DRAFT LICENSE RENEWAL INTERIM STAFF GUIDANCE
LR-ISG-2012-01

WALL THINNING DUE TO EROSION MECHANISMS

INTRODUCTION

This license renewal interim staff guidance (LR-ISG), LR-ISG-2012-01, provides interim guidance for an approach acceptable to the U.S. Nuclear Regulatory Commission (NRC) staff to manage the effects of aging during the period of extended operation for wall thinning due to various erosion mechanisms for piping and components within the scope of the License Renewal Rule (Title 10 of the *Code of Federal Regulations* Part 54 (10 CFR Part 54), "Requirements for Renewal of Operating Licenses for Nuclear Power Plants"). This LR-ISG revises Generic Aging Lessons Learned (GALL) Report aging management program (AMP) XI.M17, "Flow-Accelerated Corrosion." It also supplements, or revises, related aging management recommendations in the GALL Report and NUREG-1800, Rev. 2, "Standard Review Plan for Review of License Renewal Applications for Nuclear Power Plants," (SRP-LR).

DISCUSSION

Wall thinning due to erosion mechanisms has caused problems in the past and continues to be encountered in some operating reactor systems. Recent event reports (254/2009-004-00, 237/2007-003-00, 277/2006-003-00) have documented inoperable equipment resulting from erosion which occurred during infrequent test activities and for piping that had previously been replaced with chromium-molybdenum material that was resistant to flow-accelerated corrosion (FAC). The staff has determined that existing guidance in the SRP-LR and GALL Report does not adequately address wall thinning due to erosion mechanisms such as cavitation, flashing, droplet impingement, and solid particle impingement. Erosion, similar to FAC, is a wall-thinning phenomenon related to fluid dynamics. However, each wall-thinning mechanism has unique causes, and effective aging management of wall thinning requires consideration of these individual mechanisms.

The NRC and industry guidance for the aging management of erosion mechanisms is largely absent, but in the case of cavitation erosion, industry guidelines (EPRI 1010639, Revision 4, "Non-Class 1 Mechanical Implementation Guideline and Mechanical Tools") state that it is typically associated with improper operation and is not an applicable aging effect because it is considered to be a design deficiency. The industry guidelines also state that this deficiency will be corrected during the current term of operation. In that regard, the Statement of Considerations (60 FR 22461, 22469; May 8, 1995) for 10 CFR Part 54 notes that corrective actions that should be taken to address functional degradation logically include cause determinations, which could involve mechanisms other than aging (e.g., improper operation), but that corrective actions should focus on prevention, elimination, or management of the effects caused by these mechanisms. During recent license renewal reviews, the staff found instances where applicants continued to experience loss of material due to cavitation erosion because the design deficiency was not corrected. In some of these cases, the applicants did not identify loss of material due to erosion as an aging effect requiring management, even though they conducted ongoing wall thickness monitoring and periodic repairs.

As noted in SRP-LR Section 2.1.3.2.2, "Long-Lived," passive components that are not replaced on the basis of a qualified life or specified time period require an aging management review

(AMR) under 10 CFR 54.21(a)(1)(ii). SRP-LR Section 2.1.3.2.2 also states that components replaced on the basis of condition are not generically excluded from an AMR, and condition monitoring may be evaluated as a program to ensure functionality during the period of extended operation. If an applicant has implemented a replacement strategy for susceptible items, such as replacement frequency that utilizes actual wall thinning data from past plant-specific operating experience, then the staff recognizes these items do not meet the definition of long-lived, passive components and, therefore, they do not have to be managed for aging within the context of license renewal. However, if other strategies to manage the aging of the susceptible items are utilized, such as replacement based on periodic monitoring for loss of material by wall thickness measurements, then these items should be managed for aging, and this ISG is applicable.

GALL Report AMP XI.M17, "Flow-Accelerated Corrosion," manages wall thinning due to FAC and is well established and widely used by industry. However, the existing guidance in this program is not fully applicable to wall thinning due to erosion mechanisms. For example, the "monitoring and trending" program element of GALL Report AMP XI.M17 includes the use of software to identify locations susceptible to wall thinning due to FAC, but the software does not predict susceptible locations related to erosion. Also, the "corrective actions" program element includes the replacement of susceptible components with FAC-resistant material, such as high chromium steel, which does not necessarily prevent wall thinning due to erosion mechanisms. As such, additional consideration is needed to address wall thinning due to erosion mechanisms.

Clarifications to Definitions

Section IX.E, "Aging Effects," of the GALL Report currently includes "erosion," and "flow-accelerated corrosion," in its definition of "loss of material," but only includes "cavitation" for concrete structures. Section IX.F, "Significant Aging Mechanisms," of the GALL Report defines "erosion" as the "loss of material from a solid surface…due to mechanical interaction between that surface and a fluid." In addition, it defines "flow-accelerated corrosion" as the "co-joint activity involving corrosion and erosion in the presence of a moving corrosive fluid leading to the accelerated loss of material." Although the GALL Report definition associates flow-accelerated corrosion with erosion, EPRI Report 106611, "Flow-Accelerated Corrosion in Power Plants," states that FAC is "a pure corrosion process that does not have an erosion component." Since erosion is not involved in the FAC process, as the GALL Report definition suggests, this may lead to some confusion and inconsistencies in how NRC guidance is applied. In addition, Section IX.E of the GALL Report currently defines "wall thinning" as an aging effect that "is a specific type of loss of material attributed to general corrosion or flow-accelerated corrosion." In light of this discussion, the definitions of these aging effects and their associated mechanisms need to be revised to include additional mechanisms associated with erosion.

Although the GALL Report defines "erosion" and includes it as one of the mechanisms which causes loss of material, there are currently no specific AMR items for piping, piping components, or piping elements that cite loss of material due to erosion. This aspect has been recognized by the industry in EPRI Report 1010639, Section 3.1.6, which cites erosion as a plausible aging mechanism where particulates are not controlled or two-phase flow is present. Within AMPs in the GALL Report, only AMP XI.M20, "Open-Cycle Cooling Water System," includes erosion in its description of aging effects being managed, and this is only due to the presence of solid particles in raw water systems. There are, however, several other AMPs that

discuss erosion in the “parameters monitored,” “detection of aging effects,” and “acceptance criteria,” program elements, but the AMR items associated with these other AMPs do not address piping, piping components or piping elements.

Erosion in piping is caused by fluid motion that can involve cavitation, flashing, liquid droplet impingement, and solid particle impingement, which are found in many water systems. Erosion mechanisms are sometimes perceived as being comparable to wall thinning due to FAC; however, these other mechanisms are not addressed in the prediction methodology for FAC programs. Based on staff reviews of industry-wide operating experience, these additional mechanisms require further consideration to ensure that passive components are being maintained consistent with the current licensing basis.

Changes to the FAC Aging Management Program

GALL Report AMP XI.M17, “Flow-Accelerated Corrosion,” relies on implementation of the EPRI guidelines in Nuclear Safety Analysis Center (NSAC)-202L, Revision 2 (April 1999) or Revision 3 (May 2006), “Recommendations for an Effective Flow Accelerated Corrosion Program.” In 1989, the NRC issued Generic Letter 89-08, “Erosion/Corrosion-Induced Pipe Wall Thinning,” to ensure that operating nuclear power plants had developed these types of programs to address long-term degradation due to FAC. In general, FAC programs include analyses to determine critical locations, inspections to identify the extent of wall thinning at these locations, and follow-up inspections to monitor degradation rates. Corrective actions are taken as necessary to repair or replace the component subject to ongoing degradation to ensure it continues to meet the current licensing basis.

The FAC guideline, NSAC-202L, Revision 2 or Revision 3, states that it does not address other wall-thinning mechanisms, such as cavitation or erosive wear. The staff notes these other wall-thinning mechanisms are fundamentally different and require alternate analyses to predict susceptible locations and potentially require different solutions. In that respect, NSAC-202L, Revision 2 or Revision 3, notes that if the wear mechanism has not been identified, then inspections of components replaced with FAC-resistant materials should continue because these materials do not protect against damage from erosion mechanisms such as cavitation and liquid impingement. The staff’s review of operating experience has shown that, in some cases, wall thinning is caused by a combination of mechanisms, which includes FAC and some type of erosion (Callaway 1999, Dresden 2007).

These alternate wall-thinning mechanisms have been recognized in EPRI 1011231, “Cavitation, Flashing, Liquid Droplet Impingement, and Solid Particle Erosion in Nuclear Power Plant Piping Systems.” In addition, EPRI 112657, Revision B-A, “Revised Risk-Informed Inservice Inspection Evaluation Procedure,” includes “erosion cavitation” in the same “flow sensitive” category as FAC. Section 4.4.2 of NSAC-202L, Revision 3 provides guidance for “Susceptible-Not-Modeled” lines, where reasonably accurate analytical models cannot be developed due to unknown or widely varying operating conditions. Lines that are being monitored for wall thinning due to erosion mechanisms may be included with these other non-modeled lines and treated in a comparable fashion.

In its reviews of recent license renewal applications (e.g., Duane Arnold, Palo Verde, Columbia, South Texas Project), the staff noted that applicants were monitoring wall thinning due to various erosion mechanisms, including cavitation during infrequent operational alignments, such

as surveillance activities or pump starts/stops. In addition, the staff noted some recent licensee event reports that documented inoperable equipment associated with erosion mechanisms (Dresden 2007, Quad Cities 2009). As stated, it is the staff's view that, if an applicant has resolved these types of situations by eliminating the source of the degradation through design or operating parameter changes, and after follow-up inspections confirmed that the degradation source was eliminated, then no further age management activities would be required. The design change and effectiveness confirmation activities associated with these situations would be part of the normal corrective action program and would be considered in a license renewal review through ongoing operating experience reviews. However, if an applicant has decided to periodically monitor a component's condition instead of resolving erosion through a design change, then these monitoring activities should become part of an AMP to ensure the applicable code-required wall thicknesses are maintained consistent with the current licensing basis. In addition, if an applicant has resolved these types of situations by substituting more resistant material and not eliminating the source of the degradation, then periodic monitoring should continue. Although every plant site may not encounter erosion mechanisms, if ongoing monitoring of wall thinning due to erosion is not included as part of any other AMP, then these monitoring activities should be included in the FAC program.

ACTION

The staff has determined that the existing guidance in the SRP-LR and GALL Report does not adequately address aging management of wall thinning due to erosion mechanisms such as cavitation, flashing, droplet impingement, and solid particle impingement. Consequently, the staff is taking the following actions:

1. The staff revised the definition of "wall thinning" in the GALL Report Table IX.E, "Selected Use of Terms for Describing and Standardizing AGING EFFECTS," to include erosion mechanisms such as cavitation, flashing, droplet impingement, and solid particle impingement.

2. The staff revised the definition of "flow-accelerated corrosion," and "erosion," in the GALL Report Table IX.F, "Selected Definitions & Use of Terms for Describing and Standardizing AGING MECHANISMS," in order to better align them with the definitions commonly used in industry and to include specific forms of erosion, respectively.

3. The staff revised GALL Report AMP XI.M17 to include the following activities for applicants that have identified wall thinning due to erosion mechanisms:

    - Ensure that an extent of condition has been performed to determine if other components are susceptible to similar operational conditions. While this is clearly a corrective action program activity, its applicability to aging management reviews is also clear. As noted in SRP-LR Section A.1.2.3.4, a program based solely on detecting component failures should not be considered an effective AMP. For example, for wall thinning due to cavitation, in addition to addressing the loss of material, the extent of condition may need to consider the consequences of vibrational loading caused by cavitation.

    - If an applicant has chosen to implement design changes which will eliminate the source of the erosion mechanism, then the confirmation process discussed in

SRP-LR Section A.1.2.3.8 should periodically verify the effectiveness of the corrective actions. Periodic wall thickness measurements may be required until the effectiveness of the corrective actions has been confirmed.

- If an applicant has chosen to periodically monitor wall thickness as its basis for ensuring that the intended function(s) will be maintained in the period of extended operation, then this activity is part of a monitoring AMP that needs to be reviewed. As noted in SRP-LR Section 2.1.3.2.2, for periodic replacements based on condition, condition monitoring may be evaluated in the integrated plant assessment as a program to ensure functionality during the period of extended operation.

In addition, the staff revised GALL Report AMP XI.M17 in order to organize information in a more coherent manner and to correct inconsistencies. The "scope of program" specifies high-energy systems, and the staff notes that the term "high-energy" is not consistently defined, but it is typically associated with high pressure systems. Although this was the initial focus of the NRC's generic communication in this area, as correctly noted in NSAC-202L, Revision 2 or Revision 3, pressure does not affect the level of FAC wear, but a "failure in a low-pressure system could have significant consequences." Therefore, the reference to high-energy systems is being deleted in the "scope of program" to better align the AMP with the more accurately stated scope of NSAC-202L, Revision 2 or Revision 3.

4. The staff revised SRP-LR Table 3.0-1, "FSAR Supplement for Aging Management of Applicable Systems," for GALL Report Chapter XI.M17 to align it with the proposed change made to the scope of the program and is proposing to revise SRP-LR Tables 3.1-1, 3.2-1, 3.3-1, and 3.4-1 by adding aging management review items to align the guidance with the proposed change made to the scope of GALL Report AMP XI.M17. The staff is also proposing to add associated items in the GALL Report to correspond with the new items in the SRP-LR.

The revised portions of the SRP-LR and the GALL Report are documented in Appendix A, "Revised SRP-LR," and Appendix B, "Revised GALL Report." The extent and locations of these changes are clarified in Appendix C, "Mark-Up Showing Changes to the SRP-LR," and Appendix D, "Mark-Up Showing Changes to the GALL Report."

NEWLY IDENTIFIED SYSTEMS, STRUCTURES, AND COMPONENTS UNDER 10 CFR 54.37(b)

This LR-ISG addresses how wall thinning due to erosion mechanisms can be managed. It does not address whether components subject to wall thinning are within the scope of license renewal in accordance with 10 CFR 54.5. The NRC is not proposing to treat components being managed for wall thinning due to erosion mechanisms as "newly identified" systems, structures, and components (SSCs) under 10 CFR 54.37(b). Therefore, any additional action on such components which the NRC may impose upon current holders of renewed operating licenses under 10 CFR Part 54 would not fall within the scope of 10 CFR 54.37(b).

BACKFITTING DISCUSSION

This LR-ISG contains guidance as to one acceptable approach for managing the effects of aging during the period of extended operation caused by erosion mechanisms for components within the scope of license renewal. Set forth below is the staff's discussion on compliance with the requirements of the Backfit Rule, 10 CFR 50.109.

Compliance with the Backfit Rule

Issuance of this LR-ISG does not constitute backfitting as defined in 10 CFR 50.109(a)(1) and, as such, the NRC staff did not prepare a backfit analysis for issuing this LR-ISG. There are several rationales for this conclusion, depending upon the status of the nuclear power plant licensee.

Licensees who are currently in the license renewal process – This LR-ISG is directed to current applicants for license renewal. However, this LR-ISG is not backfitting as defined in 10 CFR 50.109(a)(1). This guidance is non-binding and provides one approach acceptable to the NRC staff for managing the effects of aging caused by erosion mechanisms in accordance with the requirements of 10 CFR Part 54. License renewal applicants are not required to use this guidance. Applicants may elect to propose an alternative approach for managing the effects of aging caused by erosion mechanisms during the period of extended operation. In addition, the Backfit Rule does not protect license renewal applicants voluntarily requesting renewed licenses from changes in NRC requirements or guidance on license renewal prior to or during the pendency of their renewal application (NRC, 2008). Therefore, issuance of this LR-ISG does not constitute backfitting as applied to current applicants for license renewal.

Licensees who already hold a renewed license – This guidance is non-binding and the LR-ISG does not require current holders of renewed licenses to take any action (i.e., programmatic or plant hardware changes for managing the aging of components caused by erosion mechanisms). However, current holders of renewed licenses should treat this guidance as operating experience and take actions as appropriate to ensure that applicable aging management programs are, and will remain, effective. If, in the future, the NRC decides to take additional action and impose requirements for management of components affected by erosion mechanisms, then the NRC will follow the requirements of the Backfit Rule.

Current operating license holders or combined license holders who have not applied for renewed licenses – This LR-ISG is not directed at holders of (original) operating licenses or combined licenses until they apply for license renewal. As such, this LR-ISG does not constitute backfitting as applied to holders of (original) operating licenses and is not otherwise inconsistent with the applicable issue finality provisions in 10 CFR Part 52 as applied to holders of combined licenses.

REFERENCES

10 CFR Part 50, Domestic Licensing of Production and Utilization Facilities, Office of the Federal Register, National Archives and Records Administration, 2011.

10 CFR Part 52, Licenses, Certifications, and Approvals for Nuclear Power Plants, Office of the Federal Register, National Archives and Records Administration, 2011.

10 CFR Part 54, Requirements for Renewal of Operating Licenses for Nuclear Power Plants, Office of the Federal Register, National Archives and Records Administration, 2011.

EPRI TR-106611, "Flow-Accelerated Corrosion in Power Plants," Revision 1, Electric Power Research Institute, Palo Alto, CA, 1998.

EPRI TR-112657, "Revised Risk-Informed Inservice Inspection Evaluation Procedure," Revision B-A, Electric Power Research Institute, Palo Alto, CA, December 1999 (Agencywide Documents Access and Management System (ADAMS) Accession No. ML013470102).

EPRI 1010639, "Non-Class 1 Mechanical Implementation Guideline and Mechanical Tools, Revision 4," Electric Power Research Institute, Palo Alto, CA, January 2006 (ADAMS Accession No. ML11356A357).

EPRI 1011231, "Recommendations for Controlling Cavitation, Flashing, Liquid Droplet Impingement, and Solid Particle Erosion in Nuclear Power Plant Piping Systems." Electric Power Research Institute, Palo Alto, CA, November 2004.

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Licensee Event Report 483/1999-003-01, Callaway Unit 1, "Manual Reactor Trip Due to Heater Drain System Pipe Rupture Caused by Flow Accelerated Corrosion," May 1, 2000 (ADAMS Accession No. ML003712775).

Licensee Event Report 277/2006-003-00, Peach Bottom Unit 2, "Elbow Leak on Piping Attached to Suppression Pool Results in Loss of Containment Integrity," December 4, 2006 (ADAMS Accession No. ML063420059).

Licensee Event Report 237/2007-003-00, Dresden Unit 2, "High Pressure Coolant Injection System Declared Inoperable," September 24, 2007 (ADAMS Accession No. ML072750663).

Licensee Event Report 254/2009-004-00, Quad Cities Unit 1, "Pinhole Leak in Core Spray Piping Results in Loss of Containment Integrity and Plant Shutdown for Repairs," November 6, 2009 (ADAMS Accession No. ML093170206).

NRC Generic Letter 89-08, "Erosion/Corrosion-Induced Pipe Wall Thinning," Washington, D.C., May 2, 1989 (ADAMS Accession No. ML072780548).

NRC Memorandum from Dale E. Klein, Chairman, to Hubert T. Bell, Office of the Inspector General, "Response to Recommendation 9 of 9/6/07 Audit Report on NRC's License Renewal Program," April 1, 2008 (ADAMS Accession No. ML080870286).

NRC NUREG-1800, “Standard Review Plan for Review of License Renewal Applications for Nuclear Power Plants,” Revision 2, Washington, D.C., December 2010 (ADAMS Accession No. ML103490036).

NRC NUREG-1801, “Generic Aging Lessons Learned (GALL) Report,” Revision 2, Washington, D.C., December 2010 (ADAMS Accession No. ML103490041).

NSAC 202L, “Recommendations for an Effective Flow Accelerated Corrosion Program,” Revision 2, Electric Power Research Institute, Nuclear Safety Analysis Center, Palo Alto, CA, April 1999.

NSAC 202L, “Recommendations for an Effective Flow Accelerated Corrosion Program,” Revision 3, Electric Power Research Institute, Nuclear Safety Analysis Center, Palo Alto, CA, May 2006.

Appendices

Appendix A, Revised SRP-LR

Appendix B, Revised GALL Report

Appendix C, Mark-up Showing Changes to the SRP-LR

Appendix D, Mark-up Showing Changes to the GALL Report

Appendix A

Revised SRP-LR

Table 3.0-1 FSAR Supplement for Aging Management of Applicable Systems				
GALL Chapter	**GALL Program**	**Description of Program**	**Implementation Schedule**	**Applicable GALL Report and SRP-LR Chapter References**
XI.M17	Flow-Accelerated Corrosion (FAC)	The program consists of (a) conducting appropriate analysis and baseline inspections, (b) determining the extent of thinning and replacement/repair of components, and (c) performing follow-up inspection to confirm or quantify and take long-term corrective actions. The program relies on implementation of EPRI guidelines of NSAC-202L-R2 or R3. [Where applicable, the program also manages wall thinning due to erosion mechanisms such as cavitation, flashing, droplet impingement, and solid particle impingement.]	Existing Program	GALL IV / SRP 3.1 GALL V / SRP 3.2 GALL VII / SRP 3.3 GALL VIII / SRP 3.4

Table 3.1-1 Summary of Aging Management Programs for Reactor Vessel, Internals, and Reactor Coolant System Evaluated in Chapter IV of the GALL Report							
ID	**Type**	**Component**	**Aging Effect/ Mechanism**	**Aging Management Programs**	**Further Evaluation Recommended**	**Rev2 Item**	**Rev1 Item**
108	BWR/ PWR	Any material, piping, piping components, and piping elements exposed to reactor coolant	Wall thinning due to erosion	Chapter XI.M17, “Flow-Accelerated Corrosion”	No	N/A	N/A

Table 3.2-1 Summary of Aging Management Programs for Engineered Safety Features Evaluated in Chapter V of the GALL Report							
ID	**Type**	**Component**	**Aging Effect/ Mechanism**	**Aging Management Programs**	**Further Evaluation Recommended**	**Rev2 Item**	**Rev1 Item**
65	BWR/ PWR	Any material, piping, piping components, and piping elements exposed to steam, treated water, treated water (borated), raw water	Wall thinning due to erosion	Chapter XI.M17, "Flow-Accelerated Corrosion"	No	N/A	N/A

Table 3.3-1 Summary of Aging Management Programs for Auxiliary Systems Evaluated in Chapter VII of the GALL Report							
ID	**Type**	**Component**	**Aging Effect/ Mechanism**	**Aging Management Programs**	**Further Evaluation Recommended**	**Rev2 Item**	**Rev1 Item**
126	BWR/ PWR	Any material, piping, piping components, and piping elements exposed to treated water, treated borated water, raw water	Wall thinning due to erosion	Chapter XI.M17, "Flow-Accelerated Corrosion"	No	N/A	N/A

Table 3.4-1 Summary of Aging Management Programs for Steam and Power Conversion System Evaluated in Chapter VIII of the GALL Report							
ID	**Type**	**Component**	**Aging Effect/ Mechanism**	**Aging Management Programs**	**Further Evaluation Recommended**	**Rev2 Item**	**Rev1 Item**
60	BWR/ PWR	Any material, piping, piping components, and piping elements exposed to steam, treated water, raw water	Wall thinning due to erosion	Chapter XI.M17, "Flow-Accelerated Corrosion"	No	N/A	N/A

Appendix B

Revised GALL Report

IV	REACTOR VESSEL, INTERNALS, AND REACTOR COOLANT SYSTEM						
C1	Reactor Coolant Pressure Boundary (BWR)						
Item	**Link**	**Structure and/or Component**	**Material**	**Environment**	**Aging Effect/ Mechanism**	**Aging Management Program (AMP)**	**Further Evaluation**
New		Piping, piping components, and piping elements	Any	Reactor Coolant	Wall thinning due to erosion	Chapter XI.M17, “Flow-Accelerated Corrosion”	No

IV	REACTOR VESSEL, INTERNALS, AND REACTOR COOLANT SYSTEM						
C2	Reactor Coolant System and Connected Lines (PWR)						
Item	**Link**	**Structure and/or Component**	**Material**	**Environment**	**Aging Effect/ Mechanism**	**Aging Management Program (AMP)**	**Further Evaluation**
New		Piping, piping components, and piping elements	Any	Reactor Coolant	Wall thinning due to erosion	Chapter XI.M17, “Flow-Accelerated Corrosion”	No

V	ENGINEERED SAFETY FEATURES						
D1	Emergency Core Cooling System (PWR)						
Item	**Link**	**Structure and/or Component**	**Material**	**Environment**	**Aging Effect/ Mechanism**	**Aging Management Program (AMP)**	**Further Evaluation**
New		Piping, piping components, and piping elements	Any	Treated Water (borated)	Wall thinning due to erosion	Chapter XI.M17, “Flow-Accelerated Corrosion”	No

V D2	ENGINEERED SAFETY FEATURES Emergency Core Cooling System (BWR)						
Item	**Link**	**Structure and/or Component**	**Material**	**Environment**	**Aging Effect/ Mechanism**	**Aging Management Program (AMP)**	**Further Evaluation**
New		Piping, piping components, and piping elements	Any	Treated water	Wall thinning due to erosion	Chapter XI.M17, “Flow-Accelerated Corrosion”	No

VII C1	AUXILIARY SYSTEMS Open-Cycle Cooling Water System (Service Water System)						
Item	**Link**	**Structure and/or Component**	**Material**	**Environment**	**Aging Effect/ Mechanism**	**Aging Management Program (AMP)**	**Further Evaluation**
New		Piping, piping components, and piping elements	Any	Raw water	Wall thinning due to erosion	Chapter XI.M17, “Flow-Accelerated Corrosion”	No

VII E1	AUXILIARY SYSTEMS Chemical and Volume Control System (PWR)						
Item	**Link**	**Structure and/or Component**	**Material**	**Environment**	**Aging Effect/ Mechanism**	**Aging Management Program (AMP)**	**Further Evaluation**
New		Piping, piping components, and piping elements	Any	Treated water (borated)	Wall thinning due to erosion	Chapter XI.M17, “Flow-Accelerated Corrosion”	No

VII E3	AUXILIARY SYSTEMS Reactor Water Cleanup System						
Item	**Link**	**Structure and/or Component**	**Material**	**Environment**	**Aging Effect/ Mechanism**	**Aging Management Program (AMP)**	**Further Evaluation**
New		Piping, piping components, and piping elements	Any	Treated water	Wall thinning due to erosion	Chapter XI.M17, “Flow-Accelerated Corrosion”	No

VIII D1	STEAM AND POWER CONVERSION SYSTEM Feedwater Systems (PWR)						
Item	**Link**	**Structure and/or Component**	**Material**	**Environment**	**Aging Effect/ Mechanism**	**Aging Management Program (AMP)**	**Further Evaluation**
New		Piping, piping components, and piping elements	Any	Treated water	Wall thinning due to erosion	Chapter XI.M17, “Flow-Accelerated Corrosion”	No

VIII D2	STEAM AND POWER CONVERSION SYSTEM Feedwater Systems (BWR)						
Item	**Link**	**Structure and/or Component**	**Material**	**Environment**	**Aging Effect/ Mechanism**	**Aging Management Program (AMP)**	**Further Evaluation**
New		Piping, piping components, and piping elements	Any	Treated water	Wall thinning due to erosion	Chapter XI.M17, “Flow-Accelerated Corrosion”	No

VIII G	STEAM AND POWER CONVERSION SYSTEM Auxiliary Feedwater System (PWR)						
Item	**Link**	**Structure and/or Component**	**Material**	**Environment**	**Aging Effect/ Mechanism**	**Aging Management Program (AMP)**	**Further Evaluation**
New		Piping, piping components, and piping elements	Any	Treated water	Wall thinning due to erosion	Chapter XI.M17, “Flow-Accelerated Corrosion”	No

Table IX.E, Selected Use of Terms for Describing and Standardizing AGING EFFECTS

Term	Usage in this Document
Wall thinning	Wall thinning is a specific type of loss of material attributed in the AMR line items to general corrosion, flow-accelerated corrosion, and erosion mechanisms including cavitation, flashing, droplet impingement, or solid particle impingement.

Table IX.F, Selected Definitions & Use of Terms for Describing and Standardizing AGING MECHANISMS

Term	Usage in this Document
Erosion	Erosion is the progressive loss of material due to the mechanical interaction between a surface and a high-velocity fluid. Different forms of erosion may include cavitation, flashing, droplet impingement, or solid particle impingement.
Flow-accelerated corrosion (FAC)	Flow-accelerated corrosion is a corrosion mechanism which results in wall thinning of carbon steel piping exposed to moving, high temperature, low-oxygen water, such as PWR primary and secondary water, and BWR reactor coolant. FAC is the result of dissolution of the surface film of the steel which is transported away from the site of dissolution by the movement of water. [In previous versions of the GALL Report and past NRC generic communications, this type of corrosion has been incorrectly called erosion-corrosion, which is misleading since erosion implies a mechanical process instead of chemical dissolution.]

XI.M17 FLOW-ACCELERATED CORROSION

Program Description

This program manages wall thinning caused by flow-accelerated corrosion (FAC) and may be used to manage wall thinning due to various erosion mechanisms, if the erosion mechanisms are not being managed by another program. The program relies on implementation of the Electric Power Research Institute (EPRI) guidelines in the Nuclear Safety Analysis Center (NSAC)-202L-R2 or -R3 for an effective FAC program. The program includes performing (a) an analysis to determine critical locations, (b) limited baseline inspections to determine the extent of thinning at these locations, and (c) follow-up inspections to confirm the predictions, or repairing or replacing components as necessary. NSAC-202L-R2 or -R3 provide general guidelines for the FAC program. To provide reasonable assurance that all the aging effects caused by FAC are properly managed, the program includes the use of a predictive code, such as CHECWORKS, that uses the implementation guidance of NSAC-202L-R2 or -R3 to satisfy the criteria specified in 10 CFR Part 50, Appendix B, for development of procedures and control of special processes.

In addition, as noted in NSAC 202L-R2 or -R3, if wall thinning has been caused by a mechanism other than FAC (e.g., erosion mechanisms such as cavitation, flashing, droplet impingement, and solid particle impingement), and it is being managed through periodic monitoring, then an appropriate inspection program to address the suspected phenomenon should be developed. This program may include wall-thinning mechanisms as described in EPRI 1011231, "Recommendations for Controlling Cavitation, Flashing, Liquid Droplet Impingement, and Solid Particle Erosion in Nuclear Power Plant Piping Systems."

Evaluation and Technical Basis

1. ***Scope of Program:*** The FAC program, described by the EPRI guidelines in NSAC-202L-R2 or -R3, includes procedures or administrative controls to assure that structural integrity is maintained for carbon steel piping containing two-phase and single-phase fluids. This program also covers valve bodies that retain pressure in these systems. The FAC program was originally outlined in NUREG-1344 and was further described through the Nuclear Regulatory Commission (NRC) Generic Letter 89-08, "Erosion/Corrosion-Induced Pipe Wall Thinning." The program may also include piping and components that are susceptible to erosion wall-thinning mechanisms such as cavitation, flashing, droplet impingement, or solid particle impingement in various water systems. Since there are no known materials that are immune to wall thinning due to erosion, piping and components of any material may be included in the non-FAC portion of the program.
2. ***Preventive Actions:*** The FAC program is an analysis, inspection, and verification program; no preventive action has been recommended in this program. However, it is noted that monitoring of water chemistry to control pH and dissolved oxygen content, and selection of appropriate piping material, geometry, and hydrodynamic conditions, are effective in reducing FAC and erosion mechanisms.
3. ***Parameters Monitored/Inspected:*** The aging management program monitors the effects of wall thinning due to FAC and erosion on the intended function of piping and components by measuring wall thickness.
4. ***Detection of Aging Effects:*** Degradation of piping and components occurs by wall thinning. For FAC, the inspection program delineated in NSAC-202L-R2 or -R3 consists of identification of susceptible locations, as indicated by operating conditions or special considerations. This program specifies ultrasonic or radiographic testing to detect wall

thinning. A representative sample of components is selected based on the most susceptible locations for wall thickness measurements at a frequency in accordance with NSAC-202L guidelines to ensure that degradation is identified and mitigated before the component integrity is challenged. The extent and schedule of the inspections ensure detection of wall thinning before the loss of intended function.

For erosion mechanisms, the program includes the identification of susceptible locations based on plant-specific or industry operating experience. If wall thinning due to an erosion mechanism (e.g., cavitation, flashing, droplet impingement, or solid particle impingement) is identified, then the applicant performs an extent-of-condition review to identify other components that are comparably susceptible to the same mechanism. Components in this category can be treated in a manner similar to other "susceptible–not-modeled" lines discussed in NSAC-202L-R2 or -R3. EPRI 1011231 provides guidance for identifying potential damage locations. EPRI TR-112657, "Revised Risk-Informed Inservice Inspection Evaluation Procedure," Revision B-A, or NUREG/CR-6031, "Cavitation Guide for Control Valves," provides additional insights for cavitation. For cavitation, in addition to loss of material, the extent-of-condition review may need to consider the consequences of vibrational loading caused by cavitation.

5. ***Monitoring and Trending:*** CHECWORKS or a similar predictive code estimates component degradation in the systems conducive to FAC, as indicated by specific plant data, including material, hydrodynamic, and operating conditions. CHECWORKS was developed and benchmarked by comparing CHECWORKS predictions against actual measured component thickness measurements obtained from many plants. It is recognized that CHECWORKS is not always conservative in predicting component thickness; therefore, when measurements show the predictions to be non-conservative, the model must be re-calibrated using the latest field data. The use of such a predictive code to develop an inspection schedule provides reasonable assurance that structural integrity will be maintained between inspections. The program includes the evaluation of inspection results to determine if additional inspections are needed to ensure that the extent of wall thinning is adequately determined, that intended function will not be lost, and that corrective actions are adequately identified. Previous wear rate predictions due to FAC may change after a power uprate is implemented. The program includes updating wear rates in CHECWORKS according to power uprate conditions. Subsequent field measurements are used to calibrate or benchmark the predicted wear rates.

   For erosion mechanisms, the program includes trending of wall thickness measurements at susceptible locations to adjust the monitoring frequency and to predict the remaining service life of the component for scheduling repairs or replacements. Inspection results are evaluated to determine if assumptions in the extent-of-condition review remain valid. If degradation is associated with infrequent operational alignments, such as surveillances or pump starts/stops, then trending activities may need to consider the number or duration of these occurrences. Periodic wall thickness measurements of replacement components may be required and should continue until the effectiveness of corrective actions have been confirmed.

6. ***Acceptance Criteria:*** Inspection results are input for a predictive computer code, such as CHECWORKS or for use in component-specific analyses, to calculate the number of refueling or operating cycles remaining before the component reaches the minimum allowable wall thickness. If calculations indicate that an area will reach the minimum allowed wall thickness before the next scheduled outage, the program should include corrective action.

7. ***Corrective Actions:*** The program includes reevaluation, repair, or replacement of components for which the acceptance criteria are not satisfied prior to their return to service. Long-term corrective actions could include adjusting operating parameters or selecting materials resistant to FAC. When susceptible components are replaced with FAC-resistant materials, such as high chromium material, the downstream components should be monitored to identify any increased wear. For erosion mechanisms, the effectiveness of corrective actions intended to eliminate the cause of the wall thinning should be verified, or corrective actions which initiate ongoing monitoring activities should be evaluated as part of an AMP. The selection of replacement material requires consideration of a number of factors, because a material that is completely erosion resistant is not available. As discussed in the Appendix for the GALL Report, the staff finds the requirements of 10 CFR Part 50, Appendix B, acceptable to address the corrective actions.

8. ***Confirmation Process:*** Site quality assurance (QA) procedures, review and approval processes, and administrative controls are implemented in accordance with the requirements of 10 CFR Part 50, Appendix B. As discussed in the Appendix for the GALL Report, the staff finds the requirements of 10 CFR Part 50, Appendix B, acceptable to address the confirmation process.

9. ***Administrative Controls:*** Site QA procedures, review and approval processes, and administrative controls are implemented in accordance with the requirements of 10 CFR Part 50, Appendix B. As discussed in the Appendix for the GALL Report, the staff finds the requirements of 10 CFR Part 50, Appendix B, acceptable to address the administrative controls.

10. ***Operating Experience:*** Wall-thinning problems in single-phase systems have occurred in feedwater and condensate systems (NRC IE Bulletin No. 87-01; NRC Information Notice [IN] 92-35, IN 95-11, IN 2006-08) and in two-phase piping in extraction steam lines (NRC IN 89-53, IN 97-84) and moisture separation reheater and feedwater heater drains (NRC IN 89-53, IN 91-18, IN 93-21, IN 97-84). Observed wall thinning may be due to mechanisms other than FAC or due to a combination of mechanisms (NRC IN 99-19, Licensee Event Report (LER) 483/1999-003-01, LER 277/2006-003-00, LER 237/2007-003-00, LER 254/2009-004-00). (See References below for titles and dates.)

References

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NRC Information Notice 93-21, *Summary of NRC Staff Observations Compiled during Engineering Audits or Inspections of Licensee Erosion/Corrosion Programs*, U.S. Nuclear Regulatory Commission, March 25, 1993.

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NRC Information Notice 99-19, *Rupture of the Shell Side of a Feedwater Heater at the Point Beach Nuclear Plant,* U.S. Nuclear Regulatory Commission, June 23, 1999.

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NUREG-1344, *Erosion/Corrosion-Induced Pipe Wall Thinning in U.S. Nuclear Power Plants*, P. C. Wu, U.S. Nuclear Regulatory Commission, April 1989.

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Appendix C

Mark-up Showing Changes to SRP-LR

Additions shown in underline, bold
Deletions marked with strikethrough

Table 3.0-1 FSAR Supplement for Aging Management of Applicable Systems				
GALL Chapter	**GALL Program**	**Description of Program**	**Implementation Schedule**	**Applicable GALL Report and SRP-LR Chapter References**
XI.M17	Flow-Accelerated Corrosion (FAC)	The program consists of (a) conducting appropriate analysis and baseline inspections, (b) determining the extent of thinning and replacement/repair of components, and (c) performing follow-up inspection to confirm or quantify and take long-term corrective actions. The program relies on implementation of EPRI guidelines of NSAC-202L-R2 or R3. **[Where applicable, the program also manages wall thinning due to erosion mechanisms such as cavitation, flashing, droplet impingement, and solid particle impingement.]**	Existing Program	GALL IV / SRP 3.1 GALL V / SRP 3.2 GALL VII / SRP 3.3 GALL VIII / SRP 3.4

Table 3.1-1 Summary of Aging Management Programs for Reactor Vessel, Internals, and Reactor Coolant System Evaluated in Chapter IV of the GALL Report							
ID	**Type**	**Component**	**Aging Effect/ Mechanism**	**Aging Management Programs**	**Further Evaluation Recommended**	**Rev2 Item**	**Rev1 Item**
108	**BWR/ PWR**	**Any material, piping, piping components, and piping elements exposed to reactor coolant**	**Wall thinning due to erosion**	**Chapter XI.M17, "Flow-Accelerated Corrosion"**	**No**	**N/A**	**N/A**

Table 3.2-1 Summary of Aging Management Programs for Engineered Safety Features Evaluated in Chapter V of the GALL Report							
ID	**Type**	**Component**	**Aging Effect/ Mechanism**	**Aging Management Programs**	**Further Evaluation Recommended**	**Rev2 Item**	**Rev1 Item**
65	**BWR/ PWR**	**Any material, piping, piping components, and piping elements exposed to steam, treated water, treated water (borated), raw water**	**Wall thinning due to erosion**	**Chapter XI.M17, "Flow-Accelerated Corrosion"**	**No**	**N/A**	**N/A**

Table 3.3-1 Summary of Aging Management Programs for Auxiliary Systems Evaluated in Chapter VII of the GALL Report							
ID	**Type**	**Component**	**Aging Effect/ Mechanism**	**Aging Management Programs**	**Further Evaluation Recommended**	**Rev2 Item**	**Rev1 Item**
126	**BWR/ PWR**	**Any material, piping, piping components, and piping elements exposed to treated water, treated borated water, raw water**	**Wall thinning due to erosion**	**Chapter XI.M17, "Flow-Accelerated Corrosion"**	**No**	**N/A**	**N/A**

Table 3.4-1 Summary of Aging Management Programs for Steam and Power Conversion System Evaluated in Chapter VIII of the GALL Report							
ID	**Type**	**Component**	**Aging Effect/ Mechanism**	**Aging Management Programs**	**Further Evaluation Recommended**	**Rev2 Item**	**Rev1 Item**
60	**BWR/ PWR**	**Any material, piping, piping components, and piping elements exposed to steam, treated water, raw water**	**Wall thinning due to erosion**	**Chapter XI.M17, "Flow-Accelerated Corrosion"**	**No**	**N/A**	**N/A**

Appendix D

Mark-up Showing Changes to the GALL Report

Additions shown in underline, bold
Deletions marked with strikethrough

IV C1	REACTOR VESSEL, INTERNALS, AND REACTOR COOLANT SYSTEM Reactor Coolant Pressure Boundary (BWR)						
Item	**Link**	**Structure and/or Component**	**Material**	**Environment**	**Aging Effect/ Mechanism**	**Aging Management Program (AMP)**	**Further Evaluation**
New		**Piping, piping components, and piping elements**	**Any**	**Reactor Coolant**	**Wall thinning due to erosion**	**Chapter XI.M17, "Flow-Accelerated Corrosion"**	**No**

IV C2	REACTOR VESSEL, INTERNALS, AND REACTOR COOLANT SYSTEM Reactor Coolant System and Connected Lines (PWR)						
Item	**Link**	**Structure and/or Component**	**Material**	**Environment**	**Aging Effect/ Mechanism**	**Aging Management Program (AMP)**	**Further Evaluation**
New		**Piping, piping components, and piping elements**	**Any**	**Reactor Coolant**	**Wall thinning due to erosion**	**Chapter XI.M17, "Flow-Accelerated Corrosion"**	**No**

V D1	ENGINEERED SAFETY FEATURES Emergency Core Cooling System (PWR)						
Item	**Link**	**Structure and/or Component**	**Material**	**Environment**	**Aging Effect/ Mechanism**	**Aging Management Program (AMP)**	**Further Evaluation**
New		**Piping, piping components, and piping elements**	**Any**	**Treated Water (borated)**	**Wall thinning due to erosion**	**Chapter XI.M17, "Flow-Accelerated Corrosion"**	**No**

V ENGINEERED SAFETY FEATURES D2 Emergency Core Cooling System (BWR)							
Item	**Link**	**Structure and/or Component**	**Material**	**Environment**	**Aging Effect/ Mechanism**	**Aging Management Program (AMP)**	**Further Evaluation**
New		**Piping, piping components, and piping elements**	**Any**	**Treated water**	**Wall thinning due to erosion**	**Chapter XI.M17, "Flow-Accelerated Corrosion"**	**No**

VII AUXILIARY SYSTEMS C1 Open-Cycle Cooling Water System (Service Water System)							
Item	**Link**	**Structure and/or Component**	**Material**	**Environment**	**Aging Effect/ Mechanism**	**Aging Management Program (AMP)**	**Further Evaluation**
New		**Piping, piping components, and piping elements**	**Any**	**Raw water**	**Wall thinning due to erosion**	**Chapter XI.M17, "Flow-Accelerated Corrosion"**	**No**

VII AUXILIARY SYSTEMS E1 Chemical and Volume Control System (PWR)							
Item	**Link**	**Structure and/or Component**	**Material**	**Environment**	**Aging Effect/ Mechanism**	**Aging Management Program (AMP)**	**Further Evaluation**
New		**Piping, piping components, and piping elements**	**Any**	**Treated water (borated)**	**Wall thinning due to erosion**	**Chapter XI.M17, "Flow-Accelerated Corrosion"**	**No**

VII AUXILIARY SYSTEMS E3 Reactor Water Cleanup System							
Item	**Link**	**Structure and/or Component**	**Material**	**Environment**	**Aging Effect/ Mechanism**	**Aging Management Program (AMP)**	**Further Evaluation**
New		**Piping, piping components,**	**Any**	**Treated water**	**Wall thinning due to erosion**	**Chapter XI.M17, "Flow-Accelerated Corrosion"**	**No**

		and piping elements					

VIII D1	STEAM AND POWER CONVERSION SYSTEM Feedwater Systems (PWR)						
Item	**Link**	**Structure and/or Component**	**Material**	**Environment**	**Aging Effect/ Mechanism**	**Aging Management Program (AMP)**	**Further Evaluation**
New		**Piping, piping components, and piping elements**	**Any**	**Treated water**	**Wall thinning due to erosion**	**Chapter XI.M17, "Flow-Accelerated Corrosion"**	**No**

VIII D2	STEAM AND POWER CONVERSION SYSTEM Feedwater Systems (BWR)						
Item	**Link**	**Structure and/or Component**	**Material**	**Environment**	**Aging Effect/ Mechanism**	**Aging Management Program (AMP)**	**Further Evaluation**
New		**Piping, piping components, and piping elements**	**Any**	**Treated water**	**Wall thinning due to erosion**	**Chapter XI.M17, "Flow-Accelerated Corrosion"**	**No**

VIII G	STEAM AND POWER CONVERSION SYSTEM Auxiliary Feedwater System (PWR)						
Item	**Link**	**Structure and/or Component**	**Material**	**Environment**	**Aging Effect/ Mechanism**	**Aging Management Program (AMP)**	**Further Evaluation**
New		**Piping, piping components, and piping elements**	**Any**	**Treated water**	**Wall thinning due to erosion**	**Chapter XI.M17, "Flow-Accelerated Corrosion"**	**No**

Table IX.E, Selected Use of Terms for Describing and Standardizing AGING EFFECTS

Term	Usage in this Document
Wall thinning	Wall thinning is a specific type of loss of material attributed in the AMR line items to general corrosion, flow-accelerated corrosion, **and erosion mechanisms including cavitation, flashing, droplet impingement, or solid particle impingement.**

Table IX.F, Selected Definitions & Use of Terms for Describing and Standardizing AGING MECHANISMS

Term	Usage in this Document
Erosion	Erosion~~, or~~ **is** the progressive loss of material ~~from a solid surface is~~ due to the mechanical interaction between ~~that~~ **a** surface and a **high-velocity** fluid~~, a multicomponent fluid, or solid particles carried by the fluid~~. **Different forms of erosion may include cavitation, flashing, droplet impingement, or solid particle impingement.**
Flow-accelerated corrosion (FAC)	Flow-accelerated corrosion~~, also termed "erosion-corrosion," is a co-joint activity involving corrosion and erosion in the presence of a moving corrosive fluid, leading to the accelerated loss of material. Susceptibility may be determined using the review process outlined in Section 4.2 of NSAC-202L-R2 and R3 recommendations for an effective FAC program. [Ref. 27]~~ **is a corrosion mechanism which results in wall thinning of carbon steel piping exposed to moving, high temperature, low-oxygen water, such as PWR primary and secondary water, and BWR reactor coolant. FAC is the result of dissolution of the surface film of the steel which is transported away from the site of dissolution by the movement of water. [In previous versions of the GALL Report and past NRC generic communications, this type of corrosion has been incorrectly called erosion-corrosion, which is misleading since erosion implies a mechanical process instead of chemical dissolution.]**

XI.M17 FLOW-ACCELERATED CORROSION

Program Description

This program manages wall thinning caused by flow-accelerated corrosion (FAC) and may be used to manage wall thinning due to various erosion mechanisms. if the erosion mechanisms are not being managed by another program. The program relies on implementation of the Electric Power Research Institute (EPRI) guidelines in the Nuclear Safety Analysis Center (NSAC)-202L-R2 or **-**R3 for an effective flow-accelerated corrosion (FAC) program. The program includes performing (a) an analysis to determine critical locations, (b) limited baseline inspections to determine the extent of thinning at these locations, and (c) follow-up inspections to confirm the predictions, or repairing or replacing components as necessary. NSAC-202L-R2 or **-**R3 provides general guidelines for the FAC program. To provide reasonable assurance that all the aging effects caused by FAC are properly managed, the program includes the use of a predictive code, such as CHECWORKS, that uses the implementation guidance of NSAC-202L-R2 or -R3 to satisfy the criteria specified in 10 CFR Part 50, Appendix B, for development of procedures and control of special processes.

In addition, as noted in NSAC 202L-R2 or -R3, if wall thinning has been caused by a mechanism other than FAC (e.g., erosion mechanisms such as cavitiation, flashing, droplet impingement, and solid particle impingement), and it is being managed through periodic monitoring, then an appropriate inspection program to address the suspected phenomenon should be developed. This program may include wall thinning mechanisms as described in EPRI 1011231, "Recommendations for Controlling Cavitation, Flashing, Liquid Droplet Impingement, and Solid Particle Erosion in Nuclear Power Plant Piping Systems."

Evaluation and Technical Basis

1. ***Scope of Program:*** The FAC program, described by the EPRI guidelines in NSAC-202L-R2 or **-**R3, includes procedures or administrative controls to assure that ~~the~~ structural integrity **is maintained for carbon steel piping containing two-phase and single-phase fluids** ~~of all carbon steel lines containing high-energy fluids (two-phase as well as single-phase) is maintained~~. **This program also covers** ~~V~~**v**alve bodies **that** retain~~ing~~ pressure in these ~~high-energy~~ systems ~~are also covered by the program~~. The FAC program was originally outlined in NUREG-1344 and was further described through the Nuclear Regulatory Commission (NRC) Generic Letter 89-08**, "Erosion/Corrosion-Induced Pipe Wall Thinning." The program may also include piping and components that are susceptible to erosion wall-thinning mechanisms such as cavitation, flashing, droplet impingement, or solid particle impingement in various water systems. Since there are no known materials that are immune to wall thinning due to erosion, piping and components of any material may be included in the non-FAC portion of the program.**
2. ***Preventive Actions:*** The FAC program is an analysis, inspection, and verification program; no preventive action has been recommended in this program. However, it is noted that monitoring of water chemistry to control pH and dissolved oxygen content, and selection of appropriate piping material, geometry, and hydrodynamic conditions, are effective in reducing FAC **and erosion mechanisms**.
3. ***Parameters Monitored/Inspected:*** The aging management program monitors the effects of ~~loss of material~~ **wall thinning** due to ~~wall thinning~~ **FAC and erosion** on the intended function of piping and components by measuring wall thickness.

4. ***Detection of Aging Effects:*** Degradation of piping and components occurs by wall thinning. **For FAC,** ~~T~~the inspection program delineated in NSAC-202L-R2 or **-**R3 consists of identification of susceptible locations, as indicated by operating conditions or special considerations. **This program specifies** ~~U~~**u**ltrasonic or radiographic testing ~~is used~~ to detect wall thinning. A representative sample of components is selected based on the most susceptible locations for wall thickness measurements at a frequency in accordance with NSAC**-**202L guidelines to ensure that degradation is identified and mitigated before the component integrity is challenged. The extent and schedule of the inspections ensure detection of wall thinning before the loss of intended function.

   For erosion mechanisms, the program includes the identification of susceptible locations based on plant-specific or industry operating experience. If wall thinning due to an erosion mechanism (e.g., cavitation, flashing, droplet impingement, or solid particle impingement) is identified, then the applicant performs an extent-of-condition review to identify other components that are comparably susceptible to the same mechanism. Components in this category may be treated in a manner similar to other "susceptible-not-modeled" lines discussed in NSAC-202L-R2 or -R3. EPRI 1011231 provides guidance for identifying potential damage locations. EPRI TR-112657, "Revised Risk-Informed Inservice Inspection Evaluation Procedure," Revision B-A, or NUREG/CR-6031, "Cavitation Guide for Control Valves," provides additional insights for cavitation. For cavitation, in addition to loss of material, the extent-of-condition review may need to consider the consequences of vibrational loading caused by cavitation.

5. ***Monitoring and Trending:*** CHECWORKS or a similar predictive code estimates component degradation in the systems conducive to FAC, as indicated by specific plant data, including material, hydrodynamic, and operating conditions. ~~CHECWORKS is acceptable because it provides a bounding analysis for FAC. The analysis is bounding because in general the predicted wear rates and component thicknesses are conservative when compared to actual field measurements.~~ **CHECWORKS was developed and benchmarked by comparing CHECWORKS predictions against actual measured component thickness measurements obtained from many plants.** It is recognized that CHECWORKS is not always conservative in predicting component thickness; therefore, when measurements show the predictions to be non-conservative, the model must be re-calibrated using the latest field data. ~~CHECWORKS was developed and benchmarked by comparing CHECWORKS predictions against actual measured component thickness measurements obtained from many plants.~~ The **use of such a predictive code to develop an** inspection schedule ~~developed by the licensee on the basis of the results of such a predictive code~~ provides reasonable assurance that structural integrity will be maintained between inspections. **The program includes the evaluation of** ~~I~~**i**nspection results ~~are evaluated~~ to determine if additional inspections are needed to ensure that the extent of wall thinning is adequately determined, that intended function will not be lost, and that corrective actions are adequately identified. Previous wear rate predictions due to FAC may change after a power uprate is implemented. **The program includes updating** ~~W~~**w**ear rates ~~are updated~~ in CHECWORKS according to power uprate conditions. Subsequent field measurements are used to calibrate or benchmark the predicted wear rates.

   For erosion mechanisms, the program includes trending of wall thickness measurements at susceptible locations to adjust the monitoring frequency and to predict the remaining service life of the component for scheduling repairs or replacements. Inspection results are evaluated to determine if assumptions in the extent-of-condition review remain valid. If degradation is associated with infrequent

operational alignments, such as surveillances or pump starts/stops, then trending activities may need to consider the number or duration of these occurrences. Periodic wall thickness measurements of replacement components may be required and should continue until the effectiveness of corrective actions have been confirmed.

6. ***Acceptance Criteria:*** Inspection results are input for a predictive computer code, such as CHECWORKS **or for use in component-specific analyses**, to calculate the number of refueling or operating cycles remaining before the component reaches the minimum allowable wall thickness. If calculations indicate that an area will reach the minimum allowed wall thickness before the next scheduled outage, **the program should include** corrective action ~~should be considered~~.

7. ***Corrective Actions:*** **The program includes reevaluation, repair or replacement of** ~~Prior to service,~~ components for which the acceptance criteria are not satisfied, **prior to their return to service** ~~are reevaluated, repaired, or replaced~~. Long-term corrective actions could include adjusting operating parameters or selecting materials resistant to FAC. When susceptible components are replaced with FAC-resistant materials, such as high **chromium** ~~Cr~~ material, the downstream components should be monitored ~~closely~~ to ~~mitigate~~ **identify** any increased wear. **For erosion mechanisms, the effectiveness of corrective actions intended to eliminate the cause of the wall thinning should be verified, or corrective actions which initiate ongoing monitoring activities should be evaluated as part of an AMP. The selection of replacement material requires consideration of a number of factors, because a material that is completely erosion resistant is not available.** As discussed in the Appendix for **the** GALL **Report**, the staff finds the requirements of 10 CFR Part 50, Appendix B, acceptable to address the corrective actions.

8. ***Confirmation Process:*** Site quality assurance (QA) procedures, review and approval processes, and administrative controls are implemented in accordance with the requirements of 10 CFR Part 50, Appendix B. As discussed in the Appendix for **the** GALL **Report**, the staff finds the requirements of 10 CFR Part 50, Appendix B, acceptable to address the confirmation process.

9. ***Administrative Controls:*** Site QA procedures, review and approval processes, and administrative controls are implemented in accordance with the requirements of 10 CFR Part 50, Appendix B. As discussed in the Appendix for **the** GALL **Report**, the staff finds the requirements of 10 CFR Part 50, Appendix B, acceptable to address the administrative controls.

10. ***Operating Experience:*** Wall-thinning problems in single-phase systems have occurred in feedwater and condensate systems (NRC IE Bulletin No. 87-01; NRC Information Notice [IN] ~~81-28, IN~~ 92-35, IN 95-11, IN 2006-08) and in two-phase piping in extraction steam lines (NRC IN 89-53, IN 97-84) and moisture separation reheater and feedwater heater drains (NRC IN 89-53, IN 91-18, IN 93-21, IN 97-84). Observed wall thinning may be due to mechanisms other than FAC~~, which require alternate materials to resolve the issue~~ **or due to a combination of mechanisms (NRC IN 99-19, Licensee Event Report (LER) 483/1999-003-01, LER 277/2006-003-00,** LER ~~50-~~237/2007-003-00, **LER 254/2009-004-00**). **(See References below for titles and dates.)**

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