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McGuire Nuclear Station Unit 1 Auxiliary Feedwater System Reliability Study Evaluation

Prepared by G. H. Bradley, Jr.

Sandia National Laboratories

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ABSTRACT

This report presents the results of the review of the Auxiliary Feedwater System Reliability Analysis for the McGuire Nuclear Station Unit 1.

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Summary and Conclusions

The accident at Three Mile Island resulted in many studies which outlined the events leading to the accident as well as those following. One of the important safety systems involved in the mitigation of such accidents was determined to be the Auxiliary Feedwater System (AFWS). Each operating plant's AFWS was studied and analyzed. The results were reported in NUREG-0611[3]. Prior to obtaining an operating license, the licensee of each nonoperating plant is required[1] to perform a reliability analysis of his AFWS for three transient conditions involving loss of main feedwater in a manner similar to the study made by NUREG-0611. Duke Power Company, the licensee for William B. McGuire Nuclear Station Unit 1, submitted a reliability report[2] to the U.S. Nuclear Regulatory Commission (NRC) in July 1980. A supplement[7] to this report was submitted in February 1981. These reports were reviewed by Sandia National Laboratories (SNL). The following conclusions resulted from the review:

1. Duke Power Company has satisfactorily complied with the requirement to make a reliability study of their AFWS.

2. A comparison of the reported reliability of McGuire's AFWS to those of operating plants shows that McGuire's reliability is in the low to medium range of the AFWS reliability for operating plants. If the flow requirements were reduced or if operator action could be taken to increase the quantity of auxiliary feedwater, McGuire's reliability would be in the medium to high range. Sandia is in agreement with these assessments. The reason for the low reliability is the fact that the AFWS at McGuire is mechanically throttled to provide protection from a break in the main feedwater line to or rupture of a steam generator.

1. Introduction

1.1 Background

The results of many studies pertaining to the Three Mile Island Nuclear Power Plant accident conclude that a proper functioning Auxiliary Feedwater System (AFWS) is of prime importance in the mitigation of such accidents. Therefore, a letter dated March 10, 1980[1] stating NRC's requirements regarding the AFWS was sent to all operating license applicants with a Nuclear Steam Supply System (NSSS) designed by Westinghouse or Combustion Engineering.

The Duke Power Company (DP) Charlotte, North Carolina, the applicant for an operating license for the McGuire Nuclear Power Station Unit 1 which has a Westinghouse-designed NSSS, provided a response in the form of a reliability analysis[2] which was prepared for them by Westinghouse Nuclear Energy Systems, Westinghouse Electric Corporation.

1.2 Review Activities

This project undertakes a review of those portions of the reliability analysis which (1) satisfy requirement (b) of the letter which states, "perform a reliability evaluation similar in method to that described in Enclosure 1 (NUREG-0611) that was performed for operating plants and submit it for staff review," and (2) provide answers to the short and long-term

recommendations of NUREG-0611 in response to requirement (c) in the letter. The review was conducted according to Schedule 189[4] which was submitted by SNL to NRC.

1.3 Content and Results of the Reliability Analysis

The reliability analysis[2] was submitted to NRC in July 1980 and was received by SNL on September 8, 1980. The analysis makes a detailed study of the failure of the AFWS to provide sufficient Auxiliary Feedwater (AFW) flow to three of the four steam generators and compares the results obtained with those obtained for the operating plants studied in NUREG-0611. The analysis places the McGuire Nuclear Station Unit 1 with those operating plants having medium to low AFWS reliability.

1.4 Scope and Level of SNL Effort

SNL reviewed the reliability analysis[2] submitted by DP. Particular attention was directed toward determining that the analysis addressed in depth the reliability of the AFWS when subjected to three transient cases (1) LMFW, Loss of Main Feedwater, (2) LMFW/LOSP, Loss of Main Feedwater/Loss of Offsite Power and (3) LMFW/LAC, Loss of Main Feedwater/Loss of all ac power. Also the methods used in the analysis were compared to those used in NUREG-0611. The specific findings are presented below in Sections 3, 4 and 5.

Comments and questions were recorded during the review and submitted to NRC on the 3rd of October 1980. These questions were forwarded to DP by NRC. DP and its contractor Westinghouse Electric Corporation met with representatives from NRC and SNL on the 27th and 28th of October at the McGuire Nuclear Station Unit 1. At this meeting a review of the McGuire AFWS and the AFWS reliability analysis was given by Westinghouse and a tour of the AFWS was conducted by DP. During the tour, observations were made to facilitate the discussion period which followed. In the discussion period each of the 33 questions asked was answered and discussed in detail. The official responses[5] were forwarded to NRC on the 10th of November. No exact verification of the results could be made since the basic events and the failure allocations associated with each event were not published in the report[2].

2. AFWS Configuration

2.1 General Description and Function of the AFWS

Figure 1 is a simplified flow diagram of the AFWS for McGuire Unit No. 1. The AFWS for McGuire Unit No. 2 is of identical design. Each unit's AFWS consists of two motor-driven pumps (450 gpm @ 3200 ft. head) and one turbine-driven pump (900 gpm @ 3200 ft. head). The pump discharge headers are connected through associated piping, valves, and controls such that motor-driven AFW pump A supplies water to A and B steam generators and motor-driven AFW pump B

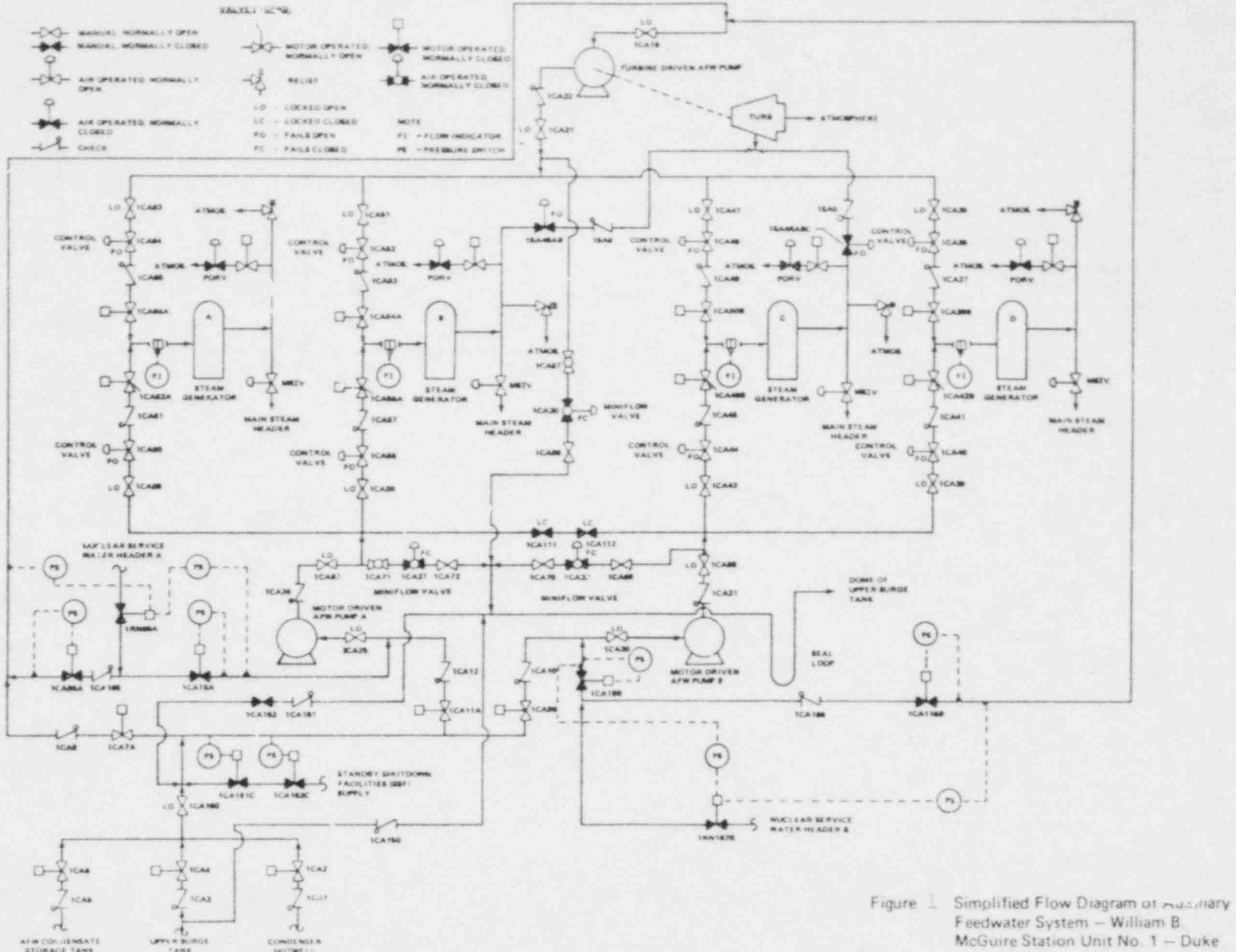

Figure 1 Simplified Flow Diagram of Auxiliary Feedwater System – William B. McGuire Station Unit No. 1 – Duke Power Company

supplies water to steam generators C and D. The turbine-driven AFW pump supplies water to all steam generators. The criterion for successful performance of the AFWS is the delivery of a minimum of 450 gpm to three of the four steam generators.

Water to the suction of each unit's AFWS is supplied from several non-safety grade water sources and one safety grade water source. The water is supplied from these sources on a priority based on water quality as follows:

Source	Safety Grade	Maximum Capacity
1. Upper Surge Tanks	No	85,000 gallons
2. Auxiliary Feedwater Condensate Storage Tank	Nc	42,500 gallons
3. Condenser Hot Well	No	170,000 gallons
4. Nuclear Service Water	Yes	Nuclear Service Water Pond (1.8×10^8 gal)

An additional 30,000 gal. (maximum) is available from the condensate storage tank when the condensate storage tank pumps are available to fill the upper surge tanks. A source of non-steam generator quality water is also available through the steam generator quality water lines from the Standby Shutdown Facilities (SSF). Layout of piping for this source of water is constructed to run through designated "vital" areas of the plant with tight security controlled access to provide a source of water that is potentially safe against acts of

sabotage by outside persons not employed at the nuclear site. Only the redundant isolation valves and the associated piping are safety grade components.

The non-safety grade water sources are headered into a common line in the Service Building. This single line is then routed to the AFW pumps located in the Auxiliary Building. The safety-grade Nuclear Service Water System (NSWS) is connected to the AFWS of each unit such that redundant nuclear service water channels A and B are aligned to the turbine-driven pump of each unit; channel A is also aligned to motor-driven AFW pump A while channel B is aligned to motor-driven AFW pump B of each unit. Safety class isolation valves are provided in the AFW pump suction lines to isolate the non-safety grade sources when supply from the NSWS is required.

The discharge from each pump flows through an air-operated control valve and a motor-operated (remote controlled) isolation valve in individual feedlines to each steam generator. The discharge from each AFW pump also has a loop for full flow pump testing that is also used as a minimum flow loop for protecting the pump during low flow operation. A locked closed interconnection for long-term use only in the case of a LOCA is provided between the AFW motor-driven pump discharge lines. This permits flow from either pump to be fed to all four steam generators. The flow from the AFWS

enters the steam generators through individual nozzles on each generator.

2.1.1 Emergency Operation

Start-up of the AFW pumps is automatic. As an accident initiated cooldown of the reactor progresses, the AFWS is controlled manually from the Control Room or locally at the pumps if the Control Room is not available. At start-up, motor-driven AFW pumps supply 170 gpm feedwater to each steam generator and the turbine-driven AFW pump supplies an additional 180 gpm per steam generator. As less water is needed to maintain the water level in the steam generators, AFWS flow is diminished by adjusting the motor-driven AFW pump discharge control valves and/or adjusting the turbine speed or pump discharge control valves on the turbine-driven pump. As the accident progresses the turbine-driven AFW pump is removed from service by the operator to minimize condensate loss to the atmosphere. The AFWS is allowed to function during an accident shutdown until the reactor coolant temperature is reduced to 350°F and a pressure of 425 psig. At this point, the Residual Heat Removal System (RHRS) is placed into operation and the AFWS taken out of service.

Water supply for the AFWS during emergency plant operation is normally from the auxiliary feedwater condensate storage tank. Under highest flow condition (two unit blackout), each unit has a

10 minute minimum supply of condensate quality water. Before depletion of this source, the operator is expected to take manual control of the AFWS and trip the turbine-driven pump. If this pump is needed, the operator can open a bypass valve (1CA152) to provide a parallel flow path from the upper surge tank and additional feedwater to prevent automatic switchover to the NSWS source. The operator also has the option of defeating the auto switchover after taking manual control of the system.

If the AFW condensate storage tank is not available, feedwater is next supplied from the Upper Surge Tank (UST). Makeup is required to the UST if it is used as the AFWS water source through an entire cooldown operation. Normal make-up to the UST is from the condensate storage tank of the Condensate System or from the Demineralized Water System. A maximum of 30,000 gallons can be supplied to the UST if two condensate storage tank pumps are available. Each pump supplies flow at 300 gpm. If two demineralized water pumps are available, a maximum of 127,500 gallons from the filtered water tanks at 475 gpm flow from each pump can be supplied to the UST. Operator action is required to align the UST to these sources. In the event the AFW Condensate Storage Tank and the UST are both unavailable, supply to the suction of the AFW pumps is next supplied from the condenser hotwell. The total gallons per minute flow from the hotwell is limited based on condenser vacuum and water level. Operator action is required to limit total flow from the AFW pumps.

Should all the previously mentioned non-safety grade feedwater sources be unavailable to the suction of the AFW pumps, the assured source of water is then supplied from the Nuclear Service Water System (NSWS). The NSWS water source is aligned automatically when the suction pressure of the AFW pumps drops below 2 psig for 3 seconds. The NSWS pumps are required to supply cooling water to the motor-driven AFW pumps. The suction lines of the AFW pumps are piped into the NSWS pump discharge piping downstream of all NSWS cooling control valves; thus, the NSWS pumps do not have to operate to supply water to the AFW turbine-driven pump.

For non-seismic plant conditions and in the event water is not available from the NSWS or from the Condensate System as explained above, feedwater may be supplied to the steam generators via the Standby Shutdown Facilities (SSF). The isolation valves that isolate the supply of water from the SSF open automatically when the suction pressure of the AFW turbine-driven pump drops below a preset value to align the AFW pumps to this source of feedwater.

2.2 Component Design Classification

The AFWS of each unit including its primary water supply from the NSWS are engineered safeguards systems. The major components of these systems are designed according to seismic and other requirements as given in the following table:

System/Component	ASME-B/PV Code Section	Seismic OBE	Seismic DBE
1. AFWS - Turbine-Driven Pumps	III - Class 3	Yes	Yes
2. AFWS - Motor-Driven Pumps	III - Class 3	Yes	Yes
3. AFWS - Valves	III - Class 2	Yes	Yes
	III - Class 3	Yes	Yes
4. NSWS - Pumps	III - Class 3	Yes	Yes
5. NSWS - Strainers	VIII	Yes	Yes
6. NSWS - Valves	III - Class 2	Yes	Yes
	III - Class 3	Yes	Yes

The components listed above are also designed for tornado, wind and missile protection. Piping for the safety-related portions of AFWS and NSWS is designed accordingly. The motors of the motor-driven pumps of the AFWS and NSWS for each unit are designated Electrical-Safety - Class 2E. This same classification is given to the motors of valve motor operators of these systems. Electrical equipment of 2E classification requires seismic qualification to a safe shutdown earthquake criterion and are so designed.

The NSWS is designed to provide cooling water for various Auxiliary Building and Reactor Building heat exchangers during all phases of station operation. Each unit has two redundant "safety-related"

headers serving two trains of equipment necessary for a safe plant shutdown and a "non-essential" header serving equipment not required for a safe shutdown. Water is normally supplied to the system from a lake (Lake Norman). Should a seismic event cause a loss of the lake, a Standby Nuclear Service Water Pond (SNSWP) that is designed to meet seismic loads provides a source of water to the NSWS. As an Engineering Safeguards System the SNSWP is automatically valved to provide feed to the channels of the NSWS of both units following a safety injection signal from either unit.

2.3 Power Sources

The turbine-driven AFW pump of each unit is supplied with steam from redundant feedlines. One feedline is supplied steam from the unit's steam generator "B" outlet header upstream of its main steam isolation valve (MSIV) and the other from the unit's steam generator "C" outlet header upstream from its MSIV. This assures steam to the turbine-driven AFW pump even with these two MSIV's closed.

Each unit of the station is equipped with an Essential Auxiliary Power System (EAPS) that includes onsite 4160 V, 600 V, 120 V ac and 125 V dc power. This system supplies power necessary for a safe shutdown of the reactor, containment isolation, containment spray and cooling, auxiliary feedwater flow, and emergency core cooling following an accident. It consists of redundant switchgear, load centers, motor control centers, panelboards, battery chargers,

batteries, inverters, diesel-engine ac generators (two per unit), protective relays, control devices, and interconnecting cable supplying two redundant load groups of each unit.

The 120 V ac and the 125 V dc Vital Instrumentation and Control Power Systems of the EAPS supply continuous power for control and instrumentation in the Reactor Protection and Control System. The EAPS of each unit is designed to meet the criteria set forth in the NRC General Design Criteria (GDC 17, GDC 18), IEEE 279-1971, IEEE 308-1971 and Regulatory Guides 1.6, 1.9, and 1.32.

The motor-driven pumps of a unit's AFWS receive power from their EAPS via two identical but separate 4160 V emergency buses. In the event of a loss of offsite power, the pumps receive power via the emergency buses from two diesel ac generators (4160 V) designated "A" and "B". Diesel generator "A" provides power to the emergency bus that feeds the unit's AFW motor-driven pump designated "A" and diesel generator "B" provides power to the bus feeding AFW pump "B". Redundant motor-operated valves and other electrical equipment designated "A" and "B" receive power in a similar manner.

2.4 Instrumentation and Controls

The controls and instrumentation of the AFWS are designed to meet NRC-imposed safety class separation requirements.

2.4.1 Controls

The control of auxiliary feedwater flow and steam generator water level is accomplished from the main control room by use of air-operated valves that automatically maintain a correct position, (set manually in the control room or at a local control panel) for the required auxiliary feedwater flow. Since the instrumentation used in the automatic control of valve position is not qualified for all accident events, safety grade solenoids are provided to assure that the AFW control valves are in the "fail-safe open" position following the automatic start of a corresponding upstream AFW pump. The pump minimum-flow valves are likewise provided with safety-grade solenoids to isolate pump minimum flow on the same automatic start signal.

After any automatic start, the operator can reposition the solenoid valves from the control room and use the non-safety control if operable. If repositioning of the solenoid valves causes a flow upset, as indicated by flow indication on each steam generator, the solenoid valves must be placed back in the fail-safe position, and the control valves manually throttled locally at the valve using handwheels provided.

All manual valves in the main flow paths of the AFWS are mechanically "lock-opened" or "lock-closed" in their normal system operation position. The motor-operated valves in the flow path are designed to fail in their "as is" position.

2.4.2 Information Available to Operator

The important information available to the operator at the control room and locally near the component's location includes for each AFW pump the suction pressure, suction flow and discharge pressure; and for each steam generator the flow, water level and pressure. Additional information is given in the following instrumentation table:

Component Control	NSSS System	Physical Location Control Room	Local
1. Motor (AFW Pump) - start/stop pump	AFWS	X	X
2. Turbine (AFW Pump) - start/stop pump	Main Steam	X	X
3. Turbine (AFW Pump) - raise/lower speed	Main Steam	X	X
4. AFW pump auto defeat - on/off	AFWS	X	X
5. UST supply motor-operated isolation valve (1CA4) - open/close	AFWS	X	X
6. Condenser hotwell supply motor-operated isolation	AFWS	X	X
valve(1CA2) - open/close	AFWS	X	X
7. AFW condensate storage tank supply motor-operated isolation valve (1CA5) - open/close	AFWS	X	X

Component Control	NSSS System	Physical Location Control Room	Physical Location Local
8. Nuclear se ice water supply motor-operated isolation valves (1CA85A, 1CA86A, 1CA18B, 1CA116B, 1CA15A and 1CA117B) - open/close	AFWS	X	X
9. AFW pump suction motor-operated isolation valves (1CA7A, 1CA9B, and 1CA11B) - open/close	AFWS	X	X
10. Feedwater air-operated flow control valves (1CA40, 1CA44, 1CA56, 1CA60, 1CA36, 1CA48, 1CA52, and 1CA64) - flow position	AFWS	X	X
11. Feedwater motor-operated isolation valves (1CA42B, 1CA46B, 1CA58A, 1CA62A, 1CA38B, 1CA50B, 1CA54A, and 1CA66A) - open/close	AFWS	X	X
12. NSWS to AFW pump suction auto switch-over switch-defeat.	AFWS		X

Component Control	NSSS System	Physical Location Control Room	Physical Location Local
13. Alternate SSF supply motor-operated isolation valves (1CA161C and 1CA162C)	AFWS		X

Process/Component Status Indicator	NSSS System	Physical Location Control Room	Local
1. AFW pumps motor - on/off	AFWS	X	X
2. AFW pump turbine - on/off	AFWS	X	X
3. AFW pump turbine - speed	Main Steam	X	X
4. AFW pump turbine - steam pressure	Main Steam	X	X
5. AFW pump auto start defeat - on/off	AFWS	X	
6. Control room overidden by local control	AFWS	X	
7. Upper surge tank - water level	Condensate	X	
8. Steam condensate storage tank - water level	Condensate	X	
9. Condenser hotwell - water level	Main Condenser	X	
10. AFW condensate storage tank - water level	AFWS	X	
11. NSWS pond - water level	NSWS	X	
12. UST supply motor-operated isolation valve (1CA4) - open/close	AFWS	X	X
13. Condenser hotwell supply motor-operated isolation valve (1CA2) - open/close	AFWS	X	X

Process/Component Status Indicator	NSSS System	Physical Location Control Room	Level
14. AFW condensate storage tank supply motor-operated isolation valve (1CA6) - open/close	AFWS	X	X
15. NSWS supply motor-operated isolation valves (1CA85A, 1CA15A, 1CA116B and 1CA117B) - open/close	AFWS	X	X
16. AFW pump suction motor-operated isolation valves (1CA7A, 1CA9B, and 1CA11B) - open/close	AFWS	X	X
17. AFW air-operated minimum flow valves (1CA20, 1CA27, and 1CA32) - open/close	AFWS	X	
18. AFW air-operated feedwater flow control valves (1CA40, 1CA44, 1CA56, 1CA60, 1CA36, 1CA48, 1CA52, 1CA64) open/close and 0-100 percent open	AFWS	X	X
19. AFW feedwater flow motor-operated isolation valves (1CA42B, 1CA46B, 1CA58A, 1CA62A, 1CA38B, 1CA50B, 1CA54A, and 1CA66A) - open/close	AFWS	X	X
20. Main feedwater pressure	Main Feedwater	X	

Process/Component Alarms	NSSS System	Physical Location Control Room
1. AFW turbine stop valve - closed	Main Steam	X
2. AFW turbine speed setting - less than 3600 rpm	Main Steam	X
3. UST - low water level	Condensate	X
4. UST supply motor-operated isolated valve (1CA4) - closed	AFWS	X
5. AFW pump suction motor-operated isolation valve (1CA7A, 1CA9B, 1CA11A) - closed	AFWS	X
6. Individual AFW pump - low suction pressure	AFWS	X
7. Individual AFW pump low suction flow	AFWS	X
8. AFW pump air-operated minimum flow valves (1CA20, 1CA27, and 1CA32) - open	AFWS	X
9. Feedwater flow air-operated control valves (1CA40, 1CA44, 1CA56, and 1CA60) - open or closed	AFWS	X

Process/Component Alarms	NSSS System	Physical Location Control Room
10. Feedwater flow air-operated control valves (1CA36, 1CA48, 1CA52, and 1CA64)-above or below setpoint	AFWS	X
11. Feedwater flow motor-operated isolation valves (1CA42B, 1CA46B, 1CA58A, 1CA62A, 1CA38B, 1CA50B, 1CA54A, and 1CA66A) - closed	AFWS	X

2.4.3 Initiation Signals for Automatic Operation

The AFW motor-driven pumps start automatically on the following signals:

1. Two out of four low-low water level signals in any steam generator,
2. Loss of all main feedwater pumps,
3. Initiation of a safety injection "S" signal,
4. Loss of offsite power (station blackout).

An auto-start-defeat switch is provided for items 1 and 2 above for use during periods not requiring an automatic motor-driven AFW pump start. During periods which require automatic start, the defeat feature is automatically removed. The AFW turbine-

driven pump starts automatically upon the generation of two out of four low-low water level signals in any two steam generators or upon loss of offsite power.

The piston-operated isolation valves (1SA48 and 1SA49) that control steam to the turbine-driven AFW pump are held closed with air through redundant normally-energized electrical solenoid control valves connected in a series configuration. De-energizing one of the redundant control solenoids will vent air from the "fail-open" valve operator allowing the isolation valve to open and admit steam to the turbine of the AFW turbine-driven pump.

Whenever any AFW pump starts automatically, the Steam Generator Blowdown System (SGBS) is automatically isolated by closing piston operated isolation valves. The SGBS does not isolate automatically on an operator induced AFW pump start so that operation of the SGBS is maintained during all normal modes of plant operation.

2.5 Testing

The AFW pumps are periodically tested to meet inservice surveillance requirements. A full flow test loop to the UST is provided at the discharge of each AFW pump. Adequate instrumentation is provided to verify pump performance. The motor-driven AFW pumps may be used during plant startup in their normal alignment to the steam generators. Pump performance and automatic feedwater flow control can be verified during this mode of operation. The turbine-driven AFW pump performance and its discharge control valve travel stop settings can also be verified during this mode of operation.

2.6 Technical Specifications

A review of the Technical Speci ication indicates that for power, start-up, or hot standby plant status the limiting conditions of the AFWS for plant operation include:

1. At least three independent auxiliary feedwater pumps and associated flow paths shall be operable with:

    a. Two motor-driven AFW pumps each capable of being powered from separate emergency buses and,

    b. One turbine-driven AFW pump capable of being powered from an operable steam supply system.

2. With one auxiliary feedwater pump inoperable, restore at least three AFW pumps (two capable of being powered from separate emergency buses and one capable of being powered by an operable steam supply system) to an operable status within 72 hours or be in at least hot standby condition within the next 6 hours and in a hot shutdown within the following 6 hours.

The Technical Specification requires all valves of the AFWS to be given inservice tests and inspections in accordance with the ASME Boiler and Pressure Vessel Code (Section XI and applicable Addenda) for Safety Class 1, 2 and 3 components. Additional surveillance requirements include:

1. At least once per 31 days

   a. Verifying that each motor-driven pump develops a discharge pressure of greater than or equal to 1210 psig at a flow of greater than or equal to 450 gpm.

   b. Verifying that the steam turbine-driven pump develops a discharge pressure of greater than or equal to 1210 psig at a flow of greater than or equal to 900 gpm when the secondary steam supply pressure is greater than 900 psig.

   c. Verifying that each non-automatic valve in the flow path that is not locked, sealed, or otherwise secured in position is in its correct position.

   d. Verifying that each automatic valve in the flow path is in the fully open position whenever the auxiliary feedwater system is placed in automatic control or when above 10 percent of RATED THERMAL POWER.

2. At least once per 18 months during shutdown

   a. Verifying that each motor-driven pump starts automatically upon receipt of each of the following test signals:

      (1) Loss of both main feedwater pumps,

      (2) Safety injection,

      (3) Steam Generator Water Level -- Low-Low from one steam generator.

b. Verifying that the steam turbine-driven pump starts automatically upon receipt of each of the following test signals:

(1) Loss of offsite power,

(2) Steam Generator Water Level -- Low-Low from two steam generators.

c. Verifying that the valve in the suction line of each auxiliary feedwater pump from the Nuclear Service Water System automatically actuates to its full open position within less than or equal to 10 seconds on a low suction pressure test signal.

3. Discussion

3.1 Mode of AFWS Initiation

The AFWS is initiated automatically. The MDP's will start on (1) two out of four low-low water level signals in any steam generator, (2) loss of all main feedwater pumps, (3) initiation of a safety injection signal, and (4) loss of offsite power. The TDP starts on the generation of two out of four low-low water level signals in any two steam generators or upon loss of offsite power. In the event of low suction pressure the NSWS is automatically aligned to the pumps and suction pressure restored.

3.2 System Control Following Initiation

After initiation, proper flow is established by adjusting the MDP discharge control valves and/or adjusting the TDP speed or discharge

control valves. When the reactor coolant condition is reduced to 350°F and 425 psig the RHRS is placed into service and the AFWS taken out of service.

3.3 Test and Maintenance Procedures and Unavailability

The technical specifications require that all valves be given in service tests and inspections in accordance with the ASME Boiler and Pressure Vessel Code (Section XI and applicable Addenda) for Safety class 1, 2, and 3 components. Also every 31 days there are (1) pump discharge pressure and flow tests (2) non-automatic valve position verification test and (3) automatic valve position verification when the AFWS sytem is in automatic control. The pumps and system are available on demand during all tests. During shutdown the automatic starting of each pump and the functioning of the automatic valves from closed to full open in 10 seconds in the suction line of each AFW pump from the NSWS are checked. There are no coincident tests or maintenance of components within the AFWS. There was no evidence that the actual Test and Maintenance Procedures were reviewed in detail to assure that the above guidelines had been observed.

3.4 Adequacy of Emergency Procedures

The Emergency Procedures were not reviewed or included in the analysis by DP. Emergency operation was discussed and it was assumed that the emergency procedures had been written to implement the emergency operations. However, answers[6]

by McGuire to the recommendations of NUREG-0611 imply that there may be no emergency procedures for the AFWS.

3.5 Adequacy of Power Sources and Separation of Power Sources

The EAPS is designed to meet the criteria set forth in the NRC General Design Criteria (GDC17, GDC18), IEEE 279-1971, IEEE 308-1971 and Regulatory guides 1.6, 1.9, and 1.32. The motor-driven pumps, associated motor-operated valves and other electrical equipment receive power from two identical but separate 4160 V emergency buses. One bus "A" supplies one pump and "B" the other. In the event of loss of offsite power the two diesel generators each supply one bus in a like manner. The TDP is supplied with steam from two steam generators. The TDP is not dependent upon ac power. Redundant power sources enhance system reliability as does the separation of these power sources which eliminates many common cause failure events.

3.6 Availability of Alternate Water Sources

DP has many alternate water sources. For water of steam generator quality the main source (non-safety grade) is the upper surge tank. Backup to this source is the AFW condensate storage tank, the upper surge tank and the condenser hotwell. The primary alternate water source is the NSWS which is safety grade but not of steam generator quality. This source is automatically available in the event the NPSH falls below 2 psig for 3 seconds. Valve operation time is 10 seconds or less. A final alternate supply is the SSF. Every

attempt is made to operate with steam generator quality feedwater. Automatic switch over to the NSWS is fast enough to prevent pump failure because of no water supply at the pump intake.

3.7 Potential Common Mode Failure

A common mode, or more generally common cause, failure is a group of component failures, with or without the same failure mode, that are the direct result of the same event, cause or condition and that leads directly to a specific system failure. DP reports that no common cause failures were discovered through the analysis that would result in both the TDP and the two MDP's not meeting the AFW flow requirements.

3.8 Application of Data Presented in NUREG-0611

The report(2) did not contain a table which included the Fault tree events. The fault tree was checked and all applicable components as shown in Figure 1 were properly included. Although the report states that the data in NUREG-0611 were used and the tables from NUREG-0611 reproduced as Appendix B, there was no way from the report review to verify this. At the meeting at McGuire, evidence was made available which showed that the analysis was made in great detail and that NUREG-0611 data were used.

3.9 Search for Single Fai[illegible] Points

There were no single failure points (SFP) associated with case 1, LMF, or Case 2, LMF/LOSP. For Case 3, LMF/LAC, there were many

SFPs since Case 3 describes a single-channel system. Any SFP has a major effect on the reliability of a redundant system and if any are found, they should be thoroughly reviewed.

3.10 Human Factor/Errors

Human Factors/Errors were considered by DP where appropriate in the fault tree. Automation is a major factor in decreasing the effect on reliability of these types of event.

3.11 NUREG-0611 Recommendations, Long- and Short-Term

3.11.1 Short-Term Generic Recommendations

I. Technical Specification Time Limit on AFW System Train Outage

Recommendation GS-1

The licensee should propose modifications to the Technical Specifications to limit the time that one AFW system pump and its associated flow train and essential instrumentation can be inoperable. The outage time limit and subsequent action time should be as required in current Standard Technical Specifications; i.e., 72 hours and 12 hours, respectively.

Response

McGuire Nuclear Station has Standard Technical Specifications and, as such, already has these requirements included in the Technical Specifications.

II. Technical Specification Administrative Controls on Manual Valves - Lock and Verify Position.

Recommendation GS-2

The licensee should lock open single valves or multiple valves in series in the AFW system pump suction piping and lock open other single valves or multiple valves in series that could interrupt all AFW flow. Monthly inspections should be performed to verify that these valves are locked and in the open position. These inspections should be proposed for incorporation into the surveillance requirements of the plant Technical Specifications. See Recommendation GL-2 for the longer-term resolution of this concern.

Response

All manual valves in the auxiliary feedwater flowpath are checked monthly to verify that they are locked open. This requirement is included in the McGuire Technical Specifications.

III. AFW System Flow Throttling - Water Hammer

Recommendation GS-3

The licensee should reexamine the practice of throttling AFW system flow to avoid water hammer.

The licensee should verify that the AFW system will supply on demand sufficient initial flow to the necessary steam generators to assure adequate decay heat removal following loss of main feedwater flow and a reactor trip from 100% power. In cases where this reevaluation results in an increase in initial AFW system flow, the licensee should provide sufficient information to demonstrate that the required initial AFW system flow will not result in plant damage due to water hammer.

Response

Auxiliary feedwater flow is not throttled initially to prevent water hammer. The required flow rate is available within 60 seconds following the initiating event.

IV. Emergency Procedures for Initiating Backup Water Supplies

Recommendation GS-4

Emergency procedures for transferring to alternate sources of AFW supply should be available to the plant operators. These procedures should include criteria to inform the operators when, and in what order, the transfer to alternate water sources should take place.

Response

Transfer of the auxiliary feedwater supply from the normal to the safety grade assured supply occurs automatically when suction pressure drops below an acceptable limit. The instru-

mentation and controls utilized in the switchover logic are safety grade.

V. Emergency Procedures for Initiating AFW Flow Following a Complete Loss of Alternating Current Power

Recommendation GS-5

The as-built plant should be capable of providing the required AFW flow for at least two hours from one AFW pump train, independent of any ac power source.

Response

The auxiliary feedwater system at McGuire is capable of automatic initiation and of providing the required flow for 2 hours independent of any ac power source. This is accomplished by means of the turbine-driven auxiliary feedwater pump and dc motor-operated/solenoid valves at appropriate locations in the system.

VI. AFWS Flow Path Verification

Recommendation GS-6

The licensee should confirm flow path availability of an AFW system flow train that has been out of service to perform periodic testing or maintenance as follows:

(1) Procedures should be implemented to require an operator to determine that the AFW system valves are properly

aligned and a second operator to independently verify that the valves are properly aligned.

(2) The licensee should propose Technical Specifications to assure that, prior to plant startup following an extended cold shutdown, a flow test would be performed to verify the normal flow path from the primary AFW system water source to the steam generators. The flow test should be conducted with AFW system valves in their normal alignment.

Response

(1) Procedures will be developed to provide for double verification of the auxiliary feedwater system alignment following maintenance activities. For normal periodic testing of the system, no realignment of manual valves is required so no verification of system status is necessary.

(2) McGuire Nuclear Station has the latest version of the Standard Technical Specifications which provide adequate assurance of the operability of the auxiliary feedwater system.

VII Non-Safety Grade, Non-Redundant AFW System Automatic Initiation Signals

Recommendation GS-7

The licensee should verify that the automatic start AFW system signals and associated circuitry are safety-grade.

Response

The McGuire auxiliary feedwater system employs safety-grade automatic initiation signals and circuits. Automatic initiation of the system is discussed in the Final Safety Analysis Report, Section 7.4.1.1.

VIII Automatic Initiation of AFWS

Recommendation GS-8

The licensee should install a system to automatically initiate AFW system flow.

Response

See response to Recommendation GS-7.

3.11.2 Additional Short-Term Recommendations

I Primary AFW Water Source Low Level Alarm

Recommendation

The licensee should provide redundant level indication and low level alarms in the control room for the AFW system primary water supply, to allow the operator to anticipate the need to make up water or transfer to an alternate water supply and prevent a low pump suction pressure condition from occurring. The low level alarm setpoint should allow at least 20 minutes

for operator action, assuming that the largest capacity AFW pump is operating.

Response

As noted in the response to Recommendation GS-4, the McGuire design utilizes an automatic transfer of the auxiliary feedwater supply to the assured supply, the nuclear service water system. In addition to this, single channel, non-safety-grade level indication and low level alarms are provided in the control room for each of the normal auxiliary feedwater sources (upper surge tank, condenser hotwell and filtered water storage tank).

II AFW Pump Endurance Test

Recommendation

The licensee should perform a 72-hour endurance test on all AFW system pumps, if such a test or continuous period of operation has not been accomplished to date. Following the 72-hour pump run, the pumps should be shut down and cooled down and then restarted and run for one hour. Test acceptance criteria should include demonstrating that the pumps remain within design limits with respect to bearing/bearing oil temperatures and vibration and that pump room ambient conditions (temperature, humidity) do not exceed environmental qualification limits for safety-related equipment in the room.

Response

It is our understanding that the Staff has modified this recommendation to perform a 48-hour endurance test on all auxiliary feedwater pumps in lieu of the 72-hour test. The motor-driven auxiliary feedwater pumps were run several days during the hot functional test period. The exact time period and system configuration will be documented. The turbine-driven auxiliary feedwater pump has not been run for an extended period. A 48-hour test of this pump will be performed after the heatup following initial fuel loading.

III Indication of AFW Flow to the Steam Generators

Recommendation

The licensee should implement the following requirements as specified by Item 2.1.7.b on page A-32 of NUREG-0578:

(1) Safety-grade indication of AFW flow to each steam generator should be provided in the control room.

(2) The AFW flow instrument channels should be powered from the emergency buses consistent with satisfying the emergency power diversity requirements for the AFW system set forth in Auxiliary Systems Branch Technical Position 10-1 of the Standard Review Plan, Section 10.4.9.

Response

This recommendation has been implemented as indicated by our response to item II.?.1.2 from NUREG-0694 contained in Duke Power Company "Response to TMI Concerns" submitted initially on May 23, 1980.

IV AFWS Availability During Periodic Surveillance Testing

Recommendation

Licensees with plants which require local manual realignment of valves to conduct periodic tests on one AFW system train and which have only one remaining AFW train available for operation should propose Technical Specifications to provide that a dedicated individual who is in communication with the control room be stationed at the manual valves. Upon instruction from the control room, this operator would re-align the valves in the AFW system from the test mode to its operational alignment.

Response

The auxiliary feedwater system design is such that no manually operated valves need to be repositioned during periodic testing of the system. Those valves which must be repositioned can be operated from the control room. In the event the system is automatically actuated, these valves will be actuated to their "safety" position.

11.3 Long-Term Generic Recommendations

I Automatic Initiation of AFWS

Recommendation GL-1

For plants with a manual starting AFW system, the licensee should install a system to automatically initiate the AFW system flow. This system and associated automatic initiation signals should be designed and installed to meet safety-grade requirements. Manual AFW system start and control capability should be retained with manual start serving as backup to automatic AFW system initiation.

Response

See response to Recommendation GS-7.

II Single Valves in the AFWS Flow Path

Recommendation GL-2

Licensees with plant designs in which all (primary and alternate) water supplies to the AFW systems pass through valves in a single flow path should install redundant parallel flow paths (piping and valves).

Response

The McGuire auxiliary feedwater system design has redundant flow paths via redundant pumps, valves and piping.

III Elimination of AFWS Dependency on Alternating Current Power Following a Complete Loss of Alternating Current Power

Recommendation GL-3

At least one AFW system pump and its associated flow path and essential instrumentation should automatically initiate AFW system flow and be capable of being operated independently of any ac power source for at least two hours. Conversion of dc power to ac power is acceptable.

Response

See response to Recommendation GS-5.

IV Prevention of Multiple Pump Damage Due to Loss of Suction Resulting from Natural Phenomena

Recommendation GL-4

Licensees having plants with unprotected normal AFW system water supplies should evaluate the design of their AFW systems to determine if automatic protection of the pumps is necessary following a seismic event or a tornado. The time available before pump damage, the alarms and indications available to the control room operator, and the time necessary for assessing the problem and taking action should be considered in determining whether operator action can be relied on to prevent pump damage. Consideration should be given to providing pump protection by means such as automatic switchover of the pump suctions to the alternate safety-grade source of water, automatic pump trips on

low suction pressure, or upgrading the normal source of water to meet seismic Category 1 and tornado protection requirements.

Response

Auxiliary feedwater system pumps are protected by automatic switchover to the safety-grade source of water following any loss of normal source resulting from natural phenomena or other causes.

V Non-Safety Grade, Non-Redundant AFWS Automatic Initiation Signals

Recommendation GL-5

The licensee should upgrade the AFW system automatic initiation signals and circuits to meet safety-grade requirements.

Response

See response to Recommendation GS-7.

4. Major Contributors to Unreliability

Duke Power lists the following major contributors to unreliability for each case.

Case No. 1 - LMFW

The dominant (controlling) contributors to system unreliability were found to be the loss of the motor- and turbine-driven pump

systems as caused by such failure modes as the pumps failing to start and run due to a pump component failure; the motor-driven pumps fail to start or run as caused by an open pump circuit breaker or a fault in the electrical control circuit used for automatic closing of a pump circuit breaker; and the turbine-driven pump fails to start and run due to faults attributed to the turbine control stop valves and the turbine speed control valve.

Other dominant contributors to AFWS system unreliability were found to be unscheduled maintenance of pumps and the testing of valves in the feedlines to each steam generator from the motor-driven pumps and the turbine-driven pump.

The redundancy employed in the design of the McGuire AFWS was found to be of the type whereby no obvious single faults (active components, manual valves or human errors) were identified that dominate the unreliability of the AFWS for a loss of main feedwater transient.

Case No. 2 - LMFW/LOOP

Because the sources of ac power are redundant the dominant failure modes for Case 2 are the same as Case 1. The reduction in AFWS reliability for this transient is caused by the loss of redundancy in ac power sources that results from a loss of offsite power.

Case No. 3 - LMFW/LOAC

In this transient, loss of both offsite and onsite ac power is postulated to occur with the coincident loss of main feedwater flow, so that the available operating pump subsystems of the AFWS are reduced to only the steam turbine-driven pump train. Thus, any single failures in this pump train alone would be sufficient to fail the AFWS for this transient. The dominant contributors to system unreliability for this case were found to include: (1) the turbine-driven pump is offline for unscheduled maintenance; (2) the pump train is down due to testing of the motor-operated valve (1CA7A) in the pump's suction line; (3) the manual valve (1CA19) in the pump suction line fails closed due to hardware failure or human error causing a loss of NPSH at the pump's suction; (4) various turbine-driven pump faults (i.e., turbine/pump hardware component failure, the turbine control stop valve fails closed or the speed control valve fails closed) causes loss of discharge flow from the pump; and (5) the manual valve (1CA21) or check valve (1CA22) in the pump's discharge line fails closed blocking flow from the turbine-driven pump.

SNL agrees with the above listing. No quantification of results was made by DP in their report nor were results quantified in NUREG-0611. The quantitative estimates obtained from notes provided by DP are for Case 1 $5.1x10^{-4}$, for Case 2 $1.2x10^{-3}$, and for Case 3 $1.2x10^{-2}$. These values are plotted in Figure 2 along with the operating plant ratings which were derived from NUREG-0611. The McGuire AFWS has medium reliability for Case No. 1, LMFW; low reliability (high end) for Case No. 2, LMFW/LOCP; and medium reliability (high end) for

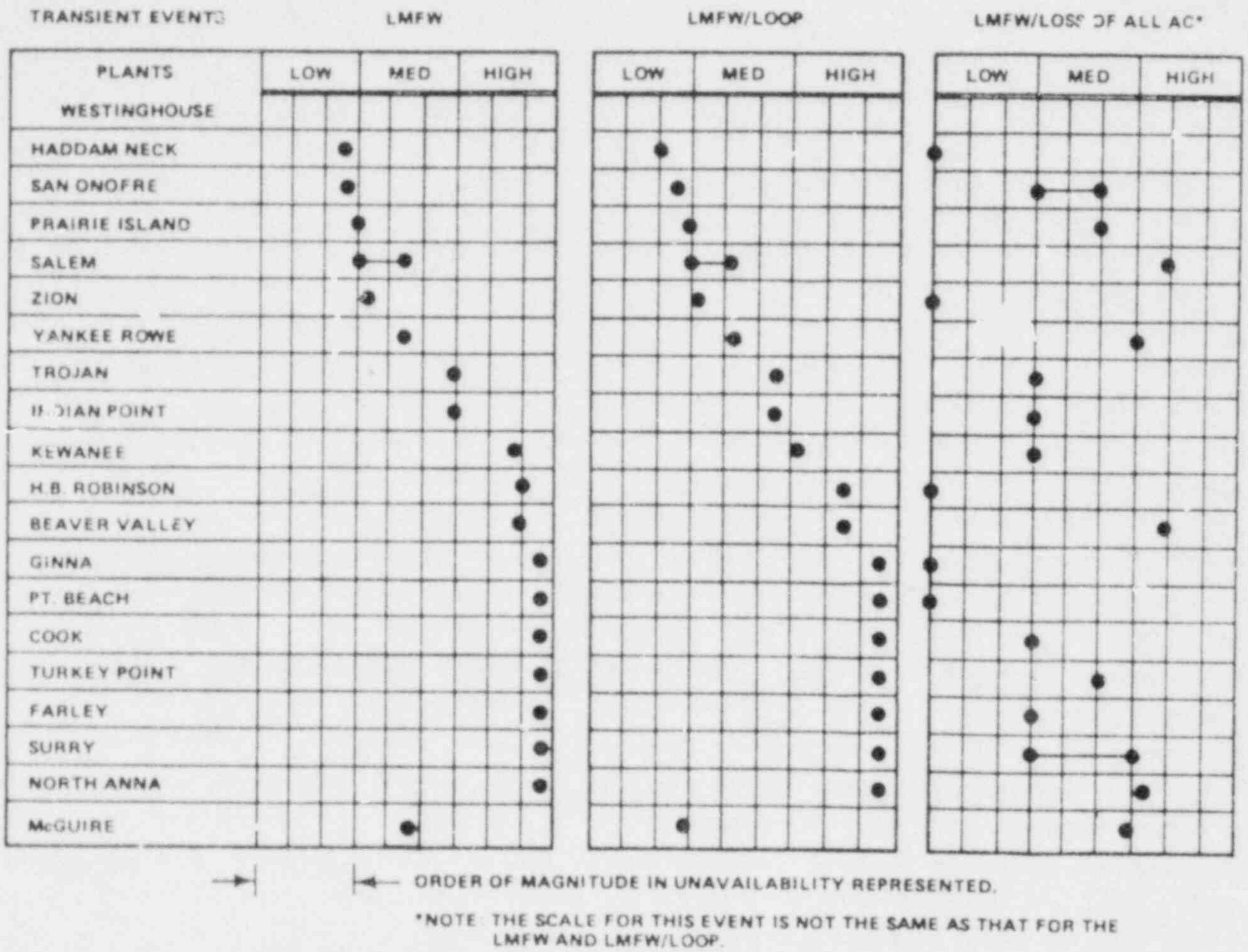

Figure 2 Comparison of McGuire AFWS Reliability to other AFWS Designs in Plants Using the Westinghouse NSSS

Case No. 3, LMFW/LOAC. Sandia agreed with these ratings after questioning the low reliability assessed for cases 1 and 2. Low reliability is caused not only by the events described above but also by the design. McGuire Nuclear Power Plant Auxiliary Feedwater System is throttled to provide protection for a fourth transient, break in the main feedwater line to or rupture of a steam generator. This precludes the pumps from delivering all the water to a main feedwater line break or ruptured steam generator. This in turn requires that more components be operable to support the three LMFW transients, and thus the lower reliability. Sandia agreed with this logic; however, it would seem that the flow control valves could be controlled so that they would automatically close on the receipt of a high flow signal as is done at the V.C. Summer Nuclear Power Plant.

In a memo[7] written after the review of the Reliability Study, Duke Power analyzed four additional LMFW cases. These cases and the failure probabilities associated with each are listed below:

Alternate Assumption	Case		
1	2	LMFW/LOOP, FSAR assumptions, operator Action	6.6×10^{-5}
1	1	LMFW, FSAR assumptions, operator action	1.96×10^{-5}
2	1	LMFW, best estimate assumptions, no operator action	9.5×10^{-6}
2	2	LMFW/LOOP, best estimate assumptions, no operator action	4.2×10^{-6}

FSAR and best estimate assumptions pertain to the quantity of AFW necessary, 490 gpm for the former and 340 for the latter. In addition, for these four cases the top level logic of the fault tree presented in WCAP-9751 was changed from system success requiring that 3 of the 4

steam generators must have adequate flow to system success requiring that 2 of the 4 steam generators must have adequate flow.

The values determined above all fall into the high reliability area if plotted on Figure 2. No new fault trees or detailed calculations were submitted, however, if Westinghouse made these calculations in a manner similar to the original calculations, they should be correct. The changes appear logical and in line with the new assumptions made.

5. Conclusions

Duke has complied with requirement (b) of the March 10th letter[1]: "(b) perform a reliability evaluation similar in method to that described in Enclosure 1 that was performed for operating plants and submit it for staff review." Enclosure 1 to the letter provides the applicable portions of NUREG-0611 which deal with the Auxiliary Feedwater Systems.

The Duke report adequately discussed the major contributors to unreliability for the three transient cases. The major contributor for cases 1 and 2 was the failure of the motor- and turbine-driven pumps. The major contributors in case 3 were the unscheduled maintenance of the turbine driven pump and the unavailability of the turbine driven pump because of tests on motor operated valve 1CA7A.

The method used by Duke was in agreement with the method used in NUREG-0611. The final assessment by Duke places McGuire I in the

medium range for Case 1, the low range for Case 2 and the medium range for Case 3. Sandia is in agreement with these assessments and with the additional assessments made with the alternate assumptions. The long-term modification suggested by Duke Power in reference 7 to simplify operation of the system, which in turn should increase system reliability, should be followed by NRC.

6. Glossary of Terms

ac	alternating current
AFW	Auxiliary Feedwater
AFWS	Auxiliary Feedwater System
ASME	American Society of Mechanical Engineers
B/PV	Boiler and Pressure Vessel
CST	Condensate Storage Tank
DBE	Design Basis Earthquake
dc	direct current
DP	Duke Power Company
EAPS	Essential Auxiliary Power System
FSAR	Final Safety Analysis Report
gpm	gallons per minute
IEEE	Institute of Electrical and Electronic Engineers
LAC	Loss of all AC power
LMFW	Loss of Main Feedwater
LOCA	Loss of Coolant Accident
LOOP	Loss of Offsite Power
MDP	Motor Driven Pump
MSIV	Main Steam Isolation Valve
NPSH	Net Positive Suction Head
NRC	Nuclear Regulatory Commission
NSSS	Nuclear Steam Supply System

Glossary of Terms (Cont'd)

NSWS	Nuclear Service Water System
OBE	Operational Basis Earthquake
psig	pounds per square inch gage
RHRS	Residual Heat Removal System
SFP	Single Failure Point
SGBS	Steam Generator Blowdown System
SNL	Sandia National Laboratories
SNSWP	Standby Nuclear Service Water Pond
SSF	Standby Shutdown Facilities
TDP	Turbine Driven Pump
TMI	Three Mile Island
UST	Upper Surge Tank
V	Volt

7. References

1. Letter to all Pending Operating License Applicants of Nuclear Steam Supply Systems Designed by Westinghouse and Combustion Engineering from D. F. Ross. Jr., Acting Director Division of Project Management Office of Nuclear Reactor Regulation, Subject, Actions Required from Operating License Applicants of Nuclear Supply Systems Designed by Westinghouse and Combustion Engineering Resulting from the NRC Bulletins and Orders Task Force Review Regarding the Three Mile Island Unit 2 Accident, dated March 10, 1980.

2. WCAP-9751 Reliability Analysis of the Auxiliary Feedwater System for the McGuire Nuclear Station Unit #1 dated July 1980 by W. E. Shopsky Westinghouse Electric Corporation.

3. NUREG-0611 "Generic Evaluation of Feedwater Transients and Small Break Loss-of-Coolant Accidents in Westinghouse-Designed Operating Plants" dated January 1980.*

4. Schedule 189 No A1121-0 Title, "Review of Auxiliary Feedwater System Reliability Evaluation Studies for Diablo Canyon I, McGuire 1, Summer 1, San Onofre 2, and Palo Verde" dated August 6, 1980.

5. Memorandum William O. Parker Jr., Vice President Steam Production Duke Power Company to Harold R. Denton, Director NRR, USNRC Re: McGuire Nuclear Station Docket No. 50-369 dated November 10, 1980.

6. Memorandum William O. Parker Jr., Vice President Steam Production Duke Power Company to Harold R. Denton, Director NRR, USNRC Re: McGuire Nuclear Station Docket No.s 50-369, 50-370, dated September 18, 1980.

7. Memorandum William O. Parker Jr., Vice President Steam Production Duke Power Company to Harold R. Denton, Director NRR, USNRC Re: McGuire Nuclear Station Dockets Nos. 50-369, 50-370, dated February 4, 1981.

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*Available for purchase from the NRC/GPO Sales Program, U.S. Nuclear Regulatory Commission, Washington, DC 20555, and/or the National Technical Information Service, Springfield, VA 22161.

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16. ABSTRACT (200 words or less)

This report presents the results of the review of the Auxiliary Feedwater System Reliability Analysis for the McGuire Nuclear Station Unit 1.

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