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Auxiliary Feedwater System Risk-Based Inspection Guide for the South Texas Project Nuclear Power Plant

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Auxiliary Feedwater System Risk-Based Inspection Guide for the South Texas Project Nuclear Power Plant

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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 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. South Texas Project was selected as a 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 the NRC inspectors in preparation of inspection plans addressing AFW risk important components at the South Texas Project 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 South Texas Project plant. This information is presented to provide inspectors with increased resources for inspection planning at South Texas Project.

The risk importance of various component failure modes was 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 South Texas Project 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 provides brief descriptions of these risk-important failure causes, and Section 5 presents more extensive discussions, with specific examples and references. The entries in the two sections are cross-referenced.

An abbreviated system walkdown table 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 importance.

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 the South Texas Project.

This inspection guidance is presented in Section 3, following a description of the South Texas Project AFW system in Section 2. Section 3 identifies the risk important system components by South Texas Project identification 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 events 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 broad events.

AFW system operating history was studied to identify the various specific failures which have been aggregated into the PRA failure events. Section 5.1 presents a summary of South Texas Project 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 broad failure events used in PRAs, which are identified in Section 3.

2 South Texas Project AFW System

This section presents an overview of the South Texas Project AFW system (Dual unit, Westinghouse 4 loop plants), 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 (S/G) to allow secondary-side heat removal when main feedwater is not available and to promote natural circulation of the Reactor Coolant System (RCS) in the event of a loss of all four reactor coolant pumps. The system is capable of functioning for extended periods during a total loss of offsite power or a loss of the main feedwater system. This allows time to restore offsite power or main feedwater flow or to proceed with an orderly cooldown of the plant to the point where the Residual Heat Removal system (RHR) can remove decay heat. A simplified schematic of the South Texas Project AFW system and TDAFW pump steam supply is shown in Figure 2.1.

The AFW system consists of one turbine-driven pump (TDAFW) and three motor-driven feed pumps (MDAFW) that provide feedwater to the steam generators, one Auxiliary Feedwater Storage Tank (AFWST), and associated piping, valves and instrumentation. Feedwater is supplied to the TDAFW and MDAFW pumps from the AFWST through individual suction headers. The TDAFW and MDAFW pumps are capable of supplying all steam generators. Steam is supplied to the TDAFW turbine from S/G "D" through an automatically controlled motor operated valve (MOV-0143) and the turbine trip and throttle valve (MS-0514). The TDAFW and MDAFW pumps are equipped with automatic recirculation valves (AF-0011, 0036, 0058, and 0091) and the TDAFW with a turbine bearing cooling system, which prevents pump deadheading and bearing overheating. The pumps are protected from runout conditions by motor operated flow control valves (AF-7523, 7524, 7525, and 7526) located in the pump discharge lines. Power, control, and instrumentation associated with the four AFW system trains are independent from each other.

The system is designed to automatically start. AFW flows are automatically controlled until manual control is taken by the operator within ten minutes. The MDAFW pumps will start upon any of the following conditions and initiate auxiliary feedwater flow:

- Low-low S/G level
- Safety Injection (MODE I)
- Loss of offsite power in MODE II (only starts pumps on recirc)
- Loss of offsite power with a Safety Injection
- ATWS Mitigation System actuation is initiated.

The TDAFW pump will start upon any of the following conditions and initiate auxiliary feedwater flow:

- Low-low S/G level
- Safety Injection (MODE I)
- ATWS Mitigation System actuation is initiated.

The AFW pumps discharge through check valves and are normally aligned to supply one S/G (MDAFW #13 to S/G "C", MDAFW #12 to S/G "B", MDAFW #11 to S/G "A", and TDAFW #14 to S/G "D"). Depending upon plant conditions, the discharge of each pump can be lined up to any S/G by opening normally closed, fail closed, pneumatic isolation valves. The AFW lines for the S/Gs are each equipped with a flow element, flow transmitter, and an automatic flow control valve.

The AFWST is the normal source of water for the AFW system. The tank is required to store a sufficient quantity of demineralized water (485,000 gallons) to maintain the reactor coolant system (RCS) at hot standby conditions for 4 hours during a feedline break with steam release to the atmosphere and then to cool the RCS to place the RHR system in service. The administratively controlled, locked open and locked closed valve configuration requires that the AFWST discharge valves (AF0093, AF0094,

AF0095, AF0096, AF0073, AF0053, AF0031, and AF0024) be locked open to supply the AFW system. Additionally, the Condensate and Fire Protection systems can be manually aligned to provide backup supply to the AFWST.

2.2 Success Criterion

System success requires the operation of either of the following: at least two pumps supplying a minimum of 540 gpm to two S/Gs in an ATWS condition, OR, at least one pump supplying a minimum of 540 gpm within one minute to: a) at least one S/Gs after a main feedwater line rupture or steam line break or b) at least two S/Gs on loss of main feedwater or after a loss of offsite power.

2.3 System Dependencies

The AFW system depends on AC and DC power at various voltage levels for TDAFW turbine governor, motor operated valve control circuits, solenoid valves, and monitor and alarm circuits. Instrument Air is required for the AFW cross connect valves (AF-FV-7515, 7516, 7516 and 7517). These valves fail closed on a loss of Instrument Air. Steam availability is required for the TDAFW pump.

2.4 Operational Constraints

When the reactor is in MODEs 1, 2, or 3 (Hot Standby through Power Operation), South Texas Project Technical Specifications require four independent AFW pumps (three motor driven each capable of being powered from

separate emergency busses and one steam turbine capable of being powered from an OPERABLE steam supply system) and associated flow paths to be OPERABLE. If the Train A MDAFW pump is inoperable, it must be restored to operable status as soon as possible. With any of the following combinations of auxiliary feedwater pumps inoperable:

- (1) Train B or Train C MDAFW pump
- (2) Train D TDAFW pump and any MDAFW pump
- (3) Train A and either Train B or Train C MDAFW pump
- (4) Train D TDAFW pump.

The affected AFW pumps must be returned to operable status within 72 hours or the unit must be placed in HOT STANDBY within the next 6 hours and HOT SHUTDOWN within the following 6 hours. When Train B and Train C MDAFW pumps, or any three AFW pumps are inoperable the unit must be placed in HOT STANDBY within 6 hours and HOT SHUTDOWN within the following 6 hours. When four AFW pumps become inoperable immediate corrective actions must be taken to restore at least one AFW pump to OPERABLE status as soon as possible.

South Texas Project Technical Specifications require the AFWST to be OPERABLE with a minimum contained water volume of 485,000 gallons. With the AFWST inoperable, the AFWST must be restored to OPERABLE status within 4 hours or the unit must be in HOT STANDBY within the next 6 hours and HOT SHUTDOWN within the following 6 hours.

Figure 2.1. South Texas Auxiliary Feedwater System

AFW System

3 Inspection Guidance for the South Texas Project AFW System

In this section the risk important components of the South Texas Project AFW system are identified, and the important failure modes for these components are briefly described. These failure modes include specific human errors, design deficiencies, and types of hardware failures which have been observed to occur for these components, both at South Texas Project 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 inspection activities. These activities include 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 in the AFW system walkdown table address the majority 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 risk-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 where additional information on historical events is presented.

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. Control switch mispositioning has caused both of the TDAFW pumps to trip on overspeed. CC1.

Inspection Suggestion - Observe Abnormal and Emergency Operating Procedure (AOP/EOP) simulator training exercises to verify that the operators comply with procedures during observed evolutions. Observe surveillance testing on the AFW system to verify it is in strict compliance with the surveillance test procedure.

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

Inspection Suggestion - Verify that the system valve alignment, air operated valve control and valve actuating air pressures are correct using 3.1 Walkdown Table, the system operating procedures, and operator rounds logsheet. Review surveillance procedures that alter the standby alignment of the AFW system. Ensure that an adequate return to normal section exists.

- Steam binding has caused failure of multiple pumps. This resulted from leakage of hot feedwater past check valves and a motor operated valve into a common discharge header. CC10. Multiple-pump steam binding has also resulted from improper valve line-ups, and from running a pump deadheaded. CC3.

Inspection Suggestion - Verify that the pump discharge temperature is within the limits specified on the operator rounds logsheet ($< 240^{\circ}\text{F}$). Assure any instruments used to verify the temperature by the utility are of an appropriate range and included in a calibration program. Verify affected pumps have been vented every 4 hours to ensure steam binding has not occurred. Verify that a maintenance work request has been written to repair leaking check valves.

- 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.

Inspection Suggestion - Review design change implementation documents for the post maintenance testing required prior to returning the equipment to service. Assure the testing verifies that all potentially impacted functions operate correctly, and includes repeating any plant start-up or hot functional testing that may be affected by the design change.

- 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.

Inspection Suggestion - The material condition of the electrical equipment is an indicator of probable reliability. Review the Preventative Maintenance (PM) records to assure the equipment is maintained on an appropriate frequency for the environment it is in and that the PMs are actually being performed as required by the program. Review the outstanding Corrective Maintenance records to assure the deficiencies found on the equipment are promptly corrected.

- 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.

Inspection Suggestion - Assure that plant conditions which could result in the blockage or degradation of the suction flow path are addressed by system maintenance and test procedures. Design changes that affect the suction flow path should repeat testing that verified an adequate suction source for simultaneous operation of all pumps. Verify that testing has at some time demonstrated simultaneous operation of all pumps. Verify that surveillances adequately test all aspects of the system design functions, for example, demonstrate that the AFW pumps will trip on low suction pressure.

- The South Texas Project has experienced stress corrosion cracking/hydrogen embrittlement of AFW pump sleeve materials which caused one pump to fail its performance test. The sleeve material was common to all pumps.

Inspection Suggestion - Review Design Modification records to ensure that the pump sleeves have been or are scheduled to be replaced with materials that are not susceptible to stress corrosion cracking.

3.1.2 Turbine Driven Pump Fails to Start or Run

- Improperly adjusted and inadequately maintained turbine governors have caused pump failures. 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.

Inspection Suggestion - Review PM records to assure the governor oil is being replaced within the designated frequency. During plant walkdowns carefully inspect the governor and linkages for loose fasteners, leaks, and unsecured or degraded conduit. Review vendor manuals to ensure PM procedures are performed according to manufacturer's recommendations and good maintenance practices.

- 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.

Inspection Suggestion - Observe the operation of the turbine driven Aux Feed pump and assure that the governor is reset as directed in OPOP02-AF-0001 by rotating the speed control knob fully in the counter-clockwise direction, then fully in the clockwise direction. Assure the turbine is not coasting over, which can result in refill of the speed setting cylinder.

- 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. Surveillance should exercise all steam supply connections. DE2.

Inspection Suggestion - Verify that the steam traps are valved in on the steam supply line. For steam traps that are on a pressurized portion of the steam line, check the steam trap temperature (if unlagged) to assure it is warmer than ambient (otherwise it may be stuck or have a plugged line). If the steam trap discharge is visible, assure there is evidence of liquid discharge.

- Trip and throttle valve (TTV) 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. The South Texas Project has experienced steam cutting of the TTV inlet flanges.

Inspection Suggestion - Carefully inspect the TTV overspeed trip linkage and assure it is reset and in good physical condition. Assure that there is a good steam isolation to the turbine, otherwise continued turbine high temperature can result in degradation of the oil in the turbine, interfering with proper

overspeed trip operation. Review training procedures to ensure operator training on resetting the TTV is current.

- Stress corrosion cracking caused failure of the turbine driven pump, allowing the final stage shaft sleeve to rub and eventually become friction welded to the stationary final stage piece of the pump.

Inspection Suggestion - Covered under 3.1.1 bullet 7.

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

Inspection Suggestion - Confirm switch position using Table 3.1. Review administrative procedures concerning documentation of procedural deficiencies. Ensure operator training on procedural changes is current.

3.1.3 Motor Driven Pump 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.

Inspection Suggestion - Review corrective maintenance records when control circuit problems occur to determine if a trend exists. Every time a breaker is racked in a PMT should be performed to start the pump, assuring no control circuit problems have occurred as a result of the manipulation of the breaker. (Control circuit stabs have to make up upon racking the breaker, as well as cell switch damage can occur upon removal and reinstallation of the breaker.)

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

Inspection Suggestion - Covered under 3.1.2 bullet 6.

3.1.4 Pump 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.

Inspection Suggestion - Review the time the AFW system and components are inoperable. Assure all maintenance is being performed that can be performed during a single outage time frame, avoiding multiple equipment outages. The maintenance should be scheduled before the routine surveillance test, so credit can be taken for both post maintenance testing and surveillance testing, avoiding excessive testing. Review surveillance schedule for frequency and adequacy to verify system operability requirements per Technical Specifications.

3.1.5 Air Operated Valves Fail Closed

AFW Cross-Connect Valves: AF-FV-7515, 7516, 7517, & 7518

The normally closed and administratively locked in neutral air operated AFW Cross-Connect valves allow manually initiated AFW flow from any AFW pump to any S/G during off normal conditions. They fail closed on a loss of Instrument Air.

- Control circuit problems have been a primary cause of failures. CF9. Valve failures have resulted from blown fuses, failure of control components (such as current/pneumatic convertors), broken or dirty contacts, misaligned or broken limit switches, control power loss, and calibration problems. Degraded operation has also resulted from improper air pressure due to the wrong type of air regulator being installed or leaking air lines. The South Texas Project has had AOVs fail to fully seat due to inadequate maintenance.
- Inadequate air pressure regulation has resulted in control valve failure to operate.

Inspection Suggestion - Check for control air system alignment and air leaks during plant walkdowns. (Regulators may have a small amount of external bleed to maintain downstream pressure.) Check for cleanliness and physical condition of visible circuit elements. Review valve stroke time surveillance for

adverse trends, especially those valves on reduced testing frequency. Review air system surveillances moisture content of air is within established limits.

3.1.6 Motor Operated Valves Fail Closed

AFW Flow Control valves: AF-7523, 7524, 7525, & 7526

TDAFW Pump Steam Admission valve: MS-0143

TDAFW Pump Trip & Throttle valve: MS-0514

AFW Stop/check valves: AF-0019, 0048, 0065, & 0085

The AFW flow control valves are used to control AFW flow and are normally open and fail as is. The TDAFW pump steam admission valve is normally open and fails open. The TDAFW pump Trip & Throttle valve is normally closed and fails as is. The AFW Stop/check valves are normally closed and fail closed.

- Common cause failure of MOVs has occurred 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. CC11.

Inspection Suggestion - Review the MOV test records to assure the testing and settings are based on dynamic system conditions. Overtorquing of the valve operator can result in valve damage such as cracking of the seat or disc. Review the program to assure overtorquing is identified and corrective actions are taken to assure valve operability following an overtorque condition. Review the program to assure EQ seals are renewed as required during the restoration from testing to maintain the EQ rating of the MOV.

- 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.

Inspection Suggestion - Review the administrative controls for documenting and changing the settings of

thermal overload protective devices. Assure the information is available to the maintenance planners.

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

Inspection Suggestion - Review PM frequency and records, only upon a trend of failure of the controllers.

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

Inspection Suggestion - Review this only if the MOV testing program reveals deficiencies in this area.

- 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.

Inspection Suggestion - None. Circuit design prevents this problem at South Texas.

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

Inspection Suggestion - Spot check MOVs during MOV testing to assure the space heaters are physically removed or disconnected.

- Leakage of hot feedwater through check valves has caused thermal binding of normally closed flow control MOVs. AOVs may be similarly susceptible. CF2

Inspection Suggestion - Covered by 3.1.1 bullet 3.

3.1.7 Manual Suction or Discharge Valves Fail Closed

TDAFW Pump: AF-0093, 0024, 0012, 0014 & 0026
MDAFW Pumps: AF-0094, 0095, 0096, 0031, 0053,
0073, 0041, 0059, 0078, 0043, 0061, 0080, 0039,
0067 & 0081

These manual valves are normally locked open. For each train, closure of the first or second valves would block pump suction and closure of the following valves would block pump discharge or recirculation.

- 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. South Texas Project personnel have inadvertently mispositioned a recirculation valve resulting in a feed rate insufficient to maintain S/G level. 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

Inspection Suggestion - Review the administrative controls that relate to valve positioning and sealing, system restoration following maintenance, valve labeling, system drawing updating, and procedure revision, for proper implementation.

3.1.8 Leakage of Hot Feedwater Through Check Valves:

MDAFW Pump #11: AF-0119, 0048, & 0036
MDAFW Pump #12: AF-0120, 0065, & 0058
MDAFW Pump #13: AF-0121, 0085, & 0091
TDAFW Pump #14: AF-0122, 0019, & 0011

- 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, as would be required for leakage to reach the motor driven or turbine driven pumps. CC10.

Inspection Suggestion - Covered by 3.1.1 bullet 3.

- Slow leakage past the final check valve of a series may not force the check valve closed. Other check valves in series may leak similarly. Piping orientation and valve design are important factors in achieving true series protection. CF1.

Inspection Suggestion - Covered by 3.1.1 bullet 3.

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, must also be addressed to ensure that their risk importances are not increased. An example would include ensuring an adequate water level in the AFWST exists.

Table 3.1 Risk Important Walkdown Table for South Texas AFW System Components

Component #	Component Name	Required Position	Actual Position
<u>Electrical</u>			
3S141MPA01	AFW Motor Driven Pump #11	Racked In/ Closed	_____
3S141MPA02	AFW Motor Driven Pump #12	Racked In/ Closed	_____
3S141MPA03	AFW Motor Driven Pump #13	Racked In/ Closed	_____
<u>Valves</u>			
AF-0275	AFWST Drain	Locked Closed*	_____
AF-0277	AFWST Drain	Locked Closed*	_____
AF-0094	AFWST to AFW pump #11	Locked Open*	_____
AF-0031	AFW pump #11 Suction Isolation	Locked Open	_____
AF-0041	AFW pump #11 Manual Discharge	Locked Open	_____
AF-0039	AFW pump #11 Recirc Isolation	Locked Open	_____
AF-0043	AFW pump #11 Manual Flow Control	Locked Open	_____
AF-0040	AFW pump #11 Test Line Isolation	Locked Closed	_____
AF-0048	Piping upstream of stop/check valve	Cool	_____
AF-0036	Piping upstream of ARC valve	Cool	_____
AF-FV-7517	AFW Cross-tie local handwheel	Locked Neutral	_____
AF-0283	S/G 1A to S/G Recirc pump 11A isolation valve	Locked Closed	_____

Table 3.1 (Continued)

Component #	Component Name	Required Position	Actual Position
AF-0282	S/G 1A to S/G Recirc pump 11A isolation valve	Locked Closed	_____
AF-0267	AF-0119 check valve bypass	Locked Closed**	_____
AF-0095	AFWST to AFW pump #12	Locked Open*	_____
AF-0053	AFW pump #12 Suction isolation	Locked Open	_____
AF-0059	AFW pump #12 Manual Discharge	Locked Open	_____
AF-0067	AFW pump #12 Recirc isolation	Locked Open	_____
AF-0061	AFW pump #12 Manual Flow Control	Locked Open	_____
AF-0070	AFW pump #12 Test Line Isolation	Locked Closed	_____
AF-0065	Piping upstream of stop/check valve	Cool	_____
AF-0058	Piping upstream of ARC valve	Cool	_____
AF-FV-7516	AFW Cross-tie local handwheel	Locked Neutral	_____
AF-0284	S/G 1B to S/G Recirc pump 11B isolation valve	Locked Closed	_____
AF-0285	S/G 1B to S/G Recirc pump 11B isolation valve	Locked Closed	_____
AF-0265	AF-0120 check valve bypass	Locked Closed**	_____
AF-0096	AFWST to AFW pump #13	Locked Open*	_____
AF-0073	AFW pump #13 Suction Isolation	Locked Open	_____
AF-0078	AFW pump #13 Manual Discharge	Locked Open	_____
AF-0087	AFW pump #13 Recirc Isolation	Locked Open	_____
AF-0080	AFW pump #13 Manual Flow Control	Locked Open	_____

Table 3.1 (Continued)

Component #	Component Name	Required Position	Actual Position
AF-0092	AFW pump #13 Test Line Isolation	Locked Closed	_____
AF-0085	Piping upstream of stop/check valve	Cool	_____
AF-0091	Piping upstream of ARC valve	Cool	_____
AF-FV-7515	AFW Cross-tie local handwheel	Locked Neutral	_____
AF-0287	S/G 1C to S/G Recirc pump 11C isolation valve	Locked Closed	_____
AF-0286	S/G 1C to S/G Recirc pump 11C isolation valve	Locked Closed	_____
AF-0263	AF-0121 check valve bypass	Locked Closed**	_____
AF-0093	AFWST to AFW pump #14	Locked Open*	_____
AF-0024	AFW pump #14 Suction isolation	Locked Open	_____
AF-0012	AFW pump #14 Manual Discharge	Locked Open	_____
AF-0026	AFW pump #14 Recirc isolation	Locked Open	_____
AF-0014	AFW pump #14 Manual Flow Control	Locked Open	_____
AF-0037	AFW pump #14 Test Line Isolation	Locked Closed	_____
AF-FV-7518	AFW Cross-tie local handwheel	Locked Neutral	_____
AF-0280	S/G 1D to S/G Recirc pump 11D Isolation valve	Locked Closed	_____
AF-0281	S/G 1D to S/G Recirc pump 11D Isolation valve	Locked Closed	_____
AF-0269	AF-0212 check valve bypass	Locked Closed**	_____
AF-0019	Piping upstream of stop/check valve	Cool	_____

Table 3.1 (Continued)

Component #	Component Name	Required Position	Actual Position
AF-0011	Piping upstream of ARC valve	Cool	_____
MS-0514	TDAFW Pump Trip & Throttle valve	Latched and Closed	_____
MS-0143	TDAFW Pump Steam Admission valve	Open	_____

* Valves are located in a pit at the base of the AFWST. Access to the pit requires that a cover be unbolted and removed. Special entry requirements may apply for enclosed space entry. Inspection of this area is best accomplished when other activities are in progress in the valve pit, which require removal of the cover.

** Valves are located in containment.

4 Generic Risk Insights from PRAs

PRAs for 13 PWRs were analyzed to identify risk-important accident sequences involving loss of AFW, 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, and Travis et al. 1988).

4.1 Risk Important Accident Sequences Involving AFW System Failure

Loss of Power System

- A loss of offsite power and main feedwater is followed by failure of AFW. Due to lack of actuating power, the power operated relief valves (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 the power conversion system (PCS), main feedwater, 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 (SGTR)

- A SGTR is followed by failure of AFW. Coolant is lost from the primary until the refueling water storage tank (RWST) is depleted. High pressure injection (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. TDAFW pump or MDAFW pump Unavailable due to Test or Maintenance.
4. AFW System Valve Failures
 - steam admission valves
 - trip and throttle valves
 - flow control valves

Generic Risk Insights

- 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 cause of AFW system component failures, as determined from a review of operating histories at South Texas Project and at other PWRs throughout the nuclear industry. Section 5.1 describes experience at South Texas Project from 1988 through 1991. 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 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 analysis of AFW system failure reports. This information was used to identify the various root causes expected for the broad PRA-based failure events identified in Section 4, resulting in the inspection guidelines presented in Section 3.

5.1 South Texas Project Experience

The AFW system at South Texas Project has experienced failures of the turbine driven AFW pump, pump discharge flow control valves, and AFW train cross connect valves. Failure modes include electrical, instrumentation and control, hardware failures, and human errors.

5.1.1 Multiple Pump Failures

There have been no reported multiple pump failures at the South Texas Project. However, South Texas Project has experienced stress corrosion cracking/hydrogen embrittlement of AFW pump sleeve materials which caused one pump to fail its performance test. The sleeve material was common to all pumps.

5.1.2 Motor Driven Pump Failures

There have been no reported motor driven pump failures at the South Texas Project.

5.1.3 Turbine Driven Pump Failures

There has been one reported occurrence that resulted in decreased operational readiness of the AFW system. The failure was in a TTV flange.

5.1.4 Flow Control and Isolation Valve Failures

Approximately seven events have resulted in impaired operational readiness of the air operated and motor operated valves. Principal failure causes were equipment wear, instrumentation and control circuit failures, instrument drift, valve hardware failures, valve wear, and human errors. Valves have failed to operate properly due to failure of control components and valve motor failures. Human errors have resulted in packing leaks. 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. The valves had been environmentally qualified, but not with the non-safety-related heaters energized.

5.1.5 Check Valve Failures

There have been no reported check valve failures at the South Texas Project.

5.1.6 Human Errors

There has been one event affecting the AFW system. Personnel have inadvertently mispositioned a recirculation valve resulting in a feed rate insufficient to maintain S/G level.

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 shut-down, 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 inverter, 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 re-analysis 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 switch-over 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 resetting 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. 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 water-hammer 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.

Failure Modes

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 change-over 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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10. SUPPLEMENTARY NOTES

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. South Texas Project was selected as one of a series of plants 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 South Texas Project plant.

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