DAVIS-BESSE UNIT No. 1

AUXILIARY FEEDWATER SYSTEM

RELIABILITY ANALYSIS

FINAL REPORT

Prepared by:
EDS Nuclear Inc.

for

Toledo Edison Company

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1.0 SUMMARY

This report presents results of a reliability analysis of the Davis-Besse Nuclear Power Station, Unit No. 1 auxiliary feedwater system (AFWS). This analysis, performed by EDS Nuclear, Inc. for Toledo Edison Company (TECo), is in support of the TECo commitment to the U.S. Nuclear Regulatory Commission (NRC) for a continual review of auxiliary feedwater system reliability. This analysis also provides a comparative probabilistic risk assessment basis for various design modifications to further upgrade the AFWS for added reliability and performance. The analysis has resulted in the quantification of AFWS unavailability, identification of major contributors to system unavailability and recommendations for system modifications to minimize unavailability.

The analysis is based on development of fault trees for the AFWS and other plant systems supporting the AFWS safety function, i.e., the delivery of cooling water to one or both steam generators whenever the main feedwater flow has been interrupted. The fault trees depict the logical relationship between the failure to deliver sufficient feedwater to the steam generators and the basic mechanical, electrical and human factors which may cause an individual system component to fail. Failure data, derived from industry sources and reviews of Davis-Besse plant-specific operating experience, are used to assign probabilities of failure to the basic component failure mechanisms. These basic event probabilities are then propagated through the fault tree, using Boolean algebra, in order to derive a probability for failure to achieve the AFWS safety function. For the purpose of this report, failure to achieve the AFWS safety function is defined as "AFWS unavailability", even though the failure may result from failures in other plant systems which support the AFWS safety function.

Initiating events which challenge the AFWS can be conveniently categorized as follows:

- Category 1 - Events in which the main feedwater flow or reactor coolant system forced circulation is interrupted, but offsite electrical power is available to the plant.
- Category 2 - Events in which offsite electrical power to the plant is interrupted.
- Category 3 - Seismic events.

The AFWS unavailability is determined for each of these categories of initiating events. The annual frequencies with which these events occur are estimated from industry experience and from reviews of Davis-Besse operating history. The frequency of the initiating event is then multiplied by the AFWS unavailability. The result is the annual frequency with which the AFWS is unavailable when called upon to perform its safety function. This is the overall figure-of-merit used to judge the relative reliability of various AFWS configurations.

The following four AFWS configurations are considered in this analysis:

"Pre-TMI" - The AFWS configuration that existed in March, 1979.

"Post-TMI" - The AFWS configuration that contains TMI-related plant changes, including those planned to be implemented in the 1982 refueling outage. Included in this configuration is a written procedure for fulfilling the AFWS safety function using the main feedwater startup pump, reactor coolant system makeup pump and power operated relief valve as a backup to the AFWS.

"Third Train" - A potential configuration, which utilizes the main feedwater startup pump, in an altered alignment, as a backup third train of auxiliary feedwater.

"Analysis-Based" - A configuration which incorporates recommendations resulting from this reliability analysis, but does not include the realigned startup pump. | 1

The unavailabilities of each AFWS configuration for the three categories of initiating events are summarized in Table 1-1. The overall figure-of-merit, the annual frequency with which each AFWS configuration is unavailable when challenged, is presented in Table 1-2.

The following conclusions are reached as a result of the analysis:

- The Pre-TMI configuration unavailability is dominated by potential human errors, primarily in valve misalignment.

- The Post-TMI configuration incorporates many changes to plant procedures which diminish the likelihood of human errors. The unavailability is then dominated by mechanical failures, primarily associated with motor operated valves.

- The third train configuration reduces the AFWS unavailability by over an order of magnitude for Category 1 and Category 2 events through the addition of a third redundant train.

- The analysis-based configuration provides over an order of magnitude improvement in AFWS availability by addressing those specific mechanical factors and procedural limitations which dominate the Post-TMI results.

Significant improvements in the Davis-Besse AFWS reliability
have already been achieved since the original NRC requests (1)
(2) for a review and upgrade following the Three Mile Island, 1
Unit 2 (TMI-2) event in March, 1979. Further improvements are
planned. Of the alternatives examined in this study, the
third train and analysis-based configurations offer the
greatest improvement in AFWS reliability. The cost of the
third train configuration is relatively high. The
analysis-based alternative offers an even greater improvement
in system reliability, and its associated costs are likely to
be relatively low. The design and procedures modification of
the analysis-based configuration are now planned as a means to
enhance the Davis-Besse AFWS reliability and performance.

TABLE 1-1

Results of AFWS Fault Tree Analysis

AFWS Configuration	AFWS Unavailability (per demand) Category 1 Events	Category 2 Events	Category 3 Events
Pre-TMI	3.3×10^{-2}	4.1×10^{-2}	8.8×10^{-2}
Post-TMI	6.6×10^{-4}	5.5×10^{-3}	1.9×10^{-2}
Third Train	4.5×10^{-5}	1.4×10^{-4}	1.9×10^{-2}
Analysis-Based	3.3×10^{-5}	9.3×10^{-5}	1.1×10^{-2}

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TABLE 1-2

Overall Figure-of-Merit for AFWS Reliability

AFWS Configuration	Frequency of AFWS Unavailability When Challenged (yr^{-1}) (Total of all event categories)
Pre-TMI	8.2×10^{-2}
Post-TMI	3.3×10^{-3}
Third Train	2.2×10^{-4}
Analysis-Based	1.4×10^{-4}

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2.0 SCOPE AND OBJECTIVES

2.1 Background

As part of its review of the Three Mile Island, Unit-2 event, the NRC issued, on May 16, 1979, a Confirmatory Order[1] to the Toledo Edison Company as part holder of the operating license of the Davis-Besse Nuclear Power Station, Unit No. 1. This order required, in part, that the licensee review all aspects of the safety grade auxiliary feedwater system to further upgrade components for added reliability and performance. On July 6, 1979, the NRC issued a letter[2] lifting the above Confirmatory Order, allowing Davis-Besse Unit No. 1 to return to power.

The safety evaluation attached to that letter indicated that the NRC would at some future time require system diversity through the installation of an additional 100 percent capacity motor operated auxiliary feedwater pump, or an alternative acceptable to the staff.

In reviewing the NRC's intended purpose for such a modification, and relating it to the magnitude of the cost impact, TECo determined that a quantification of the relative risk reduction actually provided by such a modification is appropriate.

2.2 Objectives

The overall objective of this analysis is to evaluate the reliability of the Davis-Besse Unit No. 1 auxiliary feedwater system in delivering feedwater to one, or both, steam generators whenever main feedwater is interrupted or whenever reactor coolant system forced circulation is interrupted. Each of four potential AFWS configurations, identified in Section 2.3, is evaluated.

Specific objectives with respect to the evaluation of each AFWS configuration are:

- to determine the AFWS unavailability for various categories of plant initiating events,
- to identify the most significant contributors to AFWS unavailability, when challenged.

The objectives of the comparative evaluations of the four AFWS configurations are:

- to establish an overall figure-of-merit with which to judge the relative reliabilities offered by the four AFWS configurations,
- to determine cost-effective system modifications to upgrade the AFWS reliability and performance.

Formal fault tree techniques, as discussed in Section 4.0 are utilized in achieving these analysis objectives.

2.3 Scope of Work

This reliability analysis examines four potential AFWS configurations. These are:

"Pre-TMI" Configuration

The AFWS and other plant equipment as configured prior to implementation of TMI-2 related plant modifications.

"Post-TMI" Configuration

The AFWS and other plant equipment as configured subsequent to implementation of certain TMI-2 related, and other, plant modifications. It includes those modifications planned to be implemented through the 1982 Davis-Besse refueling outage. It also includes a written procedure to fulfill the AFWS safety function using the main feedwater startup pump, the reactor coolant system makeup pump and the power operated relief valve (PORV) as a backup to the AFWS.

"Third Train" Configuration

The same AFWS configuration as for the Post-TMI case, except that a third manually initiated motor driven main feedwater startup pump would be aligned to supply auxiliary feedwater flow, without the necessity for reactor coolant system makeup flow and steam venting via the PORV.

"Analysis-Based" Configuration

The same AFWS configuration as for the Post-TMI case, except that certain recommended system modifications, resulting from this study, are assumed to be implemented.

The first two configurations are analyzed to demonstrate relative improvement to AFWS reliability resulting from system modifications already planned or implemented by TECo. The third configuration represents a system designed to address explicitly the NRC concerns with respect to AFWS reliability as outlined in references (1) and (2). The fourth configuration represents a system designed to address the most significant contributors to the Post-TMI system unavailability, as determined from a comprehensive evaluation of system reliability.

3.0 SYSTEM DESCRIPTION

3.1 AFWS Safety Function

The AFWS is designed to provide coolant to the secondary side
of the steam generators whenever the main feedwater flow has
been interrupted or to establish natural circulation whenever
the reactor coolant system forced circulation has been
interrupted. This is necessary to maintain adequate core
cooling and prevent fuel damage. In the Post-TMI
configuration, there are two ways in which this safety 1
function can be met:

1. The AFWS can deliver full capacity flow from at least one
of the redundant AFWS turbine-driven pumps to one steam
generator. The water delivery to the steam generator(s)
must begin within ten (10) minutes of the initial loss of 1
main feedwater or loss of forced circulation. The water
delivery must continue until the reactor coolant system
cools down and is depressurized to the point where the
decay heat removal system can be operated.

2. The main feedwater startup pump can be manually started
and aligned to deliver coolant to either steam
generator. The present capacity of the startup pump is
not sufficient for complete decay heat removal.
Therefore, the manual initiation of feedwater via this
path must be accompanied by the manual opening of the
power operated relief valve (PORV), initiation of primary
coolant makeup flow (through at least one makeup pump)
and isolation of the reactor coolant system letdown
line. In this mode, partial reactor coolant heat removal
is obtained by venting fluid from the primary system
through the PORV. The makeup flow is necessary to
prevent excessive reactor coolant inventory loss until
the high pressure injection pumps can provide emergency
core cooling. In this mode, the safety function is
accomplished if all actions are initiated within thirty
(30) minutes of the initial loss of feedwater. The
systems must function until the operating conditions for
the decay heat removal system are reached.

Emergency procedures for this second approach exist in the
Post-TMI configuration only for the situation in which offsite
electrical power is available at the plant site. Emergency
procedures for the second approach are presently planned for
the added situation in which offsite electrical power is not
available at the plant site. The extension to the emergency 1
procedures is credited in the analysis-based configuration.
The combination of the startup pump, makeup pump and PORV is
referred to as the "feed and bleed" method throughout the
balance of this report.

The first of the above methods is the anticipated technique for fulfilling the AFWS safety function. The second method is designed only as an emergency backup in the unlikely event that the first method is unsuccessful.

3.2 Pre-TMI System Configuration

The Pre-TMI AFWS is illustrated in Figure 3-1. The system consists of two independant trains, each containing:

- one steam-driven auxiliary feedwater pump,
- AC powered motor operated valves,
- crossover piping which allows the pump to supply water to either steam generator,
- redundant water supplies.

The primary sources of auxiliary feedwater are the condensate storage tanks (CST) with a minimum water supply of 250,000 gallons. Should this supply fail, plant procedures call for the manual transfer of the AFWS pump suction to the fire protection system. The service water system provides an automatic safety-grade backup to the other two supplies. The service water system is connected to the AFWS through motor operated valves, which are initially aligned shut. They receive an open signal on a low pressure condition at the AFWS pump inlet, as measured by redundant pressure switches.

The auxiliary feedwater pumps are both driven by steam from the main steam generators. Normally, steam generator 1 provides steam to AFWS pump turbine 1, and steam generator 2 provides steam to AFWS pump turbine 2. However, in the event of low pressure in one steam generator, the unaffected steam generator can provide steam to both turbines through crossover paths, as illustrated in Figure 3-2. Normally, the motor operated steam admission valves are aligned closed. They receive an open signal from redundant Steam and Feedwater Rupture Control System (SFRCS) channels on low steam generator level, loss of four reactor coolant pumps or high main feedwater differential pressure. The SFRCS actuation logic for the valves is explained in Table 3-1. Individual valves would subsequently close on a low pressure signal at the turbine inlet, a low pressure signal at the AFW pump suction, or a low pressure signal from one steam generator. The turbine contains a trip throttle valve which closes on a turbine overspeed signal. A turbine governor valve is used to control turbine speed. It is controlled automatically or manually from the control room through a DC-powered motor. The exhausts from both turbines come together and are vented through a common silencer.

The AFW pumps are self-cooled and have minimum flow protection through a normally open recirculation line. In addition, there is a normally closed test line connected to the pump discharge. Steam generator level is controlled at low steam generator pressures through the closing of the motor operated pump discharge valves. These valves are AC-powered and initially closed. Additional motor operated valves downstream of the pump discharge direct the auxiliary feedwater flow to the steam generators. These valves are AC-powered, are initially closed, and receive open/close signals from SFRCS. Normally, AFW pump 1 would supply the water to steam generator 1 and AFW pump 2 would supply water to steam generator 2. In the event of a steam generator isolation, crossover paths are available so that both pumps would supply water to the remaining active steam generator. The motor operated valves at the steam generator auxiliary feedwater inlet nozzles are normally open, and would only close on a steam generator low pressure isolation signal.

Prior to the TMI-2 event, no procedures existed for using the main feedwater startup pump, in conjunction with the "feed and bleed" procedure, as an alternative method for fulfilling the AFWS safety function. As a result, no credit has been taken for this backup success path in evaluating the Pre-TMI AFWS configuration.

3.3 Post-TMI System Configuration

The Post-TMI configuration represents the originally planned configuration of the AFWS at the end of the 1982 refueling outage. It incorporates a number of design improvements over the Pre-TMI configuration. Flow diagrams for the Post-TMI AFWS and main steam configurations are shown in Figures 3-3 and 3-4. Major differences between the Pre-TMI and Post-TMI configurations are: 1

1. The Post-TMI configuration has diverse electric power sources for motor operated valves. Certain valves on train 1 (AF-360, AF3870 and the main stream turbine admission valve MS-106) are powered off DC-power supplies. The remainder are AC-powered.

2. The turbine exhausts are redundant and seismically qualified. The plugging of the exhaust pipe/silencer is no longer a common cause failure for both AFWS trains.

3. Administrative procedures have been implemented to lock in position all manual valves and local control stations and hand wheels for motor operated valves in the auxiliary feedwater supply paths, the recirculation line, the test line and main steam supply paths. This reduces the probability for human error in misaligning remotely operated and remotely indicated manual valves.

4. The turbine admission valves now have automatic dual level control, with the option for manual control.

5. An emergency procedure has been implemented to manually start and align the main feedwater startup pump to provide feedwater to the steam generators in the event that both trains of the AFWS fail. This procedure includes the feed and bleed procedure for relieving fluid through the PORV while maintaining makeup flow to the reactor coolant system. This procedure effectively provides a diverse and redundant third train of AFWS.

The feedwater startup train consists of a single AC-powered pump, which is supplied from three water sources, and which discharges to either steam generator. The water sources are, first, two deaerator storage tanks and, secondly, the CST. The fire protection system is available as a backup water supply should these two sources fail.

To initiate the startup train the operator performs the following operations:

- block the SFRCS signal and open either, but not both, of the main feedwater stop valves FW-601 or FW-612 (operation performed from the control room), 1
- block the SFRCS signal and open either, but not both, of the main feedwater startup control valves SP-7A or SP-7B (operation performed from the control room),
- manually open the startup pump discharge valve FW-106 (operation performed locally),
- manually start the startup pump (operation performed from the control room).

A flow diagram for the startup pump is shown in Figure 3-5. In addition to the startup pump the operator must initiate the feed and bleed operation. This consists of manually opening a PORV and its block valve, and operating the reactor coolant system makeup pumps. The PORV and block valves are controlled from the control room. Normally, the PORV is aligned closed and the block valve aligned open. The makeup system is illustrated in Figure 3-6. The system consists of two trains of pumps discharging through a common pipe to the reactor coolant system. The makeup water tank provides a water supply of 4,480 gallons, after which the water supply is automatically switched to the borated water storage tank. A motor operated valve provides the switchover function on a low level signal from the makeup tank. In normal operation, one train of makeup is assumed to be operating at all times. In the feed and bleed mode of operation, however, the normally open reactor coolant system letdown line must be isolated to prevent additional loss of primary coolant inventory. The isolation of the letdown line involves manually closing a motor operated valve from the control room, a routine procedure with all reactor trip conditions. The feed and bleed procedure in the Post-TMI configuration applies only to situations in which offsite electrical power is available at the plant. It is not credited for initiating events in which offsite power is assumed to be lost. | 1

3.4 Third Train System Configuration

The third train configuration examined in this study consists of an independent, manually initiated train of auxiliary feedwater in parallel with the two present AFWS trains. Manual initiation is required so as to prevent excessive feedwater flow in the anticipated event that the two safety-grade steam-driven auxiliary feedwater trains function as designed. The third train would be started only if both of the steam driven trains failed.

The third train flow diagram is shown in Figure 3-7. The train consists of a single AC-powered motor driven pump, supplied from three water sources, discharging into either of the steam generator auxiliary feedwater inlet nozzles. The pump is considered to be the main feedwater startup pump, upgraded in flow capacity such that the feed and bleed operation is unnecessary. The time requirement for initiating auxiliary feedwater via the third train is 10 minutes from the initiating event. The water supplies would be the same as for the present startup pump. However, the discharge piping would be rerouted to bypass the feedwater heaters and discharge directly into the AFWS steam generator inlet nozzles. Either of two AC-powered

motor operated valves, normally isolating the train from the steam generators, would be manually opened from the control room when the pump is started.

In all other respects the third train configuration is identical to the Post-TMI configuration.

3.5 Analysis-Based Configuration

This configuration is based on results of the reliability analysis of the Post-TMI configuration. The Post-TMI configuration is found to be most susceptible to failures of motor operated valves (MOV) to open/close on demand and to the inability to implement the feed and bleed procedure following loss of offsite power events. The analysis-based configuration represents the presently planned AFWS configuration at the end of the 1982 refueling outage. It incorporates several design modifications as well as improvements to the feed and bleed procedure. These additional system modifications include the following: 1

1. The speed switch control for the pump discharge MOVs AF-360 and AF-388 is eliminated and the valves are normally aligned and locked open.

2. The MOVs AF-3870 and AF-3872 are normally aligned and locked open.

3. All four turbine steam admission valves, including the valves in the crossover paths, open on an SFRCS signal. In this case, both turbines are supplied with steam from both steam generators through parallel paths. In the event of a steam generator isolation due to low steam generator pressure the isolated steam generator discharge valves close and the steam supply system to the turbine is identical to the Post-TMI configuration.

4. Flow indication is temporarily installed in both AFW pump minimum recirculation lines during surveillance testing. This permits flow testing of pumps to be performed without opening valves AF-21 and AF-23 (for pump No. 1) or AF-22 and AF-23 (for pump No. 2). Thus, an auxiliary feedwater pump remains available if the AFWS is challenged during a surveillance test.

5. The startup pump discharge valve FW-106 is locked open and a check valve placed between the pump and FW-106.

6. The startup pump bypass valve FW-102 is locked closed.

7. Redundant steam generator pressure and level control room indicators are provided for each steam generator. The startup pump feedwater flow indication is upgraded.

8. The makeup system valve MU-33 and startup feedwater control valves SP-7A and SP-7B are controlled from the station nitrogen system or local nitrogen bottles and are therefore available following a loss of offsite power.

9. The original feed and bleed procedure is modified to better reflect the steps necessary to implement the feed 1
and bleed operation. Improved descriptions of various parameter responses enhances the ability to recover from incorrect operator actions. The revised procedure format will be similar to the Abnormal Transient Operating Guidelines emergency procedures.

10. The feed and bleed procedure is extended to the situation in which offsite electrical power is unavailable at the plant site.

3.6 AFWS Support Systems

For the purpose of this study the makeup system, PORV and main feedwater startup pump train are considered part of the AFWS, since they directly support the AFWS safety function. Other plant systems indirectly support the AFWS as well. These include:

- electric power system
- SFRCS
- service water system
- fire protection system
- station nitrogen system. 1

Of these support systems, the reliability analysis results are only impacted significantly by the electric power system. The electric power system is, therefore, considered explicitly in the reliability analysis. The impacts of other systems are conservatively estimated (as discussed in section 4.3.1) and found to be generally insignificant.

The importance of the electric power system is based upon this system providing the electric power for valves, motors and pumps throughout the AFWS. These power supplies can be categorized as:

- powered from essential AC-buses
- powered from non-essential AC-buses
- powered from DC panels

The DC panels are normally powered by battery chargers powered from essential AC buses. In the event of a bus failure, however, the DC panels are backed up by battery power supplies. As a result, the DC panels have relatively high reliability. The essential AC buses are powered by the turbine generator (through the auxiliary startup transformer), offsite power sources or a diesel generator.

For events challenging the AFWS it is assumed that a turbine generator trip has occurred and that this power source is unavailable. For events in which offsite power is assumed to be lost, the essential buses must, therefore, be powered from a diesel generator. One diesel generator powers the "C1" bus while the other powers the "D1" bus.

The startup pump is powered from bus D2 which can be powered from either diesel generator. In the Post-TMI configuration, selected non-essential buses can be fed from the diesel generators through operator action (control room operation). For other non-essential buses the power supply is limited to offsite power following a turbine generator trip.

Table 3-2 lists the interfaces between the electrical power system and the AFWS and shows the ultimate power supplies to individual AFWS components.

Major differences between the Pre-TMI configurations are:

1. In the Pre-TMI configuration a ground fault on any of the Essential Motor Control Centers would cause a loss of one of the two redundant electrical systems. This has been modified in the Post-TMI configuration with the installation of ground-fault detectors to trip the individual breakers on all loads attached to an essential bus. (Note that this is not a TMI-related plant modification, but was undertaken by TECo to upgrade the reliability of plant electrical systems.)

2. Davis-Besse has an automatic switching system that changes the plant's electric source from onsite power (main generator) to offsite power in the event of a turbine trip. There is a 30 second time-delay between the turbine trip and the generator trip. When the generator trips there is automatic transfer of the plant's electrical source from the auxiliary transformer to the startup transformer. In the Pre-TMI configuration there was a possibility that the generator 345 KV breakers could be manually opened before the 30 sec time delay and thereby fault the entire switching system by not allowing it to switch to offsite power. Procedures

have been added to insure that there are no actions done until the 30 sec time delay and automatic switching is completed. Also, if the 345 KV breakers are opened for any reason other than a degraded offsite power source, a fast dead transfer to the offsite source will occur in the Post-TMI configuration.

3. In the Pre-TMI configuration there was no way to know if there was a ground fault on one of the D.C. MCC Essential Buses. The Post-TMI configuration includes a load fault detection system to correct that situation. (This change is not being planned for completion in the 1982 refueling outage, but will be completed later.) 1

TABLE 3-1

Steam-Feedwater Rupture Control System Actuation (Post-TMI Configuration)

CHANNEL 1 (C 5767A)	MS 101	MS 100	MS 101-1 NOTE 3		MS 394 NOTE 3		ICS 11B NOTE 3		FW 612		FW 780		SP 7B NOTE 3	
CHANNEL 2 (C 5792)	MS 101	MS 100		MS100-1 NOTE 3		MS 375 NOTE 3		ICS 11A NOTE 3		FW 601		FW-779		SP 7A NOTE 3
LOW PRESSURE MAIN Steam Line 1 (600#)	SHUT	SHUT	SHUT	SHUT	SHUT	SHUT	SHUT	SHUT	SHUT	SHUT	SHUT	SHUT	SHUT	SHUT
LOW PRESSURE MAIN Steam Line 2 (600#)	SHUT	SHUT	SHUT	SHUT	SHUT	SHUT	SHUT	SHUT	SHUT	SHUT	SHUT	SHUT	SHUT	SHUT
STM. - FW ΔP SG 1 HIGH (177 PSID)	SHUT	SHUT	SHUT	SHUT	SHUT	SHUT	SHUT	SHUT	SHUT	SHUT	SHUT	SHUT	SHUT	SHUT
STM - FW ΔP SG 2 HIGH (177 PSID)	SHUT	SHUT	SHUT	SHUT	SHUT	SHUT	SHUT	SHUT	SHUT	SHUT	SHUT	SHUT	SHUT	SHUT
LOW LEVEL SG 1 (17" SUR)	SHUT	SHUT	SHUT	SHUT	SHUT	SHUT	SHUT	SHUT	SHUT	SHUT	SHUT	SHUT	SHUT	SHUT
LOW LEVEL SG 2 (17" SUR)	SHUT	SHUT	SHUT	SHUT	SHUT	SHUT	SHUT	SHUT	SHUT	SHUT	SHUT	SHUT	SHUT	SHUT
LOSS OF RC PUMPS														
CHANNEL 1 (C 5762A)	SP 6A		MS 106		MS 106A		AF3870		AF 3869		AF 608		MAIN TURBINE	
CHANNEL 2 (C 5792)		SP 6B		MS 107		MS 107A		AF3872		AF 3871		AF 599	MAIN TURBINE	
LOW PRESSURE MAIN STEAM LINE 1 (600#)	SHUT	SHUT	SHUT	OPEN NOTE 1	OPEN NOTE 1	SHUT	SHUT	OPEN NOTE 1	OPEN NOTE 1	SHUT	SHUT	OPEN	TRIP	
LOW PRESSURE MAIN STEAM LINE 2 (600#)	SHUT	SHUT	OPEN NOTE 1	SHUT	SHUT	OPEN NOTE 1	OPEN NOTE 1	SHUT	SHUT	OPEN NOTE 1	OPEN	SHUT	TRIP	
STM - FW ΔP SG 1 HIGH 177 PSID	SHUT	SHUT	OPEN	OPEN	SHUT	SHUT	OPEN	OPEN	SHUT	SHUT	OPEN	OPEN	TRIP	
STM - FW ΔP SG 2 HIGH 177 PSID	SHUT	SHUT	OPEN	OPEN	SHUT	SHUT	OPEN	OPEN	SHUT	SHUT	OPEN	OPEN	TRIP	
LOW LEVEL SG 1 (17" SUR)	SHUT	SHUT	OPEN	OPEN	SHUT	SHUT	OPEN	OPEN	SHUT	SHUT	OPEN	OPEN	TRIP	
LOW LEVEL SG 2 (17" SUR)	SHUT	SHUT	OPEN	OPEN	SHUT	SHUT	OPEN	OPEN	SHUT	SHUT	OPEN	OPEN	TRIP	
LOSS OF 4 RC PUMPS			OPEN NOTE 2	OPEN NOTE 2	SHUT	SHUT	OPEN	OPEN	SHUT	SHUT	OPEN	OPEN	TRIP	

NOTES:

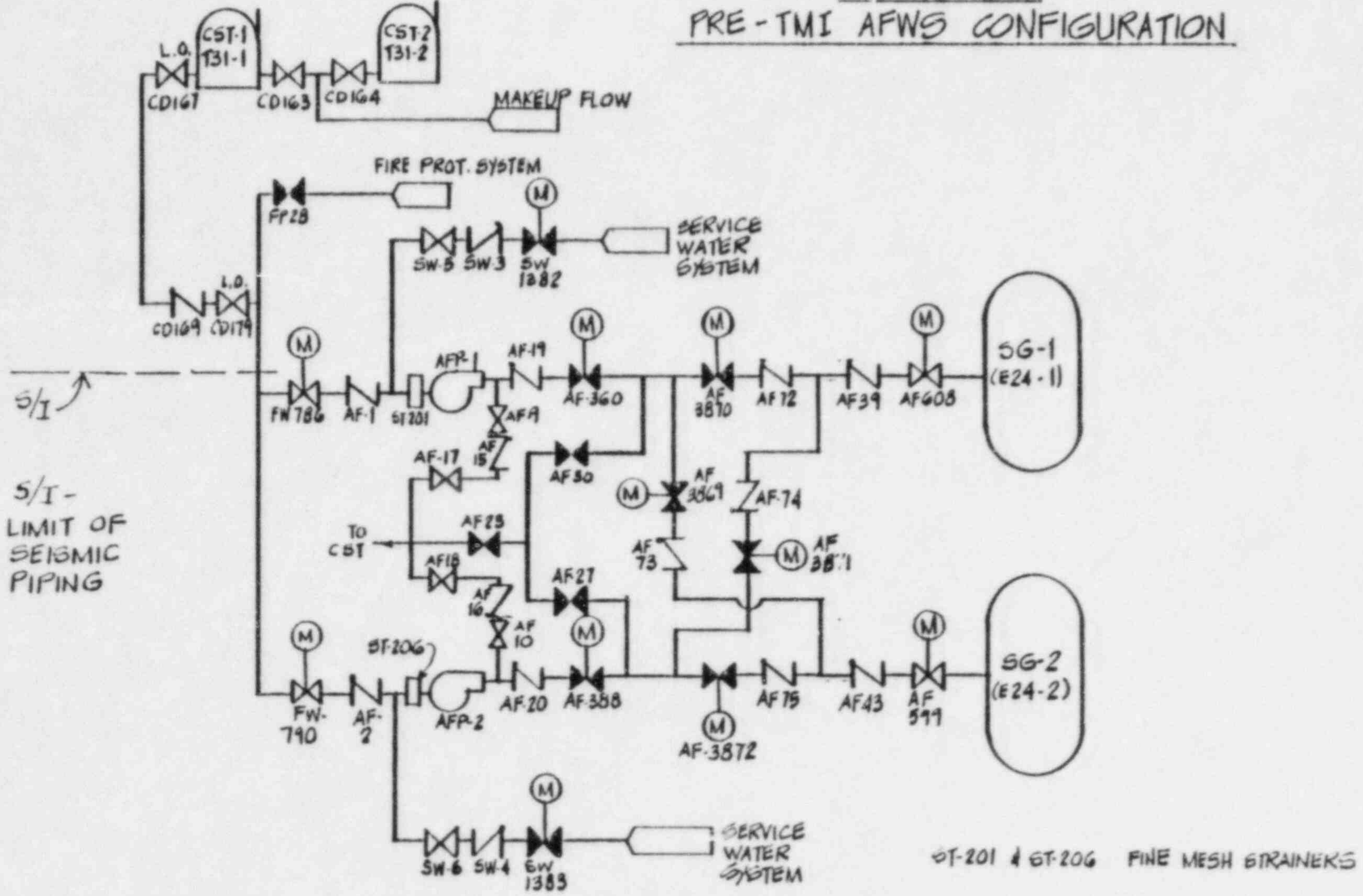
1. If both main steam lines are 600 psi, these valves shut.
2. These valves will not open if DH 11 and DH 12 (DH Suction from RCS) are open.
3. These valves are closed on a 1/2 channel trip (Pre-TMI) and a full channel trip (Post-TMI).

TABLE 3-2

AFWS/Electric Power System Interfaces

AFWS Component	Electric Power Supply	Power Supply Type	Ultimate Source	
AF-360 (Pre-TMI)	MCC-E11E	Essential AC	Diesel Generator #1	
AF-360 (Post-TMI)	DC Panel D1P	Essential DC	Battery 1P	
AF-3870 (Pre-TMI)	MCC-E11D	Essential AC	Diesel Generator #1	
AF-3870 (Post-TMI)	DC Panel D1P	Essential DC	Battery 1P	
AF-3869	MCC-E11E	Essential AC	Diesel Generator #1	
AF-388	MCC-F12A	Essential AC	Diesel Generator #2	
AF-3872	MCC-F12B	Essential AC	Diesel Generator #2	
AF-3871	MCC-F12A	Essential AC	Diesel Generator #2	
SW-1382	MCC-E12A	Essential AC	Diesel Generator #1	
SW-1383	MCC-F11C	Essential AC	Diesel Generator #2	
MS-106 (Pre-TMI)	MCC-E11C	Essential AC	Diesel Generator #1	
MS-106 (Post-TMI)	DC Panel D1N	Essential DC	Battery 1N	
MS-106A	MCC-E12B	Essential AC	Diesel Generator #1	
MS-107	MCC-F11A	Essential AC	Diesel Generator #2	
MS-107A	MCC-F11B	Essential AC	Diesel Generator #2	
ICS-38A	DC Panel D2P	Essential DC	Battery 2P	
ICS-38B	DC Panel D1P	Essential DC	Battery 1P	
AV-1	MCC-F13	Non-Essential AC	Diesel Generator #1 & 2	
AV-3	MCC-F13	Non-Essential AC	Diesel Generator #1 & 2	
Startup Pump	Bus D2	Non-Essential AC	Diesel Generator #1 & 2	
Makeup Pump #1	Bus C1	Essential AC	Diesel Generator #1	
Makeup Pump #2	Bus D1	Essential AC	Diesel Generator #2	
FW-601	MCC-F11D	Essential AC	Diesel Generator #2	
FW-612	MCC-E11C	Essential AC	Diesel Generator #1	
MU 3971	MCC-E11D	Essential AC	Diesel Generator #1	
FW-786	MCC-E11D	Essential AC	Diesel Generator #1	
FW-790	MCC-F12A	Essential AC	Diesel Generator #2	
FW-460	MCC-F32A	Non-Essential AC	Offsite Power	
MU-2B	MCC-E11B	Essential AC	Diesel Generator #1	
PORV	DC Panel DBP	Essential DC	Battery 2P	1
Block Valve	MCC-E16	Essential AC	Diesel Generator #1	

FIGURE 3-1
PRE-TMI AFWS CONFIGURATION



S/I - LIMIT OF SEISMIC PIPING

ST-201 & ST-206 FINE MESH STRAINERS

REV	BY	DATE	CHECKED	DATE

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JOB NO

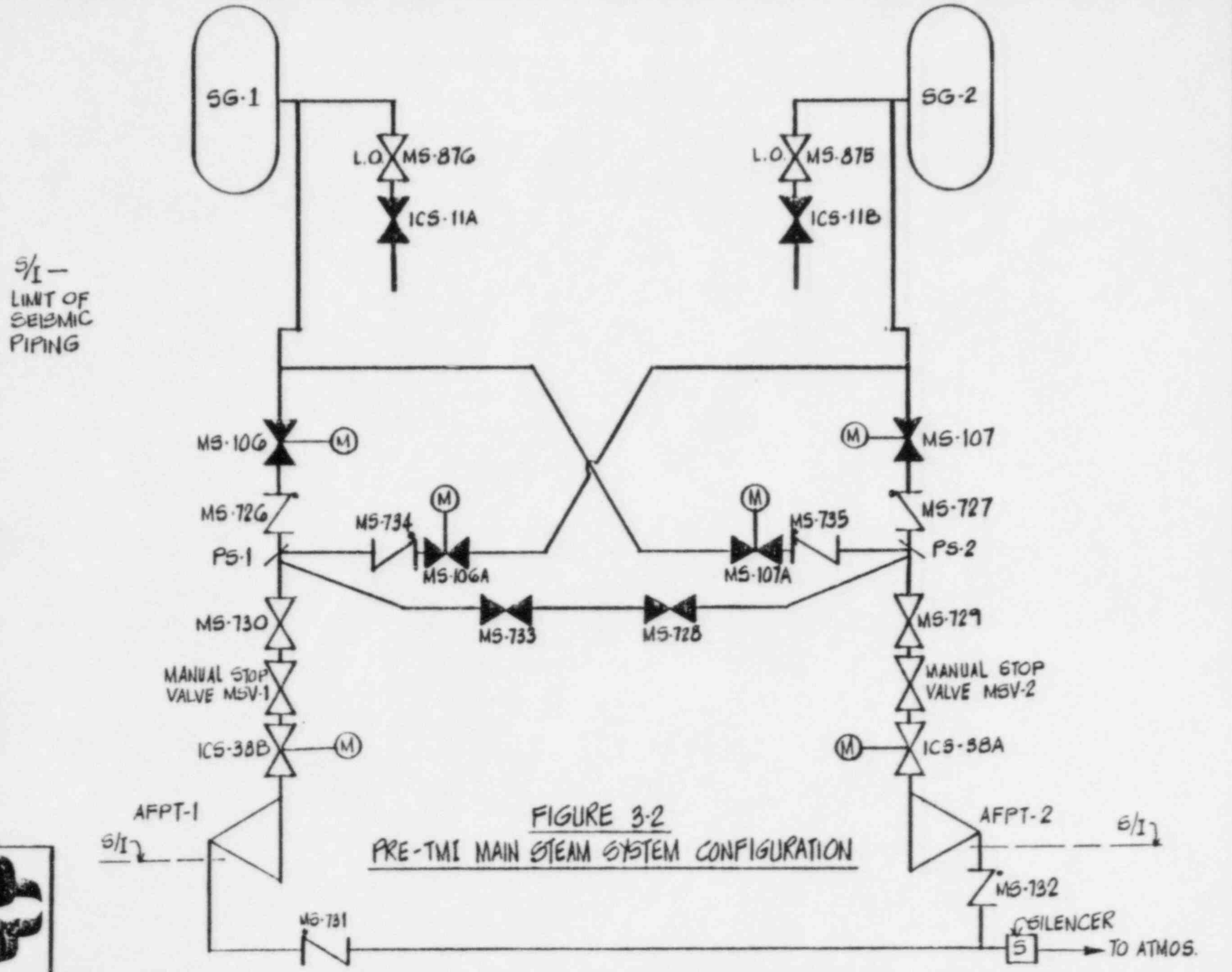

FIGURE 3-2
PRE-TMI MAIN STEAM SYSTEM CONFIGURATION

REV	BY	DATE	CHECKED	DATE
2	[illegible]	[illegible]	[illegible]	[illegible]

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JOB NO [illegible]

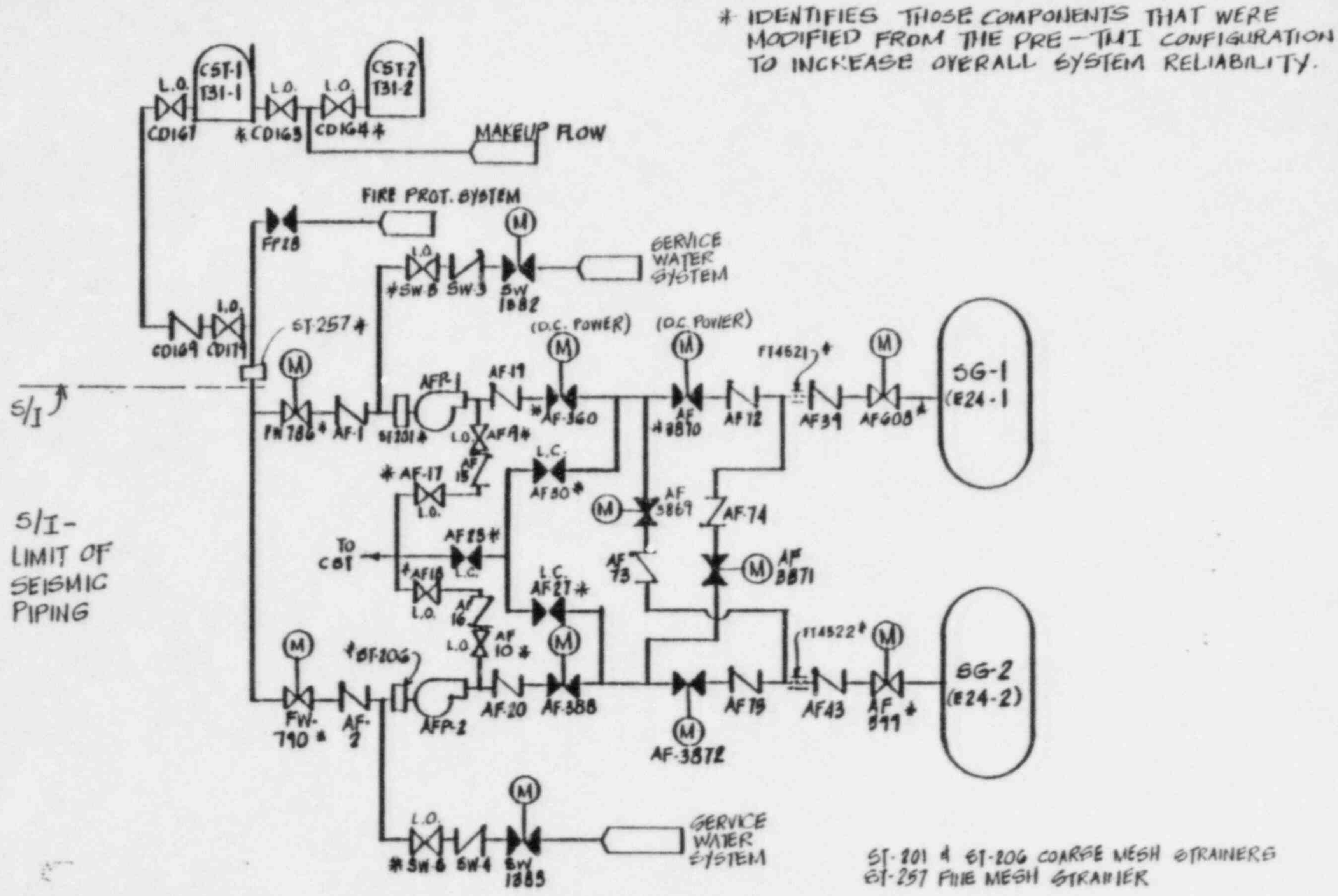

FIGURE 3-3

POST-TMI AFWS CONFIGURATION

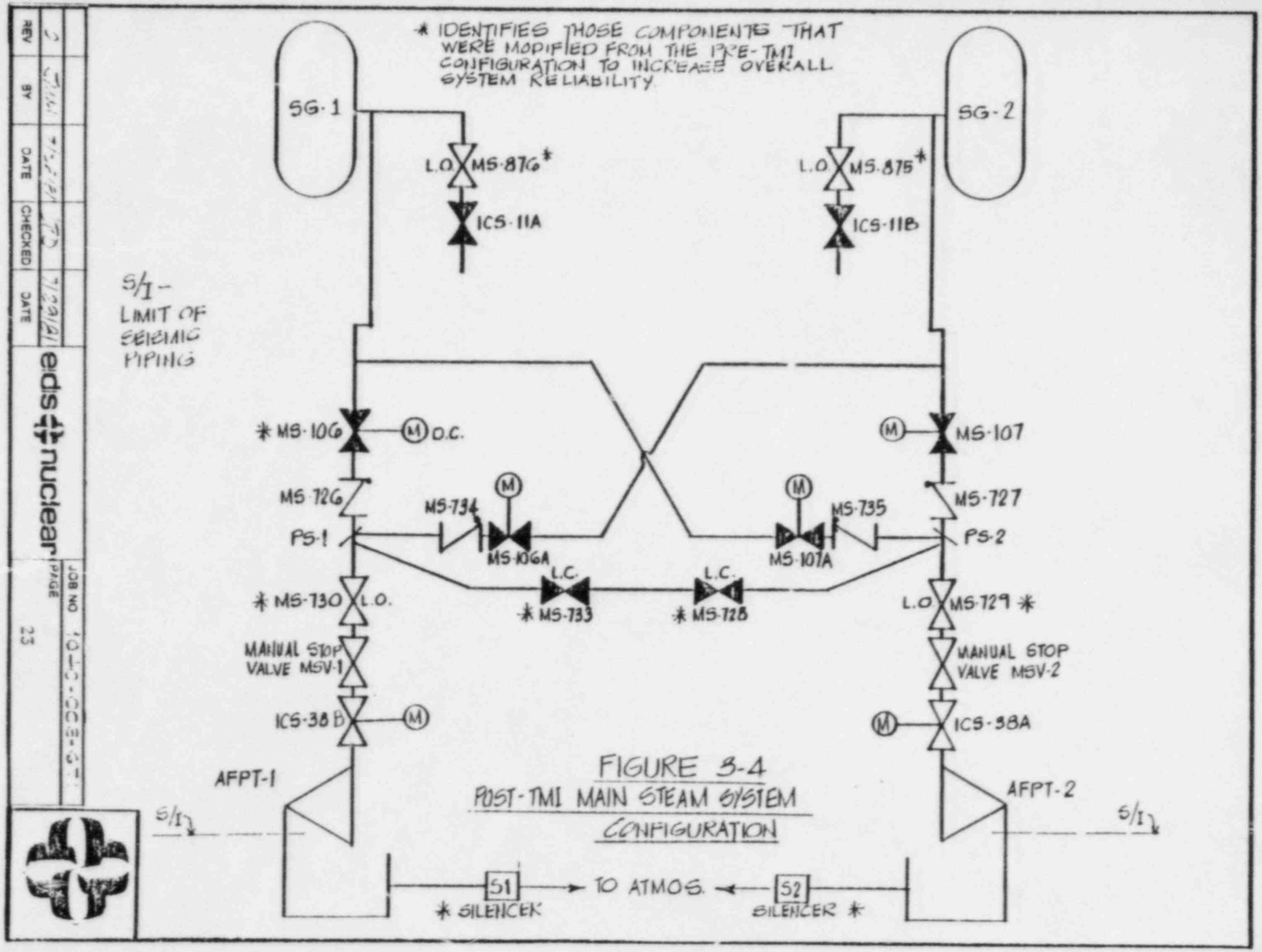

FIGURE 3-4
POST-TMI MAIN STEAM SYSTEM CONFIGURATION

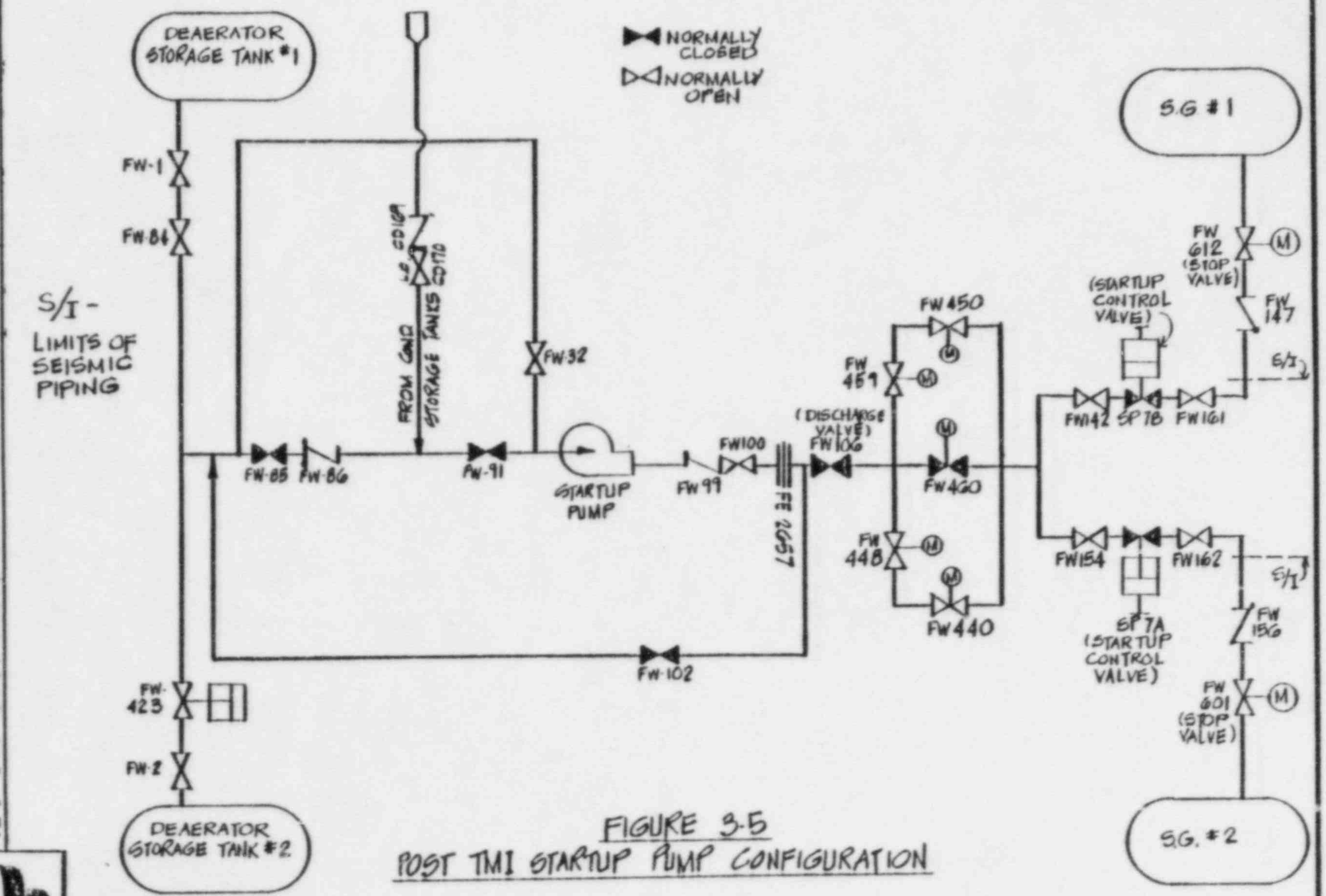

FIGURE 3.5
POST TMI STARTUP PUMP CONFIGURATION

REV	BY	DATE	CHECKED	DATE
2	[illegible]	7/23/81	GPD	7/23/81

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REV	BY	DATE	CHECKED	DATE
				7/29/91

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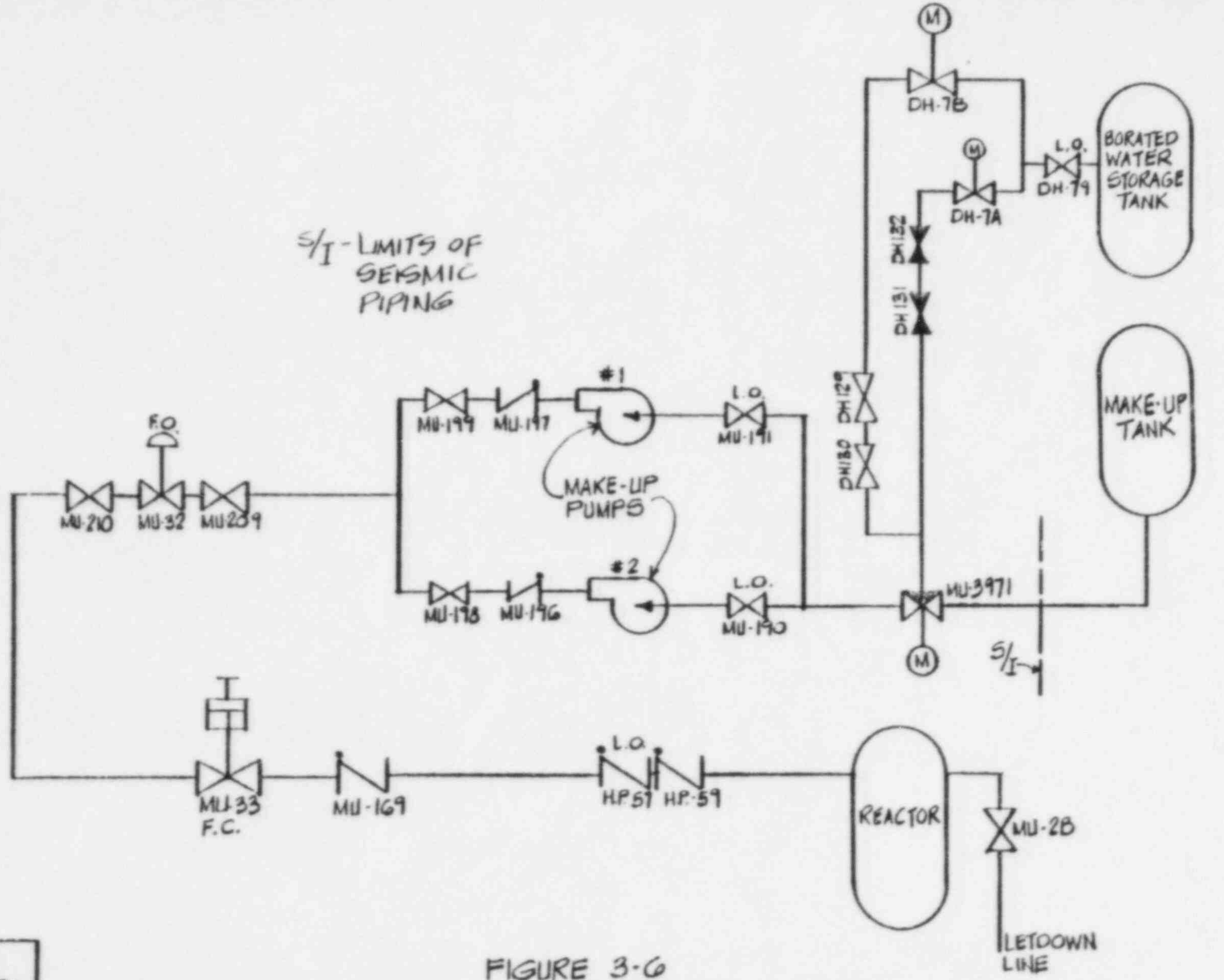
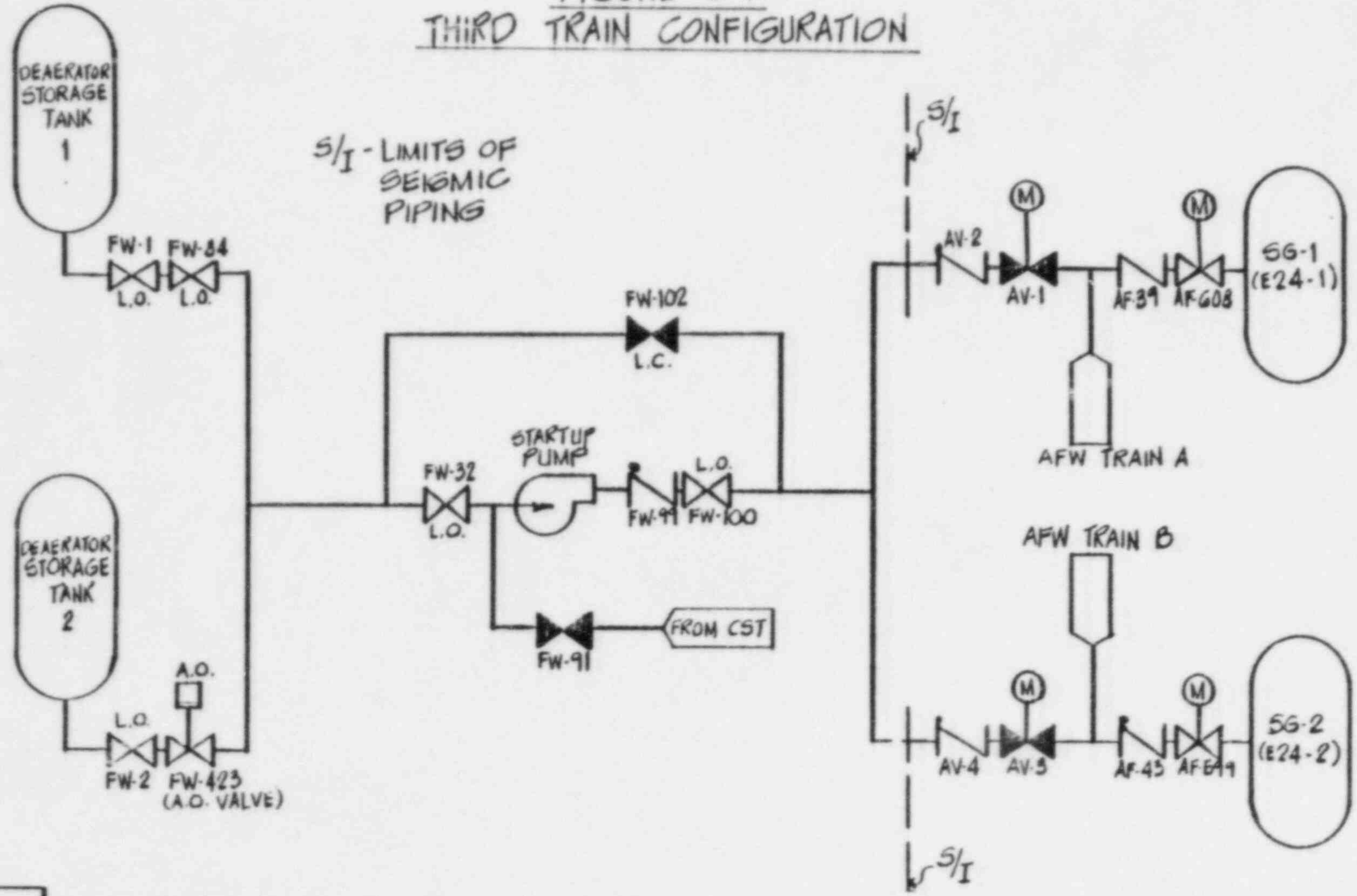


FIGURE 3-6

MAKE-UP SYSTEM CONFIGURATION

FIGURE 3-7
THIRD TRAIN CONFIGURATION



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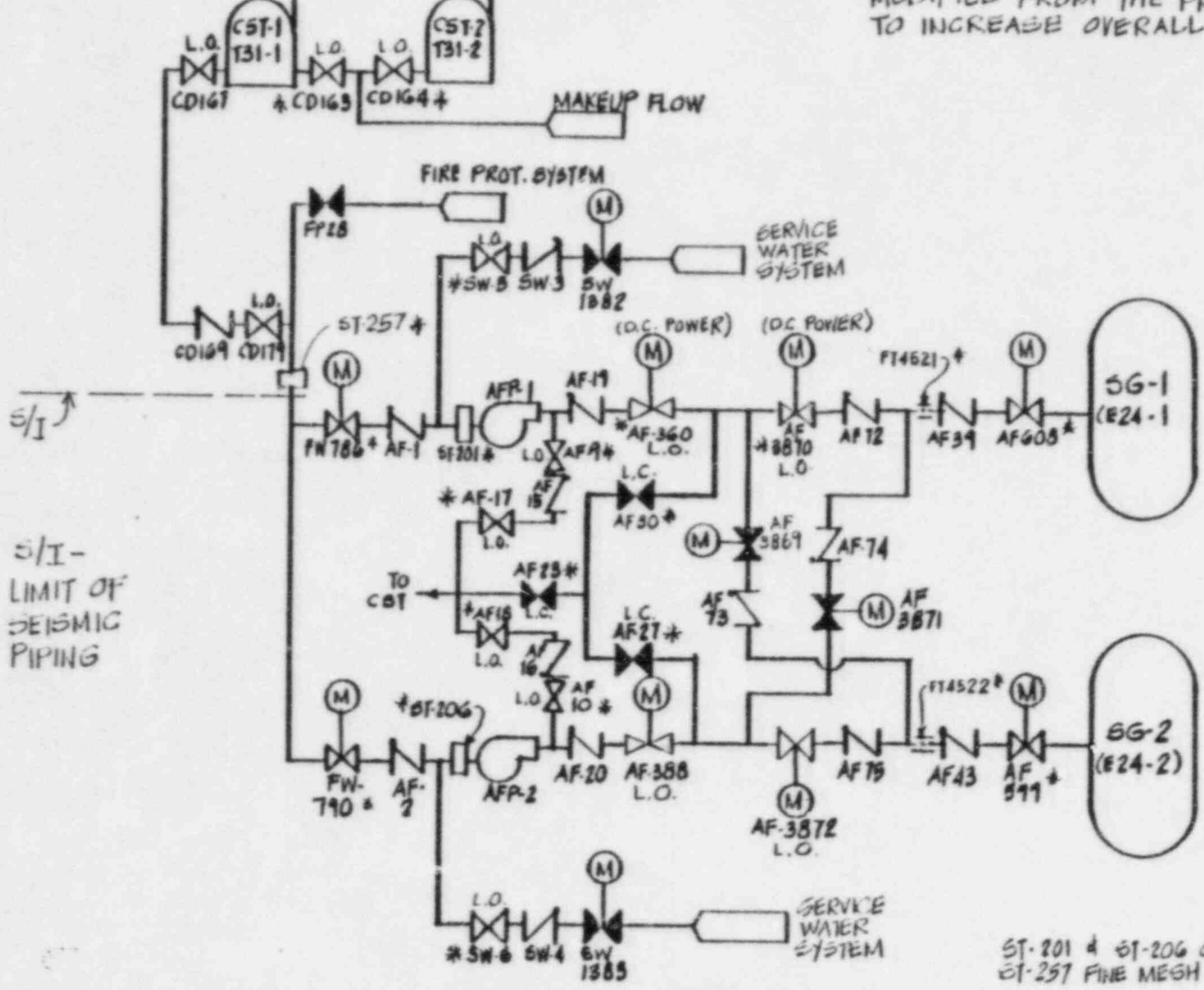
* IDENTIFIES THOSE COMPONENTS THAT WERE MODIFIED FROM THE PRE-TMI CONFIGURATION TO INCREASE OVERALL SYSTEM RELIABILITY.



ST-201 & ST-206 COARSE MESH STRAINERS
ST-257 FINE MESH STRAINER

FIGURE 3-8

ANALYSIS BASED AFWS CONFIGURATION

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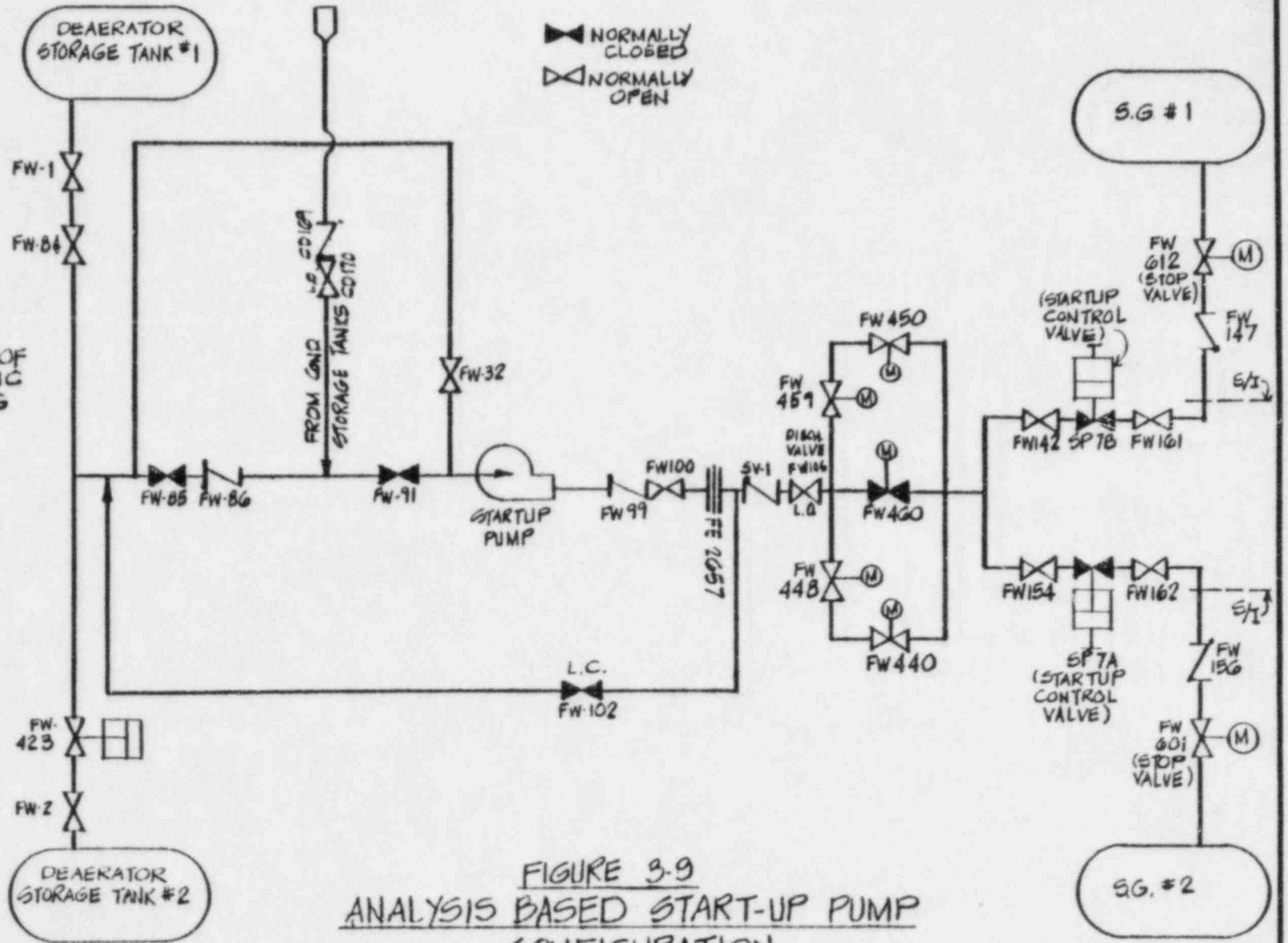

FIGURE 3-9
ANALYSIS BASED START-UP PUMP CONFIGURATION

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4.0 Methodology

The reliability analysis is based on the development of fault trees for the AFWS and its support systems. Probabilities for basic events appearing in the fault trees are assigned based on reviews of industry reliability data sources and Davis-Besse plant-specific experience. A Boolean manipulation computer code is then used to determine the AFWS unavailability. The unavailability of each AFWS configuration is determined in this manner.

The AFWS unavailability is dependent on the plant initiating event which causes the AFWS to be challenged. The relative differences in AFWS unavailability for the four configurations are also dependent on the specific initiating event. In order to develop an overall figure-of-merit for each AFWS configuration, the annual frequencies for various initiating events are estimated, again based upon industry and plant-specific operating experience. The frequency of the initiating event is multiplied by the AFWS unavailability for that initiating event. The results are summed for all initiating events. The result is the overall annual frequency with which the AFWS is unavailable when challenged. This is the overall figure-of-merit for each AFWS configuration.

The analysis can, therefore, be described in the following phases:

- system fault tree development
- data analysis
- system unavailability analysis
- initiating event analysis
- combined system/event analysis

The interrelationship among these analysis phases is illustrated in Figure 4-1.

4.1 System Fault Tree Development

4.1.1 Fault Trees Developed

Fault trees are constructed for four AFWS configurations: | 1

- Pre-TMI Configuration
- Post-TMI Configuration
- Third-Train Configuration
- Analysis-Based Configuration | 1

The fault trees contain as the "top event", the failure of the AFWS to perform its safety function. The specific safety functions are described in Section 3.1. In addition to the fault trees for each AFWS, subtrees are developed for other plant systems which support the AFWS safety function. These subtrees are limited to only those parts of the support systems which directly affect the AFWS safety function. Support system subtrees which are developed are:

- electric power system
- main steam system
- main feedwater system and startup pump
- makeup and purification system
- power operated relief valve

The attachments include fault trees and subtrees arranged as follows:

AFWS (Pre-TMI) Fault Tree
Main Steam System (Pre-TMI) Fault Tree
Electrical System (Pre-TMI) Fault Tree
AFWS (Post-TMI) Fault Tree
Main Steam System (Post-TMI) Fault Tree
Electrical System (Post-TMI) Fault Tree
Start-up Pump (Post-TMI) Fault Tree
Start-up Pump with Feed and Bleed
AFWS (Analysis-Based) Fault Tree
Main Steam System (Analysis-Based) Fault Tree 1
Startup Pump with Feed and Bleed (Analysis-Based)

Subtrees for other systems supporting the AFWS safety function are not developed. Such systems include:

- fire protection system
- service water system
- SFRCS
- station nitrogen system 1

The reliability of these systems is found to have a lesser impact on the achievement of the AFWS safety function. Conservative estimates of the unavailability of these systems are used in the quantitative analysis of the AFWS fault trees as discussed in Section 4.3.1.

4.1.2 Fault Tree Methodology

For each system fault tree or subtree, the safety function of the system is first defined, and failure criteria applied. An absolute determination for failure criteria is made for systems where a reduction in capacity leads to failure or unavailability of that system. A list of systems, safety functions and failure criteria assumed in this reliability study is presented in Table 4-1. Note that a 10 minute AFWS actuation criteria has been arbitrarily assumed, for conservatism, in this analysis.

Detailed fault trees, or subtrees, are then constructed using the methodology and symbology of WASH-1400[5] and IEEE-352[6]. The construction of the detailed fault trees, or subtrees, is done in a rigorous, systematic manner, considering every component and event which could contribute to the failure of the system. Quantitative judgements about the likelihood of failure of a component are not made during the detailed fault tree construction phase. The following mechanisms for failure are included in the fault trees:

Pre-Existing Faults

- outages for test and maintenance
- demand faults for initially inactive components
- failure mechanisms which are dependent on the duration of the standby period, and which will cause failure on demand for initially inactive components
- pre-existing human errors, e.g.; maintenance faults

Faults Occurring During Mission

- failure of an active component to change its state, e.g.; a demand fault
- failure of a component to continue operating
- human errors of commission
- human errors of omission

Only pre-existing faults which would not be detected in normal plant operation are included, e.g.; pre-existing faults in active systems (other than test and maintenance outages) are not considered.

In developing detailed system fault trees, single passive failures and double active failures are considered within a single process flow path (e.g.; within a single train of a multiple train system). A single failure is the failure of one element within a process flow path which causes the failure of the required flow path function. A double failure is the combined failure (either random failure or dependent failure) of two elements within a process flow path which causes the failure of the flow path function. A passive failure is breach of a fluid pressure boundary or blockage of a process flow path in a fluid system; or short circuit, loss of electrical charge or loss of ability to conduct electricity due to physical defects in electrical systems. An active failure is a malfunction, excluding passive failures, of a component which relies on movement to complete its intended function upon demand. Examples of active failures include the failure of a powered valve to move to its correct position; or the failure of a pump, fan, or diesel generator to start; or failure of a circuit breaker, relay, or solenoid to change position when energized. Human errors (acts of commission or omission) are considered active failures.

In constructing fault trees the following rules are applies:

- The fault tree is developed to the level where acceptable failure data exist.

- Components and basic events are coded using an eight character nomenclature as shown below:

```
                  A      PM      001A          F
                  |      |       |             |
System Code       |      |       |             | Failure Mode
(See Table--------|      |       |             |  Code (See
4-2)                     |       |             |--Table 4-4)
                         |       |
Component Code           |       |   Descriptive
(See Table 4-3)----------|       |---Nomenclature
```

- Parts of the fault tree which are only applicable to specific plant conditions (e.g.; loss of offsite power events) are combined through a gate with the "house" logic symbol.

- The symbology shown in Figure 4-2 is used.

In addition, the following assumptions are made in developing fault trees:

- The plant is assumed to be in a normal operating condition at 100% power at the time of the initiating event.

- Pre-existing faults in active plant systems (e.g.; one train of the makeup and purification system) are not considered, since such faults, if present, would have been readily detected and corrected.

- Operator action to recover from a faulted condition is only credited when the operator has sufficient instrumentation to detect the fault and a written procedure directing his recovery action. The probability for failure to take the recovery action is discussed in Section 4.2.

- Component alignments, as shown on plant P&IDs and electrical drawings, are assumed for the initial plant configuration. However, the possibility of misalignment is considered when such misalignment would contribute to system failure, and when such misalignment might not be detected in normal plant operation.

- Spurious human acts of commission, such as taking an incorrect action when there is no indication that action is required, or acts of sabotage are not considered.

4.2 Data Analysis

Data on the probabilities for failures or unavailabilities of basic events are necessary for quantification of the fault trees. Such data consist of system and component failure data and human error data. Industry data sources and Davis-Besse plant-specific operating experience have been reviewed to develop a recommended data base for this analysis.

4.2.1 Industry Data Review

Sources for failure rate data are listed in Section 7.0. These sources contain summaries of recent nuclear power industry experience for electrical and mechanical components generic to the industry. In some cases, the data is supplemented by experience with similar components in other industry applications. A major data source for nuclear power industry component reliability is the Reactor Safety Study, WASH-1400[5]. This study contains reliability data on most components found in nuclear power plant safety systems. It is based on compilations of many reliability data sources avaialble at the time of the study, in 1975. Several more recent NRC-sponsored data summaries (7,8,9) document the reliability experience of common nuclear power plant components, specifically valves, pumps and diesel generators.

These summaries are based upon Licensee Event Reports (LERs) through which safety system malfunctions are reported to the NRC. IEEE-500[10] represents a thorough compilation of electrical component reliability data. Reference (13) contains summaries of nuclear power plant equipment malfunctions as reported through the Nuclear Plant Reliability Data System (NPRDS).

Failure data from these sources have been reviewed and tabulated in Table 4-5. The table lists the recommended value for failures (expressed either as a failure rate - units of inverse time, or as a failure probability - dimensionless). Note that the recommended value is not necessarily the mean value of the data sources reviewed; in fact, the recommended values are generally the highest of the reported values. Also listed, when available, is the uncertainty factor representing a measure of the spread in the reported data. The uncertainty factor is defined as the square-root of the ratio of the maximum reported value divided by the minimum reported value. The uncertainty factors are rounded to the nearest half decade. Where only one data source is given an uncertainty factor of 10 is assumed unless the data source reported the data spread. The data in the table are presented by component type, e.g.; motor operated valves, and by failure mechanism, e.g.; failure to open on demand.

Human reliability data consist of human errors of commission and omission. Errors of omission include omitting steps from written plant procedures during routine operations (e.g.; maintenance), during emergency operations (emergency procedures) and during attempts to recover from a faulted condition. Errors of commission similarly include those committed during routine operation and those committed during the course of the accident in attempting to mitigate the accident. The primary sources for estimating the probabilities of human errors are WASH-1400[5] and a recent NRC-sponsored study [11] of human reliability in nuclear power plant operations.

Table 4-5 also lists failure probabilities, and uncertainty factors, associated with various types of human errors. The values listed are from the above two sources.

4.2.2 Review of Davis-Besse Experience

Where possible, the generic data sources have been supplemented by analysis of failures experienced at Davis-Besse, Unit No. 1. This analysis is based upon a review of LERs for Davis-Besse from the time it began commercial operation until February, 1981. Due to the rather limited

data base, this analysis concentrated on components and failure mechanisms which occur relatively more frequently in nuclear power plants and which could have a more significant impact on the AFWS reliability analysis results. The components included in this plant-specific analysis are:

- valves
- auxiliary feedwater pumps
- diesel generators
- test and maintenance outages
- human factors analysis for the feed and bleed operation,

Valves

Failure rates for Davis-Besse motor operated valves, air operated valves and check valves have been determined. Failure mechanisms are failure to open on demand and leakage (for check valves only).

Failure rates are computed by dividing the total number of failures reported in the LERs by the total number of valve demands (for failure to open/close on demand) or the total number of operating valve-hours (for leakage).

LER's are limited in terms of the plant systems in which failures are reported. In this analysis, the following six plant safety systems are considered:

- auxiliary feedwater system
- main steam system
- containment spray system
- high pressure injection system
- low pressure injection system
- chemical volume control system

Five of these systems were considered by the NRC in the development of their generic data base (Reference 7). The sixth system, main steam, was considered in this analysis since it is directly pertinent to this program.

Table 4-6 summarizes results of the analysis. The total population of valves in the system is listed along with the total valve demands, total operating hours and total valve failures. In computing the number of demands placed on valves, it is assumed that valves are only operated during testing and that the minimum testing schedule contained in the Davis-Besse Technical Specifications[12] is used. The resultant failure rate is thereby conservatively estimated. While this estimate is conservative, the procedure used is consistent with that used in the data analysis of all U.S. operating reactors considered in Reference (7).

The failure of Davis-Besse motor operated valves to open/close on demand, computed in this manner, is a factor of three greater than the same failure probability computed for all operating U.S. reactors, as reported in Reference (7). The Davis-Besse plant-specific value is used in the quantitative analysis of the AFWS fault tree. This failure mechanism turns out to be a major contributor to AFWS unavailability, as discussed in Section 5.3. Most of the motor operated valve failures are attributable to torque switches and limit switches being out of adjustment.

Auxiliary Feedwater Pumps

This analysis includes failures of the auxiliary feedwater pumps and/or turbine to start and to continue operation. The probability of failure to start is computed by dividing the total number of reported failures by the total number of attempts to start the pumps. It is assumed that each pump is only started for monthly testing, and that there is one demand of each pump per test.

Failures to continue operation are generally attributable to faults occuring during its standby period. The failure probability is calculated from the total reported failures, divided by the total standby hours for the pumps. Results are shown in Table 4-7.

During the period covered by the data reviews, there are a total of three demand failures of the AFWS pump/turbine. All three of these failures occured during the first year of commercial operation of the plant. Faulty speed control relays were the primary cause of the failures and the relays were replaced with relays capable of operating under design conditions. No subsequent failures of this type have occured since 1977. Since this type of failure appears to be associated with the plant "burn in" period, it is felt that generic industry failure probabilities are more appropriate to be used for analyzing the plant in its present phase of operation. There has recently been a fourth demand failure of the AFWS pump/turbine. It's cause is unrelated to the earlier reported failures and, while it is not included in this data review, it would not alter the conclusion that the Davis-Besse AFWS pump/turbine demand faults are consistent with reported industry average failure data. The Davis-Besse experience in failure of turbine driven pumps to continue operation is in agreement with the generic data reported in Reference (8), so again, the generic data are used in the reliability analysis.

Diesel Generator

Diesel generator failures reported in the Davis-Besse LERs can be categorized as failure to start, failure to stabilize and failure to continue operating. The failure to start includes actual failures of the diesel generator to start on demand. In computing a failure probability, only demands during monthly testing of the diesel generators are considered. This results in a conservatively high estimate of the demand failure rate since other diesel generator demands (e.g., demands imposed by other system tests) have not been included in the calculation, although any failure occurring during such demands are included. Failure to stabilize includes faults which prevent the diesel generator from operating for more than a very short time after starting. These failures are generally due to pre-existing faults occurring during the standby period. The failure rate for this mechanism is computed from the total standby hours for the diesel generators. Failure to continue operating includes faults occurring as an actual result of running the diesel generators. The failure rate for this mechanism is computed from the total operating hours logged for the diesel generators. Table 4-8 summarizes the Davis-Besse diesel generator reliability experience.

In the analysis of the electric power system fault tree a probability of failure to start and stabilize is computed. This probability is the sum of the probability for failure to start on demand and the probability for failure to stabilize, which is calculated by multiplying the failure to stabilize failure rate by one-half the mean test interval.

In general, the Davis-Besse diesel generators appear to have experienced slightly higher failure rates than the reported industry averages contained in Reference (9). Many of the diesel generator failures have occurred as a result of faults in the turbochargers. TECo plans to improve the diesel generator reliability by installing new high capacity turbochargers and modifying the lube oil system for the turbochargers. While these changes are planned for the 1982 outage and should significantly improve the diesel generator reliability, their quantitative impact on the reliability is not known. Therefore, the higher failure probabilities computed from past Davis-Besse experience are used in this reliability analysis.

Test and Maintenance Outages

Test and maintenance outages for the AFWS and diesel generators are computed in the same manner as reported in WASH-1400(5). This calculation is dependent on the plant-specific frequency of testing and the maximum time allowed by the Technical Specifications(12), during which a component can be out for maintenance while the plant is in operation.

The unavailability for a component being in maintenance is:

$$Qm = \frac{fm\ tm}{720}$$

where f_m is the frequency per month at which maintenance is performed and t_m is the average outage time per maintenance act (expressed in hours).

The unavailability for testing is:

$$Q_t = \frac{ft\ tt}{720}$$

where f_t is the testing frequency per month and t_t is the average time per test (expressed in hours). For the AFWS and diesel generators, the Davis-Besse Technical Specifications(12) limit maintenance outages to 72 hours before the plant must be shutdown and specify monthly test intervals. An hourly test duration is assumed. The frequency of maintenance acts is taken as .22 acts/month, and the mean duration of the maintenance is taken as 19 hours for the AFWS and 21 hours for the diesel generators. The maintenance values are developed in WASH-1400, Appendix III, Section 5(5).

Human Factors Analysis

The human factors probabilities used in the fault tree analysis for the feed and bleed operation are computed using NUREG/CR-1278. In each instance, the operator action contained in the procedure is analyzed and compared to specific events in NUREG/CR-1278. It was necessary in many cases to make assumptions concerning the operator system, since perfectly analogous examples do not exist. These assumptions are documented in this calculation. A typical list of assumptions is as follows: 1

1. Remotely operated and locally operated valves are treated under the generic category of "Manual Valves"

2. No recovery from error is assumed unless a specific control room annunicator is available. 1

3. Operator errors are assumed to be consistent with populational stereotypes. 1

For the purpose of fault tree analysis, one number, representing the probability of failure for that operator action, is indicated. It must be noted, however, that this single entry is a composite of unique errors that, when combined, form the operator error probability shown in the fault tree diagram. For example, the fault tree entry "Operator Fails to Open Valve" consists of the following components:

1. Operator omits step in written procedure
   or
2. Operator selects wrong valve from grouped system
   or 1
3. Operator operates valve incorrectly
   multiplied by
4. Operator stress factor (moderate)

4.2.3 Recommended Data Base

The results of the plant-specific data evaluation and the review of generic data are presented in Table 4-5. Also listed are recommended values for use in this reliability study.

The recommended values are generally based on the following prioritization.

- Whenever possible, plant-specific data are used.

- The highest value of recent generic data sources, (References 7, 8, 9, 13) is used.

- The human reliability data of Reference (11) are used, since this represents an expansion of the earlier work reported in Reference (5).

Also shown in the table are uncertainty factors on the data. These are determined by taking the maximum variance of the tabulated data sources. Some data points are discarded if they vary from the mean value by more than a factor of 100 (In all cases, such values are smaller than the mean value so that, in no case, are reported high failure rates discarded). Such values are not considered in determining maximum variances. The uncertainty factor is then rounded to the nearest half decade. If only one data source is available, an uncertainty factor of 10 is assigned.

4.3 System Unavailability Analysis

The system unavailability analysis includes quantitative analysis of the fault trees, the uncertainty analysis for AFWS unavailability, and the importance ranking of fault tree basic events in contributing to AFWS unavailability.

4.3.1 Quantitative Analysis of Fault Trees

Each AFWS configuration fault tree is analyzed for each category of initiating event. This analysis results in the qualitative determination of minimal cut sets for the fault tree and the quantitative determination for the point estimate for the probability of the top event. All support system fault trees, except that for electric power, are evaluated as part of the overall AFWS fault tree.

The electric power system fault tree is evaluated separately. Probabilities for failure of the electric power interfaces with the AFWS fault tree (see Table 3-1) are computed separately and values inserted into the AFWS fault tree. In cases where the dominant failure mode for separate electric power supplies is actually a common failure, these interfaces are treated as the same basic event in the AFWS fault tree. For example, with loss of offsite power, the dominant failure mode for failure of MCC-E12A and MCC-E12B is the failure of diesel generator #1 to start and continue running. This is treated as a single event wherever MCC-E12A and MCC-E12B interface with the AFWS fault tree.

The WAMCUT computer code (14) is used in the fault tree analysis. This is a Boolean manipulation computer code which determines the probability of occurrence of the top event (and any specified intermediate events) in the fault tree. It also identifies the minimal cut sets of the fault tree.

Since the AFWS fault trees developed in this study are very detailed, many thousands of minimal cut sets exist. In order to limit computer running time and to avoid exceeding the capacity of the code, the code has an input minimum probability cutoff. Any cut set whose probability is less than the cutoff value is discarded from the calculations. So as not to eliminate any potentially significant cut sets, this minimum probability cutoff is generally selected to be three orders of magnitude (1000 times) less than the probability of the top event of the tree. In a few cases, excessive computer time requirements dictate a minimum probability cutoff of not less than 500 times smaller that the top event probability.

Mean values for basic event failure probabilities are input to the WAMCUT code. These are assigned from the recommended data column of Table 4-5. Where failure rates are given in this table (units of inverse time) the failure rate is multiplied by either one-half the mean test interval or the mission time, as appropriate. For all initiating events, a 24 hour AFWS mission time is assumed. This is based on a conservative estimate of the time required for auxiliary feedwater prior to setting the decay heat removal system in operation. Also, the AFWS reliability analysis is based on the assumption of non-repairable component failures (except for human recovery actions not actually requiring repair of the fault). Twenty four hours after a plant initiating event, repair of components in plant safety systems would almost certainly be initiated.

For operation of the diesel generators, a ten hour mission time is assumed. This is based on the review of offsite electric power restoration experience reported in Reference (5). Once offsite power is restored, the diesel generators would no longer be required as an electric power source.

For certain categories of events, various components may have an unavailability of unity. For events involving loss of offsite power, all components not powered off the diesel generators have an unavailability of unity. Also, for seismic events, all non-seismically qualified equipment is assumed to be unavailable. One exception to this general assumption is the Pre-TMI configuration in which the common turbine exhaust silencer is not seismically qualified. This is a potential common failure mode for both AFWS trains. However, the failure mode is not the rupture of the silencer and exhaust pipe, but its becoming plugged to an extent that steam cannot be exhausted. A probability of .01 (uncertainty factor of ten) is arbitrarily assigned to this event.

For failures of support systems for which explicit fault trees are not developed, the following order-of-magnitude unavailabilities are assigned:

System	Unavailability
fluid systems (service water system, fire protection system)	.01
a specific single channel of SFRCS	.001
station nitrogen supply to any single valve (involves passive failures only)	9.6×10^{-5}

1

These values are based on judgments formed from various reliability studies on fluid systems and safety-grade electrical control systems. In all cases, an uncertainty factor of ten is applied to these unavailabilities. It should also be noted that the fire protection system has an unavailability of unity for loss of offsite power events and seismic events.

4.3.2 Uncertainty Analysis

The standard deviation of the fault tree top event unavailability, due to data uncertainties, is determined through a moments calculation. First moments (mean values) and second moments for the fault tree basic event probability distribution function are input to the WAMCUT code. The code computes the resultant top event first moment (point value) and second moment. The standard deviation of the top event, is then computed from the relationship

$$\sigma^2 = M_2 - M_1{}^2$$

where M_2 is the top event second moment and M_1 is the top event first moment. The assumed form for the probability distribution functions of basic events is a log-uniform distribution. The second moment calculation, in conjunction with the large number of events contributing to the top event, tends to make the top event standard deviation insensitive to the assumed probability distribution function. The limits of the distribution are the mean value multiplied and divided by the uncertainty factors listed in Table 4-5. Since the recommended values are greater than the true mean values (which could be compiled from the various data sources), this procedure tends to bias the standard deviation towards higher unavailabilities. The true $+ \sigma$ value reported here is, therefore, too large while the $- \sigma$ value may actually be somewhat larger. However, the intent here is not to develop absolute confidence limits, but rather to evaluate relative changes in AFWS unavailability and to develop a qualitative measure of the uncertainty in the results. Since the same bias is used in all cases, the results can be compared in relative terms.

4.3.3 Importance Ranking

The importance ranking is used to judge the relative significance of basic events in contributing to the unavailability of the AFWS. Events with a high importance measure are more significant in contributing to AFWS failure. Such a ranking is most useful in evaluating various means to improve AFWS availability.

There are several measures of importance used in reliability studies. The measure employed here is the Fussell - Vesely measure[4]. This measure, applied to a single basic event, is defined as the total probability for the occurrence of a cut set containing the event, divided by the probability for the occurrence of the top event. Basically, this is a measure of the sensitivity of the top event (AFWS unavailability) to small changes in the unavailability of a basic event. The Fussell-Vesely measure can be applied to generic categories of events, e.g., the failure of motor operated valves to open on demand, which is a feature utilized in this study.

The importance rankings in this study are computed through hand calculations, using the minimal cut set identification and probabilities generated by WAMCUT.

4.4 Initiating Event Analysis

Estimates for frequencies of initiating events requiring actuation of the AFWS are developed. Initiating events considered in the analysis are listed in Table 4-9. The events are grouped into three event categories which differ in their assumed availabilities for certain plant components, equipment and systems. These event categories are:

Category 1: Events in which main feedwater flow is lost, but offsite electrical power and non-seismically qualified equipment are available.

Category 2: Events in which offsite electrical power is assumed to be lost, but non-seismically qualified equipment is available.

Category 3: Events in which offsite electrical power and all non-seismically qualified equipment are assumed to be unavailable.

Table 4-9 shows the categorization of initiating events challenging the AFWS.

4.4.1 Frequency Estimates

Initiating event frequency estimates are developed from reviews of generic industry sources, and are supplemented from reviews of Davis-Besse operating experience. The primary generic data sources are References (5) and (15). Davis-Besse experience is summarized in LERs and unit trip reports. Results of these reviews are tabulated in Table 4-10.

Loss of Main Feedwater

Reference (15) cites B&W reactors as experiencing this type of transient slightly less frequently than other vendors' PWRs. There is evidence of a "burnin" period associated with this type of transient, with a 50% increase in the frequency during the first two years of plant operation. The generic PWR frequency listed in Table 4-10 is the frequency after this two-year period of operation. The Davis-Besse experience is in agreement with the generic PWR frequency, so the generic value is used in the reliability analysis.

Steam Generator Overfill

Davis-Besse has experienced three steam generator overfill events, but none of these actuated the AFWS. The generic value is therefore assumed.

Small Break in RCS

Reported events in this category include control rod leakage, primary system (primarily pump seal) leakage, pressurizer leakage and opening of the pressurizer safety or relief valve. Davis-Besse has experienced one initiating event of this type, which occurred at less than 10% power during the first month of operation. This event is not considered to be representative of post "burnin" operation, so the generic PWR frequency is assumed.

Loss of Forced RCS Circulation

This event includes the loss of all reactor coolant pump forced circulation as the initiating event. It does not include loss of offsite power as the initiating event, which would also result in loss of forced RCS circulation. The generic data indicates that this type of initiating event is relatively infrequent. Davis-Besse has not experienced a complete loss of RCS circulation as an intiating event. Davis-Besse did, however, experience a partial loss of forced RCS circulation (two loop flow) which resulted in low steam generator level and AFWS actuation. The "initiating event" in this instance is considered to be the partial loss of RCS circulation.

Since the frequency for partial loss of forced RCS flow is expected to be an order of magnitude greater than for total loss of flow, and since a partial loss of flow may result eventually in AFWS actuation, the larger Davis-Besse based frequency is used in this analysis.

Loss of Offsite Power

There have been three loss of offsite power events at Davis-Besse, however, one occurred during the initial power assentation and a second occurred as a result of power transfer logic which has since been modified. The Davis-Besse experience since this modification was implemented agrees well with the generic experience of all PWR's reported in Reference (15). The generic value is, therefore, used.

Tornado

The frequency estimate for tornadoes is taken from the Davis-Besse FSAR. No incidents have been recorded. This value is in general agreement with the similar frequency estimate of Reference (5), which is presented as a conservative upper bound for the entire Eastern U.S.

It is assumed in this analysis that a tornado would cause a loss of offsite power. Its impact on the AFWS and other support systems is assumed to be negligible, since the buildings housing support systems are designed to withstand the effects of a tornado.

Earthquake

The only source for this event is the estimate contained in Reference (5). The value cited is the frequency of earthquakes in the Eastern U.S. which result in ground accelerations greater than 0.1g.

4.4.2 Factors Influencing Event Frequencies

There have been many Davis-Besse design modifications, either implemented since the TMI-2 event or planned to be implemented by the 1982 refueling outage, which may affect not only the AFWS reliability, but also the frequency with which the AFWS may be challenged. Modifications which reduce the frequency of initiating events challenging the AFWS may actually contribute more to the overall plant reliability and the diminishing risk then do modifications intended to upgrade the AFWS availability.

Unfortunately, there are generally insufficient or no plant operating data available with which to quanitfy the reduction in challenges to the AFWS resulting from these modifications. This is true not only for Davis-Besse experience, but also for overall industry experience, since many plants have implemented significant changes in design and operation as a result of the TMI-2 event.

The initiating event frequencies used in this analysis are, therefore, generally based on "Pre-TMI" plant operating experience. The frequencies are, however, applied uniformly in developing overall figures-of-merit for all of the AFWS configurations. (As discussed in Section 4.5, the overall figure-of-merit is defined as the annual frequency with which AFWS is unavailable when challenged).

The resultant figures-of-merit for the "Post-TMI", "Third Train" and "Analysis-Based" configurations are, therefore, conservatively high; the figure-of-merit for the "Pre-TMI" configuration contains less conservatism. Since the same conservaitvely high frequencies are applied to each of these configurations, however, the relative differences in the results are indicative of the relative benefits attainable from each configuration. It should be noted, that significant reductions in the annual frequency with which AFWS is unavailable when challenged, could be attained through modifications to plant design and operations which are not directly linked to the AFWS.

4.5 Combined System/Event Analysis

Results of the AFWS reliability analysis are combined with initiating event frequencies in order to derive an overall figure-of-merit for each AFWS configuration. The figure-of-merit is derived as follows:

- A matrix is constructed listing each AFWS configuration and each initiating event, as shown in Figure 4-3.

- The frequency for each initiating event is multiplied by the AFWS unavailability for that event.

- The products are summed for each AFWS configuration.

The resultant figure-of-merit is the annual frequency with which the AFWS is unavailable when challenged.

TABLE 4-1

System Safety Functions

System	Safety Function	Failure Criteria for Study
AFWS (Pre-TMI)	Primary system decay heat removal	1. less than full capacity flow from at least one pump train, or 2. flow to steam generator(s) delayed more than 10 minutes from initiating event, or 3. all AFWS flow is interrupted during required mission time.
AFWS (Post-TMI and Analysis-Based)	Primary system decay heat removal	1. less than full capacity flow from at least one pump train, or 2. flow to steam generator(s) from AFWS delayed more than 10 minutes from initiating event, or 3. all AFWS flow is interrupted during required mission time. AND 1. full flow from startup pump delayed more than 30 minutes, or 2. full flow from one makeup pump to primary system delayed more than 30 minutes, or 3. letdown line not isolated at reactor trip, or 4. less than full discharge from one PORV within 30 minutes, or 5. feed and bleed procedure is interrupted prior to HPI initiation, or 6. startup pump flow is interrupted during required mission time.

TABLE 4-1 (Cont.)

System Safety Functions

System	Safety Function	Failure Criteria for Study
AFWS (Third Train)	Primary system decay heat removal	1. less than full capacity flow from one AFWS pump train, and less than full capacity flow from startup pump, or 2. flow to steam generator(s) delayed more than 10 minutes from initiating event, or 3. all AFWS flow including startup pump flow is interrupted during required mission time.
Electric Power System	Provide AC or DC power to AFWS components	1. inability to supply rated load to AFWS components.
Main Steam System	Provide steam to AFWS pump turbines	1. inability to provide sufficient steam to maintain full AFWS pump flow.

TABLE 4-2

Plant System Designator

A	Auxiliary Feedwater System
C	Condensate System
E	Electrical System
F	Fire Protection System
M	Main Steam System
S	Service Water System
P	Feedwater System

TABLE 4-3

Component Code

Mechanical Components

Diesel	DL	Valve, Check	CV
Filter or Strainer	FL	Valve, Hydraulic Operated	HV
Flow Element	FE	Valve, Manual	XV
Gas Bottle	GB	Valve, Motor Operated	MV
Nozzle	NZ	Valve, Pneumatic Operated	AV
Orifice	OR	Valve, Relief	RV
Pipe	PP	Valve, Safety	SV
Pump	PM	Valve, Solenoid Operated	KV
Tank	TK	Valve, Stop Check	DV
Tubing	TG	Vent	VT
Turbine	TB		

1

TABLE 4-3 (Cont.)

Component Code

Electrical Components

Battery	BY	Relay	RE	
Battery Charger	BC	Relay or Switch Contact	CN	
Bus	BS	Switch, Pressure	PS	
Cable	CA	Switch, Temperature	TS	
Circuit Breaker	CB	Switch, Torque	QS	
Control Switch	CS	Transformer, Power	TR	
DC Power Supply	DC	Transmitter, Flow	TF	
Flow Switch	FS	Transmitter, Level	TL	1
Fuse	FU	Transmitter, Pressure	TP	
Generator	GE	Transmitter, Temperature	TT	
Ground Switch	GS	Wire	WR	
Inverter (solid state)	IV			
Level Switch	ES			
Limit Switch	LS			
Motor	MO			
Motor Starter	MS			

TABLE 4-4

Failure Mode Code

Closed	C
Does Not Close	K
Does Not Open	D
Does Not Start	A
Exceeds Limit	M
Leakage	L
Loss of Function	F
Maintenance Fault	Y
Open	O
Open Circuit	B
Operational Fault	X
Plugged	P
Rupture	R
Short Circuit	Q
Short to Ground	S

1

TABLE 4-5

AFWS RELIABILITY STUDY

FAILURE DATA: PUMPS

** Uncertainty Factor

COMPONENT	Failure Mode	IEEE 500 (ALL MODES)	**		**	Davis-Besse	**	NUREG 0942	**	WASH 1400 TABLE III	**	NUREG 1205	**	Recommended	**
Turbine Driven Standby Pumps	Per Demand									1×10^{-3} (4-1)	3	* 1×10^{-2} (Page 65)		1×10^{-2}	3
(Complete Unit)	Per Hour					4.9×10^{-5}(4)		2.7×10^{-4}(1)		N/A	10	* 5×10^{-5}(4)		5×10^{-5} (4)	3
Motor Driven Standby Pumps	Per Demand									1×10^{-3} (4-1)	3	3×10^{-3} (Page 65)		3×10^{-3}	3
(Complete Unit)	Per Hour							2.7×10^{-5}(1)		3×10^{-5}	10	* 5×10^{-6}(4)		3×10^{-5}	3
DC Motor (Less than 300 VDC)	Per Demand	6.5×10^{-4}(2) (Pg. 210)						(Pg. 249)		3×10^{-4} (4-2)	3			6.5×10^{-4}	3
	Per Hour	5×10^{-7}						2×10^{-5}		1×10^{-5}	3			2×10^{-5}	3
Turbine Driven Pumps	In Test					1.94×10^{-3}								1.94×10^{-3}	10
	In Maintenance					5.81×10^{-3}								5.81×10^{-3}	10

* Babcock & Wilcox Generic Data
(1) Added between prime mover and component
(2) (36088) for demand failure rate
(3) All valve types are averaged
(4) Per standby HR

References will appear in the chart as follows:

| 1×10^{-4} (1) | - Note Reference
| (Pg. 284) | - Page Reference

TABLE 4-5 (Cont.)

AFWS RELIABILITY STUDY

FAILURE DATA: VALVES

** Uncertainty Factor

COMPONENT	Failure Mode	IEEE 500 (ALL MODES)	**	NUREG 1363 (VOL. 1)	**	Davis-Besse	**	NUREG 0942	**	WASH 1400 TABLE III	**		**	Recommended	**
Motor Operated	Per Demand	1 x 10^{-5} (Pg. 386)		*5 x 10^{-3} (Pg. 53)		1.5 x 10^{-2}		(Pg. 449)		1 x 10^{-3} (4-1)	3			1.5 x 10^{-2}	3
Valves (Geared)	Per Hour	6.2 x 10^{-7}		*4 x 10^{-7} (Plugged)		** No Failures Reported		1.6 x 10^{-5}		3 x 10^{-7} (Plugged)	3			4 x 10^{-7} (Plugged)	3
Air Operated	Per Demand	5.2 x 10^{-6} (Pg. 393)		*6 x 10^{-3} (Pg. 53)		3.85 x 10^{-2}		(Pg. 455)		3 x 10^{-4} (4-1)	3			3.85 x 10^{-2}	3
Valves (Double Acting)	Per Hour	1.7 x 10^{-6}		*4 x 10^{-6} (Plugged)		** No Failure Reported		1 x 10^{-6}		3 x 10^{-7} (Plugged)	3			4 x 10^{-6} (Plugged)	3
Solenoid Operated	Per Demand	1.6 x 10^{-5} (Pg. 387)		*6 x 10^{-3} (Pg. 53)				(Pg. 450)		1 x 10^{-3} (4-1)	3			6 x 10^{-3}	3
Valves (Direct Acting)	Per Hour	7 x 10^{-7}		*1 x 10^{-7} (Plugged)				2.2 x 10^{-6}			10			2.2 x 10^{-6} (Plugged)	3
Check Valves	To Open			* No Failure Reported (Pg. 53)		** No Failure Reported		(pg. 361)		1 x 10^{-4} (4-4)				1 x 10^{-4}	3
	Back Leakage			*3 x 10^{-7}		2.3 x 10^{-6}		2.3 x 10^{-6}						2.3 x 10^{-6}	10
Manual Valves	Per Demand			*2 x 10^{-4} (Pg. 53)						1 x 10^{-4} (4-1)	3			2 x 10^{-4}	3
All	Per Hour			*3 x 10^{-7}				6.7 x 10^{-7}(3)						6.7 x 10^{-7}	3
Strainer								(Pg. 124)							
Metal Mesh	Per Hour							5.4 x 10^{-6}						5.4 x 10^{-6}	10

* Babcock & Wilcox Generic Data
(1) Added between prime mover and component
(2) (36800) for demand failure rate
(3) All valve types are averaged
(4) For standby BR

References will appear in the chart as follows:

1 x 10^{-4} (1)	- Note Reference
(Pg. 204)	- Page Reference

TABLE 4-5 (Cont.)

AFWS RELIABILITY STUDY

FAILURE DATA: SENSORS

** Uncertainty Factor

COMPONENT	Failure Mode	IEEE 500 (ALL MODES)	**	NUREG 1363	**		**	NUREG 0942	**	WASH 1400 TABLE III	**		**	Recommended	**
Pressure Transmitter (Mech)	Per Hour	(Pg. 428) 3.8×10^{-6}						(Pg. 214) 5.1×10^{-6}		(4-2) 1×10^{-6}				5.1×10^{-6}	3
Flow Meter or Sensor (Orifice)	Per Demand	(Pg. 431)						(Pg. 165)		3×10^{-4} (4-1)	3			3×10^{-4}	3
	Per Hour	7×10^{-7}						3.6×10^{-6}		1×10^{-8}	10			3.6×10^{-6}	10
Pressure Switch Indicator (Bourdon Type)	Per Demand	(Pg. 429)						(Pg. 198)		1×10^{-4} (4-2)	3			1×10^{-4}	3
	Per Hour	2.9×10^{-6}						5.8×10^{-6}		1×10^{-7}	10			5.8×10^{-6}	3
Switchs All Types	Per Demand	(Pg. 175)						(pg. 203)		3×10^{-4} (4-2)	3			3×10^{-4}	3
	Per Hour	1.2×10^{-6}						5.4×10^{-6}		1×10^{-7}	10			5.4×10^{-6}	3
Relief Valves	Per Demand (Open)									1×10^{-5}	3			1×10^{-5}	3
	Per Demand (Close)			5×10^{-3} (5)										5×10^{-3}	10
Speed Sensor	Per Demand	5×10^{-9} (Pg. 442)						(Pg. 163)						5×10^{-9}	10
	Per Hour	1.2×10^{-6}						6.3×10^{-6}						6.3×10^{-6}	3

* Babcock & Wilcox Generic Data
(1) Added between prime mover and component
(2) (360HR) for demand failure rate
(3) All valve types are averaged
(4) Per standby HR

References will appear in the chart as follows:

| 1×10^{-4} (1) | - Note Reference
| (Pg. 284) | - Page Reference

TABLE 4-5 (Cont.)

AFWS RELIABILITY STUDY

FAILURE DATA: ELECTRICAL DISTRIBUTION EQUIPMENT

** Uncertainty Factor

COMPONENT	Failure Mode	IEEE 500 (ALL MODES)	**		**		**	NUREG 0942	**	WASH 1400 TABLE III	**		**	Recommended	**
Relays	Per Demand	7×10^{-6} (Pg. 162)						(Pg. 209)		1×10^{-4} (4-2)	3			1×10^{-4}	3
(Control)	Per Hour	6.7×10^{-8}						7.2×10^{-7}		3×10^{-7}	3			7.2×10^{-7}	3
Controller	Per Demand	(Pg. 169)						(Pg. 160)							
	Per Hour	1.5×10^{-7}						1.2×10^{-5}						1.2×10^{-5}	10
Buses	Per Demand	(Pg. 188)						(Pg. 114)							
	Per Hour	1.2×10^{-7}						5.2×10^{-6}						5.2×10^{-6}	10
Fuses	Per Demand	1×10^{-5} (Pg. 192)								1×10^{-5} (4-2)	3			1×10^{-5}	3
	Per Hour	2.3×10^{-8}								1×10^{-6}	3			1×10^{-6}	3
Breakers (Open)	Per Demand	2.3×10^{-4}												2.3×10^{-4}	3
(Close)	Per Demand	1×10^{-6} (Pg. 148)												1×10^{-6}	10
	Per Hour	1.4×10^{-7}						(Pg. 95) 1.8×10^{-6}						1.8×10^{-6}	3
Switch Gear	Per Demand	(Pg. 181)													
	Per Hour	1.3×10^{-7}												1.3×10^{-7}	10

* Babcock & Wilcox Generic Data
(1) Added between prime mover and component
(2) (360HR) for demand failure rate
(3) All valve types are averaged
(4) For standby HR

References will appear in the chart as follows:

1×10^{-4} (1)	- Data Reference
(Pg. 204)	- Page Reference

TABLE 4-5 (Cont.)

AFWS RELIABILITY STUDY

FAILURE DATA: ELECTRICAL DISTRIBUTION EQUIPMENT

** Uncertainty Factor

COMPONENT	Failure Mode	IEEE 500 (ALL MODES)	**		**		**	NUREG 0942	**	WASH 1400 TABLE III	**		**	Recommended	**
Transformers	Per Demand														
		(Pg. 304)						(Pg. 325)		(4-2)					
	Per Hour	3.3×10^{-7}						9.4×10^{-5}		1×10^{-6}	3			9.4×10^{-5}	10

\+ Babcock & Wilcox Generic Data
(1) Added between prime mover and component
(2) (360HR) for demand failure rate
(3) All valve types are averaged
(4) For standby HR

References will appear in the chart as follows:

1×10^{-4} (1)	- Note Reference
(Pg. 204)	- Page Reference

TABLE 4-5 (Cont.)

AFWS RELIABILITY STUDY

FAILURE DATA: POWER GENERATION EQUIPMENT

** Uncertainty Factor

COMPONENT	Failure Mode	IEEE 500 (ALL MODES)	**		**	NUREG 1362	**	NUREG 0942	**	WASH 1400 TABLE III	**		**	Recommended	**
Diesel Generator (Complete) Mission Time 10 Hours	Per Demand	8 x 10^{-3} (Pg. 227)		3.0 x 10^{-2}		≈1x10^{-2} (Pg. 80 A45)				3 x 10^{-2} (2-1)	3			3.0 x 10^{-2}	3
	Per Hour	1.3 x 10^{-4}		6.5 x 10^{-3}		≈6x10^{-3}		6.8 x 10^{-3} (1)		3 x 10^{-3}	10			6.5 x 10^{-3}	3
Battery	Per Demand	(Pg. 103)						(Pg. 85)		(4-2)					
	Per Hour	2.9 x 10^{-6}						1.4 x 10^{-7}		3 x 10^{-6}	3			3 x 10^{-6}	3
Battery Charger	Per Demand	(Pg. 87)													
	Per Hour	1.2 x 10^{-5}						4.9 x 10^{-6}			3			4.9 x 10^{-6}	3
Inverter	Per Hour	3.4 x 10^{-6} (Pg. 232)						2.5 x 10^{-5} (Pg. 136)						2.5 x 1[illegible]	3
Diesel Generator	In Test			1.94 x 10^{-3}										1.94 x 10^{-3}	10
	In Maintenance			6.42 x 10^{-3}										6.42 x 10^{-3}	10

* Babcock & Wilcox Generic Data
(1) Added between prime mover and component
(2) (360HR) for demand failure rate
(3) All valve types are averaged
(4) For standby BR

References will appear in the chart as follows:

| 1 x 10^{-4} (1) | - Note Reference
| (Pg. 204) | - Page Reference

TABLE 4-5 (Cont.)

AFWS RELIABILITY STUDY

FAILURE DATA: MISCELLANEOUS

** Uncertainty Factor

COMPONENT	Failure Mode	IEEE 500 (ALL MODES)	**		**	Davis-Besse	**	NUREG 0942	**	WASH 1400 TABLE III	**		**	Recommended	**
Pipe															
										(4-1)					
	Per Hour									1×10^{-10}	30			1×10^{-10}	30
Terminal		(Pg. 535)								(4-2)					
Boards or Block	Per Hour	6.1×10^{-6}								1×10^{-7}	10			6.1×10^{-6}	3
Solid State								(Pg. 219)		(4-2)					
Circuits	Per Hour							1.6×10^{-6}		1×10^{-6}	10			1.6×10^{-6}	3
Instrumentation								(Pg. 175)		(4-2)					
(Miscellaneous)	Per Hour							1.8×10^{-6}		1×10^{-6}	10			1.8×10^{-6}	3
Cable Open	Per Hour	6×10^{-7} (Pg. 521)								(4-2)				6×10^{-7}	10
Shorted	Per Hour	5×10^{-7}								3×10^{-6}				5×10^{-7}	3

* Babcock & Wilcox Generic Data
(1) Added between prime mover and component
(2) (360HR) for demand failure rate
(3) All valve types are averaged
(4) Per standby HR

References will appear in the chart as follows:

1×10^{-4} (1)	- Note Reference
(Pg. 204)	- Page Reference

TABLE 4-5 (Cont.)

AFWS RELIABILITY STUDY

FAILURE DATA: HUMAN ERRORS

** Uncertainty Factor

DESCRIPTION & CIRCUMSTANCES	Failure Mode	**		**		**		**	WASH 1400 (Table III)	**	NUREG 1278	**	Recommended	**
Valve Local Operation and Indication	Aligned Incorrectly								1×10^{-2}		5×10^{-2}(1)		5×10^{-2}	3
Valve Local Operation Remote Indication	Aligned Incorrectly										5×10^{-3}(2)		5×10^{-3}	10
Valve Remote Operation and Indication	Aligned Incorrectly										3×10^{-3}(3)		3×10^{-3}	3
Valve - Administrative Procedure for Tagging After Positioning	Aligned Incorrectly								1×10^{-4}		1×10^{-3} (4), (5)		1×10^{-3}	10
Valve - Administrative Procedure for Locking in Position	Aligned Incorrectly								1×10^{-4}		5×10^{-4} (4), (5)		5×10^{-4}	10
Operator, Written Procedure (Routine Task)	Omits a Step								3×10^{-3}		3×10^{-3}(6)		3×10^{-3}	3
Operator, Written Procedure (Moderately High Stress)	Omits a Step								1×10^{-2}		6×10^{-3}		6×10^{-3}	3

NOTES ON HUMAN ERRORS:

(1) Assuming no double-check procedure.
(2) Failure to properly align valve & failure of operator to detect error of omission (Table 20-16).
(3) Assuming written procedure w/o double-check, short list, Table 13-1.
(4) WASH-1400 equates this with failure to follow an administrative procedure.
(5) For NUREG/CR1278, locking or tagging constitutes following an administrative procedure that includes a form of checkoff. Short list values from Table 13-1 assumed.
(6) Long list with checkoff.
(7) Assumes controls are functionally grouped.
(8) No violation of populational stereotype assumed.
(9) Action after 30 minutes.
(10) Uncertainty band is assumed.
(11) Basis for point estimate:
Project team that developed NUREG/CR-1278 was also responsible for human factors analysis in WASH-1400. Therefore, it was assumed that NUREG/CR-1278 represented a refinement of the WASH-1400 work and probabilities from this reference are recommended. The one exception is in the case of manual valves with lock-and-chain control. In this case, the lower end of the NUREG/CR-1278 uncertainty band was recommended, primarily because it seemed likely that the requirement to lock a valve in place would draw more attention to its position than simply tagging it. In addition, the cited median value of 0.001 was more closely related to the failure to lock the valve than to the actual valve position.

TABLE 4-5 (Cont.)

AFWS RELIABILITY STUDY

FAILURE DATA: HUMAN FACTORS

** Uncertainty Factor

DESCRIPTION & CIRCUMSTANCES	Failure Mode	**		**		**		**	WASH 1400 (Table III)	**	NUREG 1270	**	Recommended	**
Operator, Written Procedure (Extremely High Stress)	Omits a Step								1×10^{-1}		2.5×10^{-1}		2.5×10^{-1}	3
Operator, (Moderately High Stress)	Failure to perform a required dynamic task								1×10^{-2}		1.5×10^{-1}		1.5×10^{-2}	3
Operator, Attempting to Perform Proper Action	Selects Wrong Control										1×10^{-3}(7)		1×10^{-3}	3
Operator, Selects Proper Control (Normal Conditions)	Manipulates It Improperly										5×10^{-4}(8)		5×10^{-4}	3
Operator, Selects Proper Control (High Stress) but	Manipulates It Improperly										5×10^{-3}(8)		5×10^{-3}	3
General Error of Commission (High Stress)									1×10^{-1}		1×10^{-1} (10)		1×10^{-1}	3
General Error of Commission (Moderate Stress)									1×10^{-2}		1×10^{-2} (10)		1×10^{-2}	3

NOTES ON HUMAN ERRORS:

(1) Assuming no double-check procedure.
(2) Failure to properly align valve & failure of operator to detect error of omission (Table 20-16).
(3) Assuming written procedure w/o double-check, short list, Table 13-1.
(4) WASH-1400 equates this with failure to follow an administrative procedure.
(5) For NUREG/CR1278, locking or tagging constitutes following an administrative procedure that includes a form of checkoff. Short list values from Table 13-1 assumed.
(6) Long list with checkoff.
(7) Common controls are functionally grouped.
(8) No violation of populational stereotype assumed.
(9) Action after 30 minutes.
(10) Uncertainty band is assumed.
(11) Basis for point estimate:
Project team that developed NUREG/CR-1278 was also responsible for human factors analysis in WASH-1400. Therefore, it was assumed that NUREG/CR-1278 represented a refinement of the WASH-1400 work and probabilities from this reference are recommended. The one exception is in the case of manual valves with lock-and-chain control. In this case, the lower end of the NUREG/CR-1278 uncertainty band was recommended, primarily because it seemed likely that the requirement to lock a valve in place would draw more attention to its position than simply tagging it. In addition, the cited median value of 0.001 was more closely related to the failure to lock the valve than to the actual valve position.

TABLE 4-5 (Cont.)

AFWS RELIABILITY STUDY

FAILURE DATA: HUMAN FACTORS

** Uncertainty Factor

DESCRIPTION & CIRCUMSTANCES	Failure Mode	**		**		**		**		**	NUREG 1278	**	Recommended	**
Pre-existing Maintenance Error is not Observed in Routine Inspection											1×10^{-2}		1×10^{-2}	3
Failure to Respond to an Annunciated Display of an Abnormal Condition											1×10^{-4}		1×10^{-4}	10
Same as Above, but Given That Five Annunciations are Activated											3×10^{-3}		3×10^{-3}	10
Same as Above, but Given That Ten Annunciations are Activated											5×10^{-2}		5×10^{-2}	10
Failure to Respond to an Un-Annunciated Display of an Abnormal Condition											5×10^{-2} (10)		5×10^{-2}	10
Failure to Properly Use Written Procedures											5×10^{-2}		5×10^{-2}	3

NOTES ON HUMAN ERRORS:

(1) Assuming no double-check procedure.
(2) Failure to properly align valve X failure of operator to detect error of omission (Table 20-26).
(3) Assuming written procedure w/o double-check, short list, Table 13-1.
(4) WASH-1400 equates this with failure to follow an administrative procedure.
(5) For NUREG/CR1278, locking or tagging constitutes following an administrative procedure that includes a form of checkoff. Short list values from Table 13-1 assumed.
(6) Long list with checkoff.
(7) Assumes controls are functionally grouped.
(8) No violation of populational stereotype assumed.
(9) Action after 30 minutes.
(10) Uncertainty band is assumed.

(11) Basis for point estimate:
Project team that developed NUREG/CR-1278 was also responsible for human factors analysis in WASH-1400. Therefore, it was assumed that NUREG/CR-1278 represented a refinement of the WASH-1400 work and probabilities from this reference are recommended. The one exception is in the case of manual valves with lock-and-chain control. In this case, the lower end of the NUREG/CR-1278 uncertainty band was recommended, primarily because it seemed likely that the requirement to lock a valve in place would draw more attention to its position than simply tagging it. In addition, the cited median value of 0.001 was more closely related to the failure to lock the valve than to the actual valve position.

TABLE 4-6

Failure Experience for Davis-Besse Valves

Component/Failure Mechanism	Total Valve Population In Selected Safety Systems	Total Demands Or Operating Hours	Total Reported Failures	Failure Probability/ Rate
Motor Operated Valves:				
Failure to open/close on demand	28	546 Demands	8	1.5×10^{-2}
Air Operated Valves:				
Failure to open/close on demand	14	182 Demands	7	3.8×10^{-2}
Check Valves:				
Failure to open on demand	43	559 Demands	0	---
Leakage		1.3×10^{6} hours	3	$2.3 \times 10^{-6} hr^{-1}$

TABLE 4-7

Failure Experience of Davis-Besse Auxiliary Feedwater Pumps

Failure Mode	Number of Pumps	Total Demands/ Standby Hours	Total Reported Failures	Failure Probability/Rate
Failure to start (since commercial operation	2	84 Demands	3	3.6×10^{-2}
Failure to start (after one year of operation)	2	52 Demands	0	---
Failure to continue operating	2	6.1×10^{4} hrs per pump	3	$4.9 \times 10^{-5} hr^{-1}$

TABLE 4-8

Failure Experience of Davis-Besse Diesel Generators

Failure Mode	Number of Diesel Generators	Total Demands/ Hours	Total Reported Failures	Failure Probability/Rate
Failure to Start	2	84 Demands	1	1.2×10^{-2}
Failure to Stabilize	2	60595(1) hrs	3	$4.9 \times 10^{-5} hr^{-1}$ (1)
Failure to Continue Operating	2	767 hrs	5	$6.5 \times 10^{-3} hr^{-1}$ (2)
Failure to Start and Stabilize				3×10^{-2}

(1) per hour of standby

(2) per hour of operation

TABLE 4-9

Initiating Events Challenging AFWS

Event	Offsite Power Availability	Non-Seismic Equipment Availability
Category 1		
Loss of main feedwater	Yes	Yes
Small break in RCS	Yes	Yes
Steam generator overfill	Yes	Yes
Loss of forced RCS Circulation	Yes	Yes
Category 2		
Loss of offsite power	No	Yes
Tornado	No	Yes
Category 3		
Earthquake	No	No

TABLE 4-10

Initiating Event Frequency Estimates

	Frequency (yr^{-1})			
Initiating Event	Reference (5)	Reference (15)	Davis-Besse Experience	Recommended Frequency
Loss of Main Feedwater	3.0	.70	.67	.67
Steam Generator Overfill		.95	(3)	.95
Small Break LOCA in RCS	1.0×10^{-3}	.17	(4)	.17
Loss of Forced RCS Circulation		.04	.3	.3
Loss of Offsite Power	.2	.32	.31	.32
Tornado	1.0×10^{-3}		6.3×10^{-4} (2)(1)	6.3×10^{-4}
Earthquake	4.3×10^{-3}		(1)	4.3×10^{-3}

(1) No events reported

(2) Davis-Besse FSAR estimate

(3) No events reported which activated the AFWS

(4) No events reported after "Burn in" period

FIGURE 4-1

DAVIS-BESSE AFW RELIABILITY PROGRAM
FLOW DIAGRAM

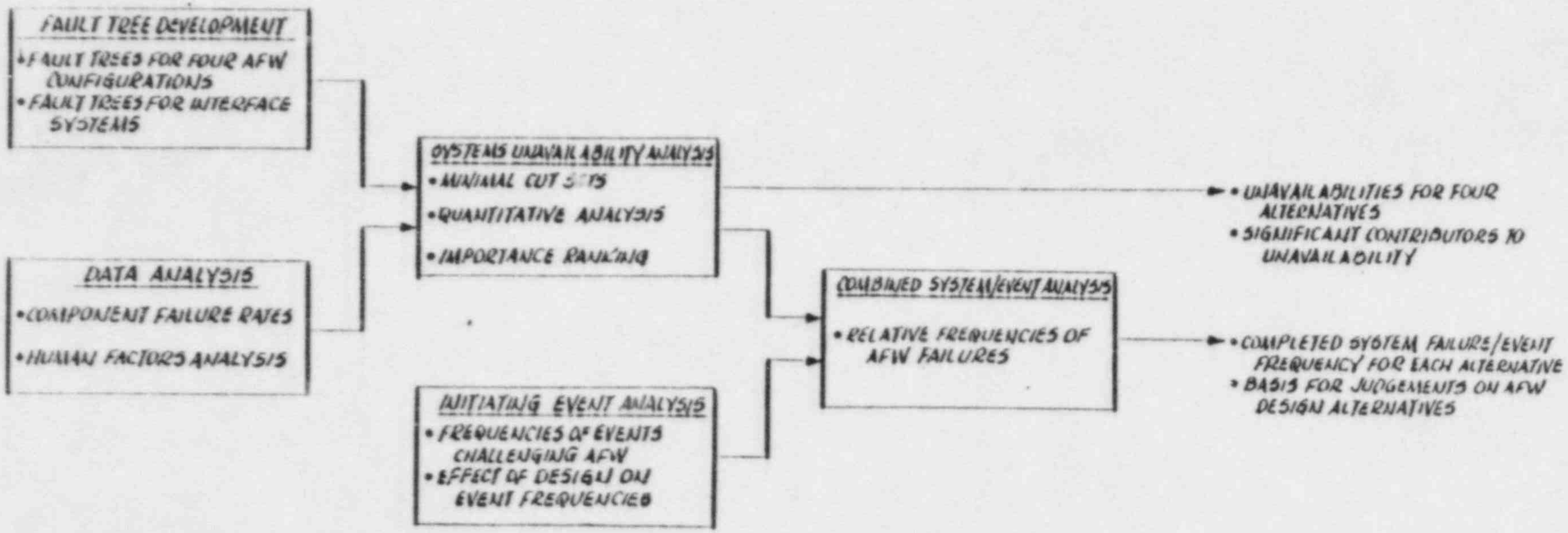
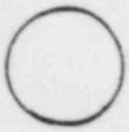


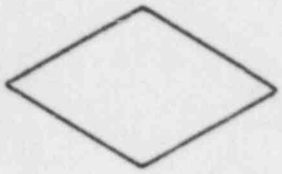
FIGURE 4-2

Symbols Used in Fault Trees

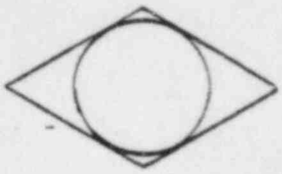
Events



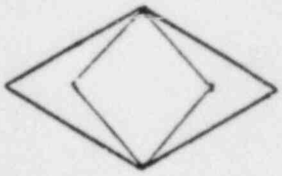
Circle -- Basic Event



Diamond -- A fault event that is not resolved any further. Though this is not a basic event, it is considered as if it were one in the analysis since it is not resolved any further, either due to lack of failure data at further resolution, or no further resolution is required for the particular analysis.



Circle within a diamond -- A fault event that is treated like a basic event. The reliability/availability characteristics of this event are calculated separately by a spearate fault tree analysis, and inserted in the main fault tree as if it were a basic event.



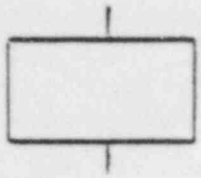
Double diamond -- An important undeveloped basic event that requires further development.

House -- An event that is normally expected to occur (probability of occurrence = 1), or never to occur (probability of occurrence = 0). It can be used as a "switch" to turn "ON" or "OFF" parts of the tree.

FIGURE 4-2 (Cont.)

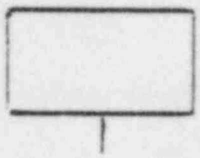
Symbols Used in Fault Trees

Events



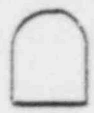
Rectangle --

i. An intermediate event that is resolved further, or

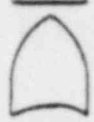


ii. The top event.

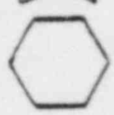
Gates



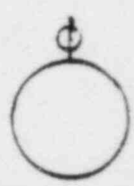
"AND" gate.



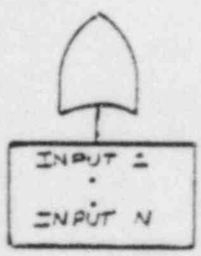
"OR" gate.



Combination gate



"NOT" -- The small circle indicates "NOT". The bigger dotted circle represents the basic event A which is "NOTed". Together they represent the complement of A.



OR gate with N inputs (listed), used in streamlined format of the simplified fault trees.

FIGURE 4-2 (Cont.)

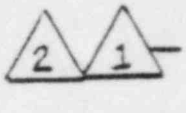
Symbols Used in Fault Trees

Other

Transfer in -- The subtree below triangle is drawn elsewhere. (This is a convenience used in drawing large fault trees.)

Transfer out -- The subtree drawn below the triangle belongs elsewhere. This complements the "transfer in" triangle, and an index number within the triangle indicates the correct match.

Multiple transfers in



Multiple transfers out

FIGURE 4-3

System/Event Analysis Matrix

Initiating Event	AFWS Configuration			
	1	2	3	4
Event 1	frequency 1x uavailability 1	frequency 1x unavailability 2	frequency 1x unavailability 3	frequency 1x unavailability 4
Event 2	frequency 2x unavailability 1	frequency 2x unavailability 2	frequency 2x unavailabilit: 3	frequency 2x unavailability 4
etc.				
Total Frequency with which AFWS is unavailable when challenged				

1

5.0 Results

5.1 Relative Unavailability Ranking of AFWS Configuration

The unavailability of the AFWS for each category of initiating event is summarized in Table 5-1. These results are based on quantitative computer analysis of detailed fault trees for each AFWS configuration. 1

In general, the results in Table 5-1 indicate that design and procedures modifications implemented since the TMI-2 event have improved the reliability of the AFWS by about an order of magnitude. The inclusion of the analysis - based system improvements or a diverse third train of AFWS results in about 1 another order of magnitude reduction in AFWS unavailability.

5.1.1 Differences Among Event Categories

For a given AFWS configuration, differences among the AFWS unavailabilities for different event categories are due to assumptions regarding the availability of systems and components. The system availability is highest (lowest unavailability) for Category 1 events. With the assumption of loss of offsite power (Category 2 events), the potential unavailability of one or both diesel generators contributes additionally to the AFWS unavailability. The large difference between Category 1 and Category 2 events results for the Post-TMI configuration is due primarily to the assumed absence of the feed and bleed procedure as a backup means to support the AFWS safety function. 1 (The original emergency procedures for using the startup pump in conjunction with primary coolant system feed and bleed apply only to the situation in which offsite power is available). With the additional assumption of loss of all non-seismically qualified equipment (Category 3 events), two of three AFWS water supplies are assumed to be unavailable. The potential unavailability of the remaining third water supply increases the AFWS unavailability significantly.

5.1.2 Differences Among AFWS Configurations

As discussed in Section 5.2, the Pre-TMI configuration unavailability is dominated by human factors. Failure of the diesel generators contributes to AFWS unavailability for Category 2 events. For Category 3 events, the plugging of the common turbine exhaust line adds to the Pre-TMI configuration unavailability.

Modifications to this exhaust line, implementation of the backup feed and bleed procedure, improvements in the control of other human factors and the design modifications discussed in Section 3.3 have improved the Post-TMI configuration availability significantly. Dominant failures in the Post-TMI configuration analysis are mechanical failures. This suggests that further improvements to the AFWS should address mechanical failure mechanisms in order to increase the overall system reliability.

The implementation of a third independent train of AFWS is one method for addressing these mechanical failures. The Third Train configuration examined in this study provides over an order of magnitude improvement in AFWS reliability. For Category 3 events, however, this Third Train provides no improvement in AFWS reliability, since the Third Train itself is assumed not to be seismically qualified.

The analysis-based design and procedural modifications provide an alternative means to address the significant contributors to the Post-TMI AFWS unavailability. The dominant Post-TMI configuration contributor, the failure of MOV to open/close on demand, becomes relatively unimportant with the analysis-based configuration valve alignment changes. Improved procedures
for locking manual valves in the start-up pump train enhance 1
the reliability of the feed and bleed procedure as an emergency backup to the AFWS. The extension of the feed and bleed procedure to loss of offsite power events, in conjunction with the analysis-based configuration design changes, provides almost two orders of magnitude improvement in AFWS reliability for category 2 events. The analysis-based configuration design changes provide some improvement for Category 3 events, as well.

The uncertainty analysis results for each configuration indicate that the standard deviation is the same order of magnitude as the point estimate (mean value) of the unavailability. The confidence in the calculated <u>order of magnitude</u> of the unavailability is, therefore, high. It is our belief that the unavailability value shown in Table 5-1 are valid for making judgements about the relative reliabilities of each AFWS configuration.

5.2 Significant Contributors to AFWS Unavailability

Tables 5-2, 5-3, 5-4, 5-5 present results of the importance ranking of events in contributing to the unavailability of the
AFWS for the Pre-TMI, Post-TMI, Third Train and Analysis-Based 1
configurations respectively. The importance ranking is applied to categories of similar events (e.g.; failure of motor operated valves to open/close on demand). Results are shown for each category of initiating event.

The dominant failure mechanism for the Pre-TMI configuration is human factors - primarily misalignment of locally operated and locally indicated valves. Also, improper manual throttling of the turbine admission valves is a relatively large contributor to the unavailability of this AFWS configuration. Failures of motor operated valves and the turbine driven pumps are the major mechanical factors contributing to unavailability. For Category 3 events, the failure of the service water system to supply water to the AFWS pumps and the potential plugging of the exhaust line are additional significant mechanical factors.

Implementation of locking procedures on manual valves and motor operated valves in the AFWS have reduced the significance of these human factors in the Post-TMI AFWS. Mechanical factors have the greatest importance in this configuration. The dominant mechanical factor is the failure of motor operated valves to open/close on demand. The failure of the turbine driven pumps to start or to be unavailable due to test/maintenance are also significant. Human factors are still significant for Category 1 events. These are associated with the feed and bleed procedure, as a backup to the two AFWS trains. For Category 3 events, the failure of the service water system is an additional significant mechanical factor.

The Third Train configuration has the same failure mechanisms as the Post-TMI configuration with regard to the two AFWS trains. The same mechanical factors, therefore, appear in Table 5-4. These AFWS failures must occur in conjunction with a failure of the Third Train in order to fail to achieve the AFWS safety function. The major failure mode for the Third Train include both mechanical factors (failure of the startup pump) and human factors (failure to manually initiate feedwater flow via the Third Train).

Significant contributors to the Analysis-Based configuration AFWS unavailability include the mechanical failure or unavailability due to maintenance of the AFWS pumps. The failure of MOVs are significant only for the backup feed and bleed procedure. For Category 2 events the failure of Diesel Generator No. 1, which provides power to MOVs in the letdown line and the makeup pump suction line, becomes a significant contributor to the failure of the feed and bleed procedure. 1

It should be noted that additional motor-operated valves exist which could be used to manually isolate the letdown line. Closure of these valves is not included in the normal letdown line isolation procedure. Thus, credit has not been taken for this additional means of letdown line isolation in the overall evaluation, although it is expected that the operator would utilize these valves, if necessary.

5.3 Results of Combined System/Event Analysis

Table 5-6 presents results of the combined system/event analysis for each of the four AFWS configurations examined in this study. The Analysis-Based configuration has the lowest figure-of-merit (lowest frequency for AFWS unavailability when challenged) followed in order by the Third Train configuration, the Post-TMI configuration and the Pre-TMI configuration. The Analysis-Based configuration and the Third 1
Train configuration offer over a factor of ten improvement over the Post-TMI configuration. A significant difference in Table 5-6 is between the Pre-TMI configuration and the Post-TMI configuration. This is due to the system design modifications already implemented and the feed and bleed procedure which reduces the frequency for loss of the AFWS safety function in Category 1 events.

Category 1 events are estimated to be significantly more frequent than Category 2 or Category 3 events. Although the AFWS reliability is greatest for Category 1 events, the greater frequency of such events makes Category 1 the major contributor to the overall figure-of-merit for the Pre-TMI, Third Train and Analysis-Based configurations. Category 2 events are the greatest contributors to the Post-TMI configuration's figure-of-merit. This is due primarily to the lack of emergency procedures (e.g., the feed and bleed procedure) as a backup to the AFWS in these events.

Table 5-7 illustrates the relative significance of the Pre-TMI - Post-TMI changes. The overall significance of each change is defined as the reduction in the overall frequency with which the AFWS is unavailable when challenged (total for all categories) assuming that only that change is made to the Pre-TMI configuration. The most significant changes are attributed to the implementation of administrative procedures to lock in position all manual valves, the utilization of the emergency "feed and bleed" procedure and the dual level controls on the turbine admission valves. The existence of the auxiliary feedwater flow indication in the control room had no effect on the analysis. The significance is, therefore, considered negligible.

5.4 Potential Common Cause Contributors to AFWS Unavailability 1

A single failure or event may cause more than one component of the AFWS to fail. This commonality in failure may result from shared power supplies, cooling water sources, operator actions, harsh environment and external causes (e.g.; fire, missiles, etc.). Where possible, such common cause contributors are explicitly modeled in the fault tree analysis. Such modeled common cause factors include electric power supplies and cooling water supplies. Other factors are not explicitly modeled. The quantitative impact of these potential common causes on the AFWS unavailability is not assessed.

TABLE 5-1

AFWS Unavailability

Event Category	AFWS Configuration	AFWS Unavailability	Standard Deviation	
1	Pre-TMI	3.3×10^{-2}	1.2×10^{-2}	
	Post-TMI	6.6×10^{-4}	3.3×10^{-4}	
	Third Train	4.5×10^{-5}	2.7×10^{-5}	
	Analysis-Based	3.3×10^{-5}	2.0×10^{-5}	1
2	Pre-TMI	4.1×10^{-2}	1.4×10^{-2}	
	Post-TMI	5.5×10^{-3}	2.2×10^{-3}	
	Third Train	1.4×10^{-4}	1.2×10^{-4}	
	Analysis-Based	9.3×10^{-5}	6.7×10^{-5}	1
3	Pre-TMI	8.8×10^{-2}	2.6×10^{-2}	
	Post-TMI	1.9×10^{-2}	1.2×10^{-2}	
	Third Train	1.9×10^{-2}	1.2×10^{-2}	
	Analysis-Based	1.1×10^{-2}	$1.1. \times 10^{-2}$	1

TABLE 5-2A

Significant Contributors to AFWS Unavailability

PRE-TMI Configuration

Category 1 Events	Importance
Mechanical Factors:	
- motor operated valves fail to open on demand	.42
- failure of turbine driven pump to start	.10
- failure of turbine driven pump to continue operating	.01
- turbine driven pump in test/maintenance	.08
Human Factors:	
- valve misalginment - recirculation line	.81
- valve misalignment - test line	.02
- improper throttling of turbine admission valves	.15

TABLE 5-2B

Significant Contributors to AFWS Unavailability

PRE-TMI Configuration

Category 2 Events	Importance
Mechanical Factors:	
- motor operated valves fail to open on demand	.37
- failure of turbine driven pump to start	.08
- failure of turbine driven pump to continue operating	.01
- turbine driven pump in test/maintenance	.06
Electric Power Factors:	
- failure of diesel generator to start	.035
- failure of diesel generator to continue operating	.075
Human Factors:	
- valve misalignment - recirculation line	.74
- valve misalignment - test line	.02
- improper throttling of turbine admission valves	.13

TABLE 5-2C

Significant Contributors to AFWS Unavailability

PRE-TMI Configuration

Category 3 Events	Importance
Mechanical Factors:	
- motor operated valves fail to open on demand	.30
- failure of turbine driven pump to start	.04
- failure of turbine driven pump to continue operating	.004
- turbine driven pump in test/maintenance	.04
- failure of service water system	.24
- plugging of turbine exhaust line	.11
Electric Power Factors:	
- failure of diesel generator to start	.031
- failure of diesel generator to continue operating	.067
Human Factors:	
- valve misalignment - recirculation line	.45
- valve misalignment - test line	.01
- improper throttling of turbine admission valves	.08

TABLE 5-3A

Significant Contributors to AFWS Unavailability

Post-TMI Configuration

Category 1 Events	Importance
Mechanical Factors:	
- motor operated valves fail to open on demand	.89
- failure of turbine driven pump to start	.29
- failure of turbine driven pump to continue operating	.03
- turbine driven pump in test/maintenance	.18
Startup Pump with Feed and Bleed	
Mechancial Factors:	
- motor operated valves fail to open on demand	.02
- isolation valve on letdown line fails to close on demand	.10
- air operated valves fail to open on demand	.05
- PORV fails to open on demand	.10
- failure to startup pump to start	.02
- failure to startup pump to continue operating	.005
- failure of makeup tank water supply	.05
Human Factors:	
- operator fails to isolate letdown line	.09
- operator fails to start startup pumps	.03
- operator operates PORV incorrectly	.05
- valve misalignments - borated water storage line	0.09
- valve misalignments - valve FW102 (startup pump train)	0.35

TABLE 5-3B

Significant Contributors to AFWS Unavailability

Post-TMI Configuration

Category 2 Events	Importance
Mechanical Factors:	
- motor operated valves fail to open on demand	.86
- failure of turbine driven pump to start	.25
- failure of turbine driven pump to continue operating	.03
- turbine driven pump in test/maintenance	.18
Electric Power Factors:	
- failure of diesel generator to start	.038
- failure of diesel generator to continue operating	.082

TABLE 5-3C

Significant Contributors to AFWS Unavailability

Post-TMI Configuration

Category 3 Events	Importance
Mechanical Factors:	
- motor operated valves fail to open on demand	.42
- failure of turbine driven pump to start	.09
- failure of turbine driven pump to continue operating	.01
- turbine driven pump in test/maintenance	.07
- failure of service water system	.54
Electric Power Factors:	
- failure of diesel generator to start	.029
- failure of diesel generator to continue operating	.062

TABLE 5-4A

Significant Contributors to AFWS Unavailability

Third Train Configuration

Category 1 Events	Importance
Mechanical Factors:	
- motor operated vavles fail to open on demand	.89
- failure of turbine driven pump to start	.28
- failure of turbine driven pump to continue operating	.01
- failure of startup pump to start	.29
- failure of startup pump to continue operating	.06
- turbine driven pump in test/maintenance	.19
Human Factors:	
- failure of operator to start startup pump	.60

TABLE 5-4B

Significant Contributors to AFWS Unavailability

Third Train Configuration

Category 2 Events	Importance
Mechanical Factors:	
- motor operated valves fail to open on demand	.80
- failure of turbine driven pump to start	.19
- failure of turbine driven pump to continue operating	.01
- failure of startup pump to start	.04
- turbine driven pump in test/maintenance	.14
Electric Power Factors:	
- failure of diesel generator to start	.35
- failure of diesel generator to continue operating	.52
- failure of bus D2	.04
Human Factors:	
- failure of operator to start startup pump	.16

TABLE 5-4C

Significant Contributors to AFWS Unavailability

Third Train Configuration

Category 3 Events	Importance
Mechanical Factors:	
- motor operated valves fail to open on demand	.42
- failure of turbine driven pump to start	.09
- failure of turbine driven pump to continue operating	.01
- turbine driven pump in test/maintenance	.07
- failure of service water system	.54
Electric Power Factors:	
- failure of diesel generator to start	.029
- failure of diesel generator to continue operating	.062

TABLE 5-5A

Significant Contributors to AFWS Unavailability

Analysis-Based Configuration

Category 1 Events	Importance
Mechanical Factors:	
- motor operated valves fail to open on demand	0.019
- failure of turbine driven pump to start	0.69
- failure of turbine driven pump to continue operating	0.07
- turbine driven pump in test/maintenance	0.48
Startup Pump with Feed and Bleed	
Mechanical Factors:	
- motor operated valves fail to open on demand	0.03
- isolation valve on letdown line fails to close on demand	0.25
- air operated valves fail to open on demand	0.06
- PORV fails to open on demand	0.26
- failure of startup pump to start	0.05
- failure of startup pump to continue operating	0.01
Human Factors:	
- valve misalignments - borated water storage line	0.11
- operator fails to isolate letdown line	0.08
- operator fails to start startup pumps	0.03
- operator operates PORV incorrectly	0.08

1

TABLE 5-5B

Significant Contributors to AFWS Unavailability

Analysis-Based Configuration

Category 2 Events	Importance
Mechanical Factors:	
- motor operated valves fail to open on demand	0.01
- failure of turbine driven pump to start	0.77
- failure of turbine driven pump to continue operating	0.08
- turbine driven pump in test/maintenance	0.41
Startup Pump with Feed and Bleed	
Mechanical Factors:	
- PORV fails to open on demand	0.08
- isolation valve on letdown line fails to close on demand	0.08
- failure of startup pump to start	0.008
Electric Power Factors:	
- failure of diesel generator to start	0.24
- failure of diesel generator to continue operating	0.52
Human Factors:	
- operator fails to start startup pump	0.03
- operator fails to isolate letdown line	0.02
- operator operates PORV incorrectly	0.02

1

TABLE 5-5C

Significant Contributors to AFWS Unavailability

Analysis-Based Configuration

Category 3 Events	Importance	
Mechanical Factors:		
- motor operated valves fail to open on demand	0.18	
- failure of turbine driven pump to start	0.09	
- failure of turbine driven pump to continue operating	0.01	
- turbine driven pump in test/maintenance	0.05	
- failure of service water system	0.89	1
Electric Power Factors:		
- failure of diesel generator to start	0.002	
- failure of diesel generator to continue operating	0.005	

TABLE 5-6

Combined System/Event Analysis Results

Initiating Event	Frequency (yr^{-1})	Frequency of AFWS Unavailability (yr^{-1}) Pre-TMI	Post-TMI	Analysis-Based	Third Train
Category 1					
- loss of main feedwater	.67	$2.2x10^{-2}$	$4.4x10^{-4}$	$2.2x10^{-5}$	$3.0x10^{-5}$
- steam generator overfill	.95	$3.1x10^{-2}$	$6.3x10^{-4}$	$3.1x10^{-5}$	$4.3x10^{-5}$
- small break in RCS	.17	$5.6x10^{-3}$	$1.1x10^{-4}$	$5.6x10^{-6}$	$7.7x10^{-6}$
- loss of forced RCS circulation	.3	$9.9x10^{-3}$	$2.0x10^{-4}$	$9.8x10^{-6}$	$1.4x10^{-5}$
Category 1 Total		$6.9x10^{-2}$	$1.4x10^{-3}$	$6.8x10^{-5}$	$9.4x10^{-5}$
Category 2					
- loss of offsite power	.32	$1.3\ 10^{-2}$	$1.8x10^{-3}$	$2.9x10^{-5}$	$4.5x10^{-5}$ 1
- tornado	$6.3x10^{-4}$	$2.6\ 10^{-5}$	$3.5x10^{-6}$	$5.8x10^{-8}$	$8.8x10^{-8}$
Category 2 Total		$1.3x10^{-2}$	$1.8x10^{-3}$	$2.9x10^{-5}$	$4.5x10^{-5}$
Category 3					
- earthquake	$4.3x10^{-3}$	$3.8x10^{-4}$	$8.2x10^{-5}$	$4.8x10^{-5}$	$8.2x10^{-5}$
Category 3 Total		$3.8x10^{-4}$	$8.2x10^{-5}$	$4.8x10^{-5}$	$8.2x10^{-5}$
Frequency with which AFWS is unavailable when challenged (Total for all categories)		$8.2x10^{-2}$	$3.3x10^{-3}$	$1.4x10^{-4}$	$2.2x10^{-4}$

TABLE 5-7

Relative Significance of the Pre-TMI - Post-TMI Changes

		Overall Significance*	
1.	Valves on Train 1 (AF-360, AF-3870, and the Main Steam Turbine Admission Valve MS-106) are powered off DC power supplies.	4.4×10^{-4}	
2.	Turbine exhausts are redundant and seismically qualified.	4.0×10^{-5}	
3.	Administrative procedures have been implemented to lock in position all manual valves and local control stations and hand wheels for motor operated valves.	6.6×10^{-2}	
4.	Turbine admission valves have automatic dual level control, with option for manual control.	1.0×10^{-2}	
5.	An emergency procedure has been implemented to manually start and align the main feedwater startup pump to provide feedwater to the steam generators in the event that both trains of AFWS fail. This also includes the feed and bleed procedure.	5.9×10^{-2}	1

*The "overall significance" is defined as the reduction in the overall frequency with which the AFWS is unavailable when challenged (total for all event categories) assuming that only that change is made to the Pre-TMI Configuration.

6.0 Conclusions 1

The methodology discussed in this report provides a useful tool with which to assess the relative reliability of various potential AFWS configurations at Davis-Besse Unit No. 1. The results may be used as input to AFWS design decisions. Such decisions include system level decisions (i.e.; the relative benefits offered by the various AFWS configurations examined) and component level decisions (i.e.; relative importance of individual components in contributing to system failure). Component level judgments can be the basis for developing improved AFWS designs, not explicitly considered in this analysis.

Major conclusions resulting from this study include the following:

- The Pre-TMI AFWS configuration has a relatively high unavailability. This is due largely to potential human factor failure mechanisms.

- The design and procedures modifications, originally 1
  planned or implemented at Davis-Besse Unit No. 1 subsequent to the TMI-2 event, effectively address the major failure mechanisms found in the Pre-TMI configuration analysis. The Post-TMI configuration reliability is over a factor of ten greater than the Pre-TMI configuration reliability.

- The major contribution to the Post-TMI AFWS unavailability is the failure of motor operated valves to open/close on demand. Mechanical failures associated with the turbine driven pumps are of lesser importance.

- The reliability of the Post-TMI "feed or bleed" method to 1
  provide backup auxiliary feedwater is not high, by itself, because of human factors. The calculated unavailability on demand is 0.14. However, this backup system does provide an additional measure of reliability to the already highly reliable AFWS.

- The inclusion of a third independent train of AFWS offers an order of magnitude improvement in AFWS reliability.

- The reliability of the feed and bleed procedure can be improved through additional administrative controls and explicit instructions for parameter response
  verification. The unavailability of the feed and bleed method with these improvements (Analysis-Based configuration) is 0.06 for Category 1 events. 1

- The AFWS design modifications which are part of the
  Analysis-Based configuration enhance the AFWS reliability,
  by themselves, nearly as much as the addition of a third 1
  train. The Analysis-Based design modifications, in
  conjunction with the procedural changes, enhance the AFWS
  reliability more than does the addition of a third train.

- The overall figure-of-merit for the AFWS is dependent not only on the system reliability, but also on the frequency with which it is challenged. Improvements in the figure-of-merit can be achieved through plant design and procedures modifications which would reduce the frequency of challenges to the AFWS (primarily Category 1 events). Such improvements may have a greater impact on the AFWS figure-of-merit than do AFWS design modifications. There have been many such improvements made at Davis-Besse Unit No. 1 since the TMI-2 event, but their impact on this analysis has not been quantified due to lack of sufficient performance data.

- The use of plant-specific data may have a significant impact on reliability analysis results. Where conservative, Davis-Besse specific data are used in this reliabilty analysis.

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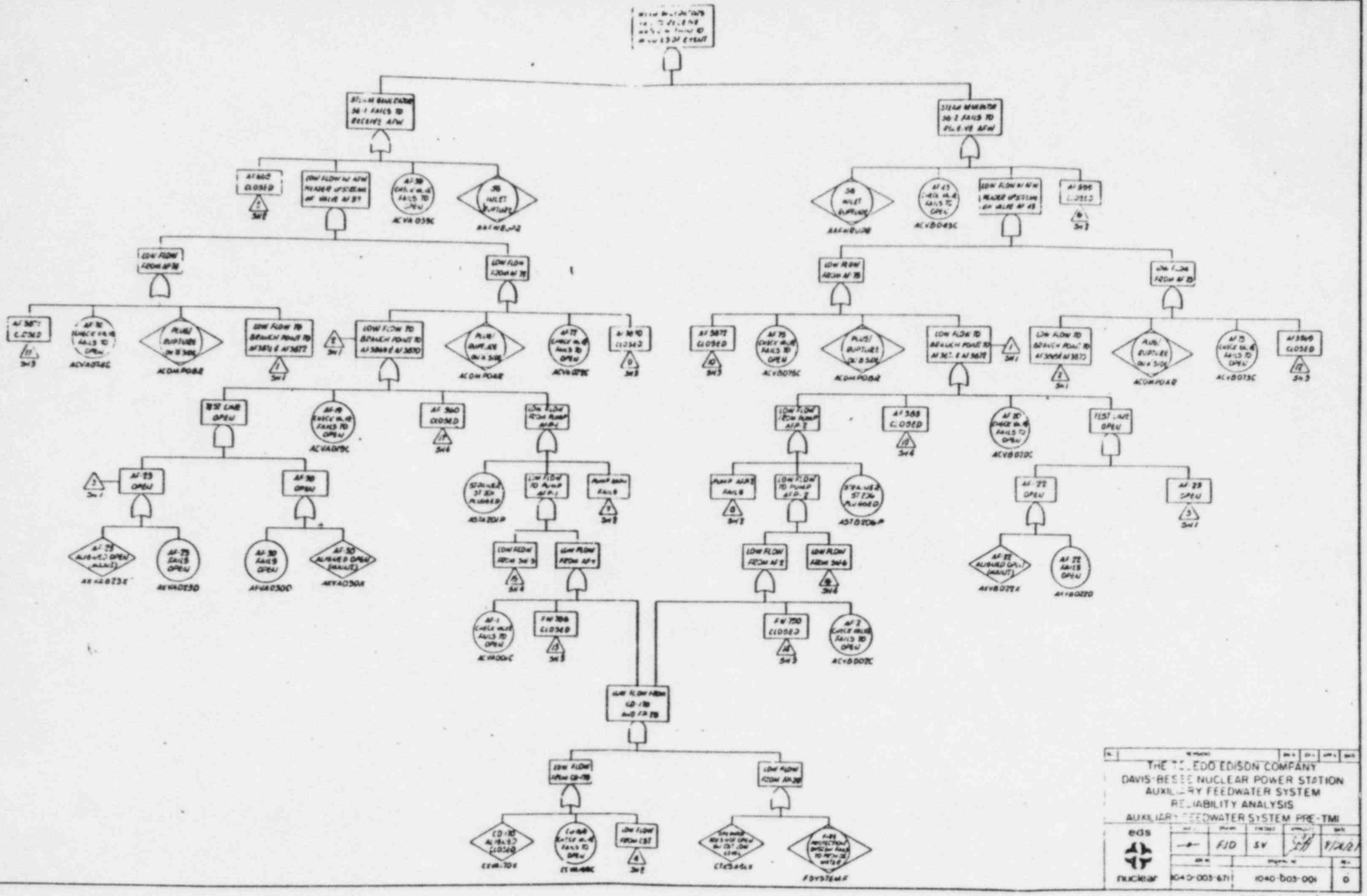

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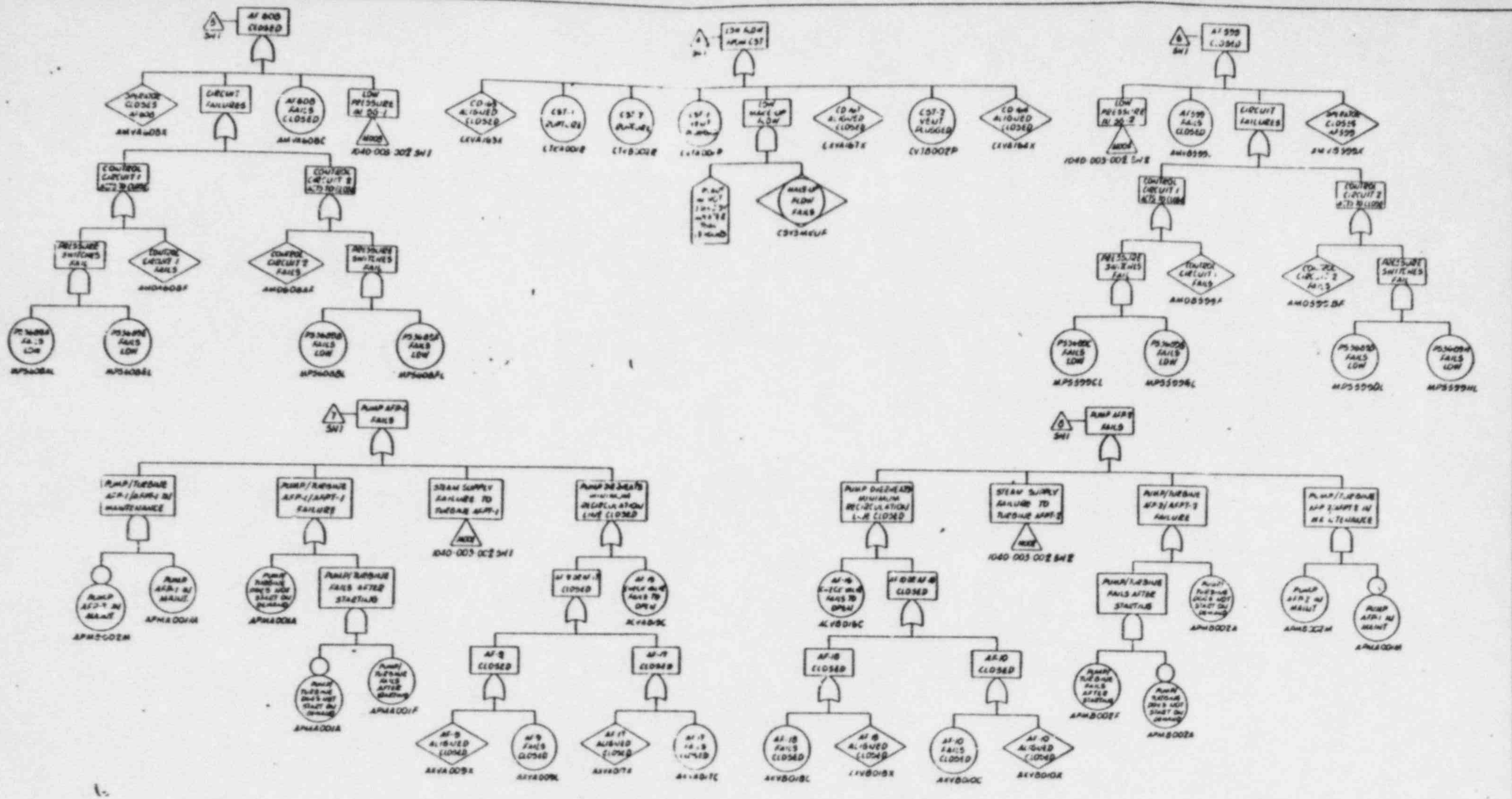

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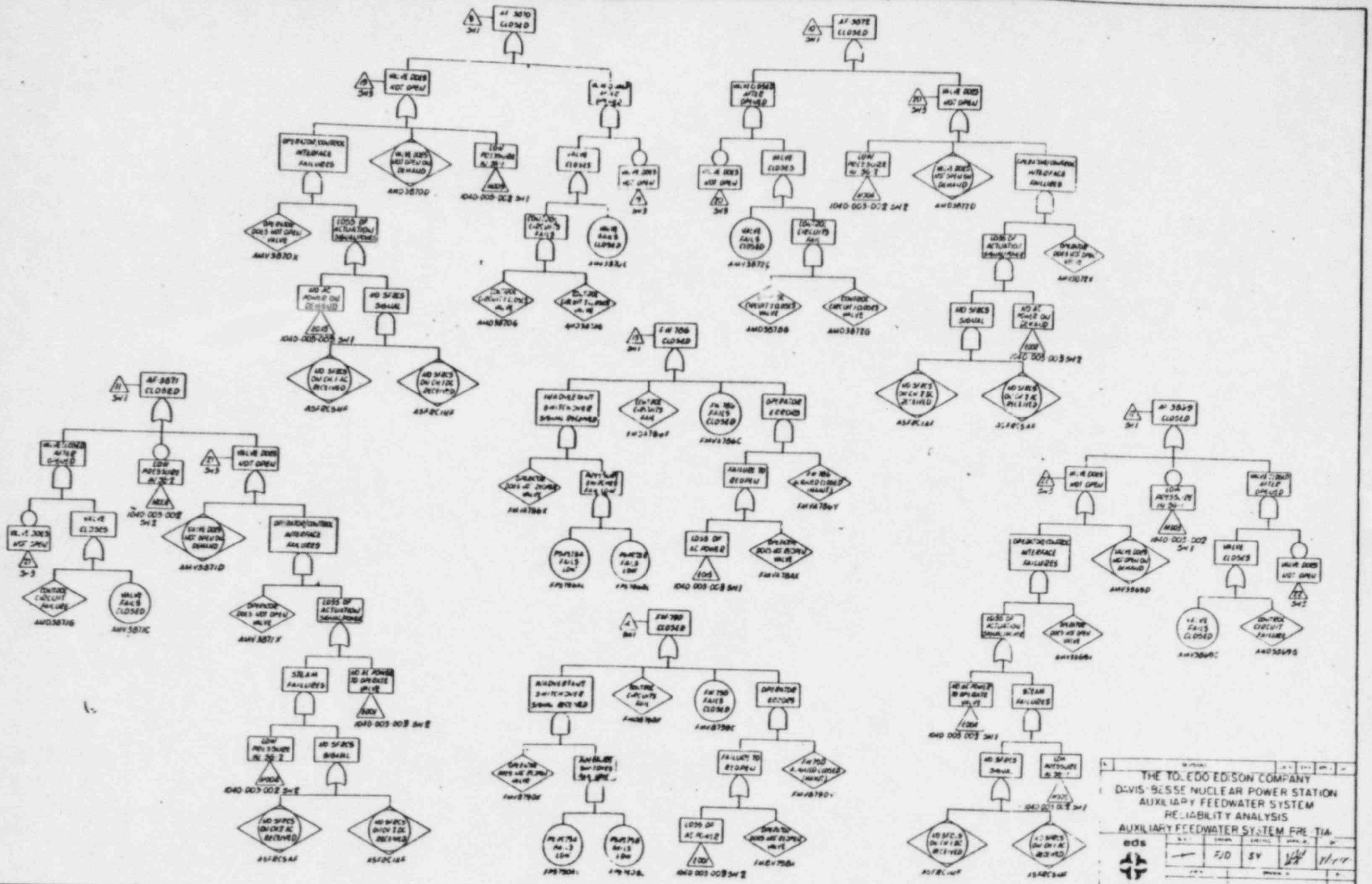

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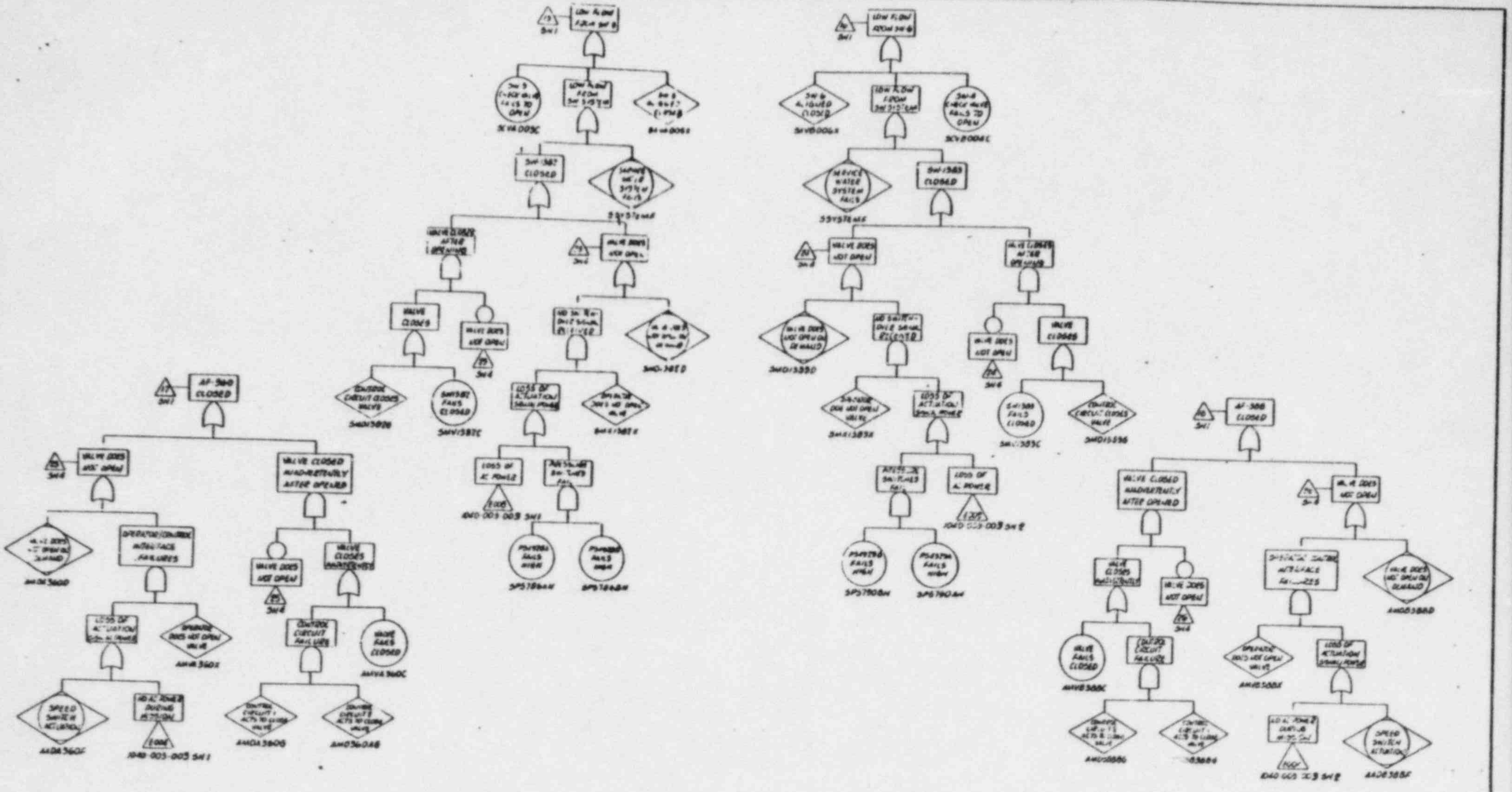

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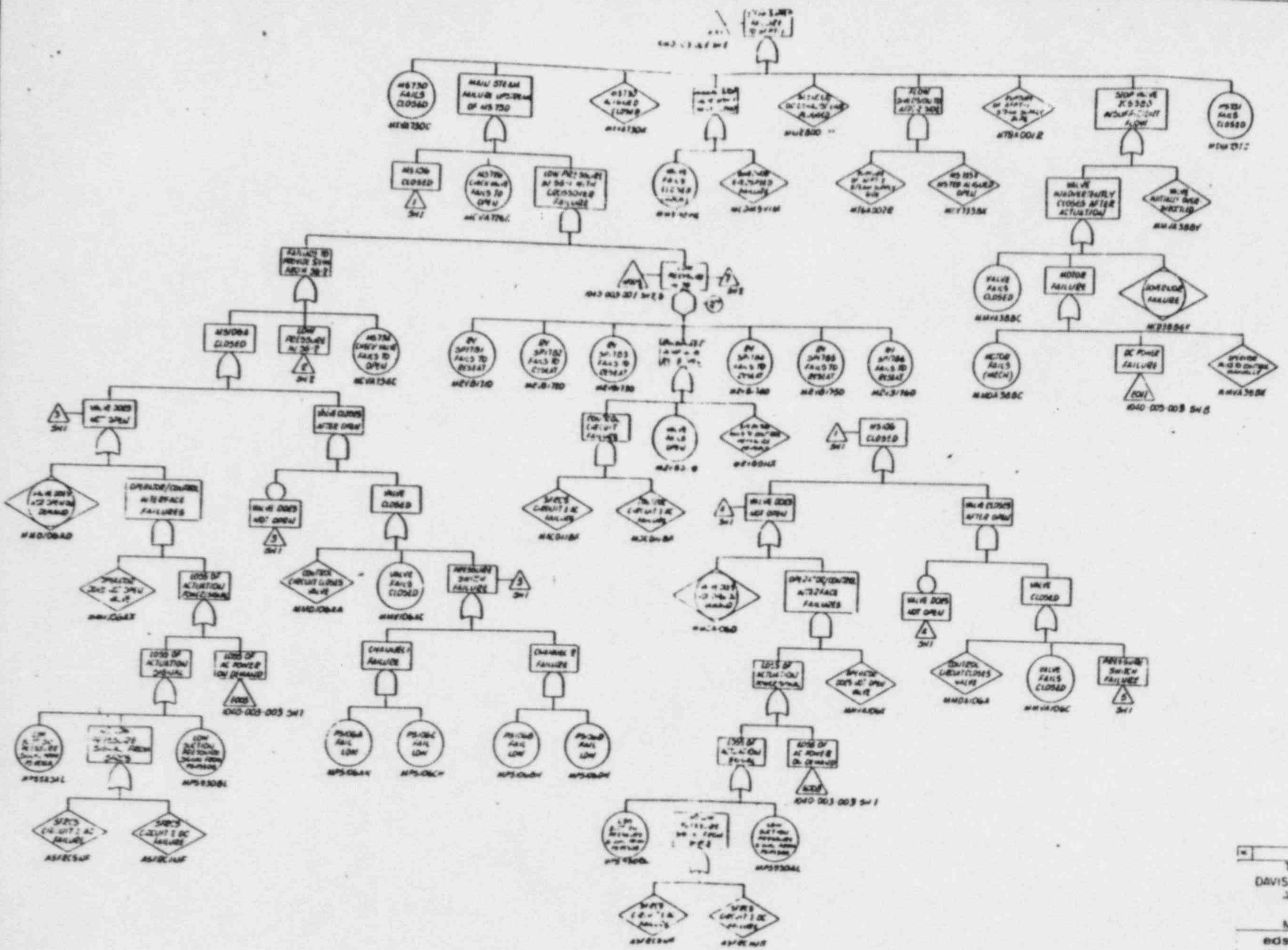

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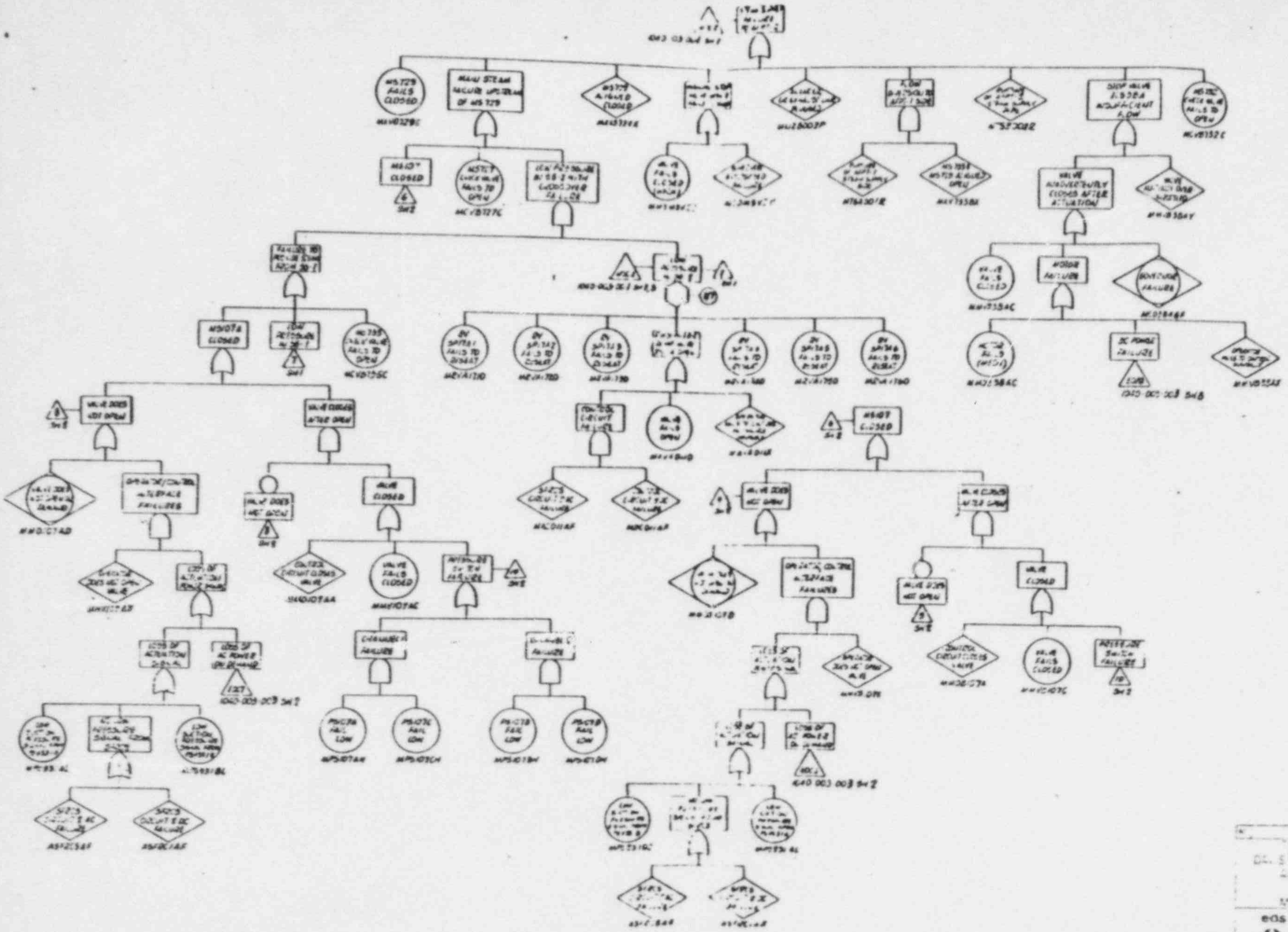

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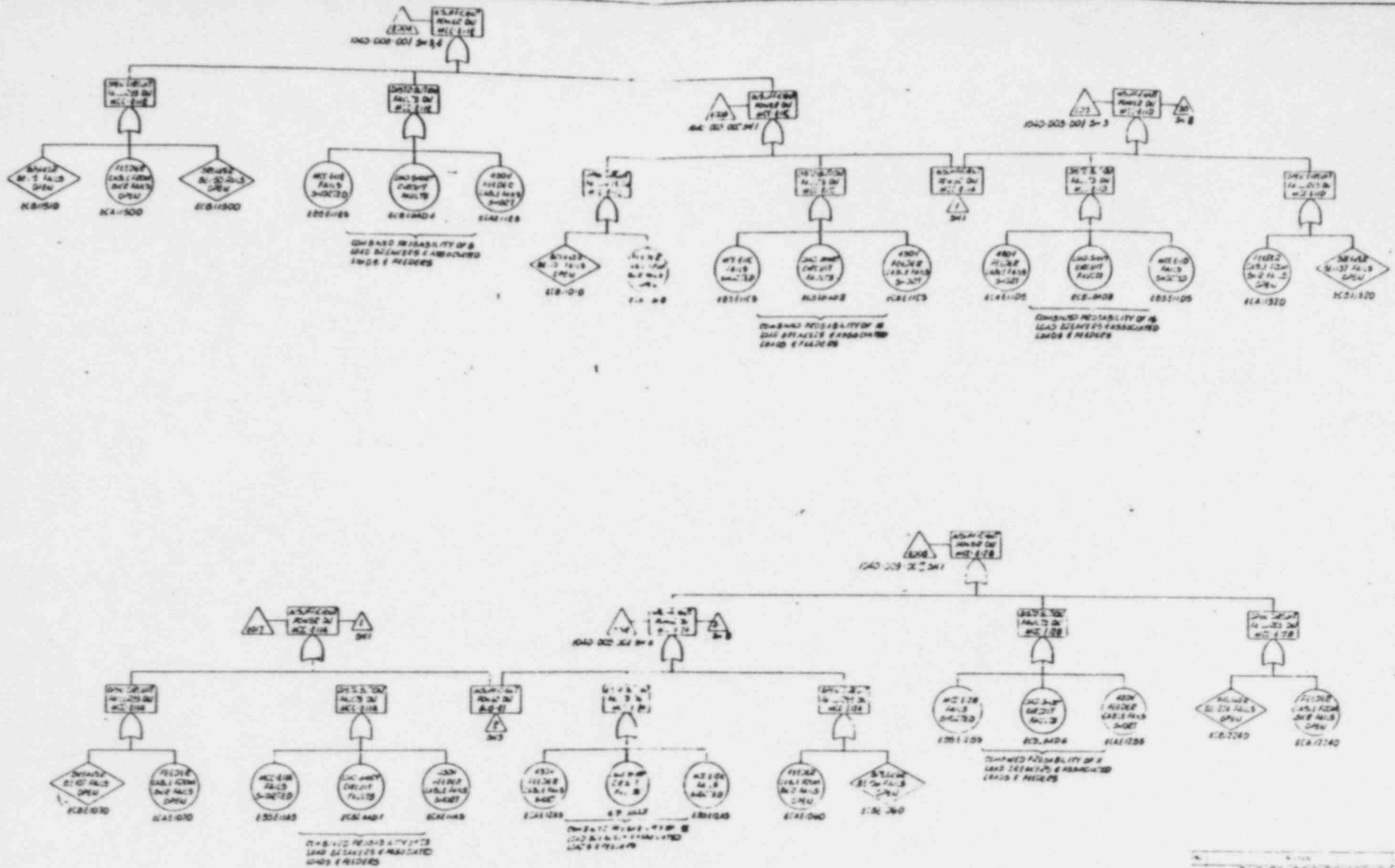

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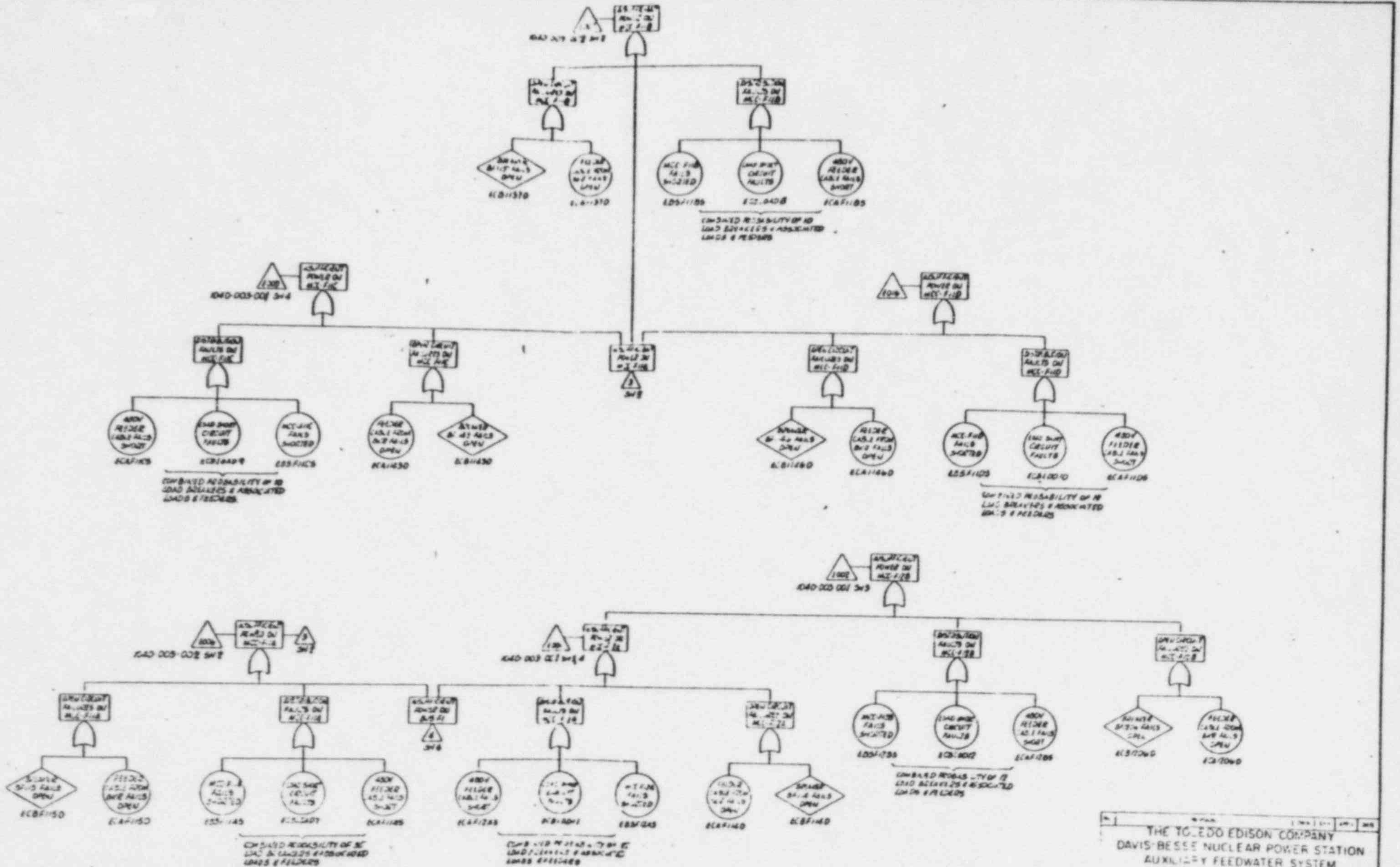

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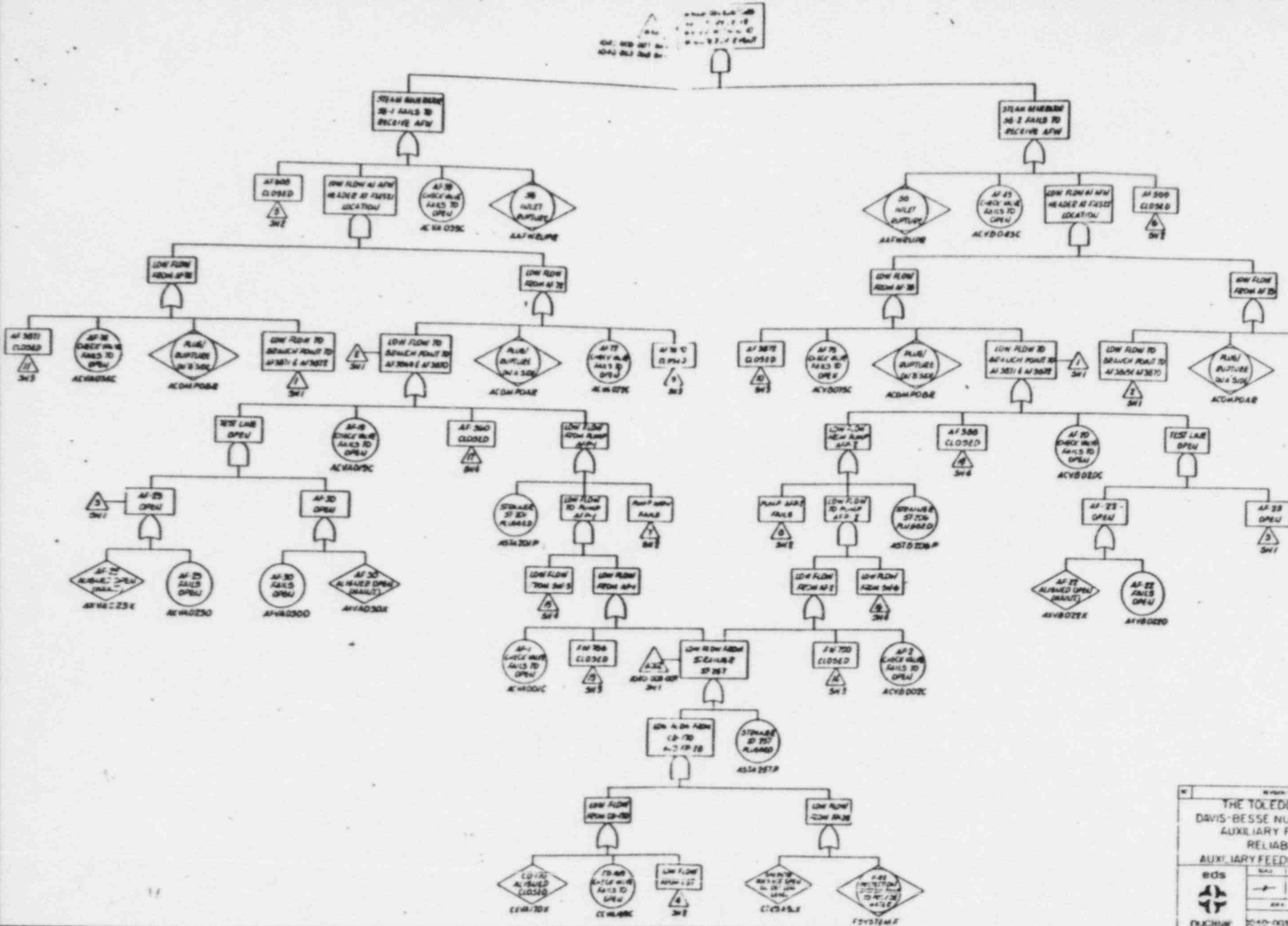

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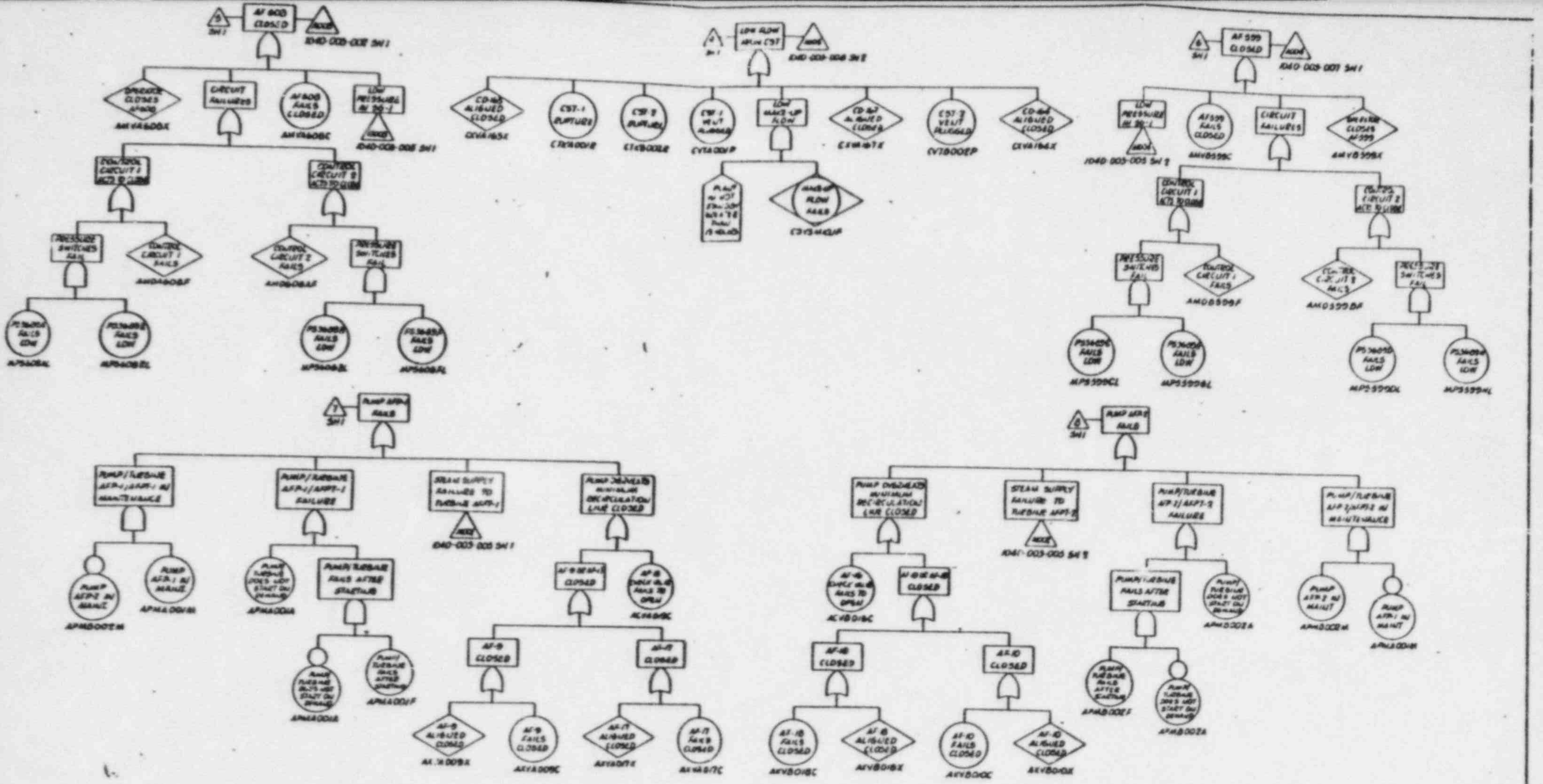

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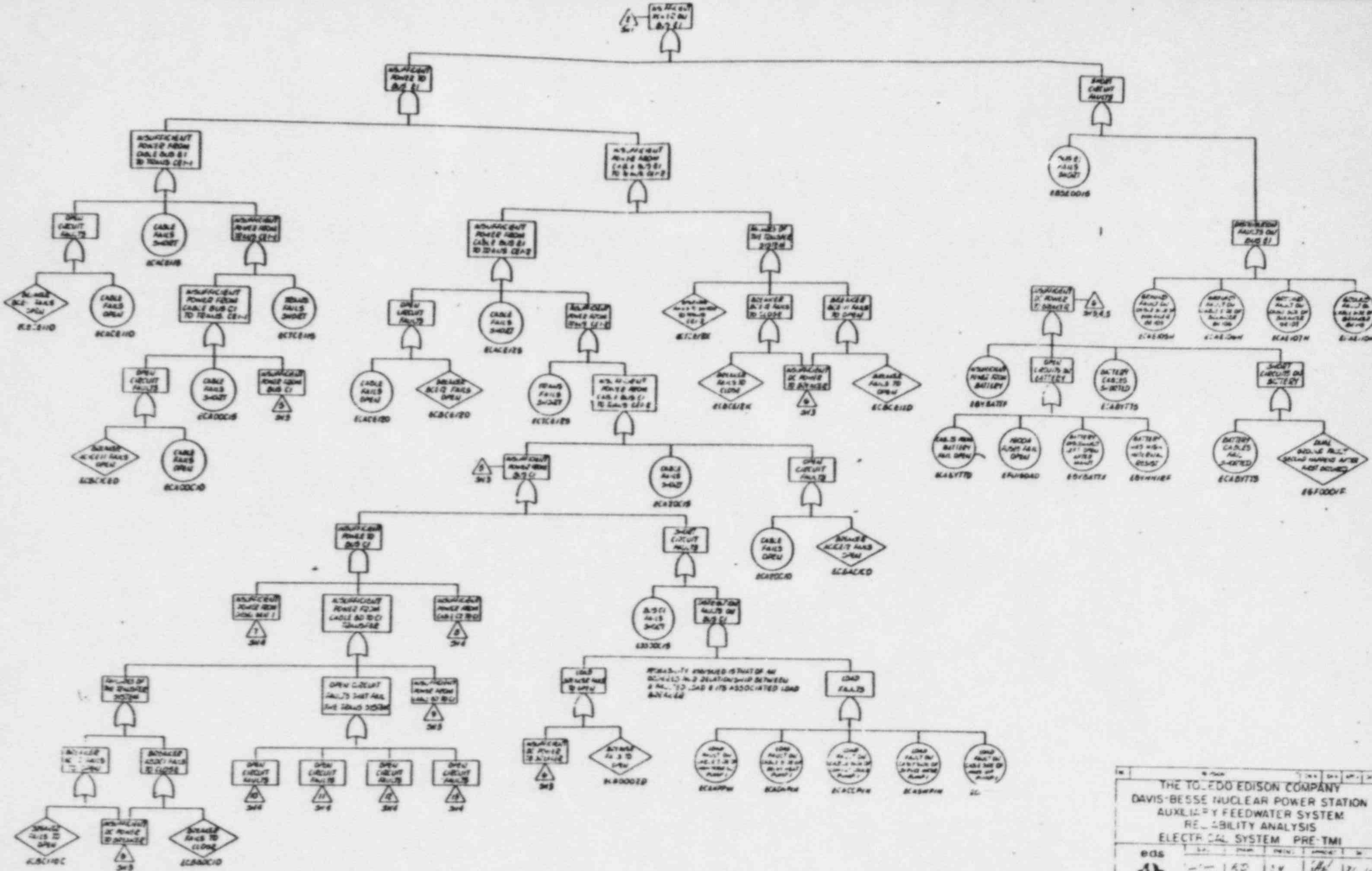

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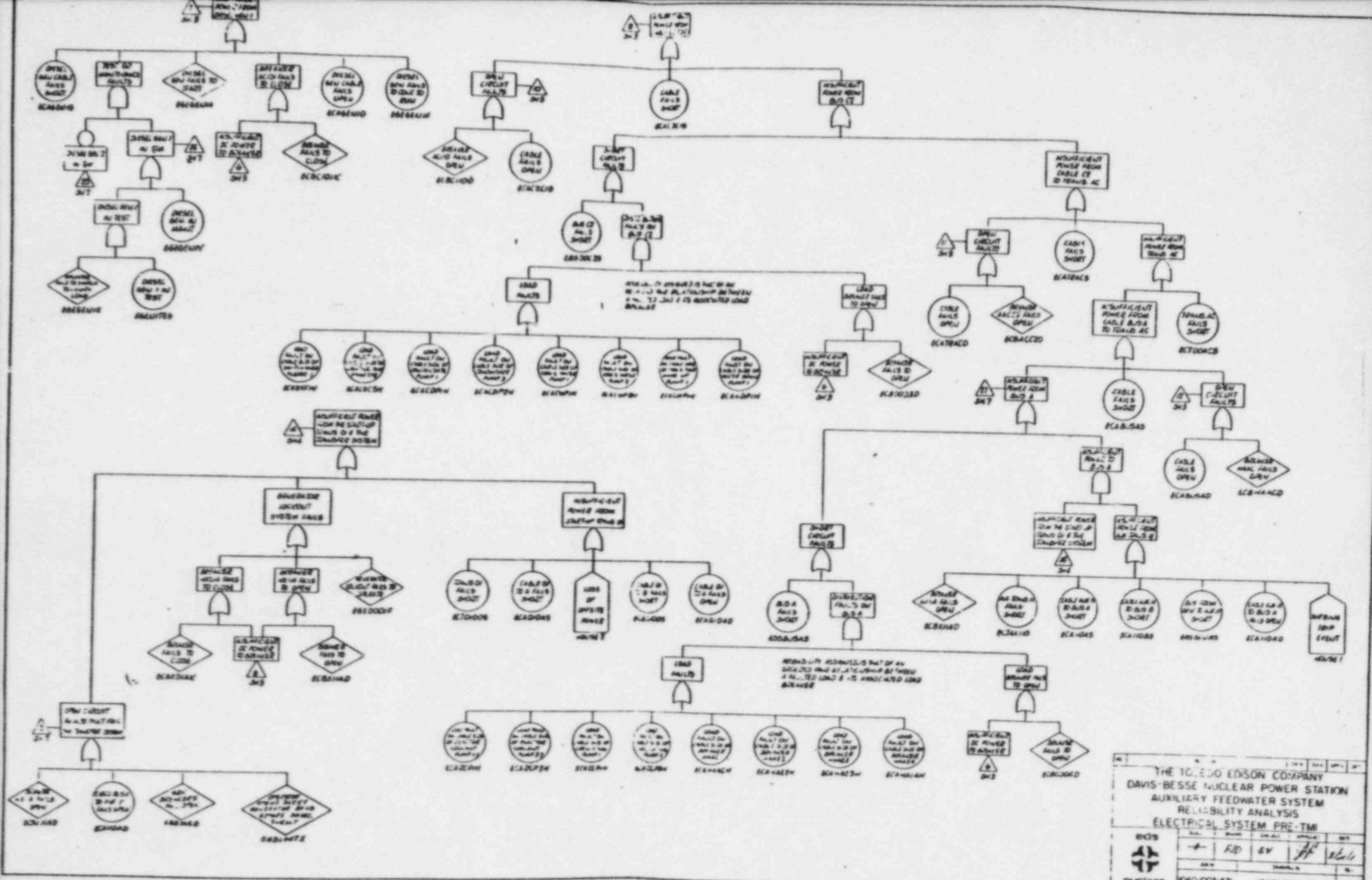

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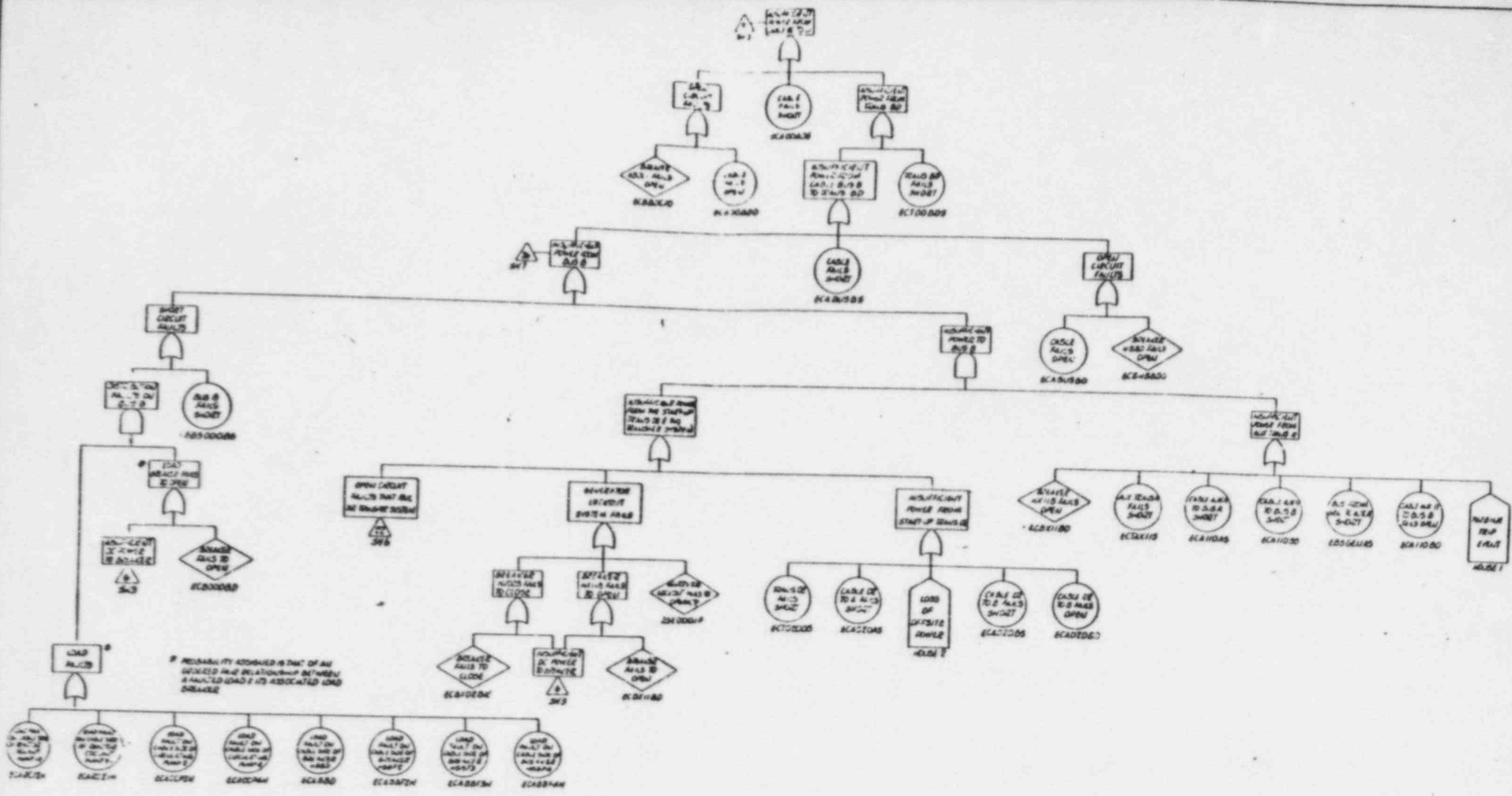

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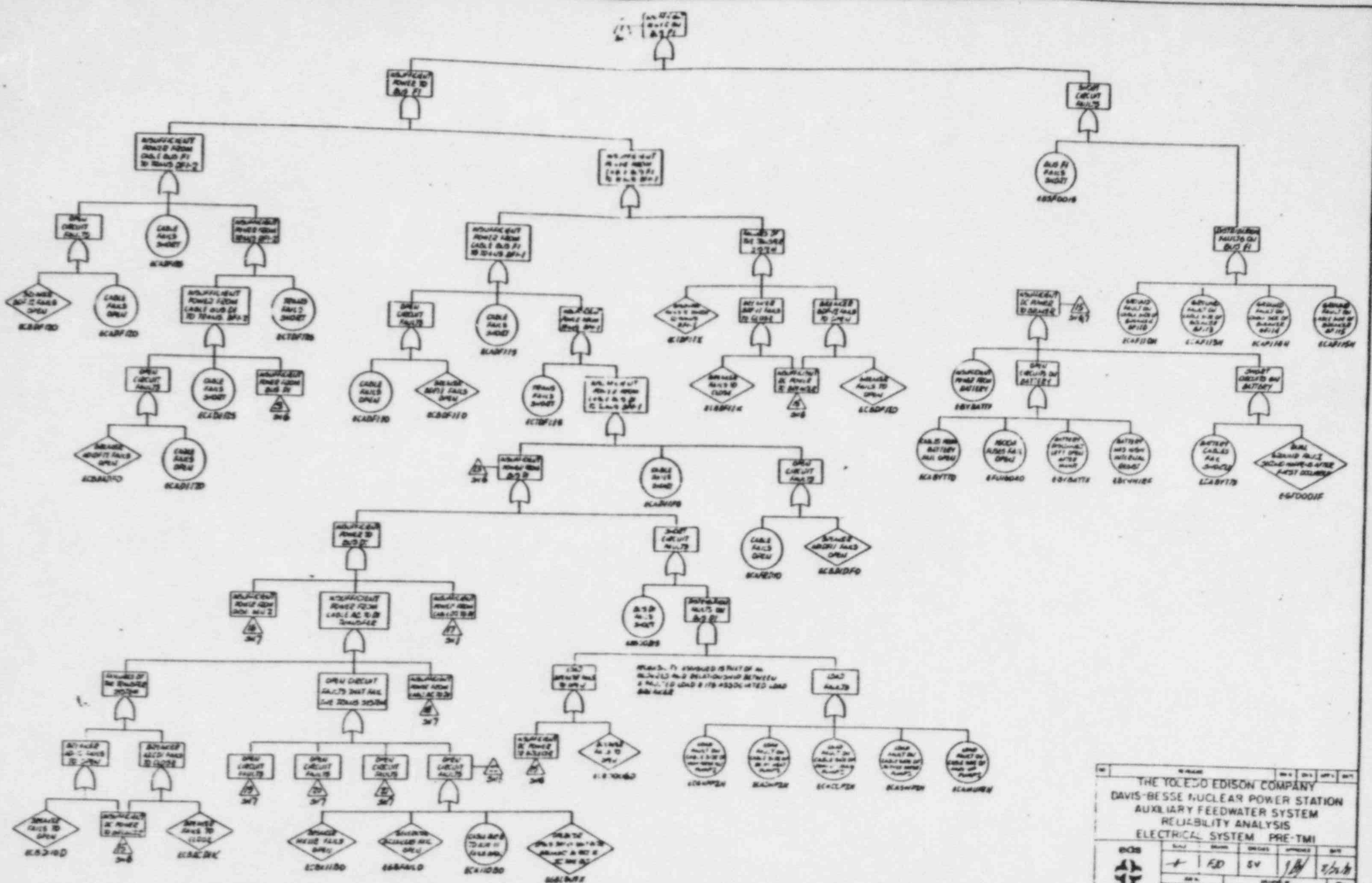

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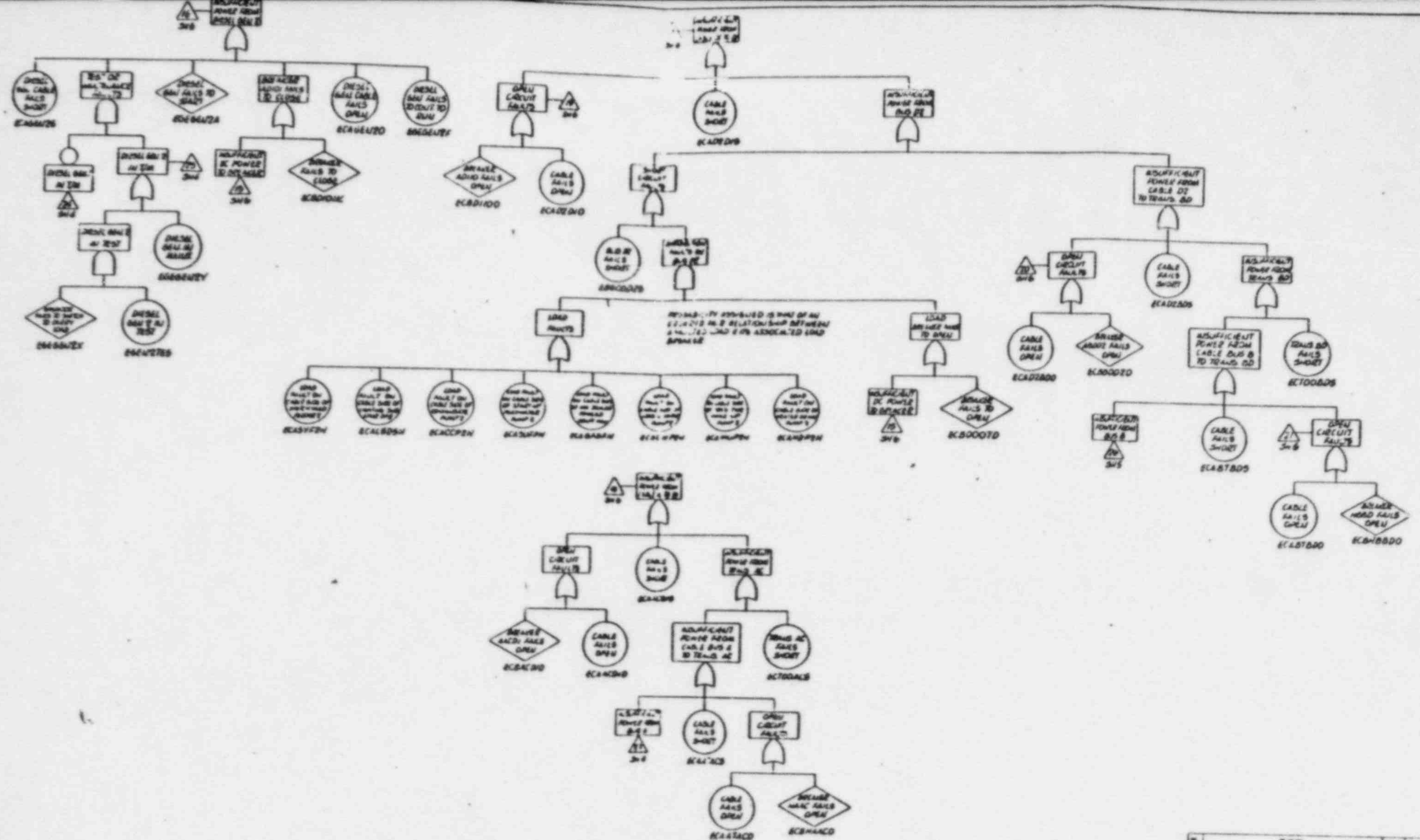

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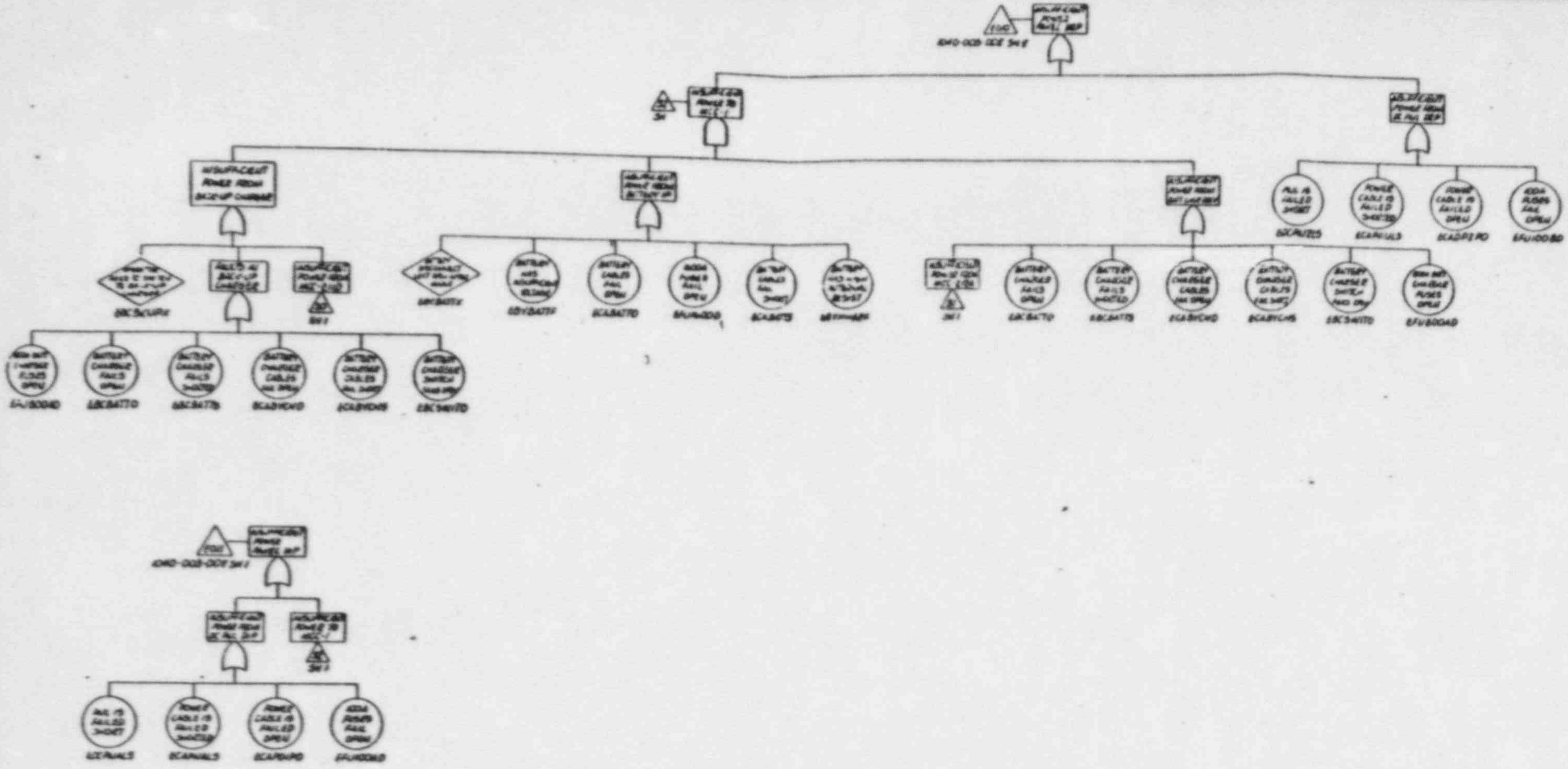

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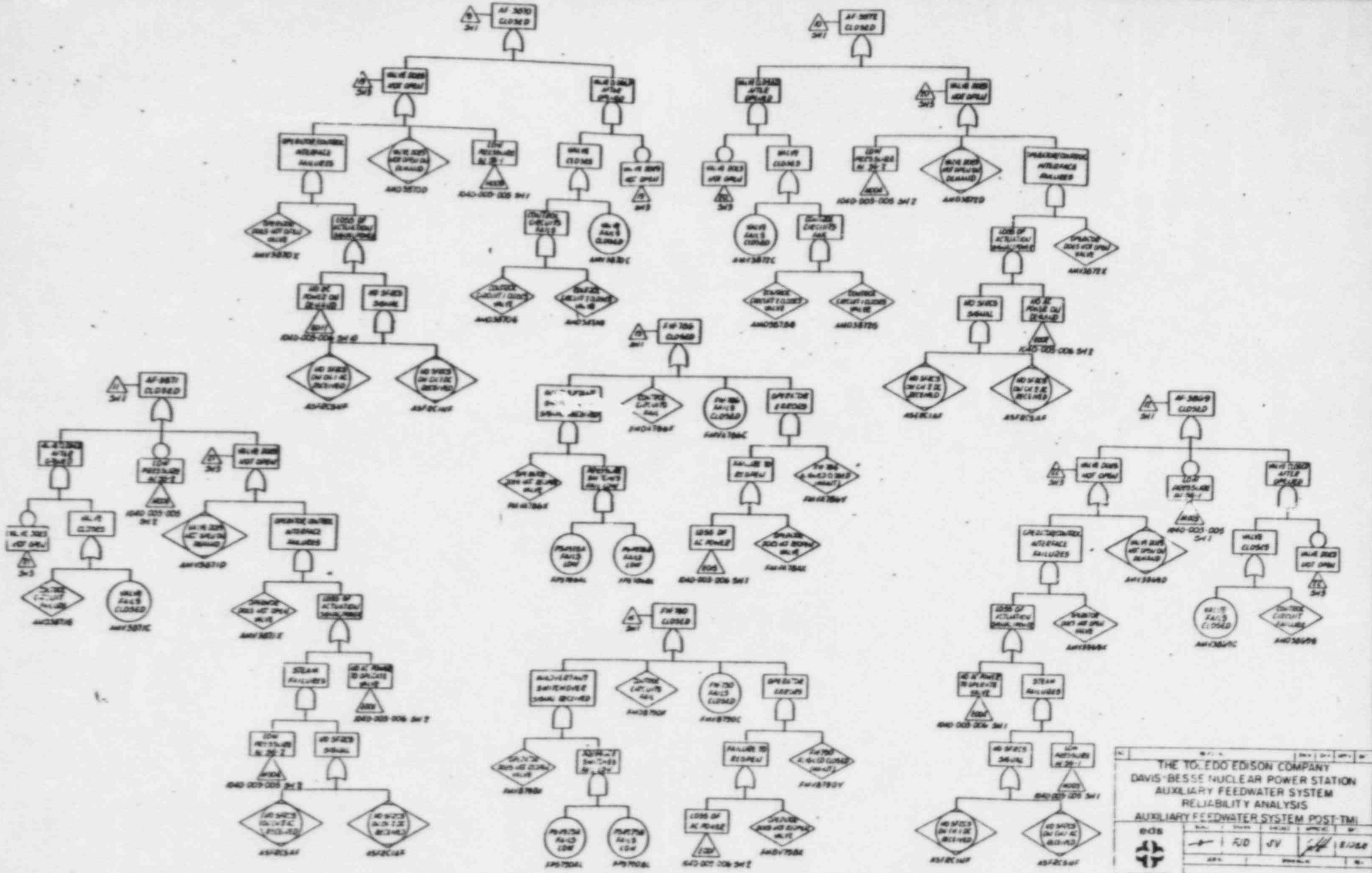

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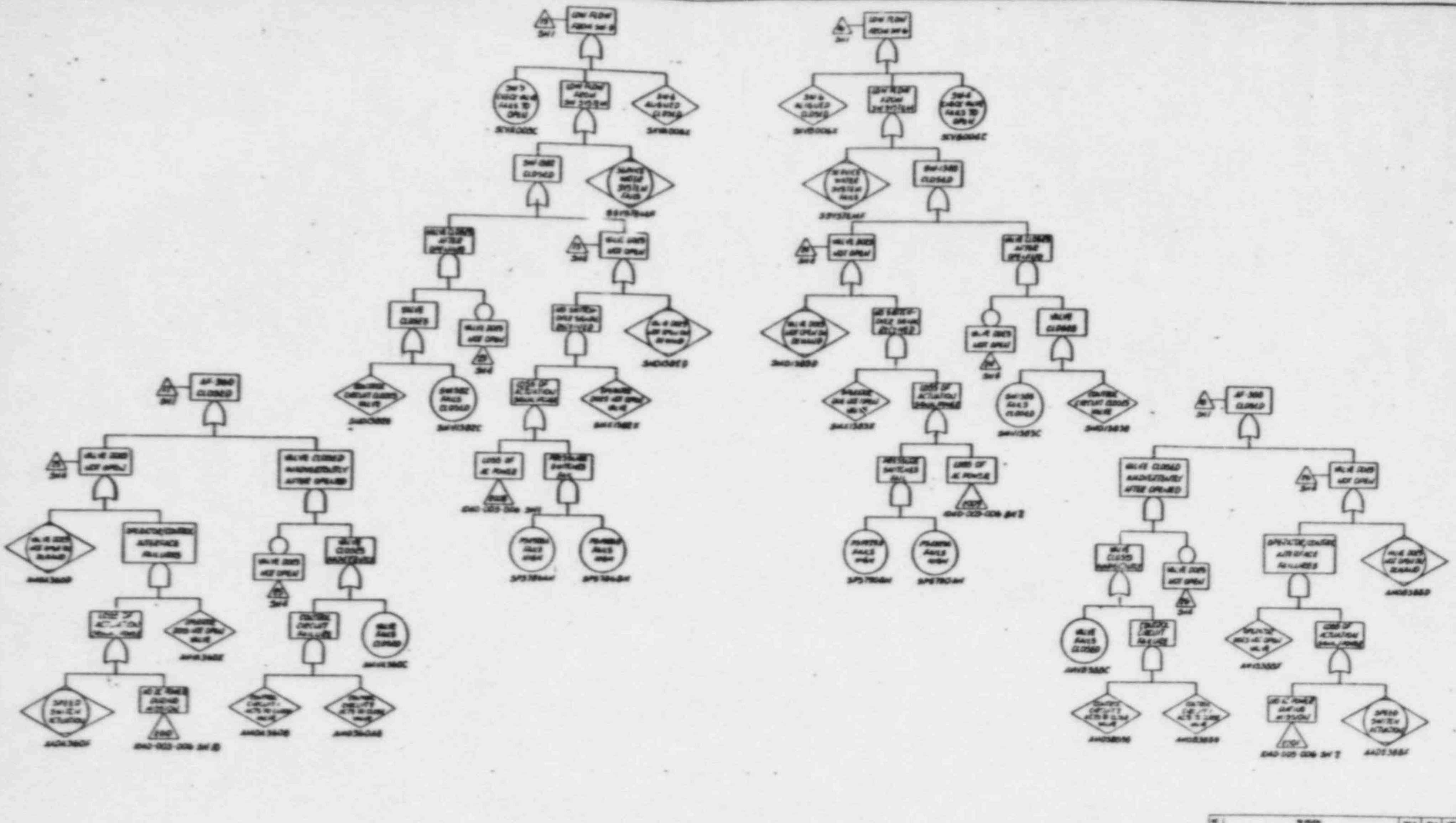

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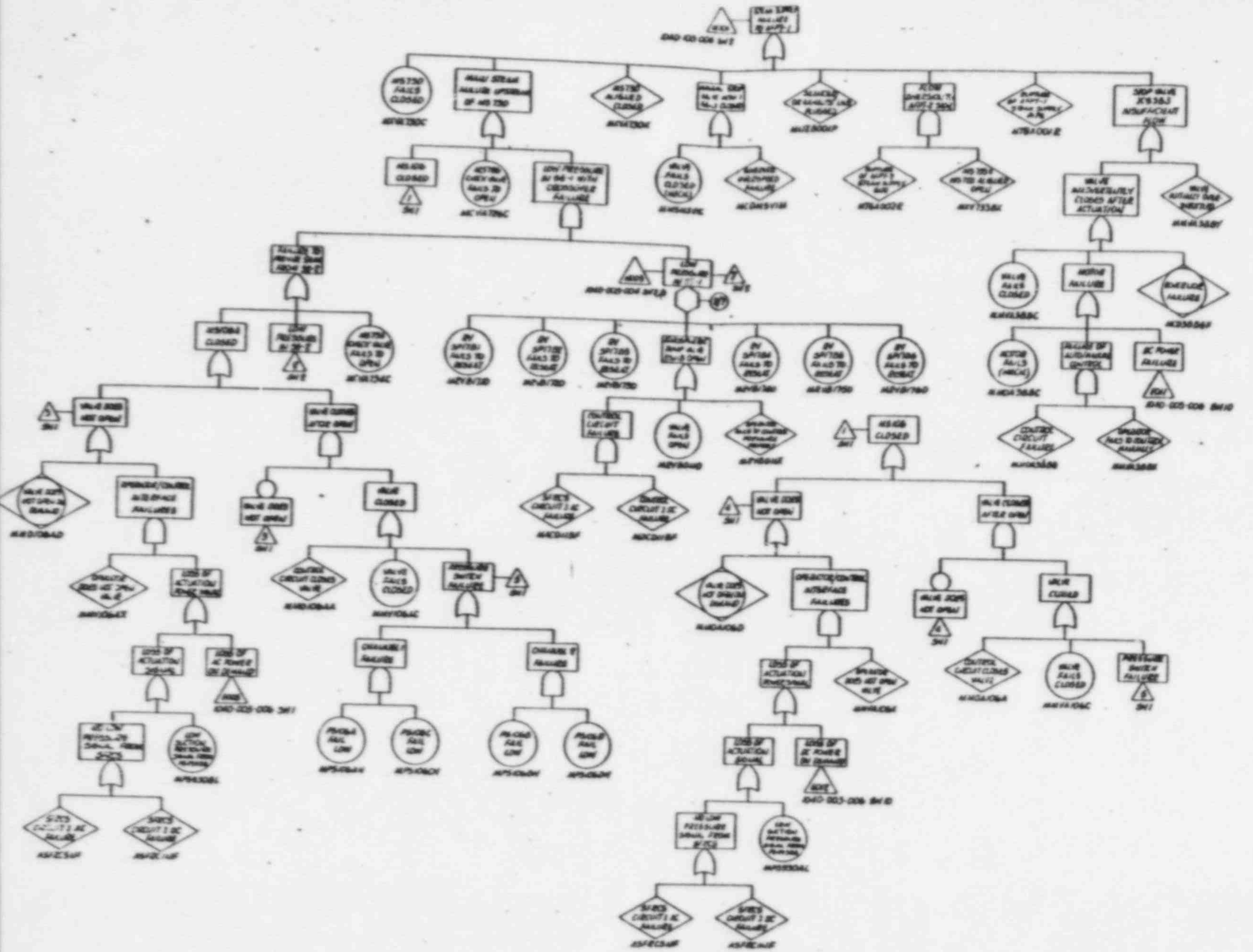

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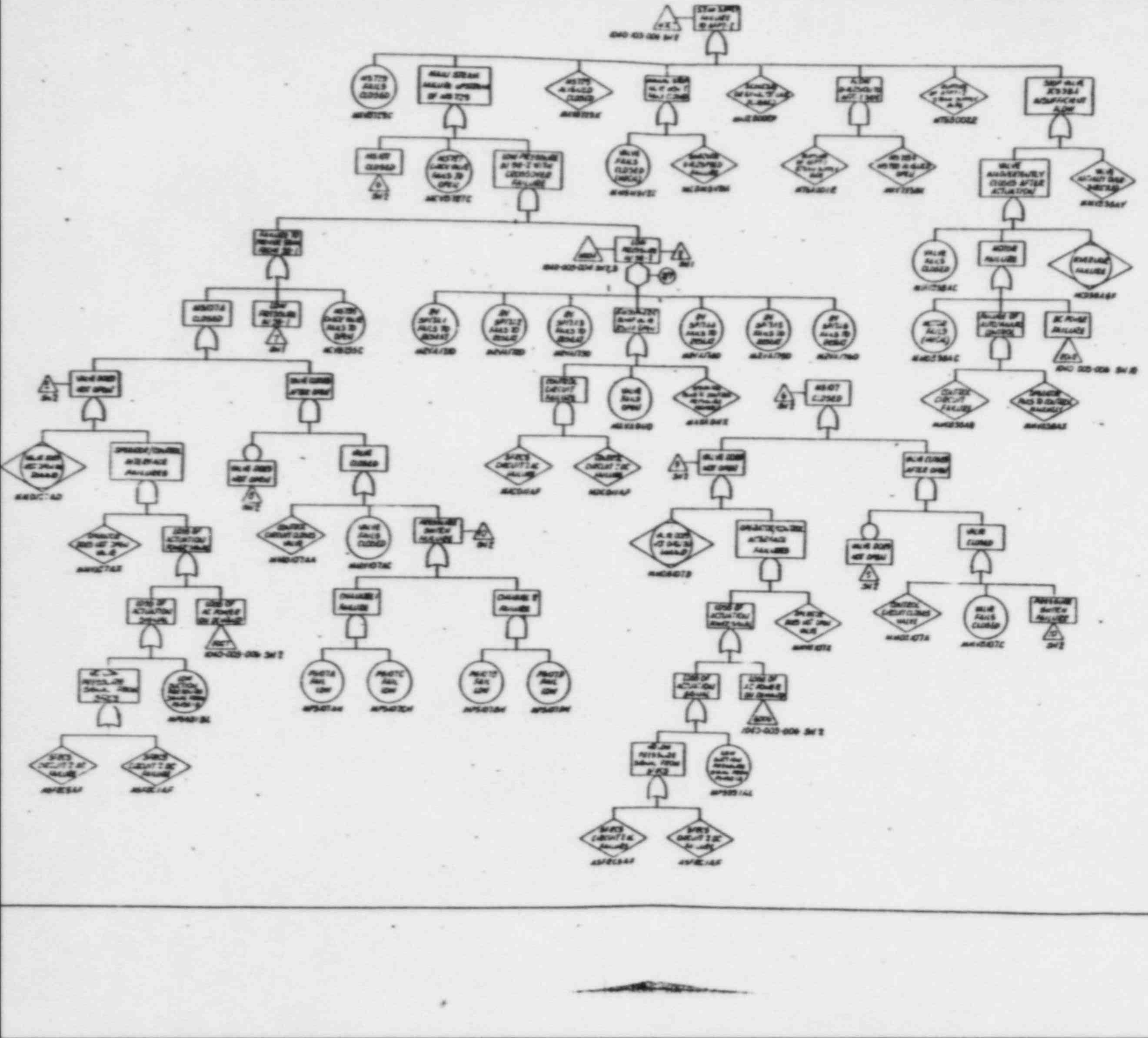

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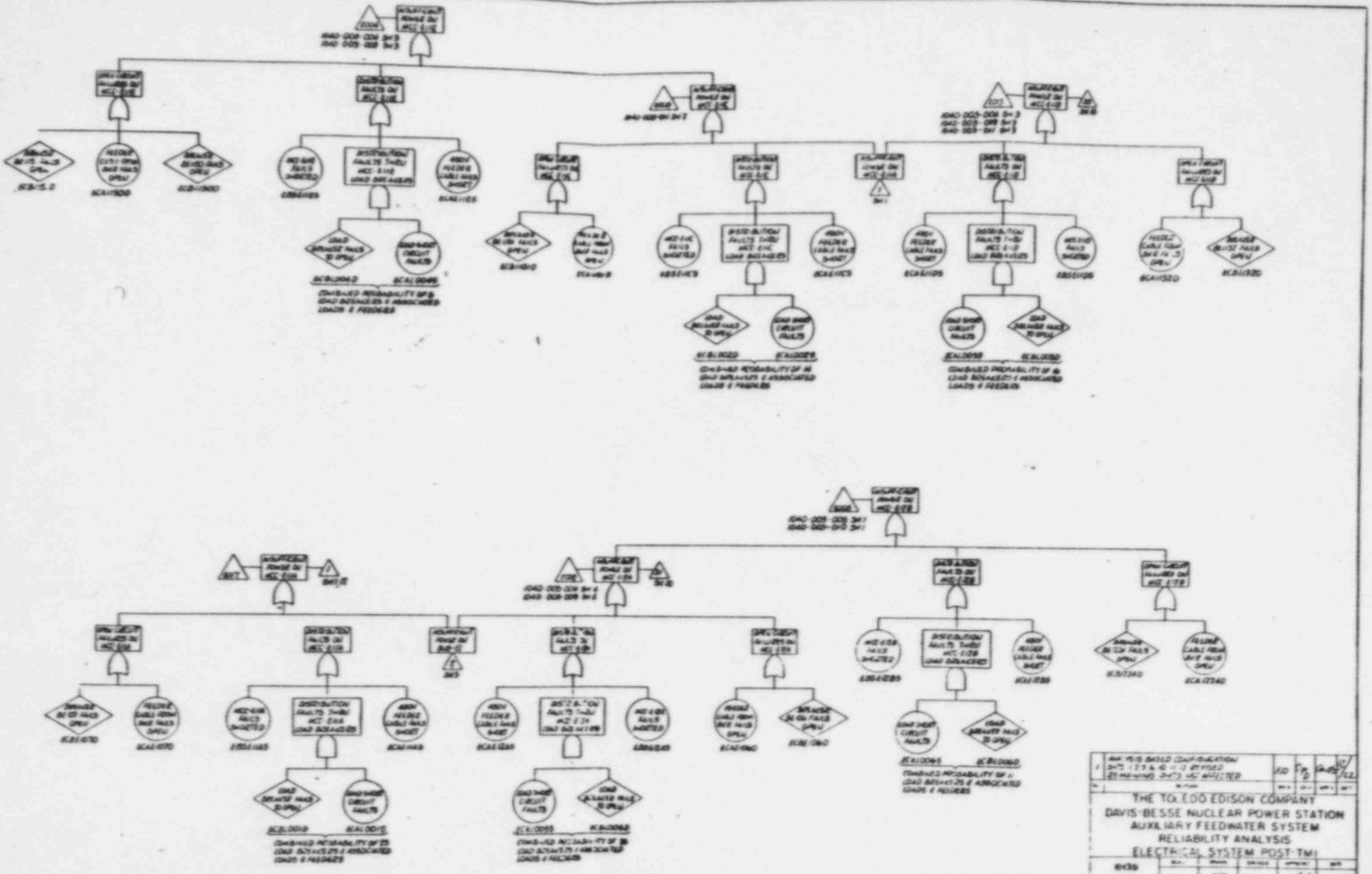

ANALYSIS BASED CONFIGURATION SHTS 1,2,3 & 10 - 12 REVISED REMAINING SHTS NOT AFFECTED

THE TOLEDO EDISON COMPANY
DAVIS-BESSE NUCLEAR POWER STATION
AUXILIARY FEEDWATER SYSTEM
RELIABILITY ANALYSIS
ELECTRICAL SYSTEM POST-TMI

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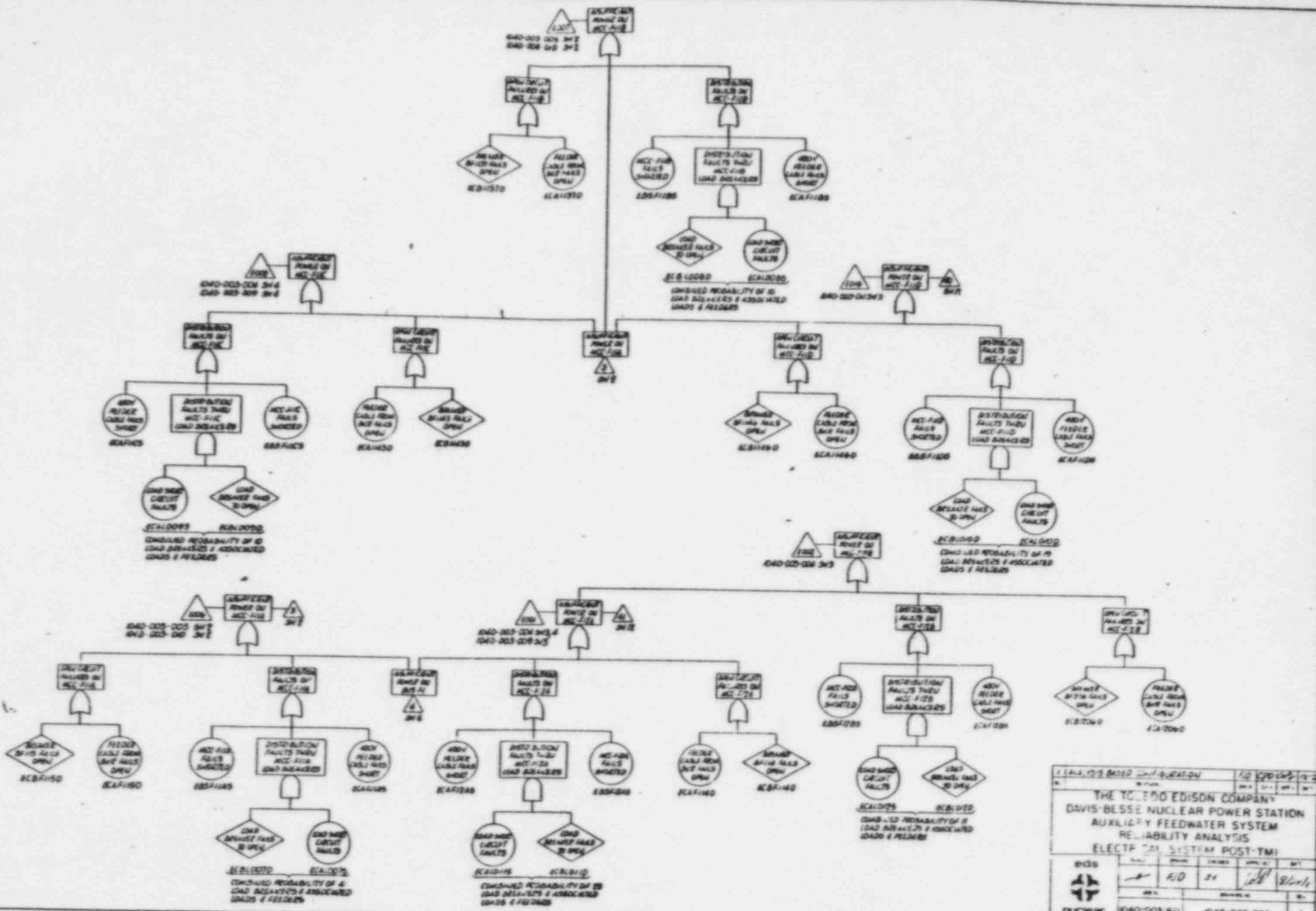

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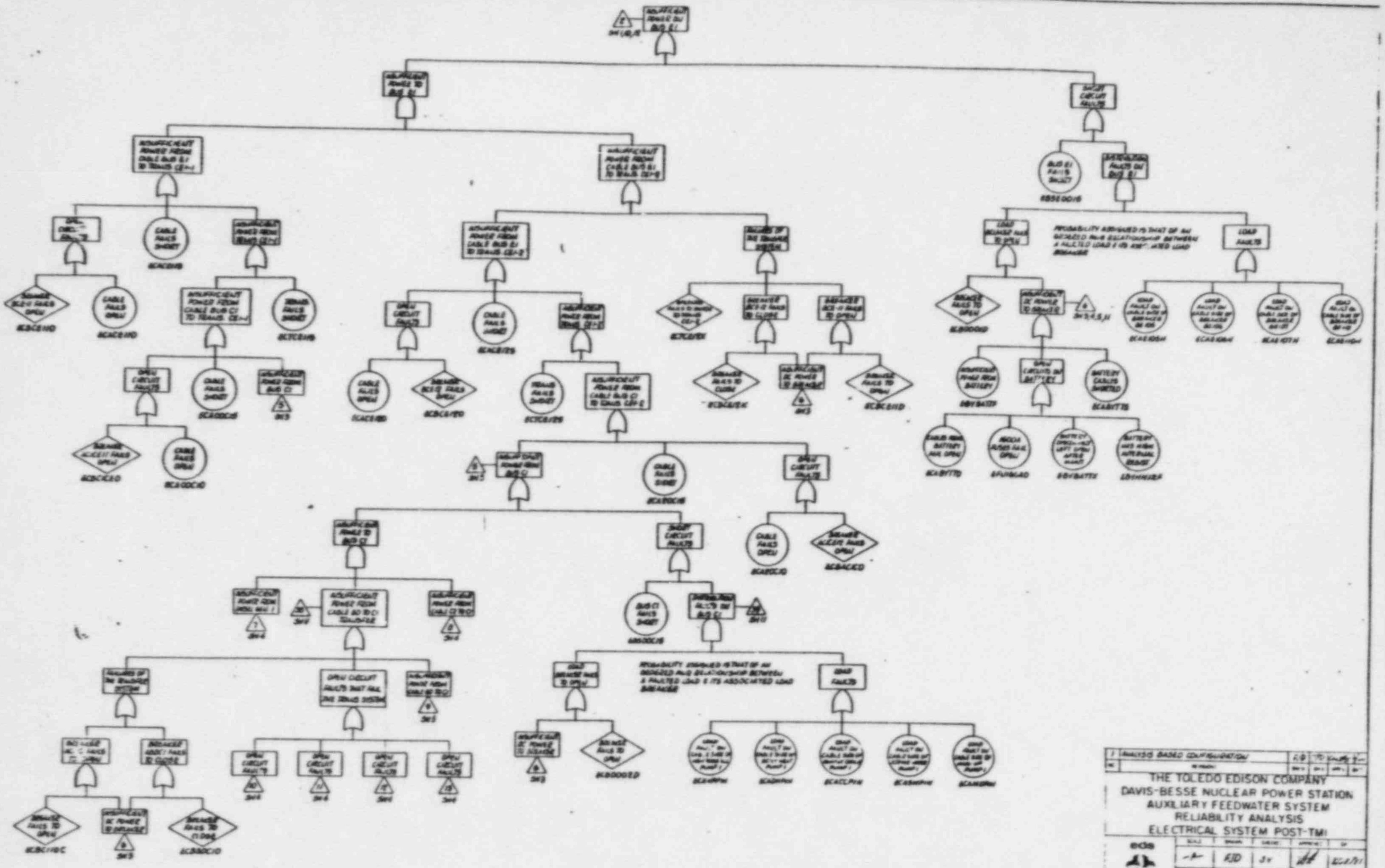

1	ANALYSIS BASED CONFIGURATION			

THE TOLEDO EDISON COMPANY
DAVIS-BESSE NUCLEAR POWER STATION
AUXILIARY FEEDWATER SYSTEM
RELIABILITY ANALYSIS
ELECTRICAL SYSTEM POST-TMI

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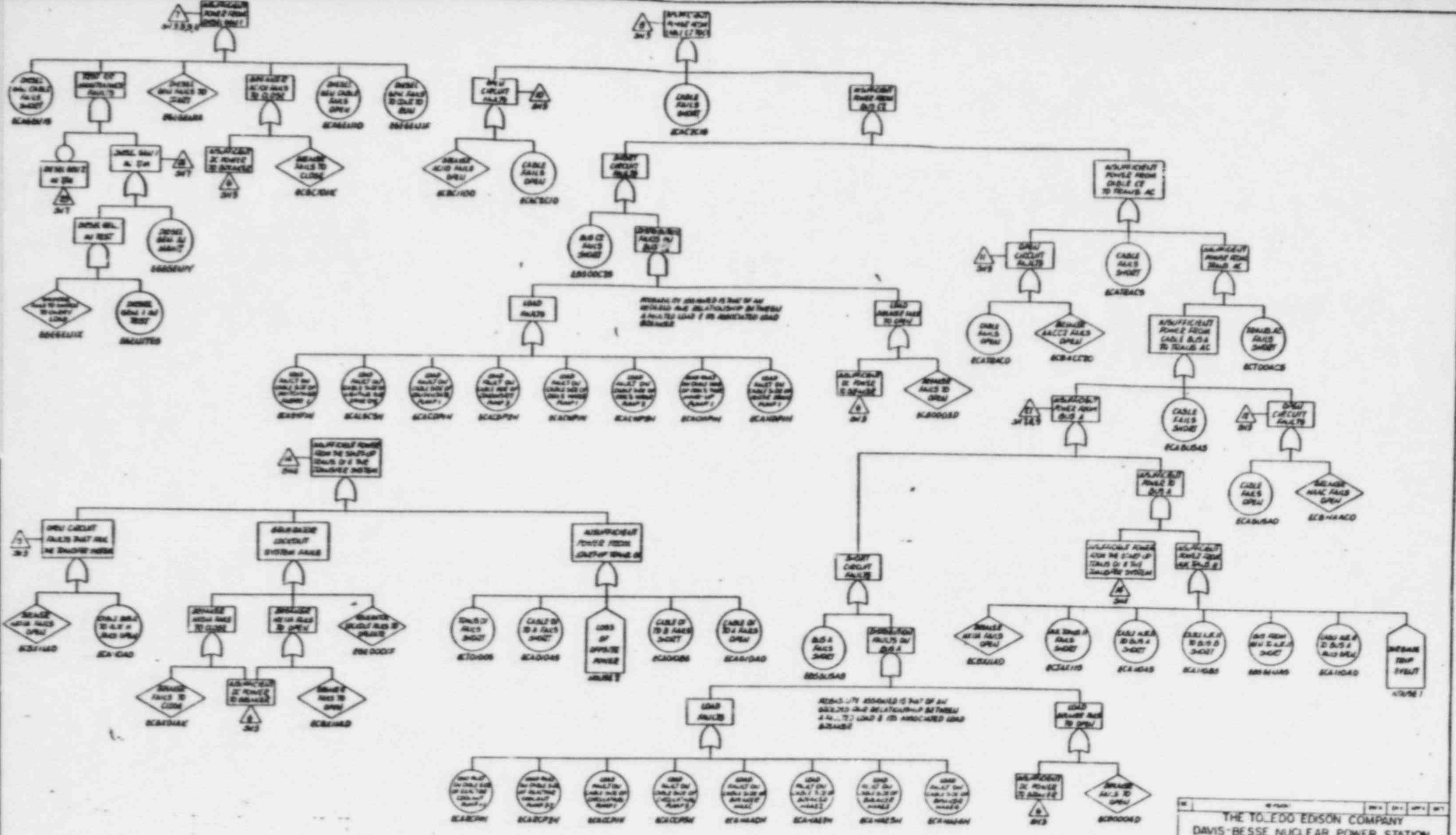

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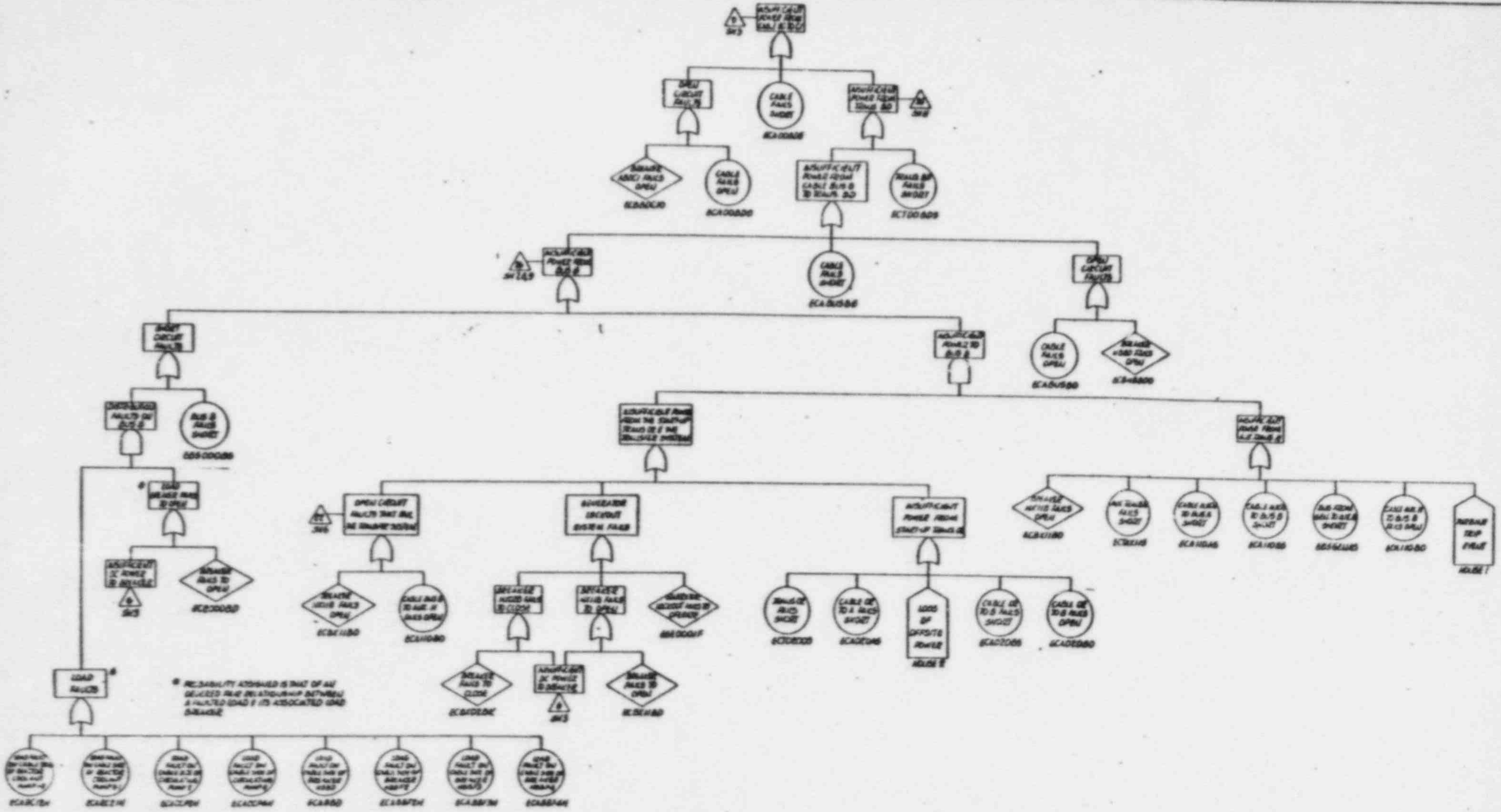

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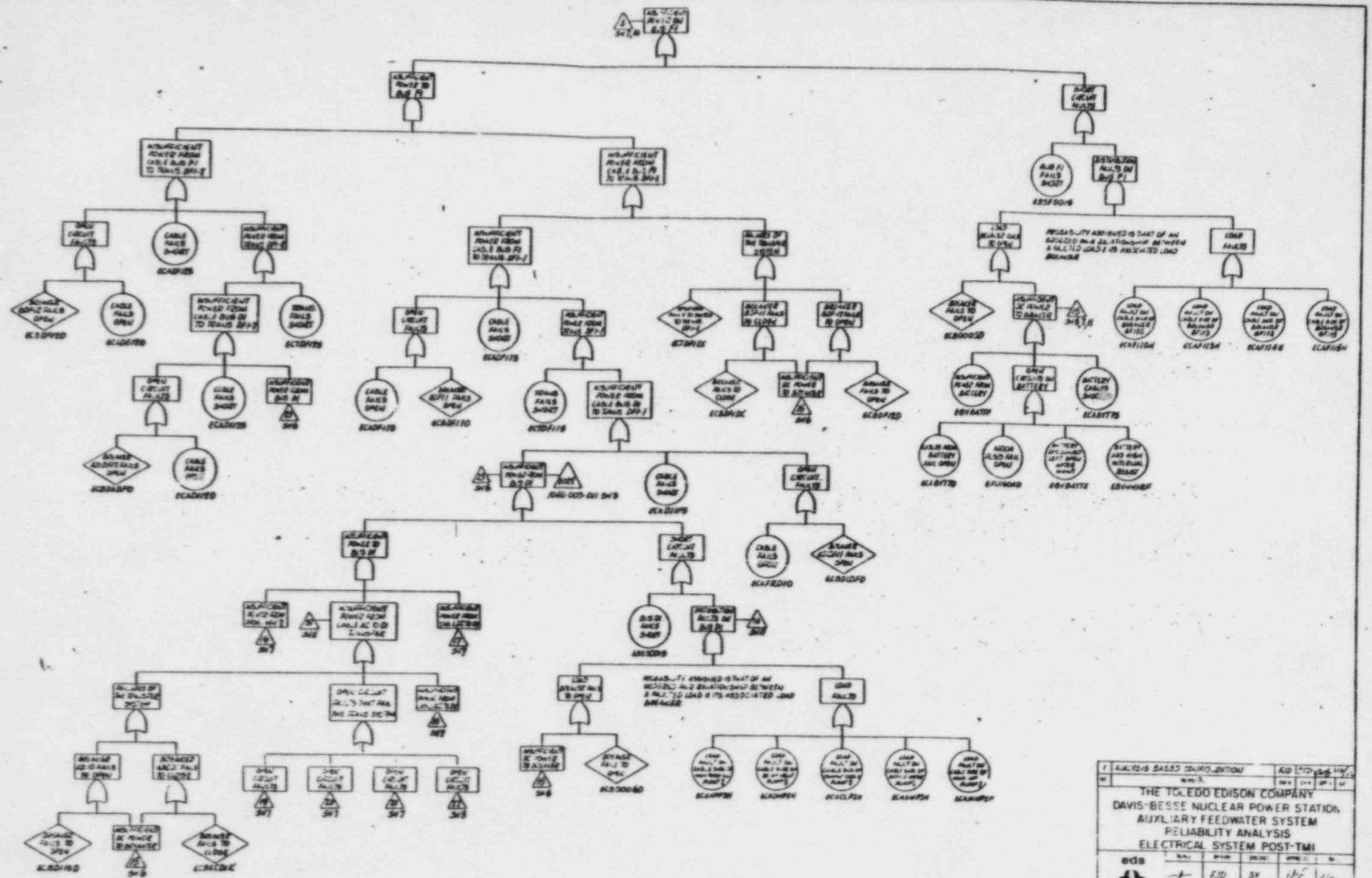


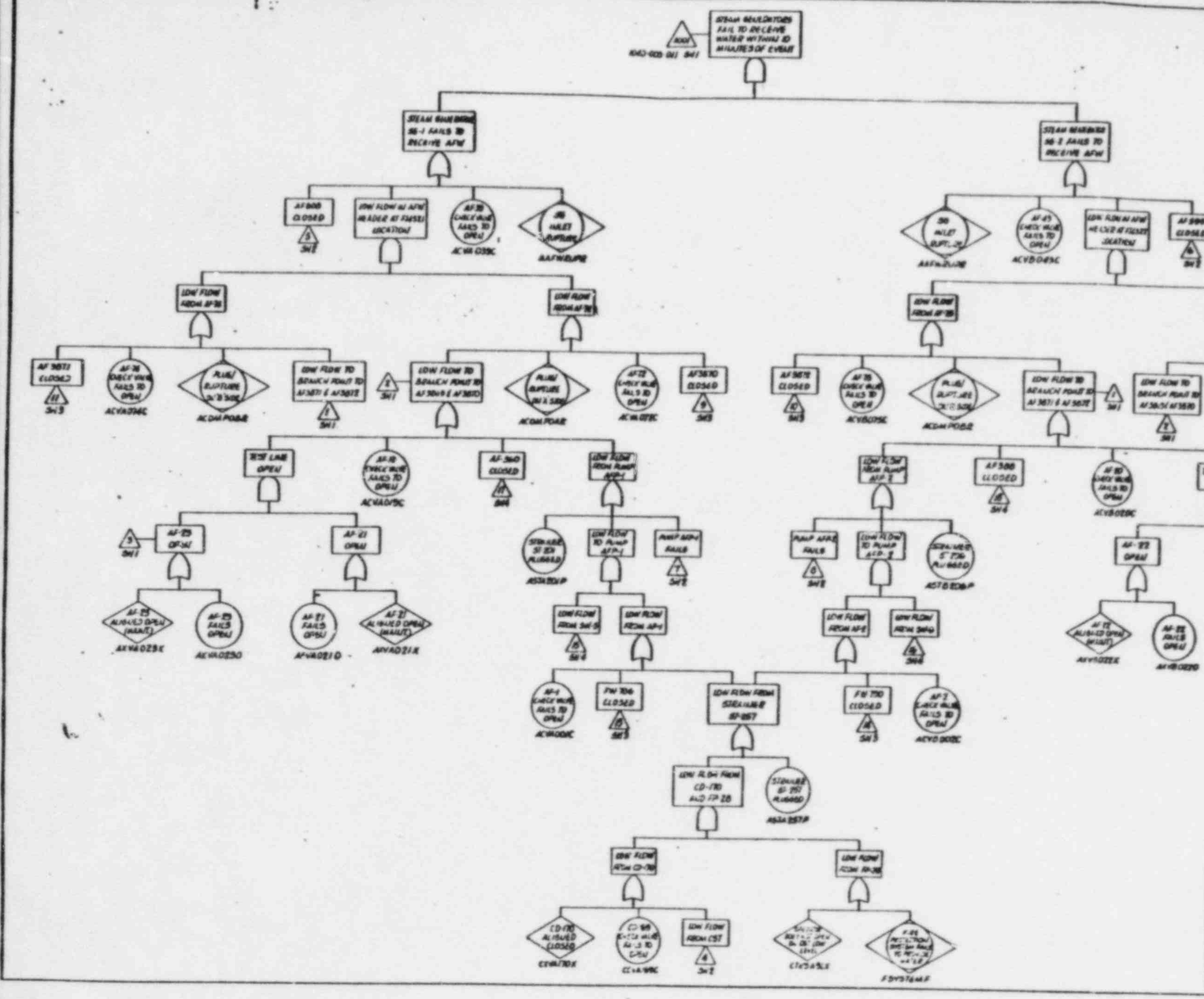
1	ANALYSIS BASED ON REVISION				

THE TOLEDO EDISON COMPANY
DAVIS-BESSE NUCLEAR POWER STATION
AUXILIARY FEEDWATER SYSTEM
RELIABILITY ANALYSIS
ELECTRICAL SYSTEM POST-TMI

eds nuclear

1040-003-671 1040-003-006 1

SHEET 5 OF 12



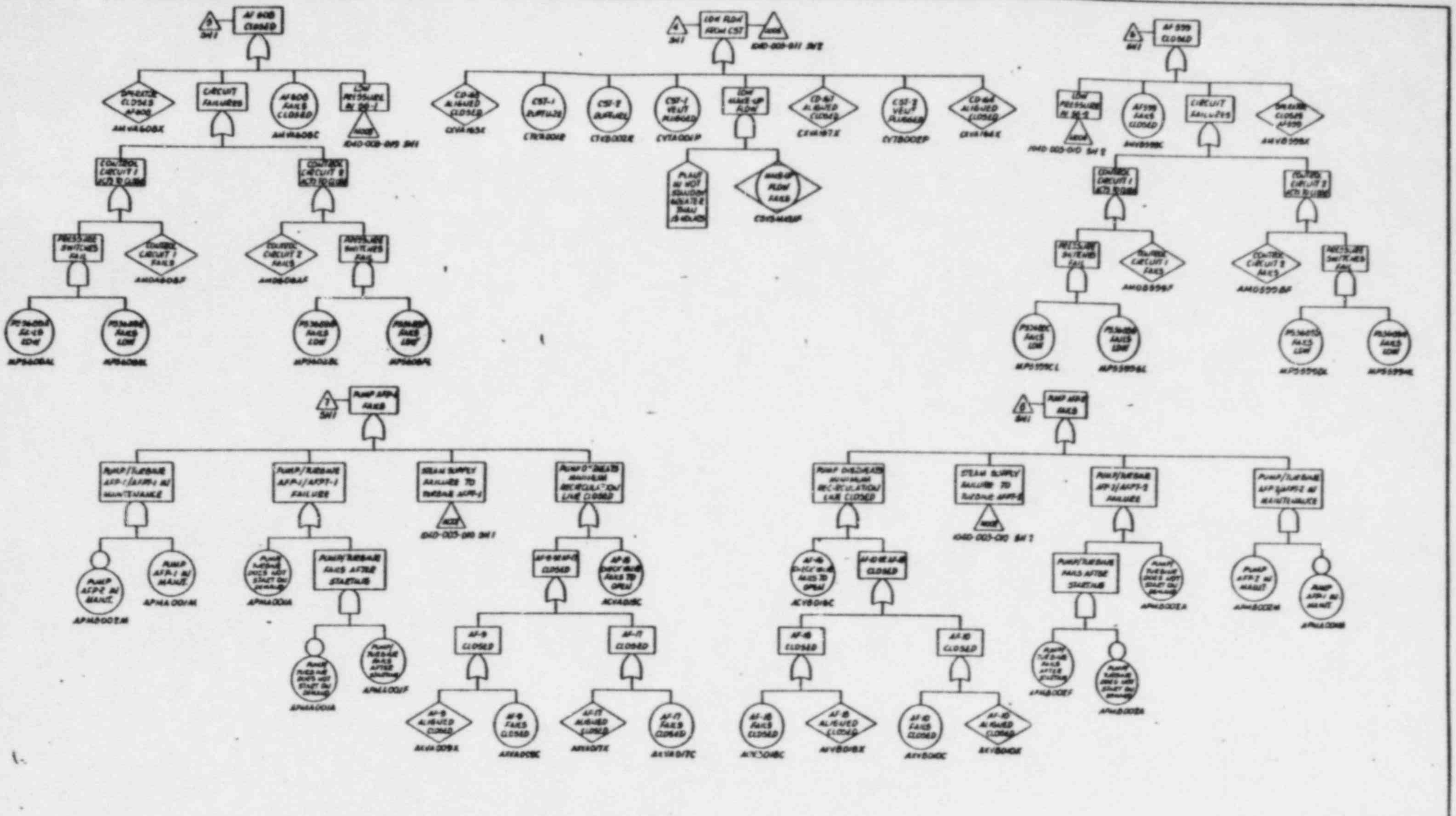
THE TOLEDO EDISON COMPANY
DAVIS-BESSE NUCLEAR POWER STATION
AUXILIARY FEEDWATER SYSTEM
RELIABILITY ANALYSIS
ANALYSIS BASED CONFIGURATION

eds nuclear

SCALE	DRAWN	CHECKED	APPROVED	DATE
—	FJD	SV	[illegible]	12-22-81

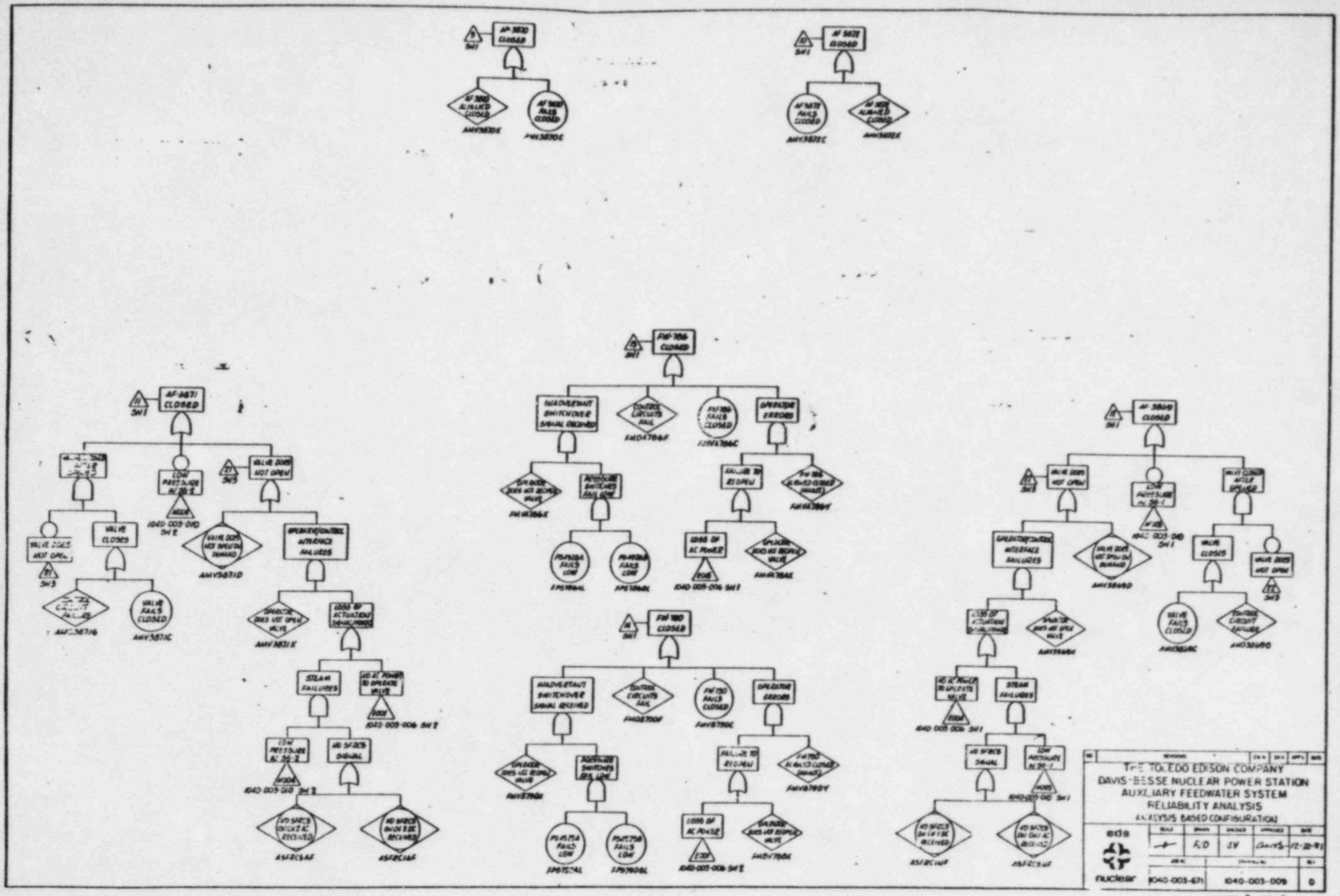
1040-003-671 | 1040-003-009 | 0

SHEET 1 OF 4

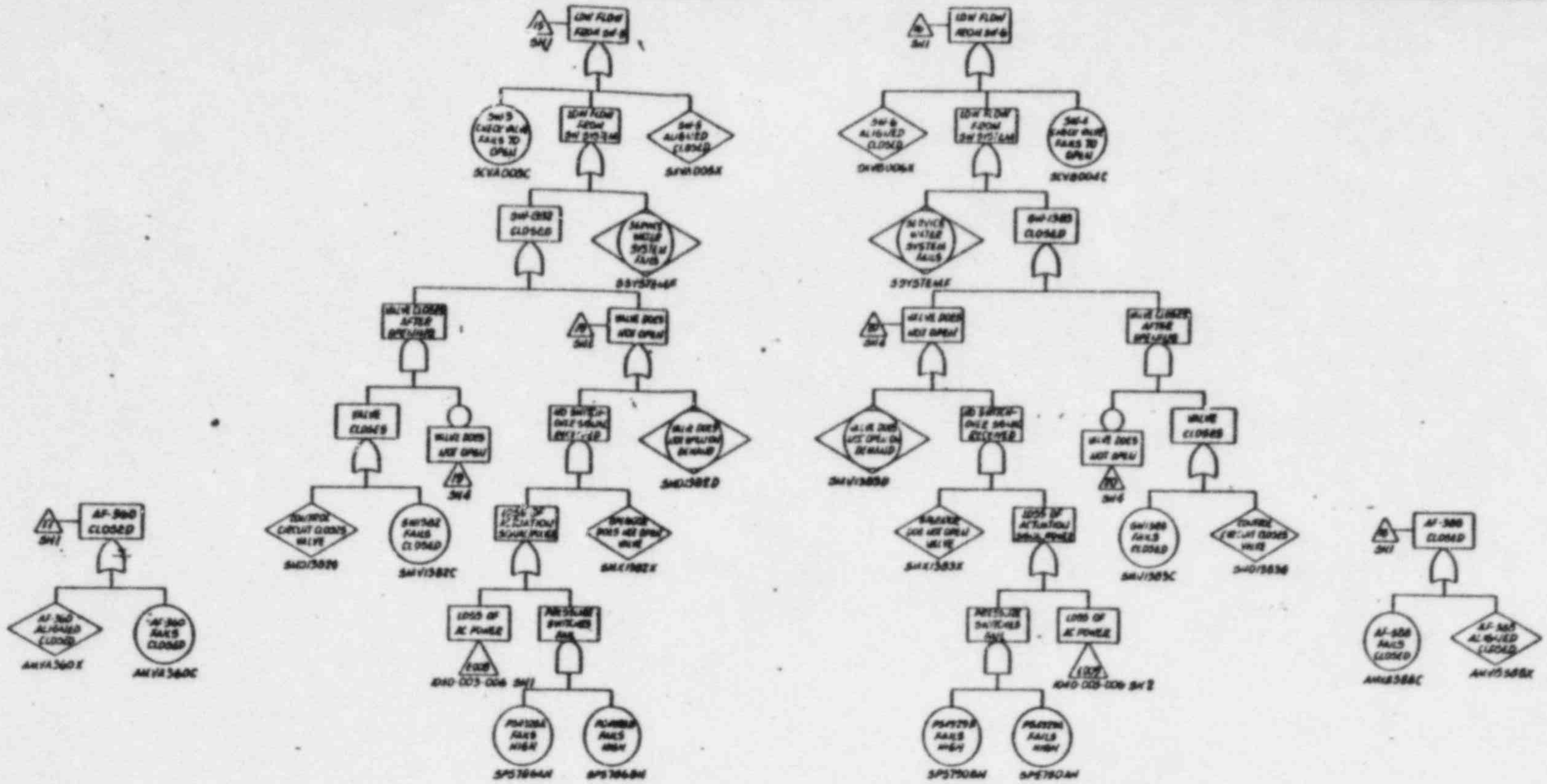


THE TOLEDO EDISON COMPANY DAVIS-BESSE NUCLEAR POWER STATION AUXILIARY FEEDWATER SYSTEM RELIABILITY ANALYSIS ANALYSIS BASED CONFIGURATION				
eds nuclear	FJD			12-22-81
	1040-003-671	1040-003-008		0

SHEET 2 OF 4


AF 3870 CLOSED
AF 3872 CLOSED
AF-3871 CLOSED
FW 786 CLOSED
FW 780 CLOSED
AF 3869 CLOSED
VALVE DOES NOT OPEN
LOW PRESSURE
VALVE CLOSES
VALVE FAILS CLOSED
OPERATOR/CONTROL INTERFACE FAILURES
LOSS OF ACTUATION SIGNAL
STEAM FAILURES
LOW PRESSURE
INADVERTANT SWITCHOVER SIGNAL RECEIVED
CONTROL CIRCUITS FAIL
OPERATOR ERRORS
FAILURE TO REOPEN
LOSS OF AC POWER
1040-003-006 SH 1
1040-003-006 SH 2
1040-003-010 SH 1
1040-003-010 SH 2
AMV3870C
AMV3871C
AMV3871D
AMV3869C
AMV3869D
FMV6786C
FMV6780C
ASFRCSAF
ASFRCSUF
THE TOLEDO EDISON COMPANY
DAVIS-BESSE NUCLEAR POWER STATION
AUXILIARY FEEDWATER SYSTEM
RELIABILITY ANALYSIS
ANALYSIS BASED CONFIGURATION
eds nuclear
R.D
SV
12-22-81
1040-003-671
1040-003-009
0

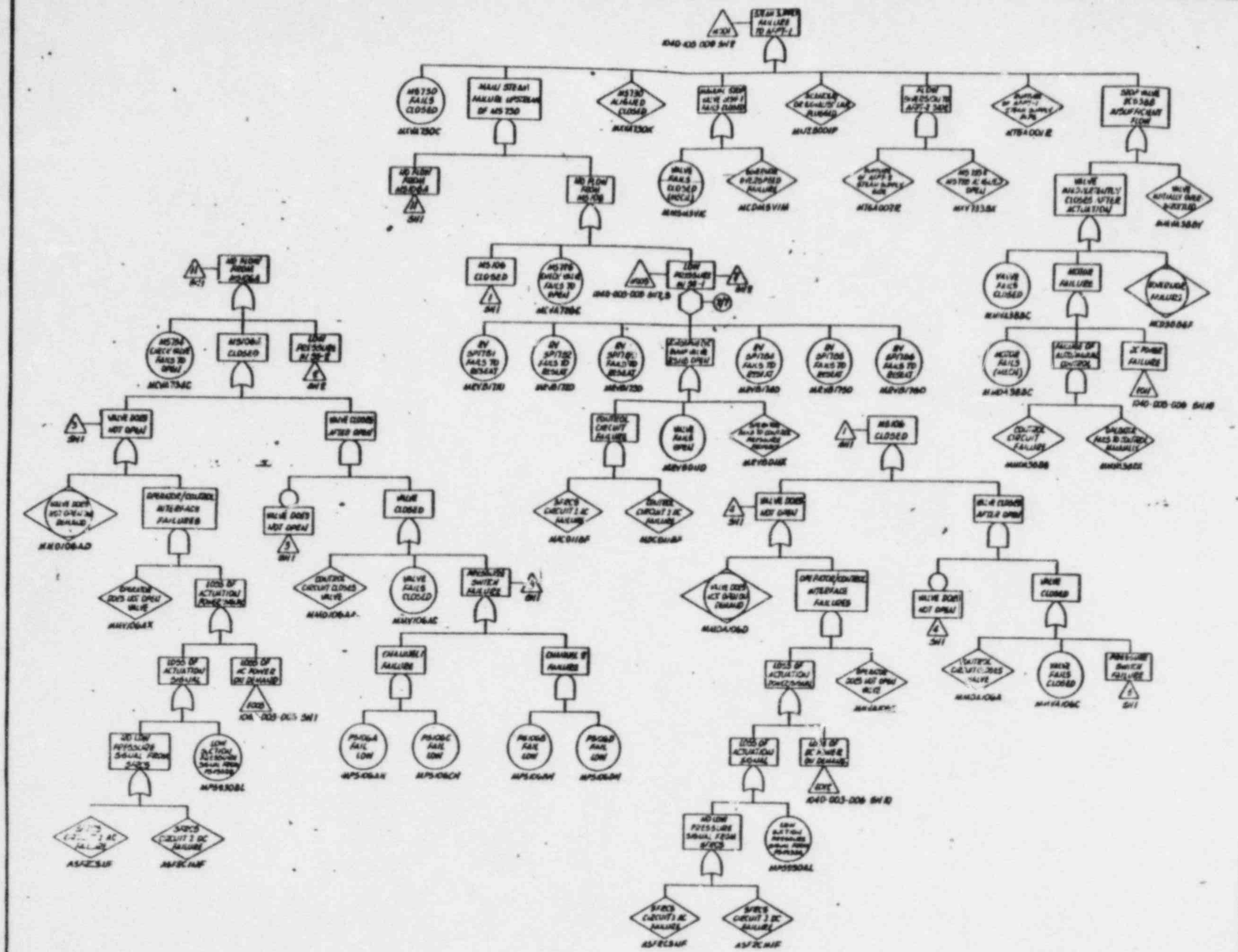
SHEET 3 OF 4



THE TOLEDO EDISON COMPANY
DAVIS-BESSE NUCLEAR POWER STATION
AUXILIARY FEEDWATER SYSTEM
RELIABILITY ANALYSIS
ANALYSIS BASED CONFIGURATION

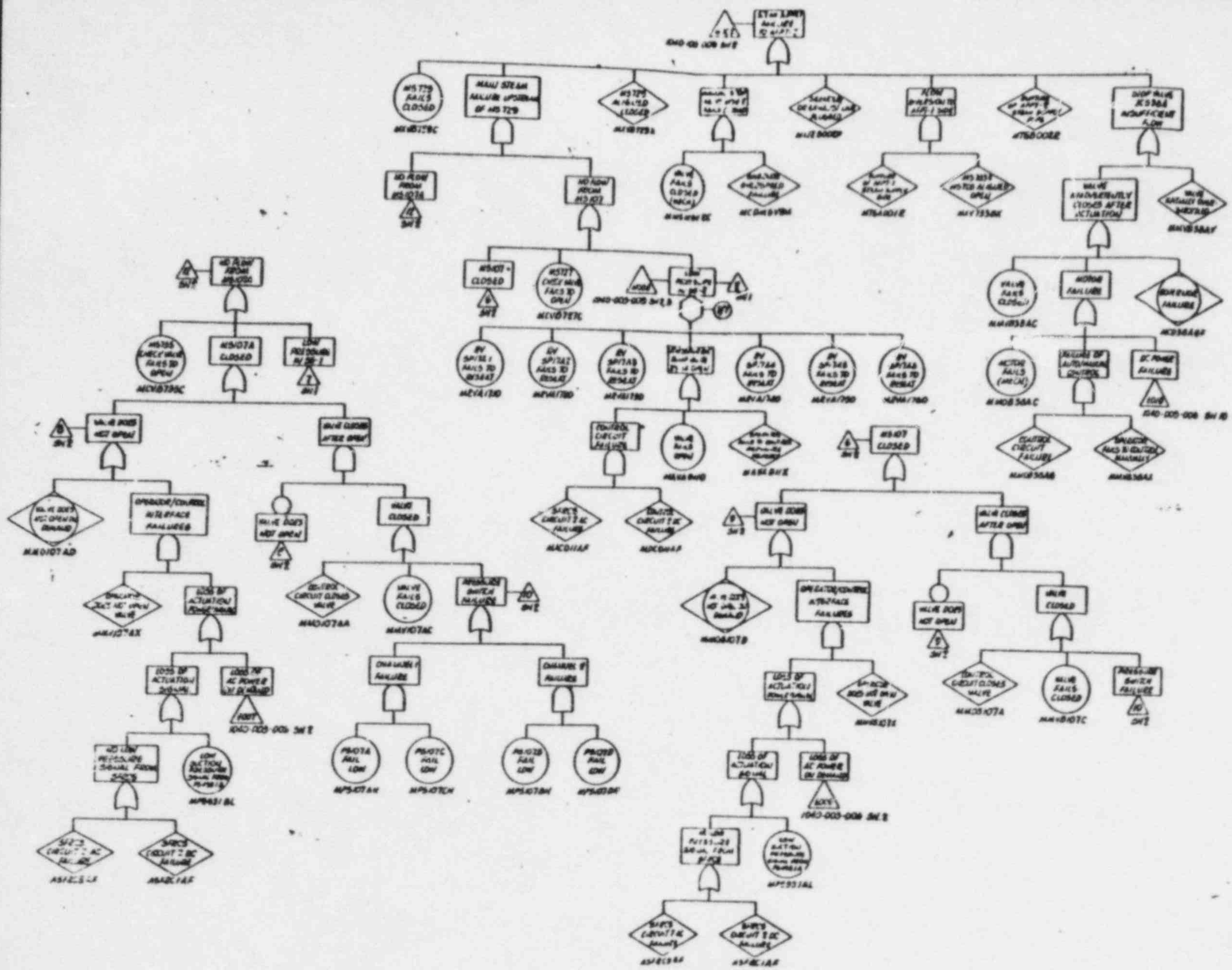
eds nuclear		FJD	EV		12-22-79
	1040-003-671	1040-003-009			0

SHEET 5 OF 5



THE TOLEDO EDISON COMPANY				
DAVIS-BESSE NUCLEAR POWER STATION				
AUXILIARY FEEDWATER SYSTEM				
RELIABILITY ANALYSIS				
MAIN STEAM SYSTEM - ANALYSIS BASED CONFIGURATION				
eds nuclear	FJD	JV	10-22-79	
1040-003-671	1040-003-010			0

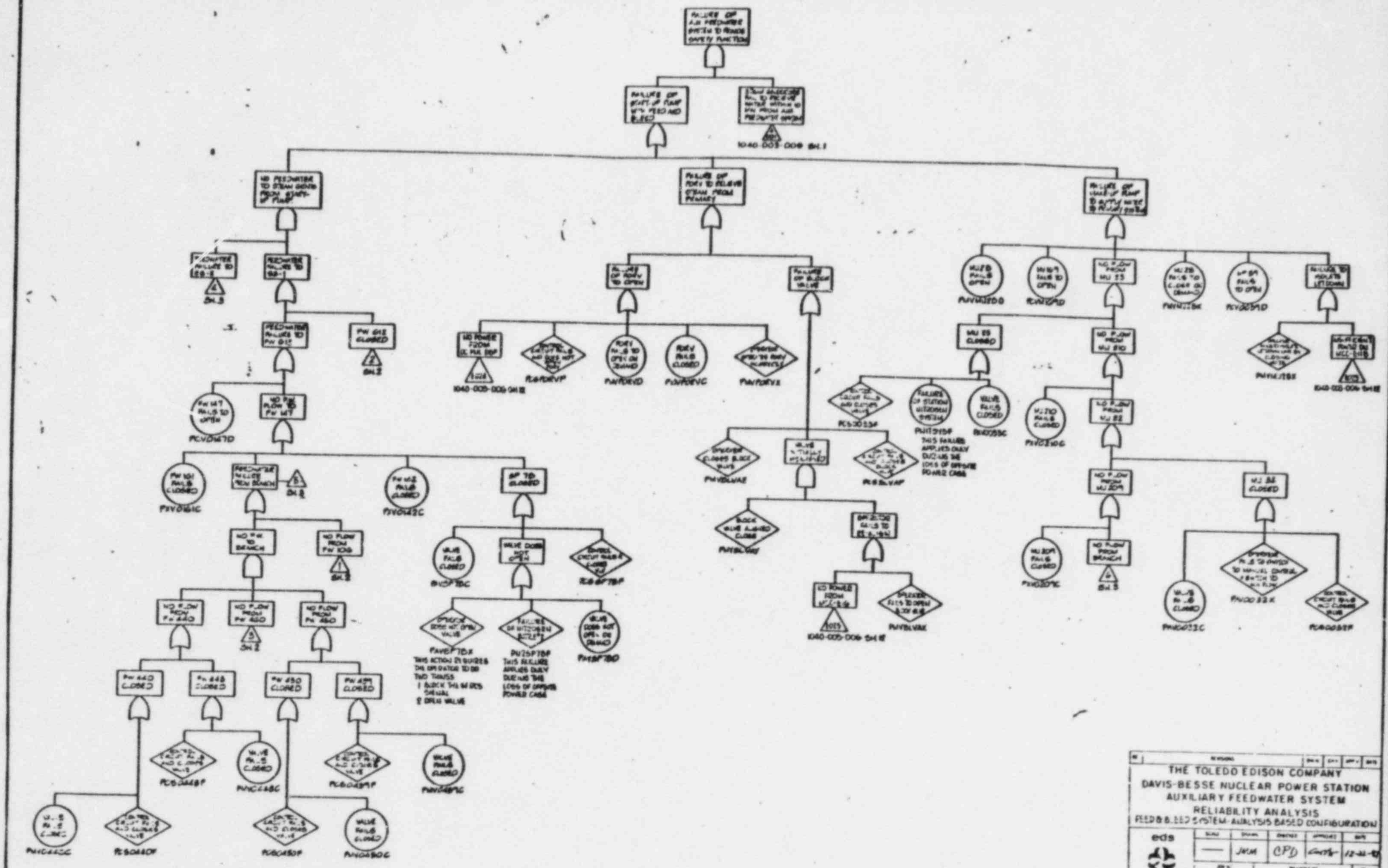
SHEET 1 OF 2



THE TOLEDO EDISON COMPANY
DAVIS-BESSE NUCLEAR POWER STATION
AUXILIARY FEEDWATER SYSTEM
RELIABILITY ANALYSIS
MAIN STEAM SYSTEM - ANALYSIS BASED CONFIGURATION

eds nuclear | FJD | SV | 1040-003-671 | 1040-003-010 | 0

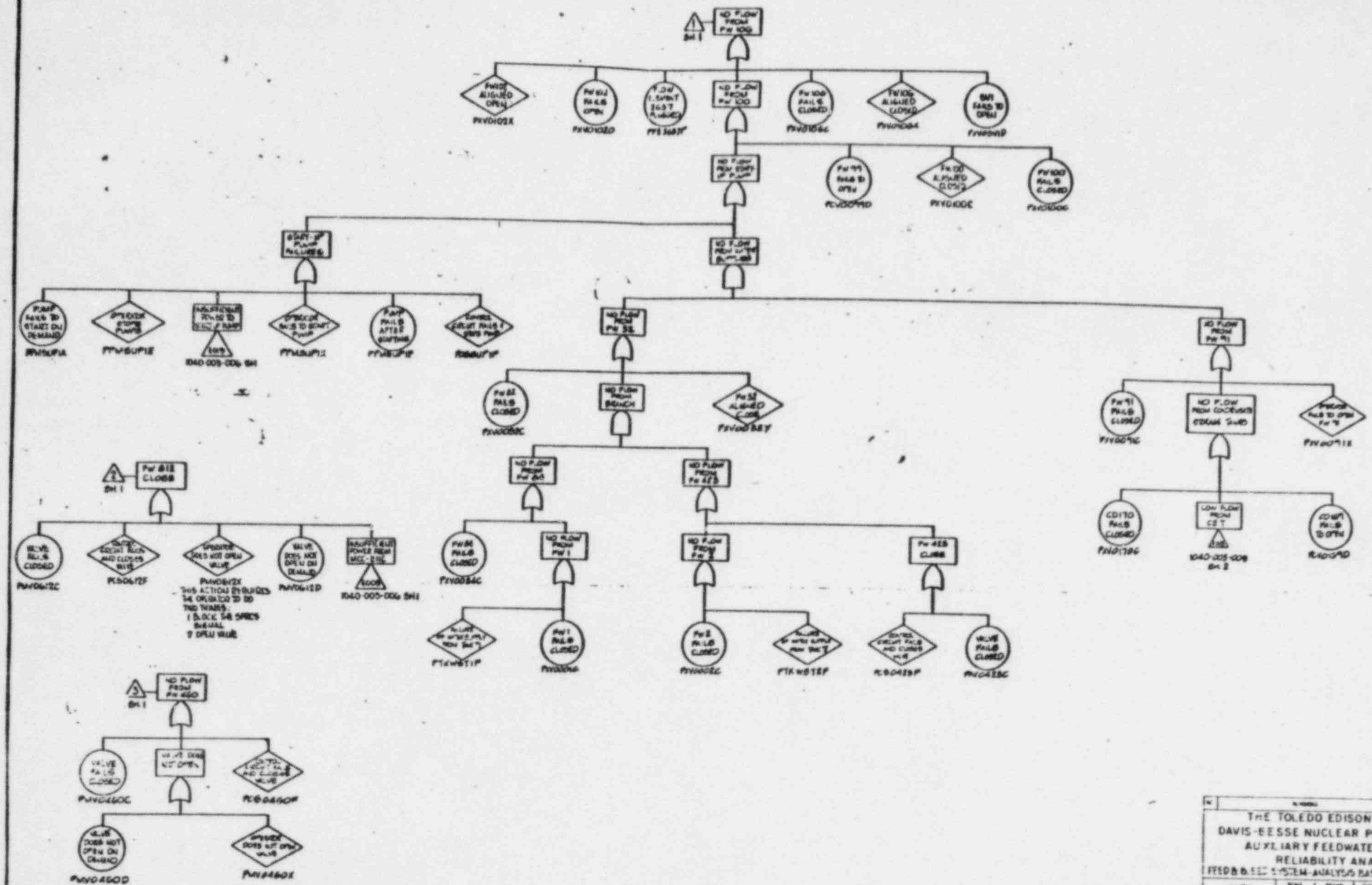
SHEET 2 OF 2



THE TOLEDO EDISON COMPANY
DAVIS-BESSE NUCLEAR POWER STATION
AUXILIARY FEEDWATER SYSTEM
RELIABILITY ANALYSIS
FEED & BLEED SYSTEM-ANALYSIS BASED CONFIGURATION

eds nuclear	—	JKM	CPD		12-11-?
	1040-003-671	1040-003-011			0

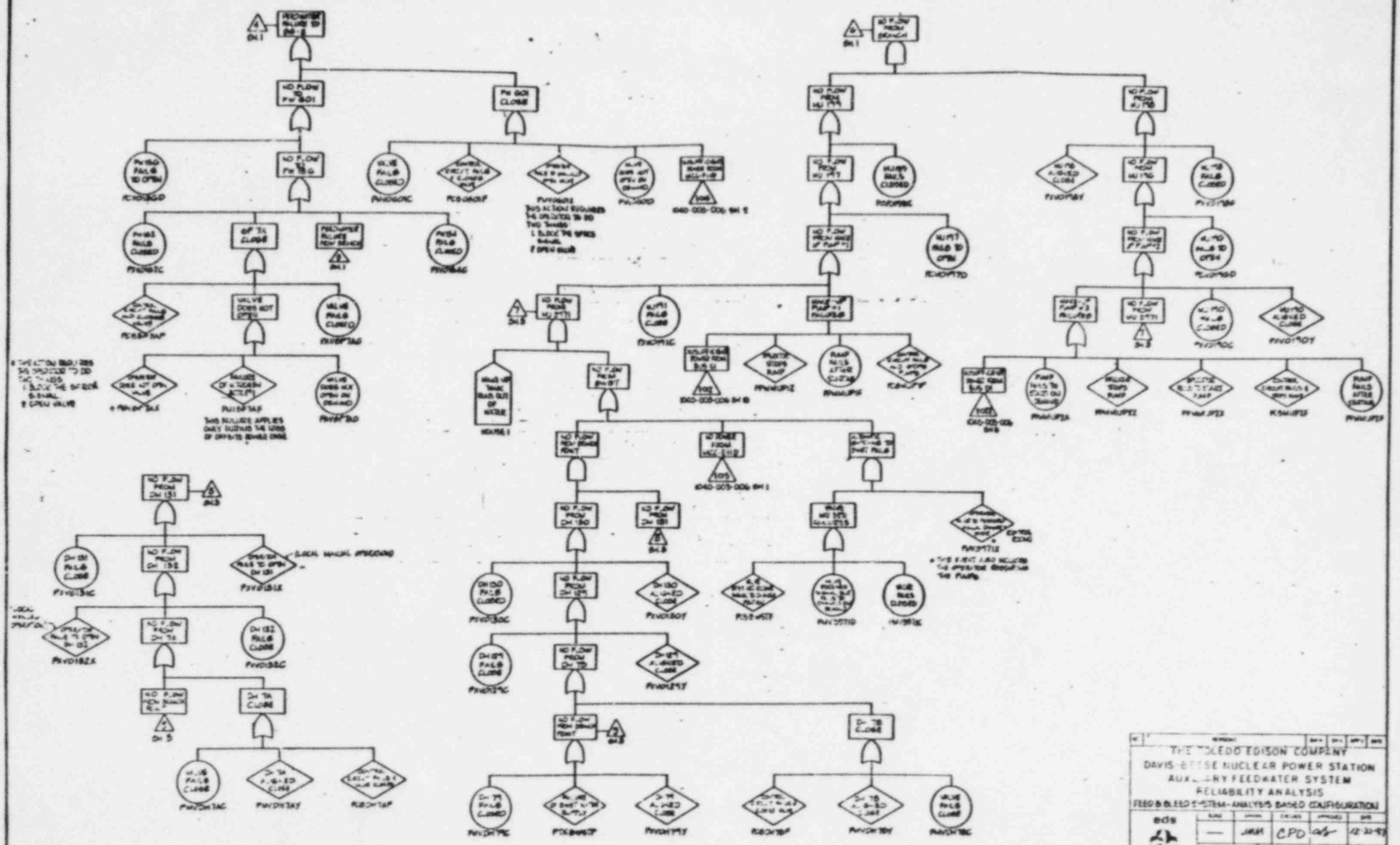
SHEET 1 OF 3



THE TOLEDO EDISON COMPANY
DAVIS-BESSE NUCLEAR POWER STATION
AUXILIARY FEEDWATER SYSTEM
RELIABILITY ANALYSIS
FEED & BLEED SYSTEM-ANALYSIS BASED CONFIGURATION

eds nuclear | — | JMM | CPD | | 12-31-81
1040-003-671 | 1040-003-011 | 0

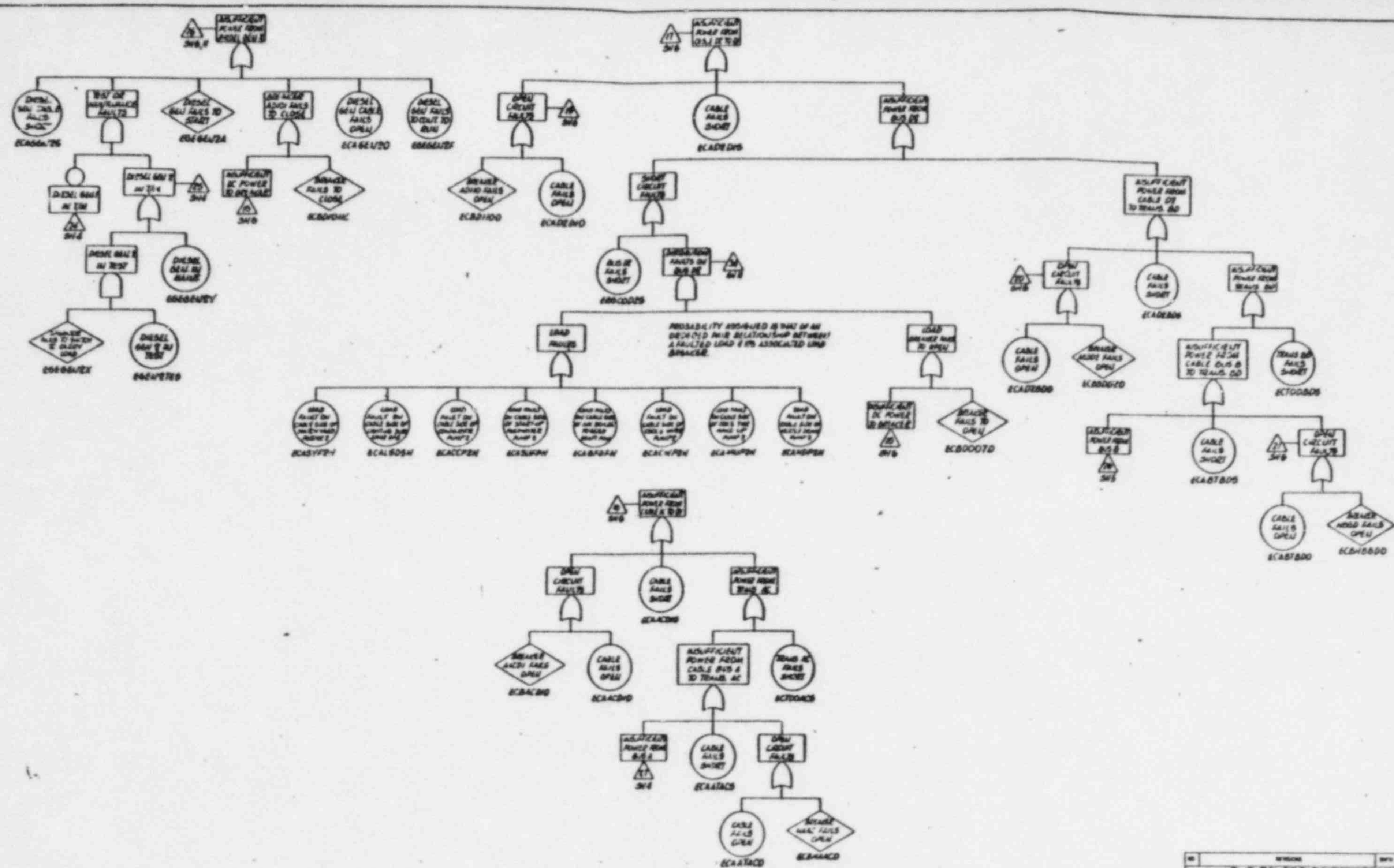
SHEET 2 OF 3



THE TOLEDO EDISON COMPANY
DAVIS-BESSE NUCLEAR POWER STATION
AUXILIARY FEEDWATER SYSTEM
RELIABILITY ANALYSIS
FEED & BLEED SYSTEM-ANALYSIS BASED CONFIGURATION

eds nuclear	—	JMM	CPD	12-31-79
	140-003-671	1040-003-011		0

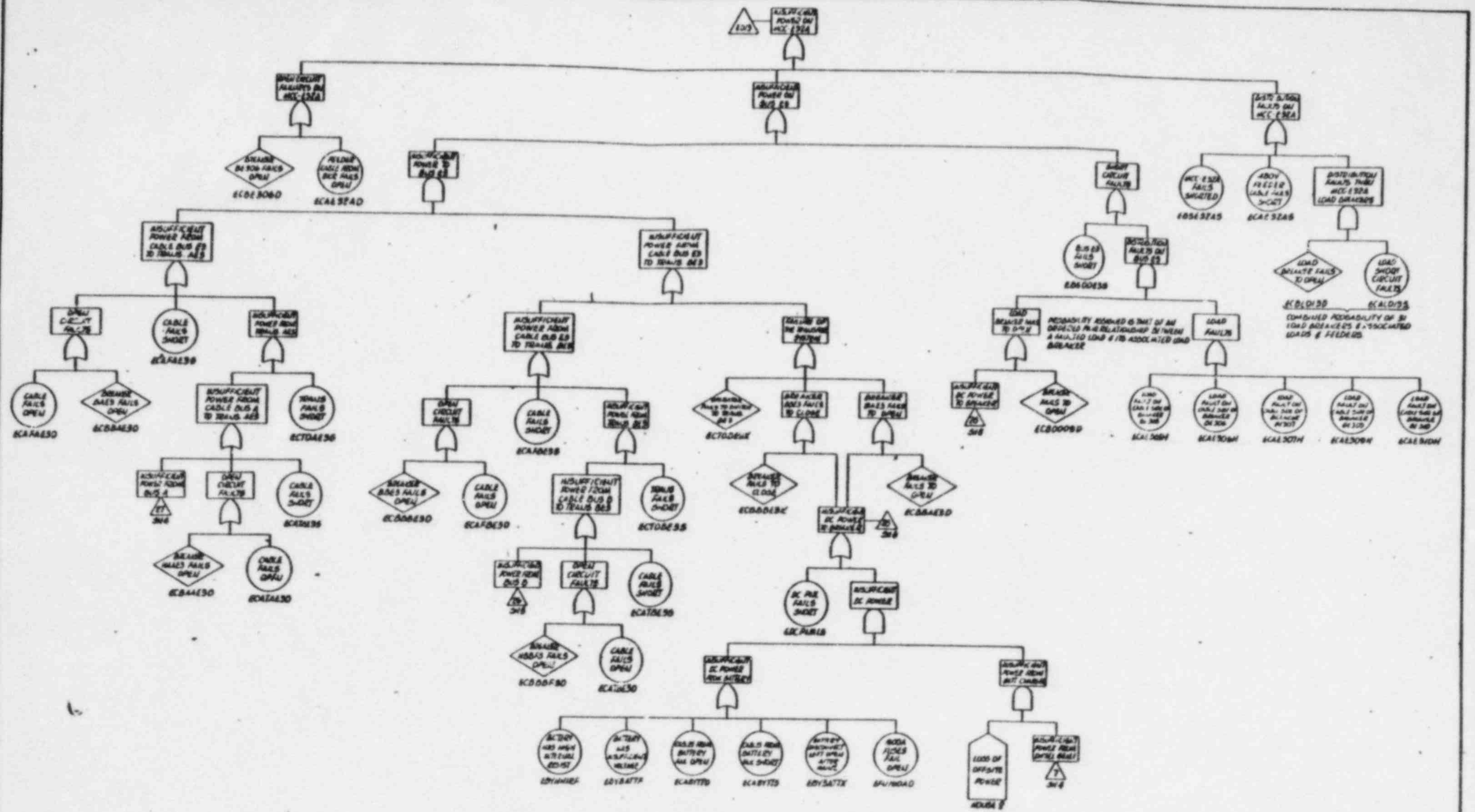
SHEET 3 OF 3



THE TOLEDO EDISON COMPANY
DAVIS-BESSE NUCLEAR POWER STATION
AUXILIARY FEEDWATER SYSTEM
RELIABILITY ANALYSIS
ELECTRICAL SYSTEM POST-TMI

eds nuclear	FJD	1040-003-671	1040-003-006	0

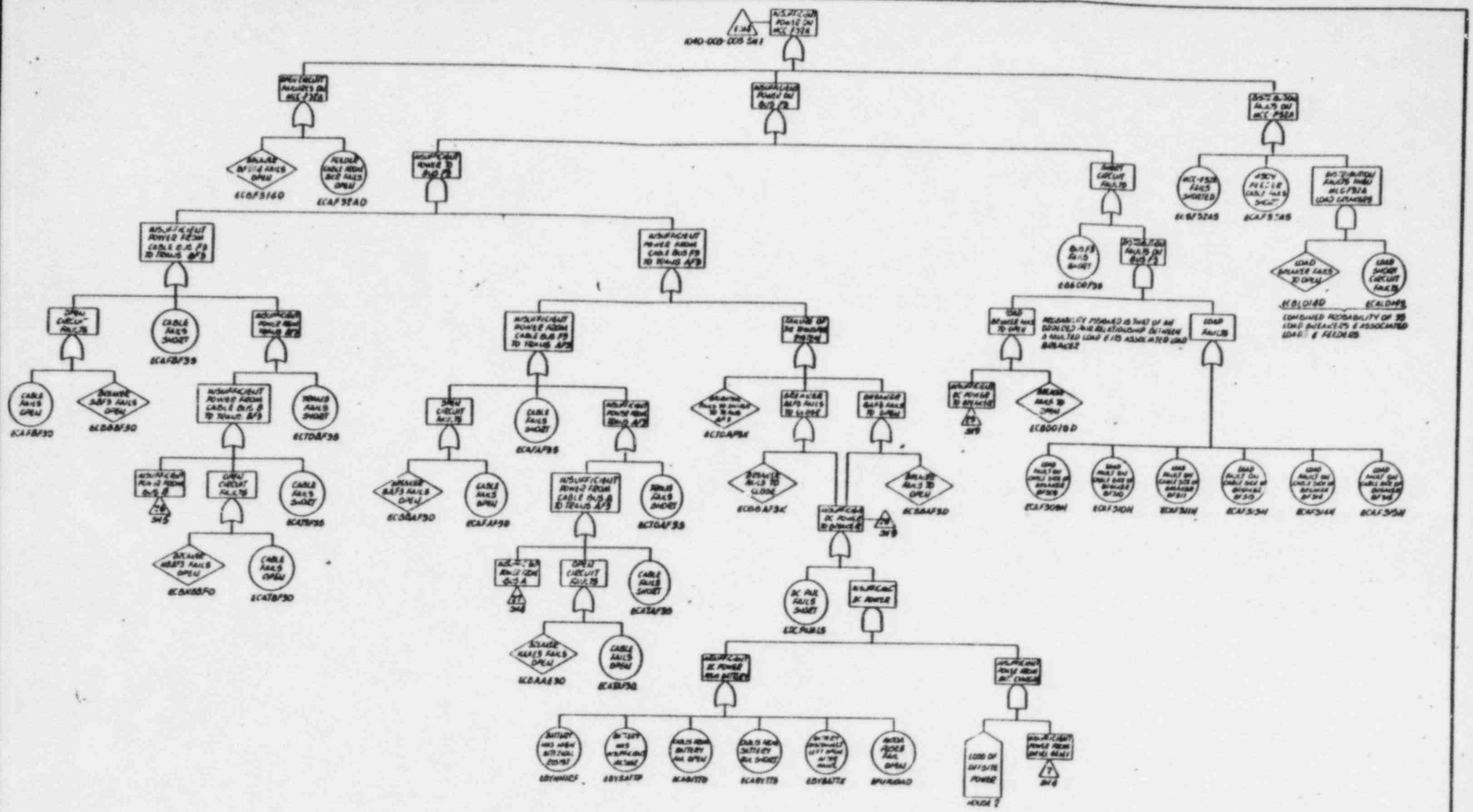
SHEET 7 OF 12



THE TOLEDO EDISON COMPANY
DAVIS-BESSE NUCLEAR POWER STATION
AUXILIARY FEEDWATER SYSTEM
RELIABILITY ANALYSIS
ELECTRICAL SYSTEM POST-TMI

eds nuclear	FJD	1040-003-671	1040-003-006	0

SHEET 8 OF 8



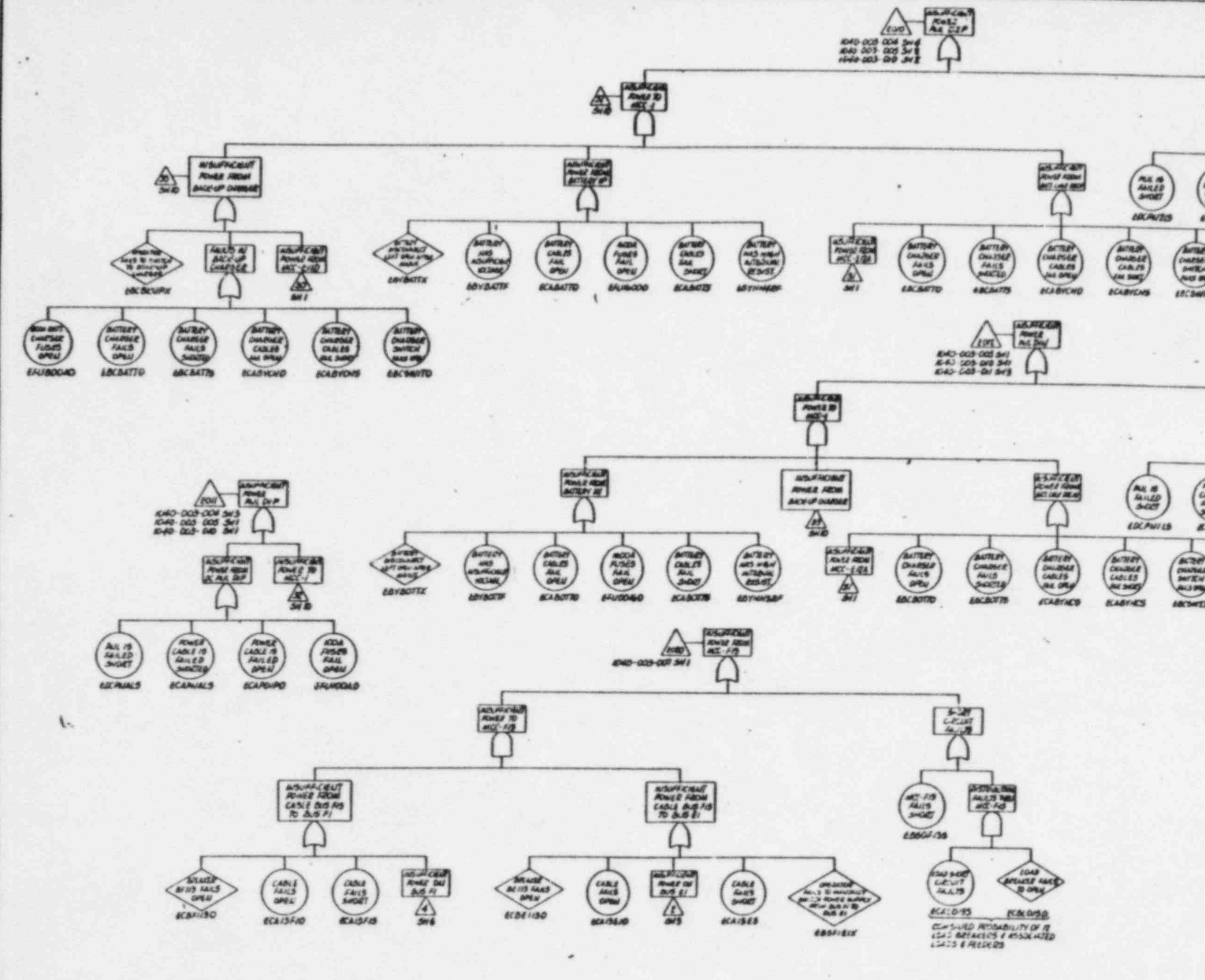
THE [illegible]EDO EDISON COMPANY
DAVIS-BESSE NUCLEAR POWER STATION
AUXILIARY FEEDWATER SYSTEM
RELIABILITY ANALYSIS
ELECTRICAL SYSTEM POST-TMI

eds nuclear

RJD | SV

[illegible]-003-671 | 1040-003-006 | 0

SHEET 9 OF 12



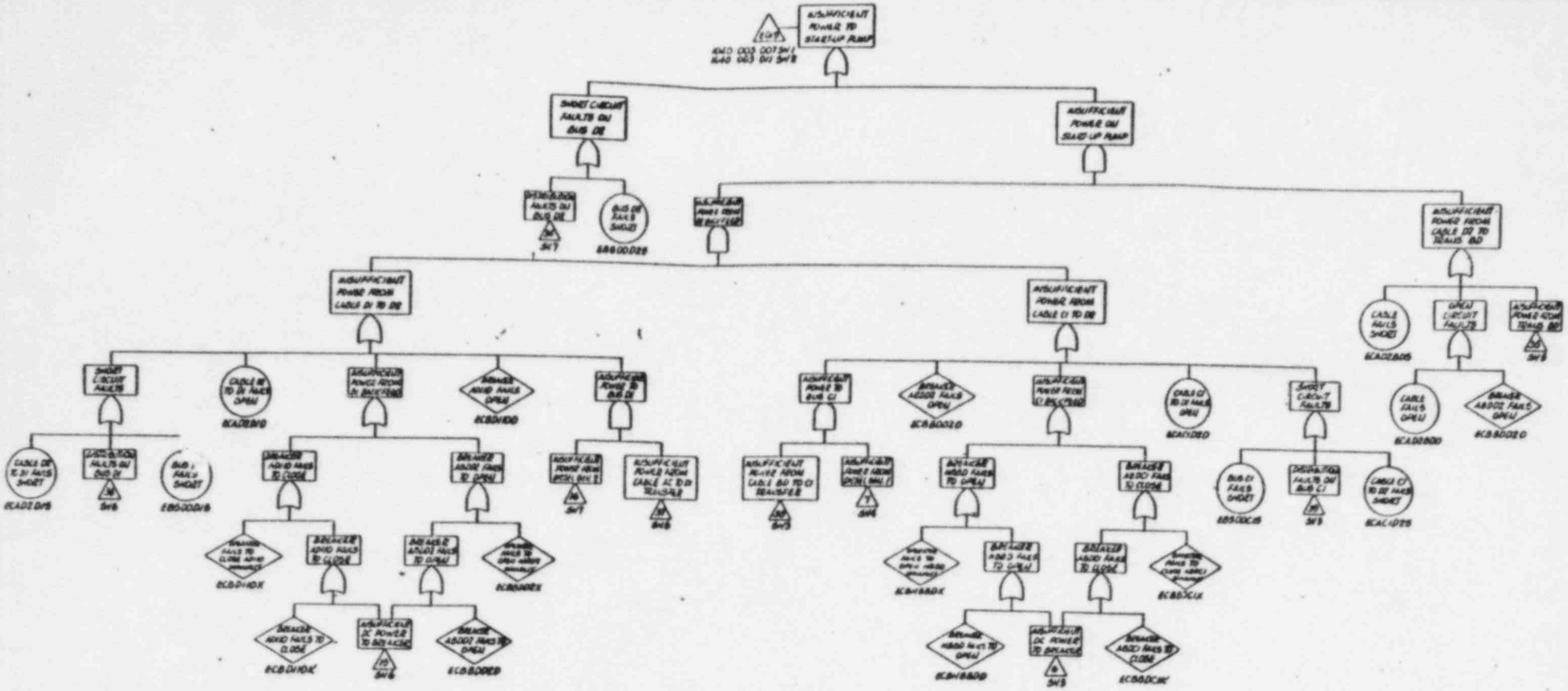
1	ANALYSIS BASED CONFIGURATION	FJD	CYD	3/4

THE TOLEDO EDISON COMPANY
DAVIS-BESSE NUCLEAR POWER STATION
AUXILIARY FEEDWATER SYSTEM
RELIABILITY ANALYSIS
ELECTRICAL SYSTEM POST-TMI

eds nuclear

1040-003-671 | 1040-003-006 | 1

SHEET 10 OF 12



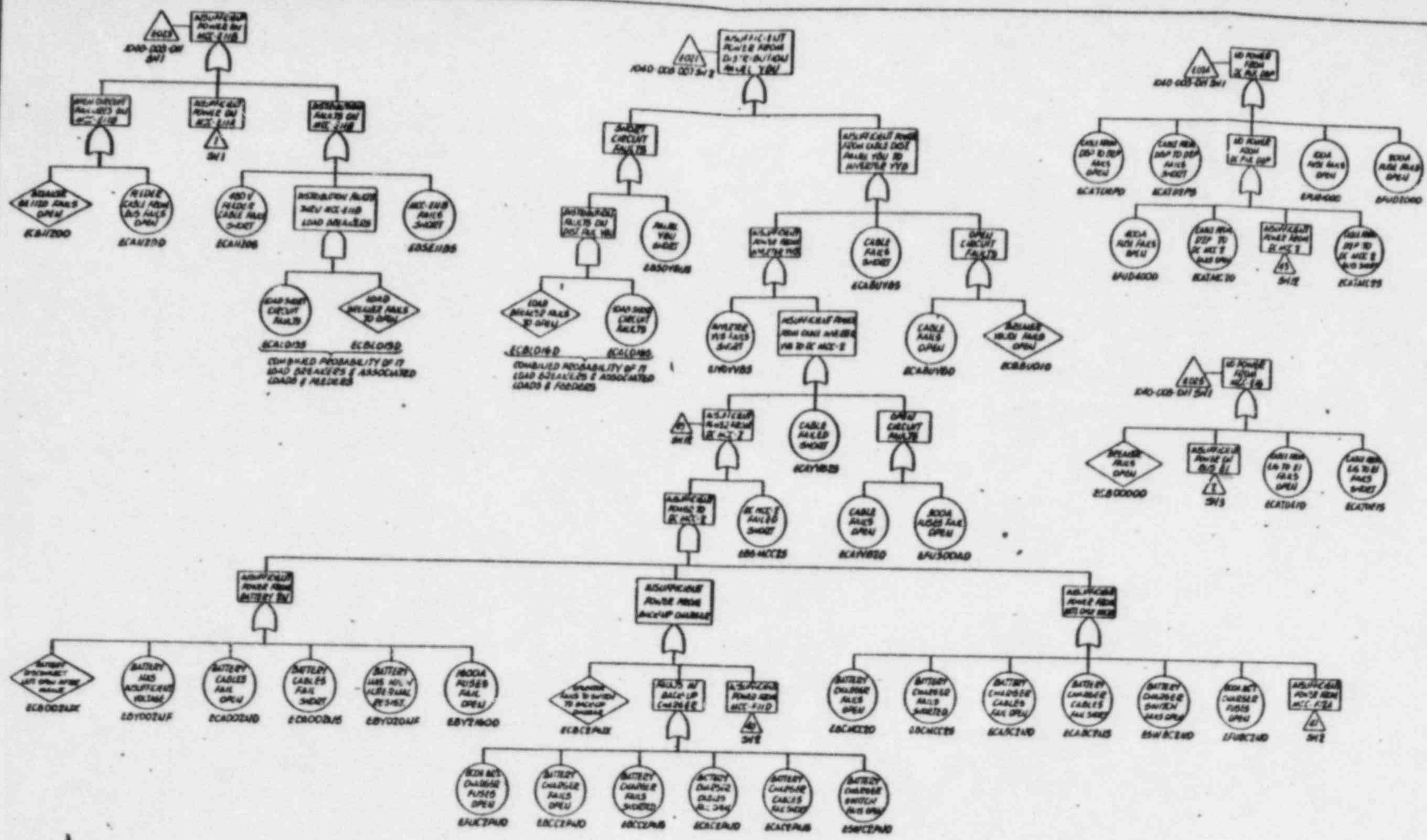
1	ANALYSIS BASED CONFIGURATION	FJD	CPD	
NO.	REVISION			

THE TOLEDO EDISON COMPANY
DAVIS-BESSE NUCLEAR POWER STATION
AUXILIARY FEEDWATER SYSTEM
RELIABILITY ANALYSIS
ELECTRICAL SYSTEM POST-TMI

eds nuclear

FJD	SV			
1040-003-571	1040-003-006	1		

SHEET 11 OF 12



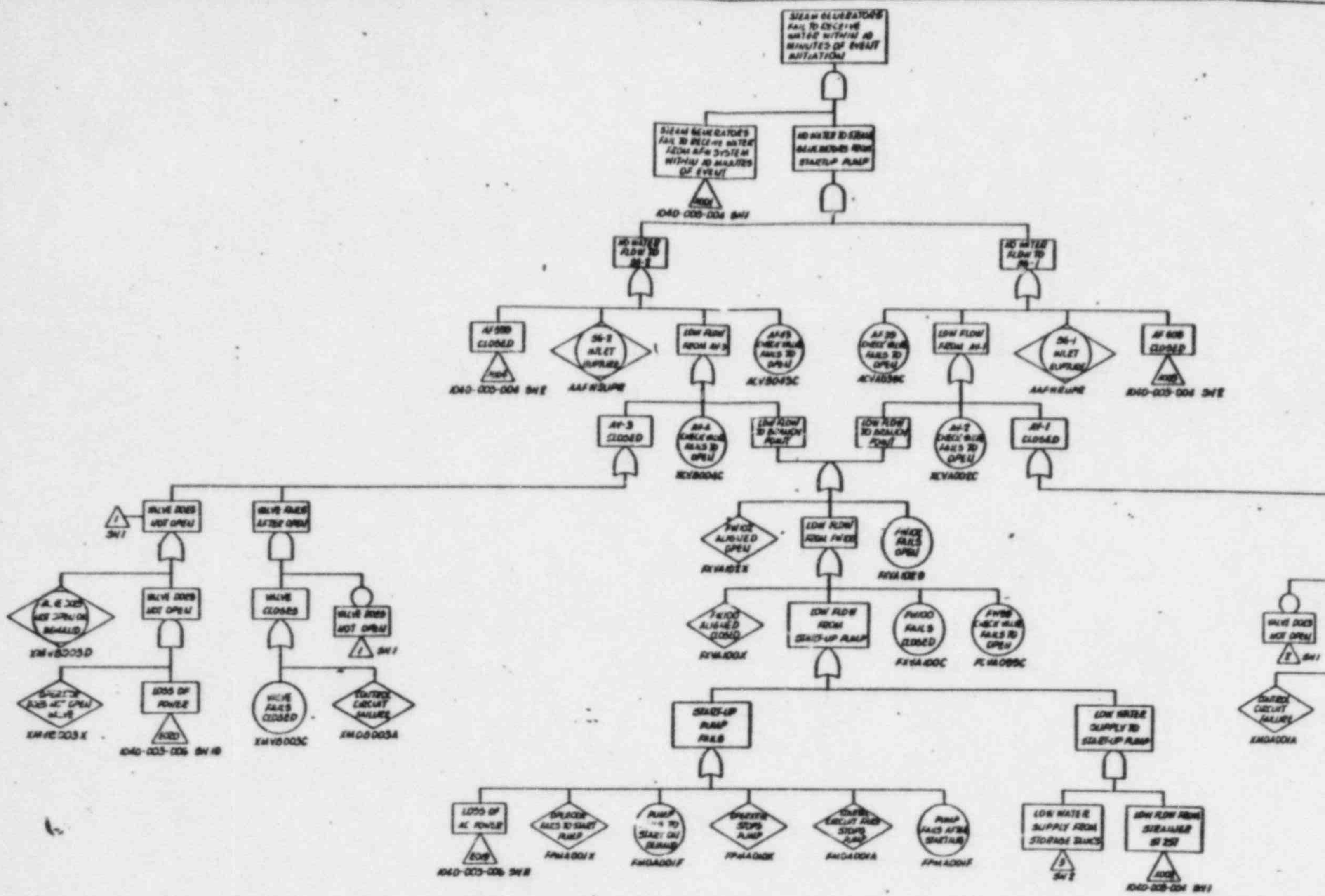
1	ANALYSIS BASED CONFIGURATION	RD	[illegible]	[illegible]	[illegible]

THE TOLEDO EDISON COMPANY
DAVIS-BESSE NUCLEAR POWER STATION
AUXILIARY FEEDWATER SYSTEM
RELIABILITY ANALYSIS
ELECTRICAL SYSTEM POST-TMI

eds nuclear

[illegible]	FJD	SV	[illegible]	7/24/81
1040-003-671	1040-003-006	1		

SHEET 12 OF 12

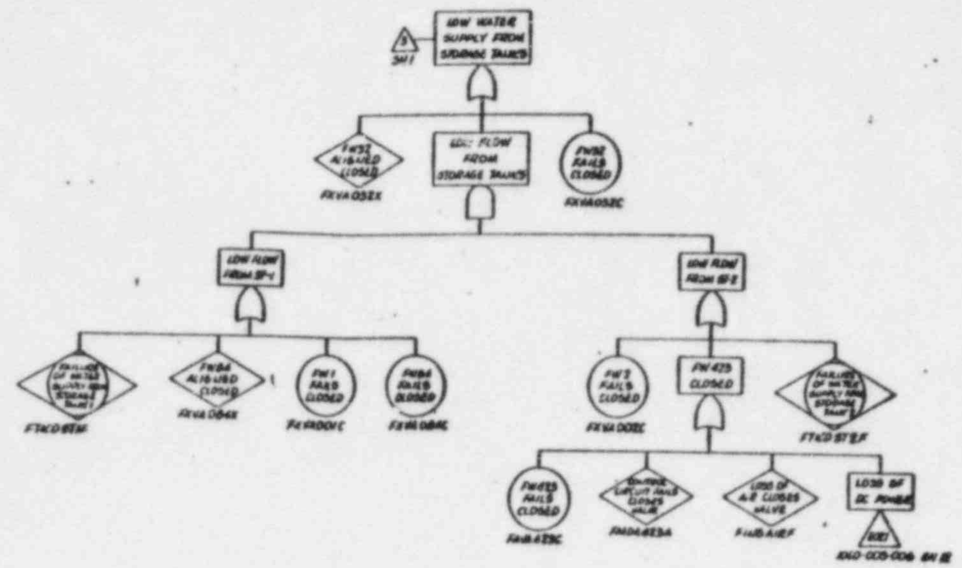


This is the third train configuration!

THE TOLEDO EDISON COMPANY
DAVIS-BESSE NUCLEAR POWER STATION
AUXILIARY FEEDWATER SYSTEM
RELIABILITY ANALYSIS
START-UP PUMP POST-TMI

eds nuclear	—	FJD	SV	3/02/81
	1040-003-671	1040-003-007		0

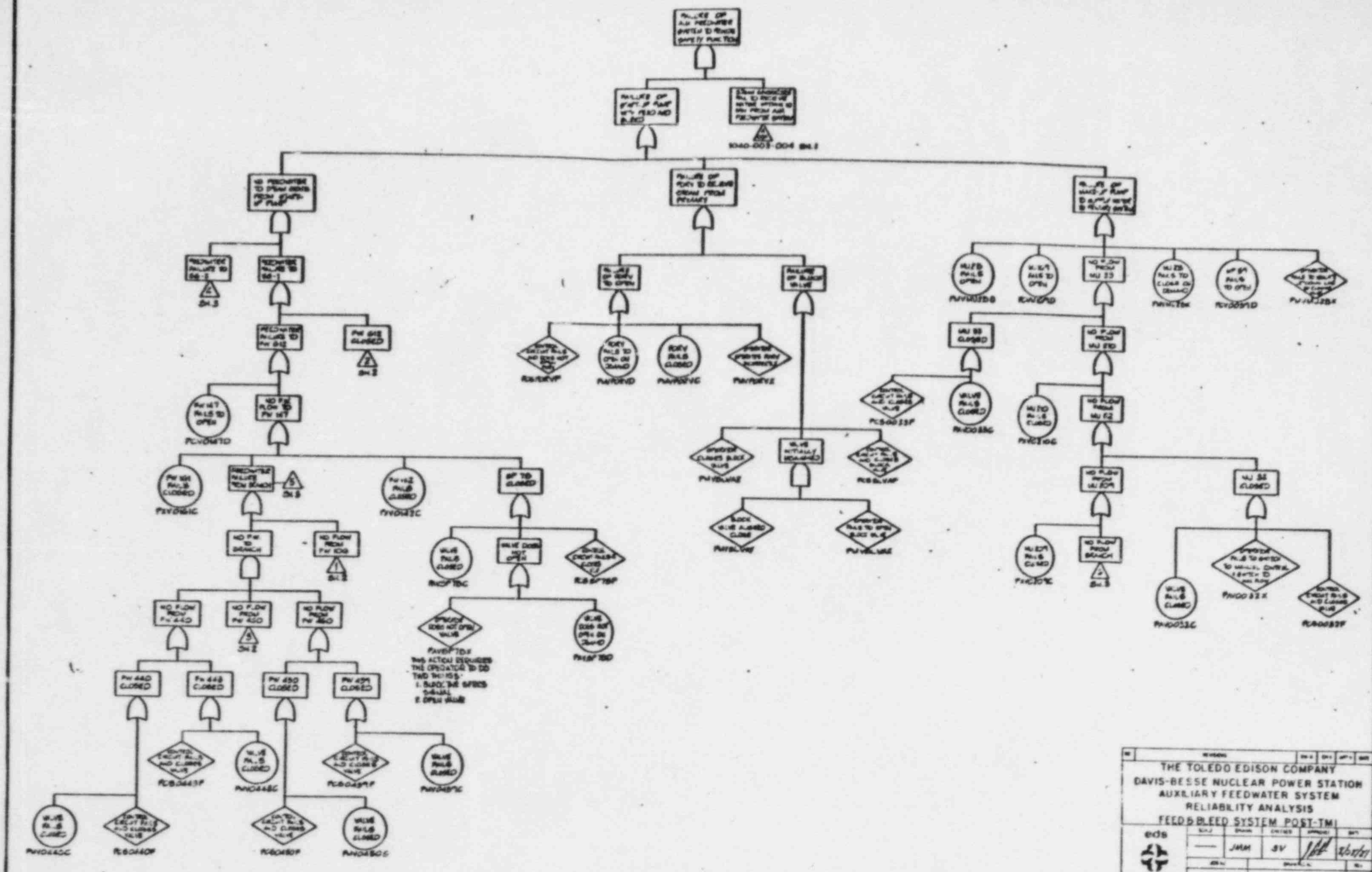
SHEET 1 OF 2



THE TOLEDO EDISON COMPANY
DAVIS-BESSE NUCLEAR POWER STATION
AUXILIARY FEEDWATER SYSTEM
RELIABILITY ANALYSIS
START-UP PUMP POST-TMI

eds nuclear	SCALE	DRAWN	CHECKED	APPROVED	DATE
	—	FJD	SV		2/26/81
	1040-003-671	1040-003-007			0

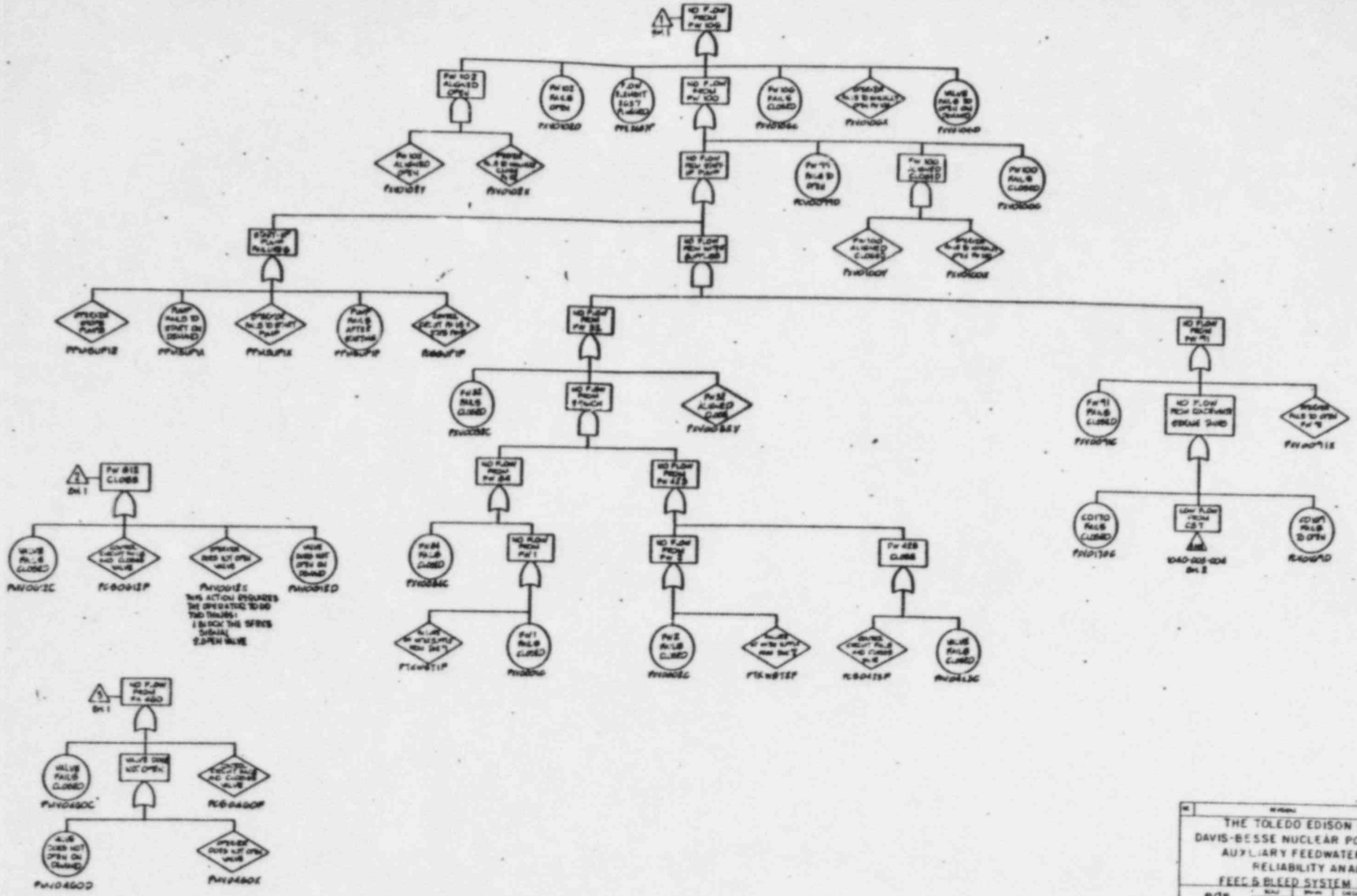
SHEET 2 OF 2



THE TOLEDO EDISON COMPANY
DAVIS-BESSE NUCLEAR POWER STATION
AUXILIARY FEEDWATER SYSTEM
RELIABILITY ANALYSIS
FEED & BLEED SYSTEM POST-TMI

eds nuclear		JAM	SV		
1040-003-671	1040-003-008	0			

SHEET 1 OF 1

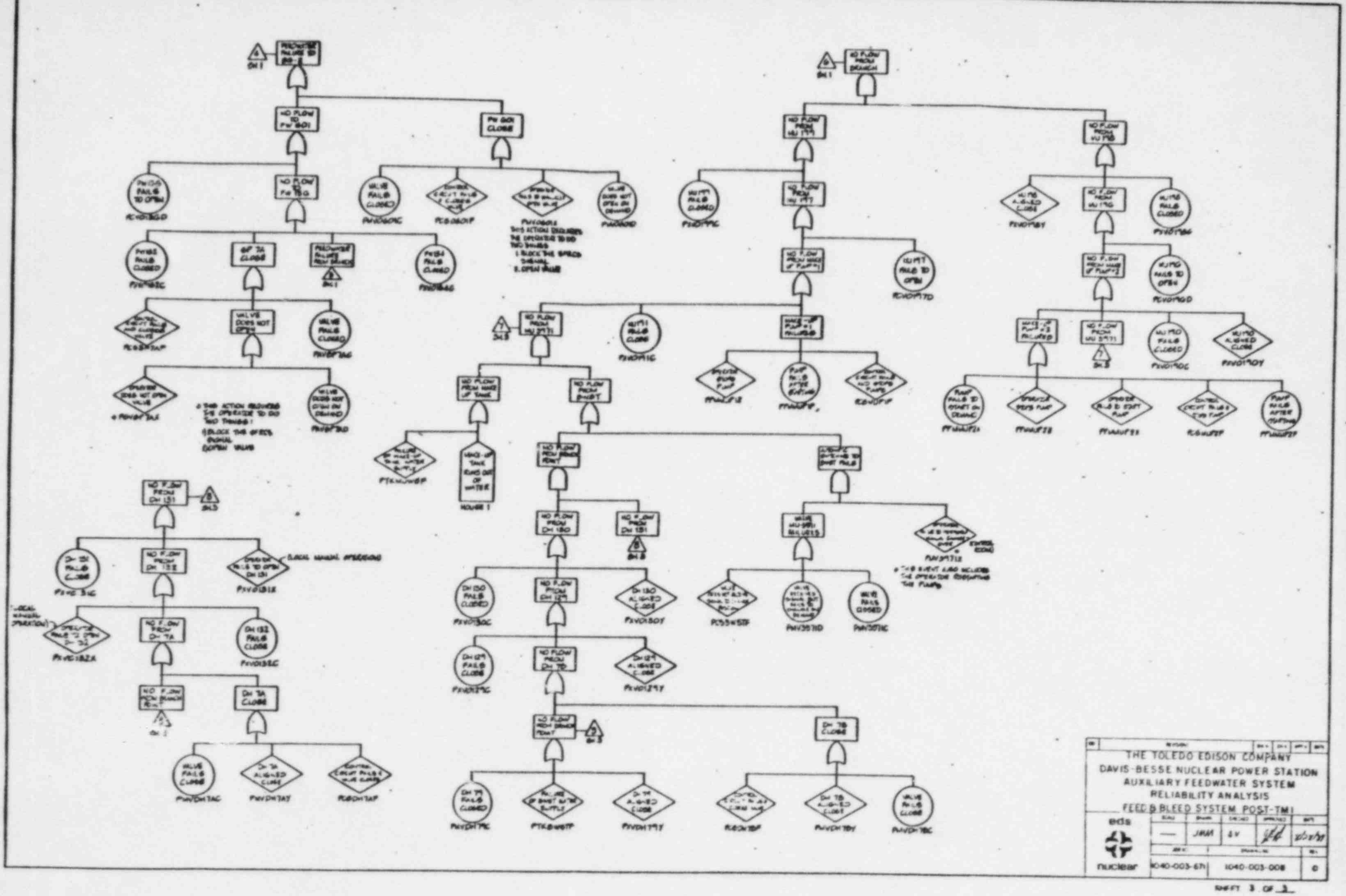


THE TOLEDO EDISON COMPANY
DAVIS-BESSE NUCLEAR POWER STATION
AUXILIARY FEEDWATER SYSTEM
RELIABILITY ANALYSIS
FEED & BLEED SYSTEM POST-TMI

eds nuclear

—	JMM	SV		
1040-003-671	1040-003-008			0

SHEET 2 OF 3


THE TOLEDO EDISON COMPANY
DAVIS-BESSE NUCLEAR POWER STATION
AUXILIARY FEEDWATER SYSTEM
RELIABILITY ANALYSIS
FEED & BLEED SYSTEM POST-TMI
eds
nuclear
JAM
1040-003-671
1040-003-008
0
SHEET 3 OF 3