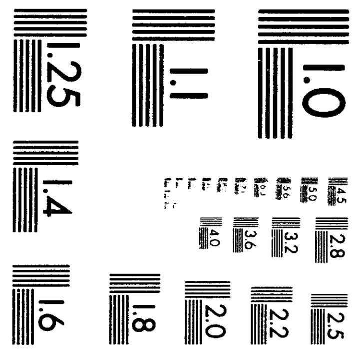
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AGING MANAGEMENT GUIDELINE FOR COMMERCIAL NUCLEAR POWER PLANTS-PUMPS

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Abstract

This Aging Management Guideline (AMG) describes recommended methods for effective detection and mitigation of age-related degradation mechanisms in BWR and PWR commercial nuclear power plant pumps important to license renewal. The intent of this AMG is to assist plant maintenance and operations personnel in maximizing the safe, useful life of these components. It also supports the documentation of effective aging management programs required under the License Renewal Rule 10 CFR Part 54. This AMG is presented in a manner that allows personnel responsible for performance analysis and maintenance to compare their plant-specific aging mechanisms (expected or already experienced) and aging management program activities to the more generic results and recommendations presented herein.

ACKNOWLEDGEMENTS

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Contents

Contents (continued)

Contents (continued)

Figures

Tables

Tables (continued)

AGING MANAGEMENT GUIDELINE FOR PUMPS

1. EXECUTIVE SUMMARY

Continued operation of nuclear power plants for periods that extend beyond their original 40-year license period is a desirable option for many U.S. utilities. U.S. Nuclear Regulatory Commission (NRC) approval of operating license renewals is necessary before such continued operation becomes a reality. Effective aging management for plant components is important to reliability and safety, regardless of current plant age or extended life expectations. However, the NRC requires that aging evaluations be performed and that the existence of appropriate aging management programs be demonstrated for components considered important to license renewal before granting approval for operation beyond 40 years. Both the NRC and the utility want assurance that high reliability for plant components which support safety functions is maintained during both the current license term and throughout the extended life operating period. This aging management guideline (AMG) was sponsored by the U.S. Department of Energy (DOE), through DOE's Light Water Reactor Technology Center at Sandia National Laboratories, as part of DOE's Plant Lifetime Improvement (PLIM) Program.

1.1 Purpose and Objectives

The purpose of this AMG is to provide guidance for effective aging management of a selected group of pumps which are important to safe and reliable nuclear power plant operation. The pump applications studied are those found in both Boiling Water Reactor (BWR) and Pressurized Water Reactor (PWR) facilities. The primary target audience for this guideline are plant engineering, operations, and maintenance personnel. It will also be of interest to those involved with nuclear plant license renewal projects. The AMG is presented in a manner which allows personnel responsible for pump performance analysis and maintenance to compare their plant-specific pump aging mechanisms (expected or already experienced) and aging management program activities to the more generic results and recommendations presented in this guideline.

The objective of this AMG is to provide an analysis of the potential degradation mechanisms for pumps and to provide acceptable guidelines for developing aging management programs for controlling significant degradation mechanisms. Use of this AMG can provide nuclear power plant operators with a basis for verifying that an effective program for managing age-related degradation of pumps is in place.

1.2 Scope

The nuclear plant pump applications included in this AMG are listed in Tables 1-1 and 1-2. These pumps are installed in either a BWR or PWR facility. All of these pumps are important to plant operability and/or safety. This listing includes all major pumps which have been identified as important to license renewal based on the NRC criteria provided in 10 CFR 54, [1.1] with the exception of BWR Reactor Recirculation System and PWR Reactor Coolant

System pumps, which have been studied extensively in previously published reports.[1.2, 1.3]

Table 1-1. BWR Plant Pump Applications

BWR Pump	Pump Fluid Type
Closed Cooling Water (Note 1)	Closed Cooling Water
Control Rod Drive Hydraulic	Treated Water
Core Spray	Treated Water
Emergency Diesel Generator Fuel Oil Transfer	Fuel Oil
Emergency Diesel Generator Jacket Cooling Water	Closed Cooling Water
High Pressure Coolant injection	Treated Water
Lubricating Oil (Note 2)	Lubricating Oil
Reactor Core Isolation Cooling	Treated Water
Reactor Water Cleanup	Primary Water
Residual Heat Removal	Treated Water
Service Water (Note 3)	Raw Water
Spent Fuel Pool Cooling	Treated Water
Standby Liquid Control	Borated Water

Notes:

1. Includes various system names, such as component cooling water, containment chilled water, emergency equipment cooling water, essential equipment cooling water, reactor building closed cooling water, and auxiliary building closed cooling water.
2. Includes lubricating oil pumps associated with the pumps listed in this table and the emergency diesel generators.
3. Includes various system names such as residual heat removal service water, auxiliary service water, emergency service water, essential service water, and nuclear service water.

Table 1-2. PWR Plant Pump Applications

PWR Pump	Pump Fluid Type
Auxiliary Feedwater	Treated Water
Boric Acid Transfer	Borated Water
Charging	Primary Water
Closed Cooling Water (Note 1)	Closed Cooling Water
Containment Recirculation	Treated Borated Water
Containment Spray	Treated Borated Water
Emergency Diesel Generator Fuel Oil Transfer	Fuel Oil
Emergency Diesel Generator Jacket Cooling Water	Closed Cooling Water
Lubricating Oil (Note 2)	Lubricating Oil
Primary Water Make-Up	Treated Borated Water
Residual Heat Removal	Treated Borated Water
Safety Injection	Treated Water
Service Water (Note 3)	Raw Water
Spent Fuel Pool Cooling	Treated Water

Notes:

1. Includes various system names, such as component cooling water, containment chilled water, emergency equipment cooling water, essential equipment cooling water, reactor building closed cooling water, and auxiliary building closed cooling water.

2. Includes lubricating oil pumps associated with the pumps listed in this table and the emergency diesel generators.

3. Includes various system names such as residual heat removal service water, auxiliary service water, emergency service water, essential service water, and nuclear service water.

Tables 1-3 and 1-4 list the pump manufacturers for PWR and BWR plants, respectively. This information was obtained from the Nuclear Plant Reliability Data System (NPRDS) database and questionnaire responses from several utilities. The aging evaluation (Section 4) and effective program evaluation (Section 5) encompass all of these pump manufacturers. Utility personnel should verify that their pump type and corresponding manufacturer are within the scope of this AMG.

Table 1-3. Pump Manufacturers - PWR Plants

Auxiliary Feedwater	Boric Acid Transfer	Charging	Closed Cooling Water	Containment Recirculation & Spray	Emergency Diesel Generator Fuel Oil	Emergency Diesel Generator Jacket Water	Lubricating Oil	Primary Water Makeup	Residual Heat Removal	Safety Injection	Service Water	Spent Fuel Pool Cooling
Ingersoll-Rand	Crane Deming	Pacific	Pacific	Byron-Jackson	Roper	Decatur	Electro-Motive	Ingersoll-Rand	Ingersoll-Rand	Pacific	Byron-Jackson	Ingersoll-Rand
Sulzer Bingham	Goulds	Byron-Jackson	Ingersoll-Rand	Ingersoll-Rand	Goulds	Colt Ind.	Viking	Bingham Williamette	Babcock & Wilcox	Byron-Jackson	Johnston	Goulds
Byron-Jackson	Ingersoll-Rand	Goulds	Goulds	Pacific	Worthington	Goulds	Roper	Goulds	Pacific	Ingersoll-Rand	Colt Ind.	Worthington
Worthington Pacific	Westinghouse	Gaulin/Manton	Worthington	Crane Deming	Worcester Controls	Crane Deming	Worcester Controls		Goulds	Bran & Lubbe	Fairbanks Morse	Bingham Williamette
Babcock & Wilcox		Crane Deming	Babcock & Wilcox	Union	Byron-Jackson	Burks	Fairbanks Morse		Worthington	Worthington	Sulzer Bingham	
		ARMCO	Sulzer Bingham	Goulds	Viking		Worthington		Byron-Jackson	Goulds	Layne & Bowler	
		Union	Ward	Worthington	Colt Industries		Blackmer		Bingham	Sulzer Bingham	Aurora	
		Crane Deming	Byron-Jackson	Babcock & Wilcox	Crane Deming		DeLaval				Worthington	
		Ajax Iron	DeLawal	Sulzer Bingham	Johnston						Ingersoll-Rand	
			Crane Deming								Peerless	
			Allis Chalmers								Babcock & Wilcox	
											Hayward-Tyler	
											Goulds	
											Bingham Williamette	

Table 1-4. Pump Manufacturers - BWR Plants

Closed Cooling Water	Control Rod Drive Hydraulic	Core Spray	Emergency Diesel Generator Fuel Oil	Emergency Diesel Generator Jacket Cooling	High Pressure Coolant Injection	Lubrication Oil	Reactor Core Isolation Cooling	Reactor Water Cleanup	Residual Heat Removal	Service Water	Spent Fuel Pool Cooling	Standby Liquid Control
Ingersoll-Rand	Worthington	Ingersoll-Rand	DeLaval	Peerless	Byron-Jackson	Viking	Crane Deming	Ingersoll-Rand	Byron-Jackson	Goulds	Goulds	Union
Milton Roy	Union	Crane Deming	Electro-Motive	Crane Deming	Tuthill	Sier-Bath Gear	Bingham Williamette	Union	Sulzer Bingham	Ingersoll-Rand	Peerless	Sulzer Bingham
Byron-Jackson		Worthington	Viking	Ingersoll-Rand		Ingersoll-Rand			Goulds	Johnston	Union	
Worthington		Goulds	Roper	Decatur		Tuthill			Pacific	Worthington		
Goulds		Byron-Jackson		Allis Chalmers		Electro-Motive			Ingersoll-Rand	Crane Deming		
Fairbanks Morse		Sulzer Bingham		Colt Ind.		Colt Ind.			Bingham Williamette	Byron-Jackson		
Peerless		Bingham				IMO				Layne & Bowler		
										Sulzer Bingham		
										Aurora		
										Hayward Tyler		
										Allis Chalmers		
										DeLaval		
										Bingham Williamette		

The scope of evaluation includes the pump pressure boundary, internal moving and stationary components, shaft/crankshaft/driveshaft/impeller, mechanical subsystems (seals, bearings, couplings), and pump support skid. The pump driver (motor, turbine, engine) and speed changer, if used, are not included in the scope of this AMG.

The strategy for preparing this AMG includes 1) identifying pump types, major pump subcomponents, and typical operating conditions, and 2) collecting and evaluating pump operating/maintenance history information, identifying the stressors acting on these pumps, and determining the significance of pump aging mechanisms. After completing these tasks and reviewing currently utilized aging management practices, guidelines are presented for effective aging management of these pumps.

The input for development of this AMG includes design data, operating/maintenance history (including degradation findings and failure incidents), and current inspection, testing and maintenance program activities. The information is obtained from a variety of sources including NRC publications, computerized industry databases, pump manufacturer literature, individual nuclear plant records, and aging management reports and papers prepared by EPRI, DOE, and engineering consultants.

1.3 Conclusions

This guideline evaluates all known aging mechanisms for the pump applications listed in Tables 1-1 and 1-2. Section 4 examines these aging mechanisms to determine which are non-significant, and which are significant. Section 5 examines aging management programs/ techniques to determine which are effective for detecting and/or mitigating significant aging mechanisms. The pump applications shown in Tables 1-1 and 1-2 involve several different fluid types, pump types, and operating modes. Unique differences exist between plants with respect to pump type, materials, and operating parameters for the same kind of service application. Therefore, in order to contend with this diversity, some consolidation and simplification is necessary in this AMG.

Common characteristics of pump designs and service applications are examined to establish groupings for aging mechanism and aging management program/technique evaluations.

The primary characteristic for grouping pumps is the pumped fluid. The pumped fluid categories are listed with the pump applications in Tables 1-1 and 1-2. Pump operating mode (standby versus continuous operation) is used as the second method for grouping pumps. In addition, all pumps were divided into logical subassembly groupings (rotating assemblies, pressure boundary parts, etc.). These subassembly groupings are maintained throughout the AMG.

It is not possible for this guideline to cover all plant-unique situations. Therefore, it is necessary to identify a generic standard representative of a majority of the existing plant applications with regard to pump design, materials, operating parameters, and safety function classification. The determination of 1) significance/non-significance for specific aging mechanisms, 2) aging mechanism/subcomponent combinations, and 3) applicability of aging management programs/techniques is, therefore, qualified against this approach. These qualifications or conditions are presented in an "if/then" format (for example; if stainless steel materials are used, then general corrosion is non-significant). With these qualifications, plant personnel can uniquely determine if the AMG results are directly applicable to their specific application.

1.3.1 Aging Mechanism Conclusions

The pump aging mechanisms evaluated in this report are listed in Table 2-2. Table 1-5 summarizes the significance of the aging mechanisms with respect to the pump components. The table identifies the aging mechanisms which are effectively managed by current plant programs. The program enhancements to effectively manage the aging mechanisms are also identified.

The mechanisms determined to be non-significant for all pump applications are listed below.

- Thermal Embrittlement (Section 4.3.1.1)
- Stress Relaxation (Section 4.3.1.1)
- Creep (Section 4.3.1.1)
- Thermal Fatigue (Section 4.3.1.3)
- Irradiation Assisted Stress Corrosion Cracking (Section 4.3.1.2)
- Neutron Embrittlement (Section 4.3.1.2)

Since these pump applications involve relatively low temperature pumped fluids and low radiation level environments, very few conditions or qualifications were necessary to establish these aging mechanisms as not significant. One exception, however, is that some BWR plants locate the Reactor Water Cleanup (RWCU) pumps upstream from the regenerative and non-regenerative heat exchangers. Therefore, the RWCU pumps are exposed to reactor coolant temperature, and thermal fatigue then becomes a significant aging mechanism. This situation is not examined in the guideline.

Mechanical fatigue, erosion and erosion/corrosion, wear, and fouling are examined generically in Sections 4.3.1.4, 4.3.1.7, 4.3.1.8, and 4.3.1.9 respectively, and are examined in Section 4.3.2 for each of the five subcomponent groupings listed below.

- Rotating or Reciprocating Internals (Section 4.3.2.1)
- Fixed Internals (Section 4.3.2.2)
- Pressure Boundary (Section 4.3.2.3)
- Mechanical Subsystems - Seals, Bearings, Couplings (Section 4.3.2.4)
- Support Components (Section 4.3.2.5)

On a generic basis, wear for pressure boundary subassemblies and fouling for mechanical subsystems components is determined to be non-significant. All of these aging mechanisms are determined to be non-significant for support components with the exception of mechanical fatigue.

Table 1-5. Pump Components and Aging Mechanism Significance Summary

Pump Subcomponents	Fatigue		Corrosion			Stress Corrosion Cracking			Erosion	Embrittlement		Wear	Stress Relaxation	Creep	Fouling
	Thermal	Mechanical	Gen.	Galv.	MIC	IGSCC*	IASCC**	TGSCC***		Thermal	Neutron				
Rotating/Reciprocating															
Shaft	—	X	X	X	—	X	—	—	—	—	—	X	—	—	—
Impeller	—	X	X	X	—	X	—	—	X	—	—	X	—	—	X
Piston/Plunger	—	—	—	—	—	NEM	—	—	—	—	—	X	—	—	—
Internal Rotor	—	X	X	—	—	—	—	—	—	—	—	X	—	—	—
Internal Valve	—	X	—	—	—	NEM	—	—	X	—	—	X	—	—	X
Driveshaft/Crankshaft	—	X	—	—	—	—	—	—	—	—	—	X	—	—	—
Fixed Internals															
Wearing Components	—	—	NEM	NEM	—	NEM	—	NEM	X	—	—	X	—	—	—
Flow Guides	—	—	NEM	NEM	X	NEM	—	X	X	—	—	—	—	—	X
Suction Strainers	—	—	NEM	NEM	X	—	—	—	X	—	—	—	—	—	X
Misc. Struct. Compts.	—	—	NEM	NEM	X	NEM	—	NEM	—	—	—	—	—	—	X
Pressure Boundary															
Casing	—	X	X	X	X	X	—	—	X	—	—	—	—	—	X
Suct./Disch. Nozzle	—	X	X	X	X	X	—	—	X	—	—	—	—	—	X
Disch. Head/Column	—	X	X	X	—	—	—	—	X	—	—	—	—	—	X
Cylinder/Plunger	—	X	—	—	X	—	—	—	X	—	—	—	—	—	—
Flange/Cover	—	X	X	X	X	—	—	—	—	—	—	—	—	—	X
Fasteners	—	X	X	—	—	—	—	—	—	—	—	—	—	—	—
Mechanical Subsystems															
Coupling	—	X	X	—	—	—	—	—	—	—	—	X	—	—	—
Radial Bearing	—	—	—	—	—	—	—	—	—	—	—	X	—	—	—
Thrust Bearing	—	X	—	—	—	—	—	—	—	—	—	X	—	—	—
Internal Rad. Bearing	—	—	X	X	—	X	—	—	X	—	—	X	—	—	—
Seals	—	—	X	X	—	X	—	—	—	—	—	X	—	—	—
Supports															
Support Feet/Skirt	—	X	X	—	—	—	—	—	—	—	—	—	—	—	—
Base Frame/Skid	—	—	X	—	—	—	—	—	—	—	—	—	—	—	—
Fasteners	—	—	X	—	—	—	—	—	—	—	—	—	—	—	—

* IGSCC Intergranular stress corrosion cracking
** IASCC Irradiation assisted stress corrosion cracking
*** TGSCC Transgranular stress corrosion cracking
— Aging mechanism is not significant for all pumped fluid applications.
X Aging mechanism is significant for some of the pumped fluid applications (see Section 4 and Tables 4-4 through 4-10) and current plant programs effectively manage pump component aging (see Section 5 and Tables 5-4 through 5-10).
NEM Aging mechanism is significant for some of the pumped fluid applications (see Section 4 and Tables 4-4 through 4-10), current plant programs do not effectively manage pump component aging (see Section 5), and enhanced aging management methods are required (see Section 6).

The evaluations in Section 4.3.2 determined that several combinations of these aging mechanisms and pump subassembly components are significant and, therefore, require effective aging management programs/techniques. The evaluation conclusions for these aging mechanisms are summarized in Tables 4-4 through 4-10. If/then criteria located in the text and table notes provide the conditions and qualifications for significance determinations.

Corrosion and stress corrosion cracking aging mechanisms are evaluated generically in Sections 4.3.1.5 and 4.3.1.6 respectively, and evaluated in Section 4.3.3 for each of the six pumped fluids.

- Primary Water (Section 4.3.3.1)
- Borated Water/Boric Acid Solution (Section 4.3.3.2)
- Treated Water (Section 4.3.3.3)
- Closed Cooling Water (Section 4.3.3.4)
- Lubricating/Fuel Oil (Section 4.3.3.5)
- Raw Water (Section 4.3.3.6)

On a generic basis, corrosion and stress corrosion cracking in primary water service and stress corrosion cracking in lubricating/fuel oil service were determined to be non-significant aging mechanisms.

The generic evaluations in Section 4.3.1 determined that selected combinations of wetted pump component materials and pumped fluids were susceptible to corrosion (general, galvanic, or microbiologically influenced) and/or stress corrosion cracking.

The specific pumped fluid service examinations in Section 4.3.3 were able to establish non-significance for various types of corrosion and stress corrosion cracking for specific wetted pump parts based on metallurgy and pump design characteristics. Examples include corrosion allowances for pressure boundary components, relatively large surface areas for the more anodic wetted parts, and the washing away of microbial growth with high fluid velocities. The evaluation conclusions for these aging mechanisms are summarized in Tables 4-4 through 4-10. If/then criteria located in the text and table notes provide the conditions and qualifications for significance determinations.

Aging management programs/techniques that effectively manage the significant aging mechanism/pump subassembly component combinations for each pump service application are discussed in Section 5.

1.3.2 Aging Management Program Guidelines

The aging management programs/techniques presented in this AMG are listed in Table 1-6. The conventional programs/techniques are currently implemented at nuclear facilities. The nonconventional programs/techniques are implemented at most nuclear plants, but in some cases may not be formalized with written procedures. The requirements for effective aging management programs are listed below.

a. Program is documented and administered in a formal manner. Written procedures describe activities, include acceptance criteria, and ensure that corrective action is specified in a timely manner.

b. The components' required functions are properly addressed.

c. The components' age-related degradation effects are properly addressed.

Aging management programs/techniques, including inspection intervals, are described generically in Section 5.2 (Conventional Programs) and Section 5.3 (Nonconventional Programs). The relationship between these aging management programs/techniques and the significant aging mechanisms determined in Section 4 is examined for pump components in each pumped fluid category. The results of this examination are shown in Tables 5-4 through 5-10. These tables relate the aging management programs/techniques to the significant aging mechanism for the individual pump components. Tables 5-4 through 5-10 can be used to compare plant-specific program coverage against programs/techniques determined to be effective at detecting and mitigating the significant aging mechanisms.

Table 1-6. Pump Aging Management Programs/Techniques

Conventional Programs
ASME Section XI Inservice Inspection and Testing
ASME Section XI Wall Thinning Program
Technical Specification Surveillance Program
Preventive Maintenance — Periodic Maintenance — Predictive Maintenance — Planned Maintenance
Pump Erosion Control
Microbiologically Influenced Corrosion Control
Nonconventional Programs
Pump Lay-Up Program
Thermography
Operator Activities
Coating Survey
Operating/Industry Experience Review
Spare Parts Shelf Life
Receipt Inspection

For some pump applications, programs/techniques may not include provisions for the timely detection of pump internal component corrosion and stress corrosion cracking. It is recommended in Section 6 that disassembly and inspection be performed periodically (the planned maintenance portion of the Preventive Maintenance Program) to effectively manage these aging mechanisms.

1.4 References

1.1 Title 10, U.S. Code of Federal Regulations, 10 CFR Part 54, "Requirements for Renewal of Operating Licenses for Nuclear Power Plants," December 13, 1991.

1.2 NUMARC Report 90-09, "BWR Primary Coolant Pressure Boundary License Renewal Industry Report," April 1992.

1.3 NUMARC Report 90-07, "PWR Reactor Coolant System License Renewal Industry Report," October 1990.

2. INTRODUCTION

2.1 Background

The DOE-sponsored PLIM Program, in cooperation with the Electric Power Research Institute (EPRI) Life Cycle Management (LCM) Subcommittee, is establishing and demonstrating a predictable license renewal process for existing light water reactors (LWRs) in the United States. An important element of this program was the development of Nuclear Management and Resource Council (NUMARC) License Renewal Industry Reports (IRs), which cover critical classes of equipment such as reactor pressure vessels, reactor coolant pressure boundary piping, containment structures, and cables. To support continued demonstration of PLIM and LCM concepts, there is a need for further industry development of guidelines that describe and evaluate acceptable aging management approaches for several groupings of equipment not evaluated in the IRs. This AMG evaluates pumps determined to be important to license renewal.[2.1]

Continued operation of nuclear power plants for periods that extend beyond the original 40-year license period may be desirable for many U.S. nuclear plant operators. To allow operation of the plant during a license renewal period, utilities must show that the aging of components important to license renewal has been managed such that these components will not degrade to the extent that they are incapable of supporting required functions. Therefore, to control the aging of components important to license renewal during the license renewal period, operators of nuclear power plants must identify and perform activities necessary to manage the aging of components so that proper function is assured.

For components to retain function during the license renewal period, activities such as preventive maintenance and refurbishment may be necessary during the current license period even though some of these activities may not have been necessary to guarantee function during the current license period. These activities would be necessary to assure that there is no loss of required functions, no unacceptable reduction in safety margins, and that higher rates of challenge to plant safety systems do not occur during the license renewal period.

2.2 Purpose and Objectives

The purpose of this AMG is to provide cost-effective, practical methods to plant technical staff for the effective management of aging of pumps used in commercial nuclear power plants. An effective aging management program will ensure that each pump will continue to perform its function or will not prevent performance of a required function during the license renewal term.

The objective of this AMG is to provide an analysis of the potential degradation modes for pumps and to provide acceptable guidelines for developing effective aging management programs that control significant age-related degradation mechanisms.

This AMG is intended for use by nuclear plant personnel performing pump aging evaluations and to provide additional information and guidance in the formulation of their aging management programs. This AMG also provides additional value to nuclear plant operators as follows.

1. The AMG is a well-researched technical document that can be used by maintenance and system engineering personnel for the identification, characterization, and management of age-related degradation in pumps. It can also be used as a base document for plants developing a license renewal application.

2. The results in this AMG are based on an extensive literature search. Therefore, nuclear plant personnel can use this AMG as an exhaustive reference document for relevant information about pumps. Some of the references used include:

    - EPRI Reports
    - EPRI Nuclear Maintenance Application Center (NMAC) Reports and Maintenance Guides
    - NRC Bulletins, Information Notices, Circulars, Generic Letters, and Reports
    - Code of Federal Regulations
    - Vendor Manuals
    - American Society of Mechanical Engineers (ASME) Codes and Standards
    - Miscellaneous References and Technical Papers

3. This AMG consolidates historical maintenance and industry operating information into one source. The plant maintenance/system engineer and inservice testing engineer will find this useful for both the identification of age-related degradation (including root causes) and the verification of appropriate corrective action. Issues discussed in the AMG include:

    - Equipment design differences relevant to aging considerations
    - Equipment obsolescence as it affects aging management
    - Service environments
    - Operating and maintenance history from the Institute for Nuclear Power Operations (INPO) NPRDS and NRC License Event Report (LER) databases
    - Historical overhaul data from refurbishment facilities
    - Additional operating and maintenance history from responses to plant surveys

4. Pump aging phenomena are described in detail. This will be useful for pump maintenance interval and reliability evaluations. The following topics are discussed:

    - Stressors acting on pump subcomponents

- Aging mechanism identification
- Significance of aging mechanisms using "if/then" criteria
- Age-related degradation of pump subcomponents
- Potential failure modes

5. The AMG can be an effective tool for pump aging management and personnel training. That is, it:

   - Identifies the need for aging management and compliance with Maintenance Rule requirements
   - Contains a correlation between the scope and frequency of maintenance practices and pump performance and rate of degradation
   - Presents information that can be used in the construction of meaningful life-cycle management charts and to improve the accuracy of cost/benefit determinations
   - Discusses both conventional and non-conventional maintenance techniques, and considers how these practices can be utilized to effectively manage equipment aging
   - Characterizes initiation and progression of equipment aging for use in training personnel responsible for maintenance and inspection activities
   - Identifies concepts, principles, and methods for evaluating pumps not in the scope of this guideline.

2.3 Contents of Aging Management Guideline

The nuclear plant pumps selected for evaluation in this AMG were chosen from previous BWR and PWR Lead Plant License Renewal studies, draft NUREG-1299,[2.2] and Appendix B of Draft Regulatory Guide DG-1009.[2.3] Pumps that are unique with respect to manufacturer/models (for example, fire protection pumps), or are used in only one or very few plants were not selected for evaluation in this AMG. The BWR and PWR Lead Plant License Renewal studies relied on a screening process to identify and select specific system pumps that are important to license renewal. The screening process primarily uses a systematic approach to identify pumps with important-to-safety operating functions or that contribute to initiating or challenging safety systems. Table 2-1 uniquely identifies those PWR and BWR plant pumps evaluated in this AMG.

The pumps listed in Table 2-1 are installed in either a BWR or PWR facility. All of these pumps are important to plant operability and/or safety. This listing includes all major pumps which have been identified as important to license renewal based on the NRC criteria provided in 10 CFR 54,[2.1] with the exception of BWR Reactor Recirculation System and PWR Reactor Coolant System pumps, which have been studied extensively in previously published reports.[1.1, 1.2]

Table 2-1. Pumps in Scope of AMG

Pumps Located in PWR Plants	Pumps Located in BWR Plants
Auxiliary Feedwater System Pumps	Closed Cooling Water System Pumps (Note 1)
Boric Acid Transfer System Pumps	Control Rod Drive Hydraulic System Pumps
Charging Pumps (Chemical and Volume Control System)	Core Spray System Pumps
Closed Cooling Water System Pumps (Note 1)	Emergency Diesel Generator Fuel Oil Transfer Pumps
Containment Recirculation System Pumps	Emergency Diesel Generator Jacket Water Cooling Pumps
Containment Spray System Pumps	High Pressure Coolant Injection System Pumps
Emergency Diesel Generator Fuel Oil Transfer Pumps	Miscellaneous Lubricating Oil System Pumps (Note 2)
Emergency Diesel Generator Jacket Water Cooling Pumps	Reactor Core Isolation Cooling System Pumps
Miscellaneous Lubricating Oil System Pumps (Note 2)	Reactor Water Cleanup System Pumps
Primary Water Makeup System Pumps	Residual Heat Removal System Pumps
Residual Heat Removal System Pumps	Service Water System Pumps (Note 3)
Safety Injection System Pumps	Spent Fuel Pool Cooling System Pumps
Service Water System Pumps (Note 3)	Standby Liquid Control System Pumps
Spent Fuel Pool Cooling System Pumps	

Notes:

1. Includes various system names, such as component cooling water, containment chilled water, emergency equipment cooling water, essential equipment cooling water, reactor building closed cooling water, and auxiliary building closed cooling water.

2. Includes lubricating oil pumps associated with the pumps listed in this table and the emergency diesels.

3. Includes various system names such as residual heat removal service water, auxiliary service water, emergency service water, essential service water, and nuclear service water.

Section 3 lists and describes the components evaluated, component boundaries and discusses manufacturers' design differences. It also includes a discussion of the design requirements that apply to pumps, including applicable Codes, Standards, and Regulations. Lastly, Section 3 includes a detailed study of the operating history of the components evaluated from LER data, NPRDS data, and from other sources.

Section 4 discusses stressors acting on the pump subcomponents. Stressors acting over time produce aging mechanisms that ultimately can cause component degradation. The results of aging studies are used to describe the aging mechanisms (see Table 2-2) known to cause degradation. An aging mechanism is significant when, if allowed to continue without detection or mitigation measures, it will cause the component to lose its ability to perform its required function. Aging mechanisms for the subcomponents are identified and evaluated. Operational demands, environmental conditions, failure data, and industry operations and maintenance history are considered, and the significance of the aging mechanisms determined.

Section 5 discusses effective aging management techniques for aging mechanisms determined to be significant in Section 4. Conventional maintenance, inspection, testing, and surveillance techniques or programs are described. A brief discussion of non-conventional activities and techniques is also included. The effectiveness of these techniques or programs to manage the significant aging mechanisms is studied. Variations in plant aging management programs or techniques are considered. Requirements for an effective technique or program are presented in the form of "if/then" criteria whenever possible.

Section 6 discusses management options to deal with action items identified in Section 5. Refurbishment criteria are also discussed.

2.4 Generic License Renewal Requirements

10 CFR 54.21[2.1] describes the requirements for the content of technical information in the license renewal application. Section 54.21 states that a supplement to the Final Safety Analysis Report (FSAR) must be prepared that contains an Integrated Plant Assessment (IPA) that must:

1. identify and list all systems, structures, and components (SSCs) important to license renewal.

2. identify those structures and components (SCs) that contribute to the performance of a required function or could, if they fail, prevent an SSC important to license renewal from performing its required function.

3. for the identified SCs, determine those that could have age-related degradation that is unique to license renewal.

Table 2-2. Aging Mechanisms

I. Fatigue

 A. High Cycle

 B. Low Cycle

 C. Thermal

II. Corrosion

 A. General/Uniform

 B. Localized and/or Galvanic

 C. Microbiologically Influenced Corrosion

III. Stress Corrosion Cracking

 A. Intergranular

 B. Irradiation Assisted

 C. Transgranular

IV. Erosion and Erosion/Corrosion

V. Embrittlement

 A. Thermal

 B. Neutron

VI. Wear

 A. Adhesive

 B. Abrasive

 C. Erosive

VII. Stress Relaxation

VIII. Creep

IX. Fouling

To identify the age-related degradation* that is unique to license renewal (in item (a)(3) of Section 54.21), the definition of age-related degradation unique to license renewal must be applied. Age-related degradation unique to the license renewal period is degradation:

1. that occurs during the term of the current operating license, but whose effects are different in character or magnitude after the term of the current operating license (the period of extended operation); or

2. whose effects were not explicitly identified and evaluated by the licensee for the period of extended operation and the evaluation found acceptable by the NRC; or

3. that occurs only during the period of extended operation.

The criteria for determining SSCs important to license renewal, the criteria for evaluating whether an SC is necessary for the performance of a required function, and the technical criteria used to determine whether an SC is subject to age-related degradation unique to license renewal must be defined.

For each of the SCs having age-related degradation that is unique to license renewal, the age-related degradation must be addressed by an effective program or shown not to need to be addressed by an effective program. An effective program is a documented program to manage age-related degradation unique to the license renewal period that ensures that a SSC important to license renewal will continue to perform its required function or will not prevent the performance of a required function during the period of extended operation.

The effective program must:

1. identify and mitigate age-related degradation unique to license renewal

2. contain acceptance criteria against which the need for corrective action can be evaluated and assure timely corrective action when the acceptance criteria are not met

3. be implemented by the facility operating procedures and reviewed by the onsite review committee.

10 CFR 54.21 continues with a discussion of changes to the current licensing basis and plant modifications, which are outside the scope of this report.

Additionally, this AMG supports the determination that existing aging management practices are satisfactory for fulfilling license renewal requirements and meeting review conditions stated in the draft version of NUREG-1299, "Standard Review Plan for the Review of License Renewal Applications for Nuclear Power Plants."[2.2] Components included in the classification of "important to license renewal" are identified, and stressors, aging mechanisms, and failure modes for these components are defined. Furthermore, this AMG states the type of

* See list of definitions for aging terminology used in this report.

existing practices that are acceptable for the management of aging as well as areas requiring further plant-specific evaluation. Exemptions and requests for relief (pursuant to 10 CFR 50.12 and 10 CFR 50.55a, respectively) were not considered under this AMG in that these issues are plant-specific in nature and therefore must be considered on a plant-by-plant basis.

This report will evaluate pumps with respect to the requirements of 10 CFR 54.21 and will provide a discussion of the types of pumps important to license renewal and the age-related degradation affecting components and subcomponents of pumps. The following sections detail the analysis leading to the determination of age-related degradation and the means necessary to address it.

2.5 Method Used to Define the Scope of Components Important to License Renewal

To determine the pumps covered by license renewal requirements, the definition of SSCs important to license renewal[2.1] must be evaluated. The current definition of SSCs important to license renewal includes:

1. Safety-related SSCs, which are those relied upon to remain functional during and following design basis events to ensure:

    (i) The integrity of the reactor coolant pressure boundary;

    (ii) The capability to shut down the reactor and maintain it in a safe shutdown condition; or

    (iii) The capability to prevent the consequences of accidents that could result in potential offsite exposure comparable to the 10 CFR 100 guidelines.

2. All non-safety-related SSCs whose failure could directly prevent satisfactory accomplishment of any of the required functions identified in paragraphs (1) (i), (ii), or (iii) of this definition.

3. All SSCs relied on in safety analyses or plant evaluations to demonstrate compliance with the Commission's regulations for fire protection (10 CFR 50.48), environmental qualification (10 CFR 50.49), pressurized thermal shock (10 CFR 50.61), anticipated transients without scram (10 CFR 50.62), and station blackout (10 CFR 50.63).

4. All SSCs subject to operability requirements contained in the facility's Technical Specifications' Limiting Conditions for Operation.

The evaluation of this definition with respect to pumps and the components determined to be important to license renewal is given in Section 3.1.

2.6 Method Used to Define Aging Mechanisms Assessed in This Study

To define the aging mechanisms assessed in this study, a two-part evaluation was performed. First, the effects of stressors, such as mechanical, hydraulic, chemical, electrical, environmental, and tribological, on equipment operation were determined. The aging mechanisms associated with those stressors that cause degradation were then determined. This evaluation is contained in Section 4.1.

Second, industry-wide operating experience, particularly that reported in NRC LERs, Information Notices, Bulletins, and Circulars and the NPRDS data, was examined. A review of NRC Information Notices, Bulletins, and Circulars was conducted to identify age-related failures. The aging mechanisms associated with reported age-related failures were then determined. Events described in the NPRDS data and LERs were then analyzed for age-related deterioration and failures to identify the numbers of particular types of failures. The aging mechanisms associated with these failures were then determined. This review of industry-wide operating experience is contained in Section 3.6 of this AMG.

This multi-source analysis (i.e., using data from NPRDS and NRC documentation) provides a comprehensive characterization of equipment aging by using actual plant and vendor data to substantiate and refine those aging mechanisms postulated to occur due to stressors.

After a list of all possible aging mechanisms was developed (see Table 2-2 and Section 4.2), the significance of each aging mechanism was determined. Those aging mechanisms that were confirmed by operating or overhaul experience, had a high probability of occurrence, or would result in a failure having a large impact on equipment operation were designated as significant aging mechanisms, and are discussed in Sections 4.3.1, 4.3.2, and 4.3.3. Aging mechanisms designated non-significant are discussed in Section 4.3.1.

Conventional maintenance, inspection, testing and surveillance techniques or programs determined to effectively manage aging of pumps are discussed in Section 5.2. A brief discussion of non-conventional activities and techniques is provided in Section 5.3. The aging management techniques and programs that effectively manage significant aging mechanisms are discussed in Section 5.4. Aging mechanisms that are not effectively managed by current techniques and programs are also discussed in Section 5.4. Effective management options for these aging mechanisms are identified in Sections 6.1 through 6.5.

It should be noted that aging mechanisms and their associated degradations were not categorized either as occurring in the current license period or as being unique to license renewal. Aging as a whole is covered in this document. There is no generically applicable methodology that has been agreed upon for identifying age-related degradation mechanisms that are unique to license renewal. Therefore, the approach herein identifies techniques that manage aging mechanisms to preclude adverse effects during the current and license renewal periods. Because the age-related degradation unique to license renewal screen was not used in the evaluation process, the scope of components in this AMG may be much larger than if screening criteria were used.

To provide a basis for the discussions of stressors, aging mechanisms, and failure modes, Section 3 describes pumps that are in common use in the nuclear industry. Appendix A provides definitions of aging terminology used in this report. Appendix B provides a list of acronyms.

2.7 References

2.1 Title 10, U.S. Code of Federal Regulations, 10 CFR Part 54, "Requirements for Renewal of Operating Licenses for Nuclear Power Plants," December 13, 1991.

2.2 NUREG-1299, "Standard Review Plan for the Review of License Renewal Applications for Nuclear Power Plants," Draft, November 1990.

2.3 Draft Regulatory Guide, DG-1009, "Standard Format and Content of Technical Information for Applications to Renew Nuclear Power Plant Operating Licenses," December 1990.

3. EQUIPMENT/COMPONENTS EVALUATED: SCOPE

This section identifies LWR pumps evaluated. Sections 3.1 through 3.4 describe the selection methodology, the pumps in the evaluation scope, and the groupings of pumps, components, and service applications established for evaluation. The key design codes and standards, operating history, and the associated aging implications are discussed in Sections 3.5 and 3.6, respectively.

3.1 Pump Selection Methodology

The list of pumps evaluated for life cycle management was established by reviewing industry documents, plant documents for a typical BWR and PWR, and a survey of utility engineers. The review of industry documents included the following.

1. Review of 10 CFR 54, Definitions of Systems, Structures, and Components Important to License Renewal.[3.1]

2. Review of BWR Lead Plant Project Technical Reports.

3. Review of PWR Technical Demonstration Project (EPRI) Technical Findings.

4. Review of 10 CFR 50.65 Maintenance Rule and Draft NUMARC Industry Guideline. [3.2, 3.3]

These documents provide current industry thinking with respect to selecting pumps that are important to a life cycle management program, and the aging and performance issues that need to be evaluated. The License Renewal Rule and Maintenance Rule use similar criteria for selecting systems, structures, and components that need to be addressed by the requirements of these rules. The License Renewal Rule focuses on the detection and mitigation of age-related degradation, while the Maintenance Rule focuses on maintaining performance. Pumps meeting the selection criteria of these two rules are also important to life cycle management. Many of these pumps are included in the scope of this evaluation. The methodology used to select the pumps evaluated in this AMG is provided in Section 2.5. The list of pumps selected (Table 3-1) compares favorably with the scope of pumps provided in Appendix B of the Draft Regulatory Guide for License Renewal (DG-1009) and the Standard Review Plan for License Renewal (NUREG-1299).

The review of industry documents resulted in an initial listing of pumps (Table 3-1). The safety analysis reports for several plants were consulted to verify that the listing is representative for all plants, and of the types of pumps used in the above functions. This activity determined that plants may use different pump name designations, but their configuration, functions, and aging characteristics are bounded by the Table 3-1 listing.

A survey/questionnaire was sent to every commercial nuclear power plant in the United States. Plant-specific pump data was provided by ten units and of the ten, six units also provided maintenance and operating histories. This data was used for comparison of pump selection and for comparison to industry document summaries of maintenance and operation histories. Utility data compared favorably with pump selection and historical data. No previously unknown degradation mechanism was identified.

Table 3-1. Pumps Evaluated

Pumps Located in PWR Plants	Pumps Located in BWR Plants
Auxiliary Feedwater System Pumps	Closed Cooling Water System Pumps (Note 1)
Boric Acid Transfer System Pumps	Control Rod Drive Hydraulic System Pumps
Charging Pumps (Chemical and Volume Control System)	Core Spray System Pumps
Closed Cooling Water System Pumps (Note 1)	Emergency Diesel Generator Fuel Oil Transfer Pumps
Containment Recirculation System Pumps	Emergency Diesel Generator Jacket Water Cooling Pumps
Containment Spray System Pumps	High Pressure Coolant Injection System Pumps
Emergency Diesel Generator Fuel Oil Transfer Pumps	Miscellaneous Lubricating Oil System Pumps (Note 2)
Emergency Diesel Generator Jacket Water Cooling Pumps	Reactor Core Isolation Cooling System Pumps
Miscellaneous Lubricating Oil System Pumps (Note 2)	Reactor Water Cleanup System Pumps
Primary Water Makeup System Pumps	Residual Heat Removal System Pumps
Residual Heat Removal System Pumps	Service Water System Pumps (Note 3)
Safety Injection System Pumps	Spent Fuel Pool Cooling System Pumps
Service Water System Pumps (Note 3)	Standby Liquid Control System Pumps
Spent Fuel Pool Cooling System Pumps	

Notes:

1. Includes various system names, such as component cooling water, containment chilled water, emergency equipment cooling water, essential equipment cooling water, reactor building closed cooling water, and auxiliary building closed cooling water.

2. Includes lubricating oil pumps associated with the pumps listed in this table and the emergency diesels.

3. Includes various system names such as residual heat removal service water, auxiliary service water, emergency service water, essential service water, and nuclear service water.

3.2 Evaluation Scope

The pump selection methodology described in Section 3.1 was used to establish the Table 3-1 listing of BWR and PWR pumps. These pumps are evaluated in this AMG. The reactor coolant pumps (PWR) and reactor recirculation pumps (BWR) are evaluated in References 3.4 and 3.5, respectively, and therefore are not in the scope of this AMG.

The design, construction, materials, and other characteristics/features of each type of pump are described in Section 3.4. Most of these pumps are of the dynamic centrifugal type. Some are reciprocating or displacement pumps. Both vertical and horizontal orientations, and single or multiple stage pumps are employed. Cast and forged carbon steel and stainless steel materials are generally used for pressure boundary elements. Bronze and alloy steels are used for internals. Some of the pumps operate continuously while others are periodically operated or are in standby (only operated during periodic testing or maintenance).

3.3 Component Boundaries

Pumps are mechanically coupled to a driver (i.e., steam turbine, engine or electric motor). The drivers are typically standard designs. The pump driver assembly for horizontally mounted pumps is mounted on a common fabricated steel base or skid that is stiffly connected to some structural floor section within the plant. For vertically mounted pumps, the pump is usually connected to the structure through a fabricated steel base or skid, and the motor is mechanically coupled and fastened to the top of the pump. The pumps are hydraulically and mechanically connected to a fluid flow circuit through their inlet (suction) and outlet (discharge) nozzles. The boundaries of the evaluation are defined by the suction and discharge nozzles, shaft coupling, pump casing, and mounting baseplate and fasteners. Pump drivers, speed changers, and attached auxiliary lubrication, cooling, etc. systems are outside of the component boundary. Degradation of these interfacing components is not evaluated in this AMG. Figure 3-1 illustrates the pump component boundaries.

3.4 Description of Components Evaluated

This section describes the pumps and the associated subassemblies and components evaluated in this AMG.

3.4.1 Major Pump Types

Pumps are machines which apply forces to fluids to raise the fluid energy level (static and velocity pressure) for the purpose of transporting the fluids from one location to another. The three major pump types utilized in nuclear power plants are centrifugal, reciprocating, and rotary. These types are described below.

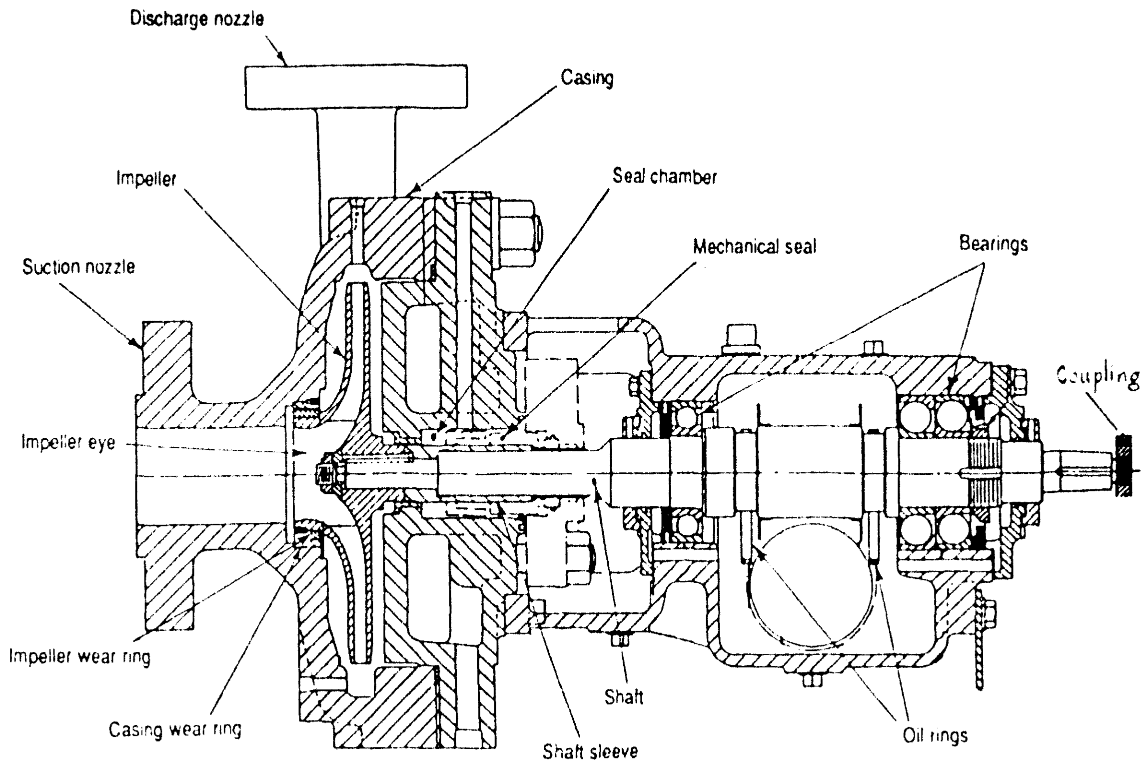


Figure 3-1. Pump Component Boundaries.[3.6]

Centrifugal Pumps

Centrifugal pumps increase the fluid energy level by spinning the fluid in a circular direction using the principle of centrifugal force. The force is transferred to the fluid by one or more paddles or vanes (typically called an impeller) which are attached to a rotating shaft. The flow rate is determined by the rotational speed of the shaft and the static and dynamic flow characteristics of the system. Fluid enters and leaves the pump in a continuous steady flow manner.

Centrifugal pumps are general service pumps that are used for liquids with relatively low viscosities. Capacities range from 3.8 to 378,500 liters per minute [1 to 100,000 gpm] and differential pressures range from 35 to 35,000 kPa [5 to 5000 psi]. The majority of the pumps in a power generation facility are centrifugal. A typical horizontally mounted multistage centrifugal pump is shown on Figure 3-2.

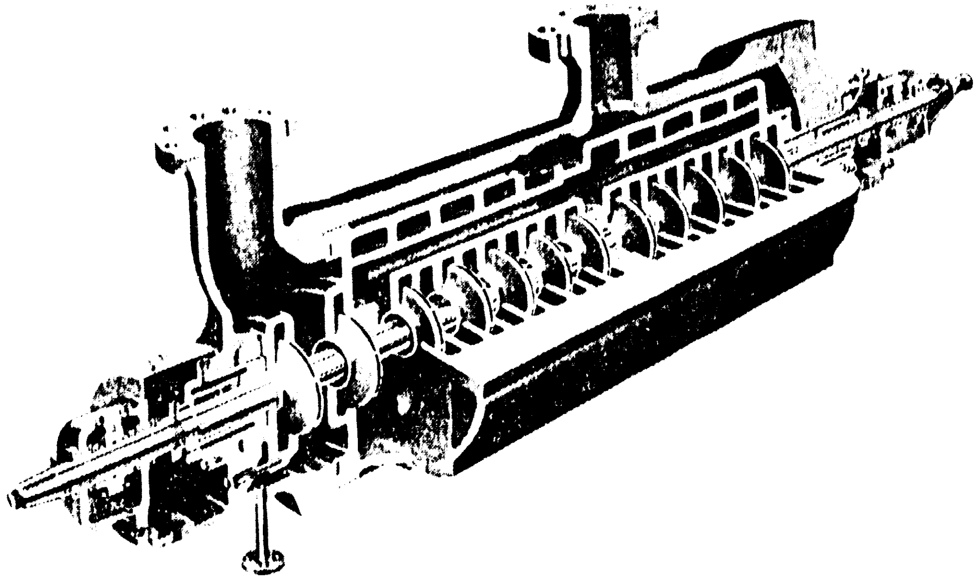


Figure 3-[illegible]. Multistage Horizontal Centrifugal Pump [illegible]

One specific category of centrifugal pumps, termed a "vertical pool" or "vertical well" pump, requires special consideration because of configuration differences and terminology. For purposes of this report, the vertical pool pump is defined as having the following characteristics:

a. Vertical orientation
b. Takes suction from a fluid pool/sump without inlet piping
c. Impeller elevation is below the normal fluid level in the pool
d. The pump discharge head and driver are usually located at the top of the pool

A typical cross section for a centrifugal vertical pool pump is shown in Figure 3-[illegible].

Reciprocating Pumps

Reciprocating pumps increase the fluid energy level by compressing the fluid in an enclosed space. The compressing force is transferred by a translating piston or plunger which continually changes direction. The enclosed space contains fluid inlet and outlet valves. The instantaneous flow rate entering and leaving the pump varies with time and is dependent on valve position and piston/plunger speed and direction. The overall flow rate is determined by the speed and displacement of the piston or plunger. Mechanically linked multiple pistons/plungers are sometimes used to smooth the flow versus time characteristic.

Reciprocating pumps are used for low capacity liquid handling and are applied in situations where flow rate control is a critical operating parameter and where high differential pressures are required at relatively low flow rates. Capacities range from 0.04 to 380 liters per minute [0.01 to 100 gpm] and differential pressures range from [illegible] to 68,950 kPa [[illegible] to 10,000 psi]. A typical reciprocating pump is shown in Figure 3-[illegible].

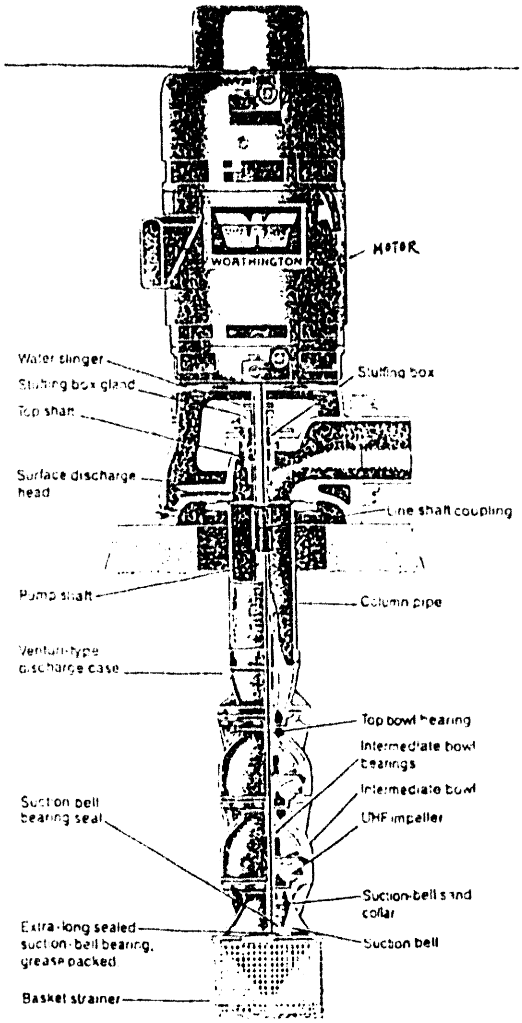


Figure 3-3. Centrifugal Vertical Pool Pump.[3.8]

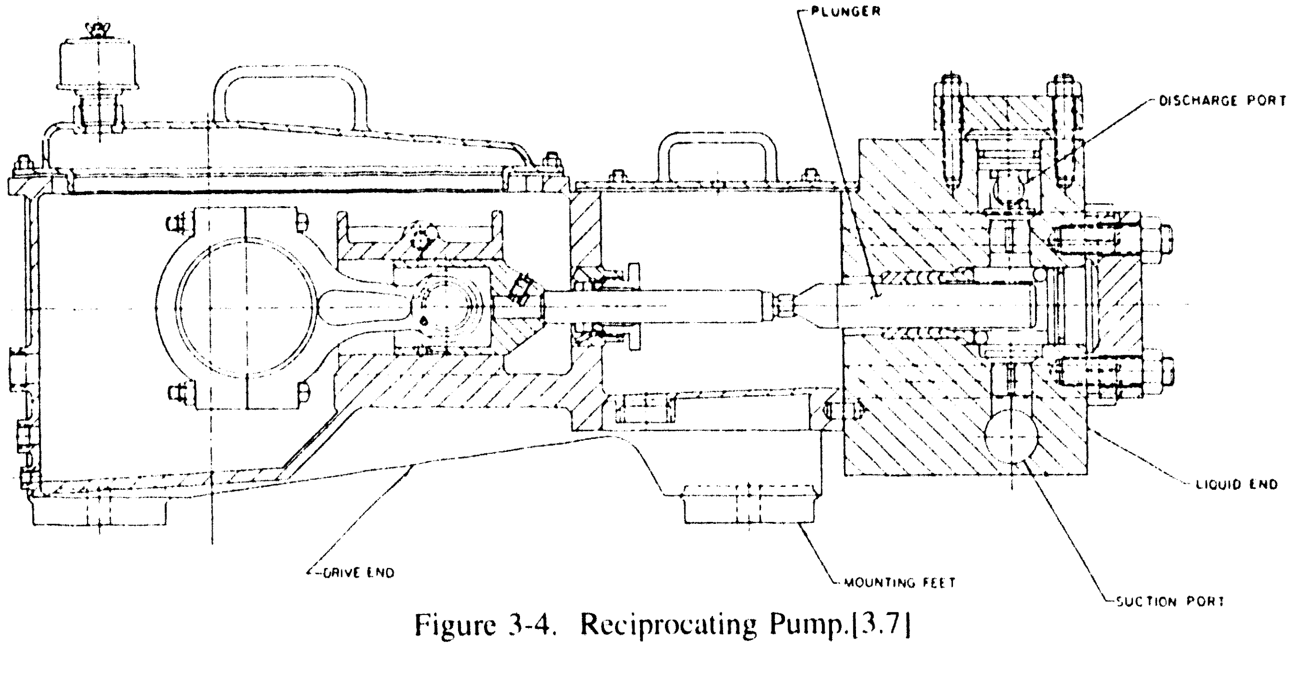


Figure 3-4. Reciprocating Pump.[3.7]

Rotary Pumps

Rotary pumps, like reciprocating pumps, increase the fluid energy level by compression. The fluid, however, travels continuously from pump inlet to outlet through contoured passages formed by moving and stationary internal pump components. Rotating elements such as gears, screws, lobes, or vanes push the fluid through the pump. Similar to centrifugal pumps, the rotating elements are attached to a constant speed drive shaft. The flow rate is determined by the rotating element displacement during one revolution and the rotative speed. Fluid enters and leaves the pump in a continuous steady flow.

Rotary pumps are used for all types of liquids but are particularly applicable for moderate to high viscosity (i.e., greater than 1.1×10^{-4} m^2/sec [10.2 ft^2/sec] or 500 SSU) liquids such as lubricating oils. Capacities range from 0.4 to 3785 liters per minute [0.1 to 1000 gpm] and differential pressures range from 6.9 to 6895 kPa [1 to 1000 psi]. A typical gear pump is shown on Figure 3-5.

Screw pumps are a special type of rotary positive displacement pump in which the flow through the pumping elements is truly axial. The liquid is carried between screw-threads on one or more rotors and is displaced axially as the screws rotate and mesh. (See Figure 3-6.) In all other rotary pumps, the liquid is forced to travel circumferentially, thus making the screw pump more applicable where liquid agitation or churning is not desired. These pumps are usually used in fuel oil and lubricating oil systems.

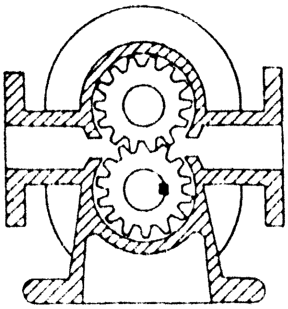
3.4.2 Common Components

Each pump can be broken down into commonly known subassemblies and components. Table 3-2 lists the primary subassemblies and component groups. The subassembly names corresponds with their general function. Commonly used materials of construction for each component are listed in Table 3-3. Manufacturer design differences are identified and discussed in Section 3.4.4.

It is regarded as standard maintenance practice to replace or refurbish various components or component parts during normal maintenance activities. These components and parts are designated as "renewable" for the purpose of the evaluation. Plant programs are stipulated to be inherently effective to manage "renewables." Table 3-4 is a listing of renewal components for pumps. Evaluations and additional actions to detect and mitigate age-related degradation of these components are not required.

3.4.3 Service Applications and Environments

Aging mechanism evaluations require a clear understanding of environments to which pump subcomponents are exposed. The four potential pump component environments are the pumped fluid, cooling water, lube oil or grease for the bearings, and the external environment. The pump subcomponent environments are summarized in Table 3-5.



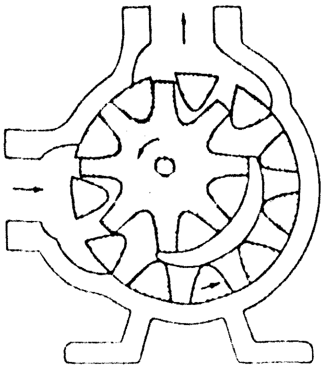


Figure 3-5. Rotary Gear Pump.[3.7]

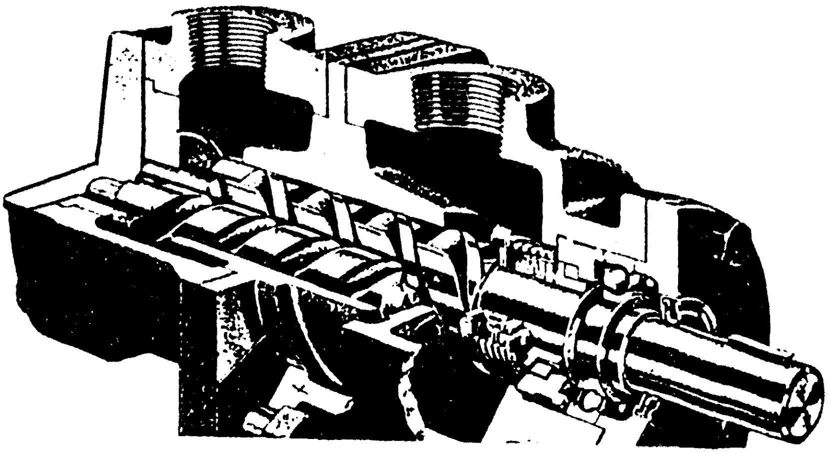


Figure 3-6. Rotary Screw Pump.[3.9]

Table 3-2. Pump Component Groups and Subcomponents

Pump Types:

C — Centrifugal (Except Vertical Pool) (Note 1)
V — Vertical Pool Centrifugal (Note 1)
R — Rotary
P — Reciprocating

I. Rotating/Reciprocating (Note 2)

Shaft (C, V, R)
Driveshaft/Crankshaft (P)
Impeller (C, V)
Internal Rotor (R) (Note 3)
Piston/Plunger (P)
Internal Valve (P)

II. Fixed Internals (Note 1)

Miscellaneous Structural Components (C, V, R, P) (Note 4)
Wearing Components (C, V, R, P) (Note 5)
Flow Guides (C, V, R, P) (Note 6)
Suction Strainer (V)

III. Pressure Boundary

Casing (C, R) (Note 7)
Discharge Head/Column/Bowl/Discharge Nozzle (V)
Cylinder/Plunger Block (P)
Suction/Discharge Nozzle (C, R, P)
Flange/Cover (C, R, P) (Note 8)
Gaskets (C, V, R, P)
Fasteners (C, V, R, P)

IV. Mechanical Subsystems (Note 1)

Coupling (C, V, R, P)
Seals (C, V, R, P) (Note 9)
Radial Bearing (C, V, R, P)
Internal Radial Bearing (V)
Thrust Bearing (C, V, R, P)

V Supports

Support Feet/Skirt (C, V, R, P)
Base Frame/Skid (C, V, R, P)
Fasteners (C, V, R, P)

Table 3-2. Pump Component Groups and Subcomponents (continued)

Notes:

1. Centrifugal shafts may be oriented horizontally or vertically. Pumps may be single or multistage and may be designed for radial, axial, or mixed flow. Casings contain inlet and discharge nozzles and one or two shaft seals. All bearings are external to the pump casing. Pumps with bearings only at one end of the casing (cantilevered shaft/impeller) may include internal guides to limit radial movement of the shaft/impeller. Pump casings may be totally submerged in an open pool of the pumped fluid with a suction strainer attached to the inlet nozzle and piping attached to the outlet nozzle. (Also applicable to vertical pool pumps.)

   Vertical pool centrifugal pump shafts are oriented vertically. Pumps may be single or multistage and may be designed for radial, axial, or mixed flow. The pressure boundary includes a bowl that contains the impellers, a column directly above the bowl that guides upward flow of the pumped fluid and that contains the shaft and usually internal radial bearings, and a discharge head directly above the column which includes a horizontally oriented discharge nozzle and a shaft seal at the top. The lower end of the pump (bowl and a portion of the column) are submerged below the open pool liquid level and a suction strainer is attached to the lower end of the bowl. The discharge head is located at the top of the open pool and has the pump support plate attached to it.

2. Rotating/reciprocating elements include small individual parts generically called "spacers" which are attached to major subcomponents with fasteners, tight fits, or shrink fits. Includes fasteners used for the assembly of major subcomponents and attachment of spacers.

3. For specific types of rotary pumps, these may be called screws, gears, lobes, etc.

4. Miscellaneous structural components include stationary internal supports, stiffeners, thermal barriers, radial shaft guides, etc.

5. Wearing components are primarily associated with centrifugal (C or V) pumps and generally called wear rings or stage rings but are occasionally used in rotary or reciprocating pumps. Functionally, it is any non-moving internal part that has a close tolerance fit with a moving part which minimizes fluid flow between internal portions of the pump that operate at different pressures.

6. Flow guides are primarily associated with centrifugal (C or V) pumps but are occasionally used in rotary or reciprocating pumps. Functionally, it is any non-moving internal part which guides, directs, or smoothes fluid flow within the pump. For centrifugal (C or V) pumps, these may be called diffusers, return channels, balance disks/heads, stage pieces, etc.

7. The casing includes volutes on large centrifugal (C) pumps which serve as both flow guides and pressure retaining boundaries.

8. Flanges are part of the connection design where the pump pressure boundary is made from two or more pieces which are not joined by welding. Covers are pump pressure boundary parts which allow the removal or inspection of pump internal components and/or are used to simplify manufacturing of the pump pressure boundary.

9. Seals are two-part subcomponents with one part attached to the rotating/reciprocating subcomponents and are partially attached to the stationary subcomponent. Functionally, the seals restrict fluid flow between internal portions of the pump that operate at different pressure (internal seals) or between the pump and the external environment (shaft seals or piston/plunger seals). In general, seals are designed for zero leakage between moving and stationary components. Controlled leakage seals such as labyrinths may be used for shaft seals and balanced disk seals on high pressure or centrifugal (C) pumps.

Table 3-3. Typical Pump Materials

Shaft	Forged Stainless Steel and Forged Carbon Steel
Impeller	Cast Low (5% Cr) Alloy Steel, Cast Iron, Bronze, Stainless Steel
Piston/Plunger	300 and 400 Series Forged Stainless Steel
Screw/Gear/Vane/Lobe	300 Series Forged Stainless Steel
Wear Ring	Cast or Forged Low Alloy Steel, Bronze
Flow Guide/Diffuser/Return Channel	Cast or Forged High Alloy (12% Cr) Steel, Low Alloy Steel
Pressure Boundary Components	Cast Low Alloy Steel, Carbon Steel, Cast Iron, Stainless Steel

Typical Materials for ASME Class 1, 2, and 3 Pressure-Retaining Boundary Parts*

Carbon steel	
Castings	SA-261, Gr WCA, WCB, WCC
Forgings	SA-105, Gr I, II
Plate	SA-515, Gr 55, 60, 65, 70
Bolting	SA-193, Gr B6, B7, B8, B16
Stainless steel	
Castings	SA-351, Gr CF8 (304), CF8M (316)
Forgings	SA-182, Gr 304, 316, 321, 347
Plate	SA-240, Gr 304, 316, 321, 347
Nonferrous	A limited number of nonferrous materials are permitted.

Base Frame/Skid	Carbon Steel Plate
Fasteners	
(Internal)	Forged Stainless Steel
(External)	Forged Carbon Steel
Non-Metallics	
(Internal)	Viton, Nylon, Teflon
(External)	PVC, Asbestos, Rubber

* Reference 3.7

Table 3-4. Renewable Components

Alarms	Gaskets	Lubricants	Retaining Rings
Bolts*	Grease	Meters	Screws
Coatings	Hoses and Clamps	Nuts	Seals
Coolant	Indicators	O-Rings	Studs*
Couplings	Keys and Pins	Oil	Thermal Insulation
Diaphragms	Lagging	Packing	Washers

* Except pressure retaining fasteners for components in the ASME Section XI Inservice Inspection Program.

Table 3-5. Pump Subcomponent Environments

Subcomponent	Pumped Fluid (Note 1)	Cooling Water	External Ambient
Rotating/Reciprocating			
• Shaft	X	X	X
• Driveshaft/Crankshaft	—	—	X
• Impeller	X	—	—
• Internal Rotor	X	—	—
• Piston/Plunger	X	X	X
• Internal Valve	X	—	—
Fixed Internals			
• Miscellaneous Structural Components	X	—	—
• Wearing Components	X	—	—
• Flow Guides	X	—	—
• Suction Strainer	X	—	—
Pressure Boundary			
• Casing	X	X	X
• Discharge Head, Column/Bowl/Discharge Nozzle	X	—	X
• Cylinder/Plunger Block	X	X	X
• Suction/Discharge Nozzle	X	—	X
• Flange/Cover	X	X	X
• Fasteners	—	—	X
• Gasket	X	—	X
Mechanical Subsystems			
• Coupling	—	X	X
• Seals	X	X	X
• Radial Bearing (Note 2)	—	X	X
• Internal Radial Bearing (Note 2)	X	—	—
• Thrust Bearing (Note 2)	—	X	X
Supports			
• Support Feet/Skirt	—		X
• Base Frame/Skid	—		X
• Fasteners	—		X

Notes:
1. These components are termed wetted pump components.
2. May also be in contact with circulating lube oil, stationary lube oil, or grease.

3.4.3.1 Service Applications (Pumped Fluid)

The characteristics and/or properties of the pumped fluid defines the service application. The pumps included in the scope of this AMG are grouped into seven service application categories, as follows.

(1) Raw Water

Fresh Water — Fresh Water entering the plant from a river, lake, pond, or bay which has not been demineralized. In general, the water has been rough-filtered to remove large particles and contains biocidal additives for control of microorganisms, zebra mussels, asiatic clams, etc. The sodium chloride content is typically below 1000 mg/l [0.062 lbm/ft^3].

Salt (Brackish) Water — Water entering the plant from a river or ocean with a sodium chloride content greater than 1000 mg/l [0.062 lbm/ft^3]. This water, like fresh water, has been rough-filtered and contains biocidal additives.

(2) Treated Water

Water which has been filtered and demineralized but generally not deaerated. The water may contain up to 5 ppm dissolved oxygen and small amounts of chemicals (i.e., potassium chromate, sodium nitrite, etc.) for process use. The spent fuel pool water in PWR plants contains 2000 to 2500 ppm boron. Also the containment spray and recirculation, safety injection, and primary water makeup pumps in PWR plants are exposed to borated treated water.

(3) Primary Water

Treated water which has been deaerated/deoxygenated. This water may contain up to 200 ppb dissolved oxygen. Primary water in PWR plants also contains a borated solution.

(4) Closed Cooling Water

Treated water containing corrosion inhibitors and biocides.

(5) Borated Water

Treated water containing at least 10 weight percent of sodium pentaborate or boric acid.

(6) Lubricating Oil

Low to medium viscosity hydrocarbons used for bearing gear and engine lubricating.

(7) Fuel Oil

Diesel oil, No.2 oil or other liquid hydrocarbons used to fuel diesels.

The pumped fluid is in contact with the group of pump components termed the "wetted parts." Referring to Table 3-2, these include all subcomponents in the rotating/reciprocating, fixed internals, and pressure boundary (except fasteners) pump component groups, and the seals and internal radial bearings.

The pumped fluid properties described here generally apply to periods when the plant is operating and producing electric power. The internal environmental conditions for pumps when the plant is not in the operating condition, 15% to 30% of the calendar time, is a function of the plant lay-up program. The environment may be the pumped fluid with changed properties/ contaminants, a different fluid, or drained and filled with air. This plant outage environment may affect the degradation rate for aging mechanisms, particularly those which are primarily related to fluid characteristics such as corrosion and stress corrosion cracking, and fouling if outage conditions increase the amount of foreign materials within the fluid system. Since plant lay-up is not within the scope of this guideline, qualification statements made for all determinations of aging mechanism significance assumes that plant outage environments will not increase the rate of degradation from these aging mechanisms during plant operating conditions. The development and implementation of a plant lay-up program which ensures that pump environments are controlled during outage periods is necessary to satisfy these qualifications (see Section 5.3).

3.4.3.2 Cooling Water

Frictional heat from pump operation is generally transferred to the pumped fluid, bearing lubrication, and the surrounding atmosphere. However, in many cases, cooling water is used for supplemental heat removal directly at the pump. Where pumped fluid temperatures are relatively low, cooling water may still be used to remove frictional heat at bearings and shaft seals thereby maintaining temperatures within specified limits. Where pumped fluid temperatures are high, cooling water may be used to remove heat from shafts, pistons/plungers, pressure boundary components, and couplings. The water used for this purpose is usually closed cooling water.

3.4.3.3 Lubrication

Lube oil or grease is used only at external pump bearings. Where pressurized or forced lubrication is required, a circulating lube oil system is utilized. Bearing lube oil has the same characteristics as previously described for lubricating oil as a pumped fluid. Lube oil or grease used in non-circulating bearing lubrication systems are medium to high viscosity hydrocarbons with appropriate lubricating characteristics. Lubricants may also be used on threaded fasteners to assist with installation/removal. The lube oils and greases used for bearings in non-circulating lubrication systems, and the lubricants used for threaded fasteners are considered to be non-aggressive fluids which will not corrode or otherwise environmentally degrade the surfaces in which they are in contact. Aging evaluations in Sections 4.3.1, 4.3.2, and 4.3.3 will not specifically consider the effects of these environments on bearings or other pump components. Tribological stressors caused by changes in lubricating properties of these materials are still, however, an aging concern.

3.4.3.4 External Environment

The external surfaces of the pressure boundary components, the mechanical subsystem and supporting base components, and portions of the rotary/reciprocating components (shaft, plunger) are in contact with the exterior ambient environment. Pumps located outdoors (generally restricted to service water pumps) are exposed to outdoor temperatures and relative humidities, weather conditions (rain, snow), and air contaminants. Plants located near oceans may be subject to a more corrosive (i.e., salt spray) environment. For pumps located within buildings (excluding primary containment), the external environment is filtered ambient building air with temperatures ranging from 4.4° to 49°C [40° to 120°F] and relative humidities up to 100 percent. Typical radiation levels in BWR safety-related pump installations are (cumulative over life of plant) 3×10^3 gray [3×10^5 rad] (normal) and 1×10^5 gray [1×10^7 rad] (accident). For a PWR, these values are 1×10^4 gray [1×10^6 rad] and 1×10^5 gray [1×10^7 rad], respectively.[3.10] All exterior component surfaces are covered with a corrosion resistant coating or made from materials which are resistant to corrosion from the exterior environment. Each plant's housekeeping maintenance program ensures exterior coatings are properly maintained. One exception (for vertical pool centrifugals) is submergence of the exterior of the lower portion of the pump casing (bowl and part of the column) in the pumped fluid.

3.4.4 Differences in Design

Various designs are used for each type of pump to accommodate leakage requirements, service applications, and ambient environments. The following paragraphs discuss some of the common differences in the design of these pumps.

Centrifugal Pumps

Centrifugal pump impellers are securely attached to a rotating shaft. The impeller is housed in a casing which also supports the suction and discharge nozzles. Shaft seals prevent fluid from leaking out. Normally, a mechanical sealing device or a series of packing rings are used for shaft sealing. To prevent higher pressure fluid from leaking internally back to the suction side of the impeller, wear rings (one stationary and one rotating) are used. There is a close clearance between the wear ring pairs to restrict bypass leakage. Where high pressures are needed, multistage pumps are used with each impeller raising the pressure of the fluid.

The most common type of centrifugal pump construction is the volute style[3.6] as shown in Figure 3-7. A volute casing is a spiral or snail-like form designed such that as the liquid exits from the impeller into the casing, the cross-sectional area increases at a rate proportional to the increasing volume of liquid.

Another common pump design is the vane or diffuser style[3.6] as shown in Figure 3-8. In this design, each set of diffuser vanes actually forms several small volutes or diverging passages in which the fluid velocity is converted to pressure. For multistage pumps, these diffusers also direct the fluid flow into the return passages, which in turn direct the fluid into the eye of the next stage impeller or discharge nozzle (Figure 3-9).

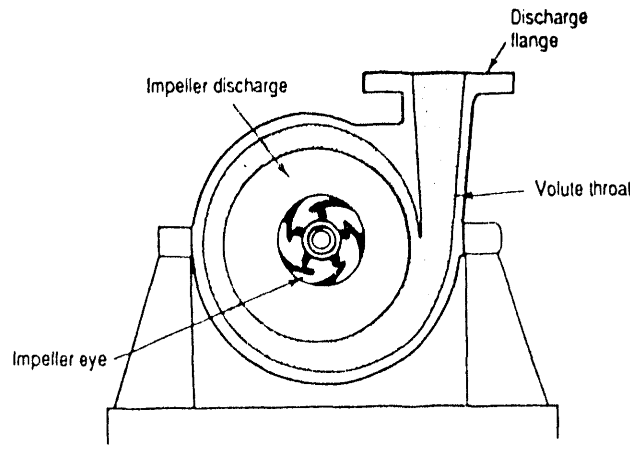


Figure 3-7. Volute Style Pump.[3.6]

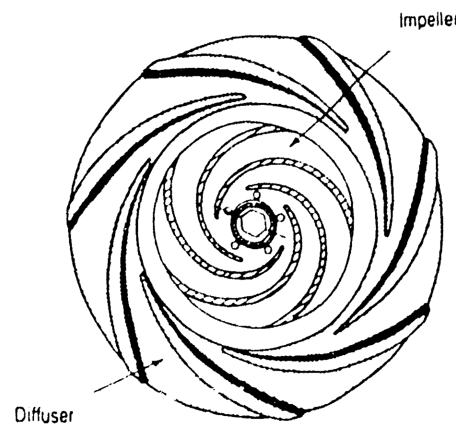


Figure 3-8. Diffuser Pump.[3.6]

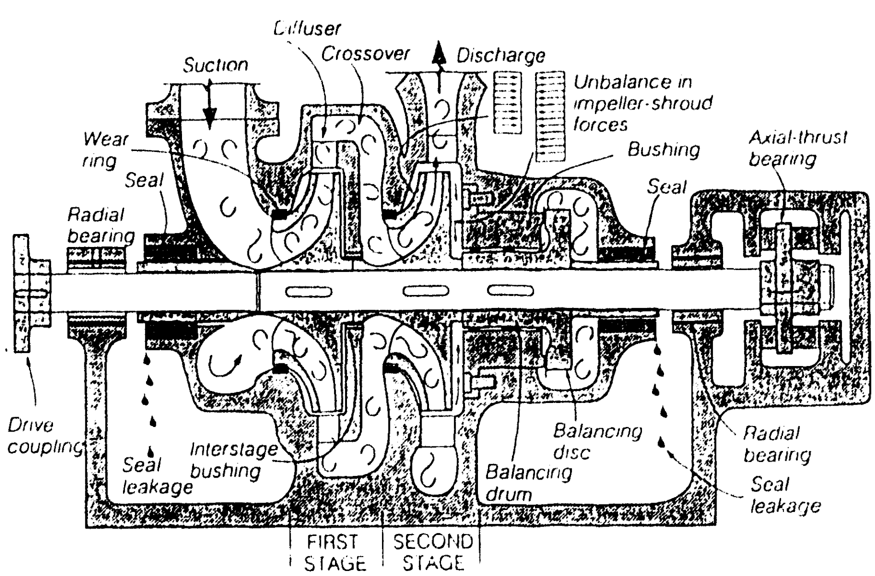
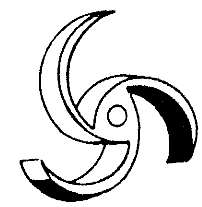


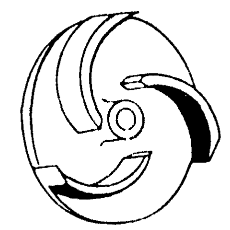
Figure 3-9. Flow Through Multistage Diffuser Pump.

Centrifugal pumps can also be classified by their impeller styles. There are three basic impeller configurations commonly used.[3.6]

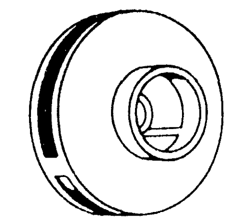
•Fully open: The vanes extend radially from the impeller hub without a back shroud or front cover plate



• Semiopen: The vanes project forward from the back shroud (no cover plate)



• Fully closed: A full back shroud and full front cover plate enclose and support the vanes. This is the most commonly used impeller style in multistage pumps



Open and semiopen impellers allow larger particles to pass through the impeller. They are typically used on small centrifugal pumps where liquids have high solids content. Due to internal leakage and recirculation, these impellers are generally less efficient than the fully closed designs. The fully closed is the most common type of impeller used for single stage and multistage pumps.

Impellers are called radial vane or radial flow when liquid discharges radially to the periphery. Impellers can also be classified by the shape and form of their vanes (straight-vane or radial-flow, Francis-vane, mixed-flow, and axial-flow). In a radial-flow impeller, the vane surfaces are generated by straight lines parallel to the axis of rotation. In a Francis-vane impeller, the vane surfaces have a double curvature. A mixed-flow impeller has both a radial-flow and axial-flow component, and in the axial-flow impeller, also known as a propeller, flow is parallel to the axis. The pumps evaluated in this guideline use mixed-flow, Francis-vane, and radial-flow impeller designs.

Designers use discharge specific speed, a nondimensional design index, to classify pump impellers as to type and physical proportions. Specific speed is the speed, in revolutions per minute, at which a geometrically similar impeller would operate if it were of such size as to deliver one gal/minute against one ft of head. Figure 3-10 is a chart of specific speed versus impeller type.[3.11]

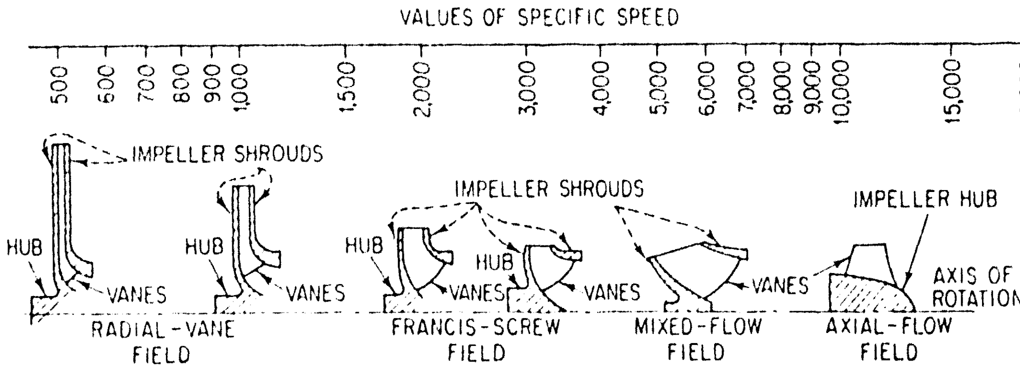


Figure 3-10. Specific Speed Vs. Impeller Type.[3.7]

Impeller styles for the lower specific speeds (500 to 1,000 rpm) are characterized by their production of high heads at low flows. Flow is primarily radial to the shaft. Many pumps have specific speeds of 1,500 to 3,000 rpm. These impellers produce medium heads at a wide range of flows. Mixed-flow impeller designs have specific speeds ranging from 4,000 to 8,000 rpm. These impellers are used for low-head, high-volume applications such as service water and cooling water. The vanes have some curvature, but the flow is primarily parallel to the axis of the shaft (axial).

Centrifugal pump flow rates are discussed in terms of minimum flow, normal flow and rated flow. The minimum flow is the lowest flow rate that the pump will see under any operating or start-up condition. The minimum flow required is limited by the pump design. Rated flow is that which the pump should be capable of delivering in a like-new condition. Rated flow is often assumed to be 110 percent of normal flow. For applications where the process flow could be less than 45 to 50 percent of normal flow, a minimum flow recirculation line is often used which bypasses a portion of the flow from the discharge of the pump back to the suction pipe. Table 3-6 lists industry documents regarding potential pump problems. Some of these documents discuss other minimum flow considerations such as parallel pump operation and hydraulic instability at low flows.

Reciprocating Pumps

Reciprocating pumps can be plunger-type or piston-type, driven through a crankshaft from an external source. Pump capacities fluctuate with the number of plungers or pistons. The reciprocating pumps evaluated in this guideline are typically triplex (three) piston or plunger pumps, installed horizontally.

Horizontal construction is typically used on plunger pumps up to 200 HP. Normally, horizontal plunger pumps have three to five plungers. Horizontal piston pumps are rated to 3,000 HP and usually have two or three pistons, which can be single-acting or double-acting (two suction and two discharge strokes for one complete reciprocating cycle). Plungers are applied to pumps with pressures from 6,895 to 207,000 kPa [1,000 to 30,000 psi]. Maximum developed pressure with a piston is about 13,790 kPa [2,000 psi].[3.7]

Table 3-6. List of NRC Information Notices, Bulletins, Generic Letters, and Circulars Related to Pump Aging Degradation

INFORMATION NOTICES	
IN 80-07	Pump Shaft Fatigue Cracking
IN 80-23	Loss Of Suction To Emergency Feedwater Pumps
IN 80-27	Degradation Of Reactor Coolant Pump Studs
IN 80-38	Cracking In Charging Pump Casing Cladding
IN 82-19	Loss Of High Head Safety Injection Emergency Boration And Reactor Coolant Makeup Capability
IN 83-51	Diesel Generator Events
IN 84-06	Steam Binding Of Auxiliary Feedwater Pumps
IN 84-66	Undetected Unavailability Of The Turbine-driven Auxiliary Feedwater Train
IN 85-03	Separation Of Primary Reactor Coolant Pump Shaft And Impeller
IN 85-03	(SUPPLEMENT 1)
IN 85-50	Complete Loss Of Main And Auxiliary Feedwater At A PWR Designed By Babcock & Wilcox
IN 85-76	Recent Water Hammer Events
IN 85-94	Potential For Loss Of Minimum Flow Paths Leading To ECCS Pump Damage During A LOCA
IN 86-19	Reactor Coolant Pump Shaft Failure At Crystal River
IN 86-39	Failures Of RHR Pump Motors and Pump Internals
IN 86-63	Loss Of Safety Injection Capability
IN 86-79	Degradation Or Loss Of Charging Systems At PWR Nuclear Power Plants Using Swing-Pump Designs
IN 86-101	Loss Of Decay Heat Removal Due To Loss Of Fluid Levels In Reactor Coolant System
IN 86-108	Degradation Of Reactor Coolant System Pressure Boundary Resulting From Boric Acid Corrosion
IN 87-06	Loss Of Suction To Low-Pressure Service Water System Pumps Resulting From Loss Of Siphon
IN 87-10	Potential For Water Hammer During Restart Of Residual Heat Removal Pumps
IN 87-23	Loss Of Decay Heat Removal During Low Reactor Coolant Level Operation
IN 87-34	Single Failures In Auxiliary Feedwater Systems
IN 87-51	Failure Of Low Pressure Safety Injection Pump Due To Seal Problems
IN 87-53	Auxiliary Feedwater Pump Trips Resulting From Low Suction Pressure
IN 87-57	Loss Of Emergency Boration Capability Due To Nitrogen Gas Intrusion
IN 87-59	Potential RHR Pump Loss

Table 3-6. List of NRC Information Notices, Bulletins, Generic Letters, and Circulars Related to Pump Aging Degradation (continued)

INFORMATION NOTICES (continued)	
IN 87-63	Inadequate Net Positive Suction Head In Low Pressure Safety Systems
IN 88-09	Reduced Reliability Of Steam-Driven Auxiliary Feedwater Pumps Caused By Instability Of Woodward PG-PL Type Governors
IN 88-23	Potential For Gas Binding Of High-Pressure Safety Injection Pumps During A Loss-Of-Coolant Accident
IN 88-23	(SUPPLEMENTS 1, 2, 3, and 4)
IN 88-36	Possible Sudden Loss Of RCS Inventory During Low Coolant Level Operation
IN 88-39	LaSalle Unit 2 Loss Of Recirculation Pumps With Power Oscillation Event
IN 88-67	PWR Auxiliary Feedwater Pump Turbine Overspeed Trip Failure
IN 88-87	Pump Wear And Foreign Objects In Plant Piping Systems
IN 89-08	Pump Damage Caused By Low-Flow Operation
IN 89-15	Second Reactor Coolant Pump Shaft Failure At Crystal River
IN 89-20	Weld Failures In A Pump Of Byron-Jackson Design
IN 89-48	Design Deficiency In The Turbine-Driven Auxiliary Feedwater Pump Cooling Water System
IN 89-58	Disablement Of Turbine-Driven Auxiliary Feedwater Pump Due To Closure Of One Of The Parallel Steam Supply Valves
IN 89-67	Loss Of Residual Heat Removal Caused By Accumulator Nitrogen Injection
IN 89-71	Diversion Of The Residual Heat Removal Pumps Seal Cooling Water Flow During Recirculation Operation Following A Loss-Of-Coolant
IN 89-80	Potential For Water Hammer, Thermal Stratification, And Steam Binding In High-Pressure Coolant Injection Piping
IN 90-26	Inadequate Flow Of Essential Service Water To Room Coolers And Heat Exchangers For Engineered Safety-Feature Systems
IN 90-39	Recent Problems With Service Water Systems
IN 90-61	Potential For Residual Heat Removal Pump Damage Caused By Parallel Pump Interaction
IN 90-64	Potential For Common-Mode Failure Of High-Pressure Safety Injection Pumps Or Release Of Reactor Coolant Outside Containment
IN 90-68	Stress Corrosion Cracking Of Reactor Coolant Pump Bolts
IN 90-70	Pump Explosions Involving Ammonium Nitrate
IN 91-12	Potential Loss Of Net Positive Suction Head (NPSH) Of Standby Liquid Control System Pumps
IN 92-85	Potential Failures of Emergency Core Cooling Systems Caused by Foreign Material Blockage
IN 91-27	Incorrect Rotation Of Positive Displacement Pump

Table 3-6. List of NRC Information Notices, Bulletins, Generic Letters, and Circulars Related to Pump Aging Degradation (continued)

INFORMATION NOTICES (continued)	
IN 92-16	Loss of Flow From Residual Heat Removal Pump During Refueling Cavity Draindown
IN 92-49	Recent Loss Or Severe Degradation Of Service Water System
BULLETINS	
BL 80-18	Maintenance Of Adequate Minimum Flow Through Centrifugal Charging Pumps Following Secondary Side High Energy Line Rupture
BL 82-02	Degradation Of Threaded Fasteners In The Reactor Coolant Pressure Boundary Of PWR Plants
BL 83-05	ASME Nuclear Code Pumps And Spare Parts Manufactured By The Hayward Tyler Pump Company
BL 85-01	Steam Binding Of Auxiliary Feedwater Pumps
BL 86-01	Minimum Flow Logic Problems That Could Disable RHR Pumps
BL 86-03	Potential Failure of Multiple ECCS Pumps Due To Single Failure Of Air-Operated Valve In Minimum Flow Recirculation Line
BL 88-04	Potential Safety-Related Pump Loss
CIRCULARS	
C 78-13	Inoperability Of Service Water Pumps
C 79-19	Loose Locking Devices On Ingersoll-Rand Pumps
GENERIC LETTERS*	
GL 89-04	Development of Acceptable IST Programs
GL 91-07	GI-23, "Reactor Coolant Pump Seal Failures" And Its Possible Effect On Station Blackout
GL 91-17	Generic Safety Issue 29, "Bolting Degradation Or Failure In Nuclear Power Plants"

* Some of the Information Notices and GL 91-07 discuss potential problems with components other than the pumps evaluated in this guideline (i.e., Reactor Coolant Pumps). These documents are listed here because the problem or degradation may indirectly apply to the aging evaluations in this guideline and, therefore, were reviewed as part of the industry data review.

Figure 3-11 shows the liquid end of a plunger-type reciprocating pump. The power end for both the plunger-type and piston-type is shown in Figure 3-12. This contains the crankshaft, connecting rod, crosshead, pony rod, bearings and frame.

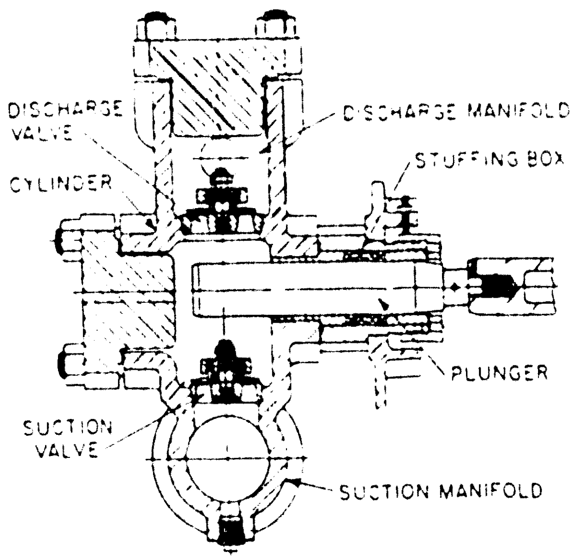


Figure 3-11. Liquid End — Reciprocating Pump.[3.7]

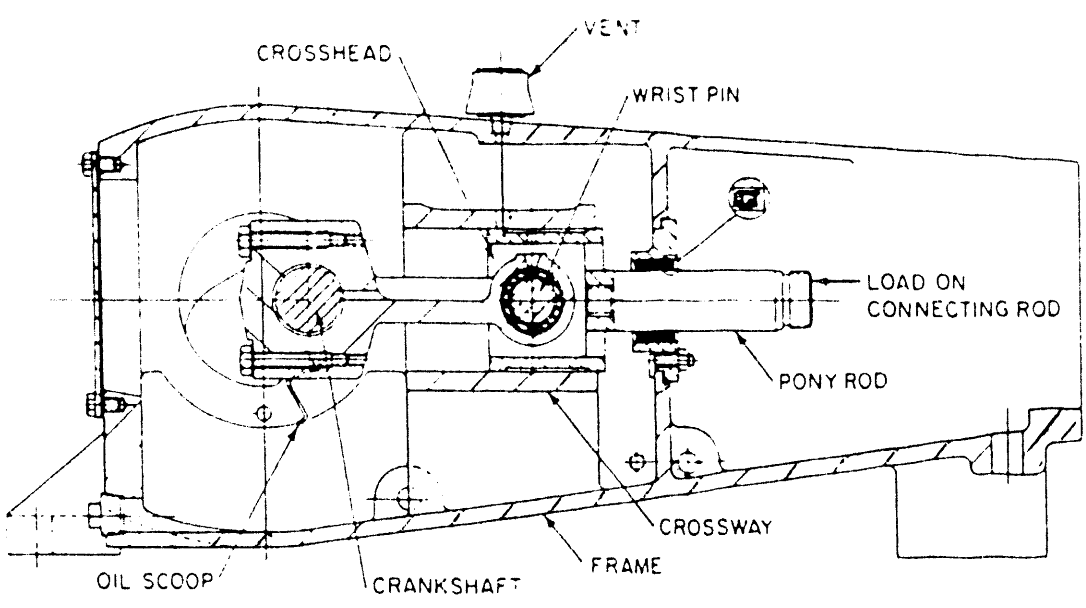


Figure 3-12. Power End — Reciprocating Pump.[3.7]

Rotary Pumps

There are many types of rotary positive displacement pumps, including gear, screw, multiple-rotor screw, circumferential piston, lobe, rotor vane, rotary piston, and flexible member pumps. However, for the pumps evaluated in this guideline, only two types, the gear-type and the screw-type, are generally used. These pumps are installed in fuel oil systems and lubricating oil systems.

The primary design difference between the gear-type and screw-type rotary pump is the flow through the pump. The flow is more axial and, subsequently, less disturbed in a screw pump. Both types of pumps can have various internal designs, depending on flow and pressure requirements. These two types of pumps are shown in Figures 3-5 and 3-6.

Pump Couplings

There are two basic types of couplings used to join pumps and their drivers. They are (1) rigid adjustable and (2) flexible. Most close-coupled vertical pumps use a rigid adjustable coupling (Figure 3-13) to transmit axial load, up or down, to the motor shaft.[3.6] This arrangement combines the pump and motor shaft as a single shaft.

Flexible couplings are used to connect the horizontally mounted pump and the motor shafts in applications where changes in temperature and loadings during normal operation, start-up, or shutdown can cause one shaft end to move relative to its companion shaft end. Flexible couplings can be mechanical flexing types.

Mechanical flexing couplings can be gear-type, grid spring design, or limited and float couplings. Flexible gear couplings (Figure 3-14) are common as they offer high torque and good performance. The disadvantage is the need for lubrication.

The gridspring design consists of two hubs with axial grooves through which the grid spring is laced back and forth. This type has less torque transmission capacity (60%) of the gear coupling and also requires grease.

Limited end float couplings are sometimes used when the driver motor has sleeve bearings, which cannot carry any thrust. The couplings are arranged to restrict the end float of the motor rotor (see Figure 3-15). Restricted end float is provided in gear-type or grid-type couplings by locating a "button" at the end of one or both shafts and by inserting a low-friction plate between the two shaft ends.

Another form of flexible coupling is the flexing-element coupling. The flexing element can be either elastomeric or metallic. The elastomeric design consists of two steel disks, with the driving disk carrying a metal-lined rubber bushing. This projects into corresponding holes in the driven half. These designs do not require lubrication; however, they are low in strength.

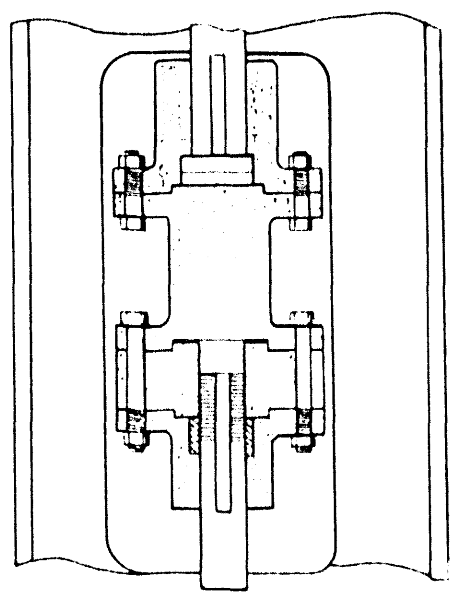


Figure 3-13. Rigid Adjustable Coupling.[3.6]

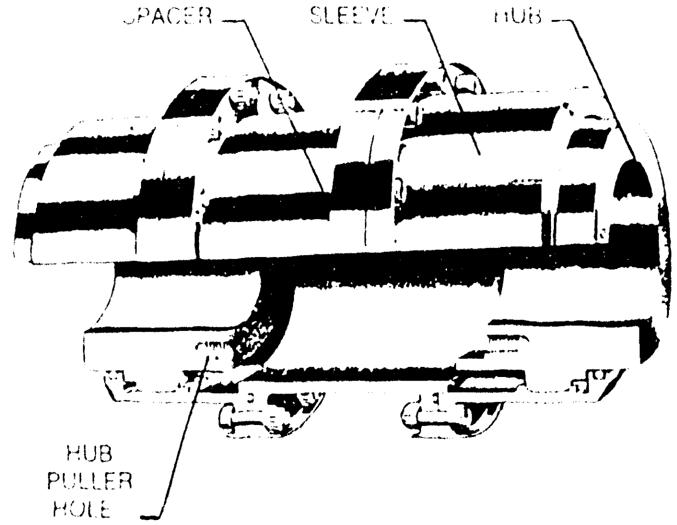


Figure 3-14. Flexible Gear Coupling.[3.6]

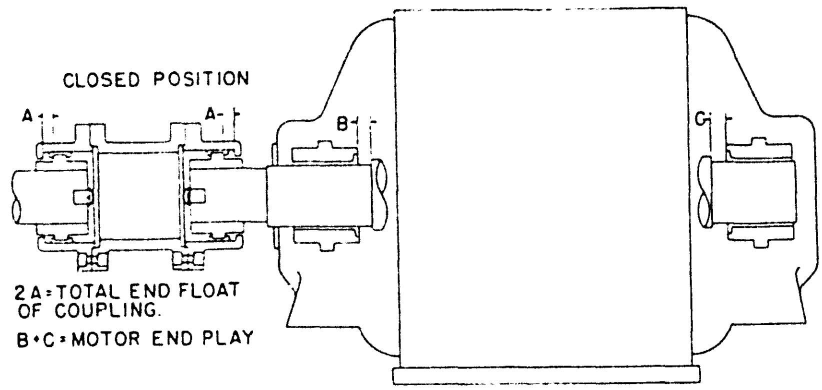


Figure 3-15. Limited End Float Coupling.[3.6]

Metallic type flexible couplings consist of two basic designs, the disk type and diaphragm type (Figure 3-16). The designs are "soft" in the axial plane, so the coupling only imposes 10-15 percent of the axial bending loads on the bearings or shafts of the pump/motor when compared to the gear coupling. The metallic couplings require no lubrication, but can only accommodate a portion (up to one-half) of the misalignment or angular offset of a gear coupling.

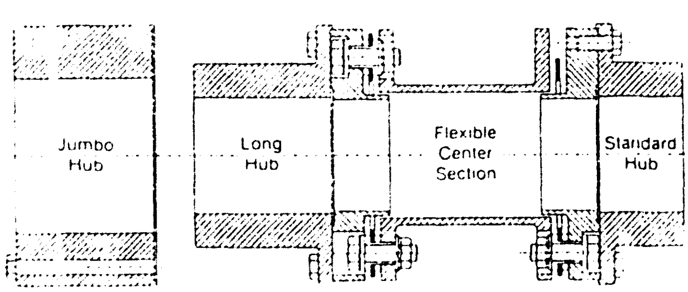


Figure 3-16. Flexible Disc Coupling.[3.6]

Bearings

The types of bearings used in centrifugal pumps are categorized according to the direction of the forces they absorb, either radial or axial thrust. The bearings may be ball or roller-type, sleeve-type journal bearings, or hydrodynamic-type (uses fluid film to support shaft) thrust bearings. Journal bearings carry radial loads only. Thrust bearings absorb loads in the axial direction. Anti-friction (ball or roller) bearings handle a combination of both radial and axial loads.

Overhung horizontal impeller pumps usually employ radial ball bearings adjacent to the impeller and thrust bearings (usually a duplex pair of angular contact bearings) on the coupling end.[3.6] In pumps where the impeller is between bearings, the ball radial and the ball thrust bearings have individual bearing housings. Double-suction pumps often use journal-type radial bearings and a ball thrust bearing. This arrangement is useful in higher horsepower and higher speed applications where ball radial bearings would be impractical due to speed, load and lubrication limitations.

Most vertical pumps differ from horizontal pumps in that the entire axial thrust, consisting of axial hydraulic forces as well as the static weight of the pump and driver motor rotor is supported by the driver thrust bearing. In these cases, the pump manufacturer, motor manufacturer and end user size the bearing jointly. The vertical pump motor design can use a hollow shaft or solid shaft. On hollow-shaft units, the pump shaft extends upward through the motor shaft and is supported at the top of the motor shaft. On solid-shaft units, a solid coupling is provided (usually by the pump manufacturer) to provide a rigid attachment between the pump shaft and motor shaft extension.

Reciprocating pumps use sleeve and antifriction bearings. Some use all of one design where others use a combination of both.

Lubrication

There are several methods used to ensure that pump components, including bearings, are sufficiently lubricated to allow long-term pump operation. Antifriction pump bearings can be grease or oil-lubricated. An oil film develops between the rotating parts, thereby reducing or eliminating wear. To establish the proper oil film, the proper grease or oil must be used.

Grease lubrication is normally limited to small, low-horsepower, non-critical pumps operating at low speeds and relatively low temperatures.[3.6] A more common lubrication system for centrifugal pumps is the oil flood system. In this system, the bearing housing contains the oil sump, with the sump level being maintained at the center line of the bearing. As the shaft turns, oil gets distributed to all parts of the bearing(s).

Ring-oiled lubrication systems are used where, due to speed or loads, a flood system is not adequate. In this design, rings of a larger diameter than the shaft are immersed in oil and when the shaft rotates, the rings carry oil up from the reservoir to oil flingers which throw the oil into the bearing.

An oil mist system is another method to lubricate pumps. In this system, an oil aerosol is dispersed into the bearing housing.

Sleeve bearings, or journal bearings, can be lubricated either by oil rings (as described above) or a pressurized forced feed. In forced-feed systems, the main oil pump can be coupled directly to the pump shaft or separately driven by an electric motor. Also, an auxiliary oil pump is used on critical pump oil systems to ensure an uninterrupted supply of oil in the event of a main oil pump failure.

Rotary pumps are designed to operate on liquids with lubricating characteristics. The rotary pumps in this guideline pump fuel oil and lubricating oil, and both are high in lubricity.

Reciprocating pumps use a splash-type lubrication system or a force-feed system. With splash lubrication, an oil scoop, mounted on the crankshaft, throws oil by centrifugal force against the frame wall. The oil then is distributed by gravity to other pump components (crosshead, wrist pin and crank pin). At low speeds, this is not adequate and requires partial force feed. Force feed systems may employ drilled passages in the crankshaft, piston rod, etc., to supply oil to all bearings.

Shaft Seals

Shaft seals prevent leakage of the pumped fluid from the pump. This is normally performed by packing or mechanical seals.

Packing is the simplest method of sealing between the shaft and pump casing. Packing rings are inserted into a "stuffing box" area. Lantern rings are often used to provide for injection of lubricant or for cooling the packing. Packing is used to control leakage, not necessarily to eliminate it. Packing materials can be proxidized polyacrylonitrile (PAN) fibers, carbon fibers, and graphite fibers.

Mechanical seals (Figure 3-17) are the most common method of sealing centrifugal pumps. There are two basic types; pusher types, where the secondary sealing members slide along the shaft sleeve as the seal moves and wears, and nonpusher (bellows) type, where the secondary seal is fixed to the shaft. Secondary seals are O-rings or other suitable gasket material.

3.4.5 Description of Predominant Types of Pumps

Most of the pumps in nuclear service are one- or two-stage centrifugal motor-driven pumps. Both vertical and horizontal types are used. Many of the pumps evaluated in this AMG, such as the charging, safety injection, auxiliary feedwater, and other high-head pumps are multistage motor-driven centrifugal units. Some centrifugal pumps are turbine-driven. Double-suction designs are frequently used for residual heat removal pumps, where service requires operation at low available Net Positive Suction Head (NPSH). Reciprocating pumps find limited service in nuclear plants for make-up flow, seal injection flow, or chemical mixing service. Rotary pumps are frequently used in lubricating oil and fuel oil systems.

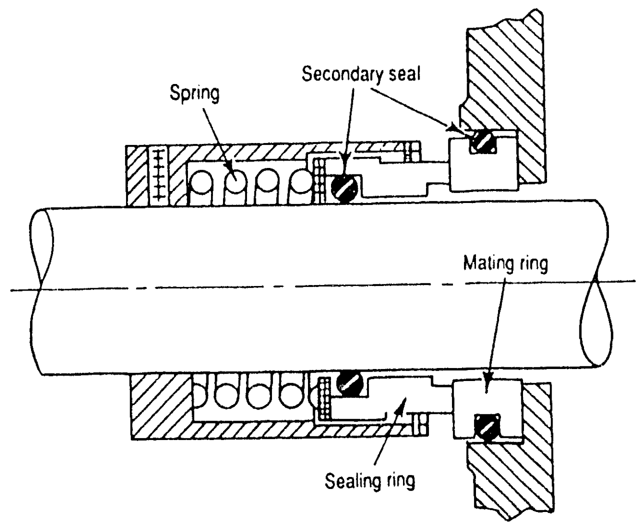


Figure 3-17. Typical Mechanical Seal.[3.6]

Tables 3-7 and 3-8 provide typical pump design and operating parameters. Tables 3-9 and 3-10 list the manufacturers for these pumps. This information was obtained from the NPRDS database and responses from several utilities to a questionnaire.

3.4.5.1 Centrifugal Pumps

Auxiliary Feedwater Pump

PWR auxiliary feedwater (AFW) pumps supply feedwater to the steam generators under plant start-up, normal shutdown, hot standby, and emergency conditions. AFW pumps are generally multistage (from 6 to 12) with low specific speed, high head per stage impellers, having either vane diffuser or volute collection chambers at the discharge section of each stage. The overall construction is always an axially (horizontal) split outer casing with internal stage-to-stage connecting flow passages.[3.12] Specific details of construction vary considerably from vendor to vendor. The main factor that determines these more specific configuration details is the design approach used to handle very large axial thrust forces on the rotor and to prevent inlet stage cavitation.

Pump design configurations can have all stages positioned in the same axial direction (in-line) or a configuration with the stages on half of the shaft axially opposed to those on the other half. The opposed stage design is for thrust cancellation. Opposed-type configurations are often designed with only a thrust bearing whereas in-line configurations are always designed with an additional thrust balancer (balancing drum or balancing disk).

Table 3-7. Pump Application Summary — PWR Pumps

Service	System	Fluid	Type	Orientation	Design Parameter Ranges: Temp °C [°F]	Flow LPM [GPM]	Head kPa [PSI]	Annual Operating Hours/Starts	Remarks
Auxiliary Feedwater	Auxiliary Feedwater System	Demineralized Water from CST	Centrifugal (Multi-Stage)	Horizontal	4-65 [40-150]	760-5,300 [200-1,400]	3,450-13,100 [500-1,900]	Standby service. Used during start-ups and shutdowns and quarterly testing.	Cast carbon or stainless steel casing. Other wetted parts stainless or cast alloy steel.
Boric Acid Transfer	Chemical and Volume Control System (CVCS)	12% Boric Acid Solution	Centrifugal (Single-Stage)	Horizontal	66-120 [150-250]	95-380 [25-100]	115-1,035 [17-150]	One runs continuous; others in standby and tested quarterly.	All materials stainless steel.
Charging	Chemical and Volume Control System (CVCS)	Borated Demineralized Water	Centrifugal	Horizontal	21-205 [70-400]	450-1,515 [120-400]	6,895-18,960 [1,000-2,750]	One pump runs continuous. Others in standby and tested quarterly.	Casing is stainless steel (SS) or carbon steel clad with SS. All wetted parts SS or equivalent.
			Reciprocating	Horizontal	21-150 [70-300]	76-380 [20-100]	15,860-18,960 [2,300-2,750]	One pump runs continuous. Others in standby and tested quarterly.	Casing is stainless steel (SS) or carbon steel clad with SS. All wetted parts SS or equivalent.
Closed Cooling Water	Component Cooling Water	Treated Demineralized Water	Centrifugal (Single-Stage)	Horizontal	26-93 [80-200]	7,570-45,420 [2000-12,000]	240-1,310 [35-190]	Continuous. An installed spare is normally available.	Cast iron or carbon steel casting, casing, bronze impeller, and SS shaft.
Containment Recirculation	Containment Recirculation	Demineralized Water and Borated Water	Centrifugal	Vertical	10-140 [50-285]	380-11,350 [100-3,000]	100-1,035 [15-150]	Standby Service. Tested only during refueling per Tech Spec.	Normally in a dry sump. Takes suction from open sump.
Containment Spray	Containment Spray	Slightly Borated Demineralized Water with NaOH	Centrifugal (Single-Stage)	Horizontal (Most) or Vertical	2-138 [35-280]	3,670-12,100 [970-3,200]	690-3,450 [100-500]	Normally operated only for testing per Tech Specs.	Materials are stainless steel or equivalent.
Emergency Diesel Generator Fuel Oil Transfer	Emergency Diesel Generator	Fuel Oil	Rotary or Centrifugal	Horizontal or Vertical	5-32 [40-90]	26-150 [7-40]	14-280 [2-41]	Intermittent. 15-30 starts/yr.	Cast alloy casing and internals.

Table 3-7. Pump Application Summary — PWR Pumps (continued)

Service	System	Fluid	Type	Orientation	Design Parameter Ranges			Annual Operating Hours/Starts	Remarks
					Temp °C [°F]	Flow LPM [GPM]	Head kPa [PSI]		
Emergency Diesel Generator Jacket Water	Emergency Diesel Generator	Treated Service Water	Centrifugal (Single-Stage)	Horizontal	26-71 [80-160]	1,890-3,785 [500-1,000]	207-276 [30-40]	Runs 90-200 hr/yr	Cast alloy casing and internals.
Lubricating Oil	Various	Oil	Rotary (Gear)	Horizontal	10-105 [50-220]	23-415 [6-110]	69-620 [10-90]	Auxiliary lube oil pumps run continuous; others intermittent.	Cast iron casing.
Primary Water	Primary Water/CVCS	Demineralized Water	Centrifugal	Horizontal	2-65 [35-150]	570-760 [150-200]	690-895 [100-130]	Intermittent	All materials stainless steel.
Residual Heat Removal	Emergency Core Cooling System	Borated Demineralized Water/Reactor Coolant	Centrifugal (Single-Stage)	Horizontal or Vertical In-Line	21-177 [70-350]	5,675-32,170 [1,500-8,500]	690-3,100 [100-450]	Intermittent — Used primarily for decay heat removal during plant outages.	All wetted parts stainless steel or corrosion-resistant material. Casings may be cast steel.
Safety Injection	Emergency Core Cooling System	Borated Demineralized Water	Centrifugal (Single-Stage and Multi-Stage)	Horizontal or Vertical	2-150 [35-300]	760-18,925 [200-5,000]	6,895-10,340 [1,000-1,500]	Normally operated only for testing per Tech Specs.	Casing, wetted parts are stainless steel or other corrosion-resistant material (A296).
Service Water	Service Water	Raw Water (Fresh, Salt, or Brackish Water)	Centrifugal (Single-Stage Multi-Stage)	Horizontal or Vertical	0-38 [33-100]	1,210-56,775 [320-15,000]	345-690 [50-100]	Continuous.	Cast iron casing.
	Essential Service Water	Strained Raw Water (Fresh, Salt, or Brackish Water)	Centrifugal (Multi-Stage)	Vertical	0-38 [33-100]	760-52,990 [200-14,000]	345-690 [50-100]	One runs continuous, others in standby.	Steel or cast iron casing. Stainless or corrosion-resistant internals.
Spent Fuel Pool Cooling	Spent Fuel Pool	Borated Demineralized Water	Centrifugal (Single-Stage)	Horizontal	27-49 [80-120]	380-680 [100-180]	150-900 [22-130]	Continuous.	All materials stainless steel.

Table 3-8. Pump Application Summary — BWR Pumps

Service	System	Fluid	Type	Orientation	Design Parameter Ranges			Annual Operating Hours/Starts	Remarks
					Temp °C [°F]	Flow LPM [GPM]	Head kPa [PSI]		
Closed Cooling Water	Component Cooling Water	Treated Demineralized Water	Centrifugal (Single-Stage)	Horizontal	26-93 [80-200]	7,570-45,420 [2,000-12,000]	240-1,310 [35-190]	Continuous. An installed spare is normally available.	Cast iron or carbon steel casting, casing, bronze impeller, and SS shaft.
Control Rod Drive	Control Rod Drive Hydraulic	Demineralized Water	Centrifugal Multi-Stage	Horizontal	4-43 [40-110]	265-360 [70-95]	9,650-11,720 [1,400-1,700]	One pump runs continuously. One in standby. Standby pump is run monthly for testing	Two pumps. Cast alloy casing, axially split. Stationary internals are cast iron. Stainless steel shaft. Cast alloy wear rings.
Core Spray	Emergency Core Cooling System	Demineralized Water from Suppression Pool or Condensate Storage Tank	Centrifugal	Vertical	4-49 [40-120]	11,355-22,710 [3,000-6,000]	1,860-2,140 [270-310]	Normally operated only for testing per Tech Spec.	Single-stage, cast steel casing, stainless steel shaft, bronze impeller, wear rings.
Emergency Diesel Generator Fuel Oil Transfer	Emergency Diesel Generator	Fuel Oil	Rotary or Centrifugal	Horizontal or Vertical	5-32 [40-90]	26-150 [7-40]	14-280 [2-41]	Intermittent 15-30 starts/yr.	Cast alloy casing and internals.
Emergency Diesel Generator Jacket Water	Emergency Diesel Generator	Treated Service Water	Centrifugal (Single-Stage)	Horizontal	26-71 [80-160]	1,890-3,785 [500-1,000]	207-276 [30-40]	Runs 90-200 hr/yr.	Cast alloy casing and internals.
High Pressure Coolant Injection	Emergency Core Cooling System	Demineralized Water from Suppression Pool or Condensate Storage Tank	Centrifugal	Horizontal	4-49 [40-120]	11,355-18,925 [3,000-5,000]	1,380-10,340 [200-1,500]	Normally operated only for testing per Tech Spec.	Carbon steel cast casing. Stainless steel or equivalent corrosion-resistant shaft and impeller. Pump is turbine-driven, variable speed.
Lubricating Oil	Various	Oil	Rotary (Gear)	Horizontal	10-105 [50-220]	23-415 [6-110]	69-620 [10-90]	Auxiliary lube oil pumps run continuous; others intermittent.	Cast iron casing.
Reactor Core Isolation Cooling	Reactor Core Isolation Cooling	Demineralized Water from Suppression Pool or Condensate Storage Tank	Centrifugal Multi-Stage	Horizontal	4-49 [40-120]	1,515-2,650 [400-700]	1,380-10,340 [200-1,500]	Normally operated only for testing per Tech Spec.	Cast steel casing, stainless steel shaft, bronze wear rings, and impeller. Turbine-driven, variable speed.

Table 3-8. Pump Application Summary — BWR Pumps (continued)

Service	System	Fluid	Type	Orientation	Design Parameter Ranges			Annual Operating Hours/Starts	Remarks
					Temp °C [°F]	Flow LPM [GPM]	Head kPa [PSI]		
Reactor Water Cleanup	Reactor Water Cleanup	Reactor Coolant	Centrifugal	Horizontal	49-295 [120-560]	360-680 [95-180]	1,515-9,650 [220-1,400]	Continuous.	All materials stainless steel or equivalent.
Residual Heat Removal	Emergency Core Cooling System or Shutdown Cooling	Demineralized Water/Reactor Coolant	Centrifugal (Single-Stage)	Horizontal or Vertical In-Line	4-177 [40-350]	5,675-32,170 [1,500-8,500]	690-3,100 [100-450]	Intermittent — Used primarily for decay heat removal during plant outages.	All wetted parts stainless steel or corrosion-resistant material. Casings may be cast steel.
Service Water	Service Water	Raw Water (Fresh, Salt, or Brackish Water)	Centrifugal (Single-Stage Multi-Stage)	Vertical or Horizontal	0-38 [33-100]	1,210-56,775 [320-15,000]	345-690 [50-100]	Continuous.	Cast iron casing.
	Residual Heat Removal Service Water	Raw Water (Fresh, Salt, or Brackish Water)	Centrifugal (Turbine-Type Multi-Stage)	Vertical	0-38 [33-100]	11,355-27,630 [3,000-7,300]	345-805 [50-117]	Normally in standby, except for testing and during refueling operations.	Carbon steel casing, stainless steel, or corrosion-resistant internals.
	Essential Service Water	Strained Raw Water (Fresh, Salt, or Brackish Water)	Centrifugal (Multi-Stage)	Vertical	0-38 [33-100]	760-52,990 [200-14,000]	345-690 [50-100]	One runs continuous, others in standby.	Steel or iron casing. Stainless or corrosion-resistant internals.
Spent Fuel Pool Cooling	Spent Fuel Pool	Demineralized Water	Centrifugal (Single-Stage)	Horizontal	27-49 [80-120]	380-680 [100-180]	150-900 [22-130]	Continuous.	All materials stainless steel.
Standby Liquid Control	Standby Liquid Control	Sodium Pentaborate Solution	Reciprocating	Horizontal	27-65 [80-150]	130-235 [34-62]	4,480-8,410 [650-1,220]	Normally operated only for testing per Tech Spec.	Cast iron casing, cast steel, or stainless internals.

Table 3-9. Pump Manufacturers - PWR Plants

Auxiliary Feedwater	Boric Acid Transfer	Charging	Closed Cooling Water	Containment Recirculation & Spray	Emergency Diesel Generator Fuel Oil	Emergency Diesel Generator Jacket Water	Lubricating Oil	Primary Water Makeup	Residual Heat Removal	Safety Injection	Service Water	Spent Fuel Pool Cooling
Ingersoll-Rand	Crane Deming	Pacific	Pacific	Byron-Jackson	Roper	Decatur	Electro-Motive	Ingersoll-Rand	Ingersoll-Rand	Pacific	Byron-Jackson	Ingersoll-Rand
Sulzer Bingham	Goulds	Byron-Jackson	Ingersoll-Rand	Ingersoll-Rand	Goulds	Colt Ind.	Viking	Bingham Williamette	Babcock & Wilcox	Byron-Jackson	Johnston	Goulds
Byron-Jackson	Ingersoll-Rand	Goulds	Goulds	Pacific	Worthington	Goulds	Roper	Goulds	Pacific	Ingersoll-Rand	Colt Ind.	Worthington
Worthington	Westinghouse	Gaulin/ Manton	Worthington	Crane Deming	Worcester Controls	Crane Deming	Worcester Controls		Goulds	Bran & Lubbe	Fairbanks/ Morse	Bingham Williamette
Pacific		Crane Deming	Babcock & Wilcox	Union	Byron-Jackson	Burks	Fairbanks Morse		Worthington	Worthington	Sulzer Bingham	
Babcock & Wilcox		ARMCO	Sulzer Bingham	Goulds	Viking		Worthington		Byron-Jackson	Goulds	Layne & Bowler	
		Union	Ward	Worthington	Colt Industries		Blackmer		Bingham	Sulzer Bingham	Aurora	
		Crane Deming	Byron-Jackson	Babcock & Wilcox	Crane Deming		DeLaval				Worthington	
		Ajax Iron	DeLawal	Sulzer Bingham	Johnston						Ingersoll-Rand	
			Crane Deming								Peerless	
			Allis Chalmers								Babcock & Wilcox	
											Hayward-Tyler	
											Goulds	
											Bingham Williamette	

Table 3-10. Pump Manufacturers - BWR Plants

Closed Cooling Water	Control Rod Drive Hydraulic	Core Spray	Emergency Diesel Generator Fuel Oil	Emergency Diesel Generator Jacket Cooling	High Pressure Coolant Injection	Lubrication Oil	Reactor Core Isolation Cooling	Reactor Water Cleanup	Residual Heat Removal	Service Water	Spent Fuel Pool Cooling	Standby Liquid Control
Ingersoll-Rand	Worthington	Ingersoll-Rand	DeLaval	Peerless	Byron-Jackson	Viking	Crane Deming	Ingersoll-Rand	Byron-Jackson	Goulds	Goulds	Union
Milton Roy	Union	Crane Deming	Electro-Motive	Crane Deming	Tuthill	Sier-Bath Gear	Bingham Williamette	Union	Sulzer Bingham	Ingersoll-Rand	Peerless	Sulzer Bingham
Byron-Jackson		Worthing-ton	Viking	Ingersoll-Rand		Ingersoll-Rand			Goulds	Johnston	Union	
Worthing-ton		Goulds	Roper	Decatur		Tuthill			Pacific	Worthing-ton		
Goulds		Byron-Jackson		Allis Chalmers		Electro-Motive			Ingersoll-Rand	Crane Deming		
Fairbanks Morse		Sulzer Bingham		Colt Ind.		Colt Ind.			Bingham Williamette	Byron-Jackson		
Peerless		Bingham				IMO				Layne & Bowler		
										Sulzer Bingham		
										Aurora		
										Hayward Tyler		
										Allis Chalmers		
										DeLaval		
										Bingham Williamette		

Charging Pump

Charging pumps in PWR Emergency Core Cooling Systems (ECCS) automatically start upon receipt of a safety injection signal and deliver low flow at high pressure to the Reactor Coolant System (RCS). These pumps are also typically a part of the Chemical and Volume Control System (CVCS) and, for this use, one of the two pumps is generally operating to provide a normal path for borating or diluting the RCS, for reactor coolant pump seal cooling, and for normal makeup.

The charging pumps are typically horizontal multistage centrifugal pumps. Pumps are generally stainless steel or carbon steel clad with stainless steel on the interior. The pumps are motor-driven.

Safety Injection Pump

Safety injection (SI) pumps are used in PWR ECCSs to automatically start upon receipt of a safety injection signal and deliver intermediate flow at intermediate pressure to the RCS. There are normally three pumps installed for this function, and all are maintained in a standby condition.

The SI pumps are typically horizontal multistage centrifugal pumps driven by motors. Some applications use vertical line shaft pumps driven by electric motors. The pumps are usually fabricated from stainless steel because they are connected to the RCS.

Containment Spray Pump

Containment spray (CTS) pumps are used for PWR containments to automatically start upon receipt of a containment spray/containment isolation signal, or may be manually initiated to spray cool water (sodium hydroxide solution) into the containment atmosphere to limit pressure buildup during accident conditions. Also, the spray removes radioactive iodine isotopes from containment. There are generally two pumps, each associated with an independent and redundant system. The pumps are normally maintained in standby condition. The pumps are mounted vertically or horizontally and are single stage centrifugal pumps fabricated from stainless steel. The pumps are located outside containment, in a mild environment. These pumps are normally operated for testing purposes only. Testing is typically performed monthly or quarterly for one to four hours.

Containment Recirculation Pump

The containment recirculation pump is used in some PWR plants; however, it is not common to all PWRs. These pumps are stainless steel vertical-mounted centrifugal pumps. The pumps are located over the containment sump. The pumps are normally maintained in standby condition and, in the event of a large pipe break, take suction from the recirculation sump and deliver spilled reactor coolant and borated refueling water back to the core. Plants which do not have containment recirculation pumps use the residual heat removal, safety injection or containment spray pumps for this function.

Since the recirculation pumps are normally in a dry sump, testing can only be performed during refueling outages by filling the sump with water.

Primary Water Makeup Pump

The primary water makeup pump, typically two per plant, is installed in PWR facilities to feed dilution water from either monitor tanks (processed water) or the primary water storage tank to the boric acid system for blending the boric acid solution. The pumps are also used to supply makeup water for intermittent flushing of equipment and piping.

The pump(s) is sized to match the maximum RCS letdown flow. Typically, one pump serves as a standby for the other. The pumps are centrifugal, constructed of austenitic stainless steel.

Boric Acid Transfer Pump

The boric acid transfer pump is used in PWR plants as part of the CVCS. This pump provides for recirculation of the boric acid system, normal makeup of boric acid solution, and provides boric acid directly to the charging pump suction for emergency boration purposes. This pump is generally a two-speed horizontal centrifugal pump. All parts in contact with the boric acid solutions are austenitic stainless steel or other adequate corrosion-resistant material. The pumps (normally there are two or more pumps per plant) are thermostatically controlled with heat tracing and insulation to maintain a temperature well above the solubility limit of the boric acid solution to prevent pump rotor binding from boric acid crystals. The boric acid solution is generally 11-13% weight percent boric acid.

High-Pressure Coolant Injection Pumps

The High-Pressure Coolant Injection (HPCI) System is a high pressure ECCS in BWR plants. This system ensures adequate core cooling takes place for all pipe breaks less than those sizes for which low-pressure coolant injection (LPCI) or core spray can satisfactorily protect the core. The HPCI pump is usually turbine-driven using reactor steam. The pump takes suction from the condensate storage tanks or the containment wetwell and injects the water to a feedwater line.

The HPCI pump is a multistage centrifugal with a carbon steel casing, stainless steel shaft and impellers, and bronze wear rings. The pump is normally on standby and is operated monthly or quarterly for testing purposes.

Reactor Core Isolation Cooling Pump

The Reactor Core Isolation Cooling (RCIC) System is a BWR system which provides an automatic supply of makeup water to the reactor core when the reactor is isolated from the turbine, the reactor feedwater system is unavailable, and the primary system relief valves are being used to maintain vessel pressure. The system starts automatically during a loss of all AC power to maintain the water level above the core. The RCIC pump is driven by a turbine.

The RCIC pump can take suction from the condensate storage tanks or suppression pool and discharges the water to a reactor feedwater line during emergency conditions. The pump is normally operated on a monthly or quarterly basis for testing purposes only. The pump is a horizontal multistage centrifugal type pump. The pump casing is typically cast carbon steel with stainless shaft and bronze impellers. Shaft seals are typically mechanical seals.

Core Spray Pumps

The Core Spray System is a low pressure ECCS in a BWR plant which functions to deliver sufficient cooling water, in the form of spray, to the core to prevent fuel clad melting. Newer BWR plants have high pressure core spray pumps as-well-as low pressure core spray pumps. The core spray pumps are vertical, single stage, double suction centrifugal pumps. In the event of a loss-of-coolant accident (LOCA), these pumps take suction from either the suppression pool or condensate storage tank and discharge to a sparger ring inside the reactor vessel inner shroud.

The core spray pumps are generally fabricated from cast carbon steel, with a stainless steel shaft, stainless or bronze impeller and bronze wear rings.

Residual Heat Removal Pumps

The residual heat removal (RHR) pumps in BWR applications are single stage, vertical, centrifugal pumps. In PWR applications, these pumps are the same type, except they may be installed vertically or horizontally. In BWRs the RHR pumps/system are aligned for LPCI as part of an ECCS to restore and maintain the core water level in the event of an LOCA and (in a BWR) head spray and containment spray/cooling. In PWRs, RHR pumps are used during plant cooldown. PWR RHR pumps take suction from a hot leg (reactor coolant) and circulate it through the reactor. During normal plant shutdown, the RHR pumps for PWRs and BWRs are utilized to remove decay heat from the reactor vessel primary coolant.

The RHR pumps are typically cast carbon steel or stainless steel casings with stainless steel shafts and impellers. A mechanical seal is usually used for shaft sealing. The wearing rings are usually bronze material.

Control Rod Drive Pump

Control rod drive (CRD) pumps are used in BWR reactor control systems. There are two pumps, each 100 percent capacity, driven by motors. One pump runs during normal operation, and one is in standby. These pumps are multistage diffuser-type horizontal centrifugal pumps. They process demineralized water, either condensate reject or water from the condensate storage tanks. Pump casings are cast alloy steel, split axially to form an upper and lower casing. The impellers are made of cast alloy steel and the stationary internals are made of gray cast iron. The shaft is stainless steel. These pumps operate at low flow, high pressure.

Closed Cooling Water Pumps

Closed cooling water pumps are used in both PWRs and BWRs. These pumps are installed in various systems, including:

- Component Cooling Water
- Auxiliary Building Closed Cooling Water
- Containment Chilled Water
- Emergency Equipment Cooling Water
- Reactor Building Closed Cooling Water

These pumps supply treated cooling water to safety-related equipment. The Closed Cooling Water Systems remove heat from the primary water system and reject it to the service water (or intake source). There are normally two or more pumps installed in separate independent loops. One pump is normally in standby (or, installed spare) with the other pump(s) running to provide normal cooling capability.

The pumps are horizontal centrifugal type, pumping chemically treated demineralized water. The water is treated with a corrosion inhibitor, such as sodium nitrite or potassium chromate.

Service Water Pumps

Service water pumps are used in both BWRs and PWRs. The service applications include auxiliary service water, essential service water, nuclear service water, residual heat removal service water, and emergency diesel generator essential service water. The system names vary from plant-to-plant. These service water pumps take suction from an intake source and provide flow and head to cool various systems equipment. The heat is rejected to the ultimate heat sink by direct discharge or sometimes with an assist from cooling towers.

The service water (SW) pumps installed in PWR facilities provide cooling water for safety-related equipment, emergency backup supply to control room air conditioners, and a backup water supply for the auxiliary feedwater system. At least one pump is normally running to supply the cooling loads, and the other pump(s) is in standby and will automatically start on low SW header pressure, a safety injection signal, and upon plant blackout signal. There are normally two separate, redundant loops, each with one or more pumps. The pumps take suction from the plant intake, after the water passes through a series of coarse and fine mesh screens. An automatic, continuous strainer is in the discharge of each pump to remove solids prior to the water entering plant equipment. The pumps are vertical centrifugal multistage sump-type or turbine-type pumps capable of high flow at low head. Depending on the plant location, the fluids pumped may be fresh water or sea (brackish) water.

The service water pumps typically installed in BWR facilities are all similar in design and function. Some of the pumps are in continuous service and others are in standby.

- Residual Heat Removal Service Water (RHRSW)
- Emergency Service Water (ESW)

- Emergency Diesel Emergency Service Water (EDG-ESW)

These pumps supply untreated cooling water to safety related equipment during normal operation and during accident conditions. The pumps are vertically mounted in the intake structure. They are multistage centrifugal turbine type, driven by electric motors. The impellers are immersed in the pump bay. Water leaving the pump bowl assembly flows vertically up the pump column along the pump shaft. The water is the lubricant for the pump bowl and line shaft bearings. These pumps are normally in standby and are operated monthly for testing. Typical pump materials are carbon steel for the casing, carbon steel or cast iron bowl, stainless steel shaft, bronze impellers and bronze or stainless steel rings.

Spent Fuel Pool Cooling Pump

The Spent Fuel Pool Cooling Pumps are part of the Fuel Pool Cooling/Demineralizer System and used in both BWR and PWR plants. There are normally two pumps which run continuously to maintain the temperature and clarity of the fuel pool water. These pumps recirculate the water in the spent fuel pool. PWR spent fuel pool water contains borated (i.e., 2,000-2,500 ppm) demineralized water whereas BWR spent fuel pools contain only demineralized water.

The pumps are single-stage horizontal centrifugal type with an overhung closed impeller. The pumps are stainless steel with stainless steel shafts and impellers.

Reactor Water Cleanup Pump

The RWCU System provides continuous purification of a portion of the reactor recirculation flow in a BWR reactor. This system contains two pumps in separate, independent loops. Each pump provides 50 percent of system capacity. The pumps are horizontal centrifugal type, fabricated from stainless steel.

Emergency Diesel Generator Jacket Water Cooling Pumps

The jacket water cooling pumps are motor-driven, horizontal, centrifugal pumps which typically run only when the diesel generator is in operation. These pumps supply chemically treated water (closed system) through the engine for cooling purposes. Pump capacities range from 1890 to 3785 liters per minute [500 to 1,000 gpm] at 207 to 276 kPa [30 to 40 psig]. Water temperature is maintained at 26° to 71°C [80° to 160°F] to cool the engine during operation and to maintain the engine in a warm, standby condition. An auxiliary jacket water pump is typically installed to circulate the warm water during standby conditions. This pump is a much smaller horizontal centrifugal pump with a capacity of 38 to 190 liters per minute [10 to 50 gpm].

3.4.5.2 Reciprocating Pumps

Charging Pump

A PWR charging pump can be a reciprocating pump as well as a centrifugal pump. The centrifugal charging pump was described in Section 3.4.5.1. The reciprocating charging pump functions similar to the centrifugal pump. They automatically start and stop on demand as pressurizer pressure decreases or increases with load transients or varying plant conditions. One of the primary purposes is to provide normal RCS makeup flow; another is to borate or deborate the RCS. Normally, one charging pump is running to balance letdown purification flow and reactor coolant pump leak-off flow with charging flow into the RCS. The pumps are typically piston triplex pumps.

Some plant installations include a reciprocating charging pump with two centrifugal charging pumps. The reciprocating pump in this configuration is typically maintained in a standby condition.

Standby Liquid Control Pumps

The Standby Liquid Control (SLC) System is used in BWR plants and is designed to inject a sodium pentaborate solution into the reactor core at a controlled rate to bring the reactor to a shutdown condition even if all the control rods are 100% withdrawn and unavailable for insertion. The system, as its name implies, is normally in standby and is manually initiated by plant operators.

The pumps are typically stainless steel reciprocating triplex plunger type which are driven by electric motors through a triple reduction gear reducer. The plungers are typically overlaid with Colmonoy or equivalent wear-resistant material.

In the standby condition, the SLC System is filled with the borated solution to the upstream side of the pump inlet valve. The suction piping and pump plunger casing are electrically heat traced to avoid crystallization of the solution. The pump plunger seals prevent the solution from entering the pump outlet and discharge lines. The suction line is drained of solution prior to testing with demineralized water.

3.4.5.3 Rotary Pumps

Lubricating Oil Pumps

Lubricating oil pumps are used in the lubricating oil subsystems of large equipment, such as the HPCI pump, centrifugal charging pump (CCP) and the emergency diesel engine. The pumps evaluated are rotary positive displacement type gear pumps. These pumps are small motor-driven pumps with capacities ranging from 23 to 415 liters per minute [6 to 110 gpm]. Depending on the design service, the pumps may be run continuously or intermittently.

Emergency Diesel Generator Fuel Oil Transfer Pumps

The fuel oil transfer pumps associated with the emergency diesel generators are usually small, motor-driven rotary gear pumps with capacities ranging from 26 to 150 liters per minute [7 to 40 gpm]. Some plants use multistage centrifugal pumps for this service. These pumps run intermittently to maintain fuel oil level in the diesel oil day tanks.

3.5 Design Requirements

The design requirements for pumps in nuclear service have evolved since the early 1960s. Prior to 1963, pumps were typically designed to the guidelines of the Hydraulic Institute (first published in 1917). For nuclear applications prior to 1965, the ASME Boiler and Pressure Vessel (B&PV) Code, Section VIII, "Unfired Pressure Vessels Built by Welding" was cited for the pressure boundary. Following issuance of the 1965 ASME B&PVC, Section III "Nuclear Vessels," pump pressure boundaries were designed to either Quality Group A, B, or C requirements. In 1968, a draft ASME Code for pumps and valves for nuclear power was issued for comment and was cited for pump design until its inclusion in the 1971 ASME B&PV, Section III. Since 1971, the design of pumps employed in mechanical systems important to nuclear plant safety and production have cited Section III for pressure boundary design. Pump designs for balance-of-plant applications commonly followed the Hydraulic Institute guidelines as a minimum.

Until 1977, the focus of the ASME B&PVC was on the design, fabrication, construction, and testing of the pressure retaining boundary (shell or casing). The 1977 code further defined the design boundary to include structural internals, integral pump support elements, and other components (except shafts, impellers, nonstructural internals, and seals). Specific design guidance based on pump classification Types A through L, per Table 3-11 was also given. Design requirements specified in later editions of ASME Section III have not been substantially modified. Code Case N-119-6 (approved September 5, 1985) set forth the material, fabrication, and examination requirements for internal components of ASME Class 1, 2, and 3 pumps. However, the design of pump components other than the pressure boundary remains in the manufacturer's jurisdiction/specification.

Pump designs are based on analytical and laboratory test results and historical performance. Formal stress and fatigue calculations in accordance with the ASME B&PV Code are performed for all pressure boundary components (casing, cover, seal, flange, etc.). The design of rotating or moving elements including the shaft and impeller also involve a stress analysis and application comparison to previous designs. Selection of materials for all elements is based on the service application, environmental data, and expected duty.

The resistance of pump components to various aging mechanisms is determined to some extent by the properties of the metals selected. Metallurgical processes which occur over long periods of time can often change the molecular structure and chemistry in localized areas which significantly reduce the original resistance to specific aging mechanisms. Metallurgical dealloying processes are usually those pertinent to the materials selected for pumps in these applications. Examples include dezincification and dealuminalization for brass and bronze materials and graphitic corrosion for cast iron materials (see Section 4). These processes are known to occur in aqueous environments, but they are as dependent on the original material chemistry/forming processes and calendar time as they are the environment. These metallurgical changes to materials usually originate at the exterior surface where they affect resistance to corrosion, erosion, fatigue, and wear.

Table 3-11. ASME B&PVC Section III Pump Classification

Pump Type	Description of Pressure Boundary
A	Single Volute, Radially Split Casing, Single Suction
B	Single Volute, Radially Split Casing, Double Suction
C	Double Volute, Radially Split Casing, Single Suction
D	Double Volute, Radially Split Casing, Double Suction
E	Volute Type Radially Split and Multivane Diffusers
F	Radially Split Axisymmetric Casing with either Tangential or Radial Outlets
G	Axially Split, Single or Double Volute (Class 2, 3)
H	Axially Split, Barrel Type Casings and Radially Split Covers (Class 2, 3)
J	All other Pumps (Class I)
K	Vertical Turbine Pump (one or more stages) with Radially Split Casing and Barrel Enclosure (Class 2, 3)
L	Vertical Turbine Pump (one or more stages) with Radially Split Casing (Class 3)

3.5.1 Compliance with Standard Review Plan

NUREG-0800[3.13] establishes the format and content requirements of the safety analysis reports prepared for nuclear plants during design and construction. NUREG-0800 does not require the licensee to specifically address the provisions for detection and mitigation of aging. Overall, the review of NUREG-0800 did not identify any criteria related to pump aging beyond the requirements for testability. Accessibility for testing ensures a method of detecting degradation.

NUREG-1299[3.14] focuses on the license renewal requirements in 10 CFR 54. The format and content of the integrated plant assessment, to be prepared in support of license renewal application, is described. The primary purpose of the assessment is to determine the effectiveness of plant programs to detect and mitigate age-related degradation of SSCs.

NUREG-1299[3.14] is a draft document only. This document identifies each system which may be important to license renewal and is intended to be used by the NRC staff during performance of safety reviews of applications for renewal of nuclear power licenses. It provides the framework to ensure that (among other things) the application identifies SSCs which are important to license renewal, significant age-related degradation has been identified and evaluated, and programs to manage aging are or will be implemented. NUREG-1299 discusses pump aging for typical SSCs important to license renewal. Typical aging age-related degradation mechanisms that could affect the operation and safety of the pumps in the systems are identified. NUREG-1299 was reviewed to ensure that this AMG considers the identified aging mechanisms and programs for management of pump aging. Sections 4 and 5 of this AMG include the evaluations and conclusions of pump aging and aging management. Where applicable, additional aging mechanisms and aging management programs identified in industry documents and lead plant license renewal studies are discussed.

3.5.2 Application and Qualification of Non-Metallic Materials

The non-metallic parts, such as gaskets, bearings, seals, packings, and lubricants are required to maintain active functions, such as rotation, or a passive function, such as prevention of leakage.

The important applications of non-metallic materials are discussed below:

- Bearings

  Non-metallic bearings are used for small, light-duty pumps. The pumps evaluated in this guideline do not use non-metallic bearings.[3.7]

- Lubricants

  Lubricants in the form of oil or grease are used for pump shafts and bearings. Oils and greases are fairly resistant to radiation. Other aging mechanisms result in thickening, hardening, and contamination, and require replacement of oils and greases.

- Bushings

  Bushings can be made of metallic or non-metallic material. Non-metallic materials, such as carbon, rubber, and impregnated graphite, are used as interstage and line-shaft bearing and stuffing box bushings. Reciprocating pump bushings are generally metallic.

- Gaskets and Packing

  Gaskets are used primarily in flanged joints, such as between pump casing halves. Gaskets are typically fully retained on all sides by metallic surfaces, protecting them from direct radiation exposure. A gasket failure or shaft seal failure results in leakage. However, the operability of the pump may not be affected.

  Packing material is often used for pump shaft seals. Although most safety-related pumps use mechanical seals to reduce the potential for leakage.

- Seals

  Seals can be in many different configurations, such as O-rings and labyrinths. O-rings are used for sealing between mating metallic surfaces. O-rings are generally elastomeric which is subject to compression set. O-ring and labyrinth seals can be used on the shaft to prevent leakage.

- Couplings

  Flexing-element couplings can be elastomeric. The oldest elastomeric design has two steel disks, with the driving disk having rigid studs and a metal lined rubber bushing. Some coupling designs place the elastomeric blocks in compression.

Qualification of other non-metallic materials is best handled by design review of materials in contact with the pump fluid and environment. Elevated temperatures affect degradation of non-metallics such as oil and elastomers. These materials require controlled operating temperatures to function properly. As a rule, non-metallic materials can be qualified by surveillance tests when operating temperatures and transient/accident temperatures are nearly the same. If higher transient or accident temperatures are anticipated, then a material evaluation needs to be performed.

The general threshold for radiation damage of non-metallic materials is 10^3 gray [10^5 rad]. However, for oils and greases, the threshold is 10^5 gray [10^7 rad], and asbestos and carbon-based materials, the threshold is 10^7 gray [10^9 rad] or greater.[3.10]

Tables 3-12 and 3-13 list published information on allowable temperatures and radiation exposure for some common non-metallic materials and lubricants used in pumps. The radiation doses are based on studies of elastomer-based electrical insulation jacket combinations.[3.10]

It should be noted that almost all the safety-related mechanical equipment using oil lubricants such as pumps and diesel engines are all located outside of containment where integrated accident radiation doses are 10^5 gray [10^7 rad], or less.

The materials listed in Tables 3-12 and 3-13 all have serviceable radiation levels of 5×10^4 gray [5×10^6 rad] or greater. This suggests that a specific review for non-metallic material qualification is appropriate only for mechanical components located in the high potential radiation zones. A threshold for all organic materials (except Teflon which is reported as 1.5×10^2 gray [1.5×10^4 rad] has been reported as 10^3 gray [10^5 rad],[3.10] while Table 3-13 shows that an oil and grease threshold should be 10^5 gray [10^7 rad]. These facts suggest the following guidelines.[3.10]

1. Oils and Greases: Conduct a design review only if the integrated post accident radiation dose exceeds 10^5 gray [10^7 rad].

2. Organic Materials: Conduct an analysis or test only if the radiation dose is $>10^4$ or if the equipment contains no teflon and radiation doses are greater than 10^3 gray [10^5 rad].

3. Graphite and Asbestos Materials: Waive further design review if the only non-metallic materials used in the equipment are graphite or asbestos based.

Table 3-12. Non-Metallic Material Allowable Temperature and Radiation Exposures*

Popular Name	Chemical Designation	Max Continuous Temperature °C [°F]	Serviceable Radiation Level gray [rad]
Butyl GRI	Isobutylene-Isoprene	85 [185]	5×10^4 [5×10^6]
Neoprene GRM	Chloroprene	93 [200]	5×10^5 [5×10^7]
Buna	Butadiene	104 [220]	5×10^4 [5×10^6]
EPR	Ethylene Propylene	149 [300]	1×10^6 [1×10^8]
Fluoro-elastomer (Viton)	Vinylidene fluoride + hexafluoro-propylene	204 [400]	5×10^5 [5×10^7]
Teflon (TFE)	Fluoroethylene	260 [500]	1.7×10^2 [1.7×10^4]
Nylon	Polyamide	149 [300]	4.7×10^4 [4.7×10^6]
Tefzel	Fluoropolymer	150 [302]	5×10^5 [5×10^7]

Note: Serviceable radiation level is intended to be an order of magnitude screening value to indicate the relative importance of radiation, as compared with other aging factors such as temperature and wear, in the overall evaluation of environmental qualification.

* Per Reference 3.10

Table 3-13. Non-Metallic Material Radiation Data

Material	Radiation gray [rad]	Trade Name
Oils	5×10^5 [5×10^7]	All Mobil Oils
	1×10^6 [1×10^8]	High Quality Conventional Mobil Oils
Grease	2×10^5 [2×10^7]	All Mobil Greases
	3×10^6 [3×10^8]	Mobilux 2 and 3 Mobilgrease Special Gargoyle 1200 and 1200W Mobilgrease 28 and 29 Mobiltemp 78 Mobilux EP2 Chevron Grease 159
Gaskets & Packing		
Asbestos & Steel	10^7 [10^9]	Flexitallic
Fluoro-Elastomer	(see Table 3-12)	

3.6 Operating and Service History

A review of industry data and documents was conducted to determine the industry-wide operating experience with the pumps evaluated in this guideline. The types of documents reviewed were:

a. LER database
b. NPRDS
c. NRC Bulletins, Information Notices, Generic Letters, and Circulars
d. Plant Operating and Service Data

A summary of the reviews of each of the above documents is discussed in this section. Section 3.6.1 contains the LER database review and conclusions and Section 3.6.2 summarizes the NPRDS review.

A list of the NRC Bulletins, Notices, Generic Letters, and Circulars applicable to the pumps evaluated in this guideline is included in Table 3-6. These documents identify pump/system degradation that is also contained in the LER and NPRDS information.

Plant operating and service data was received from several utilities in response to a questionnaire on pump types, design parameters, and maintenance history. The pump failure/degradation identified in these responses is also either included or in basic agreement with the aging mechanisms identified in the LER and NPRDS information. For this reason, the LER and NPRDS discussions adequately cover plant operating experiences and separate discussion is not necessary.

3.6.1 Licensee Event Report Evaluation

LERs are submitted to the NRC by nuclear power plants for a number of reasons. Some of the reasons which are applicable to pumps evaluated in this guideline include:

- Any operation or condition prohibited by the plant's technical specifications.
- Any event or condition that results in the condition of the nuclear power plant, including its principal safety barrier, being seriously degraded.
- Any event where a single cause or condition caused at least one independent train to become inoperable in multiple systems or two independent trains to become inoperable in a single system.

A key word search of pump failures/degradations was performed on the LER database for the period from 1980 through June 1992. The sort of LERs was further categorized to those incidents where pump failures/degradations were potentially caused by aging mechanisms. The categories are:

- Pump failures which were due to age/wear/end-of-life, fatigue or vibration

- Pump failures due to corrosion, erosion, condensation, or high humidity/steam
- Pump failures due to foreign material, aquatic organisms, inadequate lubrication, or radiation exposure
- Pump failures due to high or low temperatures
- All pump failures for the years 1980-1992

The results of this data search yielded 443 total LER abstracts dealing with pump failures/ degradation. A review of these abstracts was performed to segregate those pumps included in the scope of this guideline and where aging was identified as the primary cause of the pump failure/degradation. The results of this review show that 27.3% (121) of the LERs are associated with pumps included in the scope of the guideline and where failure/degradation was most likely caused by some form of aging. A total of 158 pump subcomponents were identified as having experienced some form of failure/degradation due to aging.

Of the 443 LER abstracts, 72.7% (i.e., 322) were omitted from consideration in this guideline. Those LERs omitted fell into one of the following four categories:

- Situations where the primary cause of pump failure/degradation was clearly due to something other than aging. For example, design error, procedure deficiency, inadequate or improperly performed maintenance, personnel error, etc.
- The pump is not in the scope of this guideline. For example, stack gas sample pumps, fire protection pumps, continuous air monitor pumps, drywell air sampling pumps, process vent radiation monitor pump, etc.
- Situations where pump failure was caused by an aging failure/degradation of a supporting piece of equipment such as the turbine drive, motor, instrumentation, electrical breaker, etc.
- Situations where the pumps covered in the LER were either the reactor coolant pump (PWR specific) or reactor recirculation pump (BWR specific). These two types of pumps are evaluated in the NUMARC Industry Reports for Reactor Coolant Primary Pressure Boundary.[3.4, 3.5]

Several conclusions can be drawn from analysis of this LER data. Figure 3-18 shows the relative percentage of the various aging mechanisms causing pump failure/degradation. Wear is the predominant aging mechanism (56.2%) that causes pump failure/degradation. Fouling and fatigue rank number two (18.2%) and three (9.1%) respectively. Other aging mechanisms are erosion and erosion/corrosion, general corrosion, IGSCC, and Microbiological Influenced Corrosion (MIC).

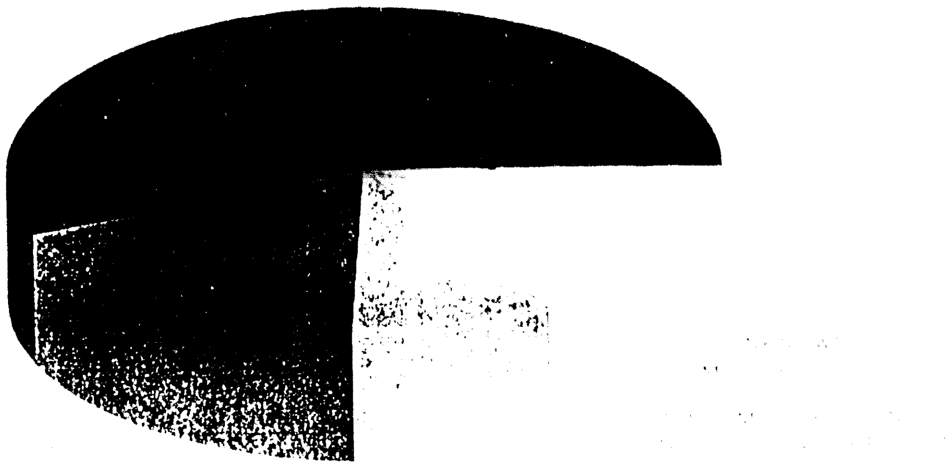


Figure 3-18. Pump Failure and Aging Causes

Wear, fouling and fatigue, as expected, account for an overwhelming majority of the total pump failures/degradations, particularly when considering the types of pumps experiencing the most failures. In BWRs, the RHRSW System pumps account for [illegible]% of the failures, followed by the ESW System pumps ([illegible]%) and the RHR System pumps (12.[illegible]%). In PWRs, the Emergency Auxiliary Feedwater System pumps account for [illegible]% of the failures followed by the Chemical and Volume Control System charging pumps ([illegible]%) and the ESW System pumps ([illegible]%). Table 3-[illegible] categorizes all of the BWR and PWR pump failures attributable to aging.

What these systems have in common is that each contain multiple pumps which are normally maintained in a standby condition. Even in the case of the Chemical and Volume Control System Charging Pumps (in a continuously operating system), only one of three pumps normally operates while the other two are placed in standby. A further commonality is that this group of system pumps is required to operate much more frequently (i.e., a greater number of start and stop cycles) than other system pumps normally maintained in standby. For example, in a BWR the RHRSW, RHR, and ESW pumps are required to undergo surveillance and ASME Section XI testing typically on a quarterly basis. In addition, these pumps are required to periodically operate in support of other plant evolutions such as shutdown cooling/decay heat removal, suppression pool cooling, and routine testing of other Engineered Safety Feature (ESF) equipment that requires cooling water. Consequently, this type of service duty causes additional stress on the various pump parts and a greater number of failures/level of degradation.

Figure 3-19 depicts the percentage of pump failure/degradations by subcomponent. The more active pump subcomponents exhibit a higher percentage of failure (i.e., rotating, reciprocating, and mechanical subsystems) while the passive subcomponents (fixed internals and pressure boundary) experience less failures. These findings confirm the fact that passive pump subcomponents tend to fail or degrade from aging over a much longer operating time period.

Table 3-14. Pump Aging Failures LER Database 1980-1992

Boiling Water Reactor Plant Pumps	Number of Failures Due to Aging	Percent of Total
	BWRs	
RHR Service Water	27	55.2
Emergency/Essential Service Water	9	18.4
Residual Heat Removal	6	12.2
CRD	2	4.1
HPCI Lube Oil Pump	2	4.1
EDG Fuel Oil	1	2.0
EDG Lube Oil	1	2.0
RWCU	1	2.0
TOTAL	49	
	PWRs	
Feedwater (Emergency/Auxiliary)	18	25.0
Charging	17	23.6
Emergency/Essential Service Water	12	16.7
Boric Acid Transfer	6	8.4
Residual Heat Removal	4	5.6
EDG Jacket Cooling	3	4.2
Charging Pump Cooling Water	3	4.2
Recirculation Spray	2	2.8
Safety Injection	2	2.8
Feedwater Oil Pump	2	2.8
Containment Spray	1	1.3
Spent Fuel Pool Cooling	1	1.3
EDG Service Water	1	1.3
TOTAL	72	

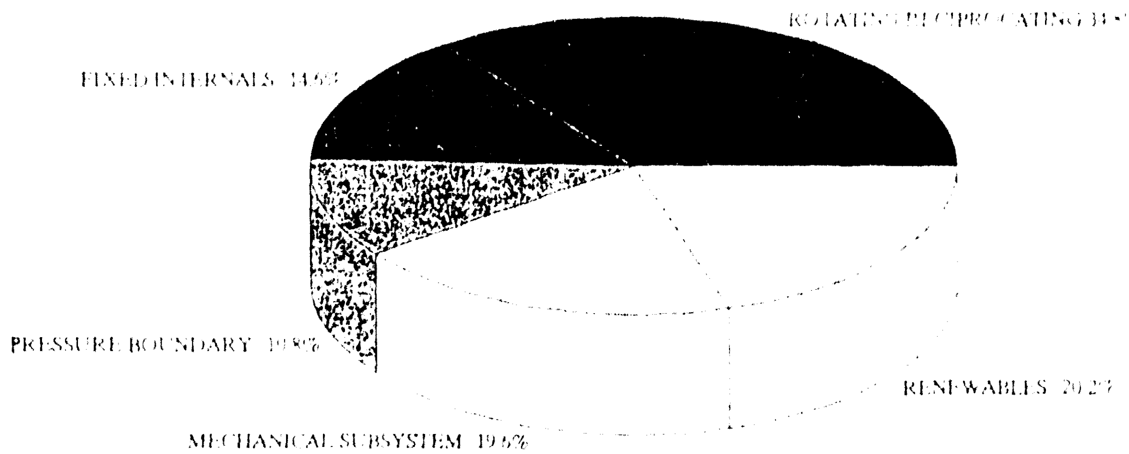


Figure 3-19. Pump Subcomponent Failures Due to Aging.

Further analysis of the LER data, shown on Tables 3-15 and 3-16, indicates, as expected, that the pump bearings, internal rotor, impellers, and wear rings collectively account for 71.4% of the total number of failures. Wear and fouling are the predominant aging mechanisms accounting for nearly 90% of the total number of failures/degradation of these subcomponents. Fatigue, which ranked as the third highest contributor to pump failures/degradation (Figure 3-18) was found to occur primarily in the pump shaft, miscellaneous spacers, and at nozzles/attachments to the pump casing. Vibration appears to be the major contributor for fatigue failure of these pump subcomponents. Also, these vibratory stresses are a contributing factor to the high incidence of wear.

All other aging mechanisms combined accounted for less than 12% of the total number of pump subcomponent failures (i.e., 18 incidents) and the cause of eight failures could not be positively identified. Of the 18 incidents, 6 were caused by erosion and erosion/corrosion, 5 by IGSCC, 5 by general corrosion, and 2 by MIC. These aging mechanisms generally manifest over long periods of time before failure occurs. This may be the reason why only 12% of the failures were attributed to either erosion, erosion/corrosion, IGSCC, uniform corrosion, or MIC. The oldest plants began commercial operation in the early 1960s. Therefore, LER data of aging failures is representative and envelopes these slower acting aging mechanisms as well as the faster acting mechanisms.

The six (6) incidents of erosion and erosion/corrosion were specifically caused by vortexing/cavitation (two incidents) and particle impingement (four incidents). Service water pumps and centrifugal charging pumps were the only pumps to experience this aging mechanism. There were no incidents of erosion and erosion/corrosion due to high temperature single-phase fluid.

Table 3-15. Pump Subcomponent Failures LER Database 1980-1992

Subcomponent	Number of Failures Due to Aging	Percent of Total
	ROTATING/RECIPROCATING	
Shaft	8	5.1
Impeller	26	16.4
Piston Plunger	2	1.3
Internal Rotor	12	7.6
Internal Valve	1	0.6
Spacers	6	3.8
TOTAL	55	SUBTOTAL 34.8%
	FIXED INTERNALS	
Wear Ring	15	9.5
Flow Guide	2	1.3
Suction Strainer	3	1.9
Spacers	3	1.9
TOTAL	23	SUBTOTAL 14.6 %
	PRESSURE BOUNDARY	
Casing	15	9.5
Suction/Discharge Nozzle	2	1.3
TOTAL	17	SUBTOTAL 10.8%
	MECHANICAL SUBSYSTEMS	
Coupling	2	1.3
Radial Bearing	24	15.1
Thrust Bearing	5	3.2
TOTAL	31	SUBTOTAL 19.6%
	RENEWABLES	
Gasket	1	0.6
Seals (packing/mechanical)	31	19.6
TOTAL	32	20.2%
GRAND TOTAL	158	100.0%

Table 3-16. Pump Subcomponent Failures and Aging Causes LER Database 1980-1993

Pump Subcomponents	Fatigue	Corrosion			Stress Corrosion Cracking			Erosion	Embrittlement		Wear	Stress Relaxation	Creep	Fouling	Total	Cause Unknown
		UNIF.	GALV	MIC	IGSCC	IASCC	TGSCC		Thermal	Neutron						
Rotating/Reciprocating																
Shaft	3				1						2				6	2
Impeller				1	1			2			10			12	26	0
Piston Plunger											1				1	1
Internal Rotor								1			6			2	9	3
Internal Valve											1				1	0
Spacers	3				1						2				6	0
Fixed Internals																
Wear Ring					1						13			1	15	0
Flow Guide					1									1	2	0
Suction Strainer														3	3	0
Spacers	1										2				3	0
Pressure Boundary																
Casing	4	1		1				2						7	15	0
Suct./Disch. Nozzle								1						1	2	0
Mechanical Subsystems																
Coupling	1														1	1
Radial Bearing		1									20			2	23	1
Thrust Bearing											5				5	0
Renewables																
Gasket											1				1	0
Seals (Packing/Mech.)	1	3									24			3	31	0
	13	5	0	2	5	0	0	6	0	0	87	0	0	32	150	8
															158	

IGSCC was identified as the cause of failure in five (5) incidents, four (4) associated with stainless steel subcomponents of two (2) separate auxiliary feedwater pumps and one (1) associated with a BWR RHR pump.

Corrosion was identified in seven (7) incidents as the primary cause of subcomponent failure. MIC was the cause of failure/degradation associated with an impeller and casing of one (1) ESW pump. General corrosion was the cause of pump packing/seal failure in four (4) incidents and in one (1) incident a boric acid transfer pump casing experienced degradation due to general corrosion from exposure to boric acid.

Figure 3-20 illustrates the stressors associated with the aging degradation mechanisms identified in the LER database. Tribological stressors (interaction of machine components, friction, and lubrication) account for the majority of pump wear. Mechanical stressors such as vibration and misalignment account for most of the other pump wear incidences. Mechanical stressors such as debris from water sources and silt buildup account for most of the fouling degradation. In summary, a significant reduction in the number of pump failures/degradation can be achieved if packing and shaft seal leakage is reduced, foreign material fouling is adequately controlled and pump vibration is monitored and controlled within acceptable limits.

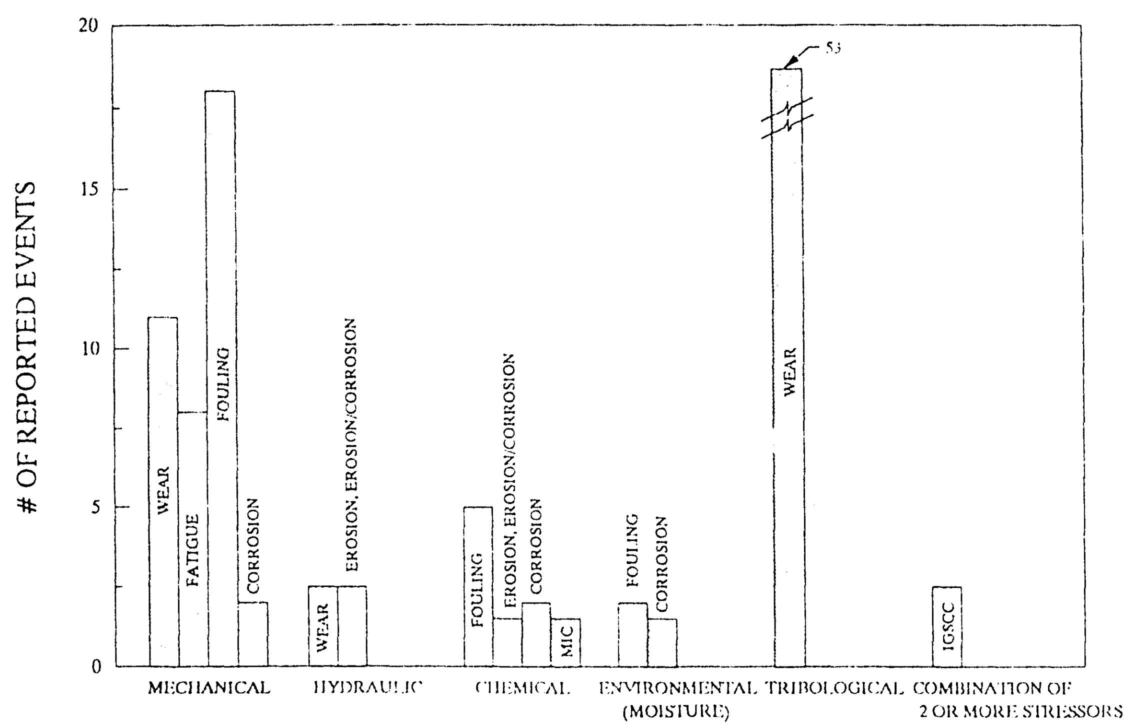


Figure 3-20. Stressors Acting on Pumps LER Database.

3.6.2 Nuclear Plant Reliability Data System Evaluation

The NPRDS was developed in 1973, to collect data on safety-related equipment. Since then, NPRDS' scope has been expanded to include other systems and components that provide critical safety functions and whose loss of function can initiate a significant transient. Utilities submit component failure records whenever an NPRDS-reportable component fails to perform one or more of its intended functions.[3.15] Reporting of failures is a voluntary industry effort and, therefore, there are many variations in interpretation of reportability requirements and contents and consistency of reports. For example, potential failures that were prevented by testing and corrective actions may not have been reported. If that is the case, mean-time-between-failure data calculated from reported failure data would not be accurate. Per INPO-89-014, United States nuclear utilities have demonstrated their support of NPRDS by dedicating resources to report all reportable failures that have occurred since January 1, 1984, or when the plant begins commercial operation. Prior to that date, the LER was widely used for reporting failures.

A key word search of pump failures/degradations was performed on NPRDS for the period of 1973 through May 1992. A total of 7,538 records involving pumps was identified. A review of these records was performed to identify those records where pump failure/degradation was potentially caused by aging mechanisms for the pumps included in the scope of this guideline. This review reduced the number of incidents to 1,103, or 14.6% of all pump failures reported. Thus, 6,435 NPRDS reported incidences (85.4%) were omitted from consideration in this guideline. NPRDS reports were omitted for the following reasons:

- Situations where the primary cause of pump failure/degradation was clearly due to something other than aging. For example, design error, procedure deficiency, inadequate or improperly performed maintenance, personnel error, etc.

- The particular pump is not in the scope of this guideline. For example, main feedwater pumps, condensate booster pumps, condenser hotwell pumps, HPCI gland seal condensate pumps, etc.

- Situations where pump failure was caused by an aging failure/degradation of a supporting piece of equipment such as the turbine drive, motor, instrumentation, electrical breaker, etc.

- Situations where the pumps were either the reactor coolant pump (PWR specific) or reactor recirculation pump (BWR specific). These two types of pumps are evaluated in the NUMARC Industry Reports for Reactor Coolant Primary Pressure Boundary. [3.4, 3.5]

- Situations where the pump failure was caused by packing leaks, seal leaks, or gasket leaks. These subcomponents are considered renewable (see Section 3.4.2).

Figure 3-21 shows the number of NPRDS-reported pump failures due to aging degradation and the number of plants in commercial operation. The trend shows a significant increase in 1984-86. Although it may be coincidental, this increase in aging failures occurred at the same

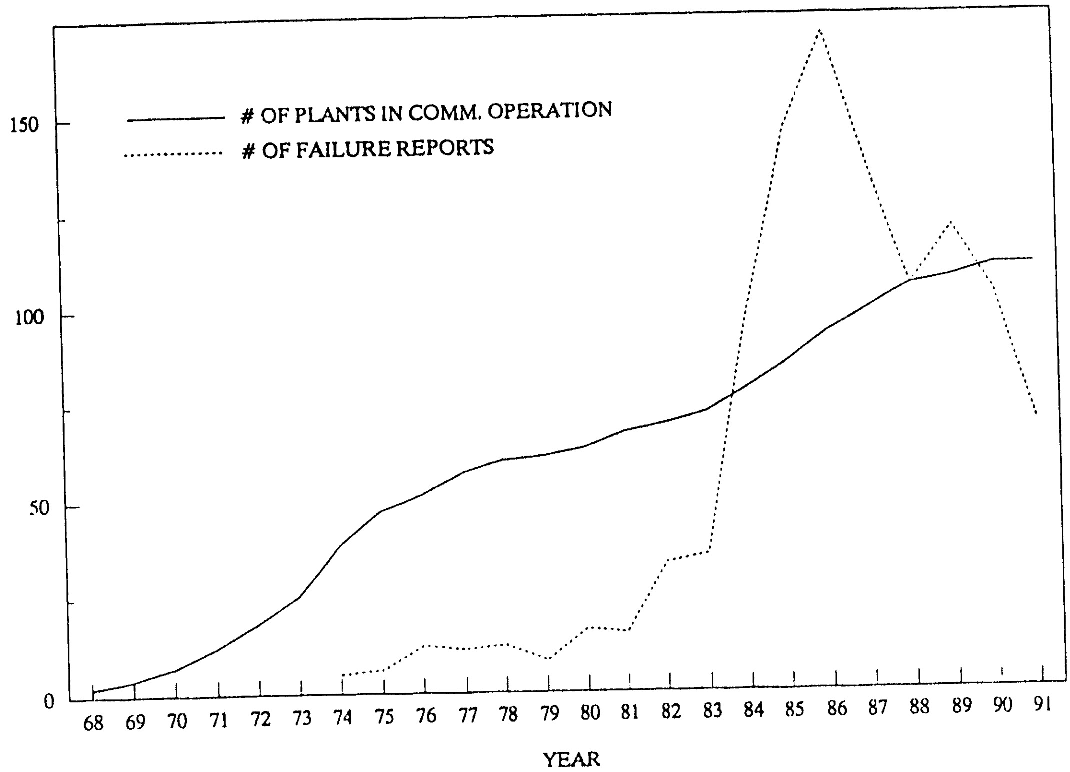


Figure 3-21. Pump Aging Failures NPRDS Database.

time that NPRDS reporting was given a higher priority by utilities and the NPRDS data system was given more emphasis in the industry. Also, several new nuclear plants achieved commercial operation during this time frame and started entering data. The increase was especially evident in PWR charging pumps, service water pumps and component cooling water pumps, and in BWR service water (includes RHRSW) pumps. Since 1987, the number of failure reports has decreased significantly due to increased emphasis on preventive maintenance and monitoring methods, better water chemistry control, and refurbishments.

Figures 3-22 and 3-23 illustrate the number of NPRDS-reported pump failures by plant type. A comparison of these graphs indicates that the failure reporting increase in the 1984-86 period was similar for both PWRs and BWRs. These graphs also illustrate that the reporting increase was independent of the number of pumps in service. In other words, the failure reporting increase did not appear to be due to a significant increase in the number of pumps.

There were 241 failures where the pumps were in service less than five years. Of the 241 failures, 93 (38.6%) were reported in 1984-86. The main causes of failure during the early years of service were not normal aging phenomenon. In many cases, the root causes for wear, fouling or erosion were sand, dirt or foreign material (operational deficiencies) in the pump or misalignment of the pump/driver. Vibration was also a root cause for wear and fatigue. Due to the differences in NPRDS reporting, misalignment and vibration were considered as wear for aging purposes unless the report specifically stated the cause of the alignment or vibration problem.

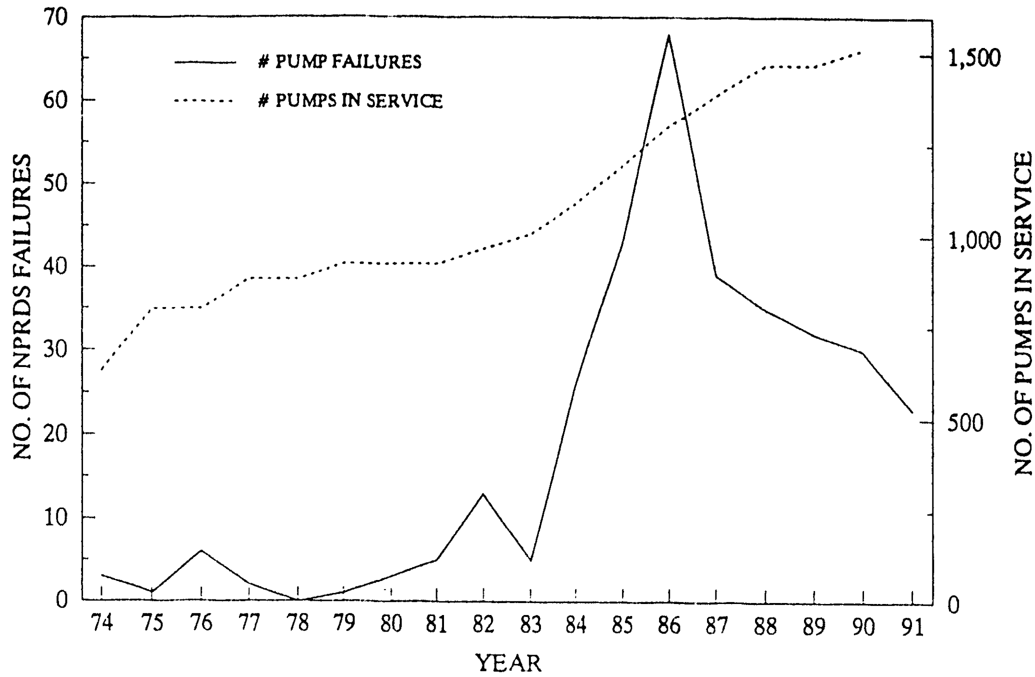


Figure 3-22. BWR Pump Aging Failures.

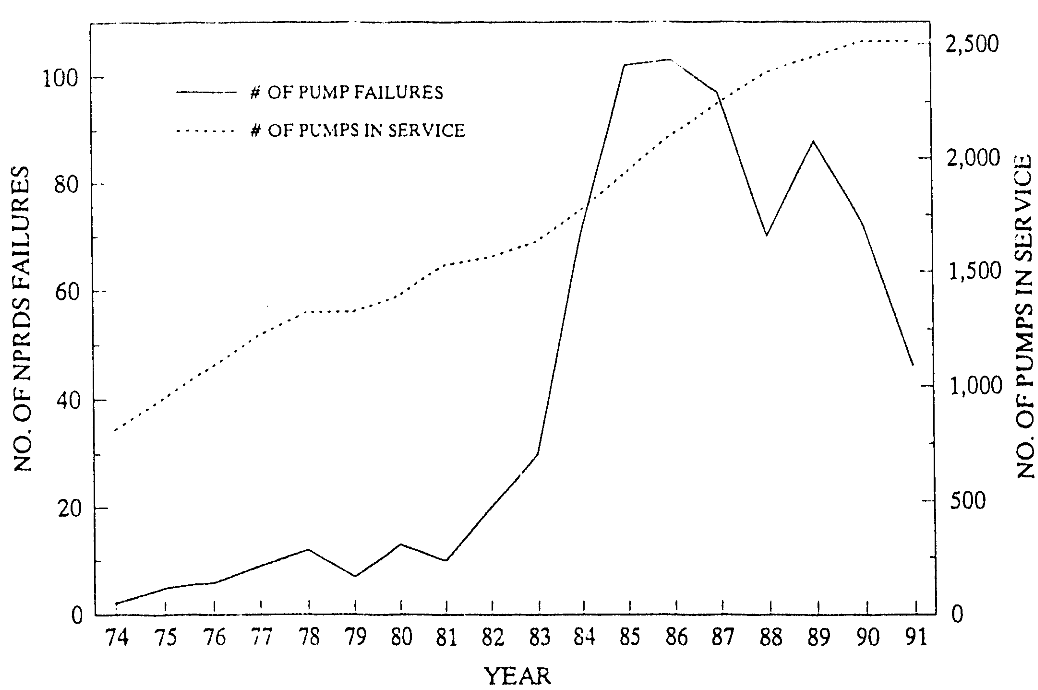


Figure 3-23. PWR Pump Aging Failures.

The reported failures were broken down into plant type and pump type. Figure 3-24 depicts the number of failures of BWR pumps. The pumps that are normally running account for 74 percent of the age-related failures. For the closed cooling water, RHR service water, and SLC pumps, most of the failures were reported by four utilities in response to a questionnaire which was sent for this AMG and not on NPRDS. Almost 80 percent of the SLC pump failures were packing leaks.

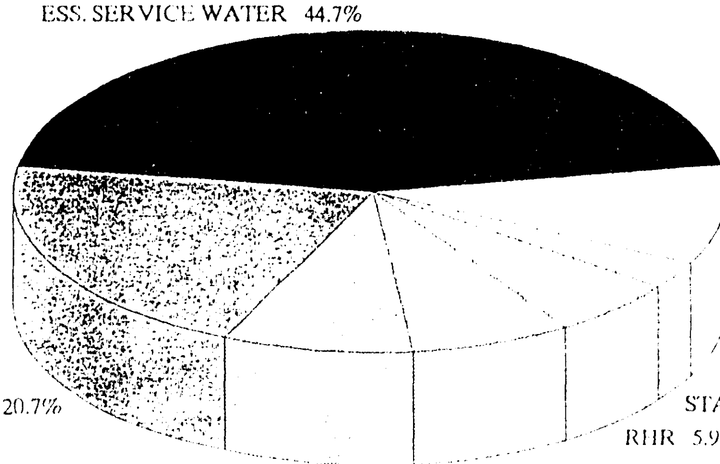


Figure 3-24. Pump Type Failures BWR Plants.

Figure 3-25 shows the distribution of PWR pump failures. Similar to the BWR pumps, the PWR pumps that are normally running (or at least one of a pair is running) account for over 74 percent of the pump failures. The three pumps that are always in standby (containment spray, safety injection, and containment recirculation sump pumps) have 29 combined failures identified (3 percent of total pump failures reported), of which 17 were reported via NPRDS. This indicates that the pumps are not degrading significantly in the standby condition and that they are properly maintained and properly tested.

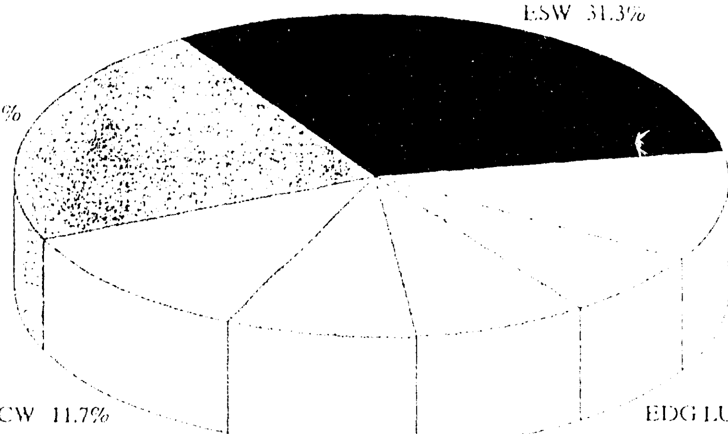


Figure 3-25. Pump Type Failures PWR Plants.

Several conclusions can be drawn from analysis of NPRDS data. Figure 3-26 shows the relative percentage of the various aging mechanisms causing pump failure/degradation. Wear is the predominant aging mechanism. Wear accounted for over 76 percent of the failures reported. Fatigue (9.2 percent) and fouling (5.9 percent) were the second and third most common aging mechanisms, followed by erosion and erosion/corrosion and uniform corrosion. Stress relaxation, intergranular stress corrosion cracking, and thermal embrittlement, combined, accounted for one percent of the mechanisms causing pump failure/degradation. There were no failure reports identifying the following degradation mechanisms.

- IASCC
- TGSCC
- Neutron Embrittlement
- MIC
- Creep
- Galvanic Corrosion

Fouling included NPRDS reported causes such as marine growth, silt, debris, foreign material, and sand.

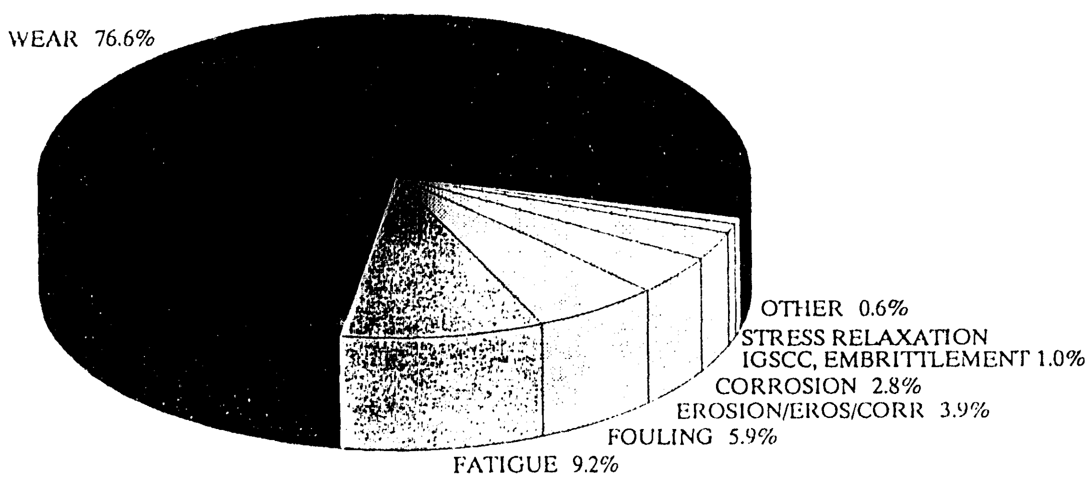


Figure 3-26. Pump Failures and Aging Causes NPRDS Database.

The analysis of failures was further expanded to include a review of the pump subcomponents which experienced aging. Table 3-17 lists the subcomponents which were identified as the primary reason for pump aging. NPRDS data shows similar results as the LER data in Section 3.6.1, in that the more active pump subcomponents (i.e., rotating/reciprocating and mechanical subsystem) exhibit a higher percentage of failures than passive subcomponents. Bearing failures include thrust and radial bearings. As mentioned in the beginning of this section, packing, gasket, and seal leaks reported in NPRDS were not counted.

Table 3-17. Pump Subcomponent Failures Due to Aging NPRDS Database 1974-1992

Subcomponent (Note 1)	Number of Failures Due to Aging (Note 2)	Percent of Total (Note 2)
Bearing	295	28.0
Impeller	140	13.3
Pump (Note 3)	136	12.9
Internal Valve	117	11.1
Pump Internals (Note 3)	106	10.1
Shaft	67	6.4
Coupling	43	4.1
Wear Rings	34	3.2
Rotating Element	30	2.8
Cylinder Block	25	2.4
Suction/End Bell	18	1.7
Casing	15	1.4
Shaft Sleeve	13	1.2
Bowl	9	0.9
Plunger	4	0.5
TOTAL (Note 3)	1,052	100

Notes:

1. Other subcomponents with age-related failures included balance drums, heads, bearing housings, bull gears, cover plates, diffusers, connecting rods, oil slingers, spacers, and flanges. There were 51 failures associated with this type of equipment. This is the difference between the 1,103 total aging failures identified at the beginning of this section and the 1,052 shown on this table. Gaskets, seals, and packing were not counted.

2. In many cases, there was more than one subcomponent listed for each failure. For example, one failure report may include impeller, bearings, and shaft. Therefore, the percentage is the percent of reports that included the subcomponent.

3. The NPRDS report only listed the pump or pump internals as the subcomponent. These failures may actually include any one or more of the other subcomponents.

Although NPRDS reporting is a voluntary industry effort, U.S. nuclear utilities have demonstrated their support by dedicating resources to report all reportable failures that have occurred since January 1, 1984, or after the date of commercial operation, whichever is latest. However, reporting of component failure data involves interpretation of reporting guidelines, component reportability, and available information regarding failures. This interpretation may affect the completeness and quality of NPRDS data.[3.15] Despite these drawbacks, the NPRDS is still the most comprehensive failure data base available to the nuclear industry. However, it should be recognized that due to different reporting interpretations, mean-time-between-failure values calculated from NPRDS data may not be accurate.

It is impractical to determine mean-time-between-failure and failure rate data for all pumps grouped into a single data base. Some pumps are located in harsh environments and are exposed to aggressive fluids while other pumps are located in relatively benign environments and are exposed to nonaggressive fluids. Therefore, mean-time-between-failure and failure rate data was determined for each pump application, taking into consideration only those pump failures attributed to aging. The mean time between failures ranged from a high of 8.3 years to a low of significantly greater than 60 years. The failure rate corresponding to the mean time between failures ranges from a high of 3.3×10^{-4} failures per day to a low of 1.3×10^{-5} failures per day.

In summary, NPRDS data indicates the following.

1. At least 14.6% of the total number of reported pump failures are age-related.

2. The failed components that contribute the most to age-related pump failures are bearings (28.0%), impellers (13.3%), and internal valves (11.1%). Other pump internal components that were not specifically identified accounted for (23.0%) of the aging failures.

3. The most significant identifiable aging mechanisms are wear (76.6%), fatigue (9.2%), and fouling (5.9%).

4. Decreasing failure rate trends suggest that current maintenance practices are effective at detecting and mitigating aging of pumps.

5. Pumps normally maintained in standby and operated primarily for testing do not fail nearly as often as pumps that are in continuous service.

6. There was insufficient NPRDS data available regarding failures/degradation for the following PWR system pumps.

   - Boric Acid Transfer
   - Spent Fuel Pool Cooling and Purification
   - Containment Recirculation
   - Primary Water Makeup

7. There was insufficient NPRDS data available regarding failures/degradation for the following BWR System pumps.

   - Spent Fuel Pool Cooling and Cleanup
   - Emergency Equipment Cooling Water
   - Reactor Water Cleanup
   - HPCI Lubricating Oil
   - RCIC Lubricating Oil

Since service water pumps exhibited a significant number of failures relative to the other pumps, a review of service water pump failures versus treated water pump failures was performed to identify the significant differences in aging. A sort of NPRDS data included service water pumps such as essential service water, RHR service water, and emergency equipment service water pumps. Typical treated water pumps were the PWR component cooling water and BWR reactor building closed cooling water pumps. This sort resulted in approximately 500 events. The following aging degradation observations were made from this sort; listed by percentage of failures caused by the various aging mechanisms.

Service Water Pump Failures		Treated Water Pump Failures	
PWR			
Wear	73.4%	Wear	91.1%
Fatigue	8.9%	Fatigue	3.3%
Erosion and E/C	5.9%	Erosion and E/C	1.1%
Fouling	5.9%	Fouling	4.5%
Corrosion	5.5%		
MIC	0.4%		
BWR			
Wear	60.3%	Wear	82.8%
Fatigue	5.3%	Fatigue	13.8%
Erosion and E/C	11.9%	Erosion and E/C	3.4%
Fouling	13.9%		
Corrosion	7.9%		
MIC	0.7%		

Several conclusions can be made from the above comparison. Wear, as expected, was the predominant failure mechanism. Fouling, corrosion, and MIC are much more prevalent in service water pumps since chemical treatments reduce or eliminate these degradation mechanisms in treated water pumps. Erosion and erosion/corrosion is significantly reduced in treated water systems because these are closed systems with water sources from tanks instead of rivers, lakes, or the ocean, where debris, sediment, and sand is much more likely to enter into the system.

A review of the NPRDS-reported pump aging failures versus time in service is shown in Figure 3-27. This graph indicates an increasing trend in number of failures as pumps age between 1 and 13 years in service. After peaking at 13 years in service, the number of failures begins to decrease. The number of pump failure events drops off significantly at year 18 because very few plants have been in commercial operation for that long. The average age of nuclear plants is 12.8 years for PWRs and 13.9 years for BWRs. The average age of all plants combined is 13.2 years for the period covered by this AMG.

For the pumps in service for 12, 13, and 14 years, a detailed review of failure date and service time since previous (NPRDS-reported) failure was performed. A total of 71% of the pumps which failed after 12 years were the first aging failure reported for each pump. Of the 91 failures reported in year 13, 67% were the first reported aging failure, and for the pumps in service for 14 years, 49% of the failures were the first aging failure. A majority (>61%) of the pumps which failed after 13 or 14 years of service were reported in 1984-86. These pumps were installed in 1970-73. For the pumps with more than 17 years of service at the time of failure, 55 percent were the first failure reported for the pump. This indicates that these pumps are either exceptionally maintained and overhauled prior to significant degradation, or the pumps are properly maintained in standby condition.

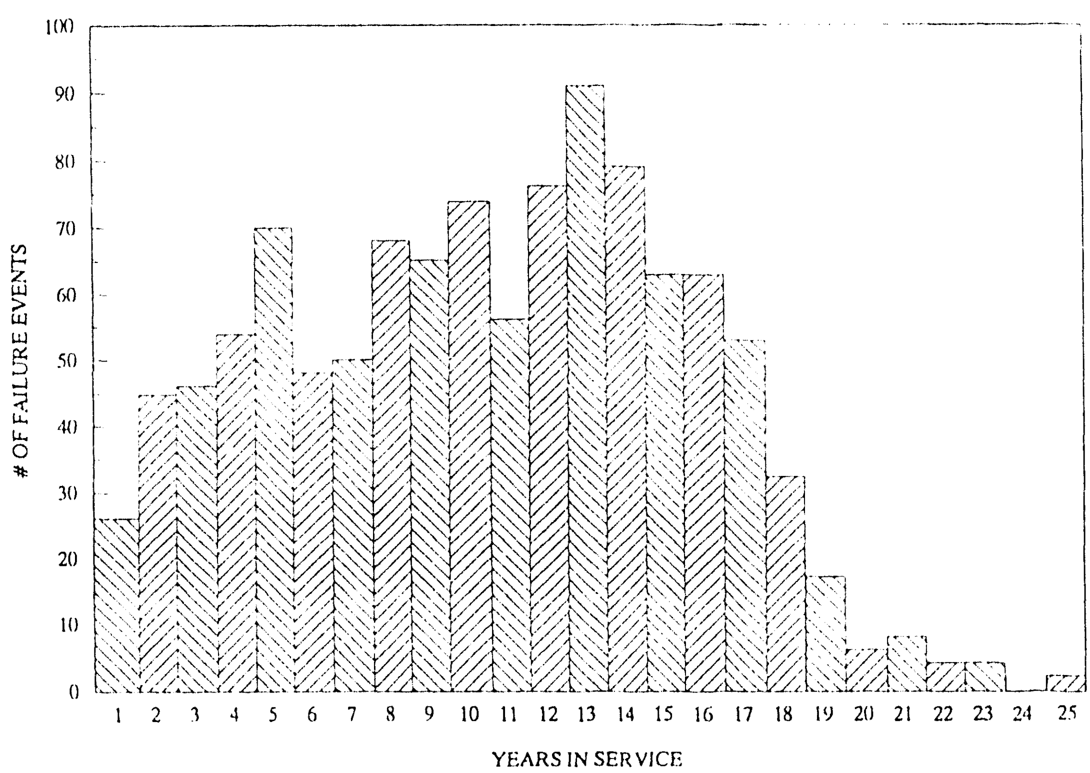


Figure 3-27. NPRDS Pumps Failures Vs. Service Time.

From this trend in failures versus service time, it is apparent that aging degradation, especially wear, increasingly affects pump performance as the pump ages, with a large number of pumps operating 12-14 years prior to failure. Figure 3-27 also indicates that some installations have problems such as wear (or, abnormal wear) and vibration early in their service life, either due to installation or design deficiencies or system problems, whereas other pumps, with proper maintenance, operation and design, can operate for extended periods with no aging degradation.

3.7 References

3.1 Title 10, U.S. Code of Federal Regulations, 10 CFR Part 54, "Requirements for Renewal of Operating Licenses for Nuclear Power Plants," Federal Register, Vol. 56, No. 240, December 13, 1991, pp. 64943 - 64980.

3.2 Title 10, U.S. Code of Federal Regulations, 10 CFR Part 50.65, "Requirements for Monitoring the Effectiveness of Maintenance at Nuclear Power Plants," Vol. 56, July 10, 1991, pg. 31324.

3.3 NUMARC Report Number 93-01, "Industry Guideline for Monitoring the Effectiveness of Maintenance at Nuclear Power Plants," Revision 2A, July 9, 1992.

3.4 NUMARC Report Number 90-09, "BWR Primary Coolant Pressure Boundary License Renewal Industry Report," April 1992.

3.5 NUMARC Report Number 90-07, "PWR Reactor Coolant System License Renewal Industry Report," May 1992.

3.6 *Centrifugal Pump Sourcebook*, J.W. Dufour and W.E. Nelson, McGraw-Hill Inc., 1993, with permission.

3.7 *Pump Handbook*, Second Edition, I.J. Karassik, et al., McGraw-Hill Book Company, 1986, with permission.

3.8 Worthington Product Brochure for Vertical Turbine Pumps, figure of wet-pit pumps, (no date).

3.9 Power's "Engineers Reference Library" brochure, section on pumps, pp. 139-168, (no date).

3.10 EPRI NP-3877, Final Report, March, 1985, "Qualification of Active Equipment for Nuclear Plants."

3.11 *Delaval Engineering Handbook*, Third Edition, Edited by Hans Gartmann, McGraw-Hill Book Company, 1970.

3.12 NUREG/CR-4597, "Aging and Service Wear of Auxiliary Feedwater Pumps for PWR Nuclear Power Plants," Volumes 1 and 2.

3.13 NUREG-0800, "Standard Review Plan for the Review of Safety Analysis Reports for Nuclear Power Plants," June 1987.

3.14 NUREG-1299, "Standard Review Plan for the Review of License Renewal Applications for Nuclear Power Plants," Draft, November 1990.

3.15 The Nuclear Plant Reliability Data System — Objectives and Uses, INPO 89-014, Revision 1, March 1991.

4. STRESSORS AND AGING MECHANISMS

A stressor is a physical state or stimulus which is caused by fabrication, installation, operational conditions, and/or environmental conditions that may result in degradation of the pump. Materials used during pump manufacture, assembly, and installation are subject to some level of degradation due to residual and/or applied stressors. Also, stressors caused by normal operation and environmental conditions have a direct affect on the manifestation of aging mechanisms. It is therefore important to understand the behavior of materials, when subject to these various stressors, in order to satisfactorily design and operate a pump and to develop methods for detecting and mitigating pump degradation.

4.1 Determination of Stressors Acting on Pumps

Steady state cyclic or other peak stressors exist on the pump components during normal operation, transient events, and testing. These stressors or loads can be in the form of either one or a combination of the following.

a. Mechanical
b. Hydraulic
c. Chemical
d. Electrical
e. Environmental
   - Thermal
   - Moisture
   - Radiation
f. Tribological (i.e., interaction of machine components, friction, and lubrication)

These initiators of stress are, in some applications, continuously present and active on various pump components. The presence of stressors causes aging mechanisms to manifest over a period of time. If left undetected and/or unmitigated, these aging mechanisms result in material distortion, degradation of the pump components, unacceptable performance or failure.

For the purpose of discussion, each pump is subdivided into five major subassemblies:

- Rotating/Reciprocating Elements
- Fixed Internals
- Pressure Boundary
- Mechanical Subsystems
- Supports

Each of these subassemblies is further subdivided into individual components as follows:

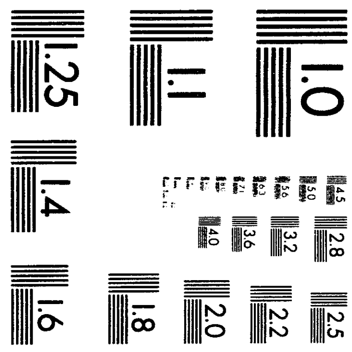
Rotating/reciprocating elements — shaft, driveshaft/crankshaft, impeller, internal rotor, piston/plunger, and internal valve

Fixed internals —	miscellaneous structural components (i.e., keyways, spacers, collars, etc.), wearing components, flow guides (i.e., volute, diffuser, and suction strainer)
Pressure boundary —	casing, suction and discharge nozzles, discharge head, column/bowl, flange/cover, cylinder/plunger block, and fasteners
Mechanical subsystems —	coupling, shaft seal/packing assembly, thrust bearing, and radial bearing
Supports —	support feet/skirt, base frame/skid, and fasteners

The following discussion of stressors is summarized in Table 4-1, Stressor Influence. To indicate a relative measure of importance, each stressor category is quantified as either low, medium, or high. The measure of importance is subjective and is based on other aging studies, field experience, and reviews of industry data. The measures of importance shown on Table 4-1 should be applied with caution. The table does not accurately reflect all possible combinations of service and material applications for the range of pumps evaluated in this AMG. This will be accomplished in Sections 4.2 and 4.3. Generally, the measures of importance reflect worst case service applications. For example, the chemical stressor is rated high for service water applications, whereas, in demineralized water applications, a medium or low rating is appropriate.

4.1.1 Mechanical Stressors

Pump components are subject to a variety of mechanical stressors. Transmitted torque loads are applied to the pump shaft, impeller, coupling, and rotating element fasteners. During pump assembly, stressors are induced in the various components due to fit-up, erection tolerances, and fastener tightening. These induced stressors are classified as assembly loads and are applied to all rotating and non-rotating pump components. Rotor dynamic loads are caused by an unbalanced characteristic of the pump. Some magnitude of unbalance exists in all pumps and can be initiated from a number of sources such as misalignment, approach of the pump operating speed to the pump's resonant frequency, deficient lubrication distribution or viscosity and bearing degradation. Rotor dynamic loads and vibration are applied to all rotating and non-rotating pump components. Fit-up and connection of suction and discharge piping causes stress to various pump components. The magnitude of stress caused by these piping loads is dependent upon the degree of misalignment during fit-up, the amount and direction of thermal expansion, and the material condition and functionality of the piping hanger/support network. Piping loads are applied at the pump suction and discharge nozzles and distributed into the casing and base frame. Seismic events can impart mechanical stressors to the pump upper and lower casing, suction and discharge nozzles, base frame, and fasteners associated with these components.



2 of 4

Table 4-1. Stressor Influence

Pump Assembly	Mechanical	Hydraulic	Chemical	Electrical	Environmental Thermal	Environmental Moisture	Environmental Radiation	Tribological
ROTATING/RECIP INTERNALS								
Shaft	Medium	Medium	Medium	Medium	High	Medium	Low	Medium
Impeller	Medium	High	High	Low	High	Low	Low	High
Piston/Plunger	Medium	High	High	Low	Medium	Low	Low	High
Driveshaft/Crankshaft	Medium	High	High	Low	High	Low	Low	High
Internal Rotor	Medium	High	High	Low	Medium	Low	Low	Medium
Internal Valve	High	High	High	Low	Medium	Low	Low	Medium
FIXED INTERNALS								
Wearing Components	Medium	High	High	Low	High	Low	Low	High
Flow Guide	Low	Medium	Medium	Low	Medium	Low	Low	Low
Suction Strainer	Low	High	Medium	Low	Medium	Low	Low	Low
Misc. Structural Components	Low	Medium	Medium	Low	Medium	Low	Low	Low
PRESSURE BOUNDARY								
Casing	Low	Medium	Medium	Low	Medium	Medium	Low	Low
Suct./Disch. Nozzle	Medium	High	Medium	Low	Medium	Medium	Low	Low
Flange/Cover	Low	Medium	Medium	Low	Medium	Medium	Low	Low
Disch. Head/Column/Bowl	Low	Medium	Medium	Low	Medium	Medium	Low	Low
Cylinder/Plunger Block	Medium	High	Medium	Low	Medium	Medium	Low	Medium
Fasteners	Medium	Low	Low	Low	Medium	Medium	Low	Low
MECHANICAL SUBSYSTEMS								
Coupling	Medium	Low	Low	Low	Medium	Medium	Low	Medium
Shaft Seal	High	High	Low	Low	High	Low	Low	High
Radial Bearing	Medium	Low	Low	Medium	High	Low	Low	High
Thrust Bearing	Medium	Low	Low	Medium	High	Low	Low	High
SUPPORT BASE								
Base Frame/Skid	Low	Low	Low	Low	Low	Medium	Low	Low
Fasteners	Low	Low	Low	Low	Low	Medium	Low	Low
Support Feet/Skirt	Low	Low	Low	Low	Low	Medium	Low	Low

4.1.2 Hydraulic Stressors

Hydraulic stressors are loads imparted on pump components as a result of the flow of fluid through the pump. The magnitude of hydraulic stress is dependent upon the characteristics of the process fluid, design parameters of the pump, and severity of operation or duty the pump is expected to encounter over its service lifetime. Fluid impingement imparts stress on the pump impellers, volutes, diffusers, return channels, wear rings, upper and lower casings, suction and discharge nozzles, and the shaft seal assembly. Cavitation imparts stress to various pump components when vapor-filled bubbles implode/collapse as the fluid passes from a low pressure region in the pump to a region of higher pressure. Pump components affected by cavitation are the impellers, diffusers, and volutes. Internal pressure causes an applied stress to the upper and lower casing, suction and discharge nozzles, and the shaft seal assembly. Static and dynamic hydraulic loads are present in all pumps and impart stress to virtually all rotating and non-rotating pump components. These loads are caused by fluid weight, developed head (i.e., differential pressure across the pump and between pump stages), mass transfer, and cyclic operation in some applications. All of these loadings to some degree result in physical movement/displacement of the rotating element and influence conditions between rotating and non-rotating components. The only pump components which would not be subject to static and dynamic hydraulic loads are the coupling and supports (i.e., base frame). Testing of pumps to satisfy technical specification requirements is often performed with the pump minimum flow test line as the flow path. Prolonged operation of the minimum flow line is recognized as being detrimental to the pump and can cause pump degradation. Although this is part of the existing design, it can contribute to aging. Operation in minimum flow mode should be minimized if the minimum flow path is "small."

4.1.3 Chemical Stressors

The process fluid reacts with both rotating and non-rotating parts of the pump internals and, depending on the chemical composition, can cause the pump parts to be stressed. The stress can be localized and/or uniformly distributed throughout the pump internal surfaces and involves a molecular chemical reaction between the metal and the liquid. The pumps covered by this AMG handle many different types of process fluid and operate over a wide range of temperature and pressure. The various different types of liquid are demineralized water, well water, river water, city water, brackish water, sea water, condensate, chromated water, borated water, fuel oil, and lubricating oils.

All of these liquids act as electrolytic solutions. An electrolyte is an electrical conducting medium which allows the flow of electrons between an anode and cathode. The metallic components internal to the pump act as anodes and cathodes depending on the material type. The galvanic series is shown on Table 4-2. Corrosion occurs when electrons leave an anodic material and enter the electrolytic solution. High levels of electrolyte ionization (i.e., conductivity) results in a greater rate of corrosion because electrical current flows better in high conductivity solutions.

Another form of chemical stressor acting on the metallic surfaces of pumps is the influence of living organisms on the corrosion process. In some circumstances, microbial activity does nothing more than provide a localized environment such as crevices where concentration cells are established to promote accelerated corrosion.

Table 4-2. Galvanic Series

Anodic End of Galvanic Series
Magnesium
Magnesium Alloys
Zinc
Aluminum 5052
Aluminum 6061
Cadmium
Aluminum AA 2017
Iron and Carbon Steel
Copper Steel
4-6% Chromium Steel
Ferritic Stainless (active) 400 Series
Austenitic Stainless (active) 18-8 Series
Lead-Tin Solder
Lead
Tin
Nickel (active)
Inconel (active)
Hastelloy C (active)
Brasses
Copper
Bronzes
Cupro-Nickel Alloys
Monel
Silver Solder
Nickel (passive)
Inconel (passive)
Ferritic Stainless (passive)
Austenitic Stainless (passive)
Titanium
Hastelloy C (passive)
Silver
Graphite
Gold
Platinum
Cathodic End of Galvanic Series

In other cases, microbes produce metabolites such as organics or mineral acids, ammonia, or hydrogen sulfide which are corrosive to metals. Microbes can concentrate halides which result in severe, localized corrosion of ferrous materials. Microbial activity interferes with the cathodic half-reaction in oxygen free environments resulting in increased anodic dissolution. In other ways, microbes can influence; 1) corrosion and oxidation of metal anions to less soluble forms, 2) destruction of protective coatings, and 3) metabolism of inhibitors.[4.1]

4.1.4 Electrical Stressors

Bearing failures are frequently caused by shaft misalignment, vibration, or improper lubrication, however, the cause of failure can also be electromagnetic (i.e., electrical stressors).

Motor shaft currents are developed by transformer action. This magnetic interaction is a separate, stray magnetic force caused by slight dissymmetrics in the motor's iron circuit. These electromagnetically induced stray voltages in the motor shaft can travel through the coupling to the pump shaft. If a closed circuit is provided, the resultant current flow can be substantial. In many cases, a closed circuit is provided at the pump bearings particularly in those cases where the motor bearings are insulated and/or an alternate low-impedance path for current flow is not installed. Rolling-element bearings are especially susceptible to damage from circulating shaft currents.

4.1.5 Environmental Stressors

The following discussion includes three general parameters as environmental stressors.

- Thermal — internal process fluid temperature and external ambient temperature effects on the various pump components
- Moisture — external ambient humidity effects on the applicable pump components
- Radiation — cumulative internal and external radiation exposure effects on the various pump components

4.1.5.1 Thermal Stressors

Thermal stresses are active on all pump components subject to temperatures greater than 93°C [200°F]. At high temperatures, application of a constant load to a metal component produces continuous deformation or creep, which will eventually lead to fracture if the load is maintained for a sufficient length of time. The stress-rupture strength is defined as the stress that a metal can withstand for a given time, at a given temperature, without breaking. With increases in temperature, stress-rupture strength decreases rapidly to values that may be considerably lower than fatigue strength. Therefore, the primary requirement of a metal that will be subjected to high temperatures is that it has adequate stress-rupture strength.[4.2]

Thermal expansion or contraction of a metal, caused by a temperature change, acting against a constraint causes thermal stress. Constraints may be external (e.g., rigid mountings) or it may be internal, in which case it is set up by a temperature gradient within the part. In thick parts, temperature gradients are likely to occur both along and through the material, causing significant triaxial stresses and reducing material ductility, even though the uniaxial ductility often increases with increasing temperature. Thermal fatigue is the basic mechanism in failures that occur because of numerous heating and cooling cycles. Stress rupture is an important consideration as the cycle times increase and is, therefore, a long-term rate process. Most thermal fatigue fractures are of the low-cycle, high-strain type.[4.2]

When steel is heated, small austenite grains form at temperatures above the point where austenite begins to form. Grain size continually increases with time at temperature, and higher temperatures result in faster grain growth. The strength, ductility, and toughness of coarse-grained metals are impaired not only by the large grain size, but also by grain boundary precipitation. The embrittling effect of large grains in ferritic steel is explained by stress concentration at the ends of slip bands and at grain boundaries. The larger the grains, the longer the slip bands and the greater the stress concentration. Severe stress concentration will cause microcracks possibly resulting in fracture.[4.3]

Exposure of metal parts to high and low temperatures, which is often accompanied by non-uniform heating rates and sharp thermal gradients, is a source of stress during operation.[4.2] In some applications, these stressors can place the material in a state of tension. When the metal, stressed in tension, is exposed to a corrosive environment, the ensuing localized electrochemical dissolution of metal, combined with localized plastic deformation, opens up a crack. With sustained tensile stress, protective films that form at the tip of the crack rupture, causing fresh anodic material to be exposed to the corrosive medium, and stress corrosion cracking is propagated.[4.2] The corrosive environment in nuclear power plants is high temperature water greater than 93°C [200°F] where the electrochemical potential of sensitized Type 304 stainless steel in the coolant is >-230 mV standard hydrogen electrode (SHE).[4.4, 4.5] At reactor coolant temperatures between 54-93°C [130-200°F], IGSCC is not observed unless dissolved oxygen is 1-2 × 10^3 ppb. At temperature less than 54°C [130°F], IGSCC is not observed.[4.5, 4.6, 4.7] Figure 4-1 is reproduced from Reference 4.5 and shows the corrosion potential vs. percent that IGSCC will occur in sensitized Type 304 stainless steel. Figure 4-2 is also reproduced from Reference 4.5 and shows an interrelation between oxygen and temperature combinations that can trigger IGSCC.

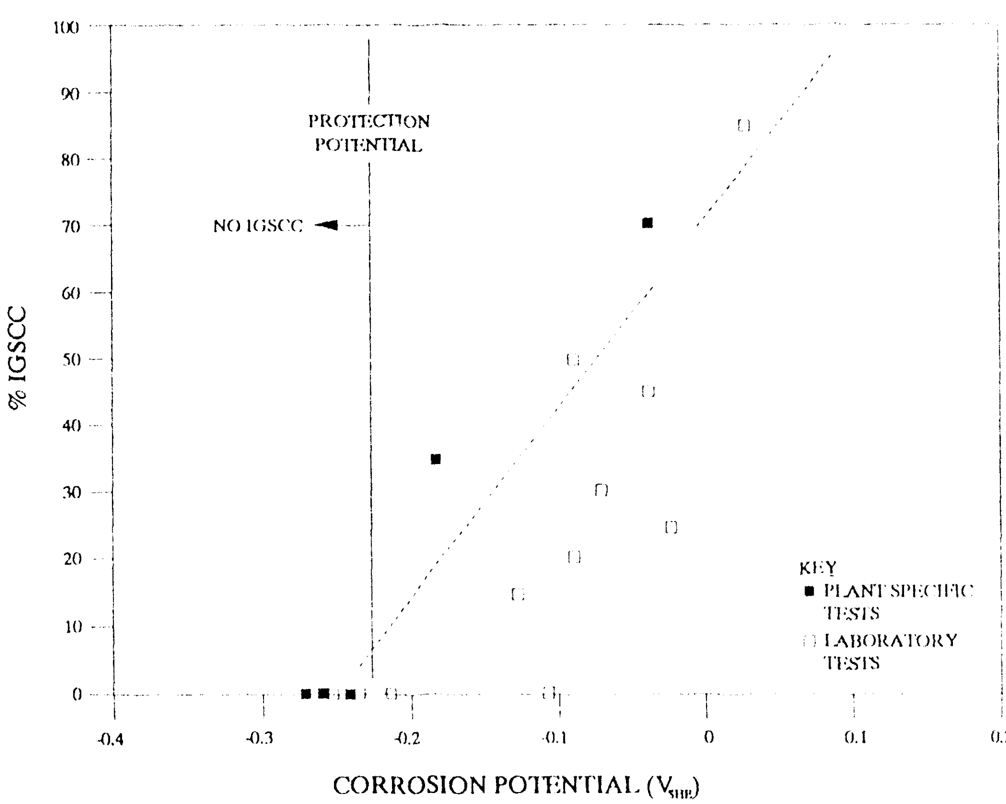


Figure 4-1. Corrosion Potential Vs. Percent IGSCC for Sensitized Type 304 Stainless Steel.[4.5]

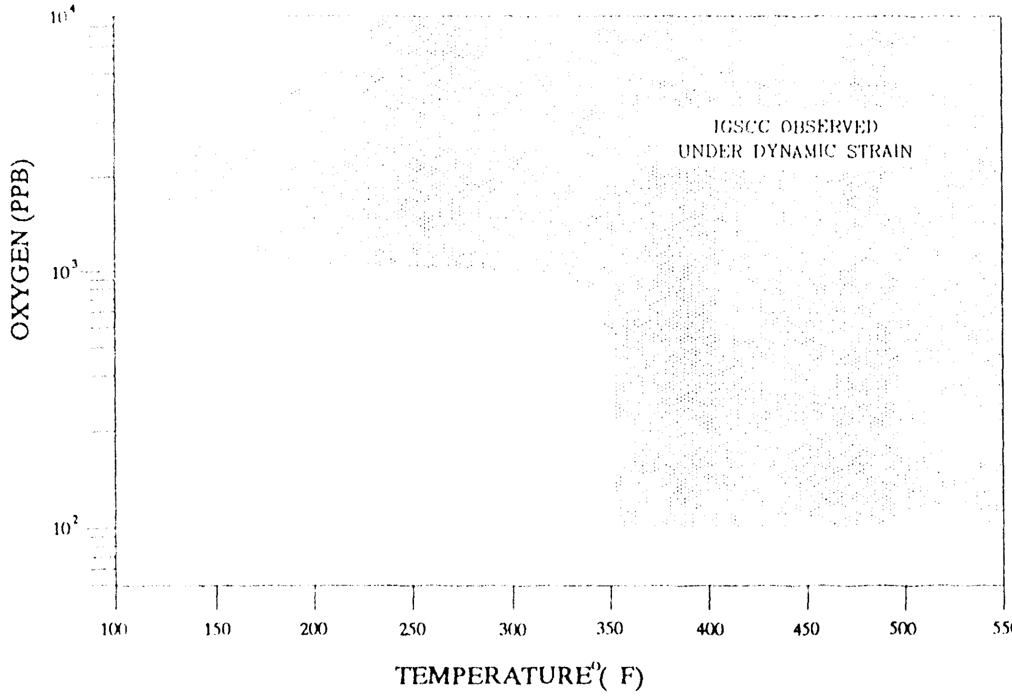


Figure 4-2. Interrelation Between Oxygen, Temperature Combinations and the IGSCC Danger Zone.[4.5]

4.1.5.2 Moisture Stressors

External ambient humidity effects on the pump suction and discharge nozzles, upper and lower casing, base frame, exposed portions of the shaft, and various fasteners result in general corrosion. In cases where dissimilar metals are in contact with one another, galvanic corrosion will occur in the presence of humid environments. Crevice corrosion may also occur due to mechanical fit-up of pump components. As this type of corrosion is initiated, it proceeds in an autocatalytic manner with all the damage and metal dissolution occurring within the crevice and little or no metal loss outside. A breakdown in the passive oxide film or protective coating of a metal can provide a path for ionic migration and the development of an electrochemical cell which produces pitting. In all of these forms of corrosion, the stresses imparted on the exterior metal surfaces of a pump from moisture are electrochemical, which is described in Section 4.1.3, Chemical Stressors.

4.1.5.3 Radiation Stressors

The following discussion of radiation stressors is applicable to all metal components of a pump and is described in generic terms. Neutrons produce energetic primary recoil atoms which displace large numbers of atoms in a metal from their crystal lattice positions by a chain of atomic collisions. This effect is characterized by exposure units such as fast fluence (> 1 MeV), neutrons per centimeter squared (n/cm^2), or displacements per atom (dpa). Displacements per atom accounts for both the fluence and neutron energy levels. Properties of certain metals begin to change at about 0.2 dpa (10^{20} n/cm^2). Experimental data shows that after prolonged exposure to neutrons, the yield strength increases by about a factor of three over its unirradiated value, ultimate tensile strength remains essentially unchanged, uniform and total elongation drops substantially, fracture toughness drops by about a factor of three, and the tearing modulus drops from several hundred to a range from five to ten.[4.8]

The extent of embrittlement depends on neutron fluence, irradiation temperature, and trace material chemistry (i.e., particularly the presence of copper, phosphorus, and nickel).[4.9] The degree of embrittlement is usually expressed as an upward shift of the brittle-to-ductile transition temperature and decrease in the upper shelf energy as measured in Charpy impact energy tests. [4.10]

Stress corrosion cracking can occur in austenitic stainless steel components of a boiling water reactor under highly irradiated conditions. This IASCC appears to involve the simultaneous interaction of highly irradiated non-sensitized material with diffusion of metal impurities such as sulfur, silicon, and phosphorus to the grain boundaries, low stress levels, high-temperature water with short-lived oxidizing species, gamma and neutron flux.[4.11] It is important to note that IASCC does not require the chromium depletion sensitization or high tensile stresses that are implicit in the failure of non-irradiated stainless steel components due to intergranular stress corrosion cracking discussed in Sections 4.1.5.1 and 4.2.3. A threshold for IASCC exists at about 5×10^{20} n/cm^2 (> 1 MeV), for austenitic stainless steel and Inconel 800.[4.12]

4.1.6 Tribological Stressors

Tribology is the science concerned with the design, friction, lubrication, and wear of contacting surfaces that move relative to each other. The pump components affected by tribological stressors are those where rubbing exists between rotating and non-rotating members and is potentially more severe in cases where the metal surfaces form an oxide layer.[4.13]

On lubricated surfaces, the wear process is usually mild and generates fine debris of a particle size as small as 1 - 2μm [$3.3 - 6.6 \times 10^{-6}$ ft]. Abrasive wear or delamination wear predominates under lubricated conditions. Electron microscope examination of worn surfaces from lubricated assemblies frequently reveals a multitude of fine scratches oriented in the direction of relative motion. The fine debris generated by abrasion becomes suspended in the lubricant.[4.2] For pumps equipped with circulating oil lubrication, spectroscopy analysis is used to diagnose deterioration by wear.

There are several basis modes of lubrication. In all modes, contacting surfaces are separated by a lubricating medium. The most common modes are hydrodynamic, hydrostatic, elastohydrodynamic, dry film, boundary film, and thin film. Hydrodynamic lubrication is a system in which the shape and relative motion of the sliding surfaces cause the formation of a fluid film having sufficient pressure to separate the surfaces. Hydrostatic lubrication is a system in which the lubricant is supplied under sufficient external pressure to separate the opposing surfaces by a fluid film. Elastohydrodynamic lubrication is a system in which the friction and film thickness between the two bodies in relative motion are determined by the elastic properties of the bodies in combination with the viscous properties of the lubricant at the prevailing pressure, temperature, and rate of shear. Dry-film lubrication is a system in which a coating of solid lubricant separates the opposing surfaces and the lubricant itself wears. Boundary lubrication is a system in which each surface is covered by a chemically bonded fluid or semisolid film that may or may not separate opposing surfaces, and viscosity of the lubricant is not a factor affecting friction and wear. Thin-film lubrication is a system in which the lubricant is usually not bonded to the surfaces, it does not separate opposing surfaces, and viscosity does affect friction and wear.[4.2]

Mechanical devices often operate under several lubrication modes simultaneously or alternately. For example, when a full journal bearing under unidirectional loading is at rest with the oil pump shut off, there is metal-to-metal contact between mating surfaces. As the bearing starts rotating, it operates under boundary lubrication and then thin-film lubrication for a short period until a stable thick oil film develops and the solid surfaces separate (i.e., hydrodynamic lubrication). The process reverses when rotation is slowed and/or stopped. Stresses develop at the metal-to-metal contact points and ultimately cause wear to occur at the surfaces. The severity of wear is related to the total number of start/stop cycles. Gears experience both elastohydrodynamic and boundary lubrication at the same time. For example, during meshing of one tooth of a spur gear with a tooth of a mating gear, initial contact is sliding in which case boundary lubrication prevails and wear occurs at the tips and roots of the teeth. Contact along the pitch line of the gear tooth is rolling motion in which case elastohydrodynamic lubrication conditions prevail. Rolling contact involves line or point contact and very large localized contact stresses. Pitch line damage takes the form of pitting or spalling and is similar to rolling contact fatigue.

Another important aspect of tribological stressors associated with various pump components is lubrication property breakdown. One of the functions of a lubricant is to carry away heat generated by two surfaces sliding under constant pressure. Liquid lubricants can dissipate heat better than solid or semi-fluid lubricants, but in all types, the shear properties of the lubricant are critical to its performance. Most lubricant failures occur by chemical decomposition, contamination, changes in properties caused by excessive heat, or loss of pressurized fluid into lubricated areas. Lubricating oils and greases can fail by any one of these processes, however, in most cases, chemical decomposition, contamination, and temperature are all involved and interrelated.

Contamination of the lubricant with water or reactive chemical substances can lead to lubricant decomposition, corrosion of contact surfaces, or both. Contamination with abrasive substances or debris can cause abrasive wear, especially when the size of the contaminant particles is about the same as the thickness of the lubricating film.

Viscosity of the lubricant is affected by both temperature and pressure. An increase in pressure causes an increase in viscosity, although the effect is not significant except at very high pressure. Conversely, any change in temperature has a very significant effect on viscosity. A temperature decrease can cause a significant increase in viscosity depending on the type of oil. Greases that are solid or semisolid at room temperature gradually soften with increasing temperature and can become fluid or free flowing if the temperature reaches the dropping point (i.e., lower boundary of the melting range of the grease). Oils containing substantial quantities of volatile compounds may lose these components when operating temperatures are too high. This process not only alters the viscosity, but also upsets the chemical nature of the oil.

Tribological stressors can be minimized and certain types of lubricant failures prevented by changes in the design of the component being lubricated, changes in the design of the lubricating system, and/or selection of appropriate lubricant for the application. Inadequate lubricant flow or clogging of oil passages can sometimes be corrected by increasing the size of oil passages. An increase or decrease in clearance between sliding surfaces will often enable the lubricant to function more effectively. Shields, covers, and seals are used to prevent contamination of the lubricant from external sources. Filtration devices can be used to remove contaminants in the lubrication system. Oil additives may serve to improve the properties of the lubricant, impart new performance characteristics to the lubricant, or to reduce the rate at which undesirable changes in the lubricant take place during normal operating service. Table 4-3 describes some of the more common additives.[4.2]

Table 4-3. Common Lubricant Additives

Viscosity — Index Improvers	These substances decrease the effect that temperature has on viscosity, making the oil more viscous at high temperature than it would be without the additive.
Pour-Point Depressants	These substances make a wax-containing oil less viscous at low temperatures by inhibiting the growth and coalescence of wax crystals suspended in the oil.
Defoamants	These additives promote the coalescence of tiny entrapped air bubbles into large bubbles, which can rise to the surface and collapse.
Wetting Agents and Emulsifiers	These additives enable the oil to displace water from metal surfaces or to absorb the water as a stable emulsion, thus promoting oil-film formation on a metal surface.
Oxidation Inhibitors	These substances combat oxidation of the oil by interrupting the chain of chemical reactions leading to deterioration or by deactivating catalytic metallic surfaces.
Detergents and Dispersants	These additives combat the formation of sludges and varnish.
Corrosion Inhibitors	These additives reduce or prevent corrosion of lubricated surfaces by contaminants in the oil, such as water, oxygen, and acids.
Lubrication Property Improvers	These additives reduce friction (especially under boundary lubrication), speed up a wearing-in process, enhance film strength, or provide lubrication under high contact pressures.

4.2 Description of Aging Mechanisms Acting on Pumps

4.2.1 Fatigue

Fatigue is the term that describes subcritical crack growth or structural deterioration under the influence of fluctuating or cyclic stress caused by applied loads and/or temperature. Fatigue is characterized as a macroscopically brittle mode of failure since there is no gross plastic deformation of the material before ultimate failure. When sufficient localized microstructural damage is accumulated in this defect or crack tip region (i.e., locally plastic deformation), crack initiation and growth can occur during subsequent cyclic loading and/or thermal stress.

Fatigue behavior of a component is related to a variety of parameters, such as stress range, mean stress, frequency or cyclic wave form, environmental conditions, metallurgy of the material, and surface toughness of the material. Cracks typically initiate at local geometric stress concentration points such as notches, surface defects, and structural discontinuities. The time between localized fatigue crack initiation and eventual detection of the growing crack may represent a large portion of a component's life. Fatigue initiation curves have been developed to indicate how many stress cycles it takes to initiate fatigue cracks in components. These curves are materials related and indicate the allowable number of stress cycles for applied cyclic stress amplitudes.

Environmental condition significantly affects fatigue initiation in a material. The presence of an active environment can accelerate fatigue crack initiation and propagation. For example, oxidation can produce pits in the surface of some alloys. The pits can then act as stress concentrators and potential fatigue crack initiation sites. Environmentally assisted fatigue is commonly referred to as corrosion fatigue.

When applied or induced loads are of such magnitude that more than about 10,000 cycles are required to produce failure, the phenomenon is usually termed high-cycle fatigue. When applied or induced loads are of such magnitude that less than about 10,000 cycles are required to produce failure, the phenomenon is usually termed low-cycle fatigue. When load or strain is produced by a fluctuating temperature field, the process is termed thermal fatigue.

4.2.2 Corrosion

Corrosion is defined as the destruction or deterioration of a material due to electrochemical reaction with its environment. It is characterized by material loss or deterioration of its properties. Corrosion reduces the component wall thickness, either locally (e.g., crevice corrosion, pitting, galvanic corrosion, microbiologically influenced corrosion, etc.) or more uniformly (e.g., rusting, oxide layering, etc.). The resultant decrease in the volume of sound material causes a decrease in the strength of the corroded material. Furthermore, the associated surface roughening causes additional weakening of the material when placed under load.

General/Uniform Corrosion

Uniform corrosion results in the formation of solid corrosion products (oxides) that protect the underlying metal surface. Localized disruptions in the oxide will re-oxidize, rendering the metal protected from further corrosion. Changes in environmental conditions, however, can have an adverse affect on the stability of the protective oxide layer rendering the material susceptible to increased corrosion.

Corrosion of metal surfaces exposed to the atmosphere is caused by the combined effects of film formation and film breakdown. Film formation is the iron oxide layering of a metal surface that develops from exposure to oxygen in the surrounding environment. This film develops cracks, disruptions, and discontinuities which are caused by: 1) external forces and/or 2) stresses internal to the oxide layer (i.e., caused by different types and volumes of metal and iron oxide located throughout the layer). Moisture in the surrounding atmosphere, from water leakage or humidity, is an electrolyte and provides a path for electrochemical reactions to occur. The most damaging reaction (i.e., film breakdown) is caused by electrical current continuously flowing between the small anodic areas of freshly exposed metal and the much larger cathodic areas of the oxide layer. The anodic areas corrode further and the process of film breakdown continues. The corrosion rate is highly dependent upon the availability and purity of the electrolyte.

Uniform oxidation corrosion rates of pump internal surfaces are dependent upon process fluid oxygen content, operating temperature, and flow rate. Pumps process various types of fluids, consisting of low temperature deionized water, high temperature deionized water, salt or brackish water, glycol or refrigerants, and various types of oils. Some systems containing pumps are maintained stagnant for long periods of time while others are maintained in a condition of continuous flow. The highest corrosion rate for metal occurs in system applications where the fluid is low temperature air saturated stagnant water.[4.11] Very little corrosion occurs in: 1) high temperature water systems because a thin black oxide film (i.e., magnetite) forms rapidly protecting the internal surfaces of the pump from further corrosion, 2) systems containing lubricating and fuel oil because oxygen content is very low, oils are not good electrolytes, and purification systems are generally installed and/or corrosion inhibitors are added to maintain the oil free of corrosion products, and 3) systems containing refrigerants because oxygen content is very low.

Gray iron is susceptible to a form of selective leaching known as graphitic corrosion when immersed in soft water, salt or brackish water, or when buried underground in some soils particularly those soils containing sulfates. The graphite in gray iron is cathodic with respect to iron. Corrosion acts on the iron matrix (i.e., iron leaching) leaving behind a soft, black graphite residue on the surface. This graphite mass is porous and very weak, however, little or no change in metal thickness takes place. Graphite corrosion usually occurs at a very low rate, and if the residue remains on the corroded surface, it serves as a protective coating and effects an appreciable reduction in corrosion rate.

Copper-zinc alloys containing more than 15% zinc are susceptible to a dealloying process called dezincification. Dezincification of copper-zinc alloys is most prevalent in waters containing a high content of oxygen, carbon dioxide, or chloride and is accelerated by elevated temperatures and low water velocity. Excessive chlorination of cooling water may promote dezincification of copper-zinc alloys. Dealloying is a corrosion process in which the more active metal is selectively removed from an alloy (i.e., zinc), leaving behind a weak, porous layer of the more noble metal (i.e., copper and copper oxide). Tin tends to inhibit dealloying and where dezincification is a problem, red brass, commercial bronze, inhibited admiralty metal, and inhibited aluminum brass can be successfully used.

Galvanic Corrosion

Galvanic corrosion is an accelerated electrochemical corrosion that occurs when two dissimilar metals in contact are made part of an electrical circuit which is completed by a connecting pool or film of electrolyte or corrosive medium. Under these circumstances, the potential difference between the dissimilar metals produces a current flow through the conducting electrolyte. In this case, the less noble of the two metals will become the anode and will corrode. This type of corrosion does not require oxygen but does require water or some other conductive medium. Galvanic corrosion will exist at dissimilar metal contact points where: 1) surfaces are not adequately protected and 2) surfaces are exposed to moisture for prolonged periods of time. Galvanic corrosion will be localized in its attack and the resultant corrosion products may cause stress to an adjacent component due to oxide wedging or formation of crevices. Stress induced on an adjacent component, caused by the volume increase in corrosion products, could cause other degradation mechanisms to occur.

All metals or alloys have certain "built-in" properties which cause them to react as an anode or a cathode when in contact with dissimilar metals or alloys. Whether a particular material will react as a cathode or an anode is determined from the relative positions of the materials with respect to one another as shown on Table 4-2, the galvanic series chart. The further apart two materials are from each other (on the chart), the greater the rate of corrosion. The material closest to the anodic end of the chart will be the one to corrode.

The rate of corrosion is also affected by the relative size of the materials and composition of the electrolyte. A small anode area in contact with a large cathode area will result in a rapid severe corrosion. Conversely, a large anode area in contact with a small cathode area will lessen the rate of galvanic corrosion since the same total current flow will be spread out over a large area. Higher levels of electrolyte ionization (i.e., conductivity) result in a greater rate of corrosion because electrical current flows better in high conductivity electrolytes.

The effects of galvanic corrosion are minimized by:

1. Insulating the dissimilar metals from each other using nonconductive coatings, such as paint.

2. Eliminate the electrolyte.

3. Where different metals are used, choose those that are close together in the galvanic series.

4. Use the anode metal for large surface area components and cathode metal for small surface area components.

5. Protect the metals with a sacrificial anodic metal.

Microbiologically Influenced Corrosion (MIC) and Tuberculation

MIC is characterized by the formation of discrete deposits (e.g., microbial colonies and associated scale and debris) on the surface of the metal or alloy, such as carbon steels, stainless steels, copper and nickel alloys. Pitted surfaces are usually covered by the micro-organism deposits with the pit entrance being smaller than the overlaying deposit. In stainless steels, the deposits and pitting are usually found in the associated weld and heat-affected zones. The deposits usually contain:

1. Large amounts of iron and manganese regardless of the type of alloy.

2. Silicon, sulfur, and chloride are often found.

3. Phosphorus is occasionally found.

4. Copper is usually found in high amounts if a copper alloy is involved.

A large number of different organisms are involved in MIC, depending on the alloy and the environmental conditions. However, there is considerable evidence that the deposit forming iron and manganese bacteria, the slime-forming Pseudomonas type of bacteria, the deposit forming and iron reducing bacillus type organisms, and the sulfate reducing bacteria are of principal importance.

Temperature, pressure, pH, water content, salinity, redox potential (i.e., oxygen) and types and quantities of nutrients available are among the important factors influencing the microbes in their attempts to live in a given location. The following discussion is a generally accepted range over which organisms as a group are known to exist.

Temperature — Microbes can survive over at least the range -20 to 99°C [-4 to 210°F]. The range of temperatures over which microbes are most often found growing are from about 0-80°C [32-176°F].

Pressure — Most organisms tolerate pressures up to 31,000 kPa [4,500 psi].

pH — Microbes as a group can thrive in environments with pH levels ranging from 1 to at least 10.0. Also, bulk water values for pH can be misleading. The pH in bulk water may be 8.0 while at the surface of the metal under the microbial deposit (i.e., where fermentation is producing organic acids), the pH level can be much lower (i.e., 4.0 or less).

Water Content — All microorganisms require metabolically available water for survival. That is, it must not be in the form of ice or chemically complexed in such a way as to be inaccessible to the microbes.

Salinity — Many fresh water or terrestrial microbes thrive in deionized or demineralized water. These microbes can survive in very low levels of salts, or they can find elevated salt concentrations at surfaces of the metal.

Redox Potential — Microbes may 1) require oxygen at levels of about 0.01 atm or greater for growth, 2) require minute levels of oxygen for growth, 3) require no oxygen for growth, or 4) grow under any of these conditions.

Nutrients — Microbes require inorganic molecules (e.g., ammonia, nitrate, methane, etc.) as a source of energy and organic molecules and/or carbon dioxide as a source of carbon for growth. Most nuclear facilities use demineralized water because the deionization removes many of the nutrients from the water. However, the remaining nutrients do accumulate and concentrate at the surfaces of pipes and tanks, and the microbes follow the nutrients to these locations.

The formation of tubercules by biological organisms acting in conjunction with electrochemical corrosion occurs in many environments and on many alloys. Tubercules can form without the presence of any microorganisms; however, tuberculation usually takes place in biologically active aqueous systems.

The process of tubercule formation is complex. Any biofilm that does not provide for complete uniform coverage of the entire immersed surface of a metal or alloy has the potential to form concentration cells. Corrosion products are formed at these concentration cells. The corrosion products generally result in formation of pits at anodic areas under the biofilm. The corrosion products also join with the biofilm to form a corrosion tubercule. A gradual buildup of these corrosion tubercules can ultimately result in macrofouling.

4.2.3 Stress Corrosion Cracking

Stress corrosion cracking (SCC) is the term given to subcritical crack growth in certain alloys when subjected to stress and a corrosive environment. Many alloys are susceptible to SCC in at least one environment; however, SCC does not occur in all environments, nor does an environment that induces SCC in one alloy necessarily induce SCC in another alloy.[4.14]

Three factors or conditions must be present simultaneously for the possibility of SCC to occur. Elimination or a reduction in any one or a combination of these three factors will significantly reduce the likelihood or eliminate the possibility for SCC to occur. The three factors are:

- Susceptible Material (Metal Alloy)
- Tensile Stress (Applied and/or Residual)
- Corrosive Environment (an environment that can provide the chemical driving force for corrosion reaction)

Tensile stresses causing stress corrosion cracking are typically at material yield strength levels. However, stress levels causing stress corrosion cracking may sometimes be below the yield strength. Material susceptibility is related to the environment and may be influenced by the metallurgical condition of the material.

4.2.3.1 Intergranular Stress Corrosion Cracking (IGSCC)

IGSCC can be divided into two basic categories: 1) grain boundary precipitation and 2) grain boundary segregation. The effect of grain boundary precipitation in austenitic stainless steel (i.e., predominantly sensitized Type 304) is carbide precipitation which causes depletion of chromium adjacent to the grain boundary. The grain boundary then becomes anodically active and susceptible to corrosion. Impurities in a metal can segregate and produce a grain boundary that approaches 50% impure. The effect of these impurities alters the corrosion and mechanical properties of the grain boundary and causes cracking by anode dissolution.

The pump materials most commonly affected by this cracking are brass and Type 304 stainless steel. Section 4.2.3.2 below provides further information about the parameters and characteristics that must be present for chloride stress corrosion cracking to occur. The stress corrosion cracks originate at stress concentration points and follow in the direction perpendicular to the existing tensile stress.

4.2.3.2 Transgranular Stress Corrosion Cracking (TGSCC)

TGSCC differs from IGSCC in that the cracking (i.e., failure mode) occurs through or across the grain boundary as opposed to along the grain boundary. Sometimes the failure mode of an alloy can be a combination of TGSCC and IGSCC and at other times the failure mode can switch either from IGSCC to TGSCC or from TGSCC to IGSCC. IGSCC and TGSCC often occur in the same alloy depending on the service environment, microstructure of the metal, or the applied or residual stress/strain state.

TGSCC is affected by metallurgical factors and is related to the corrosion behavior of the alloy. Alloying effects are a key metallurgical factor in the formation of TGSCC. In high-chloride environments, corrosion can occur and cause chloride stress corrosion cracking which can be transgranular.

The combination of aqueous chlorides and austenitic stainless steel may cause chloride stress corrosion cracking to occur. Certain parameters and characteristics must be present; however, for chloride SCC to occur. Chloride SCC of austenitic stainless steel:

- Seldom occurs at metal temperatures below 60°C [140°F] and above 199°C [390°F].
- Requires an aqueous environment containing dissolved air or oxygen or other oxidizing agents.
- Occurs at very low tensile stress levels such that stress relieving heat treatments are seldom effective as a preventive measure.
- Affects all the austenitic stainless steels about equally with regard to susceptibility, time-to-failure, etc.
- Is characterized by transgranular branchlike cracking.

Chloride SCC is a concern for austenitic stainless steel pump components exposed to a chlorinated reservoir or pond where chlorides tend to concentrate.

4.2.3.3 Irradiation Assisted Stress Corrosion Cracking (IASCC)

Manifestation of IASCC involves simultaneous interaction of highly irradiated nonsensitized material with diffusion of impurities to the grain boundary, low stress, and high temperature water containing short-lived oxidizing species associated with gamma and neutron flux. Based on available field and laboratory data, a threshold fast neutron fluence (energy > 1 MeV) of approximately 5×10^{20} n/cm^2 appears to exist for IASCC to occur in stainless steel or Alloy 600. Formation of IASCC does not require chromium depletion sensitization at the grain boundary or presence of high tensile stress.

4.2.4 Erosion and Erosion/Corrosion

Erosion is attributed to the removal of protective oxide films on a metal and/or the base metal by mechanical action of a flowing fluid or particulate. Solid particles, present in a flowing fluid, impinge on internal surfaces particularly at flow discontinuities and cause low stress scratching (i.e., abrasive wear) of the surface. Due to the principles of momentum and mass transfer, the magnitude of stress and therefore severity of abrasive wear is directly related to the fluid velocity.

When the local pressure in a flowing liquid is reduced without a change in temperature, vapor-filled bubbles can form and expand within the flowing liquid. When these bubbles, which are formed in the low pressure region, pass into a region of higher pressure, expansion is reversed and the bubbles implode/collapse very rapidly. This process is called cavitation. Cavitation causes localized force/stress to be imparted on the oxide layer and underlying base metal surface which results in damage to the material in the form of erosion.

Erosion/corrosion occurs when the fluid or particulate matter is also corrosive to the metal. The mechanism of erosion/corrosion involves electrochemical aspects of general corrosion, mass transfer and momentum transfer. In an erosion/corrosion process: 1) a corrosive fluid forms an oxide layer on the surface of the metal, 2) erosive action removes this oxide layer, and 3) the newly exposed bare metal surface continues the corrosion process. This action of simultaneous oxide formation and removal leads to a reduction of metal thickness and is usually characterized by a pattern of grooves or peaks and valleys generated by the flow pattern of the corrosive fluids.

The principal factors affecting erosion and erosion/corrosion are:

Temperature — Maximum erosion/corrosion rates in single-phase flow occurs between 129-140°C [265°F-285°F].

Materials — Low alloy and plain carbon steel are most susceptible to erosion and erosion/corrosion. Alloying elements, such as chromium and molybdenum, improve resistance to erosion and erosion/corrosion. Austenitic stainless steels are highly resistant to erosion and erosion/corrosion.

Water Chemistry — The rate of erosion/corrosion in single phase fluid flow applications varies depending on the dissolved oxygen content and pH level. When the pH value is maintained neutral, the rate of erosion/corrosion decreases as dissolved oxygen content increases. Operation near 50 ppb dissolved oxygen in a neutral pH fluid (e.g., 7) reduces the rate of erosion/corrosion in carbon steel materials to negligible levels.

Flow Velocity/Configuration — Erosion and erosion/corrosion are most prevalent in regions where 1) high flow velocity exists, 2) turbulent flow is present, and 3) where the geometry causes flow directional changes.

Neither material hardness characteristics nor corrosion resistance properties, when existing alone, are sufficient for a particular metal to resist the effects of erosion and erosion/corrosion. Therefore, metals, such as stainless steel and alloy steels, which possess both high corrosion resistance and high hardness properties are less susceptible to the effects from erosion and erosion/corrosion than metals, such as plain carbon steel, which possess lower corrosion resistance and hardness properties.

4.2.5 Embrittlement

Structural or chemical changes induced by elevated temperatures, contaminants, or radiation causes embrittlement of metals which can lead to fragility and failures under dynamic loading. There are two predominant initiators of embrittlement that could possibly affect nuclear plant components: 1) thermal embrittlement and 2) neutron embrittlement.

Thermal Embrittlement

The mechanism of thermal embrittlement is complex and varies with material composition and service conditions. Fine grained, high chromium stainless steels normally possess good ductility. However, exposure to high temperature further increase strength while at the same time reduces ductility and fracture toughness properties of the material making it more susceptible to thermal embrittlement. Susceptibility to embrittlement increases with increasing chromium content, with the highest degree of embrittlement occurring when chromium contents are greater than 19%. At least 15% chromium is necessary for embrittlement to occur. The effect of carbon content on embrittlement is minimal.[4.3] The effects of thermal embrittlement on cast austenitic stainless steel are most prevalent at temperatures between 400-500°C [750-930°F] when maintained for long periods of time (e.g., greater than 100,000 hours).

Neutron Embrittlement

The following discussion summarizes the effects of neutron irradiation on the properties of austenitic stainless steels and Ni-Cr-Fe alloys. Carbon steel is not included because it is more ductile than stainless and high alloy steels.

Neutrons produce energetic primary recoil atoms which displace large numbers of atoms from their crystal lattice positions by a chain of atomic collisions. The neutron damage exposure can be characterized by dpa, which accounts for the neutron energy spectrum as well as the fluence. However, the dpa exposure parameter is not a direct measure of the number of residual defects; the primary defects undergo temperature dependent rearrangements both within the chain and as a consequence of long range migration.

Embrittlement is a function of radiation exposure and environmental and metallurgical variables. Fluence or dpa, and copper and nickel content have been identified as the primary contributors. Important second order variables include flux, temperature, and phosphorous content. There is evidence that a number of other variables such as heat treatment may also influence embrittlement. Available experimental data suggest that the following metallurgical properties result after prolonged exposure to neutrons:

- The yield strength increases by about a factor of 3 over its unirradiated value while the ultimate tensile strength remains essentially unchanged.
- The uniform elongation and the total elongation drop substantially from their unirradiated values.
- Fracture toughness drops by about a factor of 3 to 4, tearing modulus drops from several hundred to a range from 5 to 10.

Experimental data also suggests that an accumulated fast (> 1 Mev) neutron fluence of approximately 1×10^{20} n/cm^2 is the threshold value where these metallurgical properties begin to change.[4.8, 4.9, 4.12]

4.2.6 Wear

Wear is defined as damage to a solid surface by the removal or plastic displacement of material by the mechanical action of a contacting solid, liquid, or gas. There are three primary types of wear: adhesive wear, abrasive wear, and erosive wear.

Adhesive Wear

Adhesive wear is identified by commonly known terms such as scoring, galling, seizing, and scuffing and is further characterized as transference of material from one surface to another during relative motion or sliding due to a process called solid phase welding (i.e., particles from one surface are removed and either permanently or temporarily attached to the other surface).

Abrasive Wear

Abrasive wear or abrasion is identified by commonly known terms such as scouring and gouging and is characterized as displacement of material from a solid surface due to hard particles sliding along the surface. Scouring and gouging may be due to loose particles entrapped between surfaces that are in relative motion or from hard particle impingement that fractures the surface of the material such as in grinding applications.

Erosive Wear

Erosive wear is identified by commonly known terms such as erosion, cavitation, and droplet impingement and has been fully discussed in Section 4.2.4.

4.2.7 Stress Relaxation

Stress relaxation is an elevated temperature age-related degradation mechanism important in the design of devices intended to hold components in contact under pressure (e.g., bolted components). Stress relaxation occurs under high temperature conditions of constant strain where elastic deformation is replaced by plastic deformation. Materials loaded to some initial stress may experience a reduction in stress over time at high temperatures. The reduction in prestress generally occurs at a decreasing rate with the majority of loss occurring early in life of the prestressed part.

Factors affecting stress relaxation are 1) material type, 2) neutron fluence, 3) time, 4) temperature, and 5) amount of initial prestress. A significant magnitude of fast neutron fluence will not accumulate due to location of these components relative to the reactor core, therefore, the contribution of neutron fluence is negligible. Stress relaxation is a concern only for materials that are subject to high initial prestress conditions and exposed to high temperatures for prolonged periods of time.

4.2.8 Creep

Creep is defined as time-dependent strain, or gradual elastic and plastic deformation of metal that is under a constant stress at a value lower than its normal yield strength. The type of fracture (ductile or brittle) caused by creep depends on temperature and strain rate. The effect is particularly important if the temperature of stressing is in the vicinity of the recrystallization temperature of the metal.

When tensile stress is applied to a metal, the metal undergoes initial elastic strain. Following this initial elastic strain with the tensile stress continually applied, the metal will undergo increasing plastic strain at a decreasing strain rate. This is called first stage or primary creep. Following first stage creep, there is an equilibrium condition consisting of a nominally constant rate of plastic strain. This is called second stage or secondary creep. The duration of secondary creep depends upon the temperature and applied tensile stress on the metal. Following second stage creep is a condition of drastically increased strain rate with rapid extension to fracture. This is called third stage or tertiary creep.

4.2.9 Fouling

Fouling interferes with normal flow characteristics and will reduce pump efficiency. There are three general types of fouling found in pumps.

- Particulate Fouling
- Biological Fouling
- Precipitation Fouling

4.2.9.1 Particulate Fouling

Water-borne deposits, commonly known as foulants, are loose, porous, insoluble materials suspended in water. Foulants include such substances as particulate matter from the air, migrated corrosion products; silt, clays, and sand suspended in water; organic contaminants and biological matter. Fouling interferes with normal flow characteristics and can reduce efficiency. High flow rates can sweep away ordinary deposits, but low flow rates cause the suspended foulants to settle out and deposit on metal surfaces, thus causing corrosion.

4.2.9.2 Biological Fouling

Biological fouling, commonly referred to as biofouling, occurs by attachment of large or small organisms to pump surfaces. This macrofouling is responsible for degraded performance by either one or a combination of flow retardation, accumulation of concentration cells and microbiologically influenced corrosion.

When the attached biological material layer becomes thick, water flow capability is impeded. During high flow conditions, dislodgement of shells and other debris may occur resulting in further pluggage and flow retardation. Presence of concentration cells beneath biological masses is common especially if the water is stagnant. Stagnant water systems are ideal incubators for promoting the growth and proliferation of microorganisms. If large organisms are actively growing, microbes will more than likely be present, and their activity will result in direct corrosion of pump surfaces.

The Asiatic clam and zebra mussel are the principal organisms causing macrofouling in fresh water systems. In brackish water and seawater, macrofouling is caused by the blue mussel and the American oyster.

4.2.9.3 Precipitation Fouling

Precipitation fouling occurs by the crystallization of dissolved ions from solution onto the pump surface. Calcium carbonate, calcium sulfate, calcium phosphate, magnesium silicate, iron, manganese, and silica are the precipitants most commonly found in cooling waters. Calcium carbonate is the most prevalent precipitant found in nuclear plant cooling water systems.[4.15] Primary water applications in PWR plants contain boron to control reactivity. Cases have been identified in industry data that shows precipitate fouling from borated compounds. Precipitation fouling is commonly known as scaling because of its appearance. Precipitation fouling depends mainly upon fluid temperature, alkalinity or acidity, and concentration of scale-forming ions.

Calcium Carbonate

The amount of calcium carbonate scaling within a cooling water system directly depends on the concentrations of calcium hardness and bicarbonate alkalinity. The formation of this scale increases with pH and temperature.

Calcium Phosphate

Calcium phosphate scaling is generally found in two types of waters: 1) cooling waters treated with phosphate-based corrosion inhibitors and 2) cooling water supplied by partially treated sewage waters or rivers/lakes surrounded by farm runoff. Calcium phosphate precipitates out at higher pH and temperature.

Calcium Sulfate

Calcium sulfate scaling is caused by high concentrations of calcium and sulfate. It becomes less soluble at low pHs and higher temperatures. Calcium sulfate precipitation is an indication of severe fouling, because it does not occur until after all of the carbonate has precipitated out of the water.

Magnesium Silicate

Magnesium silicate scaling forms first as magnesium hydroxide as a result of precipitation of magnesium carbonate. The magnesium hydroxide then reacts with silica to form magnesium silicate. This scale is the hardest to remove from surfaces and is common to cold water applications, because the solubility of silica increases with temperature.

Silica

Silica precipitate scaling occurs predominantly in cold water applications, because the solubility increases with temperature. Maintaining the silica concentration less than 150 ppm as SiO_2 in cooling water applications should minimize its deposition on surfaces regardless of temperature.

Iron and Manganese

Iron fouling is common in cooling water applications that are supplied by iron-laden well water or rivers high in iron concentration. Manganese deposits are usually found in the form of manganese dioxide. Relatively low concentrations of manganese will cause scaling/deposition of surfaces. Manganese concentrations of concern are usually found in cooling water applications where the source is from: 1) bodies of water where acid mine drainage influents exist and 2) bodies of water formed over pine forests. Manganese dioxide scaling/deposits will precipitate as a result of oxidation of manganese by over-chlorination or by microorganism growth on surfaces.

Boron Solutions

Borated compounds will precipitate under certain concentration and temperature conditions. Boron precipitate fouling occurs predominantly in cold water applications because the solubility increases with temperature. In a typical PWR plant the solubility limit is 20,000 ppm boron at 54°C [130°F].

4.3 Evaluation of Aging Mechanisms

This section addresses the significance of each aging mechanism described in Section 4.2. An aging mechanism is significant when, if allowed to continue without detection or mitigation measures, it will cause the pump to lose its ability to perform its required function. The aging mechanisms are evaluated for each of the five major pump subassemblies and where necessary, for the subcomponents as listed in Table 3-2 and Table 3-5. The results of the evaluations are summarized in Tables 4-4 through 4-10.

Table 4-4. Significance of Aging Mechanisms for Primary Water System Pumps (BWR RWCU Pump and PWR Charging Pump)

Pump Subassembly	Mechanical Fatigue	Corrosion			SCC		Erosion and E/C (Note 4)	Wear	Fouling
		GEN (Note 1)	GAL	MIC	IGSCC (Note 2)	TGSCC (Note 3)			
ROTATING/RECIPROCATING									
Shaft	X							X	
Driveshaft/ Crankshaft	X (Note 5)							X	
Impeller	X						X	X	
Piston/Plunger								X	
Internal Valve	X (Note 5)						X	X	X (Note 6)
FIXED INTERNALS									
Misc. Structural Components									
Wearing Components							X (Note 7)	X	
Flow Guides							X		
PRESSURE BOUNDARY									
Casing	X						X		
Cylinder/Plunger Block	X (Note 5)						X		
Suction/Dis-charge Nozzle	X						X		
Flange/Cover	X								
Fasteners	X								

Table 4-4. Significance of Aging Mechanisms for Primary Water System Pumps (BWR RWCU Pump and PWR Charging Pump) (continued)

Pump Subassembly	Mechanical Fatigue	Corrosion			SCC		Erosion and E/C (Note 4)	Wear	Fouling
		GEN (Note 1)	GAL	MIC	IGSCC (Note 2)	TGSCC (Note 3)			
MECHANICAL SUBSYSTEMS									
Coupling	X							X	
Seals								X	
Radial Bearing								X	
Thrust Bearing	X							X	
SUPPORTS									
Support Feet/ Skirt	X								
Base Frame/Skid									
Fasteners									

X — Denotes aging mechanism as significant.

Notes:

1. General corrosion is not a significant aging mechanism for stainless and high alloy steel containing >12% chrome and bronze or brass material containing <15% zinc (see Sections 4.3.1.5.1 and 4.3.3.1).

2. IGSCC is not a significant aging mechanism provided the pump is located downstream from heat exchangers such that normal primary water temperatures at the pump are < 54°C [130°F] (see Sections 4.3.1.6.1 and 4.3.3.1).

3. TGSCC would only be a significant aging mechanism for stainless and high alloy pump materials if nitrogen was not a controlled element during manufacture of the part. In most cases nitrogen is controlled by material specification (see Sections 4.3.1.6.2 and 4.3.3.1).

4. Erosion and erosion/corrosion is significant when flow rates and suction heads are such that cavitation conditions can occur. Cases of erosion and erosion/corrosion have been reported in LERs and NPRDS for the BWR RWCU pumps and PWR charging pumps (see Section 4.3.2.1.2).

5. Mechanical fatigue is conservatively evaluated to be a significant aging mechanism for the reciprocating charging pump internal valve, driveshaft/crankshaft, and cylinder/plunger block. The assumption here is that the reciprocating charging pump is in continuous service. This may not be the case for many PWR plants (i.e., where the centrifugal charging pumps are normally in service and the reciprocating charging pumps in standby) (see Section 4.3.2.1.1).

6. Fouling of the reciprocating charging pump internal valve has shown, through NPRDS data, to be a significant aging mechanism (see Section 4.3.2.1.4).

7. Erosion and erosion/corrosion is not a significant aging mechanism for the reciprocating CVCS charging pump wearing components (see Section 4.3.2.2.2).

Table 4-5. Significance of Aging Mechanisms for Borated Water System Pumps (BWR SLC Pumps and PWR BAT Pumps)

Pump Subassembly	Mechanical Fatigue (Note 1)	Corrosion			SCC		Erosion and E/C (Note 4)	Wear	Fouling (Note 5)
		GEN (Note 2)	GAL	MIC	IGSCC	TGSCC (Note 3)			
ROTATING/RECIPROCATING									
Shaft	X				X			X	
Driveshaft/ Crankshaft								X	
Impeller	X				X		X	X	
Piston/Plunger					X			X	
Internal Valve					X			X	X
FIXED INTERNALS									
Miscellaneous Structural Components				X	X				X
Wearing Components					X			X	
Flow Guides				X	X				X
PRESSURE BOUNDARY									
Casing	X			X	X		X		X
Cylinder/Plunger Block				X	X				
Suction/ Discharge Nozzle	X			X	X		X		X
Flange/Cover	X			X	X				X
Fasteners	X								
MECHANICAL SUBSYSTEMS									
Coupling	X							X	
Seals					X			X	
Radial Bearing								X	
Thrust Bearing	X							X	
SUPPORTS									
Support Feet/Skirt	X								
Base Frame/Skid									
Fasteners									

Table 4-5. Significance of Aging Mechanisms for Borated Water System Pumps (BWR SLC Pumps and PWR BAT Pumps) (continued)

X — Denotes aging mechanism as significant.

Notes:

1. The boric acid transfer pumps in a PWR are considered as continuously operating, whereas, the standby liquid control pumps in a BWR are typically operated only for testing on a quarterly basis. Therefore, mechanical fatigue is significant only for boric acid transfer pump components (see Section 4.3.2.3.1).
2. General corrosion is not a significant aging mechanism for stainless and high alloy steel containing > 12% chrome and bronze or brass material containing <15% zinc (see Sections 4.3.1.6.1 and 4.3.3.2).
3. TGSCC would only be a significant aging mechanism for stainless and high alloy pump materials if nitrogen was not a controlled element during manufacture of the part. In most cases nitrogen is controlled by material specification (see Sections 4.3.1.6.2 and 4.3.3.2).
4. Erosion and erosion/corrosion is not a significant aging mechanism for the reciprocating SLC System pump because the pump operates infrequently, and pump materials are resistant to this aging mechanism (see Sections 4.3.2.1.2 and 4.3.2.3.2).
5. Stationary pump components are susceptible to fouling because they handle fluids containing borated compounds. Borated compounds can precipitate out of solution under certain concentration and temperature conditions. One case of this phenomena occurring to a boric acid transfer pump was identified in the LER data search (see Sections 4.3.2.2.4 and 4.3.2.3.3).

Table 4-6. Significance of Aging Mechanisms for Continuously Operated Treated Water System Pumps (BWR-CRD, RHR, and Fuel Pool Cooling Pumps) (PWR-Primary Makeup, RHR, and Fuel Pool Cooling Pumps)

Pump Subassembly	Mechanical Fatigue	Corrosion			SCC		Erosion and E/C (Note 6)	Wear	Fouling
		GEN (Note 1)	GAL (Note 2)	MIC	IGSCC (Note 3) (Note 4)	TGSCC (Note 4) (Note 5)			
ROTATING/RECIPROCATING									
Shaft	X	X	X		X			X	
Impeller	X	X	X		X		X	X	
FIXED INTERNALS									
Miscellaneous Structural Components		X	X	X	X	X X			X
Wearing Components		X	X		X	X	X	X	
Flow Guides		X	X	X	X		X		X

Table 4-6. Significance of Aging Mechanisms for Continuously Operated Treated Water System Pumps (BWR-CRD, RHR, and Fuel Pool Cooling Pumps) (PWR-Primary Makeup, RHR, and Fuel Pool Cooling Pumps) (continued)

Pump Subassembly	Mechanical Fatigue	Corrosion			SCC		Erosion and E/C (Note 6)	Wear	Fouling
		GEN (Note 1)	GAL (Note 2)	MIC	IGSCC (Note 3) (Note 4)	TGSCC (Note 4) (Note 5)			
PRESSURE BOUNDARY									
Casing	X	X (Note 7)	X	X	X		X		X
Suction/Discharge Nozzle	X	X (Note 7)	X	X	X		X		X
Flange/Cover	X	X (Note 7)	X	X	X				X
Fasteners	X	X							
MECHANICAL SUBSYSTEMS									
Coupling	X	X						X	
Seals		X	X		X			X	
Radial Bearing								X	
Thrust Bearing	X							X	
SUPPORTS									
Support Feet/Skirt	X	X							
Base Frame/Skid		X							
Fasteners		X							

X — Denotes aging mechanism as significant.

Notes:

1. General corrosion is a significant aging mechanism only for carbon and low alloy steels and cast iron pump subcomponents (see Sections 4.3.1.5.1 and 4.3.3.3).

2. Galvanic corrosion is a significant aging mechanism only for carbon and low alloy steels and cast iron because these materials are anodic with respect to all other pump materials. Galvanic corrosion is a significant aging mechanism for bronze and brass materials when in contact with stainless steel (see Section 4.3.3.3).

3. IGSCC is a significant aging mechanism only for stainless and high alloy steel pump subcomponents that can, for a time, have an operating fluid temperature > 54°C [130°F] (see Section 4.3.3.3).

4. Wrought brass and bronze materials containing > 15% zinc are susceptible to IGSCC and TGSCC (see Section 4.3.3.3).

5. TGSCC would only be a significant aging mechanism for stainless and high alloy pump materials if nitrogen was not a controlled element during manufacture of the part. In most cases nitrogen is controlled by material specification (see Section 4.3.1.6.2).

Table 4-6. Significance of Aging Mechanisms for Continuously Operated Treated Water System Pumps (BWR-CRD, RHR, and Fuel Pool Cooling Pumps) (PWR-Primary Makeup, RHR, and Fuel Pool Cooling Pumps) (continued)

Notes:

6. Erosion and erosion/corrosion is a significant aging mechanism for primarily carbon and low alloy steels and cast iron when flow rates and suction heads are such that cavitation can occur. Even stainless and high alloy steels are susceptible to erosion and erosion corrosion under these circumstances (see Sections 4.3.1.7, 4.3.2.1.2, 4.3.2.2.2, and 4.3.2.3.2).

7. General corrosion is a significant aging mechanism for pump pressure boundary components where the design corrosion allowance is less than 3.2 mm [0.125 in] (see Section 4.3.3.3).

Table 4-7. Significance of Aging Mechanisms for Intermittently Operated Treated Water System Pumps (BWR-Core Spray, HPCI and RCIC Pumps) (PWR-AFW, SI, Containment Recirculation and Spray Pumps)

Pump Subassembly	Mechanical Fatigue	Corrosion			SCC		Erosion and E/C (Note 5)	Wear	Fouling
		GEN (Note 1)	GAL (Note 2)	MIC	IGSCC (Note 3)	TGSCC (Note 3) (Note 4)			
ROTATING/RECIPROCATING									
Shaft	X	X	X					X	
Impeller	X	X	X				X	X	
FIXED INTERNALS									
Miscellaneous Structural Components		X	X	X	X	X			X
Wearing Components		X	X		X	X	X	X	
Flow Guides		X	X	X			X		X
Suction Strainer (Note 6)		X	X	X			X		X
PRESSURE BOUNDARY									
Casing		X (Note 7)	X	X			X		X
Suction/Discharge Nozzle		X (Note 7)	X	X			X		X
Flange/Cover		X (Note 7)	X	X					X
Fasteners		X							

Table 4-7. Significance of Aging Mechanisms for Intermittently Operated Treated Water System Pumps (BWR-Core Spray, HPCI and RCIC Pumps) (PWR-AFW, SI, Containment Recirculation and Spray Pumps) (continued)

Pump Subassembly	Mechanical Fatigue	Corrosion			SCC		Erosion and E/C (Note 5)	Wear	Fouling
		GEN (Note 1)	GAL (Note 2)	MIC	IGSCC (Note 3)	TGSCC (Note 3) (Note 4)			
MECHANICAL SUBSYSTEMS									
Coupling	X	X						X	
Seals		X	X					X	
Radial Bearing								X	
Thrust Bearing	X							X	
SUPPORTS									
Support Feet/Skirt	X	X							
Base Frame/Skid		X							
Fasteners		X							

X — Denotes aging mechanism as significant.

Notes:

1. General corrosion is a significant aging mechanism only for carbon and low alloy steels and cast iron pump subcomponents (see Sections 4.3.1.5.1 and 4.3.3.3).
2. Galvanic corrosion is a significant aging mechanism only for carbon and low alloy steels and cast iron because these materials are anodic with respect to all other pump materials. Galvanic corrosion is a significant aging mechanism for bronze and brass materials when they are in contact with stainless steel materials (see Section 4.3.3.3).
3. Wrought brass and bronze materials containing > 15% zinc are susceptible to IGSCC and TGSCC (see Section 4.3.3.3).
4. TGSCC would only be a significant aging mechanism for stainless and high alloy pump materials of nitrogen was not a controlled element during manufacture of the part. In most cases nitrogen is controlled by material specification (see Section 4.3.1.6.2).
5. Erosion and erosion/corrosion is a significant aging mechanism for primarily carbon and low alloy steels and cast iron when flow rates and suction heads are such that cavitation can occur. Even stainless and high alloy steels are susceptible to erosion and erosion/corrosion under these circumstances. Fouling of a suction strainer can cause cavitation (see Sections 4.3.1.7, 4.3.2.1.2, 4.3.2.2.2, and 4.3.2.3.2).
6. The suction strainer is only applicable to the PWR containment recirculation pumps.
7. General corrosion is a significant aging mechanism for pump pressure boundary components where the design corrosion allowance is less than 3.2 mm [0.125 in] (see Section 4.3.3.3).

Table 4-8. Significance of Aging Mechanisms for Closed Cooling Water System Pumps (Note 1)

Pump Subassembly	Mechanical Fatigue	Corrosion			SCC		Erosion and E/C (Note 5)	Wear	Fouling
		GEN (Note 2)	GAL (Note 3)	MIC (Note 3)	IGSCC (Note 4)	TGSCC (Note 4)			
ROTATING/RECIPROCATING									
Shaft	X	X						X	
Impeller	X	X					X	X	
FIXED INTERNALS									
Miscellaneous Structural Components		X			X	X			
Wearing Components		X			X	X	X	X	
Flow Guides		X					X		
PRESSURE BOUNDARY									
Casing	X	X (Note 6)					X		
Suction/Discharge Nozzle	X	X (Note 6)					X		
Flange/Cover	X	X (Note 6)							
Fasteners	X	X							
MECHANICAL SUBSYSTEMS									
Coupling	X	X						X	
Seals		X						X	
Radial Bearing								X	
Thrust Bearing	X							X	
SUPPORTS									
Support Feet/Skirt	X	X							
Base Frame/Skid		X							
Fasteners		X							

X — Denotes aging mechanism as significant.

Notes:

1. Closed Cooling Water System pumps include systems with the following names. Most systems are common to both BWRs and PWRs.

   - Reactor Building Closed Cooling Water

Table 4-8. Significance of Aging Mechanisms for Closed Cooling Water System Pumps (Note 1) (continued)

Notes:

- Emergency Equipment Cooling Water
- Auxiliary Building Closed Cooling Water
- Containment Chilled Water
- EDG Jacket Cooling Water
- Component Cooling Water

2. General corrosion is a significant aging mechanism only for carbon and low alloy steels and cast iron pump subcomponents (see Sections 4.3.1.5.1 and 4.3.3.4).

3. Galvanic corrosion and microbiologically influenced corrosion are not significant aging mechanisms provided the water is treated with appropriate chemicals (i.e. corrosion inhibitors/biocides) and fluid analysis is routinely performed to verify chemical concentration (see Section 4.3.3.4).

4. Wrought brass and bronze materials containing > 15% zinc are susceptible to IGSCC and TGSCC (see Section 4.3.3.4).

5. Erosion and erosion/corrosion is a significant aging mechanism for continuously operated carbon and low alloy steels and cast iron pump subcomponents when flow rates and suction heads are such that cavitation can occur and/or where particle impingement exists (see Sections 4.3.1.7, 4.3.2.1.2, 4.3.2.2.2, and 4.3.2.3.2).

6. General corrosion is a significant aging mechanism for carbon and low alloy steels and cast iron pump pressure boundary components where the design corrosion allowance is less than 3.2 mm [0.125 in] (see Section 4.3.3.4).

Table 4-9. Significance of Aging Mechanisms for Lubricating and Fuel Oil System Pumps (Note 1)

Pump Subassembly	Mechanical Fatigue	Corrosion			SCC		Erosion and E/C Note	Wear	Fouling (Note 3)
		GEN (Note 2)	GAL	MIC	IGSCC	TGSCC			
ROTATING/RECIPROCATING									
Shaft	X	X						X	
Impeller	X	X						X	
Internal Rotor	X	X						X	
FIXED INTERNALS									
Miscellaneous Structural Components		X							X
Wearing Components		X						X	
Flow Guides		X							X

Table 4-9. Significance of Aging Mechanisms for Lubricating and Fuel Oil System Pumps (Note 1) (continued)

Pump Subassembly	Mechanical Fatigue	Corrosion			SCC		Erosion and E/C Note	Wear	Fouling (Note 3)
		GEN (Note 2)	GAL	MIC	IGSCC	TGSCC			
PRESSURE BOUNDARY									
Casing		X (Note 4)							X
Suction/Discharge Nozzle		X (Note 4)							X
Flange/Cover		X (Note 4)							X
Fasteners		X							
MECHANICAL SUBSYSTEMS									
Coupling	X	X						X	
Seals		X						X	
Radial Bearing								X	
Thrust Bearing	X							X	
SUPPORTS									
Support Feet/Skirt	X	X							
Base Frame/Skid		X							
Fasteners		X							

X — Denotes aging mechanism as significant.

Notes:

1. Lubricating and fuel oil system pumps include systems with the following names. Some systems are common to both BWRs and PWRs as indicated.
   - Emergency Diesel Generator Fuel Oil Transfer (Common)
   - Emergency Diesel Generator Lube Oil (Common)
   - HPCI Lubricating Oil (BWR)
   - RCIC Lubricating Oil (BWR)
   - Auxiliary Feedwater Lubricating Oil (PWR)
2. General corrosion is a significant aging mechanism only for carbon and low alloy steels and cast iron pump subcomponents (see Sections 4.3.1.5.1 and 4.3.3.5).
3. Fouling is a significant aging mechanism because of the potential for contaminants entering the oil system from reservoir bottoms, corrosion products or bearing material fines (see Sections 4.3.2.2.4 and 4.3.2.3.3).
4. General corrosion is a significant aging mechanism for pump pressure boundary components where the design corrosion allowance is less than 3.2 mm [0.125 in] (see Section 4.3.3.5).

Table 4-10. Significance of Aging Mechanisms for Raw Water System Pumps (Note 1)

Pump Subassembly	Mechanical Fatigue	Corrosion			SCC		Erosion and E/C (Note 7)	Wear	Fouling (Note 8)
		GEN (Note 2)	GAL (Note 3)	MIC	IGSCC (Note 4)	TGSCC (Note 5) (Note 6)			
ROTATING/RECIPROCATING									
Shaft	X	X	X		X			X	
Impeller	X	X	X		X		X	X	X
FIXED INTERNALS									
Miscellaneous Structural Components		X	X	X	X	X			X
Wearing Components		X	X		X	X	X	X	
Flow Guides		X	X	X	X		X		X
Suction Strainer		X	X	X	X		X		X
PRESSURE BOUNDARY									
Casing	X	X	X	X	X		X		X
Discharge Head, Column/Bowl/ Discharge Nozzle	X	X	X		X		X		X
Suction/Discharge Nozzle	X	X	X	X	X		X		X
Flange/Cover	X	X	X	X	X				X
Fasteners	X	X							
MECHANICAL SUBSYSTEMS									
Coupling	X	X						X	
Seals		X	X		X			X	
Radial Bearing								X	
Internal Radial Bearing		X	X		X		X	X	
Thrust Bearing	X							X	
SUPPORTS									
Support Feet/Skirt	X	X							
Base Frame/Skid		X							
Fasteners		X							

Table 4-10. Significance of Aging Mechanisms for Raw Water System Pumps (Note 1) (continued)

X — Denotes aging mechanism as significant.

Notes:

1. Raw water system pumps include systems with the following names. These system pumps are for the most part common to both BWR and PWR plants except where identified in parenthesis. There are essentially two different types of fluid (seawater/brackish and freshwater) use for these service water applications.
   - Residual Heat Removal Service Water (BWR)
   - Emergency Equipment Service Water
   - Essential Service Water
   - Emergency Diesel Generator Service Water
   - Nuclear Service Water
   - Auxiliary Service Water
   - Non-essential Service Water

2. General corrosion is a significant aging mechanism for carbon and low alloy steel, cast iron, stainless and high alloy steel pump subcomponents (see Sections 4.3.1.5.1 and 4.3.3.6).

3. Galvanic corrosion is a significant aging mechanism only for carbon and low alloy steels and cast iron because these materials are anodic with respect to all other pump materials. Galvanic corrosion is a significant aging mechanism for bronze and brass materials when in contact with stainless steel (see Section 4.3.3.6).

4. IGSCC is a significant aging mechanism only for stainless and high alloy steel pump subcomponents due to impurities in the pumped fluid (see Section 4.3.3.6).

5. TGSCC would only be a significant aging mechanism for stainless and high alloy pump materials if nitrogen was not a controlled element during manufacture of the part. In most cases nitrogen is controlled by material specification (see Section 4.3.1.6.2).

6. Wrought brass and bronze materials containing > 15% zinc are susceptible to IGSCC and TGSCC (see Section 4.3.3.6).

7. Erosion and erosion/corrosion is a significant aging mechanism for all wetted pump components regardless of material type when flow rates and suction heads are such that cavitation can occur. Fouling of a suction strainer can cause cavitation. Particle impingement also results in service water pump erosion (see Sections 4.3.1.7, 4.3.2.1.2, 4.3.2.2.2, and 4.3.2.3.2).

8. Service water pump applications are susceptible to severe fouling from sand, dirt, seaweed, fish and other large pieces of debris. Another form of fouling unique to service water pump application is buildup of organic/inorganic tuberculation and/or mussel formation and/or barnacles (see Sections 4.3.2.1.4, 4.3.2.2.4, and 4.3.2.3.3).

Many of the relationships between the aging mechanisms described in Section 4.2 and the pump applications listed in Tables 3-7 and 3-8 apply to all the pumps evaluated in this AMG. These relationships are described and evaluated in Section 4.3.1. The significance of some of the aging mechanisms is determined by this evaluation. In Sections 4.3.2 and 4.3.3, the mechanisms are further examined, as necessary, by considering the affected major pump subassemblies and subcomponents, service application, pumped fluid characteristics, and construction materials.

Where aging mechanisms are classified as significant or non-significant, qualification statements are included as necessary. Since many different plant-specific situations exist, aging mechanism significance may only apply to certain pump types, environments, materials, services, etc. The aging mechanism significance evaluations carefully consider whether or not the operational and environmental stressors may cause significant degradation for a specific component over long periods (40 years or more), even if industry history has not documented such degradation.

Finally, three special issues are addressed; loss of threaded fastener preload in Section 4.3.4, aging of non-metallic components in Section 4.3.5, and aging mechanism synergies and dependencies in Section 4.3.6.

4.3.1 Aging Mechanism Considerations That Apply to all Pumps

The relationships between the aging mechanisms described in Section 4.2 and the pump applications described in Section 3 are evaluated in this subsection. These evaluations apply to all the pumps and their components. The intent of this subsection is to consolidate the determinations of significance or non-significance, wherever possible, or to present the considerations that need to be examined in Sections 4.3.2 and 4.3.3; evaluations of the pump subassemblies and components and service applications, respectively.

4.3.1.1 Thermal Embrittlement, Stress Relaxation, and Creep

Normal pumped fluid operating temperatures for all of the pump applications are below the 93°C [200°F] threshold levels established for thermal embrittlement, stress relaxation, and creep[4.4, 4.16] in Sections 4.2.5, 4.2.7, and 4.2.8. The RHR, CVCS for PWRs, and RWCU for BWRs operate at fluid temperatures above 93°C [200°F] during other scheduled modes of plant operation. Transient events, or events involving operator error would be required to have fluid temperatures above 93°C [200°F] for all other pump applications. These are relatively short-term situations.

The RHR pumps operate at fluid temperatures above 93°C [200°F] for short periods directly after reactor shutdown to remove decay heat. Fluid temperatures may initially be approximately 177°C [350°F] and may remain above 93°C [200°F] for several days.

The PWR CVCS charging pumps and BWR RWCU pumps operate at reactor temperatures 260-316°C [500-600°F] for short time periods when heat exchangers upstream of the pumps are bypassed. Operation in the bypass mode only occurs following a system component degradation/failure unrelated to the pump. The duration generally would not exceed a few days. PWR CVCS and BWR RWCU System designs typically include heat exchangers upstream of the pump suction; however, this could not be confirmed for every plant.

If the PWR CVCS and BWR RWCU System designs include a heat exchanger upstream of the pumps, then thermal embrittlement, stress relaxation, and creep are not significant aging mechanisms for the CVCS charging and RWCU pumps. For the remaining pumps in the scope of this AMG, these aging mechanisms are not significant without condition.

4.3.1.2 Irradiation Assisted Stress Corrosion Cracking (IASCC) and Neutron Embrittlement

The pumps evaluated in this AMG are located outside of Primary Containment and, therefore, are exposed to very low levels of neutron fluence from external sources.

The PWR CVCS charging pump, BWR RWCU pump, and fuel pool cooling pump may be exposed to neutron fluence from the pumped fluid following a fuel assembly failure. Fuel assembly failure is an infrequent event as evident by the review of plant operating history in Section 3 of the guideline (i.e., no incidence of pump failures from IASCC or neutron embrittlement). From other aging studies, a 40-year maximum fast neutron fluence (energy > 1 MeV) for the reactor vessel beltline region is estimated to be 3.0×10^{18} n/cm^2. [4.17] Projected forward to 60 years, assuming an 80% capacity factor the maximum fast neutron fluence at the biological shield inner surface is calculated as 6.7×10^{17} n/cm^2.[4.18] The maximum fast neutron fluence at the inside surface of the containment wall nearest the reactor core region is conservatively estimated to be between 4×10^{14} - 2.6×10^{15} n/cm^2 for BWR Mark I containments. The fluence level for Mark II and III containment is much lower.[4.19, 4.20] PWR neutron fluence levels at the containment wall are typically less than 10^{14} n/cm^2. Very localized areas might see 10^{17} n/cm^2.[4.21] These fast neutron fluence levels are significantly more than 100 times lower than levels necessary to initiate these aging mechanisms (see Sections 4.2.3 and 4.2.5).

The other pumps in the scope of this AMG can not be subjected to fast neutron fluence from internal sources. Therefore, IASCC and neutron embrittlement are not significant aging mechanisms for all pumps without conditions.

4.3.1.3 Thermal Fatigue

Thermal stress is a self balancing stress produced by a non-uniform distribution of temperature. A temperature change of the pumped fluid results in a non-uniform temperature distribution in the wetted components/parts. The range of pumped fluid temperature levels are shown in Table 4-11 and 4-12 for each of the pumps. The minimum, normal, and maximum operating temperatures are steady-state operating conditions for the planned operating modes of the respective systems.

Table 4-11. Pumped Fluid Temperature Conditions — BWR Plants

Pump	Normal Operating Status	Minimum Nominal Operating Temperature	Nominal Operating Temperature	Maximum Nominal Operating Temperature	Subject to Start-up/Shutdown Thermal Cycles		Subject to Thermal Cycles from Accident Transients	
					Yes/No	Max. ΔT	Yes/No	Max. ΔT
Closed Cooling Water	Continuous	27°C [80°F]	< 35°C [95°F]	35°C [95°F]	Yes	8.3°C [15°F]	No	N/A
Control Rod Drive	Continuous	4.4°C [40°F]	< 35°C [95°F]	<43°C [110°F]	Yes	16.7°C [30°F]	Yes	38.9°C [70°F]
Core Spray	Standby	4.4°C [40°F]	< 35°C [95°F]	< 35°C [95°F]	Yes	16.7°C [30°F]	Yes	77.8°C [140°F]*
Emergency Diesel Generator Fuel Oil Transfer	Standby	4.4°C [40°F]	21°C [70°F]	32°C [90°F]	Yes	16.7°C [30°F]	No	N/A
Emergency Diesel Generator Jacket Water	Standby	27°C [80°F]	< 35°C [95°F]	< 35°C [95°F]	Yes	8.3°C [15°F]	No	N/A
High Pressure Coolant Injection	Standby	4.4°C [40°F]	< 35°C [95°F]	< 35°C [95°F]	Yes	16.7°C [30°F]	Yes	77.8°C [140°F]
Lubricating Oil	Continuous	10°C [50°F]	≈ 38°C [100°F]	66°C [150°F]	Yes	27.8°C [50°F]	No	N/A
Reactor Core Isolation Cooling	Standby	4.4°C [40°F]	< 35°C [95°F]	< 35°C [95°F]	Yes	16.7°C [30°F]	Yes	77.8°C [140°F]
Reactor Water Cleanup	Continuous	49°C [120°F]	≤ 60°C [140°F]	< 60°C [140°F]	Yes	38.9°C [70°F]	Yes	244°C [440°F]
Residual Heat Removal	Standby	4°C [40°F]	35°C [95°F]	177°C [350°F]	Yes	141°C [255°F]	Yes	141°C [255°F]
Service Water	Continuous	0°C [33°F]	0-29°C [33-85°F]	29°C [85°F]	Yes	22.2°C [40°F]	No	N/A
Spent Fuel Pool Cooling	Continuous	27°C [80°F]	≈ 27°C [80°F]	66°C [150°F]	No	N/A	No	N/A
Standby Liquid Control	Standby	27°C [80°F]	< 35°C [95°F]	< 35°C [95°F]	No	N/A	No	N/A

* The 140°F ΔT is calculated from an assumed 180°F suppression pool temperature during the accident and then switching suction to the CST at 40°F (Mark I containment). Same for HPCI and RCIC.

Table 4-12. Pumped Fluid Temperature Conditions - PWR Plants

Pump	Normal Operating Status	Minimum Nominal Operating Temperature	Nominal Operating Temperature	Maximum Nominal Operating Temperature	Subject to Start-up/Shutdown Thermal Cycles		Subject to Thermal Cycles from Accident Transients	
					Yes/No	Max. ΔT	Yes/No	Max. ΔT
Auxiliary Feedwater	Standby	4°C [40°F]	10°C [50°F]	52°C [125°F]	Yes	22.2°C [40°F]	No	N/A
Boric Acid Transfer	Continuous	66°C [150°F]	71°C [160°F]	121°C [250°F]	No	N/A	No	N/A
Charging	Standby	21°C [70°F]	43°C [110°F]	66°C [150°F]	Yes	44°C [80°F]	Yes	44°C [80°F]
Closed Cooling Water	Continuous	27°C [80°F]	< 35°C [95°F]	35°C [95°F]	Yes	8.3°C [15°F]	No	N/A
Containment Recirculation	Standby	10°C [50°F]	21°C [70°F]	38°C [100°F]	Yes	11.1°C [20°F]	Yes	111-144°C [200-260°F]
Containment Spray	Standby	2°C [35°F]	21°C [70°F]	38°C [100°F]	Yes	22.2°C [40°F]	Yes	111-144°C [200-260°F]
Emergency Diesel Generator Fuel Oil Transfer	Standby	4°C [40°F]	21°C [70°F]	32°C [90°F]	Yes	16.7°C [30°F]	No	N/A
Emergency Diesel Generator Jacket Water	Standby	27°C [80°F]	< 35°C [95°F]	< 35°C [95°F]	Yes	8.3°C [15°F]	No	N/A
Lubricating Oil	Continuous	10°C [50°F]	≈ 38°C [100°F]	66°C [150°F]	Yes	27.8°C [50°F]	No	N/A
Primary Water	Standby	2°C [35°F]	21°C [70°F]	66°C [150°F]	No	N/A	No	N/A
Residual Heat Removal	Standby	21°C [70°F]	35°C [95°F]	177°C [350°F]	Yes	141°C [255°F]	Yes	141°C [255°F]
Safety Injection	Standby	2°C [35°F]	21°C [70°F]	38°C [100°F]	Yes	22.2°C [40°F]	Yes	111-144°C [200-260°F]
Service Water	Continuous	0°C [33°F]	0-29°C [33-85°F]	29°C [85°F]	Yes	22.2°C [40°F]	No	N/A
Spent Fuel Pool Cooling	Continuous	27°C [80°F]	≈ 27°C [80°F]	27°C [80°F]	No	N/A	No	N/A

The start-up and shutdown thermal cycles are associated with operating the system during normal plant operating conditions. Many of the pumps are maintained in a standby condition. When they are started, the pump temperature changes from the local ambient temperature to the pumped fluid operating temperature. The values of "Max. ΔT" shown in Table 4-11 and 4-12 were determined for a local ambient temperature of 21°C [70°F]. The temperature changes are relatively small, except for the residual heat removal, reactor water cleanup, chemical volume and control charging, and boric acid transfer pumps. The associated thermal stresses are, therefore, small and would not be a consideration for pump design and operation. System design features and operating requirements are used to control the rate of temperature change for residual heat removal, reactor water cleanup, charging, and boric acid transfer pumps during normal plant operation. These features and operating requirements ensure that the rate of change is less than 55°C/hr [100°F/hr] during normal system operation. With these controls, the cumulative fatigue usage due to thermal cycles is negligible and not a consideration for pump design and operation.

Some of the pumps are subject to thermal cycles from plant transients (Table 4-11 and 4-12). With the exception of the control rod drive and reactor water cleanup pumps, these transients are associated with postulated accident conditions. The design assumes a very low number of accident occurrences and therefore the number of thermal cycles caused by accident conditions is very small. Consequently, cumulative fatigue usage due to accident conditions is low, and therefore not a consideration for pump design and operation. For the control rod drive pumps, however, significant thermal cycles would be caused by a quick change from a higher temperature source (condensate system) to a lower temperature source (condensate storage tank). This quick change in water supply to the CRD pumps is a low occurrence event and the temperature decrease is not greater than 55°C [100°F]. The reactor water cleanup pumps would be subject to a significant thermal cycle (i.e., >111°C/hr [200°F/hr]) if the heat exchangers upstream of the pumps fail or the heat sink is inadvertently isolated or bypassed. These transients are low occurrence events that are mitigated by good maintenance and plant operating practices. Consequently, cumulative fatigue usage due to transients is low for the reactor water cleanup pump and therefore, not a consideration for this pump design and operation.

Another source of stress results from thermal expansion of the piping connected to the pump inlets and outlets. The pump is typically treated as an anchor in the piping design. Therefore, the restrained movement of the piping imposes loads on the pump nozzles, casings, and supports.

Piping system design practices defined in ANSI B.31.1 and ASME Section III limit the loads applied to the pump from thermal expansion of the piping. The flexibility of the piping is designed to ensure that the manufacturer's maximum allowable pump nozzle loads are not exceeded. Conventional design practices also use conservative assumptions of temperature conditions when determining the pump nozzle loads. In some cases, the piping design includes expansion loops or expansion joints to achieve acceptable nozzle loading conditions. In some cases, cold spring of the pipimg may be utilized to counteract stresses applied during heatup to operating temperature. These are rare occurrences and generally avoided if at all possible. Therefore, stresses imposed on the pump nozzles from the connected piping are low and not a consideration for the continued operation of the pump.

These discussions demonstrate that thermal fatigue is not a significant aging mechanism if the following conditions are met:

a. The pumped fluid temperature conditions in Table 4-11 and 4-12 apply, or are bounding.

b. System design features and/or operating requirements limit the rate of temperature change to less than 55°F/hr [100°F/hr] during normal start-up/shutdown of the residual heat removal, reactor water cleanup, charging, and boric acid transfer pumps.

c. Maintenance and operating practices are in place to prevent a sudden loss of the heat sink function of the heat exchangers upstream of the reactor water cleanup pumps.

d. The loads imposed on the pump from the connected piping are less than the manufacturer's allowable loads as determined by analysis or measurement.

4.3.1.4 Mechanical Fatigue

Cyclic loads are applied to pump subcomponents during starts, stops, load changes, and steady state operation. These loads are caused by mechanical stressors (transmitted torque and rotor dynamic loads) and hydraulic stressors (fluid impingement and differential pressure loads). Both mechanical and hydraulic stressors are imposed on the rotating/reciprocating components. These components are the most susceptible to mechanical fatigue damage. The fixed internals and pressure boundary components are primarily exposed to hydraulic stressors. The mechanical subsystem subcomponents (bearings, couplings, and seals) and supporting base are exposed to cyclic loads from mechanical stressors.

The cyclic rotor dynamic loads (see Section 4.1.1) are associated with steady state operation for centrifugal and rotary pumps. These loads tend to be relatively low in magnitude and high in frequency and are usually the primary source of high cycle fatigue. For reciprocating pumps, cyclic fluid impingement, differential pressure, and rotor dynamic loads are all associated with steady state operation. These loads tend to be relatively high in magnitude and low in frequency and are usually the primary source of low cycle fatigue, particularly the torque and pressure loads.

Peak stresses generally occur on the exterior surface of a component at a mechanical or metallurgical stress raiser. Mechanical stress raisers are caused by geometry (small fillets, sharp corners, grooves, and keyways), configuration (shrink fit spacers and couplings), or mechanical abuse (nicks or scratches). Metallurgical stress raisers are caused by weld cracks/inclusions, base metal surface flaws, non-homogeneous chemical composition, and residual heat treatment/fabrication stresses. Mechanical stress raisers are unavoidable in the design of some pump components, and the potential for fatigue degradation is always a design consideration.

There are no metals which are immune to fatigue, but some alloys are more resistant than others (more cycles allowed for a given level of alternating stress level/higher endurance limits). Since resistance to fatigue is similar to resistance in microscopic cracking while undergoing high localized strain rates, materials with greater ductility tend to be less susceptible to fatigue cracking.

These considerations are further examined in Section 4.3.2 for the affected pump subassemblies and components.

4.3.1.5 Corrosion

Significance of the corrosion aging mechanism is generally associated with the aggressiveness of the environment and characteristics of the materials of construction. For pump applications included in this report, a variety of metals ranging from stainless steel to bronze and cast iron are utilized (Table 3-3). They are exposed to eight different environments (Section 3.4). The generic considerations related to corrosion significance are discussed in terms of the three distinct forms of corrosion (general, galvanic, and microbiologically influenced) in the following paragraphs. Due to the unique nature of the various process fluid environments, specific considerations related to corrosion significance determinations are discussed in Section 4.3.3.

4.3.1.5.1 General Corrosion

General corrosion is manifested in two ways; uniform corrosion is where wastage or removal of material has occurred over a large portion of the component surface area; local corrosion is where wastage or removal of material has occurred over a very small portion of the component surface area and may take the form of pits or cracks. Local corrosion is generally caused by non-homogeneous metallurgical characteristics at the material surface and/or a concentration of fluid contaminants at certain locations.

The pump components that are in contact with pumped fluid are identified in Table 3-5. These are referred to as the "wetted parts." The pumped fluids are described in Section 3.4. General corrosion of ferrous materials in aqueous environments is primarily associated with the type and amount of alloy constituents, the aggressiveness of the water (pH, oxygen content, and chemical contaminants) and exposure time. Although high dissolved oxygen levels generally increase uniform corrosion rates, extremely low oxygen levels (less than 5 ppb) may increase rates for materials whose corrosion resistance is dependent on the formation of a tightly adhering oxide layer over the entire surface. The potential for local corrosion is increased for geometries that contain small openings or spaces where fluid is relatively stagnant and may contain higher levels of fluid contaminants than the average in the bulk fluid. In a similar manner, unintentional crevices such as cracks, seams, or grooves could serve as sites for local corrosion initiation.

If the wetted parts are made from carbon or low alloy steel materials or cast iron and exposed to treated water, raw service water, or closed cooling water service applications, then general corrosion is a significant aging mechanism. These considerations are further examined in Section 4.3.3.

Stainless and other high alloy steel materials which contain 12% or more chromium have excellent resistance to general corrosion[4.11] for all the pumped fluids except raw water applications. Therefore, if the wetted parts are made from these materials and not exposed to raw water, then general corrosion is not a significant aging mechanism for the wetted parts of the pump.

Bronze or brass materials have excellent resistance to general corrosion[4.11] for all pumped fluids. For raw water applications, brass and bronze materials have the best resistance to corrosion of all typically used pump materials. A metallurgical dealloying process (i.e., dezincification) is a common general corrosion mechanism for bronze and brass material. This process involves zinc moving out of solution and leaving the weaker and more porous layer of copper and copper oxide. Materials containing more than 15% zinc are susceptible to dezincification. Cast materials usually contain much lower levels of zinc, but some wrought materials, particularly brasses, may have zinc levels exceeding 15%. In the fluid environments under consideration, dealloying and the resultant general corrosion occurs at a slow rate.[4.11] Therefore, if the wetted parts are made from bronze or brass with less than 15% zinc content, then general corrosion is not a significant aging mechanism for the wetted parts of the pumps.

The external ambient environment of the non-submerged pumps is mildly corrosive. With the exception of carbon steel and cast iron pump components, exterior surfaces exposed to the environment have excellent resistance to general corrosion. The external carbon steel and cast iron surfaces are usually coated or painted which effectively mitigates general corrosion. Therefore, if the pump is not submerged, and the components exposed to the external environment are made from carbon and low alloy steel or cast iron and protective coatings are applied to the external surfaces, then general corrosion is not a significant aging mechanism. Adequate maintenance of the protective coatings is a qualifying condition for carbon and low alloy steels and cast iron components. Section 5.3.5 describes an effective coatings program.

Leakage from pumps seals and adjacent piping can expose the pump external surfaces to a corrosive environment. Fluid leakage from the pumps can result in corrosion of the exposed surfaces. The PWR boric acid transfer pump and BWR standby liquid control pumps are particularly susceptible.

General corrosion is a significant aging mechanism for pump external surfaces that could be exposed to borated fluid leakage. These considerations are further examined in Section 4.3.3.

Lubricating/fuel oils in their pure form are non-aggressive and non-corrosive environments for metal components used in all pumps. However, contaminants (water, oxygen, chemicals, and particulate) can create a corrosive environment for carbon and low alloy steels and cast iron. Several incidences of carbon steel corrosion in contaminated oil systems have been reported. [4.22] The stainless and high alloy steels, bronze and brass materials, are resistant to general corrosion.[4.11] Therefore, if the pump components are made from carbon or low alloy steel or cast iron materials, and purity of the lubricating and fuel oil is not adequately maintained, then general corrosion of the exposed components is a significant aging mechanism. These considerations are further examined in Section 4.3.3.

For electric motor-driven pumps, grounding paths for stray motor currents through motor components are often eliminated by electrically insulating the bearings and/or installing an alternate low-impedance path for the current to flow. Provided that stray currents are not interrupted at the motor/pump coupling, the electrical current flow can be carried through the shaft to the bearing and grounded through the pump bearing housing and support (see Section 4.1.4). These stray currents can result in general corrosion at the pump bearing, usually in the form of local corrosion or pitting. Therefore, if the stray motor current grounding path through the shaft is eliminated, then general corrosion is not a significant aging mechanism.

4.3.1.5.2 Galvanic Corrosion

Galvanic corrosion occurs when dissimilar materials with significantly different electrical potentials (Table 4-2) are connected through a conducting fluid (or electrolyte). A review of Table 4-2 and the metallic materials typically used for pump wetted parts (Table 3-2), identified three metals groupings with significantly different electrical potentials.

Anodic	Mid-Range	Cathodic
Aluminum	Nickel	Ferritic Stainless (passive)
Iron and Carbon Steel	Brasses	Austenitic Stainless (passive)
4-6% Chromium Steel	Bronzes	Hastelloy C

The "active" ferritic and austenitic stainless materials near the anodic end of the galvanic series (Table 4-2) have not been included in these groupings. Active stainless material occurs in very low oxygen environments (1 to 2 ppb). The protective chromium oxide surface layer cannot be sustained or metallurgical flaws (primarily heat treating or welding) result in localized areas where insufficient chromium is available to react with oxygen to form the protective layer. The pump applications in the scope of this guideline are circulating fluids with oxygen levels of 20 ppb or greater. Pump manufacturing quality control programs for nuclear service require inspections to detect and repair metallurgical flaws that would result in active stainless steel surfaces.

When these dissimilar material surfaces in the metal grouping listed above are connected by an electrolyte, galvanic corrosion occurs. Solid particles move from the surface of the material which is closer to the anodic end of the galvanic series chart through the electrolyte and to the surface of materials which are further from the anodic end. The more anodic material corrodes and the more cathodic material is essentially unaffected.

Therefore, if the wetted parts are made from stainless and high alloy steel, then galvanic corrosion is not a significant aging mechanism. Wetted parts made from materials in the mid range and anodic metal groupings are further examined below for lubricating/fuel oil applications, closed cooling water applications, and the affects of external environment. Further examination is contained in Section 4.3.3.

Lubricating and fuel oils, even in the contaminated condition, are not good conducting electrolytes. Therefore, if the wetted parts are exposed to lubricating and fuel oils, then galvanic corrosion is not a significant aging mechanism. This determination applies to materials in the three metal groupings.

The fluid in closed cooling water applications provides an aqueous environment which can lead to galvanic corrosion of the materials in the anodic and mid range metal groupings.

However, the corrosion inhibitors used in these applications reduce the conductive properties of the fluid (electrolyte). Therefore, if the wetted parts are exposed to closed cooling water treated with an appropriate inhibitor, then galvanic corrosion is not a significant aging mechanism. Monitoring the water chemistry, and maintaining operational chemistry during plant outages while the system remains filled, is a qualifying condition.

The ambient environment is not a good conducting electrolyte to support galvanic corrosion. Therefore, if the external surfaces of the pump components are exposed to the ambient environment, then galvanic corrosion is not a significant aging mechanism. This determination applies to materials in the three metal groupings. Submerged pump applications are further examined in Section 4.3.3.

4.3.1.5.3 Microbiologically Influenced Corrosion

MIC occurs in fluid streams which can sustain microbiological growth and where the fluid velocities are low or there is intermittent flow conditions.[4.1] MIC can result in corrosion over large surface areas but more likely occurs in local areas where microorganisms attach themselves to metal surfaces. There are no known metals which are completely immune to MIC. MIC is generally most prevalent in raw water systems. Microorganisms are transported from raw water systems to treated water systems, because they are the source of make-up supply to systems that process water for treated water systems. Microorganism growth can also be generated in treated water systems that are open to the atmosphere (vented storage tanks and open pools). MIC is effectively mitigated in fluid systems which operate at temperatures above 100°C [212°F]. Microbes cannot survive at elevated temperatures.

Bulk fluid velocities within these pumps are high during periods of operation; however, all pump geometries contain areas such as crevices, flow diversion devices, slots, grooves, etc. where fluid velocity is very low or non-existent during operation. It is in these low flow areas where microorganisms concentrate and aggressively attack the surface. In multi-pump system applications, the pumps may be idle and filled with the pumped fluid for long periods of time. This condition further promotes the occurrence of MIC.

Several special cases of elevated temperature, lubricating/fuel oil, and closed cooling water applications are examined below. The affects of external environment are also examined. The remaining pump applications are further examined in Section 4.3.3.

The fluid upstream of the BWR RWCU pumps and PWR CVCS charging pumps is reactor coolant at temperatures above 100°C [212°F] during plant operation. Heat exchangers upstream of the pumps cool the fluid; however, the elevated temperatures of the fluid in the system eliminates the potential for MIC in the pumps. Therefore, MIC is not a significant aging mechanism for the RWCU and CVCS charging pump components.

Fluid in the RHR pumps is treated water during normal operation and periodic testing. The pumps are idle and filled during normal operation. Therefore, water in the pumps is stagnant for long periods of time. When the plant is shut down, the RHR pumps take suction from the primary pressure boundary for decay heat removal. The pumps do not operate at elevated temperatures for very long. With treated water and periodic operation at elevated temperature, the RHR pumps are not very susceptible to MIC. However, the RHR pump components are further examined in Section 4.3.3.

Lubricating and fuel oils, even in the contaminated condition, do not support microorganism growth. Therefore, if the wetted parts are exposed to lubricating and/or fuel oils, then MIC is not a significant aging mechanism, without conditions.

Microorganisms can enter closed cooling systems from two sources; storage tanks vented to the atmosphere and the biological material in the treated water make-up. However, the controlled levels of biocides normallv added to these systems creates a hostile environment for microorganisms. Therefore, if the wetted parts are exposed to closed cooling water treated with biocides, then MIC is not a significant aging mechanism. Periodically operating the pumps and maintaining operational chemistry during plant outages is a qualifying condition.

The ambient environment does not support microbiological growth on the external surfaces of exposed pump components. Therefore, if the external pump surfaces are exposed to the ambient environment, then MIC is not a significant aging mechanism. Submerged pump applications are further examined in Section 4.3.3.6.

4.3.1.6 Stress Corrosion Cracking

A variety of metals ranging from stainless steel to bronze and cast iron are utilized (Table 3-3) for the pumps evaluated in this guideline. They are exposed to eight different environments (Section 3.4). Irradiation assisted stress corrosion cracking is evaluated in Section 4.3.1.2. The two remaining forms of SCC (intergranular and transgranular) are evaluated in the following subsection. Due to the unique nature of the various process fluid environments, specific considerations related to IGSCC significance determinations are discussed in Section 4.3.3.

SCC of stainless steel material in primary coolant water operating temperatures of 260-315°C [500-600°F] has been studied extensively.[4.23] However, the pump applications evaluated in this guideline do not operate at these high temperatures. Although SCC is primarily an aging mechanism associated with stainless and high alloy steels, other materials such as wrought brass/bronze are not immune to this aging mechanism under certain conditions.

The lubricating/fuel oil and closed cooling water applications, and external ambient environments do not support the stress corrosion cracking aging mechanisms. The operating temperatures are below 54°C [130°F]. There have not been any incidents in the indust.y of stress corrosion cracking in these applications and environments (see Section 3). Therefore, if the pump components are in lubricating/fuel oil or closed cooling water applications, and the components are exposed to ambient environments, then stress corrosion cracking is not a significant aging mechanism for these components. However, as discussed below, wrought brass or bronze materials may be used in some closed cooling water pump applications for wearing and miscellaneous structural components.

4.3.1.6.1 Intergranular Stress Corrosion Cracking

Stainless steel may be susceptible to IGSCC for the conditions summarized on Figure 4-2 (see Section 4.1.5.1 above). At temperatures below 177°C [350°F], stainless steels are susceptible to IGSCC in water with dissolved oxygen levels above 1 ppm. At temperatures below 54°C [130°F], stainless steels are not susceptible to IGSCC [4.20]. Fluid in the PWR CVCS charging pumps and BWR RWCU pumps is cooled below 177°C [350°F] by heat exchangers located upstream from the pumps. The dissolved oxygen levels of water entering the pump are below 0.2 ppm. Therefore, if heat exchangers are located upstream from the pumps, then IGSCC is not a significant aging mechanism for the CVCS charging pumps and RWCU pumps.

Experimental work has been performed on high toughness carbon steels with water at elevated temperatures and dissolved oxygen content up to 8 ppm.[4.4] IGSCC was not produced under these conditions. Dissolved oxygen levels of 8 to 12 ppm are common for raw water applications. However, raw water applications are all low temperature. In treated water applications, the water has a dissolved oxygen content of 1 to 2 ppm. There have not been any incidents in the industry of IGSCC occurring to wetted parts made from carbon and low alloy steels and cast iron. Therefore, if the pump wetted parts are made from these materials, then IGSCC is not a significant aging mechanism, without conditions.

IGSCC has been reported for bronze and brass materials when zinc levels exceed 15%. [4.11] Bronze castings commonly used for centrifugal pump impellers in treated and raw water environments is typically less than 5% zinc. The wrought bronze or brass materials used for stationary spacers can have zinc levels of as high as 15%. These types of materials would be susceptible to IGSCC. Therefore, if the wetted parts are cast bronze or brass materials, then IGSCC is not a significant aging mechanism. Wetted parts made from wrought bronze or brass materials are further examined in Section 4.3.3.

IGSCC has been reported for stainless and high alloy steel components exposed to borated water service applications. Therefore, if the wetted parts are stainless or high alloy steel and exposed to borated fluids, then IGSCC is a significant aging mechanism. Wetted parts made from stainless or high alloy steel materials are further examined in Section 4.3.3.

Raw water contains chlorides which cause stress corrosion cracking in stainless steel regardless of temperature. Brackish water or seawater always contains large quantities of chlorides, and fresh water contains chlorides. Several cases of IGSCC in stainless steels have been documented.[4.11] Therefore, if the pump wetted components are made of stainless and high alloy steel and exposed to raw water, then IGSCC is a significant aging mechanism. These considerations are further examined in Section 4.3.3.

4.3.1.6.2 Transgranular Stress Corrosion Cracking

The temperature and dissolved oxygen levels established in experimental work for susceptibility materials to IGSCC also apply to TGSCC.[4.4] However, higher levels of nitrogen concentration (0.14 to 0.19%) and stress are necessary to produce TGSCC.[4.4] The stainless steel material specifications used in the industry specify nitrogen concentration ranges of 0.06

to 0.12% which are much lower than is required for susceptibility to TGSCC. Therefore, if nitrogen levels of the stainless and high alloy steel wetted parts are controlled to less than 0.12%, in the material specifications, then TGSCC is not a significant aging mechanism.

Experimental work performed on carbon steels[4.4] shows that TGSCC in aqueous solutions at elevated temperatures and moderate dissolved oxygen content (10 ppm) can only occur at unrealistically high stress and nitrogen concentrations. There has not been any incident in the industry of TGSCC for wetted parts made from carbon and low alloy steels and cast iron. Therefore, if the wetted parts are made from these materials, then TGSCC is not a significant aging mechanism without condition.

The determinations for IGSCC of bronze and brass materials in subsection 4.3.1.6.1 also apply to the susceptibility of these materials to TGSCC. Therefore, if the wetted parts are cast bronze or brass materials, then TGSCC is not a significant aging mechanism. Wetted parts made from wrought bronze or brass are examined in Section 4.3.3.

4.3.1.7 Erosion and Erosion/Corrosion

Erosion and erosion/corrosion requires fluid velocities in the moderate to high range. Erosion occurs when the liquids contain particulate matter, gases contain liquid droplets or particulate, or there is significant levels of fluid turbulence or cavitation. Erosion/corrosion occurs when the base material is susceptible to general corrosion in fluid environments.

Components made from stainless and high alloy steels are resistant to corrosion and have a high surface hardness. They are considered much less susceptible to erosion and erosion/corrosion than other materials. However, severe fluid turbulence or cavitation have resulted in erosion of high alloy materials.

Most of the pump components exposed to the process fluid are subjected to moderate or high pumped fluid velocities and are susceptible to erosion and erosion/corrosion. This includes internal water lubricated radial bearings used in raw water vertical pool centrifugal pump applications. These wetted parts are further examined for erosion and erosion/corrosion in Section 4.3.2.

External cooling water velocities through bearing housings are low to moderate, and particulate matter is controlled at low levels by corrosion inhibitors. Severe turbulence or cavitation does not occur because of the lower fluid velocities. Therefore, erosion and erosion/corrosion are not significant aging mechanisms for bearings housing in all pump applications without condition.

The other components are not exposed to moderate or high velocity fluids. These include the reciprocating pump driveshaft/crankshaft, stationary miscellaneous structural components, pressure boundary flanges/covers, pressure boundary fasteners (bolting) and gaskets, couplings, and the support base and subassemblies. The degradation affects of fluid flow between the moving parts of oil lubricated bearings and mechanical seals/packing are treated as wear. If the pump components are not exposed to moderate or high velocity fluids, then erosion and erosion/corrosion are not significant aging mechanisms without condition.

4.3.1.8 Wear

Degradation from wear requires two parts in relative motion that are in contact or the clearance between the moving parts is very small.

Components of the rotating/reciprocating subassemblies are in motion and, clearances with fixed internal components are small. Examples include impellers at stationary wear rings, swivel joints on crankshafts, and internal valve closure mechanisms. Rotating shaft spacers at impeller connection points, shaft seals, bearings, etc. are usually attached to the shaft by using fasteners or shrink fits with zero clearance. Screw-type rotary pumps have continuous wearing surfaces over the length of the pump. Gear type rotary pumps experience wear at the gear teeth. Seals located between the moving piston/plunger and the stationary cylinder/casing experience wear. Small amounts of relative movement may occur at these locations/interfaces due to normal operation, vibration, thermal expansion, or shaft accelerations/decelerations. Wear of the rotating or reciprocating subassembly components and the associated fixed internals are further examined in Section 4.3.2.

Clearances between the pump rotating/reciprocating subassembly and the fixed internal flow guides and miscellaneous structural components are typically greater than 1.3 cm [0.5 in]. Integral suction strainers or screens are used on centrifugal sump or well pump applications. There are large clearances between the strainer/screen and any moving parts. Therefore, wear is not a significant aging mechanism for flow guides, miscellaneous structural components, and suction strainers/screens, without conditions.

Shaft seal and radial/thrust bearings are wearing parts of the mechanical subassembly which can be easily replaced. Internal seals and radial bearings require significant disassembly for replacement. Couplings, which have flexible joints, are susceptible to wear due to small relative movements caused by vibration, shaft accelerations/decelerations, and minor misalignment between the pump and driver shaft. Gear type couplings are susceptible to normal gear tooth wear as well as the small relative movements. Wear of the components in the mechanical subsystem assembly are further examined in Section 4.3.2.

The pressure boundary and support base assemblies do not have components in relative motion with close clearances. Therefore, wear is a not a significant aging mechanism for these components in all pump applications, without conditions.

4.3.1.9 Fouling

Solid particles in the fluid and physical configurations that result in very low fluid velocities are required for degradation from fouling. Fouling occurs in rough filtered raw water systems. Fouling also occurs in treated water systems where pump suction is from the bottom of tanks (significant quantities of corrosion products may accumulate) and treated water that is subject to biological activity. Lubrication systems may build up solids from bearing wear. Flow blockage or binding of moving parts from foreign materials is attributed to fouling. For example, flow blockage has occurred in demineralized water applications.[4.24, 4.25] These incidents infrequently occur and is some cases were caused by operator errors or failures of other components. Fouling of fixed internal and pressure boundary components in treated water applications is further examined in Section 4.3.2.

The shaft, impeller, internal rotor, piston/plunger, and internal valves of the rotating or reciprocating subassembly are subject to high fluid velocity. Particulate matter is controlled to low levels by corrosion inhibitors and biocides in closed cooling water applications. Large particle fouling of the impeller and the strainer/screens may occur in sump, well, and raw water applications. Sediment may foul valves in borated water services. The driveshaft/crankshaft is not subject to fluid flow at any time. Therefore, if the rotating or reciprocating subassembly components are not in raw water or borated water applications, then fouling is not a significant aging mechanism. Periodically, operating the pumps and maintaining operational chemistry during plant outages is an additional qualifying condition for closed cooling water applications. The components in raw water and borated water services are further examined in Section 4.3.2.

The fixed internal subassembly wearing components are subject to moderate or high flow velocities. Therefore, fouling of these components is not a significant aging mechanism without conditions.

The geometries of stationary flow guides, miscellaneous structural components and all pressure boundary subassembly components (except fasteners and gaskets) may result in local areas of stagnant or very low fluid velocities. These areas may also accumulate significant quantities of particulate matter. The particulate matter is controlled to low levels by corrosion inhibitors and biocides in closed cooling water applications. Therefore, if the fixed internal flow guides, miscellaneous structural components, and pressure boundary components are in closed cooling water applications, then fouling is not a significant aging mechanism. Fouling of the stationary flow guides, miscellaneous structural components, and pressure boundary components in other applications is further examined in Section 4.3.2.

Primary coolant water is fine filtered to remove particulate, deionized, and is low in oxygen content. All materials in contact with primary coolant water are not susceptible to general corrosion, therefore, particulate levels are very low. Therefore, if the pump subassembly components are exposed to primary coolant water, then fouling is not a significant aging mechanism. One exception to this conclusion is fouling of the PWR CVCS reciprocating charging pump inlet valve. Industry operating experience shows that this pump component is susceptible to fouling. Therefore, fouling is a significant aging mechanism for the CVCS reciprocating charging pump inlet valve. This component is further examined in Section 4.3.2.

Pressure boundary fasteners, gaskets, couplings, and the pump support base subassemblies are not subject to fluid flow. Therefore, fouling is not a significant aging mechanism for these components, without conditions.

4.3.2 Aging Mechanism Evaluations of Component Subassemblies

This section further examines selected aging mechanisms (i.e., mechanical fatigue, erosion and erosion/corrosion, wear, and fouling) for subassembly or component considerations identified in Section 4.3.1.

For ease of evaluating the aging mechanisms, Sections 4.3.2.1 through 4.3.2.5 evaluate the aging mechanisms by pump subassembly.

Section 4.3.2.1:	Rotating/Reciprocating Subassemblies
Section 4.3.2.2:	Fixed Internal Subassemblies
Section 4.3.2.3:	Pressure Boundary Subassemblies
Section 4.3.2.4:	Mechanical Subsystem Subassemblies
Section 4.3.2.5:	Support Subassemblies

For ease of use by plant personnel, the results of the aging management evaluations are summarized in Tables 4-4 through 4-10 by the system fluid type.

Table 4-4:	Primary Water System Pumps
Table 4-5:	Borated Water System Pumps
Table 4-6:	Continuously Operated Treated Water System Pumps
Table 4-7:	Intermittently Operated Treated Water System Pumps
Table 4-8:	Closed Cooling Water System Pumps
Table 4-9:	Lubricating and Fuel Oil System Pumps
Table 4-10:	Raw Water System Pumps

4.3.2.1 Rotating/Reciprocating Subassemblies

From Section 4.3.1, the pump rotating and reciprocating subassemblies are susceptible to:

- Mechanical fatigue in all pump applications (Section 4.3.1.4).
- Erosion and erosion/corrosion of wetted components in all pump applications (Section 4.3.1.7).
- Wear in all pump applications (Section 4.3.1.8).
- Fouling in raw water and borated water applications (Section 4.3.1.9).

4.3.2.1.1 Mechanical Fatigue

The rotating assemblies of centrifugal pumps (shaft and impellers), rotary pumps (internal rotors), and reciprocating pumps (driveshaft/crankshaft) are subjected to cyclic mechanical loads during starts, stops, and load changes due to acceleration/deceleration. The cyclic loads during steady state operation occur during every shaft revolution. Every point on the periphery of the rotating assembly sustains at least a tensile stress and then a compressive stress once per revolution. The magnitude of bending and torsional stresses are dependent on the distances between shaft bearings, stiffness, and weight distribution, minor mechanical imbalance, and fluid forces. Residual stresses from manufacturing (heat treatment, machining, and assembly) may add to the overall stress distribution in the rotating assembly.

Shafts are typically more vulnerable to mechanical fatigue than impellers, rotors, and driveshafts/crankshafts. Total unconcentrated shaft stresses have less margin to their allowable levels than impellers, rotors, and driveshafts/crankshafts, because mechanical stress raisers are unavoidable due to shaft design requirements. However, industry experience has recorded fatigue degradation/failure incidents for impellers, rotors, and driveshafts/crankshafts. Fatigue cracking of these components may be caused by high cycle fatigue, low cycle fatigue, or combination of the two. Pump manufacturers generally use very conservative designs for shafts, impellers, rotors, and driveshafts/crankshafts. However, due to high loads and a variety of stress raisers, mechanical fatigue of the shaft, impellers, rotor, and driveshafts/crankshafts in all pump applications is a significant aging mechanism.

Reciprocating pump internal valves experience cyclic mechanical loads. These valves may open and close more than 100 times per minute during normal operation. The valves are subjected to fluid pressure loads and mechanical impact loads during each open/close cycle. Valve designs and manufacturing practices minimize mechanical and metallurgical stress raisers; however, these stresses are not totally eliminated. Therefore, mechanical fatigue of the reciprocating pump internal valve is a significant aging mechanism.

Reciprocating pump pistons and plungers are subjected to cyclic loads. Pump start-up and shutdown causes cyclic loads which are the same as those experienced during normal operation. Therefore, high cycle fatigue is the only concern. Pistons and plungers are continually accelerated and decelerated as they operate; however, the inherent stiffness of the cylindrical geometry ensures that the stress levels are very low. Fluid pressure loads cause stress at one end of the piston or plunger. Since the stroke length is several times greater than the diameter, cyclic fluid pressure stresses are not significant. As the piston/plunger movement direction changes, frictional forces on the cylindrical surfaces cause stress. The piston/plunger seal materials have relatively low friction coefficients. The stresses experienced during normal operation would damage the seal and degraded pump performance before mechanical fatigue of the piston/plunger would be experienced. Therefore, mechanical fatigue of the reciprocating pump piston/plunger is not a significant aging mechanism, without condition.

4.3.2.1.2 Erosion and Erosion/Corrosion

From Section 4.3.1.7, the rotating/reciprocating subassembly components exposed to the process fluid (i.e., wetted parts) are susceptible to erosion and erosion/corrosion. Also from Section 4.3.1.7, erosion and erosion/corrosion is not a significant aging mechanism for the reciprocating pump driveshaft/crankshaft, without conditions, because this component is not exposed to the process fluid.

Most pump shafts in these service applications are manufactured from 400 series stainless steel. When low alloy or carbon steels are used for shafts, the surface is either heat treated to increase surface hardness or covered with a hard, tightly adhering surface coating. This surface hardening is primarily applied to resist wear, however, it also increases resistance to erosion and erosion/corrosion. If the pump shafts are manufactured from either stainless or high alloy steel, or manufactured from carbon or low alloy steel and heat treated to increase surface hardness, or have been coated with a hard surfacing material, then erosion and erosion/corrosion are not significant aging mechanisms.

Maximum reciprocating pump piston/plunger speed results in fluid velocities which are very low when compared to typical fluid velocities in centrifugal pumps. In addition, the plungers/pistons are typically manufactured from stainless or high alloy material or are surface hardened. If the piston/plunger is manufactured from either stainless or high alloy steel or carbon or low alloy steel and surface hardened, then erosion and erosion/corrosion are not significant aging mechanisms for the reciprocating pump piston/plunger component.

Specific pump applications are considered, in the following paragraphs, to determine the susceptibility and significance of erosion and erosion/corrosion occurring to the rotary pump internal rotor, reciprocating pump internal valve, and centrifugal pump impeller.

Rotary pumps are used in lubricating and fuel oil applications. All lubricating and fuel oil pumps in the scope of this guideline operate intermittently (i.e., monthly or quarterly) to support plant technical specification surveillance testing. The total operating time to complete a surveillance test typically ranges from two to eight hours. Total accumulated operating time for these lubricating and fuel oil pumps is, therefore, very low. Strict controls are placed on the quality/purity of the lubricating and fuel oil. The chemical properties of these oils are regularly checked. Impurities and particulate matter, which contributes to erosion and erosion/corrosion, are monitored and corrective actions implemented if oil quality/purity fails to meet acceptance standards. Therefore, if the lubricating and fuel oil pump is operated intermittently (i.e., testing purposes) and chemical analysis of the lubricating and fuel oil is regularly checked, then erosion and erosion/corrosion of the internal rotor are not significant aging mechanisms.

Industry experience shows evidence of erosion and erosion/corrosion, in some service applications, occurring to the reciprocating pump internal valves.

The BWR SLC System reciprocating pumps are operated intermittently (i.e., quarterly) to support plant technical specification surveillance testing. The operating time to complete a SLC pump surveillance test ranges from four to six hours, therefore, the accumulated operating time is very low. SLC pump internal valve components are manufactured from stainless and high alloy steel materials. Therefore, if the BWR SLC pumps are operated intermittently (i.e., testing purposes) and the internal valves are manufactured from stainless or high alloy steel, then erosion and erosion/corrosion of the SLC pump internal valves are not significant aging mechanisms.

The PWR CVCS reciprocating charging pumps are assumed to be continuously operated. It is recognized that many PWR plants have centrifugal CVCS charging pumps that operate continuously with the reciprocating CVCS charging pump maintained in standby. However, industry experience (NPRDS) identifies erosion and erosion/corrosion as having occurred to the internal valve of the reciprocating CVCS charging pump. Therefore, if the reciprocating CVCS charging pumps are continuously operated, then erosion and erosion/corrosion is a significant aging mechanism.

Erosion and erosion/corrosion of centrifugal pump impellers is a significant aging mechanism for all pump fluid service applications and operating time characteristics, except in lubrication and fuel oil applications. The discussion above, for rotary pump erosion and erosion/corrosion, applies to centrifugal pump impellers in these applications. Industry experience (NPRDS) documents many cases of centrifugal pump impeller erosion and erosion/corrosion without regard to fluid service application, materials, or operating times. This aging mechanism is caused by fluid and particle impingement, cavitation, water temperature and dissolved oxygen content (i.e., single phase erosion phenomenon), fluid velocity, etc.

4.3.2.1.3 Wear

From Section 4.3.1.8, all pump rotating/reciprocating subassembly components are susceptible to wear. Industry experience (NPRDS and LER) documents that wear is responsible for over 50% of pump failures. Many of the failures are associated with pump rotating/reciprocating subassembly components.

4.3.2.1.4 Fouling

From Section 4.3.1.9, some of the rotating/reciprocating subassembly components exposed to the process fluid are susceptible to fouling. Also, from Section 4.3.1.9, fouling is not a significant aging mechanism for:

- All pump rotating/reciprocating subassembly components in primary coolant fluid applications except the PWR CVCS reciprocating charging pump internal valve component.

- All pump rotating/reciprocating subassembly components in treated water (i.e., demineralized) application, without conditions.

- All pump rotating/reciprocating subassembly components in closed cooling water applications provided corrosion inhibitors and biocides are used to control corrosion product material buildup.

- All pump rotating/reciprocating subassembly components in lubricating/fuel oil applications, without conditions.

Industry experience (NPRDS) documents several cases of PWR CVCS reciprocating charging pump internal valve fouling. PWRs plants using both centrifugal and reciprocating CVCS charging pumps usually operate the centrifugal pumps and maintain the reciprocating pumps in standby. As such, particulate matter can settle in the reciprocating pump suction and become lodged in the internal valve when this pump is started. If the CVCS reciprocating charging pumps are normally operated, then accumulation of particulate matter is not a concern and fouling of the internal valve is not a significant aging mechanism.

The BWR SLC System reciprocating pump internal valve has experienced fouling. Precipitate of sodium pentaborate solution can foul the pump internal valves. The SLC pump driveshaft/crankshaft component is not exposed to the sodium pentaborate solution, therefore, fouling of this component is not a significant aging mechanism. The SLC pump piston/plunger component is exposed to the sodium pentaborate solution, however, during operation (i.e., primarily testing each quarter) highly pure demineralized water is used. During testing with sodium pentaborate, flow velocities within the SLC pump are high and pump geometric configuration is not conducive to fouling. Therefore, fouling of the SLC pump piston/plunger component is not a significant aging mechanism.

In raw water service applications, vertical well centrifugal pumps are utilized. The pump shafts do not have geometric configurations that are susceptible to fouling. Therefore, fouling of the pump shaft in raw water service applications is not a significant aging mechanism.

From the viewpoint of contaminants (chemicals, microbes, and foreign particles), raw water is an uncontrolled fluid. Fresh raw water contains dissolved oxygen levels (8-12 ppm), various amounts of free oxygen, solid organic and inorganic foreign materials, bivalves and other aquatic species, and various types of chemical and biological contaminants.[4.26] Brackish water or seawater is similar to the fresh water constituents in addition to having a high salt content, mainly sodium chloride. These high levels of foreign materials such as sand and dirt, seaweed, microbes, and other aquatic species increases the potential for fouling.

Rough screens located at the raw water pump inlet remove large foreign materials, however, industry experience documents many instances where these materials have entered the pump and caused fouling of the impeller.[4.27, 4.28] In some cases, fouling of the pump impellers has caused decreased flow rate and developed head and has caused cavitation. Therefore, fouling is a significant aging mechanism for all pump impellers in raw service water applications.

4.3.2.2 Fixed Internal Subassemblies

From Section 4.3.1, the pump fixed internal subassemblies are susceptible to:

- Mechanical fatigue in all pump applications (Section 4.3.1.4)
- Erosion and erosion/corrosion of wetted components in all pump applications (Section 4.3.1.7)
- Wear in all pump applications (Section 4.3.1.8)
- Fouling in raw water and borated water applications (Section 4.3.1.9)

4.3.2.2.1 Mechanical Fatigue

From Section 4.3.1.4, fixed internal components, consisting of miscellaneous structural components, wearing components, flow guides, and suction strainers are susceptible to alternating hydraulic stressors. These fixed internal components are designed in a conservative manner which results in operating stresses that are well below allowable levels.

Centrifugal and rotary pump fixed internal components are exposed to cyclic hydraulic stresses during each pump start/operate/stop cycle and during flow rate changes. The pumps in the scope of this guideline are either continuously operated or operated intermittently for testing purposes (i.e., monthly or quarterly). Cumulative alternating hydraulic stress (from starts and stops) on the centrifugal and rotary pumps fixed internal components is very low.

Steady state operation of centrifugal and rotary pumps causes fluid impact stress and differential pressure stresses across the fixed internal components. Impact and differential pressure forces are moderate, and pump design conservatisms result in relatively low stresses on the fixed internal components. Pump fixed internal geometric configurations typically exclude mechanical stress raisers (i.e., initiating points for fatigue cracks). Pump flow rate changes cause changes in the fluid flow pattern within the pump. However, the resultant changes in impact loadings, and differential pressures across fixed internals are minimal and will not produce sufficient hydraulic stresses to initiate fatigue cracking of the centrifugal and rotary pump fixed internal components. The industry operating experience data has not recorded any incidents of fatigue failure for centrifugal and rotary pump fixed internal components. Therefore, mechanical fatigue is not a significant aging mechanism for these components, without conditions.

Due to the discontinuous flow pattern associated with reciprocating pumps, cyclic hydraulic loads are applied during starts, stops, load changes, and steady state operation. Reciprocating pump designs generally include very few fixed internal components. Fixed internal flow guides may be used as part of the reciprocating pump inlet/discharge and valve configurations, and piston/plunger stops may be located within the cylinders or plunger casing. These fixed internal components are exposed to alternating hydraulic stresses; however, these components are conservatively designed, and mechanical stress raisers are typically excluded. The industry operating experience data has not recorded any incidents of fatigue failure for reciprocating pump fixed internal components. Therefore, mechanical fatigue is not a significant aging mechanism for these components, without conditions.

4.3.2.2.2 Erosion and Erosion/Corrosion

From Section 4.3.1.7, the fixed internal subassembly components exposed to the process fluid (i.e., wetted parts) are susceptible to erosion and erosion/corrosion. Also, from Section 4.3.1.7, erosion and erosion/corrosion is not a significant aging mechanism for pump internal miscellaneous structural components, because this component is not subject to moderate or high fluid velocity.

Specific pump applications are considered in the following paragraphs to determine the susceptibility and significance of erosion and erosion/corrosion occurring to the wearing components and flow guides associated with rotary, reciprocating, and centrifugal pumps and wearing components, flow guides, and suction strainers associated with the sump and vertical well centrifugal pumps.

Rotary pumps are used in lubricating and fuel oil applications. All lubricating and fuel oil pumps in the scope of this AMG operate intermittently (i.e., monthly or quarterly) for technical specification surveillance testing requirements to verify mechanical and hydraulic conditions. The total operating time to complete a surveillance test typically ranges from two to eight hours. Total accumulated operating time for these lubricating and fuel oil pumps is, therefore, very low. Strict controls are placed on the quality/purity of the lubricating and fuel oil. The chemical properties of these oils are regularly checked. Impurities and particulate matter, which contributes to erosion and erosion/corrosion, are monitored and corrective actions implemented if oil quality/purity falls below standards. Therefore, if the lubricating and fuel oil pumps are operated intermittently (i.e., testing purposes), and chemical analysis of the lubricating and fuel oil is regularly checked, then erosion and erosion/corrosion of the wearing components and flow guides are not significant aging mechanisms.

The BWR SLC System reciprocating pumps are operated intermittently (i.e., quarterly) to support plant technical specification surveillance testing. The operating time to complete a SLC pump surveillance test ranges from four to six hours; therefore, the accumulated operating time is very low. SLC pump fixed internal flow guides and wearing components are manufactured from stainless or high alloy steel materials. Therefore, if the BWR SLC pumps are operated intermittently (i.e., testing purposes), and the fixed internal flow guides and wearing components are manufactured from stainless or high alloy steel, then erosion and erosion/corrosion of the SLC pump fixed internal flow guides and wearing components are not significant aging mechanisms.

The PWR CVCS reciprocating charging pumps are assumed to be continuously operated. It is recognized that many PWR plants have centrifugal CVCS charging pumps operating continuously with the reciprocating CVCS charging pump maintained in standby. However, industry experience (NPRDS) identifies erosion and erosion/corrosion as having occurred to the fixed internal flow guides of the reciprocating CVCS charging pump. Therefore, if the reciprocating CVCS charging pumps are continuously operated, then erosion and erosion/corrosion are significant aging mechanisms.

The PWR CVCS reciprocating charging pump wearing components are not exposed to moderate or high velocity fluid. These wearing components provide a pressure boundary integrity between the reciprocating piston/plunger and the cylinder wall. Fluid does not flow across the wearing component unless failure of the component due to wear has occurred. Therefore, erosion and erosion/corrosion are not significant aging mechanisms for the CVCS reciprocating charging pump wearing component.

Erosion and erosion/corrosion of centrifugal pump fixed internal flow guides and wearing components are significant aging mechanisms for all pump fluid service applications and operating time characteristics, except in lubrication and fuel oil applications. The discussion above, for rotary pump erosion and erosion/corrosion, applies to centrifugal pump fixed internal flow guides and wearing components in these applications. Industry experience (NPRDS) documents many cases of erosion and erosion/corrosion occurring to centrifugal pump fixed internal flow guide, wearing component, and suction strainer without regards to fluid service application, materials, or operating times. This aging mechanism is caused by fluid and particle impingement, cavitation, water temperature and dissolved oxygen content (i.e., single phase erosion phenomenon), fluid velocity, etc.

4.3.2.2.3 Wear

From Section 4.3.1.8, wear is not a significant aging mechanism for all pump fixed internal miscellaneous structural components, flow guides, and suction strainers, without condition. However, all pump fixed internal wearing components are susceptible to wear. Industry experience (NPRDS and LER) documents that wear is responsible for over 50% of pump failures. Many of the failures are associated with pump fixed internal wearing components.

Section 5 discusses programs/techniques to effectively manage wear of the pump fixed internal wearing components.

4.3.2.2.4 Fouling

From Section 4.3.1.9, some of the fixed internal subassembly components exposed to the process fluid are susceptible to fouling. Also, from Section 4.3.1.9, fouling is not a significant aging mechanism for:

- All pump fixed internal subassembly components in primary coolant fluid applications.
- All pump fixed internal wearing components for all fluid applications, without conditions.
- All pump fixed internal subassembly components in closed cooling water applications provided corrosion inhibitors and biocides are used to control corrosion product material buildup.

From the viewpoint of contaminants (chemicals, microbes, and foreign particles), raw water is an uncontrolled fluid. Fresh raw water contains dissolved oxygen levels (8-12 ppm), various amounts of free oxygen, solid organic and inorganic foreign materials, bivalves and other aquatic species, and various types of chemical and biological contaminants.[4.26] Brackish water or seawater is similar to the fresh water constituents in addition to having a high salt content, mainly sodium chloride. These high levels of foreign materials such as sand and dirt, seaweed, microbes, and other aquatic species increases the potential for fouling.

Rough screens located at the raw water pump inlet remove large foreign materials; however, industry experience documents many instances where these materials have entered the pump and caused fouling of the suction strainers, flow guides, and miscellaneous structural components.[4.27, 4.28] In some cases, fouling of the pump suction strainers, flow guides, and miscellaneous structural components has caused decreased flow rate and developed head and has caused cavitation. Therefore, fouling is a significant aging mechanism for all pump suction strainers, flow guides, and miscellaneous structural components in raw service water applications.

Industry operating experience documents several cases of fouling occurring to the pump fixed internal flow guides, suction strainers, and miscellaneous structural components in treated water service applications. These cases are predominantly associated with pump suction being supplied from large reservoirs. Sediment settles in the bottom of these reservoirs and is drawn into the pump causing fouling. Therefore, if the pump suction is from a reservoir in treated water applications, then fouling is a significant aging mechanism for the pump fixed internal flow guides, suction strainers, and miscellaneous structural components.

The BWR SLC System pump and PWR Boric Acid Transfer (BAT) System pump fixed internal flow guides and miscellaneous structural components are particularly susceptible to fouling because they process fluids containing borated compounds. The borated compounds can precipitate under certain concentration and temperature conditions. Industry operating experience has documented cases where fouling of borated water service pump fixed internal components has occurred. Therefore, fouling is a significant aging mechanism for borated water pump fixed internal flow guides and miscellaneous structural components.

Sediment, particulate, and impurities can accumulate in the bottom of lubricating and fuel oil reservoirs if strict controls are not placed on oil quality/purity. These materials can be drawn into the pump and foul the fixed internal flow guides and miscellaneous structural components. Therefore, if strict controls are not placed on lubricating and fuel oil purity, then fouling is a significant aging mechanism for the pump fixed internal flow guides and miscellaneous structural components.

4.3.2.3 Pressure Boundary Subassemblies

From Section 4.3.1, the pump pressure boundary subassemblies are susceptible to:

- Mechanical fatigue in all pump applications (Section 4.3.1.4)
- Erosion and erosion/corrosion of wetted components in all pump applications (Section 4.3.1.7)
- Fouling in raw water and borated water applications (Section 4.3.1.9)

4.3.2.3.1 Mechanical Fatigue

From Section 4.3.1.4 pump pressure boundary components, consisting of the casing, cylinder/plunger block, suction/discharge nozzle, discharge head (column, bowl and nozzles), flange/cover, and fasteners are susceptible to alternating hydraulic stressors.

Centrifugal and rotary pump pressure boundary components are exposed to cyclic hydraulic stresses during each pump start/operate/stop cycle and during flow rate changes. The pumps in the scope of this guideline are either continuously operated or operated intermittently for testing purposes (i.e., monthly or quarterly). Cumulative alternating hydraulic stress (from pump starts and stops and flow rate changes) on these very thick centrifugal and rotary pump pressure boundary components is low.

Steady state operation of centrifugal and rotary pumps causes fluid impact stress and pressure stresses on the pressure boundary components. Pressure stresses within these components are substantial and in localized regions can reach 50% or more of the material yield strength. Geometric irregularities at nozzles, flanges, and shaft openings, for example, are exposed to higher stress levels than other pressure boundary components. Pressure boundary designs minimize mechanical stress raisers; however, metallurgical stress raisers are often present in these relatively thick pressure boundary components, especially situations where cast material forms are utilized. The industry operating experience data reports some incidents of fatigue failure for continuously operated centrifugal and rotary pump pressure boundary components. Therefore, if the centrifugal or rotary pump is continuously operated, then mechanical fatigue is a significant aging mechanism for these components. If the centrifugal or rotary pump is intermittently operated, then mechanical fatigue is not a significant aging mechanism for these pressure boundary components.

The reciprocating BWR SLC System pump pressure boundary components are exposed to cycling pressure stresses during normal operation as well as during start and stop cycles. This pump is typically operated for testing purposes only (i.e., quarterly), and industry operating experience has not identified mechanical fatigue failure of SLC pump pressure boundary components. Therefore, if the SLC pump is intermittently operated quarterly for testing purposes only, then mechanical fatigue is not a significant aging mechanism for these pressure boundary components.

The reciprocating PWR CVCS charging pump pressure boundary components are also exposed to cyclic pressure stresses during normal operation. However, this pump is considered to be continuously operated, and industry operating experience has identified incidents of mechanical fatigue failure of pressure boundary components associated with this reciprocating pump. Therefore, if the CVCS reciprocating charging pump is continuously operated, then mechanical fatigue is a significant aging mechanism for these pressure boundary components.

4.3.2.3.2 Erosion and Erosion/Corrosion

From Section 4.3.1.7, the pressure boundary subassembly components exposed to the process fluid (i.e., wetted parts) are susceptible to erosion and erosion/corrosion. Also, from Section 4.3.1.7, erosion and erosion/corrosion is not a significant aging mechanism for pressure boundary flange/cover and fasteners, because these components are not subject to moderate or high fluid velocity.

Specific pump applications are considered in the following paragraphs to determine the susceptibility and significance of erosion and erosion/corrosion occurring to the pressure boundary subassembly components associated with rotary, reciprocating, and centrifugal pumps.

Rotary pumps are used in lubricating and fuel oil applications. All lubricating and fuel oil pumps in the scope of this guideline operate intermittently (i.e., monthly or quarterly) to support plant technical specification surveillance testing. The total operating time to complete a surveillance test typically ranges from two to eight hours. Total accumulated operating time for these lubricating and fuel oil pumps is , therefore, very low. Strict controls are placed on the quality/purity of the lubricating and fuel oil. The chemical properties of these oils are regularly checked. Impurities and particulate matter, which contributes to erosion and erosion/corrosion, are monitored and corrective actions implemented if oil quality/purity fails to meet acceptance standards. Therefore, if the lubricating and fuel oil pump is operated intermittently (i.e., testing purposes) and chemical analysis of the lubricating and fuel oil is regularly checked, then erosion and erosion/corrosion of the pressure boundary components are not significant aging mechanisms.

The maximum speed of reciprocating pump pistons and plungers results in fluid velocities within the cylinder/plunger block which are relatively low. These low velocities decrease the potential for erosion and erosion/corrosion to occur.

The BWR SLC System reciprocating pumps are operated intermittently (i.e., quarterly) to support plant technical specification surveillance testing. The operating time to complete SLC pump surveillance test ranges from four to six hours; therefore, the accumulated operating time is very low. SLC pump pressure boundary cylinder/plunger blocks are manufactured from stainless and high alloy steel materials. Therefore, if the BWR SLC pumps are operated intermittently (i.e., testing purposes) and the pressure boundary cylinder/plunger blocks are manufactured from stainless or high alloy steel, then erosion and erosion/corrosion of the SLC pump pressure boundary cylinder/plunger block are not significant aging mechanisms.

The PWR CVCS reciprocating charging pumps are assumed to be continuously operated. It is recognized that many PWR plants have centrifugal CVCS charging pumps operating continuously with the reciprocating CVCS charging pump maintained in standby. However, industry experience (NPRDS) identifies erosion and erosion/corrosion as having occurred to the pressure boundary cylinder/plunger block of the reciprocating CVCS charging pump. Therefore, if the reciprocating CVCS charging pumps are continuously operated, then erosion and erosion/corrosion are significant aging mechanisms.

Erosion and erosion/corrosion of centrifugal pump pressure boundary casing, suction and discharge nozzles, discharge head, column, and bowl is a significant aging mechanism for all pump fluid service applications and operating time characteristics, except in lubrication and fuel oil applications. The discussion for rotary pump erosion and erosion/corrosion applies to centrifugal pump pressure boundary casing, suction and discharge nozzles, discharge head, column, and bowl in these applications.

Industry experience (NPRDS) documents many cases of centrifugal pump pressure boundary casing, suction and discharge nozzles, discharge head, column, and bowl erosion and erosion/corrosion without regards to fluid service application, materials, or operating times. This aging mechanism is caused by fluid and particle impingement, cavitation, water temperature and dissolved oxygen content (i.e., single phase erosion phenomenon), fluid velocity, etc.

4.3.2.3.3 Fouling

From Section 4.3.1.9, some of the pressure boundary subassembly components exposed to the process fluid are susceptible to fouling. Also, from Section 4.3.1.9, fouling is not a significant aging mechanism for:

- All pump pressure boundary fasteners for all fluid applications, without conditions, because these components are not exposed to the process fluid.
- All pump pressure boundary subassembly components in primary coolant fluid applications.
- All pump pressure boundary subassembly components in closed cooling water applications provided corrosion inhibitors, and biocides are used to control corrosion product material buildup.

The SLC System reciprocating pumps provide the fluid discharge pressure through compression, and the force of the piston or plunger is very high during the compression stroke. These forces are large enough to scour the internal cylinder/plunger block surfaces and prevent foreign material from accumulating on these surfaces. Therefore, fouling is not a significant aging mechanism for the SLC reciprocating pump cylinders/plunger blocks, without conditions.

The centrifugal PWR BAT System pump pressure boundary casing, flange/cover, and suction/discharge nozzles are particularly susceptible to fouling, because they process fluids containing borated compounds. The borated compounds can precipitate under certain concentration and temperature conditions. Industry operating experience has documented cases where fouling of borated water service pump pressure boundary components has occurred. Therefore, fouling is a significant aging mechanism for borated water pump pressure boundary casing, flange/cover, and suction/discharge nozzles.

Industry operating experience documents several cases of fouling occurring to the pump pressure boundary casing, flange/cover, and suction/discharge nozzles in treated water service applications. These cases are predominantly associated with pump suction being supplied from large reservoirs. Sediment settles in the bottom of these reservoirs and is drawn into the pump causing fouling. Therefore, if the pump suction is from a reservoir in treated water applications, then fouling is a significant aging mechanism for the pump pressure boundary casing, flange/cover, and suction/discharge nozzles.

Sediment, particulate, and impurities can accumulate in the bottom of lubricating and fuel oil reservoirs if strict controls are not placed on oil quality/purity. These materials can be drawn into the pump and foul the pressure boundary casing, flange/cover, and suction/discharge nozzles. Therefore, if strict controls are not placed on lubricating and fuel oil purity, then fouling is a significant aging mechanism for the pump pressure boundary casing, flange/cover, and suction/discharge nozzles.

From the viewpoint of contaminants (chemicals, microbes, and foreign particles), raw water is an uncontrolled fluid. Fresh raw water contains dissolved oxygen levels (8-12 ppm), various amounts of free oxygen, solid organic and inorganic foreign materials, bivalves and other aquatic species, and various types of chemical and biological contaminants.[4.26] Brackish water or seawater is similar to the fresh water constituents in addition to having a high salt content, mainly sodium chloride. These high levels of foreign materials such as sand and dirt, seaweed, microbes, and other aquatic species increases the potential for fouling.

Rough screens located at the raw water pump inlet remove large foreign materials; however, industry experience documents many instances where these materials have entered the pump and caused fouling of the casing, discharge head, column/bowl, flange/cover, and suction/discharge nozzles.[4.27, 4.28] In some cases, fouling of the pump casing, discharge head, column/bowl, flange/cover, and suction/discharge nozzles has caused decreased flow rate and developed head and has caused cavitation. Therefore, fouling is a significant aging mechanism for all pump casing, discharge head, column/bowl, flange/cover, and suction/discharge nozzles in raw service water applications.

4.3.2.4 Mechanical Subsystems

From Section 4.3.1, the mechanical subsystem subassemblies are susceptible to:

- Mechanical fatigue in all pump applications (Section 4.3.1.4)
- Erosion and erosion/corrosion in water lubricated radial bearings of vertical well centrifugal pumps in raw water service applications (Section 4.3.1.7)
- Wear in all pump applications (Section 4.3.1.8)

4.3.2.4.1 Mechanical Fatigue

Mechanical subsystems (couplings, shaft seals, bearings) are composed of a large number of parts which are assembled with fasteners, chemical bonding processes, or shrink fits. Both metallic and non-metallic components are used in these subsystems.

Couplings (or half couplings) are attached to the ends of the pump and driver shafts and rotate with the shaft. Shaft seals and bearings have both stationary and rotating assemblies. The rotating assembly is usually attached to the shaft with a shaft sleeve or other type of spacer. Although the attachment method may create a stress raiser and cause built-in residual stresses, the sleeve or spacer locally increases shaft stiffness. The net affect reduces alternating stress and, therefore, the potential for fatigue cracking. The stationary assembly is attached to the pump casing for the shaft seal and to the bearing housing for the bearings.

Cyclic loads applied to pump couplings are similar to those described in Section 4.3.2.1.1 for shafts, impellers, and rotors with the exception of fluid induced loadings. Couplings on smaller pumps may use a solid bolted connection between the pump and driver shaft; however, most couplings contain flexible metallic elements. These flexible elements not only transmit torque but also reduce dynamic loads by absorbing, through flexure, the slight differential movement between the pump and driver during start-up, shutdown, and normal operation. The sources of differential movement may be caused by imperfect alignment between the pump and driver shaft center lines and dissimilar vibration patterns between the pump and driver rotating assemblies.

The coupling flexural element is also exposed to high cycle loading from absorbing the differential movements between the pump and driver. Couplings which use gears rather than flexible elements absorb differential movements between the pump and driver through the clearance between the mating gears. Therefore, mechanical fatigue is a significant aging mechanism for the coupling.

Shaft seals and bearings are typically located at one or both ends of the pump shaft. Exceptions are vertical well centrifugal pumps water lubricated radial bearings which are located at various points on the shaft within the pump column and; reciprocating pump piston/plunger seals that prevent leakage of the fluid. These reciprocating pump seals are sliding seals between the piston/plunger and cylinder/plunger block and are generally made from non-metallic materials. Non-metallics are evaluated in Section 4.3.5.

Cycling loads applied to pump rotating assembly portions of shaft seals and radial bearings are also similar to those described in Section 4.3.2.1.1 for shafts, impellers, and rotors, with the exception of fluid-induced loadings. These assemblies have relatively simple geometries which do not extend very far from the shaft outside surface. The shaft seals and radial bearings locally stiffen the shaft cross section which reduces nominal cyclic stresses in a manner similar to the effects of other shaft spacers. Radial vibration displacement and vibration loads tend to be low because of shaft support provided at the shaft seals and bearings. These loads are dependent on the type and thickness of lubricating fluid and the interface between rotating and stationary assemblies. The stationary assembly of shaft seals are exposed to cyclic pressure loads as a result of pump starts and stops. However, the design of these components is such that the stress ranges are small. The stationary assembly portions of shaft seals and radial bearings are also subject to the same low radial vibration loads as described above for the rotating assemblies. Therefore, if the radial bearings and seals are satisfactorily assembled and the proper lubrication is utilized, then mechanical fatigue of the shaft seals and radial bearings is not a significant aging mechanism.

The rotating assembly portion of the thrust bearing (generally a thrust collar) has a geometry that is more complex than radial bearings. The rotating assembly may extend several inches beyond the shaft outside surface to provide sufficient area for absorbing axial loads. Small axial movements/loads are absorbed by spring loaded pads or pads designed to pivot under load. In this type of configuration, axial thrust loads result in significant compression, tension, or bending stresses. The rotating assembly portion of some thrust bearing components are also subject to cyclic loads similar to those described in Section 4.3.2.1.1 for shafts, impellers, and rotors with the exception of fluid-induced loadings. Because of the combinations of cyclic loads, mechanical fatigue is a significant aging mechanism for the pump thrust bearing assembly.

4.3.2.4.2 Erosion and Erosion/Corrosion

From Section 4.3.1.7, the water lubricated radial bearings in raw water service vertical pool centrifugal pumps are susceptible to erosion and erosion/corrosion. Also, from Section 4.3.1.7, erosion and erosion/corrosion are not significant aging mechanisms for all other mechanical subsystem subassemblies because either the component is not exposed to the process fluid (i.e., couplings) or fluid velocity is low (i.e., seals and oil lubricated radial and thrust bearings).

The internal radial bearings of vertical pool centrifugal pumps in raw water service applications are subject to moderate or high fluid velocity. Erosion and erosion/corrosion of this component is caused by fluid and particle impingement and has been observed to occur in situations where the pump is not continuously operated. Therefore, if the water lubricated radial bearing is in raw service water pump applications, then erosion and erosion/corrosion are significant aging mechanisms.

4.3.2.4.3 Wear

From Section 4.3.1.8, all pump mechanical subsystem subassembly components are susceptible to wear. Industry experience (NPRDS and LER) documents that wear is responsible for over 50% of pump failures. Many of the failures are associated with pump mechanical subsystem subassembly components.

4.3.2.5 Support Subassemblies

From Section 4.3.1, the pump support subassemblies are susceptible to:

- Mechani :al fatigue in all pump applications (Section 4.3.1.4)

4.3.2.5.1 Mechanical Fatigue

The support feet or skirt are generally welded to the pump casing (discharge head for vertical well centrifugal pumps). The intersection between the support feet/skirt and the pump pressure boundary are subject to the same cyclic loadings described in Section 4.3.2.3.1 for the pressure boundary components. Therefore, mechanical fatigue is a significant aging mechanism for the pump support feet/skirt components.

Cyclic mechanical loads imposed on the support base frame/skid and fasteners are transmitted from the bearing (through the bearing housing) and the shaft seal (through the pressure boundary and support feet/skirt). These cyclic loads are due to starts/stops, load changes, and steady state vibration as described in Section 4.3.2.1.1 for the rotating/reciprocating components. The support base/frame and fasteners are designed in a conservative manner to support weight loadings and seismic loadings. The cyclic loads, transmitted to these support components at the bearings and seals, are low to moderate for two reasons. First, fluids (lubricating oil and pumped fluid) at the bearing and seal rotating/stationary interface dampens the load. Second, high loads would imply that vibration displacements are close to or exceeding the specified limits and operation for long periods of time under these conditions would not be allowed. Therefore, if vibration amplitude (or acceleration) is maintained below specified limits, then mechanical fatigue is not a significant aging mechanism for the pump support skid/frame and fasteners.

4.3.3 Aging Mechanism Evaluations of Selected Service Applications

Section 4.3.1 determined that corrosion and stress corrosion cracking required further examination of significance. These mechanisms are primarily influenced by service application and to a lesser extent by component subassembly materials and design features. Therefore, this section further examines these mechanisms by considering each of the service applications. These evaluations lead to a final determination of aging mechanism significance in each service application. Tables 4-4 through 4-10 summarize these evaluation conclusions.

4.3.3.1 Primary Water Service Application

The following determinations, regarding the significance of corrosion (Section 4.3.1.5) and stress corrosion cracking (Section 4.3.1.6), were made as they pertain to pumps located in primary water system application. These determinations are summarized on Table 4-4.

- Section 4.3.1.5.1 concluded that if the pump wetted parts are made of stainless or high alloy steel containing ≥ 12% chromium and the pump was not a raw service water application, then general corrosion is not a significant aging mechanism for these components.

- Section 4.3.1.5.1 concluded that if the pump wetted parts are made of bronze or brass containing less than 15% zinc, regardless of pump service application, then general corrosion is not a significant aging mechanism for these components.

- Section 4.3.1.5.1 concluded that for electric motor-driven pump applications, if the stray motor current grounding path through the shaft is eliminated, (by electrically insulating the bearings and/or installing an alternate low-impedance path for the current to flow), then general corrosion is not a significant aging mechanism.

- Section 4.3.1.5.1 concluded that if the pump is not submerged, and the components exposed to the external environment are made from stainless or high alloy steel, then general corrosion is not a significant aging mechanism.

- Section 4.3.1.5.2 concluded that if the pump wetted parts are made from stainless or high alloy steel, then galvanic corrosion is not a significant aging mechanism.

- Section 4.3.1.5.2 concluded that if the pump external component surfaces are exposed to the ambient environment then galvanic corrosion is not a significant aging mechanism.

- Section 4.3.1.5.3 concluded that if the pump wetted parts are exposed to reactor coolant, then microbiologically influenced corrosion is not a significant aging mechanism.

- Section 4.3.1.5.3 concluded that if the pump external component surfaces are exposed to the ambient environment, then microbiologically influenced corrosion is not a significant aging mechanism.

- Section 4.3.1.6.1 concluded that if heat exchangers are located upstream from the pumps, then intergranular stress corrosion cracking is not a significant aging mechanism for the CVCS charging pumps and RWCU System pumps.

- Section 4.3.1.6.2 concluded that if nitrogen levels of the stainless and high alloy steel wetted parts are controlled to less than 0.12 w/o in the material specification, then transgranular stress corrosion cracking is not a significant aging mechanism.

Corrosion and Stress Corrosion Cracking

The PWR CVCS charging pumps and BWR RWCU pumps are the only pumps evaluated in this guideline that are located in primary water service applications.

The aging mechanism significance determinations, pertaining to primary water pump service applications, are derived in Section 4.3.1.5 for corrosion and Section 4.3.1.6 for stress corrosion cracking and summarized above in Section 4.3.3.1. Therefore, if all of the criteria described in these aging mechanism significance determinations is met, then general corrosion, galvanic corrosion, microbiologically influenced corrosion, intergranular stress corrosion cracking, and transgranular stress corrosion cracking are not significant aging mechanisms for all of the primary water pump rotating/reciprocating, fixed internal, pressure boundary, mechanical subsystem, and support base subassembly components.

4.3.3.2 Borated Water Service Applications

The following determinations, regarding the significance of corrosion (Section 4.3.1.5) and stress corrosion cracking (Section 4.3.1.6), were made as they pertain to pumps located in borated water system application. These determinations are summarized on Table 4-4.

- Section 4.3.1.5.1 concluded that if the pump wetted parts are made of stainless or high alloy steel containing ≥ 12% chromium and the pump was not a raw service water application, then general corrosion is not a significant aging mechanism for these components.

- Section 4.3.1.5.1 concluded that if the pump wetted parts are made of bronze or brass containing less than 15% zinc, regardless of pump service application, then general corrosion is not a significant aging mechanism for these components.

- Section 4.3.1.5.1 concluded that for electric motor-driven pump applications, if the stray motor current grounding path through the shaft is eliminated, (by electrically insulating the bearings and/or installing an alternate low-impedance path for the current to flow), then general corrosion is not a significant aging mechanism.

- Section 4.3.1.5.1 concluded that if the pump is not submerged, and the components exposed to the external environment are made from stainless or high alloy steel, then general corrosion is not a significant aging mechanism.

- Section 4.3.1.5.1 concluded that if borated fluid leakage exists, then general corrosion is a significant aging mechanism for all pump exterior surfaces exposed to the fluid leakage.

- Section 4.3.1.5.2 concluded that if the pump wetted parts are made from stainless or high alloy steel, then galvanic corrosion is not a significant aging mechanism.

- Section 4.3.1.5.2 concluded that if the pump external component surfaces are exposed to the ambient environment, then galvanic corrosion is not a significant aging mechanism.

- Section 4.3.1.5.3 concluded that if the pump is exposed to treated water where the source is from a reservoir open to the atmosphere, then microbiologically influenced corrosion is a significant aging mechanism.

- Section 4.3.1.5.3 concluded that if the pump external component surfaces are exposed to the ambient environment, then microbiologically influenced corrosion is not a significant aging mechanism.

- Section 4.3.1.6.1 concluded that if the pump wetted parts are stainless or high alloy steel and exposed to borated fluid, then intergranular stress corrosion cracking is a significant aging mechanism.

- Section 4.3.1.6.2 concluded that if nitrogen levels of the stainless and high alloy steel wetted parts are controlled to less than 0.12 w/o in the material specification, then transgranular stress corrosion cracking is not a significant aging mechanism.

Corrosion and Stress Corrosion Cracking

The PWR boric acid transfer pumps and BWR standby liquid control pumps are the only pumps evaluated in this guideline that are located in borated water service applications.

The aging mechanism significance determinations, pertaining to borated water pump service applications, are derived in Section 4.3.1.5 for corrosion and Section 4.3.1.6 for stress corrosion cracking, and summarized above in Section 4.3.3.2.

From the criteria above, associated with the discussion of general corrosion, microbiologically influenced corrosion and intergranular stress corrosion cracking, further examination is required to determine significance.

Stainless steel materials, particularly low carbon austenitic stainless steels have exhibited excellent corrosion resistance to both the SLC System borated water and CVCS boric acid solution.[4.29] The wetted and non-wetted components for these pumps are required by specification to be stainless steels or materials with equivalent corrosion resistance. Therefore, if the wetted parts and non-wetted parts are required by material specification to be stainless or high alloy steel, then, even if borated water leakage occurs, general corrosion is not a significant aging mechanism for the wetted components and non-wetted external surfaces exposed to fluid leakage in these two pump applications.

The primary constituent of the borated water and boric acid solution is treated water. From Section 4.2.2, treated water can contain microbes at system temperatures below 100°C [212°F]. The PWR boric acid make-up system and BWR standby liquid control system both contain an atmospheric tank which could be a source of microbes. However, MIC is not a concern for wetted components exposed to moderate or high fluid velocities, because the microbes are swept away under these conditions.[4.1] Wetted pump components exposed to moderate or high fluid velocity consist of:

- Shaft
- Impeller
- Piston/Plunger
- Internal Valve
- Wearing Components

- Seals

Therefore, MIC is not a significant aging mechanism for these pump components.

Wetted pump components exposed to low fluid velocity are susceptible to MIC and consist of:

- Miscellaneous Structural Components
- Flow Guides
- Casing
- Cylinder/Plunger Block
- Suction/Discharge Nozzle
- Flange/Cover

Therefore, MIC is a significant aging mechanism for these components.

All stainless or high alloy steel materials exposed to borated water service applications are susceptible to IGSCC. Therefore, IGSCC is a significant aging mechanism for the wetted components of the BWR standby liquid control pump (i.e., piston/plunger, internal valve, miscellaneous structural components, wearing components, flow guides, cylinder/plunger block, and nozzles and seal) and PWR boric acid transfer pumps (shaft, impeller, miscellaneous structural components, wearing components, flow guides, casing and nozzles, flange/cover and seals).

4.3.3.3 Treated Water Service Applications

The following determinations regarding the significance of corrosion (Section 4.3.1.5) and stress corrosion cracking (Section 4.3.1.6) were made as they pertain to pumps located in treated water system applications. These determinations are summarized on Tables 4-6 and 4-7.

- Section 4.3.1.5.1 concluded that if the pump wetted parts were made of carbon and low alloy steel or cast iron and exposed to treated water application, then general corrosion is a significant aging mechanism.

- Section 4.3.1.5.1 concluded that if the pump wetted parts are made of stainless or high alloy steel containing ≥ 12% chromium and the pump was not a raw service water application, then general corrosion is not a significant aging mechanism for these components.

- Section 4.3.1.5.1 concluded that if the pump wetted parts are made of bronze or brass containing less than 15% zinc, regardless of pump service application, then general corrosion is not a significant aging mechanism for these components.

- Section 4.3.1.5.1 concluded that for electric motor-driven pump applications, if the stray motor current grounding path through the shaft is eliminated, (by electrically insulating the bearings and/or installing an alternate low-impedance path for the current to flow), then general corrosion is not a significant aging mechanism.

- Section 4.3.1.5.1 concluded that if the pump is not submerged, and components exposed to the external environment are made from carbon and low alloy steel or cast iron and protective coatings are applied to the external surfaces, then general corrosion is not a significant aging mechanism.

- Section 4.3.1.5.2 concluded that if the pump wetted parts are made from stainless or high alloy steel, then galvanic corrosion is not a significant aging mechanism.

- Section 4.3.1.5.2 concluded that if the pump external component surfaces are exposed to the ambient environment, then galvanic corrosion is not a significant aging mechanism.

- Section 4.3.1.5.3 concluded that if the pump is exposed to treated water where the reservoir is open to the atmosphere, then microbiologically influenced corrosion is a significant aging mechanism.

- Section 4.3.1.5.3 concluded that if the pump external component surfaces are exposed to the ambient environment, then microbiologically influenced corrosion is not a significant aging mechanism.

- Section 4.3.1.6.1 concluded that if the pump wetted parts are made from carbon and low alloy steel materials or cast iron, then IGSCC is not a significant aging mechanism.

- Section 4.3.1.6.1 concluded that if the pump wetted parts are made from stainless or high alloy steel materials and operate at temperatures less than 54°C [130°F], then IGSCC is not a significant aging mechanism.

- Section 4.3.1.6.1 and 4.3.1.6.2 concluded that if the pump wetted parts are made of bronze or brass containing less than 15% zinc, regardless of pump service application, then IGSCC and TGSCC are not significant aging mechanisms.

- Section 4.3.1.6.2 concluded that if nitrogen levels of the stainless and high alloy steel wetted parts are controlled to less than 0.12 w/o in the material specification, then transgranular stress corrosion cracking is not a significant aging mechanism.

Corrosion and Stress Corrosion Cracking

The majority of the pumps covered by this guideline are located in treated water service applications as noted in Tables 3-7 and 3-8. These applications use only centrifugal pumps. The wetted components for these pumps are made from a variety of materials consisting of stainless and high alloy steels, low alloy steel, carbon steel, cast iron, bronze, and brass.

From the criteria above, further examination is required to determine significance of general corrosion, galvanic corrosion, microbiologically influenced corrosion, intergranular stress corrosion cracking, and transgranular stress corrosion cracking.

Many wetted components are susceptible to general corrosion over long periods of time in the treated water environment. Uniform corrosion rates of 0.025 mm [0.001 in] per year or greater are possible for carbon and low alloy steel and cast iron materials, and localized corrosion rates (pitting) are significantly greater. This general corrosion rate may have no effect on the performance of pressure boundary components because they have design corrosion allowances of 3.2 mm [1/8 in] or greater;[4.19] however, the performance of other carbon and low alloy steels and cast iron components can be significantly affected by general corrosion. Therefore, if the pressure boundary components are carbon and low alloy steel or cast iron and are designed with corrosion allowances less then 3.2 mm [1/8 in], then general corrosion is a significant aging mechanism. Also, general corrosion is a significant aging mechanism for all other carbon and low alloy steel and cast iron pump components in treated water services.

Treated water is a fluid which will support galvanic corrosion between dissimilar metals. The various combinations of wetted component materials within each pump is the primary parameter for determining significance of galvanic corrosion. The material combinations which result in galvanic corrosion are:

- Stainless/High Alloy Steel (Cathodic) and Bronze/Brass (Anodic)
- Stainless/High Alloy Steel (Cathodic) and Low Alloy/Carbon Steel (Anodic)
- Stainless/High Alloy Steel (Cathodic) and Cast Iron (Anodic)
- Bronze/Brass (Cathodic) and Low Alloy/Carbon Steel (Anodic)
- Bronze/Brass (Cathodic) and Cast Iron (Anodic)

Another factor which must be taken into consideration when determining the significance of galvanic corrosion is surface area of the anodic and cathodic (i.e., dissimilar metal) pump components. The effects of galvanic corrosion are minimized if the surface area of the anodic material is larger than the surface area of the cathodic material. Therefore, if the wetted pump component is an anodic material and the surface area is relatively small with respect to other wetted pump components that are cathodic, then galvanic corrosion is a significant aging mechanism for the anodic pump component.

From, Section 4.2.2 , treated water can contain microbes at system temperatures below 100°C [212°F]. The source of microbes can be transferred from other water supplies (used to make the treated water) or from reservoirs that contain treated water which are open to the atmosphere. MIC is not a concern for wetted components exposed to moderate or high fluid velocities, because the microbes are swept away under these conditions.[4.1] Wetted components in these centrifugal pump application exposed to moderate or high fluid velocity consist of:

- Shaft
- Impeller
- Wearing Components
- Seals

Therefore, MIC is not a significant aging mechanism for these pump components.

Wetted pump components exposed to low fluid velocity are susceptible to MIC and consist of:

- Miscellaneous Structural Components
- Flow Guides
- Casing
- Suction/Discharge Nozzle
- Flange/Cover
- Suction Strainer

Therefore, MIC is a significant aging mechanism for these components.

Some treated water pump applications operate at temperatures greater than 54°C [130°F] for short periods of time. Industry operating experience documents that IGSCC has occurred to stainless and high alloy steel pump components in treated water service. Therefore, if the pump wetted components are exposed to treated water and are exposed to temperatures greater than 54°C [130°F] and made from stainless or high alloy steel materials, then IGSCC is a significant aging mechanism.

In some treated water pump applications, wrought brass or bronze materials, containing greater than 15% zinc, may be used for fixed internal wearing and miscellaneous structural components. These materials are susceptible to IGSCC and TGSCC. Therefore, if wrought brass or bronze materials containing greater than 15% zinc are used, then IGSCC and TGSCC are significant aging mechanisms.

4.3.3.4 Closed Cooling Water Service Applications

The following determinations regarding the significance of corrosion (Section 4.3.1.5) and stress corrosion cracking (Section 4.3.1.6) were made as they pertain to pumps located in closed cooling water system applications. These determinations are summarized on Table 4-8.

- Section 4.3.1.5.1 concluded that if the pump wetted parts were made of carbon and low alloy steel or cast iron and exposed to closed cooling water applications, then general corrosion is a significant aging mechanism.

- Section 4.3.1.5.1 concluded that if the pump wetted parts are made of stainless or high alloy steel containing ≥ 12% chromium and the pump was not a raw service water application, then general corrosion is not a significant aging mechanism for these components.

- Section 4.3.1.5.1 concluded that if the pump wetted parts are made of bronze or brass containing less than 15% zinc, regardless of pump service application, then general corrosion is not a significant aging mechanism for these components.

- Section 4.3.1.5.1 concluded that for electric motor-driven pump applications, if the stray motor current grounding path through the shaft is eliminated (by electrically insulating the bearings and/or installing an alternate low-impedance path for the current to flow), then general corrosion is not a significant aging mechanism.

- Section 4.3.1.5.1 concluded that if the pump is not submerged, and the components exposed to the external environment are made from carbon and low alloy steel or cast iron, and protective coatings are applied to the external surfaces, then general corrosion is not a significant aging mechanism.

- Section 4.3.1.5.2 concluded that if the pump wetted parts are made from stainless or high alloy steel, then galvanic corrosion is not a significant aging mechanism.

- Section 4.3.1.5.2 concluded that if the pump wetted parts are exposed to closed cooling water treated with an inhibitor, then galvanic corrosion is not a significant aging mechanism.

- Section 4.3.1.5.2 concluded that if the pump external component surfaces are exposed to the ambient environment, then galvanic corrosion is not a significant aging mechanism.

- Section 4.3.1.5.3 concluded that if the pump wetted parts are exposed to closed cooling water treated with biocides, then microbiologically influenced corrosion is not a significant aging mechanism.

- Section 4.3.1.5.3 concluded that if the pump external component surfaces are exposed to the ambient environment, then microbiologically influenced corrosion is not a significant aging mechanism.

- Section 4.3.1.6.1 concluded that if the pump wetted parts are made from carbon and low alloy steel materials or cast iron, then IGSCC is not a significant aging mechanism.

- Section 4.3.1.6.1 concluded that if the pump wetted parts are made from stainless or high alloy steel materials and operate at temperatures less than 54°C [130°F], then IGSCC is not a significant aging mechanism.

- Sections 4.3.1.6.1 and 4.3.1.6.2 concluded that if the pump wetted parts are made of bronze or brass containing less than 15% zinc, regardless of pump service application, then IGSCC and TGSCC are not significant aging mechanisms.

- Section 4.3.1.6.2 concluded that if nitrogen levels of the stainless and high alloy steel wetted parts are controlled to less than 0.12 w/o in the material specification, then transgranular stress corrosion cracking is not a significant aging mechanism.

Corrosion and Stress Corrosion Cracking

The pump applications which use closed cooling water as the pumped fluid are the various Closed Cooling Water Systems and the EDG Jacket Cooling Water System. The closed cooling water applications use only centrifugal pumps. Wetted components for these pumps are made from a variety of materials consisting of stainless and high alloy steels, low alloy steel, carbon steel, cast iron, bronze, and brass.

From the criteria above, further examination is required to determine significance of general corrosion, intergranular stress corrosion cracking, and transgranular stress corrosion cracking.

Wetted components made from carbon and low alloy steel or cast iron materials are susceptible to general corrosion over long periods of time in the closed cooling water environment. The inclusion of corrosion inhibitors in the closed cooling water environment reduce the rate of general corrosion. However, even under these conditions, uniform or localized general corrosion rates of up to 1 mil [0.001 in] per year on average are possible. This general corrosion rate may have no effect on the performance of pressure boundary components because they have corrosion allowances of 3.2 mm [1/8 in] or greater; however, the performance of other carbon and low alloy steel and cast iron components can be significantly affected by general corrosion. Therefore, if the pressure boundary components are carbon and low alloy steel or cast iron and designed with corrosion allowances less than 3.2 mm [1/8 in], then general corrosion is a significant aging mechanism. Also, general corrosion is a significant aging mechanism for all other carbon and low alloy steel and cast iron pump components in closed cooling water service applications.

All closed cooling water pump applications operate at temperatures less than 54°C [130°F]. Industry operating experience has not identified IGSCC of stainless and high alloy steel pump components to be a concern in closed cooling water service applications. Therefore, if the closed cooling water pump components operate at temperatures less then 54°C [130°F], then IGSCC is not a significant aging mechanism for the stainless and high alloy components.

In some closed cooling water pump applications, wrought brass or bronze materials, containing greater than 15% zinc, may be used for fixed internal wearing and miscellaneous structural components. These materials are susceptible to IGSCC and TGSCC. Therefore, if wrought brass or bronze materials containing greater than 15% zinc are used, then IGSCC and TGSCC are significant aging mechanisms.

4.3.3.5 Lubricating/Fuel Oil Service Applications

The following determinations, regarding the significance of corrosion (Section 4.3.1.5) and stress corrosion cracking (Section 4.3.1.6) were made as they pertain to pumps located in lubricating and fuel oil system application. These determinations are summarized on Table 4-9.

- Section 4.3.1.5.1 concluded that if the pump wetted parts are made of stainless or high alloy steel containing ≥ 12% chromium and the pump was not a raw service water application, then general corrosion is not a significant aging mechanism for these components.

- Section 4.3.1.5.1 concluded that if the pump wetted parts are made of bronze or brass containing less than 15% zinc, regardless of pump service application, then general corrosion is not a significant aging mechanism for these components.

- Section 4.3.1.5.1 concluded that if the pump components are made from carbon and low alloy steel or cast iron and purity of the lubricating/fuel oil is not adequately maintained, then general corrosion is a significant aging mechanism.

- Section 4.3.1.5.1 concluded that for electric motor-driven pump applications, if the stray motor current grounding path through the shaft is eliminated (by electrically insulating the bearings and/or installing an alternate low-impedance path for the current to flow), then general corrosion is not a significant aging mechanism.

- Section 4.3.1.5.1 concluded that if the pump is not submerged, and the components exposed to the external environment are made from stainless or high alloy steel, then general corrosion is not a significant aging mechanism.

- Section 4.3.1.5.2 concluded that if the pump wetted parts are exposed to lubricating and fuel oils, then galvanic corrosion is not a significant aging mechanism.

- Section 4.3.1.5.2 concluded that if the pump external component surfaces are exposed to the ambient environment, then galvanic corrosion is not a significant aging mechanism.

- Section 4.3.1.5.3 concluded that if the pump wetted parts are exposed to lubricating and fuel oil, then microbiologically influenced corrosion is not a significant aging mechanism.

- Section 4.3.1.5.3 concluded that if the pump external component surfaces are exposed to the ambient environment, then microbiologically influenced corrosion is not a significant aging mechanism.

- Section 4.3.1.6 concluded that if the pump wetted parts are exposed to lubricating and fuel oil, then IGSCC and TGSCC are not significant aging mechanisms.

Corrosion

The pump applications which use lubricating or fuel oil as the pumped fluid are lubricating oil systems and EDG Fuel Transfer Systems. The lubricating/fuel oil applications only use centrifugal and rotary pumps. The wetted components for these pumps are made from a variety of materials consisting of stainless and high alloy steels, low alloy and carbon steels, cast iron, bronze and, brass. From the criteria above, further examination is required to determine significance of general corrosion.

Wetted components made from carbon and low alloy and cast iron steels are susceptible to general corrosion over long periods of time in the lubricating/fuel oil environment, especially when these oils are contaminated with other materials. Uniform corrosion rates of 1 mil [0.001 in] per year are possible and localized corrosion may be significantly greater. This corrosion rate may have no effect on the performance of pressure boundary components because they have design corrosion allowances greater than 3.2 mm [1/8 in]; however, the performance of other carbon and low alloy steel and cast iron components can be significantly affected by general corrosion. Therefore, if the pressure boundary components are carbon and low alloy steel or cast iron and designed with corrosion allowances less than 3.2 mm [1/8 in], then general corrosion is a significant aging mechanism. Also, general corrosion is a significant aging mechanism for all other carbon and low alloy steel and cast iron wetted pump components in lubricating/fuel oil service applications.

4.3.3.6 Raw Water Service Applications

The following determinations regarding the significance of corrosion (Section 4.3.1.5) and stress corrosion cracking (Section 4.3.1.6) were made as they pertain to pumps located in raw water service applications. These determinations are summarized on Table 4-10.

- Section 4.3.1.5.1 concluded that if the pump wetted parts were made of carbon and low alloy steel, cast iron, or stainless and high alloy steel, and exposed to raw water application, then general corrosion is a significant aging mechanism.

- Section 4.3.1.5.1 concluded that if the pump wetted parts are made of bronze or brass containing less than 15% zinc, regardless of pump service application, then general corrosion is not a significant aging mechanism for these components.

- Section 4.3.1.5.1 concluded that for electric motor-driven pump applications, if the stray motor current grounding path through the shaft is eliminated (by electrically insulating the bearings and/or installing an alternate low-impedance path for the current to flow), then general corrosion is not a significant aging mechanism.

- Section 4.3.1.5.1 concluded that if the pump is not submerged, and the components exposed to the external environment are made from carbon and low alloy steel or cast iron, and protective coatings are applied to the external surfaces, then general corrosion is not a significant aging mechanism.

- Section 4.3.1.5.2 concluded that if the pump wetted parts are made from stainless or high alloy steel, then galvanic corrosion is not a significant aging mechanism.

- Section 4.3.1.5.2 concluded that if the pump external component surfaces are exposed to the ambient environment, then galvanic corrosion is not a significant aging mechanism.

- Section 4.3.1.5.3 concluded that if the pump is exposed to raw water, then microbiologically influenced corrosion is a significant aging mechanism.

- Section 4.3.1.5.3 concluded that if the pump external component surfaces are exposed to raw water (i.e., submerged), then microbiologically influenced corrosion is a significant aging mechanism.

- Section 4.3.1.5.3 concluded that if the pump external component surfaces are exposed to the ambient environment, then microbiologically influenced corrosion is not a significant aging mechanism.

- Section 4.3.1.6.1 concluded that if the pump wetted parts are made from carbon and low alloy steel materials or cast iron, then IGSCC is not a significant aging mechanism.

- Section 4.3.1.6.1 concluded that if the pump wetted parts are made from stainless or high alloy steel materials and exposed to raw water, then IGSCC is a significant aging mechanism.

- Sections 4.3.1.6.1 and 4.3.1.6.2 concluded that if the pump wetted parts are made of bronze or brass containing less than 15% zinc, regardless of pump service application, then IGSCC and TGSCC are not significant aging mechanisms.

- Section 4.3.1.6.2 concluded that if nitrogen levels of the stainless and high alloy steel wetted parts are controlled to less than 0.12 w/o in the material specification, then transgranular stress corrosion cracking is not a significant aging mechanism.

Corrosion and Stress Corrosion Cracking

The pump applications which use raw water are the various service water pumps. These pump applications use centrifugal pumps and vertical well centrifugal pumps. The wetted pump components are made primarily from carbon steel, cast iron, and bronze materials. However, stainless and high alloy steels, low alloy steels, and brass may be used for a few components, and 400 series stainless steel shafts are relatively common.

From the criteria above, further examination is required to determine significance of general corrosion, galvanic corrosion, microbiologically influenced corrosion, intergranular stress corrosion cracking, and transgranular stress corrosion cracking.

Wetted components made from carbon and low alloy steel, cast iron, and stainless and high alloy steels are susceptible to general corrosion over long periods of time exposed to a raw water environment.[4.30] Some raw waters are quite aggressive with regard to corrosion. Uniform and localized general corrosion rates may be as high as 0.25 mm [0.010 in] per year in some environments.[4.31, 4.32] General corrosion rates of stainless steel can exceed those of carbon steel depending on the mineral content of the raw water source. High levels of chloride and sulfate ions may result in severe localized corrosion of austenitic stainless steels.[4.14] Graphitic corrosion, a metallurgical dealloying process of cast iron material, may result in increasing rates of corrosion after 20 or 30 years of service. The service water pumps experience long periods of low flow or stagnation which allow contaminants that promote corrosion to accumulate and concentrate at certain locations. The vertical well centrifugal pump wetted components experience periods when surfaces are alternately wet and dry. The dry periods allow concentration of salts (such as sodium chloride in seawater) to deposit on the pump metal surfaces. Therefore, if the pump component is made from carbon and low alloy steel, cast iron, or stainless and high alloy steel and exposed to a raw water service application, then general corrosion is a significant aging mechanism.

Raw water is a fluid which will support galvanic corrosion between dissimilar metals. The various combinations of wetted component materials within each pump is the primary parameter for determining significance of galvanic corrosion. The material combinations which result in galvanic corrosion are:

- Stainless/High Alloy Steel (Cathodic) and Bronze/Brass (Anodic)
- Stainless/High Alloy Steel (Cathodic) and Low Alloy/Carbon Steel (Anodic)
- Stainless/High Alloy Steel (Cathodic) and Cast Iron (Anodic)
- Bronze/Brass (Cathodic) and Low Alloy/Carbon Steel (Anodic)
- Bronze/Brass (Cathodic) and Cast Iron (Anodic)

Another factor, which must be taken into consideration when determining the significance of galvanic corrosion, is surface area of the anodic and cathodic (i.e., dissimilar metal) pump components. The effects of galvanic corrosion are minimized if the surface area of the anodic material is larger than the surface area of the cathodic material. Therefore, if the wetted pump component is an anodic material and the surface area is relatively small with respect to other wetted pump components that are cathodic, then galvanic corrosion is a significant aging mechanism for the anodic pump components.

From Section 4.2.2, raw water contains microbes and other living organisms at temperatures below 100°C [212°F]. These microbes will cause microbiologically influenced corrosion to occur on metallic surfaces. Microbiologically influenced corrosion is not a concern for wetted components exposed to moderate or high fluid velocities because the microbes are swept away under these conditions.[4.1] Wetted components in these centrifugal and vertical well centrifugal pumps exposed to moderate or high velocity consist of:

- Shaft
- Impeller
- Wearing Components
- Seals
- Internal Radial Bearings

Therefore, MIC is not a significant aging mechanism for these pump components.

Wetted pump components exposed to low fluid velocity are susceptible to MIC and consist of:

- Miscellaneous Structural Components
- Flow Guides
- Casing
- Suction/Discharge Nozzle
- Flange/Cover
- Suction Strainer

Therefore, MIC is a significant aging mechanism for these components.

Chlorides and sulfates significantly increase the potential for IGSCC to occur in stainless steel materials.[4.14] Chlorides and sulfates are present in fresh water, and chloride levels are very high in brackish water and seawater. Service water pump components may be exposed to alternate wet and dry periods which will allow concentration of the chloride containing salts on pump component surfaces. Therefore, if the pump contains stainless and high alloy steels that are exposed to raw water, then IGSCC is a significant aging mechanism.

In some raw water pump applications, wrought brass or bronze materials, containing greater than 15% zinc, may be used for fixed internal wearing and miscellaneous structural components. These materials are susceptible to IGSCC and TGSCC. Therefore, if wrought brass or bronze materials containing greater than 15% zinc are used, then IGSCC and TGSCC are significant aging mechanisms.

4.3.4 Loss of Threaded Fastener Preload

The satisfactory performance of threaded fasteners depends on their ability to maintain the initial preload. Threaded fasteners which become loose and partially/completely back-out of threaded holes can result in performance degradation and damage to other pump components. Some of the aging mechanisms which are evaluated as significant for fasteners in Sections 4.3.1, 4.3.2, and 4.3.3 (corrosion, fatigue) can also result in the loss of initial preload. However, threaded fastener loosening is frequently the result of vibration, fluid induced or caused by mechanical imbalance. Vibration tends to increase with running time due to the effects of aging mechanisms on various pump components. Although erosion, erosion/corrosion and wear are the primary mechanisms which affect vibration, all of the significant aging mechanisms noted in Sections 4.3.1, 4.3.2, and 4.3.3 can play a role. Vibration measurements are one of the most frequently recorded operating parameters for pumps. However, even measured vibration magnitudes which are clearly within the acceptable range for a specific pump application, can result in the loosening of threaded fasteners. Industry operating experience has identified cases where this has occurred for threaded fasteners that are part of the pump internals, shaft seal, coupling, or external anchorage. From an aging mechanism viewpoint, this type of degradation is synergistic in nature, with vibration as the common link.

4.3.5 Non-Metallic Component Aging

A listing of the types of non-metallic materials and other renewable components used in the pump applications included in this AMG are provided in Section 3.5. Tables 3-12 and 3-13 identify some additional non-metallic materials commonly used in pumps. These non-metallics are utilized parts of wetted pump components (shaft seals, internal stationary and rotating bushings/seals) and utilized in non-wetted pump components (bearings, couplings).

Evaluation of non-metallics was excluded from the aging mechanism evaluations in Sections 4.3.1, 4.3.2, and 4.3.3, because age-related degradation is frequently associated with a change in material properties due to the long-term exposure to the environment (temperature, pressure or load, radiation, fluid chemistry, and relative humidity) or to dust, dirt, or other contaminants. Although failures of non-metallic components may be due to fatigue, wear or erosion, the change in material properties (such as tensile strength of solid bushings or spacers, hardness for bearing materials, and lubricity for lubricating oils or greases) is generally the root cause.

Non-metallic components such as lubricants and those used in shaft seals, couplings, pressure boundary gaskets, and bearings are considered to be renewables and are replaced after a specified period of calendar time or a number of operating hours. However, non-metallics which are part of internal pump components are impossible to replace without substantial pump disassembly and are expected to have lifetimes equal to that of other internal rotating and stationary parts.

4.3.6 Aging Mechanisms Synergies and Dependencies

This section provides a basic understanding relative to the affect that several aging mechanisms acting together can have on pump availability and performance. As such, the root cause of pump failure can be difficult to identify because of aging mechanism synergies and dependencies. It is intended, however, not to evaluate in this section, the specific aging mechanism synergies and dependencies occurring to the various pump subassemblies.

Aging mechanisms were evaluated in Sections 4.3.1, 4.3.2, and 4.3.3 as if they manifested individually on a pump component. Both theoretical considerations and field history indicate that the affects of two or more aging mechanisms acting simultaneously on a component may cause degradation and failure. The time duration for significant degradation to occur under these conditions will naturally be less than the duration for each individually acting aging mechanism.

Corrosion and erosion can both result in material wastage. Acting together they can reduce material thickness to the point where excessive deformation or complete failure occurs or where enlarged clearances degrade hydraulic performance. Significant material thickness reductions have occurred in turbulent regions of pump casings near inlet and outlet nozzles and enlarged clearance problems have occurred at impellers, wear rings, interstage flow guides, and balance disks.[4.33]

The surface discontinuities caused by localized corrosion can increase the peak stresses caused by cyclic loads. This combination of aging mechanisms termed corrosion fatigue has been addressed in the literature[4.34] and is applicable to pump pressure boundary components (suction/discharge nozzles) and highly stressed rotating components (shafts).

Pumps require that many subcomponents work together to provide satisfactory performance. The aging mechanisms evaluated in Sections 4.3.1, 4.3.2, and 4.3.3 do not consider the dependence between aging mechanisms and components. There are many situations where aging and degradation of one component can be the primary reason for degradation of a different component. Such situations can occur when erosion/corrosion of internal rotating components causes a dynamic unbalance and an increase in vibration levels, resulting in accelerated wear at the wear ring, spacers, seals, or bearings. Fouling of the suction nozzle or strainer causes cavitation and erosion/corrosion of the pump casing and impeller. There are a multitude of situations in which wear of one component may cause accelerated wear of a second component. In situations where the centrifugal pumps' impeller is supported only by an inboard bearing, wear of the bearing may cause extensive impeller/wear ring wear.

4.3.7 Comparison of AMG with NPAR Results

Several Nuclear Plant Aging Research (NPAR) reports, that evaluate aging and degradation of nuclear plant pumps, have been written for the NRC. The NPAR reports that cover pump aging/degradation are identified in References 4.13, 4.35, 4.36, 4.37, 4.38, 4.39, 4.40, 4.41, 4.42, 4.43, 4.44, and 4.45.

Each of these NPAR reports presents the results of an assessment associated with time-related degradation (i.e., aging) of nuclear plant pumps that: 1) are used in safety-related systems, or 2) provide normal operating capability. Aging information, evaluated in these NPAR reports, was obtained from various sources of nuclear plant operating experience documentation. The LER and NPRDS databases were predominantly used to categorize aging mechanisms and pump failure causes.

References 4.40 and 4.41 are aging failure surveys associated with a wide variety of nuclear plant systems and components including pumps. The data collection and analysis process for this pump AMG was conducted in a similar manner to that of these two NPAR reports. A comparison of Table 3-14 of this AMG and Figure 4 of Reference 4.41 reveals that service water system pumps and auxiliary feedwater system pumps experience the greatest number of failures. References 4.40 and 4.41 indicate that wear, corrosion, fouling, and fatigue (in that order) are the predominant aging mechanisms that cause failure to a wide cross section of nuclear plant components including pumps. Pump failures were dominated by wear and fouling as cited in these two NPAR reports. Figures 3-18 and 3-26 of this AMG (LER and NPRDS data respectively) show that wear, fatigue, fouling and erosion/corrosion are the predominant aging mechanisms for pumps. These results compare quite favorably.

References 4.13, 4.35 through 4.39, 4.42, and 4.43 are NPAR aging studies on specific nuclear plant systems. A review of these documents confirm that the stressors and aging mechanism evaluations presented in Sections 4.1 and 4.3.1, 4.3.2, and 4.3.3 respectively of the AMG compare favorably. No new or different stressors and the corresponding aging mechanisms were identified to be significant in these NPAR documents.

4.4 References

4.1 EPRI Research Project RP2812-2, "Sourcebook for Microbiologically Influenced Corrosion in Nuclear Power Plants," Prepared by Structural Integrity Associates, Inc., 1988, pp. 2-1 & 2-2.

4.2 *Metals Handbook*, Ninth Edition, Volume 11, "Failure Analysis and Prevention," American Society for Metals, Copyright 1986, pp. 130-133, 203-208, 150-154.

4.3 *Metals Handbook*, Ninth Edition, Volume 1, "Properties and Selection: Irons and Steels," American Society for Metals, Copyright 1978, p. 701.

4.4 NUMARC Report Number 90-09, "BWR Primary Coolant Pressure Boundary License Renewal Industry Report," April 1992, pp. 4-16 through 4-22.

4.5 EPRI NP-7154, "Summary of BWR Owners Group Intergranular Stress Corrosion Cracking Research Program 1979-1988," February 1991, pp. 5-50 and 5-51, 6-21 through 6-23, with permission.

4.6 G. Cragnolino and D.D. MacDonald, "Intergranular Stress Corrosion Cracking of Austenitic Stainless Steel at Temperatures Below 100°C - A Review," National Association of Corrosion Engineers, Volume 38; Number 8; August 1982; pp. 406-408.

4.7 J.K. Lee and Z. Szklarska - Smialowska, "Stress Corrosion Cracking of Sensitized AISI 304 Stainless Steel in Aqueous Chloride Solutions Containing Sulfur Species at 50 through 200°C," National Association of Corrosion Engineers, Volume 44; Number 8; August 1988; p. 564.

4.8 NUMARC Report Number 90-03, "Boiling Water Reactor Vessel Internals License Renewal Industry Report," June 1992.

4.9 NUMARC Report Number 90-02, "Boiling Water Reactor Pressure Vessel License Renewal Industry Report," August 1992.

4.10 NUMARC Report Number 90-07, "PWR Reactor Coolant System License Renewal Industry Report," May 1992.

4.11 *Metals Handbook*, Ninth Edition, Volume 13, "Corrosion," American Society for Metals, Copyright 1987, pp. 935-936.

4.12 EPRI Report NP-3673-LD, "Long Term Integrity of Nuclear Power Plant Components," October 1984, pp. 1-1, 2-44 through 2-50.

4.13 NUREG/CR-4597, "Aging and Service Wear of Auxiliary Feedwater Pumps for PWR Nuclear Power Plants," Volume 1, "Operating Experience and Failure Identification," July 1986, p. 13.

4.14 Stress Corrosion Cracking - Material Performance and Evaluation, American Society of Materials, 1992, Chapters 1 and 4.

4.15 EPRI TR-100385, "Balance-of-Plant Heat Exchanger Condition Assessment Guidelines," July 1992, Appendix D.

4.16 Bednar, Henry H., *Pressure Vessel Design Handbook*, Van Nostrand Reinhold Company, 1981, p. 270.

4.17 EPRI NP-5181 SP, Volume 3, "BWR Pilot Plant Life Extension Study at the Monticello Plant: Phase 1, Volume 3: Appendices," Final Report, May 1987, p. N-63.

4.18 MDC Calculation No. NSPL-04-12578, "Neutron Fluence and Temperature at the Biological Shield Inner Surface," August 1991.

4.19 NUMARC Report Number 90-10, "BWR Containment License Renewal Report," July 1990.

4.20 NUREG/CR-4652, "Concrete Component Aging and Its Significance Relative to Life Extension," D. Naus, Oak Ridge National Laboratory, September 1986.

4.21 NUMARC Report Number 90-10, "PWR Containment Structures License Renewal Industry Report," Revision 1, September 1991, pp. 4-26.

4.22 NRC Information Notice No 91-46, "Degradation of Emergency Diesel Generator Fuel Oil Delivery Systems," July 18, 1991.

4.23 EPRI NP-5181 SP, Volume 2, "BWR Pilot Plant Life Extension Study at the Monticello Plant: Phase 1," pp. I-3 to I-13.

4.24 NPRDS Reports:

a. Discovery Date — August 28, 1986 — Foreign Material Stuck in Impeller of RHR LP Injection Pump.

b. Discovery Date — September 22, 1991 — Foreign Material Found in Casing of HP Injection Pump.

4.25 NRC Information Notice No 88-87, "Pump Wear and Foreign Objects in Plant Piping System," November 16, 1988.

4.26 *Mark's Standard Handbook for Mechanical Engineers*, Eighth Edition, 1979.

4.27 NRC Generic Letter 89-13, "Service Water System Problems Affecting Safety Related Equipment," July 18, 1989.

4.28 NPRDS Reports:

a. Discovery Date — April 11, 1990 — Foreign Material was Blocking Suction of Nuclear Service Water Pump.

b. Discovery Date — August 19, 1991 — Debris Lodged within Essential Service Water Pump.

4.29 *Handbook of Corrosion Data*, American Society for Metals, 1989, pp. 182-184.

4.30 *Piping Handbook*, Fifth Edition, McGraw-Hill, Reno C. King and Sabin Crocker, Chapter 9 - Corrosion in Piping Systems, 1967.

4.31 EPRI NP-7240, "In-Plant Electrochemical and Corrosion Studies of Service Water Systems," March 1991.

4.32 NRC Information Notice No 90-39, "Recent Problems with Service Water Systems," June 1, 1990.

4.33 NPRDS Reports:

a. Discovery Date — March 21, 1990 — Erosion and Corrosion of Internals for Nuclear Service Water Pump.

b. Discovery Date — April 5, 1989 — Erosion of Balance Chamber for CRD Supply Pump.

4.34 Nuclear Regulatory Commission, Branch Technical Position PDLR D-1, "Fatigue Evaluation Procedures," Draft, December 12, 1991.

4.35 NUREG/CR-5052, "Operating Experience and Aging Assessment of Component Cooling Water Systems in Pressurized Water Reactors," J.C. Higgins, R. Lofaro, M. Subudhi, R. Fullwood, and J. H. Taylor, Brookhaven National Laboratory, July 1988.

4.36 NUREG/CR-4967, "Nuclear Plant Aging Research on High Pressure Injection Systems," L. C. Meyer, Idaho National Engineering Laboratory, August 1989.

4.37 NUREG/CR-5268, "Aging Study of Boiling Water Reactor Residual Heat Removal System," R. Lofaro, M. Subudhi, W. E. Gunther, W. Shier, R. Fullwood, and J. H. Taylor, Brookhaven National Laboratory, June 1989.

4.38 NUREG/CR-5379, "Nuclear Plant Service Water System Aging Degradation Assessment: Phase 1," Volume 1, D. B. Jarrell, A. B. Johnson, Jr., P. W. Zimmerman, and M. L. Gore, Pacific Northwest Laboratory, June 1989.

4.39 NUREG/CR-5404, "Auxiliary Feedwater System Aging Study," Volume 1, D. A. Casada, Oak Ridge National Laboratory, March 1990.

4.40 NUREG/CR-3543, "Survey of Operating Experiences from LERs to Identify Aging Trends," G. A. Murphy, R. B. Gallaher, M. L. Casada, and H. C. Hoy, Oak Ridge National Laboratory, January 1984.

4.41 NUREG/CR-4747, "An Aging Failure Survey of Light Water Reactor Safety Systems and Components," Volume 1 and 2, B. M. Meale and D. G. Satterwhite, Idaho National Engineering Laboratory, July 1987.

4.42 NUREG/CR-4590, "Aging of Nuclear Station Diesel Generators: Evaluation of Operating and Expert Experience," Volumes 1 and 2, K. R. Hoopingarner, J. W. Vause, D. A. Dingee, and J. F. Nesbitt, Pacific Northwest Laboratory, August 1987.

4.43 NUREG/CR-5057, "Aging Mitigation and Improved Programs for Nuclear Service Diesel Generators," K. R. Hoopingarner, and F. R. Zaloudek, Pacific Northwest Laboratory, December 1989.

4.44 NUREG/CR-5706, "NRC Bulletin 88-04: Potential Safety-Related Pump Loss — An Assessment of Industry Data," D. A. Casada, Oak Ridge National Laboratory, June 1991.

4.45 PNL-SA-18407, "Understanding and Managing Corrosion in Nuclear Power Plants," A. B. Johnson, Jr., D. B. Jarrell, U. P. Sisnha, and V. N. Shah, Pacific Northwest Laboratory, August 1990.

5. EFFECTIVE MANAGEMENT OF AGING MECHANISMS

An effective program for addressing pump degradation will provide for both understanding and managing the aging mechanisms. Key elements of an effective program reflect the technical aging issues and potential consequences of the aging process being mitigated.

Aging mechanisms and their effects must be understood with sufficient accuracy and detail to provide the basis for developing and implementing aging management strategies that address actual or potential root causes of pump failures. The requisite understanding may be either empirical or mechanistic, depending on the nature and potential consequences of a particular aging mechanism. An understanding of degradation requires a detailed awareness of pump design, fabrication, installation, testing, inservice operation, and maintenance cycles. Degradation of pumps is a time dependent phenomena that depends on the interactions of materials with environmental and operational stressors.

The programs discussed in this section are suggested. They are meant to be guidelines that provide alternative methods that can be used to establish an effective program. Different combinations of maintenance techniques can be used to create plant-specific effective programs.

5.1 Generic Elements of an Effective Aging Management Program

Continued safe nuclear plant operation requires that pumps evaluated in this AMG continue to reliably function throughout their service life. Degradation of a pump is a regulatory concern when the pump normally functions to ensure plant safety and the degradation progresses to the point of impaired safety performance.

The License Renewal Rule[5.1] requires that certain nuclear plant components, including pumps, be subject to programs that effectively manage component degradation and their associated aging mechanisms. The Maintenance Rule[5.2] requires that nuclear plant components, including pumps, meet specified performance parameters. In addition, quality assurance criteria[5.3] requires development and implementation of programs to ensure that conditions adverse to quality, including degraded pump performance, are promptly identified and corrected.

Criteria has been established for determining if a plant program is effective for detecting and mitigating the effects of aging. These criteria are provided in Reference 5.1 and state that a program is effective if:

- The program is documented, its implementing procedures are approved by on-site review committees, and it is implemented in accordance with plant administrative procedures, and
- The program procedures ensure that the component's required functions are properly addressed considering the effects of age-related degradation, as appropriate, and

- The program establishes specific acceptance criteria against which the need for corrective action is to be evaluated and requires timely corrective actions to be taken when the acceptance criteria are not met.

Reference 5.2 states in part under paragraph [A] [1] "Each holder of an operating license . . . shall monitor the performance or condition of SSCs . . . in a manner sufficient to provide reasonable assurance that SSCs . . . are capable of fulfilling their intended functions."

Paragraph [A] [2] states in part "Monitoring . . . is not required where it has been demonstrated that the performance or condition of a SSC is being effectively controlled through the performance of appropriate preventive maintenance, such that the SSC remains capable of performing its intended function."

The three criteria for determining program effectiveness are broken down into distinct categories. The following provides further guidance for each category to determine if a program satisfies the criteria.

5.1.1 Program is Documented

The criteria for a program to be documented satisfies 10 CFR 50 Appendix B - Quality Assurance Criteria which states in part "Every applicant for an operating license is required to include, in its final safety analysis report, information pertaining to the managerial and administrative controls to be used to assure safe operation." Therefore, a program being documented means that specific commitments have been and are included on the respective plant docket. Docketed commitments are included in the updated final safety analysis report, responses to generic letters, bulletins, notices, orders, NUREGs, 10 CFR 50.59 evaluations, notices of violations, open items, etc., and any other programmatic or procedural commitment made to ensure compliance with the Code of Federal Regulations.

5.1.2 Program Implementing Procedures Approved by Operations Review Committee and Program Implemented Via Administrative Procedures

These two criteria for procedural approvals and administration of the program also satisfy 10 CFR 50 Appendix B. Item I. - *Organization of this Appendix* states in part "the authority and duties of persons and organizations performing activities affecting the safety related functions of structures, systems, and components shall be clearly established and delineated in writing." This Appendix further states in Item II - *Quality Assurance Program*, that "This program shall be documented by written policies, procedures, or instructions and shall be carried out throughout plant life in accordance with those policies, procedures, or instructions."

Each program must be documented with written policies (i.e., administrative procedures) and the program implementing procedures must be reviewed and approved by on-site review committees to ensure that activities affecting the required function of pumps are correctly performed.

5.1.3 Component's Required Functions Properly Addressed

Each pump evaluated in this guideline either provides a support function or directly functions to prevent or mitigate the consequences of postulated accidents that could cause undue risks to the health and safety of the public. Methods by which a pump accomplishes this action is termed its required function. A pump may have only one or several required functions.

The significant required function(s) for each pump are identified in the program implementing procedures. The scope and content of all program implementing procedures credited for effective management of aging are reviewed to ensure that aging mechanisms and degradation, affecting the capability of the pump to satisfy its required function(s), are adequately detected and mitigated.

5.1.4 Age-Related Degradation Effects Properly Addressed

All aging mechanisms occurring to these pumps will manifest and progress at different rates and are affected by many variables such as material composition, operating service conditions, environmental parameters, geometric configuration, etc. As such, program implementing procedures must be performed at a frequency commensurate with the rate of aging to ensure detection and mitigation of degradation. Detection and mitigation of degradation provides assurance that the pump required function will not be compromised during its service life. Inspection, test, replacement, and refurbishment procedures are performed at frequencies which are based on code requirements, regulatory specifications, vendor recommendations, industry experience, observations by knowledgeable plant personnel, etc. and can be adjusted as experience dictates.

5.1.5 Acceptance Criteria Established to Determine Need for Corrective Action, Corrective Actions Specified, and Timely Action Taken

These three criteria dealing with acceptance criteria and corrective actions also satisfy 10 CFR 50 Appendix B. Item V states in part that "Instructions, procedures, or drawings shall include appropriate quantitative and quantitative acceptance criteria for determining that important activities have been satisfactorily accomplished." Item XVI. *Corrective Action*, states that "Measures shall be established to assure that conditions adverse to quality are promptly identified and corrected."

All program implementing procedures should contain acceptance criteria in the form of recorded data, documented observances, procedural step signoffs, etc. to demonstrate that activities performed on pumps for detecting and mitigating degradation have been either satisfactorily accomplished or corrective actions identified to ensure required function capability.

The corrective actions required may encompass a wide range of activities which cannot be clearly identified in the program implementing procedure. Provisions shall be made, however, to document what corrective actions were taken. These corrective actions may be in the form of references to work request, additional diagnosis, retesting, non-destructive examinations, etc.

Program administrative procedures and/or specific implementing procedures shall provide guidance relative to the timeless of corrective actions taken. This guidance shall be considered with respect to the aggressiveness of the aging mechanism (i.e., rate of degraded performance or function) and the frequency of program activities to detect and mitigate degradation. Performing timely corrective action ensures that pump required functions are not compromised throughout the pump's service life.

5.1.6 Program Effectiveness Matrix

Table 5-1 entitled, "Effective Program Criteria Assessment Matrix," can be used to document the evaluation of a program and corresponding implementing procedures to effectively detect and mitigate pump age-related degradation.

Table 5-1. Effective Program Criteria and Assessment Matrix

Description of Pump Being Evaluated	Effective Program(s) Name									
Program Criteria										
Program is Documented (See Note 1)										
Implementing Procedure(s) Approved by Plant Review Committees										
Implemented Via Administrative Procedures										
Component Safety Functions Properly Addressed										
Age-Related Degradation Effects Properly Addressed (Mechanism(s) and Rate of Degradation)										
Acceptance Criteria Established to Determine Need for Corrective Action										
Corrective Action Specified										
Timely Action Taken (See Note 2)										

Notes:

F = Full compliance
P = Partial compliance, subject to program enhancement
N = Not in compliance, subject to program enhancement
NA = Not applicable
1 = Documented means specific commitments are included on the docket (i.e., Updated SAR, responses to GL, IEB, IEN, NUREGs, Orders, 10 CFR 50.59, etc.)
2 = "Timely" is considered with respect to the aggressiveness of the degradation and frequency of the program activities to ensure that required functions are not compromised.

Author:	Date:
Reviewer(s):	Date:

5.2 Conventional Programs Commonly Used in the Industry

Demonstrating the adequacy of plant procedures to detect and mitigate degradation is accomplished by 1) substantiating that established programs and procedures effectively ensure the capability of the associated pumps to perform their required function(s) throughout their entire service life, or 2) taking actions in the form of program and/or procedural enhancements necessary to manage the aging mechanism(s) which are not adequately addressed by current established programs and/or procedures. Adequacy of programs and procedures for detecting and mitigating degradation must be demonstrated for each pump using one of these methods.

It is recognized that many pumps are subject to a variety of inspection, test, replacement and/or refurbishment programs to address diverse functional requirements and various aging mechanisms. As such, to establish the adequacy of existing plant programs, several programs may be required for a given pump. Through a combination of such programs as necessary, the basis for safe and reliable operation throughout the pumps entire service life is established.

Following is a discussion of the conventional maintenance and surveillance programs commonly used, as determined from other aging studies, to be effective in detecting manifestation of aging mechanisms and mitigating the degradation of pumps within acceptable limits.

5.2.1 ASME Section XI Inservice Inspection and Testing Program

The committee on Operation and Maintenance of Nuclear Power Plants (O&M Committee) is chartered to develop standards for maintenance of nuclear power plant equipment, methods, and components. The O&M Committee is responsible for reviewing ASME Section XI to determine where O&M standards can replace Section XI requirements. One of the areas of Section XI where an O&M standard was developed is Article IWP, Inservice Testing of Pumps.

ASME OM Code ISTB[5.4] "Inservice Testing of Pumps in Light-Water Reactor Power Plants" establishes the requirements for inservice testing to assess the operational readiness of certain centrifugal and positive displacement pumps. The pumps covered are those, provided with an emergency power source, which are required in shutting down the reactor to the cold shutdown condition, maintaining the cold shutdown condition, or mitigating the consequences of an accident. This ASME Code also establishes test intervals, parameters to be measured and evaluated, acceptance criteria, corrective actions, and records requirements. Section 5.2.3 describes the testing activities required by this ASME Code.

Section XI of the ASME Code[5.5] also provides the rules and requirements for inservice inspection, repair, and replacement of Class 1, 2, and 3 pressure retaining components, including pumps. All pumps evaluated in this AMG are either Class 2 or 3. No Class 1 pumps are included in the scope. Classes 2 and 3 refer to components constructed in accordance with the rules of ASME Section III. Section XI categorizes the areas subject to inspection and defines responsibilities, provisions for accessibility, examination methods and procedures, personnel qualifications, frequency of inspection, record keeping and reporting requirements, procedures for evaluation of inspection results, disposition of results, and repair requirements. Article IWC applies to Class 2 components, and Article IWD applies to Class 3 components.

The ASME Section XI requirements for Class 2 pumps are as follows.

- Surface (liquid penetrant or magnetic particle) examination of 100 percent of the pump casing welds is performed. The examination may be performed from either the inside or outside surface of the pump. In the case of multiple pumps of similar design, size, function, and service in a system, the examination of only one pump among each group of multiple pumps is required. The pumps initially selected for examination shall be re-examined each ten-year inspection interval over the service life of the pump.

- The pressure retaining component (i.e., pump casing) within each Class 2 system boundary shall be subject to visual (VT-2) examination during system pressure testing. A leakage test shall be conducted at least once each inspection period at a test pressure equal to the nominal operating pressure during system operation. A hydrostatic test shall be performed at or near the end of each 10-year inspection interval at a value not to exceed 125 percent of normal operating pressure depending on the test temperature of the fluid. In lieu of a Section XI hydrostatic test, the requirements of ASME Code Case N-498[5.6] can be performed.

- Volumetric examination is performed on pump pressure retaining bolts and studs that are greater than two inches in diameter. The examinations may be performed on these fasteners either in place under load or upon disassembly of the connection. The examination of fasteners may be conducted on one pump among a group of pumps in each system required to be examined which are similar in design, size, function, and service. Also, where one pump to be examined contains a group of bolted connections of similar design and size (such as a flanged connection) the examinations may be conducted on one bolted connection among the group. The pump fasteners initially selected for examination shall be re-examined each inspection interval over the service life of the fastener.

- Surface (liquid penetrant or magnetic particle) examination is performed on those integrally welded attachments that meet all of the following conditions.

    1. The attachment is on the outside surface of the pump,

    2. The attachment provides support for the pump,

    3. The attachment base material design thickness is 19 mm [0.75 in] or greater, and

    4. The attachment weld joins the attachment either directly to the surface of the pump or to an integrally cast or forged attachment to the pump.

The extent of the examination includes 100 percent of the required areas of each welded attachment. The areas of the welded attachment initially selected for examination shall be reexamined each inspection interval over the service life of the attachment.

The ASME Section XI requirements for Class 3 pumps are as follows.

- Visual (VT-3) examination is performed on those integrally welded attachments that meet all of the following conditions.

  1. The attachment is on the outside surface of the pump,

  2. The attachment provides support for the pump, and

  3. The attachment weld joins the attachment either directly to the surface of the pump or to an integrally cast or forged attachment to the pump.

The extent of the examination includes 100 percent of the required areas of each welded attachment. In the case of multiple pumps within a system of similar design, function, and service, the integral attachment of only one of the multiple pumps must be examined. The areas of the welded attachment initially selected for examination shall be re-examined each inspection interval over the service life of the attachment.

- The pressure retaining component (i.e., pump casing) within each Class 3 system boundary shall be subject to visual (VT-2) examination during system pressure testing. A leakage test snall be conducted at least once each inspection period at a test pressure equal to the nominal operating pressure during system operation. A hydrostatic test shall be performed at or near the end of each inspection interval at a value not to exceed 125 percent of normal operating pressure depending on the test temperature of the fluid.

ASME Section XI also provides rules and requirements for the repair and replacement of Class 2 and 3 pressure retaining components, including pumps. A pump repair/replacement program is a document or set of documents that defines the managerial and administrative control for completion of repairs or replacement of items. A repair/replacement plan is developed to identify a number of requirements to be adhered to while performing the repair/replacement. Some of the more significant requirements are:

- Applicable ASME Codes

- Description of the work to be performed including flaw characterization and flaw removal method

- Applicable weld procedures, nondestructive examinations, tests, and material requirements

- Applicable examinations, tests, and acceptance criteria to verify acceptability of the repair/replacement

- Intended life of the repair/replacement when less than the remainder of the design life of the pump

When repair or replacement is required because of failure, the evaluation shall consider the cause of failure to ensure that the selected repair or replacement is suitable. Repair/ replacement activities shall reflect appropriate corrective provision to mitigate recurrence of the failure.

5.2.2 ASME Section XI Wall Thinning Program

Article IWH of ASME Section XI, which covers wall thinning due to single phase erosion/corrosion, is currently under development by an ASME subcommittee. In the interim, ASME Code Case N-480[5.7] provides the rules and requirements for analytical evaluation, inservice inspection, repair and replacement of Class 1, 2, and 3 carbon and low alloy steel "piping items" susceptible to wall thinning as a result of single phase (water) erosion/corrosion. From Section 4.2.4, single phase erosion/corrosion is a high temperature aging mechanism (i.e., 129-140°C [265-285°F]. The term "piping items" is meant to include individual pumps.

There are no Class 1 pumps included in the scope of this AMG. However, the rules and requirements are the same for all classes of pumps.

The analytical evaluation shall consider the effect of nominal or actual pump material chemical composition when available, system water chemistry, system temperature, flow rate, and pump geometry. Susceptible pumps shall be ranked both in order or predicted erosion/corrosion rate and in order of time remaining to reach minimum acceptable wall thickness. A sample of the most susceptible pumps is then selected for inspection. For pumps within a system having identical configuration and process variables including operating hours (i.e., equal susceptibility to wall thinning), only one (1) of the pumps need be included in the sample.

Two (2) systems containing pumps within the scope of this AMG known to have experienced wall thinning as a result of single phase erosion/corrosion, are the Auxiliary Feedwater System in PWRs and the RWCU System in BWRs. Identification of these two (2) systems is not meant to be all inclusive relative to the total scope of pumps evaluated by this guideline. Only performances of the plant unique analytical evaluation can determine which pumps are susceptible to wall thinning from single phase erosion/corrosion.

ASME Code Case N-480 requirements for pumps are as follows.

- Volumetric examination shall be conducted from either the inside or outside surface of the pump. The examination technique must be capable of measuring wall loss with an accuracy of ±5% of nominal wall thickness of the pump to be measured.

- A reference system or grid pattern must be established for identification of each examination point.

- The examination shall extend two (2) pipe diameters downstream from the pump. If wall thickness is decreasing in downstream piping, the extent of examination shall continue until an increasing thickness trend is established and thickness readings are greater than 70% of nominal wall thickness, or greater than minimum wall thickness, whichever is greater.

- The pumps selected for examination shall be re-examined within 12 to 24 months of completion of the initial examination. Subsequent examinations shall be in accordance with an examination cycle based upon the erosion/corrosion rate and the least time remaining to 70% of nominal wall thickness or minimum wall thickness whichever is greater.

Pumps whose examination reveal a wall thickness less than 87.5% of the nominal wall thickness determined to be a result of erosion/corrosion shall be repaired or replaced unless evaluation is performed which shows that an acceptable safety margin exists for continued system operation.

When a predicted (calculated) erosion rate indicates that a pump could reach minimum acceptable wall thickness prior to the next inservice examination, the pump shall be repaired, replaced, or evaluated as acceptable for continued service.

5.2.3 Technical Specification Surveillance Program

Each licensed commercial nuclear power plant is operated, in part, in accordance with its own unique Technical Specifications. To ensure that a system, subsystem, train, or component is operable (as defined in Technical Specifications), surveillance requirements are performed at specified intervals.

The pumps subjected to Technical Specification surveillance requirements are predominantly Emergency Core Cooling (ECC) Systems pumps and those pumps required to operate to support safe plant operation. Testing performed to satisfy the associated surveillance requirements is described under ASME OM Code ISTB[5.4]. Specific testing, conducted quarterly on each pump (with minor exceptions), consists of recording and analyzing data associated with pump differential pressure (i.e., developed head), rotational speed, vibration, and flow rate. All pump surveillance tests are conducted in accordance with approved procedures. These procedures contain acceptance criteria against which the test results are compared. Test results are evaluated by knowledgeable plant personnel to determine if acceptance criteria has been met or to determine appropriate corrective action. If deviations fall within the alert range, the frequency of testing is doubled until the cause of the deviation is determined and the condition corrected. If deviations fall within the required action range, the pump is declared inoperable until the cause of the deviation has been determined and the condition corrected. When a pump is declared inoperable, the Limiting Conditions for Operation (LCO) action requirements are performed as required. Implementation of LCO action requirements ensures that the health and safety of the public is maintained while deviation causes are identified and corrective actions performed.

5.2.4 Preventive Maintenance

Preventive maintenance (PM) is defined as periodic, predictive, or planned activities performed on a pump prior to its failure. The objective of conducting PM is to sustain or extend the service life of a pump by controlling degradation and failures to an acceptable level.

Periodic maintenance activities are accomplished on a routine basis (typically based on operating hours, number of cycles, or calendar time). For pumps, these activities include such items as replacement of bearings, gaskets, seals and other renewable components, changing out lubrication, alignment checks, stuffing box/mechanical seal adjustment, verification of fastener torque, and inspections for leakage and/or other abnormal conditions.

Predictive maintenance activities involve continuous or periodic condition monitoring of pump operating parameters and/or functional performance testing of the pump. Elements of predictive maintenance also include data gathering, analysis, diagnosis, and trending to determine the material condition and performance characteristic of the pump. Typical predictive maintenance activities associated with pumps include monitoring of vibration, chemical analysis of lubrication, and monitoring of flow rate and developed head (i.e., verification of pump curve). These activities are very similar to the pump testing described above under the heading Technical Specification Surveillance Program and generally mirror requirements described in ASME OM Code ISTB.[5.4]

Planned maintenance activities are primarily scheduled on the basis of information obtained and trends derived from performing periodic and predictive maintenance. These activities consist of refurbishment, overhaul, and major part replacement and are conducted prior to pump failure. Also, planned maintenance activities can be identified and initiated based on vendor recommendations, industry operating experience, and plant specific operating and maintenance history.

The PM Program is governed by approved administrative controlling documents and conducted in accordance with detailed implementing procedures. PM plans are developed to outline task requirements and to coordinate scheduling and implementation of PM activities associated with all plant equipment encompassed by the program, including pumps. The frequency of performing PM is dependent upon engineering assessments, plant/industry operating experience, environmental conditions, manufacturers recommendations, and feedback from maintenance personnel. Typically, internal inspections are performed during refueling outages while external inspections are performed quarterly or monthly.

Completed PM activities are reviewed by cognizant personnel. The results are compared with acceptance criteria and timely corrective actions are initiated as appropriate. Data is extracted from the completed PM and analyzed for the purpose of detecting adverse trends. The frequency of performing a PM activity may be increased or decreased depending upon the observations made and conclusions drawn from review of the completed PM activity.

5.2.5 Pump Erosion Control Program

Section 5.2.2 discusses the ASME Wall Thinning Program which deals with high temperature single phase water erosion/corrosion of pump casings. The Pump Erosion Control Program covers effective aging management for pump subcomponent erosion/corrosion caused by 1) particle impingement in low temperature raw service water applications and 2) cavitation in low temperature raw service water and borated water applications due to fouling. Pump subcomponents manufactured from carbon steel, low alloy steel, brass, and bronze are susceptible to erosion/corrosion. Stainless steel and high alloy steels have been determined to effectively resist the effects from an erosive operating service condition.

An evaluation shall be conducted to determine which pumps and pump subcomponents are susceptible to erosion. Factors to be taken into consideration for identifying these pumps consist of material composition, water chemistry and particle characterization, fouling potential, flow rate, and pump internal geometry. Susceptible pumps shall be ranked in order of predicted erosion rate. A sample of the most susceptible pumps is then selected for further monitoring and inspection. For pumps within a system having identical configuration and process variables, including operating hours (i.e., equal susceptibility to erosion), only one (1) of the pumps need be included in the sample.

Pump Erosion Control Program requirements for those pumps susceptible to particle impingement or cavitation due to fouling are as follows.

- Volumetric examination of the pump casing and nozzles shall be conducted from the outside surface of the pump. The examination technique must be capable of measuring wall loss with an accuracy of ±5% of nominal pump wall thickness.

- A reference system or grid pattern should be established for identification of each examination point.

- The pumps selected for examination shall be re-examined at an interval not to exceed ten years from the initial examination date provided the predicted (calculated) erosion rate will not reach 70% of nominal wall thickness or minimum wall thickness, whichever is greater within that time frame prior to the re-examination date. More frequent re-examination intervals must be established if the wall thickness criteria cannot be achieved with ten-year examination intervals.

- Trending of quarterly surveillance test data and periodic preventive maintenance activities shall be performed to determine the material condition of the pump internals. Though subjective and not definitive, trending of these data may reveal degradation of pump internals due to erosion.

- Whenever the pump, or a similar pump having identical configuration and process variables, is disassembled for maintenance a visual examination (VT-3) shall be performed on the internal surfaces of pump subcomponents. Evidence of erosion shall be documented and repair or replacement activities completed unless an evaluation is performed which shows that an acceptable safety margin exists for continued system operation.

5.2.6 Microbiologically Influenced Corrosion (MIC) Control Program

Proper diagnosis is particularly important in situations where MIC is suspected since treatment can be expensive in terms of time, equipment, materials, and environmental impact. Background information such as materials of construction, fabrication methods, and operating history can yield significant insights into potential microbiological influences. Examples of operating history are: source of water, types of water treatment, lay-up methods, and operating characteristics (i.e., stagnation, low flow, intermittent operation and operating time).

5.2.6.1 Water Sampling

Sampling of the water at the source and immediately upstream and downstream from the pump during quarterly testing is sufficient to assess seasonal variations in microbial content, oxygen, and critical nutrients. A complete water analysis will assist in separating corrosive affects of the water from microbial influence. Sampling of the water at these locations is useful to 1) identify heavily infested areas requiring further investigation, 2) evaluate the effectiveness of biocide treatments, 3) locate areas where microbes may be reproducing rapidly, and 4) detect trends over time to focus sampling.

5.2.6.2 Solid Sampling

When the pump is opened up for maintenance purposes, areas of interest should be visually examined and solid samples removed for detailed chemical and microbiological examination. Typically, deposits, tubercules, or volumes of corrosion products in the vicinity of the corrosion site are the areas where the samples should be removed for analysis. Additional visual examination of the under deposit area and removal of metal samples for metallurgical analysis may be appropriate. MIC leaves a particular set of chemical fingerprints that can be used to determine whether or not MIC is at work. When a sample exhibits very low organic content and, essentially no enrichment in sulfur or chloride is noted (as compared to the base metal and/or water analysis), MIC is not likely to have been a contributor to the corrosion.

5.2.6.3 Treatment

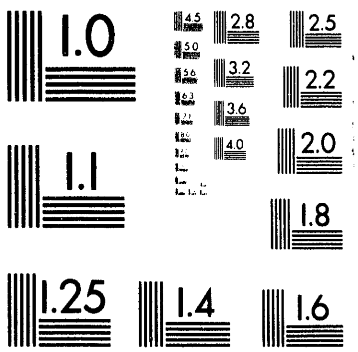
Treatments to control MIC fall into three general categories: mechanical cleaning, chemical treatment, and engineering and operational controls.[5.8]

Mechanical Cleaning

Mechanical methods are used to physically remove deposits from material surfaces. In this way, impediments to flow are also removed. Since MIC is always associated with biofilms on metal surfaces the first objective is to remove the film. In some cases, these biofilms are extremely difficult to remove with biocides or corrosion inhibitors, as such, mechanical cleaning methods must be applied. When the pump is opened up for maintenance purposes and after the solid samples have been removed, hydrolazing and/or steam lancing can be performed to remove deposits and tubercles. Abrasive particles (i.e., sandblasting) can also be used; however, a disadvantage with this method is the collection and cleanup of the material.

Chemical Treatment

Chemical water treatments include the use of biocides, corrosion inhibitors, and dispersants. Biocides may be oxidizing or non-oxidizing agents with injection to the fluid stream made on a continuous base or scheduled as a batch/slug process. Biocides can be used in combination with one another to increase their effectiveness, decrease effluent concentrations, or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3 of 4

reduce costs. Biocides may also be used in conjunction with dispersants to prevent accumulation of deposits. Inhibitors may be used independently or along with biocides or dispersants for corrosion control.

Oxidizing biocides, particularly chlorine, is by far the most commonly utilized agent for MIC control. Economics, simplicity of use, and the vast experience base are the overriding considerations for the utilization of chlorine. Depending on water and solid sample analysis results, other oxidizing biocides such as chlorine dioxide, bromine compounds, ozone, and/or hydrogen peroxide may be used. Non-oxidizing biocides which may be used are acrolein, glutaraldehyde, isothiazoline, and quartenary ammonia compounds.

Used in conjunction with biocides, dispersants help to remove organisms killed by the biocidal treatment along with nutrients and debris that may have become attached to the biofilm. Dispersants keep such materials suspended in the fluid stream.

Corrosion inhibitors, such as chromates, have biocidal properties and can be effective in the treatment of MIC provided the biological growth has been removed from the pump surfaces either mechanically or chemically and the microbial infestation has been controlled. Corrosion inhibitors are used primarily in Closed Cooling Water Systems.

Engineering and Operational Controls

Engineering and operational controls may involve draining and drying pumps during outages, elimination of stagnation by periodic operation of the pumps, or periodic flushing with high velocity fluid. Engineering controls may also include implementation of modifications or thermal treatment with high temperature.

For carbon steels and copper alloys, where sulfate reducing bacteria activity is high, intermittent flow provides cyclic oxidation and can produce the worst case corrosion situation. For stainless steels, intermittent flow conditions are preferable to stagnation, because the attachment of bacteria to pump surfaces is minimized thereby reducing the effects of MIC.

It may be possible in some pump applications to design and install sacrificial anodes to cathodically protect the pump subcomponents. The size and location of the sacrificial anode, and the anode material must be selected in such a way that the protective current density on any location is larger than the corrosion current density. Common shapes of sacrificial anodes include bars, plates, cylinders, and ribbons. Most of the anodes for application in water are cast with a galvanized steel core, wire, or strap to facilitate welding or bolting.

5.3 Non-Conventional Programs Commonly Used in the Industry

This section is a discussion of some of the non-conventional maintenance and surveillance programs commonly used, as determined from aging studies, to be effective in detecting manifestation of aging mechanisms and mitigating the degradation of pumps within acceptable limits.

5.3.1 Pump Lay-Up Program

Lay-up practices have historically been performed on a random basis. Development of a lay-up program provides organization to these lay-up practices and a comprehensive structure for their implementation. Rigorous implementation of plant lay-up procedures will result in enhanced equipment preservation, personnel dose reduction, improved water chemistry, and quicker plant start-up and power ascension.[5.9]

Condition assessments provide the basis for a plant lay-up program and should be utilized to monitor effectiveness of the lay-up methods. In addition to refining lay-up procedures, condition assessment will ensure that component performance and functional requirements are met during plant operation.

Practical and convenient lay-up methods for these pumps and their associated systems should address several criteria. It must be practical to continuously circulate the lay-up fluid. Where dry lay-up is used, it must be practical to purge the fluid from the system in a reasonable amount of time, and the volume of fluid must be stored or processed. The lay-up practices should be flexible so that maintenance access can be readily achieved. Existing access openings should be used to the maximum extent possible. The appropriate lay-up method should be fast and easy to implement.

There are several different types of lay-up methods that can be used. The length of outage time and scheduled maintenance activities to be performed on the particular pump and/or associated system will dictate the most appropriate and cost-effective lay-up method to be implemented.

5.3.1.1 Dry Lay-Up Method

The dry lay-up method is the most flexible approach for accommodating maintenance during outages, because the lay-up fluid (i.e., air) is not hazardous. The pump and/or associated system should be rapidly drained and purged with air such that internal surfaces are dry and the atmosphere is well below saturation. Recent advances in desiccant air dryer technology have increased the attractiveness of this method by lowering the cost of high volume dry air.

5.3.1.2 Wet Lay-Up Method

To implement wet lay-up, the pump and/or associated system is completely filled with water or filled with water and an overpressure of nitrogen. Normally, some method of water circulation is used to facilitate homogeneous mixing of chemicals used to treat the water. In some applications, hydrazine, which is an oxygen scavenger, may be used to treat the water. Higher than normal concentration of chlorine may be maintained in raw water systems. Corrosion inhibitors, such as chromates in Closed Cooling Water Systems, can be considered a form of wet lay-up. Any chemical addition for the purpose of corrosion control in wet lay-up must be approved by plant Chemistry Department personnel.

5.3.1.3 Nitrogen Lay-Up Methods

The nitrogen lay-up method entails draining the pump and/or associated system, connecting a nitrogen supply, and purging the region volume with four times the volume of nitrogen. After filling, the pump and/or system is isolated and the nitrogen supply regulators are set to maintain a slightly positive pressure.

It is extremely important to note that a nitrogen environment can result in asphyxiation. Therefore, adequate safety precautions are necessary to prevent personnel access into lay-up regions where nitrogen accumulation could occur until adequate ventilation has been provided. Periodic checks for oxygen deficiency should be performed in these areas prior to entry.

5.3.1.4 "No Treatment" Lay-Up Methods - Drained and "As-Is"

In the drained lay-up condition, the pump is allowed to drain. For this method, the volume of drained water must be stored or processed. Subsequent to draining, the equipment is exposed to moisture laden air and/or water in contact with air. Under this environment, corrosion of unprotected carbon steel can be quite severe. However, it should be noted that many of the surfaces in PWRs will be covered with a film of magnetite formed under the reducing conditions associated with normal operating chemistries and in BWRs, a film of hematite is formed on the surfaces.[5.9, 5.10] Some level of general surface corrosion protection is expected from these surface films for several weeks or longer.

In the "As-Is" lay-up condition, the pump and/or associated system remains without any special treatment after being isolated. For system pumps that normally process deoxygenated primary coolant they will remain moderately non-corrosive as long as the pump and/or system is kept isolated. For carbon steel system pumps that normally process raw water or demineralized water containing a high oxygen content, the corrosion process will proceed at a decreasing rate provided a fresh source of oxygen is not allowed ingress to the system (i.e., the system remains isolated). This is because as the corrosion process progresses, the oxygen reacts with the carbon steel to form iron oxide which results in less oxygen available to continue the corrosion process.

5.3.2 Thermography

Infrared thermography scans are used to detect "hot spots" in equipment. This type of program is not typically a formal program; however, many plants incorporate thermography in their preventive/predictive maintenance programs. The scans can be used for electrical equipment and connections, rotating equipment (i.e., bearing wear) and cables. Thermography would typically be used to monitor the condition of pump bearings under those situations where bearing temperature instrumentation is not installed. Results are used in conjunction with other maintenance program data to determine if corrective action is required to prevent further degradation. Individual plants should determine if thermography is cost effective versus other methods.

5.3.3 Operator Activities

Operators routinely tour the plant (i.e., operator walkdown) to observe pump conditions and record results on a checklist that contains qualitative and quantitative acceptance criteria. Individual checklist items are performed at various frequencies ranging from hourly to monthly. The frequency is established based on experienced rates of change or degradation potential for the observed item. If acceptance criteria is not met, the operators inform the shift supervisor who initiates corrective or investigative action.

Equalizing pump run times on parallel pumps where one pump normally operates and one pump is in standby will result in even wear for the two pumps and prolong satisfactory operation of the system.

Another operator action is the annunciator response procedure (ARP). These procedures prescribed the actions that operators must take in response to individual automatic alarms. When degradation causes a change in system or component operating parameters, and that parameter is monitored by an automatic alarm, the operator will take specific actions in response. If the operator cannot correct the alarming condition (as in a degraded state), then the operator reports the condition to the shift supervisor who initiates corrective or investigative actions. For most normally operating pumps, the pump alarms before the limiting criteria is exceeded, to allow time to evaluate, correct, or transfer to a standby pump without impacting plant operations.

5.3.4 Coatings Survey Program

This program maintains protective coatings on plant equipment including pumps. Periodic walkdowns of the pumps ensures that visible degradation will be detected prior to significant damage occurring to the pump. This program aids in maintaining the exterior surfaces of the pumps to reduce the potential for undetected age-related degradation. Only approved coatings for each application may be used and are specified in the program. Surface cleaning and preparation are also specified in program documents.

5.3.5 Operating/Industry Experience Program

The operating experience program tracks problems identified by in-house and external industry pump operating experience and initiates corrective actions or evaluations to mitigate the problems.

This program supports the other main pump aging management programs by providing feedback on pump failures or degradation. This program can capture Part 21 notices, NRC Bulletins, Notices, and Generic Letters, vendor experiences, INPO Reports, Significant Operating Event Reports (SOERs), etc., involving pumps, and ensure all known potential problems are addressed at the plant before failure occurs.

5.3.6 Spare Parts Shelf-Life Program

An important program to all plants is the spare parts/shelf life program. This program is typically set up on a computer database with maximum and minimum quantities assigned to each part. Parts are automatically recorded when minimum quantities are exceeded. Seals, gaskets, O-rings and other pump parts with a prescribed shelf life are controlled to ensure parts which have exceeded their shelf life are not installed in pumps or to ensure an engineering evaluation is performed on a part which exceeds its shelf life. Spare parts are stored in a controlled atmosphere to ensure they are maintained in excellent condition. All of these activities ensure that pumps are repaired and maintained properly and ensure that replacement parts do not cause abnormal degradation to occur to the inservice pump.

5.3.7 Receipt Inspection

10 CFR 50, Appendix B requires control of purchased material, equipment, and services. This requirement is typically performed by a receipt inspection program.

The receipt inspection program provides a baseline for critical dimensions, material type, and various other attributes important to a pump. Proper inspection and detection of flaws, defects, cracks, and other discrepancies ensures that pumps are in excellent condition prior to installation and that the pump can be expected to provide acceptable service for its previously determined service life.

Documentation required by receipt inspection procedures for pumps is beneficial in that the material properties are accurately defined. The receipt inspection program also verifies proper documentation is received with the components which proves to be beneficial in assuring effective management of aging.

This program may also include activities such as lubrication, lubrication refurbishment, and periodic rotation of pumps that are in storage. These activities are important to ensure that the pumps in storage will be in excellent condition prior to being placed in service.

5.4 Programs/Techniques Applied to Pumps

This section assesses and evaluates the effectiveness of the various programs/techniques described in Sections 5.2 and 5.3 with respect to their capability for detection and/or mitigation of the significant aging mechanisms identified in Section 4.3 and summarized in Tables 4-4 through 4-10.

The frequencies of conducting these programs/techniques are based on current codes and standards as well as industry practice. The failure data conclusions presented in Section 3.6 indicate that current industry practices are effective at detecting and mitigating aging of nuclear plant pumps. Other conclusions, also drawn from the failure data, that were considered in selecting the program/technique implementing intervals are:

- Since many of the pumps evaluated are in continuous operation, at least some of the program activities should be implemented on shorter rather than longer intervals.

- Since pump bearings, impellers, wear rings, and internal valve and rotor failures dominate the NPRDS and LER failure data, actions to detect aging of these pump components should be implemented on a shorter rather than longer implementing interval.

- Since the primary aging mechanisms for pump bearings, impellers, wear rings, and internal valves and rotors are wear, fatigue, and fouling, the programs/techniques implemented more frequently should concentrate on detecting these aging mechanisms.

Section 5.4.1 will correspond to the system pumps and significant aging mechanisms depicted on Table 4-4, Section 5.4.2 will correspond to Table 4-5, through Section 5.4.7 and Table 4-10.

5.4.1 Primary Water System Pumps

The primary water system pumps discussed in this section are the BWR RWCU System pumps (i.e, centrifugal) and both types (i.e, centrifugal and reciprocating) of PWR CVCS charging pumps. These pumps were evaluated by subcomponent and are considered to be continuously operated. The pump subcomponents and associated aging mechanisms determined in Section 4.3 to be significant are:

- Rotating/Reciprocating
  — Mechanical Fatigue
  — Erosion and Erosion/Corrosion
  — Wear
  — Fouling

- Fixed Internals
  — Erosion and Erosion/Corrosion
  — Wear

- Pressure Boundary
  — Mechanical Fatigue
  — Erosion and Erosion/Corrosion

- Mechanical Subsystems
  — Mechanical Fatigue
  — Wear

- Supports
  — Mechanical Fatigue

The following programs/techniques are considered effective for detection and mitigation of these aging mechanisms.

- Mechanical Fatigue
  — ASME Section XI Inservice Inspection and Testing
  — Technical Specification Surveillance Testing
  — Preventive Maintenance

- Erosion and Erosion/Corrosion
  — ASME Section XI Wall Thinning
  — Pump Erosion Control
  — Technical Specification Surveillance Testing
  — Preventive Maintenance

- Wear
  — Technical Specification Surveillance Testing
  — Preventive Maintenance

- Fouling
  — Technical Specification Surveillance Testing
  — Preventive Maintenance

Table 5-2 summarizes the results and conclusions associated with the following effective program/technique evaluations.

5.4.1.1 Mechanical Fatigue

Detecting the presence of mechanical fatigue in the primary water system pump subcomponents is virtually impossible to achieve until such time as the subcomponent begins to exhibit abnormal behavior. Therefore, programs/techniques to effectively manage mechanical fatigue are performance based. Through pump performance monitoring and data acquisition, the trending of key operational parameters may provide sufficient information, prior to pump failure, so that planned maintenance activities can be conducted to repair/replace the affected pump subcomponent(s). Visual inspections are also helpful for fatigue detection in some situations. A combination of programs/techniques must be implemented to effectively manage mechanical fatigue of BWR RWCU pump subcomponents and PWR CVCS charging pump subcomponents.

For the pumps' rotating/reciprocating and mechanical subsystem components, vibration monitoring in accordance with either the plant's Preventive Maintenance Program or Surveillance Testing Program, which ever applies, is the most effective method to detect significant degradation and pump failure from mechanical fatigue. Since these pumps are continuously operated, permanently installed vibration monitoring equipment would be the optimum; however, this is not a requirement to acquire the necessary data for analysis.

Table 5-2. Effective Programs/Techniques for Primary Water System Pumps (BWR RWCU Pump and PWR Charging Pump)

Pump Subcomponent	Required Effective Programs/Techniques						Supplemental Programs/Techniques				
	ASME Section XI ISI/IST	ASME Section XI Wall Thinning	Tech Spec Surveillance	Preventive Maintenance	Pump Erosion Control	MIC Control	Pump Lay-up	Thermography	Operator Activities	Coatings Surveys	Industry Experience
ROTATING/RECIPROCATING											
Centrifugal Pump											
• Shaft											
- Mech. Fatigue			Vibration	Vibration							
- Wear			Vibration	Vibration							
• Impeller											
- Mech. Fatigue			Vibration	Vibration							
- Erosion and E/C			TDH & Flow Rate	TDH & Flow Rate							
- Wear			Vibration	Vibration							
Reciprocating Pump											
• Driveshaft/Crankshaft											
- Mech. Fatigue			Vibration	Vibration							
- Wear			Vibration	Vibration							
• Piston/Plunger											
- Wear			TDH & Flow Rate	TDH & Flow Rate							
• Internal Valve											
- Mech. Fatigue			TDH & Flow Rate	TDH & Flow Rate							
- Erosion and E/C			TDH & Flow Rate	TDH & Flow Rate							
- Wear			TDH & Flow Rate	TDH & Flow Rate							
- Fouling			TDH & Flow Rate	TDH & Flow Rate							

Table 5-2. Effective Programs/Techniques for Primary Water System Pumps (BWR RWCU Pump and PWR Charging Pump) (continued)

Pump Subcomponent	Required Effective Programs/Techniques						Supplemental Programs/Techniques				
	ASME Section XI ISI/IST	ASME Section XI Wall Thinning	Tech Spec Surveillance	Preventive Maintenance	Pump Erosion Control	MIC Control	Pump Lay-up	Thermography	Operator Activities	Coatings Surveys	Industry Experience
FIXED INTERNALS											
Centrifugal Pump											
• Wearing Components											
- Wear			TDH & Flow Rate	TDH & Flow Rate							
• Flow Guides											
- Erosion and E/C			TDH & Flow Rate	TDH & Flow Rate							
Reciprocating Pump											
• Wearing Components											
- Wear			TDH & Flow Rate	TDH & Flow Rate							
PRESSURE BOUNDARY											
Centrifugal Pumps											
• Casing											
- Mech. Fatigue	Surface Exam & Pressure Testing										
- Erosion and E/C		Volumetric Exam			Volumetric Exam						
• Flange Cover											
- Mech. Fatigue	Surface Exam & Pressure Testing										

Table 5-2. Effective Programs/Techniques for Primary Water System Pumps (BWR RWCU Pump and PWR Charging Pump) (continued)

Pump Subcomponent	Required Effective Programs/Techniques						Supplemental Programs/Techniques				
	ASME Section XI ISI/IST	ASME Section XI Wall Thinning	Tech Spec Surveillance	Preventive Maintenance	Pump Erosion Control	MIC Control	Pump Lay-up	Thermography	Operator Activities	Coatings Surveys	Industry Experience
PRESSURE BOUNDARY (continued)											
Reciprocating Pump											
• Cylinder/Plunger											
- Mech Fatigue	Surface Exam & Pressure Testing										
Both Types of Pumps											
• Suct./Disch. Nozzle											
- Mech. Fatigue	Surface Exam & Pressure Testing										
- Erosion and E/C		Volumetric Exam			Volumet-ric Exam						
• Fasteners											
- Mech. Fatigue				Torque Verification							
MECHANICAL SUBSYSTEMS											
Centrifugal Pumps											
• Thrust Bearing											
- Mech. Fatigue			Vibration	Vib. & Lube Analysis				Temp. Monitoring	Temp. Monitoring		
- Wear			Vibration	Vib. & Lube Analysis				Temp. Monitoring	Temp. Monitoring		
Both Types of Pumps											
• Coupling											
- Mech. Fatigue			Vibration	Vibration							

Table 5-2. Effective Programs/Techniques for Primary Water System Pumps (BWR RWCU Pump and PWR Charging Pump) (continued)

Pump Subcomponent	Required Effective Programs/Techniques						Supplemental Programs/Techniques				
	ASME Section XI ISI/IST	ASME Section XI Wall Thinning	Tech Spec Surveillance	Preventive Maintenance	Pump Erosion Control	MIC Control	Pump Lay-up	Thermography	Operator Activities	Coatings Surveys	Industry Experience
MECHANICAL SUBSYSTEMS (continued)											
- Wear			Vibration	Vibration							
• Seals											
- Wear				Visual Insp.					Visual Insp.		
• Radial Bearing											
- Wear			Vibration	Vib. & Lube Analysis				Temp. Monitoring	Temp Monitoring		
SUPPORTS											
Both Types of Pumps											
• Support Feet/Skirt											
- Mech. Fatigue				Vib. & Inspection							

For centrifugal pump rotating members (i.e, shaft, impeller, thrust bearing, and coupling) and reciprocating pump, rotating members (i.e., radial bearing, driveshaft/crankshaft and coupling) subject to fatigue, horizontal, vertical, axial and shaft vibration data should be acquired. Torsional vibration data would provide some additional information but is not necessary because these primary water system pumps (i.e., RWCU and CVCS Charging) are relatively small, consequently, the rotating elements do not develop large axial torque and torsional inertia. Torsional vibration problems are generally associated with larger, more massive and higher horsepower rotating elements. Also, bearing lubrication samples should be chemically analyzed or the lubrication changed out on a scheduled basis. Another method which will provide information regarding thrust bearing failure is monitoring of thrust bearing temperatures by operating personnel, if permanent instrumentation is provided, or through the use of contact pyrometers and/or thermography. Therefore, if vibration data is obtained and trended, and bearing lubrication verified to be satisfactory on a quarterly basis (or other frequency determined to be adequate by plant-specific operating history), then mechanical fatigue of the pumps' rotating members is effectively managed.

For the reciprocating pump internal valve, mechanical fatigue is effectively managed through pump performance testing in accordance with the plants' Preventive Maintenance Program or Surveillance Testing Program, which ever applies. Failure of the internal valves will cause a deviation in the pumps' normal developed head and flow rate characteristics. This phenomenon will be detected by trending the operating parameters and comparing the data against the design pump curve. Therefore, if normal operating developed head and flow rate data are obtained and trended on a quarterly basis (or other frequency determined to be adequate by plant-specific operating history), and compared against the design pump curve, then mechanical fatigue of the reciprocating pump internal valve is effectively managed.

Mechanical fatigue of pressure boundary components associated with the centrifugal pumps (i.e., casing, flange/cover, suction and discharge nozzle, and fasteners) and the reciprocating pumps (i.e., cylinder/plunger, suction and discharge nozzle, and fasteners) is effectively managed through implementation of the plants' ASME Section XI Inservice Inspection Program and Preventive Maintenance Program. Surface examinations, consisting of either the liquid penetrant or magnetic particle process, and hydrostatic pressure tests are performed to verify pressure boundary integrity. Preventive maintenance activities consisting of inspections, replacements and fastener torque verification are also performed. Through a combination of ASME Section XI and Preventive Maintenance tasks, mechanical fatigue of pressure boundary components will be detected and corrective actions implemented to ensure safe and reliable pump operation. Therefore, if surface examination and hydrostatic pressure tests are performed each inspection interval and visual inspection, parts replacement, and fastener torque verification is performed each refueling outage (or other frequency determined to be adequate by plant-specific operating history), then mechanical fatigue of the pumps' pressure boundary components is effectively managed.

Mechanical fatigue failure of the pump support feet/skirt will be detected during preventive maintenance inspections and vibration monitoring. Therefore, if vibration data is obtained and trended on a quarterly basis (or other frequency determined to be adequate by plant-specific operating history), and visual inspection and fastener torque verification performed each refueling outage (or other frequency determined to be adequate by plant-specific operating history), then mechanical fatigue of the pumps' support feet/skirt is effectively managed.

5.4.1.2 Erosion and Erosion/Corrosion

Detecting the presence of erosion and erosion/corrosion associated with primary water system pump impellers and flow guides (i.e., centrifugal pumps) and internal valves (i.e., reciprocating pumps) is virtually impossible to achieve until such time as the pump begins to exhibit abnormal behavior. Programs/techniques to effectively manage this aging mechanism are performance based. Through pump performance monitoring and data acquisition, the trending of key operational parameters may provide sufficient information, prior to pump failure, so that planned maintenance activities can be conducted to repair/replace the affected pump subcomponents.

For the centrifugal pump impellers and flow guides, and for the reciprocating pump internal valves, erosion and erosion/corrosion are effectively managed through pump performance testing in accordance with the plants' Preventive Maintenance or Surveillance Testing Program, which ever applies. Degradation of the centrifugal pump impeller and/or flow guides due to erosion and erosion/corrosion will cause a reduction in pump performance as measured by total developed head and flow rate. Therefore, if total developed head and flow rate data are obtained on a quarterly basis (or other frequency determined to be adequate by plant-specific operating history), and compared against the design pump curve, then erosion and erosion/corrosion of the centrifugal pump impellers and flow guides are effectively managed.

Failure of the reciprocating pump internal valves will also cause a deviation in the pumps' normal developed head and flow rate characteristics. Therefore, if total developed head and flow rate data are obtained on a quarterly basis (or other frequency determined to be adequate by plant-specific operating history), and compared against the design pump curve, then erosion and erosion/corrosion of the reciprocating pump internal valves are effectively managed.

Degradation of the RWCU System pump pressure boundary components (i.e, casing and suction/discharge nozzles) from erosion and erosion/corrosion is effectively managed through implementation of the plants' ASME Section XI Wall Thinning Program. This program is for the single phase erosion phenomenon and is currently under development by ASME. In the interim, Code Case N-480 provides guidance relative to the detection methods and acceptance standards for wall thinning of pump pressure boundary casings and nozzles due to single phase erosion and erosion/corrosion. Volumetric examination is performed to detect the amount of wall thinning. The data is analyzed, and wall thinning rates are calculated. Corrective actions are implemented when the analysis shows that the minimum acceptable wall thickness will be exceeded prior to the next scheduled examination. Therefore, if volumetric examination data is obtained and analyzed and wall thinning rates calculated each inspection interval (or other frequency determined to be adequate based on wall thinning projections), and corrective actions implemented prior to exceeding minimum acceptable wall thickness, then erosion and erosion/corrosion of the pumps' pressure boundary components are effectively managed.

Similarly, degradation of the CVCS charging pump (i.e, both centrifugal and reciprocating) pressure boundary components from erosion and erosion/corrosion is effectively managed through implementation of the plants' Pump Erosion Control Program. This program is for effectively managing wall thinning of pressure boundary casings and nozzles due to erosion caused by cavitation and/or particle impingement. Volumetric examinations are performed to detect the amount of wall thinning. The data is analyzed, and wall thinning rates are calculated. Corrective actions are implemented when the analysis shows that the minimum acceptable wall thickness will be exceeded prior to the next schedule examination. Therefore, if volumetric examination data is obtained and analyzed and wall thinning rates calculated each inspection interval (or other frequency determined to be adequate based on wall thinning projections), and corrective actions implemented prior to exceeding minimum acceptable wall thickness, then erosion and erosion/corrosion of the pumps' pressure boundary components are effectively managed.

5.4.1.3 Wear

Detecting the presence of wear associated with the various primary water system pump subcomponents is achievable through a combination of programs. As subcomponent wear progresses, the pump operating characteristics will begin to deviate from normally observed values. Through pump performance monitoring, data acquisition, trending of key operational parameters and diagnostic analysis, sufficient information will be obtained, prior to failure, so that planned maintenance activities can be conducted to repair/replace/refurbish the affected pump subcomponent(s). Visual inspections are also helpful for wear detection in some situations.

For most of the pumps' rotating/reciprocating and mechanical subsystem components, vibration monitoring in accordance with either the plant's Preventive Maintenance Program or Surveillance Program, which ever applies, is the most effective method to detect adverse vibration trends due to wear of these subcomponents. Since these pumps (i.e., RWCU and CVCS Charging) are continuously operating, permanently installed vibration pickups with monitoring capability would be the optimum installation; however, this is not a requirement to acquire the necessary vibration data.

For centrifugal pump rotating members (i.e., shaft, impeller, radial bearing, thrust bearing, and coupling) and reciprocating pump rotating members (i.e., driveshaft/crankshaft, coupling and radial bearing) subject to wear, horizontal, vertical, axial, and shaft vibration data should be acquired. As discussed in Section 5.4.1.1, torsional vibration data is not required because these pumps are small. Also, bearing lubrication samples should be chemically analyzed or the lubrication changed out on a scheduled basis. Another method which provides pertinent data regarding bearing wear is the monitoring of bearing temperatures. If permanent instrumentation is installed, bearing temperatures can be monitored by operating personnel. Otherwise, contact pyrometers and/or thermography should be utilized. Therefore, if vibration data is obtained and trended and bearing lubrication verified to be satisfactory on a quarterly basis (or other frequency determined to be adequate by plant-specific operating history), then wear of the pumps' rotating members is effectively managed.

For the reciprocating pump piston/plunger and internal valve and for the fixed internal wearing components associated with both the centrifugal and reciprocating pump, wear is effectively managed through pump performance testing in accordance with the plants' Preventive Maintenance or Surveillance Testing Program, which ever applies. As these components wear, a deviation in the pumps' normal developed head and flow rate characteristics will be observed. This phenomenon will be detected by trending these operating parameters and comparing the data against the design pump curve. Therefore, if normal operating developed head and flow rate data are obtained and trended on a quarterly basis (or other frequency determined to be adequate by plant-specific operating history), and compared against the design pump curve, then wear of the reciprocating pump piston/plunger and internal valve is effectively managed.

For the mechanical seal/packing assembly associated with both types of pumps, wear is effectively managed through inspections conducted in accordance with the plants' Preventive Maintenance Program. As the mechanical seal/packing assembly wears it will begin to leak fluid. This leakage can be readily detected by visual observation during operator rounds activities or preventive maintenance inspections. Therefore, if visual inspections are performed on a quarterly basis (or other frequency determined to be adequate by plant-specific operating history), then wear of the pumps' mechanical seal/packing assembly is effectively managed.

5.4.1.4 Fouling

Detecting the presence of reciprocating pump internal valve fouling is achieved through implementation of pump performance testing in accordance with the plants' Preventive Maintenance Program or Surveillance Testing Program, which ever applies. Through pump performance monitoring, data acquisition, trending of key operational parameters and diagnostic analysis, sufficient information will be obtained so that planned maintenance can be performed to repair, replace, or refurbish the internal valve. As the internal valve begins to foul, a deviation in the pumps' normal developed head and flow rate characteristics will be observed. Internal valve fouling will be detected by trending these operating parameters and comparing the data against the design pump curve. Therefore, if total developed head and flow rate data are obtained on a quarterly basis (or other frequency determined to be adequate by plant-specific operating history), and compared against the design pump curve, then fouling of the reciprocating pump internal valves is effectively managed.

5.4.2 Borated Water System Pumps

The borated water system pumps discussed in this section are the BWR SLC System pumps (i.e., reciprocating) and the PWR BAT System pumps (i.e., centrifugal). The SLC pump is normally maintained in standby service and intermittently operated, primarily for testing. The boric acid transfer pump is considered to be continuously operating because it provides recirculation for the Boric Acid System, normal makeup of solution, and suction to the CVCS Charging pump in emergency situations. The pump subcomponents and associated aging mechanisms, determined in Section 4.3 to be significant, are:

- Rotating/Reciprocating
  - — Mechanical Fatigue
  - — IGSCC
  - — Erosion and Erosion/Corrosion
  - — Wear
  - — Fouling

- Fixed Internals
  — MIC
  — IGSCC
  — Wear
  — Fouling

- Pressure Boundary
  — Mechanical Fatigue
  — MIC
  — IGSCC
  — Fouling

- Mechanical Subsystems
  — Mechanical Fatigue
  — IGSCC
  — Wear

- Supports
  — Mechanical Fatigue

The following programs/techniques are considered effective for detection and mitigation of these aging mechanisms:

- Mechanical Fatigue
  — ASME Section XI Inservice Inspection and Testing
  — Technical Specification Surveillance Testing
  — Preventive Maintenance

- Microbiologically Influenced Corrosion (MIC)
  — MIC Control

- Intergranular Stress Corrosion Cracking (IGSCC)
  — ASME Section XI Inservice Inspection and Testing
  — Technical Specification Surveillance Testing
  — Preventive Maintenance

- Erosion and Erosion/Corrosion
  — Preventive Maintenance
  — Technical Specification Surveillance Testing

- Wear
  — Technical Specification Surveillance Testing
  — Preventive Maintenance

- Fouling
  — Technical Specification Surveillance Testing
  — Preventive Maintenance

Table 5-3 summarizes the results and conclusions associated with the following effective program/technique evaluations.

5.4.2.1 Mechanical Fatigue

Detecting the presence of mechanical fatigue in the borated water system pump subcomponents is virtually impossible to achieve until such time as the subcomponent begins to exhibit abnormal behavior. Programs/techniques to effectively manage mechanical fatigue are performance based. Through pump performance monitoring and data acquisition, the trending of key operational parameters may provide sufficient information, prior to pump failure, so that planned maintenance activities can be conducted to repair/replace the affected pump subcomponent(s). Visual inspections are also helpful for fatigue detection in some situations. A combination of programs/techniques must be implemented to effectively manage mechanical fatigue of PWR BAT pump subcomponents. BWR SLC pump subcomponents are not susceptible to mechanical fatigue.

For the centrifugal pumps' rotating and mechanical subsystem components, vibration monitoring in accordance with either the plant's Preventive Maintenance Program or Surveillance Testing Program, which ever applies, is the most effective method to detect significant degradation and pump failure from mechanical fatigue of these subcomponents. Since these pumps are continuously operated, permanently installed vibration monitoring equipment would be the optimum; however, this is not a requirement to acquire the necessary data for analysis.

For centrifugal pump rotating members (i.e, shaft, impeller, thrust bearing, and coupling) subject to fatigue, horizontal, vertical, axial and shaft vibration data should be acquired. Torsional vibration data would provide some additional information but is not necessary because this boric acid transfer pump is relatively small, consequently, the rotating elements do not develop large axial torque and torsional inertia. Torsional vibration problems are generally associated with larger, more massive and higher horsepower rotating elements. Also, bearing lubrication samples should be chemically analyzed or the lubrication changed out on a scheduled basis. Another method which will provide information regarding thrust bearing failure is monitoring of thrust bearing temperatures by operating personnel, if permanent instrumentation is provided, or through the use of contact pyrometers and/or thermography. Therefore, if vibration data is obtained and trended and bearing lubrication verified to be satisfactory on a quarterly basis (or other frequency determined to be adequate by plant-specific operating history), then mechanical fatigue of the pumps' rotating members is effectively managed.

Mechanical fatigue of pressure boundary components associated with the centrifugal pumps (i.e., casing, flange/cover, suction and discharge nozzle, and fasteners) is effectively managed through implementation of the plants' ASME Section XI Inservice Inspection Program and Preventive Maintenance Program. Surface examinations, consisting of either the liquid penetrant or magnetic particle process, and hydrostatic pressure tests are performed to verify pressure boundary integrity. Preventive maintenance activities consisting of inspections, replacements and fastener torque verification are also performed. Through a combination of ASME Section XI and Preventive Maintenance tasks, mechanical fatigue of pressure boundary components will be detected and corrective actions implemented to ensure safe and reliable pump operation. Therefore, if surface examination and hydrostatic pressure tests are performed each

Table 5-3. Effective Programs/Techniques for Borated Water System Pumps (BWR SLC Pumps and PWR BAT Pumps)

Pump Subcomponent	Required Effective Programs/Techniques						Supplemental Programs/Techniques				
	ASME Section XI ISI/IST	ASME Section XI Wall Thinning	Tech Spec Surveillance	Preventive Maintenance	Pump Erosion Control	MIC Control	Pump Lay-up	Thermography	Operator Activities	Coatings Surveys	Industry Experience
ROTATING/RECIPROCATING											
Centrifugal Pump											
• Shaft											
- Mech. Fatigue			Vibration	Vibration							
- IGSCC			Vibration	Vibration							
- Wear			Vibration	Vibration							
• Impeller											
- Mech. Fatigue			Vibration	Vibration							
- IGSCC			Vibration	Vibration							
- Wear			Vibration	Vibration							
Reciprocating Pump											
• Driveshaft/Crankshaft											
- Wear			Vibration	Vibration							
• Piston/Plunger											
- IGSCC				Surface Exam							
- Wear			TDH & Flow Rate	TDH & Flow Rate							
• Internal Valve											
- IGSCC				Surface Exam							
- Wear			TDH & Flow Rate	TDH & Flow Rate							
- Fouling			TDH & Flow Rate	TDH & Flow Rate							

Table 5-3. Effective Programs/Techniques for Borated Water System Pumps (BWR SLC Pumps and PWR BAT Pumps) (continued)

Pump Subcomponent	Required Effective Programs/Techniques						Supplemental Programs/Techniques				
	ASME Section XI ISI/IST	ASME Section XI Wall Thinning	Tech Spec Surveillance	Preventive Maintenance	Pump Erosion Control	MIC Control	Pump Lay-up	Thermography	Operator Activities	Coatings Surveys	Industry Experience
FIXED INTERNALS											
Centrifugal Pump											
• Flow Guides											
- MIC						Sampling	Preser-vation				
- IGSCC				Surface Exam							
- Fouling			TDH & Flow Rate	TDH & Flow Rate							
Both Types of Pumps											
• Misc. Struct. Comp.											
- MIC						Sampling	Preser-vation				
- IGSCC				Surface Exam							
- Fouling			TDH & Flow Rate	TDH & Flow Rate							
• Wearing Components											
- IGSCC				Surface Exam							
- Wear			TDH & Flow Rate	TDH & Flow Rate							
PRESSURE BOUNDARY											
Centrifugal Pumps											
• Casing											
- Mech. Fatigue	Surface Exam & Pressure Testing										

Table 5-3. Effective Programs/Techniques for Borated Water System Pumps (BWR SLC Pumps and PWR BAT Pumps) (continued)

Pump Subcomponent	Required Effective Programs/Techniques						Supplemental Programs/Techniques				
	ASME Section XI ISI/IST	ASME Section XI Wall Thinning	Tech Spec Surveillance	Preventive Maintenance	Pump Erosion Control	MIC Control	Pump Lay-up	Thermography	Operator Activities	Coatings Surveys	Industry Experience
PRESSURE BOUNDARY (continued)											
- MIC						Sampling	Sam-pling				
- IGSCC	Surface Exam & Pressure Testing										
- Fouling			TDH & Flow Rate	TDH & Flow Rate							
• Flange/Cover											
- Mech. Fatigue	Surface Exam & Pressure Testing										
- MIC						Sampling	Preser-vation				
- IGSCC	Surface Exam & Pressure Testing										
- Fouling			TDH & Flow Rate	TDH & Flow Rate							
• Suct./Disch. Nozzle											
- Mech. Fatigue	Surface Exam & Pressure Testing										
- MIC						Sampling	Preser-vation				

Table 5-3. Effective Programs/Techniques for Borated Water System Pumps (BWR SLC Pumps and PWR BAT Pumps) (continued)

Pump Subcomponent	Required Effective Programs/Techniques						Supplemental Programs/Techniques				
	ASME Section XI ISI/IST	ASME Section XI Wall Thinning	Tech Spec Surveillance	Preventive Maintenance	Pump Erosion Control	MIC Control	Pump Lay-up	Thermography	Operator Activities	Coatings Surveys	Industry Experience
PRESSURE BOUNDARY (continued)											
- IGSCC	Surface Exam & Pressure Testing										
- Fouling			TDH & Flow Rate	TDH & Flow Rate							
• Fasteners											
- Mech. Fatigue				Torque Verification							
Reciprocating Pump											
• Cylinder/Plunger											
- MIC						Sampling	Preser-vation				
- IGSCC	Surface Exam & Pressure Testing										
• Suct./Disch. Nozzle											
- MIC						Sampling	Preser-vation				
- IGSCC	Surface Exam & Pressure Testing										
- Fouling			TDH & Flow Rate	TDH & Flow Rate							

Table 5-3. Effective Programs/Techniques for Borated Water System Pumps (BWR SLC Pumps and PWR BAT Pumps) (continued)

Pump Subcomponent	Required Effective Programs/Techniques						Supplemental Programs/Techniques				
	ASME Section XI ISI/IST	ASME Section XI Wall Thinning	Tech Spec Surveillance	Preventive Maintenance	Pump Erosion Control	MIC Control	Pump Lay-up	Thermography	Operator Activities	Coatings Surveys	Industry Experience
MECHANICAL SUBSYSTEMS											
Centrifugal Pumps											
• Thrust Bearing											
- Mech. Fatigue			Vibration	Vib. & Lube Analysis							
- Wear			Vibration	Vib. & Lube Analysis				Temp. Monitoring	Temp. Monitoring		
• Coupling											
- Mech. Fatigue			Vibration	Vibration							
- Wear			Vibration	Vibration							
Reciprocating Pumps											
• Coupling											
- Wear			Vibration	Vibration							
Both Types of Pumps											
• Seals											
- IGSCC				Inspection					Inspection		
- Wear				Inspection					Inspection		
• Radial Bearing											
- Wear			Vibration	Vib. & Lube Analysis				Temp. Monitoring	Temp. Monitoring		
SUPPORTS											
Centrifugal Pumps											
• Support Feet/Skirt											
- Mech. Fatigue				Vib. & Inspection							

inspection interval and visual inspection, parts replacement, and fasteners torque verification is performed each refueling outage (or other frequency determined to be adequate by plant-specific operating history), then mechanical fatigue of the pumps' pressure boundary components is effectively managed.

Mechanical fatigue failure of the centrifugal pump support feet/skirt will be detected during preventive maintenance inspections and vibration monitoring. Therefore, if vibration data is obtained and trended on a quarterly basis (or other frequency determined to be adequate by plant-specific operating history), and visual inspection and fastener torque verification performed each refueling outage (or other frequency determined to be adequate by plant-specific operating history), then mechanical fatigue of the pumps' support feet/skirt is effectively managed.

5.4.2.2 Microbiologically Influenced Corrosion (MIC)

Detecting the presence of MIC associated with the various borated water system pump subcomponents is accomplished by sampling the fluid and by sampling any solid materials found when the pump is opened up to perform maintenance. A complete fluid analysis should be performed, during pump testing activities, to identify heavily infested areas, to evaluate the effectiveness of the treatment method (i.e., if MIC was previously discovered), to locate areas where microbes are rapidly reproducing, and to trend the data. If the pump is opened up for maintenance purposes, deposits, tubercules, and/or corrosion products should be removed for analysis. The analysis should assess the magnitude and severity of microorganism growth and determine the appropriate treatment method to mitigate further propagation of MIC.

Through fluid and solid material sampling, analysis and trending of the data sufficient information is available to effectively detect the presence of MIC. Planned maintenance and/or treatment methods can be implemented to ensure safe and reliable operation of the pumps' fixed internal and pressure boundary subcomponents. Therefore, if fluid sampling, analysis and trending of data is performed quarterly during pump testing (or other frequency determined to be adequate by plant-specific operating history), and; solid sampling, analysis and trending of data is performed whenever the pump is opened up for maintenance, and; corrective actions are implemented as appropriate, then microbiologically influenced corrosion of the pumps fixed internal and pressure boundary components is effectively managed.

During plant outages, appropriate lay-up activities should be implemented to reduce the potential for MIC to occur in these treated water system pumps.

5.4.2.3 Intergranular Stress Corrosion Cracking (IGSCC)

Detecting the presence of IGSCC associated with borated water system pump internal subcomponents is virtually impossible to achieve until such time as the subcomponent begins to exhibit abnormal behavior. Otherwise the pump will require disassembly for internal inspection. Therefore, pump performance monitoring, data acquisition, and trending of key parameters may provide sufficient information, prior to pump failure, so that planned maintenance activities can be conducted to repair or replace the affected pump internal subcomponent(s). Visual inspection is also helpful for IGSCC detection in some situations. A combination of programs/techniques must be implemented to effectively manage IGSCC of BWR SLC and PWR BAT pump internal subcomponents.

For the centrifugal boric acid transfer pump rotating members (i.e., shaft and impeller) vibration monitoring in accordance with either the plants' Preventive Maintenance Program or Surveillance Testing Program, which ever applies, is the most effective method to detect significant degradation and pump failure from IGSCC. Horizontal, vertical, axial, and shaft vibration data should be acquired. As discussed in Section 5.4.2.1, torsional vibration data is not required because these pumps are small. Since the BAT pumps are continuously operated, permanently installed vibration pickups with monitoring capability would be the optimum installation; however, this is not a requirement to acquire the necessary vibration data. Therefore, if vibration data is obtained and trended on a quarterly basis (or other frequency determined to be adequate by plant-specific operating history), then intergranular stress corrosion cracking of the centrifugal pumps' rotating members is effectively managed.

For the centrifugal boric acid transfer pump fixed internal members (i.e., flow guides, miscellaneous structural components, and wearing components) and for the following standby liquid control reciprocating pump subcomponents, IGSCC can only be effectively managed by surface examination.

- Piston/Plunger
- Internal Valve
- Miscellaneous Structural Components
- Wearing Components

Section 6 provides information regarding the requirements to effectively manage IGSCC of these pump components. This is accomplished by performing surface examinations of these pump components once each inspection interval.

IGSCC of pressure boundary components associated with the centrifugal boric acid transfer pumps (i.e, casing, flange/cover, suction and discharge nozzle and fasteners) and the reciprocating standby liquid control pumps (i.e, cylinder/plunger block and suction/discharge nozzles) is effectively managed through implementation of the plants' ASME Section XI Inservice Inspection Program. Surface examinations, consisting of either liquid penetrant or the magnetic particle process, and hydrostatic pressure tests are performed to verify pressure boundary integrity. IGSCC of these pressure boundary components will be detected and pressure boundary integrity verified through performance of these ASME Section XI requirements. Corrective actions are implemented as necessary to ensure safe and reliable pump operation. Therefore, if surface examination and hydrostatic pressure tests are performed each inspection interval, then IGSCC of the pumps' pressure boundary components is effectively managed.

IGSCC of the pumps' mechanical seal/packing assembly associated with both types of pumps will be detected and effectively managed through inspections conducted in accordance with the plants' Preventive Maintenance Program. Fluid leakage can be readily detected by visual observation during operator rounds activities or preventive maintenance inspections. Therefore, if visual inspections are performed on a quarterly basis (or other frequency determined to be adequate by plant-specific operating history), then IGSCC of the pumps' mechanical seal/packing assembly is effectively managed.

5.4.2.4 Erosion and Erosion/Corrosion

Detecting the presence of erosion and erosion/corrosion associated with the centrifugal boric acid transfer pump impellers and flow guides is virtually impossible to achieve until such time as the pump begins to exhibit abnormal behavior. Programs/techniques to effectively manage this aging mechanism for these pump subcomponents are performance based. Through pump performance monitoring and data acquisition, the trending of key operational parameters may provide sufficient information, prior to pump failure, so that planned maintenance activities can be conducted to repair/replace the affected pump subcomponents.

For the centrifugal boric acid transfer pump impellers and flow guides, erosion and erosion/corrosion are effectively managed through pump performance testing in accordance with the plants' Preventive Maintenance or Surveillance Testing Program, which ever applies. Degradation of the centrifugal boric acid transfer pump impeller and/or flow guides due to erosion and erosion/corrosion will cause a reduction in pump performance as measured by total developed head and flow rate. Therefore, if total developed head and flow rate data are obtained on a quarterly basis (or other frequency determined to be adequate by plant-specific operating history), and compared against the design pump curve, then erosion and erosion/corrosion of the centrifugal boric acid transfer pump impellers and flow guides are effectively managed.

5.4.2.5 Wear

Detecting the presence of wear associated with the various borated water system pump subcomponents is achievable through a combination of programs. As subcomponent wear progresses, the pump operating characteristics will begin to deviate from normally observed values. Through pump performance monitoring, data acquisition, trending of key operational parameters and diagnostic analysis, sufficient information will be obtained, prior to failure, so that planned maintenance activities can be conducted to repair/replace/refurbish the affected pump subcomponent(s). Visual inspection is also helpful for detection of wear in some situations.

For most of the pumps' rotating/reciprocating and mechanical subsystem components, vibration monitoring in accordance with either the plant's Preventive Maintenance Program or Surveillance Program, which ever applies, is the most effective method to detect adverse vibration trends due to wear of these subcomponents. Since the Boric Acid Transfer pump is continuously operating, permanently installed vibration pickups with monitoring capability would be the optimum installation; however, this is not a requirement to acquire the necessary vibration data. The standby liquid control pump is operated intermittently primarily for testing purposes.

For centrifugal pump rotating members (i.e., shaft, impeller, radial bearing, thrust bearing, and coupling) and reciprocating pump rotating members (i.e., driveshaft/crankshaft, coupling and radial bearing) subject to wear, horizontal, vertical, axial, and shaft vibration data should be acquired. As discussed in Section 5.4.2.1, torsional vibration data is not required because these pumps are small. Also, bearing lubrication samples should be chemically analyzed or the lubrication changed out on a scheduled basis. Another method which provides pertinent data regarding bearing wear is the monitoring of the bearing temperatures. If permanent instrumentation is installed, bearing temperatures can be monitored by operating personnel. Otherwise, contact pyrometers and/or thermography should be utilized. Therefore, if vibration data is obtained and trended and bearing lubrication verified to be satisfactory on a quarterly basis (or other frequency determined to be adequate by plant-specific operating history), then wear of the pumps' rotating members is effectively managed.

For the SLC reciprocating pump piston/plunger and internal valve and for the fixed internal wearing components associated with the centrifugal BAT pump, wear is effectively managed through pump performance testing in accordance with the plants' Preventive Maintenance or Surveillance Testing Program, which ever applies. As these components wear, a deviation in the pumps' normal developed head and flow rate characteristics will be observed. This phenomenon will be detected by trending these operating parameters and comparing the data against the design pump curve. Therefore, if normal operating developed head and flow rate data are obtained and trended on a quarterly basis (or other frequency determined to be adequate by plant-specific operating history), and compared against the design pump curve, then wear of the reciprocating pump piston/plunger and internal valve and centrifugal pump fixed internal wearing components is effectively managed.

For the mechanical seal/packing assembly associated with both types of pumps, wear is effectively managed through inspections conducted in accordance with the plants' Preventive Maintenance Program. As the mechanical seal/packing assembly wears it will begin to leak fluid. This leakage can be readily detected by visual observation during operator rounds activities or preventive maintenance inspections. Therefore, if visual inspections are performed on a quarterly basis (or other frequency determined to be adequate by plant-specific operating history), then wear of the pumps' mechanical seal/packing assembly is effectively managed.

5.4.2.6 Fouling

Detecting the presence of fouling associated with the SLC pump subcomponents (i.e., internal valve, miscellaneous structural components, and nozzles) and the BAT pump subcomponents (i.e., flow guides, miscellaneous structural components, casing, flange/cover, and nozzles) is achieved through implementation of pump performance testing in accordance with the plants' Preventive Maintenance Program or Surveillance Testing Program, which ever applies. Through pump performance monitoring, data acquisition, trending of key operational parameters and diagnostic analysis, sufficient information will be obtained so that planned maintenance can be performed to repair, replace, or refurbish these subcomponents. As these subcomponents begin to foul, a deviation in the pumps' normal developed head and flow rate characteristics will be observed. Fouling will be detected by trending these operating parameters and comparing the data against the design pump curve. Therefore, if total developed head and flow rate data are obtained on a quarterly basis (or other frequency determined to be adequate by plant-specific operating history), and compared against the design pump curve, then fouling of the reciprocating SLC pump internal valves, miscellaneous structural components, and nozzles, and centrifugal boric acid transfer pump fixed internal wearing components is effectively managed.

5.4.3 Continuously Operated Treated Water System Pumps

The continuously operated treated water system pumps discussed in this section are all centrifugal pumps and consist of the following.

- For BWR plants
  — control rod drive (CRD) pumps
  — residual heat removal (RHR) pumps
  — fuel pool cooling (FPC) pumps

- For PWR plants
  — primary makeup pumps
  — residual heat removal (RHR) pumps
  — fuel pool cooling (FPC) pumps

These pumps were evaluated by subcomponent and are considered to be continuously operated. The pump subcomponents and associated aging mechanisms determined in Section 4.3 to be significant are:

- Rotating Members
  — Mechanical Fatigue
  — General Corrosion
  — Galvanic Corrosion
  — IGSCC
  — Erosion and Erosion/Corrosion
  — Wear

- Fixed Internals
  — General Corrosion
  — Galvanic Corrosion
  — MIC
  — IGSCC and TGSCC
  — Erosion and Erosion/Corrosion
  — Wear
  — Fouling

- Pressure Boundary
  — Mechanical Fatigue
  — General Corrosion
  — Galvanic Corrosion
  — MIC
  — IGSCC
  — Erosion and Erosion/Corrosion
  — Fouling

- Mechanical Subsystems
  — Mechanical Fatigue
  — General Corrosion
  — Galvanic Corrosion
  — IGSCC
  — Wear

- Supports
  — Mechanical Fatigue
  — General Corrosion

The following programs/techniques are considered effective for detection and mitigation of these aging mechanisms.

- Mechanical Fatigue
  — Technical Specification Surveillance Testing
  — Preventive Maintenance
  — ASME Section XI Inservice Inspection and Testing

- General and Galvanic Corrosion
  — Preventive Maintenance
  — Technical Specification Surveillance Testing
  — Pump Erosion Control

- Microbiologically Influenced Corrosion (MIC)
  — MIC Control

- Intergranular and Transgranular Stress Corrosion Cracking (IGSCC)
  — Technical Specification Surveillance Testing
  — Preventive Maintenance
  — ASME Section XI Inservice Inspection and Testing

- Erosion and Erosion/Corrosion
  — Technical Specification Surveillance Testing
  — Preventive Maintenance
  — Pump Erosion Control

- Wear
  — Technical Specification Surveillance Testing
  — Preventive Maintenance

- Fouling
  — Technical Specification Surveillance Testing
  — Preventive Maintenance

Table 5-4 summarizes the results and conclusions associated with the following effective program/technique evaluations.

Table 5-4. Effective Programs/Techniques for Continuously Operated Treated Water System Pumps (BWR - CRD, RHR, and Fuel Pool Cooling Pumps) (PWR - Primary Makeup, RHR, and Fuel Pool Cooling Pumps)

Pump Subcomponent	Required Effective Programs/Techniques						Supplemental Programs/Techniques				
	ASME Section XI ISI/IST	ASME Section XI Wall Thinning	Tech Spec Surveillance	Preventive Maintenance	Pump Erosion Control	MIC Control	Pump Lay-up	Thermography	Operator Activities	Coatings Surveys	Industry Experience
ROTATING/RECIPROCATING											
Centrifugal Pumps											
• Shaft											
- Mech. Fatigue			Vibration	Vibration							
- General Corr.			Vibration	Vibration			Preser-vation				
- Galvanic Corr.			Vibration	Vibration			Preser-vation				
- IGSCC			Vibration	Vibration							
- Wear			Vibration	Vibration							
• Impeller											
- Mech. Fatigue			Vibration	Vibration							
- General Corr.			Vibration	Vibration			Preser-vation				
- Galvanic Corr.			Vibration	Vibration			Preser-vation				
- IGSCC			Vibration	Vibration							
- Erosion and E/C			TDH & Flow Rate	TDH & Flow Rate							
- Wear			Vibration	Vibration							
FIXED INTERNALS											
• Misc. Struct. Comp.											
- General Corr.				Visual Exam			Preser-vation				
- Galvanic Corr.				Visual Exam			Preser-vation				

Table 5-4. Effective Programs/Techniques for Continuously Operated Treated Water System Pumps (BWR - CRD, RHR, and Fuel Pool Cooling Pumps) (PWR - Primary Makeup, RHR, and Fuel Pool Cooling Pumps) (continued)

Pump Subcomponent	Required Effective Programs/Techniques						Supplemental Programs/Techniques				
	ASME Section XI ISI/IST	ASME Section XI Wall Thinning	Tech Spec Surveillance	Preventive Maintenance	Pump Erosion Control	MIC Control	Pump Lay-up	Thermography	Operator Activities	Coatings Surveys	Industry Experience
FIXED INTERNALS (continued)											
- MIC						Sampling	Preservation				
- IGSCC & TGSCC				Surface Exam							
- Fouling			TDH & Flow Rate	TDH & Flow Rate							
• Wearing Components											
- General Corr.				Visual Exam			Preservation				
- Galvanic Corr.				Visual Exam			Preservation				
- IGSCC & TGSCC				Surface Exam							
- Erosion and E/C			TDH & Flow Rate	TDH & Flow Rate							
- Wear			TDH & Flow Rate	TDH & Flow Rate							
• Flow Guides											
- General Corr.				Visual Exam			Preservation				
- Galvanic Corr.				Visual Exam			Preservation				
- MIC						Sampling	Preservation				
- IGSCC				Surface Exam							
- Erosion and E/C			TDH & Flow Rate	TDH & Flow Rate							
- Fouling			TDH & Flow Rate	TDH & Flow Rate							

Table 5-4. Effective Programs/Techniques for Continuously Operated Treated Water System Pumps (BWR - CRD, RHR, and Fuel Pool Cooling Pumps) (PWR - Primary Makeup, RHR, and Fuel Pool Cooling Pumps) (continued)

Pump Subcomponent	Required Effective Programs/Techniques						Supplemental Programs/Techniques				
	ASME Section XI ISI/IST	ASME Section XI Wall Thinning	Tech Spec Surveillance	Preventive Maintenance	Pump Erosion Control	MIC Control	Pump Lay-up	Thermography	Operator Activities	Coatings Surveys	Industry Experience
PRESSURE BOUNDARY											
• Casing and Nozzles											
- Mech. Fatigue	Surface Exam & Pressure Test										
- General Corr.				Inspection	Volumetric Exam		Preservation			Inspection	
- Galvanic Corr.				Inspection	Volumetric Exam		Preservation			Inspection	
- MIC						Sampling	Preservation				
- IGSCC	Surface Exam & Pressure Test										
- Erosion and E/C					Volumetric Exam						
- Fouling			TDH & Flow Rate	TDH & Flow Rate							
• Flange/Cover											
- Mech. Fatigue	Surface Exam & Pressure Test										
- General Corr.				Inspection	Volumetric Exam		Preservation			Inspection	
- Galvanic Corr.				Inspection	Volumetric Exam		Preservation			Inspection	

Table 5-4. Effective Programs/Techniques for Continuously Operated Treated Water System Pumps (BWR - CRD, RHR, and Fuel Pool Cooling Pumps) (PWR - Primary Makeup, RHR, and Fuel Pool Cooling Pumps) (continued)

Pump Subcomponent	Required Effective Programs/Techniques						Supplemental Programs/Techniques				
	ASME Section XI ISI/IST	ASME Section XI Wall Thinning	Tech Spec Surveillance	Preventive Maintenance	Pump Erosion Control	MIC Control	Pump Lay-up	Thermography	Operator Activities	Coatings Surveys	Industry Experience
PRESSURE BOUNDARY (continued)											
- MIC						Sampling	Preservation				
- IGSCC	Surface Exam & Pressure Test										
- Fouling			TDH & Flow Rate	TDH & Flow Rate							
• Fasteners											
- Mech. Fatigue	Volumetric Exam			Torque Verification							
- General Corr.				Inspection							
MECHANICAL SUBSYSTEMS											
• Coupling											
- Mech. Fatigue			Vibration	Vibration							
- General Corr.				Inspection							
- Wear			Vibration	Vibration							
• Seals											
- General Corr.				Inspection					Inspection		
- Galvanic Corr.				Inspection					Inspection		
- IGSCC				Inspection					Inspection		
- Wear				Inspection					Inspection		
• Radial Bearing											
- Wear			Vibration	Vib. & Lube Analysis				Temp. Monitoring	Temp. Monitoring		

Table 5-4. Effective Programs/Techniques for Continuously Operated Treated Water System Pumps (BWR - CRD, RHR, and Fuel Pool Cooling Pumps) (PWR - Primary Makeup, RHR, and Fuel Pool Cooling Pumps) (continued)

Pump Subcomponent	Required Effective Programs/Techniques						Supplemental Programs/Techniques				
	ASME Section XI ISI/IST	ASME Section XI Wall Thinning	Tech Spec Surveillance	Preventive Maintenance	Pump Erosion Control	MIC Control	Pump Lay-up	Thermography	Operator Activities	Coatings Surveys	Industry Experience
MECHANICAL SUBSYSTEMS (continued)											
• Thrust Bearing											
- Mech. Fatigue			Vibration	Vib. & Lube Analysis				Temp. Monitoring	Temp. Monitoring		
- Wear				Vib. & Lube Analysis				Temp. Monitoring	Temp. Monitoring		
SUPPORTS											
• Support Feet/Skirt											
- Mech. Fatigue				Vib. & Inspection							
- General Corr.				Inspection						Inspection	
• Base Frame/Skid											
- General Corr.				Inspection						Inspection	
• Fasteners											
- General Corr.				Inspection							

5.4.3.1 Mechanical Fatigue

Detecting the presence of mechanical fatigue in the treated water system pump subcomponents is virtually impossible to achieve until such time as the subcomponent begins to exhibit abnormal behavior. Programs/techniques to effectively manage mechanical fatigue are performance based. Through pump performance monitoring and data acquisition, the trending of key operational parameters may provide sufficient information, prior to pump failure, so that planned maintenance activities can be conducted to repair/replace the affected pump subcomponent(s). Visual inspection is also helpful for fatigue detection in some situations. A combination of programs/techniques must be implemented to effectively manage mechanical fatigue of these treated water system pump subcomponents.

For the pumps' rotating and mechanical subsystem components, vibration monitoring in accordance with either the plant's Preventive Maintenance Program or Surveillance Testing Program, which ever applies, is the most effective method to detect significant degradation and pump failure from mechanical fatigue of these subcomponents. Since these pumps are continuously operated, permanently installed vibration monitoring equipment would be the optimum; however, this is not a requirement to acquire the necessary data for analysis.

For centrifugal pump rotating members (i.e., shaft, impeller, thrust bearing, and coupling) subject to fatigue, horizontal, vertical, axial, and shaft vibration data should be acquired. Torsional vibration data would provide some additional information but is not necessary for the BWR CRD and FPC pumps and PWR primary makeup and FPC pumps because these treated water system pumps are relatively small, consequently, the rotating elements do not develop large axial torque and torsional inertia. Torsional vibration problems are generally associated with larger, more massive and higher horsepower rotating elements. Therefore, torsional vibration data should be obtained and analyzed for the BWR and PWR RHR pumps. Also, bearing lubrication samples should be obtained for all of these pumps and chemically analyzed or the lubrication changed out on a scheduled basis. Another method which will provide information regarding thrust bearing failure is monitoring of thrust bearing temperatures by operating personnel, if permanent instrumentation is provided, or through the use of contact pyrometers and/or thermography. Therefore, if vibration data is obtained and trended and bearing lubrication verified to be satisfactory on a quarterly basis (or other frequency determined to be adequate by plant-specific operating history), then mechanical fatigue of the pumps' rotating members is effectively managed.

Mechanical fatigue of pressure boundary components associated with the centrifugal pumps (i.e., casing, flange/cover, suction and discharge nozzle, and fasteners) is effectively managed through implementation of the plants' ASME Section XI Inservice Inspection Program and Preventive Maintenance Program. Surface examinations, consisting of either the liquid penetrant or the magnetic particle process, and hydrostatic pressure tests are performed to verify pressure boundary integrity. Volumetric examination is performed on pressure boundary fasteners that are greater than 5.1 cm [2 in] in diameter. For fasteners less than 5.1 cm [2 in] in diameter, preventive maintenance activities, consisting of inspections, replacements, and fastener torque verification are performed. Through a combination of ASME Section XI and preventive maintenance tasks, mechanical fatigue of pressure boundary components will be detected and corrective actions implemented to ensure safe and reliable pump operation. Therefore, if surface examinations, hydrostatic pressure tests, and volumetric examinations on fasteners greater than 5.1 cm [2 in] in diameter are performed each inspection interval and; visual inspection, parts replacement, and fastener torque verification (on fasteners less than 5.1 cm [2 in] in diameter) is performed each refueling outage (or other frequency determined to be adequate by plant-specific operating history), then mechanical fatigue of the pumps' pressure boundary components is effectively managed.

Mechanical fatigue failure of the pump support feet/skirt will be detected during preventive maintenance inspections and vibration monitoring. Therefore, if vibration data is obtained and trended on a quarterly basis (or other frequency determined to be adequate by plant-specific operating history), and visual inspection and fastener torque verification performed each refueling outage (or other frequency determined to be adequate by plant-specific operating history), then mechanical fatigue of the pumps' support feet/skirt is effectively managed.

5.4.3.2 General and Galvanic Corrosion

From Table 4-6, general corrosion is a significant aging mechanism for: 1) all pump subcomponents manufactured from carbon and low alloy steel and cast iron and; 2) pressure boundary components (made from these materials) where the design corrosion allowance is less than 3.2 mm [0.125 in]. Also, from Table 4-6, galvanic corrosion is a significant aging mechanism for: 1) all pump subcomponents manufactured from carbon and low alloy steel and cast iron and; 2) bronze and brass materials when in contact with stainless and high alloy steels.

Detecting the presence of general and galvanic corrosion associated with treated water system pump internal subcomponents is virtually impossible to achieve until such time as the subcomponent begins to exhibit abnormal behavior. Otherwise, the pump will require disassembly for internal inspection. Therefore, pump performance monitoring, data acquisition, and trending of key parameters may provide sufficient information, prior to pump failure, so that planned maintenance activities can be conducted to repair or replace the affected pump internal subcomponent(s). Visual inspection is also helpful for corrosion detection in some situations. A combination of programs/techniques must be implemented to effectively manage general and galvanic corrosion of BWR CRD, RHR, and FPC and PWR primary makeup, RHR, and FPC pump internal subcomponents.

For centrifugal pump rotating members (i.e., shaft and impeller) vibration monitoring in accordance with either the plants' Preventive Maintenance Program or Surveillance Testing Program, which ever applies, is the most effective method to detect significant degradation and pump failure from general and galvanic corrosion. Horizontal, vertical, axial, and shaft vibration data should be acquired. Torsional vibration data is not required because general and galvanic corrosion occurring to the shaft and impeller will not alter axial torque and torsional inertia of these rotating members. Since these pumps are continuously operated, permanently installed vibration pickups with monitoring capability would be the optimum installation; however, this is not a requirement to acquire the necessary vibration data. Therefore, if vibration data is obtained and trended on a quarterly basis (or other frequency determined to be adequate by plant-specific operating history), then general and galvanic corrosion of the pump rotating members are effectively managed.

For centrifugal pump fixed internal members (i.e., flow guides, miscellaneous structural members, and wearing components) general and galvanic corrosion can only be effectively managed by visual (VT-3) examination. Section 6 provides information regarding the requirements to effectively manage general and galvanic corrosion of these pump subcomponents. This is accomplished by performing a visual examination of these pump components once each inspection interval.

Degradation of internal pressure boundary component surfaces associated with treated water system pumps from general and galvanic corrosion is effectively managed through implementation of the Plants' Pump Erosion Control Program. Internal surface corrosion will cause wall thinning. Volumetric examinations are performed to detect the amount of wall thinning. The data is analyzed and wall thinning rates are calculated. Corrective actions are implemented when the analysis shows that the minimum acceptable wall thickness will be exceeded prior to the next scheduled examination. Therefore, if volumetric examination data is obtained and analyzed and wall thinning rates calculated each inspection interval (or other frequency determined to be adequate based on wall thinning projections), and corrective actions implemented prior to exceeding minimum acceptable wall thickness, then general and galvanic corrosion of the pumps' pressure boundary components is effectively managed.

During plant outages, when these treated water system pumps are not operating, appropriate lay-up practices should be implemented to inhibit general and galvanic corrosion of all wetted pump subcomponents.

For all pump external pressure boundary surfaces, mechanical subsystem components, and support components susceptible to general and/or galvanic corrosion, inspections conducted in accordance with the Plants' Preventive Maintenance Program will effectively manage these aging mechanisms. Protective coatings applied to the casing, nozzles, flange/cover, support feet/skirt, and base frame/skid are verified to be intact. The fasteners are inspected and verified to be free from excessive corrosion product accumulation and the tightness is checked. As the mechanical seal/packing assembly deteriorates from corrosion, fluid leakage will be detected by visual observation during operator rounds or preventive maintenance inspection. The coupling is verified to be free from corrosion product accumulation. If corrosion is observed to be detrimental to safe and reliable pump operation, corrective actions in the form of repair/ replacement/refurbishment is performed to restore the pump to a condition where safe and reliable operation is assured. Therefore, if visual inspection, parts replacement, and fastener torque verification is performed each refueling outage (or other frequency determined to be adequate by plant-specific operating history), then general and galvanic corrosion of the pumps' external surfaces, mechanical subsystem components and support base components is effectively managed.

5.4.3.3 Microbiologically Influenced Corrosion

Detecting the presence of MIC associated with the various treated water system pump subcomponents is accomplished by sampling the fluid and by sampling any solid materials found when the pump is opened up to perform maintenance. During pump testing, fluid samples shall be obtained and an analysis performed to identify heavily infested areas, evaluate the effectiveness of the treatment method (i.e., if MIC was previously discovered), locate areas where microbes are rapidly reproducing, and to trend the data. If the pump is opened up for maintenance purposes, deposits, tubercules, and/or corrosion products should be removed for analysis. The analysis should assess the magnitude and severity of microorganism growth and determine the appropriate treatment method to mitigate further propagation of MIC.

Through fluid and solid material sampling, analysis, and trending of the data sufficient information is available to effectively detect the presence of MIC. Planned maintenance and/or treatment methods can be implemented to ensure safe and reliable operation of the pumps' fixed internal and pressure boundary subcomponents. Therefore, if fluid sampling, analysis and trending of data is performed quarterly during pump testing (or other frequency determined to be adequate by plant-specific operating history), and; solid sampling, analysis and trending of data is performed whenever the pump is opened up for maintenance, and; corrective actions are implemented as appropriate, then microbiologically influenced corrosion of the pumps' fixed internal and pressure boundary components is effectively managed.

During plant outages, appropriate lay-up activities should be implemented to reduce the potential for MIC to occur in these treated water system pumps.

5.4.3.4 Intergranular and Transgranular Stress Corrosion Cracking (IGSCC and TGSCC)

From Table 4-6, IGSCC is significant for treated water system pump subcomponents made from stainless and high alloy steel that operate for a time with fluid temperatures greater than 54°C [130°F]. Also, fluid impurities such as chlorides can contribute to incidences of IGSCC. From Tables 3-7 and 3-8, only the BWR and PWR RHR pumps operate at temperatures greater than 54°C [130°F] (i.e., shutdown cooling/decay heat removal). The BWR control rod drive and fuel pool cooling pumps and the PWR primary makeup and fuel pool cooling pumps operate at temperatures less than 54°C [130°F] and process highly pure treated water. Therefore, IGSCC is not a concern for these pumps.

Detecting the presence of IGSCC associated with the treated water system RHR pump internal subcomponents is virtually impossible to achieve until such time as the subcomponent begins to exhibit abnormal behavior. Otherwise the pump will require disassembly for internal inspection. Therefore, pump performance monitoring, data acquisition, and trending of key parameters may provide sufficient information, prior to pump failure, so that planned maintenance activities can be conducted to repair or replace the affected pump internal subcomponent(s). Visual inspection is also helpful for IGSCC detection in some situations. A combination of programs/techniques must be implemented to effectively manage IGSCC of BWR and PWR RHR pump internal subcomponents.

For the centrifugal RHR pump rotating members (i.e., shaft and impeller) vibration monitoring in accordance with either the plants' Preventive Maintenance Program or Surveillance Testing Program, which ever applies, is the most effective method to detect significant degradation and pump failure from IGSCC. Horizontal, vertical, axial, and shaft vibration data should be acquired. As discussed in Section 5.4.3.1, torsional vibration data should be obtained if possible to provide additional information regarding shaft condition. Permanently installed vibration pickups with monitoring capability would be the optimum installation for RHR pumps;

however, this is not a requirement to acquire the necessary vibration data. Therefore, if vibration data is obtained and trended on a quarterly basis (or other frequency determined to be adequate by plant-specific operating history), then intergranular stress corrosion cracking of the centrifugal RHR pump rotating members is effectively managed.

For the centrifugal RHR pump fixed internal members (i.e., flow guides, miscellaneous structural components, and wearing components) IGSCC can only be effectively managed by surface examination. Section 6 provides information regarding the requirements to effectively manage IGSCC of these pump subcomponents. This is accomplished by performing surface examinations of these components once each inspection interval.

IGSCC of pressure boundary components associated with the centrifugal RHR pumps (i.e, casing, flange/cover, and suction and discharge nozzle) is effectively managed through implementation of the plants' ASME Section XI Inservice Inspection Program. Surface examinations, consisting of either liquid penetrant or the magnetic particle process, and hydrostatic pressure tests are performed to verify pressure boundary integrity. IGSCC of these pressure boundary components will be detected and pressure boundary integrity verified through performance of these ASME Section XI requirements. Corrective actions are implemented as necessary to ensure safe and reliable pump operation. Therefore, if surface examination and hydrostatic pressure tests are performed each inspection interval, then IGSCC of the pumps' pressure boundary components is effectively managed.

IGSCC of the pumps' mechanical seal/packing assembly associated with the RHR pumps will be detected and effectively managed through inspections conducted in accordance with the plants' Preventive Maintenance Program. Fluid leakage can be readily detected by visual observation during operator rounds activities or preventive maintenance inspections. Therefore, if visual inspections are performed on a quarterly basis (or other frequency determined to be adequate by plant-specific operating history), then IGSCC of the pumps' mechanical seal/packing assembly is effectively managed.

From Table 4-6, TGSCC is significant for miscellaneous structural components and wearing components made from wrought brass or bronze materials containing > 15% zinc. For these centrifugal pump fixed internal members, TGSCC can only be effectively managed by surface examination. Section 6 provides information regarding the requirements to effectively manage TGSCC of these pump subcomponents. This is accomplished by performing surface examinations of these components once each inspection interval.

5.4.3.5 Erosion and Erosion/Corrosion

Detecting the presence of erosion and erosion/corrosion associated with treated water system pump impellers and flow guides (i.e., centrifugal pumps) is virtually impossible to achieve until such time as the pump begins to exhibit abnormal behavior. Programs/techniques to effectively manage this aging mechanism for these pump subcomponents are performance based. Through pump performance monitoring and data acquisition, the trending of key operational parameters may provide sufficient information, prior to pump failure, so that planned maintenance activities can be conducted to repair/replace the affected pump subcomponents.

For the centrifugal pump impellers, flow guides, and wearing components, erosion and erosion/corrosion is effectively managed through pump performance testing in accordance with the plants' Preventive Maintenance or Surveillance Testing Program, which ever applies. Degradation of the centrifugal pump impeller, flow guides, and/or wearing components due to erosion and erosion/corrosion will cause a reduction in pump performance as measured by total developed head and flow rate. Therefore, if total developed head and flow rate data are obtained on a quarterly basis (or other frequency determined to be adequate by plant-specific operating history), and compared against the design pump curve, then erosion and erosion/corrosion of the centrifugal pump impellers, flow guides, and wearing components are effectively managed.

Degradation of the treated water system pump pressure boundary components (i.e, casing and suction/discharge nozzles) from erosion and erosion/corrosion are effectively managed through implementation of the plants' Pump Erosion Control Program. This program is for effectively managing wall thinning of pressure boundary casings and nozzles due to erosion caused by cavitation and/or particle impingement. Volumetric examinations are performed to detect the amount of wall thinning. The data is analyzed, and wall thinning rates are calculated. Corrective actions are implemented when the analysis shows that the minimum acceptable wall thickness will be exceeded prior to the next schedule examination. Therefore, if volumetric examination data is obtained and analyzed and wall thinning rates calculated each inspection interval (or other frequency determined to be adequate based on wall thinning projections), and corrective actions implemented prior to exceeding minimum acceptable wall thickness, then erosion and erosion/corrosion of the pumps' pressure boundary components are effectively managed.

5.4.3.6 Wear

Detecting the presence of wear associated with the various treated water system pump subcomponents is achievable through a combination of programs. As subcomponent wear progresses, the pump operating characteristics will begin to deviate from normally observed values. Through pump performance monitoring, data acquisition, trending of key operational parameters and diagnostic analysis, sufficient information will be obtained, prior to failure, so that planned maintenance activities can be conducted to repair/replace/refurbish the affected pump subcomponent(s). Visual inspection is also helpful for wear detection in some situations. A combination of programs/techniques must be implemented to effectively manage wear of treated water system pump subcomponents.

For most of the pumps' rotating and mechanical subsystem components, vibration monitoring in accordance with either the plant's Preventive Maintenance Program or Surveillance Program, which ever applies, is the most effective method to detect adverse vibration trends due to wear of these subcomponents. Since these treated water system pumps are continuously operating, permanently installed vibration pickups with monitoring capability would be the optimum installation; however, this is not a requirement to acquire the necessary vibration data.

For centrifugal pump rotating members (i.e., shaft, impeller, radial bearing, thrust bearing, and coupling) subject to wear, horizontal, vertical, axial, and shaft vibration data should be acquired. As discussed in Section 5.4.3.1, torsional vibration data is not required for the BWR CRD and FPC pumps and PWR primary makeup and FPC pumps because these pumps are small.

However, torsional vibration data should be obtained and analyzed for the BWR and PWR RHR pumps. Also, bearing lubrication samples should be obtained for all of these pumps and chemically analyzed or the lubrication changed out on a scheduled basis. Another method which provides pertinent data regarding bearing wear is the monitoring of bearing temperatures. If permanent instrumentation is installed, bearing temperatures can be monitored by operating personnel. Otherwise, contact pyrometers and/or thermography should be utilized. Therefore, if vibration data is obtained and trended and bearing lubrication verified to be satisfactory on a quarterly basis (or other frequency determined to be adequate by plant-specific operating history), then wear of the pumps' rotating members is effectively managed.

For the fixed internal wearing components associated with the treated water system centrifugal pumps, wear is effectively managed through pump performance testing in accordance with the plants' Preventive Maintenance or Surveillance Testing Program, which ever applies. As these components wear, a deviation in the pumps' normal developed head and flow rate characteristics will be observed. This phenomenon will be detected by trending these operating parameters and comparing the data against the design pump curve. Therefore, if normal operating developed head and flow rate data are obtained and trended on a quarterly basis (or other frequency determined to be adequate by plant-specific operating history), and compared against the design pump curve, then wear of the centrifugal pump fixed internal wearing components is effectively managed.

For the mechanical seal/packing assembly associated with these treated water system pumps, wear is effectively managed through inspections conducted in accordance with the plants' Preventive Maintenance Program. As the mechanical seal/packing assembly wears it will begin to leak fluid. This leakage can be readily detected by visual observation during operator rounds activities or preventive maintenance inspections. Therefore, if visual inspections are performed on a quarterly basis (or other frequency determined to be adequate by plant-specific operating history), then wear of the pumps' mechanical seal/packing assembly is effectively managed.

5.4.3.7 Fouling

Detecting the presence of fouling associated with treated water system pump pressure boundary and fixed internal components is achieved through implementation of pump performance testing in accordance with the plants' Preventive Maintenance Program or Surveillance Testing Program, which ever applies. Through pump performance monitoring, data acquisition, trending of key operational parameters and diagnostic analysis, sufficient information will be obtained so that planned maintenance can be performed to repair, replace, or refurbish these components. As fouling progresses, a deviation in the pumps' normal developed head and flow rate characteristics will be observed. Fouling will be detected by trending these operating parameters and comparing the data against the design pump curve. Therefore, if total developed head and flow rate data are obtained on a quarterly basis (or other frequency determined to be adequate by plant-specific operating history), and compared against the design pump curve, then fouling of the centrifugal pumps' pressure boundary and fixed internal components is effectively managed.

5.4.4 Intermittently Operated Treated Water System Pumps

The intermittently operated treated water system pumps discussed in this section are either centrifugal pumps or vertical well centrifugal pumps and consist of the following.

- For BWR plants — Core spray pumps (HP and LP)
  — High pressure coolant injection (HPCI) pumps
  — Reactor core isolation cooling (RCIC) pumps

- For PWR plants — Auxiliary feedwater (AFW) pumps
  — Safety injection (SI) pumps
  — Containment recirculation pumps
  — Containment spray pumps

These pumps were evaluated by subcomponent and are considered to be intermittently operated. The pump subcomponents and associated aging mechanisms, determined in Section 4.3, to be significant are:

- Rotating Members
  — Mechanical Fatigue
  — General Corrosion
  — Galvanic Corrosion
  — Erosion and Erosion/Corrosion
  — Wear

- Fixed Internals
  — General Corrosion
  — Galvanic Corrosion
  — MIC
  — IGSCC & TGSCC
  — Erosion and Erosion/Corrosion
  — Wear
  — Fouling

- Pressure Boundary
  — General Corrosion
  — Galvanic Corrosion
  — MIC
  — Erosion and Erosion/Corrosion
  — Fouling

- Mechanical Subsystems
  — Mechanical Fatigue
  — General Corrosion
  — Galvanic Corrosion
  — Wear

- Supports
  — Mechanical Fatigue
  — General Corrosion

The following programs/techniques are considered effective for detection and mitigation of these aging mechanisms.

- Mechanical Fatigue
  — Technical Specification Surveillance Testing
  — Preventive Maintenance

- General and Galvanic Corrosion
  — Preventive Maintenance
  — Technical Specification Surveillance Testing
  — Pump Erosion Control

- Microbiologically Influenced Corrosion (MIC)
  — MIC Control

- Intergranular and Transgranular Stress Corrosion Cracking (IGSCC and TGSCC)
  — Preventive Maintenance

- Erosion and Erosion/Corrosion
  — Technical Specification Surveillance Testing
  — Preventive Maintenance
  — Pump Erosion Control

- Wear
  — Technical Specification Surveillance Testing
  — Preventive Maintenance

- Fouling
  — Technical Specification Surveillance Testing
  — Preventive Maintenance

Table 5-5 summarizes the results and conclusions associated with the following effective program/technique evaluations.

Table 5-5. Effective Programs/Techniques for Intermittently Operated Treated Water System Pumps (BWR - Core Spray, HPCI, and RCIC) (PWR - AFW, SI, Containment Recirc. and Spray Pumps)

Pump Subcomponent	Required Effective Programs/Techniques						Supplemental Programs/Techniques				
	ASME Section XI ISI/IST	ASME Section XI Wall Thinning	Tech Spec Surveillance	Preventive Maintenance	Pump Erosion Control	MIC Control	Pump Lay-up	Thermography	Operator Activities	Coatings Surveys	Industry Experience
ROTATING/RECIPROCATING											
• Shaft											
- Mech. Fatigue			Vibration	Vibration							
- General Corr.			Vibration	Vibration			Preser-vation				
- Galvanic Corr.			Vibration	Vibration			Preser-vation				
- Wear			Vibration	Vibration							
• Impeller											
- Mech. Fatigue			Vibration	Vibration							
- General Corr.			Vibration	Vibration			Preser-vation				
- Galvanic Corr.			Vibration	Vibration			Preser-vation				
- Erosion and E/C			TDH & Flow Rate	TDH & Flow Rate							
- Wear			Vibration	Vibration							
FIXED INTERNALS											
• Misc. Struct. Comp.											
- General Corr.				Visual Exam			Preser-vation				
- Galvanic Corr.				Visual Exam			Preser-vation				
- MIC						Sampling	Preser-vation				
- IGSCC & TGSCC				Surface Exam							

Table 5-5. Effective Programs/Techniques for Intermittently Operated Treated Water System Pumps (BWR - Core Spray, HPCI, and RCIC) (PWR - AFW, SI, Containment Recirc. and Spray Pumps) (continued)

Pump Subcomponent	Required Effective Programs/Techniques						Supplemental Programs/Techniques				
	ASME Section XI ISI/IST	ASME Section XI Wall Thinning	Tech Spec Surveillance	Preventive Maintenance	Pump Erosion Control	MIC Control	Pump Lay-up	Thermography	Operator Activities	Coatings Surveys	Industry Experience
FIXED INTERNALS (continued)											
- Fouling			TDH & Flow Rate	TDH & Flow Rate							
• Wearing Components											
- General Corr.				Visual Exam			Preser-vation				
- Galvanic Corr.				Visual Exam			Preser-vation				
- IGSCC & TGSCC				Surface Exam							
- Erosion and E/C			TDH & Flow Rate	TDH & Flow Rate							
- Wear			TDH & Flow Rate	TDH & Flow Rate							
• Flow Guides											
- General Corr.				Visual Exam			Preser-vation				
- Galvanic Corr.				Visual Exam			Preser-vation				
- MIC						Sampling	Preser-vation				
- Erosion and E/C			TDH & Flow Rate	TDH & Flow Rate							
- Fouling			TDH & Flow Rate	TDH & Flow Rate							
• Suction Strainer											
- General Corr.				Visual Exam							
- Galvanic Corr.				Visual Exam							

Table 5-5. Effective Programs/Techniques for Intermittently Operated Treated Water System Pumps (BWR - Core Spray, HPCI, and RCIC) (PWR - AFW, SI, Containment Recirc. and Spray Pumps) (continued)

Pump Subcomponent	Required Effective Programs/Techniques					
	ASME Section XI ISI/IST	ASME Section XI Wall Thinning	Tech Spec Surveillance	Preventive Maintenance	Pump Erosion Control	MIC Control
FIXED INTERNALS (continued)						
- MIC						Sampling
- Erosion and E/C			TDH & Flow Rate	TDH & Flow Rate		
- Fouling			TDH & Flow Rate	TDH & Flow Rate		
PRESSURE BOUNDARY						
• Casing and Nozzles						
- General Corr.				Inspection	Volumetric Exam	
- Galvanic Corr.				Inspection	Volumetric Exam	
- MIC						Sampling
- Erosion and E/C					Volumetric Exam	
- Fouling			TDH & Flow Rate	TDH & Flow Rate		
• Flange/Cover						
- General Corr.				Inspection	Volumetric Exam	
- Galvanic Corr.				Inspection	Volumetric Exam	
- MIC						Sampling
- Fouling			TDH & Flow Rate	TDH & Flow Rate		

Pump Subcomponent	Supplemental Programs/Techniques				
	Pump Lay-up	Thermography	Operator Activities	Coatings Surveys	Industry Experience
FIXED INTERNALS (continued)					
- MIC	Preservation				
- Erosion and E/C					
- Fouling					
PRESSURE BOUNDARY					
• Casing and Nozzles					
- General Corr.	Preservation			Inspection	
- Galvanic Corr.	Preservation			Inspection	
- MIC	Preservation				
- Erosion and E/C					
- Fouling					
• Flange/Cover					
- General Corr.	Preservation			Inspection	
- Galvanic Corr.	Preservation			Inspection	
- MIC	Preservation				
- Fouling					

Table 5-5. Effective Programs/Techniques for Intermittently Operated Treated Water System Pumps (BWR - Core Spray, HPCI, and RCIC) (PWR - AFW, SI, Containment Recirc. and Spray Pumps) (continued)

Pump Subcomponent	Required Effective Programs/Techniques						Supplemental Programs/Techniques				
	ASME Section XI ISI/IST	ASME Section XI Wall Thinning	Tech Spec Surveillance	Preventive Maintenance	Pump Erosion Control	MIC Control	Pump Lay-up	Thermography	Operator Activities	Coatings Surveys	Industry Experience
PRESSURE BOUNDARY (continued)											
• Fasteners											
- General Corr.				Inspection							
MECHANICAL SUBSYSTEMS											
• Coupling											
- Mech. Fatigue			Vibration	Vibration							
- General Corr.				Inspection							
- Wear			Vibration	Vibration							
• Seals											
- General Corr.				Inspection					Inspection		
- Galvanic Corr.				Inspection					Inspection		
- Wear				Inspection					Inspection		
• Radial Bearing											
- Wear			Vibration	Vib. & Lube Analysis				Temp. Monitoring	Temp. Monitoring		
• Thrust Bearing											
- Mech. Fatigue			Vibration	Vib. & Lube Analysis				Temp. Monitoring	Temp. Monitoring		
- Wear				Vib. & Lube Analysis				Temp. Monitoring	Temp. Monitoring		

Table 5-5. Effective Programs/Techniques for Intermittently Operated Treated Water System Pumps (BWR - Core Spray, HPCI, and RCIC) (PWR - AFW, SI, Containment Recirc. and Spray Pumps) (continued)

Pump Subcomponent	Required Effective Programs/Techniques						Supplemental Programs/Techniques				
	ASME Section XI ISI/IST	ASME Section XI Wall Thinning	Tech Spec Surveillance	Preventive Maintenance	Pump Erosion Control	MIC Control	Pump Lay-up	Thermography	Operator Activities	Coatings Surveys	Industry Experience
SUPPORTS											
• Support Feet/Skirt											
- Mech. Fatigue				Vib. & Inspection							
- General Corr.				Inspection						Inspec-tion	
• Base Frame											
- General Corr.				Inspection						Inspec-tion	
• Fasteners											
- General Corr.				Inspection							

5.4.4.1 Mechanical Fatigue

Detecting the presence of mechanical fatigue in the treated water system pump subcomponents is virtually impossible to achieve until such time as the subcomponent begins to exhibit abnormal behavior. Programs/techniques to effectively manage mechanical fatigue are performance based. Through pump performance monitoring and data acquisition, the trending of key operational parameters may provide sufficient information, prior to pump failure, so that planned maintenance activities can be conducted to repair/replace the affected pump subcomponent(s). Visual inspection is also helpful for detection of fatigue in some situations. A combination of programs/techniques must be implemented to effectively manage mechanical fatigue of these treated water system pump subcomponents.

For the pumps' rotating and mechanical subsystem components, vibration monitoring in accordance with either the plant's Preventive Maintenance Program or Surveillance Testing Program, which ever applies, is the most effective method to detect significant degradation and pump failure from mechanical fatigue of these subcomponents. Since these pumps are intermittently operated, permanently installed vibration monitoring equipment is not a requirement to acquire the necessary data for analysis.

For centrifugal pump rotating members (i.e., shaft, impeller, thrust bearing, and coupling) subject to fatigue, horizontal, vertical, axial, and shaft vibration data should be acquired. Torsional vibration data is not necessary for any of these pumps because the pumps operate intermittently (primarily for testing). Torsional vibration problems are generally associated with pumps that are continuously operated. Also, bearing lubrication samples should be chemically analyzed or the lubrication changed out on a scheduled basis. Another method which will provide information regarding thrust bearing failure is monitoring of thrust bearing temperatures by operating personnel, if permanent instrumentation is provided, or through the use of contact pyrometers and/or thermography. Therefore, if vibration data is obtained and trended and bearing lubrication verified to be satisfactory on a quarterly basis (or other frequency determined to be adequate by plant-specific operating history), then mechanical fatigue of the pumps' rotating members is effectively managed.

Mechanical fatigue failure of the pump support feet/skirt will be detected during preventive maintenance inspections and vibration monitoring. Therefore, if vibration data is obtained and trended on a quarterly basis (or other frequency determined to be adequate by plant-specific operating history), and visual inspection and fastener torque verification performed each refueling outage (or other frequency determined to be adequate by plant-specific operating history), then mechanical fatigue of the pumps' support feet/skirt is effectively managed.

5.4.4.2 General and Galvanic Corrosion

From Table 4-7, general corrosion is a significant aging mechanism for: 1) all pump subcomponents manufactured from carbon and low alloy steel and cast iron and; 2) pressure boundary components (made from these materials) where the design corrosion allowance is less than 3.2 mm [0.125 in]. Also, from Table 4-7, galvanic corrosion is a significant aging mechanism for: 1) all pump subcomponents manufactured from carbon and low alloy steel and cast iron and; 2) bronze and brass materials when in contact with stainless and high alloy steels.

Detecting the presence of general and galvanic corrosion associated with treated water system pump internal subcomponents is virtually impossible to achieve until such time as the subcomponent begins to exhibit abnormal behavior. Otherwise, the pump will require disassembly for internal inspection. Therefore, pump performance monitoring, data acquisition, and trending of key parameters may provide sufficient information, prior to pump failure, so that planned maintenance activities can be conducted to repair or replace the affected pump internal subcomponent(s).

A combination of programs/techniques must be implemented to effectively manage general and galvanic corrosion of BWR Core Spray, HPCI, and RCIC and PWR AFW, SI, containment recirculation and containment spray pump internal subcomponents.

For these centrifugal pump rotating members (i.e., shaft and impeller) vibration monitoring in accordance with either the plants' Preventive Maintenance Program or Surveillance Testing Program, which ever applies, is the most effective method to detect significant degradation and pump failure from general and galvanic corrosion. Horizontal, vertical, axial, and shaft vibration data should be acquired. Torsional vibration data is not required because general and galvanic corrosion occurring to the shaft and impeller will not alter axial torque and torsional inertia of these rotating members. Since these pumps are intermittently operated, permanently installed vibration pickups with monitoring capability is not a requirement to acquire the necessary vibration data. Therefore, if vibration data is obtained and trended on a quarterly basis (or other frequency determined to be adequate by plant-specific operating history) , then general and galvanic corrosion of the pump rotating members is effectively managed.

For these centrifugal pump fixed internal members (i.e., flow guides, miscellaneous structural members, suction strainer, and wearing components) general and galvanic corrosion can only be effectively managed by visual (VT-3) examination. Section 6 provides information regarding the requirements to effectively manage general and galvanic corrosion of these pump subcomponents. This is accomplished by performing a visual examination of these pump components once each inspection interval.

Degradation of internal pressure boundary component surfaces associated with these treated water system pumps from general and galvanic corrosion is effectively managed through implementation of the Plants' Pump Erosion Control Program. Internal surface corrosion will cause wall thinning. Volumetric examinations are performed to detect the amount of wall thinning. The data is analyzed and wall thinning rates are calculated. Corrective actions are implemented when the analysis shows that the minimum acceptable wall thickness will be exceeded prior to the next scheduled examination. Therefore, if volumetric examination data is obtained and analyzed and wall thinning rates calculated each inspection interval (or other frequency determined to be adequate based on wall thinning projections), and corrective actions implemented prior to exceeding minimum acceptable wall thickness, then general and galvanic corrosion of the pumps' pressure boundary components is effectively managed.

During plant outages, when these treated water system pumps are not required to be operable, appropriate lay-up practices should be implemented to inhibit general and galvanic corrosion of all wetted pump subcomponents.

For all pump external pressure boundary surfaces, mechanical subsystem components, and support components susceptible to general and/or galvanic corrosion, inspections conducted in accordance with the Plants' Preventive Maintenance Program will effectively manage these aging mechanisms. Protective coatings applied to the casing, nozzles, flange/cover, support feet/skirt, and base frame/skid are verified to be intact. The fasteners are inspected and verified to be free from excessive corrosion product accumulation and the tightness is checked. As the mechanical seal/packing assembly deteriorates from corrosion fluid leakage will be detected by visual observation during operator rounds or preventive maintenance inspection. The coupling is verified to be free from corrosion product accumulation. If corrosion is observed to be detrimental to safe and reliable pump operation, corrective actions in the form of repair/ replacement/refurbishment is performed to restore the pump to a condition where safe and reliable operation is assured. Therefore, if visual inspection, parts replacement, and fastener torque verification is performed each refueling outage (or other frequency determined to be adequate by plant-specific operating history), then general and galvanic corrosion of the pumps' external surfaces, mechanical subsystem components, and support base components is effectively managed.

5.4.4.3 Microbiologically Influenced Corrosion

Detecting the presence of MIC associated with the various treated water system pump subcomponents is accomplished by sampling the fluid and by sampling any solid materials found when the pump is opened up to perform maintenance. During pump testing, fluid samples shall be obtained and an analysis performed to: identify heavily infested areas, evaluate the effectiveness of the treatment method (i.e., if MIC was previously discovered), locate areas where microbes are rapidly reproducing, and to trend the data. If the pump is opened up for maintenance purposes, deposits, tubercules, and/or corrosion products should be removed for analysis. The analysis should assess the magnitude and severity of microorganism growth and determine the appropriate treatment method to mitigate further propagation of MIC.

Through fluid and solid material sampling, analysis, and trending of the data sufficient information is available to effectively detect the presence of MIC. Planned maintenance and/or treatment methods can be implemented to ensure safe and reliable operation of the pumps' fixed internal and pressure boundary subcomponents. Therefore, if fluid sampling, analysis and trending of data is performed quarterly during pump testing (or other frequency determined to be adequate by plant-specific operating history), and; solid sampling, analysis and trending of data is performed whenever the pump is opened up for maintenance, and; corrective actions are implemented as appropriate, then microbiologically influenced corrosion of the pumps' fixed internal and pressure boundary components is effectively managed.

During plant outages, appropriate lay-up activities should be implemented to reduce the potential for MIC to occur in these treated water system pumps.

5.4.4.4 Intergranular and Transgranular Stress Corrosion Cracking (IGSCC and TGSCC)

From Table 4-7, IGSCC and TGSCC is significant for miscellaneous structural components and wearing components made from wrought brass or bronze materials containing > 15% zinc. For these centrifugal pump fixed internal members, IGSCC and TGSCC can only be effectively managed by surface examination. Section 6 provides information regarding the requirements to effectively manage IGSCC and TGSCC of these pump subcomponents. This is accomplished by performing surface examinations of these components once each inspection interval.

5.4.4.5 Erosion and Erosion/Corrosion

Detecting the presence of erosion and erosion/corrosion associated with treated water system pump impellers, flow guides, wearing components, and suction strainers is virtually impossible to achieve until such time as the pump begins to exhibit abnormal behavior. Programs/techniques to effectively manage this aging mechanism for these pump subcomponents are performance based. Through pump performance monitoring and data acquisition, the trending of key operational parameters may provide sufficient information, prior to pump failure, so that planned maintenance activities can be conducted to repair/replace the affected pump subcomponents.

For the centrifugal pump impellers, flow guides, wearing components, and suction strainers, erosion and erosion/corrosion are effectively managed through pump performance testing in accordance with the plants' Preventive Maintenance or Surveillance Testing Program, which ever applies. Degradation of the centrifugal pump impeller, flow guides, wearing components, and/or suction strainer due to erosion and erosion/corrosion will cause a reduction in pump performance as measured by total developed head and flow rate. Therefore, if total developed head and flow rate data are obtained on a quarterly basis (or other frequency determined to be adequate by plant-specific operating history), and compared against the design pump curve, then erosion and erosion/corrosion of the centrifugal pump impellers, flow guides, wearing components, and suction strainer are effectively managed.

Degradation of the treated water system pump pressure boundary components (i.e, casing and suction/discharge nozzles) from erosion and erosion/corrosion is effectively managed through implementation of the plants' Pump Erosion Control Program. This program is for effectively managing wall thinning of pressure boundary casings and nozzles due to erosion caused by cavitation and/or particle impingement. Volumetric examinations are performed to detect the amount of wall thinning. The data is analyzed, and wall thinning rates are calculated. Corrective actions are implemented when the analysis shows that the minimum acceptable wall thickness will be exceeded prior to the next schedule examination. Therefore, if volumetric examination data is obtained and analyzed and wall thinning rates calculated each inspection interval (or other frequency determined to be adequate based on wall thinning projections), and corrective actions implemented prior to exceeding minimum acceptable wall thickness, then erosion and erosion/corrosion of the pumps' pressure boundary components are effectively managed.

5.4.4.6 Wear

Detecting the presence of wear associated with the various treated water system pump subcomponents is achievable through a combination of programs. As subcomponent wear progresses, the pump operating characteristics will begin to deviate from normally observed values. Through pump performance monitoring, data acquisition, trending of key operational parameters and diagnostic analysis, sufficient information will be obtained, prior to failure, so that planned maintenance activities can be conducted to repair/replace/refurbish the affected pump subcomponent(s). Visual inspection is also helpful for wear detection in some situations.

For most of the pumps' rotating and mechanical subsystem components, vibration monitoring in accordance with either the plant's Preventive Maintenance Program or Surveillance Program, which ever applies, is the most effective method to detect adverse vibration trends due to wear of these subcomponents. Permanently installed vibration pickups with monitoring capability is not a requirement to acquire the necessary vibration data.

For centrifugal pump rotating members (i.e., shaft, impeller, radial bearing, thrust bearing, and coupling) subject to wear, horizontal, vertical, axial, and shaft vibration data should be acquired. As discussed in Section 5.4.4.1, torsional vibration data is not required for these pumps because they operate intermittently (primarily for testing). Also, bearing lubrication samples should be chemically analyzed or the lubrication changed out on a scheduled basis. Another method which provides pertinent data regarding bearing wear is the monitoring of bearing temperatures. If permanent instrumentation is installed, bearing temperatures can be monitored by operating personnel. Otherwise, contact pyrometers and/or thermography should be utilized. Therefore, if vibration data is obtained and trended and bearing lubrication verified to be satisfactory on a quarterly basis (or other frequency determined to be adequate by plant-specific operating history), then wear of the pumps' rotating members is effectively managed.

For the fixed internal wearing components associated with the treated water system centrifugal pumps, wear is effectively managed through pump performance testing in accordance with the plants' Preventive Maintenance or Surveillance Testing Program, which ever applies. As these components wear, a deviation in the pumps' normal developed head and flow rate characteristics will be observed. This phenomenon will be detected by trending these operating parameters and comparing the data against the design pump curve. Therefore, if normal operating developed head and flow rate data are obtained and trended on a quarterly basis (or other frequency determined to be adequate by plant-specific operating history), and compared against the design pump curve, then wear of the centrifugal pump fixed internal wearing components is effectively managed.

For the mechanical seal/packing assembly associated with these treated water system pumps, wear is effectively managed through inspections conducted in accordance with the plants' Preventive Maintenance Program. As the mechanical seal/packing assembly wears it will begin to leak fluid. This leakage can be readily detected by visual observation during operator rounds activities or preventive maintenance inspections. Therefore, if visual inspections are performed on a quarterly basis (or other frequency determined to be adequate by plant-specific operating history), then wear of the pumps' mechanical seal/packing assembly is effectively managed.

5.4.4.7 Fouling

Detecting the presence of fouling associated with treated water system pump pressure boundary and fixed internal components is achieved through implementation of pump performance testing in accordance with the plants' Preventive Maintenance Program or Surveillance Testing Program, which ever applies. Through pump performance monitoring, data acquisition, trending of key operational parameters and diagnostic analysis, sufficient information will be obtained so that planned maintenance can be performed to repair, replace, or refurbish these components. As fouling progresses, a deviation in the pumps' normal developed head and flow rate characteristics will be observed. Fouling will be detected by trending these operating parameters and comparing the data against the design pump curve. Therefore, if total developed head and flow rate data are obtained on a quarterly basis (or other frequency determined to be adequate by plant-specific operating history), and compared against the design pump curve, then fouling of the centrifugal pumps' pressure boundary and fixed internal components is effectively managed.

5.4.5 Closed Cooling Water System Pumps

The closed cooling water system pumps discussed in this section are all centrifugal pumps. There are various plant-specific names given to these pumps, for example, reactor building closed cooling water (RBCCW), emergency equipment closed cooling water (EECW), component cooling water (CCW), emergency diesel generator jacket water, etc. The pumps were evaluated by subcomponent and are considered to be continuously operated. The pump subcomponents and associated aging mechanisms, determined in Section 4.3 to be significant, are:

- Rotating Members
  - — Mechanical Fatigue
  - — General Corrosion
  - — Erosion and Erosion/Corrosion
  - — Wear
- Fixed Internals
  - — General Corrosion
  - — IGSCC and TGSCC
  - — Erosion and Erosion/Corrosion
  - — Wear
- Pressure Boundary
  - — Mechanical Fatigue
  - — General Corrosion
  - — Erosion and Erosion/Corrosion
- Mechanical Subsystems
  - — Mechanical Fatigue
  - — General Corrosion
  - — Wear

- Supports
  — Mechanical Fatigue
  — General Corrosion

The following programs/techniques are considered effective for detection and mitigation of these aging mechanisms.

- Mechanical Fatigue
  — Technical Specification Surveillance Testing
  — Preventive Maintenance
  — ASME Section XI Inservice Inspection and Testing

- General Corrosion
  — Technical Specification Surveillance Testing
  — Preventive Maintenance
  — Pump Erosion Control

- Intergranular and Transgranular Stress Corrosion Cracking (IGSCC and TGSCC)
  — Preventive Maintenance

- Erosion and Erosion/Corrosion
  — Technical Specification Surveillance Testing
  — Preventive Maintenance
  — Pump Erosion Control

- Wear
  — Technical Specification Surveillance Testing
  — Preventive Maintenance

Table 5-6 summarizes the results and conclusions associated with the following effective program/technique evaluations.

5.4.5.1 Mechanical Fatigue

Detecting the presence of mechanical fatigue in the closed cooling water system pump subcomponents is virtually impossible to achieve until such time as the subcomponent begins to exhibit abnormal behavior. Programs/techniques to effectively manage mechanical fatigue are performance based. Through pump performance monitoring and data acquisition, the trending of key operational parameters may provide sufficient information, prior to pump failure, so that planned maintenance activities can be conducted to repair/replace the affected pump subcomponent(s). Visual inspection is also helpful for fatigue detection in some situations. A combination of programs/techniques must be implemented to effectively manage mechanical fatigue of these closed cooling water system pump subcomponents.

Table 5-6. Effective Programs/Techniques for Closed Cooling Water System Pumps

Pump Subcomponent	Required Effective Programs/Techniques						Supplemental Programs/Techniques				
	ASME Section XI ISI/IST	ASME Section XI Wall Thinning	Tech Spec Surveillance	Preventive Maintenance	Pump Erosion Control	MIC Control	Pump Lay-up	Thermography	Operator Activities	Coatings Surveys	Industry Experience
ROTATING/RECIPROCATING											
• Shaft											
- Mech. Fatigue			Vibration	Vibration							
- General Corr.			Vibration	Vibration			Preser-vation				
- Wear			Vibration	Vibration							
• Impeller											
- Mech. Fatigue			Vibration	Vibration							
- General Corr.			Vibration	Vibration			Preser-vation				
- Erosion and E/C			TDH & Flow Rate	TDH & Flow Rate							
- Wear			Vibration	Vibration							
FIXED INTERNALS											
• Misc. Struct. Comp.											
- General Corr.				Visual Exam			Preser-vation				
- IGSCC & TGSCC				Surface Exam							
• Wearing Components											
- General Corr.				Visual Exam			Preser-vation				
- IGSCC & TGSCC				Surface Exam							
- Erosion and E/C			TDH & Flow Rate	TDH & Flow Rate							
- Wear			TDH & Flow Rate	TDH & Flow Rate							

Table 5-6. Effective Programs/Techniques for Closed Cooling Water System Pumps (continued)

Pump Subcomponent	Required Effective Programs/Techniques						Supplemental Programs/Techniques				
	ASME Section XI ISI/IST	ASME Section XI Wall Thinning	Tech Spec Surveillance	Preventive Maintenance	Pump Erosion Control	MIC Control	Pump Lay-up	Thermography	Operator Activities	Coatings Surveys	Industry Experience
FIXED INTERNALS (continued)											
• Flow Guides											
- General Corr.				Visual Exam			Preser-vation				
- Erosion and E/C			TDH & Flow Rate	TDH & Flow Rate							
PRESSURE BOUNDARY											
• Casing and Nozzles											
- Mech. Fatigue	Surface Exam & Pressure Test										
- General Corr.				Inspection	Volumet-ric Exam		Preser-vation				
- Erosion and E/C					Volumet-ric Exam						
• Flange/Cover											
- Mech. Fatigue	Surface Exam & Pressure Testing										
- General Corr.				Inspection	Volumet-ric Exam		Preser-vation				
• Fasteners											
- Mech. Fatigue	Volumetric Exam			Torque Verification							
- General Corr.				Inspection							

Table 5-6. Effective Programs/Techniques for Closed Cooling Water System Pumps (continued)

Pump Subcomponent	Required Effective Programs/Techniques						Supplemental Programs/Techniques				
	ASME Section XI ISI/IST	ASME Section XI Wall Thinning	Tech Spec Surveillance	Preventive Maintenance	Pump Erosion Control	MIC Control	Pump Lay-up	Thermography	Operator Activities	Coatings Surveys	Industry Experience
MECHANICAL SUBSYSTEMS											
• Coupling											
- Mech. Fatigue			Vibration	Vibration							
- General Corr.				Inspection					Inspection		
- Wear			Vibration	Vibration							
• Seals											
- General Corr.				Inspection					Inspection		
- Wear				Inspection					Inspection		
• Radial Bearing											
- Wear			Vibration	Vib. & Lube Analysis				Temp. Monitoring	Temp. Monitoring		
• Thrust Bearing											
- Mech. Fatigue			Vibration	Vib. & Lube Analysis				Temp. Monitoring	Temp. Monitoring		
- Wear				Vib. & Lube Analysis				Temp. Monitoring	Temp. Monitoring		

Table 5-6. Effective Programs/Techniques for Closed Cooling Water System Pumps (continued)

Pump Subcomponent	Required Effective Programs/Techniques						Supplemental Programs/Techniques				
	ASME Section XI ISI/IST	ASME Section XI Wall Thinning	Tech Spec Surveillance	Preventive Maintenance	Pump Erosion Control	MIC Control	Pump Lay-up	Thermography	Operator Activities	Coatings Surveys	Industry Experience
SUPPORTS											
• Support Feet/Skirt											
- Mech. Fatigue				Vib. & Inspection							
- General Corr.				Inspection						Inspection	
• Base Frame/Skid											
- General Corr.				Inspection						Inspection	
• Fasteners											
- General Corr.				Inspection						Inspection	

For the pumps' rotating and mechanical subsystem components, vibration monitoring in accordance with either the plant's Preventive Maintenance Program or Surveillance Testing Program, which ever applies, is the most effective method to detect incipient pump failure from mechanical fatigue of these subcomponents. Since these pumps are continuously operated, permanently installed vibration monitoring equipment would be the optimum; however, this is not a requirement to acquire the necessary data for analysis.

For centrifugal pump rotating members (i.e., shaft, impeller, thrust bearing, and coupling) subject to fatigue, horizontal, vertical, axial, and shaft vibration data should be acquired. Torsional vibration data would provide some additional information but is not necessary because these closed cooling water system pumps are relatively small, consequently, the rotating elements do not develop large axial torque and torsional inertia. Torsional vibration problems are generally associated with larger, more massive and higher horsepower rotating elements. Also, bearing lubrication samples should be chemically analyzed or the lubrication changed out on a scheduled basis. Another method which will provide information regarding thrust bearing failure is monitoring of thrust bearing temperatures by operating personnel, if permanent instrumentation is provided, or through the use of contact pyrometers and/or thermography. Therefore, if vibration data is obtained and trended and bearing lubrication verified to be satisfactory on a quarterly basis (or other frequency determined to be adequate by plant-specific operating history), then mechanical fatigue of the pumps' rotating members is effectively managed.

Mechanical fatigue of pressure boundary components associated with the centrifugal pumps (i.e., casing, flange/cover, suction and discharge nozzle, and fasteners) is effectively managed through implementation of the plants' ASME Section XI Inservice Inspection Program and Preventive Maintenance Program. Surface examinations, consisting of either the liquid penetrant or magnetic particle process, and hydrostatic pressure tests are performed to verify pressure boundary integrity. Volumetric examination is performed on pressure boundary fasteners that are greater than 5.1 cm [2 in] in diameter. For fasteners less than 5.1 cm [2 in] in diameter, preventive maintenance activities, consisting of inspections, replacements, and fastener torque verification are performed. Through a combination of ASME Section XI and preventive maintenance tasks, mechanical fatigue of pressure boundary components will be detected and corrective actions implemented to ensure safe and reliable pump operation. Therefore, if surface examinations, hydrostatic pressure tests, and volumetric examinations on fasteners greater than 5.1 cm [2 in] in diameter are performed each inspection interval and; visual inspection, parts replacement, and fastener torque verification (on fasteners less than 5.1 cm [2 in] in diameter) is performed each refueling outage (or other frequency determined to be adequate by plant-specific operating history), then mechanical fatigue of the pumps' pressure boundary components is effectively managed.

Mechanical fatigue failure of the pump support feet/skirt will be detected during preventive maintenance inspections and vibration monitoring. Therefore, if vibration data is obtained and trended on a quarterly basis (or other frequency determined to be adequate by plant-specific operating history), and visual inspection and fastener torque verification performed each refueling outage (or other frequency determined to be adequate by plant-specific operating history), then mechanical fatigue of the pumps' support feet/skirt is effectively managed.

5.4.5.2 General Corrosion

From Table 4-8, general corrosion is a significant aging mechanism for: 1) all pump subcomponents manufactured from carbon and low alloy steel and cast iron and; 2) pressure boundary components (made from these materials) where the design corrosion allowance is less than 3.2 mm [0.125 in].

Detecting the presence of general corrosion associated with closed cooling water system pump internal subcomponents is virtually impossible to achieve until such time as the subcomponent begins to exhibit abnormal behavior. Otherwise, the pump will require disassembly for internal inspection. Therefore, pump performance monitoring, data acquisition, and trending of key parameters may provide sufficient information, prior to pump failure, so that planned maintenance activities can be conducted to repair or replace the affected pump internal subcomponent(s). Visual inspection is also helpful for corrosion detection in some situations. A combination of programs/techniques must be implemented to effectively manage general corrosion of closed cooling water pump internal subcomponents.

For these centrifugal pump rotating members (i.e., shaft and impeller) vibration monitoring in accordance with either the plants' Preventive Maintenance Program or Surveillance Testing Program, which ever applies, is the most effective method to detect significant degradation and pump failure from general corrosion. Horizontal, vertical, axial, and shaft vibration data should be acquired. Torsional vibration data is not required because general corrosion occurring to the shaft and impeller will not alter axial torque and torsional inertia of these rotating members. Since these pumps are continuously operated, permanently installed vibration pickups with monitoring capability would be the optimum installation; however, this is not a requirement to acquire the necessary vibration data. Therefore, if vibration data is obtained and trended on a quarterly basis (or other frequency determined to be adequate by plant-specific operating history), then general corrosion of the pump rotating members is effectively managed.

For these centrifugal pump fixed internal members (i.e., flow guides, miscellaneous structural members, and wearing components) general corrosion can only be effectively managed by visual (VT-3) examination. Section 6 provides information regarding the requirements to effectively manage general corrosion of these pump subcomponents. This is accomplished by performing a visual examination of these pump components once each inspection interval.

Degradation of internal pressure boundary component surfaces associated with these closed cooling water system pumps from general corrosion is effectively managed through implementation of the Plants' Pump Erosion Control Program. Internal surface corrosion will cause wall thinning. Volumetric examinations are performed to detect the amount of wall thinning. The data is analyzed and wall thinning rates are calculated. Corrective actions are implemented when the analysis shows that the minimum acceptable wall thickness will be exceeded prior to the next scheduled examination. Therefore, if volumetric examination data is obtained and analyzed and wall thinning rates calculated each inspection interval (or other frequency determined to be adequate based on wall thinning projections), and corrective actions implemented prior to exceeding minimum acceptable wall thickness, then general corrosion of the pumps' pressure boundary components is effectively managed.

During plant outages, when these closed cooling water system pumps are not operating, appropriate lay-up practices should be implemented to inhibit general corrosion of all wetted pump subcomponents.

For all pump external pressure boundary surfaces, mechanical subsystem components, and support components susceptible to general corrosion, inspections conducted in accordance with the Plants' Preventive Maintenance Program will effectively manage these aging mechanisms. Protective coatings applied to the casing, nozzles, flange/cover, support feet/skirt, and base frame/skid are verified to be intact. The fasteners are inspected and verified to be free from excessive corrosion product accumulation and the tightness is checked. As the mechanical seal/packing assembly deteriorates from corrosion, fluid leakage will be detected by visual observation during operator rounds or preventive maintenance inspection. The coupling is verified to be free from corrosion product accumulation. If corrosion is observed to be detrimental to safe and reliable pump operation, corrective actions in the form of repair/ replacement/refurbishment is performed to restore the pump to a condition where safe and reliable operation is assured. Therefore, if visual inspection, parts replacement, and fastener torque verification is performed each refueling outage (or other frequency determined to be adequate by plant-specific operating history), then general corrosion of the pumps' external surfaces, mechanical subsystem components and support base components is effectively managed.

5.4.5.3 Intergranular and Transgranular Stress Corrosion Cracking (IGSCC and TGSCC)

From Table 4-8, IGSCC and TGSCC are significant for miscellaneous structural components and wearing components made from wrought brass or bronze materials containing >15% zinc. For these centrifugal pump fixed internal members, IGSCC and TGSCC can only be effectively managed by surface examination. Section 6 provides information regarding the requirements to effectively manage IGSCC and TGSCC of these pump subcomponents. This is accomplished by performing surface examinations of these components once each inspection interval.

5.4.5.4 Erosion and Erosion/Corrosion

Detecting the presence of erosion and erosion/corrosion associated with closed cooling water system pump impellers, flow guides, and wearing components (i.e., centrifugal pumps) is virtually impossible to achieve until such time as the pump begins to exhibit abnormal behavior. Programs/techniques to effectively manage this aging mechanism for these pump subcomponents are performance based. Through pump performance monitoring and data acquisition, the trending of key operational parameters may provide sufficient information, prior to pump failure, so that planned maintenance activities can be conducted to repair/replace the affected pump subcomponents.

For the centrifugal pump impellers, flow guides, and wearing components, erosion and erosion/corrosion are effectively managed through pump performance testing in accordance with the plants' Preventive Maintenance or Surveillance Testing Program, which ever applies. Degradation of the centrifugal pump impeller, flow guides, and/or wearing components due to erosion and erosion/corrosion will cause a reduction in pump performance as measured by total developed head and flow rate. Therefore, if total developed head and flow rate data are obtained on a quarterly basis (or other frequency determined to be adequate by plant-specific operating history), and compared against the design pump curve, then erosion and erosion/corrosion of the centrifugal pump impellers, flow guides, and wearing components are effectively managed.

Degradation of the closed cooling water system pump pressure boundary components (i.e, casing and suction/discharge nozzles) from erosion and erosion/corrosion are effectively managed through implementation of the plants' Pump Erosion Control Program. This program is for effectively managing wall thinning of pressure boundary casings and nozzles due to erosion caused by cavitation and/or particle impingement. Volumetric examinations are performed to detect the amount of wall thinning. The data is analyzed, and wall thinning rates are calculated. Corrective actions are implemented when the analysis shows that the minimum acceptable wall thickness will be exceeded prior to the next schedule examination. Therefore, if volumetric examination data is obtained and analyzed and wall thinning rates calculated each inspection interval (or other frequency determined to be adequate based on wall thinning projections), and corrective actions implemented prior to exceeding minimum acceptable wall thickness, then erosion and erosion/corrosion of the pumps' pressure boundary components are effectively managed.

5.4.5.5 Wear

Detecting the presence of wear associated with the various closed cooling water system pump subcomponents is achievable through a combination of programs. As subcomponent wear progresses, the pump operating characteristics will begin to deviate from normally observed values. Through pump performance monitoring, data acquisition, trending of key operational parameters and diagnostic analysis, sufficient information will be obtained, prior to failure, so that planned maintenance activities can be conducted to repair/replace/refurbish the affected pump subcomponent(s). Visual inspection is also helpful for wear detection in some situations.

For most of the pumps' rotating and mechanical subsystem components, vibration monitoring in accordance with either the plant's Preventive Maintenance Program or Surveillance Program, which ever applies, is the most effective method to detect adverse vibration trends due to wear of these subcomponents. Since these closed cooling water system pumps are continuously operating, permanently installed vibration pickups with monitoring capability would be the optimum installation; however, this is not a requirement to acquire the necessary vibration data.

For centrifugal pump rotating members (i.e., shaft, impeller, radial bearing, thrust bearing, and coupling) subject to wear, horizontal, vertical, axial, and shaft vibration data should be acquired. As discussed in Section 5.4.5.1, torsional vibration data is not required for these closed cooling water pumps. Also, bearing lubrication samples should be chemically analyzed or the lubrication changed out on a scheduled basis. Another method which provides pertinent data regarding bearing wear is the monitoring of bearing temperatures. If permanent instrumentation is installed, bearing temperatures can be monitored by operating personnel. Otherwise, contact pyrometers and/or thermography should be utilized. Therefore, if vibration data is obtained and trended and bearing lubrication verified to be satisfactory on a quarterly basis (or other frequency determined to be adequate by plant-specific operating history), then wear of the pumps' rotating members is effectively managed.

For the fixed internal wearing components associated with the closed cooling water system centrifugal pumps, wear is effectively managed through pump performance testing in accordance with the plants' Preventive Maintenance or Surveillance Testing Program, which ever applies. As these components wear, a deviation in the pumps' normal developed head and flow rate characteristics will be observed. This phenomenon will be detected by trending these operating parameters and comparing the data against the design pump curve. Therefore, if normal operating developed head and flow rate data are obtained and trended on a quarterly basis (or other frequency determined to be adequate by plant-specific operating history), and compared against the design pump curve, then wear of the centrifugal pump fixed internal wearing components is effectively managed.

For the mechanical seal/packing assembly associated with these closed cooling water system pumps, wear is effectively managed through inspections conducted in accordance with the plants' Preventive Maintenance Program. As the mechanical seal/packing assembly wears it will begin to leak fluid. This leakage can be readily detected by visual observation during operator rounds activities or preventive maintenance inspections. Therefore, if visual inspections are performed on a quarterly basis (or other frequency determined to be adequate by plant-specific operating history), then wear of the pumps' mechanical seal/packing assembly is effectively managed.

5.4.6 Lubricating and Fuel Oil System Pumps

The lubricating and fuel oil system pumps discussed in this section are either centrifugal or rotary pumps. The lubricating oil pumps supply forced lubrication to various emergency core cooling system pumps and the emergency diesel generators. The fuel oil pumps supply combustion fuel to the emergency diesel generator engines. The pumps were evaluated by subcomponent and are considered to be intermittently operated. The pump subcomponents and associated aging mechanisms, determined in Section 4.3 to be significant, are:

- Rotating Members
  — Mechanical Fatigue
  — General Corrosion
  — Wear

- Fixed Internals
  — General Corrosion
  — Wear
  — Fouling

- Pressure Boundary
  — General Corrosion
  — Fouling

- Mechanical Subsystems
  — Mechanical Fatigue
  — General Corrosion
  — Wear

- Supports
  — Mechanical Fatigue
  — General Corrosion

The following programs/techniques are considered effective for detection and mitigation of these aging mechanisms.

- Mechanical Fatigue
  — Technical Specification Surveillance Testing
  — Preventive Maintenance

- General Corrosion
  — Technical Specification Surveillance Testing
  — Preventive Maintenance
  — Pump Erosion Control

- Wear
  — Technical Specification Surveillance Testing
  — Preventive Maintenance

- Fouling
  — Technical Specification Surveillance Testing
  — Preventive Maintenance

Table 5-7 summarizes the results and conclusions associated with the following effective program/technique evaluations.

5.4.6.1 Mechanical Fatigue

Detecting the presence of mechanical fatigue in the lubricating and fuel oil system pump subcomponents is virtually impossible to achieve until such time as the subcomponent begins to exhibit abnormal behavior. Programs/techniques to effectively manage mechanical fatigue are performance based. Through pump performance monitoring and data acquisition, the trending of key operational parameters may provide sufficient information, prior to pump failure, so that planned maintenance activities can be conducted to repair/replace the affected pump subcomponent(s). Visual inspection is also helpful for fatigue detection in some situations. A combination of programs/techniques must be implemented to effectively manage mechanical fatigue of these lubricating and fuel oil system pump subcomponents.

Table 5-7. Effective Programs/Techniques for Lubricating and Fuel Oil System Pumps

Pump Subcomponent	Required Effective Programs/Techniques						Supplemental Programs/Techniques				
	ASME Section XI ISI/IST	ASME Section XI Wall Thinning	Tech Spec Surveillance	Preventive Maintenance	Pump Erosion Control	MIC Control	Pump Lay-up	Thermography	Operator Activities	Coatings Surveys	Industry Experience
ROTATING/RECIPROCATING											
Centrifugal Pump											
• Shaft											
- Mech. Fatigue			Vibration	Vibration							
- General Corr.			Vibration	Vibration			Preser-vation				
- Wear			Vibration	Vibration							
• Impeller											
- Mech. Fatigue			Vibration	Vibration							
- General Corr.			Vibration	Vibration			Preser-vation				
- Wear			Vibration	Vibration							
Rotary Pump											
• Internal Rotor											
- Mech. Fatigue			Vibration	Vibration							
- General Corr.			Vibration	Vibration			Preser-vation				
- Wear			Vibration	Vibration							
FIXED INTERNALS											
• Misc. Struct. Comp.											
- General Corr.				Visual Exam			Preser-vation				
- Fouling			TDH & Flow Rate	TDH & Flow Rate							

Table 5-7. Effective Programs/Techniques for Lubricating and Fuel Oil System Pumps (continued)

Pump Subcomponent	Required Effective Programs/Techniques						Supplemental Programs/Techniques				
	ASME Section XI ISI/IST	ASME Section XI Wall Thinning	Tech Spec Surveillance	Preventive Maintenance	Pump Erosion Control	MIC Control	Pump Lay-up	Thermography	Operator Activities	Coatings Surveys	Industry Experience
FIXED INTERNALS (continued)											
• Wearing Components											
- General Corr.				Visual Exam			Preser-vation				
- Wear			TDH & Flow Rate	TDH & Flow Rate							
• Flow Guides											
- General Corr.				Visual Exam			Preser-vation				
- Fouling			TDH & Flow Rate	TDH & Flow Rate							
PRESSURE BOUNDARY											
• Casing and Nozzles											
- General Corr.				Inspection	Volumet-ric Exam		Preser-vation			Inspec-tion	
- Fouling			TDH & Flow Rate	TDH & Flow Rate							
• Flange/Cover											
- General Corr.				Inspection	Volumet-ric Exam		Preser-vation				
- Fouling			TDH & Flow Rate	TDH & Flow Rate							
• Fasteners											
- General Corr.				Inspection							
MECHANICAL SUBSYSTEMS											
• Coupling											
- Mech. Fatigue			Vibration	Vibration							

Table 5-7. Effective Programs/Techniques for Lubricating and Fuel Oil System Pumps (continued)

Pump Subcomponent	Required Effective Programs/Techniques						Supplemental Programs/Techniques				
	ASME Section XI ISI/IST	ASME Section XI Wall Thinning	Tech Spec Surveillance	Preventive Maintenance	Pump Erosion Control	MIC Control	Pump Lay-up	Thermography	Operator Activities	Coatings Surveys	Industry Experience
MECHANICAL SUBSYSTEMS (continued)											
- General Corr.				Inspection							
- Wear			Vibration	Vibration							
• Seals											
- General Corr.				Inspection					Inspection		
- Wear				Inspection					Inspection		
• Radial Bearing											
- Wear			Vibration	Vib. & Lube Analysis				Temp. Monitoring	Temp. Monitoring		
• Thrust Bearing											
- Mech. Fatigue			Vibration	Vib. & Lube Analysis							
- Wear			Vibration	Vib. & Lube Analysis				Temp. Monitoring	Temp. Monitoring		
SUPPORTS											
• Support Feet/Skirt											
- Mech. Fatigue				Vib. & Inspection							
- General Corr.				Inspection						Inspection	
• Base Frame/Skid											
- General Corr.				Inspection						Inspection	
• Fasteners											
- General Corr.				Inspection						Inspection	

For the pumps' rotating and mechanical subsystem components, vibration monitoring in accordance with either the plant's Preventive Maintenance Program or Surveillance Testing Program, which ever applies, is the most effective method to detect significant degradation and pump failure from mechanical fatigue of these subcomponents. Since these pumps are intermittently operated, permanently installed vibration monitoring equipment is not a requirement to acquire the necessary data for analysis.

For centrifugal pump rotating members (i.e., shaft, impeller, thrust bearing, and coupling) and rotary pump rotating members (i.e., internal rotor and coupling) subject to fatigue, horizontal, vertical, axial, and shaft vibration data should be acquired. Torsional vibration data is not necessary for any of these pumps because the pumps operate intermittently (primarily for testing) and are small. Torsional vibration problems are generally associated with large pumps that are continuously operated. Also, bearing lubrication samples should be chemically analyzed or the lubrication changed out on a scheduled basis. Another method which will provide information regarding thrust bearing failure, for those pumps containing a thrust bearing, is monitoring of temperatures by operating personnel, if permanent instrumentation is provided, or through the use of contact pyrometers and/or thermography. Therefore, if vibration data is obtained and trended and bearing lubrication verified to be satisfactory on a quarterly basis (or other frequency determined to be adequate by plant-specific operating history), then mechanical fatigue of the pumps' rotating members is effectively managed.

Mechanical fatigue failure of the pump support feet/skirt will be detected during preventive maintenance inspections and vibration monitoring. Therefore, if vibration data is obtained and trended on a quarterly basis (or other frequency determined to be adequate by plant-specific operating history), and visual inspection and fastener torque verification performed each refueling outage (or other frequency determined to be adequate by plant-specific operating history), then mechanical fatigue of the pumps' support feet/skirt is effectively managed.

5.4.6.2 General Corrosion

From Table 4-9, general corrosion is a significant aging mechanism for: 1) all pump subcomponents manufactured from carbon and low alloy steel or cast iron and; 2) pressure boundary components (made from these materials) where the design corrosion allowance is less than 3.2 mm [0.125 in].

Detecting the presence of general corrosion associated with lubricating and fuel oil system pump internal subcomponents is virtually impossible to achieve until such time as the subcomponent begins to exhibit abnormal behavior. Otherwise, the pump will require disassembly for internal inspection. Therefore, pump performance monitoring, data acquisition, and trending of key parameters may provide sufficient information, prior to pump failure, so that planned maintenance activities can be conducted to repair or replace the affected pump internal subcomponent(s). Visual inspection is also helpful for corrosion detection in some situations. A combination of programs/techniques must be implemented to effectively manage general corrosion of lubricating and fuel oil pump internal subcomponents.

For the centrifugal and rotary pump rotating members (i.e., shaft, impeller, and internal rotor) vibration monitoring in accordance with either the plants' Preventive Maintenance Program or Surveillance Testing Program, which ever applies, is the most effective method to detect significant degradation and pump failure from general corrosion. Horizontal, vertical, axial, and shaft vibration data should be acquired. Torsional vibration data is not required because, 1) general corrosion occurring to the shaft, impeller, or internal rotor will not alter axial torque and torsional inertia of these rotating members and 2) these pumps are small. Since these pumps are intermittently operated, permanently installed vibration pickups with monitoring capability is not a requirement to acquire the necessary vibration data. Therefore, if vibration data is obtained and trended on a quarterly basis (or other frequency determined to be adequate by plant-specific operating history), then general corrosion of the pump rotating members is effectively managed.

For these centrifugal and rotary pump fixed internal members (i.e., flow guides, miscellaneous structural members, and wearing components) general corrosion can only be effectively managed by visual (VT-3) examination. Section 6 provides information regarding the requirements to effectively manage general corrosion of these pump subcomponents. This is accomplished by performing a visual examination of these pump components once each inspection interval.

Degradation of internal pressure boundary component surfaces associated with these lubricating and fuel oil system pumps from general corrosion is effectively managed through implementation of the Plants' Pump Erosion Control Program. Internal surface corrosion will cause wall thinning. Volumetric examinations are performed to detect the amount of wall thinning. The data is analyzed and wall thinning rates are calculated. Corrective actions are implemented when the analysis shows that the minimum acceptable wall thickness will be exceeded prior to the next scheduled examination. Therefore, if volumetric examination data is obtained and analyzed and wall thinning rates calculated each inspection interval (or other frequency determined to be adequate based on wall thinning projections), and corrective actions implemented prior to exceeding minimum acceptable wall thickness, then general corrosion of the pumps' pressure boundary components is effectively managed.

During plant outages, when these lubricating and fuel oil system pumps are not required to be operable, appropriate lay-up practices should be implemented to inhibit general corrosion of all wetted pump subcomponents.

For all pump external pressure boundary surfaces, mechanical subsystem components, and support components susceptible to general corrosion, inspections conducted in accordance with the Plants' Preventive Maintenance Program will effectively manage these aging mechanisms. Protective coatings applied to the casing, nozzles, flange/cover, support feet/skirt, and base frame/skid are verified to be intact. The fasteners are inspected and verified to be free from excessive corrosion product accumulation and the tightness is checked. As the mechanical seal/packing assembly deteriorates from fluid leakage it will be detected by visual observation during operator rounds or preventive maintenance inspection. The coupling is verified to be free from corrosion product accumulation. If corrosion is observed to be detrimental to safe and reliable pump operation, corrective actions in the form of repair/replacement/refurbishment is performed to restore the pump to a condition where safe and reliable operation is assured. Therefore, if visual inspection, parts replacement, and fastener torque verification is performed each refueling outage (or other frequency determined to be adequate by plant-specific operating history), then general corrosion of the pumps' external surfaces, mechanical subsystem components and support base components is effectively managed.

5.4.6.3 Wear

Detecting the presence of wear associated with the various lubricating and fuel oil system pump subcomponents is achievable through of a combination of programs. As subcomponent wear progresses, the pump operating characteristics will begin to deviate from normally observed values. Through pump performance monitoring, data acquisition, trending of key operational parameters and diagnostic analysis, sufficient information will be obtained, prior to failure, so that planned maintenance activities can be conducted to repair/replace/refurbish the affected pump subcomponent(s). Visual inspection is also helpful for wear detection in some situations.

For most of the pumps' rotating and mechanical subsystem components, vibration monitoring in accordance with either the plant's Preventive Maintenance Program or Surveillance Program, which ever applies, is the most effective method to detect adverse vibration trends due to wear of these subcomponents. Since these lubricating and fuel oil system pumps are intermittently operating, permanently installed vibration pickups with monitoring capability is not a requirement to acquire the necessary vibration data.

For centrifugal and rotary pump rotating members (i.e., shaft, impeller, internal rotor, radial bearing, thrust bearing, and coupling) subject to wear, horizontal, vertical, axial, and shaft vibration data should be acquired. As discussed in Section 5.4.6.1, torsional vibration data is not required for these pumps because they operate intermittently (primarily for testing) and are small. Also, bearing lubrication samples should be chemically analyzed or the lubrication changed out on a scheduled basis. Another method which provides pertinent data regarding bearing wear is the monitoring of bearing temperatures. If permanent instrumentation is installed, bearing temperatures can be monitored by operating personnel. Otherwise, contact pyrometers and/or thermography should be utilized. Therefore, if vibration data is obtained and trended and bearing lubrication verified to be satisfactory on a quarterly basis (or other frequency determined to be adequate by plant-specific operating history), then wear of the pumps' rotating members is effectively managed.

For the fixed internal wearing components associated with the lubricating and fuel oil system pumps, wear is effectively managed through pump performance testing in accordance with the plants' Preventive Maintenance or Surveillance Testing Program, which ever applies. As these components wear, a deviation in the pumps' normal developed head and flow rate characteristics will be observed. This phenomenon will be detected by trending these operating parameters and comparing the data against the design pump curve. Therefore, if normal operating developed head and flow rate data are obtained and trended on a quarterly basis (or other frequency determined to be adequate by plant-specific operating history), and compared against the design pump curve, then wear of the pump fixed internal wearing components is effectively managed.

For the mechanical seal/packing assembly associated with these lubricating and fuel oil system pumps, wear is effectively managed through inspections conducted in accordance with the plants' Preventive Maintenance Program. As the mechanical seal/packing assembly wears it will begin to leak fluid. This leakage can be readily detected by visual observation during operator rounds activities or preventive maintenance inspections. Therefore, if visual inspections are performed on a quarterly basis (or other frequency determined to be adequate by plant-specific operating history), then wear of the pumps' mechanical seal/packing assembly is effectively managed.

5.4.6.4 Fouling

Detecting the presence of fouling associated with lubricating and fuel oil system pump pressure boundary and fixed internal components is achieved through implementation of pump performance testing in accordance with the plants' Preventive Maintenance Program or Surveillance Testing Program, which ever applies. Through pump performance monitoring, data acquisition, trending of key operational parameters and diagnostic analysis, sufficient information will be obtained so that planned maintenance can be performed to repair, replace, or refurbish these components. As fouling progresses, a deviation in the pumps' normal developed head and flow rate characteristics will be observed. Fouling will be detected by trending these operating parameters and comparing the data against the design pump curve. Therefore, if total developed head and flow rate data are obtained on a quarterly basis (or other frequency determined to be adequate by plant-specific operating history), and compared against the design pump curve, then fouling of the pumps' pressure boundary and fixed internal components is effectively managed.

5.4.7 Raw Water System Pumps

The raw water system pumps discussed in this section are either centrifugal pumps or vertical well centrifugal pumps. There are various plant-specific names given to these pumps, for example, essential service water, emergency service water, nuclear service water, emergency diesel generator service water, residual heat removal service water, auxiliary service water, non-essential service water, etc. Some pumps may operate continuously while others are maintained in standby and operate intermittently for testing. These raw water pumps are exposed to either fresh water or brackish/seawater. The pump subcomponents and associated aging mechanisms, determined in Section 4.3 to be significant, are:

- Rotating Members
  - — Mechanical Fatigue
  - — General Corrosion
  - — Galvanic Corrosion
  - — IGSCC
  - — Erosion and Erosion/Corrosion
  - — Wear
  - — Fouling

- Fixed Internals
  - — General Corrosion
  - — Galvanic Corrosion
  - — MIC
  - — IGSCC & TGSCC
  - — Erosion and Erosion/Corrosion

— Wear
— Fouling

- Pressure Boundary
  — Mechanical Fatigue
  — General Corrosion
  — Galvanic Corrosion
  — MIC
  — IGSCC
  — Erosion and Erosion/Corrosion
  — Fouling

- Mechanical Subsystems
  — Mechanical Fatigue
  — General Corrosion
  — Galvanic Corrosion
  — IGSCC
  — Erosion and Erosion/Corrosion
  — Wear

- Supports
  — Mechanical Fatigue
  — General Corrosion

The following programs/techniques are considered effective for detection and mitigation of these aging mechanisms.

- Mechânical Fatigue
  — Technical Specification Surveillance Testing
  — Preventive Maintenance
  — ASME Section XI Inservice Inspection and Testing

- General and Galvanic Corrosion
  — Preventive Maintenance
  — Technical Specification Surveillance Testing
  — Pump Erosion Control

- Microbiologically Influenced Corrosion (MIC)
  — MIC Control

- Intergranular and Transgranular Stress Corrosion Cracking (IGSCC and TGSCC)
  — Preventive Maintenance
  — Technical Specification Surveillance Testing
  — ASME Section XI Inservice Inspection and Testing

- Erosion and Erosion/Corrosion
  — Technical Specification Surveillance Testing

— Preventive Maintenance
— Pump Erosion Control

- Wear
  — Technical Specification Surveillance Testing
  — Preventive Maintenance

- Fouling
  — Technical Specification Surveillance Testing
  — Preventive Maintenance

Table 5-8 summarizes the results and conclusions associated with the following effective program/technique evaluations.

5.4.7.1 Mechanical Fatigue

Detecting the presence of mechanical fatigue in the raw water system pump subcomponents is virtually impossible to achieve until such time as the subcomponent begins to exhibit abnormal behavior. Programs/techniques to effectively manage mechanical fatigue are performance based. Through pump performance monitoring and data acquisition, the trending of key operational parameters may provide sufficient information, prior to pump failure, so that planned maintenance activities can be conducted to repair/replace the affected pump subcomponent(s). Visual inspection is also helpful for fatigue detection in some situations. A combination of programs/techniques must be implemented to effectively manage mechanical fatigue of these raw water system pump subcomponents.

For the pumps' rotating and mechanical subsystem components, vibration monitoring in accordance with either the plant's Preventive Maintenance Program or Surveillance Testing Program, which ever applies, is the most effective method to detect significant degradation and pump failure from mechanical fatigue of these subcomponents. For these raw service water pumps, permanently installed vibration monitoring equipment is not a requirement to acquire the necessary data for analysis.

For centrifugal pump rotating members (i.e., shaft, impeller, thrust bearing, and coupling) subject to fatigue, horizontal, vertical, axial, and shaft vibration data should be acquired. Torsional vibration data is not necessary for many of these pumps because they operate intermittently (primarily for testing). However, torsional vibration problems are generally associated with large pumps that are continuously operated. Therefore, torsional vibration data should be obtained and analyzed for continuously operated raw service water pumps. Also, bearing lubrication samples should be obtained for all of these pumps and chemically analyzed or the lubrication changed out on a scheduled basis. Another method which will provide information regarding thrust bearing failure is monitoring of thrust bearing temperatures by operating personnel, if permanent instrumentation is provided, or through the use of contact pyrometers and/or thermography. Therefore, if vibration data is obtained and trended and bearing lubrication verified to be satisfactory on a quarterly basis (or other frequency determined to be adequate by plant-specific operating history), then mechanical fatigue of the pumps' rotating members is effectively managed.

Table 5-8. Effective Programs/Techniques for Raw Water System Pumps

Pump Subcomponent	Required Effective Programs/Techniques						Supplemental Programs/Techniques				
	ASME Section XI ISI/IST	ASME Section XI Wall Thinning	Tech Spec Surveillance	Preventive Maintenance	Pump Erosion Control	MIC Control	Pump Lay-up	Thermography	Operator Activities	Coatings Surveys	Industry Experience
ROTATING/RECIPROCATING											
• Shaft											
- Mech. Fatigue			Vibration	Vibration							
- General Corr.			Vibration	Vibration			Preser-vation				
- Galvanic Corr.			Vibration	Vibration			Preser-vation				
- IGSCC			Vibration	Vibration							
- Wear			Vibration	Vibration							
• Impeller											
- Mech. Fatigue			Vibration	Vibration							
- General Corr.			Vibration	Vibration			Preser-vation				
- Galvanic Corr.			Vibration	Vibration			Preser-vation				
- IGSCC			Vibration	Vibration							
- Erosion and E/C			TDH & Flow Rate	TDH & Flow Rate							
- Wear			Vibration	Vibration							
- Fouling			TDH & Flow Rate	TDH & Flow Rate							
FIXED INTERNALS											
• Misc. Struct. Comp.											
- General Corr.				Visual Exam			Preser-vation				
- Galvanic Corr.				Visual Exam			Preser-vation				

Table 5-8. Effective Programs/Techniques for Raw Water System Pumps (continued)

Pump Subcomponent	Required Effective Programs/Techniques						Supplemental Programs/Techniques				
	ASME Section XI ISI/IST	ASME Section XI Wall Thinning	Tech Spec Surveillance	Preventive Maintenance	Pump Erosion Control	MIC Control	Pump Lay-up	Thermography	Operator Activities	Coatings Surveys	Industry Experience
FIXED INTERNALS (continued)											
- MIC						Sampling	Preservation				
- IGSCC & TGSCC				Surface Exam							
- Fouling			TDH & Flow Rate	TDH & Flow Rate							
• Wearing Components											
- General Corr.				Visual Exam			Preservation				
- Galvanic Corr.				Visual Exam			Preservation				
- IGSCC & TGSCC				Surface Exam							
- Erosion and E/C			TDH & Flow Rate	TDH & Flow Rate							
- Wear			TDH & Flow Rate	TDH & Flow Rate							
• Flow Guides											
- General Corr.				Visual Exam			Preservation				
- Galvanic Corr.				Visual Exam			Preservation				
- MIC						Sampling	Preservation				
- IGSCC				Surface Exam							
- Erosion and E/C			TDH & Flow Rate	TDH & Flow Rate							
- Fouling			TDH & Flow Rate	TDH & Flow Rate							

Table 5-8. Effective Programs/Techniques for Raw Water System Pumps (continued)

Pump Subcomponent	Required Effective Programs/Techniques						Supplemental Programs/Techniques				
	ASME Section XI ISI/IST	ASME Section XI Wall Thinning	Tech Spec Surveillance	Preventive Maintenance	Pump Erosion Control	MIC Control	Pump Lay-up	Thermography	Operator Activities	Coatings Surveys	Industry Experience
FIXED INTERNALS (continued)											
• Suction Strainer											
- General Corr.				Visual Exam			Preser-vation				
- Galvanic Corr.				Visual Exam			Preser-vation				
- MIC						Sampling	Preser-vation				
- IGSCC				*Surface Exam*							
- Erosion and E/C			TDH & Flow Rate	TDH & Flow Rate							
- Fouling			TDH & Flow Rate	TDH & Flow Rate							
PRESSURE BOUNDARY											
• Casing and Nozzles											
- Mech. Fatigue	Surface Exam & Pressure Test										
- General Corr.				Inspection	Volumet-ric Exam		Preser-vation				
- Galvanic Corr.				Inspection	Volumet-ric Exam		Preser-vation				
- MIC						Sampling	Preser-vation				
- IGSCC	Surface Exam & Pressure Test										

Table 5-8. Effective Programs/Techniques for Raw Water System Pumps (continued)

Pump Subcomponent	Required Effective Programs/Techniques						Supplemental Programs/Techniques				
	ASME Section XI ISI/IST	ASME Section XI Wall Thinning	Tech Spec Surveillance	Preventive Maintenance	Pump Erosion Control	MIC Control	Pump Lay-up	Thermography	Operator Activities	Coatings Surveys	Industry Experience
PRESSURE BOUNDARY (continued)											
- Erosion and E/C					Volumet-ric Exam						
- Fouling			TDH & Flow Rate	TDH & Flow Rate							
• Disch. Head/Column/ Bowl/Nozzles											
- Mech. Fatigue	Surface Exam & Pressure Test										
- General Corr.				Inspection	Volumet-ric Exam		Preser-vation			Introduc-tion	
- IGSCC	Surface Exam & Pressure Test										
- Erosion and E/C					Volumet-ric Exam						
- Fouling			TDH & Flow Rate	TDH & Flow Rate							
• Flange/Cover											
- Mech. Fatigue	Surface Exam & Pressure Test										
- General Corr.				Inspection	Volumet-ric Exam		Preser-vation			Inspec-tion	
- Galvanic Corr.				Inspection	Volumet-ric Exam		Preser-vation			Inspec-tion	
- MIC						Sampling	Preser-vation				

Table 5-8. Effective Programs/Techniques for Raw Water System Pumps (continued)

Pump Subcomponent	Required Effective Programs/Techniques						Supplemental Programs/Techniques				
	ASME Section XI ISI/IST	ASME Section XI Wall Thinning	Tech Spec Surveillance	Preventive Maintenance	Pump Erosion Control	MIC Control	Pump Lay-up	Thermography	Operator Activities	Coatings Surveys	Industry Experience
PRESSURE BOUNDARY (continued)											
- IGSCC	Surface Exam & Pressure Test										
- Erosion and E/C					Volumetric Exam						
- Fouling			TDH & Flow Rate	TDH & Flow Rate							
• Fasteners											
- Mech. Fatigue	Volumetric Exam			Torque Verification							
- General Corr.				Inspection							
MECHANICAL SUBSYSTEMS											
• Coupling											
- Mech. Fatigue			Vibration	Vibration							
- General Corr.				Inspection					Inspection		
- Wear			Vibration	Vibration							
• Seals											
- General Corr.				Inspection					Inspection		
- Galvanic Corr.				Inspection					Inspection		
- IGSCC				Inspection					Inspection		
- Wear				Inspection					Inspection		
• Radial Bearing											
- Wear			Vibration	Vib. & Lube Analysis				Temp. Monitoring	Temp. Monitoring		

Table 5-8. Effective Programs/Techniques for Raw Water System Pumps (continued)

Pump Subcomponent	Required Effective Programs/Techniques						Supplemental Programs/Techniques				
	ASME Section XI ISI/IST	ASME Section XI Wall Thinning	Tech Spec Surveillance	Preventive Maintenance	Pump Erosion Control	MIC Control	Pump Lay-up	Thermography	Operator Activities	Coatings Surveys	Industry Experience
MECHANICAL SUBSYSTEMS (continued)											
• Internal Radial Bearing											
- General Corr.			Vibration	Vibration			Preser-vation				
- Galvanic Corr.			Vibration	Vibration			Preser-vation				
- IGSCC			Vibration	Vibration							
- Erosion and E/C			Vibration	Vibration							
- Wear			Vibration	Vibration							
• Thrust Bearing											
- Mech. Fatigue			Vibration	Vib. & Lube Analysis				Temp. Monitoring	Temp. Monitoring		
- Wear			Vibration	Vib. & Lube Analysis				Temp. Monitoring	Temp. Monitoring		
SUPPORTS											
• Support Feet/Skirt											
- Mech. Fatigue				Vib. & Inspection							
- General Corr.				Inspection						Inspec-tion	
• Base Frame/Skid											
- General Corr.				Inspection						Inspec-tion	
• Fasteners											
- General Corr.				Inspection						Inspec-tion	

Mechanical fatigue failure of the pump support feet/skirt will be detected during preventive maintenance inspections and vibration monitoring. Therefore, if vibration data is obtained and trended on a quarterly basis (or other frequency determined to be adequate by plant-specific operating history), and visual inspection and fastener torque verification performed each refueling outage (or other frequency determined to be adequate by plant-specific operating history), then mechanical fatigue of the pumps' support feet/skirt is effectively managed.

Mechanical fatigue of pressure boundary components associated with the centrifugal pumps (i.e., casing, flange/cover, discharge head/column/bowl, suction and discharge nozzle, and fasteners) is effectively managed through implementation of the plants' ASME Section XI Inservice Inspection Program and Preventive Maintenance Program. Surface examinations, consisting of either the liquid penetrant or magnetic particle process, and hydrostatic pressure tests are performed to verify pressure boundary integrity. Volumetric examination is performed on pressure boundary fasteners that are greater than two inches in diameter. For fasteners less than 5.1 cm [2 in] in diameter, preventive maintenance activities, consisting of inspections, replacements, and fastener torque verification are performed. Through a combination of ASME Section XI and preventive maintenance tasks, mechanical fatigue of pressure boundary components will be detected and corrective actions implemented to ensure safe and reliable pump operation. Therefore, if surface examinations, hydrostatic pressure tests, and volumetric examinations on fasteners greater than 5.1 cm [2 in] in diameter are performed each inspection interval and; visual inspection, parts replacement, and fastener torque verification (on fasteners less than 5.1 cm [2 in] in diameter) is performed each refueling outage (or other frequency determined to be adequate by plant-specific operating history), then mechanical fatigue of the pumps' pressure boundary components is effectively managed.

5.4.7.2 General and Galvanic Corrosion

From Table 4-10, general corrosion is a significant aging mechanism for all wetted pump subcomponents manufactured from carbon and low alloy steel, cast iron, stainless and high allay steel. Also, from Table 4-10 , galvanic corrosion is a significant aging mechanism for: 1) all pump subcomponents manufactured from carbon and low alloy steel or cast iron and; 2) bronze and brass materials when in contact with stainless and high alloy steels.

Detecting the presence of general and galvanic corrosion associated with raw water system pump internal subcomponents is virtually impossible to achieve until such time as the subcomponent begins to exhibit abnormal behavior. Otherwise, the pump will require disassembly for internal inspection. Therefore, pump performance monitoring, data acquisition, and trending of key parameters may provide sufficient information, prior to pump failure, so that planned maintenance activities can be conducted to repair or replace the affected pump internal subcomponent(s). Visual inspection is also helpful for corrosion detection in some situations. A combination of programs/techniques must be implemented to effectively manage general and galvanic corrosion of raw service water pump internal subcomponents.

For these centrifugal pump rotating members (i.e., shaft, impeller, and internal radial bearing) vibration monitoring in accordance with either the plants' Preventive Maintenance Program or Surveillance Testing Program, which ever applies, is the most effective method to detect significant degradation and pump failure from general and galvanic corrosion. Horizontal, vertical, axial, and shaft vibration data should be acquired. Torsional vibration data is not required because general and galvanic corrosion occurring to the shaft and impeller will not alter axial torque and torsional inertia of these rotating members. Permanently installed vibration pickups with monitoring capability would be the optimum installation; however, this is not a requirement to acquire the necessary vibration data. Therefore, if vibration data is obtained and trended on a quarterly basis (or other frequency determined to be adequate by plant-specific operating history), then general and galvanic corrosion of the pump rotating members are effectively managed.

For these centrifugal pump fixed internal members (i.e., flow guides, miscellaneous structural members, suction strainers, and wearing components) general and galvanic corrosion can only be effectively managed by visual (VT-3) examination. Section 6 provides information regarding the requirements to effectively manage general and galvanic corrosion of these pump subcomponents. This is accomplished by performing a visual examination of these pump components once each inspection interval.

Degradation of internal pressure boundary component surfaces associated with these raw water system pumps from general and galvanic corrosion is effectively managed through implementation of the Plants' Pump Erosion Control Program. Internal surface corrosion will cause wall thinning. Volumetric examinations are performed to detect the amount of wall thinning. The data is analyzed and wall thinning rates are calculated. Corrective actions are implemented when the analysis shows that the minimum acceptable wall thickness will be exceeded prior to the next scheduled examination. Therefore, if volumetric examination data is obtained and analyzed and wall thinning rates calculated each inspection interval (or other frequency determined to be adequate based on wall thinning projections), and corrective actions implemented prior to exceeding minimum acceptable wall thickness, then general and galvanic corrosion of the pumps' pressure boundary components are effectively managed.

During plant outages, when these raw water system pumps are not required to be operating, appropriate lay-up practices should be implemented to inhibit general and galvanic corrosion of all wetted pump subcomponents.

For all pump external pressure boundary surfaces, mechanical subsystem components, and support components susceptible to general and/or galvanic corrosion, inspections conducted in accordance with the Plants' Preventive Maintenance Program will effectively manage these aging mechanisms. Protective coatings applied to the casing, nozzles, flange/cover, support feet/skirt, and base frame/skid are verified to be intact. The fasteners are inspected and verified to be free from excessive corrosion product accumulation and the tightness is checked. As the mechanical seal/packing assembly deteriorates from corrosion, fluid leakage will be detected by visual observation during operator rounds or preventive maintenance inspection. The coupling is verified to be free from corrosion product accumulation. If corrosion is observed to be detrimental to safe and reliable pump operation, corrective actions in the form of repair/replacement/refurbishment is performed to restore the pump to a condition where safe and reliable operation is assured. Therefore, if visual inspection, parts replacement, and fastener torque verification is performed each refueling outage (or other frequency determined to be adequate by plant-specific operating history), then general and galvanic corrosion of the pumps' external surfaces, mechanical subsystem components and support base components are effectively managed.

5.4.7.3 Microbiologically Influenced Corrosion

Detecting the presence of MIC associated with the various raw water system pump subcomponents is accomplished by sampling the fluid and by sampling any solid materials found when the pump is opened up to perform maintenance. During pump testing, fluid samples shall be obtained and an analysis performed to; identify heavily infested areas, evaluate the effectiveness of the treatment method (i.e., if MIC was previously discovered), locate areas where microbes are rapidly reproducing, and to trend the data. If the pump is opened up for maintenance purposes, deposits, tubercules, and/or corrosion products should be removed for analysis. The analysis should assess the magnitude and severity of microorganism growth and determine the appropriate treatment method to mitigate further propagation of MIC.

Through fluid and solid material sampling, analysis, and trending of the data sufficient information is available to effectively detect the presence of MIC. Planned maintenance and/or treatment methods can be implemented to ensure safe and reliable operation of the pumps' fixed internal and pressure boundary subcomponents. Therefore, if fluid sampling, analysis and trending of data is performed quarterly during pump testing (or other frequency determined to be adequate by plant-specific operating history), and; solid sampling, analysis and trending of data is performed whenever the pump is opened up for maintenance, and; corrective actions are implemented as appropriate, then microbiologically influenced corrosion of the pumps' fixed internal and pressure boundary components is effectively managed.

During plant outages, appropriate lay-up activities should be implemented to reduce the potential for MIC to occur in these raw water system pumps.

5.4.7.4 Intergranular and Transgranular Stress Corrosion Cracking (IGSCC and TGSCC)

From Table 4-10, IGSCC is significant for raw water system pump subcomponents made from stainless and high alloy steel due to the presence of fluid impurities such as chlorides.

Detecting the presence of IGSCC associated with the raw water system pump internal subcomponents is virtually impossible to achieve until such time as the subcomponent begins to exhibit abnormal behavior. Otherwise the pump will require disassembly for internal inspection. Therefore, pump performance monitoring, data acquisition, and trending of key parameters may provide sufficient information, prior to pump failure, so that planned maintenance activities can be conducted to repair or replace the affected pump internal subcomponent(s). Visual inspection is also helpful for IGSCC and TGSCC detection in some situations. A combination of programs/techniques must be implemented to effectively manage IGSCC of raw water pump internal subcomponents.

For the centrifugal pump rotating members (i.e., shaft, impeller, and internal radial bearing) vibration monitoring in accordance with either the plants' Preventive Maintenance Program or Surveillance Testing Program, which ever applies, is the most effective method to detect significant degradation and pump failure from IGSCC. Horizontal, vertical, axial, and shaft vibration data should be acquired. As discussed in Section 5.4.7.1, torsional vibration data should be obtained if possible to provide additional information regarding shaft condition. Since some of these raw service water pumps are continuously operated, permanently installed vibration pickups with monitoring capability would be the optimum installation; however, this is not a requirement to acquire the necessary vibration data. Therefore, if vibration data is obtained and trended on a quarterly basis (or other frequency determined to be adequate by plant-specific operating history), then intergranular stress corrosion cracking of the centrifugal raw water pump rotating members is effectively managed.

For the centrifugal raw water pump fixed internal members (i.e., flow guides, suction strainers, miscellaneous structural components, and wearing components) IGSCC can only be effectively managed by surface examination. Section 6 provides information regarding the requirements to effectively manage IGSCC of these pump subcomponents. This is accomplished by performing surface examinations of these components once each inspection interval.

Most raw service water pump pressure boundary components are not made from stainless or high alloy steel. However, if they are, then IGSCC of the pressure boundary components (i.e, casing, flange/cover, discharge head/column/bowl, and suction and discharge nozzle) is effectively managed through implementation of the plants' ASME Section XI Inservice Inspection Program. Surface examinations, consisting of either liquid penetrant or the magnetic particle process, and hydrostatic pressure tests are performed to verify pressure boundary integrity. IGSCC of these pressure boundary components will be detected and pressure boundary integrity verified through performance of these ASME Section XI requirements. Corrective actions are implemented as necessary to ensure safe and reliable pump operation. Therefore, if surface examination and hydrostatic pressure tests are performed each inspection interval, then IGSCC of the pumps' stainless or high alloy steel pressure boundary components is effectively managed.

IGSCC of the pumps' mechanical seal/packing assembly associated with the raw water pumps will be detected and effectively managed through inspections conducted in accordance with the plants' Preventive Maintenance Program. Fluid leakage can be readily detected by visual observation during operator rounds activities or preventive maintenance inspections. Therefore, if visual inspections are performed on a quarterly basis (or other frequency determined to be adequate by plant-specific operating history), then IGSCC of the pumps' mechanical seal/packing assembly is effectively managed.

From Table 4-10, IGSCC and TGSCC is significant for miscellaneous structural components and wearing components made from wrought brass or bronze materials containing >15% zinc. For these centrifugal pump fixed internal members, IGSCC and TGSCC can only be effectively managed by surface examination. Section 6 provides information regarding the requirements to effectively manage IGSCC and TGSCC of these pump subcomponents. This is accomplished by performing surface examinations of these components once each inspection interval.

5.4.7.5 Erosion and Erosion/Corrosion

Detecting the presence of erosion and erosion/corrosion associated with raw water system pump impellers, flow guides, wearing components, and suction strainers (i.e., centrifugal pumps) is virtually impossible to achieve until such time as the pump begins to exhibit abnormal behavior. Programs/techniques to effectively manage this aging mechanism for these pump subcomponents are performance based. Through pump performance monitoring and data acquisition, the trending of key operational parameters may provide sufficient information, prior to pump failure, so that planned maintenance activities can be conducted to repair/replace the affected pump subcomponents.

For the centrifugal pump impellers, flow guides, wearing components, and suction strainers, erosion and erosion/corrosion are effectively managed through pump performance testing in accordance with the plants' Preventive Maintenance or Surveillance Testing Program, which ever applies. Degradation of the centrifugal pump impeller, flow guides, suction strainers, and/or wearing components due to erosion and erosion/corrosion will cause a reduction in pump performance as measured by total developed head and flow rate. Therefore, if total developed head and flow rate data are obtained on a quarterly basis (or other frequency determined to be adequate by plant-specific operating history), and compared against the design pump curve, then erosion and erosion/corrosion of the centrifugal pump impellers, flow guides, suction strainer, and wearing components are effectively managed.

Degradation of the raw water system pump pressure boundary components (i.e, casing, discharge head/column/bowl, flange/cover, and suction/discharge nozzles) from erosion and erosion/corrosion is effectively managed through implementation of the plants' Pump Erosion Control Program. This program is for effectively managing wall thinning of pressure boundary casings and nozzles due to erosion caused by cavitation and/or particle impingement. Volumetric examinations are performed to detect the amount of wall thinning. The data is analyzed, and wall thinning rates are calculated. Corrective actions are implemented when the analysis shows that the minimum acceptable wall thickness will be exceeded prior to the next schedule examination. Therefore, if volumetric examination data is obtained and analyzed and wall thinning rates calculated each inspection interval (or other frequency determined to be adequate based on wall thinning projections), and corrective actions implemented prior to exceeding minimum acceptable wall thickness, then erosion and erosion/corrosion of the pumps' pressure boundary components are effectively managed.

Degradation of the raw water system pump internal radial bearings from erosion and erosion/corrosion is effectively managed by vibration monitoring in accordance with the plant's Preventive Maintenance Program or Surveillance Program, which ever applies. Horizontal, vertical, axial, and shaft vibration data should be acquired. Torsional vibration data is not required because erosion of the internal radial bearings will not alter axial torque and torsional inertia of the rotating members. Therefore, if vibration data is obtained and trended on a quarterly basis (or other frequency determined to be adequate by plant-specific operating history), then erosion and erosion/corrosion of the pumps' internal radial bearing are effectively managed.

5.4.7.6 Wear

Detecting the presence of wear associated with the various raw water system pump subcomponents is achievable through a combination of programs. As subcomponent wear progresses, the pump operating characteristics will begin to deviate from normally observed values. Through pump performance monitoring, data acquisition, trending of key operational parameters and diagnostic analysis, sufficient information will be obtained, prior to failure, so that planned maintenance activities can be conducted to repair/replace/refurbish the affected pump subcomponent(s). Visual inspection is also helpful for wear detection in some situations.

For most of the pumps' rotating and mechanical subsystem components, vibration monitoring in accordance with either the plant's Preventive Maintenance Program or Surveillance Program, which ever applies, is the most effective method to detect adverse vibration trends due to wear of these subcomponents. Since some of these raw water system pumps are continuously operating, permanently installed vibration pickups with monitoring capability would be the optimum installation; however, this is not a requirement to acquire the necessary vibration data.

For centrifugal pump rotating members (i.e., shaft, impeller, radial bearing, internal radial bearings, thrust bearing, and coupling) subject to wear, horizontal, vertical, axial, and shaft vibration data should be acquired. As discussed in Section 5.4.7.1, torsional vibration data is not required for many of these pumps because they operate intermittently. However, torsional vibration data should be obtained and analyzed for the large continuously operated raw water pumps. Also, bearing lubrication samples should be obtained for all of these pumps and chemically analyzed or the lubrication changed out on a scheduled basis. Another method which provides pertinent data regarding bearing wear is the monitoring of bearing temperatures. If permanent instrumentation is installed, bearing temperatures can be monitored by operating personnel. Otherwise, contact pyrometers and/or thermography should be utilized. Therefore, if vibration data is obtained and trended and bearing lubrication verified to be satisfactory on a quarterly basis (or other frequency determined to be adequate by plant-specific operating history), then wear of the pumps' rotating members is effectively managed.

For the fixed internal wearing components associated with the raw water system centrifugal pumps, wear is effectively managed through pump performance testing in accordance with the plants' Preventive Maintenance or Surveillance Testing Program, which ever applies. As these components wear, a deviation in the pumps' normal developed head and flow rate characteristics will be observed. This phenomenon will be detected by trending these operating parameters and comparing the data against the design pump curve. Therefore, if normal operating developed head and flow rate data are obtained and trended on a quarterly basis (or other frequency determined to be adequate by plant-specific operating history), and compared against the design pump curve, then wear of the centrifugal pump fixed internal wearing components is effectively managed.

For the mechanical seal/packing assembly associated with these raw water system pumps, wear is effectively managed through inspections conducted in accordance with the plants' Preventive Maintenance Program. As the mechanical seal/packing assembly wears it will begin to leak fluid. This leakage can be readily detected by visual observation during operator rounds activities or preventive maintenance inspections. Therefore, if visual inspections are performed on a quarterly basis (or other frequency determined to be adequate by plant-specific operating history), then wear of the pumps' mechanical seal/packing assembly is effectively managed.

5.4.7.7 Fouling

Detecting the presence of fouling associated with raw water system pump, rotating, pressure boundary, and fixed internal components is achieved through implementation of pump performance testing in accordance with the plants' Preventive Maintenance Program or Surveillance Testing Program, which ever applies. Through pump performance monitoring, data acquisition, trending of key operational parameters and diagnostic analysis, sufficient information will be obtained so that planned maintenance can be performed to repair, replace, or refurbish these components. As fouling progresses, a deviation in the pumps' normal developed head and flow rate characteristics will be observed. Fouling will be detected by trending these operating parameters and comparing the data against the design pump curve. Therefore, if total developed head and flow rate data are obtained on a quarterly basis (or other frequency determined to be adequate by plant-specific operating history), and compared against the design pump curve, then fouling of the centrifugal pumps' rotating, pressure boundary, and fixed internal components is effectively managed.

5.5 References

5.1 Title 10, U.S. Code of Federal Regulations, 10 CFR Part 54, "Requirements for Renewal of Operating Licenses for Nuclear Power Plants," December 13, 1991.

5.2 Title 10 of the Code of Federal Regulation, 10 CFR 50.65, "Requirements for Monitoring the Effectiveness of Maintenance at Nuclear Power Plants," July 10, 1991.

5.3 Title 10 of the Code of Federal Regulation, 10 CFR 50 Appendix B, "Quality Assurance Criteria for Nuclear Power Plants and Fuel Reprocessing Plants," 1992.

5.4 ASME OM Code, "Code for Operation and Maintenance of Nuclear Power Plants," Subsection ISTB, Inservice Testing of Pumps in Light-Water Reactor Power Plants, 1990 Edition.

5.5 ASME Boiler and Pressure Vessel Code Section XI, "Rules for Inservice Inspection of Nuclear Power Plant Components," 1991 Addenda, December 31, 1991.

5.6 ASME Code Case N-498, "Alternative Rules for 10-Year Hydrostatic Pressure Testing for Class 1 and 2 Systems Section XI, Division 1," May 13, 1991.

5.7 ASME Code Case N-480, "Examination Requirements for Pipe Wall Thinning Due to Single Phase Erosion and Corrosion Section XI, Division I," May 10, 1990.

5.8 EPRI Research Project RP2812-2, "Sourcebook for Microbiologically Influenced Corrosion in Nuclear Power Plants," Prepared by Structural Integrity Associates, Inc., 1988.

5.9 EPRI NP-5106, "Plant Layup and Equipment Preservation Sourcebook," Prepared by Multiple Dynamics Corporation, March 1987, p. 5-6.

5.10 *Metals Handbook*, Ninth Edition, "Corrosion," Volume 13, 1987, p. 489.

6. OTHER AGING MANAGEMENT CONSIDERATIONS

The aging mechanisms affecting the various pump components in the scope of this guideline were discussed in Section 4. Section 5 evaluated each significant aging mechanism with respect to current maintenance, inspection, trending, and testing programs/techniques. For the majority of significant aging mechanisms, it was determined that current programs/techniques are effective in detecting and/or mitigating degradation and in ensuring long-term safe and reliable operation of these pumps. For the few cases where current programs/techniques do not adequately detect or mitigate pump degradation caused by the significant aging mechanisms, additional aging management considerations are required.

The specific pump components, significant aging mechanisms, and pumped fluid services that warrant further aging management considerations are discussed below.

6.1 Borated Water Service Pumps

From Section 5.4.2.3, IGSCC of various BWR standby liquid control pump components and PWR boric acid transfer pump components is not effectively managed by current plant programs/techniques. Therefore, the plants' Preventive Maintenance Program should require that once each ten-year inspection interval, at least one pump of each type be opened up for inspection. Surface examinations, in accordance with equivalent criteria as established in ASME Section XI,[6.1] should be performed on the internal pump components identified as susceptible to IGSCC. The reciprocating Standby Liquid Control System pump components which must be examined are the piston/plunger, internal valve, miscellaneous structural components, and wearing components. The centrifugal Boric Acid Transfer System pump components which must be examined are the flow guides, miscellaneous structural components, and wearing components.

6.2 Treated Water Service Pumps

From Section 5.4.3.4, IGSCC of the BWR and PWR residual heat removal pump fixed internal components, manufactured from stainless or high alloy steel, is not effectively managed by current plant programs/techniques. Therefore, the plant Preventive Maintenance Program should require that once each ten-year inspection interval, at least one RHR pump be opened up for inspection. Surface examinations, in accordance with equivalent criteria as established in ASME Section XI,[6.1] should be performed on the fixed internal wearing components, flow guides, and miscellaneous structural components that are made from stainless and high alloy steel materials.

From Sections 5.4.3.4 and 5.4.4.4, IGSCC and TGSCC of the treated water system pump miscellaneous structural components and wearing components manufactured from wrought bronze or brass containing >15% zinc is not effectively managed by current plant programs/techniques. Therefore, the Plant Preventive Maintenance Program should require that once each ten-year inspection interval, at least one pump in each of the treated water systems (BWR-CRD, RHR, FPC, Core Spray, HPCI and RCIC/PWR-Primary Makeup, RHR, FPC, AFW, SI, Containment Recirculation, and Containment Spray) be opened up for inspection. Surface examinations, in accordance with equivalent criteria as established in ASME Section XI,[6.1] should be performed on the fixed internal miscellaneous structural components and wearing components that are made from wrought bronze or brass materials.

From Sections 5.4.3.2 and 5.4.4.2, general and galvanic corrosion of the treated water system pump fixed internal components, manufactured from carbon and low alloy steel, cast iron, bronze and/or brass is not effectively managed by current plant programs/techniques. Therefore, the plants' Preventive Maintenance Program should require that once each ten-year inspection interval, at least one pump in each treated water system (BWR-CRD, RHR, FPC, Core Spray, HPCI and RCIC/PWR-Primary Makeup, RHR, FPC, AFW, Containment Recirculation, and Containment Spray) be opened up for inspection. Visual examinations, in accordance with equivalent criteria (i.e., VT-3) as established in ASME Section XI,[6.1] should be performed on the fixed internal components that are made from these materials.

6.3 Closed Cooling Water Pumps

From Section 5.4.5.2, general corrosion of the closed cooling water system pump fixed internal components, manufactured from carbon and low alloy steel, cast iron, bronze, and/or brass is not effectively managed by current plant programs/techniques. Therefore, the plant Preventive Maintenance Program should require that once each ten-year inspection interval, at least one pump in each closed cooling water system be opened up for inspection. Visual examinations, in accordance with equivalent criteria (i.e., VT-3) as established in ASME Section XI,[6.1] should be performed on the fixed internal components that are made from these materials.

From Section 5.4.5.3, IGSCC and TGSCC of the closed cooling water system pump miscellaneous structural components and wearing components manufactured from wrought bronze or brass containing >15% zinc is not effectively managed by current plant programs/techniques. Therefore, the plant Preventive Maintenance Program should require that once each ten-year inspection interval, at least one pump in each closed cooling water system be opened up for inspection. Surface examinations, in accordance with equivalent criteria as established in ASME Section XI,[6.1] should be performed on the fixed internal miscellaneous structural components and wearing components that are made from these materials.

6.4 Lubrication and Fuel Oil Pumps

From Section 5.4.6.2, general corrosion of the lubrication and fuel oil system pump fixed internal components, manufactured from carbon and low alloy steel and cast iron is not effectively managed by current plant programs/techniques. Therefore, the plant Preventive Maintenance Program should require that once each ten-year inspection interval, at least one pump in each lubrication and fuel oil system be opened up for inspection. Visual examinations, in accordance with equivalent criteria (i.e., VT-3) as established in ASME Section XI,[6.1] should be performed on the fixed internal components that are made from these materials.

6.5 Raw Water Service Pumps

From Section 5.4.7.2; 1) general and galvanic corrosion of the raw water system pump fixed internal components, manufactured from carbon and low alloy steel, cast iron, bronze and/or brass and; 2) general corrosion of the raw water system pump fixed internal components, manufactured from stainless and high alloy steel, are not effectively managed by current plant programs/techniques. Therefore, the plant Preventive Maintenance Program should require that once each ten-year inspection interval, at least one pump in each raw water system be opened up for inspection. Visual examinations, in accordance with equivalent criteria (i.e., VT-3) as established in ASME Section XI,[6.1] should be performed on the fixed internal components that are made from these materials.

From Section 5.4.7.4; 1) IGSCC of the raw water system pump flow guides, suction strainers, miscellaneous structural components, and wearing components manufactured from stainless and high alloy steel and; 2) IGSCC and TGSCC of the raw water system pump miscellaneous structural components and wearing components manufactured from wrought bronze or brass containing >15% zinc are not effectively managed by current plant programs/techniques. Therefore, the Plant Preventive Maintenance Program should require that once each ten-year inspection interval, at least one pump in each raw water system be opened up for inspection. Surface examinations, in accordance with equivalent criteria as established in ASME Section XI, [6.1] should be performed on the fixed internal components made from these materials.

6.6 References

6.1 ASME B&PV Code Section XI, "Rules for Inservice Inspection of Nuclear Power Plant Components," 1989 Edition, 1991 Addenda.

APPENDIX A
DEFINITIONS[A.1]

accelerated aging artificial aging in which the simulation of natural aging approximates, in a short time, the aging effects of longer-term service conditions

acceptance criterion specified limit of a functional or condition indicator used to assess the ability of an SSC* to perform its design function

age (noun) time from fabrication of an SSC to a stated time

age conditioning simulation of natural aging effects in an SSC by the application of any combination of artificial and natural aging

age-related degradation synonym for **aging degradation**

aging (noun) general process in which characteristics of an SSC gradually change with time or use

aging assessment evaluation of appropriate information for determining the effects of aging on the current and future ability of SSCs to function within acceptance criteria

aging degradation aging effects that could impair the ability of an SSC to function within acceptance criteria

aging effects net changes in characteristics of an SSC that occur with time or use and are due to aging mechanisms

aging management engineering, operations, and maintenance actions to control within acceptable limits aging degradation and wearout of SSCs

aging mechanism specific process that gradually changes characteristics of an SSC with time or use

artificial aging simulation of natural aging effects on SSCs by application of stressors representing plant pre-service and service conditions, but perhaps different in intensity, duration, and manner of application

breakdown synonym for **complete failure**

characteristic property or attribute of an SSC (such as shape, dimension, weight, condition indicator, functional indicator, performance or mechanical, chemical, or electrical property)

---

* SSC = system, structure, or component

combined effects net changes in characteristics of an SSC produced by two or more stressors

common cause failure two or more failures due to a single cause

common mode failure two or more failures in the same manner or mode due to a single cause

complete failure failure in which there is complete loss of function

condition the state or level of characteristics of an SSC that can affect its ability to perform a design function

condition surrounding physical state or influence that can affect an SSC

condition indicator characteristic that can be observed, measured, or trended to infer or directly indicate the current and future ability of an SSC to function within acceptance criteria

condition monitoring observation, measurement, or trending of condition or functional indicators with respect to some independent parameter (usually time or cycles) to indicate the current and future ability of an SSC to function within acceptance criteria

condition trending synonym for **condition monitoring**

corrective maintenance actions that restore, by repair, overhaul, or replacement, the capability of a failed SSC to function within acceptance criteria

degradation immediate or gradual deterioration of characteristics of an SSC that could impair its ability to function within acceptance criteria

degraded condition marginally acceptable condition of an unfailed SSC that could lead to a decision to perform planned maintenance

degraded failure failure in which a functional indicator does not meet an acceptance criterion, but design function is not completely lost

design basis conditions synonym for **design conditions**

design basis event any of the events specified in the station's safety analysis that are used to establish acceptable performance for safety-related functions of SSCs; events include anticipated transients, design basis accidents, external events, and natural phenomena

design basis event conditions service conditions produced by design basis events

design basis event stressor stressor that stems from design basis events and can produce immediate or aging degradation beyond that produced by normal stressors

design conditions specified service conditions used to establish the specifications of an SSC (generally includes margin of conservatism beyond expected service conditions)

design life period during which an SSC is expected to function within acceptance criteria

design service conditions synonym for **design conditions**

deterioration synonym for **degradation**

diagnosis examination and evaluation of data to determine either the condition of an SSC or the causes of the condition

diagnostic evaluation synonym for **diagnosis**

environmental conditions ambient physical states surrounding an SSC

error-induced aging degradation aging degradation produced by error-induced conditions

error-induced conditions adverse pre-service or service conditions produced by design, fabrication, installation, operation, or maintenance errors

error-induced stressor stressor that stems from error-induced conditions and can produce immediate or aging degradation beyond that produced by normal stressors

failure inability or interruption of ability of an SSC to function within acceptance criteria

failure analysis systematic process of determining and documenting the mode, mechanism, causes, and root cause of failure of an SSC

failure cause circumstances during design, manufacture, test, or use that have led to failure

failure evaluation synonym for **failure analysis**

failure mechanism physical process that results in failure

failure mode the manner or state in which an SSC fails

failure modes and effects analysis systematic process for determining and documenting potential failure modes and their effects on SSCs

failure trending recording, analyzing, and extrapolating in-service failures on an SSC with respect to some independent parameter (usually time or cycles)

functional conditions influences on an SSC resulting from the performance of design functions (operation of a system or component and loading of a structure)

functional indicator condition indicator that is a direct indication of the current ability of an SSC to function within acceptance criteria

inservice inspection methods and actions for assuring the structural and pressure-retaining integrity of safety-related nuclear power plant components in accordance with the rules of this Section [ASME Code, Section XI]

inservice life synonym for **service life**, (especially in discussions involving ASME Code Section XI)

inservice test a test to determine the operational readiness of a component or system [ASME Code, Section XI]

inspection synonym for **surveillance**

installed life period from installation to retirement of an SSC

life period from fabrication to retirement of an SSC

life assessment synonym for **aging assessment**

life cycle management synonym for **life management**

life management integration of aging management and economic planning to: (1) optimize the operation, maintenance, and useful life of SSCs; (2) maintain an acceptable level of performance and safety; and (3) maximize return on investment over the useful life of the plant

lifetime synonym for **life**

maintenance aggregate of direct and supporting actions that detect, preclude, or mitigate degradation of a functioning SSC, or restore to an acceptable level the design functions of a failed SSC

malfunction synonym for **failure**

mean time between failures arithmetic average of operating times between failures of an item [IEEE Std 100]

natural aging aging of an SSC that occurs under pre-service and service conditions, including error-induced conditions

normal aging natural aging from error-free pre-service or service conditions

normal aging degradation aging degradation produced by normal conditions

normal conditions operating conditions of a properly designed, fabricated, installed, operated and maintained SSC excluding design basis event conditions

normal operating conditions synonym for **normal conditions**

normal stressor stressor that stems from normal conditions and can produce aging mechanisms and effects in an SSC

operating conditions service conditions, including normal and error-induced conditions, prior to the start of a design basis accident or earthquake

operating service conditions synonym for **operating conditions**

operational conditions synonym for **functional conditions**

overhaul (noun) extensive repair, refurbishment, or both

performance indicator synonym for **functional indicator**

periodic maintenance form of preventive maintenance consisting of servicing, parts replacement, surveillance, or testing at predetermined intervals of calendar time, operating time, or number of cycles

planned maintenance form of preventive maintenance consisting of refurbishment or replacement that is scheduled and performed prior to failure of an SSC

post-maintenance testing testing after maintenance to verify that maintenance was performed correctly and that the SSC can function within acceptance criteria

preconditioning synonym for **age conditioning**

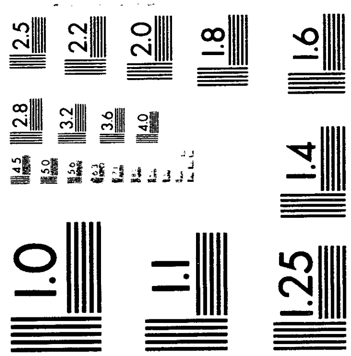
predictive maintenance form of preventive maintenance performed continuously or at intervals governed by observed condition to monitor, diagnose, or trend an SSC's functional or condition indicators; results indicate current and future functional ability or the nature and schedule for planned maintenance

premature aging aging effects of an SSC that occur earlier than expected because of errors or pre-service and service conditions not considered explicitly in design

pre-service conditions actual physical states or influences on an SSC prior to initial operation (e.g., fabrication, storage, transportation, installation, and pre-operational testing)

preventive maintenance actions that detect, preclude, or mitigate degradation of a functional SSC to sustain or extend its useful life by controlling degradation and failures to an acceptable level; there are three types of preventive maintenance: periodic, predictive, and planned.

qualified life period for which an SSC has been demonstrated, through testing, analysis, or experience, to be capable of functioning within acceptance criteria during specified operating conditions while retaining the ability to perform its safety functions in a design basis accident or earthquake



4 of 4

random failure any failure whose cause or mechanism, or both, make its time of occurrence unpredictable [IEEE Std 100]

reconditioning synonym for **overhaul**

refurbishment planned actions to improve the condition of an unfailed SSC

remaining design life period from a stated time to planned retirement of an SSC

remaining life actual period from a stated time to retirement of an SSC

remaining service life synonym for **remaining life**

remaining useful life synonym for **remaining life**

repair actions to return a failed SSC to an acceptable condition

replacement removal of an undegraded, degraded, or failed SSC or a part thereof and installation of another in its place that can function within the original acceptance criteria

residual life synonym for **remaining life**

retirement final withdrawal from service of an SSC

rework correction of inadequately performed fabrication, installation, or maintenance

root cause fundamental reason(s) for an observed condition of an SSC that if corrected prevents recurrence of the condition

root cause analysis synonym for **failure analysis**

service conditions actual physical states or influences during the service life of an SSC, including operating conditions (normal and error-induced), design basis event conditions, and post design basis event conditions

service life actual period from initial operation to retirement of an SSC

servicing routine actions (including cleaning, adjustment, calibration, and replacement of consumable) that sustain or extend the useful life of an SSC

simultaneous effects combined effects from stressors acting simultaneously

stress synonym for **stressor**

stressor agent or stimulus that stems from pre-service and service conditions and can produce immediate or aging degradation of an SSC

surveillance observation or measurement of condition or functional indicators to verify that an SSC currently can function within acceptance criteria

surveillance requirements test, calibration, or inspection to assure that the necessary quality of systems and components is maintained, that facility operation will be within the safety limits, and that the limiting conditions of operation will be met [10 CFR 50.36] (for use only when specific regulatory and legal connotations are called for)

surveillance testing synonym for **surveillance, surveillance requirements**, and **testing** (use only when specific regulatory and legal connotations are called for)

synergistic effects portion of changes in characteristics of an SSC produced solely by the interaction of stressors acting simultaneously, as distinguished from changes produced by superposition from each stressor acting independently

testing observation or measurement of condition indicators under controlled conditions to verify that an SSC currently conforms to acceptance criteria

time in service time from initial operation of an SSC to a stated time

useful life synonym for **service life**

wearout failure produced by an aging mechanism

References

A.1 EPRI TR-100844, "Nuclear Power Plant Common Aging Terminology," prepared by MPR Associates, Inc., November 1992.

APPENDIX B
ACRONYMS

AFW	Auxiliary feedwater
AMG	Aging Management Guideline
ARP	Annunciator response procedure
ASME	American Society of Mechanical Engineers
BAT	Boric Acid Transfer
BEP	Best efficiency point
BL	NRC Bulletin
BWR	Boiling Water Reactor
B&PVC	ASME Boiler and Pressure Vessel Code
C	NRC Circular
CCP	Centrifugal charging pump
CCW	Component Cooling Water System
CFR	Code of Federal Regulations
Cr	Chrome
CRD	Control rod drive
CS	Containment spray
CVCS	Chemical and Volume Control System
DOE	U.S. Department of Energy
dpa	Displacements per atom
ECC	Emergency Core Cooling
ECCS	Emergency Core Cooling System
EECW	Emergency equipment closed cooling water
EPRI	Electric Power Research Institute
ESF	Engineered safety feature
ESW	Emergency/essential service water
FPC	Fuel pool cooling
FSAR	Final Safety Analysis Report
GL	NRC Generic Letter
HPCI	High-Pressure Coolant Injection

IASCC	Irradiation assisted stress corrosion cracking
IGSCC	Intergranular stress corrosion cracking
IN	NRC Information Notice
INPO	Institute for Nuclear Power Operations
IPA	Integrated Plant Assessment
IR	Industry Report
LCM	Life Cycle Management
LCO	Limiting condition for operation
LER	Licensee Event Report
LOCA	Loss-of-coolant accident
LPCI	Low-Pressure Coolant Injection
LWR	Light Water Reactor
MIC	Microbiological Influenced Corrosion
MTBF	Mean time between failure
NMAC	Nuclear Maintenance Application Center (EPRI)
NPAR	Nuclear Plant Aging Research (NRC sponsored)
NPRDS	Nuclear Plant Reliability Data System (INPO)
NPSH	Net positive suction head
NRC	U.S. Nuclear Regulatory Commission
NUMARC	Nuclear Management and Resources Council
O&M	Operations and maintenance
PAN	Polyacrylonitrile
PLIM	Plant Lifetime Improvement
PM	Preventive maintenance
ppm	Parts per million
PVC	Polyvinyl chloride
PWR	Pressurized Water Reactor
RBCCW	Reactor building closed cooling water
RCIC	Reactor Core Isolation Cooling
RCS	Reactor Coolant System
RHR	Residual heat removal

RHRSW	Residual heat removal service water
RWCU	Reactor Water Cleanup
SCs	Structures and components
SCC	Stress corrosion cracking
SHE	Standard hydrogen electrode
SI	Safety Injection
SLC	Standby Liquid Control
SNL	Sandia National Laboratories
SOER	Significant Operating Experience Report
SS	Stainless steel
SSCs	Systems, structures, and components
SSU	Saybolt Seconds Universal
SW	Service Water
TGSCC	Transgranular stress corrosion cracking

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