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Auxiliary Feedwater System Risk-Based Inspection Guide for the San Onofre Unit 2 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. San Onofre-2 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 San Oaofre-2 plant.

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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 San Onofre-2 Nuclear Power Plant. This information is presented to provide inspectors increased resources for inspection planning at San Onofre-2.

The risk importance of various component failures 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 the rank and root causes of these component failures. Both San Onofre 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 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.

Acknowledgments

We wish to thank the personnel at the San Onofre Nuclear Generating Station for their efforts in reviewing and validating this report. A special note of thanks is given to Greg Becker of the Operations group for his efforts in validating the walkdown table.

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 San Onofre-2.

This inspection guidance is presented in Section 3.0, following a description of the San Onofre AFW system in Section 2.0. Section 3.0 identifies the risk important system components by San Onofre-2 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 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 San Onofre 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 San Onofre-2 AFW System

This section presents an overview description of the San Onofre-2 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 shutdown cooling system (SCS) can remove decay heat. A simplified schematic diagram of the AFW system is shown in Figure 2.1.

The AFW system is controlled automatically by an Emergency Feedwater Actuation Signal (EFAS). Initiation of an EFAS automatically actuates the AFW system to provide an AFW supply to the steam generators on low steam generator water level. When an EFAS signal is generated, the turbine-driven pump (P-140) and the corresponding motor-driven pump (P-141 or P-504) dedicated to the steam generator that is initiating the signal are automatically started. To deliver flow to the affected steam generator, auxiliary feedwater control valves and isolation valves are fully opened. When the EFAS signal clears, the control valves and isolation valves are driven closed. Initiation of a Main Steam Isolation Signal (MSIS) automatically shuts all remotely actuated auxiliary feedwater control valves and isolation valves unless an EFAS signal is present. Actuation of both a MSIS and an EFAS automatically isolates auxiliary feedwater flow to the ruptured steam generator and controls flow to the intact steam generator.

The normal AFW pump suction is from a seismic category I condensate storage tank T-121 (150,000 Gal.). Each pump draws from a separate header through two locked-open isolation valves. Power, control, and instrumentation associated with each motor-driven pump are independent from one another. Steam for the turbine driven pump is supplied by each of the two main steam lines from a point between the containment penetration and the main steam isolation valves. Each of the steam supply lines to the turbine has a check valve and a pneumatically-actuated steam supply isolation valve. The steam from both supply lines combines and is then directed to the turbine via a stop valve and a governor valve. Both pneumatically-actuated isolation valves, the stop valve, and the controls to the governor are supplied with power from an emergency DC power source. Each AFW pump is equipped with a continuous recirculation flow system, which prevents pump deadheading. The minimum flow lines from each AFW pump are independent flow paths back to tank T121.

Each auxiliary feedwater pump discharge is provided with a check valve and locally operated isolation valve. The discharge lines from the motor-driven auxiliary feedwater pumps are equipped with AC motor-operated control valves and AC electrohydraulic bypass control valves. The discharge lines from the turbine-driven pump are equipped with DC motor-operated control valves. Each motor-driven pump normally supplies feedwater to only one steam generator, but the headers may be cross-connected. The turbine-driven pump normally supplies both steam generators. Two parallel containment isolation valves are provided in each auxiliary feedwater line to each steam generator immediately outside containment. One isolation valve to each pair is AC electrohydraulic powered; the other valve is DC motor powered. This arrangement assures a flow path to at least one steam generator if a valve failure occurs concurrent with a loss of AC or DC power.

CST T-121 is the normal source of water for the AFW System and is required to store sufficient demineralized water to maintain the reactor coolant system (RCS) at hot standby conditions for 2 hours followed by cooldown to shutdown cooling initiation, with steam discharge to atmosphere. Makeup to CST T-121 is normally supplied from the demineralized water "Hill Tanks". Alternate makeup to CST T-121 is available from the demineralization system, condensate tank T-120 or the fire protection system in an emergency condition.

2.2 Success Criterion

System success requires the operation of at least one pump supplying rated flow to at least one of the two steam generators.

2.3 System Dependencies

The AFW system depends on AC power for motor-driven pumps and level control valves, DC power for control power to pumps and valves, and an automatic actuation signal. In addition, the turbine-driven pump also requires steam availability.

2.4 Operational Constraints

When the reactor is critical the San Onofre-2 Technical Specifications require that all three AFW pumps and associated flow paths are operable with each motor-driven pump powered from a different vital bus. If one AFW pump becomes inoperable, it must be restored to operable status within 72 hours or the plant must shut down to hot standby within the next six hours. If two AFW pumps are inoperable, the plant must be shut down to hot standby within six hours. With three AFW pumps inoperable, corrective action to restore at least one pump to operable status must be initiated immediately.

The San Onofre-2 Technical Specifications require a 144,000 gallon supply of water to be stored in the CST T-121 and a 280,000 gallon supply of water stored in CST T-120.

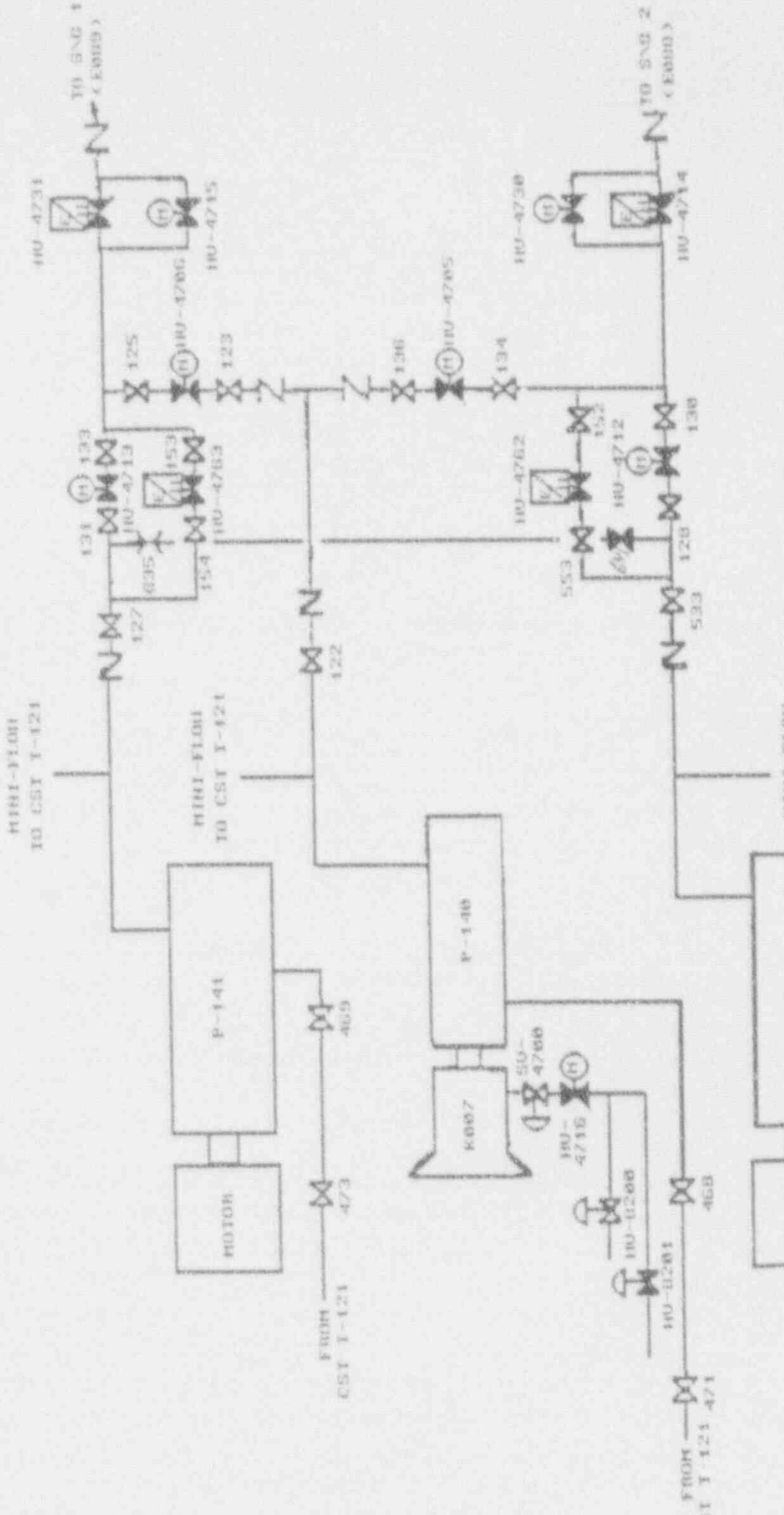

Figure 2.1 San Onofre Unit 2 Auxiliary Feedwater System

3 Inspection Guidance for the San Onofre-2 AFW System

In this section the risk important components of the San Onofre-2 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 San Onofre 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 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 backleakage 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, from San Onofre-2 and other plants. 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 with a 3-digit code 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.

  Inspection Suggestion - Observe Abnormal and Emergency Operating Instruction (AOI/EOI) 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. The multiple AFW system flowpaths at San Onofre-2 minimize the hazard associated with valve mispositioning.

  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. CC7. Multiple-pump steam binding has also resulted from improper valve lineups, and from running

a pump deadheaded. CC10. The multiple isolation valves in each AFW flowpath which are normally closed minimize the hazard associated with steam binding at San Onofre-2.

Inspection Suggestion - Verify that the pump discharge piping temperature is ambient. Assure any instruments used to verify the temperature by the utility are of an appropriate range and included in a calibration program.

- 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. C3. Incorrect setpoints and control circuit calibrations have also prevented proper operation of multiple pumps. CC4.

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. CC5. The pumps at San Onofre-2 are electrically independent, which minimizes the risk in this area.

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). CC11. At H. B. Robinson, design reviews have identified inadequately sized suction piping which could have yielded insufficient NPSH to support operation of more than one pump. CC12. At San Onofre-2 the pumps have multiple flowpaths, but a common suction source.

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. Examples include, if the AFW system has an emergency source from a water system with the potential for biofouling, then the system should be periodically treated to prevent buildup and routinely tested to assure an adequate flow can be achieved to support operation of all pumps, or inspected to assure that bio-fouling is not occurring. 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 sometime, 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.

3.1.2 Turbine Driven Pump P140 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 or sampled and analyzed 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.

- 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. At San Onofre, DCP 6020.OSJ installed an automatic opening sequence for HV-4716, which limits steam flow to the turbine upon an automatic start. Manual starts require careful operation of HV-4716 to avoid a turbine overspeed. Direction is given in operating instructions on specific operations required of HV-4716 during a manual start.

  Inspection Suggestion - Observe the operation of the turbine driven Aux Feed pump during pump testing and assure that HV-4716 stops for 2.5 seconds at a valve stroke of approximately 5/32" during an automatic start sequence. Review IST records for the valve stroke time trend.

- 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. Surveillances should exercise all steam supply connections. DE2. A design change is being planned for possible implementation in 1993 at San Onofre-2 to change the steam supply tap point on the main steam system to the top of the pipe, as well as changing the supply pipe configuration and replacing steam traps with orifices. Until the time that this is accomplished, one of the steam supply isolation valves (2HV8200/8201) must remain closed to minimize condensate build-up in the steam supply piping.

  Inspection Suggestion - Verify that the steam traps are valved or bypassed on the steam supply line. Some of the traps are in areas that require an oxygen monitor for entry; recommend checking these traps with operations during the monthly surveillance. If the steam trap discharge is visible, assure there is evidence of liquid discharge.

- Trip and throttle valve (HV-4716) 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, and unambiguity of control room and local indication of TTV position and overspeed trip linkage reset status, all affect the likelihood of these errors. DE3. The TTV at the San Onofre-2 plant has a history of being found in a tripped condition, and is now tested for trip and reset monthly under Surveillance Instruction SO23-3-3.16.

  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. Observe operators during the monthly surveillance, and randomly select operators and have them simulate a reset of the linkage. Verify the placard with the reset instructions is installed near the turbine.

3.1.3 Motor Driven Pump P141 or P504 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. Control circuit problems and a blown fuse due to overload have occurred at San Onofre-2.

  Inspection Suggestion - Review corrective maintenance records and non-conformance reports 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 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.

3.1.4 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. Review quarterly risk graphs for the Auxiliary Feed system.

3.1.5 Electrohydraulic Controlled Valves HV-4714, 4731, 4762, or 4763 Fail Closed

These EHCVs control or isolate flow from the AFW pumps to each of the steam generators. They fail as-is during motor failure and fail closed on loss of hydraulic pressure.

- EHCV performance has been poor at other facilities, primarily due to hydraulic problems. CF6.

  Inspection Suggestion - Monitor hydropack cycle time. If the pump starts often it is an indicator of internal leakage in the hydraulic system. Hydropack fluid should be periodically sampled or changed out.

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

  Inspection Suggestion - Covered by 3.1.1 bullet 3.

3.1.6 Motor Operated Valves HV-4705, 4706, 4712, 4713, 4715 and 4730

These MOVs control or isolate flow of the service water to the AFW pumps. 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. CC11. Diaphragm failure, packing leakage, electrical component failure and seat leakage have been the main causes of valve failure at San Onofre-2.

  Inspection Suggestion - Review the MOV analytical 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.

- 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.

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

- Manually reversing the direction of motion of operating or coasting down 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 - Verify procedures and training address reversal of valve direction midstroke.

- 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.

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

3.1.7 Manual Suction or Discharge Valves Fail Closed

TD Pump P140: Valves S21305MU468, S21305MU122
MD Pump P141: Valves S21305MU469, S21305MU127
MD Pump P504: Valves S21305MU538, S21305MU533

These manual valves are all normally locked open. For each train, closure of the first valve listed would block pump suction and closure of the second valves would block pump discharge.

- 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

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:

At MFW connections: Valves S21305MU124, S21305MU448
Between Pump P140 and MFW: Valves S21305MU547
Between Pump P141 and MFW: Valves S21305MU126
Between Pump P504 and MFW: Valves S21305MU532

- Leakage of hot feedwater through several check valves in series has caused steam binding of multiple 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. The lineup indicated is for normal power operation. 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 comments. 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 importance are not increased. Examples include the (open) steam lead isolation valves upstream of HV-4716, 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

Component #	Component Name	Required Position	Actual Position
	Electrical		
Train A Electrical Switchgear Room			
2A0404	2P-141 Motor Breaker	Indicating Lights Lit	____
2BY39H	2P-141 Motor Heater	Switch On Light Lit	____
Train B Electrical Switchgear Room			
2A0603	2P-504 Motor Breaker	Indicating Lights Lit	____
2BZ39H	2P-504 Motor Heater	Switch On Light Lit	____
Auxiliary Feed Pump Room			
	P-140 Flowpath		
S21305MU468	2P-140 Suction Valve	Locked Open	____
S21305MU122	2P-140 Discharge Valve	Locked Open	____
S21305MU123	2HV-4706 Inlet Valve	Locked Open	____
2HV-4706	2P-140 Discharge to S/G E-089	Closed	____
S21305MU125	2HV-4706 Outlet Valve	Locked Open	____
S21305MU136	2HV-4705 Inlet Valve	Locked Open	____
2HV-4705	2P-140 Discharge to 2E-088	Closed	____
S21305MU134	2HV-4705 Outlet Valve	Locked Open	____
	P-141 Flowpath		
S21305MU127	2P-141 Discharge Valve	Locked Open	____
S21305MU131	2HV-4713 Inlet Valve	Locked Open	____
2HV-4713	2P-141 Disch. Flow Control Valve	Closed	____
S21305MU133	2HV-4713 Outlet Valve	Locked Open	____
S21305MU154	2HV-4763 Inlet Valve	Open	____
2HV-4763	2P-141 Disch. Bypass Flow Control Valve	Closed	____
S21305MU153	2HV-4763 Outlet Valve	Open	____

Table 3.1. (Continued)

Component #	Component Name	Required Position	Actual Position
	P-504 Flowpath		
S21305MU469	2P-141 Suction Valve	Locked Open	___
S21305MU538	29-504 Suction Valve	Locked Open	___
S21305MU533	2P-504 Discharge Valve	Locked Open	___
S21305MU128	2HV-4712 Inlet Valve	Locked Open	___
2HV-4712	2P-504 Flow Control Valve	Closed	___
S21305MU130	2HV-4712 Outlet Valve	Locked Open	___
S21305MU553	2HV-4762 Inlet Valve	Open	___
2HV-4762	2P-504 Bypass Flow Control Valve	Closed	___
S21305MU152	2HV-4762 Outlet Valve	Open	___
	Cross-Connect Valves		
S21305MU634	2P-504 and 2P-141 Disch. X-Tie	Locked Closed	___
S21305MU635	2P-504 and 2P-141 Disch. X-Tie	Locked Closed	___
	Steam Supply Valve		
2HV-4716	Turbine 2K-007 Trip Throttle Valve	Reset	___
Outside Auxiliary Feed Pump Room			
SA2301MU330	Fire Water Header Isolation Valve	Open	___
SA2301MU362	Deluge Isolation Valve	Open	___
SA2301MU363	Deluge Isolation Valve	Open	___
Steam Generator 1 Main Steam Safety Valve Area			
2HV8200	Main Steam to Terry Turbine	Open *	___
Steam Generator 2 Main Steam Safety Valve Area			
2HV8201	Main Steam to Terry Turbine	Closed *	___
Condensate Pit			
Entry into the condensate pit requires an oxygen monitor. It is recommended that these valves be checked with the operator during the monthly valve lineup surveillance.			
S21305MU471	CST T-121 Outlet to 2P-140	Locked Open	___
S21305MU473	CST T-121 Outlet to 2P-141	Locked Open	___
S21305MU542	CST T-121 Outlet to 2P-504	Locked Open	___

Table 3.1. (Continued)

Component #	Component Name	Required Position	Actual Position
Control Room Panel 52			
	Steam Generator Isolation		
2HV-4714	Aux. Feed Disch. to 2E-088	Closed	____
2HV-4715	Aux. Feed Disch. to 2E-089	Closed	____
2HV-4730	Aux. Feed Disch. to 2E-088	Closed	____
2HV-4731	Aux. Feed Disch. to 2E-089	Closed	____

* (One of the above 2 steam isolation valves must remain closed until the modification to reduce condensate intrusion to the steam lines is installed; after which both valves will be open.)

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, and 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, 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. 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.

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 renders emergency condensate unusable, and AFW fails resulting in core damage.

Steam Generator Tube Rupture

- A SGTR is followed by failure of AFW, main feedwater, and emergency condensate. 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.

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

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

(4) Turbine Driven Pump Fails to Run.

(5) AFW Steam Admission Valve Failures

- steam admission valves
- trip and throttle valve

(6) AFW System Valve Failures

- flow control valves
- pump discharge valves
- pump suction valves
- valves in testing or maintenance.

(5) Supply/Suction Sources

- condensate storage tank stop valves

- 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 San Onofre and at other PWRs throughout the nuclear industry. Section 5.1 describes experience at San Onofre. 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. 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.

5.1 San Onofre Experience

There were 86 reports of AFW system equipment failures at San Onofre between November of 1983 and July of 1990. These include failures of the AFW pumps, pump discharge flow control valves to steam generators, and pump suction and discharge valves. Failure modes include electrical, instrumentation, and hardware failures, and human errors.

AFW Pump Control Logic, Instrumentation and Electrical Failures

Nineteen failures of the AFW pumps to start, run, trip when required or achieve rated speed were found in the events examined. These occurrences resulted from failures of the turbine governor, breakers, relays and contacts, turbine overspeed device, faulty wiring and power supplies. The failure causes are mechanical wear, corrosion, or improper design and installation.

Failure of AFW Pump Discharge Flow Control and Bypass Valve to Steam Generators

Nineteen failures of the AFW pump discharge flow control and bypass valves were found in the events examined. These resulted from failures of valve control circuits, valve operators and valve breakers. Failures have resulted from DC control grounds, valve binding, dirty or worn contacts, improper torque switch operation, electrical component failure, frayed wiring, valve operator mechanical failure and low hydraulic fluid pressure. Failure causes are mechanical wear, contact oxidation, inadequate maintenance or testing activities and improper design and/or installation. These valves have also experienced various packing leaks, as have pump discharge check valves.

AFW Steam Generator Isolation Valve Failures

Eleven failures of the AFW steam generator isolation valves were found in the events examined. These failures resulted from valve binding, solenoid coil failure, fouled torque switch contacts, oil line leaks, pressure switch settings, hydraulic relief valve failure, control power short circuits, and low hydraulic operating pressure. Failure causes are mechanical wear, contact oxidation, component aging, and inadequate maintenance or testing activities.

AFW Turbine Stop Valve

Fourteen failures of the AFW turbine stop valve were found in the events examined. These failures resulted from valve binding, condensation in the balancing chamber, seat leakage, control circuit grounds, actuator motor failure, torque switch misadjustment or failure, improper trip plunger adjustment, bent or damaged declutch shaft, and missing hardware. Failure causes are mechanical wear, component aging, contact oxidation or fouling, inadequate maintenance or testing activities and improper design.

Human Errors

Ten events relating directly to significant human errors affecting the AFW system were found in the events examined. Motor stator end coil insulation was apparently damaged during repair or inspection. External motor components have been found broken off or damaged. System leakage has resulted from improperly adjusted bolts. Foreign material has been found between switch contacts. Components have failed due to missing parts or hardware. 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. 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).

CC4. 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.

CC5. 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.

CC6. 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.

CC7. 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.

CC8. 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.

CC9. 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.

CC10. 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.

CC11. 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.

CC12. 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.

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 (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, additional weights were added to the back sides of the check valve disks to ensure proper seating. 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. San Onofre-2 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 San Onofre-2 plant.

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