EMERGENCY FEEDWATER SYSTEM
RELIABILITY ANALYSIS
FOR THE
VIRGIL C. SUMMER NUCLEAR STATION
UNIT 1

PREPARED FOR

SOUTH CAROLINA ELECTRIC AND GAS COMPANY
COLUMBIA, SOUTH CAROLINA

Prepared by

Gilbert/Commonwealth
Reliability Section
Reading, PA 19603

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LIST OF ABBREVIATIONS USED IN THE FAULT TREE ANALYSIS OF THE EMERGENCY FEEDWATER SYSTEM

AOV	Air Operated Valve
BISI	By-Pass and Inoperable Status Indication
CRT	Circuit
CST	Condensate Storage Tank
CV	Check Valve
DG	Diesel Generator
DT#2	Denny Terrace Station #2
EF	Emergency Feedwater
EFS	Emergency Feedwater System
FCV	Flow Control Valve
FE	Flow Element
FT	Flow Transmitter
ICV	Isolation Check Valve
IFV	Isolation Flow Valve
LAC	Loss of AC
LFW	Loss of Feedwater (same as LMF)
LMF	Loss of Main Feedwater
LOSP	Loss of Off-Site Power
MCC	Motor Control Center
MDP	Motor Driven Pump
MIV	Manual Isolation Valve
MOV	Motor Operated Valve
MS	Main Steam
MSIV	Main Steam Isolation Valve
PORV	Power Operated Relief Valve
SG	Steam Generator

SRV	Safety Relief Valve
SW	Service Water
SWS	Service Water System
TDP	Turbine Driven Pump
TSC	Technical Support Center

1.0 INTRODUCTION

1.1 Background

The NRC has requested that plants with Westinghouse-designed reactors that are under operating license review evaluate and consider means for upgrading the Emergency Feedwater System (EFS) reliability. This report presents the results of that reliability study for the V. C. Summer Nuclear Station Unit 1 in a form comparable with the information contained in NUREG-0611.

1.2 Objectives

The objectives of this study are:

A. To perform a reliability assessment of the V. C. Summer EFS and to compare its expected performance with similar systems at operating Westinghouse reactors.

B. To consider any design or operational modifications necessary, based on insights from the reliability analysis and the NRC Generic Recommendations.

1.3 Scope

The EFS design was analyzed for the following three feedwater transients:

Case 1 - Loss of Main Feedwater with Reactor Trip (LMF)

Case 2 - Loss of Main Feedwater Coincident with Loss of Offsite Power (LMF/LOSP)

Case 3 - Loss of Main Feedwater coincident with Loss of All AC Power (LMF/LAC)

The analysis was limited to finding the probability of EFS failure on the occurrence of each of the above postulated initiating event cases. The causes and probabilities of the initiating sequences were not considered. External events, such as earthquakes, were also not considered.

1.4 Analysis Technique

The technique used for the study is Fault Tree Analysis, which is a deductive approach where an undesirable (top) event is postulated, and the system is examined with a view to finding combinations of component failure events and human errors which can cause the top event. The technique has been applied extensively to nuclear safety analysis, most notably in the Reactor Safety Study (WASH-1400).

1.5 Organization of Report

In addition to the considerations identified above under Background (see Section 1.1), this report addresses specific requirements identified in Enclosure 1 and Enclosure 2 of the NRC March 10, 1980 letter*, as follows:

Reference	Response
Enclosure 1	Text plus Appendix A (Fault Tree Analysis)
Enclosure 2	Appendix B (Basis of Auxiliary Feedwater System Flow Requirements)

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* Letter dated March 10, 1980 from D. F. Ross, Jr., Acting Director, Division of Project Management, Office of Nuclear Reactor Regulation, to all Pending Operating License Applicants of Nuclear Steam Supply Systems Designed by Westinghouse and Combustion Engineering. Subject: "Actions Required From Operating License Applicants of Nuclear Steam Supply Systems Designed by Westinghouse and Combustion Engineering Resulting From the NRC Bulletins and Orders Task Force Review Regarding the Three Mile Island Unit 2 Accident."

2.0 ASSUMPTIONS AND CRITERIA

2.1 Definition of System Failure (Fault Tree Top Event)

In order to determine what combinations of component failures or human errors will cause system failure, it is first necessary to define explicitly what constitutes system failure. For the purposes of the present study, EFS failure is defined as failure of the EFS to provide sufficient flow to at least two of the three steam generators.

2.2 Availability of Electrical Supply

Case 1 - LMF - All AC and DC power was assumed available with a probability of 1.0.

Case 2 - LMF/LOSP - DC power was assumed available with a probability of 1.0. All possible combinations of diesel generator availability were considered.

Case 3 - LMF/LAC - DC power was assumed available with a probability of 1.0.

2.3 Data

Wherever applicable, reliability data for hardware, operator actions, and maintenance were taken from NUREG-0611 and WASH-1400.

2.4 Degradation VS Failure

No degradation or degraded failures were considered, i.e., equipment either operates as required or is in a failed state.

2.5 EF Pump Susceptibility to Suction Starvation

Based on system engineering analysis, there is considerable concern about the ability of the EF pumps to survive startup in a starved condition. An EF pump startup with a closed suction flow path is assumed to fail with a probability of 1.0.

2.6 Human Errors of Commission and Omission

Five basic human errors were defined in the analysis based on likely system maintenance, valve locking, valve position monitoring, walk around, mispositioning of valves, etc. Values for these errors were assigned from NUREG-0611 and WASH-1400.

2.7 Human Errors of Commission and Omission Pertaining to EF Supply Line Maintenance Valve

The single manual valve (#1010) in the EFS suction line is locked open (L.O.) and repositioned only on EF suction line maintenance. The position of this valve is verified at least monthly. A limit switch initiates an audible alarm in the Control Room when the valve is closed. Its closed status is input into the Bypass and Inoperable Status Indication (BISI) computer system wherein the closed status is displayed on a CRT screen. An unavailability of 5×10^{-5} per demand due to maintenance and operating error was assigned based on considerations in NUREG-0611 and WASH-1400 concerning the measures taken to confirm its status.

2.8 Plugging Contribution of the EF Supply Line Maintenance Valve

Based upon data in WASH-1400, Appendix III, all manual valves are lumped into one statistical figure for the primary failure mode which is 3×10^{-4} to 3×10^{-5} per demand and is based upon plugging. This range is primarily based upon globe valves which are more prone to plugging than other manual valves.

The upper bound assessed value for the type butterfly valve utilized in the Emergency Feedwater System should be lower because plugging cannot take place in butterfly valves as frequently as in globe valves due to inherent design. A change of flow with varying velocity as found in globe-type valves creates an environment where debris and other foreign material may accumulate near the seating surfaces and affect the opening or closing action or cause plugging. An unavailability of 3×10^{-5} due to plugging was assigned.

2.9 EF Delivery Requirements

Consistent with the most recent thermal hydraulic analysis to date, adequate primary loop cooling is achieved with a minimum of one half capacity motor driven pump or one full capacity turbine driven pump on loss of main feedwater transient providing no main steam or feedwater line break has occurred.

2.10 Pump Flow Recirculation

Failure to establish EF pump recirculation has been included in the reliability assessment. However, this area is believed to be mainly of concern when approaching Hot Standby where EFS flow is continually throttled back.

2.11 Control Circuit Definition

Motor and valve control circuits are defined analogously to those appearing in the WASH-1400 AFWS analysis and includes the starter control circuit, power to the start control, DC bus, breaker coils, breaker contacts, and power and control cables.

2.12 Undetected Loss of CST

This quasi-basic event affects the ability of the EFS during startup by placing a rapid demand on the automatic switchover to the SW backup supply which precludes any operator intervention. Tank rupture, tornado-induced catastrophic failure and undetected maintenance error during plant operation were considered. A value of 7×10^{-7} was used in the assessment.

2.13 Power Source Availability

All AC sources were assumed available for the LMF case. For the LMF/LOSP case one diesel generator set was assumed to fail to start and accept load with a probability of 1×10^{-2}; the second diesel generator set was assigned a start and load acceptance failure probability of zero.

3.0 SYSTEM DESCRIPTION

3.1 Overall Configuration

A diagram of the V. C. Summer EFS is shown in Figure 1. The system consists of two feedwater trains, one supplied by two half-capacity motor-driven pumps(MDP) and one by a full-capacity steam turbine-driven pump (TDP), all with a common suction source. Either of the trains can supply sufficient emergency feedwater to any of the three steam generators.

3.2 Fluid System

3.2.1 Suction

The primary water source for the EFS is the condensate storage tank (CST). Of the tank's 500,000-gallon storage capacity, 150,000 gallons are available exclusively to the EFS.

A common suction header for all three EFS pumps is supplied through a 10" line from the CST. This line has a manual valve which is locked open*, and is provided with an audible alarm in the Control Room. The line from the suction header to each EF pump has a check valve and a manual locked-open valve.*

The backup supply is the Service Water System which is automatically actuated by pressure sensors (two-out-of-four logic) in the common suction line downstream of the locked-open manual valve from the CST. Service Water Loop A can supply the "A" MDP and the TDP. Service Water Loop B can supply the "B" MDP and the TDP. There is a normally closed motor-operated valve in each loop before the pump suction lines as well as a normally closed motor-operated valve and a check valve in the suction line of each pump. The motor-operated valves are isolation valves capable of both manual (local and remote) and automatic operation.

* Status of this valve indicated in CR and TSC as part of BISI.

3.2.2 Pumps and Discharge Headers

There are two discharge headers, one connected to the TDP and the other to the MDP's. The discharge line from each pump to the header has a check valve and a locked-open, manually operated isolation valve.* The TDP is rated at 570 gpm including recirculation at a steam generator pressure of 1211 psig and each MDP is rated 440 gpm including recirculation at a steam generator pressure of 1211 psig.

Each pump is provided with a recirculation path. This path consists of a check valve, a breakdown orifice and locked-open manual valve.* The recirculation line is sized 2" for each MDP and 3" for the TDP. Each recirculation line can pass the required pump minimum flow of 100 gpm. The recirculation lines discharge to a 4" recirculation header which returns the recirculation flow to the CST through a check valve.

The TDP and MDP discharge headers each split into three flow paths, one for each steam generator. Each flow path has a locked-open manual valve,* a flow control valve* and a locked-open stop check valve.* Downstream of the stop check valve, the flow paths from the TDP and MDP discharge headers combine to form one EF line to each steam generator. The common line to each steam generator contains a pneumatically operated spring-assisted check valve which serves as a containment isolation valve and two check valves near each steam generator nozzle to limit the effects of a pipe break.

3.2.3 Flow Control Valves

Two normally open pneumatically operated flow control valves* are provided for each steam generator; one valve controls flow from the MDP's, the other controls TDP flow. Remote manual/automatic control of the flow control valves is from the Control Room with provision for local manual operation. Safety class air accumulators with sufficient

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* Status of this valve indicated in CR and TSC as part of BISI.

capacity to ensure valve closure for approximately three hours in the case of a secondary line break are provided for the valves. The flow control valves fail open on loss of electric power or control air.

3.2.4 Steam Supply for the TDP Turbine

The steam supply to the TDP consists of a connection taken from the safety class sections of each of two Main Steam lines (from Steam Generators B and C) upstream of the Main Steam isolation valves. Two connections are provided to obtain redundancy of supply in the event of a Main Steam line break. Each connection has a check valve and a motor-operated gate valve for positive isolation in the event of Main Steam line break. A normally closed, fail open, pneumatically operated steam inlet valve[*] which pneumatically fails safe upon loss of AC or control air and is opened from 2 logic trains in automatic switchover, is provided in the common line to the turbine, which then connects to a turbine trip and throttle valve.

3.2.5 Valve Operation and Indication

All motor-operated valves are AC powered from Class 1E buses, are controllable from and have their position indicated in the control room. Position indication and control for each valve is from the valve motor power source.

The pneumatically operated flow control valves can be manually controlled from the control room or the control room evacuation panel. Audible and visual alarms will be activated and repeated at sixty-minute intervals whenever an emergency feedwater flow control valve control switch is not in the auto position (valve is open when control switch is in the auto position). Flow control in manual control (e.g., closed during EF pump test) will go to the full, wide-open position upon automatic initiation (excluding main feedwater pump trip) of the EFS.

[*] Status of this valve indicated in CR and TSC as part of BISI.

Locked-open valves critical to system successful functioning and several normally closed valves are monitored on the Bypass and Inoperable Station Indication (BISI) system. An input entry to the BISI computer is made whenever a valve is placed into a position contrary to successful system function. This record is displayed on the control room and technical support center CRT.

3.3 Support Systems and Backup Water Source

The EFS pumps, pump motors, and turbine are all independent of support systems such as plant cooling systems. The turbine can operate without air or electrical power. Motor cooling and turbine lubrication oil cooling are accomplished using EF flow.

In addition to the minimum of 150,000 gallons reserve in the CST, any extra inventory of water in the CST and makeup from the 500,000-gallon Demineralized Water Storage Tank (DWST) is available to the EFS. In the present design, the manual action required to connect the backup water source, i.e., Service Water to the EF suction, is the remote manual opening of 6 MOV's. The operator has 20 minutes after the sounding of the CST low-low levels to accomplish this switchover. If this is not accomplished, automatic switchover to the SW is initiated by sensing in the common suction header from the CST downstream of the locked-open manual valve. This signal automatically activates the motor-operated valves in the SW supply lines to the MDP's and the TDP using 2 of 4 sensor logic to the two separate SW trains.

3.4 Electrical Power Sources

A simplified diagram showing electrical power distribution to major EFS components is shown in Figure 2. AC power for EFS components necessary to establish emergency feedwater flow is derived from diesel generator backed 7200 V buses 1DA and 1DB. Normally (Case 1), these buses are supplied from offsite power through the switchyard. However, in the event of LMF/LOSP (Case 2), the diesel generators start automatically and ESF loads are connected in Engineered Safety Features Loading Sequence (ESFLS) Step 5. Service water also remains available in this case if the CST source is unavailable. Service water is connected in ESFSL Step 3 ten seconds before initiation of the EFS pumps. At a predetermined pressure, the decreasing pressure in the EFS header initiates the transfer of EF source from the Service Water System with approximately twenty seconds of water remaining in the header.

In the event of LMF/LAC (Case 3), EFS is still adequately operable because startup and operation of the TDP is not AC dependent.

3.5 Instrumentation and Control

3.5.1 Initiation Logic

A functional logic diagram for EFS initiation is shown in Figure 3. The diagram is simplified and does not show the redundancy, independence, and divisional separation of the hardware.

The MDP's will start on low-low level in any one steam generator, Safety Injection Signal, or undervoltage on either ESF Bus or loss of all three main feedwater pumps. The feedwater pump trip signal is a non Class 1E electrical anticipatory start signal. The TDP starts on low-low level in any two steam generators or undervoltage on both ESF buses.

The control logic shown in Figure 3 is powered from battery-backed buses.

3.5.2 EFS Flow Control

The flow of emergency feedwater to each steam generator from the MDP's or the TDP can be controlled by air-operated flow control valves. Flow rates through the valves to the steam generators can be manually adjusted individually by hand controllers at either the main control board or the Control Room Evacuation Panel (CREP). On EFS initiation logic that starts either the MDP's (except feedwater pump trip) or the TDP, the corresponding flow control valve for each steam generator will receive an open signal regardless of its position. Upon reset at the valve control switch the operator can regain flow control.

A high flow signal, such as in the event of a secondary line break, automatically closes the respective valve.

3.5.3 Instrumentation

In addition to the valve position indication previously described, the following EFS parameters are indicated in the Control Room:

- Pressure in the common feed line to each steam generator
- Suction pressure at each pump
- Level in the CST
- Flow in the common feed line to each steam generator

3.6 Operator Actions

Assuming the CST is available, no operator actions are required to establish EFS flow in Cases 1, 2 or 3. If the CST is not available initially, or if the CST level has been depleted after EFS operation for several hours, operator action, backed up by automatic switch-over, establishes service water supply to the EFS or replenish CST inventory as required.

3.7 Testing

Each EF Pump is tested once a month to demonstrate operability. Pump testing is accomplished by closing the appropriate FCV's from the TDP or MDP headers. If the EFS is initiated, the FCV's will open; therefore, no EF pump is unavailable due to testing. When this test is performed, it is also verified that each nonautomatic valve in the flow path that is not locked, sealed or otherwise secured in position, is in its correct position and that each automatic valve in the flow path is in the fully open position whenever the EFS is placed in automatic control.

At least once every 18 months during shutdown, the EFS is tested to verify that each pump starts automatically and upon receipt of each EF actuation test signal.

3.8 Technical Specifications

Technical specifications require:

1. All three EF pumps and associated flow paths to be operable whenever the reactor is in Mode 1, 2, or 3. With one pump inoperable, three pumps shall be made operable within 72 hours or the reactor should be brought to at least Hot Standby within the next 6 hours and to hot shutdown within the following 6 hours.

2. Both independent service water loops be operable whenever the reactor is in Mode 1, 2, 3, or 4. With only one service water loop operable, restore at least two loops to operable status within 72 hours or be in at least Hot Standby within the next 6 hours and in Cold Shutdown within the following 30 hours.

3. The condensate storage tank shall be operable containing a minimum volume of 150,000 gallons of water. With the condensate storage tank inoperable, within 4 hours either:

   a. Restore the CST to OPERABLE status or be in at least HOT STANDBY within the next 6 hours and in HOT SHUTDOWN within the following 6 hours, or

b. Demonstrate the OPERABILITY of the service water system as a backup supply to the emergency feedwater pumps and restore the condensate storage tank to OPERABLE status within 7 days or be in at least HOT STANDBY within the next 6 hours and in HOT SHUTDOWN within the following 6 hours.

4.0 RELIABILITY ASSESSMENT

4.1 Fault Tree Approach

Fault tree analysis was used to assess system unavailability to a demand. In this assessment unavailability is taken as being synonomous with unreliability. This approach is consistent with NUREG-0611 and the Reactor Safety Study (WASH-1400).

The analysis primarily considered the automatic initiation of the V. C. Summer EFS combined with test and maintenance-induced failures. Limited operator backup actions in the event of partial automatic startup failures were included in the assessment. These actions were in general limited to those actions that could be performed within the first five minutes of EFS initiation. In-plant corrective actions such as turning an incorrectly positioned valve were not explicitly considered because valve alignment, locking, checklist and position monitoring procedures provided adequate flow path availability compared to other more dominant system failure contributors. NUREG-0611 generic short- and long-term recommendations currently complied with or to be implemented (see Section 5.0) have been included in the fault tree and/or event data selection where appropriate.

The LMF fault tree appears in Appendix A. The top event in the tree is failure to achieve the minimum success criterion defined earlier in Section 2.1. The tree branches downward and is stopped at levels corresponding to the resolution of the available data. At this level there are usually basic event circles.

Major tree branches consist of those failures affecting EF flow supply (pump train oriented) and the flow path to the steam generators. The EF flow supply failure branches dominate system unavailability with common mode and maintenance-related failures being major contributors. The interrelationship between component failure, tech spec maintenance outages and human error are developed in terms of the tree logic. The degree of development is consistent with the reliability assessment goals and data available in NUREG-0611.

Modifications were made to the LMF tree of Appendix A for assessing the LMF/LOSP and LMF/LAC scenarios. Hand calculations were performed for each of the three feedwater transient cases to obtain values for EFS unavailability.

4.2 Comparative Reliability Assessment with NUREG-0611

Figure 4 presents the results of this reliability assessment for the V. C. Summer EFS where the demand unavailability has been determined from the constructed fault trees.

The range of AFWS unavailability for 25 currently licensed units with Westinghouse NSSS is shown on this figure for comparative purposes. The basic format for Figure 4, including characterization of Low, Medium and High reliability, was adopted from Table III-5 of NUREG-0611. Because of basic limitations in the data and intended scope of this assessment and those performed as part of the NUREG-0611 effort, calculated unavailabilities are shown in comparative form only. Numerical values permitting construction of Figure 4 were obtained from Reference 3. Note the direct cross-comparisons of the LMF/LAC case with Cases 1 and 2 cannot be made because the scale on Figure 4 encompasses differing orders of magnitude; the LMF and LFM/LOSP magnitude scales are identical.

4.3 Failure Contributors to EFS Unavailability

4.3.1 Case 1 - LMF

Dominant factors resulting in EFS unavailability at startup include:

1. A single point vulnerability was identified in that the EFS suction header condensate valve (#1010) in the closed position at EFS initiation will likely lead to pump failure. This item is the single most important contributor to EFS unavailability.

A related single point failure can occur if a loss of CST head occurs such that the reaction time required for the operator to manually initiate transfer to the SWS is not available. In this case failure of the automatic switchover would result in similar failure of the pumps. However, probability of occurrence is so small as to have no credible effect on the results of the study.

2. Preventive maintenance outages on the EF pumps account for the greatest contribution to system unavailability. An MDP in maintenance presents a greater restriction on EF availability than the TDP in maintenance.

3. Motor circuit start failures dominate individual MDP failure.

4. Contributors to TDP failure were maintenance errors on the lube oil cooling system and failure to locally reset the turbine after trip.

5. Mispositioned pump suction isolation valves can lead to pump damage at startup.

   Mispositioned pump discharge valves will result in either insufficient or no flow to the MDP or TDP header, respectively. Pump recirculation and flow instrumentation are available allowing control room diagnosis of the problem without pump destruction occurring. Operator correction of closed discharge valves were not considered in this analysis as discussed in Section 4.1. Header discharge valves and EF flow paths to the steam generators had no substantial effect on EFS unavailability. This is due to the normally open EF flow control valves and automatic opening whenever the valves are in manual control including during pump test.

4.3.2 Case 2 - LMF/LOSP

The failure contributors for this case are similar to those in Case 1. Loss of offsite power has no effect on the system availability when both diesel generators are available because all AC dependences are supplied by the ESF buses 1DA and 1DB.

Loss of one diesel generator reduces system availability because of the loss of an MDP. All other contributors remained unaffected.

4.4.4 Case 3 - LMF/LAC

The TDP train of the EFS is independent of all AC and air supplies. Primary contributors to the EFS unavailability of the TDP are those described in 4.3.1 above applicable to the steam turbine. These items include lube oil cooling and turbine reset failures, and turbine maintenance performed within Tech Spec limits.

5.0 RESPONSES TO GENERIC RECOMMENDATIONS

5.1 General

This section identifies short-term and long-term generic recommendations in terms of the concerns and the recommendation details, and indicates the specific responses for the V. C. Summer Plant.

5.2 Short-Term Generic Recommendations

5.2.1 Technical Specification Time Limit on AFW System Train Outage

Concern

Several of the plants reviewed have Technical Specifications that permit one of the AFW system trains to be out of service for an indefinite time period. Indefinite outage of one train reduces the defense-in-depth provided by multiple AFW system trains.

Recommendation GS-1

The licensee should propose modifications to the Technical Specifications to limit the time that one AFW system pump and its associated flow train and essential instrumentation can be inoperable. The outage time limit and subsequent action time should be as required in current Standard Technical Specifications; i.e., 72 hours and 12 hours, respectively.

Response

V.C. Summer Technical Specification 3.7.1.2 complies.

5.2.2 Technical Specification Administrative Controls on Manual Valves - Lock and Verify Position

Concern

Several of the plants reviewed use a single manual valve or multiple valves in series in the common suction piping between the primary water source and the AFW system pump suction. At some plants the valves are locked open, while at others, they are not locked in position. If the valves are inadvertently left closed, the AFW system would be inoperable, because the water supply to the pumps would be isolated. Since there is no remote valve position indication for these valves, the operator has no immediate means of determining valve position.

Further, the Technical Specifications for plants with locked-open manual valves do not require periodic inspection to verify that the valves are locked and in the correct position. For most plants where the valves are not locked open, valve position is verified on some periodic basis.

Recommendation GS-2

The licensee should lock open single valves or multiple valves in series in the AFW system pump suction piping and lock open other single valves or multiple valves in series that could interrupt all AFW flow. Monthly inspections should be performed to verify that these valves are locked and in the open position. These inspections should be proposed for incorporation into the surveillance requirements of the plant Technical Specifications. See Recommendation GL-2 for the longer-term resolution of this concern.

Response

See long-term item 5.4.2. (GL-2).

5.2.3 AFW System Flow Throttling-Water Hammer

Concern

Several of the plants reviewed apparently throttle down the AFW system initial flow to eliminate or reduce the potential for water hammer. In such cases, the overall reliability of the AFW system can be adversely affected.

Recommendation GS-3

The licensee has stated that it throttles AFW system flow to avoid water hammer. The licensee should reexamine the practice of throttling AFW system flow to avoid water hammer.

The licensee should verify that the AFW system will supply on demand sufficient initial flow to the necessary steam generators to assure adequate decay heat removal following loss of main feedwater flow and a reactor trip from 100% power. In cases where this reevaluation results in an increase in initial AFW system flow, the license should provide sufficient information to demonstrate that the required initial AFW system flow will not result in plant damage due to water hammer.

Response

The EF system is not throttled to avoid water hammer.

5.2.4 Emergency Procedures for Initiating Backup Water Supplies

Concern

Most of the plants do not have written procedures for transferring to alternate sources of AFW supply if the primary supply is unavailable or exhausted. Without specific criteria and procedures for an operator to follow to transfer to alternate water sources, the primary supply could be echausted and result in pump damage or a long interruption of AFW flow.

Recommendation GS-4

Emergency procedures for transferring to alternate sources of AFW supply should be available to the plant operators. These procedures should include criteria to inform the operators when, and in what order, the transfer to alternate water sources should take place. The following cases should be covered by the procedures:

(1) The case in which the primary water supply is not initially available. The procedures for this case should include any operator actions required to protect the AFW system pumps against self-damage before water flow is initiated.

(2) The case in which the primary water supply is being depleted. The procedure for this case should provide for transfer to the alternate water sources prior to draining of the primary water supply.

Response

South Carolina Electric and Gas Co. procedures provide criteria for transfer to the alternate water source in the above cases.

5.2.5 Emergency Procedures for Initiating AFW Flow Following a Complete Loss of Alternating Current Power

Concern

Some operating plants depend on ac power for all sources of AFW system supply, including the turbine-driven pump train. In the event of loss of offsite and onsite ac power, ac-dependent lube oil supply or lube oil cooling for the pump will stop, and/or manual actions are required to initiate AFW flow from the turbine-driven pump by manually opening the turbine steam admission valve and/or AFW system flow control valves. There are no procedures available to the plant operators for AFW system initiation and control under these conditions. This could result in a considerable time delay for AFW system initiation, since the operators would not be guided by procedures dealing with this event.

Recommendation GS-5

The as-built plant should be capable of providing the required AFW flow for at least two hours from one AFW pump train, independent of any ac power source. If manual AFW system initiation or flow control is required following a complete loss of ac power, emergency procedures should be established for manually initiating and controlling the system under these conditions. Since the water for cooling of the lube oil for the turbine-driven pump bearings may be dependent on ac power, design or procedural changes shall be made to eliminate this dependency as soon as practicable. Until this is done, the emergency procedures should provide for an individual to be stationed at the turbine-driven pump in the event of the loss of all ac power to monitor pump bearing and/or lube oil temperatures. If necessary, this operator would operate the turbine-driven pump in an on-off mode until ac power is restored. Adequate lighting powered by direct current (ac) power sources and communications at local stations should also be provided if manual initiation and control of the AFW system is needed. (See Recommendation GL-3 for the longer term resolution of this concern).

Response

See long-term item 5.4.3 (GL-3).

5.2.6 AFW System Flow Path Verification

Concern

Periodic testing of the AFW system is accomplished by testing of individual components of one flow train (periodic pump recirculation flow test or automatic valve actuation), thus altering the normal AFW system flow path(s). The flow capability of the entire AFW system, or at least one integral AFW system train, is only demonstrated on system demand following a transient, or if the AFW system is used for normal plant startup or shutdown.

Recent Licensee Event Reports indicate a need to improve the quality of system testing and maintenance. Specifically, periodic testing and maintenance procedures inadvertently result in (1) more than one AFW system flow train being unavailable during the test, or (2) the AFW system flow train under test not being properly restored to its operable condition following the test or maintenance work. The Office of Inspection and Enforcement has taken action to correct Item (1); the recommendation below is made to correct Item (2).

Recommendation GS-5

The licensee should confirm flow path availability of an AFW system flow train that has been out of service to perform periodic testing or maintenance as follows:

(1) Procedures should be implemented to require an operator to determine that the AFW system valves are properly aligned and a second operator to independently verify that the valves are properly aligned.

(2) The licensee should propose Technical Specifications to assure that, prior to plant startup following an extended cold shutdown, a flow test would be performed to verify the normal flow path from the primary AFW system water source to the steam generators. The flow test should be conducted with AFW system valves in their normal alignment.

Response

South Carolina Electric and Gas Co. procedures require that the EF system flow path be verified after it has been out of service to perform periodic testing or maintenance.

5.2.7 Non-Safety Grade, Non-Redundant AFW System Automatic Initiation Signals

Concern

Some plants with an automatically initiated AFW system utilize some initiation signals that are not safety-grade, do not meet the single failure criterion, and are not required by the Technical Specifications to be tested periodically. This can result in reduced reliability of the AFW system.

Recommendation GS-7

The licensee should verify that the automatic start AFW system signals and associated circuitry are safety-grade. If this cannot be verified, the AFW system automatic initiation system should be modified in the short-term to meet the functional requirements listed below. For the longer-term, the automatic initiation signals and circuits should be upgraded to meet safety-grade requirements, as indicated in Recommendation GL-5.

(1) The design should provide for the automatic initiation of the AFW system flow.

(2) The automatic initiation signals and circuits should be designed so that a single failure will not result in the loss of AFW system function.

(3) Testability of the initiation signals and circuits shall be a feature of the design.

(4) The initiation signals and circuits should be powered from the emergency buses.

(5) Manual capability to initiate the AFW system from the control room should be retained and should be implemented so that a single failure in the manual circuits will not result in the loss of system function.

(6) The ac motor-driven pumps and valves in the AFW system should be included in the automatic actuation (simultaneous and/or sequential) of the loads to the emergency buses.

(7) The automatic initiation signals and circuits shall be designed so that their failure will not result in the loss of manual capability to initiate the AFW system from the control room.

Response

See long-term item 5.4.5 (GL-5).

5.2.8 Automatic Initiation of AFW Systems

Concern

For plants with a manually initiated AFW system, there is the potential for fail of the operator to manually actuate the system following a transient in time to maintain the steam generator water level high enough to assure reactor decay heat removal via the steam generator(s). While IE Bulletin 79-06A requires a dedicated individual for W-designed operating plants with a manually initiated AFW system further action should be taken in the short-term. This concern is identical to Item 2.1.7a of NUREG-0578.(13)

Recommendation GS-8

The licensee should install a system to automatically initiate AFW system flow. This system need not be safety-grade; however, in the short-term, it should meet the criteria listed below, which are similar to Item 2.1.7.a of NUREG-0578.(13) For the longer-term, the automatic initiation signals and circuits should be upgraded to meet safety-grade requirements, as indicated in Recommendation GL-2.

(1) The design should provide for the automatic initiation of the AFW system flow.

(2) The automatic initiation signals and circuits should be designed so that a single failure will not result in the loss of AFW system function.

(3) Testability of the initiating signals and circuits should be a feature of the design.

(4) The initiating signals and circuits should be powered from the emergency buses.

(5) Manual capability to initiate the AFW system from the control room should be retained and should be implemented so that a single failure in the manual circuits will not result in the loss of system function.

(6) The ac motor-driven pumps and valves in the AFW system should be included in the automatic actuation (simultaneous and/or sequential) of the loads to the emergency buses.

(7) The automatic initiation signals and circuits should be designed so that their failure will not result in the loss of manual capability to initiate the AFW system from the control room.

Response

See long-term item 5.4.1 (GL-1).

5.3 Additional Short-Term Recommendations

5.3.1 Primary AFW Water Source Low Level Alarm

Concern

Plants which do not have level indication and alarm for the primary water source may not provide the operator with sufficient information to properly operate the AFW system.

Recommendation

The licensee should provide redundant level indication and low level alarms in the control room for the AFW system primary water supply, to allow the operator to anticipate the need to make up water or transfer to an alternate water supply and prevent a low pump suction pressure condition from occurring. The low level alarm setpoint should allow at least 20 minutes for operator action, assuming that the largest capacity AFW pump is operating.

Response

V.C. Summer has redundant level indication and low level alarms in the control room for the Condensate Storage Tank, the EF system primary water supply, as shown on FSAR Figure 10.4-16. The low level alarm setpoint allows at least 20 minutes for operator action, assuming that the largest capacity EF pump is operating.

5.3.2 AFW Pump Endurance Test

Concern

Since it may be necessary to rely on the AFW system to remove decay heat for extended periods of time, it should be demonstrated that the AFW pumps have the capability for continuous operation over an extended time period without failure.

Recommendation

The licensee should perform a 72 hour endurance test on all AFW system pumps, if such a test or continuous period of operation has not been accomplished to date. Following the 72 hour pump run, the pumps should be shut down and cooled down and then restarted and run for one hour. Test acceptance criteria should include demonstrating that the pumps remain within design limits with respect to bearing/bearing oil temperatures and vibration and that pump room ambient conditions (temperature, humidity) do not exceed environmental qualification limits for safety-related equipment in the room.

Response

A 72 hour endurance test on all EF pumps will be performed during startup testing.

5.3.3 Indication of AFW Flow to the Steam Generators

Concern

Indication of AFW flow to the steam generators is considered important to the manual regulation of AFW flow to maintain the required steam generator water level. This concern is identical to Item 2.1.7.b of NUREG-0578.(13)

Recommendation

The licensee should implement the following requirements as specified by Item 2.1.7.b on page A-32 of NUREG-0578:(13)

(1) Safety-grade indication of AFW flow to each steam generator should be provided in the control room.

(2) The AFW flow instrument channels should be powered from the emergency buses consistent with satisfying the emergency power diversity requirements for the AFW system set forth in Auxiliary Systems Branch Technical Position 10-1 of the Standard Review Plan, Section 10.4.9.

Response

Safety-grade, redundant indication of EF flow to each steam generator is provided in the control room. The EF flow instrument channels are powered from the emergency buses.

5.3.4 AFW System Availability During Periodic Surveillance Testing

Concern

Some plants require local manual realignment of valves to conduct periodic pump surveillance tests on one AFW system train. When such plants are in this test mode and there is only one remaining AFW system train available to respond to a demand for initiation of AFW system operation, the AFW system redundancy and ability to withstand a single failure are lost.

Recommendation

Licensees with plants which require local manual realignment of valves to conduct periodic tests on one AFW system train and which have only one remaining AFW train available for operation should propose Technical Specifications to provide that a dedicated individual who is in communication with the control room be stationed at the manual valves. Upon instruction from the control room, this operator would re-align the valves in the AFW system from the test mode to its operational alignment.

Response

The V.C. Summer plant does not require the realignment of local manual valves to conduct periodic tests on one EF system. The EF control valves may be operated from the control room to isolate the EF pumps for periodic testing.

5.4 Long-Term Generic Recommendations

5.4.1 Automatic Initiation of AFW Systems

Concern

This concern is the same as short-term generic recommendation GS-8; namely, failure of an operator to actuate a manual start AFW system in time to maintain steam generator water level high enough to assure reactor decay heat removal via the steam generator(s).

Recommendation GL-1

For plants with a manual starting AFW system, the licensee should install a system to automatically initiate the AFW system flow. This system and associated automatic initiation signals should be designed and installed to meet safety-grade requirements. Manual AFW system start and control capability should be retained with manual start serving as backup to automatic AFW system initiation.

Response

The V.C. Summer plant EF system is automatically initiated.

5.4.2 Single Valves in the AFW System Flow Path

Concern

This concern is the same as short-term generic recommendation GS-2; namely, AFW system inoperability due to an inadvertently closed manual valve that could interrupt all AFW system flow.

Recommendation GL-2

Licensees with plant designs in which all (primary and alternate) water supplies to the AFW systems pass through valves in a single flow path should install redundant parallel flow paths (piping and valves).

Licensees with plant designs in which the primary AFW system water supply passes through valves in a single flow path, but the alternate AFW system water supplies connect to the AFW system pump suction piping downstream of the above valve(s), should install redundant valves parallel to the above valve(s) or provide automatic opening of the valve(s) from the alternate water supply upon low pump suction pressure.

The licensee should propose Technical Specifications to incorporate appropriate periodic inspections to verify the valve positions into the surveillance requirements.

Response

In the EF system design the primary EF system water supply passes through a valve, 1010-EF, in a single flow path, but the alternate EF system water supply connects to the EF system pump suction piping downstream of the above valve. Automatic opening of the valves from the alternate water supply, Service Water System, upon low pump suction pressure is provided. Also, valve 1010-EF has a limit switch which, through the BISI system, is alarmed in the control room when it is not in the full open position.

Periodic inspections to verify the valve position will be incorporated into the surveillance requirements of the Technical Specifications.

5.4.3 Elimination of AFW System Dependency on Alternating Current Power Following A Complete Loss of Alternating Current Power

Concern

This concern is the same as short-term generic recommendation GS-5; namely, delay in initiation of AFW system operation or maintaining AFW system operation following a postulated loss of onsite and offsite ac power; i.e., ac power blackout.

Recommendation GL-3

At least one AFW system pump and its associated flow path and essential instrumentation should automatically initiate AFW System flow and be capable of being operated independently of any ac power source for at least two hours. Conversion of dc power to ac power is acceptable.

Response

The turbine driven EF pump and its associated flow path and essential instrumentation automatically initiate EF system flow and is capable of being operated independent of any ac power source for at least two hours.

5.4.4 Prevention of Multiple Pump Damage Due to Loss of Suction Resulting From Natural Phenomena

Concern

In many of the operating plants, the normal water supply to the AFW system pumps (including the interconnected piping) is not protected from earthquakes or tornadoes. Any natural phenomenon severe enough to result in a loss of the water supply could also be severe enough to cause a loss of offsite power with loss of main feedwater, resulting in an automatic initiation signal to start the AFW system pumps. The pumps would start without any suction head, leading to cavitation and multiple pump damage in a short period of time, possibly too short for the operators to take action that would protect the pumps. This may lead to unacceptable consequences for some plants, due to a complete loss of feedwater (main and auxiliary).

Recommendation GL-4

Licensees having plants with unprotected normal AFW system water supplies should evaluate the design of their AFW systems to determine if automatic protection of the pumps is necessary following a seismic event or a tornado. The time available before pump damage, the alarms and indications available to the control room operator, and the time necessary for assessing the problem and taking action should be considered in determining whether operator action can be relied on to prevent pump damage. Consideration should be given to providing pump protection by means such as automatic switchover of the pump suctions to the alternate safety-grade source of water, automatic pump trips on low suction pressure, or upgrading the normal source of water to meet seismic Category I and tornado protection requirements.

Response

Automatic switchover of the pump suctions to the alternate safety-grade source of water is being provided to provide protection for the EF pumps.

5.4.5 Non-Safety Grade, Non-Redundant AFW System Automatic Initiation Signals

Concern

This concern is the same as short-term generic recommendations GS-7 - namely, reduced AFW system reliability as a result of use of non-safety-grade, non-redundant signals, which are not periodically tested, to automatically initiate the AFW system.

Recommendation GL-5

The licensee should upgrade the AFW system automatic initiation signals and circuits to meet safety-grade requirements.

Response

The EF system automatic initiation signals and circuits are redundant and meet safety-grade requirements. In addition, a non-safety-grade, anticipatory signal, from a trip of all main feedwater pumps, is used to start the two motor driven emergency feedwater pumps.

REFERENCES

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

2. WASH-1400 (NUREG-75/014), "Reactor Safety Study," October 1975.

3. Various personal communications.

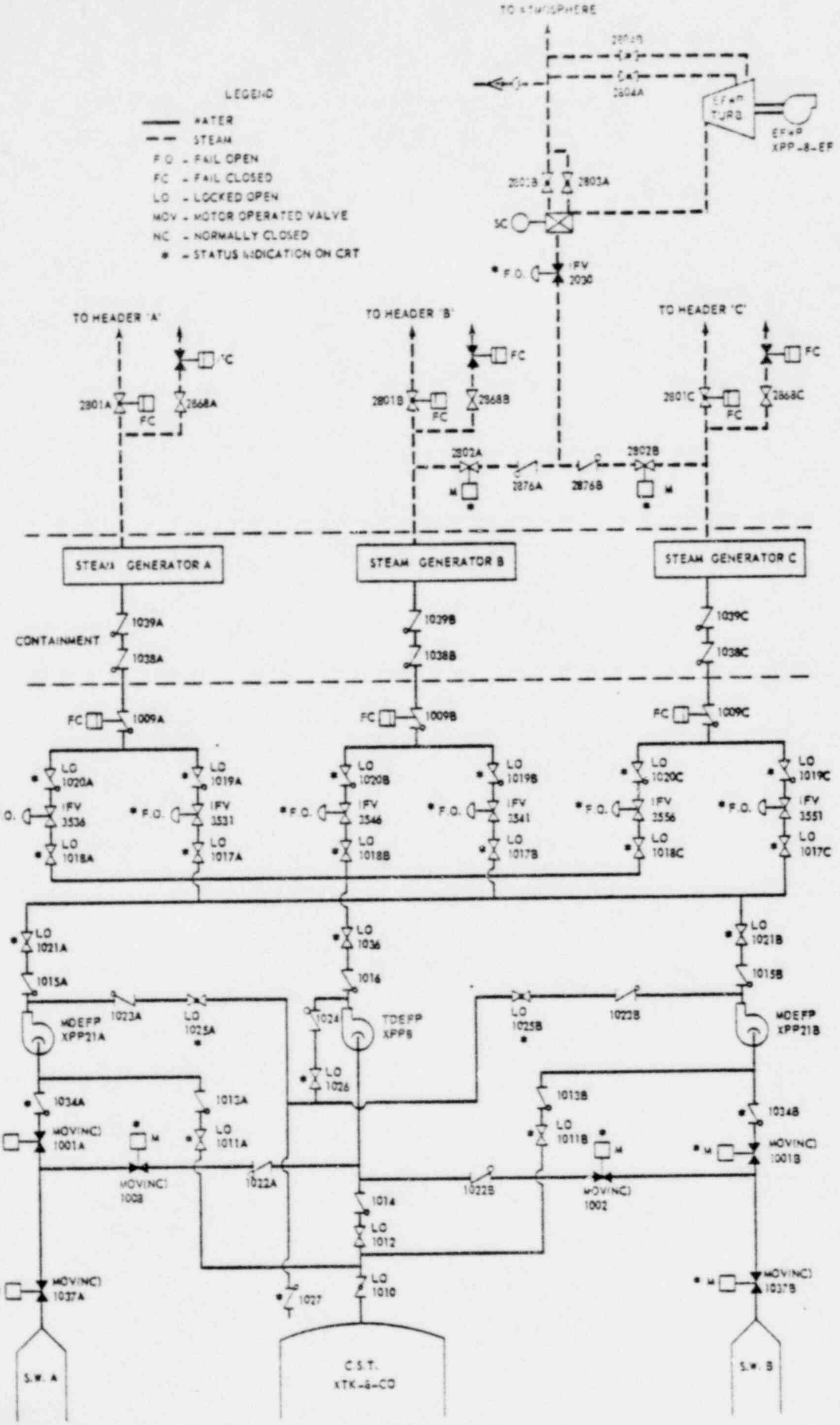


FIGURE 1   EFS FLOW SCHEMATIC

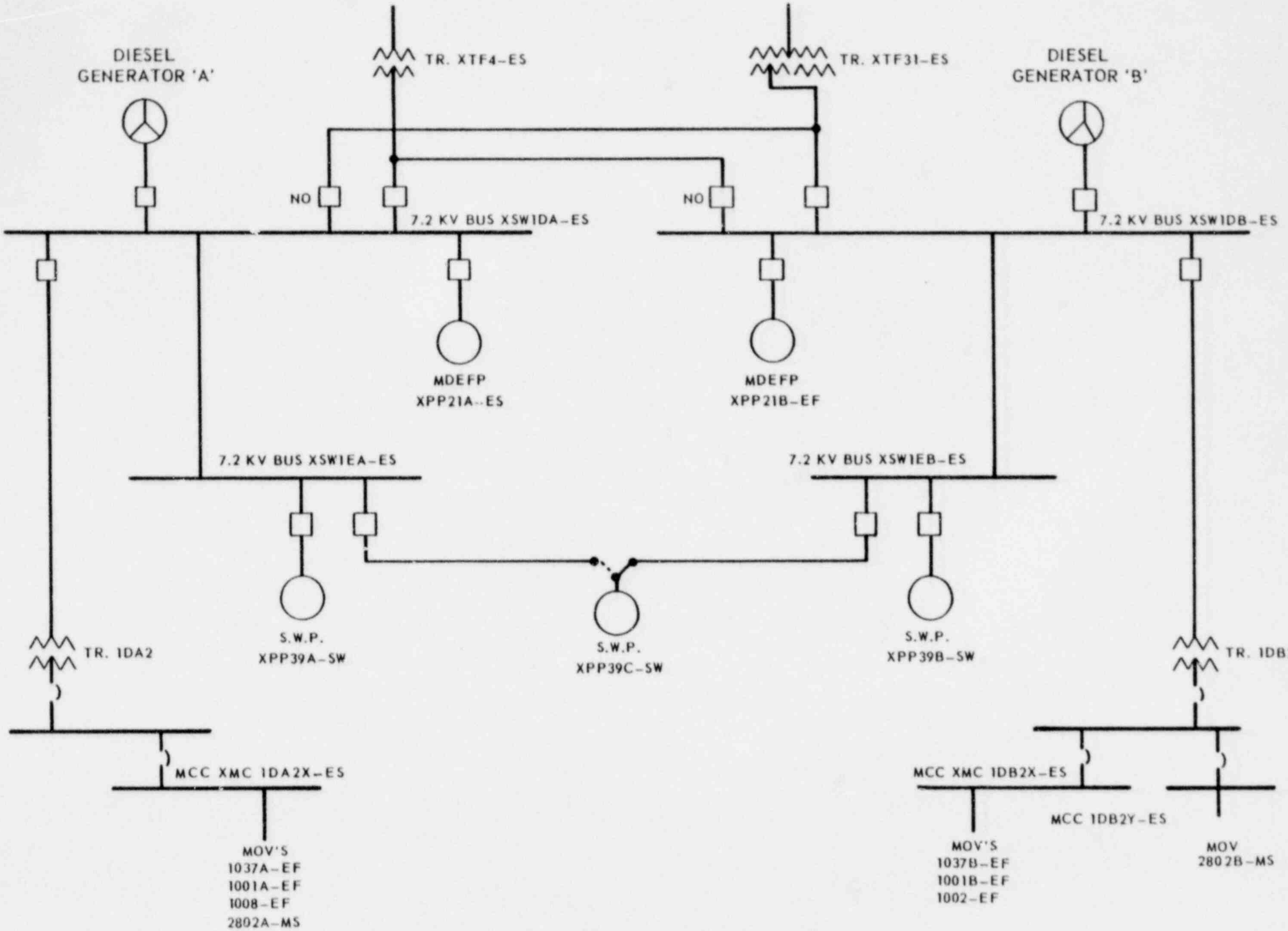


FIGURE 2 AC POWER DISTRIBUTION TO EFS COMPONENTS

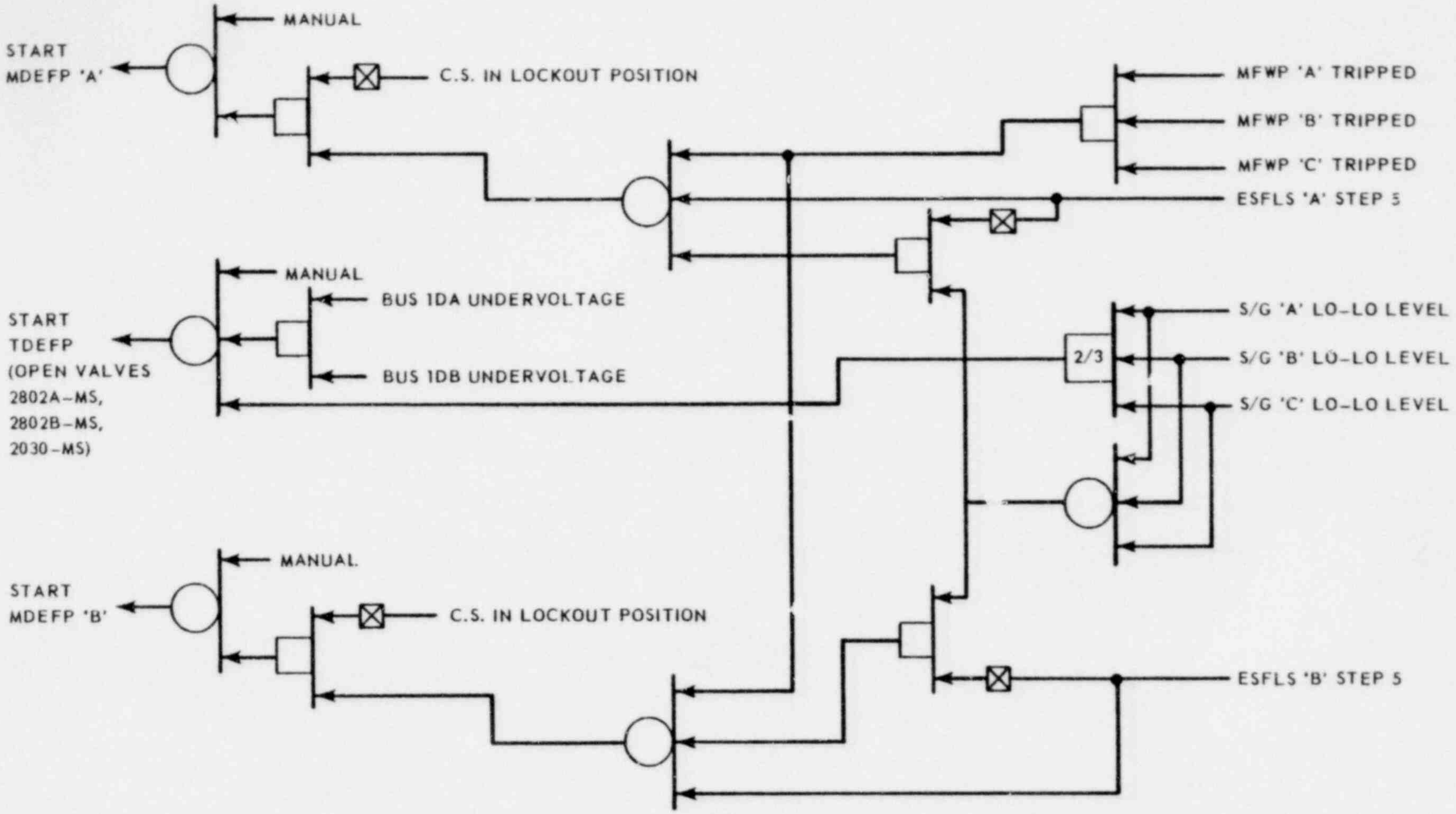
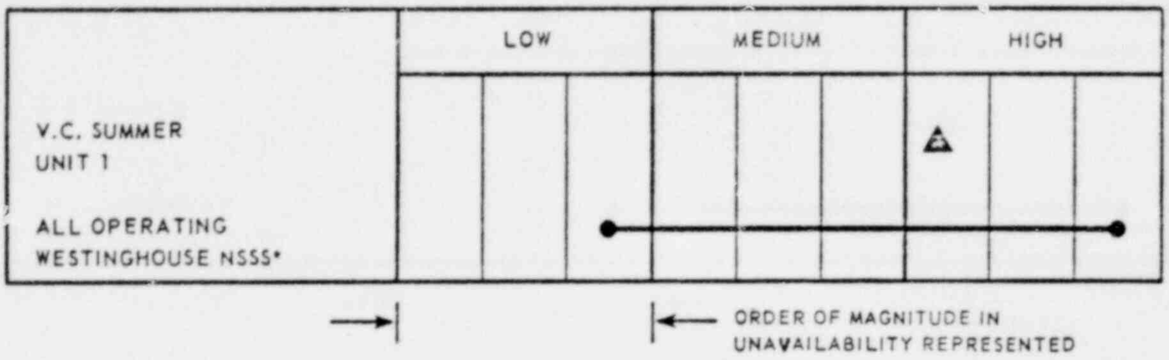
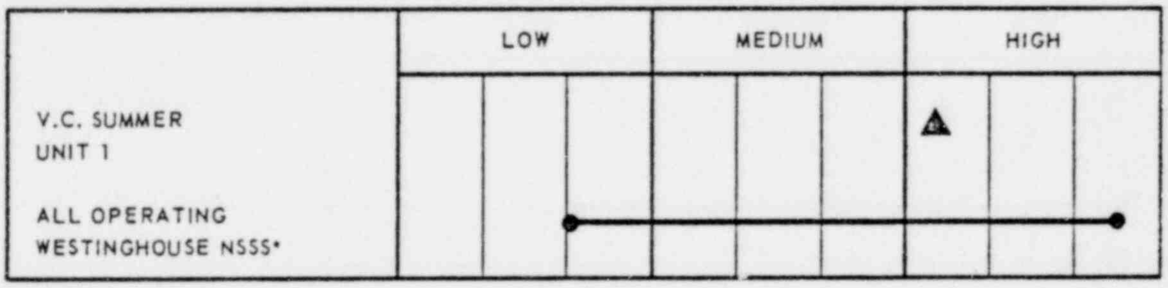


FIGURE 3 EFS INITIATION LOGIC

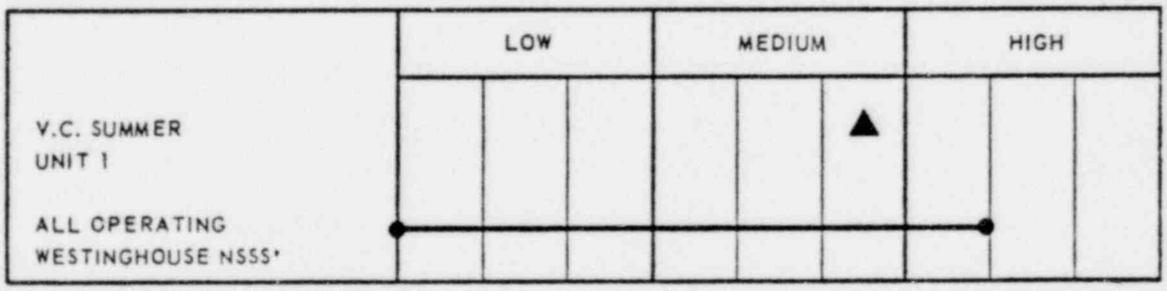
LOSS OF MAIN FEEDWATER (LMF)



LOSS OF MAIN FEEDWATER WITH LOSS OF OFFSITE POWER (LMF/LOSP)



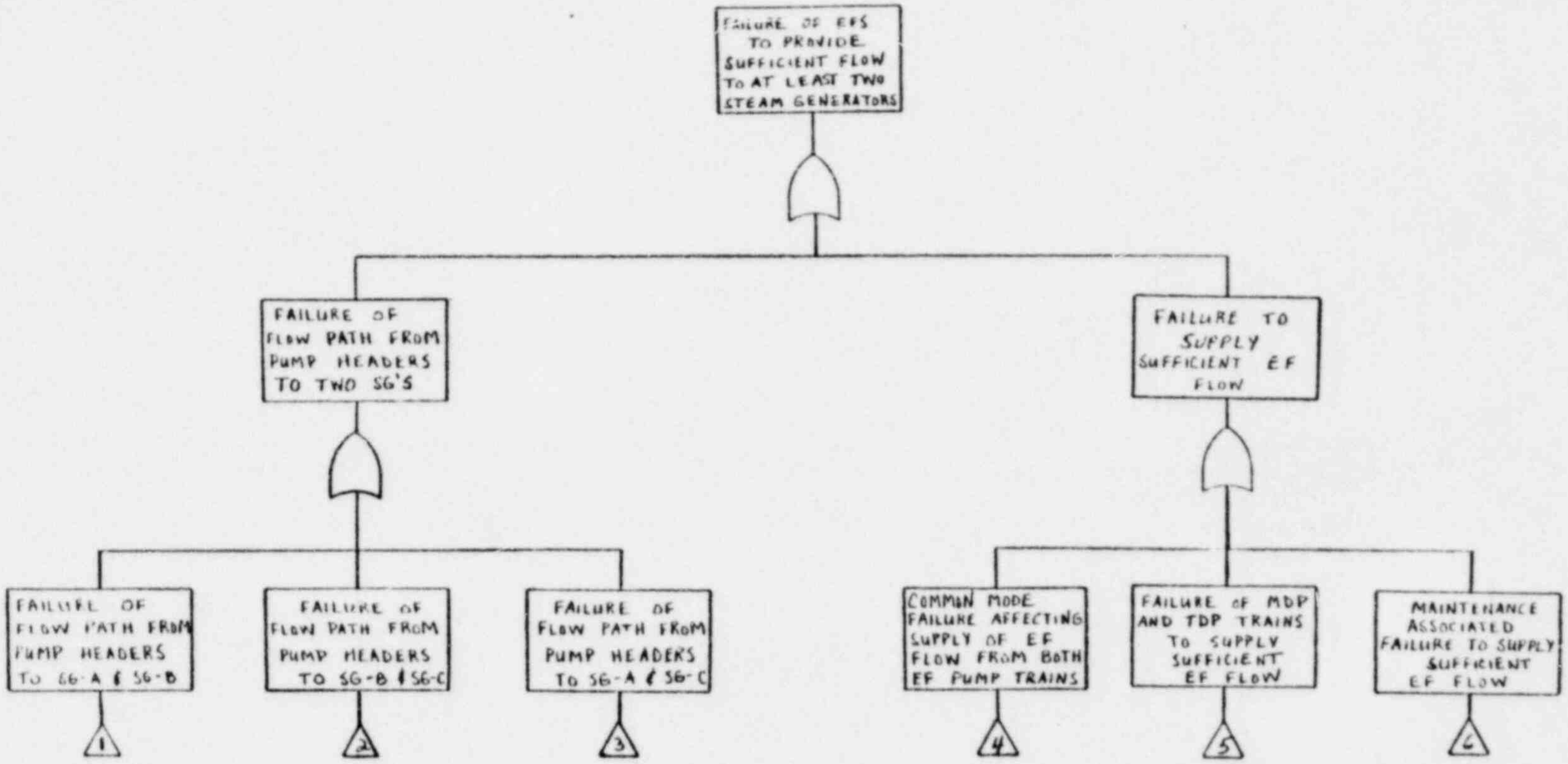
LOSS OF MAIN FEEDWATER WITH LOSS OF ALL AC** (LMF/LAC)



* RELIABILITY CHARACTERIZATIONS FOR AFWS DESIGNS IN PLANTS USING THE WESTINGHOUSE NSSS, FIGURE III-5, NUREG-0611.

** THE SCALE FOR THIS EVENT IS NOT THE SAME AS THAT FOR THE LMF AND LMF/LOSP CHARTS.

FIGURE 4
COMPARISON OF V.C. SUMMER UNIT 1 EFS
RELIABILITY WITH THAT OF OPERATING WESTINGHOUSE PLANTS



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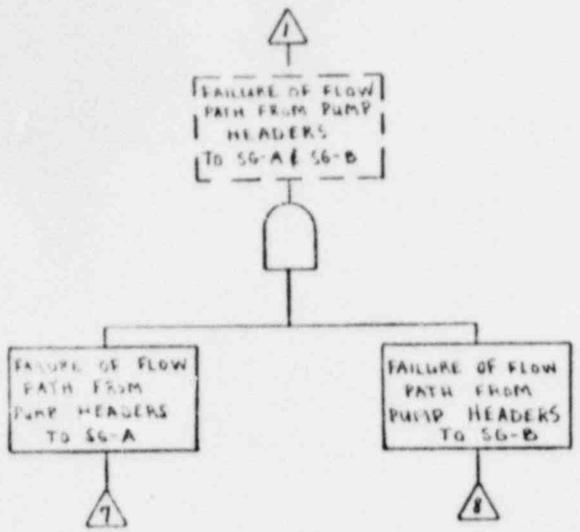

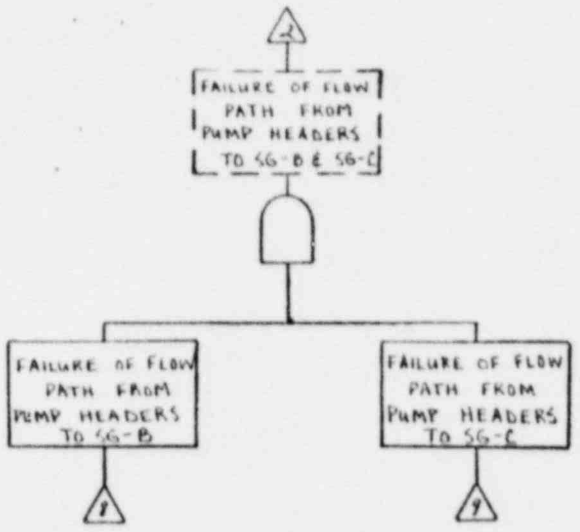

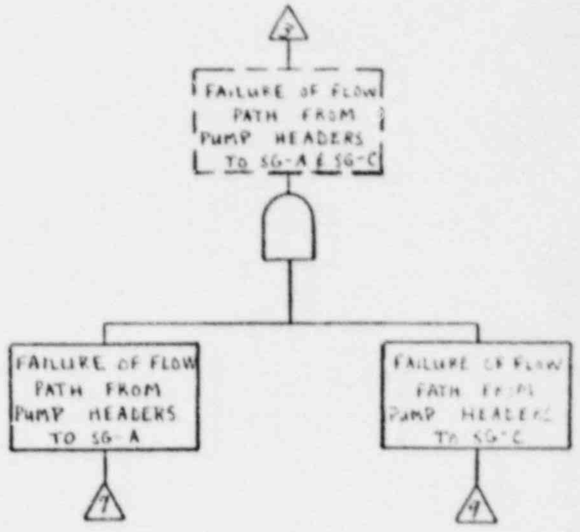

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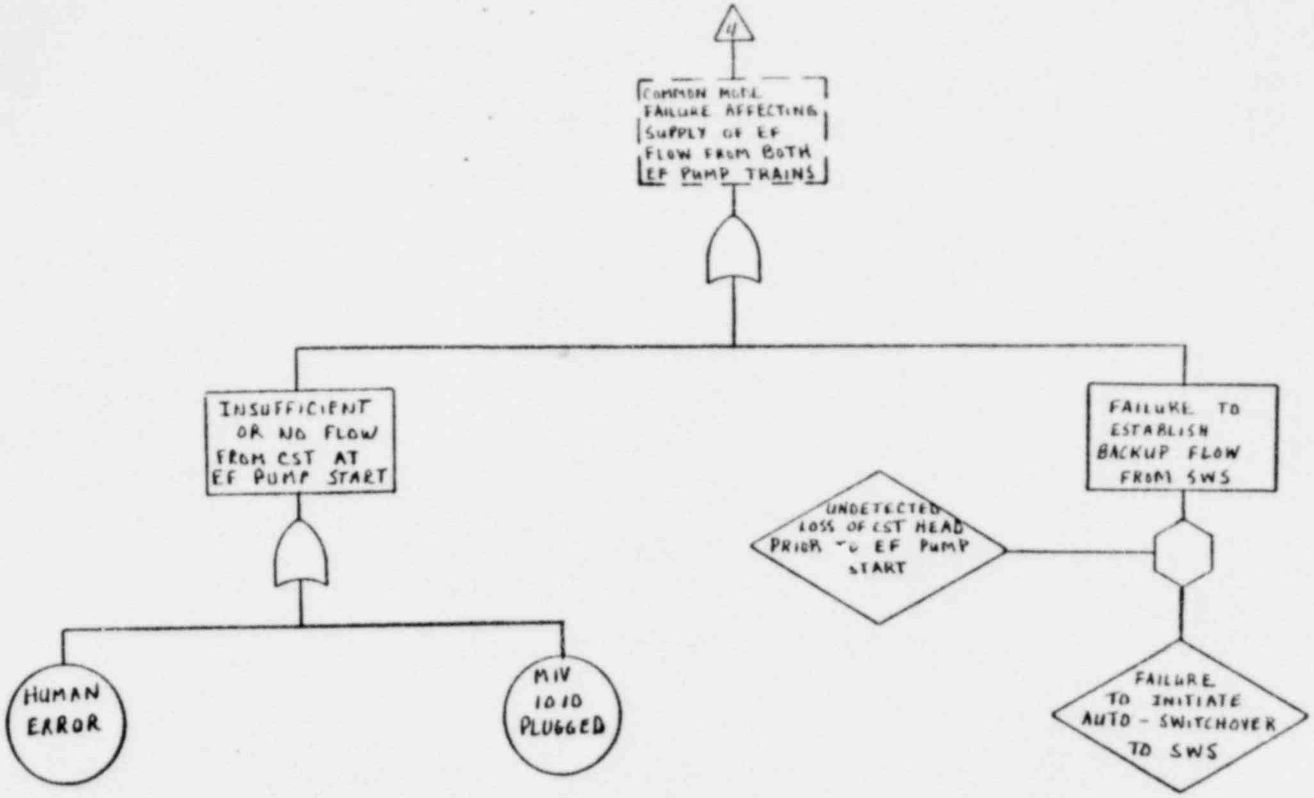
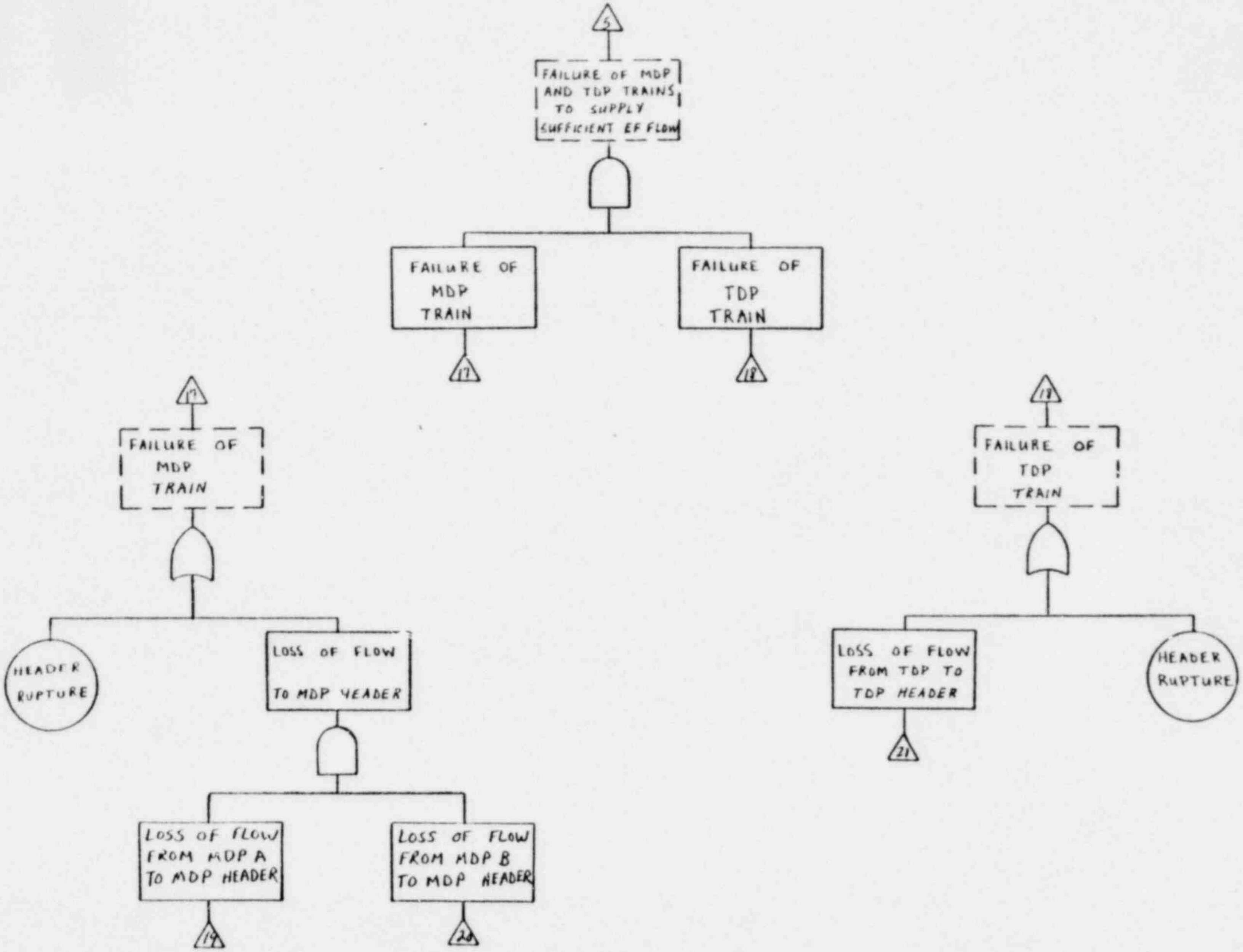

4
COMMON MODE FAILURE AFFECTING SUPPLY OF EF FLOW FROM BOTH EF PUMP TRAINS
INSUFFICIENT OR NO FLOW FROM CST AT EF PUMP START
FAILURE TO ESTABLISH BACKUP FLOW FROM SWS
UNDETECTED LOSS OF CST HEAD PRIOR TO EF PUMP START
HUMAN ERROR
MIV 1010 PLUGGED
FAILURE TO INITIATE AUTO - SWITCHOVER TO SWS



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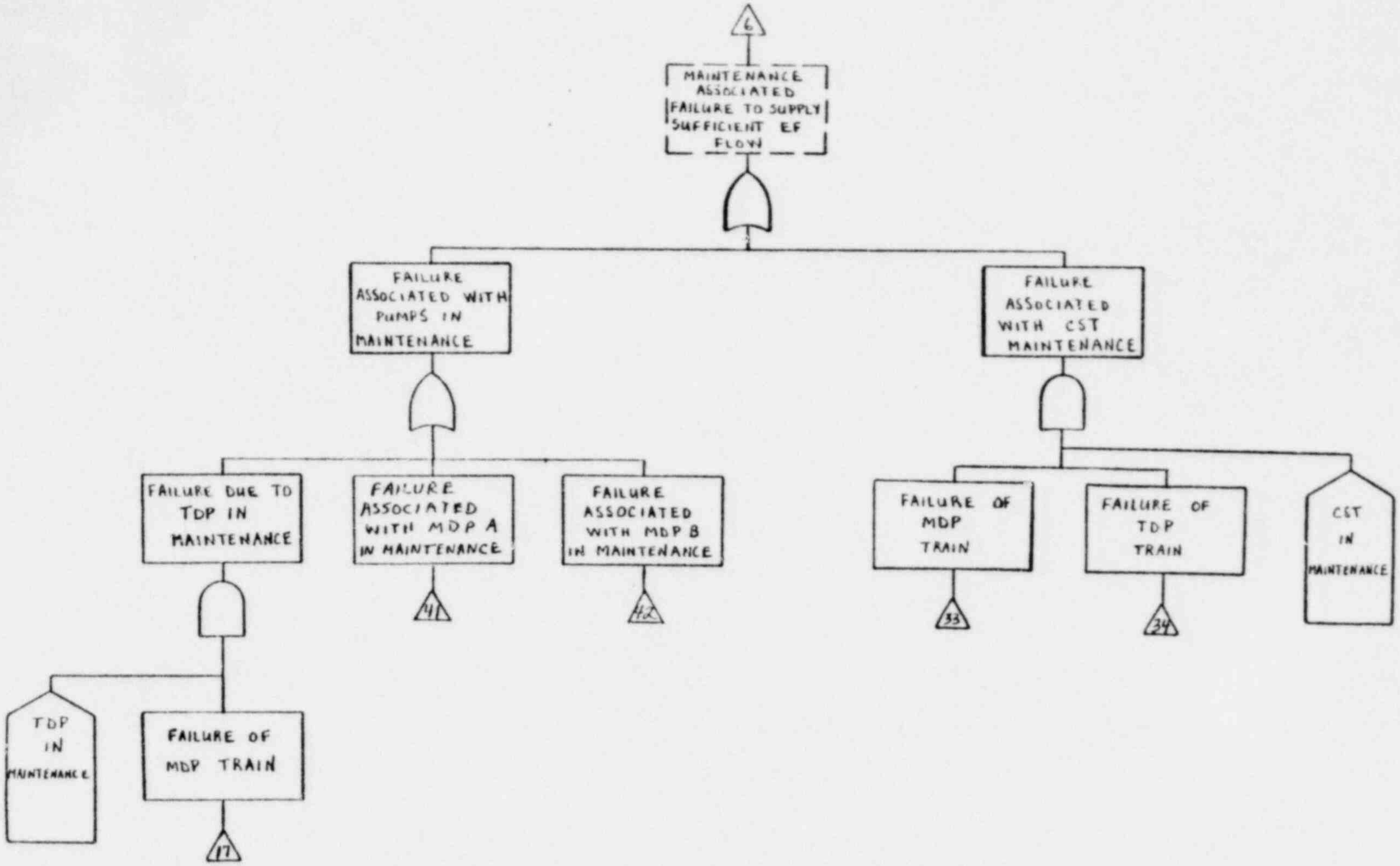

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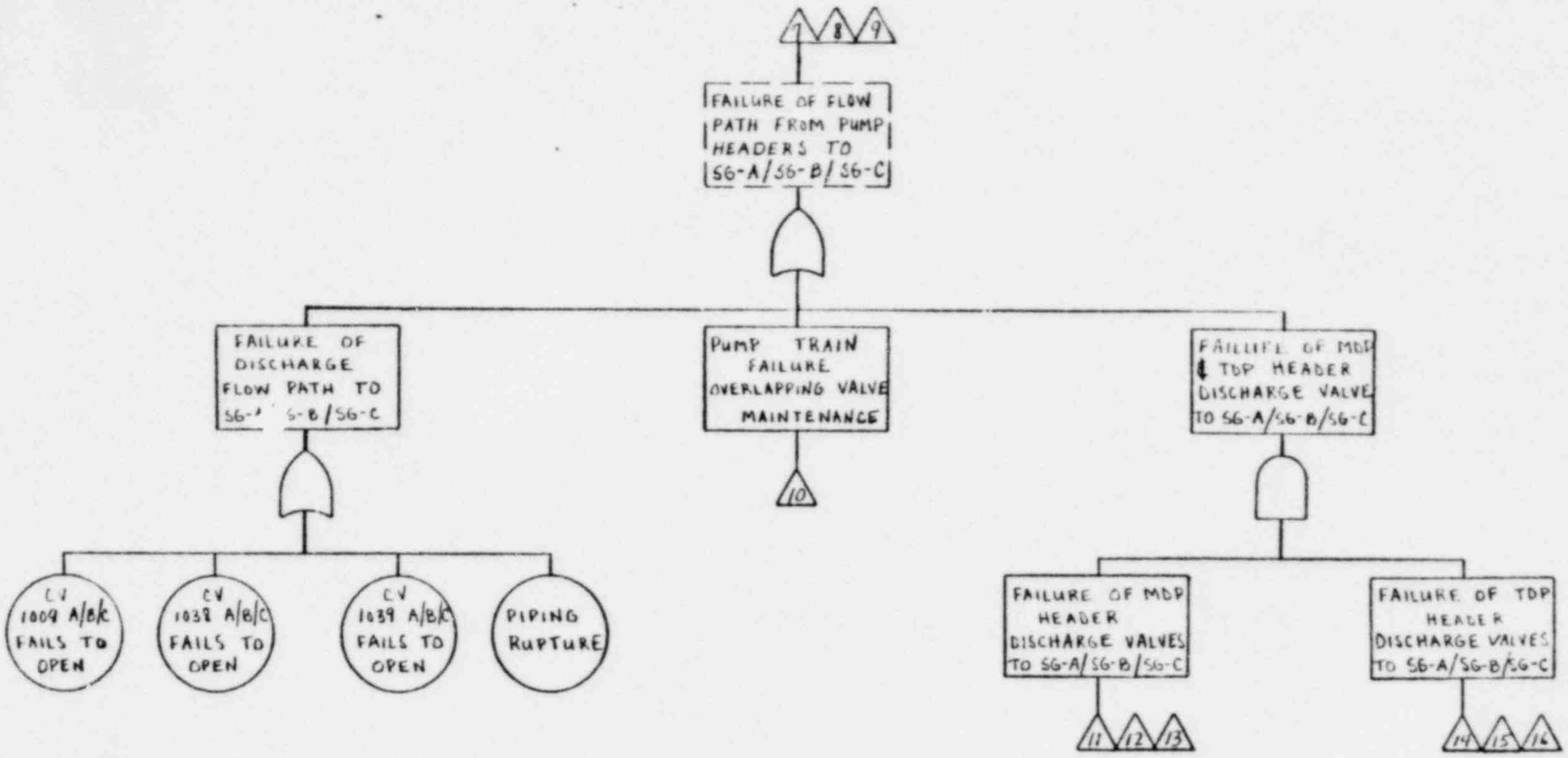

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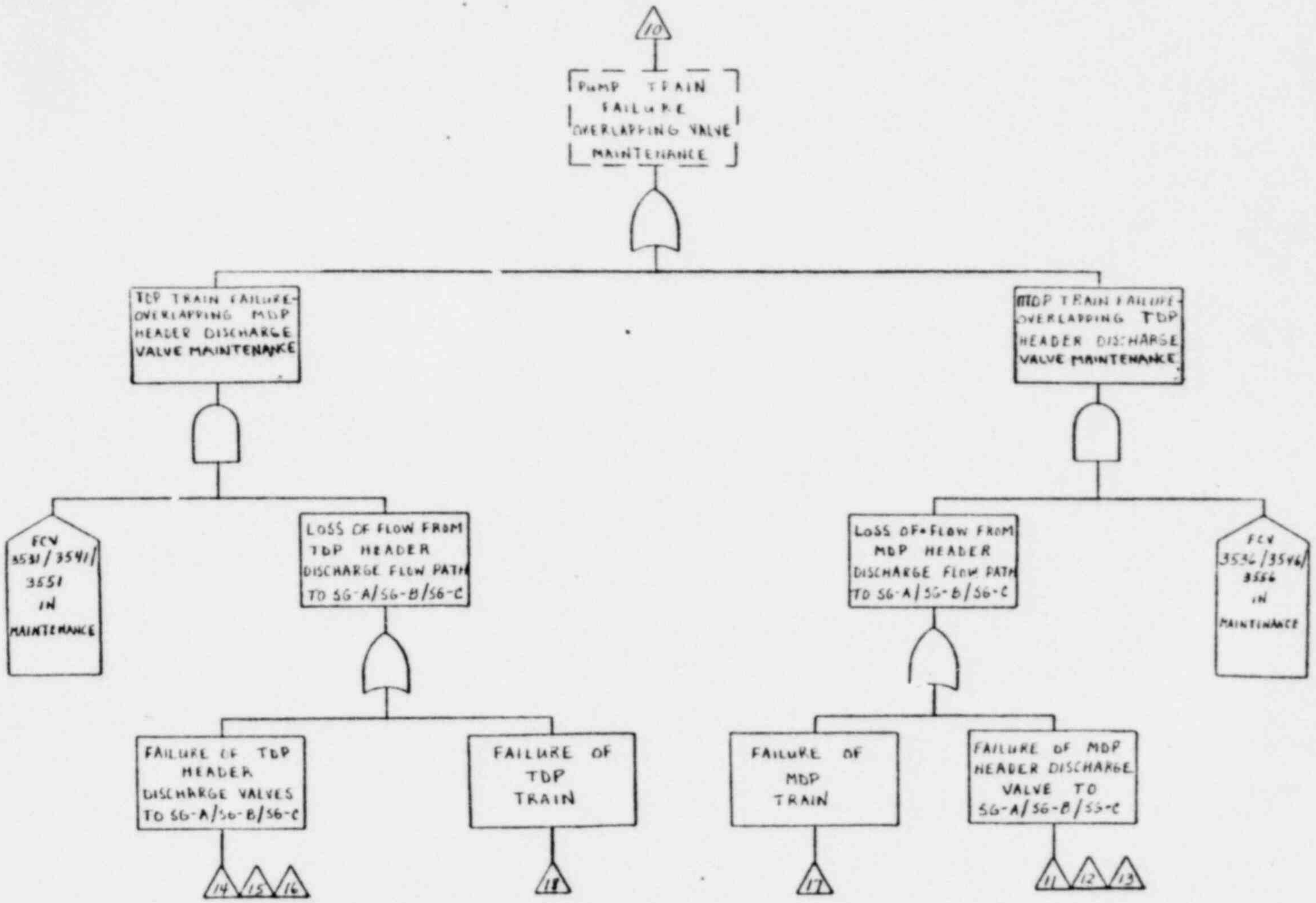

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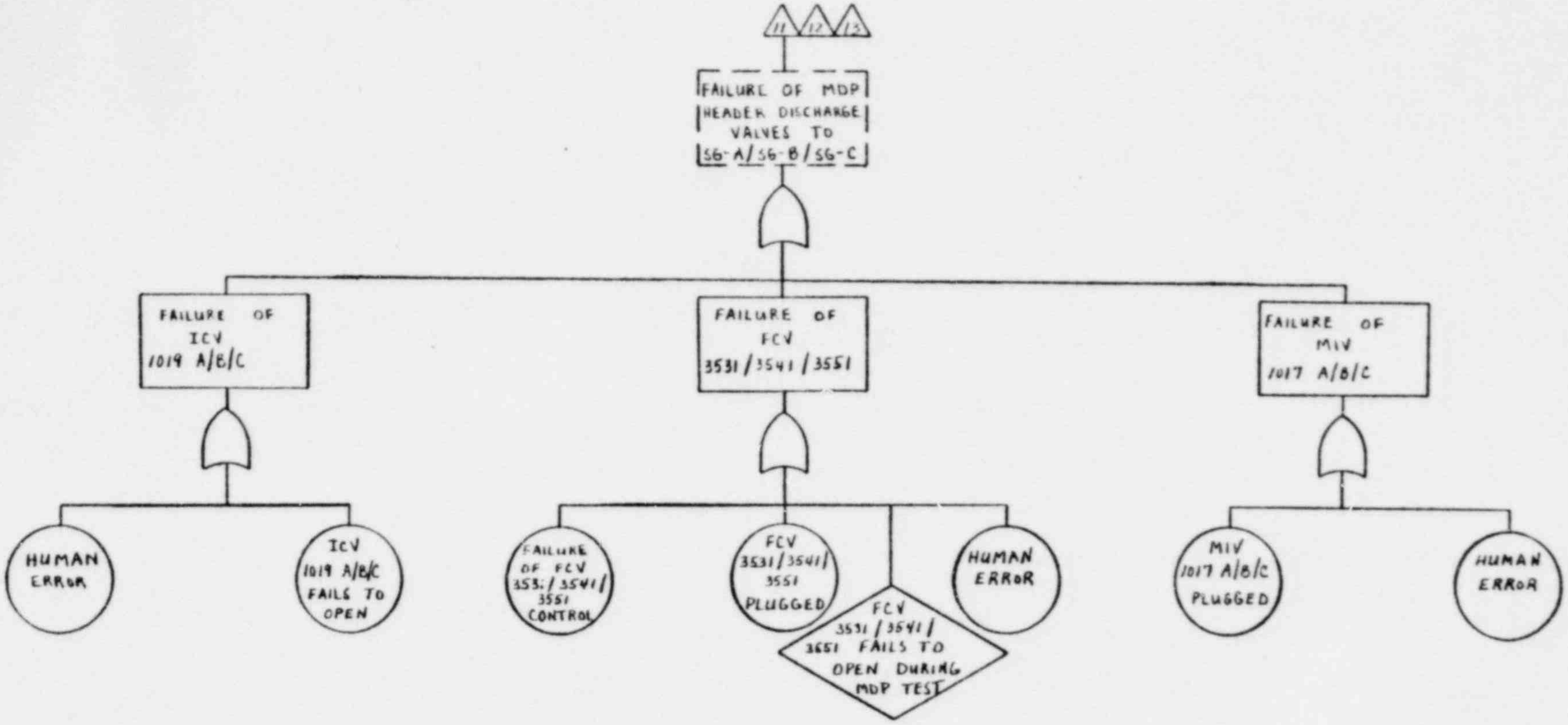
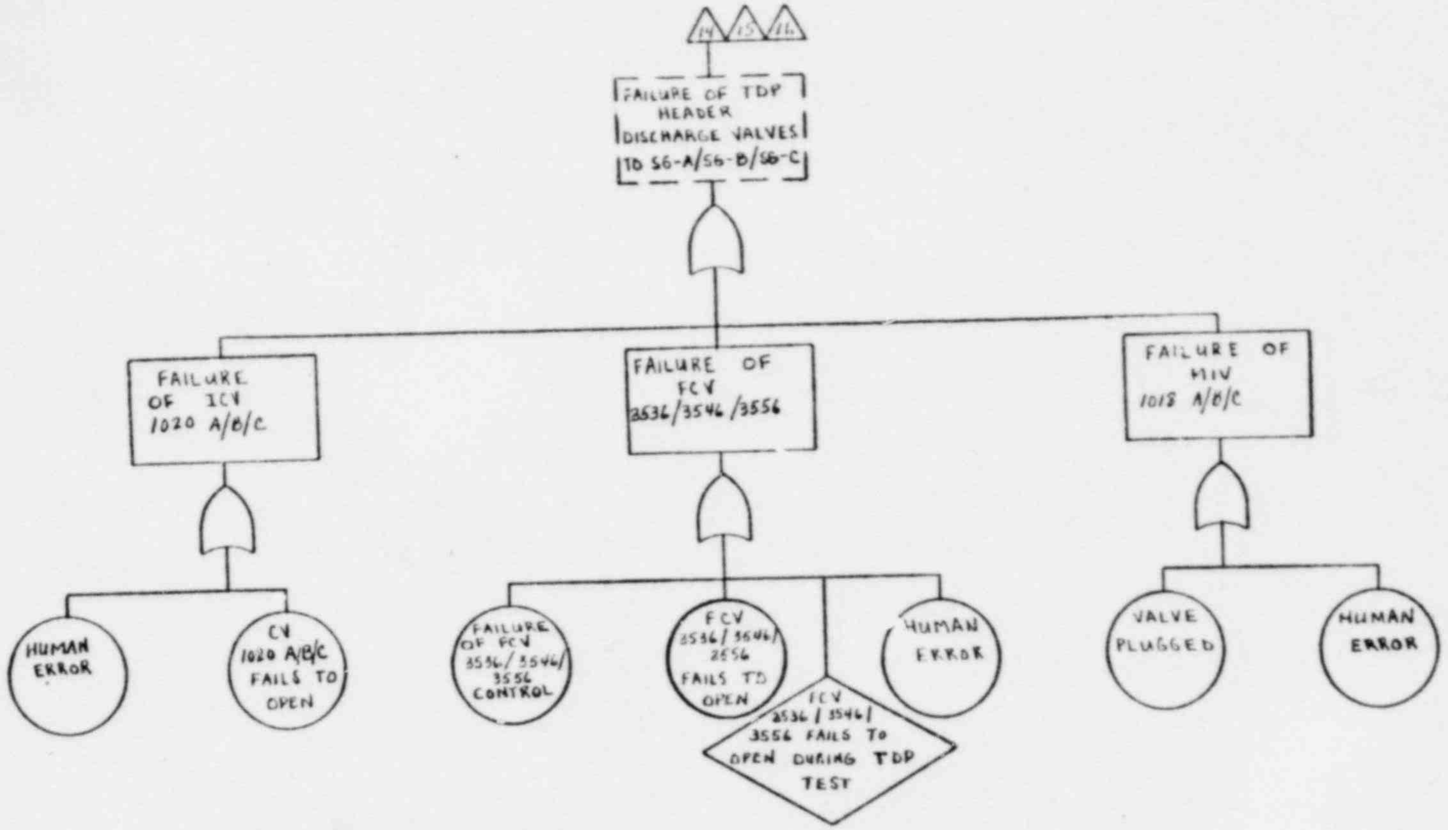

11
12
13
FAILURE OF MDP HEADER DISCHARGE VALVES TO SG-A/SG-B/SG-C
FAILURE OF ICV 1019 A/B/C
FAILURE OF FCV 3531/3541/3551
FAILURE OF MIV 1017 A/B/C
HUMAN ERROR
ICV 1019 A/B/C FAILS TO OPEN
FAILURE OF FCV 3531/3541/3551 CONTROL
FCV 3531/3541/3551 PLUGGED
FCV 3531/3541/3551 FAILS TO OPEN DURING MDP TEST
HUMAN ERROR
MIV 1017 A/B/C PLUGGED
HUMAN ERROR



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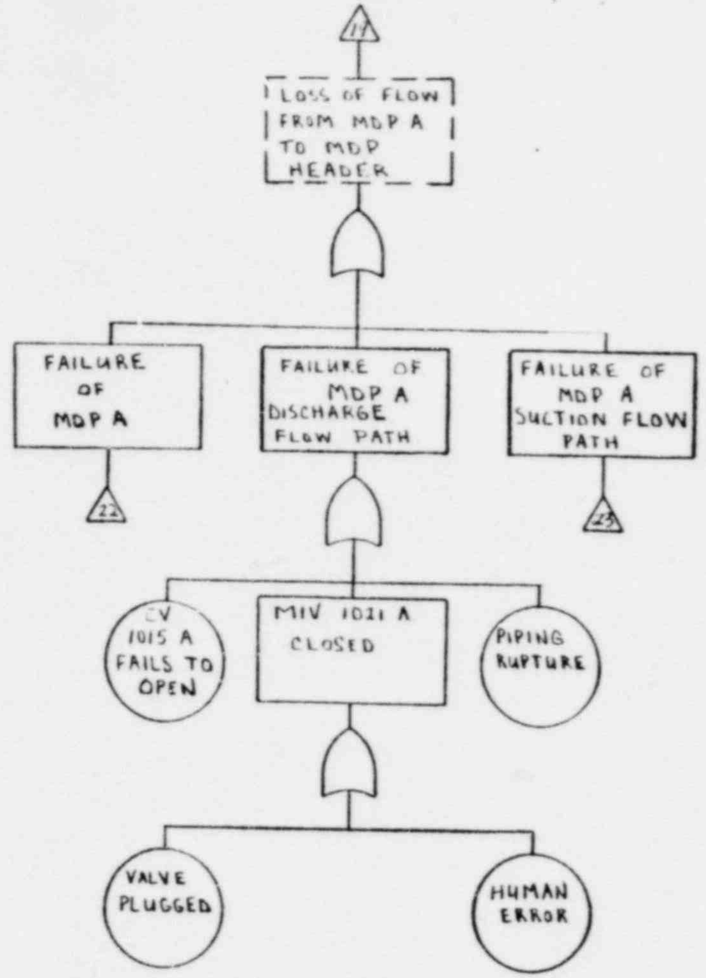

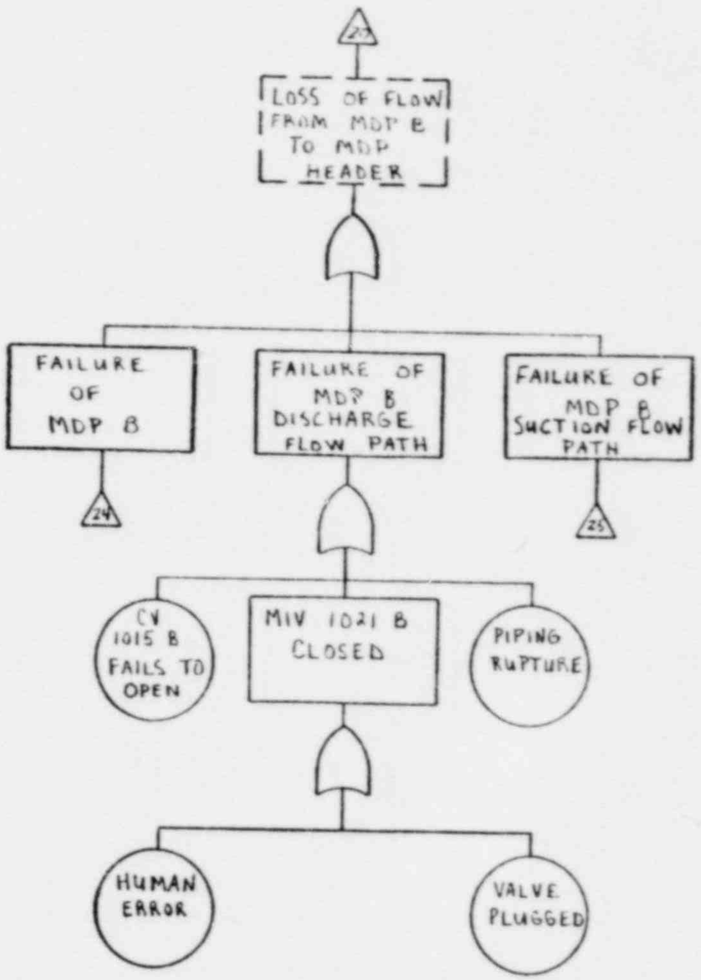

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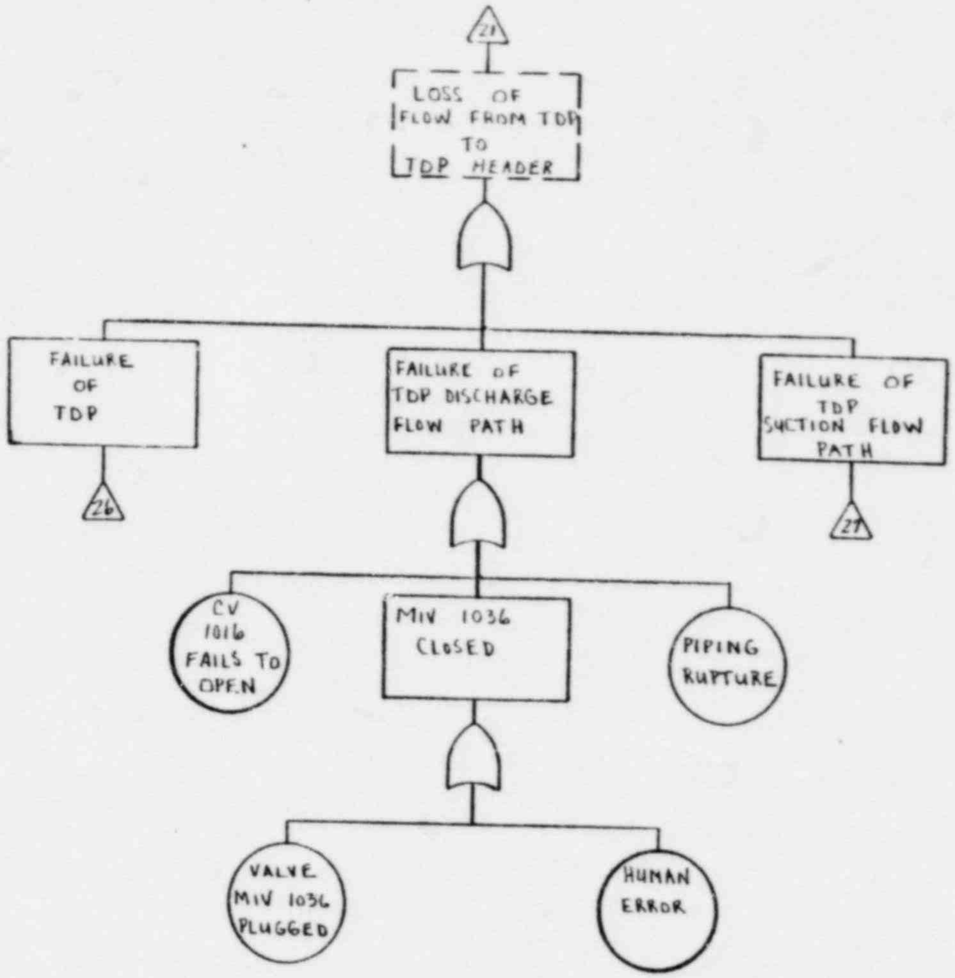
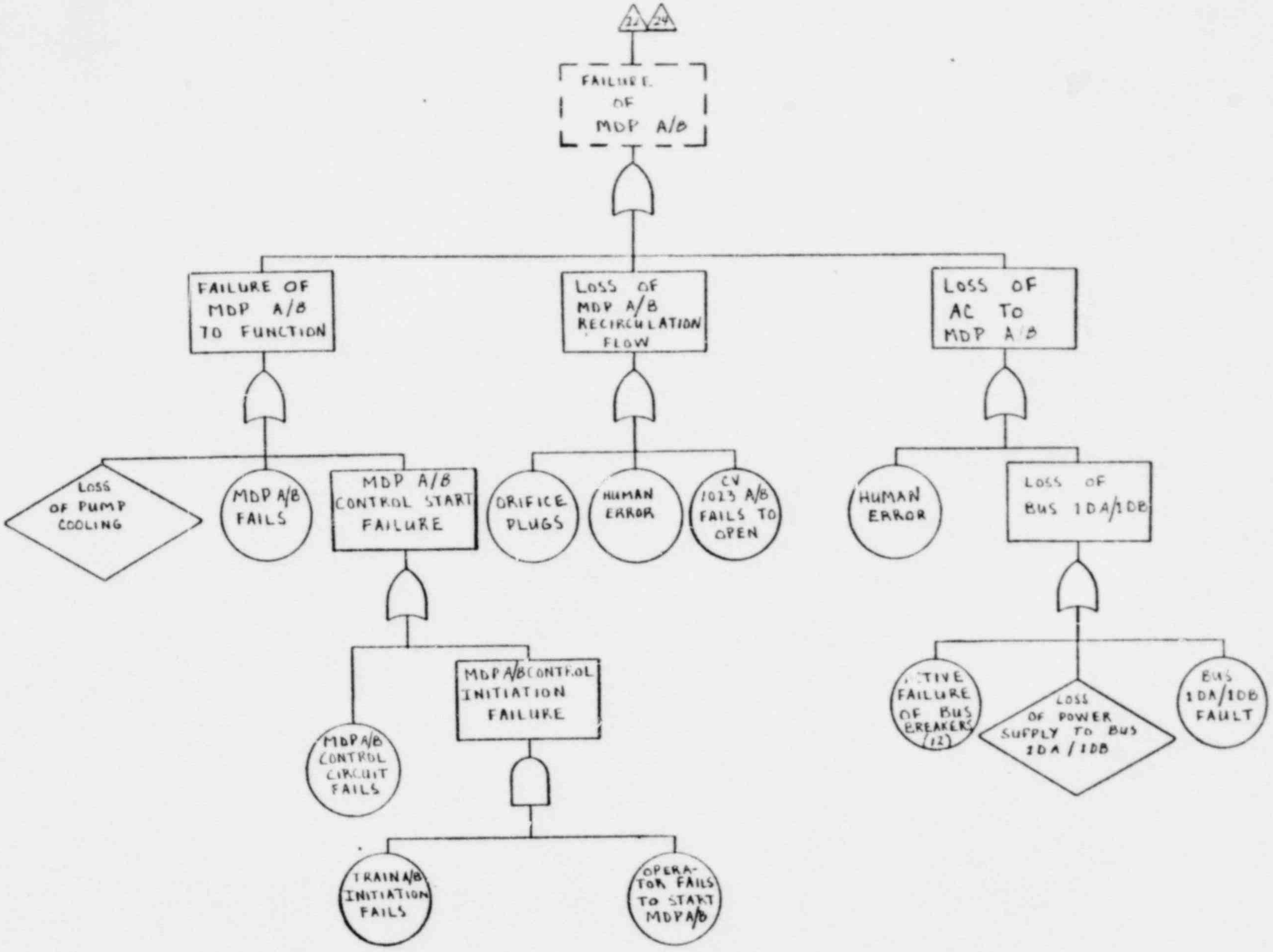

21
LOSS OF FLOW FROM TDP TO TDP HEADER
FAILURE OF TDP
26
FAILURE OF TDP DISCHARGE FLOW PATH
FAILURE OF TDP SUCTION FLOW PATH
27
CV 1016 FAILS TO OPEN
MIV 1036 CLOSED
PIPING RUPTURE
VALVE MIV 1036 PLUGGED
HUMAN ERROR



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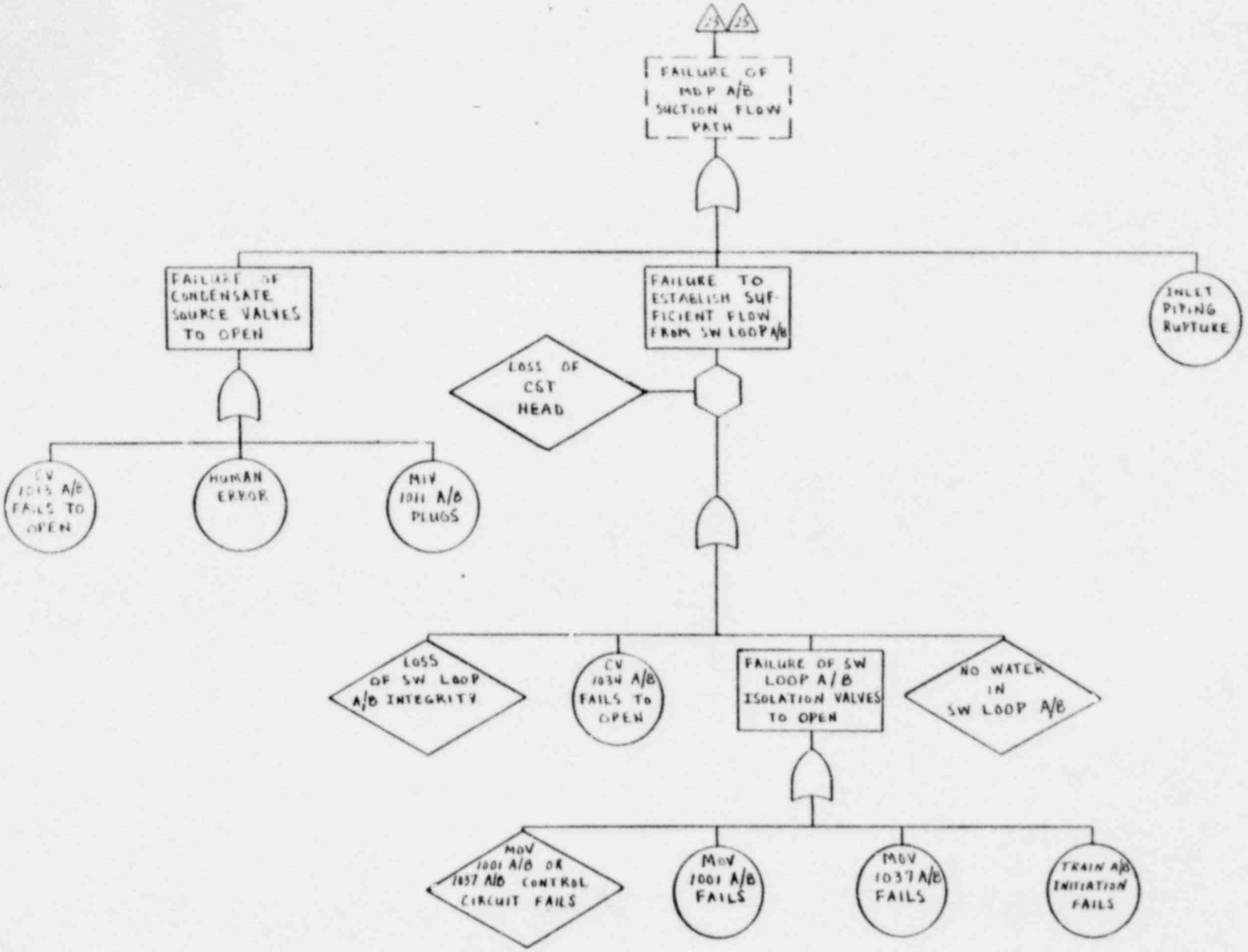

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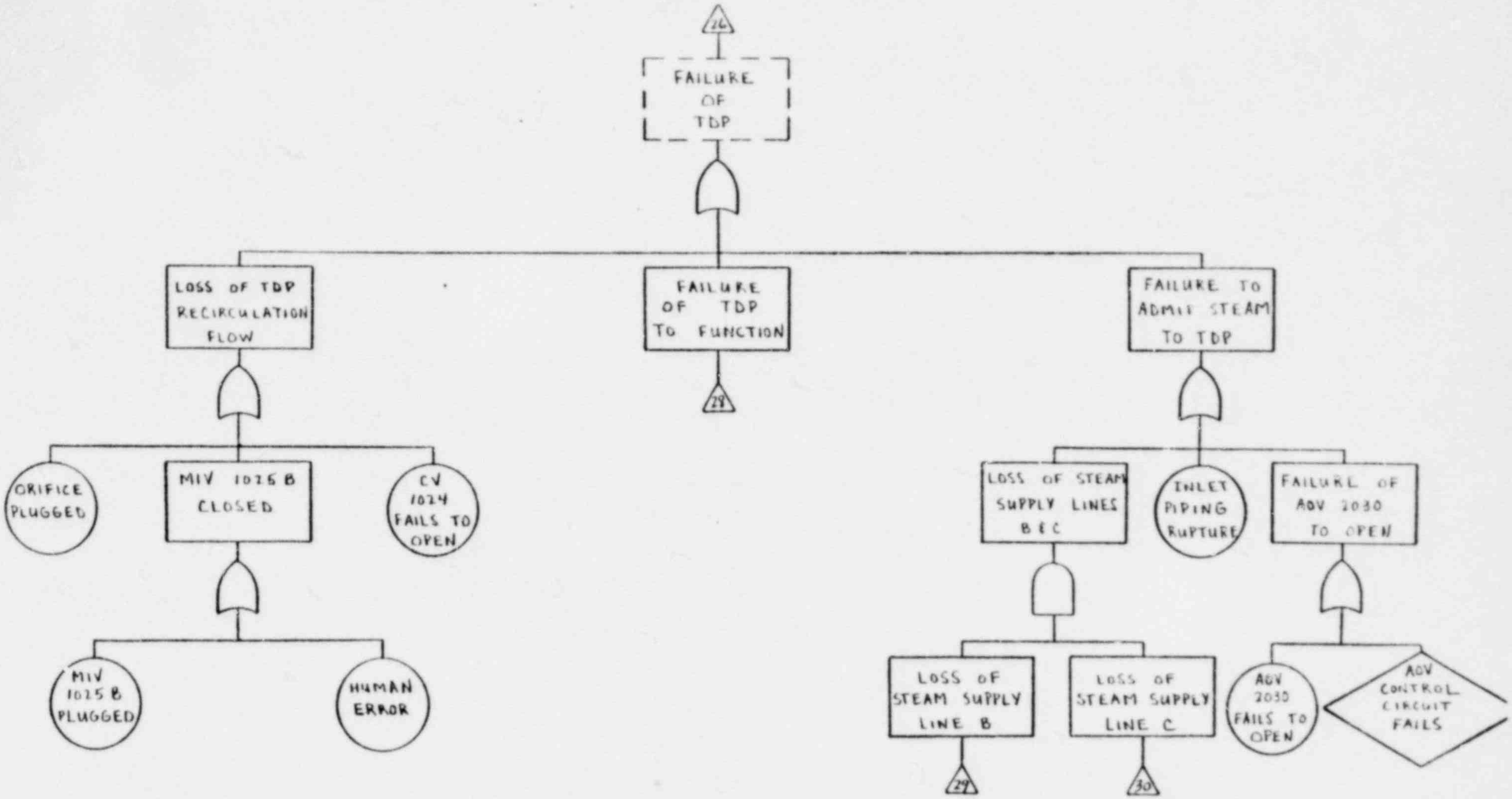

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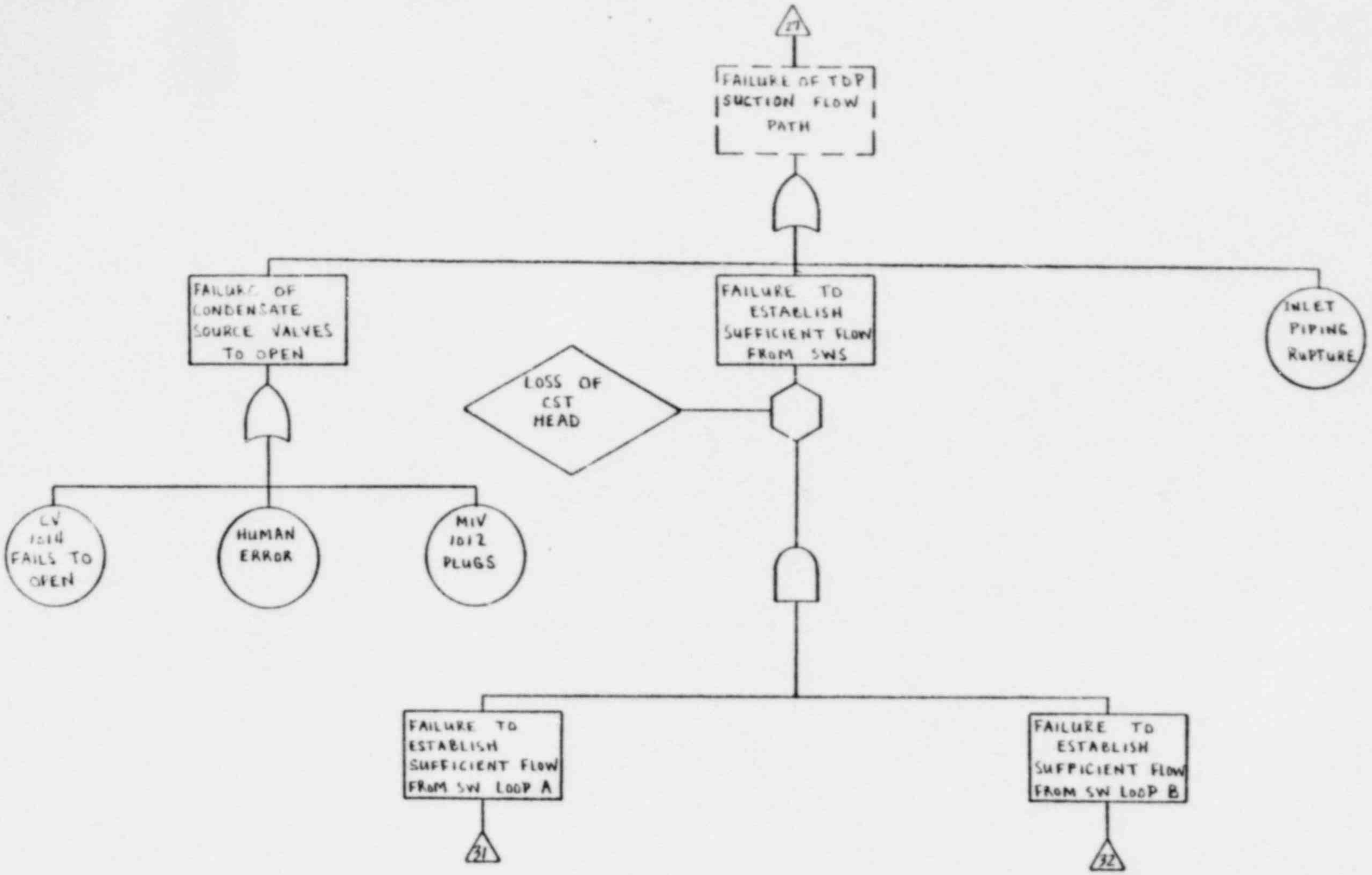

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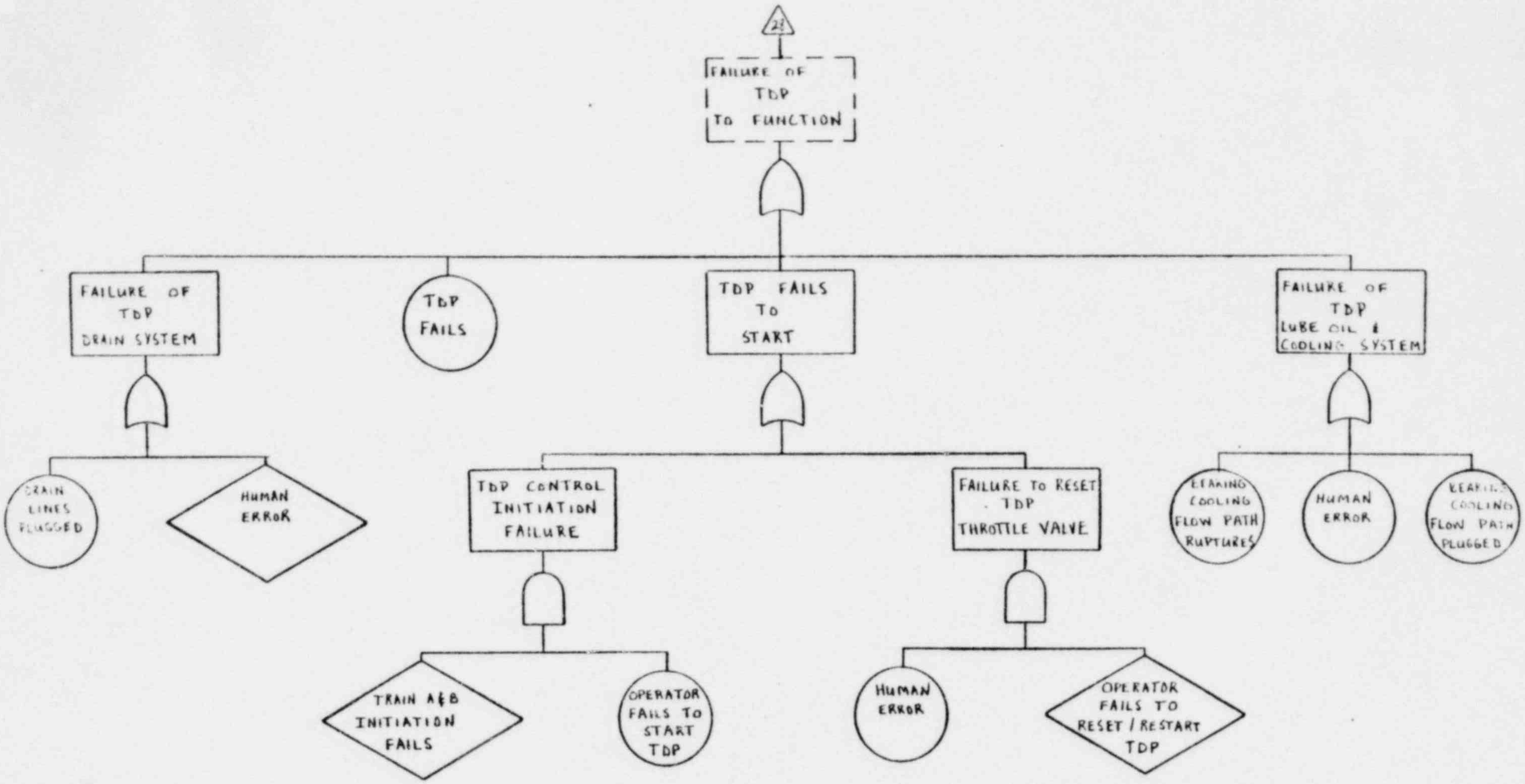

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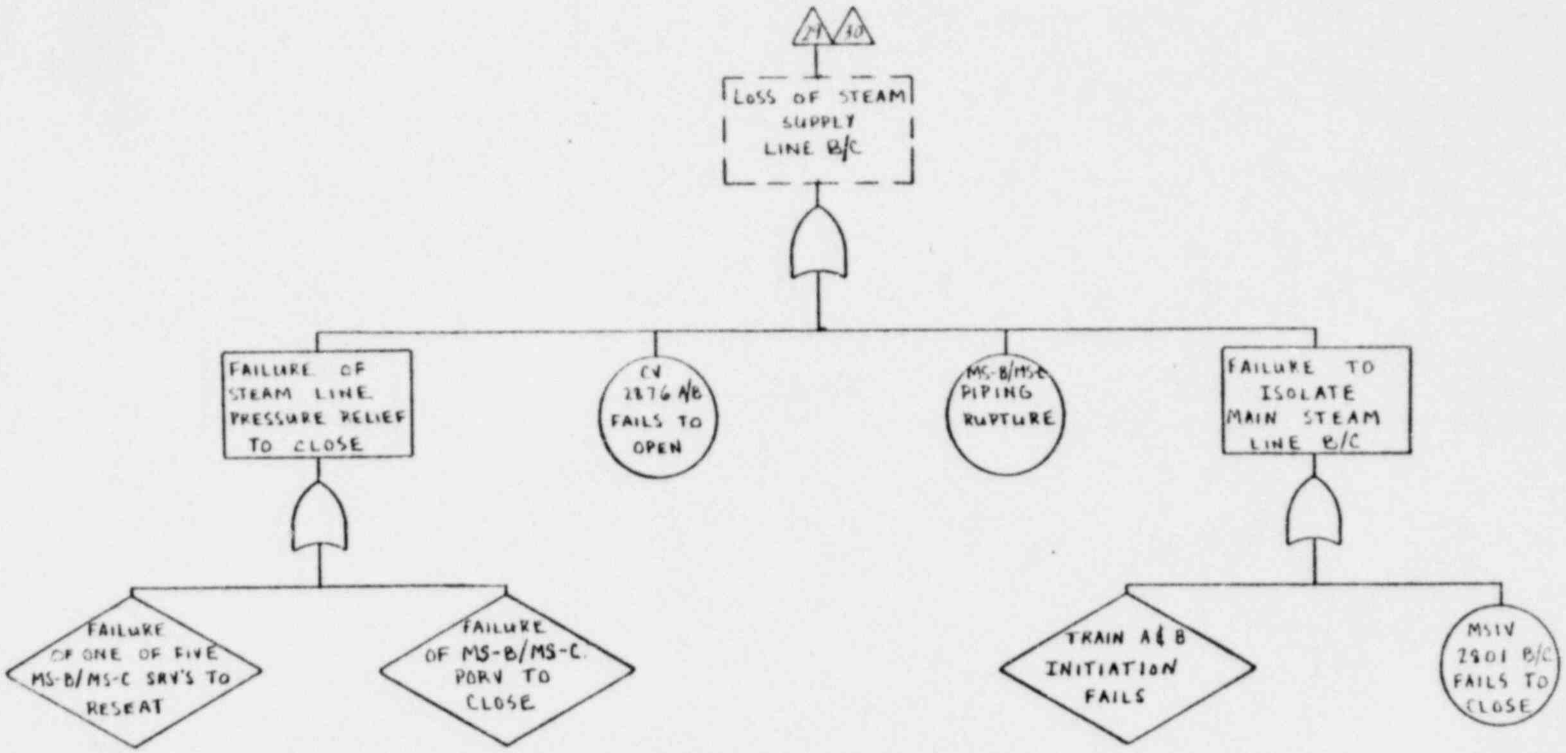

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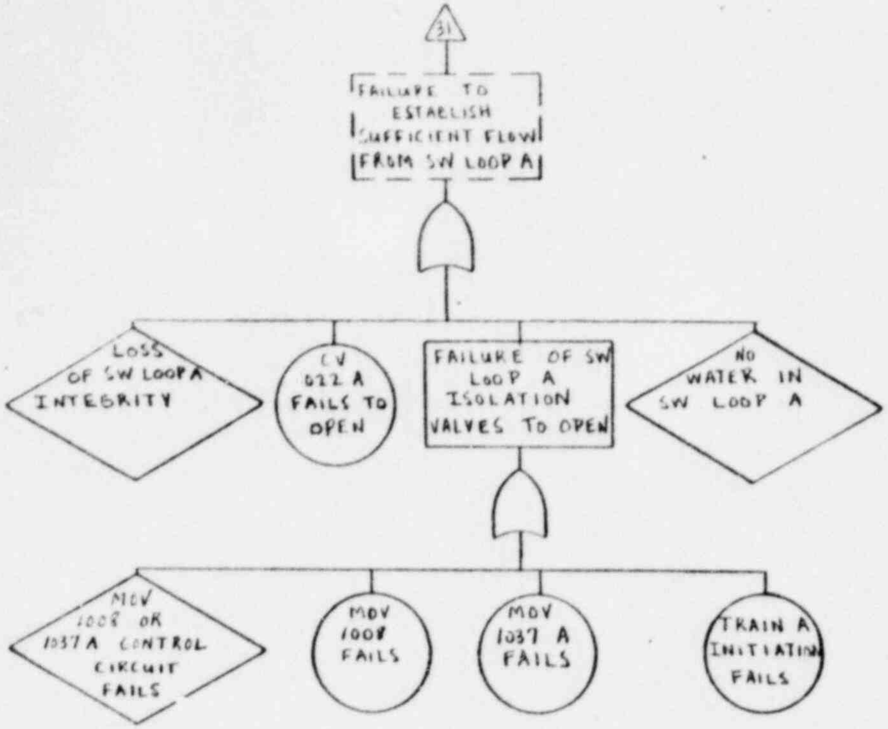

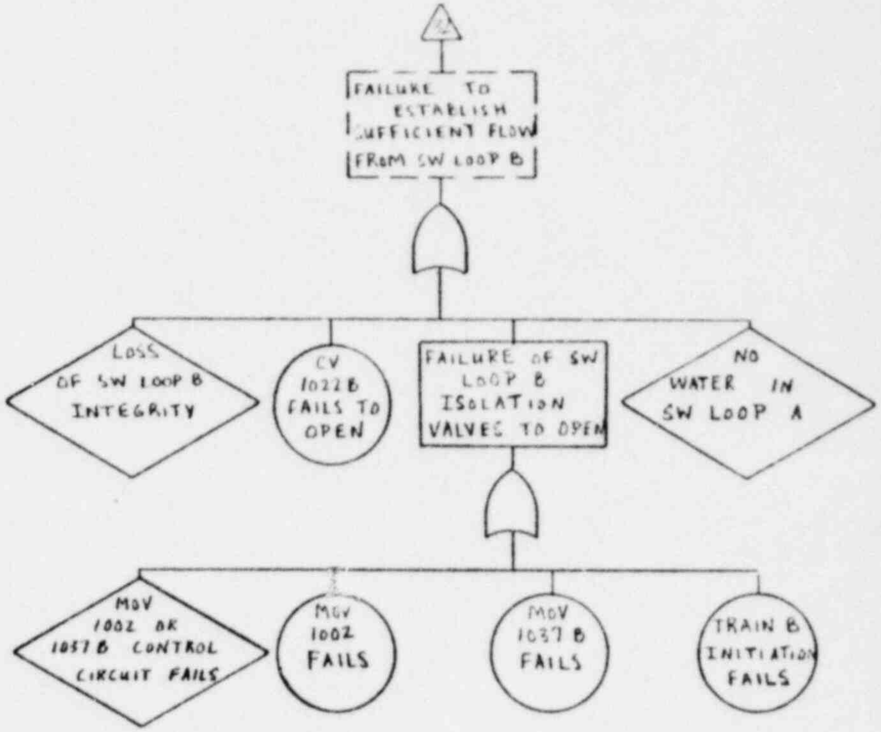

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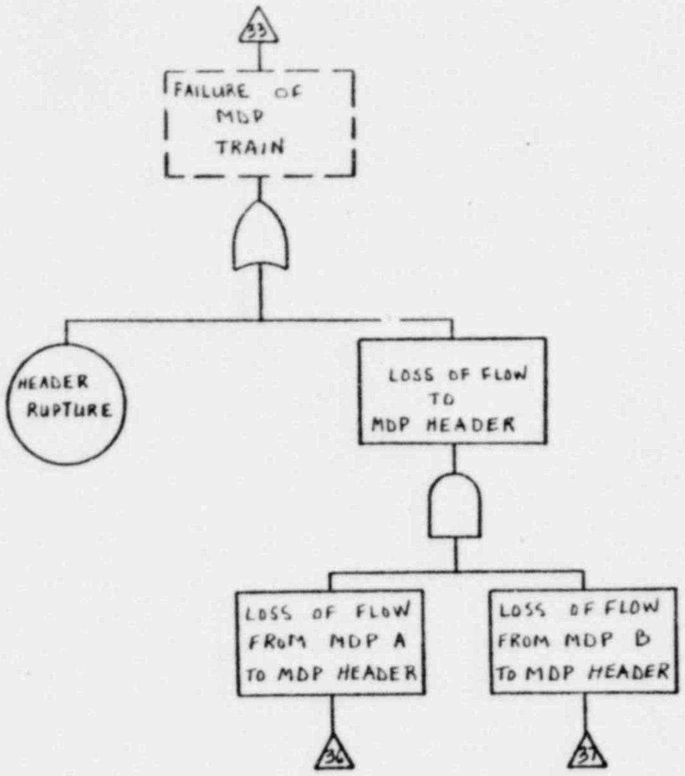
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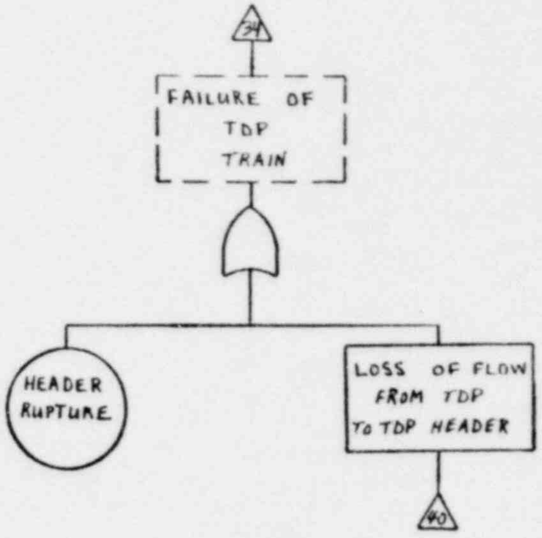
FAILURE OF MDP TRAIN
HEADER RUPTURE
LOSS OF FLOW TO MDP HEADER
LOSS OF FLOW FROM MDP A TO MDP HEADER
36
LOSS OF FLOW FROM MDP B TO MDP HEADER
37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LOSS OF FLOW FROM TDP TO TDP HEADER
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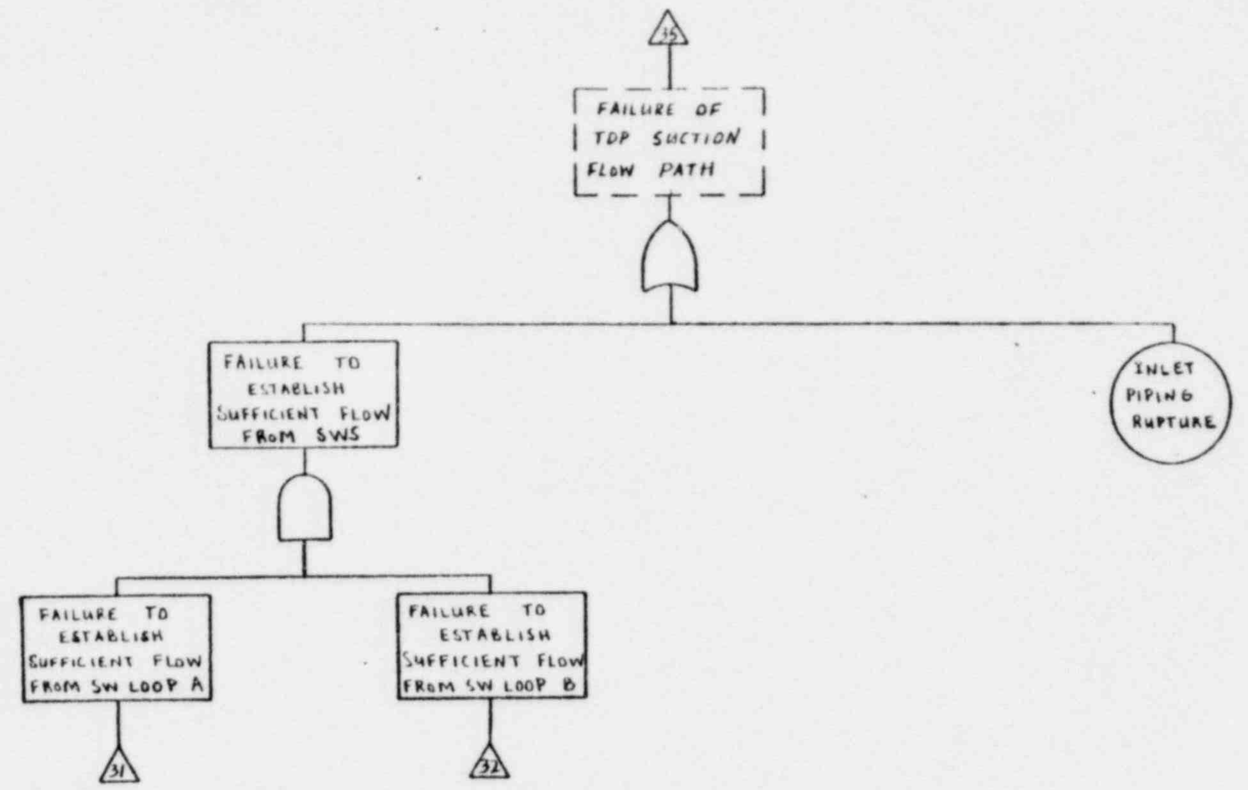
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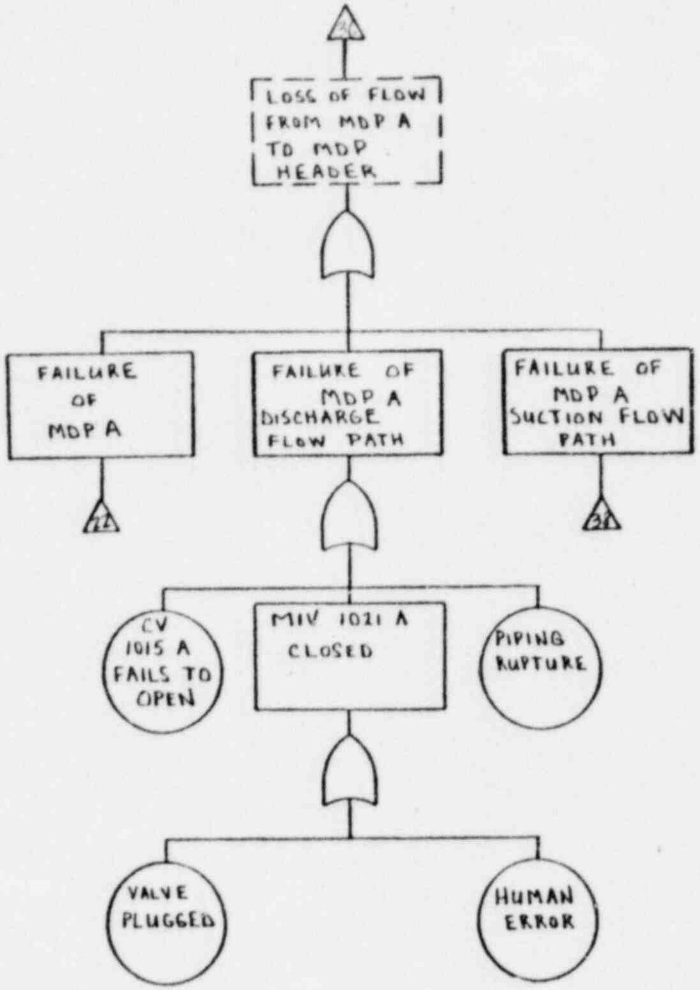
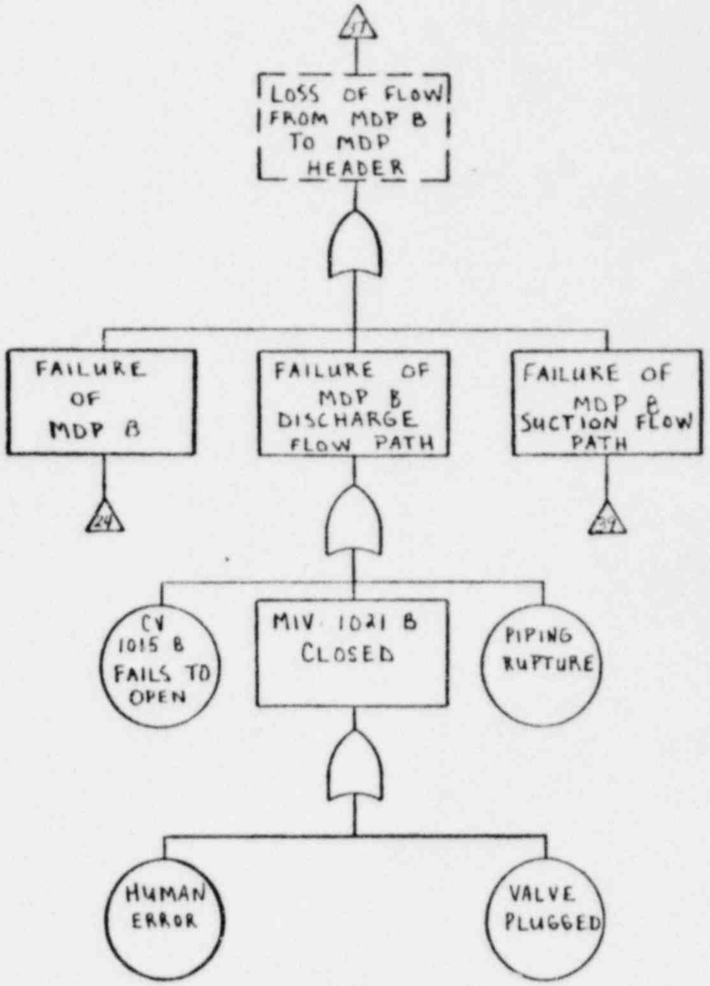
FAILURE OF TDP SUCTION FLOW PATH
FAILURE TO ESTABLISH SUFFICIENT FLOW FROM SWS
INLET PIPING RUPTURE
FAILURE TO ESTABLISH SUFFICIENT FLOW FROM SW LOOP A
FAILURE TO ESTABLISH SUFFICIENT FLOW FROM SW LOOP B
31
32





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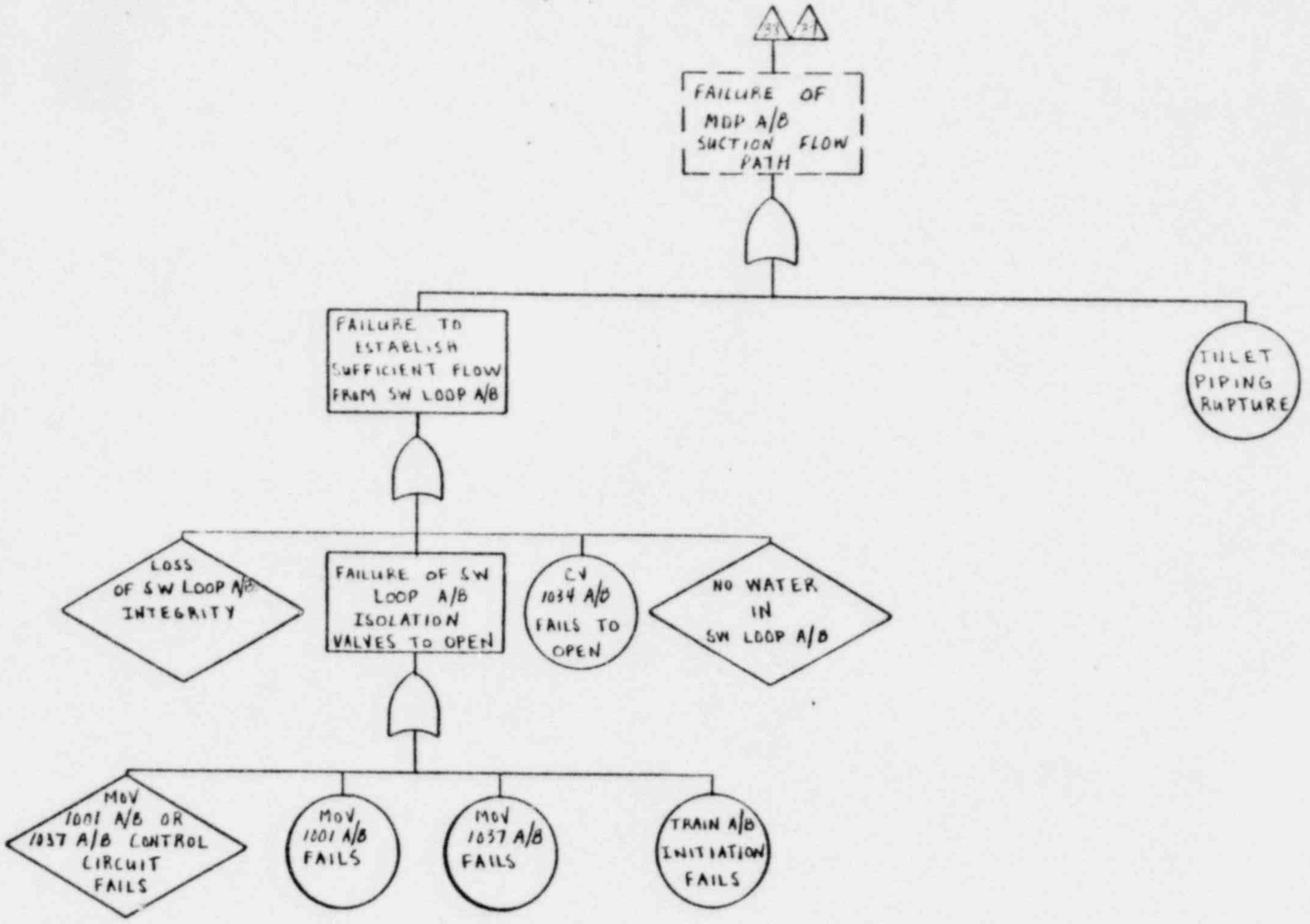

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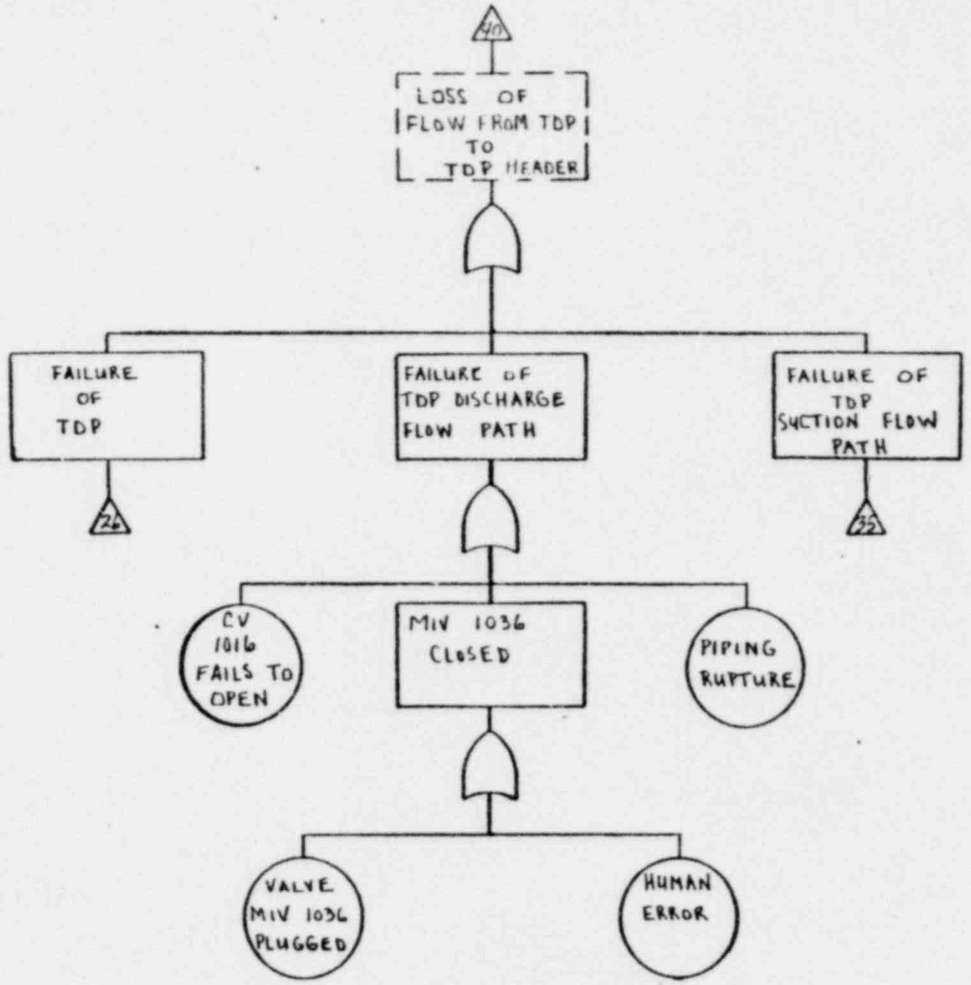
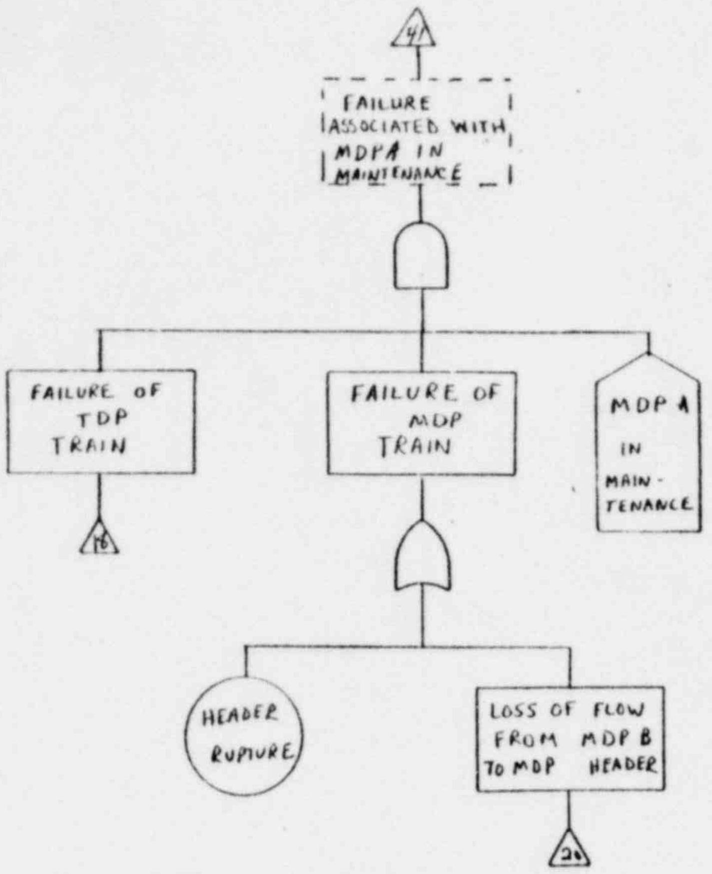
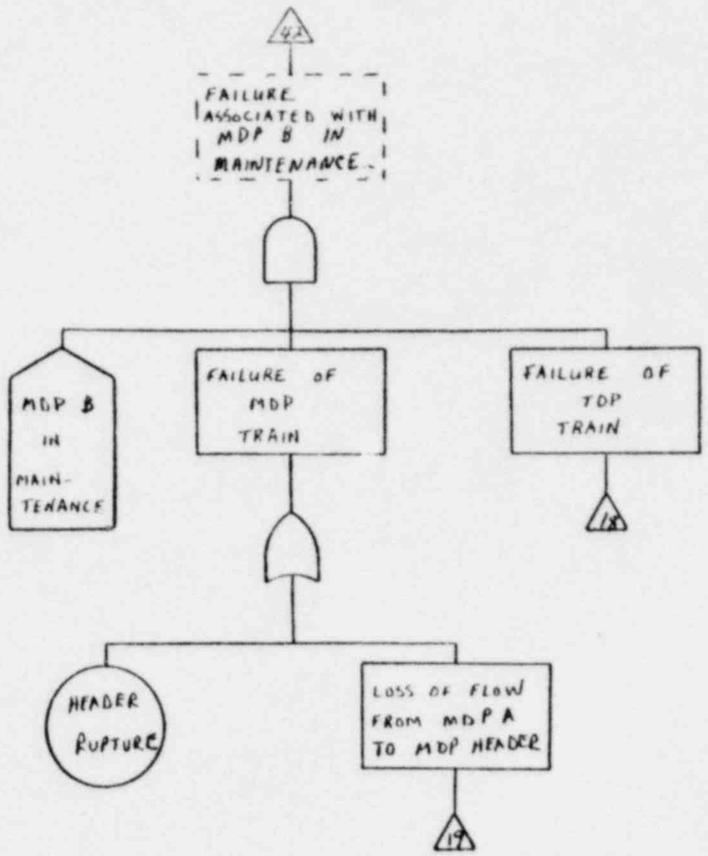

40
LOSS OF FLOW FROM TDP TO TDP HEADER
FAILURE OF TDP
26
FAILURE OF TDP DISCHARGE FLOW PATH
FAILURE OF TDP SUCTION FLOW PATH
32
CV 1016 FAILS TO OPEN
MIV 1036 CLOSED
PIPING RUPTURE
VALVE MIV 1036 PLUGGED
HUMAN ERROR





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Basis of Auxiliary Feedwater System Flow Requirements

Question 1

a. Identify the plant transient and accident conditions considered in establishing AFWS flow requirements, including the following events:

1) Loss of Main Feed (LMFW)
2) LMFW w/loss of offsite AC power
3) LMFW w/loss of onsite and offsite AC power
4) Plant cooldown
5) Turbine trip with and without bypass
6) Main steam isolation valve closure
7) Main feed line break
8) Main steam line break
9) Small break LOCA
10) Other transient or accident conditions not listed above.

b. Describe the plant protection acceptance criteria and corresponding technical bases used for each initiating event identified above. The acceptance criteria should address plant limits such as:

1) Maximum RCS pressure (PORV or safety valve actuation)
2) Fuel temperature or damage limits (DNB, PCT, maximum fuel central temperature)
3) RCS cooling rate limit to avoid excessive coolant shrinkage
4) Minimum steam generator level to assure sufficient steam generator heat transfer surface to remove decay heat and/or cool down the primary system.

Response to 1.a

The Auxiliary Feedwater System (Emergency Feedwater System (EFWS) in the Virgil C. Summer Plant) serves as a backup system for supplying feedwater to the secondary side of the steam generators at times when the feedwater system is not available, thereby maintaining the heat sink capabilities of the steam generator. As an Engineered Safeguards System, the Emergency Feedwater System is directly relied upon to prevent core damage and system overpressurization in the event of transients such as a loss of normal feedwater or a secondary system pipe rupture, and to provide a means for plant cooldown following any plant transient.

Following a reactor trip, decay heat is dissipated by evaporating water in the steam generators and venting the generated steam either to the condensers through the steam dump or to the atmosphere through the steam generator safety valves or the power-operated relief valves. Steam generator water inventory must be maintained at a level sufficient to ensure adequate heat transfer and continuation of the decay heat removal process. The water level is maintained under these circumstances by the Emergency Feedwater System which delivers an emergency water supply to the steam generators. The Emergency Feedwater System must be capable of functioning for extended periods, allowing time either to restore normal feedwater flow or to proceed with an orderly cooldown of the plant to the reactor coolant temperature where the Residual Heat Removal System can assume the burden of decay heat removel. The Emergency Feedwater System flow and the emergency water supply capacity must be sufficient to remove core decay heat, reactor coolant pump heat, and sensible heat during the plant cooldown. The Emergency Feedwater System can also be used to maintain the steam generator water levels above the tubes following a LOCA. In the latter function, the water head in the steam generators serves as a barrier to prevent leakage of fission products from the Reactor Coolant System into the secondary plant.

DESIGN CONDITIONS

The reactor plant conditions which impose safety-related performance requirements on the design of the Emergency Feedwater System are as follows for the Virgil C. Summer plant.

- Loss of Main Feedwater Transient
    - Loss of main feedwater with offsite power available
    - Station blackout (i.e., loss of main feedwater without offsite power available)

- Secondary System Pipe Ruptures
    - Feedline rupture
    - Steamline rupture

- Loss of Coolant Accident (LOCA)

- Cooldown

Loss of Main Feedwater Transients

The design loss of main feedwater transients are those caused by:

- Interruptions of the Main Feedwater System flow due to a malfunction in the feedwater or condensate system

- Loss of offsite power or blackout with the consequential shutdown of the system pumps, auxiliaries, and controls

Loss of main feedwater transients are characterized by a rapid reduction in steam generator water levels which results in a reactor trip, a turbine trip, and emergency feedwater actuation by the protection system logic. Following reactor trip from high power, the power quickly falls to decay heat levels. The water levels continue to decrease, progressively uncovering the steam generator tubes as decay heat is transferred and discharged in the form of steam either through the steam dump valves to the condenser or through the steam generator safety or power-operated relief valves to the atmosphere. The reactor coolant temperature increases as the residual heat in excess of that dissipated through the steam generators is absorbed. With increased temperature, the volume of reactor coolant expands and begins filling the pressurizer. Without the addition of sufficient emergency feedwater, further expansion will result in water being discharged through the pressurizer safety and relief valves. If the temperature rise and the resulting volumetric expansion of the primary coolant are permitted to continue, then (1) pressurizer safety valve capacities may be exceeded causing overpressurization of the Reactor Coolant System and/or (2) the continuing loss of fluid from the primary coolant system may result in bulk boiling in the Reactor Coolant System and eventually in core uncovering, loss of natural circulation, and core damage. If such a situation were ever to occur, the Emergency Core Cooling System would be ineffectual because the primary coolant system pressure exceeds the shutoff head of the safety injection system pumps, the nitrogen over-pressure in the accumulator tanks, and the design pressure of the Residual Heat Removal Loop. Hence, the timely introduction of sufficient emergency feedwater is necessary to arrest the decrease in the steam generator water levels, to reverse the rise in reactor coolant temperature, to prevent the pressurizer from filling to a water solid condition, and eventually to establish stable hot standby conditions. Subsequently, a decision may be made to proceed with plant cooldown if the problem cannot be satisfactorily corrected.

The blackout transient differs from a simple loss of main feedwater in that emergency power sources must be relied upon to operate vital equipment. The loss of power to the electric driven condenser circulating water pumps results in a loss of condenser vacuum and condenser dump valves. Hence, steam formed by decay heat is relieved through the steam generator safety valves or the power-operated relief valves. The calculated transient is similar for both the loss of main feedwater and the blackout, except that reactor coolant pump heat input is not a consideration in the blackout transient following loss of power to the reactor coolant pump bus.

The station blackout transient serves as the basis for the minimum flow required from either the two motor driven pumps acting together or the turbine driven pump by itself for the EFWS for the Virgil C. Summer plant. The pumps are sized so that they will provide sufficient flow against the steam generator safety valve set pressure (with 3% accumulation) via the above groupings to prevent water relief from the pressurizer. The same criterion is met for the loss of feedwater transient where A/C power is available.

Secondary System Pipe Ruptures

The feedwater line rupture accident not only results in the loss of feedwater flow to the steam generators but also results in the complete blowdown of one steam generator within a short time if the rupture should occur downstream of the last nonreturn valve in the main feedwater piping to an individual steam generator. Another significant result of a feedline rupture may be the pumping of emergency feedwater to the faulted steam generator through the connection which is separate from the main feedwater nozzle. Such situations can result in the pumping of a disproportionately large fraction of the total emergency feedwater flow to the faulted steam generator and out the break because the system preferentially pumps water to the lowest pressure steam generator rather than to the effective steam generators which are at relatively high pressure. The system design must allow for terminating, limiting, or minimizing that fraction of emergency feedwater flow which is delivered to a faulted loop in order to ensure that sufficient flow will be delivered to the remaining effective steam generator(s). The concerns are similar for the main feedwater line rupture as those explained for the loss of main feedwater transients.

Main steamline rupture accident conditions are characterized initially by plant cooldown and, for breaks inside containment, by increasing containment pressure and temperature. Emergency feedwater is not needed during the early phase of the transient but flow to the faulted loop will contribute to the release of mass and energy to containment. Thus, steamline rupture conditions establish the upper limit on emergency feedwater flow delivered to a faulted loop. Eventually, however, the Reactor Coolant System will heat up again and emergency feedwater flow will be required to be delivered to the unfaulted loops, but at somewhat lower rates than for the loss of feedwater transients described previously. Provisions must be made in the design of the Emergency Feedwater System to limit, control, or terminate the emergency feedwater flow to the faulted loop as necessary in order to prevent containment overpressurization following a steamline break inside containment, and to ensure the minimum flow to the remaining unfaulted loops.

Loss-of-Coolant Accident (LOCA)

The loss of coolant accidents do not impose on the emergency feedwater system any flow requirements in addition to those required by the other accidents addressed in this response. The following description of the small LOCA is provided here for the sake of completeness to explain the role of the emergency feedwater system in this transient.

Small LOCA's are characterized by relatively slow rates of decrease in reactor coolant system pressure and liquid volume. The principal contribution from the Emergency Feedwater System following such small LOCAs is basically the same as the system's function during hot shutdown or following spurious safety injection signal which trips the reactor. Maintaining a water level inventory in the secondary side of the steam generators provides a heat sink for removing decay heat and establishes the capability for providing a buoyancy head for natural circulation. The emergency feedwater system may be utilized to assist in a system cooldown and depressurization following a small LOCA while bringing the reactor to a cold shutdown condition.

Cooldown

The cooldown function performed by the Emergency Feedwater System is a partial one since the reactor coolant system is reduced from normal zero load temperatures to a hot leg temperature of approximately 350°F. The latter is the maximum temperature recommended for placing the Residual Heat Removal System (RHRS) into service. The RHR system completes the cooldown to cold shutdown conditions.

Cooldown may be required following expected transients, following an accident such as a main feedline break, or during a normal cooldown prior to refueling or performing reactor plant maintenance. If the reactor is tripped following extended operation at rated power level, the EFWS is capable of delivering sufficient emergency feedwater to remove decay heat and reactor coolant pump (RCP) heat following reactor trip while maintaining the steam generator (SG) water level. Following transients or accidents, the recommended cooldown rate is consistent with expected needs and at the same time does not impose additional requirements on the capacities of the emergency feedwater pumps, considering a single failure. In any event, the process consists of being able to dissipate plant sensible heat in addition to the decay heat produced by the reactor core.

Response to 1.b

Table 1B-1 summarizes the criteria which are the general design bases for each event, discussed in the response to Question 1.a, above. Specific assumptions used in the analyses to verify that the design bases are met are discussed in response to Question 2.

The primary function of the Emergency Feedwater System is to provide sufficient heat removal capability for heatup accidents following reactor trip to remove the decay heat generated by the core and prevent system overpressurization. Other plant protection systems are designed to meet short term or pre-trip fuel failure criteria. The effects of excessive coolant shrinkage are bounded by the analysis of the rupture of a main steam pipe transient. The maximum flow requirements determined by other bases are incorporated into this analysis, resulting in no additional flow requirements.

TABLE 1B-1

Criteria for Emergency Feedwater System Design Basis Conditions

Condition or Transient	Classification*	Criteria*	Additional Design Criteria
Loss of Main Feedwater (LMFW)	Condition II	Peak RCS pressure not to exceed design pressure. No consequential fuel failures	
Station Blackout	Condition II	(same as LMFW)	Pressurizer does not fill with either 2 motor driven or one turbine driven emergency feed pump feeding 2 SGs.
Steamline Rupture	Condition IV	10CFR100 dose limits containment design pressure not exceeded	
Feedline Rupture	Condition IV	10 CFR 100 dose limits. RCS design pressure not exceeded	Core does not uncover
Loss of all A/C Power	N/A	Note 1	Same as blackout assuming turbine driven pump
Loss of Coolant	Condition III	10 CFR 100 dose limits 10 CFR 50 PCT limits	
	Condition IV	10 CFR 100 dose limits 10 CFR 50 PCT limits	
Cooldown	N/A		100°F/hr 557°F to 350°F

*Ref: ANSI N18.2 (This information provided for those transients performed in the FSAR).

Note 1 Although this transient establishes the basis for emergency feedwater pump powered by a diverse power source, this is not evaluated relative to typical criteria since multiple failures must be assumed to postulate this transient.

Question 2

Describe the analyses and assumptions and corresponding technical justification used with plant condition considered in 1.a above including:

a. Maximum reactor power (including instrument error allowance) at the time of the initiating transient or accident.

b. Time delay from initiating event to reactor trip.

c. Plant parameter(s) which initiates AFWS flow and time delay between initiating event and introduction of AFWS flow into steam generator(s).

d. Minimum steam generator water level when initiating event occurs.

e. Initial steam generator water inventory and depletion rate before and after AFWS flow commences -- identify reactor decay heat rate used.

f. Maximum pressure at which steam is released from steam generator(s) and against which the AFW pump must develop sufficient head.

g. Minimum number of steam generators that must receive AFW flow; e.g., 1 out of 2? 2 out of 4?

h. RC flow condition -- continued operation of RC pumps or natural circulation.

i. Maximum AFW inlet temperature.

j. Following a postulated steam or feed line break, time delay assumed to isolate break and direct AFW flow to intact steam generator(s). AFW pump flow capacity allowance to accommodate the time delay and maintain minimum steam generator water level. Also identify credit taken for primary system heat removel due to blowdown.

k. Volume and maximum temperature of water in main feed lines between steam generator(s) and AFWS connection to main feed line.

l. Operating condition of steam generator normal blowdown following initiating event.

m. Primary and secondary system water and metal sensible heat used for cooldown and AFW flow sizing.

n. Time at hot standby and time to cooldown RCS to RHR system cut in temperature to size AFW water source inventory.

Response to 2

Analyses have been performed for the limiting transients which define the EFWS performance requirements. These analyses have been provided for review in the Virgil C. Summer FSAR. Specifically, they include:

- Loss of Main Feedwater (Station Blackout)
- Rupture of a Main Feedwater Pipe
- Rupture of a Main Steam Pipe Inside Containment

In addition to the above analyses, calculations have been performed specifically for the Virgil C. Summer plant to determine the plant cooldown flow (storage capacity) requirements. The Loss of All AC Power is evaluated via a comparison to the transient results of a Blackout, assuming an available emergency pump having a diverse (non-AC) power supply. The LOCA analysis, as discussed in response 1.b, incorporates the system flow requirements as defined by other transients, and therefore is not performed for the purpose of specifying EFWS flow requirements. Each of the analyses listed above are explained in further detail in the following sections of this response.

Loss of Main Feedwater (Blackout)

A loss of feedwater, assuming a loss of power to the reactor coolant pumps, was performed in FSAR Section 15.2.8 for the purpose of showing that for a station blackout transient, either two motor driven or one turbine driven emergency feedwater pump delivering flow to two steam generators does not result in filling the pressurizer. Furthermore, the peak RCS pressure remains below the criterion for Condition II transients and no fuel failures occur (refer to Table 1B-1). Table 2-1 summarizes the assumptions used in this analysis. The transient analysis begins at the time of reactor trip. This can be done because the trip occurs on a steam generator level signal, hence the core power, temperatures and steam generator level at time of reactor trip do not depend on the event sequence prior to trip. Although the time from the loss of feedwater until the reactor trip occurs cannot be determined from this analysis, this delay is expected to be 20-30 seconds. The analysis assumes that the plant is initially operating at 102% (calorimetric error) of the Engineered Safeguards design (ESD) rating shown on the table, a very conservative assumption in defining decay heat and stored energy in the RCS. The reactor is assumed to be tripped on low-low steam generator level, allowing for level uncertainty. The FSAR shows that there is margin with respect to filling the pressurizer. A loss of normal feedwater transient with the assumption that the two smallest emergency feedwater pumps and reactor coolant pumps are running results in even more margin.

This analysis establishes the capacity of the motor driven and turbine driven pumps and also establishes train association of equipment so that this analysis remains valid assuming the most limiting single failure.

Rupture of Main Feedwater Pipe

The double ended rupture of a main feedwater pipe downstream of the main feedwater line check valve is analyzed in FSAR Section 15.4.2.2. Table 2-1 summarizes the assumptions used in this analysis. Reactor trip is assumed to be actuated by low-low level in the affected steam generator when the water level falls below the top of the U-tubes. This conservative assumption maximizes the stored heat prior to reactor trip and minimizes the ability of the steam generator to remove heat from the RCS following reactor trip due to a conservatively small total steam generator inventory. As in the loss of normal feedwater analysis, the initial power rating was assumed to be 102% of the ESD rating. The Virgil C. Summer emergency feedwater design is assumed to supply a total of 380 gpm to the two intact steam generators, including allowance for feeding the affected steam generator. The criteria listed in Table 1B-1 are met.

This analysis establishes the capacity of the emergency feedwater pumps, establishes requirements for layout to preclude indefinite loss of emergency feedwater to the postulated break, and establishes train association requirements for equipment so that the EFWS can deliver the minimum flow required in 1 minute assuming the worst single failure.

Rupture of a Main Steam Pipe Inside Containment

Because the steamline break transient is a cooldown, the EFWS is not needed to remove heat in the short term. Furthermore, addition of excessive emergency feedwater to the faulted steam generator will affect the peak containment pressure following a steamline break inside containment. This transient is performed at four power levels for several break sizes. Emergency feedwater is assumed to be initiated at the time of the break, independent of system actuation signals. The maximum flow is used for this analysis, considering pump runout. Table 2-1 summarizes the assumptions used in this analysis. At 30 minutes after the break, it is assumed that the operator has isolated the EFWS from the faulted steam generator which subsequently blows down to ambient pressure. The criteria stated in Table 1B-1 are met.

This transient establishes the maximum allowable emergency feedwater flow rate to a single faulted steam generator assuming all pumps operating, establishes the basis for runout protection, if needed, and establishes layout requirements so that the flow requirements may be met considering the worst single failure.

Plant Cooldown

Maximum and minimum flow requirements from the previously discussed transients meet the flow requirements of plant cooldown. This operation, however, defines the basis for tankage size, based on the required cooldown duration, maximum decay heat input and maximum stored heat in the system. As previously discussed in response 1A, the emergency feedwater system partially cools the system to the point where the RHRS may complete the cooldown, i.e., 350oF in the RCS. Table 2-1 shows the assumptions used to determine the cooldown heat capacity of the emergency feedwater system.

The cooldown is assumed to commence at 102% of engineered safeguards design power, and maximum trip delays and decay heat source terms are assumed when the reactor is tripped. Primary metal, primary water, secondary system metal and secondary system water are all included in the stored heat to be removed by the EFWS. See Table 2-2 for the items constituting the sensible heat stored in the NSSS.

This operation is analyzed to establish minimum tank size requirements for emergency feedwater fluid source which are normally aligned.

TABLE 2-1

Summary of Assumptions Used in EFWS Design Verification Analyses

Transient	Loss of Feedwater (station blackout)	Cooldown	Main Feedline Break	Main Steamline Break (containment)
a. Max reactor power	102% of ESD rating (102% of 2910 MWt)	2969 MWt	102% of ESD rating (102% of 2910 MWt)	0, 30, 70, 102% of (% of MWt)
b. Time delay from event to Rx trip	2 sec (delay from lo-lo SG level setpoint)	2 sec	2 sec	variable
c. EFWS actuation signal/time delay for EFWS flow	lo-lo SG level 1 minute	NA	low-low SG level 1 minute	Assumed immediately 0 sec (no delay)
d. SG water level at time of reactor trip	(lo-lo SG level) 0% NR span	NA	top of U-tubes in 1 SG	N/A
e. Initial SG inventory	55,000 lbm/SG (at trip)	64,780 lbm/SG @ 540.2°F	102200 lbm/SG	consistent with power
Rate of change before & after EFWS actuation	See FSAR Figure 15.2-27	N/A	turnaround ≈ 3200 sec.	N/A
decay heat	FSAR Figure 15.1-6	FSAR Figure 15.1-6	FSAR Figure 15.1-6	FSAR Figure 15.1-6
f. EFW pump design pressure	1226 psia	1226 psia	1226 psia	N/A
g. Minimum # of SGs which must receive EFW flow	2 of 3	N/A	2 of 3	N/A
h. RC pump status	Tripped @ reactor trip	Tripped	All operating	All operating
i. Maximum EFW temperature	120°F	100°F	120°F	equal to main feed temperature
j. Operator action	none	N/A	> 20 min.	30 min.
k. EFW purge volume/temp.	50 ft³/438°F	150 ft³/per loop 435°F	200 ft³/435°F	ft³/loop (for dryout time)
l. Normal blowdown	none assumed	none assumed	none assumed	none assumed
m. Sensible heat	see cooldown	Table 2-2	see cooldown	N/A
n. Time at standby/time to cooldown to RHR	2 hr/4 hr	2 hr/4 hr	2 hr/4 hr	N/A
o. EFW flow rate	180 GPM - constant (min. requirement)	variable	630 gpm constant (Min. requirement)	GPM (constant) to broken SG. (max. requirement)

TABLE 2-2

Summary of Sensible Heat Sources

Primary Water Sources (initially at engineered safeguards design power temperature and inventory)
- RCS fluid
- Pressurizer fluid (liquid and vapor)

Primary Metal Sources (initially at engineered safeguards design power temperature)
- Reactor coolant piping, pumps and reactor vessel
- Pressurizer
- Steam generator tube metal and tube sheet
- Steam generator metal below tube sheet
- Reactor vessel internals

Secondary Water Sources (initially at engineered safeguards design power temperature and inventory)
- Steam generator fluid (liquid and vapor)
- Emergency feedwater piping purge fluid.

Secondary Metal Sources (initially at engineered safeguards design power temperature)
- All steam generator metal above tube sheet, excluding tubes.

Question 3

Verify that the AFW pumps in your plant will supply the necessary flow to the steam generator(s) as determined by items 1 and 2 above considering a single failure. Identify the margin in sizing the pump flow to allow for pump recirculation flow, seal leakage and pump wear.

Response to 3

FSAR Figure 10.4-16 schematically shows the major features and components of the Emergency Feedwater System for Virgil C. Summer . Flow rates for all of the design transients described in Response 2 have been met by the system for the worst single failure. The flows for those single failures considered are tabulated for the various transients in Table 3-1, including the following:

A. A/C Train Failure
B. Turbine Driven Pump Failure
C. Motor Driven Pump Failure

TABLE 3-1

Emergency Feedwater Flow(1) to Steam Generators Following an Accident/Transient with Selected Single Failure - GPM

		Single Failure		
	Accident/Transient	Elec. Train Failure	TD Pump Failure	MD Pump FAilure
		A	B	C
1.	Loss of Main FW	872 gpm	704 gpm	872 gpm
2.	Feedline Rupture	471 gpm	704 gpm	872 gpm
3.	Cooldown	958 gpm	796 gpm	958 gpm
4.	Main steamline rupture (max. requirement)	979 gpm	0 gpm	0 gpm

Notes:

(1) Items 1 thru 3 are minimum expected flows to intact loops; item 4 is maximum possible flow to the faulted loop.