MIDLAND PLANT UNITS 1 AND 2

AUXILIARY FEEDWATER SYSTEM

DESIGN REVIEW PRESENTATION

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AUXILIARY FEEDWATER SYSTEM

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1.0 INTRODUCTION

1.1 PURPOSE OF PRESENTATION

1.2 PRESENTATION FORMAT

1.3 INTRODUCTION OF SPEAKERS

2.0 DESIGN BASES

The auxiliary feedwater (AFW) system provides feedwater to the once-through steam generators (OTSGs) during normal plant startup, cooldown, and hot standby conditions. The AFW system is not required during normal plant power operation, but remains in the standby mode. During emergency conditions, the AFW system is also designed to automatically supply feedwater to the OTSGs allowing the removal of decay heat from the reactor coolant system (RCS) through the secondary system to a point at which the decay heat removal system can be placed in operation.

In general, the AFW system consists of diverse feedwater supplies, two AFW pumps, a double crossover discharge piping arrangement, and level control logic. A simplified diagram of the AFW system is provided as Figure 2-1.

2.1 SAFETY DESIGN BASES

The following AFW system safety design bases were determined to be required to meet regulatory criteria and to directly or indirectly ensure the health and safety of the public.

2.1.1 Safety Design Basis One

The AFW system provides feedwater for the removal of reactor core decay heat to preclude damage to the reactor core following a loss of main feedwater, and to ensure the reactor coolant temperature can be reduced to the point at which the decay heat removal system may be placed in operation.

2.1.2 Safety Design Basis Two

The AFW and supporting systems ensure the required flow to the steam generators in the event of a single active failure.

2.1.3 Safety Design Basis Three

In the unlikely event that the control room must be evacuated, the AFW system is operated from the auxiliary shutdown panel.

2.1.4 Safety Design Basis Four

The AFW system, including the two sources of service water, is designed to remain functional following the safe shutdown earthquake.

2.1.5 Safety Design Basis Five

The AFW system is designed with two independent full-capacity systems, each with diverse motive and control power sources. On complete loss of ac power (station blackout), the turbine-driven

AFW pump is capable of meeting the feedwater requirements for a minimum of 2 hours.

2.1.6 <u>Safety Design Basis Six</u>

The AFW system is designed to avoid the effects of hydraulic instability (water hammer).

2.2 POWER GENERATION DESIGN BASES

2.2.1 <u>Power Generation Design Basis One</u>

The AFW system may be used to supply feedwater to the steam generators during startup, cooldown, and hot standby.

2.3 CODES AND STANDARDS

Codes and standards applicable to the AFW system are listed in Table 2-1. The AFW system is designed and constructed in accordance with quality Group C requirements up to the containment isolation valves, and with quality Group B requirements within the containment.

3.0 SYSTEM DESIGN AND OPERATION

3.1 AUXILIARY FEEDWATER SUPPLY PIPING AND SUCTION SOURCES

The auxiliary feedwater (AFW) pumps take suction from the sources described in Subsections 3.1.1 and 3.1.2 below.

3.1.1 Nonsafety-Grade Sources

The normal water source of the AFW system is the non-Seismic Category I, 300,000-gallon condensate storage tank (CST). The CST is sized to accommodate the plant at hot shutdown for approximately 4 hours followed by a 6-hour cooldown to 280F.

Alternate water sources for the AFW system are the deaerator storage tanks and the condenser hotwell. Water from the deaerator storage tanks is normally used during hot standby or normal plant cooldown to minimize thermal shock to the once-through steam generators (OTSGs). Water from the condenser hotwell is considered to be a backup source to be used if water from the deaerators and the CST is unavailable.

3.1.2 Safety-Grade Source

A Seismic Category I supply to the AFW pump suction is provided by the service water system (SWS) to supply feedwater in the event that the CST or other sources of water are not available.

3.1.3 Suction Piping Configuration

The AFW suction piping, as shown in Figure 3-1, is arranged to enable the motor-driven AFW pump to operate independently of the turbine-driven AFW pump. Normal alignment of the AFW suction is from the non-Seismic Category I CST when the AFW system is in standby. All suction valves required for system initiation and control are power operated.

Suction can be aligned either to the deaerators or the condenser hotwell by opening or closing remote manual valves operated from the main control room (MCR).

Each AFW pump train connects to the SWS through two motor-operated, automatically actuated butterfly valves in series. Switchover of the AFW pump suction to the SWS is accomplished automatically using a two-out-of-four low pump suction pressure logic concurrent with the presence of an AFW actuation signal (AFWAS). Upon actuation of this switchover, the nonsafety suction sources are isolated and the two butterfly valves to each service water train are opened. To prevent spurious opening of the service water valves due to normal transients, the low suction pressure must persist for 4 seconds before the transfer is initiated. The valves admitting service water can also be opened from the control room or auxiliary shutdown panel in response to an alarm of low AFW pump suction pressure.

3.2 AUXILIARY FEEDWATER PUMPS

There are two safety-grade AFW pumps, one motor-driven and one turbine-driven, for each of the two units. Each pump is a horizontal centrifugal unit rated at 885 gpm and 2,700 feet total developed head. The discharge head is sufficient to establish the necessary flowrate against a steam generator pressure corresponding to the lowest pressure setpoint of the main steam safety valves. The flowrate of each AFW pump is equal to, or greater than, the flowrate required to remove the decay heat generated at 40 seconds into the transient. The 40-second time was chosen to allow the AFW system to inject feedwater and begin increasing OTSG level to the 50% operating range level, required for natural circulation, prior to completing reactor coolant pump coastdown.

The motor-driven AFW pump associated with each unit is supplied with power from the Class 1E ac power system. Following initiation of an AFWAS, the motor-driven AFW pump is capable of supplying feedwater to the steam generators within 40 seconds, including an allowance of 10 seconds for starting the emergency diesel generators.

The turbine-driven AFW pump associated with each unit provides system redundancy of AFW supply and diversity of motive pumping power. Steam supply piping to the turbine driver, as shown in Figure 3-2, is taken from each of the main steam lines inside the containment. A line from each steam generator, equipped with a normally closed dc motor-operated isolation valve, supplies steam to a common header. This header leads to the turbine through the containment isolation valve and throttle trip valve. The steam lines are designed to prevent the accumulation of condensate in the lines. The turbine driver can operate with steam inlet pressures ranging from 45 to 1,160 psig. Exhaust steam from the turbine driver is vented to the atmosphere above the auxiliary building roof.

Cooling for the turbine-driven AFW pump bearings and the turbine lubricating oil is provided by internal recirculation of the pumped fluid through the pump seal coolers and the turbine primary lube oil cooler. This system is designed to provide sufficient cooling with pumpage temperatures at or below 130F, and satisfies cooling requirements when suction is taken from either the CST or SWS. Though not intended for normal use, but provided to allow further operating flexibility, a secondary cooler using service water is used when suction is desired from the deaerators. Valves and controls necessary for the function of the turbine-driven pump and its associated equipment are energized by Class 1E dc power supplied as discussed in Section 3.5.

Following initiation of an AFWAS, steam is admitted to the turbine-driven AFW pump. The feed-only-good generator (FOGG) signals are provided to the steam supply isolation valves of both steam generators, ensuring that only the good steam generator provides motive steam to the turbine driver by closure of the steam isolation valves from the faulted steam generator. This ensures a steam supply to the AFW pump turbine driver. The time required to open the steam supply isolation valve and bring the turbine-driven pump to speed is less than 40 seconds.

The AFW pumps are located in separate flood-protected rooms at el 584'-0" of the auxiliary building. Each AFW pump room is provided with an engineered safety features (ESF) unit cooler to control room temperature at a level consistent with environmental requirements for proper operation of the AFW system components. The ESF coolers begin operation in conjunction with the pump they cool, and stop when the corresponding pump stops and the room temperature is reduced below the room thermostat control setpoint. The fan of each unit cooler is powered from the same train as the pump with which it is associated. When the pump served by the unit cooler is off, the unit cooler fan is controlled by the pump room thermostat.

3.3 AUXILIARY FEEDWATER DISCHARGE PIPING

The AFW pump discharge headers, as shown in Figure 3-3, are provided with a double crossover piping arrangement for system redundancy. Each discharge header splits into two lines: one line for the lead-level control valve of the associated steam generator and another line for the crossover redundant-level control valve of the other steam generator. The level control valve in the crossover piping normally remains closed as long as the lead valve is functioning properly. If either the AFW pump or the lead-level control valve of one train fails to supply the necessary feedwater to its associated steam generator, the AFW pump of the other train would then supply feedwater via the crossover piping.

Parallel containment isolation valves are provided on the discharge piping to each steam generator. One of the parallel valves is ac powered and the other is dc powered.

The AFW pump discharge headers are also provided with minimum recirculation and test lines. The discharge flowpath is to the condensate storage tank or the cooling pond, depending on the suction source. When AFW suction is taken from the deaerators, minimum pump recirculation flow is satisfied by recirculation to the deaerator storage tanks through the auxiliary-to-main feedwater system crosstie.

3.4 OPERATING MODES

3.4.1 Plant Startup

During startup, the motor-driven AFW pumps may be used to supply feedwater from the deaerating storage tank to the steam generators.

3.4.2 Normal Plant Operation

The AFW system is not activated during normal power generation. The pumps are placed in the standby mode and are lined up to take suction from the CST if this becomes necessary.

3.4.3 Hot Standby

During hot standby, the AFW system may be used to provide water to each steam generator to maintain the water level. Auxiliary feedwater pump suction may be taken from the deaerator storage tanks, which maintain the temperature at approximately 229F. Feedwater flow would be pumped into the main feedwater nozzles of the steam generator via the auxiliary-to-main feedwater system crosstie.

3.4.4 Normal Plant Cooldown

During cooldown, the motor-driven AFW pump may be used to supply water to the steam generators from the deaerator storage tanks, CST, or the condenser hotwell. The deaerator storage tanks would be the primary source of this water to minimize thermal shock to the steam generators.

Steam generated during normal cooldown is bypassed to the main condenser. The AFW pump may be used until the reactor coolant (RC) temperature drops to approximately 280F, at which point the decay heat removal (DHR) system is activated.

After the DHR system is placed in operation, the OTSGs are placed in a wet layup condition by using the AFW system. During wet layup, all required AFW components will be manually controlled to accomplish OTSG filling.

3.4.5 Shutdown After High-Energy Line Breaks

The events following a postulated break in AFW piping depend upon the plant conditions at the time of break. The technical specifications will not permit using the turbine-driven AFW pump during hot standby except in emergencies. In the event of a postulated failure in the piping associated with the electric-driven pump, the break is isolated and the turbine-driven pump is started. Because the turbine-generator is not paralleled to the offsite grid during hot standby, availability of offsite power is assumed. This permits use of the main feedwater pumps in the event that the turbine-driven AFW pump fails to start.

- Emergency shutdown is not required following a failure outside the containment in the AFW system during normal or hot standby operation.

3.4.6 Emergency Operation

The AFWAS automatically starts both AFW pumps in less than 40 seconds. These pumps continuously supply the required feedwater to the steam generators until the flow is terminated by operator administrative control.

Under emergency conditions, heat is removed from the RC system (RCS) by boiling the feedwater in the steam generators and venting the steam to the atmosphere through the power-operated atmospheric vent valves and/or the main steam safety valves. If the main steam isolation valves are open, steam may be relieved via the turbine bypass system if a condenser is available, or through the modulating atmospheric dump valves, if the condenser is unavailable. Either method is capable of lowering the RCS temperature to a point where the DHRS can be placed in operation.

3.5 AUXILIARY FEEDWATER ACTUATION

The safety-grade AFWAS automatically starts both the turbine-driven and motor-driven AFW pumps. AFWAS also automatically positions the AFW valves both to mitigate the consequences of a loss of main feedwater or loss of offsite power incident and to provide feedwater to allow primary heat removal through the steam generators. The AFWAS will automatically start the AFW pumps under any of the following conditions:

a. Low pressure in either OTSG

b. Low level in either OTSG

c. Class 1E bus undervoltage

d. Loss of reactor coolant flow indicated by loss of power to three out of four reactor coolant pumps

e. Loss of both main feedwater pumps

f. Emergency core cooling actuation signal (ECCAS)

In addition to automatic initiation, AFW equipment may be manually actuated from the control room or from the auxiliary shutdown panel.

3.5.1 Bypasses

A bypass is provided to avoid actuation of both the AFWAS and the main steam line isolation signal (MSLIS) systems by a low steam generator pressure during normal startup and shutdown conditions. Bypasses are also provided to avoid actuation of AFWAS either by loss of the main feed pump trip signal or by loss of three out of four reactor coolant pumps during normal startup and shutdown.

3.5.2 Interlocks

The AFW system is equipped with a FOGG control system which operates to terminate AFW flow to a faulted steam generator. The FOGG system continuously monitors the differential pressure between the steam generators. When a preselected differential pressure is sensed, FOGG automatically closes the following:

a. The AFW isolation and control valves supplying the lower pressure OTSG

b. The steam valve supplying the turbine-driven AFW pump from the lower pressure OTSG

The continuous interrogation feature of this system permits isolation any time during a secondary pressure transient and allows the lower pressure OTSG to be returned to service should the pressure differential be reduced by corrective action, such as main steam and feedwater line isolation.

The OTSGs are protected from overfilling by automatic closure of both the AFW level control and isolation valves feeding the affected OTSG on high-high level.

3.6 POWER SUPPLY

3.6.1 Normal Operation

The AFW system power supplies are derived from Class 1E sources. Each AFW train (A and B) is fed from entirely independent Class 1E sources. These sources include:

a. AC components are fed from trains A and B Class 1E ac buses.

b. DC components are fed from trains A and B Class 1E dc buses.

c. DC buses are normally fed through rectifiers from their respective ac buses.

d. Station batteries feed the dc buses whenever ac power is unavailable.

3.6.2 Train A

The train A AFW system consists of the motor-driven AFW pump and its related components. Major components of the system receive Class 1E power supplies as follows:

a. Motor-driven AFW pump - ac power

b. Room cooler fans - ac power

c. Level control valves - ac power through inverters from the dc bus

d. Parallel containment isolation valves - ac power to one valve, dc power to one valve

e. Other valves - ac power

3.6.3 Train B

The train B AFW system consists of the turbine-driven AFW pump and its related components. Major components of the system receive Class 1E power supplies as follows:

a. Turbine-driven AFW pump controls - dc power

b. Room cooler fans - ac power

c. Turbine steam supply isolation and control valves - dc power/hydraulic

d. Level control valves - ac power through inverters from the dc bus

e. Parallel containment isolation valves - ac power to one valve, dc power to one valve

f. Other valves - ac power

3.6.4 Loss of Offsite Power

Upon loss of offsite power, all components in trains A and B receive power from the trains A and B emergency diesel generators.

To provide further AFW system flexibility, the motor-driven AFW pump and associated components (train A) are capable of being fed off of the train B diesel generator by manually switching the power supply breakers via mechanical interlocks.

3.6.5 Station Blackout

Upon loss of all ac power (station blackout), the train B AFW system will operate using 125V dc Class 1E battery-backed sources. In such an event, the batteries will supply dc power to the components listed above and will provide ac power, through inverters, to the ac-powered AFW level control valves. System alignment is such that other ac powered valves do not need to operate following the blackout. The dc system has sufficient capability to supply the required power for AFW system operation during station blackout for at least 2 hours.

3.7 INSTRUMENTATION AND CONTROLS

Instrumentation for the control and monitoring of the AFW system is located in the MCR. Instrumentation for AFW system operation needed to achieve plant safe shutdown is also contained on the auxiliary shutdown panel (ASP) and may be used in the event the control room is evacuated. Manual control of any equipment at the ASP overrides the automatic and manual control capabilities of that equipment in the MCR. This allows full control from the ASP regardless of the mode selected in the MCR. The manual status of the controls at the ASP is indicated by lights on the MCR panel.

The following controls are provided both in the MCR and on the ASP:

a. Motor-driven AFW pump (start/stop)

b. Turbine-driven AFW pump (start/stop)

c. AFW level control valve position

d. Service water supply isolation valve position (open/close)

e. Essential power-operated valves in system (open/close)

f. AFW pump turbine speed control valve position

Alarms are provided in the MCR for the following:

a. Condensate storage tank minimum level

b. AFW pumps low suction pressure

c. Remote control being overridden by local control

d. Service water supply isolation valves and CST recirculation block valves open simultaneously

e. AFW low flow

The following parameters are indicated both in the MCR and on the ASP:

a. OTSG water level

b. OTSG pressure

c. AFW pump suction pressure

d. Motor-driven AFW pump (running/stopped)

e. Turbine-driven AFW pump (running/stopped)

f. AFW pump discharge pressure

g. AFW flowrate to each OTSG

h. Turbine driver steam inlet pressure

i. Condensate storage tank level

j. Position indicators for:

   1. All AFW power-operated isolation and control valves (open/closed)

   2. Service water supply and condensate storage supply isolation valves (open/closed)

   3. Turbine driver steam inlet isolation valves (open/closed)

   4. Essential manually operated valves in the recirculation line (open/closed)

4.0 STEAM GENERATOR CONTROL/SYSTEM RESPONSE

4.1 STEAM GENERATOR LEVEL CONTROL

.1.1 Purpose

Auxiliary feedwater (AFW) is initiated by the auxiliary feedwater actuation system (AFWAS). Initiation of AFW occurs under two conditions: 1) loss of main feedwater and 2) loss of forced circulation on the primary system. The primary means of detecting a loss of main feedwater is low water level in either steam generator. This signal detects a loss of feedwater from any cause. In addition to low steam generator level, a loss of main feedwater is also detected by a loss of both main feedwater pumps, low pressure in either steam generator, or an emergency core cooling actuation signal (ECCAS). The low steam generator pressure and ECCAS signals are used to isolate main feedwater and, therefore, the signal is also used as an anticipatory start for the AFW. A loss of both main feed pumps' signal, though not Class 1E, is also used as an anticipatory start for the AFW. While these anticipatory start signals will not detect all loss of feedwater events, they will provide an earlier initiation of AFW for those events that are detected.

When forced circulation is lost in the primary system, auxiliary feedwater is used to obtain natural circulation. The primary signal used to detect this condition is the loss of three out of four reactor coolant pumps. In addition to this signal, a Class 1E bus undervoltage signal is used to detect a loss of offsite power. Either signal will initiate AFW.

Once the AFW system is initiated, it is controlled to a level that is dependent on plant conditions. If more than one reactor coolant pump is running, the AFW is controlled to approximately a 2-foot level. If forced circulation is lost in the primary system, the level is raised to approximately 20 feet to establish a high thermal center for natural circulation. In the event of a small break LOCA, the operator must take manual control of the system and raise the level to approximately 30 feet to establish steam condensation natural circulation.

Initiating full AFW flow and rapidly filling the system to 20 feet can result in a large cooldown of the primary system. This cooldown could cause a loss of indicated pressurizer level and possible actuation of the ECCAS because of a low re r coolant (RC) pressure. To minimize the potential for th .apid cooldown, a level rate control system has been implemented.

The design objectives of this control system are to:

a. Minimize operator action needed to prevent:

   1. Loss of indicated pressurizer level

   2. Low pressure engineered safety features actuation system (ESFAS) actuation

b. Allow a minimum of 10 minutes prior to requiring operator action to prevent loss of pressurizer level indication

4.1.2 Input/Output

The functional design for accomplishing these objectives is as follows.

Following AFW actuation, control of steam generator level is accomplished using AFW control valves in each AFW loop. Control signals for each AFW level control valve are supplied by redundant and independent Class 1E level transmitters on the associated steam generators. Figure 4-1 provides a simplified diagram illustrating the installation of these transmitters. Controllers for each valve are located in the main control room (MCR) and on the auxiliary shutdown control panel (ASP). In addition to automatic actuation by the AFWAS, manual control of the AFW level control valves for startup, shutdown, or emergency operations can be initiated using these controllers.

Auxiliary feedwater level control signals are continuously being generated by level controllers for the associated steam generator but are blocked from reaching the associated normally closed valve. Upon AFWAS actuation, the signal blocks are automatically removed and AFW level control commences. Dual level setpoints are used for level control. A low-level setpoint is utilized when more than one of the reactor coolant pumps (RCPs) is operating (signifying forced circulation) and a high-level setpoint is used when three out of four RCPs are tripped (anticipating natural circulation). The setpoint switchover is achieved by a safety-grade auctioneering device which senses RCP status. In addition, when the plant changes from forced circulation to natural circulation, the low-level setpoint is ramped at a controlled rate to the high-level setpoint to preclude overcooling of the primary loop. The function of the ramp generator is put on hold when either of the control stations is put in the manual mode. A reset pushbutton for each ramp generator is provided in the MCR and on the ASP. Manual activation of this pushbutton allows the level setpoint to drop to 2 feet, at which point the ramp function is restarted automatically. A simplified diagram of the level control scheme is provided in Figure 4-2.

The AFW level control valve control systems are redundant. These systems include redundant Class 1E level transmitters on the steam generator and redundant Class 1E level controllers on the main and auxiliary shutdown control panels. Power for the AFW level control system and control valve is from the Class 1E 120 V ac preferred power power supplies (battery-backed).

In the event of level transmitter failure, the AFW control valves may be manually controlled by placing the controller to the AFW control valve in manual. In this mode, the level setpoint can be manually changed for manual level control.

The transfer to manual control from the ASP overrides automatic control capabilities and removes manual operation from the control room. This allows full control from the ASP regardless of the mode selected in the control room. Manual status of the ASP controller is displayed by an indicating light on the control room panel. This indicating light is used to bring attention to an abnormal condition affecting the associated controls.

The following conditions are used as bases for level control system design.

a. Maintenance of safe shutdown capability using the auxiliary feedwater system is required.

b. Steam generator level is required to be monitored to provide AFW system control.

c. Steam generator level, isolation and control valve positions, AFW pump operation, and AFW flow are the minimum indications necessary to adequately monitor AFW operation.

d. The normal operating water level for the steam generators is 2 feet during forced circulation and 20 feet during natural circulation.

e. The maximum and minimum design water levels for the steam generators are approximately 36.5 feet and 1 foot above the bottom tubesheet, respectively.

f. Auxiliary feedwater actuation signal response time (not including sensors or actuated devices) is less than 500 milliseconds. Subsequent to establishing AFW flow, the level in the steam generators can be allowed to vary somewhat during safe shutdown; therefore, response time for AFW level control is not critical for performance. Auxiliary feedwater operation is initiated by the AFWAS when steam generator level reaches 1 foot. Auxiliary feedwater level controllers are preset to automatically control steam generator level at 20 feet during natural circulation and at 2 feet during forced circulation.

g. Applicable design bases are also given in Section 2.0.

4.1.3 System Response

The high AFW injection point provides sufficient heat transfer high in the steam generator to establish natural circulation. Because of this high injection point, a rapid filling of the steam generator is not required. A conceptual study of level rate control was performed prior to the development of a specific hardware design. This conceptual study confirmed that the level rate control concept is viable and established a preliminary AFW fill rate. This level rate limit was established by examining both high and low decay heat cases.

When the initial decay heat level is low and all RCPs are off (i.e., no pump heat is available) almost any rate of once-through steam generator (OTSG) level increase, however small, will result in cooling of the RCS. At the same time, other factors dictate the need for higher fill rates. First, if one fill rate limit is to be used for all initial conditions, then it must provide adequate coolant at high decay heat levels. Second, the time required to reach the high-level setpoint must be the minimum practical to ensure adequate natural circulation flow is established. And finally, the rate limit chosen must be of a large enough magnitude to allow smooth control by the electronic circuitry.

Two bounding conditions were chosen as the criteria for rate selection: 1) the rate must be high enough to provide adequate cooling with 100% decay heat, and 2) the rate must be low enough to provide a minimum of 10 minutes for operator action with 15% decay heat. A level rate limit of 4 inches per minute satisfied these conditions.

Figures 4-3 through 4-5 depict the results of the 15, 40, and 100% power cases using a 4-inch-per-minute level rate. Auxiliary feedwater flowrate to each steam generator was varied from about 180 gpm to about 200 gpm to achieve the level rate of 4 inches per minute for the various decay heat levels.

The 15% case resulted in the most rapid cooldown, with pressurizer level going off-scale at about 890 seconds (14.8 minutes) into the transient. At that time, OTSG levels were about 4 inches on the startup range; thus, operator action would be required before 14.8 minutes to maintain indicated pressurizer level.

The 40% case does not show pressurizer level going off-scale, but extrapolation of the rate of pressurizer level decrease with the rate of OTSG level increase indicates operator action would be required before approximately 21 minutes into the transient.

The 100% case shows a very gradual RCS cooldown and thus, a very gradual loss in indicated pressurizer level. This case is not expected to result in the need for operator action; i.e., the 240-inch level setpoint would be reached before indicated pressurizer level is lost.

Figure 4-6 provides a graphic representation of time available for operator action versus initial decay heat level using a 4-inch-per-minute fill rate. This graph shows that a minimum of 10 minutes will be available for all initial conditions and, for initial decay heat levels ≥90%, no operator action is required.

Thus, a fill rate on the order of 4 inches per minute satisfies both criteria of providing at least 10 minutes for operator action to preclude loss of indicated pressurizer level and providing adequate cooling for maximum decay heat levels.

4.2 FEED-ONLY-GOOD GENERATOR INTERLOCK

4.2.1 Purpose

The AFW system is equipped with a feed-only-good generator (FOGG) interlock which operates to terminate AFW flow to a faulted steam generator. Following a steam line or feedwater line break, the heat removal from the primary system must be controlled to avoid excessive overcooling resulting in a possible return to power. Continued feeding of AFW to a depressurized steam generator creates the potential for this overcooling. In addition, if the break is inside the reactor building, continued feeding of the faulted steam generator can result in excessive mass and energy release to the reactor building. The FOGG system is intended to detect the steam generator with the break and to isolate AFW to that steam generator for those breaks where prompt automatic action is required. A second consideration in the FOGG design is to ensure that continued heat removal is always available through at least one steam generator. As a result, the FOGG system can isolate AFW to either steam generator A or B, but cannot isolate feedwater to both steam generators.

The method for detecting the steam generator with the break is to measure the pressure difference between the two steam generators. When the pressure difference exceeds a setpoint, AFW is terminated to the low-pressure steam generator. If this pressure difference is the result of a break in the system, then the low-pressure steam generator will continue to depressurize as the remaining inventory in the steam generator is lost through the break. If the pressure difference was caused by some unexpected system perturbation or if the break is isolated, the steam generator would repressurize. When this happens, the pressure differential between the two steam generators would be reduced below the setpoint. The FOGG system would then reestablish AFW flow to both steam generators.

4.2.2 Input/Output

The FOGG system continuously monitors the differential pressure between the steam generators. When a predetermined differential pressure is sensed, FOGG automatically closes the AFW isolation and control valves supplying the lower pressure OTSG and the steam supply valve from the lower pressure OTSG to the steam turbine-driven AFW pump. The FOGG logic is developed as part of the plant ESFAS. The continuous interrogation feature of this system permits isolation any time during a secondary pressure transient and allows the lower pressure OTSG to be returned to service should the pressure differential be reduced by corrective action (i.e., main steam and feedwater line isolation). In addition, manual actuation/block of FOGG is provided for the operator to feed the good generator during a tube break in the other steam generator. A simplified diagram of the FOGG system is provided in Figure 4-7.

Redundant actuation and controls are provided throughout the AFWAS on a one-to-one basis with mechanical equipment trains to ensure the required flow to both steam generators in the event of a single failure.

4.2.3 System Response

A typical system response to a steam line break is shown in Figure 4-8. This case is a 2.0 square foot steam line break which has been determined to be the worst case overcooling transient. For this case, both steam generators rapidly depressurize and are isolated by a low RC system pressure ECCAS signal which results in closure of the main steam and main feedwater isolation valves. The FOGG system will also isolate AFW to the affected steam generator. As can be seen from the plots, the steam generator with the break will continue to depressurize while the depressurization on the other steam generator is stopped. The pressure in the unaffected steam generator is then controlled by the temperature in the primary system. That is, the steam generator will repressurize to the saturation pressure corresponding to the temperature in the primary system. If this case were calculated further out in time, decay heat would gradually heat up the primary system and the steam generators would then repressurize to the atmospheric dump valve or safety valve setpoint.

4.3 STEAM GENERATOR OVERFILL PROTECTION

4.3.1 Purpose

Overfilling of a steam generator that causes liquid carry-over into the steam lines has several potentially serious consequences. Potential consequences include: 1) steam-water hammer can impose excessive thrust loads on valves, piping, and supports, and 2) two-phase flow to the turbine-driven AFW pump can damage the controls or turbine preventing its operation. For these reasons, an AFW overfill protection system has been implemented to automatically terminate AFW flow when an overfill condition is imminent. This overfill protection system uses a high-high level signal in the steam generators to terminate feedwater and allows a return to normal AFW level control when the level falls below a predetermined setpoint.

4.3.2 Input/Output

Steam generator high-high level signals are developed from the wide-range steam generator level transmitters. These are the same transmitters that are used for the AFW level control system. Interlocks are provided to demand closure of level control and isolation valves to prohibit AFW flow to a steam generator if the level has reached the high-high level setpoint. A demand closure signal to the valve will remain active until the steam generator level drops to 10% of the transmitter span below the high-high level setpoint. As the demand closure signal is removed, the normal AFW control system will regain control of the AFW system.

4.3.3 System Response

An auxiliary feedwater overfill transient occurs much slower than a main feedwater overfill transient because of the lower flow capability of the AFW system. As a result, specific simulations of an AFW overfill event have not been performed.

5.0 AFW SYSTEM RELIABILITY

The Midland Plant Auxiliary Feedwater System Reliability Analysis Synopsis, prepared by Pickard, Lowe, and Garrick, Inc., is provided in Appendix A.

6.0 DESIGN EVALUATION/REGULATIONS

This section provides the auxiliary feedwater (AFW) system safety evaluation and compliance with the Standard Review Plan 10.4.9 Acceptance Criteria (including general design criteria/regulatory guides/branch technical positions) and other regulatory guidance. (Refer to Figure 6-1.) Wherever "position" or "guideline" statements appear in the following section, the words have been paraphrased from the referenced regulatory document for the purpose of brevity. Midland-specific terminology has replaced generic designations where appropriate.

6.1 SAFETY EVALUATION

The following safety evaluations correspond to the similarly numbered safety design bases as given in Section 2.1.

6.1.1 Safety Evaluation One

The AFW system, in conjunction with the condensate storage tank (CST) [or the service water systems (SWS) if the CST is unavailable], provides a means of pumping sufficient feedwater to prevent damage to the reactor following a loss-of-main feedwater incident. The AFW system can also cool the reactor coolant system (RCS) at a maximum rate of 100F per hour (via the turbine bypass system) if the main condenser and circulating water systems are available.

During normal cooldown with the condenser available, the motor-driven pump reduces the reactor coolant temperature directly to 280F, at which point the decay heat removal system is initiated. During an abnormal cooldown, i.e., a loss of offsite ac power, unavailability of the main condenser, or loss of the motor-driven AFW pump, the turbine-driven AFW pump is capable of reducing the temperature of secondary system once-through steam generator (OTSG) to approximately 310F. However, under these conditions, the decay heat removal system is capable of being initiated at 325F, instead of the normal 280F, to further cool down the RCS.

Pump capacities are discussed in Section 3.2. The capacity of the AFW pump equals the flow at 105F which, when injected in the steam generator, will offset by evaporation the decay heat released following a reactor trip from full power (as determined by using the method prescribed in Branch Technical Position APCSB-9.2 for calculating decay heat generation). The pump discharge head sufficiently establishes the necessary flowrate against a steam generator pressure corresponding to the lowest pressure setpoint of the main steam safety valves. The minimum condensate storage tank volume adequately accommodates the plant at hot standby for approximately 4 hours followed by a 6-hour cooldown to 280F.

6.1.2 Safety Evaluation Two

The AFW system provides a redundant and diverse means of supplying feedwater to the steam generators for cooling the RCS under emergency conditions. Either pump has the capability of supplying 100% of the feedwater requirements for safe cooldown of the RCS. Complete physical and electrical separation is maintained throughout the pump controls, control signals, electrical power supplies, and instrumentation for each AFW pump. The AFW system can perform its safety-related function assuming any single active component failure coincident with loss of offsite power.

6.1.3 Safety Evaluation Three

Instrumentation and controls are provided that enable operation of the pumps at the auxiliary shutdown panel (ASP) in the event of control room evacuation. Instruments provided at the ASP are described in Section 3.7.

6.1.4 Safety Evaluation Four

The AFW system is designed to meet Seismic Category I requirements.

The AFW pumps take emergency suction from two sources. The normal source is the non-Seismic Category I CST. If the CST is unavailable due to a tornado or seismic event, the operator is notified by low-pressure alarms on the pump suction, and an automatic switchover to the Seismic Category I tornado-protected SWS occurs. One service water train supplies each AFW pump. Upon initiation of service water, the affected AFW train is automatically isolated by power-operated valves from the non-Seismic Category I piping leading to the CST, condenser hotwell, and deaerator storage tank. Check valves are also provided to prevent backflow to the CST, condenser hotwell, and deaerators. Each SWS train is isolated from the other so that failure of one does not affect the other.

6.1.5 Safety Evaluation Five

Diversity is provided in the type and number of pumps, sources of water supply, power supplies, and arrangement of piping and pump and valve controls, so that any single failure will not negate the AFW system's ability to perform its safety function. The motor-driven pump and associated equipment are powered by Class 1E ac power supplies. The turbine-driven pump receives steam from either or both main steam lines before they leave the containment. Valves and controls necessary for the function of the turbine-driven pump and its associated equipment are energized by Class 1E dc power supplies.

Assuming a temporary loss of all offsite, normal onsite, and emergency onsite ac power (station blackout), the AFW system is designed to perform its safety function for at least 2 hours. The steam turbine-driven AFW pump provides the required feedwater to both steam generators during station blackout.

6.1.6 Safety Evaluation Six

The AFW system incorporates the following design features to minimize the effects of hydraulic instability (water hammer):

a. AFW piping rises vertically to the OTSG AFW nozzle to prevent drainage of the lines into the OTSGs.

b. AFW lines have check valves to prevent back drainage of the lines.

c. Low-temperature AFW is fed directly at the upper section of the OTSGs into the tube bundle, independent of the main feedwater nozzles, so that the injected water is heated to within a few degrees of saturation prior to pooling above the lower tubesheet.

6.2 GENERAL DESIGN CRITERIA

The AFW system conforms to the general design criteria (GDC) provided in 10 CFR 50, Appendix A, as discussed below.

6.2.1 GDC 2, Design Bases for Protection Against Natural Phenomena

Guideline: Structures, systems, and components important to safety shall be designed to withstand the effects of natural phenomena such as earthquakes, tornados, hurricanes, floods, tsunami, and seiches without loss of capability to perform their safety functions.

Design: Structures, systems, and components required for AFW system performance are designed to meet Seismic Category I requirements and to withstand the effects of other credible natural phenomena such as tornados and floods. The natural phenomena and their magnitudes are selected in accordance with their probability of occurrence at the Midland site.

6.2.2 GDC 4, Environmental and Missile Design Bases

Guideline: Structures, systems, and components important to safety shall be designed for the environmental conditions associated with normal operation, maintenance, testing, and postulated accidents, including loss-of-coolant accidents. They shall be appropriately protected against dynamic effects, including the effects of missiles, pipe whipping, and discharging fluids, that may result from equipment failures and from events and conditions outside the nuclear power unit.

Design: The AFW system design includes two redundant, independent, safety-grade AFW trains that ensure the system function will not be compromised by postulated environmental conditions and dynamic effects. Further details, including environmental qualification, are provided in FSAR Chapter 3.0.

6.2.3 GDC 5, Sharing of Structures, Systems, and Components

Guideline: Structures, systems, and components important to safety shall not be shared among nuclear power units unless it can be shown that this sharing will not significantly impair their ability to perform safety functions, including, in the event of an accident in one unit, an orderly shutdown and cooldown of the remaining units.

Design: The only shared system/component in the AFW system is the backup safety-grade SWS. The SWS, while shared between units, contains two redundant independent trains. Each SWS train is capable of simultaneously supplying the emergency feedwater requirements of both units.

6.2.4 GDC 19, Control Room

Guideline: A control room shall be provided from which actions can be taken to operate the nuclear power unit safely under normal conditions and to maintain it in a safe condition under accident conditions. Equipment shall also be provided at appropriate locations outside the control room with a capability for prompt hot standby, maintaining a safe condition during hot standby, and with a potential capability for subsequent cold shutdown.

Design: Instrumentation and controls required for operating and monitoring the AFW system are provided in the main control room and on the ASP. Further detail is provided in Section 3.7.

6.2.5 GDC 44, Cooling Water

Guideline: A system shall be provided to transfer the combined heat load from structures, systems, and components important to safety to an ultimate heat sink under normal operating and accident conditions.

Suitable redundancy in components and features, and suitable interconnections, leak detection, and isolation capabilities shall be provided to ensure that for onsite electric power system operation (assuming offsite power is not available) and for offsite electric power system operation (assuming onsite power is not available) the system safety function can be accomplished, assuming a single failure.

Design: The AFW system provides sufficient feedwater to the OTSGs to transfer the RCS decay heat loads to the main condenser or, if the condenser is unavailable, to the atmosphere through the atmospheric dump valves, power-operated atmospheric vent valves, and/or the main steam safety valves. The AFW system is designed with redundant isolatable trains that ensure its safety function will not be compromised, assuming any single active failure concurrent with a loss of offsite power.

6.2.6 GDC 45, Inspection of Cooling Water System

Guideline: The cooling water system shall be designed to permit appropriate periodic inspection of important components, such as heat exchangers and piping, to assure the integrity and capability of the system.

Design: The AFW system design allows inspection of components essential to the system's safety function in accordance with the ASME Boiler and Pressure Vessel Code, Section XI.

6.2.7 GDC 46, Testing of Cooling Water System

Guideline: The cooling water system shall be designed to permit appropriate periodic pressure and functional testing to assure 1) the structural and leaktight integrity of its components, 2) the operability and the performance of the active components of the system, and 3) the operability of the system as a whole and, under conditions as close to design as practical, the performance of the full operational sequence that brings the system into operation for reactor shutdown and for loss-of-coolant accidents, including operation of applicable portions of the protection system and the transfer between normal and emergency power sources.

Design: The AFW system design allows testing of the ASME components in accordance with ASME Code Section XI. The AFW system instrumentation design allows testing in accordance with Section 4.10 of IEEE Standard 279-1971.

6.3 REGULATORY GUIDES

The AFW system conforms to the applicable regulatory guides as discussed below.

6.3.1 Regulatory Guide 1.26, Quality Group Classification and Standards (6/75)

Position: Portions of the AFW system extending from and including the secondary side of steam generators up to and including the outermost containment isolation valves and connected piping up to and including the first valve (including a safety or relief valve) that is either normally closed or capable of automatic closure during all modes of normal reactor operation shall meet the requirements of ASME Code Section III, Class 2.

Design: The AFW system piping and valves that are part of the containment pressure boundary meet the requirements of ASME Code Section III, Class 2.

Position: Portions of the AFW system important to safety, but not included in the guideline above, shall meet the requirements of ASME Code Section III, Class 3.

Design: AFW system components important to safety meet the requirements of ASME Code Section III, Class 3.

6.3.2 Regulatory Guide 1.29, Seismic Design Classification (8/73)

Position: The AFW system shall be designated as Seismic Category I, designed to withstand the effects of the safe shutdown earthquake and to remain functional, and meet the quality assurance requirements of 10 CFR 50, Appendix B.

Design: The portions of the AFW system required for its safety function are designed to meet Seismic Category I requirements and are housed in Seismic Category I structures.

6.3.3 Regulatory Guide 1.62, Manual Initiation of Protective Actions (10/73)

Position: The AFW system shall be capable of manual initiation at the system level, from the control room, and perform all actions performed by automatic initiation.

Design: Each train of the AFW actuation signal can be manually initiated from the control room and results in the same system response as automatic initiation.

Position: Equipment common to both manual and automatic initiation shall be minimized.

Design: The number of AFW components common to both manual and automatic initiation has been minimized to the extent practicable. No single failure in either the manual or automatic controls will preclude operation of the AFW system.

Position: Equipment required to manually initiate protective actions shall be minimized.

Design: A single pushbutton on the main control boards is capable of initiating each AFW train (two trains per unit).

6.3.4 Regulatory Guide 1.102, Flood Protection for Nuclear Power Plants (9/76)

Position: The AFW system should be designed to withstand the most severe flood conditions postulated to occur due to severe hydrometeorological conditions, seismic activity, or both.

Design: The safety-related structures housing the AFW system are capable of protecting the system from the effects of the probable maximum flood, including maximum water level concurrent with wind wave activity.

6.3.5 Regulatory Guide 1.117, Tornado Design Classification (4/78)

Position: The AFW system should be designed to withstand the effects of the design basis tornado (DBT).

Design: The AFW system can withstand the DBT including tornado-generated missiles, and maintain its safety function.

6.4 BRANCH TECHNICAL POSITIONS

6.4.1 BTP APCSB 3-1, Protection Against Postulated Piping Failures In Fluid Systems Outside Containment/ BTP MEB 3-1, Postulated Break and Leakage Locations In Fluid System Piping Outside Containment

AFW system compliance with the applicable portions of BTP APCSB 3-1 and BTP MEB 3-1 is described in Section 3.4.5. A detailed discussion of high- and moderate-energy pipe failure protection is provided in FSAR Section 3.6.

6.4.2 BTP ASB 10-1 (Revision 1), Design Guidelines for Auxiliary Feedwater System Pump Drive and Power Supply Diversity for PWRs

Guideline: The AFW system should consist of at least two full-capacity, independent systems that include diverse power sources.

Design: The Midland design contains two full-capacity, independent AFW trains, each capable of supplying the feedwater requirements for a safe cooldown of the RCS. One train contains a motor-driven pump, the other a turbine-driven pump. Redundant and diverse Class 1E power sources supply the pumps and valves.

Redundant Class 1E power sources are provided for the controls and instrumentation required to operate and monitor the AFW system. Refer to Sections 3.0 and 4.0 for further detail.

Guideline: Other powered components of the AFW system should also use the concept of separate and multiple sources of motive energy.

Design: Refer to the previous design response paragraph.

Guideline: The AFW intake and discharge piping arrangement for each train should permit the pumps to supply feedwater to any combination of steam generators.

The Midland AFW system piping arrangement is capable of supplying feedwater to any steam generator considering any single active component, power supply, or control system failure. The suction piping arrangement enables independent operation of each AFW pump. The discharge piping arrangement includes a crossover design allowing each pump to feed either steam generator. Each train is fed by independent, diverse power sources and is capable of remote manual/automatic control. Refer to Section 3.0 for further detail.

Guideline: The AFW system should be designed to offset a single active component failure.

Design: The AFW system is designed to withstand any single active failure coincident with a loss of offsite power.

Guideline: When considering a high-energy line break, the system should be so arranged to assure the capability to supply necessary emergency feedwater to the steam generators, despite the postulated rupture of any high-energy section of the system, assuming a concurrent single active failure.

Design: Normal operation of the electric-driven AFW pump occurs during periods when the turbine-generator is not paralleled to the offsite grid. Operation of the turbine-driven AFW pump for any normal operation is precluded by FSAR Technical Specification 16.3/4.7.1.2. Under any potential operating condition for which a high-energy line rupture must be postulated, availability of offsite power is assumed. Therefore, in the event of a high-energy line rupture at the discharge of one pump (worst case) and a single active failure of the other pump, the main feed pumps are available as a water-injection source.

6.5 OTHER REGULATORY GUIDANCE

The following section discusses the conformance of the AFW system to applicable regulatory guidance not covered in Sections 6.2 through 6.4.

6.5.1 NRC 10 CFR 50.54(f) Request, B&W System Sensitivity

Formal responses to the B&W system sensitivity concerns were provided by Consumers Power Company in letters to the NRC from S.H. Howell to H.R. Denton, dated November 30 and December 4, 1979, and April 1, 1980. The following items are applicable to the AFW system. The responses to these items is as referenced below.

Item 5, Fully Safety Grade AFW System - Refer to Sections 3.0, 4.0, and 6.5.4.1

Item 6, FOGG System - Refer to Sections 4.2 and 6.5.4.3

Item 9a, Reliability Analysis - Refer to Section 5.0

Item 9b, Flow Indication Upgrade - Refer to Section 6.5.5.2

Item 9c, Piping Modifications - Refer to Section 3.0

Item 10, Improved AFW Flow Control - Refer to Sections 3.0, 4.0, and 6.5.6

6.5.2 AFW System Flow Requirements

Responses to the requests for information regarding the basis for AFW system flow requirements, transmitted in Enclosure 2 of D.F. Ross, Jr.'s letter to S.H. Howell of April 24, 1980, is provided in Section 10A.4 of Appendix B.

6.5.3 NUREG-0611, Generic Evaluation of Feedwater Transients and Small-Break LOCAs in Westinghouse-Designed Operating Plants

A comparison of the Midland AFW system design with the recommendations of NUREG-0611, Appendix III, is provided in Section 10A.3 of Appendix B. The preliminary Midland Technical Specification 16.3/4.7.1.2, AFW System, is provided as Appendix C for information.

6.5.4 NUREG-0667, Transient Response of B&W-Designed Reactors

The following recommendations correspond numerically to the recommendations contained in Section 2.2 of NUREG-0667.

6.5.4.1 Recommendation 1, AFW System Upgrade

Position: The AFW system should meet safety-grade requirements.

Design: All essential portions of the AFW system are safety-grade and designed to meet Seismic Category I requirements.

6.5.4.2 Recommendation 2, AFW System Initiation and Control

Position: The AFW system should be automatically initiated and controlled by safety-grade systems independent of the integrated control system (ICS), nonnuclear instrumentation (NNI), and other nonsafety systems.

Design: The AFW system is automatically initiated by the safety-grade AFW actuation signal (AFWAS). Automatic alignment and/or modulation of AFW-related valves is accomplished with safety-grade controls. Both the automatic initiation and control functions are independent of the ICS, NNI, and other nonsafety systems.

6.5.4.3 Recommendation 4, Steam Line Break Detection and Mitigation

Position: The steam line break detection and mitigation system should eliminate adverse interactions between it and the AFW system. It should be capable of differentiating between an actual steam line break and undercooling or overcooling events caused by feedwater transients.

Design: The feed-only-good generator (FOGG) control system operates to terminate AFW flow to the lower pressure OTSG when the differential pressure between the two steam generators exceeds a predetermined value. This system allows the higher pressure OTSG to remain in service at all times for decay heat removal duty. Therefore, positive differentiation between steam or feedwater line breaks and feedwater transients is not required.

6.5.4.4 Recommendation 9, Post-Trip Pressure and Level Response

Position: Following a reactor trip, pressurizer level should remain on scale, and system pressure should remain above the high-pressure injection actuation setpoint. The system response (e.g., secondary pressure) should be modified to meet these two objectives. Meeting these objectives should be independent of all manual operator actions.

Design: A response to this position is provided in Appendix D.

6.5.4.5 Recommendation 10, Sensitivity Studies to Reduce OTSG Response

Position: B&W licensees should perform sensitivity studies of possible modifications which would reduce the response of the OTSG to secondary coolant flow perturbations. Both passive and active measures should be investigated to mitigate overcooling and undercooling events.

Design: A response to this position is provided in Appendix D.

6.5.4.6 Recommendation 21, Reevaluation of AFW System Injection Point

Position: The need to introduce AFW through the top spray sparger during anticipated transients shall be evaluated. The reduced depressurization response if AFW could be introduced through the main feedwater nozzle and could enter the tube region from the bottom of the unit shall be considered.

Design: A response to this position is provided in Appendix D.

6.5.5 <u>NUREG-0737, Clarification of TMI Action Plan Requirements</u>

The following items correspond with the AFW-related items provided in NUREG-0737.

6.5.5.1 Item II.E.1.1, AFW System Initiation

Position: An AFW system reliability analysis shall be provided to determine the potential for AFW system failure.

Design: The Midland Plant Auxiliary Feedwater Reliability Analysis, performed by Pickard, Lowe, and Garrick, Inc., has been forwarded to the NRC by letter from J.W. Cook to H.R. Denton, Serial 11223, dated February 23, 1981. A synopsis of the analysis is presented in Section 5.0.

Position: An evaluation of the AFW system using the acceptance criteria of SRP 10.4.9 shall be provided.

Design: An evaluation is provided above in Section 6.0, along with design details provided in Sections 3.0 and 4.0.

Position: The AFW system flowrate design bases and criteria shall be reevaluated.

Design: Refer to Section 10A.4 of Appendix B.

6.5.5.2 Item II.E.1.2, AFW System Automatic Initiation and Flow Indication

Position: Safety-grade automatic initiation of the AFW system and safety-grade flow indication to each steam generator shall be provided.

Design: The AFW system design incorporates safety-grade automatic system initiation and flow indication as described in Sections 3.0 and 4.0. As a result of clarifications to the requirements associated with this item, the Midland design will be revised to incorporate two safety-grade flowrate indicators in the main control room for each steam generator.

6.5.5.3 Item II.K.2.2, Initiation and Control of AFW Independent of the Integrated Control System

Position: Procedures and training to initiate and control the AFW system independent of the integrated control system (ICS) shall be provided.

Design: The AFW system is independent of the ICS. Procedures and training associated with AFW initiation and control are being developed to comply with the above guidelines.

6.5.6 <u>Open Items Associated with Staff Review of Midland Plants (NRC Letter, 3/30/79; Meetings of 4/10-11/79 and 4/19-20/79)</u>

6.5.6.1 RSB-4

Guideline: This open item expresses concern about primary system overcooling when using AFW to control OTSG level during loss-of-offsite-power events.

The Midland design incorporates a level rate limiting circuit in the control logic of the AFW flow control valves. This feature minimizes AFW-induced overcooling of the RCS and permits the pressurizer level to remain in the indicating range following reactor trips. Analyses of plant performance during such events are provided in the response to FSAR Question 211.184 (Appendix E). Section 4.1 provides further detail.

6.5.6.2 ICSB-11

Guideline: This open item requests further information on the instrumentation and controls for automatic switchover of the AFW pump suction from the nonsafety condensate storage tank to the safety-grade SWS.

Design: Appropriate portions of FSAR Chapter 7 have been revised to address this concern. Refer to Appendix F.

LIST OF ABBREVIATIONS

AFW	Auxiliary feedwater
AFWAS	Auxiliary feedwater actuation signal
ASP	Auxiliary shutdown panel
CST	Condensate storage tank
DHR	Decay heat removal
ECCAS	Emergency core cooling actuation system
ESFAS	Emergency safety features actuation system
FOGG	Feed-only-good generator
MCR	Main control room
OTSG	Once-through steam generator
RC	Reactor coolant
RCP	Reactor coolant pumps
RCS	Reactor coolant system
SWS	Service water system

TABLES

TABLE 2-1

AUXILIARY FEEDWATER SYSTEM

CODES AND STANDARDS

Component	Location	Quality Group[1]	Code/ Standard[2]	Seismic Category[3]
Turbine-driven AFW pump	Aux	C	III-3	I
Motor-driven AFW pump	Aux	C	III-3	I
AFW pump turbine	Aux	NA	NA	I
AFW pump motor	Aux	NA	IEEE 323/344	I
Piping and valves to penetration	Aux	C	III-3	I
Piping and valves to OTSG	Cont	B	III-2	I

[1] C,B: Quality group classification as defined in Regulatory Guide 1.26

[2] III-2, III-3: ASME Boiler and Pressure Vessel Code, Section III, Class 2, 3

[3] I: Construction in accordance with seismic requirements of Regulatory 1.29 and Appendix A to 10 CFR 100

FIGURES

AUXILIARY FEEDWATER SYSTEM

(Simplified)

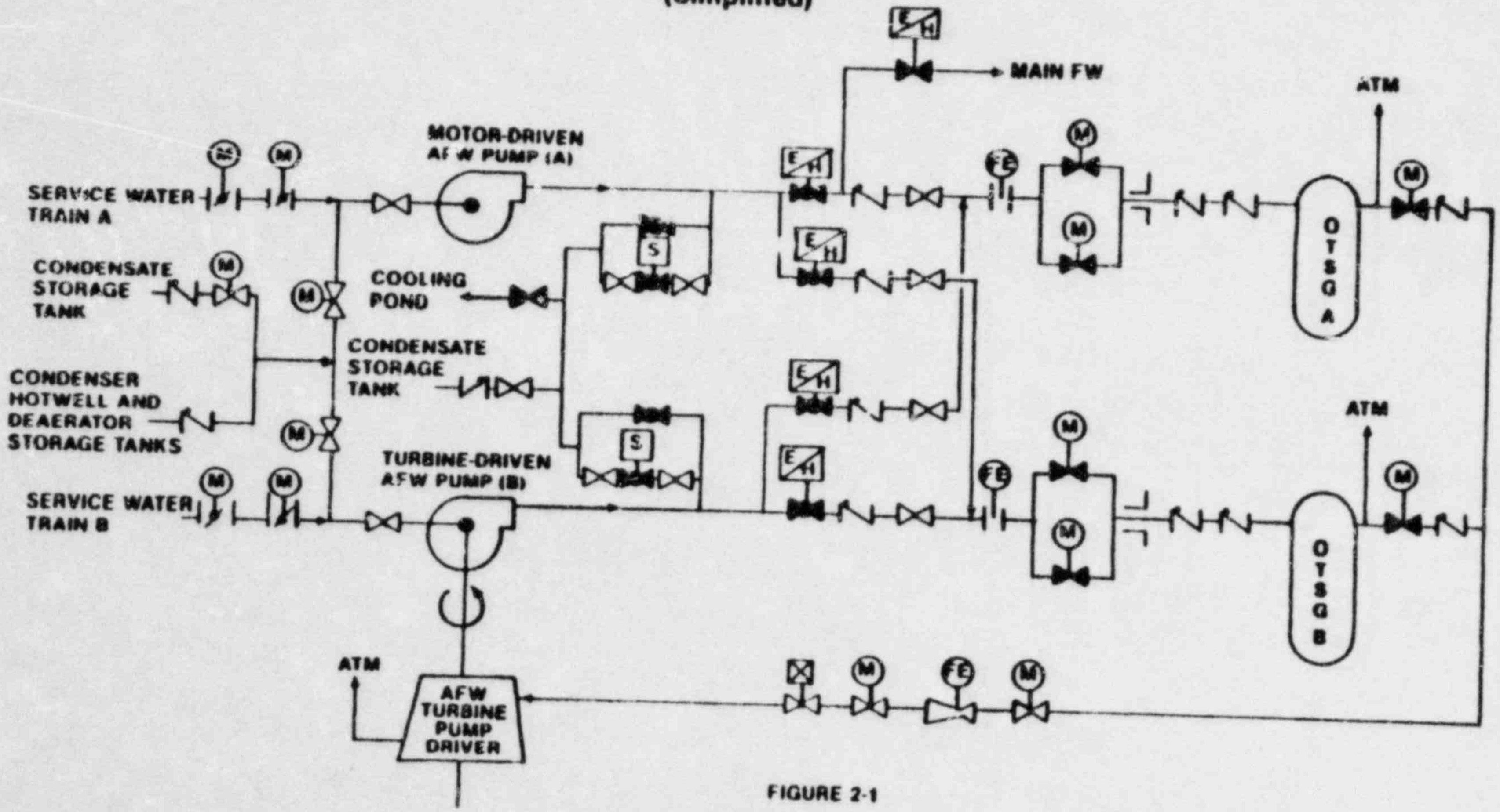


FIGURE 2-1

AUXILIARY FEEDWATER
SUCTION CONFIGURATION

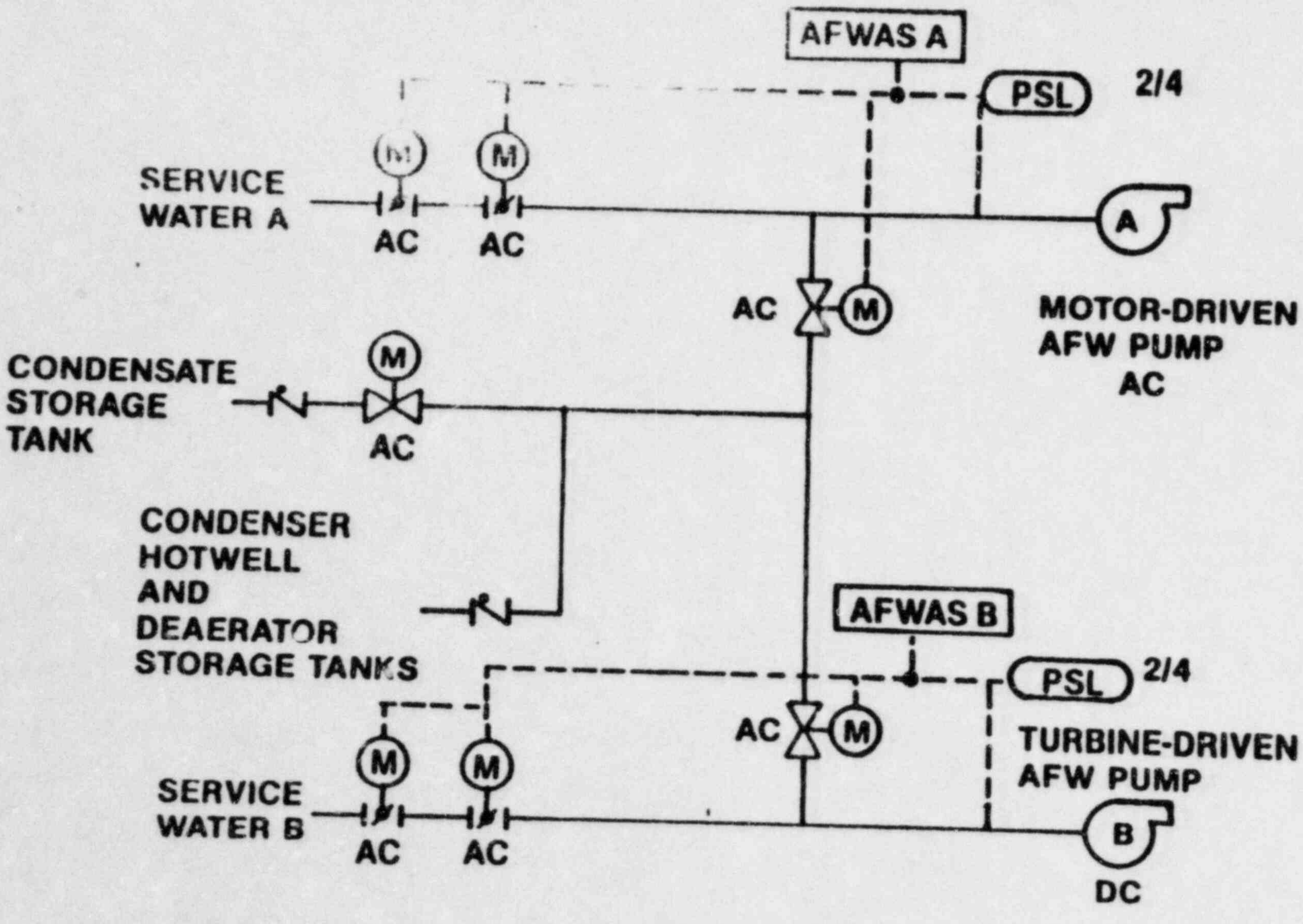


FIGURE 2.1

AUXILIARY FEEDWATER
PUMP TURBINE DRIVER

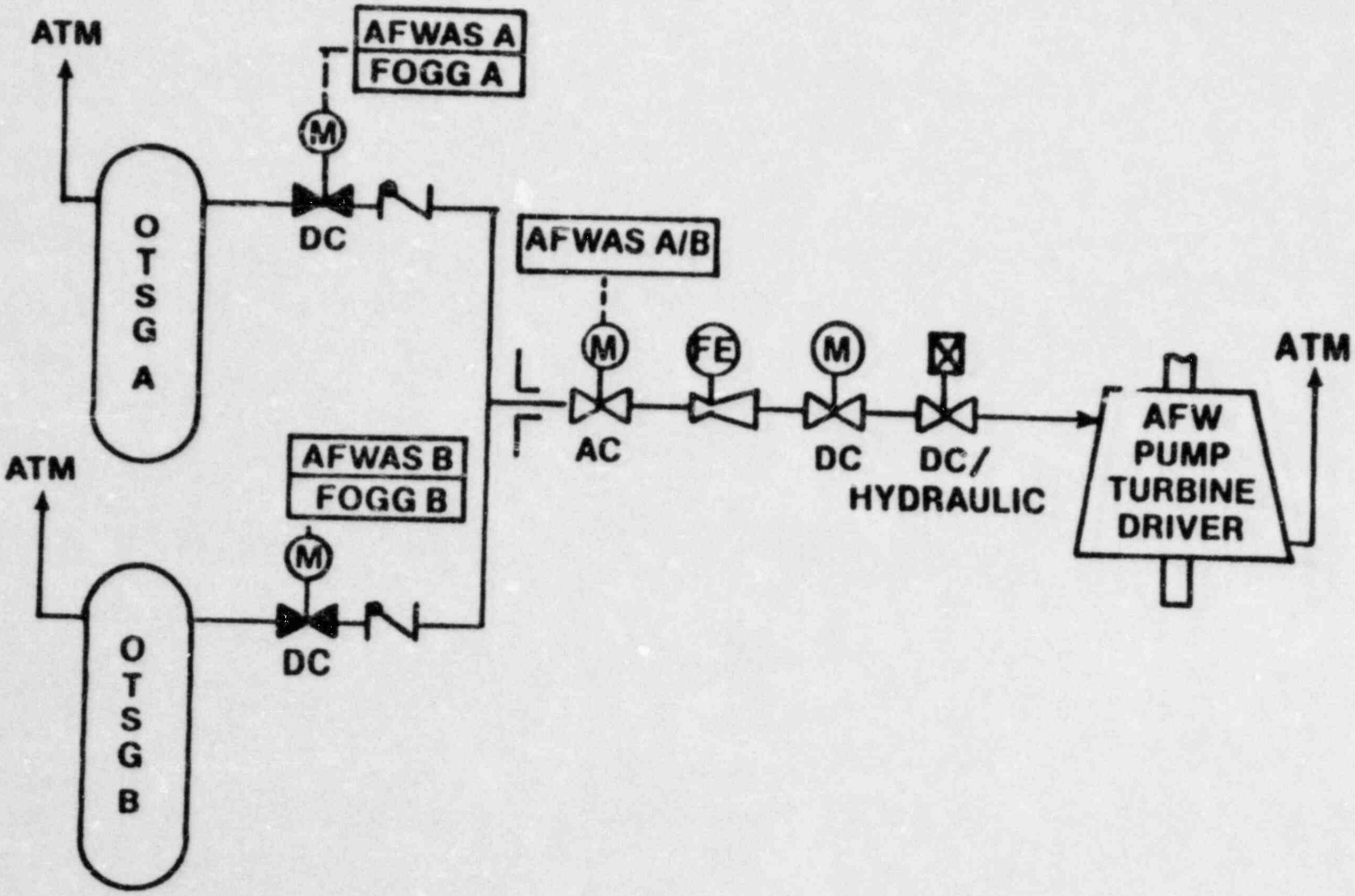
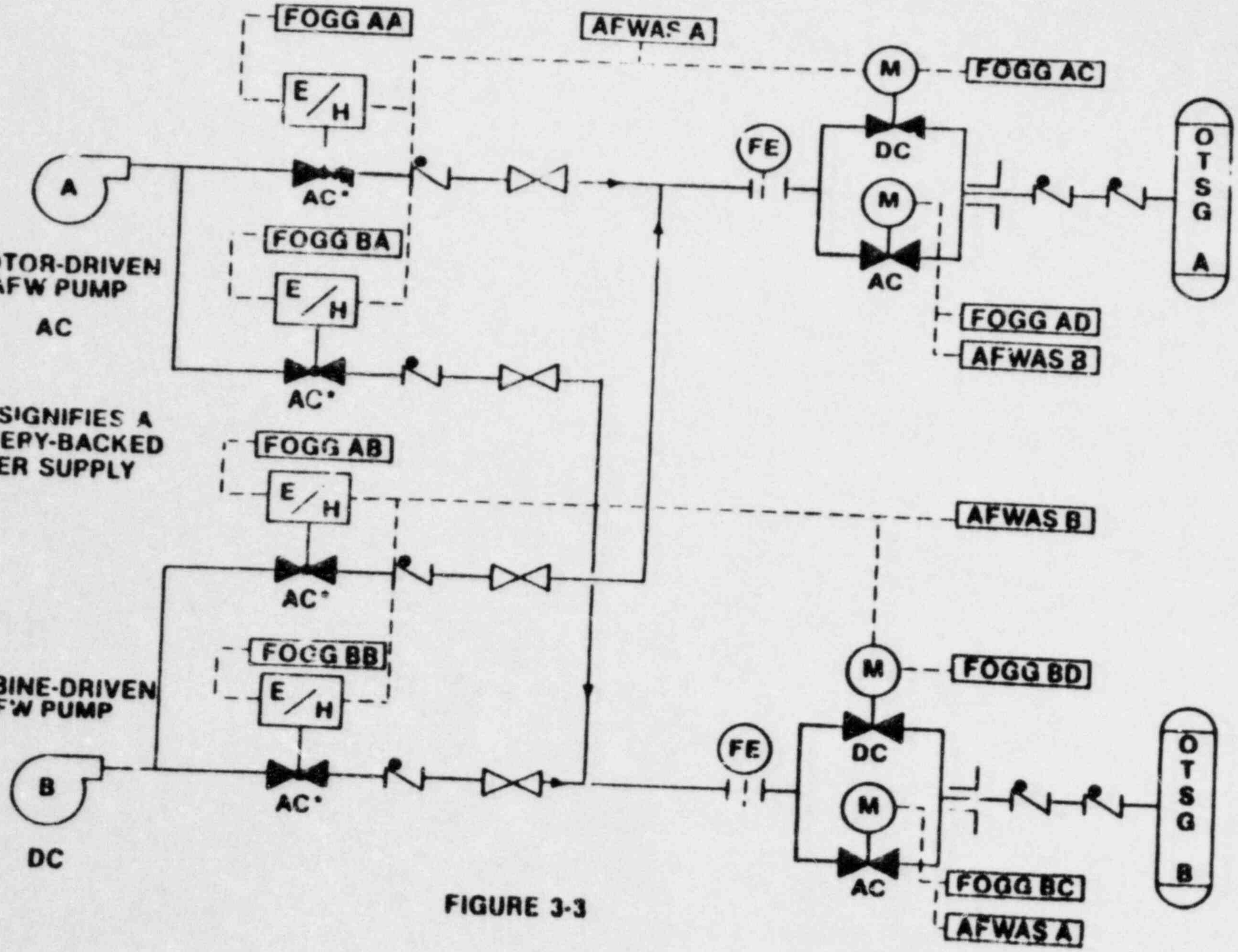


FIGURE 3-2

AUXILIARY FEEDWATER
DISCHARGE CONFIGURATION



NOTE: AC* SIGNIFIES A BATTERY-BACKED POWER SUPPLY

FIGURE 3-3

AUXILIARY FEEDWATER
INITIATION

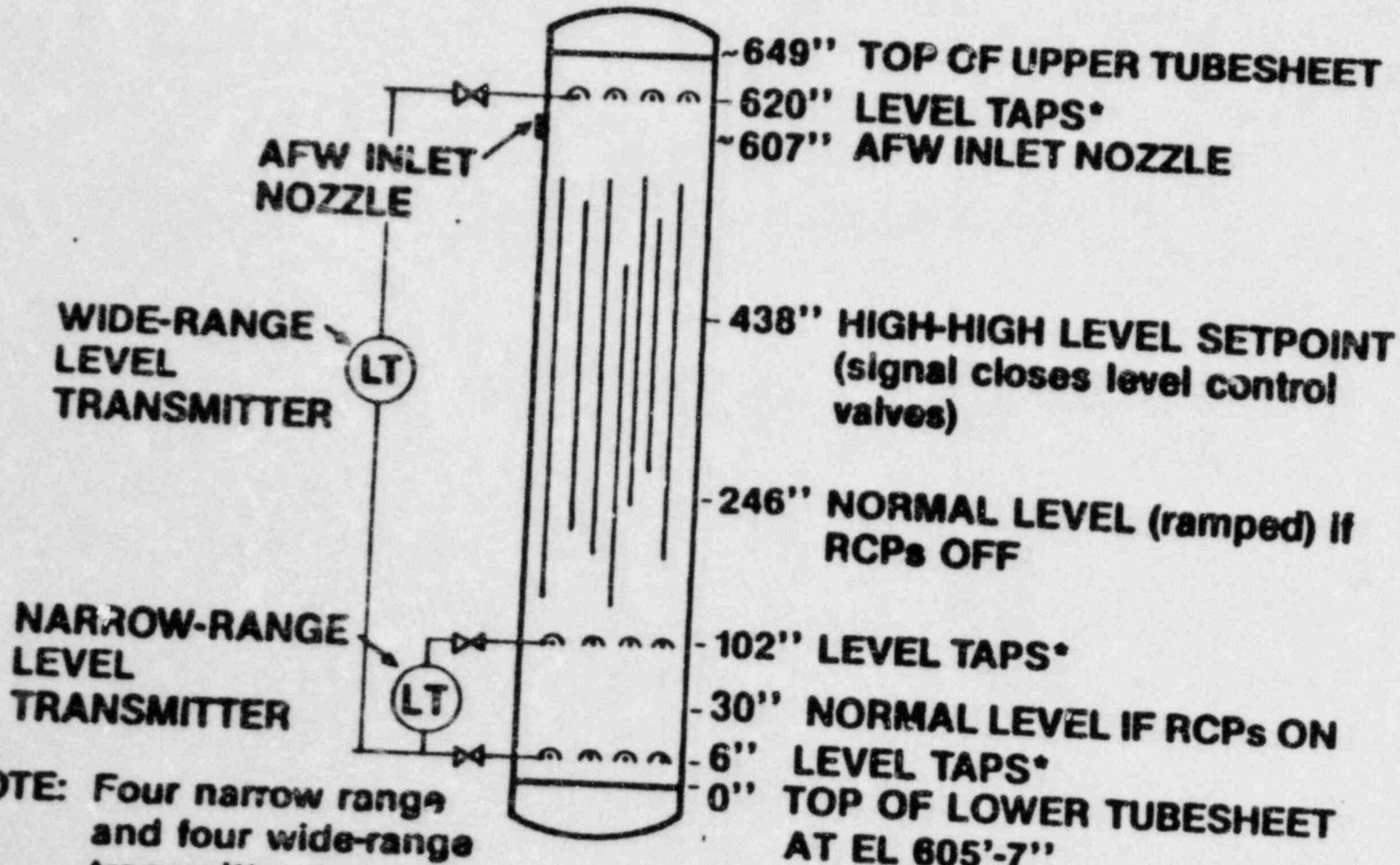
- **LOSS OF MAIN FEEDWATER**
  - **Low OTSG Level**
  - **Loss of MFW Pumps**
  - **Low OTSG Pressure**
  - **ECCAS**

- **LOSS OF FORCED RC SYSTEM CIRCULATION**
  - **Loss of 3-out-of-4 RC Pumps**
  - **Class 1E Bus Undervoltage**

AUXILIARY FEEDWATER
CONTROL

- LEVEL CONTROL
  - 2 Feet - RC Pumps Running
  - 20 Feet - Natural Circulation
  - 30 Feet - Small LOCA (operator action required to raise level to 30 feet)
- RATE OF FILL CONTROL
  - Level Raised at Approximately 4 Inches per Minute to Prevent Overcooling

AUXILIARY FEEDWATER
TYPICAL STEAM GENERATOR

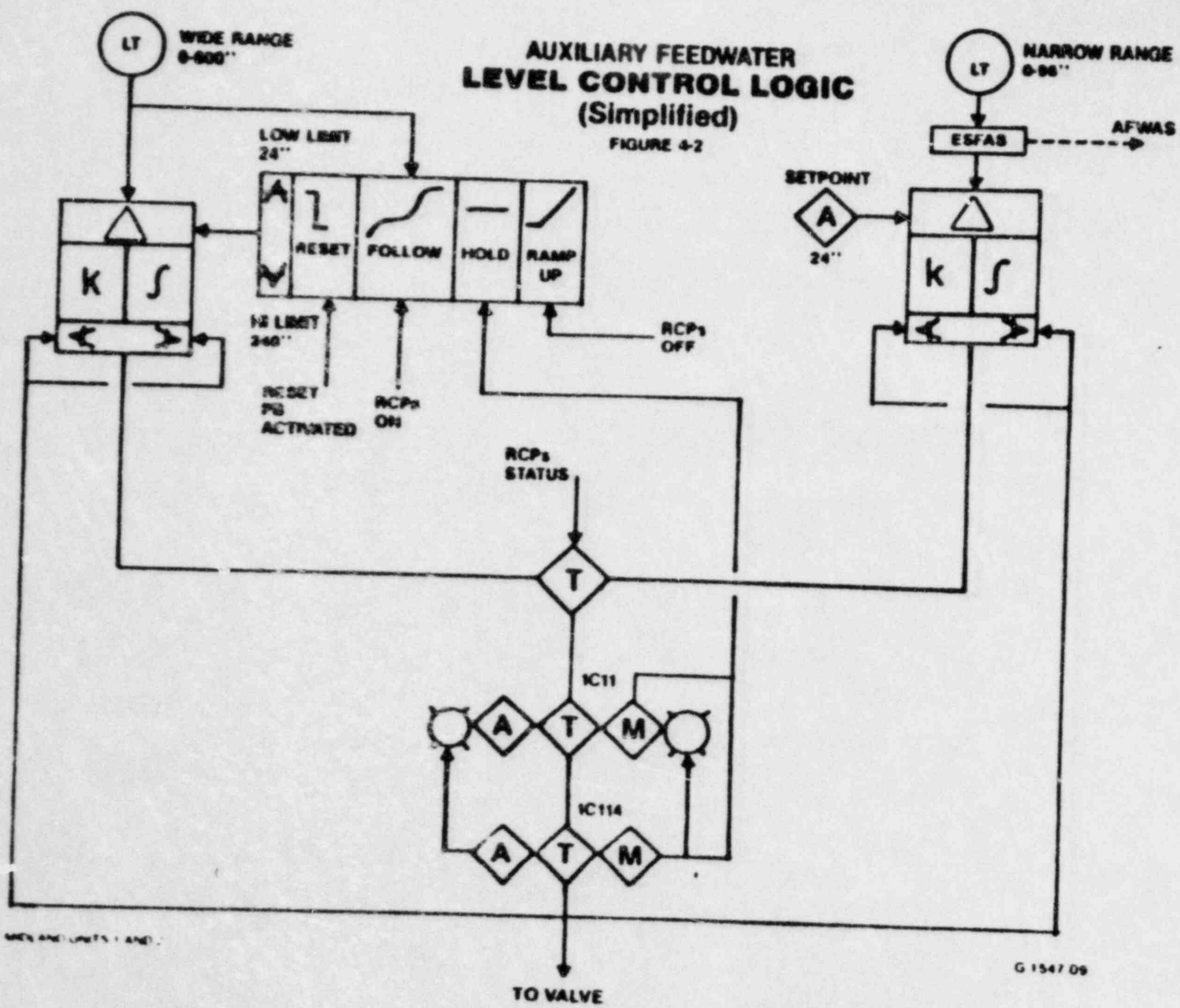


*NOTE: Four narrow range and four wide-range transmitters per OTSG. Transmitters share bottom taps.

MIDLAND UNITS 1 AND 2

G-1547-08

FIGURE 4-1



AUXILIARY FEEDWATER
LEVEL CONTROL LOGIC
(Simplified)
FIGURE 4-2

AUXILIARY FEEDWATER

CONTROL SYSTEM DESIGN OBJECTIVES

- MINIMIZE OPERATOR ACTION NEEDED TO PREVENT
  - Loss of Indicated Pressurizer Level
  - Low-Pressure ECCAS Actuation
- ALLOW MINIMUM OF 10 MINUTES PRIOR TO REQUIRING OPERATOR ACTION TO PREVENT LOSS OF PRESSURIZER LEVEL INDICATION

AUXILIARY FEEDWATER

CONCEPTUAL DESIGN STUDY RESULTS

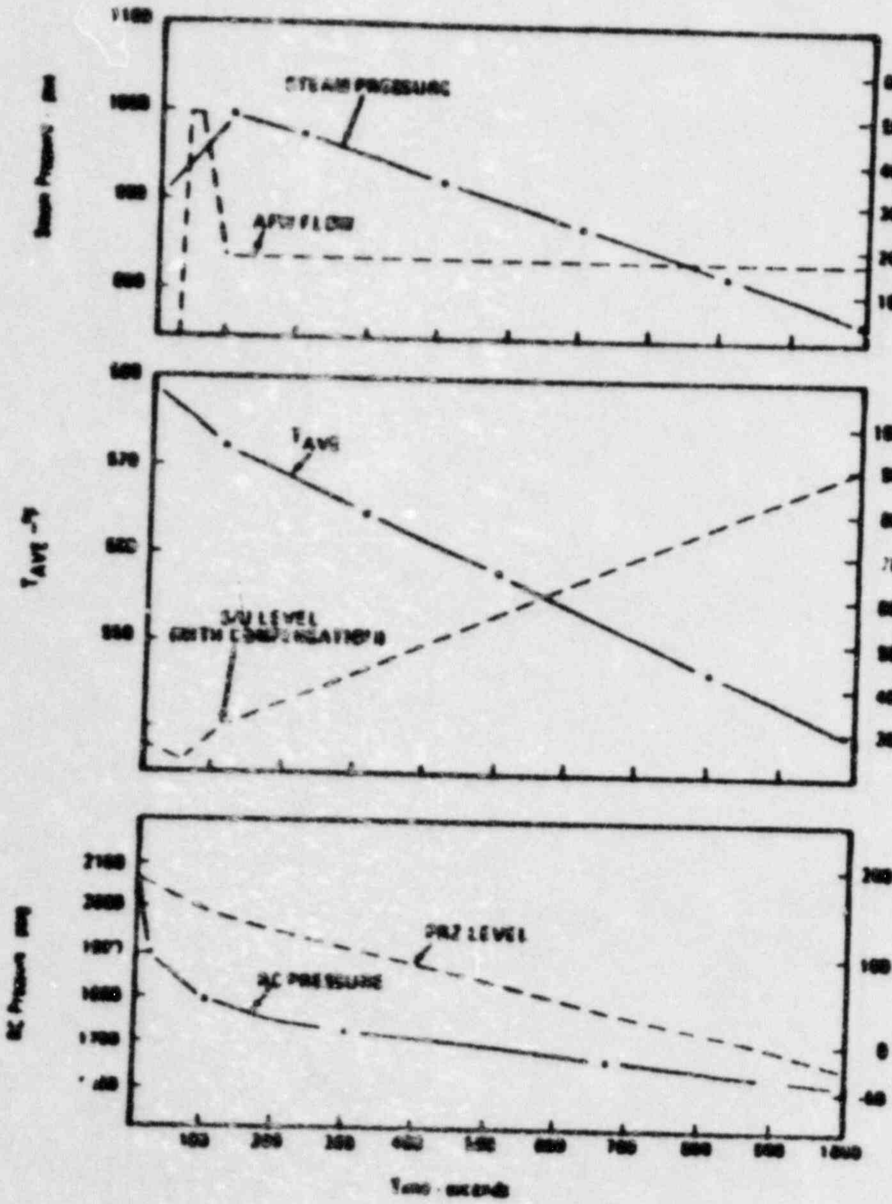
- CONTROL OF AFW ADDITION IS NOT REQUIRED WHEN FILLING TO 2-FOOT SETPOINT

- CONTROL OF AFW ADDITION AT RATE OF 3 TO 4 INCHES PER MINUTE IS SUFFICIENT TO PROVIDE ADEQUATE HEAT REMOVAL FOR NATURAL CIRCULATION FOR MAXIMUM DECAY HEAT AND WILL MINIMIZE OVERCOOLING FOR MINIMUM DECAY HEAT

MIDLAND UNITS 1 AND 2

G 1547 10

AUXILIARY FEEDWATER



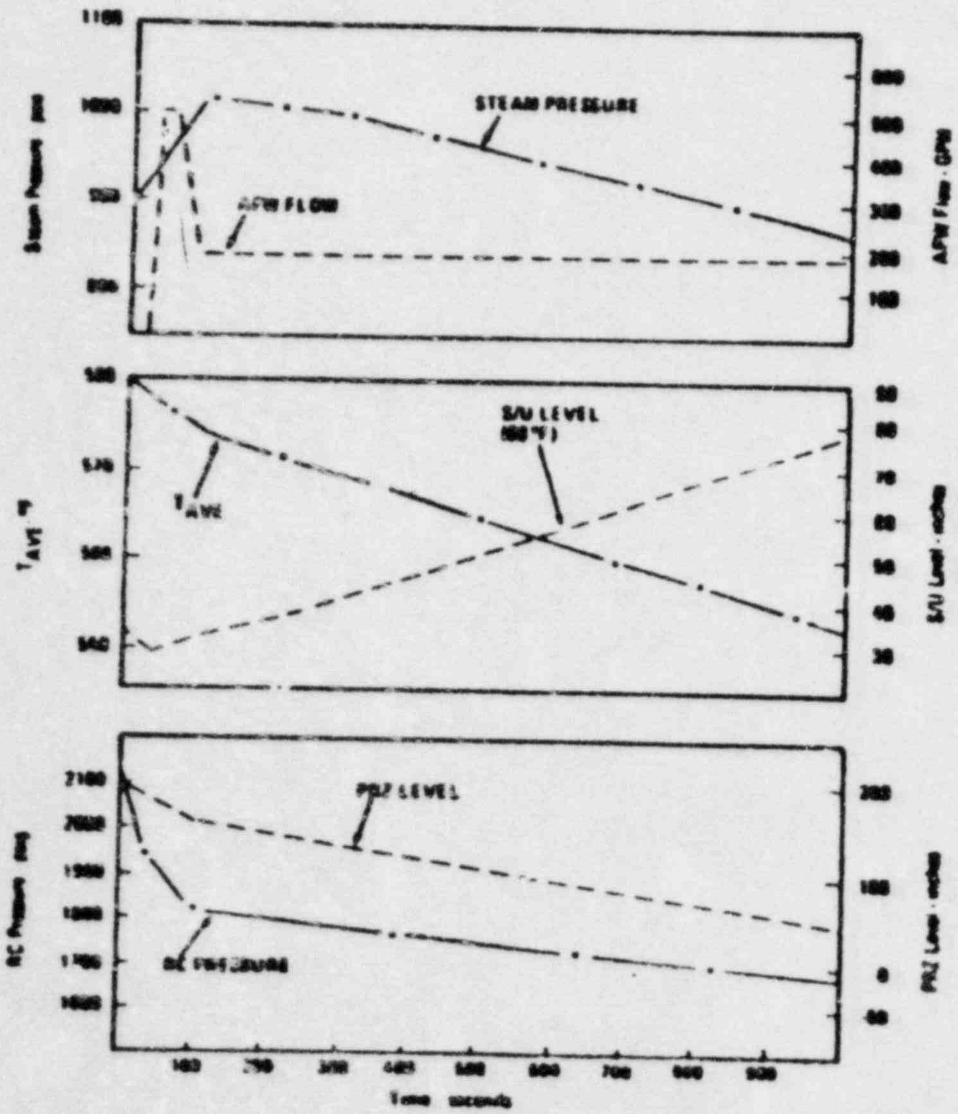
LOSS OF OFFSITE
POWER EFFECTS
FROM 15% POWER
FILL RATE AT
≈4 INCHES/MINUTE

FIGURE 4-3

AND UNITS 1 AND 2

G 1547 11

AUXILIARY FEEDWATER



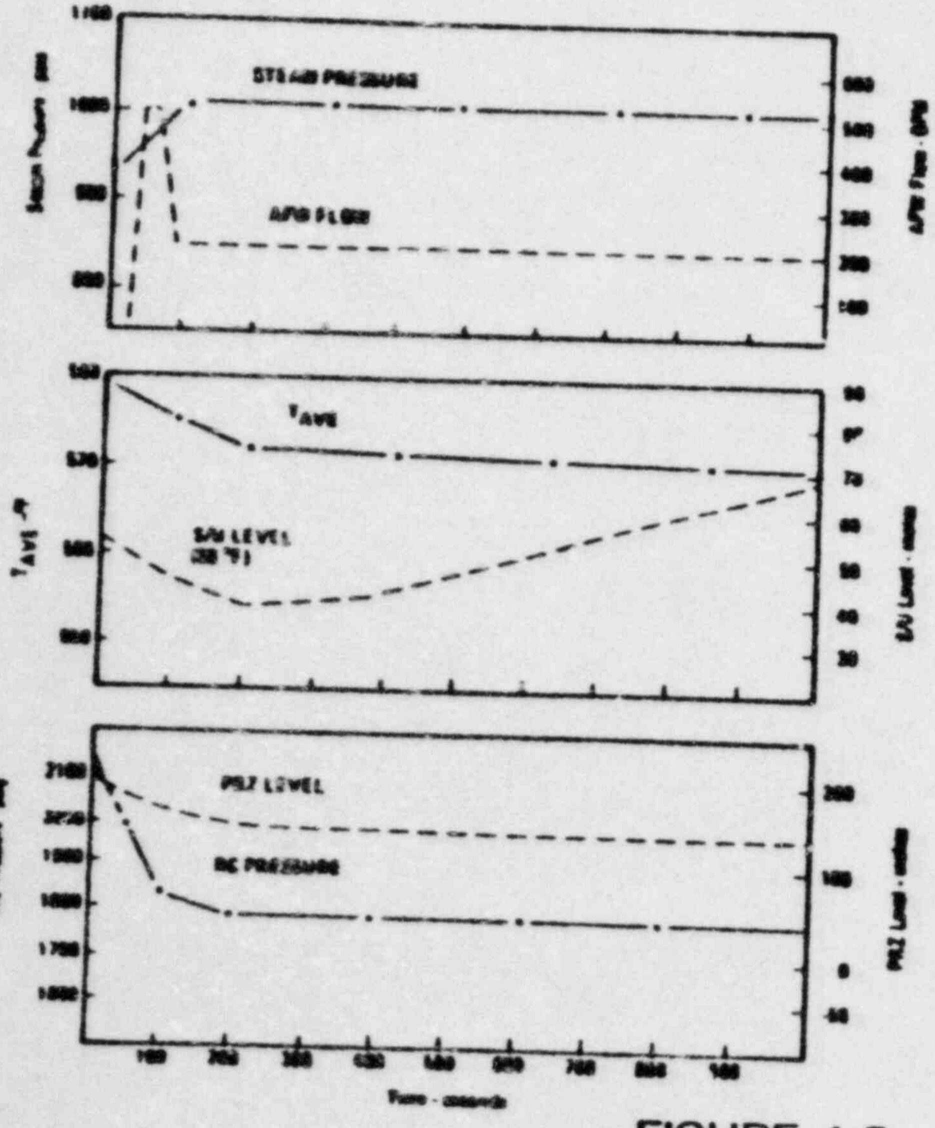
LOSS OF OFFSITE POWER EFFECTS FROM 40% POWER FILL RATE AT ≃ 4 INCHES/MINUTE

MIDLAND UNITS 1 AND 2

FIGURE 4-4

G 1547-12

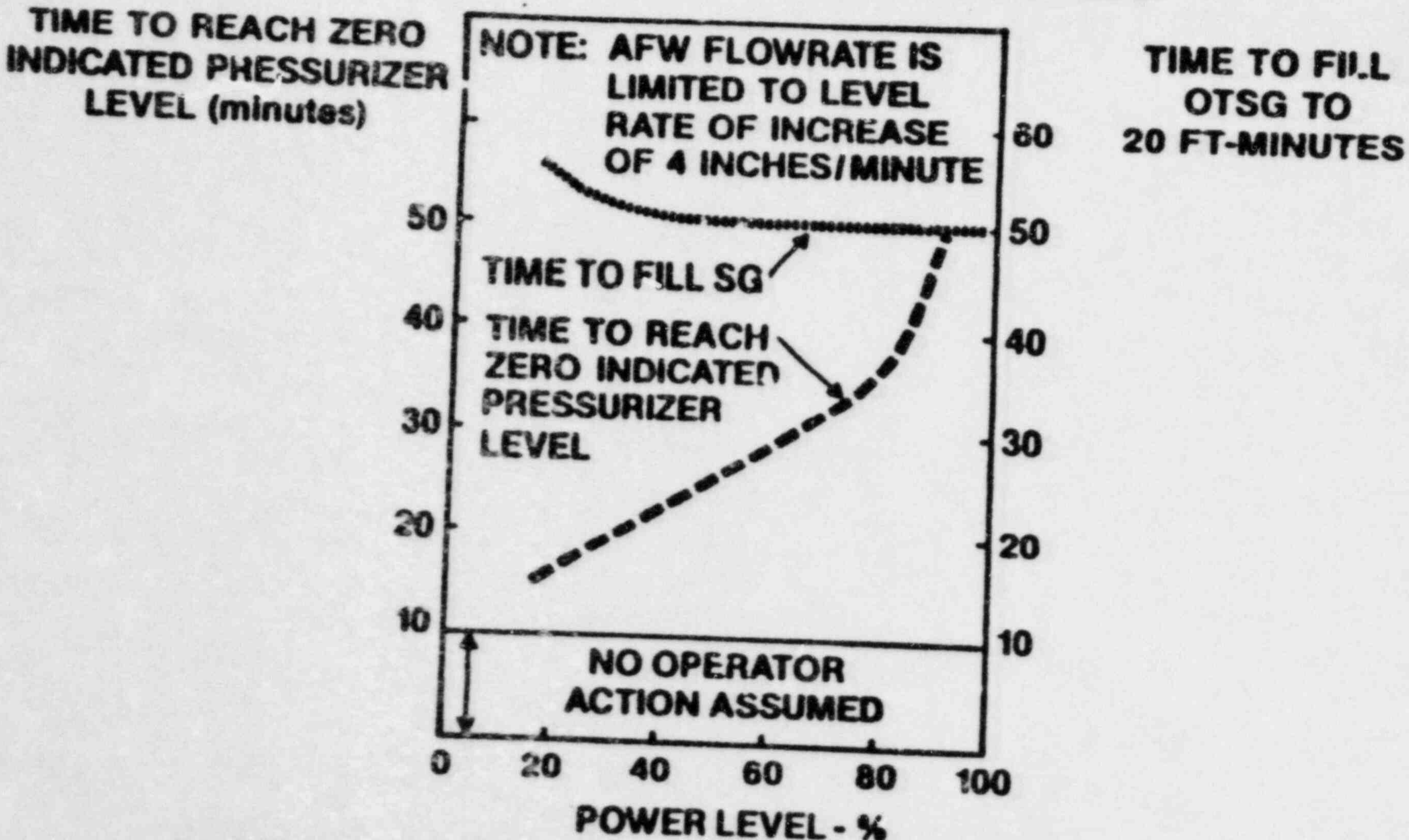
AUXILIARY FEEDWATER



LOSS OF OFFSITE
POWER EFFECTS
FROM 100% POWER
FILL RATE AT
≈ 4 INCHES/MINUTE

FIGURE 4-5

AUXILIARY FEEDWATER



TIME TO REACH ZERO INDICATED PRESSURIZER LEVEL AND TO FILL OTSG TO 20 FEET VS POWER LEVEL PRIOR TO REACTOR TRIP

FIGURE 4-6

G-1547-15

AUXILIARY FEEDWATER

FEED-ONLY-GOOD GENERATOR LOGIC

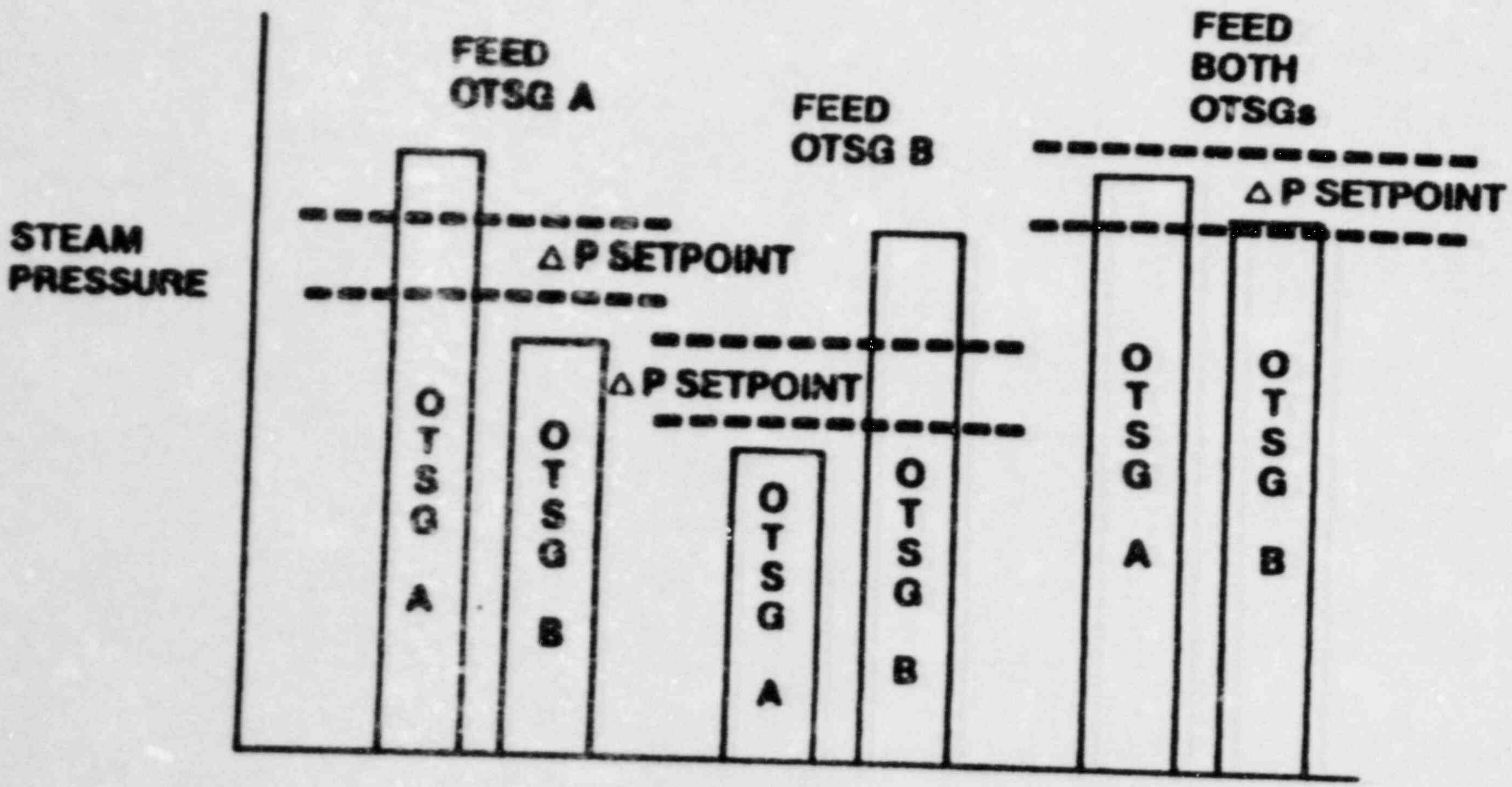
IV-11

PURPOSE

- Isolate AFW to Faulted OTSG Following Steam Line Break or Feedwater Line Break
- Limit Reactor Coolant System Overcooling
- Limit Mass and Energy Releases to Reactor Building
- Ensure Heat Removal Is Always Available Through Minimum of One OTSG

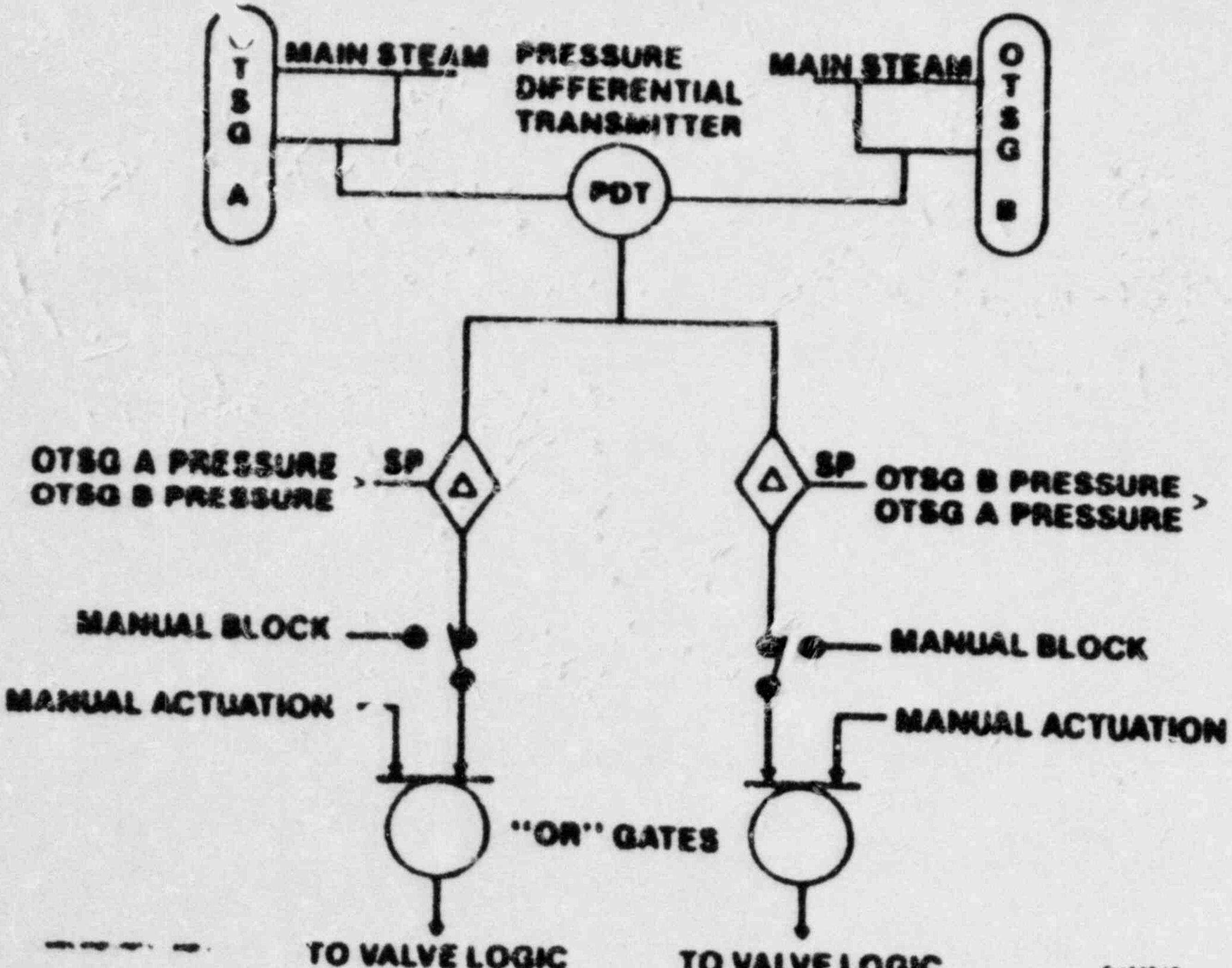
G 1547 16

AUXILIARY FEEDWATER
FOGG LOGIC



G 1547 17

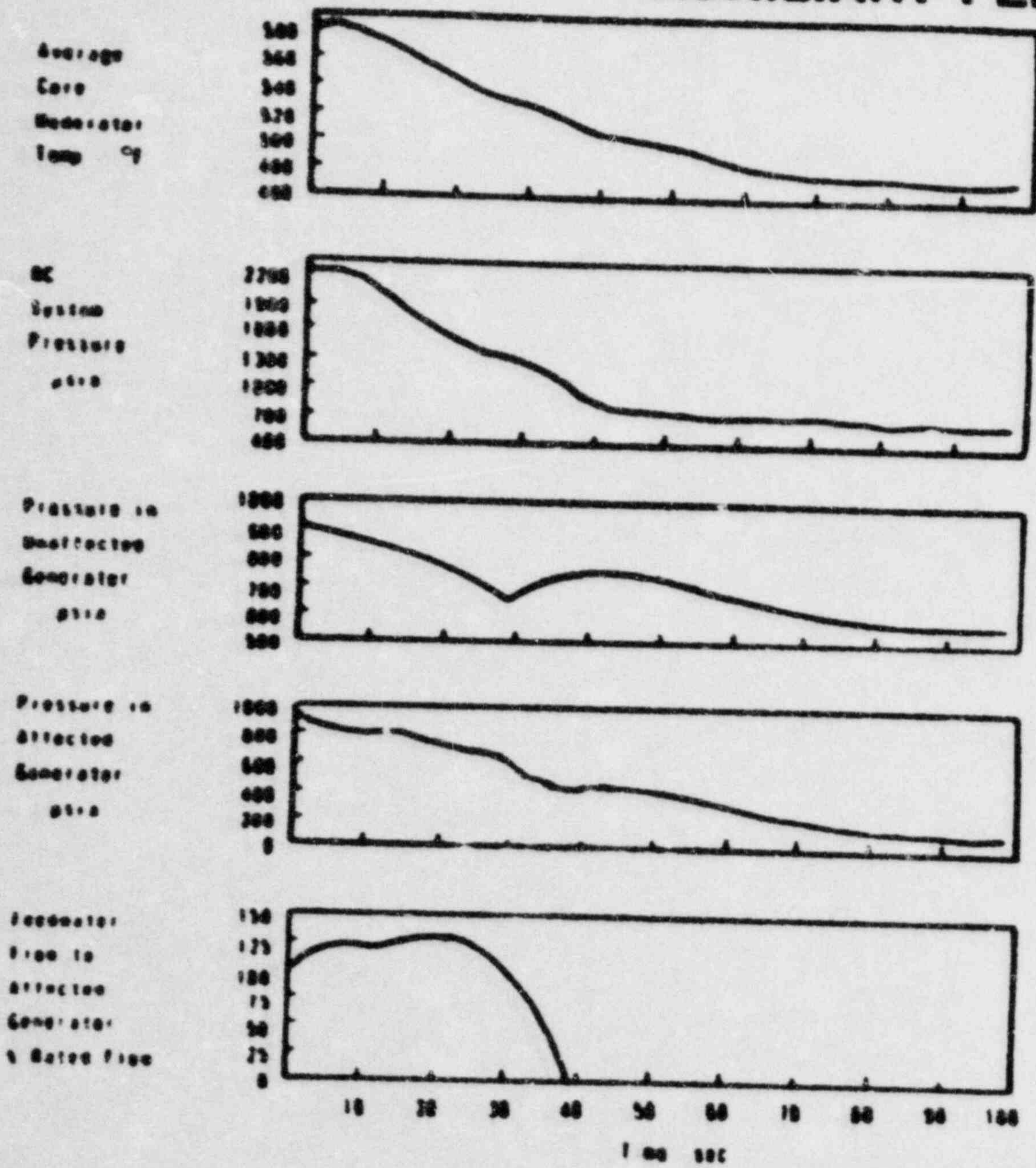
AUXILIARY FEEDWATER



FEED-ONLY-GOOD GENERATOR LOGIC
CHANNEL A
(typical for Channels B, C, and D)

FIGURE 4-7

AUXILIARY FEEDWATER



2.0 FT^2 STEAM LINE BREAK
WORST OVERCOOLING CASE

FIGURE 4-8

AUXILIARY FEEDWATER
OTSG OVERFILL PROTECTION

- **DETECTION**
  - **High OTSG Level**
- **ACTION**
  - **Isolate AFW to Full OTSG**
  - **Allow AFW System to Regain Control When OTSG Level Has Dropped Below Setpoint**

G 1547 19

AUXILIARY FEEDWATER

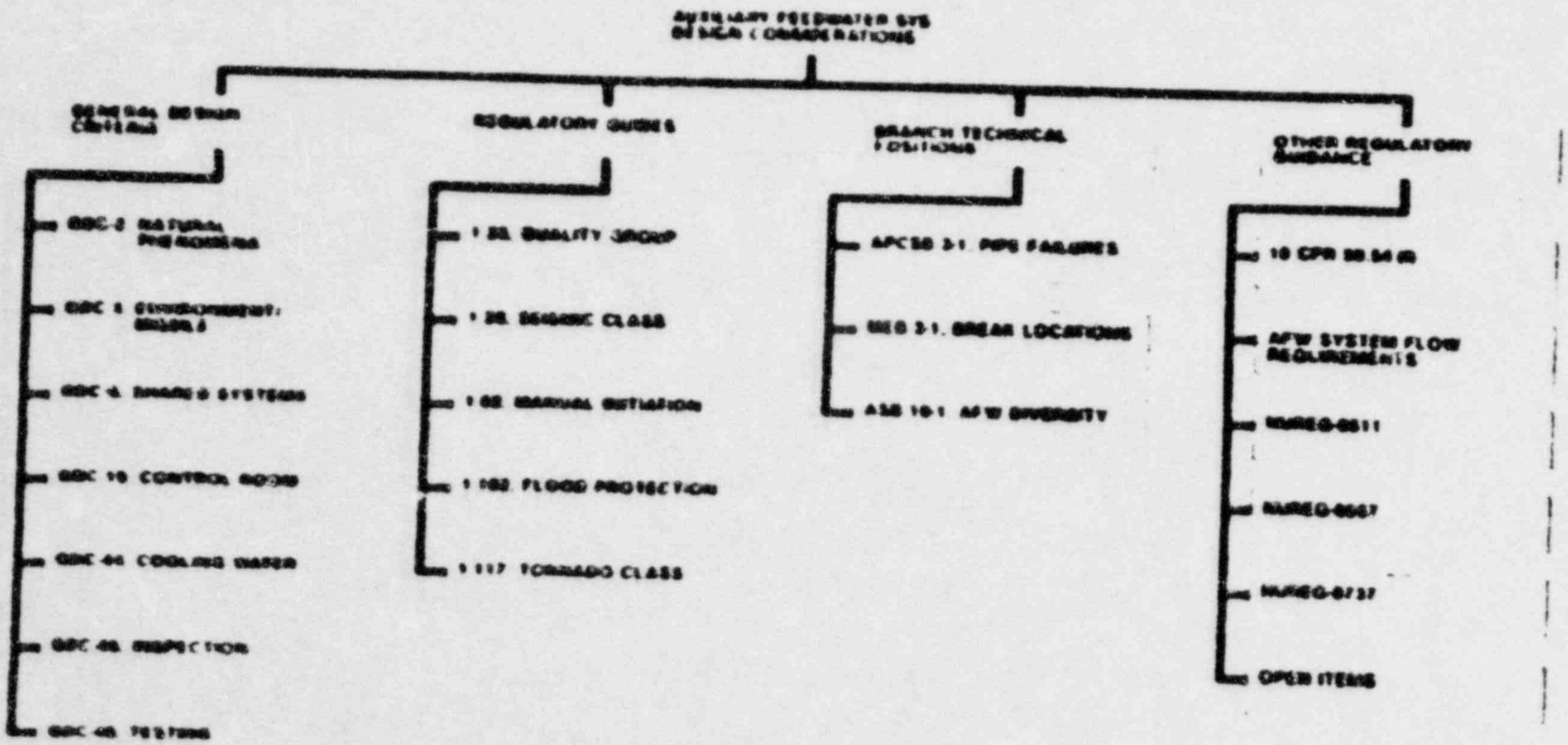


FIGURE 6-1

APPENDIX A

MIDLAND PLANT

AUXILIARY FEEDWATER SYSTEM

RELIABILITY ANALYSIS

SYNOPSIS

PLG-0166 .

MIDLAND PLANT
AUXILIARY FEEDWATER SYSTEM
RELIABILITY ANALYSIS
SYNOPSIS

by
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Daniel W. Stillwell
B. John Garrick

Prepared for
CONSUMERS POWER COMPANY
Jackson, Michigan
March, 1981

PICKARD, LOWE AND GARRICK, INC.
CONSULTANTS - NUCLEAR POWER
IRVINE, CALIFORNIA WASHINGTON, D.C.

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1. STATEMENT OF PURPOSE

A study was made of the reliability of the Midland auxiliary feedwater system for Consumers Power Company (CPCo) of Jackson, Michigan. The purpose of the study was to:

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

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

2. SUMMARY

The emergency function of the auxiliary feedwater system (AFWS) is to provide heat removal for the primary system when the main feedwater system is not available. Water is supplied from the condensate storage tank (CST) or service water system through two pumps to each of two steam generators. The AFWS must provide this function during small loss of coolant accidents (LOCA) as well as following transients that lead to a loss of main feedwater. The AFWS provides initial cooling to prevent overpressurization of the primary system and has sufficient preferred water supply to maintain hot standby conditions for 4 hours followed by a cooldown to 320°F. The system is also used during normal plant startup, shutdown, and hot standby conditions. Requirements for success under emergency conditions are that flow from a least one pump be delivered to at least one steam generator immediately following initial demand.

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

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

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

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

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

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

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

Three alternative pump configuration designs are analyzed. Their block diagrams are shown in Figure 1:

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

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

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

Results for the DCO design are displayed in Table 1 for each of the three transient cases and each data set. The results using the NRC Data for each of the three cases are plotted in Figure 2 along with similar results[2] for other Babcock and Wilcox (B&W) plants. Midland appears to be one of the better performing B&W auxiliary feedwater systems.

Tables 2 and 3 present the results using plant-specific data for comparisons of the base case and the three pump designs against the DCO. The Base Case and the DCO have nearly identical reliability results. The DCO is clearly better than the Three Pump design analyzed. These results, including the effects of uncertainty, are placed in better perspective by the curves of Figure 3.

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

Contributors to Unavailability	Loss of Main Feedwater		Loss of Main Feedwater Due to Loss of Offsite Power		Loss of Main Feedwater and Loss of All AC Power	
	Double Crossover (Plant Specific Data)	Double Crossover (NRC Data)	Double Crossover (Plant Specific Data)	Double Crossover (NRC Data)	Double Crossover (Plant Specific Data)	Double Crossover (NRC Data)
Random failures	7.0 E-5[+] (1.1 E-8)	3.5 E-5	6.6 E-4 (8.4 E-6)	2.5 E-4	1.7 E-2 (5.3 E-4)	6.4 E-3
Test and maintenance and random system failures	1.2 E-4 (3.9 E-8)	6.9 E-5	3.4 E-4 (6.5 E-7)	2.8 E-4	5.9 E-3 (1.9 E-4)	5.9 E-3
Human error (test--failure to close full flow test valve)	6.3 E-[illegible] (1.1 E-10)	3.7 E-6	1.8 E-5 (2.8 E-9)	1.5 E-5	3.1 E-4 (5.3 E-7)	3.1 E-4
Common cause (full flow test valve open after test)	8.4 E-6 (5.9 E-13)	8.4 E-6	8.4 E-6 (5.9 E-10)	8.4 E-6	8.6 E-6 (5.9 E-10)	8.4 E-6
Other	ε	ε	ε	ε	ε	ε
System Total						
Mean	2.0 E-4		1.0 E-3		2.3 E-2	
Variance	4.7 E-8		6.0 E-4		6.7 E-4	
5th	3.4 E-5		4.1 E-5		3.5 E-3	
95th	5.8 E-4		3.0 E-3		5.8 E-2	
Median	1.4 E-4	1.2 E-4	6.0 E-4	5.5 E-4	1.6 E-2	1.3 E-2

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

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

[+]7.0 E-5 read 7.0 x 10^{-5}.

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

POOR ORIGINAL

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

Contributors to Unavailability	Loss of Main Feedwater		Loss of Main Feedwater Due to Loss of Offsite Power		Loss of Main Feedwater and Loss of All AC Power	
	Double Crossover	Base Case	Double Crossover	Base Case	Double Crossover	Base Case
Random failures	7.0 E-5 (1.1 E-8)	7.3 E-5 (1.9 E-8)	6.6 E-4 (8.4 E-6)	6.6 E-4 (3.3 E-6)	1.7 E-2 (5.3 E-4)	1.6 E-2 (7.5 E-3)
Test and maintenance and random system failures	1.2 E-4 (3.9 E-8)	1.2 E-4 (1.2 E-7)	3.4 E-4 (6.5 E-7)	3.6 E-4 (3.2 E-7)	5.9 E-3 (1.9 E-4)	5.9 E-3 (1.9 E-4)
Human error (test—failure to close full flow test valve)	6.3 E-6 (1.1 E-10)	6.4 E-6 (3.4 E-10)	1.0 E-5 (2.8 E-9)	1.0 E-5 (9.2 E-10)	3.1 E-4 (5.3 E-7)	3.1 E-4 (5.3 E-8)
Common cause (full flow test valve open after test)	8.4 E-6 (5.9 E-10)	8.4 E-6 (5.9 E-10)	8.4 E-6 (5.9 E-10)	8.4 E-6 (5.9 E-10)	8.4 E-6 (5.9 E-10)	8.4 E-6 (5.9 E-10)
Other	ε	ε	ε	ε	ε	ε
System Total						
Mean	2.0 E-4	2.1 E-4	1.0 E-3	1.0 E-3	2.3 E-2	2.2 E-2
Variance	4.7 E-8	1.1 E-7	6.0 E-6	2.9 E-6	6.7 E-4	8.8 E-4
5th	3.4 E-5	1.7 E-5	4.1 E-5	7.9 E-5	3.5 E-3	3.5 E-3
95th	5.0 E-4	7.0 E-4	3.0 E-3	3.5 E-3	6.0 E-2	7.0 E-2
Median	1.4 E-4	1.1 E-4	4.0 E-4	5.3 E-4	1.0 E-2	1.3 E-2

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

LMFW: Offsite AC power is continuously available.

LMFW/LOOP: Offsite AC power is unavailable—diesel generators may or may not accept load.

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

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

†7.0 E-5 read 7.0×10^{-5}.

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

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POOR ORIGINAL

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

Contributors to Unavailability	Loss of Main Feedwater		Loss of Main Feedwater Due to Loss of Offsite Power		Loss of Main Feedwater and Loss of All AC Power	
	Double Crossover	Three Pump	Double Crossover	Three Pump	Double Crossover	Three Pump
Random failures	7.0 E-5*** (1.1 E-8)	4.1 E-4 (1.4 E-6)	6.6 E-4 (8.4 E-6)	2.0 E-3 (1.1 E-5)	1.7 E-2 (5.3 E-4)	1.7 E-2 (3.6 E-5)
Test and maintenance and random system failures	1.2 E-4 (3.9 E-8)	4.9 E-4 (1.0 E-7)	3.4 E-4 (6.5 E-7)	9.2 E-4 (2.[illegible] E-6)	5.9 E-3 (1.9 E-4)	5.9 E-3 (1.9 E-4)
Human error (test—failure to close full flow test valve)	6.3 E-6 (1.1 E-13)	2.6 E-5 (2.0 E-9)	1.8 E-5 (2.3 E-9)	4.9 E-5 (8.8 E-9)	3.1 E-4 (5.3 E-7)	3.1 E-4 (5.3 E-7)
Common cause (full flow test valve open after test)	8.4 E-6 (5.9 E-10)	8.4 E-6 (5.9 E-10)	8.4 E-6 (5.9 E-10)	8.4 E-6 (5.9 E-10)	8.4 E-6 (5.9 E-10)	8.4 E-6 (5.9 E-10)
Other	ε	ε	ε	ε	ε	ε
System Total						
Mean	2.0 E-4	1.3 E-3	1.0 E-3	3.0 E-3	2.3 E-2	2.3 E-2
Variance	6.7 E-8	2.3 E-4	4.9 E-6	1.3 E-5	6.7 E-4	2.2 E-4
5th	3.4 E-5	2.2 E-4	4.1 E-5	4.0 E-4	3.5 E-3	8.0 E-3
95th	5.8 E-4	3.0 E-3	3.0 E-3	9.0 E-3	6.0 E-2	5.2 E-2
Median	1.4 E-4	9.2 E-4	4.3 E-4	1.9 E-3	1.6 E-2	2.3 E-2

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

LMFW: Offsite AC power is continuously available.

LMFW/LOOP: Offsite AC power is unavailable—diesel generators may or may not accept load.

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

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

***7.0 E-5 read 7.0×10^{-5}.

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

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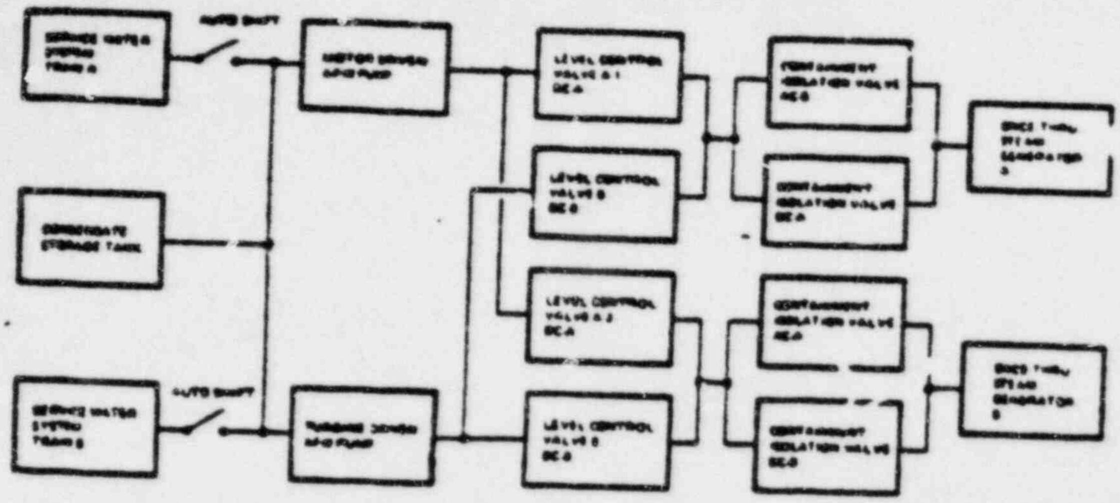
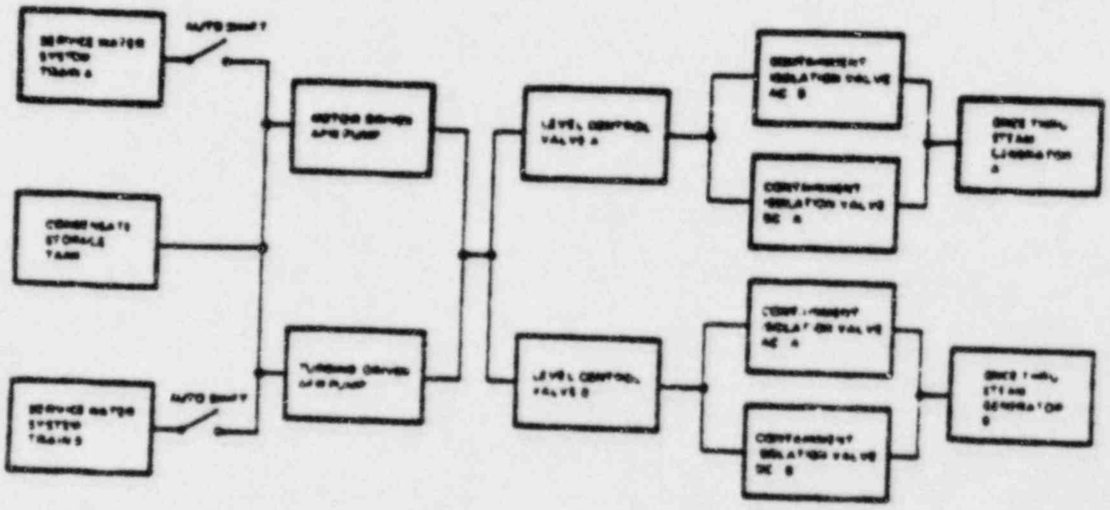
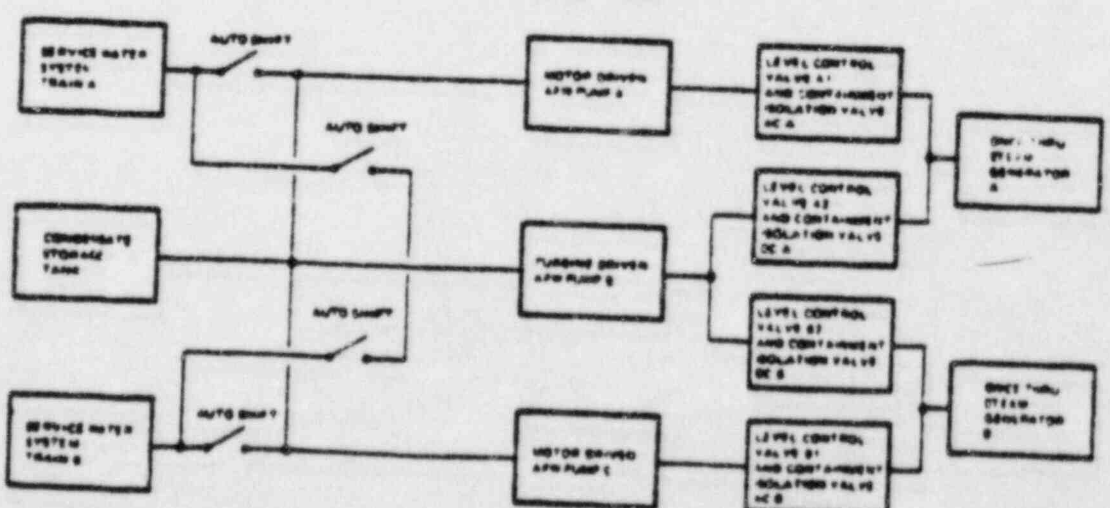


a. Double Crossover

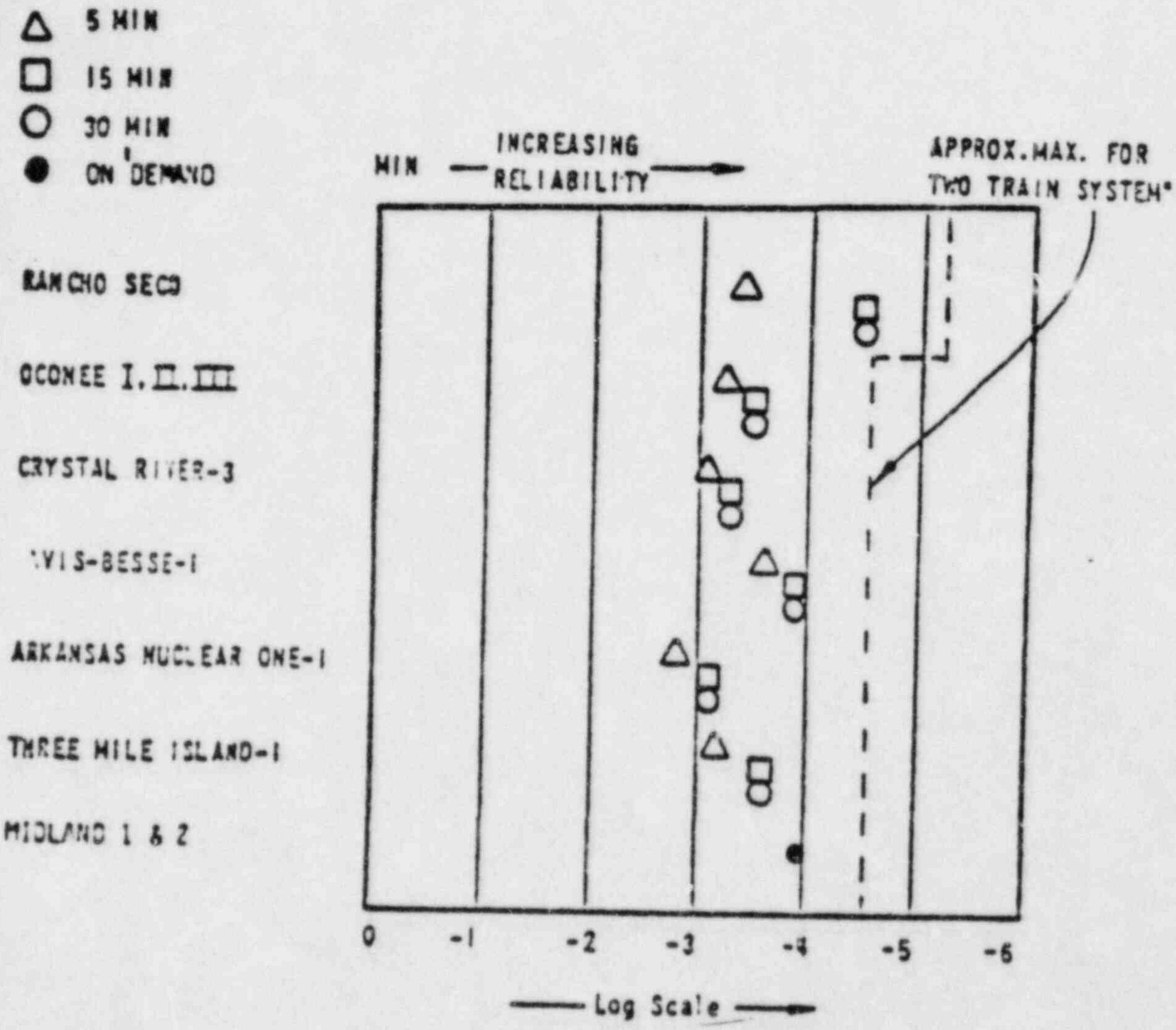


b. Base Case



c. Three Pump

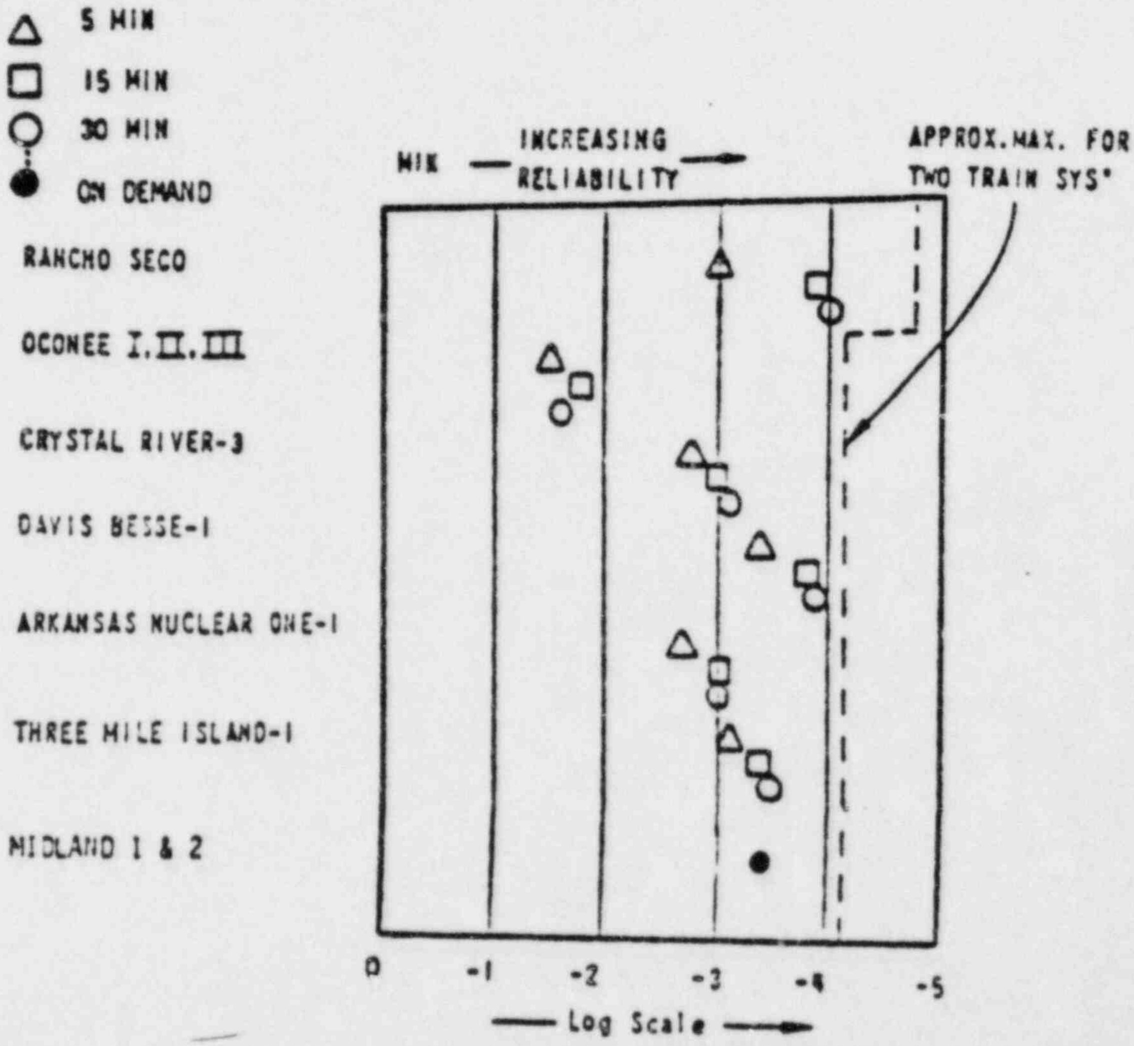
FIGURE 1. BLOCK DIAGRAMS OF THREE ALTERNATIVE PUMP CONFIGURATION DESIGNS FOR THE MIDLAND PLANT AFW SYSTEM



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

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

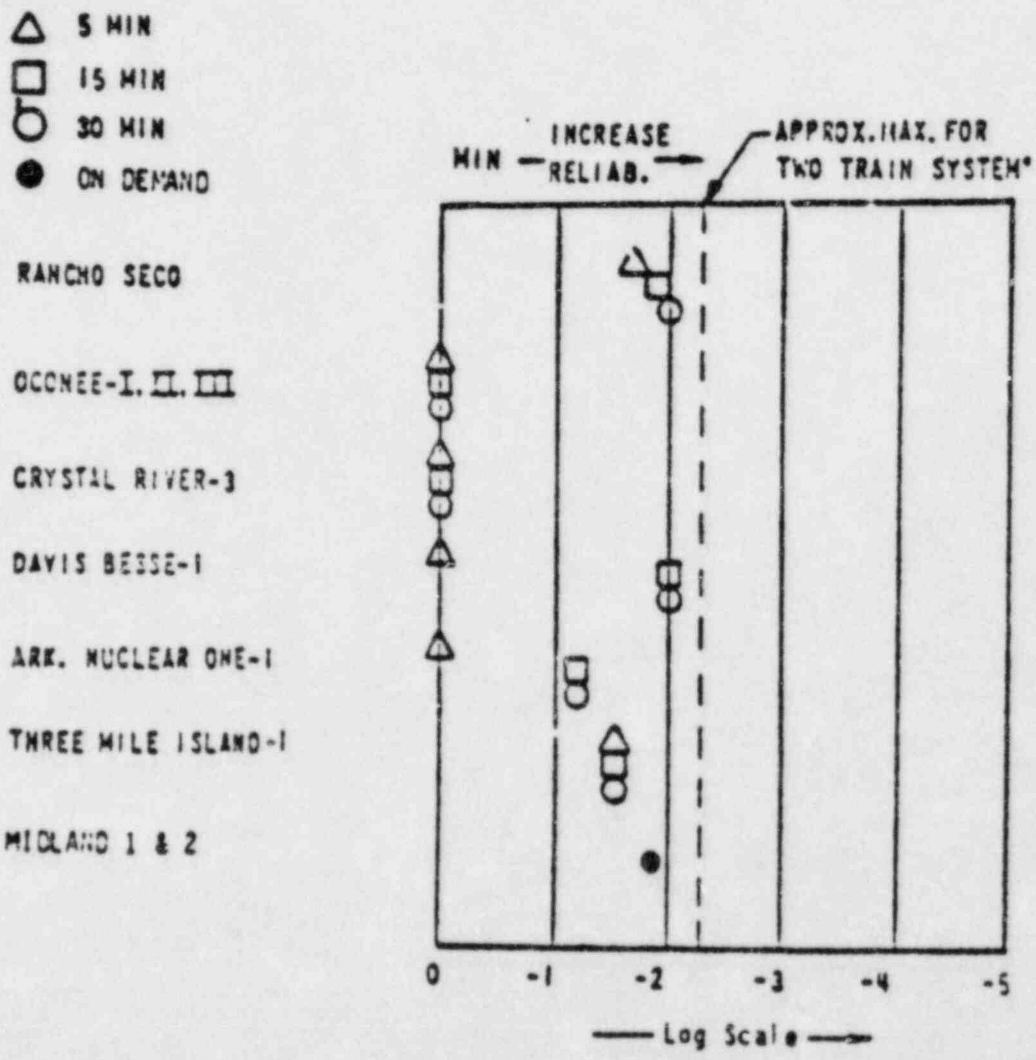
Figure 2(a): LMFW



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

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

FIGURE 2(b): LMFW/LOOP



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

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

FIGURE 2(c): LMFW/LOAC

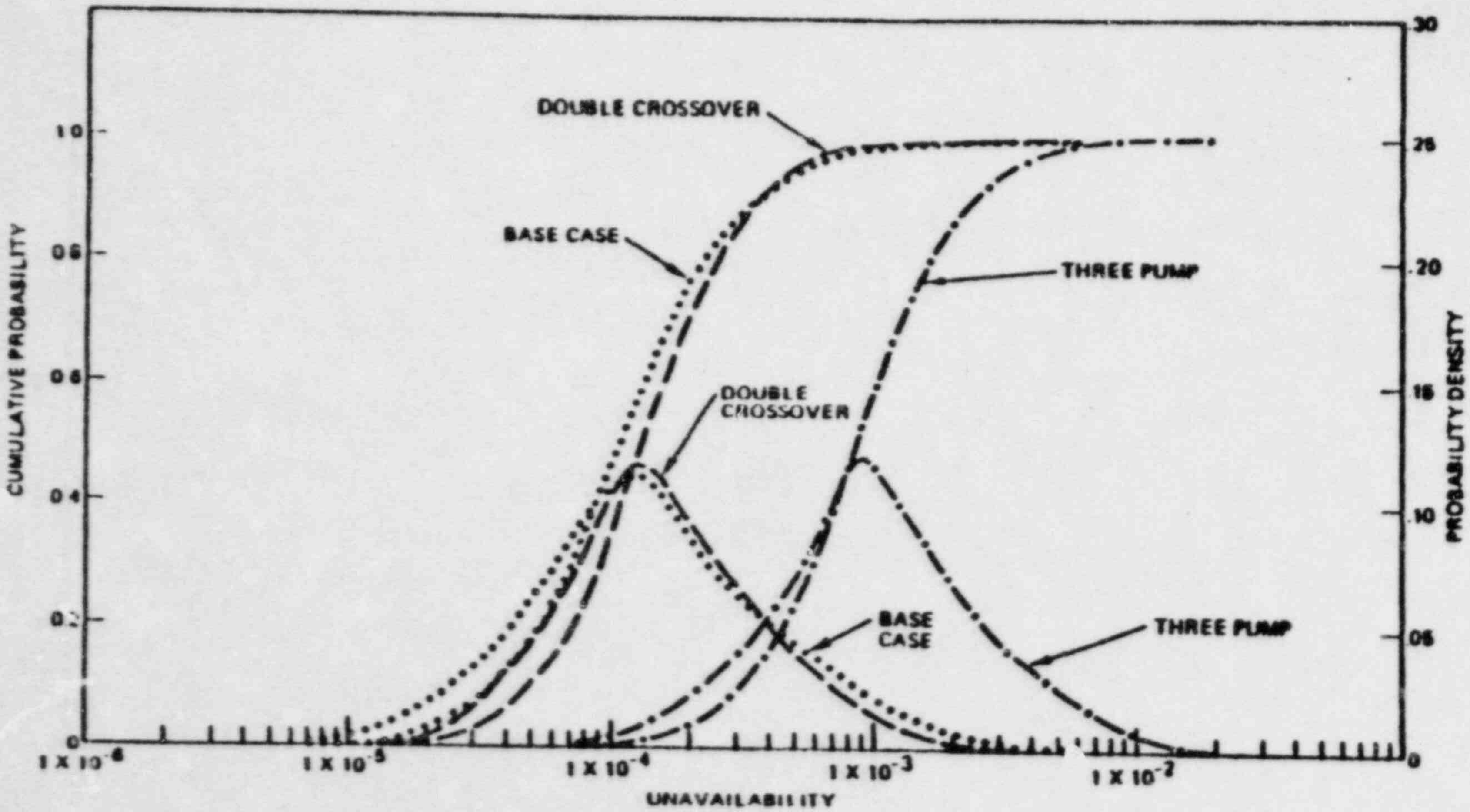


FIGURE 3. CONDITIONAL UNAVAILABILITY OF THE MIDLAND PLANT AFWS - THREE ALTERNATIVE DESIGNS, PLANT-SPECIFIC DATA - LOSS OF MAIN FEEDWATER

3. METHODOLOGY

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

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

A simplified fault tree for the Midland AFWS is shown in Figure 4. The TOP event, "No Or Insufficient Flow (NOIF) To Both Steam Generators," can only occur if there is NOIF from the motor pump section AND from the turbine pump section. NOIF from a pump section can only occur on NOIF from all water sources or failures within the pump sections. The detailed fault trees are shown in the Main Report [16] for the base case, double crossover, and three pump designs respectively.

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

The cause tree for the Midland AFWS, Figure 5, lays out the overall solution approach of this report. NOIF to both steam generators can only occur if one or more failure mode cutsets are failed. Such failures must be caused by:

Random Independent Failures
OR
Independent Human Errors
OR
Test and Maintenance in Conjunction With Other Causes
OR
Common Cause Failures
OR
Other Failure Causes.

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

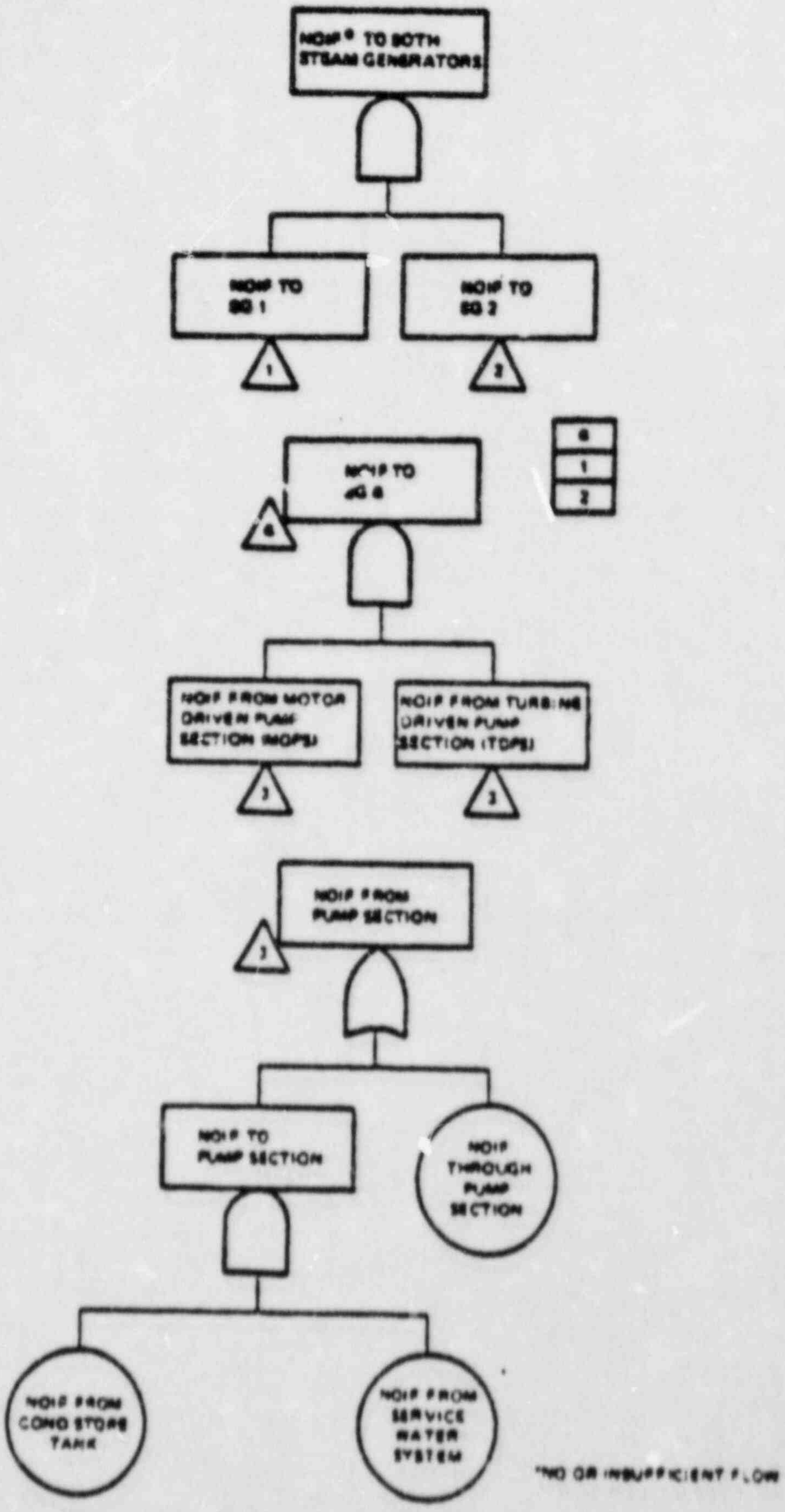


FIGURE 4. SIMPLIFIED FAULT TREE

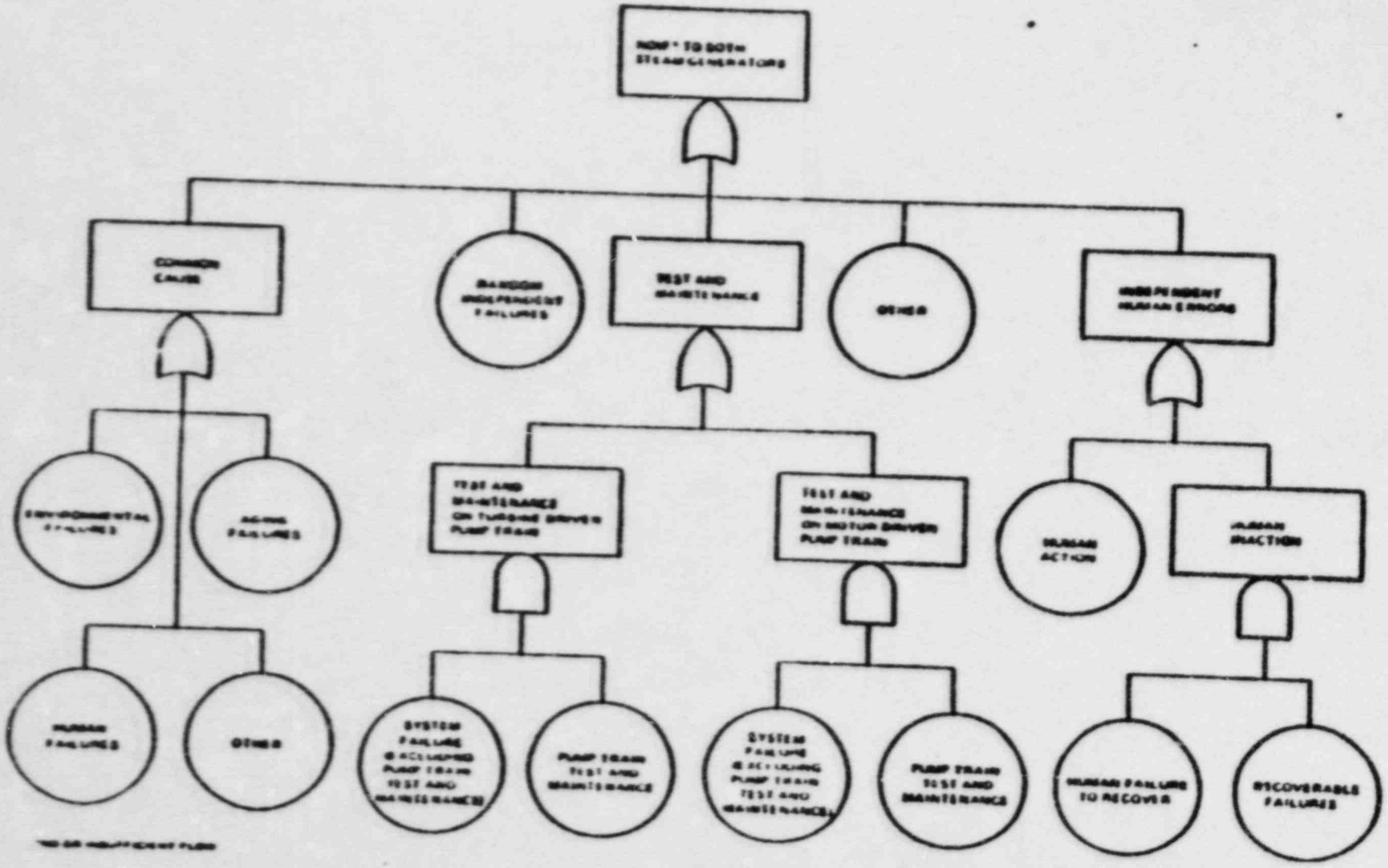


FIGURE 5. CAUSE TREE FOR THE MIDLAND AUXILIARY FEEDWATER SYSTEM

4. SYSTEM ANALYSIS

4.1 SYSTEM MODELS

4.1.1 Simplified System Piping Diagrams

Piping diagrams for each of the three proposed designs are presented here as Base Case, Figure 6, Double Crossover, Figure 7, and Three Pump, Figure 8. These simplified P&IDs are graphical models of the important flowpaths and components in the AFWS. These diagrams, along with other pertinent design information discussed in the Main Report [16], serve as the basis for all further modeling and analysis.

4.1.2 Functional Block Diagrams

The block diagrams shown earlier as Figure 1 provide simple understanding of the functional connection among major system component groups. The overall reliability logic becomes clear as well.

4.1.3 System Fault Tree

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

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

4.1.4 Computer Programs

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

4.1.5 Data

The complete data bases used in the study are given in the Main Report.

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

Generic and Plant-Specific Data. A plant-specific data base for Midland was prepared. The best available data to describe the specific equipment in place at Midland is included. It is based upon generic data that includes a wide uncertainty band to account for plant-to-plant variability and where sufficient Midland-specific data is available those generic distributions have been updated to account for the specific equipment and practices in place at Midland.

4.2 RANDOM FAILURES

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

4.3 TEST AND MAINTENANCE

4.3.1 Testing

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

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

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

Every 18 months, the auxiliary feedwater pumps are checked to ensure that they start upon receipt of an auxiliary feedwater actuation signal.

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

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

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

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

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

Every 18 months each automatic valve is verified to actuate to its correct position upon receipt of an essential safeguards features actuation signal (ESFAS) and each service water pump is verified to start on an ESFAS test signal.

4.3.2 Maintenance

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

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

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

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

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

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

The AFW pump motor breaker and control circuit requires periodic maintenance and repair. Because the 4,160V breakers are interchangeable between 4,160V cubicles, and spare breakers are available, major breaker repair is not included in the maintenance unavailability of the motordriven pump train. All other control and breaker maintenance is included in the unavailability of the motor-driven AFW pump train.

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

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

Based upon the preceding discussion, Table 4 presents the maintenance unavailability contributions for AFW pump trains.

4.4 HUMAN INTERACTION

4.4.1 Human Interaction/Recoverable Failures

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

There are some system failures from which the operator could recover. The most significant of these is a turbine-driven auxiliary feedwater pump trip. The dominant contributor to turbine-driven auxiliary feedwater pumps failure to start on demand is a failure of the turbine controls, primarily due to turbine trip on overspeed during startup. The operator may manually reset the overspeed trip, or take control of the turbine-driven AFW pump if, during a demand, this pump did not operate.

4.4.2 Human Error/Testing

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

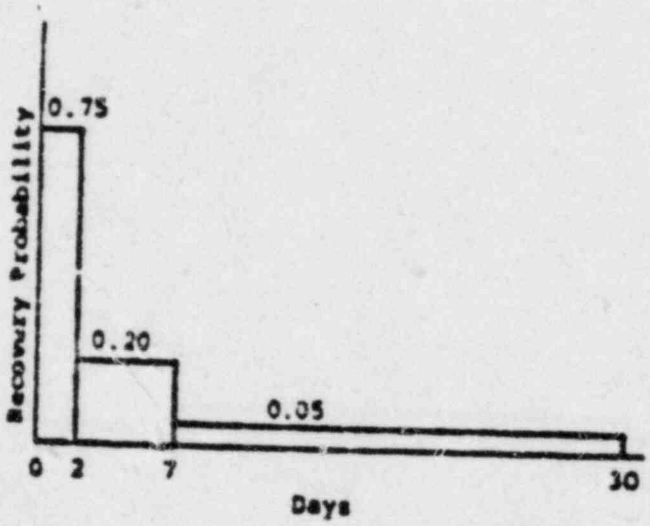
$$\frac{15 \text{ minutes}}{\text{month}} \times \frac{\text{hour}}{60 \text{ minutes}} \times \frac{\text{month}}{720 \text{ hours}} = 3.5 \times 10^{-4}.$$

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

4.4.3 Human Error -- Common Cause

A common cause human error has been identified for the AFWS. The error can occur after the pump monthly flow testing. Essentially, after each pump test, the auxiliary plant operator must close the full flow test valve. The pumps themselves are controlled from the main control board, and position indication is available for the full flow test valve at the main control board. If the pumps are tested sequentially (i.e., one pump is tested and at the completion of this test the other pump is tested) common human error or combinations of errors is possible. These errors consist of: the auxiliary plant operator failing to close the full flow test valve for the first pump and failing to close the second pump's full flow test valve (close coupling is assumed); and the main control board operator failing to notice the valve position indication for the full flow test valves on the main control board (also close coupled if the first valve position indication is missed). The recovery time for this failure is based upon the probability of the improper valve position being discovered during shift change when the oncoming and offgoing operators "walk down" the main control boards from NUREG-0611, Table III-2, the point value estimate for this potential human error is 1×10^{-4} with an estimated error factor of 30.

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



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

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

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

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

4.5 COMMON CAUSE ANALYSIS

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

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

The susceptibility codes for the causes of failure considered in this analysis are given in Table 5. Due to the limits of the available information, assumptions were made concerning maintenance actions, test procedures, and manufacturers. These links are assumed to be different for different generic components.

4.5.1 The First Criterion

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

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

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

4.5.2 The Second Criterion

The coding of failure sensitivity to causes of failure are given for each generic component type in Table 6. The final information that needs to be coded for the AFWS common cause analysis is the physical location of the basic events. Table 7 is the reference used in location definition. The exhibit identifies the equipment locations used in the study. Each fault tree basic event was assigned to its appropriate location.

4.5.3 Results of Common Cause Analysis

All cutsets with common susceptibilities were found to be in the same location, CLCV, the area of the auxiliary building outside the AFW pump rooms. Moisture, grit, and impact were found in this location. The number and order (number of basic events in the cutset) for each of these causes of failure are given in Table 8. Moisture was found to be a common susceptibility for the four level control valves and for four two-event cutsets in the pump suction lines (consisting of the pump suction MOVs and various combinations of the service water supply MOVs). The design of these valves protects the motor operators from high humidity and other minor sources of water. Flooding or pipe rupture could, however, prevent these valves from operating when demanded. The level control valves are the most susceptible to this cause because they must move from their normally closed position to permit AFW flow to the steam generators. The suction valves are only required to operate in the event of low pressure at the pump suction and a coincident AFWAS signal.

From WASH-1400, the probability of a pipe rupture is 1×10^{-4} per reactor year of operation. However, this system is called upon to operate (and therefore pressurized) 16 times per year (six actuations and ten startup/ shutdowns). The average run time is about two hours. The resulting probability of failure is 4×10^{-7} which is significantly less than the common cause human error identified in Section 4.4 but was found to be a common susceptibility for the same cutsets as moisture. Motor operated valve design protects the motor operators from the normal sources of airborne grit or dust during plant operation. During maintenance periods, the plant general maintenance procedures limit the sources of grit as a general housekeeping practice. This practice in conjunction with the safety system testing that occurs prior to plant operation results in a large reduction in the probability of failure due to grit because of maintenance. In addition, because failure due to grit is not an instantaneous failure, but rather a slow degradation in operation, any common cause failures will most likely be detected and corrected as a result of normal testing and preventive maintenance.

Because of the above reasons, the probability of system failure due to the common cause susceptibility -- grit -- is very much less than the common cause human error identified earlier in Section 4.4.

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

The pump discharge piping is a high energy system when the AFW system is in operation and is the only high energy system in the vicinity. If one assumes that pipe rupture leads directly to pipe whip (a conservative assumption considering piping support design), impact as a source of common cause failure can be no more severe than moisture as a source which has been discussed above. Therefore, the probability of failure due to impact is less than 4×10^{-7}, which is significantly less than the common cause human error identified in Section 4.4.

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

4.6 EVENT TREE ANALYSIS

Time sequential behavior, key system dependencies, and reduced system performance states can be modeled using event tree methods. The event tree of Figure 9 lays out such a model for the Midland Plant auxiliary feedwater system. Here, the initiating event is an auxiliary feedwater actuation signal. Next, the question of "good" and "bad" steam generators is addressed. We have defined a bad steam generator to be one with a steam break that has not been isolated. WASH-1400 gives the failure rate as 1×10^{-4} per year for pipes. Further containment and steam generator analyses could lead to a revised definition.

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

The next three events define successful start of the AFWS. Turbine train starts, turbine restarts after turbine trip, and motor train starts. Probabilities of successful starting will be derived from decompositions of the system fault tree. Without success in at least one start path, the system fails on demand. When some electric power is available we must now ask if the FOGG system operates. For cases with a single bad steam generator, FOGG must keep auxiliary feedwater isolated from that steam generator and must permit flow to a good steam generator. Lacking a final FOGG system design, we have assigned a reasonable unavailability of 10^{-4} per demand per train based on high quality actuation systems in WASH-1400. Given that the system has started, we next ask if the failure in the level control system leads to overcooling in either steam generator. Again lacking complete level control system information, we have assigned a probability of failure of 10^{-4} per demand. Finally, given a successful start, we ask if the system continues to run successfully for 8 hours.

Seven final system states have been identified on the tree. State-S stands for complete success. The system starts successfully, does not overcool, and continues to run for 8 hours. State-F1 is immediate failure; the system does not start on demand. State-F2 is initial cooling; the system starts successfully but long-term failure and no overcooling. State-F3 is overcooling in one steam generator; the system starts and continues to run successfully but level control malfunction leads to overcooling in one steam generator. State-F4 is early overcooling in one steam generator; the system starts successfully but fails to run for 8 hours and level control malfunction leads to overcooling in one steam generator. State-F5 is over-cooling in both steam generators; the system starts successfully and continues to run for 8 hours but overcools both steam generators, and State-F6 is overcooling in both steam generators and failure to run for 8 hours; the system successfully starts but fails to run for 8 hours and level control malfunctions lead to overcooling in both steam generators.

TABLE 4. PUMP TRAIN UNAVAILABILITY DUE TO TEST AND MAINTENANCE

Q maintenance turbine	$= \frac{1 \text{ actuation}}{4.5 \text{ months}} \times \frac{19 \text{ hours}}{\text{actuation}} \times \frac{\text{month}}{720 \text{ hours}} = 5.9 \times 10^{-3}$
Q maintenance motor	$= \frac{1 \text{ actuation}}{4.5 \text{ months}} \times \frac{19 \text{ hours}}{\text{actuation}} \times \frac{\text{month}}{720 \text{ hours}} = 5.9 \times 10^{-3}$
Q test turbine (operator error)	$= \frac{15 \text{ minutes}}{\text{month}} \times \frac{\text{hour}}{60 \text{ minutes}} \times \frac{\text{month}}{720 \text{ hours}} \times 0.9 = 3.1 \times 10^{-4}$
Q test motor (operator error)	$= \frac{15 \text{ minutes}}{\text{month}} \times \frac{\text{hour}}{60 \text{ minutes}} \times \frac{\text{month}}{720 \text{ hours}} \times 0.9 = 3.1 \times 10^{-4}$

System Unavailability Due to Test and Maintenance

Q system_{T+M} = (Q maintenance turbine + Q test turbine)
(Q system with turbine pump down)
+ (Q maintenance motor + Q test motor)
(Q system with motor pump down)

TABLE 5. SUSCEPTIBILITY CODES

First Criterion	
Maintenance Action	– MA MB MD M1 M2 M3 M4
Test Procedure	– T1 T2 T3 T4 TD TE TF TG TI TJ TK TL TN TP TS TT TU TV TW
Manufacturer	
Anchor Darling	– AD
Byron Jackson	– BJ
Control Component	– CC
Henry Pratt	– HP
Limitorque	– LI
Terry Turbine	– TT
Unknown (Similar Components Grouped Together)	– X1 X2 X3 X4 X5 X7 X8
Second Criterion	
Impact	– I
Vibration	– V
Moisture	– M
Grit	– G
Stress	– S

TABLE 6. GENERIC COMPONENTS AND THEIR SENSITIVITIES TO FAILURE

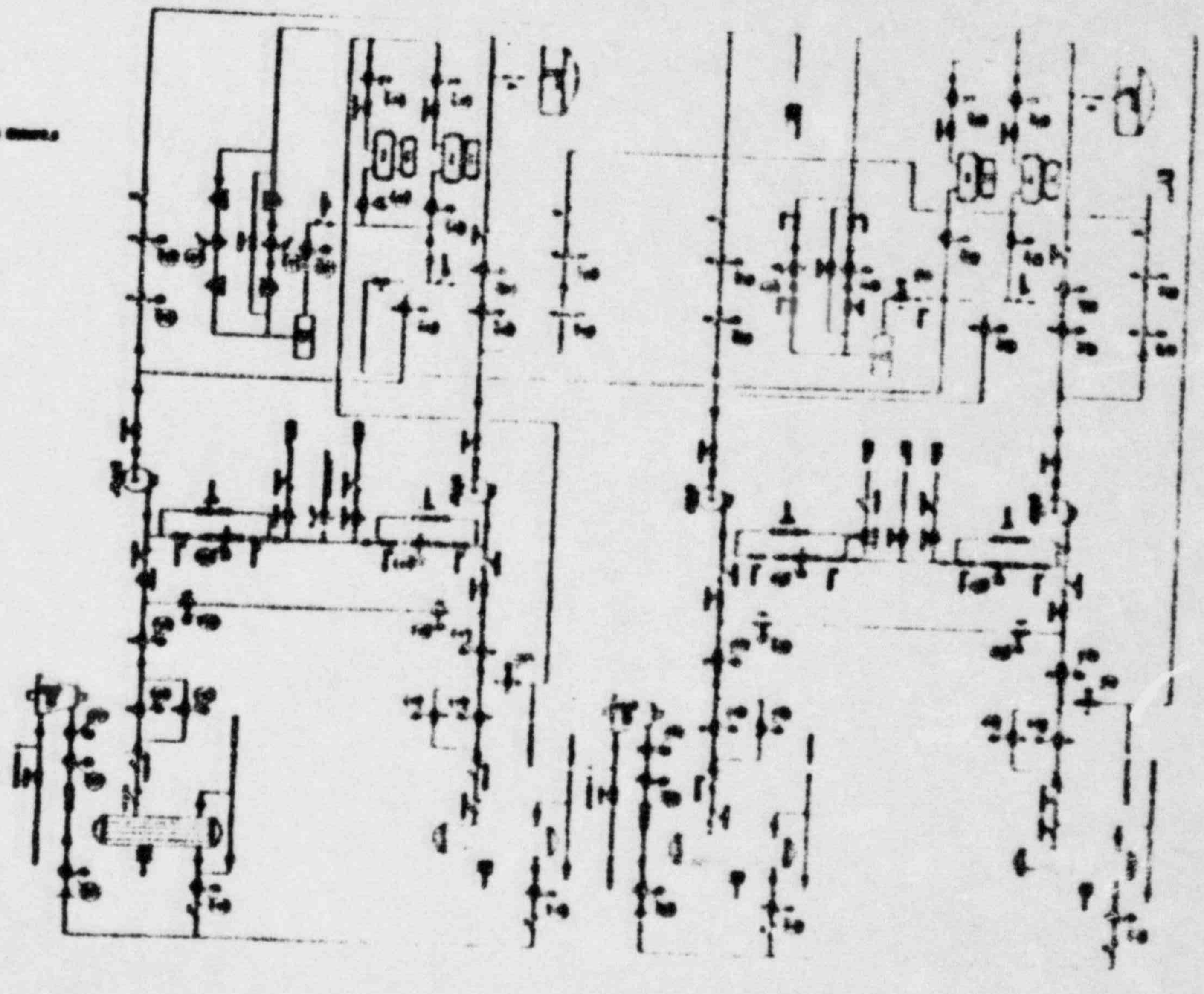
Component Type	Code	Special Condition	Susceptibility
Level Valve	LV	T M	I S
Manual Valve	XV	T M	I S
Pump	PM	T M	I V
Turbine (includes controls)	TB	T	I V M G
Contact	CN	T	I V M G
Circuit Breaker	CB	T	I V M G
Control Circuit	ST	T	I V M G
Power Bus	OO	T	I V M G
Control Circuit	CC	T M	I V M G
Motor Valve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

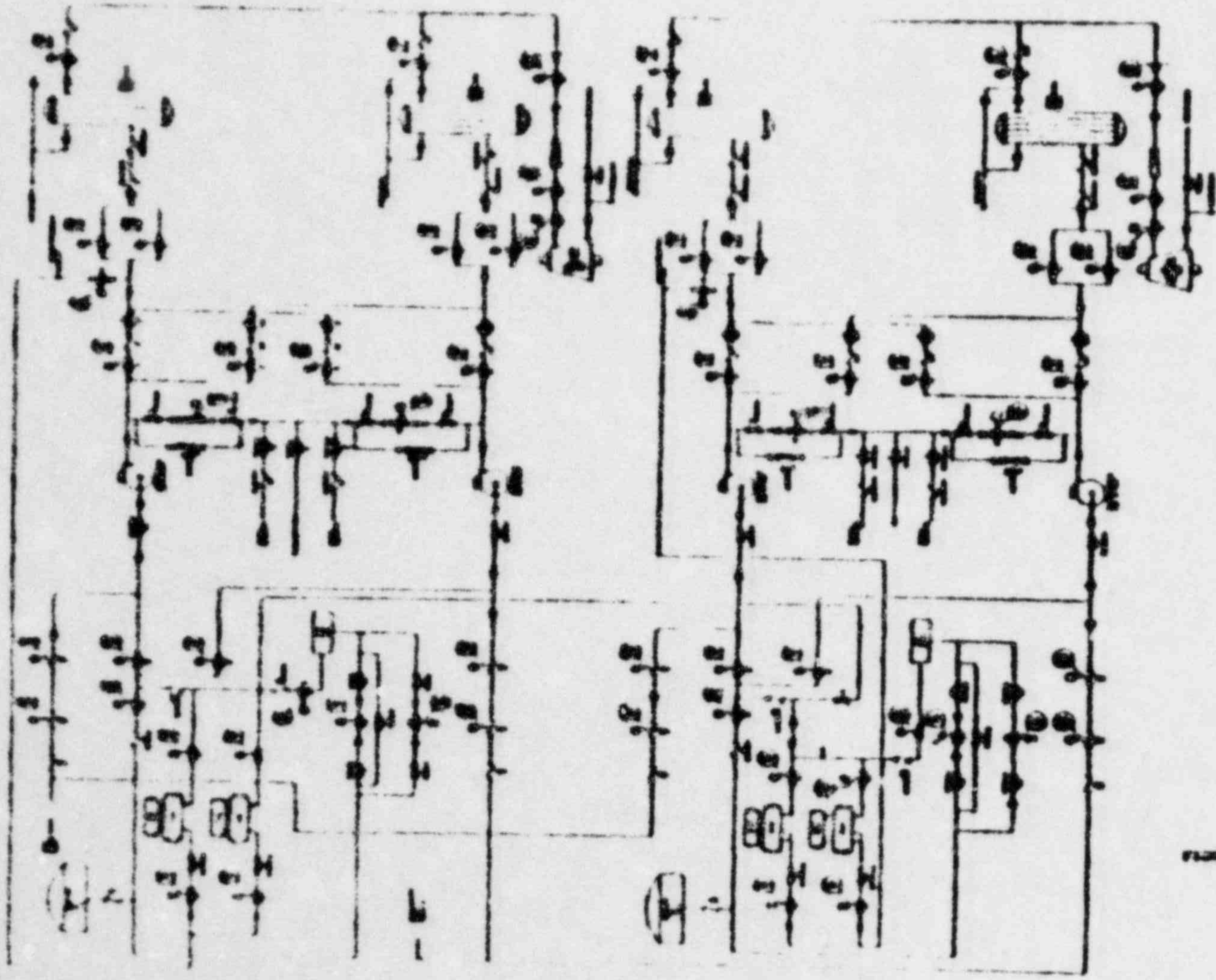
TABLE 7. PHYSICAL BARRIER INFORMATION

Equipment Locations Used in the Midland AFW System Analysis
R15A R15B - inside reactor building. R5DC
PISO - auxilary building pipe chase.
CLCV - auxilary building outside AFW pump rooms.
MAAA - auxilary building motor driven pump room.
TBAA - auxilary building turbine driven pump room.
YARD - exterior of buildings.
SAAA - 4160VAC switchgear room A. SABA - 480VAC switchgear room A. SBBA - 480VAC switchgear room B.
BAAD - 125VDC battery room A, Panel 1D11. BBAD - 125VDC battery room B, Panel 1D21.
PABA - service water pump room A. PBBA - service water pump room B.
OCNA - ESF actuation - AFWAS channel A. OCNB - ESF actuation - AFWAS channel B.

TABLE 8. COMMON CAUSE CANDIDATES
IN PHYSICAL LOCATION CLCV

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





[illegible]

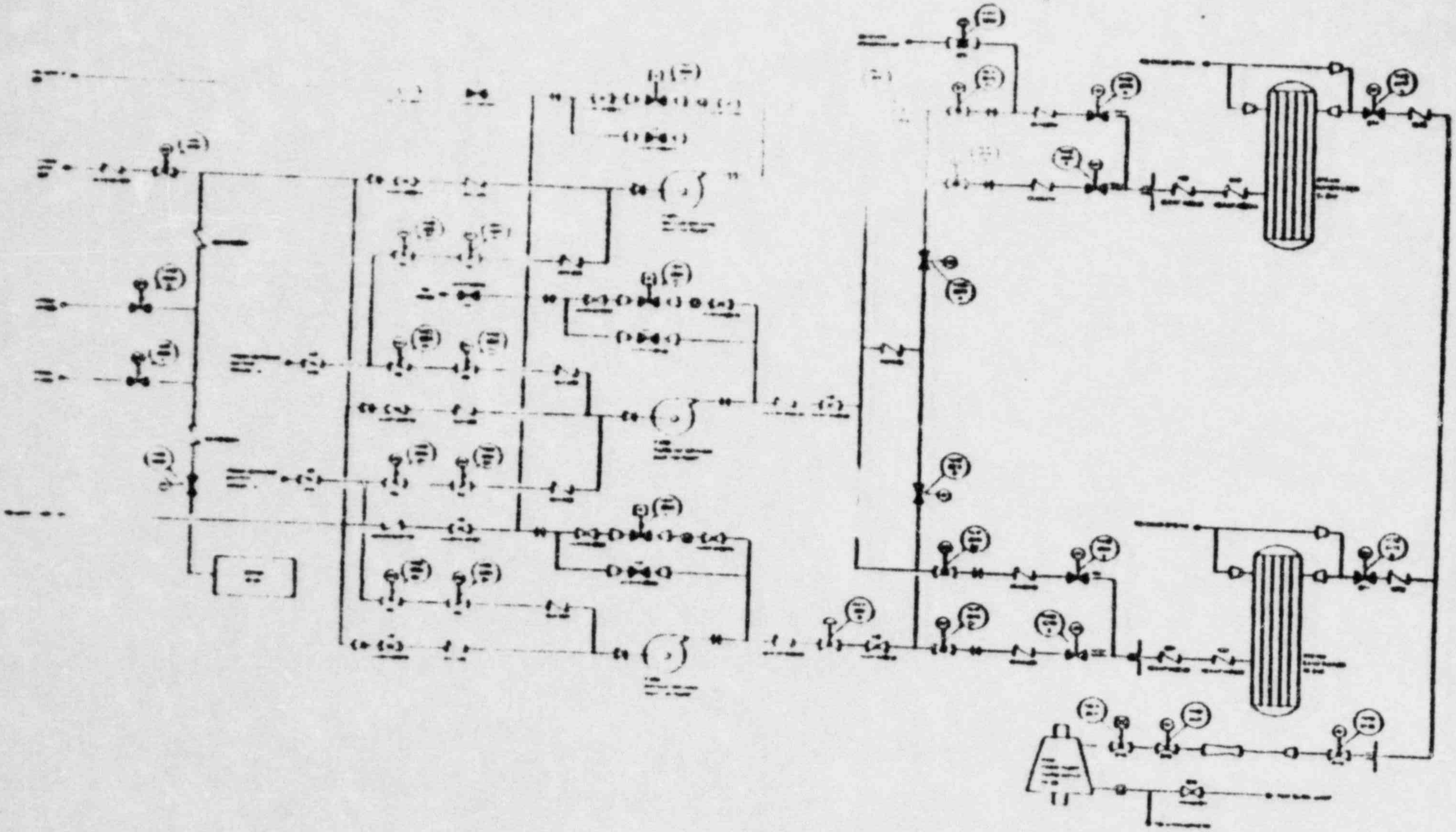
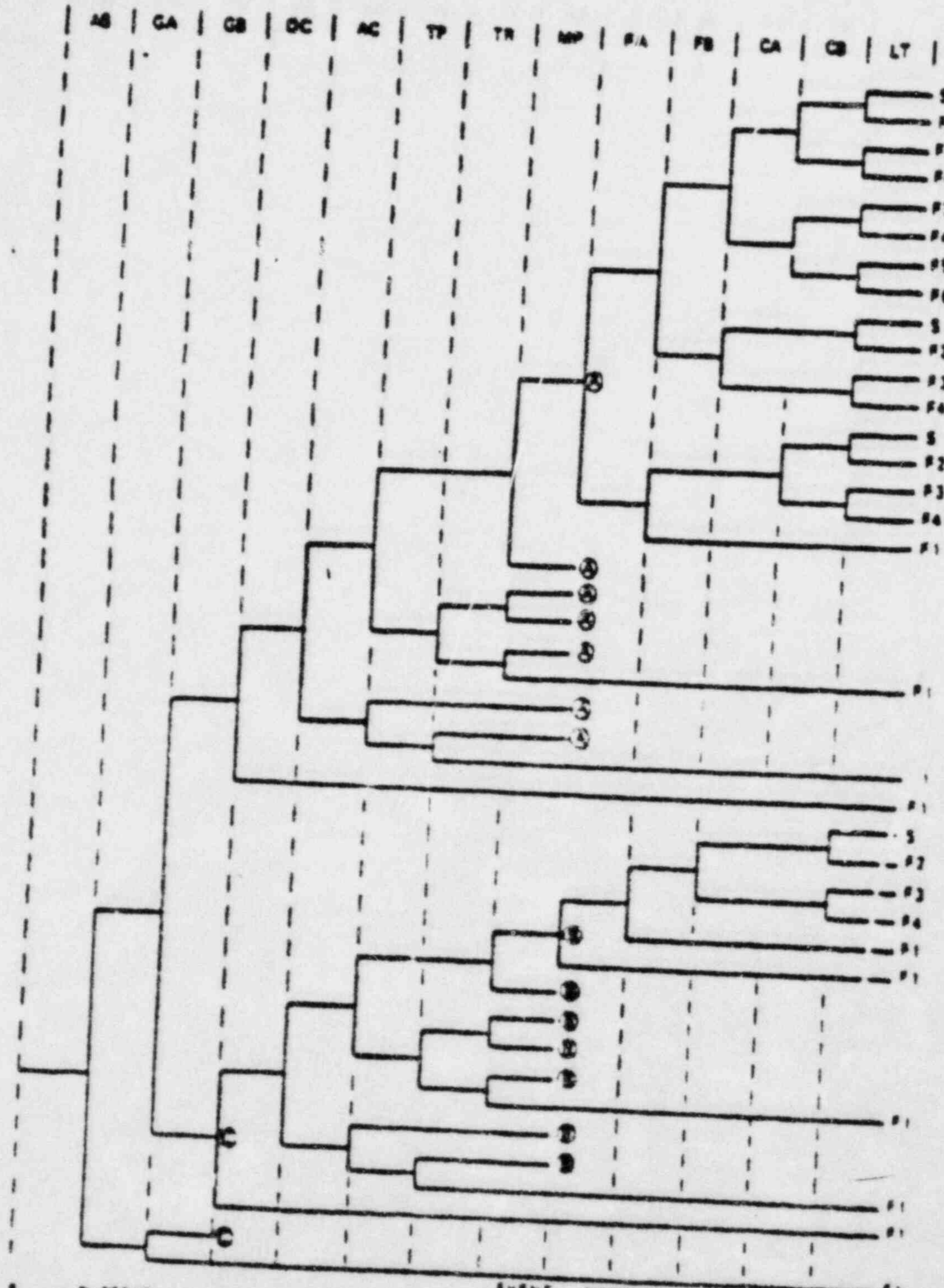


FIGURE 8. MIDLAND AUXILIARY FEEDWATER SYSTEM - THREE PUMP



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

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

FIGURE 9. ABBREVIATED VERSION OF MIDLAND AUXILIARY FEEDWATER EVENT TREE GIVEN AN ACTUATION SIGNAL

5. RESULTS

The results presented in this section show that in the emergency mode the Midland Plant AFWS is very reliable. Redundancy, separation, and availability during testing are applied in combinations that make the system quite sound. The results presented here follow from the detailed fault trees, the data, and the analysis described in Section 4. They are based on failure of the auxiliary feedwater system to deliver sufficient flow immediately upon demand to at least one SG; therefore, human intervention to recover from some system failures is not considered. If further analyses of the B&W nuclear plant demonstrate that a time window exists during which actuation of the auxiliary feedwater system can provide adequate core cooling, then the effects of operator intervention to restore system function should improve the system reliability. Such considerations will require reviewing emergency procedures to determine the likelihood of successful operator action.

5.1 RESULTS OF SYSTEM ANALYSIS

The results for all three initiating event cases from NUREG-0611 are given in Tables 1, 2, and 3 shown earlier. In Table 1, the point values based on NUREG-0611 data are tabulated along with means and variances based on plant-specific data for the double crossover design. In Table 2, means and variances based on plant-specific data are provided for the double crossover and the base case designs. In Table 3, means and variances based on plant-specific data are provided for the double crossover and the three pump designs.

Test and maintenance in combination with random system failures are the dominant contributors to unavailability. They are followed by random failures alone, human error, and common human error in importance. For the three pump design and in all cases given a loss of all AC power, random independent failures are the dominant contributors. The dominant random independent failure contributions are associated with the pumps: either the pumps themselves, their prime movers -- motors or turbines, and the power supply to the motor-driven pumps. Dominant human errors are associated with failure of the operator to close the full flow recirculation test valve either during a test when the system is demanded to function, or following a test in which the valve is left in the wrong position. Tables 9 through 20 describe the dominant contributions to conditional unavailability for each of the four situations described in Tables 1, 2, and 3.

The dominant contributors for the double crossover design system using NRC data are given in Tables 9, 10, and 11 for the three cases of NUREG-0611. In each case, maintenance on the turbine-driven auxiliary feedwater pump combined with random failures in the motor pump train is the dominant contributor. For the loss of main feedwater case, maintenance on the motor-driven auxiliary feedwater pump combined with random failures in the turbine train ranks second. In the other two cases, this failure mode is not as important because of the reduced availability of AC electrical power. Next in all cases is turbine or turbine control failure coupled with failure of the motor-driven pump motor. Using plant-specific data for the double crossover system, Tables 12, 13, and 14 show the same dominant contributors appear with some changes in ordering.

Dominant contributors for the base case design using plant-specific data are presented in Tables 15, 16, and 17. These results are very similar to the double crossover case using plant-specific data both in the rank order of the individual contributors and in the quantification. Tables 18, 19, and 20 present the dominant contributors for the three pump design using plant-specific data. The overall results of this design are not as good as for the double crossover or base case designs. Although there are three pumps, success requires either the turbine pump operating or both 50% motor pumps operating. The leading contributor for the cases when AC power may be available is maintenance of the turbinedriven auxiliary feedwater pump combined with random failures in the motor-driven pump trains. However, the large number of fairly important contributors due to random failures throughout the system leads to the overall effect that combined random failures provide the dominant contribution to system unavailability. Such random failures include failure of the turbine or turbine controls combined with single motor pump train level control valve failing, failure of the turbine-driven pump combined with failure of power to either electrically driven pump, turbine or turbine control failure and a single pressure control valve in a motordriven pump train failing, and failure of the turbine-driven pump combined with failure of a motor-operated valve in either motor-driven pump train. This design suffers from the fact that success, given a failure in a turbine pump train, requires that two complete trains of motor-driven pumps operate.

The selected design, the double crossover system, has very low unavailability. Nevertheless, it is instructive to list possible system modifications that have potential to further reduce that unavailability. To improve unavailability, the modifications must attack dominant contributors of Tables 9 through 14. For example, consider the following dominant contributors and the possible modifications that might address them.

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

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

- Turbine or turbine controls fail combined with random failures in the motor-driven pump train — modifications to improve reliability of turbine controls, perhaps provisions for preheating control fluid and positive identification that the turbine trip is reset.

- Human errors associated with the full recirculation flow valve during and following pump test — carefully written test procedures to ensure the valves are reclosed, staggered testing to avoid sequential highly coupled human failures, automatic closing of these test valves when an AFWAS is present.

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

5.2 RESULTS OF EVENT TREE ANALYSIS

The event tree analysis described in Section 4 has been performed for the double crossover system (see Figure 9). A decomposition of the double crossover system event tree and time dependent reliability calculations have been used to quantify the system event tree. Probabilities have been calculated for each sequence in Figure 9. We have summarized those calculations in the following brief table.

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

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

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

TABLE 9. DOMINANT CONTRIBUTORS TO CONDITIONAL UNAVAILABILITY

LOSS OF MAIN FEEDWATER

Double Crossover (NRC Data)

Rank	Event Description	Unavailability
1	Maintenance of turbine-driven AFWP an system failure on demand without this pump.	3.5×10^{-5}
2	Maintenance of motor-driven AFWP and system failure on demand without this pump.	3.4×10^{-5}
3	Turbine or turbine controls fail and P05A motor fails to start.	1.6×10^{-5}
4	Common cause--human error—full flow test valves open after test.	6.4×10^{-6}
5	Turbine or turbine controls fail and P05A fails to deliver sufficient water.	4.0×10^{-6}
6	P05B fails to deliver sufficient water and P05A motor fails to start.	4.0×10^{-6}
7	P05B test valve is open and P05A motor fails to start.	2.0×10^{-6}
8	Turbine or turbine controls fail and P05B test valve is open.	2.0×10^{-6}
9	P05B in test (operator error) and system failure on demand without this pump.	1.9×10^{-6}
10	P05A in test (operator error) and system failure on demand without this pump.	1.9×10^{-6}

TABLE 10. DOMINANT CONTRIBUTORS TO CONDITIONAL UNAVAILABILITY

LOSS OF MAIN FEEDWATER DUE TO LOSS OF OFFSITE POWER

Double Crossover (NRC Data)

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

TABLE 11. DOMINANT CONTRIBUTORS TO CONDITIONAL UNAVAILABILITY

LOSS OF ALL AC

Double Crossover (NRC Data)

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

TABLE 12. DOMINANT CONTRIBUTORS TO CONDITIONAL UNAVAILABILITY

LOSS OF MAIN FEEDWATER

Double Crossover (Plant-Specific Data)

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

TABLE 13. DOMINANT CONTRIBUTORS TO CONDITIONAL UNAVAILABILITY

LOSS OF MAIN FEEDWATER DUE TO LOSS OF OFFSITE POWER

Double Crossover (Plant-Specific Data)

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

TABLE 14. DOMINANT CONTRIBUTORS TO CONDITIONAL UNAVAILABILITY

LOSS OF ALL AC

Double Crossover (Plant-Specific Data)

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

TABLE 15. DOMINANT CONTRIBUTORS TO CONDITIONAL UNAVAILABILITY

LOSS OF MAIN FEEDWATER

Base Case (Plant-Specific Data)

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

TABLE 16. DOMINANT CONTRIBUTORS TO CONDITIONAL UNAVAILABILITY

LOSS OF MAIN FEEDWATER DUE TO LOSS OF OFFSITE POWER

Base Case (Plant-Specific Data)

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

TABLE 17. DOMINANT CONTRIBUTORS TO CONDITIONAL UNAVAILABILITY

LOSS OF ALL AC

Base Case (Plant-Specific Data)

Rank	Event Description	Unavailability
1	Turbine or turbine controls fail.	1.1×10^{-2}
2	Maintenance of turbine-driven AFWP.	5.9×10^{-3}
3	P01B fails to deliver sufficient water.	4.7×10^{-3}
4	P01B in test (operator error).	3.1×10^{-4}
5	Common cause—human error—full flow test valves open after test.	8.4×10^{-5}

TABLE 18. DOMINANT CONTRIBUTORS TO CONDITIONAL UNAVAILABILITY

LOSS OF MAIN FEEDWATER

Three Pump (Plant-Specific Data)

Rank	Event Description	Unavailability
1	Maintenance of turbine-driven AFWP and system failure on demand without this pump.	2.9×10^{-4}
2	Turbine or turbine controls fail and LV3875B1 transfers closed (controls).	1.5×10^{-4}
3	Maintenance on motor-driven AFWP (P05A) and system failure on demand without this pump.	9.8×10^{-5}
4	Maintenance on motor-driven AFWP (P05C) and system failure on demand without this pump.	9.8×10^{-5}
5	P05B fails to deliver sufficient water and LV3875B1 transfers closed (controls).	6.9×10^{-5}
6	Turbine or turbine controls fail and LV3875A1 transfers closed (controls).	5.6×10^{-5}
7	Turbine or turbine controls fail and pressure control valve 020B fails closed.	5.8×10^{-5}
8	Turbine or turbine control fail and pressure control valve 020A fails closed.	5.8×10^{-5}
9	Turbine or turbine controls fail and MO3870B motor operator fails.	3.7×10^{-5}
10	Turbine or turbine controls fail and MO3870A motor operator fails.	3.7×10^{-5}
11	Turbine or turbine controls fail and P05C fails to deliver sufficient water.	3.3×10^{-5}
12	Turbine or turbine controls fail and P05A fails to deliver sufficient water.	3.3×10^{-5}
13	P05B fails to deliver sufficient water and LV3875A1 transfers closed (controls).	2.6×10^{-5}
14	P05B fails to deliver sufficient water and pressure control valve 020B fails closed.	2.6×10^{-5}
15	P05B fails to deliver sufficient water and pressure control valve 020A fails closed.	2.6×10^{-5}
16	P05B fails to deliver sufficient water and MO3870B motor operator fails.	1.7×10^{-5}
17	P05B fails to deliver sufficient water and MO3870A motor operator fails.	1.7×10^{-5}
18	P05B in test (operator error) and system failure on demand without this pump.	1.6×10^{-5}
19	P05B fails to deliver sufficient water and P05C fails to deliver sufficient water.	1.5×10^{-5}

TABLE 18. DOMINANT CONTRIBUTORS TO CONDITIONAL UNAVAILABILITY (continued)

LOSS OF MAIN FEEDWATER

Three Pump (Plant-Specific Data)

Rank	Event Description	Unavailability
20	P05B fails to deliver sufficient water and P05A fails to deliver sufficient water.	1.5×10^{-5}
21	Common cause—human error—full flow test valves open after test.	8.4×10^{-6}
22	Turbine or turbine controls fail and level control valve LV387581 fails closed.	6.1×10^{-6}
23	Turbine or turbine controls fail and P05C motor fails to start.	5.8×10^{-6}
24	Turbine or turbine controls fail and P05A motor fails to start.	5.8×10^{-6}
25	P05A in test (operator error) and system failure on demand without this pump.	5.3×10^{-6}
26	P05C in test (operator error) and system failure on demand without this pump.	5.3×10^{-6}

TABLE 19. DOMINANT CONTRIBUTORS TO CONDITIONAL UNAVAILABILITY

LOSS OF MAIN FEEDWATER DUE TO LOSS OF OFFSITE POWER

Three Pump (Plant-Specific Data)

Rank	Event Description	Unavailability
1	Maintenance of turbine-driven AFWP and system failure on demand without this pump.	7.2×10^{-4}
2	Turbine or turbine controls fail and 4,160V bus 1A05 fails to supply power.	3.9×10^{-4}
3	Turbine or turbine controls fail and 4,160V bus 1A06 fails to supply power.	3.9×10^{-4}
4	P05B fails to deliver sufficient water and 4,160V bus 1A05 fails to supply power.	1.7×10^{-4}
5	P05B fails to deliver sufficient water and 4,160V bus 1A06 fails to supply power.	$1.7 \times 10_{-4}$
6	Turbine or turbine controls fail and LV3875BA transfers closed.	1.5×10^{-4}
7	Maintenance on motor-driven AFWP (P05A) and system failure on demand without this pump.	9.8×10^{-5}
8	Maintenance on motor-driven AFWP (P05C) and system failure on demand without this pump.	9.8×10^{-5}
9	P05A fails to deliver sufficient water and LV3875B1 transfers closed.	6.9×10^{-5}
10	Turbine or turbine controls fail and LV3875A1 transfers closed.	5.9×10^{-5}
11	Turbine or turbine controls fail and pressure control valve 020B fails closed.	3.8×10^{-5}
12	Turbine or turbine controls fail and pressure control valve 020A fails closed.	3.8×10^{-5}
13	P05B in test (operator error) and system failure on demand without this pump.	3.8×10^{-5}
14	Turbine or turbine controls fail and MO3870B motor operator fails (and controls).	3.7×10^{-5}
15	Turbine or turbine controls fail and MO387[illegible] motor operator fails (and controls).	3.7×10^{-5}
16	Turbine or turbine controls fail and [illegible] fails to deliver sufficient water.	3.3×10^{-5}
17	Turbine or turbine controls fail and P05A fails to deliver sufficient water.	3.3×10^{-5}
18	P05B fails to deliver sufficient water and LV3875A1 transfers closed.	2.6×10^{-5}
19	P05B fails to deliver sufficient water and pressure control valve 020B fails closed.	2.6×10^{-5}

TABLE 19. DOMINANT CONTRIBUTORS TO CONDITIONAL UNAVAILABILITY (continued)

LOSS OF MAIN FEEDWATER DUE TO LOSS OF OFFSITE POWER

Three Pump (Plant-Specific Data)

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

TABLE 20. DOMINANT CONTRIBUTORS TO CONDITIONAL UNAVAILABILITY

LOSS OF ALL AC

Three Pump (Plant-Specific Data)

Rank	Event Description	Unavailability
1	Turbine or turbine controls fail.	1.1×10^{-2}
2	Maintenance of turbine-driven AFWP.	5.9×10^{-3}
3	P05B fails to deliver sufficient water.	4.7×10^{-3}
4	P05B in test (operator error).	3.1×10^{-4}
5	P05B discharge valve transfers closed.	2.9×10^{-4}
6	LV3875B2 transfers closed (controls) and LV3875A2 transfers closed (controls).	2.2×10^{-4}
7	LV3875A8 transfers closed (controls) and MO3870B fails closed.	2.1×10^{-4}
8	LV3875B2 transfers closed (controls) and MO3870A fails closed.	2.1×10^{-4}
9	Common cause--human error--full flow test valves open after test.	8.4×10^{-6}

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APPENDIX B

FSAR APPENDIX 10A

APPENDIX 15A

AUXILIARY FEEDWATER SYSTEM EVALUATION

15A.1 COMPARISON OF THE MIDLAND AUXILIARY FEEDWATER SYSTEM DESIGN WITH THE REVIEW PROCEDURES OF NRC STANDARD REVIEW PLAN 10.4.9 REVISION 1

SRP 10.4.9 Rev. 1 Section III, Review Procedures	Summary of FSAR Text and/or Reference to Applicable Sections
Question 15A.1	
15A.1.1 The SAR is reviewed to determine that the system description and piping and instrumentation diagrams (P&IDs) identify the AFS equipment and arrangement that is used for normal operation and for safe plant shutdown (cooldown) operation. The system P&IDs, layout drawings, and component descriptions and characteristics are then reviewed to verify that:	Auxiliary feedwater (AFW) system and component descriptions can be found in Subsection 10.4.9. P&IDs are shown in Figures 10.4-10 Sheets 1 and 2 and 10.4-11 Sheets 1 and 2. Piping isometric drawings are shown in Figures 3.6-36 through 49.
a. Minimum performance requirements for the system are sufficient for the various functions of the AFS.	AFW system performance requirements and capabilities are described in Subsection 10.4.9.3.
b. Essential portions of the AFS are isolable (sic) from non-essential portions, so that system performance is not impaired in the event of a failure of a non-essential component.	Essential portions of the AFW system are isolable from nonessential portions, as shown in Figures 10.4-10 and 10.4-11.
c. Component and system descriptions in the SAR include appropriate seismic and quality group classifications, and the P&IDs indicate any points of change in piping quality group classification.	AFW system seismic and quality group classifications can be found in Subsections 10.4.9.3 and 10.4.9.1.3, respectively. The Midland P&IDs do indicate points of change in piping classification.
d. Design provisions have been made that permit appropriate inservice inspection and functional testing of system components important to safety. It is acceptable if the SAR information delineates a testing and inspection program and if the system drawings show the necessary recirculation loops around pumps or isolation valves as may be required (sic) by this program.	Periodic testing of the AFW system to demonstrate readiness and operability will be conducted in accordance with the plant technical specifications (Subsection 16.3/4.7.1.2). Inservice inspection of the ASME Code Class 2 and 3 components in the AFW system will be conducted in accordance with Section XI of the Code as described in Subsection 3.9.6 and Section 6.6.

15A.1.2 The reviewer verifies that the system safety function will be maintained as required in the event of adverse environmental phenomena, breaks or cracks in fluid system piping outside containment, system component failures, loss of an onsite active power source, or loss of offsite power. The reviewer uses

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10A.1 COMPARISON OF THE MIDLAND AUXILIARY FEEDWATER SYSTEM DESIGN WITH THE REVIEW PROCEDURES OF NRC STANDARD REVIEW PLAN 10.4.9 REVISION 1 (continued)

SRP 10.4.9 Rev. 1 Section III, Review Procedures	Summary of FSAR Text and/or Reference to Applicable Sections
engineering judgment and the results of failure modes and effects analyses to determine that:	
a. The failure of portions of the system or of other systems not designed to seismic Category I standards and located close to essential portions of the system, or of non-seismic Category I structures that house, support, or are close to essential portions of the AFS, will not preclude operation of the essential portions of the AFS. Reference to SAR sections describing site features and the general arrangement and layout drawings will be necessary, as well as the SAR tabulation of seismic design classifications for structures and systems.	Failure of non-seismic Category I systems and components will not preclude the required operation of the AFW system, as discussed in Subsection 10.4.9.3.
b. The essential portions of the AFS are protected from the effects of floods, hurricanes, tornadoes, and internally or externally generated missiles. Flood protection and missile protection criteria are discussed and evaluated in detail under the SRP Section 3 series. The location and design of the system, structures, and pump rooms (cubicles) are reviewed to determine that the degree of protection provided is adequate. A statement to the effect that the system is located in a seismic Category I structure that is tornado missile and flood protected, or the components of the system will be located in individual cubicles or rooms that will withstand the effects of both flooding and missiles is acceptable.	The AFW pumps and pipe runs are located in the auxiliary building, which is a seismic Category I structure. Protection of the AFW system from wind and tornado effects is discussed in Section 3.3. Flood design is discussed in Section 3.4. Missile protection is discussed in Section 3.5.
c. The essential portions of the system are protected from the effects of high and moderate energy line breaks in accordance with Branch Technical Position ASB 3-1. Layout drawings are reviewed to assure that no high or moderate energy piping systems are close to essential portions of the AFS, or that	The AFW system is protected against the dynamic effects of high and moderate energy line breaks as described in Section 3.6.

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10A.1 COMPARISON OF THE MIDLAND AUXILIARY FEEDWATER SYSTEM DESIGN WITH THE REVIEW PROCEDURES OF NRC STANDARD REVIEW PLAN 10.4.9 REVISION 1 (continued)

	SRP 10.4.9 Rev. 1 Section III, Review Procedures	Summary of FSAR Text and/or Reference to Applicable Sections
	protection from the effects of failure will be provided. The means of providing such protection will generally be given in Section 3.6 of the SAR and procedures for reviewing this information are given in SRP Section 3.6.	
d	Essential components and subsystems necessary for safe shutdown can function as required in the event of loss of offsite power. The SAR is reviewed to see that for each AFS component or subsystem affected by the loss of offsite power, system flow and heat transfer capability meet minimum requirements. Statements in the SAR and the results of failure modes and effects analyses are considered in assuring that the system meets these requirements.	Following a loss of offsite power, all essential components of the AFW system automatically receive power from the emergency diesel generators, as described in Subsection 8.3.1.
e	The system is designed with adequate redundancy to accommodate a single active component failure without loss of function.	A discussion of the ability of the Midland AFW systems to withstand a single active component failure is found in Subsection 10.4.9.3.
f	Diversity in pump motive power sources and essential instrumentation and control power sources has been provided. The diverse system including pump(s), controls and valves should be independent of offsite AC power sources in accordance with the guidelines of Branch Technical Position ASB 10-1.	The diversity of pump motive power, sources of water, and instrumentation and control power supplies is discussed in Subsection 10.4.9.3.
g	The system is designed with adequate instrumentation to automatically initiate auxiliary feedwater flow to the steam generators upon receipt of an actuation signal. The initiation signal should start all auxiliary feedwater pumps and supporting systems, align the auxiliary feedwater sources, and open flow paths from the auxiliary feedwater pumps to the steam generator(s).	The Midland auxiliary feedwater actuation system (AFWAS) is described in Subsection 7.3.3.2.6.

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10A.1 COMPARISON OF THE MIDLAND AUXILIARY FEEDWATER SYSTEM DESIGN WITH THE REVIEW PROCEDURES OF NRC STANDARD REVIEW PLAN 10.4.9 REVISION 1 (continued)

	SRP 10.4.9 Rev. 1 Section III, Review Procedures	Summary of FSAR Text and/or Reference to Applicable Sections
[illegible]	The system is designed with the capability to manually initiate the protective actions necessary so that the auxiliary feedwater system design satisfies the recommendations of Regulatory Guide 1.62	Provisions for manual actuation and control of AFW are discussed in Subsections 10.4.9.3 and 7.3.2.3.12.
[illegible]	The AFS is designed with redundant instrumentation so that the system will automatically limit or terminate auxiliary feedwater flow to a depressurized steam generator and to assure that the minimum required flow is directed to the intact steam generator(s)	The feed-only-good generator (FOGG) control feature is described in Subsection 7.3.3.2.5.
3	The AFS is designed with sufficient flow capacity so that the system can remove residual heat over the entire range of reactor operation and achieve a cold shutdown condition	The criteria used in determining the required AFW flow capacity for Midland are discussed in Section 10A.4. Flow capacities of the AFW pumps are given in Table 10.4-7.

10A.2 MIDLAND PLANT AUXILIARY FEEDWATER SYSTEM RELIABILITY ANALYSIS

The Midland Plant Auxiliary Feedwater System Reliability Analysis, performed by Pickard, Lowe and Garrick, Inc, has been forwarded by J W Cook's letter dated February 27, 1981, Serial 11223, to H.R. Denton. 30 33

10A.3 COMPARISON OF THE MIDLAND AUXILIARY FEEDWATER SYSTEM DESIGN WITH THE RECOMMENDATION OF NUREG-0611, APPENDIX III

Recommendation	Response
Question 10A.3	
10A.3.1 Short-Term Recommendations	
Recommendation GL-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.	Refer to Subsection 16.3/4.7.1.2.
Recommendation GL-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.	Refer to Subsection 16.3/4.7.1.2 and the response to Recommendation GL-2. 30
Recommendation GL-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 Midland AFW systems do not rely on the throttling of AFW flow for protection against water hammer. See Subsection 10.4.9.3 for additonal information.
Recommendation GL-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:	An automatic transfer of the AFW system water supply from the condensate storage tank to service water is provided at Midland. Manual alignment to the condenser hotwell, deaerator storage tanks, and water sources in the opposite unit are also available.
(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	

10A.3 COMPARISON OF THE MIDLAND AUXILIARY FEEDWATER SYSTEM DESIGN WITH THE RECOMMENDATION OF NUREG-0611, APPENDIX III

Recommendation	Response	
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.		30
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 those 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 should operate the turbine-driven pump in an on-off mode until ac power is restored. Adequate lighting powered by direct current (dc) 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.)	See the response to Recommendation GL-3.	33 30
Recommendation GS-6 - 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:		33
(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.	Verification of AFW system valve alignment is incorporated in the Midland testing procedures.	30

10A.3 COMPARISON OF THE MIDLAND AUXILIARY FEEDWATER SYSTEM DESIGN WITH THE RECOMMENDATION OF NUREG-0611, APPENDIX III (continued)

Recommendation	Response
(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.	See Subsection 16.3/4.7.1.2.
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.	See the response to Recommendation GL-1.
(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	

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10A.3 COMPARISON OF THE MIDLAND AUXILIARY FEEDWATER SYSTEM DESIGN WITH THE RECOMMENDATION OF NUREG-0611, APPENDIX III (continued)

Recommendation	Response
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.	
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 sort-term, it should meet the criteria listed below, which are similar to Item 2.1.7.a of NUREG-0578. For the longer-term, the automatic initiation signals and circuits should be upgraded to meet safety-grade requirements, as indicated in Recommendation GL-1.	See the response to Recommendation GL-1.
(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 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	

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10A.3 COMPARISON OF THE MIDLAND AUXILIARY FEEDWATER SYSTEM DESIGN WITH THE RECOMMENDATION OF NUREG-0611, APPENDIX III (continued)

Recommendation	Response
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.	
10A.3.2 Additional Short-Term Recommendations:	
Recommendation #1 - 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.	A description of the condensate storage tank, its operation, and the instrumentation provided for it can be found in Subsection 9.2.6.2.
Recommendation #2 - 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.	A 72 hour endurance test of the AFW pumps will be conducted during the initial testing program. 10
Recommendation #3 - The licensee should implement the following requirements as specified by Item 2.1.7.b on page A-32 of NUREG-0578:	
(1) Safety-grade indication of AFW flow to each steam generator should be provided in the control room.	Safety grade flow indication of the AFW flow to each once-through steam generator (OTSG) is provided at Midland in accordance with NUREG-0578, Recommendation 2.1.7.b. Redundancy is provided through safety grade level indication of each OTSG.
(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	

10A.3 COMPARISON OF THE MIDLAND AUXILIARY FEEDWATER SYSTEM DESIGN WITH THE RECOMMENDATION OF NUREG-0611, APPENDIX III (continued)

Recommendation	Response
10-1 of the Standard Review Plan. Section 10.4.9.	
Recommendation 84 - 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.	The Midland procedures for periodic surveillance testing of AFW will include provisions for operator communication with the control room any time an AFW train is removed from service for testing.
10A.3.3 Long-Term Recommendations	
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.	Automatic safety grade initiation of AFW is provided at Midland. A detailed description of the AFW/S and a listing of the initiating signals can be found in Subsection 7.3.3.2.6. 30
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).	Parallel piping is provided in the Midland AFW system for the primary and secondary water sources (see Figures 10.4-10 Sheet 2 and 10.4-13 Sheet 2).
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.	The steam turbine driven AFW pump is capable of supplying feedwater to the steam generators for at least 2 hours following a loss of all ac power as discussed in Subsection 10.4.9.3.
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	Protection of the Midland AFW pumps against a loss of the primary water source (condensate storage tank) is provided by an automatic switchover to the safety grade service water system. See Subsection 10.4.9.3.

10A.3 COMPARISON OF THE MIDLAND AUXILIARY FEEDWATER SYSTEM DESIGN WITH THE RECOMMENDATION OF NUREG-0611, APPENDIX III (continued)

Recommendation	Response	
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 suctions pressure, or upgrading the normal source of water to meet seismic Category I and tornado protection requirements.		10
Recommendation GL-5 - The licensee should upgrade the AFW system automatic initiation signals and circuits to meet safety-grade requirements.	See the response to Recommendation GL-1.	33 30

10A.4 RESPONSES TO THE REQUESTS FOR INFORMATION REGARDING THE BASIS FOR AFW SYSTEMS FLOW REQUIREMENTS TRANSMITTED IN ENCLOSURE 2 OF D.F. ROSS JR. LETTER TO S.H. HOWELL, APRIL 24, 1980 30 33

Question	Response
Question 10A.4 30	
10A.4.1	
• 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	The minimum auxiliary feedwater system (AFWS) flowrate was set by functional requirements. That flowrate was then verified to be acceptable using the transient which would require the greatest AFWS flow. The transients considered were analyzed and are identified in Table 10A-1. The events listed in this question which are not included in Table 10A-1 will also be addressed. The functional requirements for the AFWS flowrate are to remove the decay heat generated after a reactor shutdown and to provide a smooth reactor coolant flow transition from forced circulation to natural circulation should a loss of offsite power (LOOP) occur simultaneously with the need for AFW. The functional requirements resulted in an AFWS flowrate of 850 gpm to be delivered to the steam generator within 40 seconds of the initiation signal. The time of 40 seconds was chosen to allow the AFWS to inject feedwater and begin increasing steam generator level to the 50% operating range level, required for natural circulation, prior to completion of the reactor coolant pump coastdown. At that time, the design flowrate was selected to be equal to or greater than the decay heat generation rate. Because decay heat rate changes with time, other values than 40 seconds and 850 gpm could have been used and been acceptable. 33 These parameters were then used in transient and accident evaluations. The loss of feedwater (LOFW) transient is the most limiting for AFWS flow. The analysis assumptions for this event are addressed in the response to Question 10A.4.2. All other transients which either require or assume the availability of AFW in the safety analysis use the design values derived from the functional requirements. The events listed in Enclosure 2 of the D.F. Ross, Jr.,

10A.4 RESPONSES TO THE REQUESTS FOR INFORMATION REGARDING THE BASIS FOR AFW SYSTEMS FLOW REQUIREMENTS TRANSMITTED IN ENCLOSURE 2 OF D.F. ROSS JR. LETTER TO S.H. HOWELL, APRIL 24, 1980 30 33 30

Question	Response
	letter to S.H. Howell, dated April 24, 1980, which are not included in Table 10A-1, are discussed below: Loss of Main Feedwater (LMFW) With Loss of Onsite and Offsite AC Power - This event is not a design basis of the plant and consequently is not included in Chapter 15. However, following a temporary loss of all ac power, the steam turbine driven AFW pump can be used to supply sufficient feedwater to both steam generators as discussed in Subsection 10.4.9.3. Plant Cooldown - Plant cooldown with AFW is a controlled event with decay heat levels equal to or lower than in the emergency condition identified as the design basis event. The design basis event bounds this case for AFW flow required. Protection against potential AFW overcooling is provided by the AFW level control system described in Subsection 10.4.9. Turbine Trip with and Without Bypass - This event does not affect the AFWS unless MFW fails, in which case the LMFW event previously addressed would bound the AFWS design. 33 Main Steam Isolation Valve Closure - Again, this event does not directly affect the AFWS unless MFW is lost as discussed above. Small-Break Loss-of-Coolant Accident (LOCA) - The AFW criteria assumed for this event are described in Topical Report BAW-10052 updated by letter report, J.H. Taylor (B&W) to S.A. Varga (NRC), 7/18/78, and the recently submitted B&W report entitled Evaluation of Transient Behavior and Small Reactor Coolant System Breaks in the 177 FA Plant, 5/07/79. These documents discuss the AFWS flowrate and show that it will not lead to the violation of the acceptance criteria.
b. Describe the plant protection acceptance criteria and corresponding technical bases used for each initiating event identified above. The acceptance criteria should address	The plant protection acceptance criteria for each accident are listed in Table 10A-1 along with the technical basis for each acceptance criterion. The transient events identified in Question 1 which are not

10A.4 RESPONSES TO THE REQUESTS FOR INFORMATION REGARDING THE BASIS FOR AFW SYSTEMS FLOW REQUIREMENTS TRANSMITTED IN ENCLOSURE 2 OF D.F. ROSS JR. LETTER TO S.H. HOWELL, APRIL 24, 1980 30 33 30

Question	Response
plant limits such as: - Maximum RCS pressure (PORV or safety valve actuation) - Fuel temperature or damage limits (DNB, PCT, maximum fuel central temperature) - RCS cooling rate limit to avoid excessive coolant shrinkage - Minimum steam generator level to assure sufficient steam generator heat transfer surface to remove decay heat and/or cooldown the primary system.	included in Table 10A-1 are not bounding events, have not been analyzed, and as such do not have acceptance criteria. The acceptance criteria for a small break LOCA are included in the documents identified in response to Question 1a. The reactor coolant system (RCS) cooling rate is not a limit relative to accident acceptance criteria. The safety limit for all transients which use AFW for mitigation is that the core remain cooled with ultimate acceptance criteria being those addressed in Table 10A-1. For transients which result in draining the pressurizer or for which natural circulation is slowed or interrupted, restoration of pressurizer level and subcooling is accomplished by swelling due to core heat input and inventory restoration by high-pressure injection. Steam generator level is not based on decay heat removal rate or cooldown capability. Steam generator level is variable depending on the plant condition. The level is normally low when removing decay heat with forced primary circulation. The level is normally high when removing decay heat with natural circulation. It is also set high for small LOCA as described in Topical Report BAW-10052, and in the B&W report, Evaluation of Transient Behavior and Small Reactor Coolant System Breaks. 33
10A.4.2 Describe the analyses and assumptions and corresponding technical justification used with plant condition considered in 1.a. above including:	As discussed in the response to Question 1a above, the design basis event which verifies the AFWS design requirements is loss of main feedwater. The analysis assumptions for this event are listed below (keyed to the letters of the question). Corresponding technical justification, where not specifically listed below, is based on licensing requirements and prudent engineering judgment at the time of the analysis. The information is not provided for the other events identified in Question 1a and Table 10A-1 because the loss-of-feedwater event is the most limiting.

10A.6 RESPONSES TO THE REQUESTS FOR INFORMATION REGARDING THE BASIS FOR AFW SYSTEMS FLOW REQUIREMENTS TRANSMITTED IN ENCLOSURE 2 OF D.F. ROSS JR. LETTER TO S.H. HOWELL, APRIL 24, 1980 30 | 33 | 30

Question	Response
a. Maximum reactor power (including instrument error allowance) at the time of the initiating transient or accident	a. Maximum Reactor Power - 102% based on a 2% instrument error in neutron flux measurement
b. Time delay from initiating event to reactor trip.	b. Time Delay Initiating Event to Reactor Trip - The reactor will trip on high RCS pressure approximately 9 seconds after an LOFW event.
c. Plant parameter(s) which initiates AFWS flow and time delay between initiating event and introduction of AFWS flow into steam generator(s).	c. AFWS Initiating Signal and Time Delay - The AFW initiation signal for the LOFW event is a low steam generator level signal to the auxi ary feedwater actuation system (AFWAS). The design basis time delay from initiation signal to full AFW flow into the steam generator is 40 seconds. The FSAR LOFW analysis shows that the time from the LOFW event to full AFW flow into the steam generator is 143 seconds. 33
d. Minimum steam generator water level when initiating event occurs.	d. Steam Generator Level at Initiation Event - Steam generator inventory is dependent on power level.
e. Initial steam generator water inventory and depletion rate before and after AFWS flow commences - identify reactor decay heat rate used.	e. Steam Generator Inventory and Decay Heat - For discussion of water inventory, see Item d above. Reactor decay heat rate is based on one times the value derived from ANS Standard 5.1-1979.
f. Maximum pressure at which steam is released from generator(s) and against which the AFW pump must develop sufficient head.	f. Maximum Steam Generator Pressure - The maximum steam generator pressure at which the AFW pumps must develop sufficient head is 1,050 psig. This is based on the lowest set pressure of the main steam safety valves.
g. Minimum number of steam generators that must receive AFW flow; e.g. 1 out of 2?, 2 out of 4?	g. Minimum Number of Steam Generators - The number of generators was not specified in the analysis; heat removal capab....y is the pertinent parameter and can be accommodated by one steam generator.
h. RC flow condition - continued operation of RC pumps or natural circulation	h. Reactor Coolant Flow Condition - Continued reactor coolant pump operation was assumed.

10A.4 RESPONSES TO THE REQUESTS FOR INFORMATION REGARDING THE BASIS FOR AFW SYSTEMS FLOW REQUIREMENTS TRANSMITTED IN ENCLOSURE 2 OF D.F. ROSS JR. LETTER TO S.H. HOWELL, APRIL 24, 1980 30 33

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Question	Response
i. Maximum AFW inlet temperature.	i. Maximum AFW Inlet Temperature - The maximum AFW inlet temperature assumed was 90F. This inlet temperature could exceed 90F under the unlikely situation where service water must be used as the AFW source. However, the AFW pump capacity was based on 105F inlet water temperature with adequate margins for wear and seal leakage. As such, the present capacity is adequate to handle the additional volume required with hotter water. For additional information on the AFW pump capacity, see the response in Subsection 10A.4.3.
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 removal due to blowdown.	j. Steam, Feedline Break Time Delay - Refer to Subsection 15.2.8 and Appendix 15C for feedwater line break analytical information. Refer to Subsection 15.1.5 and Appendix 15D for steam line break analytical information. 33
k. Volume and maximum temperature of water in main feed lines between steam generator(s) and AFWS connection to main feed line.	k. Main Feedline Volume and Temperature Between Steam Generators and AFWS - N/A. The MFWS and AFWS are cross connected. This provision has been provided so that the AFWS may be used to supply feedwater to the steam generators during periods of startup, cooldown, and hot standby; however, these lines are isolated by AFWAS (at which time AFW is fed directly to the OTSGs), and therefore this item has no bearing on the design basis.
l. Operating condition of steam generator normal blowdown following initiating event.	l. Steam Generator Normal Blowdown - The OTSGs have a manually controlled blowdown system that is available for use during startup up to 15% power. During plant operation above 15% power the system is normally isolated. For this analysis the blowdown system was assumed to be isolated.
m. Primary and secondary system water and metal sensible heat used for cooldown and AFW flow sizing.	m. Water and Metal Sensible Heat Used - Plant cooldown was not considered in the design basis analysis. A heat capacity of 1.256 x 10^6 Btu/°F was used for calculating the

10A.4 RESPONSES TO THE REQUESTS FOR INFORMATION REGARDING THE BASIS FOR AFW SYSTEMS FLOW REQUIREMENTS TRANSMITTED IN ENCLOSURE 2 OF D.F. ROSS JR. LETTER TO S.H. HOWELL, APRIL 24, 1980 30 33

Question	Response
	volume of feedwater required to cool the RCS to decay heat system parameters.
a. Time at hot standby and time to cooldown RCS to RHR system cut in temperature to size AFW water source inventory.	a. Time at Hot Standby, Etc. Relative to AFW Inventory - The condensate storage tank is sized to accommodate the plant at hot shutdown for at least 4 hours followed by a cooldown to 280F. The maximum cooldown rate of the RCS is 100F per hour. 33

10A.4.3

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	The Midland AFW pumps are rated to supply 885 gpm with a total dynamic head of 2,700 feet of water. The pumps can supply the necessary flow of 850 gpm to the steam generators at a pressure of 1,050 psig (2,426 feet of water) with adequate margins for seal leakage and pump wear. Because the pumps are not on continuous recirculation, no margin was provided for recirculation flow in the sizing of the pumps. Feedwater demand during any of the plant transient and accident conditions discussed in item 1 is met by the AFW pumps in conjunction with the AFW level control described in Subsection 10.4.9. 32 33 32

APPENDIX C

TECHNICAL SPECIFICATION 16.3/4.7.1.2

PLANT SYSTEMS

AUXILIARY FEEDWATER SYSTEM

LIMITING CONDITION FOR OPERATION

3.7.1.2 Two independent steam generator auxiliary feedwater pumps and associated flowpaths shall be OPERABLE with:

a. One auxiliary feedwater pump capable of being powered from an OPERABLE emergency bus.

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

c. Operation of the steam driven auxiliary feedwater pump for MODES 1, 2, 3, and 4, except for surveillance and testing requirements and when actuated by station emergency conditions, is prohibited unless the electric driven feedwater pump is inoperable.

APPLICABILITY: MODES 1, 2, and 3.

ACTION:

a. With one auxiliary feedwater system inoperable, restore the inoperable system to OPERABLE status within 72 hours or be in HOT SHUTDOWN within the next 12 hours.

SURVEILLANCE REQUIREMENTS

4.7.1.2 Each auxiliary feedwater system shall be demonstrated OPERABLE:

a. At least once per 31 days on a STAGGERED TEST BASIS by:

1. Verifying that the steam turbine driven pump develops a discharge pressure of ≥ 1,160 psig above suction pressure at a flow of ≥ 850 gpm when the secondary steam supply pressure is greater than 885 psig when tested as required by Specification 4.0.5.

PLANT SYSTEMS

SURVEILLANCE REQUIREMENTS (continued)

2. Verifying that the motor driven pump develops a discharge pressure of ≥ (LATER) psig at a flow of ≥ (LATER) gpm when tested as required by Specification 4.0.5.

3. Verifying that each valve (manual, power operated, or automatic) in the flowpath that is not locked, sealed or otherwise secured in position, is in its correct position.

4. Entry into Mode 3 is allowed for the purpose of performing surveillance testing Requirement 4.7.1.2.a.1. | 20

b. At least once per 18 months, during shutdown, by:

1. Verifying that each automatic valve in the flowpath actuates to its correct position on an auxiliary feedwater actuation test signal.

2. Verifying that each pump starts automatically upon receipt of an auxiliary feedwater actuation test signal.

3. Verifying that the auxiliary feedwater steam generator level control valves maintain a steam generator level of (LATER).

4. Verifying that the auxiliary feedwater pump stops and the auxiliary feedwater crosstie valve closes automatically upon a high level in the associated loop steam generator of (LATER) feet concurrent with an auxiliary feedwater actuation test signal.

5. Verifying that the auxiliary feedwater pump restarts when the associated steam generator level falls below (LATER) feet from the high level in Item 4 above, concurrent with an auxiliary feedwater actuation test signal.

APPENDIX D

NUREG-0667 RESPONSES,

RECOMMENDATIONS 9,10,21

PART III
NUREG-0667 RESPONSES

Recommendation 9 - Post-Trip Pressure and Level Response

Response

The following performance criteria for acceptable normal post-trip plant response have been developed:

a. Reactor coolant system (RCS) pressure remains above the setpoint for automatic high-pressure injection (HPI) actuation.

b. RCS pressure remains below the setpoint for RCS code safety valve actuation.

c. RCS temperature decrease does not exceed technical specification limits (100F decrease in 1 hour).

d. Reactor coolant is contained within the primary RCS and quench tank.

e. Indicated pressurizer level remains on scale.

f. Indicated steam generator level remains on scale.

These criteria are based on measured plant variables and reflect the expected Midland response for normal reactor trips. A review of reactor trip data identified several instances where performance criteria were not met. The causes of these abnormal responses and the Midland design features expected to prevent these occurrences are addressed below: 30

a. Excessive Main Feedwater

Improper control of main feedwater after a reactor trip can lead to overcooling of the primary system with a potential for loss of pressurizer level indication and challenge to the HPI system. Eventually, control problems could lead to once-through steam generator (OTSG) overfill. The Midland design has been reviewed with respect to this concern. A failure modes and effects analysis (FMEA) was conducted on the integrated control system (ICS) and is being completed on the main feedwater system. It is anticipated that these studies will verify the capability to automatically control the post-trip main feedwater flow to ensure acceptable plant response. A review of the main feedwater overfill concern has led to a recommended design modification which will be implemented to ensure feedwater is terminated before the OTSG is filled.

b. **Excessive Auxiliary Feedwater**

In the event of a reactor trip coincident with loss of main feedwater, auxiliary feedwater (AFW) provides the source of cooling water used to remove decay heat. Under these circumstances, improper control of AFW may lead to overcooling or overfill problems similar to those of main feedwater as discussed above. Due to the importance of proper AFW control, several design features exist or will be incorporated by amendment within the Midland design. First, the AFW level control system is being modified to provide for the addition of AFW at a programmed rate. This rate will be sufficient to ensure establishment and maintenance of natural circulation while limiting the extent to which the RCS is cooled. The result will be a smoother and dampened post-trip response. Secondly, OTSG overfill due to improper AFW control is precluded by existing plant features which terminate AFW injection before the steam generator is filled. Analysis of the plant performance during such events is provided in the Response to NRC Question 211.184. A description of the AFW level control system is provided in Subsections 10.4.9, 7.3.3.2.6, and 7.4.1.1.1. Finally, the acceptability of the entire AFW system, including its control systems, is being evaluated through the preparation of an extensive AFW reliability analysis. Although not anticipated, any design deficiencies identified by this study will be satisfactorily remedied. 30

c. **OTSG Underfeeding Due to Loss of Main Feedwater and Delayed Auxiliary Feedwater**

The potential for this concern is affected by the reliability of both the main and auxiliary feedwater systems. Evaluation of these reliabilities, and improvements where necessary, are being addressed through FMEA and reliability analyses and design changes discussed in Items a and b above. In addition to these studies and improvements, additional modifications are being made to the AFW system which are expected to improve its reliability. Specifically, changes are being made to the AFW suction piping to remove system interconnections and therefore unitize the systems. The discharge piping is also being modified to provide redundant flow paths from each AFW pump to each steam generator. These efforts, to be documented through the use of FMEA and reliability analysis techniques, are expected to result in highly reliable systems for assuming timely and adequate secondary heat removal.

d. Excessive Steam Relief

Improper control of secondary system pressure after a reactor trip can result in overcooling of the primary system and undesirable primary pressure/temperature response. To prevent this occurrence, the ICS must be tuned for proper operation of the turbine bypass system and the lift and blowdown setpoints of the main steam safety valves must be adjusted correctly. Careful attention will be paid to these requirements during preoperational testing to ensure proper system operation.

e. Stuck-Open Power Operated Relief Valve

Excessive primary system blowdown resulting from failure of the power operated relief valve (PORV) to reseat will be prevented by automatic isolation by the two PORV block valves. An isolation signal will be transmitted when coincident logic of PORV open position and low RCS pressure is satisfied. This design feature will ensure that, for anticipated transient or accident conditions calling for PORV actuation, the failure of the PORV to reseat or improper blowdown will be automatically mitigated. 30

f. Excessive High-Pressure Injection Fluid

The RCS may become water solid or the pressurizer relief valves may be challenged by the prolonged operation of the HPI system. Termination of HPI flow requires satisfaction of certain small break operator guidelines and, therefore, relies upon reliable and sufficient indication of plant status. Midland plant operators will be provided with indication of pressurizer level, hot-leg temperature, RCS pressure and saturation margin independent of nonnuclear instrumentation or ICS availability. With this instrumentation available to the operator, termination of HPI flow, when warranted, can occur on a timely basis.

PART III
NUREG-0667 RESPONSES

These design features are expected to ensure satisfaction of the established post-trip response performance criteria. No immediate operator action will be necessary. 30

PART III
NUREG-0667 RESPONSES

Recommendation 10 - Sensitivity Studies to Reduce OTSG Response

Response

A review of plant trip data compiled for the current B&W operating plants has identified several causes for overcooling and undercooling events. These causes, and the design features existing or planned for Midland plant Units 1 and 2 that address them, are presented in the response to Recommendation 9. In general, features currently exist or are being added to ensure proper feedwater and steam pressure control. Additionally, instrumentation will be provided to ensure adequate information to allow the operator to properly and promptly interface with automatic plant features. Finally, a failure modes and effects analysis and reliability analyses are being conducted to ensure that systems called upon to prevent or respond to secondary coolant flow perturbations meet design criteria requirements. 30

Recommendation 21 - Reevaluation of Auxiliary Feedwater System Injection Point

Response

Introduction of auxiliary feedwater (AFW) through the top spray sparger was a conscious design decision aimed at improving natural circulation flow capabilities while minimizing the potential for thermal shock concerns. The elevated injection point is of particular benefit under conditions during which reactor coolant pumps are unavailable creating a larger thermal driving head in the steam generator and, therefore, improved natural circulation flow. In addition, for automatic AFW initiation due to loss of main feedwater, the elevated AFW addition minimizes thermal shock of the steam generator vessel wall and lower tube sheet. 30

The concern that initiated this recommendation is overcooling of the reactor coolant system due to AFW injection. Relocating the AFW injection point will provide minimal relief. Overcooling due to AFW injection can be properly and adequately prevented through the proper control of AFW flow. The Midland AFW level (flow) control design is discussed in the Response to NUREG-0447 Recommendation 2.

APPENDIX E

FSAR QUESTION 211.184

Question 211.184 (15.2)

During the recent review of the loss-of-offsite-power preoperative test procedure for another plant, a concern arose regarding the control of OTSG level by the auxiliary feedwater system during the event. Specifically, overcooling of the primary system could result from feeding the OTSG with the cold auxiliary feedwater. The cooldown could be large enough to empty the pressurizer and cause a steam bubble to form in the hot leg high points, which could impede natural circulation and core cooling. Address this concern for the Midland units. Provide the results of an analysis of a loss-of-offsite power assuming the worst-case initial conditions (low power appears to be worst since programmed steam generator level is lowest). Include plots of steam generator level, reactor coolant system temperature, and pressurizer level. Discuss your assumptions regarding auxiliary feedwater control. Show that MDNBR will remain above 1.30 and core cooling will not be impaired. 17

Response

Operating experience at other B&W plants has clearly demonstrated the potential for auxiliary feedwater (AFW) induced overcooling events during low decay heat load conditions. An investigation of potential modifications which would reduce the likelihood of such events at Midland has been conducted by B&W. As a result of the study, the following features have been incorporated into the design of the Midland AFW level control systems:

a. Dual steam generator level setpoints of approximately 2 feet when forced circulation is available and 20 feet when forced circulation is not available have been added to the AFW level control system. The lower level setpoint provides adequate decay heat removal without overcooling when the reactor coolant pumps (RCPs) are running, and the higher level setpoint ensures the establishment of natural circulation in the reactor coolant system (RCS) when at least three of four RCPs are off. The AFW level control system will monitor the status of all RCPs and automatically select the appropriate setpoint. 30

b. After the correct setpoint is determined, the AFW level control valves will respond in proportion to the error between the actual level and the setpoint to maintain a constant once-through steam generator level. However, logic has been added to the controls of each AFW level control valve which will automatically limit the rate of increase of the steam generator level to a value which prevents excessive heat removal from the RCS and rapid shrinkage of the reactor coolant.

The AFW level control system, including the above modifications, is safety grade, as discussed in FSAR Subsections 7.4.1.1.1 and 10.4.9.

The maximum allowable rate of steam generator level increase under worst case conditions has been calculated by B&W to be approximately 4 inches per minute. However, preoperational and post-fuel load tests will be conducted to verify that the setpoints and flowrates utilized in this level control system are adequate to maintain the reactor in hot standby.

The B&W investigation of AFW induced overcooling transients indicated that a loss-of-offsite power (LOOP) event at low reactor power levels would produce the greatest potential for overcooling. Analyses of predicted Midland performance following a LOOP have been performed using a 4 inch per minute rate limit on steam generator level and the results are shown for initial power levels of 100%, 40%, and 15% in Figures 15.2-11, 15.2-12, and 15.2-13, respectively. These analyses were performed with the AUX-1 computer code developed by B&W for use in analyzing steam generator performance following AFW system actuation. The 15% initial power case shows that the indicated pressurizer level reaches zero at approximately 14.8 minutes into the transient. However, this analysis was performed using the following conservative assumptions:

a. Net makeup flow into the RCS is zero.

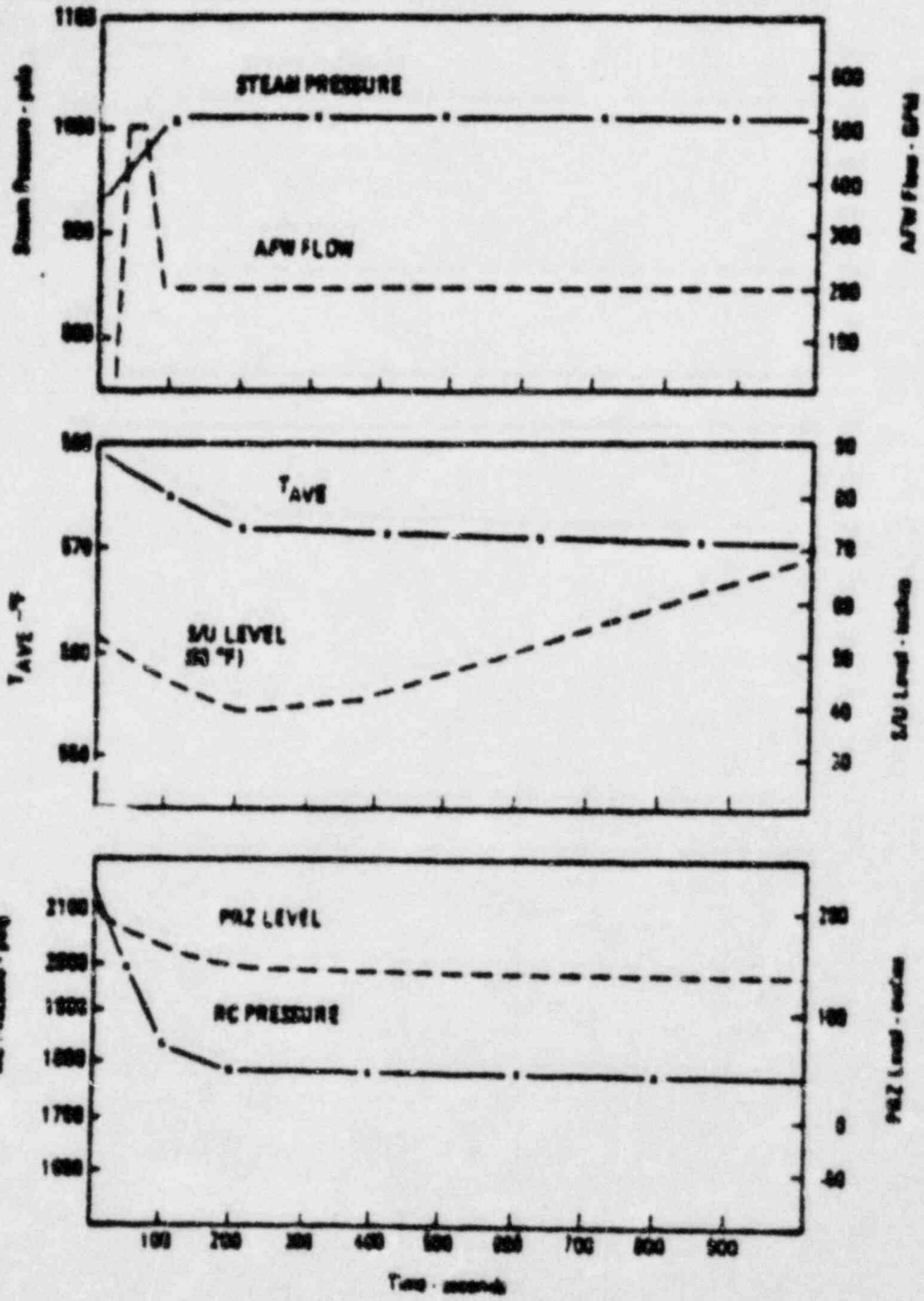
b. An indicated pressurizer range of 320 inches was used instead of the actual 400 inch range. 30

c. Initial pressurizer level was set at 180 inches.

The improved safety grade AFW level control system, combined with Midland's extended pressurizer level indicating range and the operator's ability to establish makeup flow, will provide adequate protection against AFW induced overcooling transients.

For event scenarios which include emergency core cooling actuation system actuation, priority will be given to maintaining AFW flow regardless of indicated pressurizer level.

FSAR Subsection 15.3.1 shows that the minimum departure from nucleate boiling ratio (DNBR) is reached approximately 1.8 seconds after the loss of all RCPs. During this brief time, the heat transfer process in the steam generators is independent of AFW system operation and depends only on the coastdown capability of the RCPs (including the RCP high inertia flywheels) and the initial inventory of water in the steam generators, with some slight effects due to variations in RCS pressure or steam pressure. In addition, AUX-1 and the data on which it is benchmarked show that maximum overcooling (and minimum pressurizer level) occurs 5 minutes or more into the LOOP event. Therefore, there is no potential for reaching minimum DNBR during AFW induced overcooling transients. 30



LOOP FROM 100% POWER

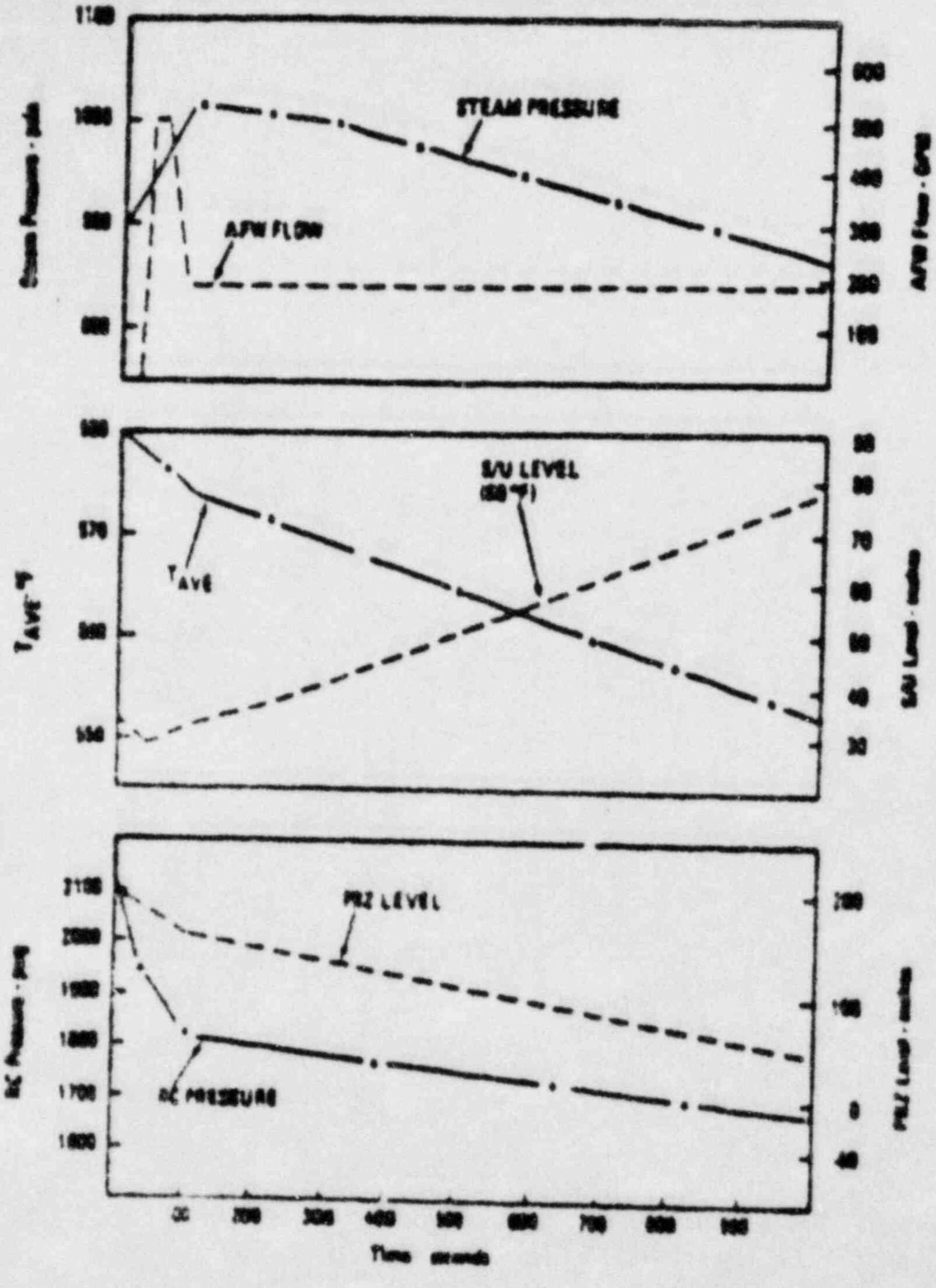
FILL RATE = 4 inches PER MIN

FIGURE 1

CONSUMERS POWER COMPANY
MIDLAND PLANT UNITS 1 & 2
FINAL SAFETY ANALYSIS REPORT

Loss of Offsite Power
Effects from 100% Power

Q&R Figure 15.2-11



LOOP FROM 40% POWER

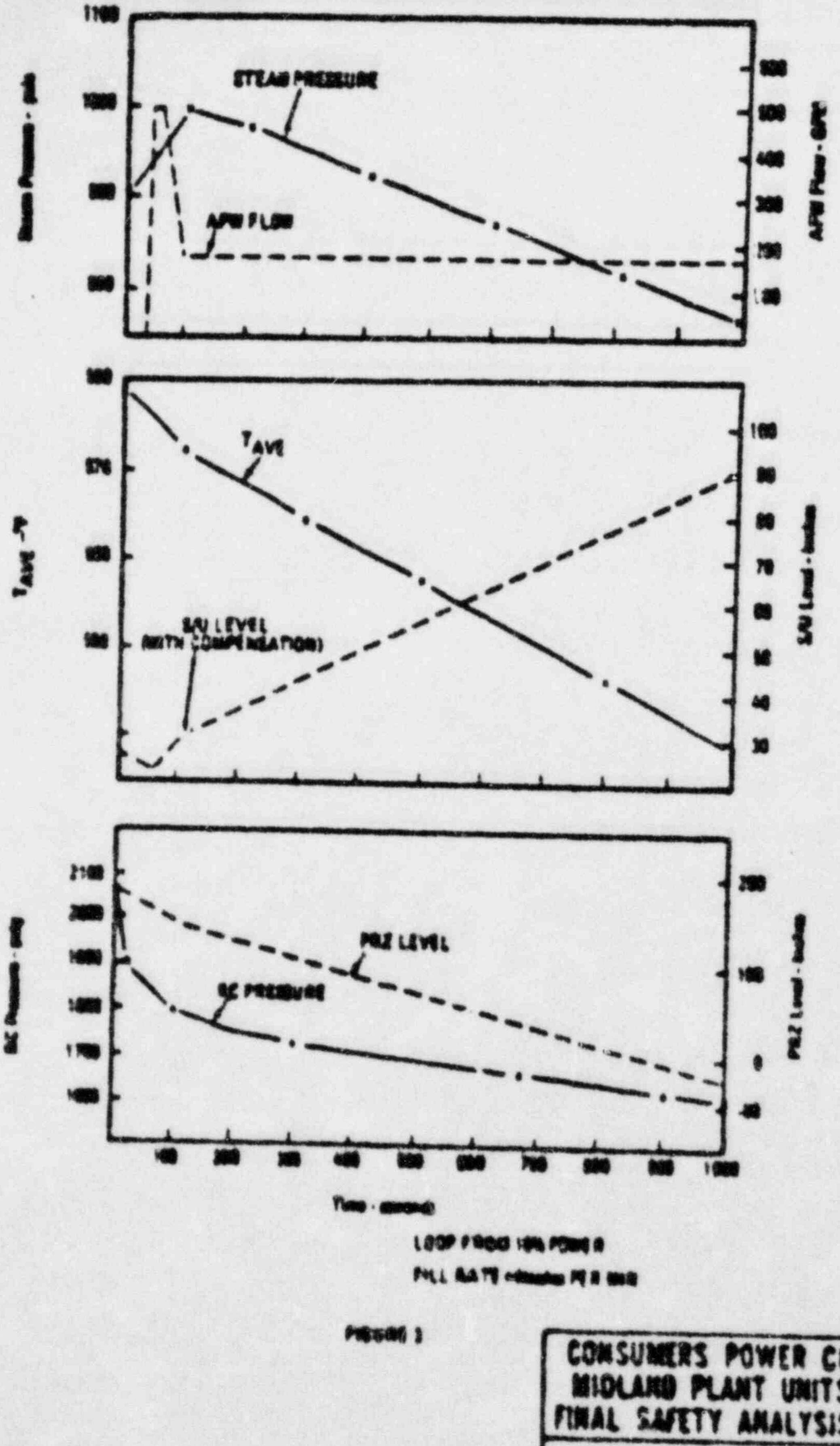
FILL RATE 4 inches PER MIN

FIGURE 2

CONSUMERS POWER COMPANY
MIDLAND PLANT UNITS 1 & 2
FINAL SAFETY ANALYSIS REPORT

Loss of Offsite Power
Effects from 40% Power

Q&R Figure 15.2-12



LOOP FROM 100% POWER

FILL RATE

FIGURE 3

CONSUMERS POWER COMPANY
MIDLAND PLANT UNITS 1 & 2
FINAL SAFETY ANALYSIS REPORT

Loss of Offsite Power
Effects from 15% Power

Q&R Figure 15.2-13

APPENDIX F

FSAR CHAPTER 7

(SELECTED SECTIONS)

REDUNDANCY - The equipment and systems actuated by MSLIS are of themselves independent and redundant (except the main steam line isolation valve described in Section 10.3). Independent actuation channels are provided on a one-to-one basis with the mechanical equipment trains to be controlled. Redundant actuation signals from two independent actuation channels are isolated, then combined using OR logic on the main steam isolation valve actuator.

Through a hydraulic testing mechanism one actuation channel may be tested through its output device to partially stroke the main steam line isolation valve without the loss of the protection function. During such testing, the OR logic on the main steam isolation valve actuator converts to AND logic and emergency closure will occur when both actuation channels are actuated either manually or automatically. When valve test is completed the actuator logic reverts automatically to normal OR logic. The testing sequence of the final output device is continuously annunciated in the main control room. 4

DIVERSITY - Diversity of the sensed variables which initiate MSLIS is provided by the use of either an ECCAS actuation, or low steam generator pressure in either steam generator to sense a main steam line or steam generator rupture. 32

ACTUATED DEVICES - Table 7.3-3 shows the devices actuated by MSLIS.

DESIGN BASES - The design bases for MSLIS are the process system requirements listed in Subsection 6.2.4 and additional actuation system requirements are discussed in Subsection 7.3.3.3.

7.3.3.2.6 Auxiliary Feedwater Actuation System

The purpose of the AFWAS is to initiate the supply of auxiliary feedwater to the steam generators to allow primary heat removal through the steam generators following a loss of main feedwater or a loss of offsite power incident. AFWAS automatically starts both the turbine driven and motor driven AFW pumps and correctly positions the AFW valves. The AFW system is described in Subsection 10.4.9. 33

In addition to conformance with the general description of the owner supplied ESFAS subsystems (see Subsection 7.3.3.1), the AFWAS also has the following special features. 4

INITIATING CIRCUITS - AFWAS will be initiated by any of several possible input signals: low pressure in either steam generator, a low water level in either steam generator, loss of three out of four reactor coolant pumps, loss of both main feed pumps, a Class 1E bus undervoltage, presence of emergency core cooling actuation signal, or a manual trip. Setpoints, ranges, and the locations of the sensors may be found in Table 7.3-2. 30 33 30

33

LOGIC - The logic for AFWAS is shown in Figure 7.3-4. | 33

BYPASS - The integrated leak rate test bypass is discussed with RBIS-I in Subsection 7.3.3.2.1.

A bypass of MSLIS is provided to avoid actuation of both the | 33
AFWAS and the MSLIS systems by a low steam generator pressure during normal startup and shutdown conditions as described in the MSLIS subsection. Bypasses are also provided to avoid actuation of AFWAS by loss of both main feed pumps trip signal and by loss of three out of four reactor coolant pumps signal during normal startup and shutdown. Indication of the system bypasses is | 4
described in Section 7.5.

INTERLOCKS - The Midland AFW systems are equipped with a feed-only-good generator (FOGG) control system which operates to terminate AFW flow to a faulted steam generator. The FOGG system continuously monitors the differential pressure between the steam generators. When a differential pressure of (by amendment) or greater is sensed, FOGG automatically closes the AFW isolation and control valves supplying the lower pressure once-through | 30
steam generator (OTSG) and the steam supply valve from the lower pressure OTSG to the steam turbine driven AFW pump. The continuous interrogation feature of this system permits isolation any time during a secondary pressure transient and allows the lower pressure OTSG to be returned to service should the differential pressure difference be reduced by corrective action (i.e., main steam and feedwater line isolation). The valves actuated by FOGG are indicated in the FOGG section of Table 7.3-3. The logics are shown in Figures 7.3-3, 7.3-4, and 7.3-9.

REDUNDANCY - Redundant actuation and controls are provided throughout the AFWAS on a one-to-one basis with mechanical equipment trains to ensure the required flow to both steam generators in the event of a single failure.

DIVERSITY - The AFWAS is diversified by utilizing steam driven pumps with dc train B control and 120Vac preferred power level
control valves, and motor driven pumps with 120Vac preferred | 32
power level control valves. Diversity in the actuation signals | 30
is provided by the sensing of multiple parameters (see Initiating Circuits above) any of which will cause AFW actuation if an abnormal condition is detected. In addition, manual actuation is provided at the subsystem level.

ACTUATED DEVICES - Table 7.3-3 shows the devices actuated by AFWAS and their characteristics.

DESIGN BASES - The design bases of the AFWAS are the process system requirements listed in Subsection 10.4.9.1 and the specific actuation system requirements listed in Subsection 7.3.3.3.

a. Main steam isolation valve (MSIV) and main feedwater isolation valve (MFIV) controls

b. Auxiliary feedwater (AFW) control

c. Auxiliary feedwater supply switchover

d. Main steam safety valves (no remote control required)

e. Essential service water system controls

f. Essential component cooling water system controls

The following instrumentation capability is provided to monitor adequate temperature control during safe shutdown:

a. RCS hot and cold leg temperature

b. RCS flowrate

c. Once-through steam generator (OTSG) pressure

d. OTSG level

e. AFW flowrate

7.4.1.1.3.1 Main Steam Isolation Valve and Main Feedwater Isolation Valve Control 33

Controlled heat transfer from the RCS to the secondary side of the steam generator must be established for cooldown. To ensure control of heat removal, the MSIVs and MFIVs can be closed manually from the control room. In addition, the MSIVs and MFIVs close automatically on low pressure in either steam generator or on an ECCAS signal, as described in Subsection 7.3.3.2.5. MFIVs also close on high OTSG level to prevent overfill.

7.4.1.1.3.2 Auxiliary Feedwater Control

On loss of main feedwater, feedwater is automatically supplied to the steam generators from the AFW system. The mechanical and safety aspects of the AFW system are discussed in detail in Subsection 10.4.9. Automatic actuation is from the AFW actuation system (AFWAS) which is one of the engineered safety features actuation systems. A complete discussion of the AFWAS is given in Subsection 7.3.3.2.6. 27

Subsequent to AFW actuation, control of level in the steam generators is accomplished using the AFW control valves in each AFW loop. 33 Control signals for each AFW level control valve are supplied by redundant and independent Class 1E level transmitters 30 on the associated steam generators. Controllers for each valve are located in the main control room and on the auxiliary shutdown panel. In addition to automatic actuation by the AFWAS, control to the AFW level control valves for startup, shutdown, or emergency operations can be initiated using these controllers.

INITIATING CIRCUITS - AFW level control signals are continuously generated by level controllers for the associated steam generator 33
but are blocked from reaching the associated normally closed valve. Upon AFWAS actuation, the signal blocks are automatically removed and AFW level control commences. Dual level setpoints are used for level control. A low level setpoint is utilized when more than one of the reactor coolant pumps (RCPs) is operating (signifying forced circulation) and a high level setpoint is used when three out of four RCPs are tripped (anticipating natural circulation). The setpoint switchover is achieved by a safety grade auctioneering device which senses RCP 30
status. In addition, when the plant changes from forced circulation to natural circulation, the low level setpoint is ramped at a controlled rate to the high level setpoint to prohibit overcooling of the primary loop.

LOGIC - In the event of level transmitter failure, the AFW control valves may be manually controlled by means of the bypass provisions discussed below.

BYPASSES - Bypass of the AFWAS initiating logic is discussed in Subsection 7.3.3.2.6. Bypass of automatic level control may be 27
accomplished by placing the controller to the AFW control valve 30
in the manual mode. In this mode, the level setpoint can be manually changed for manual level control.

The transfer to manual control from the auxiliary shutdown panel 33
overrides automatic control capabilities and removes manual operation from the control room. This allows full control from the auxiliary shutdown panel regardless of the mode selected in the control room. Auto/manual status of the auxiliary shutdown panel controller is displayed by indicating lights on the control 33
room controller. These indicating lights are used to bring attention to an abnormal condition affecting the associated controls. For design basis information for the auxiliary shutdown panel see Subsection 7.4.3.1.3.

INTERLOCKS - AFW control interlocks are discussed in Subsection 7.3.3.2.6.

REDUNDANCY - The AFW level control valve control systems are redundant. 33
These systems include redundant Class 1E level transmitters on the steam generator and redundant Class 1E level controllers on the main and auxiliary shutdown panels. 30

DIVERSITY - The AFW level control valve control systems are not diverse.

ACTUATED DEVICES - The AFW level control valves are the actuated devices.

SUPPORTING SYSTEMS - Power for the AFW level control system is
from the Class 1E 125Vdc system. Power for the AFW level control 33
valve is from the Class 1E 120Vac preferred power supplies (see 30
Subsection 8.3.2.1).

PORTIONS NOT REQUIRED FOR SAFETY - All portions of the AFW level control system are required for safety.

DESIGN BASIS INFORMATION - The design bases of the AFW level control system (per Section 3 of IEEE Std 279-1971) are:

a. The generating station condition which requires protective action is the maintenance of safe shutdown using the auxiliary feedwater system.

b. The generating station variable that is required to be monitored in order to provide control of the AFW system is steam generator level.

c. Steam generator level, isolation and control valve 30
positions, AFW pump operation, and AFW flowrate are the 33
minimum indications necessary to adequately monitor AFW
operation.

d. The normal operating water level for the steam
generators is 2 feet during forced circulation, 20 feet
during natural circulation. 32

e. The maximum and minimum design water levels for the steam generators are approximately 50 feet and 1 foot above the bottom tubesheet.

f. The AFW level controls are designed for the 33
environmental conditions stated in Section 3.11. The
range of the environmental parameters for the electrical
power supplies is discussed in Chapter 8.

g. The AFW controls are designed to withstand the effects of the safe shutdown earthquake without loss of operation. The valves and controls are located to prevent loss of function from missile damage.

h. AFWAS response time (not including sensors or actuated
devices) is less than 500 ms. Subsequent to 33
establishing AFW flow, the level in the steam generators
can be allowed to vary somewhat during safe shutdown;
therefore, response time for AFW level control is not
critical for performance. AFW operation is initiated by 33
the AFWAS when steam generator level reaches 1 foot (see
Subsection 7.3.3). AFW level controllers are preset to
automatically control steam generator level at 20 feet 30

during natural circulation and at 2 feet during forced circulation. 30

In addition to the AFW level controls described above, the AFW system has the following Class 1E controls and switches to act as a backup to the level control system:

a. Steam generator high-high level AFW level control and isolation valve trip switches 30

b. AFW pump turbine speed controls

c. AFW motor driven pump on-off controls

d. AFW system motor operated supply isolation valve controls

DRAWINGS - Logic diagrams will be submitted by amendment; P&IDs, see Figures 10.4-10 and 10.4-13; electrical schematics, see E-133, E-154, and E-158 (submitted with drawings listed in Table 1.7-13); control boards will be submitted by amendment. 30

7.4.1.1.3.3 Auxiliary Feedwater Supply Switchover

Feedwater is normally supplied to AFW pump suction from the nonseismic Category I condensate storage tank. If the condensate storage tank or other sources of water are not available, a seismic Category I makeup supply from the service water system is provided. When required, the AFW pump suction will automatically switch over to the service water system, which will supply feedwater through two redundant trains. Concurrent with this switchover, nonseismic Category I portions of the AFW system suction piping are isolated. 33

INITIATING CIRCUITS - Automatic switchover to service water is initiated by an AFWAS signal combined with a two-out-of-four AFW pump low suction pressure. To prevent spurious opening of the service water supply valves because of normal pump start transients, the low suction pressure must persist for 4 seconds before initiating opening of these valves. A complete discussion of the AFWAS is given in Subsection 7.3.3.2.6.

LOGIC - There are four pressure transmitters on the suction side of each AFW pump. Before the service water motor operated valves are actuated, there must be an AFWAS signal concurrent with low pressure signals from two of the four pressure transmitters and these signals must persist for 4 seconds.

MANUAL CONTROL - The service water supply valves can be manually opened from the main control room or the auxiliary shutdown panels. For design basis information for the auxiliary shutdown panel, see Subsection 7.4.3.1.3. 20 27

INTERLOCKS - AFW supply automatic switchover actuation is interlocked with the AFW pump low suction pressure to avoid any spurious actuation of the switchover. 33

REDUNDANCY - Redundant AFW suction pressure instrumentation has been used to provide a reliable system.

DIVERSITY - The AFW supply switchover control systems are not diverse. 20

ACTUATED DEVICES - The service water and the condensate storage water supply valves are the actuated devices.

DRAWINGS - Logic diagrams, see Drawings J-227 and J-252 (submitted with drawings listed in Table 1.7-11), and J-299 (Figures 7.3-2 through 7.3-9); loop diagrams, see Drawings J-337 and J-338 (submitted with drawings listed in Table 1.7-12); electrical schematics, see Drawing E-158 (submitted with drawings listed in Table 1.7-15); control boards, see Drawings J-726, J-908, and J-909 (submitted with drawings listed in Table 1.7-9); and P&IDs, see Figures 10.4-10 and 10.4-13.

7.4.1.1.3.4 Main Steam Safety Valves

The relief function of the main steam safety valves is entirely mechanical and takes place automatically on high main steam line pressure. There are no control systems. A complete discussion of the main steam system and the main steam safety valves is given in Section 10.3. Additional steam relief capability is provided by the power operated atmospheric vent (POAV) valves as described in Subsection 7.4.1.2.3.2. 33

7.4.1.1.3.5 Essential Service Water System Controls

The essential service water system controls are discussed in Subsection 9.2.1.

7.4.1.1.3.6 Essential Component Cooling Water System Controls

The essential component cooling water system controls are discussed in Subsection 9.2.2.

7.4.1.1.4 Supporting Systems for Safe Shutdown Instrumentation and Control Systems

The auxiliary support systems required for the operation of the safe shutdown instrumentation and control systems described in Subsections 7.4.1.1.1, 7.4.1.1.2, and 7.4.1.1.3 are as follows:

a. Class 1E Power System

7.4.2.1.3.2 Auxiliary Feedwater Control

This section will address only AFW level control. A complete analysis of the AFWAS controls is included in the engineered safety features actuation system analysis (Subsection 7.3.3.4).

CONFORMANCE TO IEEE STD 279-1971 - The AFW level controls comply with the following applicable portions of IEEE Std 279-1971: 33

a. Single-Failure Criterion - Any single failure in the AFW flow controls will not prevent proper initiation of safety functions. This is accomplished through the use of completely independent controls for each of the two AFW supply systems and redundant control loops for the AFW level control valves.

b. Quality of Components and Modules - Equipment manufacturers are required to use high quality components and modules in equipment construction. Quality control procedures, used during fabrication and testing, verify compliance with this requirement.

c. Equipment Qualification - Type test data are available to verify that the AFW level control equipment meets the performance requirements necessary for achieving the required system response. 33

d. Channel Independence - Each level control channel is powered from an independent Class 1E power supply. In order to prevent interaction between redundant systems, the controls are wired independently and separated, with no electrical interconnections.

e. System Interaction - The transmission of signals from nonsafety equipment to the AFW control system is buffered by Class 1E, seismically qualified isolators which ensure that failure of the nonsafety equipment will not prevent the protection system from meeting the minimum performance requirements specified in the design bases. 33

f. Capability for Test and Calibration - Manual testing facilities have been built into the auxiliary feedwater controls for preoperational and online testing.

g. Information Readout - The following are indicated on the main control panels and on the auxiliary shutdown panel: 33

   1. Steam generator level

   2. AFW flow

   3. AFW pumps running 33

4. AFW isolation and supply valve positions | 33

h. Identification - Physical identification of safety grade power supplies and safety-related signal channels is done as described in Subsection 8.3.1.3.

7.4.2.1.3.3 Auxiliary Feedwater Supply Switchover Control | 33

Because a complete analysis of the AFWAS controls is included in the ESFAS analysis (Subsection 7.3.3.4), this section will address normal AFW supply switchover to service water supply controls only. | 20

CONFORMANCE TO IEEE STD 279-1971 - The AFW supply switchover controls comply with the following applicable portions of IEEE Std 279-1971.

a. Single-Failure Criterion - Any single failure in the AFW supply switchover control will not prevent proper initiation of safety functions. This is accomplished through the use of completely independent controls for each of the two AFW supply systems and redundant pressure transmitters for the AFW supply switchover to service water. | 33

b. Quality of Components and Modules - Equipment manufacturers are required to use high quality components in equipment construction. Quality construction procedures used during fabrication and testing verify compliance with this requirement. | 20

c. System Interaction - The transmission of signals from nonsafety equipment to the AFW control system is buffered by Class 1E seismically qualified isolators | 33
such that no failure of the nonsafety equipment will prevent the protection system from meeting the minimum performance requirements specified in the design bases. | 20

d. Information Readout - The following are indicated on the main control panels and on the auxiliary shutdown panel:

1. AFW pump suction pressure
2. AFW flow
3. AFW pump running | 33
4. AFW isolation and supply valve position

CONFORMANCE TO IEEE STD 323-1971 - Conformance to this standard for electronic transmitters is discussed in Table 3.11-4.

CONFORMANCE TO IEEE STD 344-1975 - Conformance to this standard for electronic transmitters is discussed in Subsection 3.10.4.1.41. 33

CONFORMANCE TO IEEE STD 323-1971 - Conformance to this standard is discussed in Table 3.11-4 for safety-related control systems equipment.

CONFORMANCE TO IEEE STD 344-1971 - Conformance to this standard is discussed in Subsection 3.10.4.1.18 for instrument racks, rack 20 mounted instruments, and power supplies.

7.4.2.1.3.4 Main Steam Safety Valves

The safety-related function of atmospheric steam relief is satisfied by the main steam safety valves, which are entirely mechanical. The discussion of these valves is found in Section 10.3. Nonsafety atmospheric steam relief is discussed in Subsection 7.7.1.7. Cold shutdown can be achieved using the safety grade PCAV valves. These valves are discussed in Subsections 10.3.2 and 7.4.1.2.3.2.

7.4.2.1.3.5 Other Controls Required for Safe Shutdown

Essential portions of the service water system and component cooling water system that are safety-related are initiated by one of the engineered safety features actuation system (ESFAS) sysbsystems. A complete analysis of ESFAS controls is presented in Subsection 7.3.3.4. 33

7.4.1.2.4 Supporting Systems for Safe Shutdown Instrumentation and Control Systems

Subsection 7.4.1.1.4 references FSAR subsections which discuss all the auxiliary support systems for the instrumentation and control systems required for safe shutdown. These discussions include analyses of the auxiliary support systems.

7.4.2.2 Cold Shutdown Systems Analysis

7.4.2.2.1 Reactivity and Inventory Instrumentation and Control Systems

Except for CFT isolation, no control systems and instrumentation in addition to that described in Subsection 7.4.1.1.1 are required to maintain reactivity and inventory control while achieving and maintaining cold shutdown. Analyses for the systems described in Subsection 7.4.1.1.1 are provided in Subsection 7.4.2.1.1. An analysis of all the controls used to