NUREG/CR-5837
PNL-7923

Auxiliary Feedwater System Risk-Based Inspection Guide for the North Anna Nuclear Power Plants

Prepared by
J. R. Nickolaus, N. E. Moffitt, B. F. Gore, T. V. Vo

Pacific Northwest Laboratory
Operated by
Battelle Memorial Institute

Prepared for
U.S. Nuclear Regulatory Commission

AVAILABILITY NOTICE

Availability of Reference Materials Cited in NRC Publications

Most documents cited in NRC publications will be available from one of the following sources:

1. The NRC Public Document Room, 2120 L Street, NW., Lower Level, Washington, DC 20555

2. The Superintendent of Documents, U.S. Government Printing Office, P.O. Box 37082, Washington, DC 20013-7082

3. The National Technical Information Service, Springfield, VA 22161

Although the listing that follows represents the majority of documents cited in NRC publications, it is not intended to be exhaustive.

Referenced documents available for inspection and copying for a fee from the NRC Public Document Room include NRC correspondence and internal NRC memoranda; NRC bulletins, circulars, information notices, inspection and investigation notices; licensee event reports; vendor reports and correspondence; Commission papers; and applicant and licensee documents and correspondence.

The following documents in the NUREG series are available for purchase from the GPO Sales Program: formal NRC staff and contractor reports, NRC-sponsored conference proceedings, international agreement reports, grant publications, and NRC booklets and brochures. Also available are regulatory guides, NRC regulations in the *Code of Federal Regulations*, and *Nuclear Regulatory Commission Issuances*.

Documents available from the National Technical Information Service include NUREG-series reports and technical reports prepared by other Federal agencies and reports prepared by the Atomic Energy Commission, forerunner agency to the Nuclear Regulatory Commission.

Documents available from public and special technical libraries include all open literature items, such as books, journal articles, and transactions. *Federal Register* notices, Federal and State legislation, and congressional reports can usually be obtained from these libraries.

Documents such as theses, dissertations, foreign reports and translations, and non-NRC conference proceedings are available for purchase from the organization sponsoring the publication cited.

Single copies of NRC draft reports are available free, to the extent of supply, upon written request to the Office of Administration, Distribution and Mail Services Section, U.S. Nuclear Regulatory Commission, Washington, DC 20555.

Copies of industry codes and standards used in a substantive manner in the NRC regulatory process are maintained at the NRC Library, 7920 Norfolk Avenue, Bethesda, Maryland, for use by the public. Codes and standards are usually copyrighted and may be purchased from the originating organization or, if they are American National Standards, from the American National Standards Institute, 1430 Broadway, New York, NY 10018.

NUREG/CR-5837
PNL-7923

Auxiliary Feedwater System Risk-Based Inspection Guide for the North Anna Nuclear Power Plants

Manuscript Completed: September 1992
Date Published: October 1992

Prepared by
J. R. Nickolaus, N. E. Moffitt, B. F. Gore, T. V. Vo

Pacific Northwest Laboratory
Richland, WA 99352

Prepared for
Division of Radiation Protection and Emergency Preparedness
Office of Nuclear Reactor Regulation
U.S. Nuclear Regulatory Commission
Washington, DC 20555
NRC FIN L1310

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. North Anna 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 North Anna plant.

Contents

Figure

Table

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 North Anna plant. This information is presented to provide inspectors with increased resources for inspection planning at North Anna.

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 North Anna 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.

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 North Anna.

This inspection guidance is presented in Section 3.0, following a description of the North Anna AFW system in Section 2.0. Section 3.0 identifies the risk important system components by North Anna 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 North Anna 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 3.0.

2 North Anna AFW System

This section presents an overview of the North Anna AFW system (a Westinghouse 3 loop plant), including a simplifie ematic system diagram. In addition, the system suc 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 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 three 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 North Anna AFW system and TDAFW pump steam supply is shown in Figure 2.1.

The AFW system consists of one turbine-driven pump (TDAFW) and two motor-driven feed pumps (MDAFW) that provide feedwater to the steam generators, one Emergency Condensate Storage Tank (ECST), and associated piping, valves and instrumentation. Feedwater is supplied to the TDAFW and MDAFW pumps from the ECST through individual suction headers. The TDAFW and MDAFW pumps are capable of supplying all steam generators. Steam is supplied to the TDAFW turbine from all three SGs through automatically controlled air operated valves (TV-MS-111A and B) located upstream of the main steam trip valves. The TDAFW and MDAFW pumps are equipped with a continuous recirculation flow and TDAFW bearing cooling system, which prevents pump deadheading and bearing overheating. The MDAFW pumps are protected from runout conditions by Pressure Control Valves (PCV) and the TDAFW pump by a restricting orifice, all are located in the pump discharge lines.

The system is designed to automatically start. SGs levels are manually controlled. The TDAFW and the MDAFW pumps will start upon any of the following conditions and initiate auxiliary feedwater flow:

- Low-low SG level
- Main feedwater pumps breakers open
- Safety Injection
- Loss of reserve station service
- ATWS Mitigation System actuation is initiated.

The AFW pumps discharge through check valves and are normally aligned to one SG (FW-P-3A to the "C" SG via HCV-FW-100C, FW-P-3B to the "B" SG via MOV-FW-100B, and the TDAFW pump (FW-P-2) to the "A" SG via FW-MOV-100D). Depending upon plant conditions, the discharge of each pump can be lined up to any SG by opening lock-closed manual isolation valves. The AFW lines for the SGs are each equipped with a flow element, flow transmitter, and a manual flow control valve.

In addition to dual, redundant steam supply and discharge headers, power, control, and instrumentation associated with the two AFW system trains are independent from each other.

The Emergency Condensate Storage Tank is the normal source of water for the AFW system. The tank is required to store a sufficient quantity of demineralized water (110,000 gallons) to maintain the reactor coolant system (RCS) at hot standby conditions for 8 hours during a loss of power and 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 ECST discharge valves (FW-173, FW-160 and FW-143) be locked open to supply the AFW system. Additionally, the Service Water and Fire Protection systems can be manually aligned to provide backup supply to the AFW system.

2.2 Success Criterion

System success requires the operation of at least one pump supplying a minimum of 340 gpm to at least one of the three steam generators within one minute after a loss of all main feedwater.

2.3 System Dependencies

The AFW system depends on AC and DC power at various voltage levels for TDAFW turbine governors, motor operated valve control circuits, solenoid valves, and monitor and alarm circuits. Instrument Air is required for the Main Steam Admission valves (TV-MS-111A & B), AFW Hand Control Valves (FW-HCV-A, B & C) and Pressure Control Valves (FW-PCV-159A & B). The Main Steam Admission and AFW HCVs and PCVs fail open on a loss of Instrument Air or power. Steam availability is required for the TDAFW pumps.

2.4 Operational Constraints

When the reactor is in MODEs 1, 2, or 3 (Hot Standby through Power Operation), North Anna Technical Specifications require three independent AFW pumps (two motor driven 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 one AFW pump or flow path becomes inoperable, it must be restored to operable status within 72 hours or the unit must be placed in HOT SHUTDOWN within the next 6 hours. When two AFW pumps or flow path becomes inoperable, the unit must be placed in HOT STANDBY within 6 hours and in HOT SHUTDOWN within the following 6 hours. When three AFW pumps become inoperable immediate corrective actions must be taken to restore at least one AFW to OPERABLE status as soon as possible.

North Anna Technical Specifications require the Emergency Condensate Storage Tank to be operable with a minimum contained water volume of at least 110,000 gallons.

With the Emergency Condensate Storage Tank inoperable, within 4 hours either the Emergency Condensate Storage Tank is to be returned to OPERABLE status or the 300,000 gallon condensate storage tank is to be demonstrated to be OPERABLE as a backup supply to the AFW system and the Emergency Condensate Storage Tank is to be returned to OPERABLE status within 7 days or the unit is to be placed in HOT SHUTDOWN within 12 hours.

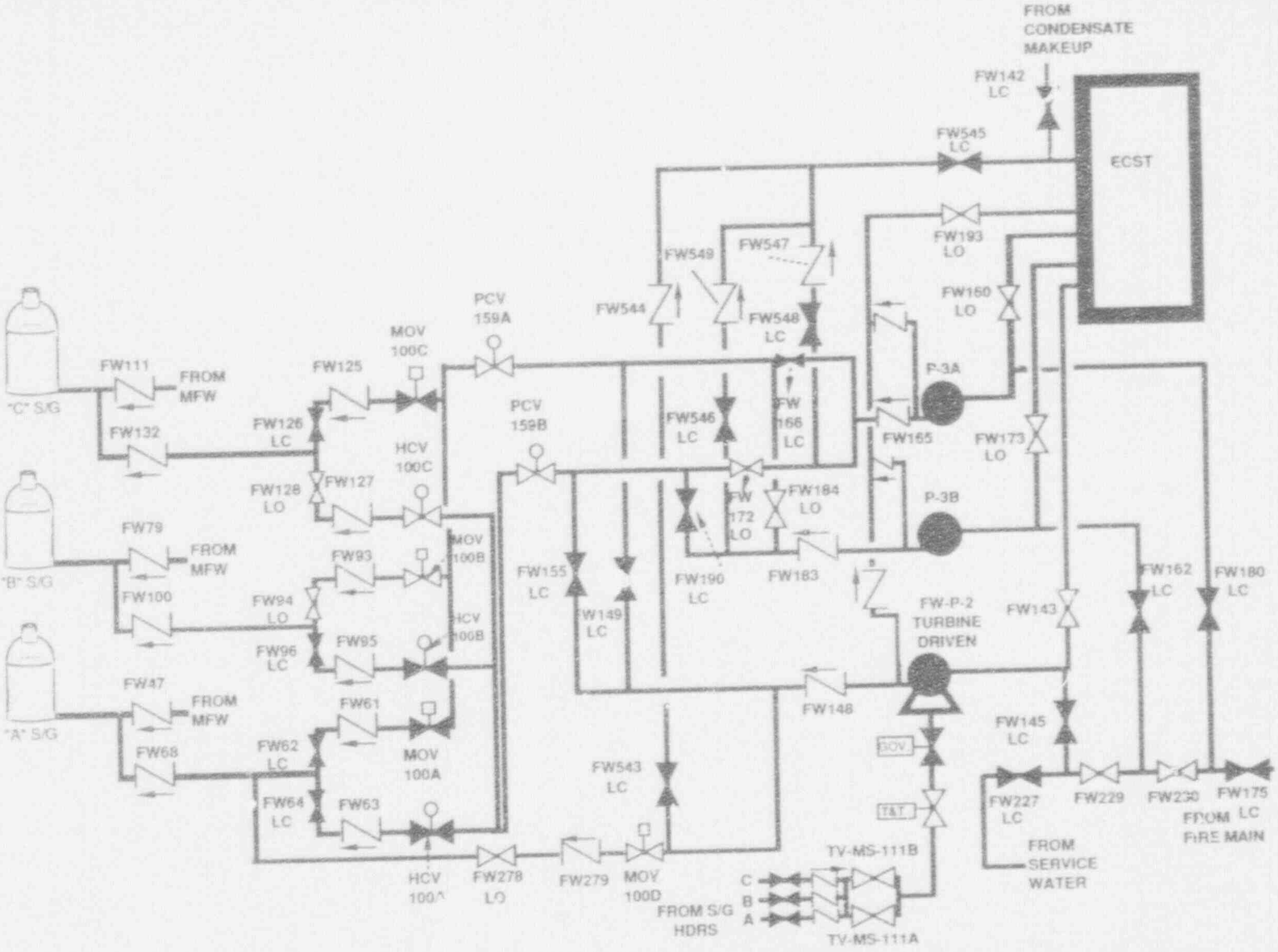

Figure 2.1. North Anna Auxiliary Feedwater System

3 Inspection Guidance for the North Anna AGW System

In this section the risk important components of the North Anna 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 North Anna 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 essentially all of the risk associated with AFW system operation.

3.1 Risk Important AFW Components and Failure Modes

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

The following sections address each of these failure modes, in decreasing order of 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.

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

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

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

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

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

3.1.2 Turbine Driven Pump 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. North Anna has experienced similar failures.

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

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

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

- 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.

- 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.

- Mispositioning of handswitches and procedural deficiencies have prevented automatic pump start. HE3. North Anna has experienced similar failings.

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. North Anna has experienced similar failures.

- Mispositioning of handswitches and procedural deficiencies have prevented automatic pump starts. HE3. North Anna has experienced similar failings.

- Low lubrication oil pressure resulting from heatup due to previous operation has prevented pump restart due to failure to satisfy the protective interlock. DE5.

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.

3.1.5 Air Operated Valves Fail Closed

Main Steam Admission valves: MS-111A & B
AFW Flow Control Valves: FW-HCV-100A, B & C
AFW Pressure Control Valves: FW-PCV-159A & B

The normally closed air operated Main Steam Admission valves admit steam to the TDAFW turbine. They fail open on loss of Instrument Air. The normally closed AFW HCVs and PCVs fail open on a loss of Instrument Air. Pump runout could occur upon failure of the PCVs open. Failure of the normally closed HCVs (FW-HCV-100A & B) open will allow different flow paths to the SGs if the downstream normally locked closed manual isolation valves are open.

- 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. North Anna has experienced similar failures.

- Inadequate air pressure regulation has resulted in control valve failure to operate.

3.1.6 Motor Operated Valves Fail Closed

TDAFW Flow Control valves: FW-MOV-100A, B & C
TDAFW Pump Discharge Isolation: FW-MOV-100D

The TDAFW Flow Control valves are used to control SG level. FW-MOV-100B is normally open and fails "As-Is". FW-MOV-100A & C are normally closed and also fail "As-Is" and are only used during off normal conditions. The TDAFW pump discharge isolation valve is normally open and is used to isolate AFW to the SGs.

- 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. North Anna has experienced similar failures.

- 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. North Anna has experienced similar failures.

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

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

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

- Space heaters designed for pre-operation storage have been found wired in parallel with valve motors which had not been environmentally qualified with them present. DE7

- Multiple flow control valves have been plugged by clams when suction switched automatically to an alternate, untreated source. CC9.

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

3.1.7 Manual Suction or Discharge Valves Fail Closed

TDAFW Pump Train: FW-143; FW-278
MDAFW Pumps: FW-68, FW-173; FW-184, FW-93, FW-172, FW-128

These manual valves are normally locked open. For each train, closure of the first valves 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

3.1.8 Leakage of Hot Feedwater through Check Valves

MDAFW Pump FW-P-3A: FW-165, FW-127, FW-132, FW-63, FW-95
MDAFW Pump FW-P-3B: FW-183, FW-93, FW-100, FW-61, FW-125
TDAFW Pump: FW-148, FW-279, FW-68

- 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. North Anna has experienced leaking check valves.

- 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.

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 CST exists.

Table 3.1. Risk Importance AFW System Walkdown Table for North Anna AFW System Components

Component Number	Component Name	Required Position-losed	Actual Position
	Electrical		
FW-P-3A	Motor Driven Pump	Racked In/Closed	________
FW-P-3B	Motor Driven Pump	Racked In/Closed	________
	Valves		
FW-545	Full Flow Recirc Line Isolation to ECST	Locked Closed	________
FW-142	Condensate Inlet to ECST	Locked Closed	________
FW-193	Inlet Isolation for Recirc to ECST	Locked Open	________
FW-143	Suction Valve to FW-P-2	Locked Open	________
FW-160	Suction Valve to FW-P-3A	Locked Open	________
FW-173	Suction Valve to FW-P-3B	Locked Open	________
FW-180	Suction Valve to Pump P-3A from Firemain	Locked Closed	________
FW-175	Isolation Valve from Firemain to AFW pumps	Locked Closed	________
FW-162	Suction Valve to Pump P-3B from Firemain	Locked Closed	________
FW-145	Suction Valve to FW-P-2 from Firemain	Locked Closed	________
FW-227	Isolation Valve for Service Water to AFW pumps	Locked Closed	________
FW-190	Discharge valve for FW-P-3B to HCV header	Locked Closed	________
FW-184	Discharge valve for FW-P-3B to MOV header	Locked Open	________
FW-546	FW-P-3B full flow Recirc isolation	Locked Closed	________
FW-172	Discharge valve for FW-P-3A to HCV header	Locked Open	________
FW-166	Discharge valve for FW-P-3A to MOV header	Locked Closed	________

Table 3.1. (Continued)

Component Number	Component Name	Required Position-losed	Actual Position
FW-548	FW-P-3A full flow Recirc isolation	Locked Closed	______
FW-155	Discharge valve for FW-P-2 to HCV header	Locked Closed	______
FW-149	Discharge valve for FW-P-2 to MOV header	Locked Closed	______
PCV-159A	Pressure Control Valve on MOV header	Set 900 psig	______
PCV-159B	Pressure Control Valve on HCV header	Set 900 psig	______
FW-62	Isolation valve downstream of FW-MOV-100A	Locked Closed	______
FW-64	Isolation valve downstream of FW-HCV-100A	Locked Closed	______
MOV-100A	MOV on AFW header RC-E-1A	Closed	______
HCV-100A	HCV on AFW header RC-E-1A	Closed	______
FW-94	Isolation valve downstream of MOV-100B	Locked Open	______
FW-96	Isolation valve downstream of HCV-100B	Locked Closed	______
MOV-100B	MOV on AFW header RC-E-1B	Open	______
HCV-100B	HCV on AFW header RC-E-1B	Closed	______
FW-126	Isolation valve downstream of FW-MOV-100C	Locked Closed	______
FW-128	Isolation valve downstream of FW-HCV-100C	Locked Open	______
MOV-100C	MOV on AFW header RC-E-1C	Closed	______
HCV-100C	HCV on AFW header RC-E-1C	Open	______
FW-543	FW-P-2 full Recirc isolation	Locked Closed	______
MOV-100D	AFW header MOV to RC-E-1A, SG A	Open	______
FW-278	MOV-100D isolation valve	Locked Open	______
FW-68	Piping upstream of check valve	Cool	______

Table 3.1. (Continued)

Component Number	Component Name	Required Position-losed	Actual Position
FW-100	Piping upstream of check valve	Cool	________
FW-132	Piping upstream of check valve	Cool	________
FW-61	Piping upstream of check valve	Cool	________
FW-63	Piping upstream of check valve	Cool	________
FW-93	Piping upstream of check valve	Cool	________
FW-95	Piping upstream of check valve	Cool	________
FW-125	Piping upstream of check valve	Cool	________
FW-127	Piping upstream of check valve	Cool	________
FW-279	Piping upstream of check valve	Cool	________
	Control Board Indicators		
	AFW Pumps	Pull-to-lock	________
	ECST Level	>91.4%	________

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

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

5. Supply/Suction Sources

- condensate storage tank stop valve
- hot w   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 North Anna and at other PWRs throughout the nuclear industry. Section 5.1 describes experience at North Anna from 1978 through 1990. 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 individually. 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 4.0, resulting in the inspection guidelines presented in Section 7.0.

5.1 North Anna Experience

The AFW system at North Anna has experienced failures of the AFW pumps and pump governors, pump discharge isolation valves, turbine trip and throttle valves, and system check valves. Failure modes include electrical, instrumentation and control, hardware failures, and human errors.

5.1.1 Multiple Pump Failures

There has been an incidence of entering Mode 3 with all AFW pumps incapable of automatic starts. The steam supply valves for the TDAFW pump were in the close position and the MDAFW pumps were in the pull-to-lock position.

5.1.2 Motor Driven Pump Failures

There have been approximately fourteen events of motor-driven pump failures. One resulted in a trip of a MDAFW pump from overcurrent. MDAFW pumps have failed to start due to instrument and control circuit failures. Failure modes have been due to oil seal adjustments, packing leaks, normal wear and aging, dirty contacts, foreign material in the oil system, and system design deficiencies.

5.1.3 Turbine Driven Pump Failures

Approximately twenty events have occurred that have resulted in decreased operational readiness of the AFW system. Failure modes involved instrumentation and control circuits, pump hardware failures, turbine hardware failures, mechanical wear, system design deficiencies, procedural deficiencies, and human failures during maintenance activities. Improper or inadequate maintenance has resulted in improper adjustment of a governor settings, and steam leaks have caused isolation of the TDAFW pump.

5.1.4 Flow Control and Isolation Valve Failures

Approximately forty-five events have resulted in impaired operational readiness of the air operated and motor operated isolation valves. Principal failure causes were equipment wear, corrosion, instrumentation and control circuit failures, instrument drift, moisture in instrument and control circuits, valve hardware failures, valve wear, and human errors. Valves have failed to operate properly due to failure of control components, contamination and corrosion products in the instrument air system, broken or dirty contacts, torque switch settings, defective torque switches, debris in the system, and calibration problems. Human errors have resulted in introduction of water to the instrument and control circuits, improper control circuit repairs, limit switch adjustment, valve regulator adjustment, and packing leaks.

5.1.5 Check Valve Failures

Approximately eleven events of check valve failure have occurred. The failure mode cited was normal wear and aging, dirty components, missing components, and improper or inadequate maintenance.

5.1.6 Human Errors

There has been one event affecting the AFW system. Personnel have inadvertently tripped a pump during positioning of control switches.

5.2 Industry Wide Experience

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

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

5.2.1 Common Cause Failures

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

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

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

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

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

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

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

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

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

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

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

CC11. Common cause failures have also failed motor operated valves. During the total loss of feedwater event at Davis Besse, the normally-open AFW isolation valves failed to open after they were inadvertently closed. The failure was due to improper setting of the torque switch bypass switch, which prevents motor trip on the high torque required to unseat a closed valve. Previous problems with these valves had been addressed by increasing the torque switch trip setpoint - a fix which failed during the event due to the higher torque required due to high differential pressure across the valve. Similar common mode failures of MOVs have also occurred in other

systems, resulting in issuance of Generic Letter 89-10, "Safety Related Motor-Operated Valve Testing and Surveillance (Partlow, 1989)." This generic letter requires licensees to develop and implement a program to provide for the testing, inspection and maintenance of all safety-related MOVs to provide assurance that they will function when subjected to design basis conditions.

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

5.2.2 Human Errors

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

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

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

5.2.3 Design/Engineering Problems and Errors

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

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

DE3. Turbine trip and throttle valve (TTV) problems are a significant cause of turbine driven pump failures (IN 84-66). In some cases lack of TTV position indication in the control room prevented recognition of a tripped TTV. In other cases it was possible to reset either the overspeed trip or the TTV without 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, check valves were changed from swing type to lift type. Check valve rework has been done at a number of plants. Different valve designs and manufacturers are involved in this problem, and recurring leakage has been experienced, even after repair and replacement.

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

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

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

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

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

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

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

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

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

CF11. For systems using AOVs, operability requires the availability of Instrument Air, backup air, or backup nitrogen. However, NRC Maintenance Team Inspections have identified inadequate testing of check valves

isolating the safety-related portion of the IA system at several utilities (Letter, Roe to Richardson). Generic Letter 88-14 (Miraglia, 1988), requires licensees to verify by test that air-operated safety-related components will perform as expected in accordance with all design-basis events, including a loss of normal IA.

6 References

Beckjord, E. S. June 30, 1989. *Closeout of Generic Issue II.E.6.1, "In Situ Testing of Valves"*. Letter to V. Stello, Jr., U.S. Nuclear Regulatory Commission, Washington, DC.

Brooks, B. P. 1988. *Application Guidelines for Check Valves in Nuclear Power Plants*. NP-5479, Electric Power Research Institute, Palo Alto, California.

Casada, D. A. 1989. *Auxiliary Feedwater System Aging Study. Volume 1. Operating Experience and Current Monitoring Practices*. NUREG/CR-5404. U.S. Nuclear Regulatory Commission, Washington, DC.

Gregg, R. E. and R. E. Wright. 1988. *Appendix Review for Dominant Generic Contributors*. BLB-31-88. Idaho National Engineering Laboratory, Idaho Falls, Idaho.

Miraglia, F. J. February 17, 1988. *Resolution of Generic Safety Issue 93, "Steam Binding of Auxiliary Feedwater Pumps" (Generic Letter 88-03)*. U.S. Nuclear Regulatory Commission, Washington, DC.

Miraglia, F. J. August 8, 1988. *Instrument Air Supply System Problems Affecting Safety-Related Equipment (Generic Letter 88-14)*. U.S. Nuclear Regulatory Commission, Washington, DC.

Partlow, J. G. June 28, 1989. *Safety-Related Motor-Operated Valve Testing and Surveillance (Generic Letter 89-10)*. U.S. Nuclear Regulatory Commission, Washington, DC.

Rothberg, O. June 1988. *Thermal Overload Protection for Electric Motors on Safety-Related Motor-Operated Valves - Generic Issue II.E.6.1*. NUREG-1296. U.S. Nuclear Regulatory Commission, Washington, DC.

Travis, R. and J. Taylor. 198[illegible] [illegible]pment *of Guidance for Generic, Functional[illegible] [illegible]ented PRA-Based Team Inspections for BWR Plants-Identification of Risk-Important Systems, Components and Human Actions*. TLR-A-3874-TGA Brookhaven National Laboratory, Upton, New York.

AEOD Reports

AEOD/C404. W. D. Lanning. July 1984. *Steam Binding of Auxiliary Feedwater Pumps*. U.S. Nuclear Regulatory Commission, Washington, DC.

AEOD/C602. C. Hsu. August 1986. *Operational Experience Involving Turbine Overspeed Trips*. U.S. Nuclear Regulatory Commission, Washington, DC.

AEOD/C603. E. J. Brown. December 1986. *A Review of Motor-Operated Valve Performance*. U.S. Nuclear Regulatory Commission, Washington, DC.

AEOD/E702. E. J. Brown. March 19, 1987. *MOV Failure Due to Hydraulic Lockup From Excessive Grease in Spring Pack*. U.S. Nuclear Regulatory Commission, Washington, DC.

AEOD/T416. January 22, 1983. *Loss of ESF Auxiliary Feedwater Pump Capability at Trojan on January 22, 1983*. U.S. Nuclear Regulatory Commission, Washington, DC.

Information Notices

IN 82-01. January 22, 1982. *Auxiliary Feedwater Pump Lock out Resulting from Westinghouse W-2 Switch Circuit Modification*. U.S. Nuclear Regulatory Commission, Washington, DC.

IN 84-32. E. L. Jordan. April 18, 1984. *Auxiliary Feedwater Sparger and Pipe Hangar Damage*. U.S. Nuclear Regulatory Commission, Washington, DC.

IN 84-66. August 17, 1984. *Undetected Unavailability of the Turbine-Driven Auxiliary Feedwater Train*. U.S. Nuclear Regulatory Commission, Washington, DC.

IN 87-34. C. E. Rossi. July 24, 1987. *Single Failures in Auxiliary Feedwater Systems*. U.S. Nuclear Regulatory Commission, Washington, DC.

IN 87-53 C. E. Rossi. October 20, 1987. *Auxiliary Feedwater Pump Trips Resulting from Low Suction Pressure.* U.S. Nuclear Regulatory Commission, Washington, DC.

IN 88-09. C. E. Rossi. March 18, 1988. *Reduced Reliability of Steam-Driven Auxiliary Feedwater Pumps Caused by Instability of Woodward PG-PL Type Governors.* U.S. Nuclear Regulatory Commission, Washington, DC.

IN 89-30. R. A. Azua. August 16, 1989. *Robinson Unit 2 Inadequate NPSH of Auxiliary Feedwater Pumps.* Also, Event Notification 16375, August 22, 1989. U.S. Nuclear Regulatory Commission, Washington, DC.

Inspection Report

IR 50-489/89-11; 50-499/89-11. May 26, 1989. *South Texas Project Inspection Report.* U.S. Nuclear Regulatory Commission, Washington, DC.

NUREG Report

NUREG-1154. 1985. *Loss of Main and Auxiliary Feedwater Event at the Davis Besse Plant on June 9, 1985.* U.S. Nuclear Regulatory Commission, Washington, DC.

Distribution

No. of
Copies

OFFSITE

10 U.S. Nuclear Regulatory Commission

B. K. Grimes
OWFN 9 A2

F. Congel
OWFN 10 E4

H. Berkow
OWFN 14 H20

W. Beckner
OWFN 10 A2

A. El Bassioni
OWFN 10 A2

E. Imbro
OWFN 9A1

S. M. Long
OWFN 10 A2

K. Campe
OWFN 1 A2

J. Chung (10)
OWFN 10 A2

B. Thomas
OWFN 12 H26

2 U.S. Nuclear Regulatory Commission - Region 1

C. Hehl
W. F. Kane

No. of
Copies

2 U.S. Nuclear Regulatory Commission - Region 2

L. Reyes
A. Herdt

4 North Anna Resident Inspector Office

J. H. Taylor
Brookhaven National Laboratory
Bldg. 130
Upton, NY 11973

R. Travis
Brookhaven National Laboratory
Bldg. 130
Upton, NY 11973

R. Gregg
EG&G Idaho, Inc.
P.O. Box 1625
Idaho Falls, ID 83415

Dr. D. R. Edwards
Professor of Nuclear Engineering
University of Missouri - Rolla
Rolla, MO 65401

ONSITE

27 Pacific Northwest Laboratory

S. R. Doctor
L. R. Dodd
B. F. Gore (10)
N. E. Moffitt
J. R. Nickolaus (5)
B. D. Shipp
F. A. Simonen
T. V. Vo
Publishing Coordination
Technical Report File (5)

NRC FORM 335 (2-89) NRCM 1102, 3201, 3202

U.S. NUCLEAR REGULATORY COMMISSION

BIBLIOGRAPHIC DATA SHEET

(See instructions on the reverse)

1. REPORT NUMBER (Assigned by NRC, Add Vol., Supp., Rev., and Addendum Numbers, if any.)

NUREG/CR-5837
PNL-7923

2. TITLE AND SUBTITLE

Auxiliary Feedwater System Risk-Based Inspection Guide for the North Anna Nuclear Power Plants

3. DATE REPORT PUBLISHED

MONTH	YEAR
October	1992

4. FIN OR GRANT NUMBER

L1310

5. AUTHOR(S)

J. R. Nickolaus, N. E. Moffitt, B. F. Gore, T. V. Vo

6. TYPE OF REPORT

Technical

7. PERIOD COVERED (Inclusive Dates)

12/91 to 8/92

8. PERFORMING ORGANIZATION — NAME AND ADDRESS (If NRC, provide Division, Office or Region, U.S. Nuclear Regulatory Commission, and mailing address; if contractor, provide name and mailing address.)

Pacific Northwest Laboratory
Richland, WA 99352

9. SPONSORING ORGANIZATION — NAME AND ADDRESS (If NRC, type "Same as above"; if contractor, provide NRC Division, Office or Region, U.S. Nuclear Regulatory Commission, and mailing address.)

Division of Radiation Protection and Emergency Preparedness
Office of Nuclear Reactor Regulation
U.S. Nuclear Regulatory Commission
Washington, D.C. 20555

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. North Anna 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 North Anna plant.

12. KEY WORDS/DESCRIPTORS (List words or phrases that will assist researchers in locating the report.)

Inspection, Risk, PRA, North Anna, Auxiliary Feedwater (AFW)

13. AVAILABILITY STATEMENT

Unlimited

14. SECURITY CLASSIFICATION

(This Page)
Unclassified

(This Report)
Unclassified

15. NUMBER OF PAGES

16. PRICE

NUREG/CR-5837

AUXILIARY FEEDWATER SYSTEM RISK-BASED INSPECTION GUIDE FOR THE NORTH ANNA NUCLEAR POWER PLANTS

OCTOBER 1992

UNITED STATES
NUCLEAR REGULATORY COMMISSION
WASHINGTON, D.C. 20555-0001

OFFICIAL BUSINESS
PENALTY FOR PRIVATE USE, $300

FIRST CLASS MAIL
POSTAGE AND FEES PAID
USNRC
PERMIT NO. G-67

120555139531 1 1AN1RG
US NRC-OADM
DIV FOIA & PUBLICATIONS SVCS
TPS-PDR-NUREG
P-211
WASHINGTON DC 20555