U.S. NUCLEAR REGULATORY COMMISSION

STANDARD REVIEW PLAN

OFFICE OF NUCLEAR REACTOR REGULATION

10.4.9 AUXILIARY FEEDWATER SYSTEM (PWR)

REVIEW RESPONSIBILITIES

Primary - Auxiliary Systems Branch (ASB)

Secondary - None

I. AREAS OF REVIEW

The auxiliary feedwater system (AFWS) normally operates during startup, hot standby and shutdown as the feedwater system for pressurized water reactor (PWR) plants. In conjunction with a seismic Category I water source, it also functions as an emergency system for the removal of heat from the primary system when the main feedwater system is not available for emergency conditions including small LOCA cases. The AFWS operates over a time period sufficient either to hold the plant at hot standby for several hours or to cool down the primary system, at a rate not to exceed limits specified in technical specifications, to temperature and pressure levels at which the low pressure decay heat removal system can operate. The design of the AFWS should meet the requirements of General Design Criteria 2, 4, 5, 19, 34, 44, 45 and 46.

The ASB reviews the AFWS from the condensate storage tank (normal operation), or the seismic Category I water supply including valving and cross-connects (emergency operation), to the connections with the steam generators, which are made either through a connection to the main feedwater piping or through separate auxiliary feedwater piping connected directly to the steam generators. All inter-connections and cross-connections are included in the review.

The review also includes AFWS components, e.g., pumps, valves, and piping, with respect to their functional performance as affected by adverse environmental occurrences, abnormal operational requirements, and off-normal conditions, e.g., small breaks in the primary system or the loss of offsite power.

The system is reviewed to determine that a single malfunction, a failure of a component, or the loss of a cooling source does not reduce the safety-related functional performance capabilities of the system. The ASB review assures that:

1. System components and piping have sufficient physical separation or shielding to protect the essential portions of the system from the effects of internally and externally generated missiles. This review is performed according to SRP Section 3.5.1.1 for internally generated missiles and Sections 3.5.1.4 and 3.5.2 for externally generated missiles.

2. The system is protected against the effects of pipe whip and jet impingement that may result from high or moderate energy piping breaks or cracks This review is performed according to SRP Section 3.6.1.

3. The failure of non-essential equipment or components does not affect essential functions of the system.

4. The system is capable of withstanding a single active failure.

5. The system possesses diversity in motive power sources such that system performance requirements may be met with either of the assigned power sources, e.g., a system with an a-c subsystem and a redundant steam/d-c subsystem.

6. The system design precludes the occurrence of fluid flow instabilities, e.g., water hammer, in system inlet piping during normal plant operation or during upset or accident conditions (see SRP Section 10.4.7).

7. Functional capability is assured by suitable protection during abnormally high water levels (adequate flood protection considering the probable maximum flood). This review is performed according to SRP Section 3.4.1.

8. The capability exists to detect, collect, and control system leakage and to isolate portions of the system in case of excessive leakage or component malfunctions.

9. Provisions are made for operational testing.

10. Instrumentation and control features are provided to verify the system is operating in a correct mode.

11. The system is capable of automatically initiating auxiliary feedwater flow upon receipt of a system actuation signal.

12. The system satisfies the recommendations of Regulatory Guide 1.62 with respect to the system capability to manually initiate protective action by the auxiliary feedwater system.

13. The system design possesses the capability to automatically terminate auxiliary feedwater flow to a depressurized steam generator, and to automatically provide feedwater to the intact steam generator. Or as an alternative if it is shown that the intact steam generator will recieve the minimum required flow without isolation of the depressurized steam generator and containment design pressure is not exceeded, then operator action may be relied upon to isolate the depressurized steam generator.

14. The system possesses sufficient auxiliary feedwater flow capacity so that a cold shutdown can be achieved. Upon request from ASB, the Reactor Systems Branch (RSB) will verify that the system meets the minimum flow requirements for decay heat removal.

15. The applicant's proposed technical specifications are such as to assure the continued reliability of the AFWS during plant operation; i.e., the limiting conditions for operation and the surveillance testing requirements are specified and are consistent with the Standard Technical Specifications.

16. In conjunction with the Instrumentation and Control Systems Branch (ICSB) the ASB verifies that the system design meets the generic short and long term recommendations identified in NUREGS-0611 and -0635. These recommendations will apply to all PWRs.

17. An AFWS reliability analysis is performed in accordance with Item II.E.1.1 of NUREG-0737 using the methodology defined by Appendix III and Annex 1 of Appendix X in NUREG-0611 and NUREG-0635 to determine the system reliability and major contributors to AFW system failure under various loss of main feedwater transients. The ICSB will evaluate the design to determine that the requirements and guidance of II.E.1.2 of NUREG-0737 are met.

18. The reviewer verifies that the system design has the capability to permit operation at hot shutdown for at least four hours followed by cooldown to the RHR cut-in temperature from the control room using only safety grade equipment and assuming the worst case single active failure in accordance with Branch Technical Postion RSB 5-1.

Coordinated reviews are performed by other branches and the results used by the ASB to complete the overall evaluation of the system. The coordinated reviews are as follows. The RSB identifies any functional interfaces between essential components of the reactor coolant or emergency core cooling systems and the AFWS that are required for operation during normal operations or accident conditions. The RSB establishes postaccident heat loads and the associated time intervals available for cooling various components. The Structural Engineering Branch (SEB) determines the acceptability of the design analyses, procedures, and criteria used to establish the ability of seismic Category I structures housing the system and supporting systems to withstand the effects of natural phenomena such as the safe shutdown earthquake (SSE), the probable maximum flood (PMF), and tornado missiles as part of its primary review responsibility for SRP Sections 3.3.1, 3.3.2, 3.5.3, 3.7.1 through 3.7.4, 3.8.4 and 3.8.5. The Mechanical Engineering Branch (MEB) determines that the components piping and structures are designed in accordance with applicable codes and standards as part of its primary review responsibility for SRP Sections 3.9.1 through 3.9.3. The MEB, also, determines the acceptability of the seismic and quality group classifications for system components as part of its primary review responsibility for SRP Sections 3.2.1 and 3.2.2. The MEB also reviews the adequacy of the inservice testing program of pumps and valves as part of its primary review responsibility for SRP Section 3.9.6. The Materials Engineering Branch (MTEB) verifies that inservice inspection requirements are met for system components as part of its primary review responsibility for SRP Section 6.6, and, upon request, verifies the compatibility of the materials of construction with services conditions. The review for Fire Protection, Technical Specifications, and Quality Assurance are coordinated and performed by the Chemical Engineering Branch, Licensing Guidance Branch and Quality Assurance Branch as part of their primary review responsibility for SRP Sections 9.5.1, 16.0 and 17.0, respectively. The Equipment Qualification Branch (EQB) reviews the seismic qualification of Category I instrumentation and electrical equipment and the environmental qualification of mechanical and electrical equipment as part of its primary review responsibility for SRP Sections 3.10 and 3.11, respectively. The ICSB and Power System Branch (PSB) evaluate system controls, instrumentation, and power sources with respect to capability, capacity, and reliability during normal and emergency conditions as part of their primary review responsibility for SRP Sections 7.1 and 7.3 through 7.5 for ICSB and Section 8.3 for PSB.

For those areas of review identified above as being reviewed as part of the primary responsibility of other branches, the acceptance criteria and their methods of application are contained in the SRP sections corresponding to those branches.

II. ACCEPTANCE CRITERIA

Acceptability of the design of the auxiliary feedwater system, as described in the applicant's safety analysis report (SAR), is based on specific general design criteria and regulatory guides. Listed below are the specific criteria used in this SRP section as they relate to the AFWS.

1. General Design Criterion 2, as related to structures housing the system and the system itself being capable of withstanding the effects of earthquakes. Acceptability is based on meeting position C.1 of Regulatory Guide 1.29 for safety-related portions and position C.2 for nonsafety-related portions.

2. General Design Criterion 4, with respect to structures housing the system and the system itself being capable of withstanding the effects of external missiles and internally generated missiles, pipe whip, and jet impingement forces associated with pipe breaks. The basis for acceptance for meeting this criterion is set forth in the SRP Section 3.5 and 3.6 series.

3. General Design Criterion 5, as related to the capability of shared systems and components important to safety to perform required safety functions.

4. General Design Criterion 19, as related to the design capability of system instrumentation and controls for prompt hot shutdown of the reactor and potential capability for subsequent cold shutdown. Acceptance is based on meeting Branch Technical Position RSB 5-1 with regards to cold shutdown from the control room using only safety grade equipment.

5. General Design Criteria 34 and 44, to assure:

   a. The capability to transfer heat loads from the reactor system to a heat sink under both normal operating and accident conditions.

   b. Redundancy of components so that under accident conditions the safety function can be performed assuming a single active component failure. (This may be coincident with the loss of offsite power for certain events.) Branch Technical Position ASB 10-1 as it relates to AFW pump drive and power supply diversity shall be used in meeting these criteria.

   c. The capability to isolate components, subsystems, or piping if required so that the system safety function will be maintained.

In meeting these criteria, the recommendations of NUREG-0611 and 0635 shall also be met. An acceptable AFWS should have an unreliability in the range of 10^{-4} to 10^{-5} per demand based on an analysis using methods and data presented in NUREG-0611 and NUREG-0635. Compensating factors such as other methods of accomplishing the safety functions of the AFWS or other reliable methods for cooling the reactor core during abnormal conditions may be considered to justify a larger unavailability of the AFWS.

6. General Design Criterion 45, as related to design provisions made to permit periodic inservice inspection of system components and equipment.

7. General Design Criterion 46, as related to design provisions made to permit appropriate functional testing of the system and components to assure structural integrity and leak-tightness, operability and performance of active components, and capability of the integrated system to function as intended during normal, shutdown, and accident conditions. In meeting this criteria the technical specifications should specify that the monthly AFWS pump test shall be performed on a staggered test basis to reduce the likelihood of leaving more than one pump in a test mode following the tests.

III. REVIEW PROCEDURES

The procedures below are used during the construction permit (CP) review to determine that the design criteria and bases and the preliminary design as set forth in the preliminary safety analysis report meet the acceptance criteria given in subsection II. For operating license (OL) applications, the procedures are utilized to verify that the initial design criteria and bases have been appropriately implemented in the final design as set forth in the final safety analysis report. The procedures for OL applications also include a determination that the content and intent of the technical specifications prepared by the applicant are in agreement with the requirements for system testing, minimum performance and surveillance developed as a result of the staff's review.

Upon request from the primary reviewer, the coordinating review branches will provide input for the areas of review stated in subsection I. The primary reviewer obtains and uses such input as required to assure that this review procedure is complete.

For the purpose of this SRP section, a typical system is assumed which has redundant auxiliary feedwater trains, with a 50% capacity motor-driven pump in each train feeding directly to the steam generators, and a 100% capacity steam turbine-driven pump able to supply either of the redundant trains. The pumping capacity should permit the system to hold the plant at hot standby and subsequently to cool down the reactor at specified cooldown rates. The 50% capacity pump is assumed to have sufficient capacity for decay heat removal following any accident or transient although cooldown to RHR cut in temperature may take longer than design. This requirement should also be met for conditions involving a small break area loss-of-coolant accident (LOCA) or a pipe break outside containment. For cases where there are variations from the typical arrangement, the reviewer adjusts the review procedures to suit the design. However, the system design is required to meet the acceptance criteria given in subsection II.

1. The SAR is reviewed to determine that the system description and piping and instrumentation diagrams (P&IDs) identify the AFWS equipment and arrangement that is used for normal operation and for safe plant shutdown (essential) operation. The system P&IDs, layout drawings, and component descriptions and characteristics are then reviewed to verify that:

   a. Minimum performance requirements for the system are sufficient for the various functions of the AFWS.

   b. Essential portions of the AFWS are isolable from non-essential portions, so that system performance is not impaired in the event of a failure of a non-essential component.

   c. Component and system descriptions in the SAR include appropriate seismic and quality group classifications, and the P&IDs indicate any points of change in piping quality group classification. The review for seismic design is performed by the SEB and the review for seismic and quality group classification is performed by the MEB as indicated in Subsection I of this SRP section.

   d. Design provisions have been made that permit appropriate inservice inspection and functional testing of system components important to safety. It is acceptable if the SAR information delineates a testing and inspection program if the system drawings show the necessary recirculation loops around pumps or isolation valves as may be required by this program.

2. The reviewer verifies that the system safety function will be maintained as required, in the event of adverse environmental phenomena, breaks or cracks in fluid system piping outside containment, system component failures, loss of an onsite motive power source, or loss of offsite power. The reviewer uses engineering judgment and the results of failure modes and effects analyses to determine that:

   a. The failure of portions of the system or of other systems not designed to seismic Category I standards and located close to essential portions of the system, or of nonseismic Category I structures that house, support, or are close to essential portions of the AFWS, will not preclude operation of the essential portions of the AFWS. Reference to SAR sections describing site features and the general arrangement and layout drawings will be necessary, as well as the SAR tabulation of seismic design classifications for structures and systems.

   b. The essential portions of the AFWS are protected from the effects of floods, hurricanes, tornadoes, and internally or externally generated missiles. Flood protection and missile protection criteria are discussed and evaluated in detail under the SRP Section 3 series. The location and design of the system, structures, and pump rooms (cubicles) are reviewed to determine that the degree of protection provided is adequate. A statement to the effect that the system is located in a seismic Category I structure that is tornado missile and flood protected, or the components of the system will be located in individual seismic Category I cubicles or rooms that will withstand the effects of both flooding and missiles is acceptable.

c. The essential portions of the system are protected from the effects of high and moderate energy line breaks. Layout drawings are reviewed to assure that no high or moderate energy piping systems are close to essential portions of the AFWS, or that protection from the effects of failure will be provided. The means of providing such protection will generally be given in Section 3.6 of the SAR and procedures for reviewing this information are given in SRP Section 3.6.1.

d. Essential components and subsystems necessary for safe shutdown can function as required in the event of loss of offsite power. The SAR is reviewed to see that for each AFWS component or subsystem affected by the loss of offsite power, system flow and heat transfer capability meet minimum requirements. Statements in the SAR and the results of failure modes and effects analyses are considered in assuring that the system meets these requirements.

e. The system is designed with adequate redundancy to accommodate a single active component failure without loss of function. This includes redundant piping and valves from the condensate storage tank (or other primary source) to the AFW pump suctions.

f. Diversity in pump motive power sources and essential instrumentation and control power sources has been provided. The diverse system including pump(s), controls and valves should be independent of offsite and onsite AC power sources in accordance with the guidelines of Branch Technical Position ASB 10-1.

g. The system is designed with adequate instrumentation to automatically initiate auxiliary feedwater flow to the steam generators upon receipt of an actuation signal. The initiation signal should start all auxiliary feedwater pumps and supporting systems, align the auxiliary feedwater sources, and open flow paths from the auxiliary feedwater pumps to the steam generator(s). The system is also designed with the capability to manually initiate the necessary protective actions. The AFWS is designed with redundant instrumentation so that the system will automatically limit (may be flow limiting orifice rather than instrumentation) or terminate auxiliary feedwater flow to a depressurized steam generator, and to assure that the minimum required flow is directed to the intact steam generator(s). The electrical portion of this review is performed by ICSB as indicated in subsection I of this SRP section. If a flow limiter is used then it must be demonstrated that sufficient flow still goes to the intact steam generator and containment design pressure is not exceeded by the AFW flow to the depressurized generator.

j. The AFWS is designed with sufficient flow capacity so that the system can remove residual heat over the entire range of reactor operation and cool the plant to the decay heat removal system cut-in temperature. This review is performed by RSB upon request as indicated in subsection I of this SRP section.

3. The reviewer verifies that the design has features to meet the generic recommendations of NUREG-0611 and 0635. For additional short term recommendation No. 2 regarding AFW pump endurance tests, a 48 hour test is

acceptable rather than the 72 hour test specified in the NUREGS. The ASB reviewer coordinates with the ICSB reviewer to assure that the instrumentation and control system aspects of these recommendations are met by the system design.

4. The reviewer verifies that an AFWS reliability evaluation has been performed in accordance with item II.E.1.1 of NUREG-0737. The reliability analysis is reviewed to determine the potential for AFW system failure under various loss of main feedwater transients.

IV. EVALUATION FINDINGS

The reviewer verifies that sufficient information has been provided and his review supports conclusions of the following type, to be included in the staff's safety evaluation report:

The auxiliary feedwater system includes all components and equipment from the condensate storage tank (normal operation) or the seismic Category I emergency water supply (including valves and cross connections) to the connection with the steam generators. The AFWS is designed to seismic Category I requirements since system operation is necessary to mitigate the consequences of an accident. This includes an automatic seismic Category I, tornado protected supply of water to the AFW pump suction. Based on the review of the applicant's proposed design criteria, design bases and safety classification for the auxiliary feedwater system, and system performance requirements during normal, abnormal, and accident conditions, the staff concludes that the design of the auxiliary feedwater system and supporting systems is acceptable and meets the Commission's regulations as set forth in General Design Criteria 2, 4, 5, 19, 34, 44, 45, and 46. This conclusion is based on the following:

1. The AFW system design meets the requirements of General Design Criterion 2 with respect to protection against the effects of earthquakes since the safety related portions are designed to seismic Category I requirements in accordance with position C.1 of Regulatory Guide 1.29 and the nonsafety-related portions are designed in accordance with position C.2 of Regulatory Guide 1.29.

2. The AFW system design meets the requirements of General Design Criterion 4 with respect to protection against the effects of pipe breaks and missiles. Acceptance was based on locating the AFW system pumps and trains in individual cubicles which separate redundant components and are protected against the effects of tornado missiles. Refer to the Chapter 3 sections of this report for a description of how this protection is accomplished.

3. The AFW system is designed in accordance with the requirements of General Design Criterion 5 with respect to sharing of structures systems and components. This is accomplished since a failure of any component including a pipe break and single active failure will not prevent the safe shutdown and cooldown of either unit (together or singularly).

4. The system design meets the requirements of General Design Criterion 19 as related to the design capability of system instrumentation and

controls for prompt hot shutdown of the reactor and potential capability for subsequent cold shutdown since the design meets the requirement of Branch Technical Position RSB 5-1 which requires the capability to bring primary plant temperature to the RHR cut-in point following four hours at hot standby from the control room using only safety grade equipment and assuming any single active failure.

5. The system design meets the requirements of Genral Design Criteria 34 and 44 since it has the capability to transfer heat loads, including decay heat from the reactor, during normal operating and accident conditions assuming any single active failure. The system has suitable redundancy such that it can withstand a pipe break and single active failure and still perform its safety function. The system deign also has sufficient diversity such that it meets the requirements of Branch Technical Position ASB 10-1. In meeting these General Design Criteria the applicant has also met the generic recommendations identified in NUREGS-0611 and -0635 and has performed a reliability analysis in accordance with NUREG-0737, item II.E.1.1. The results of the reliability analyses were acceptable since it was shown that the AFWS has an unreliability in the range of 10^{-4} to 10^{-5} per demand.

6. The pumps, valves, heat exchangers and piping of the system, to the extent practicable, are designed and located to facilitate periodic inspection as required by General Design Criterion 45. This is accomplished by providing adequate accessability to conduct the required examinations.

7. To meet the requirements of General Design Criterion 46, the auxiliary feedwater system is designed to include the capability for testing through the full operational sequence that brings the system into operation for reactor shutdown and for loss-of-coolant accidents, including operation of applicable portions of the protection system and the transfer between normal and emergency buses.

V. <u>IMPLEMENTATION</u>

The following is intended to provide guidance to applicants and licensees regarding the NRC staff's plans for using this SRP section.

Except in those cases in which the applicant proposes an acceptable alternative method for complying with specified portions of the Commission's regulations, the method described herein will be used by the staff in its evaluation of conformance with Commission regulations.

Implementation schedules for conformance to part of the method discussed herein are contained in the referenced regulatory guides and NUREGs.

VI. <u>REFERENCES</u>

1. 10 CFR Part 50, Appendix A, General Design Criterion 2, "Design Bases for Protection Against Natural Phenomena."

2. 10 CFR Part 50, Appendix A, General Design Criterion 4, "Environmental and Missile Design Bases."

3. 10 CFR Part 50, Appendix A, General Design Criterion 5, "Sharing of Structures, Systems, and Components."

4. 10 CFR Part 50, Appendix A, General Design Criterion 19, "Control Room."

5. 10 CFR Part 50, Appendix A, General Design Criterion 34, "Decay Heat Removal."

6. 10 CFR Part 50, Appendix A, General Design Criterion 44, "Cooling Water."

7. 10 CFR Part 50, Appendix A, General Design Criterion 45, "Inspection of Cooling Water System."

8. 10 CFR Part 50, Appendix A, General Design Criterion 46, "Testing of Cooling Water System."

9. Regulatory Guide 1.29, "Seismic Design Classification."

10. Branch Technical Position RSB 5-1, "Design Requirements of the Residual Heat Removal System," attached to SRP Section 5.4.7.

11. Branch Technical Position ASB 10-1, "Design Guidelines for Auxiliary Feedwater System Pump Drive and Power Supply Diversity for Pressurized Water Reactor Plants," attached to this SRP section.

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

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

14. NUREG-0737 "Clarification of TMI Action Plan Requirements," November 1980.

BRANCH TECHNICAL POSITION ASB 10-1

DESIGN GUIDELINES FOR AUXILIARY FEEDWATER SYSTEM PUMP DRIVE AND POWER SUPPLY DIVERSITY FOR PRESSURIZED WATER REACTOR PLANTS

A. BACKGROUND

Heat removal from pressurized water reactor plants following reactor trip and a loss of offsite power is accomplished by the operation of several systems including the secondary system via the steam relief system. Similar capability is required to mitigate the consequences of certain postulated piping breaks. Such heat removal involves heat transfer from the reactor to the steam generators, resulting in the production of steam which is then released to the atmosphere. In this process it becomes necessary to supply makeup water to the steam generators. This is accomplished by the use of an auxiliary feedwater system, which generally consists of redundant components that are powered by both electrical and steam-driven sources.

The auxiliary feedwater system functions as an engineered safety system because it is the only source of makeup water to the steam generators for decay heat removal when the main feedwater system becomes inoperable. It must, therefore, be designed to operate when needed, using the principles of redundancy and diversity in order to assure that it can function under postulated accident conditions. The majority of current systems are powered by electrical or steam-driven sources. Operating experience demonstrates that each type of motive power can be subject to a failure of the driving component itself, its source of energy, or the associated control system. The effects of such failures can be minimized by the utilization of diverse systems that include energy sources of at least two different and distinct types.

The provision of several independent flow paths for the auxiliary feedwater system serves to preclude the possibility of a complete loss of function due to a single event, either occurring alone, or in conjunction with the failure of an active component. The auxiliary feedwater system is categorized as a high energy system, because either that section of line which connects to the main feedwater piping or the steam generator is pressurized during plant operation or else the entire system is pressurized when in use during startup, hot standby, and shutdown.

The staff believes that it is necessary to establish design guidelines for the auxiliary feedwater system, and in this regard has developed guidelines that may be used to select the minimum diversity acceptable for auxiliary feedwater system pump drives and power supplies.

B. BRANCH TECHNICAL POSITION

1. The auxiliary feedwater system should consist of at least two full-capacity, independent systems that include diverse power sources.

2. Other powered components of the auxiliary feedwater system should also use the concept of separate and multiple sources of motive energy. An example of the required diversity would be two separate auxiliary feedwater trains, each capable of removing the afterheat load of the reactor system, having one separate train powered from either of two a-c sources and the other train wholly powered by steam and d-c electric power.

3. The piping arrangement, both intake and discharge, for each train should be designed to permit the pumps to supply feedwater to any combination of steam generators. This arrangement should take into account pipe failure, active component failure, power supply failure, or control system failure that could prevent system function. One arrangement that would be acceptable is crossover piping containing valves that can be operated by remote manual control from the control room, using the power diversity principle for the valve operators and actuation systems.

4. The auxiliary feedwater system should be designed with suitable redundancy to offset the consequences of any single active component failure; however, each train need not contain redundant active components.

5. When considering a high energy line break, the system should be so arranged as to assure the capability to supply necessary emergency feedwater to the steam generators, despite the postulated rupture of any high energy section of the system, assuming a concurrent single active failure.

C. REFERENCES

None