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Auxiliary Feedwater System Risk-Based Inspection Guide for the Prairie Island Units 1 and 2 Nuclear Power Plants

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Pacific Northwest Laboratory
Operated by
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U.S. Nuclear Regulatory Commission

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Abstract

In a study sponsored by the U.S. Nuclear Regulatory Commission (NRC), Pacific Northwest Laboratory has developed and applied a methodology for deriving plant-specific risk-based guidance for the auxiliary feedwater (AFW) system at pressurized water reactors that have not undergone probabilistic risk assessment (PRA). This methodology uses existing PRA results and plant operating experience information. Existing PRA-based inspection guidance information recently developed for the NRC for various plants was used to identify generic component failure modes. This information was then combined with plant-specific and industry-wide component information and failure data to identify failure modes and failure mechanisms for the AFW system at the selected plants. Prairie Island was selected as the seventh plant for study. The product of this effort is a prioritized listing of AFW failures which have occurred at the plant and at other PWRs. This listing is intended for use by NRC inspectors in the preparation of inspection plans addressing AFW risk-important components at the Prairie Island plant.

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Summary

This document presents a compilation of auxiliary feedwater (AFW) system failure information which has been screened for risk significance in terms of failure frequency and degradation of system performance. It is a risk-prioritized listing of failure events and their causes that are significant enough to warrant consideration in inspection planning at the Prairie Island plant. This information is presented to provide inspectors with increased resources for inspection planning at Prairie Island.

The risk importance of various component failure modes are identified by analysis of the results of probabilistic risk assessments (PRAs) for many pressurized water reactors (PWRs). However, the component failure categories identified in PRAs are rather broad, because the failure data used in the PRAs is an aggregate of many individual failures having a variety of root causes. In order to help inspectors focus on specific aspects of component operation, maintenance and design which might cause these failures, an extensive review of component failure information was performed to identify and rank the root causes of these component failures. Both Prairie Island and industry-wide failure information was analyzed. Failure causes were sorted on the basis of frequency of occurrence and seriousness of consequence, and categorized as common cause failures, human errors, design problems, or component failures.

This information is presented in the body of this document. Section 3.0 provides brief descriptions of these risk-important failure causes, and Section 5.0 presents more extensive discussions, with specific examples and references. The entries in the two sections are cross-referenced.

An abbreviated system walkdown is presented in Section 3.2 which includes only components identified as risk important. This table lists the system lineup for normal, standby system operation.

This information permits an inspector to concentrate on components important to the prevention of core damage. However, it is important to note that inspections should not focus exclusively on these components. Other components which perform essential functions, but which are not included because of high reliability or redundancy, must also be addressed to ensure that degradation does not increase their failure probabilities, and hence their risk importances.

1 Introduction

This document is one of a series providing plant-specific inspection guidance for auxiliary feedwater (AFW) systems at pressurized water reactors (PWRs). This guidance is based on information from probabilistic risk assessments (PRAs) for similar PWRs, industry-wide operating experience with AFW systems, plant-specific AFW system descriptions, and plant-specific operating experience. It is not a detailed inspection plan, but rather a compilation of AFW system failure information which has been screened for risk significance in terms of failure frequency and degradation of system performance. The result is a risk-prioritized listing of failure events and their causes that are significant enough to warrant consideration in inspection planning at Prairie Island.

This inspection guidance is presented in Section 3.0, following a description of the Prairie Island AFW system in Section 2.0. Section 3.0 identifies the risk important system components by Prairie Island identifi-cation number, followed by brief descriptions of each of the various failure causes of that component. These include specific human errors, design deficiencies, and hardware failures. The discussions also identify where common cause failures have affected multiple, redundant components. These brief discussions identify specific aspects of system or component design, operation, maintenance, or testing for inspection by observation, records review, training observation, procedures review, or by observation of the implementation of procedures. An AFW system walkdown table identifying risk important components and their lineup for normal, standby system operation is also provided.

The remainder of the document describes and discusses the information used in compiling this inspection guidance. Section 4.0 describes the risk importance information which has been derived from PRAs and its sources. As review of that section will show, the failure categories identified in PRAs are rather broad (e.g., pump fails to start or run, valve fails closed). Section 5.0 addresses the specific failure causes which have been combined under these categories.

AFW system operating history was studied to identify the various specific failures which have been aggregated into the PRA failure mode categories. Section 5.1 presents a summary of Prairie Island failure information, and Section 5.2 presents a review of industry-wide failure information. The industry-wide information was compiled from a variety of NRC sources, including AEOD analyses and reports, information notices, inspection and enforcement bulletins, and generic letters, and from a variety of INPO reports as well. Some Licensee Event Reports and NPRDS event descriptions were also reviewed. Finally, information was included from reports of NRC-sponsored studies of the effects of plant aging, which include quantitative analyses of reported AFW system failures. This industry-wide information was then combined with the plant-specific failure information to identify the various root causes of the PRA failure categories, which are identified in Section 3.0.

2 Prairie Island AFW System

This section presents an overview of the Prairie Island AFW system, including a simplified schematic system diagram. In addition, the system success criterion, system dependencies, and administrative operational constraints are also presented.

2.1 System Description

The AFW system provides feedwater to the steam generators (SG) to allow secondary-side heat removal from the primary system when main feedwater is unavailable. The system is capable of functioning for extended periods, which allows time to restore main feedwater flow or to proceed with an orderly cooldown of the plant to where the residual heat removal (RHR) system can remove decay heat. A simplified schematic diagram of the AFW system is shown in Figure 2.1.

The system consists of two steam turbine-driven pumps (200 gpm each), one for each unit, and two motor-driven pumps (200 gpm each), one for each unit. Both the turbine-driven and motor-driven pump for a unit are capable of delivering feedwater to either or both steam generators of that unit. Normal lineup is for both pumps of a unit to feed both steam generators of that unit. The discharge lines of the two motor-driven pumps may be interconnected through two normally closed motor-operated valves. There is no provision for interconnection of the discharge lines of the two turbine-driven pumps.

The system is designed to start up and establish flow within one minute of an automatic start signal. Both the motor-driven and turbine driven pump for a unit will start on the following signals from that unit: both main feedwater pumps tripped, low-low level in one steam generator, safety injection actuation, and ATWS Mitigation Actuation Circuitry (AMSAC) signal. In addition, the turbine driven pumps will receive a start signal from an undervoltage condition on both safeguard buses. Each AFW pump has a pressure switch on its suction to protect against insufficient NPSH and another pressure switch on its discharge to protect against runout. If a low pressure setpoint is reached on either switch, it will trip the pump.

Electrical power for the two motor-driven pumps is supplied by independent safety features buses, with provisions for manual transfer if the corresponding diesel generator is unavailable. The turbine-driven pumps are supplied steam from both steam generators of their respective units. Steam supply lines come from points upstream of the main steam isolation valves of each steam generator and pass through a normally open motor-operated-valve and a check valve before joining to pass through the air-operated steam admission valve (31998) for their respective unit. Failure of either DC power or the air supply to the steam admission valves will cause the valves to open, starting the associated turbine-driven pump. The turbine-driven pumps operate independent of the plant AC power sources. A cycle timer control circuit automatically runs the auxiliary motor-driven lube oil pump on each AFW pump for approximately 10 minutes twice each week. If proper lube oil pressure is not reached following this lube oil pump start, an alarm is sounded in the control room. This ensures that a sufficient oil film is maintained at all times in each AFW pump to allow pump start without requiring start of its associated auxiliary motor driven lube oil pump. Once the AFW pump starts, lube oil circulation is provided by a shaft-driven lube oil pump.

The normal AFW pump suction is from a header supplied by three 150,000 gallon condensate storage tanks, one associated with unit 1 and the other two associated with unit 2. A sufficient quantity of water (100,000 gallons) is required to be maintained in these tanks to support the reactor coolant system in Hot Standby condition for two hours followed by a cooldown to the point where the RHR system can be placed in service. All tank connections except those required for instrumentation, AFW pump suction, and tank drainage are located above the level required to maintain 100,000 gallon capacities

A normally open valve (C-41-2) can be used to isolate the CST suction header between units. Suction from the header to each pump is through a check valve and a normally open motor-operated valve. In addition, each pump is provided with a suction path to the Cooling Water System through a normally closed motor-operated valve. Because the CSTs are not seismic Class I structures, the plant's safety analysis relies on the seismic Class I Cooling Water System source. Use of the Cooling Water System source requires manual alignment. The turbine-driven pump for each unit takes suction from the side of the CST header or the Cooling Water System associated with that unit. However, the motor-driven pump for each unit takes suction from the side of the CST header or the Cooling Water System associated with the opposite unit. Three additional back-up sources of water are available: the demineralizer, the condenser hotwell, and the CVCS monitor tanks.

Each AFW pump discharges through a check valve and a normally open manual valve to its own header. From this point, a recirculation path provides continuous flow back to the CST to prevent pump deadheading and to provide for lube oil cooling. The header for each pump feeds each steam generator of its respective unit through another check valve and a normally open motor-operated valve to the point where the lines from the two pumps combine. The AFW feed line for each steam generator then passes through an additional normally open motor-operated valve, through the containment wall and through an additional check valve before joining the main feedwater line to the steam generator.

2.2 Success Criterion

System success requires operation of at least one pump supplying rated flow to at least one steam generator. Each pump is sized to provide sufficient flow against the steam generator safety valve set pressure (plus 3% accumulation) to prevent water relief from the pressurizer during a station blackout transient (no reactor coolant pump heat to the primary system).

2.3 System Dependencies

The AFW system depends on AC power for the motor-driven pumps and level control valves, DC power for control of the pumps, valves and automatic actuation signals, instrument air for AFW pump lube oil cooler control valves, and a functional lube oil system. The turbine driven pump also requires steam availability.

A three-way solenoid valve has been added to the air supply line of each turbine-driven pump steam inlet supply valve to allow manual operation of the turbine-driven pumps. A procedure has been provided for manual operation of the turbine-driven pumps by locally venting air from the diaphragm of the stream admission valve.

2.4 Operational Constraints

When both reactors are critical or their average coolant temperatures exceed 350°F, the Prairie Island Technical Specifications require that all four AFW pumps and associated flow paths are operable. When only one reactor is critical or above 350°F, its turbine-driven AFW train and one of the two motor-driven AFW trains must be operable. Inoperability of a single required AFW train is permitted for up to 72 hours, after which the affected unit must be brought to Hot Shutdown conditions in the next 6 hours and the average reactor coolant temperature reduced below 350°F within the following 6 hours.

During Startup or Power Operation, a minimum of 100,000 gallons of water is required to be available in the condensate storage tanks, and the backup supply of river water must be available through the cooling water system. The CSTs may be inoperable for 48 hours, provided the Cooling Water System is available as a backup water supply to the AFW pumps. The backup supply from the Cooling Water System may be inoperable for 48 hours provided a minimum of 100,000 gallons of water is available in the CSTs.

During operation, containment isolation valves (MV-32242, MV-3243, MV-32248 and MV-32249) are locked open with control power removed. Also, any manual valves in the system flowpath that could reduce flow below the value assumed in the safety analysis are required to be locked in their proper positions for emergency use and are under strict administrative controls. The condensate supply cross connect valves C-41-2 must be blocked and tagged open. (Cross connect valve C-41-1 has been removed and replaced by a spool piece.)

2.5 Other Significant Information

In its assessment of Generic Issue No. 124, "Auxiliary Feedwater System Reliability", NRC analysis (reported in NUREG-0611) determined that the Prairie Island AFW system was in the low reliability range. As a result, Northern States Power Company performed a probabilistic risk assessment of the AFW and supporting systems (NSPNAD-8606P Rev. 0, April 1986). Generic Issue No. 124 was closed out by an NRC Safety Evaluation Report transmitted on November 26, 1986. As the result of these studies, the following list of actions were taken:

a. The AFW system dependency on the cooling water system for lube oil cooling was removed by rerouting the AFW recirculation flow through the coolers. A step was added to the monthly surveillances for the turbine-driven pumps to verify flow from the lube oil and governor cooling water return line.

b. Manual control of the turbine-driven AFW pumps was added as described in Section 2.3, above.

c. The auto open signal to MV-32041 "Condenser Emergency Supply Valve" was removed for both units.

d. All drain valves from the AFW steam lines to the main condenser have been blocked open using safeguards hold cards.

e. A procedure was written for bypassing the AFW pump suction and discharge pressure trips in the event of faults in the actuation circuits.

f. Requirements were added for monitoring the temperatures of the AFW discharge lines once each shift. This was done to provide prompt detection of backleakage of hot feedwater through the check valves, which could lead to steam binding of the AFW pumps. Temperature indicators on each pump discharge line provide inputs to the Emergency Response Computer System (ERCS).

g. Both the high and low pressure leakoff for the turbine-driven AFW pump trip/throttle valves has been rerouted to discharge into the turbine exhaust lines. This was done to eliminate the potential for creating a steam environment in the AFW pump room during operation of the turbine driven AFW pump.

h. Condensate header valve C-41-1 was replaced by a spool piece.

i. Condensate storage tank isolation valves were administratively locked open to ensure AFW pump suction.

j. Two step ladders (of different heights) were placed in the AFW pump room to aid operators in manipulating overhead valves during emergency situations.

k. Additional emergency lighting was installed in the area of the turbine-driven AFW pumps.

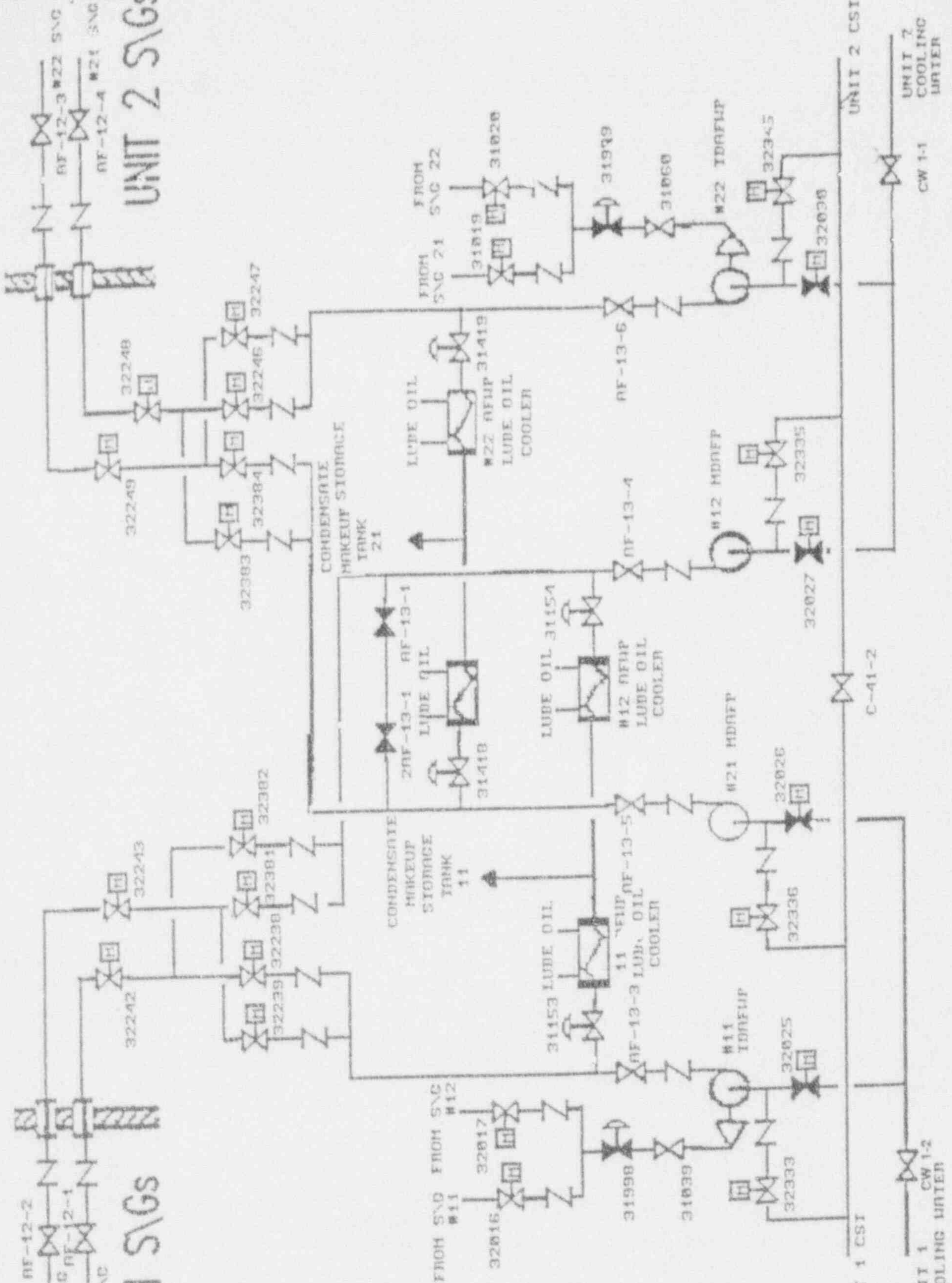

Figure 2.1. Prairie Island Auxiliary Feedwater System

3 Inspection Guidance for the Prairie Island AFW System

In this section the risk important components of the Prairie Island AFW system are identified, and the important modes by which they are likely to fail are briefly described. These failure modes include specific human errors, design problems, and types of hardware failures which have been observed to occur for these types of components, both at Prairie Island and at PWRs throughout the nuclear industry. The discussions also identify where common-cause failures have affected multiple, redundant components. These brief discussions identify specific aspects of system or component design, operation, maintenance, or testing for observation, records review, training observation, procedures review or by observation of the implementation of procedures.

Table 3.1 is an abbreviated AFW system walkdown table which identifies risk important components. This table lists the system lineup for normal, standby system operation. Inspection of the components identified addresses essentially all of the risk associated with AFW system operation.

3.1 Risk Important AFW Components and Failure Modes

Common-cause failures of multiple pumps are the most risk-important failure modes of AFW system components. These are followed in importance by single pump failures, level control valve failures, and individual check valve leakage failures.

The following sections address each of these failure modes, in decreasing order of importance. They present the important root causes of these component failure modes which have been distilled from historical records. Each item is keyed to discussions in Section 5.2 which present additional information on historical events.

3.1.1 Multiple Pump Failures due to Common Cause

The following listing summarizes the most important multiple-pump failure modes identified in Section 5.2.1, Common-Cause Failures, and each item is keyed to entries in that section.

- Incorrect operator intervention into automatic system functioning, including improper manual starting and securing of pumps, has caused failure of all pumps, including overspeed trip on startup, and inability to restart prematurely secured pumps. CC1.

- Valve mispositioning has caused failure of all pumps. Pump suction, steam supply, and instrument isolation valves have been involved. CC2.

- Steam binding has caused failure of multiple pumps. This resulted from leakage of hot feedwater past check valves into a common discharge header, with several valves involved including a motor-operated discharge valve. (See item 7 below.) CC10. Multiple-pump steam binding has also resulted from improper valve lineups, and from running a pump deadheaded. CC3.

- Pump control circuit deficiencies or design modification errors have caused failures of multiple pumps to auto start, spurious pump trips during operation, and failures to restart after pump shutdown. CC4. Incorrect setpoints and control circuit calibrations have also prevented proper operation of multiple pumps. CC5

- Loss of a vital power bus has failed both the turbine-driven and one motor-driven pump due to loss of control power to steam admission valves or to turbine controls, and to motor controls powered from the same bus. CC6.

- Simultaneous startup of multiple pumps has caused oscillations of pump suction pressure causing multiple-pump trips on low suction pressure, despite the existence of adequate static net positive suction head (NPSH). CC7. Design reviews have identified inadequately sized suction piping which could have yielded insufficient NPSH to support operation of more than one pump. CC8.

3.1.2 Turbine Driven Pump 11 or 22 Fails to Start or Run

- Improperly adjusted and inadequately maintained turbine governors have caused pump failures, both at Prairie Island and elsewhere. HE2. Problems include worn or loosened nuts, set screws, linkages or cable connections, oil leaks and/or contamination, and electrical failures of resistors, transistors, diodes and circuit cards, and erroneous grounds and connections. CF5.

- Terry turbines with Woodward Model EG governors have been found to overspeed trip if full steam flow is allowed on startup. Sensitivity can be reduced if a startup steam bypass valve is sequenced to open first. DE1.

- Turbines with Woodward Model PG-PL governors have tripped on overspeed when restarted shortly after shutdown, unless an operator has locally exercised the speed setting knob to drain oil from the governor speed setting cylinder (per procedure). Automatic oil dump valves are now available through Terry. DE4.

- Condensate slugs in steam lines have caused turbine overspeed trip on startup. Tests repeated right after such a trip may fail to indicate the problem due to warming and clearing of the steam lines. Steam traps for the steam supply lines should be properly maintained and surveillance should exercise all steam supply connections. DE2.

- Trip and throttle valve problems which have failed the turbine driven pump include physically bumping it, failure to reset it following testing, and failures to verify control room indication of reset. HE2. Whether either the overspeed trip or TTV trip can be reset without resetting the other, indication in the control room of TTV position, and unambiguous local indication of an overspeed trip affect the likelihood of these errors. DE3. Prairie Island has had the turbine driven pump trip due to a workman bumping the governor.

3.1.3 Motor Driven Pump 12 or 21 Fails to Start or Run

- Control circuits used for automatic and manual pump starting are an important cause of motor driven pump failures, as are circuit breaker failures. CF7. Similar failures have occurred at Prairie Island.

- Mispositioning of handswitches and procedural deficiencies have prevented automatic pump start. HE3.

- Low lubrication oil pressure resulting from heatup due to previous operation has prevented pump restart due to failure to satisfy the protective interlock. DE5. At Prairie Island, an improperly installed oil filter resulted in excessive differential pressure which defeated the oil pressure permissive and prevented a pump start.

3.1.4 Pump 11, 21, 12 or 22 Unavailable Due to Maintenance or Surveillance

- Both scheduled and unscheduled maintenance remove pumps from operability. Surveillance requires operation with an altered line-up, although a pump train may not be declared inoperable during testing. Prompt scheduling and performance of maintenance and surveillance minimize this unavailability.

3.1.5 Motor Operated Valves Fail Closed

MD Pump Suction Valves: MV32335, 32336
TD Pump Suction Valves: MV32333, 32345
MD Pump Flow Control Valves: MV32381, 32382, 32383, 32384
TD Pump Flow Control Valves: MV32238, 32239, 32246, 32247
Unit 1 SG Isolation Valves: MV32242, 32243
Unit 2 SG Isolation Valves: MV32248, 32249
Steam Supply TD Pump Unit 1: MV32016, 32017
Steam Supply TD Pump Unit 2: MV31019, 31020

Normally open MOVs are located at the suction and discharge of both the motor and turbine driven AFW pumps. Downstream of the discharge valves, each AFW header contains a motor operated flow control and a containment isolation valve. Steam supply lines to the turbine driven AFW pumps also contain motor operated steam isolation valves. All these MOVs are normally open and they fail as-is on loss of power.

- Common-cause failure of MOVs has resulted from failure to use electrical signature tracing equipment to determine proper settings of torque switch and torque switch bypass switches. Failure to calibrate switch settings for high torques necessary under *design basis* accident conditions has also been involved. CC1[1]. Similar failures have occurred at Prairie Island

- Valve motors have been failed due to lack of, or improper sizing or use of thermal overload protective devices. Bypassing and oversizing should be based on proper engineering for *design basis* conditions. CF4.

- Out-of-adjustment electrical flow controllers have caused improper discharge valve operation, affecting multiple trains of AFW. CC12.

- Grease trapped in the torque switch spring pack of Limitorque SMB motor operators has caused motor burnout or thermal overload trip by preventing torque switch actuation. CF8.

- Manually reversing the direction of motion of operating MOVs has overloaded the motor circuit. Operating procedures should provide cautions, and circuit designs may prevent reversal before each stroke is finished. DE7.

- Space heaters designed for preoperation storage have been found wired in parallel with valve motors which had not been environmentally qualified with them present. DE8.

3.1.6 Manual Suction or Discharge Valves Fail Closed

TD Pump Steam Supply Valves: 31039, 31060
TD Pump Discharge Valves: AF-13-3, 13-6, 12-1, 12-4
MD Pump Discharge Valves: AF 13-4, 13-5, 12-2, 12-3

Manual valves that could reduce flow in any AFW train are normally locked in the proper position for emergency use.

- Valve mispositioning has resulted in failures of multiple trains of AFW. CC2. It has also been the dominant cause of problems identified during operational readiness inspections. HE1. Events have occurred most often during maintenance, calibration, or system modifications. Important causes of mispositioning include:
  - Failure to provide complete, clear, and specific procedures for tasks and system restoration
  - Failure to promptly revise and validate procedures, training, and diagrams following system modifications
  - Failure to complete all steps in a procedure
  - Failure to adequately review uncompleted procedural steps after task completion
  - Failure to verify support functions after restoration

- Failure to adhere scrupulously to administrative procedures regarding tagging, control and tracking of valve operations

- Failure to log the manipulation of sealed valves

- Failure to follow good practices of written task assignment and feedback of task completion information

- Failure to provide easily read system drawings, legible valve labels corresponding to drawings and procedures, and labeled indications of local valve position

3.1.7 Leakage of Hot Feedwater through Check Valves

SG Check Valves: AF 16-1, 16-2, 16-3, 16-4
Flow Control Check Valves: AF 15-1, 15-2, 15-3, 15-4, 15-5, 15-6, 15-7, 15-8

- Leakage of hot feedwater through several check valves in series has caused steam binding of multiple pumps. Leakage through a closed level control valve in series with check valves has also occurred. CC10.

- Slow leakage past the final check valve of a series may not force upstream check valves closed, allowing leakage past each of them in turn. Piping orientation and valve design are important factors in achieving true series protection. CF1.

3.2 Risk Important AFW System Walkdown Table

Table 3.1 presents an AFW system walkdown table including only components identified as risk important. This information allows inspectors to concentrate their efforts on components important to prevention of core damage. However, it is essential to note that inspections should not focus exclusively on these components. Other components which perform essential functions, but which are absent from this table because of high reliability or redundancy, must also be addressed to ensure that their risk importances are not increased. Examples include the (open) steam lead isolation valves upstream of CV31998, an adequate water level in the CST, and the (closed) valves cross connecting the discharges of the two motor-driven AFW pumps.

Table 3.1. Risk Important AFW System Walkdown Table[a]

Component Number	Component Name	Location	Required Position	Actual Position
	Electrical			
Bus 16	12 Motor-Driven Pump Breaker		Racked In/Closed	______
Bus 26	21 Motor-Driven Pump Breaker		Racked In/Closed	______
Cell A2	MV 32025	MCC 1A Bus 1	Installed/Closed	______
Cell A3	11 AFW pump aux lube oil pump	MCC 1A Bus 1	Installed/Closed (Record minutes______)	______
Cell A2	12 AFW pump aux lube oil pump	MCC 1A Bus 2	Installed/Closed (Record minutes______)	______
Cell A4	MV 32027	MCC 1A Bus 2	Installed/Closed	______
Cell A4	21 AFW pump aux lube oil pump	MCC 2A Bus 1	Installed/Closed (Record minutes______)	______
Cell C2	MV 32026	MCC 2A Bus 1	Installed/Closed	______
Cell A3	MV 32030	MCC 2A Bus 2	Installed/Closed	______
Cell B3	22 AFW pump aux lube oil pump	MCC 2A Bus 2	Installed/Closed (Record minutes______)	______
	Valve			
MV32333	11 TDP Suction Valve		Open	______
MV32025	11 TDP Cooling Water Suction Valve		Closed	______
CW 1-2	Cooling water Valve to 11 TDP and 21 MDP		Open	______
MV32336	21 MDP Suction Valve		Open	______
MV32026	21 MDP Cooling Water Suction Valve		Closed	______
MV32335	12 MDP Suction Valve		Open	______

(a) Outside and in AFWS pump room.

Table 3.1. (Continued)

Component Number	Component Name	Location	Required Position	Actual Position
MV32027	12 MDP Cooling Water Suction Valve		Closed	______
CW 1-1	Cooling water Valve to 12 TDP and 22 MDP		Open	______
MV32345	22 TDP Suction Valve		Open	______
MV32030	22 TDP Cooling Water Suction Valve		Closed	______
MV32239	11 TDP to SG 12 Flow Control Valve		Open	______
MV32238	11 TDP to SG 11 Flow Control Valve		Open	______
MV32381	12 MDP to SG 12 Flow Control Valve		Open	______
MV32382	12 MDP to SG 11 Flow Control Valve		Open	______
MV32283	21 MDP to SG 21 Flow Control Valve		Open	______
MV32384	21 MDP to SG 22 Flow Control Valve		Open	______
MV32246	22 TDP to SG 21 Flow Control Valve		Open	______
MV32247	22 TDP to SG 22 Flow Control Valve		Open	______
MV32242	11 TDP to SG 11 Containment Isolation Valve		Open/ Breaker open	______
MV32243	12 MDP to SG 12 Containment Isolation Valve		Open/ Breaker open	______
MV32249	21 MDP to SG 22 Containment Isolation Valve		Open/ Breaker open	______
MV32248	21 MDP to SG 21 Containment Isolation Valve		Open/ Breaker open	______
2AF-13-1	21 MDP to Unit 1 Discharge Cross Tie Valve		Closed	______

Table 3.1. (Continued)

Component Number	Component Name	Location	Required Position	Actual Position
AF-13-1	12 MDP to Unit 2 Discharge Cross Tie Valve		Closed	________
C-41-2	CST Cross Tie Valve		Open	________
AF 13-4	12 MDP Discharge Valve		Open	________
AF 17-2	12 MDP 2-in. Flow Test Line		Closed	________
AF 18-2	12 MDP Recirc. Line Valve		Open	________
AF 25-2	12 MDP 2-in. Flow Test Line		Closed	________
AF 33-2	12 MDP Recirculation Line Valve		Open	________
AF 17-3	21 MDP 2-in. Flow Test Line		Closed	________
AF 18-5	21 MDP Recirculation Line Valve		Open	________
AF 25-3	21 MDP 2-in. Flow Test Line		Closed	________
CV31153	11 TDP Recirculation Flow Valve		Auto Open[(a)]	________
CV31154	12 MDP Recirculation Flow Valve		Auto Open[(a)]	________
CV31418	21 MDP Recirculation Flow Valve		Auto Open[(a)]	________
CV31419	22 TDP Recirculation Flow Valve		Auto Open[(a)]	________
MV32016	11 SG to TDP Main Supply Isolation Valve		Open	________
MV32017	12 SG to TDP Main Steam Supply Isolation Valve		Open	________

(a) Check central air pressures in regulator filter in mid-range (30 to 50 psig).

Table 3.1. (Continued)

Component Number	Component Name	Location	Required Position	Actual Position
MV 31019	21 SG to TDP Main Steam Supply Isolation Valve		Open	
MV 31020	22 SG to TDP Main Steam Supply Isolation Valve		Open	
AF 33-1	21 MDP Recirculation Line		Open	
AF 13-5	21 MDP Discharge Valve		Open	
CV31998	Unit 1 Steam Inlet Control Valve		Closed/Locked Security Door	
CV31999	Unit 2 Steam Inlet Control Valve		Closed/Locked Security Door	
CV31039	Unit 1 Trip & Throttle Valve		Open	
CV31060	Unit 2 Trip & Throttle Valve		Open	
AF 15-9	Piping Upstream of Check Valve		Cool	
AF 15-10	Piping Upstream of Check Valve		Cool	
AF 15-11	Piping Upstream of Check Valve		Cool	
AF 15-12	Piping Upstream of Check Valve		Cool	
AF 13-3	11 TDP Discharge Valve		Open	
AF 17-1	11 TDP 2-in. Flow Test Valve		Closed	
AF 18-1	11 TDP Recirculation Line Valve		Open	
AF 33-1	11 TDP Recirculation Line Valve		Open	
AF 25-1	11 TDP 2-in. Flow Test Valve		Closed	

Table 3.1. (Continued)

Component Number	Component Name	Location	Required Position	Actual Position
AF 13-6	22 TDP Discharge Valve		Open	
AF 17-4	22 TDP 2-in. Flow Test Valve		Closed	
AF 25-4	22 TDP 2-in. Flow Test Valve		Closed	
AF 18-6	22 TDP Recirculation Line Valve		Open	
AF 33-2	22 TDP Recirculation Line Valve		Open	
MV 32242	Piping Upstream at 715-ft Level[a]		Cool	
MV 32243	Piping Upstream at 715-ft Level[a]		Cool	
MV 32248	Piping Upstream at 715-ft Level[a]		Cool	
MV 32249	Piping Upstream at 715-ft Level[a]		Cool	

(a) It is desirable to check for leaks at locations closer to containment. These motor-operated valves are approximately 30 ft upstream of AF 15-5, AF 15-6, AF 15-7, and AF 15-8, respectively.

4 Generic Risk Insights from PRAs

PRAs for 13 PWRs were analyzed to identify risk-important accident sequences involving loss of AFW, and to identify and risk-prioritize the component failure modes involved. The results of this analysis are described in this section. They are consistent with results reported by INEL and BNL (Gregg et al. 1988: Travis et al. 1988).

4.1 Risk Important Accident Sequences Involving AFW System Failure

Loss of Power System

- A loss of offsite power is followed by failure of AFW. Due to lack of actuating power, the PORVs cannot be opened, preventing adequate feed-and-bleed cooling, and resulting in core damage.

- A station blackout fails all AC power except Vital AC from DC invertors, and all decay heat removal systems except the turbine-driven AFW pump. AFW subsequently fails due to battery depletion or hardware failures, resulting in core damage.

- A DC bus fails, causing a trip and failure of the power conversion system. One AFW motor-driven pump is failed by the bus loss, and the turbine-driven pump fails due to loss of turbine or valve control power. AFW is subsequently lost completely due to other failures. Feed-and-bleed cooling fails because PORV control is lost, resulting in core damage.

Transient-Caused Reactor or Turbine Trip

- A transient-caused trip is followed by a loss of PCS and AFW. Feed-and-bleed cooling fails either due to failure of the operator to initiate it, or due to hardware failures, resulting in core damage.

Loss of Main Feedwater

- A feedwater line break drains the common water source for MFW and AFW. The operators fail to provide feedwater from other sources, and fail to initiate feed-and-bleed cooling, resulting in core damage.

- A loss of main feedwater trips the plant, and AFW fails due to operator error and hardware failures. The operators fail to initiate feed-and-bleed cooling, resulting in core damage.

Steam Generator Tube Rupture

- An SGTR is followed by failure of AFW. Coolant is lost from the primary until the RWST is depleted. HPI fails since recirculation cannot be established from the empty sump, and core damage results.

4.2 Risk Important Component Failure Modes

The generic component failure modes identified from PRA analyses as important to AFW system failure are listed below in decreasing order of risk importance.

1. Turbine-Driven Pump Failure to Start or Run.

2. Motor-Driven Pump Failure to Start or Run.

3. TDP or MDP Unavailable due to Test or Maintenance.

4. AFW System Valve Failures

    - steam admission valves
    - trip and throttle valve
    - flow control valves
    - pump discharge valves
    - pump suction valves
    - valves in testing or maintenance.

5. Supply/Suction Sources

    - condensate storage tank stop valve
    - hot well inventory
    - suction valves.

In addition to individual hardware, circuit, or instrument failures, each of these failure modes may result from common causes and human errors. Common-cause failures of AFW pumps are particularly risk important. Valve failures are somewhat less important due to the multiplicity of steam generators and connection paths. Human errors of greatest risk importance involve: failures to initiate or control system operation when required; failure to restore proper system lineup after maintenance or testing; and failure to switch to alternate sources when required.

5 Failure Modes Determined from Operating Experience

This section describes the primary root causes of component failures of the AFW system, as determined from a review of operating histories at Prairie Island and at other PWRs throughout the nuclear industry. Section 5.1 describes experience at Prairie Island. Section 5.2 summarizes information compiled from a variety of NRC sources, including AEOD analyses and reports, information notices, inspection and enforcement bulletins, and generic letters, and from a variety of INPO reports as well. Some Licensee Event Reports (LERs) and NPRDS event descriptions were also reviewed individually. Finally, information was included from reports of NRC-sponsored studies of the effects of plant aging, which include quantitative analyses of AFW system failure reports. This information was used to identify the various root causes expected for the broad PRA-based failure categories identified in Section 4.0, resulting in the inspection guidelines presented in Section 3.0.

Some of the following experiences may no longer be applicable, due to subsequent modifications or changes.

5.1 Prairie Island Experience

The AFW system at Prairie Island has experienced failures of the AFW pumps, pump discharge flow control valves, the turbine steam supply valves, pump suction and recirculation valves and system check valves. Failure modes include electrical, instrumentation, hardware failures, and human errors.

5.1.1 Motor Driven Pump Failures

There have been two events since 1977 which involved failure of the motor-driven pumps. Failure modes involved instrument and control circuit failure, and human error during maintenance activities. Improper installation of the self cleaning oil filter resulted in excessive differential pressure which defeated the oil pressure permissive and prevented starting of the pump. The other event involved a failed relay in the steam generator low low level start circuitry.

5.1.2 Turbine Driven Pump Failures

There have been fifteen events since 1977 that have resulted in failures of the turbine driven pumps. Failure modes involved failures in instrumentation and control circuits, electrical faults, system hardware failures, and human errors. The turbine driven pumps have tripped or failed to reach proper speed as a result of suction lines clogged with clams and sludge, dirty limit switch contacts, bent governor valve stem, shorted relays in the speed control circuit, and dirty breaker contacts.

5.1.3 Flow Control and Isolation Valve Failures

More than ten events since 1977 have resulted in failures of the motor operated flow control and isolation valves. Principal failure causes were equipment wear, instrumentation, and control circuit failures, valve hardware failures, and human errors. Valves have failed to operate properly due to blown fuses, failure of control components (such as I/P convertors), broken or dirty contacts, misaligned or broken limit switches, control power loss, and valve operator calibration problems.

5.1.4 Human Errors

There have been approximately ten significant human errors affecting the AFW system since 1977. Personnel have inadvertently actuated the AFW pumps during testing, failed to calibrate equipment or improperly installed an oil filter. Both personnel error and inadequate procedures have been involved.

5.2 Industry-Wide Experience

Human errors, design/engineering problems and errors, and component failures are the primary root causes of AFW System failures identified in a review of industry-wide system operating history. Common-cause failures, which disable more than one train of this operationally redundant system, are highly risk significant, and can result from all of these causes.

This section identifies important common-cause failure modes, and then provides a broader discussion of the single failure effects of human errors, design/engineering problems and errors, and component failures. Paragraphs presenting details of these failure modes are coded (e.g., CC1) and cross-referenced by inspection items in Section 3.

5.2.1 Common-Cause Failures

The dominant cause of AFW system multiple-train failures has been human error. Design/engineering errors and component failures have been less frequent, but nevertheless significant, causes of multiple train failures.

CC1. Human error in the form of incorrect operator intervention into automatic AFW system functioning during transients resulted in the temporary loss of all safety-grade AFW pumps during events at Davis Besse (NUREG-1154 1985) and Trojan (AEOD/T416 1983). In the Davis Besse event, improper manual initiation of the steam and feedwater rupture control system (SFRCS) led to overspeed tripping of both turbine-driven AFW pumps, probably due to the introduction of condensate into the AFW turbines from the long, unheated steam supply lines. (The system had never been tested with the abnormal, cross-connected steam supply lineup which resulted.) In the Trojan event the operator incorrectly stopped both AFW pumps due to misinterpretation of MFW pump speed indication. The diesel driven pump would not restart due to a protective feature requiring complete shutdown, and the turbine-driven pump tripped on overspeed, requiring local reset of the trip and throttle valve. In cases where manual intervention is required during the early stages of a transient, training should emphasize that actions should be performed methodically and deliberately to guard against such errors.

CC2. Valve mispositioning has accounted for a significant fraction of the human errors failing multiple trains of AFW. This includes closure of normally open suction valves or steam supply valves, and of isolation valves to sensors having control functions. Incorrect handswitch positioning and inadequate temporary wiring changes have also prevented automatic starts of multiple pumps. Factors identified in studies of mispositioning errors include failure to add newly installed valves to valve checklists, weak administrative control of tagging, restoration, independent verification, and locked valve logging, and inadequate adherence to procedures. Illegible or confusing local valve labeling, and insufficient training in the determination of valve position may cause or mask mispositioning, and surveillance which does not exercise complete system functioning may not reveal mispositionings.

CC3. At ANO-2, both AFW pumps lost suction due to steam binding when they were lined up to both the CST and the hot startup/blowdown demineralizer effluent (AEOD/C404 1984). At Zion-1 steam created by running the turbine-driven pump deadheaded for one minute caused trip of a motor-driven pump sharing the same inlet header, as well as damage to the turbine-driven pump (Region 3 Morning Report, 1/17/90). Both events were caused by procedural inadequacies.

CC4. Design/engineering errors have accounted for a smaller, but significant fraction of common-cause failures. Problems with control circuit design modifications at Farley defeated AFW pump auto-start on loss of main feedwater. At Zion-2, restart of both motor driven pumps was blocked by circuit failure to deenergize when the pumps had been tripped with an automatic start signal present (IN 82-01 1982). In addition, AFW control circuit design reviews at Salem and Indian Point have identified designs where failures of a single component could have failed all or multiple pumps (IN 87-34 1987).

CC5. Incorrect setpoints and control circuit settings resulting from analysis errors and failures to update procedures have also prevented pump start and caused pumps to trip spuriously. Errors of this type may remain undetected despite surveillance testing, unless surveillance tests model all types of system initiation and operating conditions. A greater fraction of instrumentation and control circuit problems has been identified during actual system operation (as opposed to surveillance testing) than for other types of failures.

CC6. On two occasions at a foreign plant, failure of a balance-of-plant inverter caused failure of two AFW pumps. In addition to loss of the motor driven pump whose auxiliary start relay was powered by the invertor, the turbine driven pump tripped on overspeed because the governor valve opened, allowing full steam flow to the turbine. This illustrates the importance of assessing the effects of failures of balance of plant equipment which supports the operation of critical components. The instrument air system is another example of such a system.

CC7. Multiple AFW pump trips have occurred at Millstone-3, Cook-1, Trojan and Zion-2 (IN 87-53 1987) caused by brief, low pressure oscillations of suction pressure during pump startup. These oscillations occurred despite the availability of adequate static NPSH. Corrective actions taken include: extending the time delay associated with the low pressure trip, removing the trip, and replacing the trip with an alarm and operator action.

CC8. Design errors discovered during AFW system reanalysis at the Robinson plant (IN 89-30 1989) and at Millstone-1 resulted in the supply header from the CST being too small to provide adequate NPSH to the pumps if more than one of the three pumps were operating at rated flow conditions. This could lead to multiple pump failure due to cavitation. Subsequent reviews at Robinson identified a loss of feedwater transient in which inadequate NPSH and flows less than design values had occurred, but which were not recognized at the time. Event analysis and equipment trending, as well as surveillance testing which duplicates service conditions as much as is practical, can help identify such design errors.

CC9. Asiatic clams caused failure of two AFW flow control valves at Catawba-2 when low suction pressure caused by starting of a motor-driven pump caused suction source realignment to the Nuclear Service Water system. Pipes had not been routinely treated to inhibit clam growth, nor regularly monitored to detect their presence, and no strainers were installed. The need for surveillance which exercises alternative system operational modes, as well as complete system functioning, is emphasized by this event. Spurious suction switchover has also occurred at Callaway and at McGuire, although no failures resulted.

CC10. Common-cause failures have also been caused by component failures (AEOD/C404 1984). At Surry-2, both the turbine driven pump and one motor driven pump were declared inoperable due to steam binding caused by backleakage of hot water through multiple check valves. At Robinson-2 both motor driven pumps were found to be hot, and both motor and steam driven pumps were found to be inoperable at different times. Backleakage at Robinson-2 passed through closed motor-operated isolation valves in addition to multiple check valves. At Farley, both motor and turbine driven pump casings were found hot, although the pumps were not declared inoperable. In addition to multi-train failures, numerous incidents of single train failures have occurred, resulting in the designation of "Steam Binding of Auxiliary Feedwater Pumps" as Generic Issue 93. This generic issue was resolved by Generic Letter 88-03 (Miraglia 1988), which required licensees to monitor AFW piping temperatures each shift, and to maintain procedures for recognizing steam binding and for restoring system operability.

CC11. Common-cause failures have also failed motor operated valves. During the total loss of feedwater event at Davis Besse, the normally open AFW isolation valves failed to open after they were inadvertently closed. The failure was due to improper setting of the torque switch bypass switch, which prevents motor trip on the high torque required to unseat a closed valve. Previous problems with these valves had been addressed by increasing the torque switch trip setpoint--a fix which failed during the event due to the higher torque required due to high differential pressure across the valve. Similar common mode failures of MOVs have also occurred in other systems, resulting in issuance of Generic Letter 89-10, "Safety Related Motor-Operated Valve Testing and Surveillance (Partlow 1989)." This generic letter requires licensees to develop and implement a program to provide for the testing, inspection and maintenance of all safety-related MOVs to provide assurance that they will function when subjected to design basis conditions.

CC12. Other component failures have also resulted in AFW multi-train failures. These include out-of-adjustment electrical flow controllers resulting in improper discharge valve operation, and a failure of oil cooler cooling water supply valves to open due to silt accumulation.

5.2.2 Human Errors

HE1. The overwhelmingly dominant cause of problems identified during a series of operational readiness evaluations of AFW systems was human performance. The majority of these human performance problems resulted from incomplete and incorrect procedures, particularly with respect to valve lineup information. A study of valve mispositioning events involving human error identified failures in administrative control of tagging and logging, procedural compliance and completion of steps, verification of support systems, and inadequate procedures as important. Another study found that valve mispositioning events occurred most often during maintenance, calibration, or modification activities. Insufficient training in determining valve position, and in administrative requirements for controlling valve positioning were important causes, as was oral task assignment without task completion feedback.

HE2. Turbine driven pump failures have been caused by human errors in calibrating or adjusting governor speed control, poor governor maintenance, incorrect adjustment of governor valve and overspeed trip linkages, and errors associated with the trip and throttle valve. TTV-associated errors include physically bumping it, failure to restore it to the correct position after testing, and failures to verify control room indication of TTV position following actuation.

HE3. Motor-driven pumps have been failed by human errors in mispositioning handswitches, and by procedure deficiencies.

5.2.3 Design/Engineering Problems and Errors

DE1. As noted above, the majority of AFW subsystem failures, and the greatest relative system degradation, has been found to result from turbine-driven pump failures. Overspeed trips of Terry turbines controlled by Woodward governors have been a significant source of these failures (AEOD/C602 1986). In many cases these overspeed trips have been caused by slow response of a Woodward Model EG governor on startup, at plants where full steam flow is allowed immediately. This oversensitivity has been removed by installing a startup steam bypass valve which opens first, allowing a controlled turbine acceleration and buildup of oil pressure to control the governor valve when full steam flow is admitted.

DE2. Overspeed trips of Terry turbines have been caused by condensate in the steam supply lines. Condensate slows down the turbine, causing the governor valve to open farther, and overspeed results before the governor valve can respond, after the water slug clears. This was determined to be the cause of the loss-of-all-AFW event at Davis Besse (AEOD/602 1986), with condensation enhanced due to the long length of the cross-connected steam lines. Repeated tests following a cold-start trip may be successful due to system heat up.

DE3. Turbine trip and throttle valve (TTV) problems are a significant cause of turbine driven pump failures (IN 84-66). In some cases lack of TTV position indication in the control room prevented recognition of a tripped TTV. In other cases it was possible to reset either the overspeed trip or the TTV without reseting the other. This problem is compounded by the fact that the position of the overspeed trip linkage can be misleading, and the mechanism may lack labels indicating when it is in the tripped position (AEOD/C602 1986).

DE4. Startup of turbines with Woodward Model PG-PL governors within 30 minutes of shutdown has resulted in overspeed trips when the speed setting knob was not exercised locally to drain oil from the speed setting cylinder. Speed control is based on startup with an empty cylinder. Problems have involved turbine rotation due to both procedure violations and leaking steam. Terry has marketed two types of dump valves for automatically draining the oil after shutdown (AEOD/C602 1986).

At Calvert Cliffs, a 1987 loss-of-offsite-power event required a quick, cold startup that resulted in turbine trip due to PG-PL governor stability problems. The short-term corrective action was installation of stiffer buffer springs (IN 88-09 1988). Surveillance had always been preceded by turbine warmup, which illustrates the importance of testing which duplicates service conditions as much as is practical.

DE5. Reduced viscosity of gear box oil heated by prior operation caused failure of a motor driven pump to start due to insufficient lube oil pressure. Lowering the pressure switch setpoint solved the problem, which had not been detected during testing.

DE6. Waterhammer at Palisades resulted in AFW line and hanger damage at both steam generators. The AFW spargers are located at the normal steam generator level, and are frequently covered and uncovered during level fluctuations. Waterhammers in top-feed-ring steam generators resulted in main feedline rupture at Maine Yankee and feedwater pipe cracking at Indian Point-2 (IN 84-32 1984).

DE7. Manually reversing the direction of motion of an operating valve has resulted in MOV failures where such loading was not considered in the design (AEOD/C603 1986). Control circuit design may prevent this, requiring stroke completion before reversal.

DE8. At each of the units of the South Texas Project, space heaters provided by the vendor for use in pre-installation storage of MOVs were found to be wired in parallel to the Class 1E 125 V DC motors for several AFW valves (IR 50-489/89-11; 50-499/89-11 1989). The valves had been environmentally qualified, but not with the non-safety-related heaters energized.

5.2.4 Component Failures

Generic Issue II.E.6.1, "In Situ Testing Of Valves" was divided into four sub-issues (Beckjord 1989), three of which relate directly to prevention of AFW system component failure. At the request of the NRC, in situ testing of check valves was addressed by the nuclear industry, resulting in the EPRI report, "Application Guidelines for Check Valves in Nuclear Power Plants (Brooks 1988)." This extensive report provides information on check valve applications, limitations, and inspection techniques. In situ testing of MOVs was addressed by Generic Letter 89-10, "Safety Related Motor-Operated Valve Testing and Surveillance" (Partlow 1989) which requires licensees to develop and implement a program for testing, inspection and maintenance of all safety-related MOVs. "Thermal Overload Protection for Electric Motors on Safety-Related Motor-Operated Valves - Generic Issue II.E.6.1 (Rothberg 1988)" concludes that valve motors should be thermally protected, yet in a way which emphasizes system function over protection of the operator.

CF1. The common-cause steam binding effects of check valve leakage were identified in Section 5.2.1, entry CC10. Numerous single-train events provide additional insights into this problem. In some cases leakage of hot MFW past multiple check valves in series has occurred because adequate valve-seating pressure was limited to the valves closest to the steam generators (AEOD/C404 1984). At Robinson, the pump shutdown procedure was changed to delay closing the MOVs until after the check valves were seated. At Farley, check valves were changed from swing type to lift type. Check valve rework has been done at a number of plants. Different valve designs and manufacturers are involved in this problem, and recurring leakage has been experienced, even after repair and replacement.

CF2. At Robinson, heating of motor operated valves by check valve leakage has caused thermal binding and failure of AFW discharge valves to open on demand. At Davis Besse, high differential pressure across AFW injection valves resulting from check valve leakage has prevented MOV operation (AEOD/C603 1986).

CF3. Gross check valve leakage at McGuire and Robinson caused overpressurization of the AFW suction piping. At a foreign PWR it resulted in a severe waterhammer event. At Palo Verde-2 the MFW suction piping was overpressurized by check valve leakage from the AFW system (AEOD/C404 1984). Gross check valve leakage through idle pumps represents a potential diversion of AFW pump flow.

CF4. Roughly one third of AFW system failures have been due to valve operator failures, with about equal failures for MOVs and AOVs. Almost half of the MOV failures were due to motor or switch failures (Casada 1989). An extensive study of MOV events (AEOD/C603 1986) indicates continuing inoperability problems caused by: torque switch/limit switch settings, adjustments, or failures; motor burnout; improper sizing or use of thermal overload devices; premature degradation related to inadequate use of protective devices; damage due to misuse (valve throttling, valve operator hammering); mechanical problems (loosened parts, improper assembly); or the torque switch bypass circuit improperly installed or adjusted. The study concluded that current methods and procedures at many plants are not adequate to assure that MOVs will operate when needed under credible accident conditions. Specifically, a surveillance test which the valve passed might result in undetected valve inoperability due to component failure (motor burnout, operator parts failure, stem disc separation) or improper positioning of protective devices (thermal overload, torque switch, limit switch). Generic Letter 89-10 (Partlow 1989) has subsequently required licensees to implement a program ensuring that MOV switch settings are maintained so that the valves will operate under design basis conditions for the life of the plant.

CF5. Component problems have caused a significant number of turbine driven pump trips (AEOD/C602 1986). One group of events involved worn tappet nut faces, loose cable connections, loosened set screws, improperly latched TTVs, and improper assembly. Another involved oil leaks due to component or seal failures, and oil contamination due to poor maintenance activities. Governor oil may not be shared with turbine lubrication oil, resulting in the need for separate oil changes. Electrical component failures included transistor or resistor failures due to moisture intrusion, erroneous grounds and connections, diode failures, and a faulty circuit card.

CF6. Electrohydraulic-operated discharge valves have performed very poorly, and three of the five units using them have removed them due to recurrent failures. Failures included oil leaks, contaminated oil, and hydraulic pump failures.

CF7. Control circuit failures were the dominant source of motor driven AFW pump failures (Casada 1989). This includes the controls used for automatic and manual starting of the pumps, as opposed to the instrumentation inputs. Most of the remaining problems were due to circuit breaker failures.

CF8. "Hydraulic lockup" of Limitorque SMB spring packs has prevented proper spring compression to actuate the MOV torque switch, due to grease trapped in the spring pack. During a surveillance at Trojan, failure of the torque switch to trip the TTV motor resulted in tripping of the thermal overload device, leaving the turbine driven pump inoperable for 40 days until the next surveillance (AEOD/E702 1987). Problems result from grease changes to EXXON NEBULA EP-0 grease, one of only two greases considered environmentally qualified by Limitorque. Due to lower viscosity, it slowly migrates from the gear case into the spring pack. Grease changeover at Vermont Yankee affected 40 of the older MOVs of which 32 were safety related. Grease relief kits are needed for MOV operators manufactured before 1975. At Limerick, additional grease relief was required for MOVs manufactured since 1975. MOV refurbishment programs may yield other changeovers to EP-0 grease.

CF9. For AFW systems using air operated valves, almost half of the system degradation has resulted from failures of the valve controller circuit and its instrument inputs (Casada 1989). Failures occurred predominantly at a few units using automatic electronic controllers for the flow control valves, with the majority of failures due to electrical hardware. At Turkey Point-3, controller malfunction resulted from water in the Instrument Air system due to maintenance inoperability of the air dryers.

CF10. For systems using diesel driven pumps, most of the failures were due to start control and governor speed control circuitry. Half of these occurred on demand, as opposed to during testing (Casada 1989).

CF11. For systems using AOVs, operability requires the availability of Instrument Air, backup air, or backup nitrogen. However, NRC Maintenance Team Inspections have identified inadequate testing of check valves isolating the safety-related portion of the IA system at several utilities (Letter, Roe to Richardson). Generic Letter 88-14 (Miraglia 1988), requires licensees to verify by test that air-operated safety-related components will perform as expected in accordance with all design-basis events, including a loss of normal IA.

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11. ABSTRACT (200 words or less)

In a study sponsored by the U.S. Nuclear Regulatory Commission (NRC), Pacific Northwest Laboratory has developed and applied a methodology for deriving plant-specific risk-based inspection guidance for the auxiliary feedwater (AFW) system at pressurized water reactors that have not undergone probabilistic risk assessment (PRA). This methodology uses existing PRA results and plant operating experience information. Existing PRA-based inspection guidance information recently developed for the NRC for various plants was used to identify generic component failure modes. This information was then combined with plant-specific and industry-wide component information and failure data to identify failure modes and failure mechanisms for the AFW system at the selected plants. Prairie Island was selected as the seventh plant for study. The product of this effort is a prioritized listing of AFW failures which have occurred at the plant and at other PWRs. This listing is intended for use by NRC inspectors in the preparation of inspection plans addressing AFW risk-important components at the Prairie Island plant.

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