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Waterford Steam Electric Station Unit 3 Auxiliary Feedwater System Reliability Study Evaluation

Prepared by G. H. Bradley, Jr.

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Albuquerque, NM 87185

Prepared for
U.S. Nuclear Regulatory
Commission

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ABSTRACT

This report presents the results of the review of the Auxiliary Feedwater System Reliability Analysis for the Waterford Steam Electric Station Unit 3. The analysis was prepared for Louisiana Power and Light Company by Envirosphere Company, a division of Ebasco Services Incorporated.

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Summary and Conclusions

The accident at Three Mile Island (TMI) resulted in many studies of events leading to the accident, as well as events thereafter. One of the important safety systems involved in mitigating such accidents, the Emergency Feedwater System (EFS), was studied and analyzed for each plant. Results for the Combustion Engineering (CE)-Designed Plants were reported in NUREG-0635.[1] Before obtaining an operating license, the applicant for a license for each nonoperating, CE-designed plant was instructed[2] to do a reliability analysis of his EFS like the study made by NUREG-0635 for three transient conditions involving loss of main feedwater. Louisiana Power and Light Company (LP&L), the applicant for a license for Waterford Steam Electric Station (WSES) Unit 3, submitted a reliability report[3] to the US Nuclear Regulatory Commission (NRC) in December 1980. This report was updated in April 1981 by Amendment Number 17. Sandia National Laboratories (SNL) reviewed these reports and concluded that:

1. LP&L has satisfactorily complied with the requirement to make a reliability study of their EFS.

2. Waterford's reliability is at the high end of the range for operating plants for two of the transient conditions, and in the medium range for the other transient condition. These assessments were reached through a comparison of the reliability of Waterford's EFS to those of CE designed operating plants; Sandia agrees with these assessments.

1.0 Introduction

1.1 Background

Many studies of the TMI nuclear power plant accident conclude that a properly functioning EFS is of prime importance in mitigating such accidents. Therefore, a letter dated March 10, 1980[2] stating NRC requirements for the EFS was sent to all operating license applicants with a Nuclear Steam Supply System (NSSS) designed by Westinghouse or CE.

LP&L, the applicant for an operating license for Waterford Unit 3 that has a CE-designed NSSS, responded in the form of a reliability analysis,[3] prepared for them by Envirosphere Company. The analysis was made a part of the WSES Final Safety Analysis Report (FSAR).

1.2 Review Activities

This project reviews those portions of the design review and reliability analysis that satisfy requirement (b) of the letter, which states, "perform a reliability evaluation similar in method to that described in Enclosure 1 (NUREG-0635) that was performed for operating plants and submit it for staff review." Also reviewed were the responses[4] to the short and long-term recommendations of NUREG-0635 in answer to requirement (c) in the letter. The review was done according to Schedule 189[5] submitted by SNL to NRC.

1.3 Content and Results of the Reliability Analysis

The reliability analysis[3] was submitted to NRC in December 1980 and was received by SNL January 19, 1981. This analysis studies the failure of the EFS to provide sufficient Emergency Feedwater (EFW) flow to one of the two steam generators and compares results with those obtained for operating plants studied in NUREG-0635. The analysis places WSES among operating plants with high EFS reliability.

1.4 Scope and Level of SNL Effort

SNL reviewed the reliability analysis submitted by LP&L, in particular the reliability of the EFS when subjected to three transient cases (1) LMFW, Loss of Main Feedwater, (2) LMFW/LOOP, Loss of Main Feedwater/Loss of Offsite Power, and (3) LMFW/LAC, Loss of Main Feedwater/Loss of All AC Power. The methods used in the analysis were also compared to those used in NUREG-0635. Specific findings are presented in Sections 3 and 4.

Comments and questions arising during the review were submitted to NRC March 13, 1981; NRC forwarded these questions to LP&L. LP&L and its contractor met with representatives from NRC and SNL on March 26 at WSES in Taft, Louisiana. At this meeting the EFS reliability analysis was reviewed and questions were answered. LP&L provided a typed copy of the questions and answers at the meeting. In April the reliability analysis[3] was updated by Amendment No. 17 (4/81) to include the answers to the questions and recommendations made at the meeting of March 26.

2.0 EFS Configuration

2.1 General Description

Figure 1 is a flow diagram of the EFS. Major components of the EFS include three EFW pumps (two motor-driven and one driven by steam turbine) and associated piping, valves, and instrumentation.

2.2 Component Description

2.2.1 Steam Turbine and Steam Supply

Steam for the EFW pump turbine is supplied from either or both steam generators, taken upstream of the main steam isolation valves. The turbine steam supply valves (TSSV) are pneumatically operated, fail open valves, powered by dc solenoids each from a redundant Class IE dc bus. A check valve downstream of each TSSV prevents steam loss if the valve fails to close in conjunction with a secondary system depressurization. The TSSV and the check valves are designed in accordance with requirements of the ASME Section III, Code Class 2, Summer 1973 Addenda. Piping from each TSSV to the turbine is electrically heated to minimize thermal shock. Steam traps are provided to remove condensate.

The turbine for the steam driven pump is a single-stage, solid-wheel, noncondensating, horizontal split casing unit, and will discharge to atmosphere. It is designed for startup from a cold condition, and will operate with steam generator pressures from 1135 psig to 55 psig. When the available steam

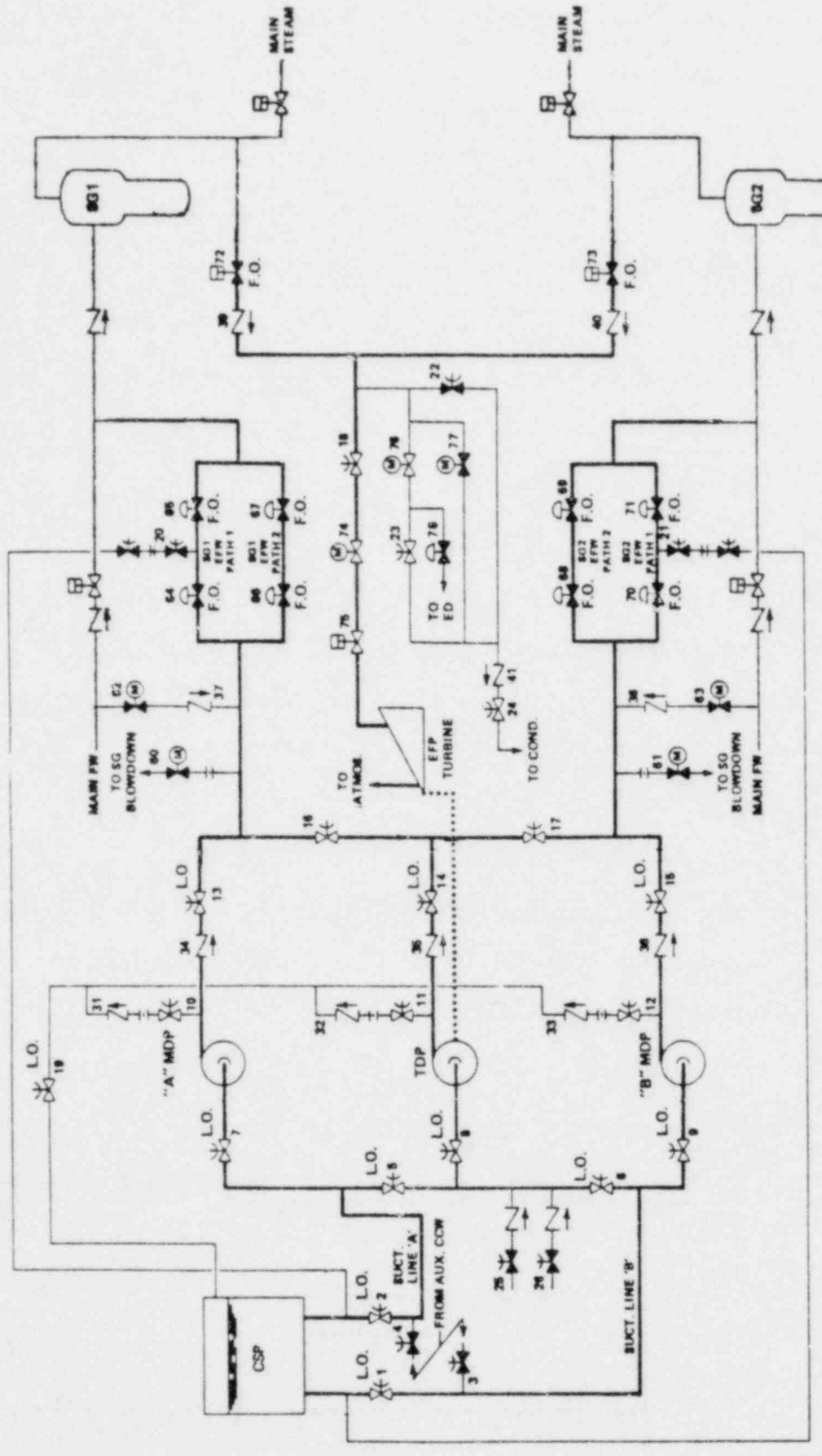

Figure 1. Emergency Feedwater System Flow Diagram

pressure is insufficient to enable the turbine electrohydraulic governor to maintain the pump speed, the pump speed will decrease.

The turbine is equipped with redundant overspeed trips; one mechanical and one electrical. The overspeed trip valve is normally open and requires solenoid actuation to allow a spring to close it. The power supply for the trip solenoid is 125 V dc, which maintains complete dc powered control for the steam driven pump. Opening of the overspeed trip valve is a nonsafety function; a motor is provided to allow remote opening of the valve. Power supply to the motor is Class IE, 480 V ac. During normal operation after the valve is opened power is disconnected to assure that the valve remains in a safe position. The valve is also provided with a handwheel for manual operation.

2.2.2 Electric Motors and Power Supply

The electric motors for the EFS pumps are Class IE and seismic Category I. The motors are able to accelerate the pumps within 4s with 75% of full line voltage. The motors are powered from the 4.16-kV safety-related buses, drawing power from the startup transformers or the auxiliary transformers, or from the emergency diesel generators. Each motor is connected to a separate channel of the electrical safety-related buses. On loss of preferred ac power, these motors are automatically sequenced on the diesel generators.

2.2.3 Pumps, Piping, and Valves

Both electric and steam driven EFS pumps are centrifugal units with horizontally split casings and are designed to ASME Section III requirements.

Suction of the EFS pumps is from the condensate storage pool (CSP) inside the Reactor Auxiliary Building. There are two separate connections to the pool, each sized to provide sufficient suction flow and NPSH to all three EFS pumps. The EFS pump suction piping is provided with manually operated locked open valves for maintenance.

Each EFS pump, when operating, recirculates a specified flow to the CSP. The pumps are sized to supply enough feedwater to steam generators plus extra for recirculation. Continuous recirculation eliminates the need for the recirculation controls normally required to ensure reliability of pumps whose discharge valves operate intermittently. Cooling water for each pump (and for the turbine oil cooler of the turbine driven pump) is supplied from an extraction point on the first stage of the associated pump. This guarantees a source of cooling water under all operating conditions.

The EFS pumps discharge into a distribution header to permit any pump to supply feedwater to either steam generator. Headers are provided with manually operated valves for maintenance.

From the distribution header, water to the steam generators is carried by two pipelines; one to feedwater line A, and the other to feedwater line B. Each pipeline is isolated by four pneumatically operated, fail-open, isolation valves to steam generator 1, and four to steam generator 2. These valves are arranged to provide that, in case of a single failure, water could be supplied to either one or both steam generators, and that water could not enter the ruptured line during the postulated feedwater or main steamline break accident. The solenoids for the isolation valves are powered by 125-V dc buses. The EFS isolation valves are also containment isolation valves, designed in accordance with the requirements of ASME Section III, Code Class 2, Summer 1973 Addenda.

Th EFS pumps are located in the Reactor Auxiliary Building and are thus protected from adverse environmental occurrences. The two motor driven pumps are located in separate compartments, and the steam driven pump is remote from both. The EFS isolation valves and TSS valves are outdoors, but protected from tornado missiles and designed for tornado winds.

In addition to the EFS function, part of the EFS supply piping is used in preoperational cleaning of the Feedwater System. Preoperational cleaning is accomplished before unit startup or restart after normal plant shutdown. Valves are opened and allow the EFS piping to convey feedwater to the blowdown filters. This is done by using only condensate pumps. To prevent the loss of EFS water when required during emergency conditions, these valves will be electrically locked out. In addition, the EFS requires no local manual realignment of valves to conduct periodic surveillance tests of pumps.

Based on NSSS requirements, 440 gpm must be provided to the steam generators upon loss of normal feedwater flow in order to remove decay heat. The EFS is automatically initiated by an emergency feedwater actuation signal (EFAS) as described below to assure that the system will start within the prescribed period. The signal is such that the EFW is fed only to the intact steam generator(s). The EFS can also be started manually from the main control room and from the auxiliary control panel.

The EFS is shut down manually from the main control room by the operator. Steam generator water level indication in the main control room informs the operator when the EFS can be shut down. Means are provided to start/stop each pump or to open/close the EFS isolation and TSSV from the main control room and from the auxiliary control panel.

The EFS pipeline to each steam generator contains a flow meter to be used:

1. To indicate in the main control room the EFW flow for the operator's information

2. To alarm in the main control room on excessive flow to prevent water loss during the postulated feedwater or main steam line break

Means are provided to throttle two isolating valves from the main control room in each EFS train and permit the operator to adjust the EFW flow rate into the steam generator.

2.2.4 Condensate Storage Pool

The Condensate Storage Pool (CSP) is inside the Reactor Auxiliary Building. It is 22 ft. wide by 41 ft., six in. long, and the bottom elevation of the pool is at elevation -4 ft. msl. The concrete floor of the pool and the walls up to elevation +17 ft. msl are lined with Type 304 stainless-steel plate. The walls above elevation +17 ft. msl and the roof are not lined. The liner concrete integral structure is designed for seismic Category I loading with the CSP full of water, plus the thermal difference between the nominal and the minimum operating temperatures. The CSP is provided with an atmospheric vent to maintain atmospheric pressure inside the pool.

The CSP has a storage capacity of 195,000 gal., enough to cool down the Reactor Coolant System (RCS) after a small Loss of Coolant Accident (LOCA) with or without loss of offsite power. This includes a 10% margin, to the temperature and pressure at which the SDCS can be placed in operation.

In addition to the water supply for the EFS, the CSP provides makeup water supply for the Component Cooling Water System, Emergency Diesel Generator Jacket Cooling Water System, and Essential Services Chilled Water System. The makeup requirements for these systems are for evaporation and leakage, and have a negligible effect upon sizing of the CSP.

Makeup is capable of being provided by the Auxiliary Component Cooling Water System (seismically designed) to the CSP from two wet cooling tower basins, each with a storage volume of 180,000 gal. This manual operation is done only after emergency shutdown caused by the design-basis tornado, which may require EFW exceeding the amount stored in the CSP because of postulated tornado-generated missile damage to the towers.

The normal makeup system to the CSP is nonseismic, but Class IE indication in the main control room is provided to alert the operator of insufficient EFW supply.

2.2.5 Emergency Feedwater Actuation

The Emergency Feedwater Actuation Signal (EFAS) is initiated to steam generator 1 either by a low steam-generator level coincident with no low-pressure trip present on steam generator 1, or by a low steam-generator level coincident with a differential pressure between the two generators with the higher pressure in steam generator 1. (An identical EFAS is generated for steam

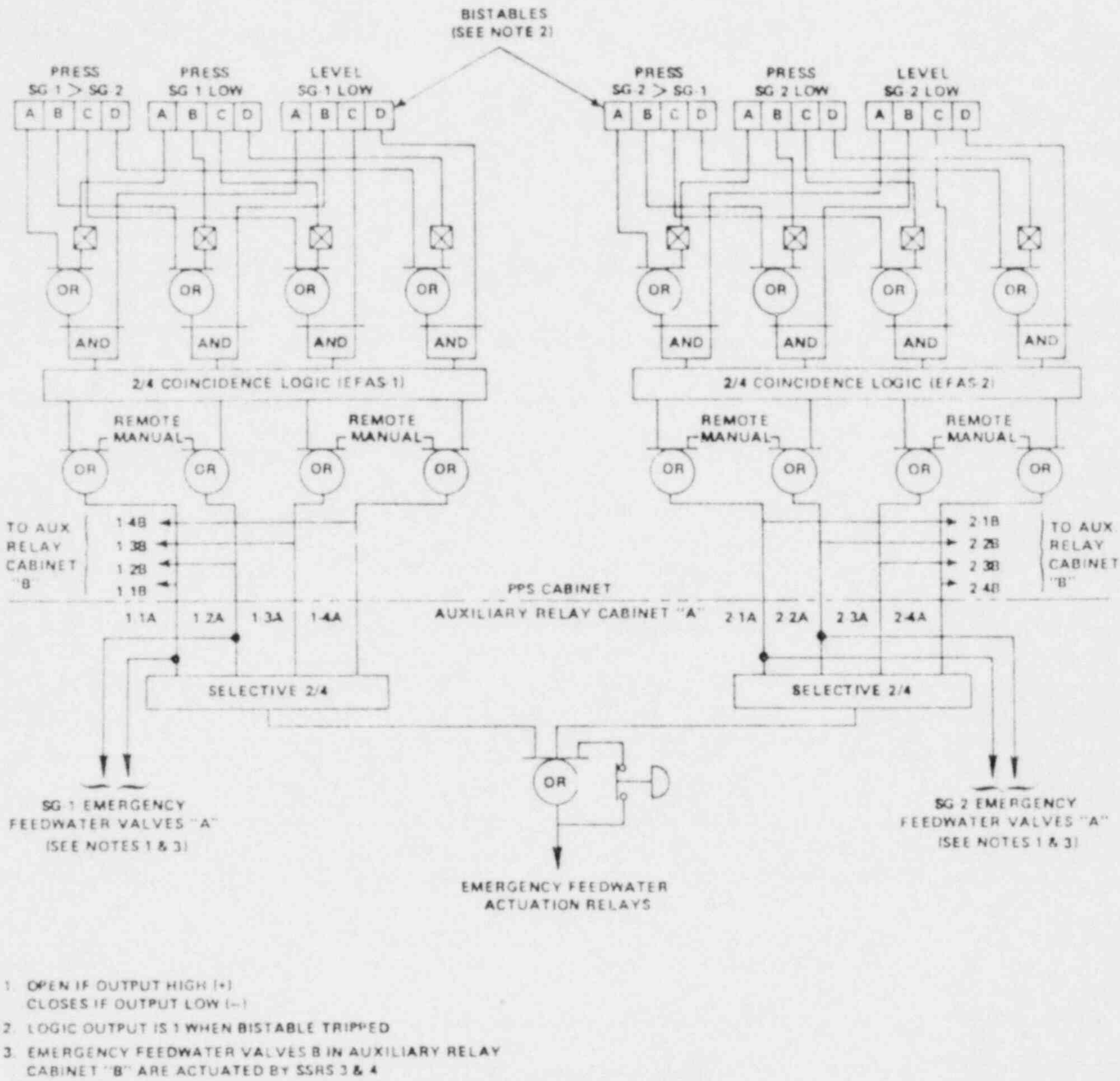

Figure 2. Emergency Feedwater Actuation System Logic Diagram

generator 2.) This logic is shown in Figure 2. The two-out-of-four logic is provided for each steam generator. When steam-generator water level returns to above the low-level setpoint, the EFS discharge valves will shut automatically to secure excess feedwater flow. The system is designed such that loss of electric power to two of the four like channels in the measurement channels or initiating logic, or to the selective two-out-of-four actuating logic, would actuate the EFS. The system is composed of redundant trains A and B. The instrumentation and controls of the components and equipment in train A are physically and electrically separate, and independent of the instrumentation and controls of the components and equipment in train B.

EFS instrumentation and controls are designed for automatic operation during emergencies such as steam line rupture, loss of normal feed, and plant blackout.

The EFAS does the following:

1. Starts the EFW pumps
2. Determines which steam generator is intact
3. Opens the EFW valves to the intact steam generator
4. Prevents high-level condition in the intact steam generator(s) by closing the EFW valves when the water level is reestablished above the low level trip setpoint

Manual control switches for the EFW pumps and valves are provided in the main control room. The safety-related display instrumentation for the EFS provides the operator with enough information to monitor and perform the required safety functions.

3.0 Discussion

3.1 Mode of EFS Initiation

The Emergency Feedwater Actuation System automatically actuates the EFS by starting the EFW pumps, determining which steam generator (SG) is intact, and fully opening the isolation and control valves to the unaffected SG. The EFAS is generated by one of the following conditions by means of a two-out-of-four logic.

1. A low SG level coincident with no low pressure trip present for that SG.

2. A low SG level coincident with a preset differential pressure present between the two SGs, with the higher pressure associated with the SG to be fed.

3.2 System Control After Initiation

After initiation, when the SG water level returns to a level above the low level setpoint, the EFW pump-discharge valves will shut automatically. Manual control of the EFS pumps and valves is also possible from the control room. If the control room becomes uninhabitable, enough EFS instrumentation and controls are provided outside the control room on a Seismic Category I evacuation shutdown panel and at other locations for operating of the EFS. Controls are available at the pump for the turbine-driven pump and at the switchgear for the motor-driven pump. The feedwater control valves can be operated by handwheels. If the reactor trips and the control room is evacuated, the auxiliary control panel can be used and the AFW pumps can still supply feedwater to the steam generators for removing reactor-decay heat and for plant cooldown.

3.3 Test and Maintenance Procedures and Unavailability

No Test and Maintenance Procedures were evaluated because none were prepared by the applicant. These activities have been planned, and these plans were used for the Reliability Analysis. The Procedures, when completed, will be reviewed to determine that there is no additional impact on reliability.

3.4 Adequacy of Emergency Procedures

No Emergency Procedures were evaluated because none were prepared by the applicant. The EFS is automatically initiated. Emergency Procedures are to be written for operator backup and for changing the system to the alternate source of EFW. When complete, these will be reviewed for their effect on reliability.

3.5 Adequacy of Power Sources and Separation of Power Sources

All safety-related power sources, supplies, etc meet the requirements for separation and redundancy in accordance with the design criteria, regulatory guides, and Institute of Electrical and Electronics Engineers (IEEE) standards.

Diverse power sources are used to ensure that the EFS can function with complete loss of ac power. Turbine and system safety controls are supplied from 125 V dc ESF buses, as follows:

1. The TSSV are pneumatically operated and fail open valves. Each valve is controlled by dc solenoids from redundant 125 V dc buses.

2. Each TSSV admits steam from a different steam generator, and each valve is sized to admit enough steam to operate the pump at full speed.

3. The turbine trip valve is solenoid spring operated to close it. The valve closure is controlled by 125 V dc A/B bus.

4. The turbine is provided with two overspeed devices. One is electronically operated (set at 110 percent of the rated speed), and has remote reset features. The other is mechanical (set at 125% of rated speed), and requires manual resetting. The solenoid for the electronic trip is powered from the 125 V dc ESF bus.

5. The Turbine Governor Control System is electrohydraulic. Power supply to the control system is from the 125-V dc ESF A/B bus.

6. The EFS isolation valves are pneumatically operated, fail open, and powered from the redundant vital 125 V dc ESF buses, so that feedwater flow to the steam generator can be admitted or stopped, assuming single failure or loss of all ac power.

3.6 Availability of Alternate Water Sources

There is no dedicated alternate source of feedwater for the Condensate Storage Pool, which has a storage capacity of 195,000 gal. The pool is a Seismic Category I structure. Makeup for the CSP can be provided from the Auxiliary Component Cooling Water System, which has two 180,000-gal. wet cooling tower basins. The operation is all manual and would be performed only for instances where the CSP is inoperative or in danger of depletion. The CSP failure probability was considered so low that no Event was described for it. (See Paragraph 3.7.7 below)

3.7 Potential Common-Mode Failures

Several events were assessed for their potential to induce common cause failures in the EFS, as discussed below.

3.7.1 Loss of Instrument Air

All air-operated valves in the EFS require instrument air to go away from their operation state (i.e., to close). A loss of instrument air would have no immediate effect on the system as the valves have air accumulators sized for several open-close cycles. It would, however, prevent the operator from reclosing the air-operated valves once the accumulators are exhausted. This has no adverse affect on system operation for the transients considered.

3.7.2 Loss of Component Cooling Water

The EFS does not rely on Component Cooling Water. The EFS pumps, unlike the Emergency Core Cooling System (ECCS) pumps, handle a relatively cool fluid that is itself sufficient for pump cooling; thus no separate source of Component Cooling Water (CCW) is required.

3.7.3 Loss of ac Power

The EFS Turbine-Driven Pump (TDP) and all power-operated valves associated with its flow and steam supply-paths are independent of ac power except the normally open, fail as-is, Turbine Trip and Throttle Valve, whose operation (closure) is equipment-protective and not required for system functioning. No TDP auxiliary functions, including lubrication, depend upon ac power.

Extended operation of the TDP indirectly relies on ac power furnished by either an off-site source of by the on-site diesel generators to the ventilation system serving the pump cubicle. Without ventilation for several hours when the pump is running, as could be the situation in Case 3, the temperature in the pump area would become high enough to affect the pump controls, possibly adversely. This would not be an immediate failure, however, and time would be available to restore some ac power. As such, this failure mechanism was not factored into the fault tree.

3.7.4 Poor Water Quality Control

If very low quality water were used for extended periods in the EFS, it might cause corrosion/particle deposition in the system, perhaps binding the moving parts of the pumps and valves. However, it is not credible that this would occur to any extent in the EFS for the following reasons:

1. Only condensate or demineralilzed quality water is used in the EFS.

2. The system is periodically treated with ammonia/hydrazine as necessary to control water chemistry.

3. The system is periodically flow tested, which not only provides some system flushing, but assures that water quality has not affected the pumps.

4. The valves are periodically stroke tested, which would detect any loss of function caused by corrosion or particle deposition.

3.7.5 Testing

System testing has no potential for causing common-mode failures because no changes in valve position are required for testing.

3.7.6 Maintenance

One maintenance operation, Condensate and Feedwater Systems Pre-Startup Cleaning, has potential for causing a system common mode failure. This has been added to the fault tree as common cause failure basic event ME1.

3.7.7 Condensate Storage Pool Problems

The CSP is the only dedicated source of water to the EFS. It is assessed for its potential to cause EFS failure by the following failure modes:

1. Tank Vent Clogging: The CSP, a stainless-steel-lined concrete room, is equipped with an 8-in. Schedule 40 (nominal wall thickness 3/8 in.) vent line that penetrates the pool ceiling and terminates in the above room (CCW pump cubicle) 6 ft. above the floor.

   There is no isolation valve on the vent line, and there is no known sources of debris in the area that could clog a pipe of such large diameter. Also, the pipe ends with a "U"-bend, with the open end turned downwards. Accidental crimping of the thick-walled pipe is not considered credible since the pipe is not within the travel path of any cranes and is located in a congested area behind an instrument cabinet, out of the path of any forklifts. As such, failure of the pool because of a restricted vent line is not considered credible.

2. Low Tank Level: The CSP is used almost exclusively as a water supply for the EFS. The only exception is its use as a makeup source to the CCWS, which places a minimal demand on the pool. The pool is equipped with redundant, safety-grade-level indicators, and the operators are required to verify that tank level is within allowable limits every 12 hours. It is not considered credible that tank level would be out of limits when a system demand occurred.

3. Pump Suction Flashing: The CSP water remains at Reactor Auxiliary Building (RAB) ambient temperatures, usually below 90°F. There are no lines from the hot, interfacing systems that connect to the lines between the CSP and pump suction, as in some other plants. Thus, flashing of the pump suction source is not considered a credible common cause failure mechanism.

3.8 Application of Data Presented in NUREG-0635

Data from Table III-3 of NUREG-0635 were used for most of the basic events described in the reliability analysis[3]. Data from Wash 1400[6] and NUREG/CR1278[7] were used when Table III-3 did not define the event described.

3.9 Search for Single Failure Points

One single failure point was identified by the licensee--a human-error event that pertained to the closing of system valves after maintenance. Enough checks after maintenance are done so that its effect is minimized. No single failure points involving equipment were found.

3.10 Human Factors/Errors

Human-error failure events were considered in the fault tree analysis. These errors consist of operator error (leaving a manual valve in the wrong position and failure to back up automatic EFW actuation) and maintenance error (components realigned for test/maintenance operation were not restored to their proper state following the operation by the test/maintenance crew). The latter is the single failure point described above; the former appear only in higher order cutsets except in Case 3, loss of all AC power. Because of the automatic operation of the EFS and redundant checks, these events assume a lesser role in the reliability analysis.

3.11 NUREG-0611 Recommendations

3.11.1 Short-Term Generic Recommendations

1. Technical Specification Time Limit on EFS Train Outage. Recommendation GS-1. The licensee should propose modifications to the Technical Specifications to limit the inoperable time of one EFS pump and its associated flow train and essential instrumentation. The outage time limit and later action time should be as required in current Technical Specifications; i.e., 72 and 12 hours, respectively.

   Response. Waterford Emergency Feedwater System limiting conditions for operation and surveillance requirements state that an inoperable EFS train should be restored to operable status in 72 hours or be in hot shutdown within the next 12 hours. This is in accordance with current standard Technical Specifications.

2. 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 EFS pump suction piping and lock open other single valves or multiple valves in series that could interrupt all EFW flow. Monthly inspections should be made to verify that these valves are locked open. These inspections should be proposed for incorporation into the surveillance requirements of the plan Technical Specifications. The long-term resolution of this concern is discussed in Recommendation GL-2.

Response. All manually operated valves in EFS suction are locked open and are provided with limit switches for position indication in the control room. In addition, the Waterford EFW system has redundant, parallel flow paths (piping and valves) so that there is no single valve that, if left closed, could interrupt all flow.

3. AFWS Flow Throttling - Water Hammer.

Recommendation GS-3. Some licensees have stated that they throttle EFS flow to avoid water hammer. If applicable, the licensee should reexamine the practice of throttling EFS flow to avoid water hammer. The licensee should verify that the EFS will supply on demand enough initial flow to the necessary steam generators to assure adequate decay-heat removal after loss of main feedwater flow and a reactor trip from 100% power. In cases where this reevaluation results in an increase in initial EFS flow, the licensee should provide enough information to demonstrate that the required initial EFS flow will not cause plant damage because of water hammer.

Response. The Waterford-3 EFS does not throttle flow to avoid water hammer. The EFS will supply on demand enough initial flow to assure adequate decay heat removal. Water hammer considerations have been taken into account in the final design.

4. Emergency Procedures for Initiating Backup Water Supplies. Recommendation GS-4. Emergency procedures for transferring to alternate sources of EFW supply should be available to the plant operators. These procedures should include criteria to inform the operator when, and in what order, the transfer to alternate water sources should occur. The following cases should be covered by the procedures.

   The case in which the primary water supply is not initially available. Procedures for this case should include any operator actions required to project the EFW pumps against self-damage before water flow is initiated.

   The case in which the primary water supply is being depleted. The procedure for this case should provide for transfer to the alternate water sources before draining the primary water supply.

   Response. Primary EFS water supply is provided by the Condensate Storage Pool (CSP). Alternate EFS water supply is provided by the Wet Cooling Tower (WCT) basins. Procedures will be provided on Waterford that will include criteria to inform the operator when, and in what order, the transfer to the alternate water supply should take place.

5. Emergency Procedures for Initiating AFW Flow Following a Complete Loss of AC Power.

Recommendation GS-5. The as-built plant should be capable of providing the required EFW flow for at least two hours from one EFW pump train, independent of any ac power source. If manual EFS initiation or flow control is required following a complete loss of ac, emergency procedures should be established for manually initiating and controlling the system under these conditions. Because the water for cooling the lube oil for the turbine-driven pump bearing may depend on ac power, design or procedural changes shall be made to eliminate this dependency as soon as practicable. Until this is done, the emergency procedures should provide for stationing an individual at the turbine-driven pump in case of loss of all ac power to monitor pump bearing and/or lube oil temperatures. If necessary, this operator would operate the turbine-driven pump in a manual on-off mode until ac power is restored. Adequate lighting powered by dc power sources and communications at local stations should also be provided if manual initiation and control of the EFS are needed. (See Recommendation GL-3 for the longer term resolution of this concern.)

Response. The EFS turbine-driven pump is independent of ac power. Lube oil supply is internal to the pump and therefore requires no oil pump. Cooling water for the turbine oil cooler is supplied from an extraction point on the first stage of the pump. The turbine steam supply valves (TSSV) are pneumatically operated, fail open valves, powered by dc solenoids each from a redundant vital dc bus.

The EFS system pipeline to each steam generator consists of two parallel branches, each with an isolation valve and a flow-control valve. These valves are pneumatically operated, fail open, and are controlled by redundant Class IE 125V dc busses.

6. EFS Flowpath Verification.

Recommendation GS-6. The licensee should confirm flowpath availability of an EFS flowtrain 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 EFS valves are properly aligned, and a second operator to independently verify proper alignment.

2. The licensee should propose Technical Specifications to assure that, before plant startup after an extended cold shutdown, a flow test would be done to verify the normal flowpath from the primary EFS water source to the steam generators. The flow test would be run with EFS valves in normal alignment.

Response. Waterford-3 maintenance procedures will be implemented requiring the operator to determine proper alignment of the EFS valves and a second operator to independently verify this. Technical Specifications will also be proposed to assure that, before plant startup after an extended cold shutdown and where an EFS flowtrain has been out of service for testing or maintenance, a test will be run to verify the normal flowpath from the primary EFS water source to the steam generators. This flow test will be run during cold shutdown, with EFS valves in normal alignment for EFS flow from the primary water source to the steam generators.

7. Nonsafety-Grade, Nonredundant EFS Automatic Initiation Signals.

   Recommendation GS-7. The licensee should verify that the automatic start EFS signals and associated circuitry are safety-grade. If this cannot be done, the EFS automatic-initiation system should be modified in the short term to meet functional requirements listed below. For the longer term, automatic-initiation signals and circuits should be upgraded to meet safety-grade requirements as indicated in Recommendation GL-5.

   1. The design should provide for automatic initiation of the EFS flow.
   2. The automatic initiation signals and circuits should be designed so that a single failure will not result in the loss of EFS function.
   3. Capability for testing the initiation signal and circuits shall be a design feature.

4. The initiation signals and circuits should be powered from the emergency buses.
5. Manual capability to initiate the EFS from the control room should be retained and implemented so that a single failure in the manual circuits will not result in loss of system function.
6. The ac motor-driven pumps and valves in the EFS should be included in the automatic actuation (simultaneous and/or sequential) of loads to the emergency buses.
7. The automatic-initiation signals and circuits shall be designed so that their failure will not result in loss of manual capability to initiate the EFS from the control room.

Response. Waterford Emergency Feedwater System signals and circuits are all safety related Class 1E. The Waterford EFS is in accordance with Recommendation GS-7.

8. Automatic Initiation of EFS.

Recommendation GS-8. The licensee shall install a system to automatically initiate EFS flow. This system need not be safety grade; however, in the short term, it should meet criteria similar to Item 2.1.7.a of NUREG-0578. For the longer term, the automatic-initiation signals and circuits should be upgraded to meet safety-grade requirements.

Response. Waterford Emergency Feedwater System is automatically initiated. The Waterford EFS is in accordance with Recommendation GS-8.

3.11.2 Additional Short-Term Recommendations

1. Primary EFW Water-Source Low-Level Alarm.

Recommendation. The licensee should provide redundant level indication and low-level alarms in the control room for the EFS primary water supply to allow the operator to anticipate the need for making up water or transferring to an alternate water supply and prevent low-pump suction pressure. The low-level alarm setpoint should allow at least 20 minutes for operator action, assuming operation of the largest capacity EFW pump.

Response. The Condensate Storage Pool (CSP), the primary EFS water source, has redundant, safety-grade level indication and low-level alarms in the control room. The low level alarm setpoint is at the Technical Specifications minimum volume of 170,000 gal. A low-low level alarm is initiated in the control room when the water inventory in the CSP is depleted to 30,000 gal. This amount is enough to supply water to one 700 gpm capacity pump or two 440 gpm capacity pumps for at least 30 minutes.

2. EFW Pump Endurance Test.

Recommendation. The licensee should do a 48-hour endurance test on all EFS pumps, if such a test or continuous period of operation has not yet been done. Then the pumps should be shut down, cooled, 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.

The licensee should summarize the conditions and results of the tests. This summary should include: (1) A brief description of the test method (including flow schematic diagram) and how the test was instrumented (i.e., where and how bearing temperatures were measured), (2) A discussion of how the test conditions (pump flow, head, speed, and steam temperature) compare to design operating conditions, (3) Plots of bearing/bearing oil temperature vs time for each bearing of each AFW pump/driver demonstrating that temperature design limits were not exceeded, (4) A plot of pump-room ambient temperature and humidity vs time demonstrating that pump-room ambient conditions do not exceed environmental qualification limits for safety-related equipment in the room, (5) A statement confirming that pump vibration did not exceed allowable limit during tests.

Response. In accordance with the Staff's position on endurance tests for EFS pumps set forth in the NRC letter dated May 2, 1980, from R. Reid to Florida Power and Light a 48 hour endurance test will be done on the Waterford-3 EFS pumps.

3. Indication of AFW Flow to the Steam Generator.

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

Safety-grade indication of EFW flow to each steam generator shall be provided in the control room. EFW flow instrument channels shall be powered from the emergency buses consistent with satisfying the emergency power diversity requirements for the EFS set forth in Auxiliary Systems Branch Technical Position 10-1 of the Standard Review Plan, Section 10.4.9.

Response. Safety-grade EFW flow indication, and safety grade, redundant steam-generator level indication are available to the operator in the control room. These instrument loops are powered by the uninterruptible 120-V ac Class IE power source.

4. EFS Availability During Periodic Surveillance Testing.

Recommendation. Licensees with plants requiring local manual realignment of valves to conduct periodic tests on one EFS train, and there is only one remaining EFW train available for operation, should propose Technical Specifications to provide for stationing a dedicated individual in communication with the control room at the manual valves. Upon instruction from the control room, this operator would realign the valves in the EFS train from the test mode to their operations alignment.

Response. Not applicable. Local manual realignment of valves to conduct periodic pump surveillance test on EFS trains is not required. Periodic pump surveillance tests can be run by merely starting the pump; water will be pumped from the CSP through the miniflow recirculation lines back to the CSP. There is no test on any EFS system active component that will reduce the availability of the EFS system flow train.

3.11.3 Long-Term Generic Recommendations

1. Automatic Initiation of EFS.

Recommendation GL-1. For plants with a manual starting EFS, the licensee should install a system to automatically initiate the EFS flow. This system and associated automatic initiation signals should be designed and installed to meet safety-grade requirements. Manual EFS start-and-control capability should be retained, with manual start backup to automatic EFS initiation.

Response. Not applicable. Waterford-3 EFS initiation is automatic, safety grade, and redundant.

2. Single Valves in the EFS Flow Path.

Recommendation GL-2. Licensees with plant designs in which all (primary and alternate) water supplies to the EFSs passthrough valves in a single flowpath should install redundant parallel flow paths (piping and valves).

Licensees with plant designs in which the primary EFS water supply passes through valves in a single flowpath, but the alternate EFS water supplies connect to the EFS pump suction piping downstream of the above valve(s), should install redundant valves parallel to the above valve(s) or provide automatic opening of the valve(s) from the alternate water supply upon low pump-suction pressure.

The licensee should propose Technical Specifications to incorporate appropriate periodic inspections to verify the valve positions into the surveillance requirements.
Response. All manually operated valves in EFS suction are locked open and are provided with limit switches for positon indication in the control room.

In additon, the Waterford EFS system has redundant, parallel flow paths (piping and valves) so that there is no single valve which, if left closed, could interrupt all flow.

3. Elimination of EFS Dependency on AC Power Following a Complete Loss of AC Power.
Recommendation GL-3. At least one EFS pump and its associated flowpath and essential instrumentation should automatically initiate EFS 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. Waterford's EFS turbine-driven pump is dc-controlled and capable of operation independent of ac

power for at least two hours. The turbine steam supply valves are pneumatically operated, fail open valves powered by dc solenoids, each from a redundant vital dc bus. The EFS system pipeline to each steam generator consists of two parallel branches, each with an isolation valve and a flow control valve. These valves are pneumatically operated, fail open, and are controlled by redundant, Class IE, 125 V dc buses.

4. Prevention of Multiple Pump Damage Caused by Loss of Suction Resulting from Natural Phenomena.

Recommendation GL-4. Licensees having plants with unprotected normal EFS water supplies should evaluate the design of their EFSs to determine if automatic protection of the pumps is needed after a seismic event or tornado. The time available to the control-room operator, and the time needed to assess the problem and take 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 I and tornado-protection requirements.

Response. Not applicable. The normal water supply to the EFS system is the Condensate Storage Pool (CSP). The CSP is inside the Reactor Auxiliary Building and thus is protected from site related phenomena. The CSP is also designed as seismic Category I.

The EFS isolation valves and TSSV are located atop the RAB and are protected from flooding and direct hurricane and tornado winds by the RAB walls. The valves are designed to withstand the pressure and differential induced by a tornado and are protected by a grating against tornado missiles.

5. Nonsafety Grade, Nonredundant EFS Automatic-Initiation Signals.

   Recommendation GL-5. The licensee should upgrade the EFS automatic-initiation signals and circuits to meet safety-grade requirements.

   Response. Waterford-3 EFS automatic initiation signals and circuits are safety-grade.

4.0 Major Contributors to Unreliability

LP&L lists the following contributors for each case:

4.1 Case 1 - Loss of Main Feedwater

1. Valve realignment, a maintenance error, contributes 37% of total system failure probability.

2. Failure of one of the pumps to start and its discharge check valve to remain closed diverts the other pumps flow through the failed pump loop. This contributes 28% of total system failure probability.

3. Failure of both automatic and operator backup actuation of the system contributes 14.4% of total system failure probability.

4. Failure of both motor-driven pumps, coupled with failures in the turbine-driven pump steam supply system, contributes 9.5% of total system failure probability.

The above failure modes account for 88.9% of total system failure probability. The remaining 11.1% is from events of lesser importance.

The absolute value of the Waterford-3 EFS unavailability for Case 1 of 1.35×10^{-5} is in the high reliability range of Reference 1 (unavailability between 10^{-4} and 10^{-5}).

4.2 Case 2 - Loss of Main Feedwater with Loss of Offsite Power

1. Valve realignment, a maintenance error, contributes 12.8% of total system failure probability.

2. Failure of one pump to start, coupled with its discharge check valve sticking open, contributes 27.4% of total system failure probability.

3. Failure of both automatic and operator backup actuation of the system contributes 5.2% of total system failure probability.

4. Failure of both motor-driven pumps, coupled with failures in the turbine-driven pump or its steam-supply system, contributes 31% of total system failure probability.

The above failure modes account for 76.4% of total system failure probability. The remaining 23.6% is from events of lesser importance. The difference between Case 1 and Case 2 is caused by the fact that a motor-driven pump failure can result from either a direct pump failure or failure of its associated diesel generator.

The absolute value of the Waterford-3 EFS unavailability for Case 2 of 3.90×10^{-5} is in the high reliability range of Reference 1 (unavailability between 10^{-4} and 10^{-5}).

4.3 Case 3 - Loss of Main Feedwater and Loss of All AC Power

There are a large number of first order events since the motor-driven pumps are deemed inoperable by the initial condition of station blackout for this case. The dominant contributions to system failure potential for this case are the turbine-driven pump and its governor valve, speed controller, and overspeed protection. Events describing these components account for roughly 90% of the total system failure probability.

The absolute value of EFS reliability for Case 3 of 2.63×10^{-2} is in the medium range of Reference 1 (unavailability between 10^{-1} and 10^{-2}).

4.4 Numerical Results

Numerical results are given below and in Reference 3. The results are plotted in Figure 3 to show how Waterford-3 compares to operating plants.

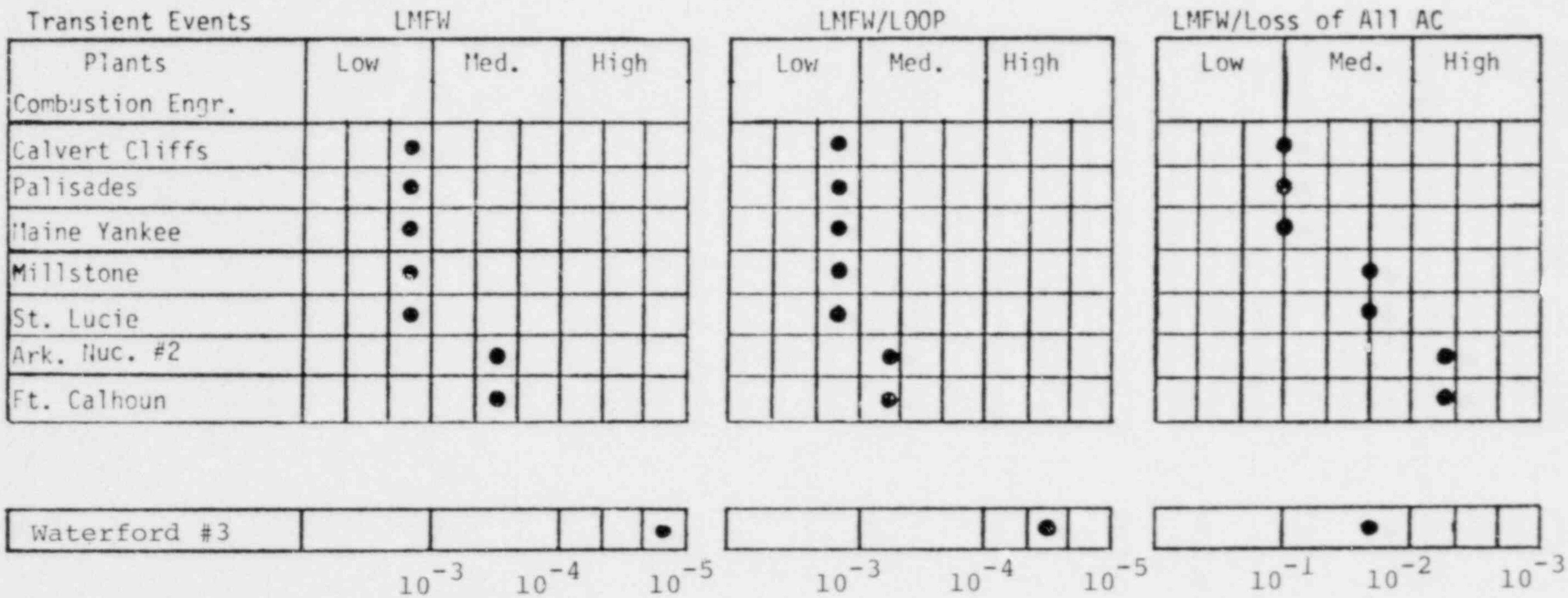

FIGURE 3

Reliability Characterizations for EFS Designs in Plants Using the C-E NSSS

Case 1	1.35×10^{-5}
Case 2	3.90×10^{-5}
Case 3	2.63×10^{-2}

This places WSES-3 in the high reliability category for Cases 1 and 2 and in the medium category for Case 3. SNL agrees with these assessments.

5.0 Conclusions

The main reasons for the favorable results are:

1. The active components and flow paths are redundant; there are no single point vulnerabilities.
2. The system is automatically actuated; no human action is required.
3. System design is such that all routine testing can be done with no incapacitating realignments or locking out of components.
4. All anticipated maintenance is done during plant shutdown.
5. There are few interconnections with other systems, minimizing the potential for adverse interactions with other systems.
6. Positions of most of the manual valves in the system are monitored by the plant computer, minimizing the probability for valve mispositioning.

Based on this review, we conclude that WSES-3 should have a high reliability for Case 1 and 2 and a medium reliability for Case 3 as reported in LP&Ls evaluation. LP&L has in our judgment completed requirement (b) of the March 10, 1980 letter.[2]

6.0 Glossary of Terms

ac	alternating current
ASME	American Society of Mechanical Engineers
CCWS	Component Cooling Water System
CE	Combustion Engineering Inc.
CSP	Condensate Storage Pool
dc	direct current
ECCS	Emergency Core Cooling System
EFAS	Emergency Feedwater Actuation Signal
EFS	Emergency Feedwater System
EFW	Emergency Feedwater
ESF	Emergency Safety Features
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
LP&L	Louisiana Power and Light Company
msl	mean sea level
NPSH	Net Positive Suction Head
NRC	Nuclear Regulatory Commission
NSSS	Nuclear Steam Supply System
psi	pounds per square inch
RAB	Reactor Auxiliary Building

RCS	Reactor Coolant System
rpm	revolutions per minute
SDCS	Shutdown Cooling System
SG	Steam Generator
SNL	Sandia National Laboratories
TDP	Turbine Driven Pump
TMI	Three Mile Island
TSS	Turbine Steam Supply
TSSV	Turbine Steam Supply Valves
WCT	Wet Cooling Tower
WSES	Waterford Steam Electric Station

7.0 References

1. NUREG-0635 "Generic Evaluation of Feedwater Transients and Small Break Loss-of-Coolant Accidents in Combustion Engineering Designed Operating Plants," January 1980.

2. 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," March 10, 1980.

3. WSES-FSAR-UNIT 3, Appendix 10.4.9B Amendment No. 13, November 1980.

4. Table 10.4.9A-2, Subject: "Evaluation of the WSES Unit No. 3 Emergency Feedwater System versus the NRC EFS Short and Long Term Recommendations," WSES-FSAR-Unit 3 Amendment No. 13, November 1980.

5. Schedule 189 FIN No. A1303-1 Title: Review of Auxiliary Feedwater System Reliability Evaluation Studies for Comanche Peak 1 & 2, Waterford 3, Watts Bar 1 & 2, and Midland 1 & 2, May 7, 1980.

6. WASH 1400 (NUREG-75/014) Reactor Safety Study, October 1975.

7. NUREG/CR-1278 Handbook of Human Reliability Analysis with Emphasis on Nuclear Power Plant Applications by A. D. Swain and H. E. Guttmann, October 1980.

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The purpose of this report is to present the results of the review of the Auxiliary Feedwater System Reliability Analysis for the Waterford Steam Electric Station Unit 3.

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