NUREG-0800
(Formerly NUREG-75/087)

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)~~Plant Systems Branch (SPLB)[1]

Secondary - ~~None~~Civil Engineering and Geosciences Branch (ECGB)[2]

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~~SPLB[3] reviews the CFS from the condenser outlet~~ to the~~, up to and including the nozzle connections with the nuclear steam supply system, the feedwater spargers, and~~ to~~[4] the heater drain system to ~~assure~~ensure[5] conformance to General Design Criteria 2, 4, 5, 44, 45, and 46. For ~~indirect cycle plants~~PWRs,[6] 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~~SPLB[7] 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~~SPLB[8] 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.

Review Interfaces[9]

~~3.~~[10]
1. The ~~ASB~~SPLB[11] also performs the following reviews under the ~~SRP~~ Standard Review Plan (SRP)[12] 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 protection against missiles generated by natural phenomena, including tornados, is performed under SRP Section 3.5.1.4.[13]

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

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

   f. Review of the fire protection program is performed under SRP Section 9.5.1.[14]

   g. Review of the environmental qualification of mechanical and electrical equipment is performed under SRP Section 3.11.[15]

   h. Review of the auxiliary feedwater system (PWR) is performed under SRP Section 10.4.9.[16]

2. The ~~ASB~~SPLB[17] will coordinate evaluations performed by other branches that interface with the overall evaluation of the system, as follows:

   a. The Reactor Systems Branch ~~(RSB)~~(SRXB)[18] 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~~.[19]

b. The SRXB determines 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.

c. The SRXB reviews the reactor core isolation cooling system (BWR) as part of its primary review responsibility under SRP Section 5.4.6.[20]

~~b~~d. The ~~Power Systems Branch (PSB)~~Electrical Engineering Branch (EELB)[21] 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.

~~c~~e. The ~~Structural and Geotechnical Engineering Branch (SGEB)~~Civil Engineering and Geosciences Branch (ECGB)[22] 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.

~~d~~f. The Mechanical Engineering Branch ~~(MEB)~~(EMEB)[23] 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. 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~~[24] EMEB 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~~ EMEB[25] reviews test programs of components that may be affected by water hammers.

g. The EMEB determines the acceptability of seismic and quality group classifications for system components as part of its primary review responsibility for SRP Section 3.2.1.[26]

h. The EMEB 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.[27]

~~e~~i. The ~~Materials Engineering Branch (MTEB)~~Civil Engineering and Geosciences Branch (ECGB)[28] 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~~.[29]

j. The EMCB evaluates feedwater system materials, including their selection and fabrication, fracture toughness of Class 2 and 3 components, and erosion/corrosion, as part of its primary review responsibility for SRP Section 10.3.6.[30]

~~f~~k. The review of ~~for Fire Protection,~~ technical specifications~~, and Quality Assurance are~~is coordinated and performed by the ~~Chemical Engineering Branch,~~

~~Standardization and Special Projects Branch,~~Technical Specifications Branch (TSB)[31] ~~and Quality Assurance Branch~~ as part of ~~their~~its primary review responsibility for SRP Section~~s 9.5.1,~~ 16.0 ~~and 17.0, respectively~~.[32]

~~g~~l. The Quality Assurance and Maintenance Branch (HQMB) reviews quality assurance programs as part of its primary review responsibility for SRP Section 17.0.[33]

~~h~~m. The ~~Equipment Qualification Branch (EQB)~~EMEB[34] reviews the seismic qualification of Category I instrumentation and electrical equipment ~~and the environmental qualification of mechanical and electrical equipment~~[35] as part of its primary review responsibility for SRP Section~~s~~ 3.10 ~~and 3.11, respectively~~.[36]

~~i~~n. ~~Upon request, t~~T[37]he ~~Instrument and Control Systems Branch (ICSB)~~Instrumentation and Controls Branch (HICB)[38] ~~will~~ reviews[39] the instrumentation and controls associated with the feedwater control system (BWR) or steam generator level control system (PWR) as part of its primary review responsibility for SRP Section 7.7.[40]

o. For new plant applicants, the Condensate and Feedwater System may be included in the systematic assessment of shutdown risks as an alternate feature that can maintain core cooling in the event of a loss of normal decay heat removal during shutdown conditions. The Probabilistic Safety Assessment Branch (SPSB) coordinates and performs the shutdown risk assessment reviews as part of its primary review responsibility for SRP Section 19.1 (Proposed).[41]

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 (GDC 2), "Design Bases for Protection Against Natural Phenomena,"[42] 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 (GDC 4), "Environmental and Dynamic Effects Design Bases,"[43] 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, "Design Guidelines for Avoiding Water Hammers in Steam Generators," attached to this SRP section,[44] 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 (GDC 5), "Sharing of Structures, Systems, and Components,"[45] as related to the capability of shared systems and components important to safety to perform required safety functions.

4. General Design Criterion 44 (GDC 44), "Cooling Water,"[46] 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 (GDC 45), "Inspection of Cooling Water System,"[47] as related to design provisions to permit periodic inservice inspection of system components and equipment.

6. General Design Criterion 46 (GDC 46), "Testing of Cooling Water System,"[48] as related to design provisions to permit appropriate functional testing of the system and components to ~~assure~~ensure[49] 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.

Technical Rationale

The technical rationale for application of these acceptance criteria to reviewing the condensate and feedwater system is discussed in the following paragraphs:[50]

1. GDC 2 requires that structures, systems, and components important to safety shall be designed to withstand the effects of natural phenomena such as earthquakes.

   This criterion applies to SRP Section 10.4.7 because the review identifies CFS components important to safety and determines that they are designed to withstand the effects of earthquakes and other natural phenomena. Regulatory Guide 1.29, Positions C.1 and C.2, provide guidance for determining compliance with this criterion.

   Meeting the requirements of this criterion provides a level of assurance that the capability to shut down the reactor safety will be maintained during the most severe expected earthquake or other natural phenomena.[51]

2. GDC 4 requires that structures, systems, and components important to safety shall be appropriately protected against dynamic effects that may result from equipment failures and from events and conditions outside the nuclear power unit.

   GDC 4 applies to SRP Section 10.4.7 because the review verifies that CFS components important to safety are protected against the effects of high-energy pipe ruptures. This review also considers the dynamic consequences of flow instabilities (specifically, water hammer) resulting from normal operation and during anticipated operational occurrences.

   Meeting the requirements of this criterion provides further assurance that the integrity of the feedwater piping inside the containment structure will be maintained, thereby minimizing the likelihood of a loss-of-coolant accident that could cause fuel damage.[52]

3. GDC 5 requires that structures, systems, and components important to safety shall not be shared by nuclear power units, unless it can be shown that such sharing will not

significantly impair the ability to perform safety functions, including an orderly shutdown and cooldown of remaining units in the event of an accident in one unit.

GDC 5 applies to SRP Section 10.4.7 because the review determines whether CFS components important to safety are shared and, if so, evaluates the impact of that sharing on safety functions.

Meeting the requirements of this criterion provides further assurance that all reactors at a multiple-unit site will be capable of completing normal shutdown in the event of a component failure in one reactor.[53]

4. GDC 44 requires that a system be provided to transfer heat from structures, systems, and components important to safety to an ultimate heat sink. The safety function of this system shall be to transfer the specified combined heat load under normal operating and accident conditions. Suitable redundancy in components and features, as well as suitable interconnections, leak detection, and isolation capabilities, shall be provided to ensure that the system safety function can be accomplished for loss of either onsite or offsite power assuming a single failure.

   GDC 44 applies to SRP Section 10.4.7 because the review establishes that the CFS is capable of providing heat removal from the reactor system during normal conditions. For PWRs, the auxiliary feedwater system provides heat removal during accident conditions involving loss of normal feedwater. (The auxiliary feedwater system is evaluated under SRP Section 10.4.9.) For BWRs, the reactor core isolation cooling system provides heat removal during accident conditions involving loss of normal feedwater. (The reactor core isolation cooling system is evaluated under SRP Section 5.4.6.) Review of the CFS is coordinated with those of alternate feedwater systems and addresses redundancy, interconnections, leak detection, and isolation capabilities to establish that containment isolation can be accomplished during accidents that occur concurrently with loss of onsite or offsite power and a single failure.

   Meeting the requirements of this criterion provides a level of assurance that the capability for heat removal from the reactor will be retained during normal and accident conditions, thus protecting fuel cladding from elevated temperatures.[54]

5. GDC 45 requires that the cooling water system shall be designed to permit appropriate periodic inspection of important components (e.g., heat exchangers and piping) to ensure the integrity and capability of the system.

   GDC 45 applies to SRP Section 10.4.7 because the CFS provides cooling water to the reactor or steam generators and because the CFS is isolated in the event of certain accidents. This review verifies that the feedwater system design facilitates inspection.

   Meeting the requirements of this criterion provides a level of assurance that the CFS will be able to perform its safety function in the event of an accident.[55]

6. GDC 46 requires that the cooling water system shall be designed to facilitate periodic pressure and functional testing that will ensure (a) the structural and leaktight integrity of CWS components, (b) the operability and the periodic performance of the system's active components, and (c) the operability of the system as a whole. The criterion further requires that the testing ensure, under conditions as close to design as practical, the performance of 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 power sources.

GDC 46 applies to SRP 10.4.7 because the CFS provides the proper cooling water inventory for PWR steam generators or BWR reactor pressure vessels during normal operation. The CFS is isolated after a loss-of-feedwater accident has occurred. During such conditions, the CFS feedwater piping inside the containment is used as the conduit for feedwater flow from alternate systems. This review determines that the CFS is designed to accommodate testing the system and its components.

Meeting the requirements of this criterion provides a level of assurance that the CFS will be able to perform reliably under normal operating conditions and will perform its safety function in the event of an accident.[56]

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~~ensure[57] that this review ~~procedure~~[58] 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)~~,~~ under[59] 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~~ensure[60] that precautions for avoidance of steam/water hammer and water hammer occurrences have been provided.

   Guidance for water hammer prevention and mitigation is found in NUREG-0927 (Reference 13).[61]

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~~ECGB[62] and the review for seismic and quality group classification is performed by ~~MEB~~EMEB[63] 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 (PWR) or the reactor core isolation cooling system (BWR),[64] if required.

5. The CFS design, or other plant systems, provide the capability to detect and control leakage from the system, including leakage from spargers.[65]

6. ~~The reviewer verifies that~~[66] ~~t~~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.

8. Piping system designs, including material standards and inspection programs, incorporate adequate considerations to avoid erosion and corrosion. Guidance for acceptable inspection programs is found in Generic Letter 89-08 and in EPRI NP-3944, "Erosion/Corrosion in Nuclear Plant Steam Piping: Causes and Inspection Guidelines."[67]

9. For BWRs, feedwater nozzle design, inspection, and testing procedures, and CFS operating procedures are adequate to minimize nozzle cracking at low feedwater flow. The review criteria for this issue are stated in NUREG-0619 and in associated Generic Letters 80-95 and 81-11.[68]

10. For multiple-unit sites, sharing of any CFS structure, system, or component important to safety will not impair its ability to perform its intended safety function.[69]

For standard design certification reviews under 10 CFR Part 52, the procedures above should be followed, as modified by the procedures in SRP Section 14.3 (proposed), to verify that the design set forth in the standard safety analysis report, including inspections, tests, analysis, and acceptance criteria (ITAAC), site interface requirements and combined license action items, meet the acceptance criteria given in subsection II. SRP Section 14.3 (proposed) contains procedures for the review of certified design material (CDM) for the standard design, including the site parameters, interface criteria, and ITAAC.[70]

IV. EVALUATION FINDINGS

The reviewer verifies that sufficient information has been provided and ~~his~~ that the[71] 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)]~~ (plus secondary makeup system and auxiliary feedwater system

interfaces for PWRs).[72] Based on the review of the applicants 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~~ Criteria[73] 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~~The[74] 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~~ensure[75] 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 of the CFS between each unit[76] are designed so that the capability to mitigate the consequences of an accident in either unit and to[77] 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~~The applicant has also demonstrated that portions of the system can be isolated during accidents that occur concurrently with loss of onsite or offsite power and a single failure[78] 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, including inspection of piping systems for erosion and corrosion, and inspection of feedwater nozzles for fatigue.[79]

6. The applicant has met the requirements of General Design Criterion ~~45~~ 46[80] 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. Functional testing ensures structural integrity and

leaktightness, operability, and performance of active components during normal, shutdown, and accident conditions.[81]

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.

For design certification reviews, the findings will also summarize, to the extent that the review is not discussed in other safety evaluation report sections, the staff's ITAAC evaluation, including design acceptance criteria (DAC), site interface requirements, and COL action items that are relevant to this SRP section.[82]

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.

This SRP section will be used by the staff when performing safety evaluations of license applications submitted by applicants pursuant to 10 CFR 50 or 10 CFR 52.[83] 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.

The provisions of this SRP section apply to reviews of applications docketed six months or more after the date of issuance of this SRP section.[84]

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~~Plants with an operating license issued prior to April 1984 and/or operating license applications docketed prior to April 1984[85] 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 with an operating license issued prior to April 1984 and ~~NTOLs~~plants where an operating license SER ~~has~~had been issued prior to April 1984,[86] 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~~Dynamic Effects[87] 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," attached to SRP Section 10.4.7.[88]

9. Generic Letter 80-95, "Final Edition of NUREG-0619, 'BWR Feedwater Nozzle and Control Rod Drive Return Line Nozzle Cracking.'"[89]

10. Generic Letter 81-11, "BWR Feedwater Nozzle Cracking."[90]

11. Generic Letter 89-08, "Erosion/Corrosion-Induced Pipe Wall Thinning."[91]

12. NUREG-0619, "BWR Feedwater Nozzle and Control Rod Drive Return Line Nozzle Cracking."[92]

13. NUREG-0927, Revision 1, "Evaluation of Water Hammer Occurrences in Nuclear Power Plants," March 1984.[93]

14. EPRI NP-3944, "Erosion/Corrosion in Nuclear Plant Steam Piping: Causes and Inspection Guidelines."[94]

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~~ 46-cm (18-in)[95] feedwater pipe and damage to the containment inner liner. The repeated occurrence of such water hammers and the potential severity of 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 to suggest design methods for ~~minimize~~ minimizing[96] 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 feed ring to minimize loss of water when uncovered, (b) early initiation of auxiliary feedwater to keep piping and feed ring full of water, (c) short horizontal FW pipe lengths at the SG nozzle to reduce magnitude of slug formation and impact, and (d) limiting[97] FW recovery flow rates to less than 9.5 l/s per SG (150 gpm/SG,[98] 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 designs,[99] 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 feed ring design concept is similar to CE & W top-feed ring concepts which have experienced water hammer before corrective design measures were implemented. For these B&W plants, the OTSGs 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 Engineering 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 feed ring following a drop in steam generator water level by means such as top discharge J-Tubes and limiting feed ring 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~~ 2.1 m (7 ft))[100] horizontal run of inlet piping to the steam generator feed ring.

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 feed ring. 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 the power level at which feedwater flow is transferred from the auxiliary feedwater nozzle to the main feedwater nozzle. The test shall be performed~~*% of power~~ by ~~using~~ pumping 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~~ Submit[101] 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.

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

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Attachment A - Proposed Changes in Order of Occurrence

Item numbers in the following table correspond to superscript numbers in the redline/strikeout copy of the draft SRP section.

Item	Source	Description
1.	Current PRB name and abbreviation	Changed PRB to Plant Systems Branch(SPLB).
2.	SRP-UDP format item	Added secondary review branch per guidance from NRR.
3.	Current PRB designation	Changed PRB to SPLB.
4.	**Integrated Impact Number 548**	Added wording to clarify that the review includes feedwater nozzles, feedwater spargers, and cladding.
5.	Editorial modification	Changed "assure" to "ensure."
6.	Editorial modification	Used "PWR" instead of "indirect cycle plant." NRC regulations do not discuss indirect cycle plants. Furthermore, the previous paragraph mentions BWRs and PWRs.
7.	Current PRB designation	Changed PRB to SPLB.
8.	Current PRB designation	Changed PRB to SPLB.
9.	SRP-UDP format item	Added "Review Interfaces" to AREAS OF REVIEW.
10.	Editorial modification	Eliminated number because the item is no longer part of the sequence and has been incorporated into "Review Interfaces."
11.	Current PRB designation	Changed PRB to SPLB. Added the article "the" to provide parallelism. Added numbering to facilitate referencing "Review Interfaces."
12.	Editorial modification	Defined "SRP" as "Standard Review Plan."
13.	Editorial modification	Added a review interface for SRP Section 3.5.1.4, "Missiles Generated by Natural Phenomena." Revision 3 of the SRP section includes an interface for 3.5.2. Omission of 3.5.1.4 seems to have been an oversight. The interfaces that follow were renumbered.
14.	Editorial modification	Relocated this review from the next group of coordinated reviews because the PRB currently performs fire protection reviews.
15.	Editorial modification	Relocated this review from the next group of coordinated reviews because the PRB currently performs the environmental qualification reviews.

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Item	Source	Description
16.	Editorial modification	A review interface was added for the auxiliary feedwater system since approval of the system is indicated in Review Procedure 4.
17.	Current PRB designation	Changed PRB to SPLB.
18.	Current review branch designation	Changed review interface branch to SRXB.
19.	Editorial modification	Reviews assigned to SRXB were broken into interfaces for clarity. The review under SRP Section 15.2.7 is now interface 2.b. The interfaces that follow 2.b have been renumbered.
20.	Editorial modification	A review interface was added for the reactor core isolation cooling system since approval of the system is indicated in Review Procedure 4.
21.	Current review branch designation	Changed review interface branch to EELB.
22.	Current PRB designation	Changed review interface branch to ECGB.
23.	Current review branch designation	Changed review interface branch to EMEB.
24.	Editorial modification	The three coordinated reviews performed by EMEB were presented as individual items to provide a better checklist for the reviewer. Two other items follow this entry.
25.	Current review branch designation	Changed review interface branch to EMEB.
26.	Editorial modification	This interface was grouped within the previous paragraph in Revision 3 of the SRP section. It was separated out and the review interface branch designation was changed to EMEB.
27.	Editorial modification	This interface was grouped within the previous paragraph in Revision 3 of the SRP section. It was separated out and the review interface branch designation was changed to EMEB.
28.	Current review branch designation	Changed review interface branch to ECGB.
29.	Editorial modification	This review is not optional. EMCB performs this review under SRP Section 10.3.6. See new interface item 2.j.
30.	Integrated Impact Number 549	Inserted a review interface with SRP Section 10.3.6 for reviewing feedwater system materials, including erosion/corrosion of feedwater piping. Deleted the phrase suggesting that this review is performed on request.
31.	Current review branch designation	Changed review interface branch to TSB.

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Attachment A - Proposed Changes in Order of Occurrence

Item	Source	Description
32.	Editorial modification	Moved fire protection review (SRP Section 9.5.1) and assigned review interface to the PRB. SPLB addresses it directly. Made a separate entry for review of quality assurance programs. Corrected the review branch names as necessary. The quality assurance review is now performed by HQMB.
33.	Editorial modification	The quality assurance review was previously included with two other reviews. It is now listed as a separate item.
34.	Current review branch designation	Changed review interface branch to EMEB.
35.	SRP-UDP format item	Moved this review to the previous section since the PRB is the primary reviewer for environmental qualification of mechanical and electrical equipment, rather than its coordinator.
36.	Editorial modification	Moved review of SRP Section 3.11 to the previous section since the PRB is the primary reviewer for environmental qualification of mechanical and electrical equipment, rather than its coordinator.
37.	Integrated Impact Number 550	Deleted the words "upon request" to strengthen the importance of this review.
38.	Current review branch designation	Changed review interface branch to HICB.
39.	Editorial, PRB Comment	Changed "will review" to "reviews" to incorporate PRB comment, NRC Memo Li to Lyons dated November 1, 1995.
40.	Integrated Impact Number 550	Added the reference to SRP Section 7.7 as a focal point for reviewing control systems to strengthen the importance of this review.

Item	Source	Description
41.	Potential Impacts 25836 and 25837	This review interface identifies reviews conducted to satisfy SECY 93-087 and ABWR FSER Staff guidance on Shutdown and Low Power Operations. The staff requested that design certification applicants complete an assessment of shutdown and low-power risk. The shutdown and low-power risk assessment must identify design-specific vulnerabilities and weaknesses and document consideration and incorporation of design features that minimize such vulnerabilities. The Condensate and Feedwater system was included in the ABWR FSER risk assessment as a system that can provide alternative core cooling capability in the event of the loss of normal decay heat removal. Consideration of this system in the shutdown and low-power risk assessment is the responsibility of the SPSB and will be included in the proposed SRP Section 19.1 on risk assessments.
42.	Editorial modification	Added initialism and title for GDC 2 to aid the reviewer.
43.	Editorial modification	Added initialism and title for GDC 4 to aid the reviewer.
44.	Editorial modification	Added title of Branch Technical Position ASB 10-2 for clarity. The reference section also failed to inform that BTP ASB 10-2 is attached.
45.	Editorial modification	Added initialism and title for GDC 5 to aid the reviewer.
46.	Editorial modification	Added initialism and title for GDC 44 to aid the reviewer.
47.	Editorial modification	Added initialism and title for GDC 45 to aid the reviewer.
48.	Editorial modification	Added initialism and title for GDC 46 to aid the reviewer.
49.	Editorial modification	Changed "assure" to "ensure."
50.	SRP-UDP format item	Added "Technical Rationale" and leadin paragraph to ACCEPTANCE CRITERIA.
51.	SRP-UDP format item - Develop technical rationale for ACCEPTANCE CRITERIA	Added technical rationale for GDC 2.
52.	SRP-UDP format item - Develop technical rationale for ACCEPTANCE CRITERIA	Added technical rationale for GDC 4.

Item	Source	Description
53.	SRP-UDP format item - Develop technical rationale for ACCEPTANCE CRITERIA	Added technical rationale for GDC 5.
54.	SRP-UDP format item - Develop technical rationale for ACCEPTANCE CRITERIA	Added technical rationale for GDC 44.
55.	SRP-UDP format item - Develop technical rationale for ACCEPTANCE CRITERIA	Added technical rationale for GDC 45.
56.	SRP-UDP format item - Develop technical rationale for ACCEPTANCE CRITERIA	Added technical rationale for GDC 46.
57.	Editorial modification	Changed "assure" to "ensure."
58.	Editorial modification	Deleted "procedure" as unnecessary and potentially misleading.
59.	Editorial modification	Added "under" to provide clarity.
60.	Editorial modification	Changed "assure" to "ensure."
61.	PRB Comment	Added reference to NUREG-0927 in response to PRB comment, NRC Memo Li to Lyons dated November 1, 1995.
62.	Current review branch designation	Changed review interface branch to ECGB.
63.	Current review branch designation	Changed review interface branch to EMEB.
64.	Editorial modification	Added parenthetical references to PWRs and BWRs for clarity.
65.	Integrated Impact Number 548	Added specific identification of sparger leakage as a concern.
66.	Editorial modification	Deleted lead-in phrase ("the reviewer verifies that"). This phrase appears at the top of the list introducing all numbered items.
67.	Integrated Impact Number 549	Added a procedure addressing review of erosion/corrosion. Added reference to EPRI NP3944 cited in the System 80 FSER for acceptance of monitoring programs for erosion/corrosion.
68.	Integrated Impact Number 548	Added a review procedure to address feedwater nozzle cracking.

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Attachment A - Proposed Changes in Order of Occurrence

Item	Source	Description
69.	Editorial modification	Added a review procedure to address acceptance criterion (GDC 5) regarding shared components.
70.	SRP-UDP format item	Added a paragraph at the end of REVIEW PROCEDURES to specify how the procedures apply to design certification reviews.
71.	Editorial modification	Revised sentence to eliminate use of gender-specific pronoun ("his").
72.	Editorial modification	Revised sentence to improve clarity.
73.	Editorial modification	Changed "Criterion" to "Criteria" to accommodate plural usage.
74.	Editorial modification	Revised to make sentence structure parallel to other evaluation findings.
75.	Editorial modification	Replaced "assume" with "ensure." "Assume" did not make sense.
76.	Editorial modification	The sentence was removed and the content was added to the next sentence. This change was made to eliminate the use of the first person ("we").
77.	Editorial modification	Added "to" for clarity and parallelism.
78.	Editorial modification	This sentence was broken into two sentences and rewritten to make it clear that the CFS does not provide cooling water during accident conditions. The review establishes that the CFS can be isolated during accident conditions. As originally written, the SRP section states that the CFS can provide cooling water during accident conditions.
79.	Integrated Impact Numbers 548 and 549	Added specific findings that inspection programs address concerns over feedwater nozzle cracking and erosion/corrosion.
80.	Editorial modification	Changed "Criterion 45" to "Criterion 46" to correct error in Revision 3 of SRP Section 10.4.7.
81.	Editorial modification	Deleted a phrase that limited testing to the safety-related portions of the CFS. Added a sentence to elaborate on the objectives of functional testing.
82.	SRP-UDP format item	Added a paragraph at the end of EVALUATION FINDINGS to specify additional findings required for a design certification review.
83.	10 CFR Part 52 Implementation	Added statement clarifying applicability to applications under both Part 50 and Part 52.

Item	Source	Description
84.	SRP-UDP Format Item	Added paragraph to clarify implementation of this revised draft.
85.	Editorial	Revised Implementation statements applicable to plants with a given docket status at the time of the previous revision to relate to the previous revision date.
86.	Editorial	Revised Implementation statements applicable to plants with a given docket status at the time of the previous revision to relate to the previous revision date.
87.	Editorial modification	Updated title of GDC 4 (based on 1987 rulemaking change).
88.	Editorial modification	Added information regarding the location of BTP ASB 10-2.
89.	Integrated Impact Number 548	Added a reference for GL 80-95 to provide guidance on reviewing feedwater nozzles.
90.	Integrated Impact Number 548	Added a reference for GL 81-11 to provide supplementary information on reviewing feedwater nozzles.
91.	Integrated Impact Number 549	Added a reference for GL 89-08 to provide guidance on reviewing erosion/corrosion in feedwater piping.
92.	Integrated Impact Number 548	Added a reference for NUREG0619 to provide guidance on reviewing feedwater nozzles.
93.	PRB Comment	Added reference to NUREG-0927 in response to PRB comment, NRC Memo Li to Lyons dated November 1, 1995.
94.	Integrated Impact Number 549	Added a reference for EPRI NP-3944 to provide guidance applicable to erosion/corrosion.
95.	Conversion to SI units	Converted 18 in to 46 cm.
96.	Editorial modification	Made minor revisions to this sentence to provide clarity and parallel construction.
97	Editorial modification	Made minor revisions to this sentence to provide clarity and parallel construction.
98.	Conversion to SI units	Converted 150 gpm/SG to 9.5 l/s SG.
99.	Editorial modification	Made minor revisions to this sentence to provide number agreement.

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Attachment A - Proposed Changes in Order of Occurrence

Item	Source	Description
100.	Conversion to SI units	Converted 7 ft to 2.1 m.
101.	Editorial modification	Moved information provided in a footnote to body of text and made other minor revision for clarity.

SRP Draft Section 10.4.7
Attachment B - Cross Reference of Integrated Impacts

Integrated Impact No.	Issue	SRP Subsections Affected
548	Incorporate staff recommendations resulting from Generic Technical Issue A-10, "BWR Nozzle Cracking."	I; III.5 and 9; IV.5; and VI.9, 10, and 12
549	Incorporate staff positions on erosion/corrosion monitoring from Generic Letter 89-08.	I, Review Interfaces, item 2.j; III.8; VI.11 and 13
550	Incorporate reference to SRP Section 7.7 review of overfill protection systems related to resolution of USI A-47.	I, Review Interfaces, item 2.n