U.S. NUCLEAR REGULATORY COMMISSION

# STANDARD REVIEW PLAN

OFFICE OF NUCLEAR REACTOR REGULATION

## 10.4.7 CONDENSATE AND FEEDWATER SYSTEM

REVIEW RESPONSIBILITIES

Primary - Auxiliary Systems Branch (ASB)

Secondary - None

## I. AREAS OF REVIEW

The condensate and feedwater system (CFS) provides feedwater at the required temperature, pressure, and flow rate to the reactor for boiling water reactor (BWR) plants and to the steam generators for pressurized water reactor (PWR) plants. Condensate is pumped from the main condenser hotwell by the condensate pumps, passes through the low pressure feedwater heaters to the feedwater pumps, and then is pumped through the high pressure feedwater heaters to the nuclear steam supply system.

ASB reviews the CFS from the condenser outlet to the connection with the nuclear steam supply system and to the heater drain system to assure conformance to General Design Criteria 2, 4, 5, 44, 45 and 46. For indirect cycle plants, there are also interfaces with the secondary water makeup system and the auxiliary feedwater system. The CFS is used for normal shutdown. The only part of the CFS classified as safety-related, i.e., required for safe shutdown or in the event of postulated accidents, is the feedwater piping from the steam generators for PWRs and from the nuclear steam supply system for BWRs, up to and including the outermost containment isolation valve.

1. The ASB reviews the characteristics of the CFS with respect to the capability to supply adequate feedwater to the nuclear steam supply system as required for normal operation and shutdown.

2. The ASB review determines that an acceptable design has been established for:

   a. The interfaces of the CFS with the auxiliary feedwater system (PWR), the reactor core isolation cooling system (BWR), and the condensate cleanup system with regard to functional design requirements and seismic design classification.

b. The feedwater system (PWR), including the auxiliary feedwater system piping entering the steam generator, with regard to possible fluid flow instabilities (e.g., water hammer) during normal plant operation as well as during upset or accident conditions.

c. The detection of major system leaks that could affect the functional performance of safety-related equipment.

3. ASB also performs the following reviews under the SRP sections indicated:

(a) Review for flood protection is performed under SRP Section 3.4.1,

(b) Review of the protection against internally generated missiles is performed under SRP Section 3.5.1.1,

(c) Review of the structures, systems, and components to be protected against externally generated missiles is performed under SRP Section 3.5.2, and

(d) Review of high- and moderate-energy pipe breaks is performed under SRP Section 3.6.1.

The ASB will coordinate evaluations performed by other branches that interface with the overall evaluation of the system as follows:

The Reactor Systems Branch (RSB) determines that transients resulting from feedwater flow control malfunctions will not violate the primary system pressure boundary integrity criterion as part of its primary review responsibility for SRP Sections 15.1.1 through 15.1.4, and that the loss of normal feedwater flow will not violate the fuel damage criterion or the system pressure boundary integrity criterion as part of its primary review responsibility for SRP Section 15.2.7.

The Power Systems Branch (PSB) evaluates the system power sources with respect to their capability to perform safety-related functions during normal, transient, and accident conditions as part of its primary review responsibility for SRP Section 8.3.1. The Structural and Geotechnical Engineering Branch (SGEB) 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 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. Upon request, the MEB determines the acceptability of design analyses, procedures, and criteria used to establish the adequacy of devices or restraints as they may relate to significant water hammers in system piping and the MEB reviews test programs of components that may be affected by water hammers. 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 service conditions. The review for Fire Protection, Technical Specifications, and Quality Assurance are coordinated and performed by the Chemical Engineering Branch, Standardization and Special Projects 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. Upon request, the Instrument and Control Systems Branch (ICSB) will review the instrumentation and controls associated with the feedwater control system (BWR) or steam generator level control system (PWR).

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

## II. ACCEPTANCE CRITERIA

Acceptability of the condensate and feedwater system, as described in the applicant's safety analysis report (SAR), is based on the specific requirements of General Design Criteria and the positions of regulatory guides. Listed below are the specific criteria as they relate to the CFS.

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

2. General Design Criterion 4, as related to the dynamic effects associated with possible fluid flow instabilities (e.g., water hammers) during normal plant operation as well as during upset or accident conditions. Acceptance is based on meeting the guidance contained in the attached Branch Technical Position ASB 10-2 for reducing the potential for water hammers in steam generators and on meeting the guidance related to feedwater control induced water hammer.

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 44, as it relates to:

   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.)

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

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

6. General Design Criterion 46, as related to design provisions 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.

## 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 of this SRP section. For the review of operating license (OL) applications, the procedures are used 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 primary reviewer will coordinate this review with the areas of review of interfacing branches as stated in subsection I of this SRP section. The primary reviewer obtains and uses such inputs as required to assure that this review procedure is complete.

The reviewer will select and emphasize material from this SRP section as may be appropriate for a particular case.

The SAR is reviewed to determine that the system description and diagrams delineate the function of the condensate and feedwater system under normal and abnormal conditions. The reviewer verifies the following:

1. The system has been designed to function as required for all modes of operation. The results of failure modes and effects analyses presented in the SAR, if any, are used in making this determination.

2. The system piping is designed to preclude hydraulic instabilities from occurring in the piping for all modes of operation. As appropriate, the reviewer evaluates the results of model tests and analyses that are relied on to verify that water hammer will not occur, or proposed tests of the installed system that are intended to verify design adequacy. Steam generators are reviewed in accordance with Branch Technical Position ASB 10-2.

   The feedwater control valve and controller design shall be verified to be stable and to be compatible with system(s), imposed operating conditions (e.g., control functions required, range of control and pressure drop characteristics, valve stroke, trim, etc.). Test data or operating experience data shall be used where available. In addition, the applicant has committed to review plant operating and maintenance procedures to assure that precautions for avoidance of steam/water hammer and water hammer occurrences have been provided.

3. The outermost containment isolation valves and all downstream piping to the nuclear steam supply system are designed in accordance with seismic Category I requirements. The review for seismic design is performed by SGEB and the review for seismic and quality group classification is performed by MEB as indicated in subsection I of this SRP section.

4. The CFS design is such that the plant can be safely shut down using the auxiliary feedwater system or the reactor core isolation cooling system, if required.

5. The CFS design, or other plant systems, provide the capability to detect and control leakage from the system.

6. The reviewer verifies that the essential portion of the system has been designed so that system function will be maintained as required in the event of adverse environmental phenomena or loss of offsite power. The review for protection against natural phenomena is performed in the Chapter 3 SRP sections. The reviewer evaluates the system, using engineering judgment and the results of failure modes and effects analyses, to determine that the failure of nonessential 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 CFS, will not preclude operation of the essential portions of the CFS.

## 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 condensate and feedwater system includes all components and equipment from the condenser outlet to the connection with the nuclear steam supply system and to the heater drain system [secondary water makeup system, and auxiliary feedwater system interfaces. (PWRs only)]. Based on the review of the applicant's proposed design criteria, the design bases, and safety classification for the safety-related portions of the condensate and feedwater system and the requirements for system performance for all conditions of plant operation, the staff concludes that the design of the condensate and feedwater system and supporting systems is in conformance with the Commission regulations as set forth in General Design Criterion 2, 4, 5, 44, 45 and 46. This conclusion is based on the following:
>
> 1. The applicant has met the requirements of General Design Criterion 2 with respect to safety-related portions of the system being capable of withstanding the effects of earthquakes by meeting Regulatory Guide 1.29 Position C.1 for the safety-related portions and Position C.2 for the nonsafety-related portions.

2. The applicant has met the requirements of General Design Criterion 4 with respect to the dynamic effects associated with possible fluid flow instabilities (e.g., water hammers) by having the feedwater system designed in accordance with the guidance contained in Branch Technical Position ASB 10-2 and thereby eliminating or reducing the possibility of water hammers in steam generators (PWRs only).

   That the applicant has adequately addressed feedwater control valve and controller designs with respect to water hammer potential and the applicant has committed to review operating and maintenance procedures to assume that precautions taken will minimize, or avoid, water hammers.

3. The applicant has met the requirements of General Design Criterion 5 with respect to the capability of shared systems and components important to safety to perform required safety functions. We have reviewed the interconnections of the CFS between each unit. The interconnections are designed so that the capability to mitigate the consequences of an accident in either unit and achieve safe shutdown in that unit is retained without reducing the capability of the other unit to achieve safe shutdown.

4. The applicant has met the requirements of General Design Criterion 44 with respect to cooling water by providing a redundant and isolable system capable of transferring heat loads from the reactor system to a heat sink under both normal operating and accident conditions. The applicant has demonstrated that the condensate and feedwater system can provide sufficient cooling water to transfer the heat load of the reactor system under normal operating conditions and accident conditions assuming loss of offsite power and a single failure and that portions of the system can be isolated so that the safety function of the system will not be compromised.

5. The applicant has met the requirements of General Design Criterion 45 with respect to inspection of cooling water systems by providing a feedwater system design that permits inservice inspection of safety-related components and equipment.

6. The applicant has met the requirements of General Design Criterion 45 with respect to testing of cooling water systems by providing a feedwater system design that permits operational functional testing of the safety-related portion of the system and its components.

The staff concludes that the design of the CFS conforms to all applicable GDCs and positions of the regulatory guide cited and is, therefore, acceptable.

## V. IMPLEMENTATION

The following is intended to provide guidance to all 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 parts of the method discussed herein are contained in the referenced regulatory guide and implementation of acceptance criterion subsection II.2, associated with water hammer loads, is as follows:

(a) Operating plants and OL applicants need not comply with the provisions of this revision.

(b) CP applicants will be required to comply with the provisions of this revision.

(c) It should be noted that steam generators in operating plants and NTOL's where a SER has been issued, now comply with the revised BTP ASB 10-2.

VI. REFERENCES


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 44, "Cooling Water."

5. 10 CFR Part 50, Appendix A, General Design Criterion 45, "Inspection of Cooling Water System."

6. 10 CFR Part 50, Appendix A, General Design Criterion 46, "Testing of Cooling Water System."

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

8. Branch Technical Position ASB 10-2, "Design Guidelines for Avoiding Water Hammer in Steam Generators."

## BRANCH TECHNICAL POSITION ASB 10-2

## DESIGN GUIDELINES FOR AVOIDING WATER HAMMERS IN STEAM GENERATORS

### BACKGROUND

Plant operational experience has shown that top-feed steam generators containing feedwater spargers with bottom drain holes incur steam condensation induced water hammers. This type of water hammer has frequently occurred after the feedwater sparger was uncovered (due to some plant transient) and cold auxiliary feedwater flow was subsequently initiated. The initiation of the auxiliary feedwater flow into the steam generator produces a water slug in the sparger or feedwater piping, which is then accelerated by the unbalanced pressures produced by the condensation of a steam pocket in the line. The resultant impulse could be of a sufficient magnitude to cause damage to the steam generator internal components and feedwater systems piping. The most damaging of such water hammer incidents occurred at Indian Point No. 2 in 1973, where the water hammer loads resulted in rupture of an 18-inch feedwater pipe and damage to the containment inner liner. The repeated occurrence of such water hammers and potential severity such flow instabilities resulted in the NRC in engaging Creare Inc. in 1976 to evaluate causes and effects, and to develop recommendations for avoidance of top feed steam generator water hammer, and design methods minimize associated dynamic loads.

The underlying causes of water hammer in top-feed steam generators were extensively studied by Creare, Inc. who reported findings and recommended design modifications to minimize or preclude such water hammer occurrence in NUREG-0291 (1977). These recommendations called for: (a) use of J-tubes on the topside of the feedring to minimize loss of water when uncovered, (b) early initiation of auxiliary feedwater to keep piping and feedring full of water, (c) short horizontal FW pipe lengths at the SG nozzle to reduce magnitude of slug formation and impact, (d) limit FW recovery flow rates to less than 150 gpm/SG to minimize steam-water entrainment and subsequent formation of a water slug. The use of top discharge feed (i.e., tubes) makes flow rate limits practical because the limit only has to be imposed until the piping is full, regardless of steam generator water level. The design and operational modifications were implemented by plants experiencing SG water hammer and appear to have essentially eliminated SGWH. NUREG-0918 details plant specific modifications which were made. In addition, experience sustains maintaining preoperational tests to verify the absence of SGWH.

More recently, Westinghouse and Combustion Engineering have introduced steam generators of the preheat type, wherein the majority of feedwater enters the steam generator at the bottom through a preheater section. The potential for condensation-induced water hammer in preheat steam generators was studied by BNL and reported in NUREG/CR-1606, "An Evaluation of Condensation-Induced Water Hammer in Preheat Steam Generators," June 1980. This report, citing the lack of definitive experimental and analytical results, recommended full scale verification tests to demonstrate the absence of damaging water hammer in preheat steam generators and connecting feedwater piping (i.e., preoperational tests).

B&W steam generators, which are a "once through" flow design, have generally not reported water hammer occurrence. However, in May 1982, several B&W plants (following inservice inspection) reported damaged internal auxiliary feedwater headers and support structures. The cause was attributed to steam pocket collapse. The internal auxiliary feedring design concept is similar to CE & W top feedring concepts which have experienced water hammer before corrective design measures were implemented. For these B&W plants, the OTSG's are being modified to return to the previous design using auxiliary feedwater injection manifolds which are external to the steam generator.

The staff believes that SGWH evidence and studies performed to date warrant the establishment of design guidelines for steam generators and the associated piping. Guidelines have been developed that may be used to reduce the probability of a damaging steam condensation induced water hammer, particularly for the Westinghouse and Combustion Engineeering PWR designs which use top-feed steam generators.

## BRANCH TECHNICAL POSITION

In CP and OL application reviews, the staff requires the applicant to provide the following design capability and verification:

### Top-Feed Steam Generator Designs

To eliminate or reduce possible water hammer in the feedwater system:

a. Prevent or delay water draining from the feedring following a drop in steam generator water level by means such as top discharge J-Tubes and limitng feedring seal assembly leakage.

b. Minimize the volume of feedwater piping external to the steam generator which could pocket steam using the shortest possible (less than seven feet) horizontal run of inlet piping to the steam generator feedring.

c. Perform tests acceptable to NRC to verify that unacceptable feedwater hammer will not occur using the plant operating procedures for normal and emergency restoration of steam generator water level following loss of normal feedwater and possible draining of the feedring. Provide the procedures for these tests for approval before conducting the tests and submit the results from such tests.

d. Implement pipe refill flow limits where practical.

### Preheat Steam Generator Designs

1. Minimize the horizontal lengths of feedwater piping between the steam generator and the vertical run of piping by providing downward turning elbows immediately upstream of the main and auxiliary feedwater nozzles.

2. Provide a check valve upstream of the auxiliary feedwater connection to the top feedwater line.

3. Maintain the top feedwater line full at all times.

4. Perform tests acceptable to NRC to verify that unacceptable feedwater hammer will not occur using plant operating procedures for normal and emergency restoration of steam generator water level following loss of normal feedwater. Also perform a water hammer test at *% of power by using feedwater through the auxiliary feedwater (top) nozzle at the lowest feedwater temperature that the plant standard operating procedure (SOP) allows and then switching the feedwater at that temperature from the auxiliary feedwater nozzle to the main feedwater (bottom) nozzle by following the SOP, and submit the results of such tests.

Once Through Steam Generator (OTSG) Designs

a. Provide auxiliary feedwater to the steam generator through an externally mounted supply top discharge header.

b. Perform tests acceptable to NRC to verify that unacceptable feedwater hammer will not occur using the plant operating procedures for normal and emergency restoration of steam generator water level following loss of normal feedwater. Provide the procedures for these tests for approval before conducting the tests, and submit the results of such tests.

REFERENCES


(1) Block, J. A. et.al., "An Evaluation of PWR Steam Generator Water Hammer," NUREG-0291, June 1977.

(2) Chapman, R. L., et.al., "Compilation of Data Concerning Known and Suspected Water Hammer Events in Nuclear Power Plants," NUREG/CR-2059, May 1982.

(3) Anderson, N. and Han, J. T., "Prevention and Mitigation of Steam Generator Water Hammer Events in PWR Plants," NUREG-0918, December 1982.


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*The power level at which feedwater flow is transferred from the auxiliary feedwater nozzle to the main feedwater nozzle.


* U.S. GOVERNMENT PRINTING OFFICE: 1984-421-297:3828