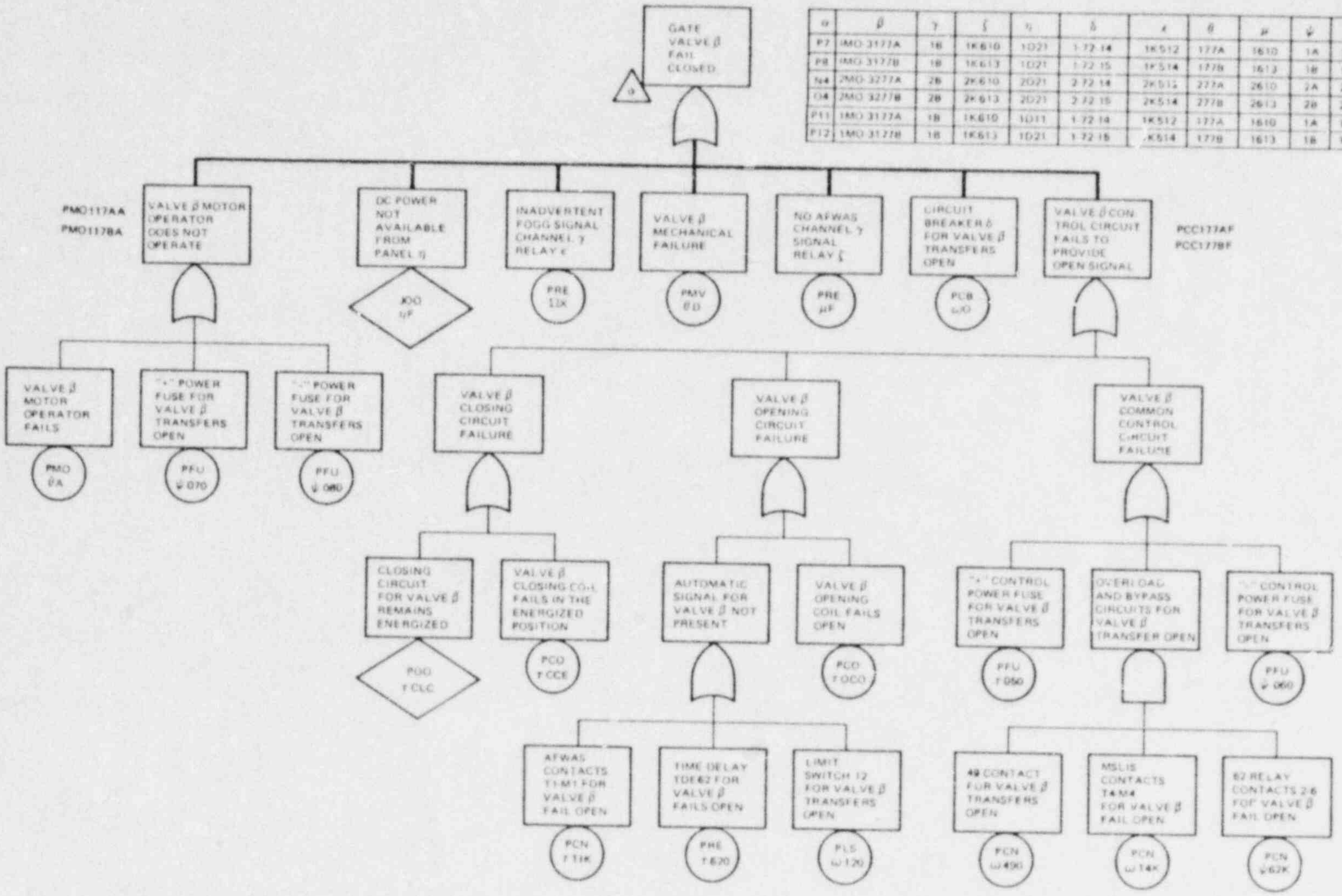



NOIF TO AFW P-05A SECTION
J3
NOIF FROM SERVICE WATER "A" SUPPLY TO P-05A
NOIF FROM CONDENSATE SUPPLY TO P-05A
BUTTERFLY VALVE 1MO-3893A1 FAILS CLOSED
E3
BUTTERFLY VALVE 1MO-3893A2 FAILS CLOSED
F3
CHECK VALVE 1CK-034A FAILS CLOSED
PCV 034A D
NOIF FROM SERVICE WATER TRAIN "A" LINK
SA
CHECK VALVE 1CK-032A FAILS CLOSED
PCV 032A D
NOIF THRU 1MO-3856
AS
MANUAL GATE VALVE 1V-001A TRANSFERS CLOSED
PXV 001A C

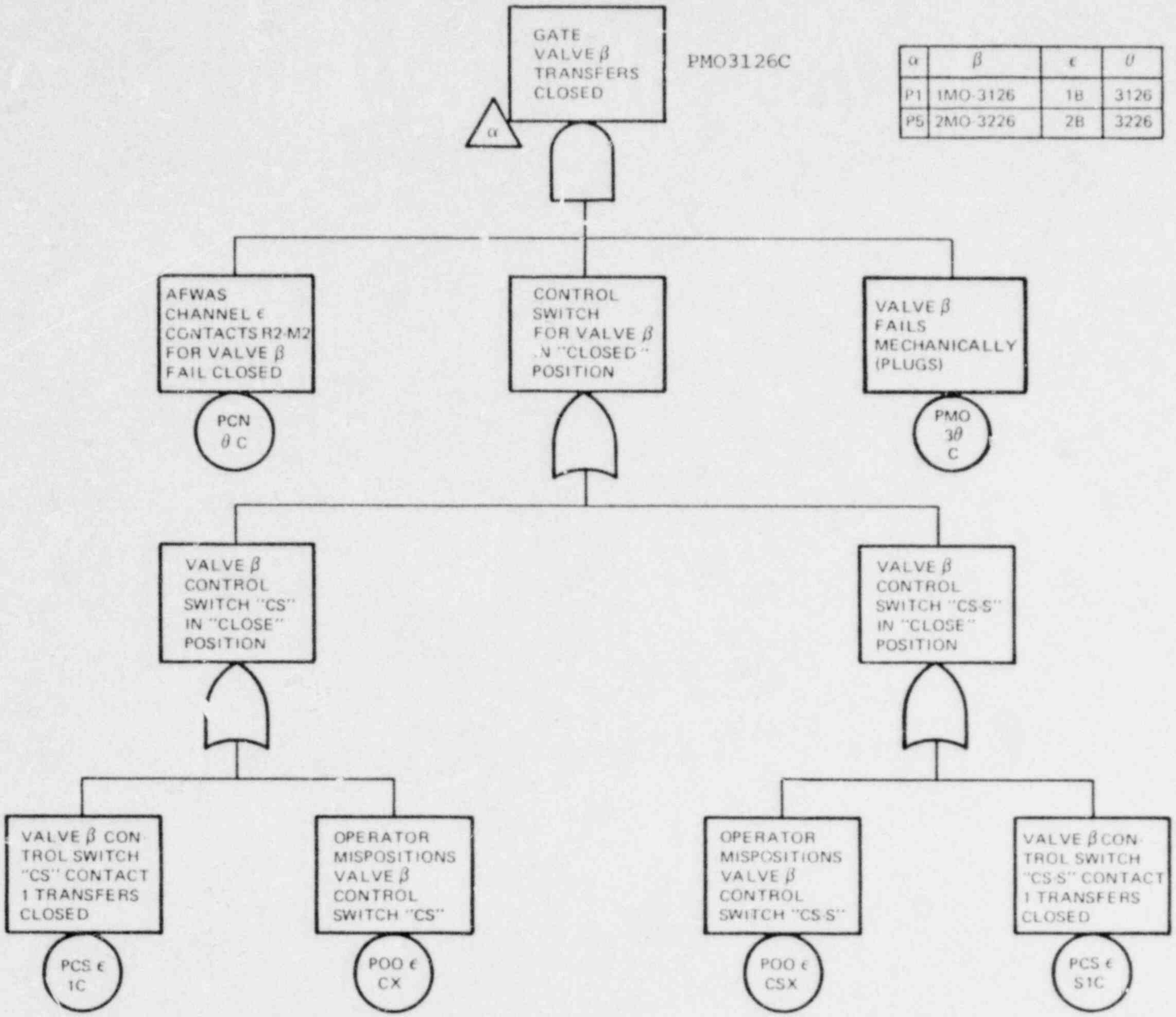

NOIF TO AFW P-05C SECTION
J4
NOIF FROM SERVICE WATER "B" SUPPLY TO P-05C
NOIF FROM CONDENSATE SUPPLY TO P-05C
BUTTERFLY VALVE 1MO-3893B1 FAILS CLOSED
G3
BUTTERFLY VALVE 1MO-3893B2 FAILS CLOSED
H3
CHECK VALVE 1CK-035A FAILS CLOSED
PCV 035A D
NOIF FROM SERVICE WATER TRAIN "B" LINK
SB
CHECK VALVE 1CK-032C FAILS CLOSED
PCV 032C D
NOIF THRU 1MO-3856
AS
MANUAL GATE VALVE 1V-001C TRANSFERS CLOSED
PXV 001C C


NOIF FROM TURBINE DRIVEN PUMP P-05B
I3
NOIF TO AFW P-05B SECTION
O3
CHECK VALVE ICK-002B FAILS CLOSED
PCV 002B D
NOIF FROM AFW PUMP IP-05B
P
INADVERTENT FLOW THRU AFW P-05B FULL FLOW TEST LOOP
MANUAL GATE VALVE IV-003B TRANSFERS CLOSED
PXV 003B C
MANUAL GLOBE VALVE IV-009B OPEN
PXV 009B O

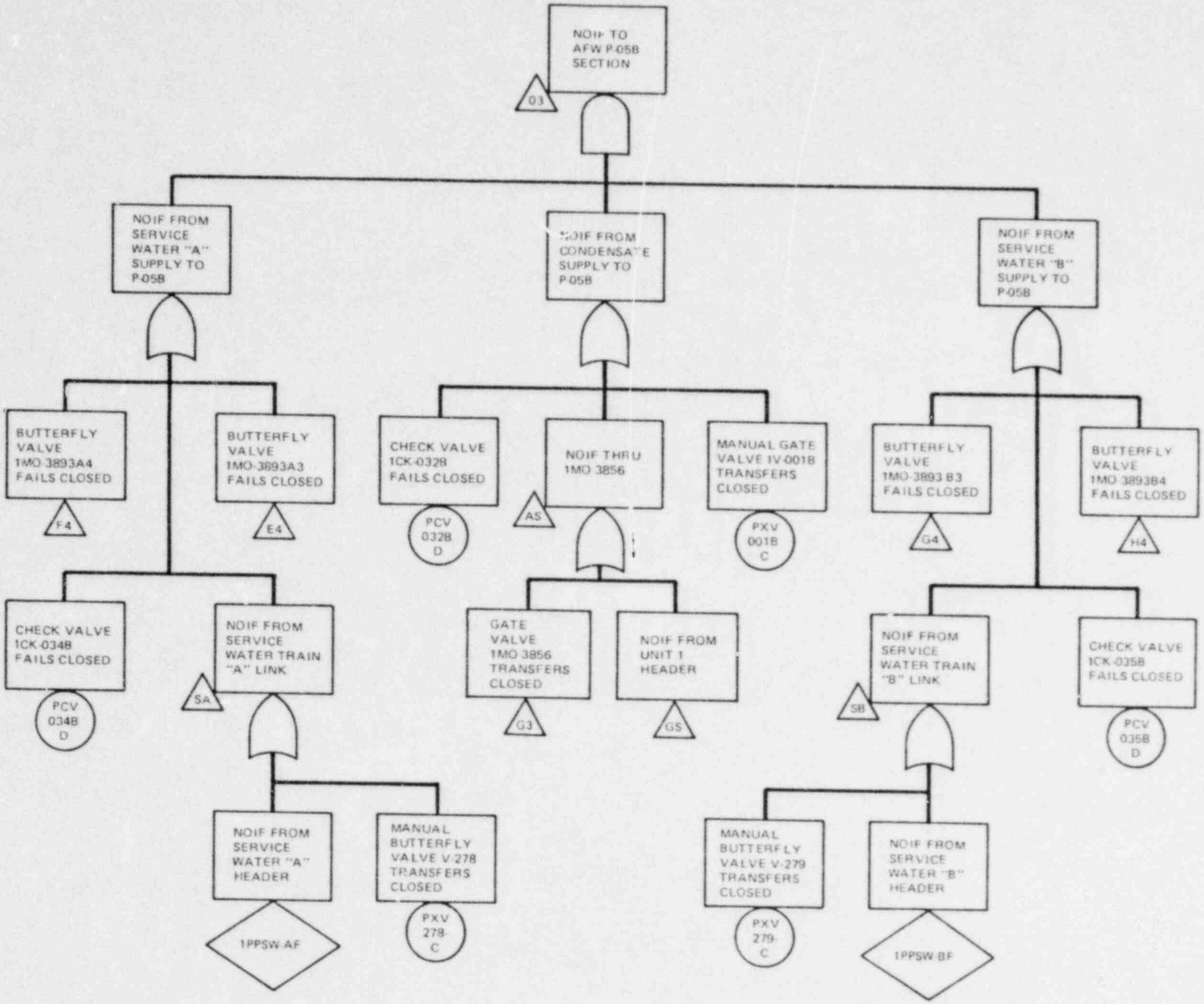

NOIF FROM AFW PUMP 1P-05B
P
INSUFFICIENT STEAM TO DRIVE P-05B TURBINE
P-05B FAILS TO SUPPLY HEAD
PPM 105BF
P-05B TURBINE OR CONTROLS FAIL TO START
PTBIG 05A
DC POWER NOT AVAILABLE
INSUFFICIENT STEAM THRU TURBINE INLET
INSUFFICIENT STEAM AT SG DISCHARGE
NO DC POWER FROM 1D11
JOO 1D11 F
NO DC POWER FROM 1D21
JOO 1D21 F
GATE VALVE 1MO-3126 TRANSFERS CLOSED
P1
INSUFFICIENT STEAM AT SGA DISCHARGE
INSUFFICIENT STEAM AT SGB DISCHARGE
GATE VALVE 1MO-3177B FAILS CLOSED
P12
CHECK VALVE V076 FAILS CLOSED
PCV 076-D
CHECK VALVE V075 FAILS CLOSED
EV
5-D
GATE VALVE 1MO-3177A FAILS CLOSED
P11

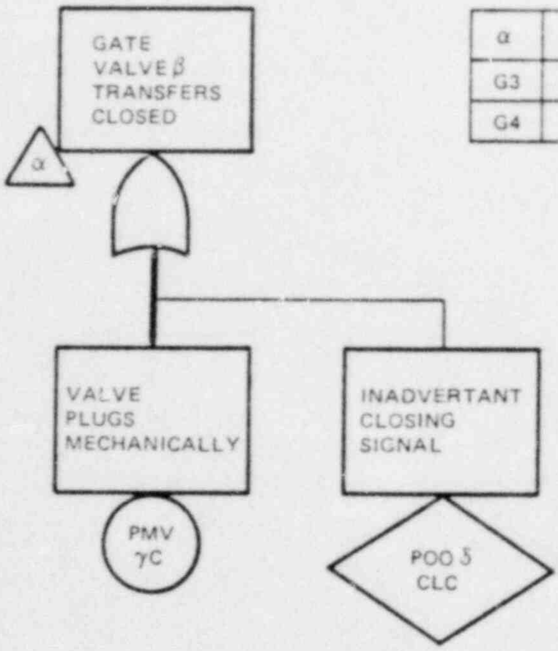


α	β	γ	ζ	η	δ	ϵ	θ	μ	ψ	ω	Ω	τ
P7	1MO 3177A	1B	1K610	1D21	1-72-14	1K512	177A	1610	1A	1714	1512	1E
P8	1MO 3177B	1B	1K613	1D21	1-72-15	1K514	177B	1613	1B	1715	1514	1F
N4	2MO 3277A	2B	2K610	2D21	2-72-14	2K512	277A	2610	2A	2714	2512	2E
O4	2MO 3277B	2B	2K613	2D21	2-72-15	2K514	277B	2613	2B	2715	2514	2F
P11	1MO 3177A	1B	1K610	1D11	1-72-14	1K512	177A	1610	1A	1714	1512	1E
P12	1MO 3177B	1B	1K613	1D21	1-72-15	1K514	177B	1613	1B	1715	1514	1F



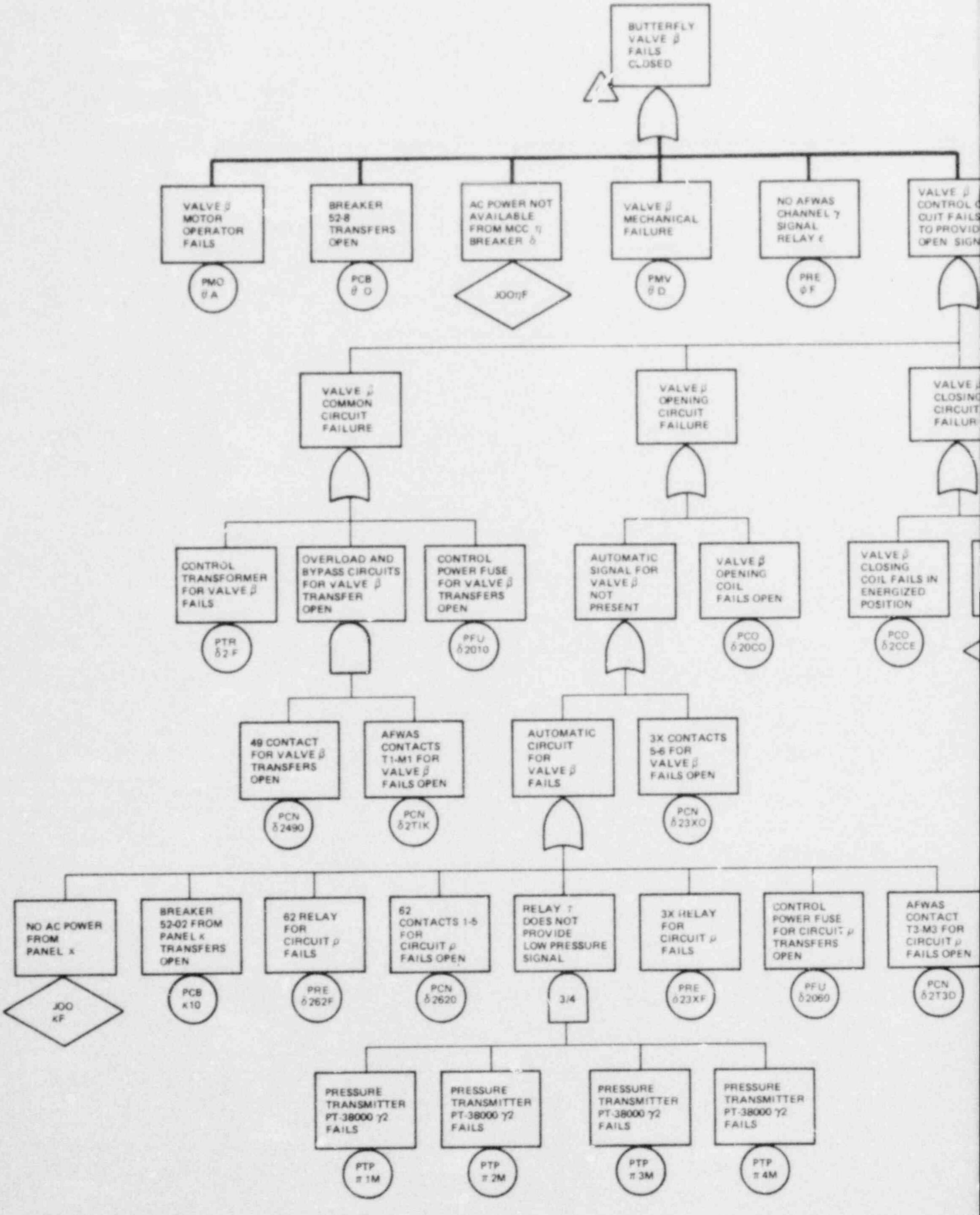
α	β	ε	θ
P1	1MO-3126	1B	3126
P5	2MO-3226	2B	3226


NOIF TO AFW P-05B SECTION
03
NOIF FROM SERVICE WATER "A" SUPPLY TO P-05B
NOIF FROM CONDENSATE SUPPLY TO P-05B
NOIF FROM SERVICE WATER "B" SUPPLY TO P-05B
BUTTERFLY VALVE 1MO-3893A4 FAILS CLOSED
F4
BUTTERFLY VALVE 1MO-3893A3 FAILS CLOSED
E4
CHECK VALVE 1CK-032B FAILS CLOSED
PCV 032B D
NOIF THRU 1MO 3856
AS
MANUAL GATE VALVE IV-001B TRANSFERS CLOSED
PXV 001B C
BUTTERFLY VALVE 1MO-3893 B3 FAILS CLOSED
G4
BUTTERFLY VALVE 1MO-3893B4 FAILS CLOSED
H4
CHECK VALVE 1CK-034B FAILS CLOSED
PCV 034B D
NOIF FROM SERVICE WATER TRAIN "A" LINK
SA
GATE VALVE 1MO 3856 TRANSFERS CLOSED
G3
NOIF FROM UNIT 1 HEADER
GS
NOIF FROM SERVICE WATER TRAIN "B" LINK
SB
CHECK VALVE 1CK-035B FAILS CLOSED
PCV 035B D
NOIF FROM SERVICE WATER "A" HEADER
1PPSW-AF
MANUAL BUTTERFLY VALVE V-278 TRANSFERS CLOSED
PXV 278-C
MANUAL BUTTERFLY VALVE V-279 TRANSFERS CLOSED
PXV 279-C
NOIF FROM SERVICE WATER "B" HEADER
1PPSW-BF

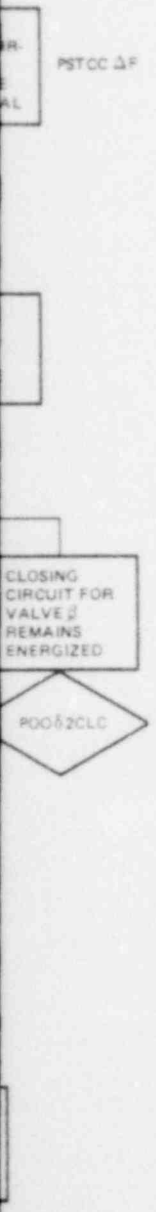


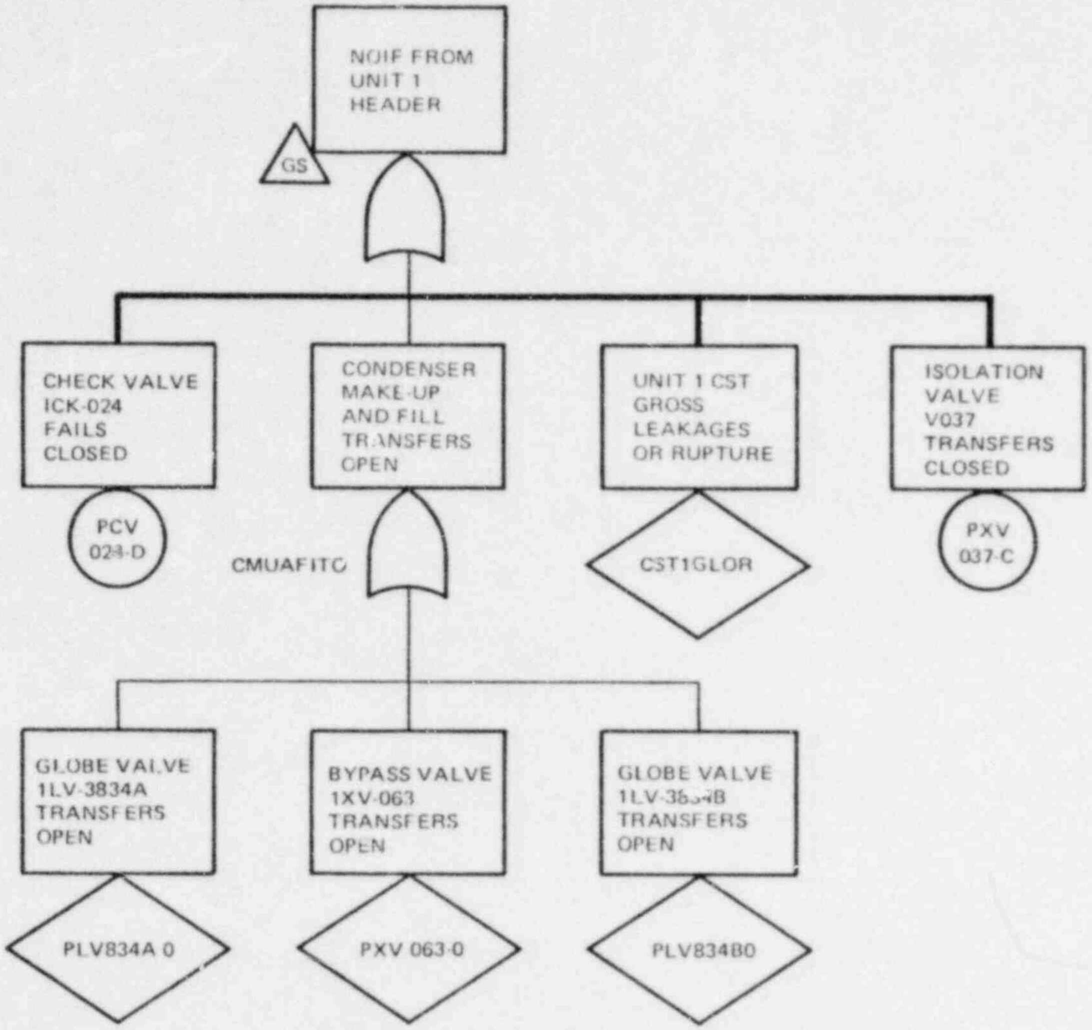
PMV3856C

α	β	γ	δ
G3	1 MO-3856	3856	1L
G4	2 MO-3956	3956	2L


BUTTERFLY VALVE β FAILS CLOSED
VALVE β MOTOR OPERATOR FAILS
PMO θ A
BREAKER 52-8 TRANSFERS OPEN
PCB θ O
AC POWER NOT AVAILABLE FROM MCC η BREAKER δ
JOOηF
VALVE β MECHANICAL FAILURE
PMV θ D
NO AFWAS CHANNEL γ SIGNAL RELAY ε
PRE φ F
VALVE β CONTROL C CUIT FAILS TO PROVID OPEN SIGN
VALVE β COMMON CIRCUIT FAILURE
VALVE β OPENING CIRCUIT FAILURE
VALVE β CLOSING CIRCUIT FAILUR
CONTROL TRANSFORMER FOR VALVE β FAILS
PTR δ2F
OVERLOAD AND BYPASS CIRCUITS FOR VALVE β TRANSFER OPEN
CONTROL POWER FUSE FOR VALVE β TRANSFERS OPEN
PFU δ2010
AUTOMATIC SIGNAL FOR VALVE β NOT PRESENT
VALVE β OPENING COIL FAILS OPEN
PCO δ20CO
VALVE β CLOSING COIL FAILS IN ENERGIZED POSITION
PCO δ2CCE
49 CONTACT FOR VALVE β TRANSFERS OPEN
PCN δ2490
AFWAS CONTACTS T1-M1 FOR VALVE β FAILS OPEN
PCN δ2T1K
AUTOMATIC CIRCUIT FOR VALVE β FAILS
3X CONTACTS 5-6 FOR VALVE β FAILS OPEN
PCN δ23XO
NO AC POWER FROM PANEL κ
JOO κF
BREAKER 52-02 FROM PANEL κ TRANSFERS OPEN
PCB κ10
62 RELAY FOR CIRCUIT ρ FAILS
PRE δ262F
62 CONTACTS 1-5 FOR CIRCUIT ρ FAILS OPEN
PCN δ2620
RELAY τ DOES NOT PROVIDE LOW PRESSURE SIGNAL
3/4
3X RELAY FOR CIRCUIT ρ FAILS
PRE δ23XF
CONTROL POWER FUSE FOR CIRCUIT ρ TRANSFERS OPEN
PFU δ2060
AFWAS CONTACT T3-M3 FOR CIRCUIT ρ FAILS OPEN
PCN δ2T3D
PRESSURE TRANSMITTER PT-38000 γ2 FAILS
PTP π 1M
PRESSURE TRANSMITTER PT-38000 γ2 FAILS
PTP π 2M
PRESSURE TRANSMITTER PT-38000 γ2 FAILS
PTP π 3M
PRESSURE TRANSMITTER PT-38000 γ2 FAILS
PTP π 4M

α	β	γ	ε	θ	η	δ	φ	δ2	κ	ρ	τ	π1	π2	π3	π4	Δ
E3	1MO-3893A1	1A	1A-K608	93A1	BP03	1-02	A801	AL	1Y31	1A1056	1KY38000A	38A1	38A2	38A3	38A4	A1
F3	1MO-3893A2	1A	1A-K603	93A2	BP03	1-03	A301	AM	1Y31	1A1055	1KY38000A	38A1	38A2	38A3	38A4	A2
E4	1MO-3893A3	1A	1A-K608	93A3	BP03	1-04	A802	AN	1Y31	1A1055	1KY38000C	38C1	38C2	38C3	38C4	A3
F4	1MO-3893A4	1A	1A-K603	93A4	BP03	1-05	A302	AP	1Y31	1A1056	1KY38000C	38C1	38C2	38C3	38C4	A4
G3	1MO-3893B1	1B	1B-K608	93B1	BP04	2-02	B801	BL	1Y32	1B1056	1KY38000B	38B1	38B2	38B3	38B4	B1
H3	1MO-3893B2	1B	1B-K603	93B2	BP04	2-03	B301	BM	1Y32	1B1055	1KY38000B	38B1	38B2	38B3	38B4	B2
G4	1MO-3893B3	1B	1B-K608	93B3	BP04	2-04	B802	BN	1Y32	1B1056	1KY38000D	38D1	38D2	38D3	38D4	B3
H4	1MO-3893B4	1B	1B-K603	93B4	BP04	2-05	B302	BP	1Y32	1B1055	1KY38000D	38D1	38D2	38D3	38D4	B4




NOIF FROM UNIT 1 HEADER
GS
CHECK VALVE ICK-024 FAILS CLOSED
PCV 024-D
CONDENSER MAKE-UP AND FILL TRANSFERS OPEN
CMUAFITC
UNIT 1 CST GROSS LEAKAGES OR RUPTURE
CST1GLOR
ISOLATION VALVE V037 TRANSFERS CLOSED
PXV 037-C
GLOBE VALVE 1LV-3834A TRANSFERS OPEN
PLV834A 0
BYPASS VALVE 1XV-063 TRANSFERS OPEN
PXV 063-0
GLOBE VALVE 1LV-3834B TRANSFERS OPEN
PLV834B0

APPENDIX D

MIDLAND AUXILIARY FEEDWATER SYSTEM

COMPONENT DATA SHEETS

The following sheets were used in developing the reliability characteristics (failure rate and time for restoration) for the components constituting the Midland AFWS. The methods for establishing repair time are as follows:

A. For components that are tested monthly

$$\text{MTTR} = \frac{720 \text{ hours}}{2} = 360 \text{ hours.}$$

B. For components that are tested quarterly

$$\text{MTTR} = \frac{2{,}160 \text{ hours}}{2} = 1{,}080 \text{ hours.}$$

C. For components that are tested when the AFW system is actuated we have 6 actuations per year (based on industry experience).

$$\text{MTTR} = \frac{8{,}760 \text{ hours}}{6 \text{ actuations} \times 2} = 730 \text{ hours.}$$

D. For components in the motor-driven pump train up to the pump train discharge check valve, we have 6 actuations per year (Item C. above), one test per month (Item A above), and 10 plant startups or shutdowns per year.

$$\text{MTTR} = \frac{8{,}760 \text{ hours}}{(6+12+10)2} = 156 \text{ hours.}$$

E. For components in the Condensate Storage Tank discharge up to MOV-3856, we have 2 tests per month (2 pumps tested once per month), 10 startups or shutdowns, and 6 actuations per year.

$$\text{MTTR} = \frac{8{,}760 \text{ hours}}{(24+10+6)2} = 109.5 \approx 110 \text{ hours.}$$

F. For components in the turbine-driven pump trains, we have one test per month and 6 actuations per year.

$$\text{MTTR} = \frac{8{,}760 \text{ hours}}{(12+6)2} = 243 \text{ hours.}$$

G. For components in the motor-driven pump train from the pump discharge valve to the MFW cross-connect, we have 10 startups or shutdowns per year and 6 actuations per year.

$$\text{MTTR} = \frac{8{,}760 \text{ hours}}{(10+6)2} = 273.75 \text{ hours} \approx 274.$$

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AVAILABILITY DATA SHEET

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JOB NO. 083 CPC
SHEET 1 OF 24
BY ______ DATE 11/79

ITEM: Valve, Check

OVERALL FAILURE RATE: 1 x 10^{-4} (3) Fail/Demand

REPAIR TIME: varies HR

Reference

1. NPRDS, pg. 364 27 Failures in 12.237 x 10^{6} hours = 2.2 x 10^{-6} F/hr.
2. WASH-1400 Fail to open 1 x 10^{-4}/Demand Range Factor (RF) = 3
Reverse leak 1 x 10^{-7}/Hour RF = 3

A. MTTR for monthly testing - 360 hours
B. MTTR for one test per month and 6 actuations per year - 243 hours
C. MTTR for 24 tests, 6 cycles for actuation and 10 SU/SD - 110 hours

SPECIFIC COMPONENTS

1.	PCV0001D	Use Reference 2.
	PCV0013D	Use Reference 2.
	PCV0015D	Use Reference 2.
	PCV0025D	Use Reference 2.
2.	PCV024-D	Use Reference 2.
3.	PCV075-D	Use Reference 2.
	PCV076-D	Use Reference 2.
4.	PCVU53AD	Use 2 x Reference 2 (two valves in series).
	PCVU53BD	Use 2 x Reference 2 (two valves in series).
5.	PCV002AD	Use Reference 2.
	PCV002BD	Use Reference 2.
	PCV002CD	Use Reference 2.
6.	PCV030AD	Use Reference 2.
	PCV030BD	Use Reference 2.
	PCV031AD	Use Reference 2.
	PCV031BD	Use Reference 2.
	PCV032AD	Use Reference 2.
	PCV032BD	Use Reference 2.
	PCV032CD	Use Reference 2.
	PCV034AD	Use Reference 2.
	PCV034BD	Use Reference 2.
	PCV035AD	Use Reference 2.
	PCV035BD	Use Reference 2.

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AVAILABILITY DATA SHEET

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JOB NO. 083 CPC
SHEET 2 OF 24
BY ______ DATE 11/79

ITEM: Valve, Manual Butterfly

OVERALL FAILURE RATE: .43 (3) FAIL/10^6 HR. REPAIR TIME: varies HR

Reference

1. NPRDS, pg. 343 - (4-11.99 inches) 2 failures in 4.631 x 10^6 hours
   (all modes) $\lambda = 0.43 \times 10^{-6}$ F/hr.

2. WASH-1400 Fail to remain open (plug) 1 x 10^{-4} F/Demand RF = 3

A. MTTR for monthly testing - 360 hours.
B. MTTR for quarterly testing - 1080 hours.
C. MTTR for valve in normal service - 4 hours.

SPECIFIC COMPONENTS

1. PXV278-C Locked open, fail closed (plug) use Ref. 1, MTTR Ref. B.
   PXV279-C Locked open, fail closed (plug) use Ref. 1, MTTR Ref. B.

2. PXV037-C Locked open, fail closed (plug) use Ref. 1, MTTR Ref. C.

3. PMV8931D Motor-operated valves, normally closed, use Ref. 1, MTTR Ref. B.
   PMV8932D Motor-operated valves, normally closed, use Ref. 1, MTTR Ref. B.
   PMV8933D Motor-operated valves, normally closed, use Ref. 1, MTTR Ref. B.
   PMV8934D Motor-operated valves, normally closed, use Ref. 1, MTTR Ref. B.
   PMV93A1D Motor-operated valves, normally closed, use Ref. 1, MTTR Ref. B.
   PMV93A2D Motor-operated valves, normally closed, use Ref. 1, MTTR Ref. B.
   PMV93A3D Motor-operated valves, normally closed, use Ref. 1, MTTR Ref. B.
   PMV93A4D Motor-operated valves, normally closed, use Ref. 1, MTTR Ref. B.
   PMV93B1D Motor-operated valves, normally closed, use Ref. 1, MTTR Ref. B.
   PMV93B2D Motor-operated valves, normally closed, use Ref. 1, MTTR Ref. B.
   PMV93B3D Motor-operated valves, normally closed, use Ref. 1, MTTR Ref. B.
   PMV93B4D Motor-operated valves, normally closed, use Ref. 1, MTTR Ref. B.

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AVAILABILITY DATA SHEET

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JOB NO. 083 CPC
SHEET 3 OF 24
BY Dcd DATE 11/79

ITEM: Valve, Manual Gate

OVERALL FAILURE RATE: 0.4 (3) FAIL/10^6 HR. REPAIR TIME: varies HR

Reference

1. NPRDS, pg. 377 - (4-11.99 inch gate valve) 10 failures in 27.162 x 10^6 hrs. (all modes) $\lambda = 3.7 \times 10^{-7}$ F/hr.

A. MTTR for 6 actuations/year - 730 hours
B. MTTR for 1 test/month, 10 SU/SD, and 6 actuations/year - 156 hours
C. MTTR for 24 test/year, 6 actuations and 10 SU/SD - 110 hours
D. MTTR for 1 test/month and 6 actuations/year - 243 hours
E. MTTR for 10 SU/SD and 6 actuations/year - 274 hours

SPECIFIC COMPONENTS

1. PMV3856C (Includes valve and false signal) use Ref. 1 and MTTR Ref. C.

2. PMO3126C (Includes valve and false signal) use Ref. 1 and MTTR Ref. D.

3. PMV868AC (Valve only) Normally open, transfers closed. Use Ref. 1 and
PMV868BC MTTR Ref. B. (868A), D (868B).

4. PMV177AD (Normally closed) use Ref. 1 and MTTR Ref. D.
PMV177BD (Normally closed) use Ref. 1 and MTTR Ref. D.
PMV870AD (Normally closed) use Ref. 1 and MTTR Ref. A.
PMV870BD (Normally closed) use Ref. 1 and MTTR Ref. A.
PMV865[illegible]D (Normally closed) use Ref. 1 and MTTR Ref. A.
PMV865BD (Normally closed) use Ref. 1 and MTTR Ref. A.

5. PMV872AC Normally open, transfers closed. Use Ref. 1 and MTTR Ref. A.
PMV872BC Normally open, transfers closed. Use Ref. 1 and MTTR Ref. A.

6. PXV001AC Normally open, transfers closed. Use Ref. 1 and MTTR Ref. B.
PXV001BC Normally open, transfers closed. Use Ref. 1 and MTTR Ref. D.
PXV001CC Normally open, transfers closed. Use Ref. 1 and MTTR Ref. B.
PXV003AC Normally open, transfers closed. Use Ref. 1 and MTTR Ref. E.
PXV003BC Normally open, transfers closed. Use Ref. 1 and MTTR Ref. A.
PXV003CC Normally open, transfers closed. Use Ref. 1 and MTTR Ref. E.
PXV0002C Normally open, transfers closed. Use Ref. 1 and MTTR Ref. A.
PXV0004C Normally open, transfers closed. Use Ref. 1 and MTTR Ref. E.
PXV0014C Normally open, transfers closed. Use Ref. 1 and MTTR Ref. A.
PXV0017C Normally open, transfers closed. Use Ref. 1 and MTTR Ref. A.

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AVAILABILITY DATA SHEET

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JOB NO. 083 CPC
SHEET 4 OF 24
BY Jul DATE 11/79

ITEM: Valve, Manual Globe

OVERALL FAILURE RATE: 0.8 FAIL/10^6 HR. REPAIR TIME: varies HR

Reference

1. NPRDS, pg. 390 (4-11.99 inch globe valve) (all modes) 3 failures in 3.750×10^6 hours $\lambda = 8 \times 10^{-7}$ F/hr.

2. Self-actuated pressure control valve. Failure rate 20×10^{-6}/hour based upon engineering judgment.

A. MTTR for 6 actuations/year - 730 hours
B. MTTR based on valve position indication indicating valve in wrong position - 1 hour
C. MTTR for 6 actuations/year and 10 SU/SD - 274 hours

SPECIFIC COMPONENTS

1. PLV75A1D (Normally closed) Use Ref. 1 and MTTR Ref. A.
PLV75A2D (valve only) PLV75A1D only use MTTR Ref. C.
PLV75B1D
PLV75B2D

2. PXV009AO (Normally closed test valve), use Ref. 1 and MTTR Ref. B.
PXV009BO (Normally closed test valve), use Ref. 1 and MTTR Ref. B.
PXV009CO (Normally closed test valve), use Ref. 1 and MTTR Ref. B.

3. PLV875AC (Normally open) Use Ref. 1 and MTTR Ref. C.
PLV875BC (Normally open) Use Ref. 1 and MTTR Ref. A.

4. PLV75A1C Normally open. Use Ref. 1 and MTTR Ref. C.
PLV75A2C Normally open. Use Ref. 1 and MTTR Ref. A.
PLV75B1C Normally open. Use Ref. 1 and MTTR Ref. A.
PLV75B2C Normally open. Use Ref. 1 and MTTR Ref. A.

5. CMUAFITO Use 3 x Reference 1 and MTTR Reference B.

6. PHV889-O Use 0.1 x Ref. 1 (Normally closed, transfer open) and MTTR Ref. B.

7. PHV020AC Use Reference 2 and MTTR Reference C.
PHV020BC Use Reference 2 and MTTR Reference C.

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AVAILABILITY DATA SHEET

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JOB NO. 083 CPC
SHEET 5 OF 24
BY [illegible] DATE 11/79

ITEM: Motor Operator, AC Reversible 480V

OVERALL FAILURE RATE: 4.3 (3) FAIL/10^6 HR. REPAIR TIME: varies HR

Reference

1. NPRDS, pgs. 448, 449 (Direct acting, reverse acting, double acting, geared) (includes valve) (includes controls) (all modes)
   255 failures in [illegible].416 x 10^6 hours $\lambda = 11.38 \times 10^{-6}$ F/hr.

2. WASH-1400 MOV Fail to operate 1×10^{-3} F/Demand RF - 3
   (Includes operator, valve and controls)

3. IEEE 500 pg. 386 MOV Fail to operate
   Low Med. Rec.
   1.25 2.5 12.5 in 10^6 cycles RF - 3

4. NPRDS pg. 243 (motor polyphase 480VAC)
   53 Failures in 12.405 x 10^6 hours $\lambda = 4.27 \times 10^{-6}$ F/hr.

A. MTTR for quarterly testing - 1080 hours

SPECIFIC COMPONENTS

1. PMO8931A Operator only, use Reference 4 and MTTR Reference A.
   PMO8932A Operator only, use Reference 4 and MTTR Reference A.
   PMO8933A Operator only, use Reference 4 and MTTR Reference A.
   PMO8934A Operator only, use Reference 4 and MTTR Reference A.
   PMO93A1A Operator only, use Reference 4 and MTTR Reference A.
   PMO93A2A Operator only, use Reference 4 and MTTR Reference A.
   PMO93A3A Operator only, use Reference 4 and MTTR Reference A.
   PMO93A4A Operator only, use Reference 4 and MTTR Reference A.
   PMO93B1A Operator only, use Reference 4 and MTTR Reference A.
   PMO93B2A Operator only, use Reference 4 and MTTR Reference A.
   PMO93B3A Operator only, use Reference 4 and MTTR Reference A.
   PMO93B4A Operator only, use Reference 4 and MTTR Reference A.

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AVAILABILITY DATA SHEET

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JOB NO. 083 CPC
SHEET 6 OF 24
BY GWS DATE 11/79

ITEM: Motor Operator, DC Reversible 125VDC

OVERALL FAILURE RATE: 19.8 (3) FAIL/10^6 HR. REPAIR TIME: 360 HR

Reference

1. NPRDS, pgs. 450, 451 (Direct acting, reverse acting, double acting, geared) (includes controls) (all modes)
   37 Failures in 1.169×10^6 hours $\lambda = 31.65 \times 10^{-6}$ F/hr.

2. WASH-1400 - see Motor Operator, AC, sheet 5, ref. 2

3. IEEE 500 - see Motor Operator, AC, sheet 5, ref. 3

4. NPRDS, pg. 249 (Motor DC commutator Single Speed)
   5 Failures in 0.253×10^6 hours $\lambda = 19.76 \times 10^{-6}$ F/hr.

A. MTTR for 1 test/month and 6 actuations/year - 240 hours

SPECIFIC COMPONENTS

1. PMO177AA
   PMO177BA

   Operator only, use Ref. 4. and MTTR Ref. A.; with power fuse use 19.8×10^{-6} F/hr.
   (see sheet 14 for fuse)
   [19.76 + .02 = 19.78 ≈ 19.8]

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JOB NO. 083 CPC
SHEET 7 OF 24
BY ____ DATE 11/79

ITEM: Pump, Centrifugal <500 to 2499

OVERALL FAILURE RATE: 19.8 (3) FAIL/10^6 HR. REPAIR TIME: varies HR

Reference

1. WASH-1400 Pumps Failure to Start (Includes Driver) 1×10^{-3}/D RF - 3
Failure to Run (Includes Drive) 3×10^{-5}/hr RF - 10

2. NPRDS, pg. 273 90 Failures in 4.555×10^6 hours $\lambda = 19.76 \times 10^{-6}$ F/hr.

A. MTTR for 1 test/month, 6 actuations/year and 10 SU/SD - 156 hours
B. MTTR for 1 test/month and 6 actuations/year - 243 hours

SPECIFIC COMPONENTS

1. PPM105AF Use Ref. 2 and MTTR Ref. A.
PPM105BF Use Ref. 2 and MTTR Ref. B.
PPM105CF Use Ref. 2 and MTTR Ref. A.

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AVAILABILITY DATA SHEET

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SHEET 8 OF 24

BY ______ DATE 11/79

ITEM: Motor, Induction Squirrel Cage 3500-4999VAC

OVERALL FAILURE RATE: 3.50 (3) FAIL/10^6 HR. REPAIR TIME: 360 HR

Reference

1. WASH-1400 Fail to Start 3×10^{-4}/D Range Factor 3
   Fail to Run 1×10^{-5}/D Range Factor 3

2. NPRDS, pg. 244 14 Failures in 3.995×10^6 hours $\lambda = 3.50 \times 10^{-6}$ F/hr.

3. IEEE 500 (201 hp and larger)
   pg. 206

	low	rec.	high	max.
All modes	.707	1.897	7.73	10.43
Catastrophic	.566	1.518	6.184	8.344
Fail to run	.336	.901	3.672	4.954
Fail to start	.230	.616	2.512	3.390

A. MTTR for 1 test/month, 6 actuations/year and 10 SU/SD - 156 hours

SPECIFIC COMPONENTS

1. PM0105AA Use Ref. 1 and MTTR Ref. A
   PM0105CA Use Ref. 1 and MTTR Ref. A

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AVAILABILITY DATA SHEET

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BY Dcs DATE 11/79

ITEM: AC Distribution Buses (4160, 480, 120)

OVERALL FAILURE RATE: 14.4 (10) FAIL/10^6 HR. REPAIR TIME: 8 HR

Reference

1. NPRDS, pg. 25 Plant electrical systems (less standby/auxiliary power)
5 System failures in 1847 x 10^3 hours
80 Component failures in 1847 x 10^3 hours
$\lambda = 4.3 \times 10^{-5}$ F/hr.

From bar graph on effect of failure by major components
≈ 1/3 of failures result in loss of subsystem/channel

$$\frac{1}{3} \times \frac{80}{1847 \times 10^3} = 14.4 \times 10^{-6} \text{ F/hr.}$$

A. MTTR Based upon technical specification requirements

SPECIFIC COMPONENTS

1. J001A05F Use Reference 1 and MTTR Reference A
J001A06F Use Reference 1 and MTTR Reference A
J001BP3F Use Reference 1 and MTTR Reference A
J001BP4F Use Reference 1 and MTTR Reference A
J001B55F Use Reference 1 and MTTR Reference A
J001B56F Use Reference 1 and MTTR Reference A
J001Y13F Use Reference 1 and MTTR Reference A
J001Y14F Use Reference 1 and MTTR Reference A
J001Y31F Use Reference 1 and MTTR Reference A
J001Y32F Use Reference 1 and MTTR Reference A
J001Y11F Use Reference 1 and MTTR Reference A
J001Y12F Use Reference 1 and MTTR Reference A

NOTE: For loss of offsite power cases, use 3.7×10^{-2} Failure on demand. Ref. WASH-1400 Appendix 2 Electric Power System Analysis (Q_{EDG} - 3.7×10^{-2} Failure on demand)

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BY ________ DATE 11/79

ITEM: Service Water System by Subsystem

OVERALL FAILURE RATE: 380 F/hr. FAIL/10^6 HR. REPAIR TIME: 72 HR

Reference

1. NPRDS, pg. 59 35 Systems 0 system failures in 951.8×10^3 hours
   109 component failures

   From effect of failure graphs ≈ 30% of equipment failures (pumps) caused loss of subsystem.

   Assume 1/3 of 109 failures cause subsystem failure

$$\frac{36}{951.8 \times 10^3} = 38 \times 10^{-6} \text{ F/hr.}$$

2. MTTR of 72 hours based on technical specification requirements

SPECIFIC COMPONENTS

1. 1PPSW-AF Use Reference 1 and MTTR Reference A
   1PPSW-BF

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ITEM: DC Distribution System

OVERALL FAILURE RATE: 11.2 (10) FAIL/10^6 HR.
REPAIR TIME: 2 HR

Reference

1. NPRDS, pg. 26 — 42 Systems; 1164.4×10^3 hours; 0 system failures in 35,630 tests. There have been 39 component failures in this time period.

   Estimate $\lambda \ \frac{39}{1164.4 \times 10^3} = 3.35 \times 10^{-5}$

2. WASH-1400 — 3×10^{-6}/hr. RF - 3 no/output (Batteries)

3. NPRDS, pg. 26 — Batteries $.42 \times 10^{-6}$ F/hr.

   From bar graph 1/3 of component failures cause subsystem failure $\frac{1}{3} \times \frac{39}{1164.4 \times 10^3} = 11.2 \times 10^{-6}$ F/hr.

A. MTTR 2 hours based on technical specification requirements

SPECIFIC COMPONENTS

1. J001D11F
   J001D21F — Use Reference 3 and MTTR Reference A

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SHEET 12a OF 24

BY [illegible] DATE 11/77

ITEM: Breaker Circuit Closer/Interrupter AC 450V [MCC] 120V Panel

OVERALL FAILURE RATE: 0.39 (3) FAIL/10^6 HR. REPAIR TIME: 4 HR

Reference

1. IEEE 500, pg. 148 Indoor design - AC Breakers RF = 5

Failure Mode (2)	Failure Rate (3)							
	Failures/10^6 Hours				Failures/10^6 Cycles			
	Low	Rec	High	Max	Low	Rec	High	Max
ALL MODES	.02	.144	.65	2.02	50	400	4000	8000
CATASTROPHIC	.006	.043	.194	.601	37.1	296.8	2968	[illegible]368
Spurious Operation	.006	.043	.194	.603	-	-	-	-
Fails to open	-	-	-	-	28.3	226.5	22[illegible]	2265
Fails to interrupt on opening	-	-	-	-	8.7	69.3	693	693
Fails to close	-	-	-	-	.1	1	10	10
DEGRADED	-	-	-	-	12.9	103.2	1032	1032
Operates prematurely								
INCIPIENT	.014	.101	.456	1.417	-	-	-	-

2. WASH-1400 Fail to operate 1×10^{-3}/D RF = 3
Premature Transfer 1×10^{-6}/hr. RF = 3

3. NPRDS, pg. 97 Indoor Sealed Manual 13 failures in 33.110 x 10^6 hours
$\lambda = 3.93 \times 10^{-7}$

A. MTTR Based on engineering judgment and announced failures - 4 hours

SPECIFIC COMPONENTS

1. PCB11030 (480V MCC CB for S.W. valves) Use Ref. 3 and MTTR Ref. A.
PCB11020 (Normally closed)
PCB21030
PCB21020
PCB93A10
PCB93A20
PCB93A30
PCB93A40
PCB93B10
PCB93B20
PCB93B30
PCB93B40

2. PCB15260 (480V MCC CB for MOV3870A, B) Use Ref. 3 and MTTR Ref. A
PCB16260 (Normally closed)

3. PCB16200 120V Panel CB Use Ref. 3 and MTTR Ref. A.
PCB16210 120V Panel CB Use Ref. 3 and MTTR Ref. A.
PCB17200 120V Panel CB Use Ref. 3 and MTTR Ref. A.
PCB17210 120V Panel CB Use Ref. 3 and MTTR Ref. A.

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ITEM: Breaker, 4160VAC Indoor Metal Clad

OVERALL FAILURE RATE: 1.29 (3) FAIL/10^6 HR. REPAIR TIME: 360 HR

Reference

1. NPRDS, pgs. 94, 95 (Indoor metal clad, magnetic, motor)
   85 failures in 65.663×10^6 hrs. $\lambda = 1.29 \times 10^{-6}$ F/hr
2. WASH-1400 Failure to operate 1×10^{-3} F/Demand RF = 3
3. IEEE 500 see sheet 13, ref. 1.

A. MTTR - 5 hours from NPRDS, pg. 36
B. MTTR For 1 test/month, 6 acutations/year and 10 SU/SD - 156 hours.

SPECIFIC COMPONENTS

1. 4160V Breaker for P5A Use Ref. 1 and MTTR Ref. B.
   4160V Breaker for P5C Use Ref. 1 and MTTR Ref. B.

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AVAILABILITY DATA SHEET

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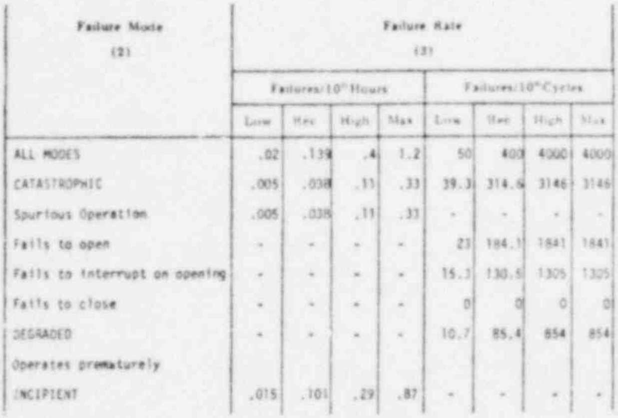
ITEM: Breaker Circuit Closer/Interrupter DC

OVERALL FAILURE RATE: .038 (5) FAIL/10^6 HR. REPAIR TIME: 4 HR

Reference

1. IEEE 500, pg. 150 Indoor design DC Breakers

RF ≈ 5



Failure Mode (2)	Failure Rate (3)							
	Failures/10^6 Hours				Failures/10^6 Cycles			
	Low	Rec	High	Max	Low	Rec	High	Max
ALL MODES	.02	.139	.4	1.2	50	400	4000	4000
CATASTROPHIC	.005	.038	.11	.33	39.3	314.6	3146	3146
Spurious Operation	.005	.038	.11	.33	-	-	-	-
Fails to open	-	-	-	-	23	184.1	1841	1841
Fails to interrupt on opening	-	-	-	-	15.3	130.5	1305	1305
Fails to close	-	-	-	-	0	0	0	0
DEGRADED	-	-	-	-	10.7	85.4	854	854
Operates prematurely								
INCIPIENT	.015	.101	.29	.87	-	-	-	-

2. NPRDS see AC Circuit Breaker 450V, sheet 12, ref. 3.

A. MTTR see sheet 12, ref. A

SPECIFIC COMPONENTS

1. PCB 17140 (Normally closed, DC) Use Ref. 3. sheet 12 MTTR
   PCB 17150 Use Ref. A. sheet 12

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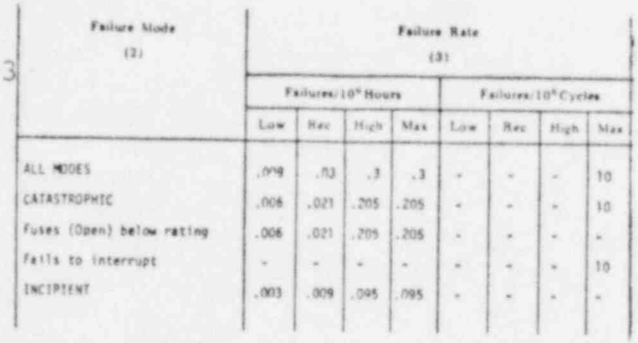
BY DRS DATE 11/79

ITEM: Fuses

OVERALL FAILURE RATE: 0.021 (5) FAIL/10^6 HR. REPAIR TIME: 1 HR

Reference

1. IEEE 500, pg. 193



Failure Mode (2)	Failure Rate (3)							
	Failures/10^6 Hours				Failures/10^6 Cycles			
	Low	Rec	High	Max	Low	Rec	High	Max
ALL MODES	.009	.03	.3	.3	-	-	-	10
CATASTROPHIC	.006	.021	.205	.205	-	-	-	10
Fuses (Open) below rating	.006	.021	.205	.205	-	-	-	-
Fails to interrupt	-	-	-	-	-	-	-	10
INCIPIENT	.003	.009	.095	.095	-	-	-	-

RF ≈ 5

A. MTTR based on announced failures - 1 hour

SPECIFIC COMPONENTS

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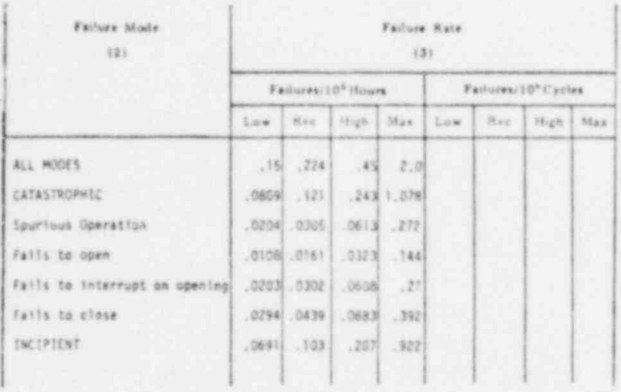
ITEM: Motor Starter

OVERALL FAILURE RATE: .12 (2) FAIL/10^6 HR. REPAIR TIME: 4 HR

Reference

1. IEEE 500, pg. 171



Failure Mode (2)	Failure Rate (3)							
	Failures/10^6 Hours				Failures/10^6 Cycles			
	Low	Rec	High	Max	Low	Rec	High	Max
ALL MODES	.15	.224	.45	2.0				
CATASTROPHIC	.0809	.121	.243	1.078				
Spurious Operation	.0204	.0305	.0613	.272				
Fails to open	.0108	.0161	.0323	.144				
Fails to interrupt on opening	.0203	.0302	.0608	.27				
Fails to close	.0294	.0439	.0883	.392				
INCIPIENT	.0691	.103	.207	.922				

RF ≈ 2

A. MTTR based on announced failures - 4 hours

SPECIFIC COMPONENTS

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ITEM: Relay Control 100-199VDC

OVERALL FAILURE RATE: 0.59 (3) FAIL/10^6 HR. REPAIR TIME: 4 HR

Reference

1. NPRDS, pg. 289 26 failures in 44.137×10^6 operating hours
   General Purpose $\lambda = .59 \times 10^{-6}$

A. MTTR see sheet 17
B. MTTR for monthly test - 360 hours

SPECIFIC COMPONENTS

1. PRE1A11F Use Reference 1 and MTTR Reference B.
   PRE1B11F Use Reference 1 and MTTR Reference B.
   PRE1A12F Use Reference 1 and MTTR Reference B.
   PRE1B12F Use Reference 1 and MTTR Reference B.
   PRE1111F Use Reference 1 and MTTR Reference B.
   PRE1112F Use Reference 1 and MTTR Reference B.
   PRE1A03F Use Reference 1 and MTTR Reference B.
   PRE1A08F Use Reference 1 and MTTR Reference B.
   PRE1B03F Use Reference 1 and MTTR Reference B.
   PRE1B08F Use Reference 1 and MTTR Reference B.
   PREA301F Use Reference 1 and MTTR Reference B.
   PREA302F Use Reference 1 and MTTR Reference B.
   PREA801F Use Reference 1 and MTTR Reference B.
   PREA802F Use Reference 1 and MTTR Reference B.
   PREB301F Use Reference 1 and MTTR Reference B.
   PREB302F Use Reference 1 and MTTR Reference B.
   PREB801F Use Reference 1 and MTTR Reference B.
   PREB802F Use Reference 1 and MTTR Reference B.
   PRE1512X Use Reference 1 and MTTR Reference B.
   PRE1514X Use Reference 1 and MTTR Reference B.
   PRE1610X Use Reference 1 and MTTR Reference B.
   PRE1613X Use Reference 1 and MTTR Reference B.

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ITEM: Relay Control 100-199VAC

OVERALL FAILURE RATE: 0.49 (3) FAIL/10^6 HR. REPAIR TIME: 4 or 360 HR

Reference

1. NPRDS, pg. 288 (General Purpose) 29 failures in 59.076 x 10^6 operating hours
$\lambda = .49 \times 10^{-6}$ F/hr.

A. MTTR for general purpose relay in energized circuit - 4 hours

SPECIFIC COMPONENTS

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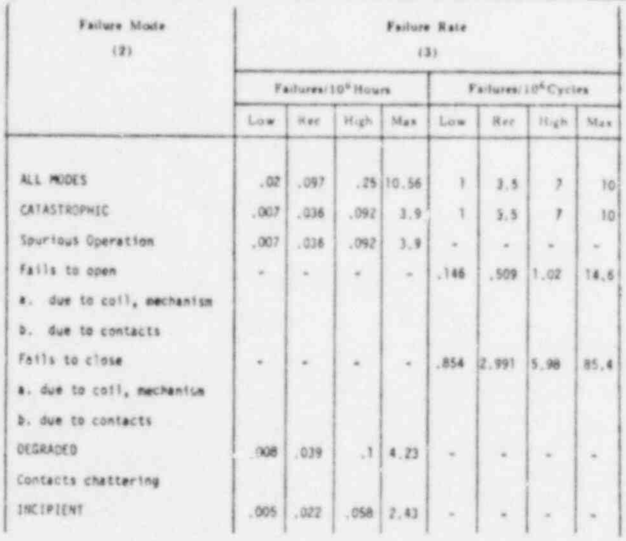
ITEM: Relays, Protective

OVERALL FAILURE RATE: 0.036 (3) FAIL/10^6 HR. REPAIR TIME: 4 HR

Reference

1. IEEE 500, pg. 155



Failure Mode (2)	Failure Rate (3)							
	Failures/10^6 Hours				Failures/10^6 Cycles			
	Low	Rec	High	Max	Low	Rec	High	Max
ALL MODES	.02	.097	.25	10.56	1	3.5	7	10
CATASTROPHIC	.007	.036	.092	3.9	1	5.5	7	10
Spurious Operation	.007	.036	.092	3.9	-	-	-	-
Fails to open	-	-	-	-	.146	.509	1.02	14.6
a. due to coil, mechanism								
b. due to contacts								
Fails to close	-	-	-	-	.854	2.991	5.98	85.4
a. due to coil, mechanism								
b. due to contacts								
DEGRADED	.008	.039	.1	4.23	-	-	-	-
Contacts chattering								
INCIPIENT	.005	.022	.058	2.43	-	-	-	-

-RF ≈ 3

A. MTTR see sheet 17
B. MTTR for monthly test - 360 hours

SPECIFIC COMPONENTS

1. PCN1C560 Use Reference 1 and MTTR Reference B
   PCN1D120 Use Reference 1 and MTTR Reference B
   PCN1C120 Use Reference 1 and MTTR Reference B
   PCN1D560 Use Reference 1 and MTTR Reference B

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ITEM: Switchgear Protective Relay

OVERALL FAILURE RATE: 0.08 (3) FAIL/10^6 HR. REPAIR TIME: 4 HR

Reference

1. NPRDS, pg. 189 (100-199VDC) 1 failure in 13.027 x 106 operating hours
$\lambda = 7.7 \times 10^{-8}$ F/hr.

A. MTTR see sheet 17

SPECIFIC COMPONENTS

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ITEM: Switchgear Auxiliary Relay 100-199VDC

OVERALL FAILURE RATE: 0.16 (3) FAIL/10^6 HR. REPAIR TIME: 4 HR

Reference

1. NPRDS, pg. 192 0 failures in 6.258×10^6 operating hours $< 1.6 \times 10^{-7}$
population 474

A. MTTR see sheet 17

SPECIFIC COMPONENTS

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ITEM: Time Delay Relay, Pneumatic, AC or DC

OVERALL FAILURE RATE: see below (3) FAIL/10^6 HR. REPAIR TIME: 4 HR

Reference

1. NPRDS, pgs. 298, 299
DC (all volt) 1 failure in 4.709 x 10^6 hours
$\lambda = .02 \times 10^{-6}$ F/hr.
AC (all volt) 1 failure in 1.246 x 10^6 hours
$\lambda = .08 \times 10^{-6}$ F/hr.

A. MTTR see sheet 17

SPECIFIC COMPONENTS

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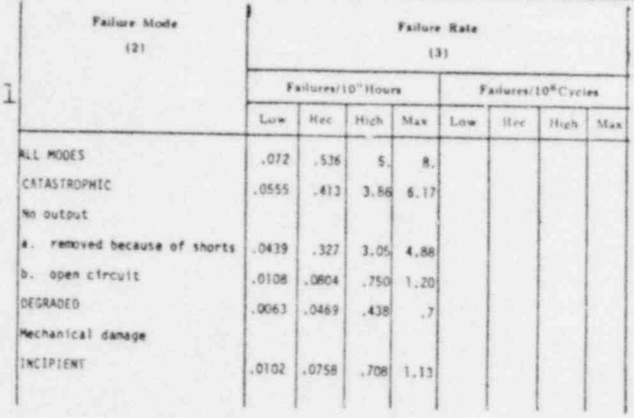
ITEM: Transformer Control 480/120VAC

OVERALL FAILURE RATE: .413 [8] FAIL/10^6 HR. REPAIR TIME: 4 HR

Reference

1. IEEE 500, pg. 371
   Potential Transformer



Failure Mode (2)	Failure Rate (3)							
	Failures/10^6 Hours				Failures/10^6 Cycles			
	Low	Rec	High	Max	Low	Rec	High	Max
ALL MODES	.072	.536	5.	8.				
CATASTROPHIC	.0555	.413	3.86	6.17				
No output								
a. removed because of shorts	.0439	.327	3.05	4.88				
b. open circuit	.0108	.0804	.750	1.20				
DEGRADED	.0063	.0469	.438	.7				
Mechanical damage								
INCIPIENT	.0102	.0758	.708	1.13				

RF ≈ 8

2. NPRDS, pg. 211 0 failures in 8.090 x 10^6 hours population 662 (0-299VAC Air Cooled Natural Circulation)

A. MTTR see sheet 17

SPECIFIC COMPONENTS

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SHEET 23a OF 24

BY DATE 11/79

ITEM: Miscellaneous Circuits

OVERALL FAILURE RATE: See below FAIL/10^6 HR. REPAIR TIME: Varies HR

Reference

SPECIFIC COMPONENTS

1.	PSTM05AF PSTM05BF	Motor operator - 19.76 (sheet 6); master contractor - 0.12 (sheet 15); 95-1 Relay - 0.49 (sheet 17); FOGG Fuse - 0.02 (sheet 14); FOGG Breaker - 0.39 (sheet 12); $\lambda = 20.8 \times 10^{-6}$, MTTR = 730 hours, RF = 3
2.	PSTMO0AF PSTMO0BF	Motor operator - 4.27 (sheet 5); Master contractor - 0.12 (sheet 15); 95 Relay - 0.49 (sheet 17); FOGG Fuse - 0.02 (sheet 14); FOGG Breaker - 0.39 (sheet 12); $\lambda = 5.29 \times 10^{-6}$, MTTR = 730 hours, RF = 3
3.	PSTBR1AF PSTBR1BF	Breaker - 1.29 (sheet 12b); 3X relay - 0.6 (sheet 16); OC Relay (2) - 0.07 (sheet 18); UV Relay - 0.04 (sheet 18); GF Relay - 0.04 (sheet 18); Fuse (2) - 0.04 (sheet 14); $\lambda = 2.12 \times 10^{-6}$, MTTR = 156 hours, RF = 3
4.	PSTCCA1F	Control transformer - 0.41 (sheet 22); Power fuse - 0.02 (sheet 14);
	PSTCCA2F PSTCCB1F PSTCCB2F PSTCCA3F PSTCCA4F PSTCCB3F PSTCCB4F	Open coil - 0.49 (sheet 17); Close coil - 0.49 (sheet 17); LP circuit consisting of: breaker - 0.39 (sheet 12); 62 Relay - 0.04 (sheet 18); 3 x Relay - 0.04 (sheet 18); Fuse - 0.02 (sheet 14). $\lambda = 1.90 \times 10^{-6}$, MTTR = 4 hours (circuit failure indicated) RF = 3

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ITEM: Miscellaneous Circuits

OVERALL FAILURE RATE: See below FAIL/10^6 HR. REPAIR TIME: Varies HR

Reference

SPECIFIC COMPONENTS

5.	PSTCC5AF PSTCC5BF PCC177AF PCC177BF	Close coil - 0.59 (sheet 16); Open coil - 0.59 (sheet 16); Power fuse (2) - 0.04 (sheet 14); Time delay relay - 0.08 (sheet 21). $\lambda = 1.30 \times 10^{-6}$, MTTR = 4 hours, RF = 3
6.	PSTCC0AF PSTCC0BF	Close coil - 0.49 (sheet 17); Open coil - 0.49 (sheet 17); Power fuse - 0.02 (sheet 14); Transformer - 0.41 (sheet 22). $\lambda = 1.41 \times 10^{-6}$, MTTR = 4 hours, RF = 3
7.	PSTSL1AF PSTSL2AF PCC1AC1E PCC1AC2E PCC1BC1E PCC1BC2E	$\lambda = 0.1 \times 10^{-6}$ F/hour based on engineering judgment. MTTR = 4 hours based on indication available in the control room. RF = 3
8.	PSTCS1AC PSTCS1BC	$\lambda = 0.01 \times 10^{-6}$ F/hour based on engineering judgment. MTTR = 4 hours. RF = 3
9.	POOCCA1X POOCCA2X POOCCB1X POOCCB2X	$\lambda = 20 \times 10^{-6}$ F/hour based on engineering judgment as no data was available for electrohydraulic valves. MTTR (POOCCA1X) = 274 hours MTTR (all others) = 720 hours RF = 3

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ITEM: Miscellaneous Hardware Failures
OVERALL FAILURE RATE: See below (3) FAIL/10^6 HR.
REPAIR TIME: See below HR

Reference

1\. CST1GLOR Condensate Storage Tank Rupture or Gross Leakage
$\lambda = 1 \times 10^{-10}$ from WASH-1400 Appendix 2 AFW System Analysis. MTTR = 1 hour based upon rapid detection.
RF = 30

2\. 1RUPTLOF AFW flow lost in main feedwater header.
$\lambda = 1 \times 10^{-8}$ based on engineering judgment (must pass through a check valve and a closed MOV)
MTTR = 1 hour, based upon rapid detection.
RF = 10

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17840 Skypark Boulevard
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JOB NO. 083 CPC

SHEET 24 OF 24

BY [illegible] DATE 3/80

AVAILABILITY DATA SHEET

ITEM: Turbine Pump Controls and Turbine

OVERALL FAILURE RATE: (3) 1.06×10^{-2} FAIL/DEMAND REPAIR TIME: ______ HR.

Reference

1. EGG Pump Report supplied values that yielded a 1.06×10^{-2} F/demand.

SPECIFIC COMPONENTS

1. PTB1G05A Controls fail to perform function, turbine fails to start

REFERENCES

	Reference	Source	Date
1.	Nuclear Plant Reliability Data System 1978 Annual Reports of Cumulative System and Component Reliability, NUREG/CR0942	National Technical Information Service, Springfield, VA 22161	1979
2.	Reactor Safety Study WASH-1400 (NUREG-75/014) Appendix III	U.S. Nuclear Regulatory Commission	1975
3.	IEEE Guide to the Selection and Presentation of Electrical, Electronic and Sensing Component Reliability Data for Nuclear-Power Generating Stations, IEEE Std. 500-1977	The Institute of Electrical and Electronic Engineers, Inc. or John Wiley & Sons, Inc.	1977
4.	Data Summaries of Licensee Event Reports of PUMPS at U.S. Commercial Nuclear Power Plants NUREG/CR-1205	National Technical Information Service, Springfield, VA 22161	1980