Aging Effects for Structures and Structural Components (Structural Tools)

B&W Owners Group Generic License Renewal Program, BAW-2279P, 1997



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Final Report, April 2000

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REPORT SUMMARY

As part of the application process for license renewal, nuclear utilities must perform an evaluation to confirm that they have appropriately considered any aging effects on plant components. A management plan must be developed for all components subject to aging effects. This report identifies structures and structural components subject to aging management review for five Babcock and Wilcox (B&W) nuclear plants. The report also describes aging mechanisms that may impact each component.

Background

Structures subject to aging management review (AMR) are those that support, house, and protect systems and components needed to operate the plant safely, such as the auxiliary building and intake structure. Structural components subject to AMR are attached to or reside within structures and are defined as items used to support mechanical components, electrical components, and other structural members. Both structures and structural components must be capable of withstanding, without loss of function, the effects of design basis events. The B&W Owners Group conducted this research to identify applicable aging effects associated with structures and structural components subject to AMR for license renewals.

Objective

To perform a generic evaluation of several B&W nuclear plants to determine which aging effects are applicable to plant structural components—including structural steel and steel components (in air or in fluid), threaded fasteners, concrete structures and components, fire barriers, elastomers, earthen structures, and Teflon.

Approach

The project team identified the structures and structural components subject to AMR at five B&W plants—Arkansas Nuclear One Unit 1; Oconee Nuclear Station Units 1, 2, and 3; and Three Mile Island Unit 1. The team compiled a list of all potential aging mechanisms for each identified component. Finally, they evaluated the lists to determine which mechanisms could be responsible for component aging under bounding environmental and operating conditions.

Results

This report addresses the following topics**:**

- Structures and structural components subject to AMR, including materials of construction
- Representative bounding operating environments for structures and structural components

- Evaluation of aging effects based on materials of construction and operating environment
- An industry performance history to identify past incidents of applicable aging effects for components under review

Based on these considerations, it was determined that certain aging mechanisms were applicable to all of the structural components evaluated. However, a large number of mechanisms were eliminated because they do not result in significant aging degradation under operating conditions. The three participating utilities will use this reduced list of mechanisms to develop plant-specific aging management plans, key elements of which are included in this report.

EPRI Perspective

The structural tools described in this report will be used by utility engineers to determine applicable aging effects when evaluating structures and structural components subject to AMR. The generic evaluation performed here eliminated the need for each of the three participating B&W utilities to perform plant-specific evaluations to determine applicable aging mechanisms. EPRI is considering future updates of the report to 1) extend applicability of the structural tools to a broader range of plants and 2) provide an industry standard for evaluating structures and structural components subject to AMR for license renewals. Related EPRI work includes Non-Class 1 Mechanical Implementation Guideline and Mechanical Tools (TR-114882).

TR-114881

Keywords

Structures
Aging (materials)
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ABSTRACT

Structures and structural components subject to aging management review have been identified by each of the participating B&W plants in accordance with 10 CFR Part 54. The participating B&W plants include Arkansas Nuclear One Unit 1 (ANO-1), Oconee Nuclear Station Units 1, 2 and 3 (ONS-1, -2, and -3), and Three Mile Island Unit 1 (TMI-1).

Structures and structural components subject to aging management review were divided into the following major groups based on materials of construction and operating environments: (1) structural steel and steel components, (2) structural steel and steel components in fluid environments, (3) threaded fasteners, (4) concrete structures and concrete components, (5) fire barriers, (6) elastomers , (7) earthen structures, and (8) teflon. An aging effects evaluation was performed for each material and environment group; the evaluation included (1) identification of representative bounding operating environments, (2) determination of applicable aging effects, and (3) recommendations for technical elements of aging management programs.

This topical report will be used by the participating B&W plants to determine applicable aging effects when evaluating structures and structural components subject to aging management review. Demonstration of aging management to provide reasonable assurance that structure and structural component intended function(s) will be maintained consistent with the current licensing basis (CLB) during the period of extended operation, as required by 10 CFR Part 54.21 (a)(3), will be performed on a plant-specific basis. Time limited aging analyses (TLAA) applicable to structures and structural components within the scope of license renewal will be identified and resolved on a plant-specific basis and are not addressed in this topical report.

ACRONYMS AND ABBREVIATIONS

ACI ..... American Concrete Institute
AISC..... American Institute of Steel Construction
ANO-1..... Arkansas Nuclear One Unit 1
ASME..... American Society of Mechanical Engineers
ASTM..... American Society for Testing and Materials
AWS..... American Welding Society
B&W ..... Babcock & Wilcox
B&WOG..... Babcock & Wilcox Owners Group
BL..... NRC Bulletin
BWNT..... B&W Nuclear Technologies
CEGB ..... Civil Engineering and Geosciences Branch
CFR ..... Code of Federal Regulations
CLB ..... Current Licensing Basis
DBA ..... Design Basis Accident
EPRI ..... Electric Power Research Institute
fps..... feet per second
GL..... NRC Generic Letter
GLRP..... Generic License Renewal Program
HAZ..... Heat Affected Zone
IE ..... Inspection and Enforcement
IGA..... Intergranular Attack
IGSCC ..... Intergranular Stress Corrosion Cracking
IN..... NRC Information Notice
IR..... Industry Report (a EPRI/NUMARC/NEI document)
LER ..... Licensee Event Report
MIC ..... Microbiologically Induced Corrosion
NEI ..... Nuclear Energy Institute (formerly NUMARC)
NPRDS..... Nuclear Plant Reliability Data System
NRC..... U.S. Nuclear Regulatory Commission
NUMARC .. Nuclear Management And Resources Council (now NEI)
ONS..... Oconee Nuclear Station
ppm..... Parts per Million
psi ..... Pounds per Square Inch
PWR ..... Pressurized Water Reactor
SBO ..... Station Blackout
SCC ..... Stress-Corrosion Cracking
SSC..... System Structure and Component
TLAA ..... Time-Limited Aging Analyses
TMI-1 ..... Three Mile Island Unit 1

DEFINITIONS

Applicable Aging Effects are aging effects that are (1) plausible for a given material, environment, and stress combination, and, (2) if undetected, could result in the loss of the component intended function such that the system intended function(s) could not be assured in the period of extended operation.

Component Intended Function(s) are those component level functions that support system level intended functions.

Integral Attachments are attachments that are welded to or fabricated as an integral part of the component.

Intended Function(s) are system, structure, and component functions required to demonstrate compliance with the requirements defined in 10 CFR Part 54.4 (i.e., safety-related, SSCs relied upon to remain functional during and following design-basis events, non-safety related SSCs whose failure could prevent accomplishment of safety-related functions, and SSCs relied upon for the regulated events).

Raw Water is fresh water from a river, lake, pond, or groundwater source.

Regulated Events are NRC 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).

Treated Water is demineralized water and is the base water for all clean systems.

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1. INTRODUCTION

The Structural Tools deal exclusively with structures and structural components subject to aging management review in support of license renewal. The Structural Tools are presented as a set of material and environment based guidelines that will be used by each utility to identify applicable aging effects associated with structures and structural components subject to aging management review. For license renewal, utilities must review existing programs to ensure that the identified aging effects are managed so that structures and structural components may perform their intended function(s) during the period of extended operation. In addition, the Structural Tools may be used by plant engineers to identify structures and structural components beyond the license renewal scope that may require aging management attention.

1.1 Purpose

A structure is defined as a building or facility whose purpose is to support, house, and protect systems or components that are within the scope of license renewal. Structures are comprised of structural components such as beams, columns, floors, walls, and foundations. In addition, structural components may be used to support mechanical components, electrical components, and other structural members; these structural components typically are attached to or reside within structures. Structures and structural components subject to aging management review have been identified by each of the participating B&W plants in accordance with 10 CFR Part 54 [1]. The participating nuclear power plants include Arkansas Nuclear One Unit 1 (ANO-1), Oconee Nuclear Station Units 1, 2, and 3 (ONS-1, -2, and -3), and Three Mile Island Unit 1 (TMI-1).

After reviewing materials of construction and environments for structures and structural components subject to aging management review, applicable aging effects (e.g., cracking and loss of material) are identified based on evaluation of materials and environments. The purpose of the Structural Tools is to describe these generic material and environment based age-related degradation guidelines and their application to the materials and environments within the scope of license renewal.

In addition, technical elements of aging management programs are presented for material and environment combinations for which applicable aging effects are identified; however, demonstration of aging management will be performed on a plant-specific basis using the NEI 95-10 [2] Industry Guideline for Implementing the Requirements of 10 CFR Part 54. Time limited aging analyses (TLAA) applicable to structures and structural components within the scope of license renewal will be identified and resolved on a plant-specific basis and are not addressed in this Structural Tool.

1.2 Scope

Structures subject to aging management review support, house, and protect systems and components that are required for safe plant operation. These structures must be capable of withstanding, without loss of function, the effects of design basis events. Examples of structures subject to aging management review include the reactor building (the prestressed reactor building shell is not within the scope of this report and will be addressed on a plant-specific basis), auxiliary building, and intake structure. Structures are fabricated from structural components such as beams, columns, floors, walls, and foundations.

Structural components that are attached to or reside within structures are used to support mechanical components, electrical components, and other structural members. The category of other structural members includes, but is not limited to, (1) structural components whose function is to carry dynamic loads caused by postulated design basis events, e.g., pipe whip restraints, jet barriers, and missile shields; (2) electrical and instrumentation enclosures; (3) pipe, conduit, and cable tray supports; (4) fire barriers; (5) elastomers; and (6) teflon. Structural components are constructed from structural members such as beams, girders, joists, trusses, columns, frames, and bolting

1.3 Structures and Structural Components--Evaluation Boundaries

The purpose of this section is to provide guidance for establishing evaluation boundaries between mechanical components, electrical components, and structures and structural components subject to an aging management review.

1.3.1 Evaluation Boundaries--Structures

Structures support, house, and protect systems and components that are relied upon to operate the plant safely. Structures are comprised of structural items such as beams, columns, floors, walls, and foundations. The evaluation boundary of structures subject to aging management review is to be determined on a plant-specific basis, and will be based on the intended function(s) of the structure.

1.3.2 Evaluation Boundaries--Structural Components

Structural components that are attached to a structure or reside within a structure may be categorized as (1) component supports, and (2) other structural members. Suggested guidelines for establishing evaluation boundaries are provided below.

1.3.2.1 Component Supports

Supports--Mechanical Components

The evaluation boundaries for mechanical component supports may be established in accordance with rules governing inspection of component supports, i.e., ASME Section XI, Subsection IWF

[3]. Component support examination boundaries for integral and nonintegral (i.e., mechanically attached) supports are defined in article IWF-3100, Figure IWF-1300-1, which is reproduced as Figure 1-1. In general, the support boundary extends to the surface of the building structure, but does not include the building structure. It is recommended that the evaluation of component supports be limited to the portions of supports within the IWF boundary.

As shown in Figure 1-1, a support may be defined as integral or nonintegral depending on the specific conditions existing at a jurisdictional boundary. Boundaries of jurisdiction are specified in ASME Section III [4], Subsection NF, and may be followed when establishing evaluation boundaries between mechanical components, component supports, and the building structure.

An integral support may be a portion of a support that is welded to, or cast or forged integral with an integral attachment, the building structure, or an intervening element in the component support load path. A nonintegral support may be a portion of a support that is bolted, pinned, or clamped or which may bear upon the pressure retaining component, the building structure, or an intervening element in the component support load path. Nonintegral supports may include sliding joints, cradles, saddles, or straps. Intervening elements include, but are not limited to, diesel engines, electric motors, coolers, instrument racks, and access structures.

Supports--Electrical Components

Supports for electrical components include cable trays and conduit supports, electrical panels, racks, cabinets, and other enclosures. The evaluation boundary for these items include all supporting elements including mechanical or integral attachments to the building structure.

1.3.2.2 Other Structural Members

Evaluation boundaries for other structural members whose function is to carry dynamic loads caused by postulated design basis events should be consistent with the method for establishing boundaries for supports specified above. That is, the boundary should include the structural component and the associated attachment to the building structure. The portion of the attachment embedded in the building structure should be considered part of the structure.

1.4 Functions

Structures and structural components subject to an aging management review perform one or more of the following functions:

- Provides essentially leaktight barrier to prevent uncontrolled release of radioactivity.
- Provides structural and/or functional support to safety related equipment.

- Provides structural and/or functional support to nonsafety related equipment where failure of this structural component could directly prevent satisfactory accomplishment of any of the required safety related functions.

- Provides shelter/protection to safety related equipment (including radiation shielding).

- Provides rated fire barrier to confine or retard a fire from spreading to or from adjacent areas of the plant.

- Provides source of cooling water (e.g., canals, intake structure, dam) for plant shutdown .

- Serves as missile (internal or external) barrier.

- Provides a protective barrier for flood (internal or external) event.

- Provides structural integrity of unit vent stack and provides path for release of filtered and unfiltered gaseous discharge.

- Provides heat sink during a design basis accident (DBA), or station blackout (SBO).

1.5 Approach

Structures and structural components subject to aging management review may be divided into the following major groups based on materials of construction and operating environment.

1) Structural steel and steel components
2) Structural steel and steel components in fluid environments
3) Threaded fasteners
4) Concrete structures and concrete components
5) Fire barriers
6) Elastomers
7) Earthen structures
8) Teflon

The following chapters of this document address the following:

- Structures and structural components subject to aging management review including materials of construction

- Description of the representative bounding operating environments for the structures and structural components

- Evaluation of aging effects based on materials of construction and operating environment. The evaluation will identify applicable aging effects that may challenge

the intended function of the structures and structural components. When possible, a generic evaluation of applicable aging effects is performed for the specified representative bounding environment. In addition, each chapter contains an overview of industry performance history to identify past incidents of the applicable aging effects for the components under review.

- Identification of technical elements of aging management programs

This Structural Tool will be used by utility engineers to determine applicable aging effects when evaluating structures and structural components subject to aging management review. Demonstration of aging management to provide reasonable assurance that structure and structural component intended function(s) will be maintained consistent with the current licensing basis (CLB) during the period of extended operation, as required by 10 CFR Part 54.21(a)(3), will be performed on a plant-specific basis.

1.6 References

1. Title 10, Chapter 1, Code of Federal Regulations - Energy, Part 54 - Requirements for Renewal of Operating Licenses for Nuclear Power Plants, USNRC, as modified in Federal Register/Vol. 60, No. 88, Monday, May 8, 1995, Final rule, 10 CFR Part 54.

2. "Industry Guideline for Implementing the Requirements of 10 CFR Part 54 - The License Renewal Rule," NEI 95-10, Revision 0, March 1996.

3. ASME, Boiler and Pressure Vessel Code, Section XI, Rules for Inservice Inspection of Nuclear Power Plant Components, 1989 Edition, American Society of Mechanical Engineers, New York, NY.

4. ASME, Boiler and Pressure Vessel Code, Section III, Rules for Construction of Nuclear Power Plant Components, 1989 Edition, American Society of Mechanical Engineers, New York, NY.

Figure 1-1 Illustrations of Typical Support Examination Boundaries
Reproduction of Fig. IWF-1300-1—ASME Section XI, 1989 Edition

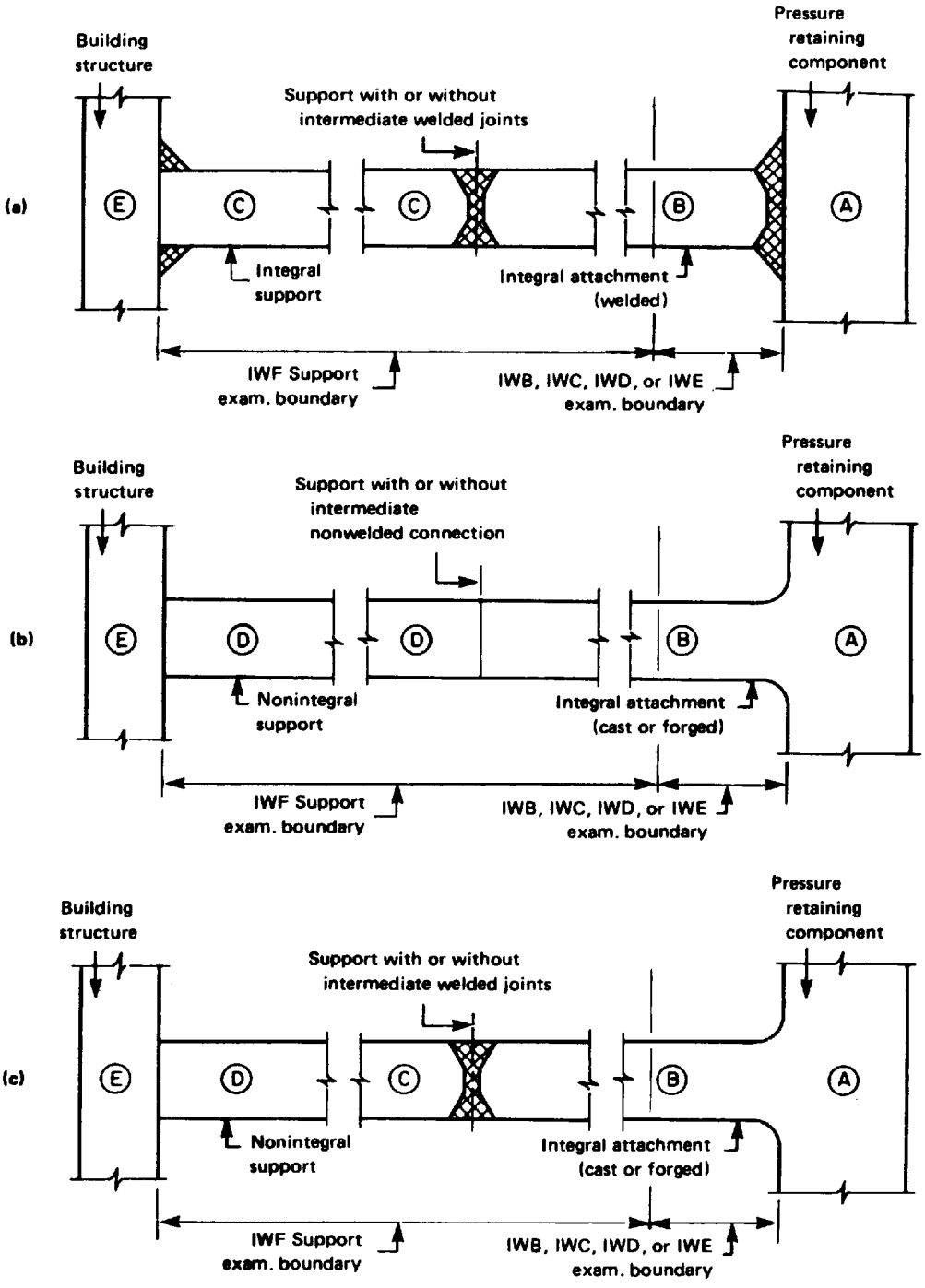
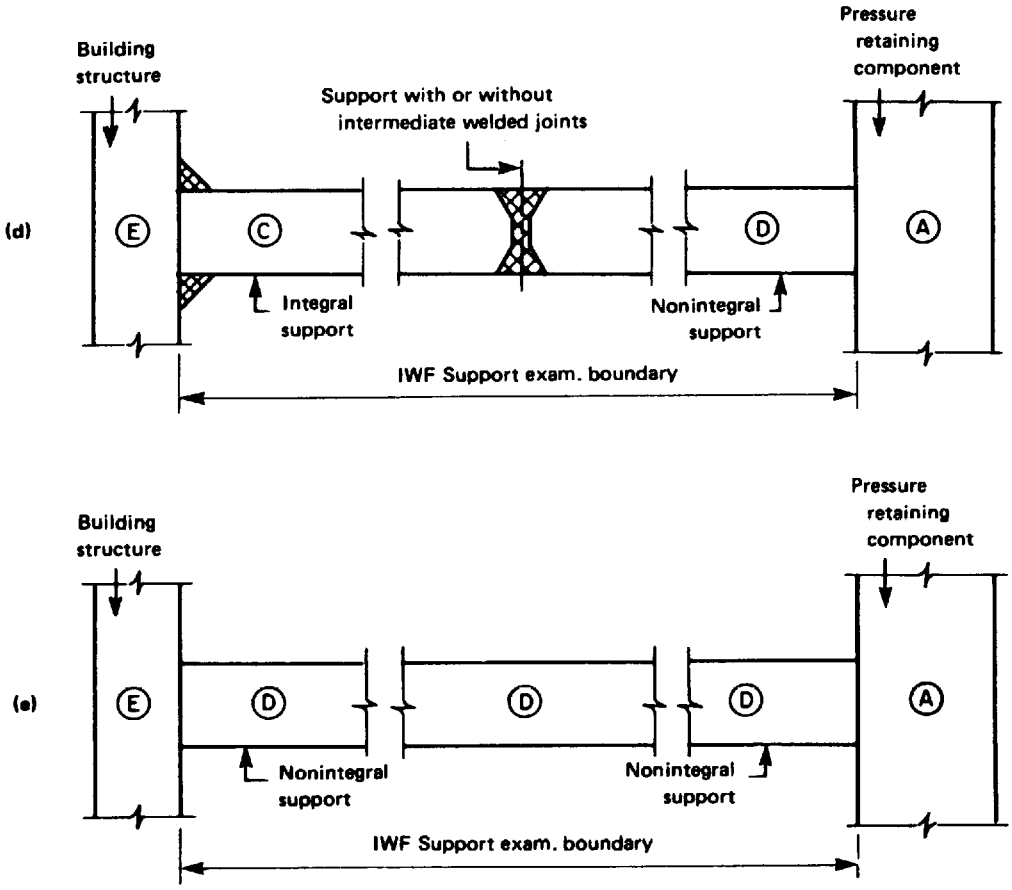


Figure 1-1 Illustrations of Typical Support Examination Boundaries
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2. STRUCTURAL STEEL AND STEEL COMPONENTS

This chapter of the Structural Tools is intended to cover structural steel and steel components used in the construction of building structures, mechanical and electrical supports, and other steel structural members that are exposed to ambient environments. A description of structural steel and steel components covered in this chapter is provided in Section 2.1. Environments that structural steel and steel components are exposed to are discussed in Section 2.2. Aging effects for material and environment combinations are discussed in Section 2.3. Recommendations for aging management programs are provided in Section 2.4.

2.1 Description and Scope

Steel structures are comprised of structural members such as beams, girders, joists, trusses, frames, columns, posts, girts, baseplates, bearing plates, bracing, splice assemblies, connections, decking, grating, bolts, washers and nuts, welds, studs, shims, and other steel items. Steel components that are attached to or reside within structures include mechanical and electrical component supports, and other structural members. Other structural members include, but are not limited to, metal partition walls, pipe whip restraints, pipe and conduit supports, jet barriers, missile shields, crane girders and rails, flood curbs, flood and fire doors, stairs and platforms, electrical and instrumentation enclosures, and fire hose racks. Structural steel and steel components identified above are manufactured from carbon steel, low-alloy steel, galvanized steel, and stainless steel.

Steel embedments in concrete, consisting of anchor bolts, plates, structural shapes and other items that were cast-in-place or grouted in drilled holes are covered in Chapter 4.0. The exposed surfaces of such cast-in-place or grouted steel and all post-installed concrete anchors are included in this chapter.

Carbon steel is used throughout nuclear plants in various applications. It is the material of choice for most structural applications. Carbon steels are unalloyed steels that may contain specified amounts of manganese, phosphorus, silicon, sulfur, and carbon. Carbon steels used in structural applications include, but are not limited to, ASTM Specifications A 1, A 6, A 36, A 53, A 67, A 106, A 307, A 366, A 516, A 500, A 501, A 510, A 563, A 573, A 611, A 641, and F436, and ASME Specifications SA-36, SA-181, and SA-500.

High strength low-alloy steels contain manganese and silicon or copper in quantities greater than those for carbon steels. These alloying additions enhance mechanical properties and fabricating characteristics. Their resistance to atmospheric corrosion is of primary importance, and their use in power plants for structural steels and related components has been limited to date. The ASTM Specifications used for high strength

low-alloy steel include, but are not limited to, A 242, A 325, A 441, A 449, A 490, A 529, A 572, A 588, A 606, A 607 and A 689.

Carbon and low-alloy steels may be joined using various arc-welding processes. All weld filler materials used in welding carbon steel and low-alloy steel are assumed to be equivalent to the carbon steel and low-alloy steel base metal with respect to the discussion of aging effects.

Galvanized steel is produced by taking steel sheets and coating them with zinc or iron-zinc alloys. The corrosion resistance of the galvanized steel is directly proportional to the amount of zinc in the coating. The metallic zinc is applied to the iron and steel by one of three processes: hot dip galvanizing, electrogalvanizing, or zinc spraying. The majority of the galvanized steel used at nuclear plants is produced by the hot dip process. In the hot dip process, an adherent protective coating of zinc and iron-zinc alloys is applied by immersing the steel in a bath of molten zinc. This process utilizes a series of layers with each successive layer containing a higher concentration of zinc. Galvanized steel materials include, but are not limited to, ASTM Specifications A 570, A 446, and A 366.

Stainless steels in structural applications contain less than 0.08% carbon, and large amounts of chromium (17-19%) and nickel (10-12%) which enhance resistance to corrosion and fatigue resistance. Stainless steels include ASTM Specifications A 193, A 240, A 276, and ASME Specifications SA-240, and SA-479, as Types 302, 303, 304L, 316, and 316L. The stainless steel weld metal is assumed to be equivalent to stainless steels with respect to discussions on aging effects of the structural steel and steel components.

2.2 Environment

Structural steel and steel components are exposed to environmental conditions that may be divided into three general categories:

1) protection from atmosphere/weather,

2) exposure to atmosphere/weather, and

3) exposure to fluid environments.

Structural steel and steel components exposed to fluid are discussed in Chapter 3.0. The environment definitions for steel protected from and exposed to atmosphere/weather are provided below.

Steel Protected from Atmosphere/Weather

Steel inside buildings and facilities protected from atmosphere/weather may be exposed to ambient temperatures up to 150 °F, relative humidity of 100 percent, and neutron and gamma radiation. Steel components attached to high temperature piping in buildings and facilities protected from atmosphere/weather, may be subjected to a maximum operating temperature of 650 °F. Steel protected from atmosphere/weather may temporarily be in contact with aggressive chemicals resulting from accidental spills. The resulting aging effect is considered negligible since spills are cleaned relatively quickly in accordance with house keeping procedures.

Steel Exposed to Atmosphere/Weather

Steel not located in buildings and exposed to atmospheric conditions and weather are subjected to temperatures ranging from -15 °F to 115 °F, relative humidity of 100 percent, and negligible radiation levels. The nuclear power plants within the scope of this document are not located in areas near major industrial plants that would expose them to corrosive chemicals in the atmosphere. Salt-water atmospheric environment is not within the scope of this report.

2.3 Aging Effects

The information used to document the aging effects for structural steel and steel components is gathered from industry sources. Where specific mechanisms are not applicable under the environmental and material conditions, justification is provided for a "not applicable" determination. For those effects that are applicable, a discussion of the environmental conditions necessary for the effects to occur is included. Aging effects discussed below include loss of material, cracking, mechanical distortion, and change in material properties. This chapter evaluates potential aging effects for carbon, low-alloy, galvanized, and stainless steels .

2.3.1 Loss of Material

Aging mechanisms that may lead to loss of material include general corrosion, galvanic corrosion, crevice corrosion, pitting corrosion, erosion and erosion-corrosion, microbiologically induced corrosion, and wear. Loss of material may be seen as material dissolution, corrosion product build-up, and pitting. Loss of material may be uniform or localized.

2.3.1.1 General Corrosion

General corrosion is the result of a chemical or electrochemical reaction between a material and its environment. It is normally characterized by uniform attack resulting in material dissolution and sometimes corrosion product buildup. At ordinary temperatures

and in neutral or near neutral media, both oxygen and moisture must be present to corrode steel.

Generally, when humidity exceeds 70 percent, an invisible film of moisture forms on the surface of steel providing an electrolyte [11]. The ratio between humidity and temperature determines the thickness of the film. The thinner the film, the easier the diffusion of oxygen through the film that drives the corrosion reaction. Corrosion rates of carbon and low-alloy steels increase with rising surface temperatures until the electrolyte is evaporated.

Carbon Steel and Low-Alloy Steel

Basic corrosion of carbon and low-alloy steels proceeds by formation of hydrated oxides. When the surface oxides lose water during dry periods, they revert to anhydrous ferrous and ferric oxides and other compounds, all products of corrosion commonly termed rust, which tend to absorb any available moisture from the air to continue the corrosion process. Thus, the steel surface exposed to alternating wet and dry conditions will corrode at a faster rate than one exposed to continuously wet conditions.

The rate of basic corrosion of carbon and low-alloy steel is accelerated by contaminants such as chlorides, sulfides, sulfur dioxide, nitrogen compounds and dust that may be found in industrial, marine, and rural atmospheres. In addition to containing contaminants, the dust particles trap solutions against the steel surface enhancing the corrosion process. The alloyed copper contents and an initial protective film of rust reduces corrosion rates in high strength low-alloy steels to one half or one quarter the rate of carbon steel.

Structural steel components subject to aging management review are not located in environments that could be classified as corrosive; however, high humidity and elevated temperatures are common to interior and exterior plant environments. Loss of material by general corrosion is an applicable aging effect for carbon and high strength low-alloy structural steels and steel components in all environments.

Galvanized Steel

Zinc coatings protect steel from corrosion by two methods: (1) by forming a barrier between the underlying steel and the environment—zinc corrodes at a much slower rate than steel; and, (2) by electrochemical protection—the underlying steel becomes polarized and zinc will preferentially corrode should a defect develop in the zinc barrier. The corrosion rate of zinc coatings depends on the type of ambient conditions involved. Factors such as the frequency and duration of moisture content, rate of drying, and the extent of industrial pollution have significant impact on the corrosion rate. Galvanized steel that is protected from the atmosphere/weather is expected to have negligible corrosion rates since it is protected from conditions that lead to loss of the protective zinc

barrier. However, galvanized steel exposed to atmosphere/weather may be susceptible to general corrosion.

A large-scale long term test was conducted by ASTM to determine the service life of galvanized steel [11]. The service life of the zinc coating exposed to atmosphere/weather appears to be in direct proportion to the weight of the coating. For galvanized structural steel and steel components subjected to atmosphere/weather, the corrosion rates are not expected to exceed those observed in the ASTM tests [11] conducted in rural environments (i.e., 0.04 to 0.07 oz/ft2/yr).

Loss of zinc by general corrosion is an applicable aging effect for galvanized steel exposed to atmosphere/weather and is not an applicable aging effect for galvanized steel protected from atmosphere/weather.

Stainless Steel

Stainless steel is very resistant to general corrosion. Only high concentrations of chlorides (as in coastal saltwater marine areas) and metallic iron dust can cause general corrosion. Such environments are not considered in this document. Loss of material by general corrosion is not an applicable aging effect for stainless structural steel and steel components protected from or exposed to weather/atmosphere.

2.3.1.2 Galvanic Corrosion

Galvanic corrosion occurs when two or more metals of differing electrochemical potential are in electrical contact in a conducting environment, (the presence of an electrolyte). Under these conditions an electrolytic cell is formed transmitting an electrical current between an anode and a cathode. Loss of material occurs when ions of the metal with the lower potential, the anode, are being depleted and deposited onto the more noble metal, the cathode. Galvanic corrosion will not occur in a dry environment, an electrolyte must be present and remain liquid. The ratio between surface areas of the metals in contact is of significant importance. Corrosion rates increase when the more noble metal has a greater surface area than the more active metal.

Carbon, Low-Alloy, Galvanized, and Stainless Steels

Galvanic corrosion is generally precluded by design; however, rare instances of galvanic corrosion in carbon steel base plate installations utilizing stainless steel anchor bolts have been noted. In these cases, given the favorable plate to anchor surface area ratio, the loss of carbon steel, if any, has been minimal.

Because of the potential contact of differing materials, lead-shielding supports, which are made from carbon steel, are a candidate for galvanic corrosion. However, given that the electromotive potential between lead and carbon steel is not large, and the lack of a sufficient electrolyte to drive the electrochemical process, galvanic corrosion is unlikely.

Furthermore, although not credited, carbon steel supports are typically coated eliminating direct contact between material.

Loss of material by galvanic corrosion is not an applicable aging effect for structural steel and steel components protected from or exposed to atmosphere/weather.

2.3.1.3 Crevice Corrosion

Crevice corrosion is intense, localized corrosion within crevices or shielded areas [6]. It most frequently occurs in connections, lap joints, splice plates, bolt threads, under bolt heads, and is associated with a stagnant solution (an electrolyte). The crevice must be wide enough to permit liquid entry and narrow enough to maintain stagnant conditions, typically a few thousandths of an inch or less [6].

The level of oxygen concentration in the electrolyte when present, is lower in the crevice making it anodic to surrounding areas in this differential oxygen cell and commencing active corrosion. The same cell is formed when the amount of oxygen reaching metal that is covered by rust or other insoluble reaction product is less than the amount that contacts other portions where the permeable coating is thinner or absent.

The crevice also retains moisture for a longer time than adjacent external surfaces, allowing a longer duration for corrosion damage to occur. In cases where the environment is particularly aggressive, localized crevice corrosion may be precluded by uniform corrosion.

Carbon, Low-Alloy, and Galvanized Steels

Carbon, low-alloy, and galvanized steels exposed to ambient conditions are not generally susceptible to crevice corrosion unless their external surface is wetted. Carbon, low-alloy, and galvanized steels within the scope of this chapter are not located in chloride containing environments; steels with continuously wetted surfaces are covered in Chapter 3.0. Therefore, loss of material by crevice corrosion is not an applicable aging effect for carbon, low-alloy, and galvanized structural steels and steel components protected from or exposed to atmosphere/weather.

Stainless Steels

Stainless steels are prone to crevice corrosion attack, especially in aqueous, chloride containing environments at temperatures above 200 °F [1]. Stainless steels located in non-wetted environments are not exposed to chlorides and are below the threshold temperature required to initiate crevice corrosion. Therefore, loss of material by crevice corrosion is not an applicable aging effect for stainless structural steel and steel components protected from or exposed to atmosphere /weather.

2.3.1.4 Pitting Corrosion

Pitting corrosion is an extremely localized corrosive attack in aqueous environments containing desolved oxygen and chlorides that is more common in austenitic (300 series) stainless than in carbon steels. When passivity breaks down at a spot on a metal surface, an electrolytic cell is formed with the anode at the minute area of active metal, and the cathode at the considerable area of passive metal. The large electric potential difference between the two areas accounts for considerable flow of current with rapid corrosion at the anode. The anode does not spread because it is surrounded by passive metal, and as the mechanism continues it penetrates deeper into the metal forming a pit.

Carbon, Low-Alloy, Galvanized, and Stainless Steels

Dissolved oxygen and chlorides are required for pitting to occur. Carbon steel buried in wet soils may exhibit damage owing to pitting corrosion. However, structural steel and steel components buried in wet soils are not within the scope of this chapter. Therefore, loss of material by pitting is not an applicable aging effect for carbon, low-alloy, galvanized, and stainless structural steel and steel components protected from or exposed to atmosphere/weather.

2.3.1.5 Erosion and Erosion Corrosion

Erosion is the loss of material due to a flowing fluid. Impingement and solid particle erosion is caused by the impact of particles or liquid on a material. Erosion corrosion is an aging mechanism in which fluid flow erodes or dissolves the protective oxide on the surface of steel causing additional corrosion by reoxidation. This mechanism is not applicable to the materials and environments covered in this chapter. Erosion corrosion of carbon, low-alloy, and stainless steel exposed to fluid environments is covered in Chapter 3.0.

2.3.1.6 Microbiologically Induced Corrosion

Microbiologically Induced Corrosion (MIC) occurs by the action of microorganisms. Microorganisms are usually classified according to their ability to grow in the presence or absence of oxygen. Aerobic organisms grow in nutrient mediums containing dissolved oxygen. Anaerobic organisms grow most favorably in environments containing little or no oxygen. Selected aerobic organisms produce sulfuric acid by oxidizing sulfur or sulfur-bearing compounds. Selected anaerobic organisms reduce sulfate to sulfide ions which influences both anodic and cathodic reactions on iron surfaces. These microscopic organisms have been observed to live in media with pH values between 0 and 11, temperatures between 30 °F and 180 °F, and under pressure up to 15,000 psi [6]. MIC is facilitated by stagnant conditions, fouling internal crevices, and contact with untreated water from a natural source. Microorganisms such as iron bacteria are important in their effect on steel as they live by digesting iron and manganese ions in the presence of oxygen after taking these ions into their cells. Iron bacteria flourish in running and

stagnant water environments with temperatures of 40 °F to 100 °F and pH environments between 4 and 10 [16].

MIC is applicable to those structural steel components that are submerged in water or saturated soils for long periods of time. The structural steel and steel components covered in this chapter are not submerged in water or buried in soils. Therefore, loss of material by MIC is not an applicable aging effect for carbon, low-alloy, galvanized, and stainless structural steel and steel components protected from or exposed to atmosphere/weather.

2.3.1.7 Wear

General wear may occur as a result of movement of one material with respect to another. In structural steel components under consideration, wear by personnel and equipment traffic is plausible on access surfaces and crane rails. In the first instance, wear will occur mostly on the softer material, i.e., the soles of footwear worn by plant personnel. Wear of crane rails due to rolling or sliding wheels is not expected in any measurable amount owing to the infrequent crane use. Loss of material by wear is not an applicable aging effect for carbon, low-alloy, galvanized, and stainless structural steel and steel components protected from or exposed to atmosphere/weather.

2.3.2 Cracking

Cracking of base metal and or weld metal may result from one or more of the following aging mechanisms: hydrogen blistering, stress corrosion and/or intergranular attack, and fatigue. Each of these aging mechanisms is evaluated for carbon, low-alloy, galvanized, and stainless structural steel and steel components protected from or exposed to atmosphere/weather in the following sections.

2.3.2.1 Hydrogen Damage

Hydrogen damage results from the absorption of hydrogen into the metal. It includes the degradation mechanisms of hydrogen blistering and embrittlement [2,6]. Another term for hydrogen embrittlement is sulfide stress cracking if the cracking is due to the presence of hydrogen sulfide; a few ppm of absorbed hydrogen can cause cracking. In each case, atomic hydrogen enters the metal either as a result of a corrosion reaction at the surface or by cathodic polarization, which results in the evolution of hydrogen gas [5]. In blistering, hydrogen within the metal causes high pressure and local damage in the form of "blistered" regions of the metal surface. Hydrogen embrittlement results in low ductility and intergranular cracking (similar to stress corrosion cracking). The phenomenon of hydrogen cracking is usually seen as delayed cracking, at or near room temperature, after stress is applied [5]. A certain critical stress, which may take the form of weld residual stress, is required to cause cracking. Cracking of welds due to hydrogen embrittlement and hydrogen induced cracking is a concern in higher strength steels as in hydrogen cracking in bolts [17]. High strength bolts (generally with ultimate tensile strength

greater than about 180 ksi and hardness greater than Rockwell C41, such as A354 grade BD, and A490 and A325 bolts, and turbine steels are susceptible to hydrogen cracking.

Carbon, Low-Alloy Steel, and Galvanized Steels

Hydrogen blistering is most prevalent in the petroleum industry occurring in storage tanks and in refining processes [6]. A review of failure data for PWR systems shows no evidence of hydrogen blistering for carbon steels, therefore, it is considered not applicable for carbon steels in PWR applications. Since the yield strength of most of the structural steel and steel components (except bolting) is on the order of 30 to 45 ksi, hydrogen embrittlement is considered not applicable to the carbon steels and low-alloy steels within the scope of this chapter. Therefore, cracking by hydrogen damage is not an applicable aging effect for carbon, low-alloy, and galvanized steels protected from or exposed to atmosphere/weather.

Stainless Steel

In most cases, austenitic stainless steels are immune to hydrogen damage [2,4]. Therefore, cracking due to hydrogen damage is not considered an applicable aging effect for stainless structural steel and steel components protected from or exposed to atmosphere/weather.

2.3.2.2 Stress Corrosion

Stress-corrosion cracking (SCC) is a type of corrosive attack that occurs through the combined actions of stress (both applied and residual tensile stresses), a corrosive environment, and a susceptible material. All three of these factors are necessary to initiate SCC. For a particular material, high tensile stresses require less corrosive environments and highly corrosive environments require less tensile stress to initiate and propagate cracking. Elimination or reduction of any of these factors will decrease the likelihood of SCC to occur. SCC may be categorized as either intergranular stress corrosion cracking (IGSCC) or transgranular stress corrosion cracking (TGSCC), depending on the primary crack morphology.

IGSCC is characterized by cracks propagating along the grain boundaries of the material. It is typically associated with materials containing excessive grain boundary precipitation or impurity segregation and usually occurs in relatively low dissolved oxygen environments. Preferential grain boundary precipitation of carbides in austenitic stainless steels can lead to a localized depletion of chromium in the vicinity of the grain boundary. This is known as sensitization and is one of the mechanisms believed to promote IGSCC. Grain boundary segregation of impurities such as phosphorous, sulfur, and silicon is another mechanism believed to promote IGSCC. It can produce a grain boundary chemical composition with a significantly different electrochemical potential from that of the bulk alloy composition. The effect of this electrochemical potential difference is an increase in corrosion susceptibility at the grain boundaries.

TGSCC is characterized by cracks that propagate through (or across) the grains of the material. Numerous metallurgical factors, such as crystal structure, grain size and shape, dislocation density and geometry, and phase composition, affect TGSCC. It is most prevalent in austenitic stainless steels subjected to chlorides and oxygenated environments.

Carbon, Low-Alloy, and Galvanized Steels

Stress corrosion, as a phenomenon is not usually associated with carbon steel and low-alloy materials. Corrosion of carbon and low-alloy steels is well documented and aggressive conditions can develop under deposits and in crevices, which could ultimately lead to cracking of the material. Cracking following corrosion of carbon steel in raw water environments has been observed and has been attributed, at least in part, to MIC occurring in these deposits and crevices.

The extreme alteration of the local environment caused by MIC could lead to what could be described as SCC of the carbon and low-alloy steel, but SCC of the carbon and low-alloy steels from direct exposure to the raw water environment is not an applicable aging effect. See discussion on SSC in raw water environments in Section 3.3.2.2. As discussed in Section 2.3.3.1, high strength low-alloy bolting materials may be susceptible to stress-corrosion cracking if exposed to molybdenum disulfide, moisture, or contaminants. See Chapter 4.0 for a discussion of aging effects applicable to structural bolting. Therefore, cracking due to stress corrosion is not an applicable aging effect for carbon and low-alloy structural steel and steel components protected from or exposed to atmosphere/weather.

Stainless Steel

Type 304 and 316 stainless steels are affected by stress corrosion cracking and intergranular attack in sensitized (heat affected) zones, especially in fluid environments where chlorides and sulfates exceed 35 ppm and 100 ppb concentration limits, respectively [3,11]. The heat required for welding stainless steel sensitizes the metal in heat-affected zones, or areas adjacent to the welds. Stainless steels with low carbon contents (304L and 316L) are less susceptible to cracking.

The environment required for stress-corrosion cracking or intergranular attack may be induced by burying the sensitized stainless steel in soil, submerging it, or wetting its surface continuously. The stainless steel components within the scope of this chapter are not located in such environments; therefore, cracking owing to stress corrosion or intergranular attack is not applicable to stainless structural steel and steel components protected from or exposed to atmosphere/weather.

2.3.2.3 Fatigue

Fatigue is the progressive localized permanent structural change that occurs in structural materials subject to repeated or fluctuating strains, at nominal stresses having maximum values much less than the tensile strength of the material. Fatigue may result in cracks or fractures after a sufficient number of fluctuations. See the discussion of fatigue in Section 2.3.3.2 as it relates to mechanical distortion.

2.3.3 Mechanical Distortion

Two aging mechanisms that may result in a physical or mechanical distortion of carbon, low-alloy, galvanized, and stainless structural steel and steel components protected from or exposed to atmosphere/weather are creep and fatigue. Distortion that may occur as a result of improper design is not considered an applicable aging effect. Examples of improper design include component support movement owing to water and steam hammer or unanticipated thermal expansion.

2.3.3.1 Creep

Creep is a time dependent strain (deformation) in metals occurring under constant load at constant temperature. There are three stages of creep during which the shear and elasticity moduli of the material decrease and the Poisson ratio increases. An increase in either stress or temperature accelerates creep. If stress or temperature is increased beyond certain levels, the increased deformation can alter the temperature distribution in the system which may cause local zones to be overheated, eventually resulting in failure. For structural steels and steel components, creep is not a concern for structural steels below 700 °F [18]. Mechanical distortion due to creep is not an applicable effect for carbon, low-alloy and stainless structural steel and steel components protected from or exposed to atmosphere/weather since operating temperatures are below the threshold for creep damage.

2.3.3.2 Fatigue

In structural steel and steel components, fatigue failure is initiated by a plastic deformation in a localized region. A non-uniform stress distribution across a member cross-section may cause concentrated stresses to exceed the yield point within a small area of the cross-section resulting in a small plastic movement and a minute crack. The reduced cross-sectional area aggravates the stress distribution, which causes the crack to progress. After a relatively small number of stress cycles, a final, sudden fracture of the remaining cross-section occurs.

Generally, structural steel and steel components are not prone to fatigue. Loads, for the most part, are applied gradually and remain constant. Dynamic loads such as wind and seismic loads are too infrequent to initiate fatigue cracking. Members subjected to

fatigue loading conditions such as crane runways are accounted for by code in their design. In addition, crane use is limited and the number of stress cycles experienced is low in terms of fatigue service life when considering the period of extended operation.

Fatigue of structural components fabricated from carbon, low-alloy, galvanized, and stainless steel is adequately addressed in accordance with the design requirements for the particular application. Fatigue is a TLAA and will be addressed on a plant-specific basis.

2.3.4 Change in Material Properties

Change in material properties is observed in structural steel and steel components as an increase or reduction in yield strength, a reduction in modulus of elasticity, reduction of fracture toughness, reduction in ultimate tensile ductility, and an increase in ductile-to-brittle transition temperature [3]. Conditions that may lead to changes in material properties for structural steel and steel components include elevated temperature and irradiation embrittlement.

2.3.4.1 Elevated Temperature

Thermal aging embrittlement is a mechanism by which the mechanical properties of material are affected by prolonged exposure to high temperature or by improper cooling after such exposures. The carbon and low-alloy steels are not susceptible to thermal embrittlement. Cast austenitic stainless steels, precipitation-hardened stainless steels, and galvanized steels are known to be susceptible to thermal embrittlement. However, structural steel must be exposed to relatively high temperatures (i.e., greater than 700 °F) to initiate thermal embrittlement, [2,3].

Cast austenitic stainless steels and precipitation-hardened stainless steels are not considered structural steel and are not within the scope of this chapter. Structural steel and steel components within the scope of this chapter are typically exposed to temperatures below 150 °F. However, selected piping supports connected to high temperature piping may be exposed to temperatures up to 650 °F, which is below the threshold temperature for embrittlement. Change in material properties owing to thermal embrittlement is not an applicable aging effect for carbon, low-alloy and stainless structural steel and steel components protected from or exposed to atmosphere/weather.

Galvanized Steel

Embrittlement of galvanized steel can result from long term exposure at elevated temperatures below the melting point of the zinc (approximately 785 °F). Zinc diffuses from the coating to the steel resulting in a brittle iron-metallic compound, which may lead to brittle fracture [11]. Intermetallic embrittlement has been observed at temperatures extending from approximately three quarters of the melting temperature of zinc up to the melting temperature [19].

It is unlikely that the galvanized steel applications within the scope of license renewal would experience long periods at elevated temperatures that could lead to intermetallic embrittlement. Embrittlement of galvanized steel is not an applicable aging effect provided the galvanized components are not exposed to temperatures in excess of 400 °F, which is the recommended maximum temperature use limit for galvanized components in accordance with the American Galvanizers Association.

2.3.4.2 Irradiation Embrittlement

Irradiation embrittlement may result in a reduction of fracture toughness, an increase of yield strength, and a rise in the ductile-to-brittle transition temperature of steel. Available data indicate that radiation effects on mechanical properties of structural steel are measurable only when fast neutron fluence (E>1 MeV) exceeds 10^{18} n/cm^2 [3].

A generic best estimate 48 EFPY fluence analysis was completed to determine the peak fluence at the inside surface of the primary shield wall for the participating plants. The bounding best estimate peak insider surface fluence is predicted to be approximately 9.8 x 10^{17} n/cm^2 [15] (E > 1 MEV) at 48 EFPY. Therefore, reduction of fracture toughness due to irradiation embrittlement is not an applicable aging effect for carbon, low-alloy, galvanized, and stainless structural steel and steel components protected from (located outside the primary shield wall) or exposed to atmosphere/weather. Assessment of irradiation embrittlement for structural steel and steel components that reside within the primary shield wall will be addressed on a plant-specific basis.

2.3.5 Industry Experience

Reports on failures in structural steel components as reported by various organizations (INPO Nuclear Plant Reliability Data System, NRC Inspection and Enforcement Information Bulletins, Licensee Event Reports, and Generic Letters) were reviewed for applicability in the determination of applicable aging effects. A summary of NPRDS review is provided in Section 2. 3.5.1 and a summary of NRC generic correspondence review is provided in Section 2.3.5.2.

2.3.5.1 NPRDS Review

NPRDS is maintained by the Institute of Nuclear Power Operations (INPO) to gather and track information related to various commercial nuclear power plant components, systems, and structures. However, INPO has not required licensees to submit NPRDS information for “supports”, “hangers”, “restraints”, “snubbers”, among other related items, since 1989. Therefore, most, if not all of the NPRDS information presented in the following summary is pre-1990. The following summary is based on a review and evaluation that was performed of more than 3600 Nuclear Plant Reliability Data System (NPRDS) “hits” for issues and items related to Structures and Structural Components.

1
2

Table 2-1 Summary of NPRDS Findings for Structural Steel and Steel Components			
Selected Component: Support Find Narrative: N/A		2922	
	Snubber Related	2752	Active component
	Bolt Failure	13	Cause: missing, high preload, vibration, salt water corrosion, corrosion due to boric acid dripping
	Pipe Support	157	Cause: improper maintenance, improper installation, design not met, water hammer, aging, cyclic wear, weld crack, abnormal stress, overload, wear, thermal movement, cyclic fatigue, improper fabrication, inadequate design, mechanical adjustment, inadequate base plate design, low cycle fatigue from vibration
Selected Component: Support Find Narrative: Beam, Girder, and Joist		6	
	Snubber Related	3	Active component
	Cracked Weld	2	Cause: unknown
	Anchor Bolt	1	Cause: salt water corrosion
Selected Component: Support Find Narrative: Column, Post, and Girth		5	
	Snubber Related	3	Active component
	Pipe Support	2	Cause: Maintenance, rubbing due to vibration
Selected Component: Support Find Narrative: Missile Shield, Crane Girders, and Rails		1	
	Snubber Related	1	Active component
Selected Component: N/A Find Narrative: Enclosure		185	
	Component Failure (Structural Related)	178	Improper maintenance, electrical problem—not water leakage, shorting, normal wear and tear, packing leak, instrument failure
	Enclosure Corrosion	1	Excessive moisture

Table 2-1 Summary of NPRDS Findings for Structural Steel and Steel Components

	Pipe Corrosion	2	Inadequate design, impingement corrosion
	Valve Pit Flood	2	Blocked drain
	Tank damage	2	Water hammer
Selected Component: Support Find Narrative: Bearing, Plate, and Bracing		337	
	Snubber related	303	Active component
	Pipe Support	34	Cause: Improper installation, improper maintenance, water hammer, unknown, vibration, general wear, cracked welds, thermal expansion, undue stress, failed grout at base plate, excessive wear, abnormal stress w/high vibration, design load exceeded, inadequate base plate design, missing components, pipe whip
Selected Component: Support Find Narrative: Bolting, Studs, and Bolt		82	
	Snubber related	28	Active component
	Pipe support	25	Cause: Missing bolt, steam hammer, improper installation, vibration, water hammer, thermal expansion, improper maintenance, improper design
	Bolt Failure	18	Cause: too much preload, unknown, abnormal stress, water hammer, water hammer caused by gas void, operating transients, upgrade, normal wear and aging, grout failure, excessive tensile load, pull-out
	Hilti-Bolt & Redhead Failure:	10	Cause: vibration, water hammer, pull-out due to thermal expansion, inadequate design
	Bolt corrosion	1	Cause: exposure to salt water
Selected Component: Support Find Narrative: Splice Assembly, Connection, and Decking		29	
	Snubber related	26	Active component
	Failed support connection	3	cause: unknown, abnormal stress, water hammer

Table 2-1 Summary of NPRDS Findings for Structural Steel and Steel Components			
Selected Component: Support Find Narrative: Nut, Washer, and Shim		97	
	Snubber related	75	Active component
	Pipe support	22	(Cause: vibration, unknown, improper installation, water hammer, improper maintenance, design defect, normal wear and aging)

NPRDS Data Review and Evaluation

It is estimated that approximately 85% of the NPRDS information is duplicated at least one or more times due to the selection criteria. The vast majority of the NPRDS items address and/or are related to snubbers and pipe supports. In accordance with NEI 95-10, snubbers are considered to be active components. Based on the summary review and evaluation, the following NPRDS "hits" for issues and items related to aging of structures and structural components were deemed to be significant.

- Abnormal stress/water hammer/shock/vibration/line surge/thermal expansion/operating transients/ increased loads due to plant trips to a pipe support, resulting in damage to the support, adjacent support structure, and/or support anchorage.
  (i.e., bent support rods, enlarged expansion anchor holes, broken welds, hanger/support components vibrating loose, overloaded support resulting in cracked bolts, pulled Hilti bolts from concrete wall/foundation)
- Damaged support/support welds/support components due to excessive and/or long-term pipe movement.
- Corrosion of pipe support components due to submergence, spray, and/or drip.
- Normal wear and aging
  (i.e., loose nuts and bolts, loose pipe clamp nuts)

Based on the review and evaluation of the NPRDS data the vast majority of the NPRDS items were "snubber related." There were less than 10 occurrences where the stated means of failure was "aging, wear related, general wear, aging and normal wear," or corrosion "salt water corrosion, corrosion due to boric acid dripping" related. The text of the NPRDS reports with respect to aging was usually vague. For those items that mentioned "aging" or "wear" as a possible cause, they were usually prefaced by "Cause unknown, but it is believed to be aging and normal wear." The review of the NPRDS data did not reveal any new aging mechanisms or concerns that have not been considered in Sections 2.3.1 through 2.3.4.

2.3.5.2 NRC Generic Communications

NRC generic communications dating back to 1973 were reviewed for their applicability to Structural Steel and Steel Components. Applicable Information Notices, IE Bulletins, and Generic Letters are reported below. Approximately one-half of the generic communications deal with structural bolting applications; the structural bolting communications are reported below even though aging of structural bolting is discussed in Chapter 4.

Information Notices

IN 83-40: Need to Environmentally Qualify Epoxy Grouts and Sealers
In 1981, TVA reported that at Watts Bar two epoxy grouts, used to install various anchor bolts inside the containment building, had been specified by trade name without consideration of the thermal aging and radiation environment. Follow-up testing showed that the compounds had shown significant loss of strength at temperatures above 120F. The notice implies that full confidence in the results of strength at elevated temperatures or resistance to radiation damage can only be achieved by product testing. The notice also points out that where anchor bolts are bedded in epoxy grout, and tensioned to any appreciable preload, it may be important to periodically verify that the preload has not been lost by creep in the grout.

IN 83-80: Use of Specialized "Stiff" Pipe Clamps
This information notice provided notification of a potential significant problem in the use of specialized "stiff" pipe clamps, which may result in significant local stresses in the piping. The NRC staff does not believe that the clamp design is deficient; however, they do believe that potential safety concerns could exist if the piping designers are not aware of the conditions under which high stress can be induced by the clamp or do not properly evaluate piping stresses for the installed condition of the clamp. The notice states that the clamp vendors typically qualifies the clamp stresses but do not test or evaluate the effect of the preload on the piping stresses. This notice pertains to design, construction, or operations issues and does not identify age related degradation issues.

IN 84-32: Auxiliary Feedwater Sparger and Pipe Hanger Damage
This information notice advises licensees of an event involving sparger and pipe hanger damage, apparently caused by water hammer in the auxiliary feedwater system. The notice advises plant operations staff to be alert to the possibility of water hammer phenomenon even though the plant is designed to reduce susceptibility to it. A recommendation is made for the plant engineering staff to investigate loose or damaged hangers and operational parameters for the possibility of water hammer. This notice pertains to design, construction, or operations issues and does not identify age related degradation issues.

IN 85-05: Pipe Whip Restraints
Byron Nuclear Generating Station tested the energy absorbing material used in the pipe whip restraints and reported that the dynamic crush strength of some samples were considerably lower than the values used in the design. The function of the materials to slow the motion of major piping in the event of a double-ended guillotine pipe break and the material is contained within the pipe whip restraint. This structure is not intended to serve as a restraint in normal operation or seismic loading. This notice pertains to design, construction, or operations issues and does not identify age related degradation issues.

IN 86-99: Degradation of Steel Containments
This notice relates to a BWR but is included here to point out the significance of wetted containment steels. This notice provides recipients with information of a potentially significant safety problem regarding the degradation of a steel containment resulting from corrosion. At Oyster Creek water was discovered in the gap between the boiling-water-reactor drywell and the concrete shield. Investigating, loss of metal was observed on the gap side immediately above the concrete floor. In this area the gap is packed with sand for drainage. The outside surface is protected with a red lead coating from above the drywell down to a certain level and the interface between the lead paint and unprotected steel was in contact with the sand. Red lead protects steel by providing a stable and impenetrable surface, but the steel is sacrificial with respect to the lead in dilute, acidic water conditions. It is possible that condensation during initial construction, moisture pickup through the drain line during operation, and a leaking bellows wetted the sand, thereby causing corrosion of the containment steel plates.

IN 86-94: HILTI Concrete Expansion Anchor Bolts
This notice was issued to inform recipients of a revision to the published ultimate tensile capacities for ½-inch-diameter Hilti Kwik bolts that could potentially affect pipe support designs covered by IE Bulletin 79-02. This revision resulted from a Hilti review of all on site test data developed at nuclear power plants after a 10 CFR Part 21 report identified that on site tests at the Susquehanna plant produced results that were significantly below the published values contained in Hilti's "Architects and Engineers Anchor and Fastener Design Manual" for several sizes of anchor bolts. Recipients were to review the information for applicability to their facilities and consider actions, if appropriate. This notice pertains to design, construction, or operations issues and does not identify age related degradation issues.

IN 86-99: Degradation of Steel Containments
This supplement to IN 89-99 updates the status of the Oyster Creek containment corrosion and elaborates on the licensee's mitigation program.

IN 88-25: Minimum Edge Distance for Expansion Anchor Bolts
This notice was issued to alert addressees to test results indicating that the recommended minimum edge distance for the design and installation of expansion anchor bolts may be non conservative with respect to effectively resisting the shear forces imposed on anchor bolts during a design-basis event such as a safe-shutdown earthquake. Addressees were

asked to review the information and consider appropriate actions if this information indicates that a significant safety hazard exists at their facility. This notice pertains to design, construction, or operations issues and does not identify age related degradation issues.

IN 89-79: Degraded Coatings and Corrosion of Steel Containment Vessels
This notice relates to ice condenser containment vessels but is included here to point out the significance of wetted containment steels. This notice was intended to alert addressees to the discovery of severely degraded coatings and the corrosion of steel ice condenser containment vessels that are caused by boric acid and collected condensation in the annular space between the steel shell and the surrounding concrete shield. Duke Power Company reported significant coating damage and base metal corrosion in the McGuire units and Catawba units. Both have ice condenser-type containments consisting of a freestanding steel shell surrounded by a concrete shield building. The probable cause of the degradation is attack by condensed boric acid coolant leaking from instrument line compression fittings. Drains are provided in the annulus floor, but they are widely separated and the floor is not sufficiently graded to prevent pooling of the condensate between the drain locations. The degradation of the containments is considered significant because the observed rate of corrosion exceeds the allowance made for corrosion in the containment design. Appendix J to 10 CFR Part 50 requires visual inspection of the accessible surfaces of the containment be performed before each integrated leak rate test; however these tests are only required to be performed three times in each 10-year period. The notice suggests that additional efforts to inspect steel containment surfaces potentially susceptible to corrosion may be prudent.

IN 92-42: Fraudulent Bolts in Seismically Designed Walls
This notice was issued to alert addressees to fraudulent anchor and through wall bolts found in seismic structures. Recipients were to review the information for applicability to their facility and consider actions to avoid similar problems. This notice pertains to design, construction, or operations issues and does not identify age related degradation issues.

IN 92-52: Barriers and Seals between Mild and Harsh Environments
This notice was issued to alert addressees to problems that could result from missing or deteriorated barriers or seals that protect equipment designed to operate in a mild environment from areas that could have a harsh environment following a design basis accident. At Millstone 1, Northeast Nuclear Energy Company performed a walkdown inspection of the environmental qualification barriers in the switchgear area and found a number of postulated steam paths into the area, including gaps between floor hatch covers and the surrounding floors, openings around doors where gasket material was missing, and miscellaneous small gaps and openings. If safety-related equipment intended for mild environments were operated at more demanding conditions, it could cause safety concerns. This notice pertains to design, construction, or operations issues and does not identify age related degradation issues.

IE Bulletins

BL 74-03: Failure for Structural or Seismic Support Bolts on Class I Components
This bulletin was sent to the addressees to provide information reported by Connecticut Yankee as an abnormal occurrence at the Haddam Neck reactor facility. During a visual inspection, several steam generator seismic support holddown bolts were observed to be loose. Subsequent inspections by ultrasonic and impact testing of all 256 bolts identified a total of 24 which failed and were unable to perform their design function. A preliminary evaluation indicated the bolts had failed in tension apparently from over-torque during the original installation. It was later ascertained by metallurgical and electron microscopic techniques that the failures were the result of stress corrosion, associated with the high pre-stressing, stress risers at the root of the bolt threads and the presence of moisture originally from the concrete and continuing from miscellaneous spills, leakage or high humidity commonly found within containment areas. It was noted that ASME Section XI does not address the inspection of support structures. Action requested included inspection at the next outage.

BL 74-03: Failure for Structural or Seismic Support Bolts on Class I Components, Supplement
This supplement was sent to provide additional information relative to the omission of certain stiffeners and gussets in addition to defective welding reported at other facilities. This bulletin pertains to design, construction, or operations issues and does not identify age related degradation issues.

BL 79-02: Pipe Support Base Plate Designs Using Concrete Expansion Anchor Bolts, Rev.1, Supp. 1, and Rev. 2.
IE Bulletin 79-02 reported structural failures of piping supports for safety equipment at Millstone Unit 1. Subsequent inspections of undamaged supports showed a large percentage of the concrete anchor bolts were not tightened properly. Deficiency reports filed by Long Island Lighting on Shoreham Unit 1 indicate that design of base plates using rigid plate assumptions has resulted in underestimation of loads on some anchor bolts. Inspection of anchor bolt installations at Shoreham has shown over fifty percent of the bolt installations to be deficient. The notice required a number of actions for verifications, documentation/calculations/testing, and information regarding anchors. This bulletin pertains to design, construction, or operations issues and does not identify age related degradation issues.

Generic Letters

GL 80-47: Additional Guidance on "Potential for Low Fracture Toughness and Lamellar Tearing on PWR Steam Generator and Reactor Coolant Pump Supports", NUREG-0577
The staff requested that BWR and PWR applicants demonstrate the adequacy of the applicable support structures of their facility from a fracture toughness standpoint. For PWR's the applicable support structures are the steam generators, reactor coolant pumps,

pressurizer, and reactor vessel. This generic letter pertains to design, construction, or operations issues and does not identify age related degradation issues.

GL 80-85: Implementation of Guidance from Unresolved Safety Issue A-12, "Potential For Low Fracture Toughness and Lamellar Tearing on Component Supports"
Previous letters removed the option of using linear elastic fracture mechanics analyses to demonstrate adequate structural integrity. Comments indicated a desire to retain linear elastic fracture mechanics analyses as an alternative means to demonstrate adequate structural integrity using an EPRI-proposed alternative program. The NRC met to discuss the issue and asked the licensees to be prepared to commit to alternative programs at a December 1980 meeting. This generic letter pertains to design, construction, or operations issues and does not identify age related degradation issues.

GL 80-105: Implementation of Guidance for Unresolved Safety Issue (USI) A-12, "Potential For Low Fracture Toughness and Lamellar Tearing on Component Supports"
The letter attached a summary of a November 12, 1980 meeting of the NRC staff, EPRI, and interested licensees, license applicants, and consultant organizations. The staff modified its position such that both programs in GL 80-85 may be used as necessary during the analysis. This generic letter pertains to design, construction, or operations issues and does not identify age related degradation issues.

NUREGs

NUREG/-2999: USNRC Anchor Bolt Study Data Survey and Dynamic Testing
A survey was performed to determine the adequacy of existing concrete expansion anchor test data. Based upon the survey findings, additional dynamic testing to assess the benefits of preload was undertaken. Exploratory testing was performed on typical wedge and shell anchors. It was found that, providing the installation torque is properly applied, residual preload does not significantly affect anchor load-displacement characteristics until the preload drops to less than 50% of the full installation preload. It was concluded that this must be considered in design situations where support stiffness is an important factor. This document pertains to design, construction, or operations issues and does not identify age related degradation issues.

NUREG/CR-3604: Bolting Applications
An investigation of bolting practices specific to the nuclear industry was performed. The report covered a large spectrum of topics e.g. bolts embedded in concrete, specifications, inspection of bolting, both at receipt and inservice. Plots of preload versus yield strength for different bolting materials in different environments are presented as well as information relative to the stress corrosion cracking resistance of the more recent reactor internals bolting materials A286 and Inconel X-750. Part of the report contains input by Standard Pressed Steel Inc. (a bolting consultant) relative to bolting standards, cottering methods and potential areas for bolting improvement.

Summary

A review of NRC generic communications indicated that the majority of issues related to structural steel and steel components may be attributed to inadequate design and construction; very few age related degradation issues were identified. Design related issues could have been precluded by improved design features such as appropriate materials selection, proper post tensioning, improved preservice inspection methods, and updated analysis methods. Construction related issues could have been precluded by improved site practices and procedures.

Age related degradation issues include general corrosion and cracking of high strength bolting. Most notable of the age related degradation concerns is the presence of moisture and acidic water conditions and its effect on steels such as general corrosion and stress corrosion cracking. The review of the generic correspondence did not reveal any new aging mechanisms or concerns that have not been considered in Sections 2.3.1 through 2.3.4.

2.3.6 Summary of Applicable Aging Effects

The previous sections discuss various aging effects and their applicability within the bounds of the specific materials and environments for structural steel and steel components. Based on the preceding discussions, loss of material due to general corrosion is the primary aging mechanism that will affect structural steel and steel components. Hydrogen damage and stress corrosion cracking may affect low-alloy structural bolting, which is discussed further in Chapter 4. A summary of applicable aging effects and the associated aging mechanisms for the materials and environments discussed in this chapter is provided in Table 2-2.

Table 2-2 Applicable Aging Effects for Structural Steel and Steel Components

APPLICABLE AGING EFFECTS	CARBON STEEL	LOW-ALLOY STEEL	GALVANIZED STEEL	STAINLESS STEEL
Loss of Material				
General Corrosion	Y	Y	N-protected atmosphere/weather Y-exposed atmosphere/weather	N
Galvanic Corrosion	N	N	N	N
Crevice Corrosion	N	N	N	N
Pitting Corrosion	N	N	N	N
Erosion and Erosion Corrosion	NA	NA	NA	NA
Microbiologically Induced Corrosion	N	N	N	N
Wear	N	N	N	N
Cracking				
Hydrogen Damage	N	N	N	N
Stress Corrosion	N	N	N	N
Fatigue	N	N	N	N
Mechanical Distortion				
Creep	N	N	N	N
Fatigue	N	N	N	N
Change in Material Properties				
Elevated temperatures	N	N	N	N
Irradiation Embrittlement	N*	N*	N*	N*
Intermetallic Embrittlement	NA	NA	N-provided temperature < 400 °F	NA

Key: Y- aging mechanism is applicable.
N- aging mechanism is not applicable
NA- Not Applicable to this chapter
*- Outside Primary Shield Wall.

2.4 Aging Management Programs

Loss of material due to general corrosion was identified as an applicable aging effect for carbon and low-alloy high strength structural steel and steel components protected from and exposed to atmosphere /weather. In addition loss of material was identified as an applicable aging effect for galvanized steel exposed to atmosphere/weather.

General corrosion of steel components may be prevented or minimized by existing protective coatings programs. Visual inspection of structural steel components performed as part of routine plant maintenance and ASME Section XI requirements provide early indication of age related degradation due to corrosion. Coating repair and replacement provides adequate mitigation of corrosion.

Each plant is responsible to ensure that the existing maintenance program addresses the structural steel component aging issues discussed above.

2.5 References

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3. STRUCTURAL STEEL AND STEEL COMPONENTS IN FLUID ENVIRONMENTS

This chapter of the Structural Tools is intended to cover structural steel and steel components used in the construction of building structures, mechanical and electrical supports, and other steel structural members that are exposed to wetted (i.e., borated water and raw water) environments. A description of the items covered in this chapter is provided in Section 3.1. Environments that structural steel and steel components are exposed to are discussed in Section 3.2. Aging effects for material and environment combinations are discussed in Section 3.3. Recommendations for aging management programs are provided in Section 3.4.

3.1 Description and Scope

Structural steel and steel components exposed to fluid environments include, but are not limited to, spent fuel racks, intake structure trash racks and screens, selected component supports, and the liner plate of the spent fuel pool. Structural steel and steel components may be constructed from carbon steel, low-alloy steel, galvanized steel, or stainless steel. Structural steel and steel components exposed to air environments are addressed in Chapter 2.

Carbon steel is used throughout nuclear plants for various applications. It is the material of choice for most structural applications. Carbon steel is used in flood panels, intake structure trash racks and screens, and other components exposed to raw water environments. Carbon steels are unalloyed steels that may contain specified amounts of manganese, phosphorus, silicon, sulfur, and carbon. Carbon steels used in structural applications include, but are not limited to, ASTM Specifications A 1, A 6, A 36, A 53, A 67, A 106, A 307, A 366, A 516, A 500, A 501, A 510, A 563, A 573, A 611, A 641, and F 436, and ASME Specifications SA-36, SA-181, and SA-500.

Low-alloy steels contain small amounts of alloying elements such as nickel, chromium, molybdenum, and manganese, which enable them to be hardened by quench and temper heat treatment.

Carbon and low-alloy steels may be joined using various arc welding processes. All weld filler materials used in welding carbon steel and low-alloy steel are assumed to be equivalent to the carbon steel and low-alloy steel base metal with respect to the discussion of aging effects.

Galvanized steel is produced by taking steel sheets and coating them with zinc or iron-zinc alloys. The corrosion resistance of the galvanized steel is directly proportional to the amount of zinc in the coating. The metallic zinc is applied to the iron and steel by one of

three processes: hot dip galvanizing, electrogalvanizing, or zinc spraying. The majority of the galvanized steel used at nuclear plants is produced by the hot dip process. In the hot dip process, an adherent protective coating of zinc and iron-zinc alloys is applied by immersing the steel in a bath of molten zinc. This process produces a series of layers with each successive layer containing a higher concentration of zinc.

The wrought austenitic stainless steels (300 series) are Type 302, 304, 304L and 316 or 316L. Type 304 is used predominantly in borated water environments. Stainless steels are an iron based alloy containing between 12% and 25% chromium which makes them highly resistant to corrosion. The stainless steel weld metal is assumed to be equivalent to the stainless steels with respect to the discussions on the aging effects of the structural components.

3.2 Environment

Steel components in fluid environments are exposed to fluid environmental conditions that may be divided into two general categories:

1. Raw Water

2. Borated Water

Raw Water

The raw water environment is associated with fresh water from a river, lake, pond, or groundwater source. Sodium chloride content is below 1000 ppm for fresh water. Table 3-1 contains the environmental parameters of raw water for the plants addressed in this report. Lake, river, and groundwater parameters are provided for those structures and structural components that are exposed to raw water. Raw water may be from a lake, river, pond, or groundwater source. Structures and structural components that are located below grade are exposed to either groundwater or pond/lake/river water, or a combination of both environments.

Table 3-1 Representative Plant Raw Water Analysis

	Plant					
	ANO-1		**ONS 1, 2, & 3**		**TMI**	
Parameter	Ground-water	Lake Water	Ground-water	Lake Water	Ground-water	River Water
pH	5.7 - 8.8	6.7 - 8.4	5.5 - 6	6 - 7	6 - 7	7 - 8.5
Chlorides	< 206 ppm	< 405 ppm	< 10 ppm	< 10 ppm	< 100 ppm	< 25 ppm
Sulfates	< 687 ppm	< 139 ppm	< 600 ppm	< 10 ppm	< 70 ppm	< 100 ppm

Borated Water

The borated water environment is associated with the spent fuel pool. The spent fuel pool contains an oxygen-saturated borated water environment with a concentration of approximately 1800 ppm boron. The spent fuel pool is designed with a cleanup system that removes corrosion products, fission products, and other debris. Water quality is monitored and controlled on a regular basis by checking the water chemistry (e.g., chloride, fluoride, boron, and pH). The normal pool water temperature for the plants addressed in this report is approximately 120 °F with a maximum design temperature less than 250 °F. The heat generated by the spent fuel is removed by a pool cooling system.

3.3 Aging Effects

The information used to document the associated aging effects for carbon steel and stainless steel exposed to raw water and borated water is gathered from industry sources. Where specific mechanisms are not applicable under the environmental and material conditions, justification is provided for a "not applicable" determination. For those effects that are applicable, a detailed discussion of the environmental conditions necessary for the effects to occur is included. Aging effects discussed below include loss of material, cracking, mechanical distortion, and change in material properties. This chapter evaluates potential aging effects for carbon, low-alloy, galvanized, and stainless steels in a raw water environment and stainless steel in a borated water environment.

3.3.1 Loss of Material Assessment

Aging mechanisms that may lead to loss of metallic materials include general corrosion, galvanic corrosion, crevice corrosion, pitting corrosion, erosion and erosion-corrosion, and microbiologically induced corrosion. The applicability of each aging mechanism is discussed below.

3.3.1.1 General Corrosion

General corrosion is the result of a chemical or electrochemical reaction between a material and its environment. General corrosion is normally characterized by uniform attack resulting in material dissolution and sometimes corrosion product buildup [1]. At ordinary temperatures and in neutral or near neutral media, both oxygen and moisture must be present to corrode iron.

Carbon Steel and Low-Alloy Steel in Raw Water

Carbon steel and low-alloy steels are susceptible to corrosion in systems using raw water. Corrosion products consisting of hydrated oxides of iron (rust) form on exposed, unprotected surfaces of the steel. Corrosion of structural steel is visible. Loss of material

by general corrosion is an applicable aging effect for carbon steel and low-alloy steel exposed to raw water.

Stainless Steel in Raw Water

Stainless steels which contain 12% chromium minimum have excellent resistance to general corrosion for all fluids except raw water [3]. The chloride content of the water affects the corrosion of stainless steel in raw water applications. Therefore, loss of material owing to general corrosion is an applicable aging effect for stainless steels in raw water.

Stainless Steel in Borated Water

Wrought austenitic stainless steel is not susceptible to general corrosion when subjected to borated water environments defined by the EPRI Water Chemistry Guidelines [4]. In addition, for stainless steel in oxygen-saturated borated water, the corrosive deterioration of the Type 304 stainless steel should not exceed a depth of 7.00×10^{-5} inches in 100 years, which is negligible relative to the initial thickness [5]. Therefore, loss of material by general corrosion is not an applicable aging effect for stainless steel borated water environments.

3.3.1.2 Galvanic Corrosion

Galvanic corrosion occurs when materials with different electrochemical potentials are in contact in an electrolyte. Generally, the effects of galvanic corrosion are precluded by design (e.g., isolation to prevent electrolytic connection or using similar materials).

Carbon Steel and Low-Alloy Steel in Raw Water

Carbon steel and low-alloy steel have lower potential than stainless steels and would be preferentially attacked in a galvanic couple [6]. Therefore, loss of material by galvanic corrosion is an applicable aging effect for carbon steel and low-alloy steel in raw water if either of these materials are in contact with a metal of higher potential.

Stainless Steel in Raw Water

Stainless steel in contact with carbon or low-alloy steel would act as the cathode and dissolution of the ferritic material would occur. Therefore, loss of material by galvanic corrosion in raw water is not an applicable aging effect for stainless steel.

Stainless Steel in Borated Water

Dissolution of the ferritic materials would occur when in contact with austenitic stainless steel in an electrolyte [6] since the more corrosion resistant material (i.e., stainless steel)

acts as the cathode. Therefore, loss of material by galvanic corrosion of wrought austenitic stainless steels in a borated water environment is not an applicable aging effect.

3.3.1.3 Crevice Corrosion

Crevice corrosion occurs in crevices or shielded areas where stagnant or low flow conditions allow a corrosive environment to develop within the crevice. In addition to stagnant conditions, an oxygen content above 100 ppb in the fluid is required to initiate and perpetuate crevice corrosion [7]. Temperature has a marked effect on crevice corrosion as well. Although not required for crevice corrosion, any impurities and high temperatures significantly increase the rate at which crevice corrosion occurs.

Carbon Steel and Low-Alloy Steel in Raw Water

Carbon steels and low-alloy steels are susceptible to some degree to crevice corrosion [9]. Loss of material by crevice corrosion is an applicable aging effect for carbon and low-alloy steel in a raw water environment.

Stainless Steel in Raw Water

Stainless steel is susceptible to some degree to crevice corrosion in a raw water environment [9]. Therefore, loss of material by crevice corrosion is an applicable aging effect for stainless steel in a raw water environment.

Stainless Steel in Borated Water

Wrought austenitic stainless steels are susceptible to crevice corrosion above 200 °F in oxygenated (>100 ppb) water. The only consideration for structural stainless steels in oxygenated borated water is in the spent fuel pool structures. Crevice corrosion is not expected to cause excessive degradation in crevice joints in properly controlled high purity water environment [7]. As such, the spent fuel pool structures are not subject to damaging corrosion [21] and loss of material by crevice corrosion is not an applicable aging effect for stainless steel in borated water.

3.3.1.4 Pitting Corrosion

Pitting corrosion is an aggressive corrosion mechanism that is more common with passive materials such as wrought austenitic stainless steels. Pitting corrosion attacks the passive films in localized areas. Once a pit penetrates the passive film, galvanic conditions occur because the metal in the pit is anodic relative to the passive films. With stagnant or low flow conditions, impurities such as halides and sulfates remain in the pit and dissolution of the metal continues.

Carbon Steel and Low-Alloy Steel in Raw Water

Pitting corrosion can be inhibited by maintaining an adequate flow rate, thus preventing impurities from adhering to the material surface [2]. Low flow for carbon steel in raw water is defined to be < 3 fps [8]. Therefore, loss of material due to pitting corrosion is not an applicable aging effect for carbon steel in water unless the flow is less than 3 fps.

Stainless Steel in Raw Water

The most common cause of pitting corrosion in stainless steel is due to contact with moisture that contains halide ions, particularly chlorides. The raw water in contact with stainless steel contains varying levels of chlorides and provides the medium for pitting corrosion when chloride levels exceed 150 ppb. Therefore, loss of material due to pitting corrosion is an applicable aging effect for stainless steel in raw water when chloride levels exceed 150 ppb in stagnant and low flow areas.

Stainless Steel in Borated Water

Oxygen levels in the fluid above 100 ppb are required to initiate pitting in wrought austenitic stainless and some form of impurity such as chloride, fluoride, sulfates is required to continue dissolution of the material [3]. Stagnant or low flow conditions that enable the impurity to adhere to the metal surface are also required for pitting corrosion to occur. Pitting corrosion is an applicable aging effect for stainless steel in a borated water environment when chloride levels exceed 150 ppb in stagnant and low flow areas.

3.3.1.5 Erosion and Erosion-Corrosion

Erosion is the loss of material due to a flowing fluid. Impingement and solid particle erosion is caused by the impact of particles or liquid on a material. Erosion-corrosion is a mechanism where fluid flow erodes or dissolves the protective oxide or passive film of a metal, causing increased corrosion and reoxidation. The process repeats itself over time, causing general thinning of the material [3] due to material loss. Flow rates less than 6 fps do not cause erosion-corrosion of carbon steel and low-alloy steel [19].

The extent of the erosion-corrosion is influenced by (1) fluid flow velocity, (2) fluid temperature and chemistry, and (3) material susceptibility.

Carbon Steel and Low-Alloy Steel in Raw Water

Carbon steels are susceptible to erosion-corrosion where flow rates exceed 6 fps. Therefore, loss of material due to erosion and erosion-corrosion is an applicable aging effect for carbon steel in raw water where fluid velocities exceed 6 fps. In comparison to ordinary carbon steel, erosion corrosion rates may be reduced by three to ten times by the use of selected low-alloy steels. Even though low-alloy steels are more resistant to

erosion-corrosion than carbon steels, loss of material by erosion-corrosion will conservatively be assumed to be an applicable aging effect for low-alloy steels.

Stainless Steel in Raw Water

Austenitic stainless steels are immune to erosion/corrosion owing to a high chromium content (>12%) which allows a tenacious, tough, passive film to resist erosion of single phase flows [9]. Therefore, loss of material by erosion-corrosion is not an applicable aging effect for stainless steels in raw water. Cavitation erosion has occurred in systems containing raw water, generally due to improper operation of pumps and valves. However, stainless steel structural components are not subjected to fluid velocities that could cause cavitation-erosion.

Stainless Steels in Borated Water

The stainless steels used in borated water environments are not susceptible to corrosion and are considered resistant to erosion/corrosion in a borated water environment. Austenitic stainless steels are immune to erosion/corrosion owing to a high chromium content (>12%) which allows a tenacious, tough, passive film to resist erosion of single phase flows [9]. Therefore, loss of material by erosion-corrosion is not an applicable aging effect for stainless steels in borated water.

3.3.1.6 MIC

Microbiologically Induced Corrosion (MIC) occurs by the action of microorganisms. Microorganisms are usually classified according to their ability to grow in the presence or absence of oxygen. Aerobic organisms grow in nutrient mediums containing dissolved oxygen. Anaerobic organisms grow most favorably in environments containing little or no oxygen. Selected aerobic organisms produce sulfuric acid by oxidizing sulfur or sulfur-bearing compounds. Selected anaerobic organisms reduce sulfate to sulfide ions which influences both anodic and cathodic reactions on iron surfaces. These microscopic organisms have been observed to live in media with pH values between 0 and 11, temperatures between 30 °F and 180 °F, and under pressure up to 15,000 psi [6]. MIC is facilitated by stagnant conditions, fouling internal crevices, and contact with untreated water from a natural source. Microorganisms such as iron bacteria are important in their effect on steel as they live by digesting iron and manganese ions in the presence of oxygen after taking these ions into their cells. Iron bacteria flourish in running and stagnant water environments with temperatures of 40 °F to 100 °F, and pH environments between 4 and 10 [10].

Carbon Steel and Low-Alloy Steel in Raw Water

MIC occurs in carbon steel and low-alloy steel particularly under deposits and in crevices. Buildup of slime and bacteria in crevices can lead to MIC despite high fluid

flow rates [11]. Therefore, loss of material due to MIC is an applicable aging effect for carbon steel and low-alloy steel in raw water.

Stainless Steel in Raw Water

MIC is almost always confined to welds and weld heat-affected zones (HAZs) in austenitic stainless steels. Fluid velocities and buildup of slime and bacteria in crevices, as discussed above, also apply. Therefore, loss of material by MIC is an applicable aging effect for stainless steel components in raw water.

Stainless Steel in Borated Water

MIC is an inactive mechanism in borated water systems owing to low sulfate (<100 ppb) and water treatment with biocides. Therefore, loss of material by MIC is not an applicable aging effect for stainless steel in a borated water environment.

3.3.2 Cracking

Cracking of base metal and/or weld metal may result from one or more of the following aging mechanisms: hydrogen damage, stress corrosion, intergranular attack, and fatigue. Each of these aging mechanisms is evaluated in the following sections for carbon steel, low-alloy steel, and stainless steel in a raw water environment and stainless steel in a borated water environment.

3.3.2.1 Hydrogen Damage

Hydrogen damage results from the absorption of hydrogen into the metal. It includes the degradation mechanisms of hydrogen blistering and embrittlement. Diffusion of atomic hydrogen into a void in the steel structure and the subsequent formation of molecular hydrogen which cannot diffuse through the metal, results in high localized pressure. High localized pressures are sufficient to cause blistering and cracking of the steel structure. Hydrogen damage usually manifests itself as hydrogen embrittlement in high strength steels and hydrogen blistering in low strength steels. Corrosion and the application of cathodic protection, electroplating, and other processes are major sources of hydrogen in metals.

Carbon Steel and Low-Alloy Steel in Raw Water

Hydrogen blistering occurs primarily in low strength carbon steel and low-alloy steel in the temperature range of 30 °F to 300 °F [12]. Hydrogen blistering is most prevalent in the petroleum industry, in storage tanks and in refining processes [6]. A review of the failure data for PWR raw water systems show no evidence of hydrogen blistering; therefore, it is considered not applicable for carbon and low-alloy steels in raw water.

Stainless Steel in Raw Water

Although austenitic stainless steels are highly susceptible to stress-corrosion cracking, they are almost completely resistant to failure by hydrogen damage. A major factor in the resistance to hydrogen damage is their microscopic structure which is relatively impermeable to diffusion of atomic hydrogen [20]. Therefore, cracking due to hydrogen damage is not an applicable aging effect for stainless steels in raw water.

Stainless Steel in Borated Water

Austenitic stainless steels are almost completely resistant to failure by hydrogen damage. A major factor in the resistance to hydrogen damage is their microscopic structure which is relatively impermeable to diffusion of atomic hydrogen [20]. Therefore, cracking owing to hydrogen damage is not an applicable aging effect for stainless steel in a treated water (borated water) environment.

3.3.2.2 Stress Corrosion

Stress-corrosion cracking (SCC) is a type of corrosive attack that occurs through the combined actions of stress (both applied and residual tensile stresses), a corrosive environment, and a susceptible material. All three of these "factors" (susceptible material, tensile stress, and corrosive environment) are necessary to initiate SCC. For a particular material, high tensile stresses require less corrosive environments and highly corrosive environments require less tensile stress to initiate and propagate cracking. Elimination or reduction of any of these factors will decrease the likelihood of SCC occurring. SCC can be categorized as either intergranular stress corrosion cracking (IGSCC) or transgranular stress corrosion cracking (TGSCC), depending upon the primary crack morphology.

IGSCC is characterized by cracks propagating along the grain boundaries of the material. It is typically associated with materials containing excessive grain boundary precipitation or impurity segregation and usually occurs in relatively low dissolved oxygen environments. Preferential grain boundary precipitation of carbides in austenitic stainless steels can lead to a localized depletion of chromium in the vicinity of the grain boundary. This is known as sensitization and is one of the mechanisms believed to promote IGSCC. Grain boundary segregation of impurities such as phosphorous, sulfur, and silicon is another mechanism believed to promote IGSCC. It can produce a grain boundary chemical composition with a significantly different electrochemical potential from that of the bulk alloy composition. The effect of this electrochemical potential difference is an increase in corrosion susceptibility at the grain boundaries.

TGSCC is characterized by cracks that propagate through (or across) the grains of the material. Numerous metallurgical factors, such as crystal structure, grain size and shape, dislocation density and geometry, and phase composition, affect TGSCC. It is most

prevalent in austenitic stainless steels subjected to chlorides and oxygenated environments.

Carbon Steel and Low-Alloy Steel in Raw Water

Stress corrosion as a phenomena is not usually associated with carbon steel and low-alloy materials. However, corrosion of carbon and low-alloy steels is well documented and aggressive conditions can develop under deposits and in crevices which could ultimately lead to cracking of the material. Cracking following corrosion of carbon steel in raw water has been observed and has been attributed, at least in part, to MIC occurring in these deposits and crevices. The extreme alteration of the local environment caused by MIC could lead to what could be described as SCC of the carbon and low-alloy steel, but SCC of the carbon and low-alloy steels from direct exposure to the raw water environment is not an applicable aging effect. Therefore, cracking due to stress corrosion is not an applicable aging effect for carbon and low-alloy steels in raw water.

Stainless Steel in Raw Water

The most aggressive contributors to stainless steel SCC in a raw water environment are the oxygen concentration and chloride levels of the raw water. Austenitic stainless steels are susceptible to SCC in oxidizing environments, particularly those with sensitized microstructures such as the welds and HAZ of the structural materials. The critical stress levels required to cause cracking in an oxidizing environment in a sensitized structural material can be quite low. Residual stresses remaining from welding processes are often sufficient to cause SCC for susceptible materials given the proper environment.

In a raw water environment, regardless of temperature and dissolved oxygen, if chloride levels are greater than 150 ppb, SCC of austenitic stainless steel is an applicable aging effect, especially for the welds and HAZ of the stainless steel structural materials.

In a high temperature (T > 200 °F) raw water environment, the oxygen present can cause SCC to be an applicable aging effect. By design, no stainless steel structural components in oxygenated raw water are exposed to temperatures greater than 200 °F, so SCC due to these conditions is not an applicable aging effect. In lower temperature (T< 200 °F) raw water environments with chloride levels less than 150 ppb, the presence of oxygen is not as significant an environmental factor and SCC of austenitic stainless steels is not a concern. Therefore, SCC of stainless steels in raw water is an applicable aging effect for the welds and HAZ when the chloride content exceeds 150 ppb.

Stainless Steel in Borated Water

In a sensitized condition, as in the heat affected zones of a weld and base metal, Type 304 stainless steel may develop stress corrosion cracking under certain environmental conditions.

Environmental effects play a large part in causing SCC in these sensitized areas. One of the most aggressive contributors to SCC is the dissolved oxygen concentration. At higher temperatures (T> 200 °F), dissolved oxygen creates an aggressive environment that can lead to SCC of stainless steel. Control of temperatures to less then 200 °F, eliminates oxygen as an aggressive environmental factor and SCC is not an applicable aging effect for the stainless steel structural materials. Also important is the chloride and sulfate levels in the borated water. In a borated water environment, regardless of temperature and dissolved oxygen, if chloride levels are greater than 150 ppb, SCC of austenitic stainless steel is an applicable aging effect, especially for the welds and the HAZ. The degree of sensitization is dependent on metal composition. For example, Type 304L stainless steel is relatively immune to IGSCC in borated water environment. This is because the low carbon content (0.03% maximum) for Type 304L results in sensitization levels during welding so low that its heat affected zones are resistant to IGSCC in the borated water environment [14]. In addition to chlorides, sulfates may induce stress corrosion cracking at the welds and heat affected zones of the base metal. Cracking can occur where sulfates routinely exceed 100 ppb [13]. Cracking owing to stress corrosion is an applicable aging effect for stainless steel in an oxygenated borated water environment where chlorides and sulfates exceed the concentration limits defined above or where temperatures routinely exceed 200 °F.

3.3.2.3 Intergranular Attack (IGA)

Intergranular attack (IGA), also known as intergranular corrosion, is similar in some respects to SCC; however, it is distinguished from SCC in that stress is not necessary for it to proceed. IGA is characterized by deterioration of grain boundaries without appreciable attack of adjacent grains, i.e., the rate of attack on grain boundaries greatly exceeds that of the matrix material. Generally, materials and conditions that are susceptible to stress corrosion cracking will also be susceptible to IGA.

Carbon Steel and Low-Alloy Steel in Raw Water

Based on the discussion in Section 3.3.2.2, carbon steel and low-alloy steel in raw water are not susceptible to stress corrosion, so cracking owing to IGA is not an applicable aging effect for these materials in a raw water environment.

Stainless Steel in Raw Water

Based on the discussion in Section 3.3.2.2, stainless steel in raw water is susceptible to stress corrosion, so cracking owing to IGA is an applicable aging effect for stainless steel in a raw water environment.

Stainless Steel in Borated Water

Based on the discussion in Section 3.3.2.2, stainless steel in borated water is susceptible to stress corrosion where chloride and sulfates exceed certain concentrations, so cracking owing to IGA is an applicable aging effect for stainless steel in a borated water environment where chlorides and sulfates exceed the concentration limits defined in Section 3.3.2.2.

3.3.3 Mechanical Distortion

Mechanical distortion of carbon, low-alloy and stainless steel may be caused by creep or fatigue. In general, distortion is addressed by the design codes and is not considered an applicable aging effect. Creep is not a plausible aging mechanism since the high temperatures required for this mechanism to occur (generally at temperatures > 40% of the alloy melting point) are not observed for structural components [3]. Distortion due to fatigue may be applicable, but is addressed during the design phase. Fatigue is also addressed for the period of extended operation during the time limited aging analyses (TLAA) evaluations on a site specific basis. Therefore, mechanical distortion due to creep and fatigue is not an applicable aging effect for carbon, low-alloy, and stainless steels in fluid environments. Where fatigue is applicable it will be addressed on a site specific basis.

3.3.4 Change in Material Properties

The change in material properties aging effect is seen in steel structures and components as an increase in yield strength, reduction in modulus of elasticity, reduction in ultimate tensile ductility, reduction in fracture toughness, and an increase in ductile-to-brittle transition temperature. Conditions that may lead to changes in material properties for steel components include

- Elevated Temperature
- Irradiation Embrittlement

The applicability of each condition to carbon steel, low-alloy steel, and stainless steel is discussed below.

3.3.4.1 Elevated Temperature

Thermal aging is a time- and temperature-dependent mechanism where microstructural changes lead to increased yield and tensile strength properties, decreased ductility, and degradation of toughness properties. Structural steel must be exposed to relatively high temperatures (700 °F) to experience thermal embrittlement [14].

Carbon Steel, Low-Alloy Steel and Stainless Steel in Raw Water

Since raw water temperatures are well below the threshold temperatures expected to cause thermal embrittlement, thermal aging is not an applicable aging effect for carbon, low-alloy, and stainless steel in a raw water environment.

Stainless Steel in Borated Water

Since borated water temperatures are well below the threshold for thermal embrittlement, wrought austenitic stainless steels are not susceptible to thermal embrittlement in PWR environments [15]. Therefore, reduction of fracture toughness owing to thermal embrittlement is not an applicable aging effect for wrought stainless steel in a borated water environment.

3.3.4.2 Irradiation Embrittlement

Irradiation embrittlement can result in a decrease in fracture toughness of metals. Currently available data indicate that these effects on the mechanical properties of steel are measurable at 10^{18} n/cm^2 (E> 1 MeV) [14].

Carbon Steel, Low-Alloy Steel and Stainless Steel in Raw Water

Carbon steel, low-alloy steel, and stainless steel in a raw water environment are exposed to fluence levels far below the threshold; therefore, reduction of fracture toughness owing to irradiation embrittlement is not an applicable aging effect for carbon and low-alloy stainless steels in a raw water environment.

Stainless Steel in Borated Water

The stainless used in structural components in the spent fuel pool are exposed to much lower neutron fluence than the threshold provided for steel which is approximately 10^{18} n/cm^2 (E>1 MeV). The irradiation effect is moderated by the water medium and the neutron absorbing material used in the spent fuel rack system. Therefore, reduction of fracture toughness owing to irradiation embrittlement is not an applicable aging effect for stainless steel in a borated water environment.

3.3.5 Industry Experience

Industry failure data and NRC generic communications were reviewed to determine additional aging effects or mechanisms that should be considered for carbon steel, low-alloy steel, and stainless steel in a raw water environment. This review included searches of INPO Nuclear Plant Reliability Data System (NPRDS) databases, NRC Inspection and Enforcement (IE) Information Bulletins, and NRC Licensee Event Reports (LER). The search was performed for components such as sump liners, flood panels, trash racks and rakes, spent fuel racks, and spent fuel pool liners.

Raw Water Environment

NUREG-1522 documents the inspection of six older plants (licensed before 1977) by the staff of the Civil Engineering and Geosciences Branch (ECGB) in the Division of Engineering of the Office of Nuclear Reactor Regulation. The report identifies corrosion of intake structure steel components in raw water.

A search of NPRDS did not find any failure reports related to the carbon steel, low-alloy steel, or stainless steel structural components in raw water environments.

Borated Water Environment

A search of NPRDS did not find any failure reports related to the stainless steel structural components in a borated water environment. NRC Bulletin 94-01 [16] was issued to address concerns over spent fuel pool integrity. Leak chase systems are installed to monitor any loss of fluid inventory and to bring attention to degradation and failure of the spent fuel pool liner.

A survey of spent fuel pool experience between 1969 and 1985 identified ten events involving corrosion and/or cracking of stainless steel liner plates [17,18]. Intrusion of impurities into the spent fuel storage pool and fuel transfer canal is the suspected cause of the degradation in most cases. These events were detected during routine monitoring for liner leakage. Where required, repairs were completed such that none of the events jeopardized the ability of the structure to perform its function.

As a result of the review of NRC, industry, and utility records, corrosion was verified as an applicable aging effect for carbon steel and low-alloy steel in a raw water environment and stainless steel in a borated water environment. No other applicable aging effects were identified.

3.3.6 Summary of Applicable Aging Effects

The previous sections discuss a number of aging mechanisms and the applicability within the bounds of the specific material and environments for carbon steel, low-alloy steel, and stainless steel in a raw water environment and stainless steel in a borated water environment. Aging mechanisms which are deemed plausible under these conditions have been described and the associated aging “effects” identified. A summary of applicable aging effects and the associated aging mechanisms for the materials and environments discussed in this chapter is provided in Table 3-2.

Table 3-2 Applicable Aging Effects for Steel Components in Fluid Environments

Environment/ Material	Loss of Material						Cracking			Change in Material Properties	
	General Corrosion	Galvanic Corrosion	Crevice Corrosion	Pitting Corrosion	Erosion & Erosion/ Corrosion	MIC	Hydrogen Damage	Stress Corrosion	IGA	Thermal Aging	Irradiation Embrittlement
Raw Water											
Carbon Steel & Low-Alloy Steel	Y	Y	Y	Y	Y	Y	N	N	N	N	N
Stainless Steel	Y	N	Y	Y	N	Y	N	Y	Y	N	N
Borated Water											
Stainless Steel	N	N	N	Y	N	N	N	Y	Y	N	N

Key: Y means aging mechanism is applicable for the material and environment.
N means aging mechanism is not applicable for the material and environment.

3.4 Aging Management Programs

Raw Water

Loss of material was identified as an applicable aging effect for carbon steel, low-alloy steel, and stainless steel in a raw water environment. In addition, cracking was identified as an applicable aging effect for stainless steel components in a raw water environment. Each nuclear power plant is responsible for identifying carbon steel, low-alloy steel, and stainless steel in this environment and demonstrating that the aging effects will be managed for the period of extended operation.

Borated Water

Loss of material due to pitting and cracking owing to stress corrosion and IGA were identified as applicable aging effects for stainless steel in a borated water environment when the chloride and sulfate concentrations exceed the prescribed limits. Where the chemistry program for the spent fuel pool maintains these impurities below 150 ppb for chlorides and 100 ppb for sulfates, loss of material due to pitting and cracking owing to stress corrosion and IGA is not likely to occur. Each nuclear power plant is responsible for reviewing their chemistry program to ensure that it contains the appropriate guidance for maintaining chloride and sulfate concentrations in the spent fuel pool.

In addition to the chemistry program, a liner leak chase system located behind the liner plate seam welds is provided to detect and generally locate any leakage in the spent fuel pool liner plate. The leak chases are connected to drain lines that terminate in a leak detection sump.

3.5 References

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4. THREADED FASTENERS

Bolting applications within the scope of license renewal may be divided into pressure boundary bolting and structural and component support bolting. Pressure boundary bolting is discussed in the B&W GLRP document BAW-2270, Revision 1, entitled "Non-Class 1 Mechanical Implementation Guideline and Mechanical Tools," and is not discussed in this chapter. Structural and component support bolting applications include bolted joints and threaded connections for structural steel and steel components used in the construction of building structures, mechanical and electrical component supports, and other structural members. These bolted joints and threaded connections are hereafter referred to as threaded fasteners.

Threaded fasteners covered in this chapter are discussed in Section 4.1 Environments that the threaded fasteners are exposed to are discussed in Section 4.2 Aging effects for materials and environments are discussed in Section 4.3. Aging management programs required to ensure bolted connection integrity will be addressed on a plant-specific basis using the general recommendations provided in Section 4.4.

4.1 Description and Scope

Threaded fasteners include joint components such as bolts, studs, nuts, washers, screws, and anchorage to concrete. Member faying surfaces (i.e., mating surfaces of bolted parts) are also considered part of threaded fastener scope. Rivets are not typically used in nuclear power plants and are not covered in this chapter. Typical fastener materials include carbon steel—ASTM A 307, A 36, A 325, A 449, A 490, and SAE J429; low alloy steel—ASTM A 193 B7, B7M, A 320 L7, L7M, L70; maraging steel; and austenitic stainless steel—ASTM A 193 B8 and A 320, B8 and B8M, and A 320 B8 and B8M.

Steel embedments in concrete, consisting of anchor bolts (material below the concrete line), plates, structural shapes and other items that were cast-in-place or grouted in holes drilled are covered in Chapter 5. The exposed surfaces of such cast-in-place or grouted steel and the entire length of concrete expansion anchors, above and below the concrete line, are included in this chapter.

4.2 Environment

Threaded fasteners for structural steel components are exposed to a limited variety of environments. These environments may be divided into three general categories:

1) threaded fasteners protected from atmosphere/weather

2) threaded fasteners exposed to atmosphere/weather, and

3) threaded fasteners exposed to fluid environments.

Threaded fasteners exposed to fluid environments are not within the scope of this chapter. However, aging effects for threaded fasteners in fluid may be determined by reviewing Chapter 3.

Threaded Fasteners Protected from Atmosphere/Weather

Threaded fasteners inside buildings protected from atmosphere/weather may be exposed to ambient temperatures up to 150°F, relative humidity of 100 percent, and neutron and gamma radiation. Threaded fasteners attaching components to high temperature piping in buildings protected from atmosphere/weather may be subjected to a maximum operating temperature of 650 °F. Threaded fasteners protected from atmosphere/weather may temporarily be in contact with aggressive chemicals resulting from spills. The resulting aging effect is considered negligible since spills are quickly cleaned in accordance with house keeping procedures.

Threaded Fasteners Exposed to Atmosphere/Weather

Threaded fasteners not located in buildings and exposed to atmospheric conditions and weather are subjected to temperatures ranging from -15 °F to 115 °F, relative humidity of 100 percent, and negligible radiation levels. The nuclear power plants within the scope of this document are not located in areas near major industrial plants that would expose them to corrosive chemicals in the atmosphere. Salt water atmospheric environment is not within the scope of this report.

4.3 Aging Effects

The intended function of threaded fasteners is to maintain mechanical connection integrity. Loss of mechanical connection integrity may be attributed to one or more of the following aging effects that may be applicable to the threaded connection: loss of preload, cracking of bolting material, and loss of bolting material. Aging mechanisms that may cause these aging effects to occur are discussed below. The discussion of aging mechanism definitions are extracted from the EPRI manuals on good bolting practices [3,4]. All aging mechanisms and associated effects discussed pertain to the environments defined in Section 4.2.

4.3.1 Loss of Preload

Preload is the tension force developed in a fastener when it is tightened against the joint. This preload often decreases which may be attributed to one or more of the following mechanisms: embedment, cyclic load embedment, gasket creep, thermal effects (e.g., differential expansion and creep), and self loosening. These mechanisms are discussed at length in References 3 and 4 and are briefly summarized below. Many of these

mechanisms are adequately addressed when the joint is assembled and may not be applicable aging mechanisms since they would be observed during the current license term.

4.3.1.1 Embedment

Fastener and joint surfaces are microscopically rough. When first assembled, these surfaces (nut, bolt threads, and joint members) only contact each other at high spots. When initially loaded the high spots tend to creep and flow. Preload is lost as the parts settle in together. The loss of preload is considered small and will have minimal affect on connection integrity. Therefore, loss of preload due to embedment is not an applicable aging effect for structural steel and steel component threaded fasteners.

4.3.1.2 Cyclic Load Embedment

Joints subjected to cyclic loads, especially large loads, will embed and relax more than joints under static loads. If external loads approximate the yield strength of the bolt, preload losses of 25% or even 50% may occur. Threaded fasteners in structural steel and steel components are not subjected to cyclic loads. Therefore loss of preload due to cyclic embedment is not an applicable aging effect for structural steel and steel component threaded fasteners.

4.3.1.3 Gasket Creep

Gaskets must be partially plastic to function properly and will creep after initial loading. Preload loss at room temperature may be 2-5% and will occur in 10 to 20 minutes after initial loading. Gaskets are not usually used with structural connections and structural fastening. Therefore, loss of preload due to gasket creep is not an applicable aging effect for structural steel and steel component threaded fasteners.

4.3.1.4 Thermal Effects

A joint subjected to a change in temperature can lose preload. Differential expansion between threaded fastener and joint members can increase stresses and increase embedment or gasket creep. The fastener may expand away from the joint. The gasket may be compressed beyond the original compression and, due to hysteresis, won't fully recover as the temperature change is reversed. Gaskets are not usually associated with structural connections and structural fastening and loss of preload due to embedment is minimal. Creep of bolting may lead to loss of preload; however, creep is not a plausible aging mechanism since the high temperatures required for this mechanism to occur are not observed in structural bolting applications. Therefore, loss of preload due to thermal effects is not an applicable aging effect for structural steel and steel component threaded fasteners.

4.3.1.5 Self-Loosening

Vibration, flexing of the joint, cyclic shear loads, thermal cycles and other causes can cause whole or partial self-loosening of a fastener. These causes of loosening are minor contributors in structural steel and steel component threaded connections and are eliminated by initial preload bolt torquing. Therefore, loss of preload due to self-loosing is not an applicable aging effect for structural steel and steel component threaded fasteners.

4.3.2 Cracking of Bolting Materials

Cracking of bolting materials may be attributed to stress corrosion cracking and/or fatigue.

4.3.2.1 Stress Corrosion Cracking

Stress corrosion cracking is a condition in which a fastener that is statically loaded well below the material yield strength can suddenly fail. SCC threaded fastener failures have occurred in materials with nominal chemical and mechanical properties [2]. Service and laboratory failures have been observed in bolting materials subjected to water or steam environments containing various contaminants. Carbon and alloy steel fasteners are not intentionally exposed to water or steam, but inadvertent exposure may result from gasket leaks. If leakage is combined with contaminant species, such as sulfides or chlorides, an aggressive environment that can promote SCC may result. Decomposition products from lubricants and sealant compounds injected into leaking closures may produce environments capable of causing SCC in stressed carbon and alloy steel fasteners.

A common factor in several of the reported failures appears to be the use of lubricants containing MoS_2 (molybdenum disulfide)[2]. Laboratory tests indicate that H_2S may be released from MoS_2 decomposition in aqueous environments; however, there is no data that conclusively show that MoS_2 decomposition will cause SCC. Data generated by the oil and gas industry show that, even at low temperatures, H_2S will cause SCC in carbon and alloy steel fasteners. Therefore, MoS_2-induced SCC is viewed as a possible explanation for some of the reactor coolant pressure boundary bolted closure failures.

At present, reported failures of structural bolting owing to SCC have been limited to high strength or ultra high strength bolting (i.e., Sy >150 ksi)[2]. Specifically, failures have been reported for two classes of component support bolting materials: high-nickel maraging steels and low-alloy quenched and tempered steels. Therefore, cracking by SCC of high strength maraging steel and low-alloy quenched and tempered bolts is an applicable aging effect. The majority of applications where high strength bolting is used in PWRs is with preinstalled anchor bolts used to secure Class 1 component supports to the building structure.

4.3.2.2 Fatigue

Cracking of bolting material owing to fatigue is typically characterized by the following characteristics: (1) the failure is sudden with little or no necking-down of the part, (2) the component has been subjected to cyclic tensile loads, and (3) usually the cyclic loads are well below the material tensile strength. The susceptibility to fatigue depends upon many factors including the properties of the fastener materials, fastener processing, defects in the material, stress levels, and the shape of the fastener. However, cracking of bolting due to thermal fatigue is not expected to be a concern for structural bolting applications due to low operating temperatures. High cycle fatigue is not a concern for license renewal since it would be discovered during the current license period. Therefore, cracking of bolting material due to fatigue is not an applicable aging effect for structural steel and steel component threaded fasteners.

4.3.3 Loss of Material

Aging mechanisms that may lead to loss of material include boric acid wastage and general corrosion. The applicability of loss of material to threaded fastener applications may be determined by reviewing Chapters 2 and 3.

4.3.3.1 Boric Acid Wastage

Loss of material due to boric acid wastage is the most common aging affect observed for Class 1 ferritic threaded fasteners. Although considered a common aging mechanism, boric acid wastage is generally found in closures of reactor coolant systems. Structural steel and component connections may be exposed to boric acid if the closures leak. Therefore, loss of material owing to boric acid wastage is an applicable aging effect for structural steel and steel component threaded fasteners.

4.3.3.2 General Corrosion

General corrosion of ferritic threaded fasteners has typically been attributed to leaking joints; this is not normally associated with structural steel and steel component connections. Most structural and component fasteners are located in dry environments, are coated with a lubricant, and are not expected to corrode. However, as discussed in Section 2.3.1.1, carbon and low-alloy steel may be susceptible to general corrosion.

Applications of threaded fasteners in fluid environments are covered on a material basis in Chapter 3. Stainless steel fasteners are generally immune to loss of material due to general corrosion. Therefore, loss of material due to general corrosion of stainless steel bolting materials is not an applicable aging effect.

4.3.4 Industry Experience

A review of NPRDS was performed to determine documented instances of loss of mechanical connection integrity of bolted connections for structural bolting applications; the results of the review are reported in Section 2.3.6. In addition**,** the following Generic Letter provided licensees with information regarding loss of mechanical connection integrity: GL 91-17--Bolting Degradation or Failure in Nuclear Power Plants. GL 91-17 provided licensees with information on GSI 29 which addressed degradation of all safety-related bolts, studs, embedments, machine cap screws, and other threaded fasteners. The NRC concluded that existing requirements, in combination with actions taken in response to industry initiatives, are sufficient to assure integrity of safety-related bolting.

Information Notices

IN 79-33: Improper Closure of Primary Containment Equipment Access Hatches
This information notice informed licensees of an instance where improper closure of primary containment access hatches resulted from a lack of procedures for torque values, sequence of torquing, and alignment of closing dogs. Local leak rate testing yielded values ten times the allowable containment leakage rate. Recipients were to review the adequacy of their procedures for access hatch installation at all facilities.

IN 80-36: Failure of Steam Generator Support Bolting
This information notice reported extensive cracking of the bolting for the supports attached to the bottom of the Prairie Island steam generators. The notice mentions that the susceptibility for stress corrosion cracking was identified in NUREG-0577 which identifies those facilities which have used maraging steels for reactor coolant pump and steam generator support bolting. Licensees are encouraged to review the bolting materials used at their respective facilities and consider inspection of maraging steel bolting that are either preloaded or significantly loaded during operation.

NUREGs

NUREG/CR-2952: Preloading of Bolted Connections in Nuclear Reactor Component Supports
A number of failures of threaded fasteners in nuclear reactor component supports have been reported. Many of those failures were attributed to stress corrosion cracking. This report discusses how stress corrosion cracking can be avoided in bolting by controlling the maximum bolt preloads so that the sustained stresses in the bolts are below the level required to cause stress corrosion cracking. This is a basic departure from ordinary bolted joint design where the only limits on preload are on the minimum preload. Emphasis is placed on the importance of detailed analysis to determine the acceptable range of preload and the selection of a method for measuring the preload that is sufficiently accurate to ensure that the preload is actually within the acceptable range. Procedures for determining acceptable preload range are given, and the accuracy of various methods of measuring preload is discussed.

NUREG/CR-3604: Bolting Applications

An investigation of bolting practices specific to the nuclear industry was performed. The report covered many topics, e.g., bolts embedded in concrete, specifications, inspection of bolting, both at receipt and inservice. Plots of preload versus yield strength for different bolting materials in different environments are presented as well as information relative to the stress corrosion cracking resistance of the more recent reactor internals bolting materials A 286 and Inconel X-750. The report contains input by Standard Pressed Steel Inc. (a bolting consultant) on bolting standards, cottering methods, and potential areas for bolting improvement.

4.3.5 Summary of Applicable Aging Effects

A summary of applicable aging effects and associated aging mechanisms for the materials and environments discussed in this chapter is provided below.

Table 4-1 Applicable Aging Effects for Threaded Fasteners Protected from and Exposed to Ambient

AGING EFFECT	THREADED FASTENER-ALL ENVIRONMENTS
Loss of Preload	
Embedment	No
Cyclic Load Embedment	No
Gasket Creep	No
Thermal Effects	No
Self Loosening	No
Cracking of Bolting Material	
Stress Corrosion Cracking	Yes (high strength—Sy>150 ksi--LAQT and maraging steel bolting)
Fatigue	No
Loss of Material	
Boric Acid Wastage	Yes (carbon and low-alloy fasteners)
General Corrosion	Yes (carbon and low-alloy fasteners)

4.4 Aging Management Programs

In order to conclude that loss of mechanical connection integrity is not an applicable aging effect, the evaluator must identify materials that comprise the bolted connection and evaluate the aging effects discussed in Chapter 4. Gaskets are not usually associated with structural bolting and are not subject to aging management review.

As discussed in Section 4.2 and in the review of operating experience reported in Section 4.3, the most common failures of structural bolting in safety-related equipment were attributed to boric acid corrosion wastage and a few instances of stress corrosion cracking (SCC) of high-strength ferritic materials. Plant-specific programs that were implemented in response to IE Bulletin 74-03 and Generic Letter 91-17 and which apply to the structural bolted connections subject to aging management review should be continued through the period of extended operation. Recommendations of program technical elements to manage mechanical connection integrity are provided below.

1. Bolted connections within the scope of license renewal should be identified.

2. Bolting integrity programs instituted as a result of IE Bulletin 74-03 and GL 91-17 that affect structural bolted connections should be continued through the period of extended operation.

3. A review of EPRI NP-5769, Volumes 1 and 2, should be performed to ensure that high strength structural support bolting applications have been identified and that their susceptibility to SCC has been assessed.

4. Programs credited for managing loss of structural connection integrity should become commitments for the period of extended operation.

4.5 References

1. "Resolution of Generic Safety Issue 29: Bolting Degradation or Failure in Nuclear Power Plants," NUREG-1339, June 1990.
2. "Degradation and Failure of Bolting in Nuclear Power Plants," Volumes 1 and 2, EPRI NP-5769, Project 2520-7, Final Report, April 1988.
3. John Bickford and Michael Looram, "Good Bolting Practices, A Reference Manual for Nuclear Power Plant Maintenance Personnel, Volume 1: Large Bolt Manual," EPRI-NP-5067, 1987.
4. Daniel A. Van Duyne, "Good Bolting Practices, A Reference Manual for Nuclear Power Plant Maintenance Personnel, Volume 2: Small Bolts and Threaded Fasteners," EPRI, December 1990.

5. CONCRETE STRUCTURES AND CONCRETE COMPONENTS

This chapter of the Structural Tools is intended to cover concrete structures and concrete components subject to aging management review; however prestressed concrete structures, such as the reactor building outer shell, are not discussed in this chapter and will be addressed on a plant-specific basis. A description of the items covered in this chapter is provided in Section 5.1. Environments that concrete structures and structural members are exposed to are discussed in Section 5.2. Aging effects for material and environment combinations are discussed in Section 5.3. Recommendations for aging management programs are provided in Section 5.4.

5.1 Description and Scope

This chapter is intended to describe concrete structures and concrete components that are subject to aging management review other than the reactor building or any other pre-stressed concrete structure. Prestressed concrete structures will be evaluated on a plant-specific basis. Tunnels and canals were excluded since they are not within the scope of License Renewal.

The following concrete structures and concrete components are included in the scope of this chapter [1,4]:

- Foundations (basemat)
- Exterior concrete--above grade walls
- Exterior concrete--below grade walls
- Interior concrete--walls and columns
- Interior concrete slabs (including concrete beams)
- Masonry block walls

Concrete is used in nuclear power plants for equipment foundations, pipe trenches, electrical duct banks, embedments, hatches, missile shields, biological shields, tank foundations, pond walls, pilings, water intakes and discharges, spillways, and cooling towers.

Concrete is defined by the American Concrete Institute (ACI) as “a composite material that consists essentially of a binding medium within which are embedded particles or fragments of aggregate; usually a combination of fine aggregate and coarse aggregate; in Portland cement concrete, the binder is a mixture of Portland cement and water.” The

concrete typically used in structures at nuclear power plants consists of Type II Portland cement because of its improved sulfate resistance and reduced heat of hydration relative to the general purpose Type I Portland cement, but the potential aging effects of both types will be reviewed in this chapter. The various admixtures that are used to improve air entrainment, improve workability, modify the hardening or setting characteristics, aid in curing, reduce evolution of heat, or provide other property improvements will also be included in the scope of review of this chapter.

The reinforcements that are permanently and internally embedded in the concrete are also included in the scope of this chapter. (This does not include removable tendons.) Reinforcements are defined as any embedded bars, wires, strands, or other slender members that act together with the concrete in resisting forces. Aging effects for any permanently embedded portions of bolting are also evaluated as part of this chapter. It should be noted that embedments, as defined in this topical report, are those items that (1) were installed while the concrete (or grout) was in a plastic state, and (2) are surrounded by concrete. For example, the only portions of cast in place, embedded anchor bolts that are in-scope of this chapter would be the portion of the bolt below the surface of the concrete. The protruding portion of the bolt is addressed in Chapters 2.0 and 4.0. The nonexposed portion of an embed plate is included in the scope of this chapter, while a post-installed anchor (e.g., expansion anchor bolt) is excluded from the scope of this chapter.

5.2 Environment

Concrete may be used in many different structures and structural members that are exposed to a variety of environments. The environmental conditions applicable to the concrete structures and structural members may be divided into the following general categories:

1) Concrete protected from atmosphere/weather

2) Concrete exposed to atmosphere/weather

Concrete Protected from Atmosphere/Weather

Concrete that is inside buildings and facilities protected from atmosphere/weather may be exposed to ambient temperatures up to 150 °F, a relative humidity of 100 percent, and radiation. Concrete components adjacent to high temperature piping in buildings and facilities protected from atmosphere/weather, may be subjected to a maximum operating temperature of 650 °F. Concrete protected from atmosphere/weather may also temporarily be in contact with aggressive chemicals resulting from accidental spills. The resulting aging effect is considered negligible since spills are quickly in accordance with house keeping procedures. In addition, concrete protected from atmosphere/weather may be exposed to treated (borated) water owing to leakage from bolted closures. Treated

water and water containing boron may through alternate wetting and drying cycles, lead to chemical and concentrated boron solution exposure which could result in corrosion of the concrete. Leakage from bolted closures is considered event driven and not within the scope of this document.

Concrete Exposed to Atmosphere/Weather

Concrete that is not located in buildings and is exposed to atmospheric conditions and weather are subjected to temperatures ranging from -15 °F to 115 °F, a relative humidity of 100 percent, and negligible radiation levels. Concrete that is below grade is exposed to the chemicals in the groundwater or raw water which may be acidic or contain chlorides and sulfates. The concrete may also be in direct contact with subgrade or backfill materials. Table 3-1 contains environmental parameters of raw water for the participating nuclear power plants within the scope of this document. Concrete that is above grade, and exposed to weather will be exposed to rainfall, snowfall, wind loading, and outdoor temperature of that specific plant location. The exposed surfaces of concrete located near industrial plants may be vulnerable to industrial pollution from sulfur-based acid rain. Sulfate attack is a particular problem in arid areas such as the northern great plains area and the western United States. There are no nuclear power plants within the scope of this document located in areas near major industrial plants that would expose them to corrosive chemicals in the atmosphere. Salt water atmospheric environment is not within the scope of this report.

5.3 Aging Effects

Portland cement has been used in concrete structures since the 1820s, and its resistance to aging is widely recognized as being one of the main reasons for its widespread use. Test results show that the compressive strength of concrete actually increases with age. Studies of the decommissioned reactor at Shippingport by the US Department of Energy found that the concrete structures were in excellent condition [1]. However, concrete that is exposed for an extended time to extreme environments (e.g., aggressive chemicals, flowing abrasive fluids, and elevated temperature) may experience significant aging effects.

The information used to document the associated aging effects of concrete exposed to the environments found at nuclear power-generating facilities is gathered from industrial resources. Where specific mechanisms are not applicable under the environmental and material conditions, justification is provided for a “not applicable” determination. For those effects that are applicable, a detailed discussion of the environmental conditions necessary for the effects to occur is included. The aging effects that will be evaluated for all concrete and the steel reinforcements in the following sections include loss of material, cracking, and change in material properties.

Masonry block walls have also been widely used in a variety of structural applications. These block walls are generally constructed from concrete and grout, and may or may not

be reinforced. In general, block walls are subject to the same degradation mechanisms as concrete walls and are to be screened accordingly. Aging effects that are unique to masonry block walls are discussed in Section 5.3.4.

5.3.1 Loss of Material

Loss of material is manifested in concrete structures and structural members as scaling, spalling, rust staining, pitting, and erosion. These effects are a result of one or more of the following aging mechanisms: freeze-thaw, abrasion and cavitation, elevated temperature, aggressive chemical attack, and corrosion of embedded steel.

5.3.1.1 Freeze-Thaw

Repeated cycles of freezing and thawing may alter both the mechanical properties and physical form of concrete that is susceptible to such action. The resistance of absorptive coarse aggregates to freeze-thaw damage depends primarily on the absorption characteristics (volume of fine pores) of the aggregate, the presence of moisture to saturate the aggregate, and the permeability of the hardened cement mortar matrix to the passage of water. For damage to occur by freezing of absorptive coarse aggregates, the aggregate must be saturated. Saturation may occur when water is available from an outside source. Freeze-thaw damage typically occurs on relatively flat concrete surfaces such as pavement, where water remains in contact with the concrete. Freeze-thaw damage starts at the surface and is readily detected by surface inspections. Freeze-thaw damage, if present, is expected to be a local condition and by itself will not affect the strength of the concrete.

Freeze-thaw is not a concern for any type of concrete located in areas of the country that are not exposed to numerous significant freeze thaw cycles. ASTM C 33-82, “Standard Specification for Concrete Aggregates,” groups the areas of the US into severe, moderate, and negligible weathering regions depending on the weathering index, which is the product of the average annual number of freezing cycle days and the average annual winter rainfall. Of the nuclear power plants in the scope of this report, the Arkansas Nuclear One and the Oconee nuclear power plants are in the “moderate” weathering region and the TMI nuclear power plant is in the “severe” weathering region.

Freeze-thaw is not applicable for concrete structures and structural members in structures in the scope of the license renewal program if the concrete is of an appropriate mix and construction quality *or* is located in geographic regions not subject to numerous significant subfreezing weather conditions. Concrete structures designed and constructed to ACI 318-63 or later versions or ACI 349-85 are not susceptible to freeze-thaw effects. This code or any equivalent concrete specification that ensures low permeability and adequate air entraining (by the use of air-entraining cement or an admixture) may be utilized as a basis for concluding that loss of material owing to freeze thaw is not an applicable aging effect. Freeze thaw is not an applicable aging mechanism for concrete structures designed in accordance with ACI 318-63, or later, and constructed in

accordance with ACI 301-66 or later using materials conforming to ACI and ASTM standards.

5.3.1.2 Abrasion and Cavitation

Water moving on concrete surfaces may carry abrasive materials or create a negative pressure (vacuum) that leads to abrasion and cavitation of the surface of the concrete. If significant amounts of concrete are removed by either of these processes, pitting or aggregate exposure occurs.

Abrasion and cavitation may cause a loss of material in concrete structures and structural members that are continuously exposed to flowing water containing abrasives. The water velocity and amount of abrasives present must be individually evaluated to determine the potential for significant degradation. Cavitation damage is not common at water velocities of less than 40 fps [13], and it is expected that most uses of concrete in the nuclear power plants in the scope of license renewal are not exposed to excessive velocities of water containing abrasives. Although absolute guidance on the allowable velocities and quantity of abrasives cannot be provided, degradation may be readily detected by visual examination in accessible locations, and past experience may be used to determine the expected applicability of this effect.

Loss of material owing to abrasion and cavitation is limited to concrete structures and components that are exposed to continuous running water such as intake and discharge structures, spillways, and cooling towers.

5.3.1.3 Elevated Temperature

Long term exposure to high temperature (>300 °F) may cause concrete surface scaling and cracking which is discussed in Section 5.3.2.5. A change in the material properties may occur at temperatures less than 300°F which is discussed in Section 5.3.3.3. Otherwise, there is no visible evidence of concrete degradation due to elevated temperatures [1]. The primary effects of elevated temperature on concrete are evaluated in the cracking and change in material properties section.

5.3.1.4 Aggressive Chemicals

Concrete, being highly alkaline (pH > 12.5), is vulnerable to degradation by strong acids. Acid attack may increase porosity and permeability of concrete, reduce its alkaline nature at the surface of the attack, reduce strength, and render the concrete subject to further deterioration. Portland cement concrete is not acid-resistant, although varying degrees of resistance can be achieved depending on the materials used and the attention to placing, consolidating, and curing. Portland cement concrete, regardless of its composition, will not withstand exposure to highly acidic fluids for long periods [1].

Below grade, sulfate solutions of sodium, potassium, and magnesium sometimes found in groundwater may attack concrete, often in combination with chlorides. The exposed surfaces of structures located near industrial plants may be vulnerable to industrial pollution from the sulfur-based acid rain and are subject to deterioration. Sulfate attack produces significant expansive stresses within the concrete, leading to cracking, spalling, and strength loss. Once established, these conditions allow further exposure to aggressive chemicals. Sulfate attack is a particular problem in arid areas, such as the northern great plains area and in parts of the Western United States. At inland sites, corrosion owing to aggressive chemical chloride attack has not been significant unless exposed to brackish water, deicing salt, or other salt sources. Groundwater chemicals may also damage foundation concrete.

A dense concrete with low permeability may provide an acceptable degree of protection against mild acid attack. Factors that tend to improve the compressive strength of the concrete will have a beneficial effect on low permeability. Therefore, the better the quality of the constituent material, the less permeable the concrete. Low water-to-cement ratio, smaller aggregate, long curing period, entrained air, and thorough consolidation contribute to watertightness [1]. Concrete so constructed has low permeability and is effectively protected against sulfate and chloride attack. Minimum degradation threshold limits for concrete have been established at 500 ppm chloride or 1,500 ppm sulfates. The use of an appropriate cement type (e.g., ASTM C 150, Type II) and pozzolana (e.g., fly ash) also increase sulfate resistance [1].

Continued or frequent cyclic exposure to the following aggressive chemical environments is necessary for aggressive chemicals to cause significant concrete degradation:

- Acidic solutions with pH < 5.5
- Chloride solutions >500 ppm
- Sulfate solutions >1500 ppm

The concrete structures and structural members within the scope of license renewal at the participating nuclear power plants were designed in accordance with ACI 318-63 and constructed in accordance with ACI 301 using ingredients conforming to ACI and ASTM standards. This resulted in a concrete with a high cement content, low water-cement ratio, and proper curing. Concrete with these attributes have low permeability and a high resistance to aggressive chemical solutions.

The above grade concrete structures and structural members for the plants in the scope of this report are exposed to an exterior environment below the chemical limits; therefore, chemical degradation is not applicable. Table 3-1 contains raw water data from each of the three participating nuclear power plants addressed by this report. Since the acid and aggressive chemicals concentrations are all below the threshold limits, aggressive

chemical attack is not an applicable aging mechanism for concrete structures and structural members for these sites.

Since aggressive chemicals are contained at the plant sites, system leakage is possible that could cause the concrete to be exposed to chemicals beyond these limits. However, leaks are not expected to continue for the extensive periods required for degradation, and repairs would be completed prior to loss of intended function.

5.3.1.5 Corrosion of Embedded Steel

Corrosion is an electrochemical process that results in the formation of ferric oxide (rust). The corrosion products have a significantly greater volume than the original metal resulting in tensile stresses and spalling in the surrounding concrete. The high alkalinity (pH > 12.5) of concrete provides an environment around embedded steel and steel reinforcement which protects them from corrosion. If the pH is lowered (e.g., to 10 or less), corrosion may occur. However, the corrosion rate is still insignificant until a pH of 4.0 is reached. A reduction in pH can be caused by the leaching of alkaline products through cracks, the entry of acidic materials, or carbonation. Chlorides can be present in constituent materials of the original concrete mix (i.e., cement, aggregates, admixtures, and water), or they may be introduced environmentally. The severity of corrosion is influenced by the properties and type of cement and aggregates as well as the concrete moisture content.

The degree to which concrete will provide satisfactory protection for embedded steel reinforcement depends in most instances on the quality of the concrete and the depth of concrete cover over the steel. The permeability of the concrete is also a major factor affecting corrosion resistance. Concrete of low permeability contains less water under a given exposure and is more likely to have lower electrical conductivity and better resistance to corrosion. Such concrete also resists absorption of salts and their penetration into the embedded steel and provides a barrier to oxygen, an essential element of the corrosion process. Low water-to-cement ratios and adequate air entrainment increase resistance to water penetration and thereby provide greater resistance to corrosion [1].

Corrosion of embedded steel is not an applicable aging mechanism for concrete structures and structural members. However, if the concrete is degraded by other mechanisms, which reduce the protective cover of the steel reinforcement, corrosion may occur. Adequate management of the other aging effects will in effect manage the corrosion of embedded steel reinforcement.

If embedded steel is exposed to aggressive groundwater (pH < 11.5 or 500 ppm chlorides with oxygen available) for extended periods, age related degradation due to corrosion of the reinforcing steel should be considered a potentially significant aging mechanism. If an aggressive environment is present, the corrosion of the embedded reinforcing steel may be prevented from causing significant age related degradation of the concrete if

adequate design considerations have been implemented. Use of concrete having a low water-to-cement mix ratio (0.35 to 0.45) and adequate air entrainment (3 to 6%), which results in low permeability, and sufficient reinforcement distribution to minimize crack development will prevent corrosion of the embedded reinforcement and degradation of the concrete. For the participating nuclear power plants within the scope of this report, aggressive groundwater is not experienced and age related degradation due to corrosion of the reinforcing steel should not be considered a potentially significant aging mechanism [1].

The concrete structures and structural members at the participating nuclear power plants included in this report are designed and constructed in accordance with ACI and ASTM standards which provide a good quality, dense, low permeability concrete that provides adequate concrete cover over the embedded steel. Since good design and construction practices are sufficient to preclude embedded steel reinforcement corrosion in the absence of other aging mechanisms, corrosion of embedded steel is not an applicable aging mechanism for concrete structures and structural members for the participating nuclear power plants.

5.3.2 Cracking

Cracking may occur in concrete structures and structural members as general cracking, map cracking, hairline cracking, pitting, and erosion. These effects are a result of one or more of the following aging mechanisms: freeze-thaw, reaction with aggregates, shrinkage, settlement, elevated temperature, irradiation, and fatigue.

5.3.2.1 Freeze-Thaw

Based on the review in Section 5.3.1.1, repeated cycles of freezing and thawing may alter both the mechanical properties and physical form of the concrete, thus causing cracking of the concrete.

Freeze-thaw damage starts at the surface and is readily detected by surface inspections. Freeze-thaw damage is expected to be a local condition and by itself will not affect the strength function of the concrete. Freeze-thaw initiation of cracking is not applicable for concrete structures and structural members if the concrete is of an appropriate mix and construction quality, *or* is located in geographic regions not subject to subfreezing weather conditions. Since the concrete structures in the scope of license renewal at the participating nuclear power plants were constructed with concrete that met or exceeded these codes, freeze-thaw is not an applicable aging effect.

5.3.2.2 Reaction with Aggregates

Certain mineral constituents of aggregates react with chemical compounds that compose the Portland cement, most notably alkalis. Alkalis may also be introduced from improper admixtures, salt-contaminated aggregates, seawater or deicing salt. However, it is only

when the expansive reaction products become extensive and cause cracking of concrete that aggregate reactivity is considered a deleterious reaction. Three principal deleterious reactions between aggregates and alkalis have been identified as alkali-aggregate, cement-aggregate, and expansive alkali-carbonate reactions.

Operating history does not indicate that structural integrity is significantly affected by alkali-aggregate reactions. Nonreactive aggregates were used at the participating nuclear power plants. Aggregates were subjected to petrographic testing in accordance with ASTM C 295 or ASTM C 227 to show that the aggregate is nonreactive. Therefore, reaction with aggregates is not an applicable aging mechanism.

5.3.2.3 Shrinkage

A workable concrete mix typically contains more water than is needed to offset the effects of hydration. When concrete is exposed to air, large portions of the free water evaporate. As water evaporates, capillary tension develops in the water remaining in the concrete while the concrete dries and shrinks in volume. Should these stresses exceed the tensile strength of the concrete, a crack forms. Initial shrinkage occurs during curing and continues months after placement. Subsequent drying and shrinkage occurs in concrete that is not continuously wet or submerged. According to ACI 209R-82, 91% of the shrinkage occurs during the first year, 98% in 5 years, and 100% in 20 years. Shrinkage in concrete is not a long-term aging mechanism and is not expected to continue after 40 years and into the license renewal period. Therefore, cracking owing to shrinkage is not an applicable aging effect.

5.3.2.4 Settlement

All structures settle to some extent during construction and for months after construction. The amount of settlement depends on the physical properties of foundation material and the total load. These properties of the foundation material range from rock with little or no settlement to compacted soil where some settlement is expected, especially immediately following construction.

Any structure located on a site that is susceptible to settlement could experience cracking as an aging effect. The buildings within the scope of this report are typically located on rock strata or a suitable foundation, and as such any settlement would have occurred during or immediately following construction of the structure. If concrete buildings or structures are not located on rock strata or a suitable foundation, inspections may be performed to verify that excessive settlement has not occurred. However, the majority of settlement should have occurred prior to the current licensing renewal period, and cracking owing to settlement is not an applicable aging effect for the structures within the scope of license renewal at the participating nuclear plants.

5.3.2.5 Elevated Temperatures

Long term exposure to elevated temperatures in excess of 300 °F may cause surface scaling and cracking of the concrete [1]. Very few localized areas would experience temperatures in this range. Where concrete is exposed to these elevated temperatures, high temperature concrete is typically used or provisions are provided to eliminate the concern. The change in the material properties that can occur at temperatures less than 300 °F is covered in Section 5.3.3.3. However, if concrete that is not of the high temperature construction is exposed to temperatures in excess of 300 °F for a long period of time, surface cracking should be evaluated as a potential aging effect.

Since it is expected that the concrete structures in the scope of license renewal at the three plants in the scope of this report are not designed where general area temperatures are above this temperature limit, cracking owing to general area excessive temperatures is not an applicable aging effect. Each site should review their specific plant structures in the scope of license renewal to determine if any localized temperatures are above this threshold.

5.3.2.6 Irradiation of Concrete

Exposure to extremely high levels of fast and slow neutrons may cause aggregate growth, decomposition of water, or thermal warming of concrete. Extremely high gamma radiation affects the cement paste portion of the concrete, producing heat and causing water migration. As the temperature of concrete increases and free water within the concrete evaporates, the structural characteristics of concrete may be degraded. With water loss, concrete may experience a decrease in its compressive, tensile, and bonding strengths, and as well as its modulus of elasticity. Degradation owing to irradiation is not always observable, but may be evidenced as cracking owing to thermal stress. The thresholds for irradiation damage are 1.0×10^{18} n/cm^2 (neutron energy > 1 MeV) and gamma dose of 1.0×10^{10} rads, respectively [1].

The location in pressurized water reactors where radiation may approach levels to initiate cracking is the reinforced concrete primary shield wall near the reactor vessel. Generic bounding estimates of neutron fluence (E>1MeV) and total integrated gamma dose at the primary shield wall for 48 EFPY were calculated for the participating nuclear power plants and are estimated to be 9.8×10^{17} n/cm^2 and 4.9×10^{9} rads, respectively [12]. These values are below the threshold levels where degradation is expected. Degradation of the material properties of reinforced concrete owing to radiation embrittlement, which may lead to cracking and/or crack growth, is not an applicable aging effect for the period of extended operation.

5.3.2.7 Fatigue

Fatigue is a degradation of structural members produced by large periodic or cyclic loadings that are less than the maximum allowable static loading. Fatigue results in progressive, localized damage to structural materials. Two types of fatigue exist for concrete structures and structural members. The first mechanism, sometimes referred to as low-cycle fatigue, is low frequency (<100 cycles for concrete structures and $<1 \times 10^5$ for steel structures) application of high-level repeated loads due to abnormal events such as SSE or design basis winds. The fatigue degradation caused by such loading may occur only a few times during the service life of a structure.

The other fatigue mechanism is high frequency application of low-level, repeated loads such as equipment vibration. This mechanism is referred to as high-cycle fatigue. If high cycle fatigue is present, failures would be detected early in plant life and actions would be taken to prevent reoccurrence. Therefore, cracking due to high-cycle fatigue is not an applicable aging mechanism for the period of extended operation.

The fatigue strength of concrete structures has become a concern owing to the widespread adoption of ultimate strength design procedures and the use of high-strength materials that require concrete structural members to perform satisfactorily under high-stress levels. Repeated loading causes cracking in component materials of a concrete member and alters its static load-carrying characteristics.

Fatigue failure of reinforcing steel has not been a significant factor in its application as reinforcement in concrete structures. There have been few documented cases of reinforcing fatigue failures in the concrete industry. ACI report 215R-74 notes that the lowest stress range known to have caused a fatigue failure of a straight hot-rolled deformed bar embedded in a concrete beam is 21 ksi. This failure occurred after 1.25×10^6 cycles of loading on a concrete beam containing a No. 11, Grade 60 rebar, when the minimum stress level was 17.5 ksi.

The concrete structures and structural members in the scope of license renewal were designed in accordance with ACI-318. The ACI-318 working stress method was utilized for many of the concrete component designs. This design method limited the maximum permissible design stress level to less than 50 percent of static strength of the concrete. This is less than the fatigue strength of concrete (55 percent of static strength). Those concrete structures and structural members designed in accordance with the ACI-318 ultimate strength method also have a great amount of durability for cyclical loading. The factored load approach of the ultimate strength method produces a wider spectrum of loading possibilities and therefore, a greater difficulty in establishing the design strength-to-static strength relationship for all conditions. For both design methods, the actual concrete stresses induced by cyclic loads during normal plant operation, such as those from machine vibration, are a small portion of the combined stresses resulting from static and dynamic loads. This means that the stress range (magnitude of stress fluctuation) is

also small and within the limit that yields extremely long fatigue life (> 10^7 cycles, which is equivalent to infinite life).

Thus fatigue is not an applicable aging mechanism for concrete structures and structural members in the scope of license renewal. However, any structural member that is exposed to cyclic high stress loadings of greater than 50% of the static strength of the concrete, fatigue should be evaluated as a potential aging mechanism that could cause cracking of the concrete.

5.3.3 Change in Material Properties

Change in material properties is evidenced in concrete structures and structural members as increased permeability, increased porosity, reduction in pH, reduction in tensile strength, reduction in compressive strength, reduction in modulus of elasticity, and reduction in bond strength. These are a result of one or more of the following aging mechanisms: leaching of calcium hydroxide, aggressive chemical attack, elevated temperature, irradiation, and creep. In addition, the potential for changes in the material properties of the reinforcing steel from irradiation will be discussed.

5.3.3.1 Leaching of Calcium Hydroxide

Water, either from rain or melting snow, that contains small amounts of calcium ions can readily dissolve calcium compounds in concrete when it passes through cracks, inadequately prepared construction joints, or areas inadequately consolidated during placement. The most readily soluble calcium compound is calcium hydroxide (lime). The aggressiveness or affinity of water to leach calcium hydroxide depends on its dissolved salt content and its temperature. Since leaching occurs when water passes through the concrete, structures that are subject to flowing liquid, ponding, or hydraulic pressure are more susceptible to degradation by leaching than those structures that water merely passes over. When calcium hydroxide is leached away, other cement constituents become exposed to chemical decomposition, eventually leaving behind silica and alumina gels with little or no strength. Leaching over a long period of time increases the porosity and permeability of concrete, making it more susceptible to other forms of aggressive attack and reducing the strength of concrete. Leaching also lowers the pH of concrete and threatens the integrity of the exterior protective oxide film of reinforcing material.

Resistance to leaching and efflorescence may be enhanced by using concrete with low permeability. A dense concrete with a suitable cement content that has been well cured is less susceptible to calcium hydroxide loss from percolating water because of its low permeability and low absorption rate.

The concrete structures and structural members in the scope of license renewal at the participating nuclear power plants are not exposed to hydraulic pressure, and are constructed of dense and well-cured high strength concrete which provides a low

permeability. Therefore, leaching of calcium hydroxide is not an applicable aging mechanism for concrete structures included in the scope of this report.

5.3.3.2 Aggressive Chemical Attack

Based on the review in Section 5.3.1.4, aggressive chemical attack may change the material properties of concrete. Continued or frequent cyclic exposure to aggressive chemical environment is necessary for aggressive chemicals to cause significant concrete degradation. For concrete exposed to these chemicals, a change in the material properties owing to the aggressive chemical attack is a potential aging effect. As discussed in Section 5.3.1.4, aggressive chemicals are not an applicable aging effect for the concrete structures and structural members at the participating nuclear power plants in the scope of this report.

5.3.3.3 Elevated Temperature

Elevated temperatures may cause a change in the material properties of concrete [1]. The compressive strength, tensile strength, and modulus of elasticity of concrete are reduced following prolonged exposure to elevated temperatures. ASME Boiler and pressure Vessel Code, Section III, Division 2 indicates that as long as concrete temperatures do not exceed 150 °F, aging due to elevated temperature exposure is not significant. ACI-349 allows local area temperatures to reach 200 °F before special provisions are required.

At most nuclear power plants, very few general areas or localized spots would experience temperatures of 200 °F or above. Where concrete is exposed to elevated temperature hot spots, high temperature concrete is typically used or provisions are provided to eliminate the concern.

Long term exposure to high temperature (>150 °F general area, or >200 °F localized) may cause a change in the material properties to be a significant aging effect for the period of license renewal. If the temperature limits are exceeded, plant-specific justification may be provided to verify the change in material properties is not excessive for the application or that high temperature concrete was used in this application.

Since the concrete structures in the scope of license renewal at the participating nuclear power plants are not designed where general area temperatures are above this temperature limit, change in material properties owing to general area excessive temperatures is not an applicable aging effect. Each site should review their specific plant structures in the scope of license renewal to determine if localized concrete temperatures are above this threshold.

5.3.3.4 Irradiation of Concrete

As described in Section 5.3.2.6, concrete exposed to significant amounts or radiation may experience material property changes. The significance of these changes is fully discussed in that discussion.

5.3.3.5 Irradiation of the Reinforcing Steel

Steel degradation owing to neutron irradiation is caused by the displacement of atoms from their normal lattice positions to form both interstices and vacancies. The effect of this mechanism is to *increase* yield strength, decrease ductility, and increase the ductile-to-brittle transition temperature. These defects on a macroscopic level produce what is referred to as radiation-induced embrittlement, which is encountered in the design and operation of reactor pressure vessels.

The peak fluence at the primary shield wall at 48 EFPY is estimated to be 9.87×10^{17} n/cm^2 (Section 5.3.2.6). Current available data indicate the effects on the mechanical properties of steel reach measurable effects at 10^{18} n/cm^2 for fast neutrons(>1 MeV). The ASME code also provides a basis for allowable radiation exposure with a threshold limit of 10^{21} n/cm^2 (ASME makes no distinction between fast and slow neutrons). Even if irradiation of the reinforcing steel reaches levels that affect the mechanical properties of the steel, no significant degradation is expected in the steel's ability to perform its intended function. Since the rebar was fabricated prior to radiation exposure and already embedded when subjected to radiation, the bending requirement to ensure that no cracking occurs during fabrication is not applicable. The irradiated rebar has ample margin to satisfy ductility requirements [1]. Therefore, irradiation of the reinforcing steel is not expected to significantly change the material properties of the steel and is not an applicable aging mechanism.

5.3.3.6 Creep

Creep is the time-dependent increase of strain in hardened concrete that has been subjected to sustained stress. The sustained stress results from the dead load, live load, and prestress on the structure and from temperature effects. Creep deformation is a function of loading history, environment, and material properties of the concrete. The time-dependent deformation of concrete under compressive load consists of strain resulting from progressive cracking at the aggregate-cement paste interface, from moisture exchange with the atmosphere, and from moisture movement within the concrete.

Creep-induced concrete cracks are not large enough to result in concrete deterioration or in exposure of the reinforcing steel to environmental stresses. Creep degradation of this magnitude does not reduce the concrete's compressive strength. Creep is significant when new concrete is subjected to load; the effects of creep decrease exponentially with

time. Any degradation is noticeable in the first few years of plant life. According to ACI 209R-82, 78 percent of creep occurs within the first year, 93 percent within 10 years, 95 percent within 20 years, and 96 percent within 30 years. Since the effects of creep are small and occur early in the concrete life, creep is not an applicable aging mechanism.

5.3.4 Review of Aging Effects Specific to Masonry Block Walls

Masonry block walls are generally constructed from concrete and grout and are susceptible to the aging effects previously listed for concrete. Cracking mechanisms that are unique to block walls are reviewed in this section.

Restraints on a concrete block wall may prevent the wall from freely expanding or contacting and thereby induce stresses within the wall. Restraints against expansion generally results in stresses that are small compared to the strength of the wall and therefore rarely cause degradation. Restraints against free contraction are much more likely to cause cracks. Expansion or contraction of masonry block walls may be caused by changes in temperature or moisture content, carbonation, and/or movement of adjacent structures and structural members. Shrinkage owing to moisture loss is one of the principal causes of volume changes in masonry block walls.

If proper isolation is not provided at the joint between the masonry block wall and the supporting structures and structural members, long term creep and variation in stiffness in the supporting structures and structural members could cause cracking of the masonry block walls. Cracking of masonry joints is also possible from water entering the masonry joints and freezing.

Cracking of masonry block walls is an applicable aging effect. Although cracking is caused by ongoing processes throughout plant life, most cracking occurs in the early stages of plant operation. Each plant has addressed block wall concerns in detail in their responses to NRC Bulletin 80-11. The commitments that were required varied greatly at each site depending on whether unreinforced block walls were used and the loadings that were required of the block walls. Plant specific reviews and commitments made in response to this Bulletin should form the basis for evaluation of the acceptability of the block walls at each site.

5.3.5 Summary of Applicable Aging Effects

The previous sections discuss various aging mechanisms and the applicability within the bounds of the specific material and environments for concrete structures and structural components. A summary of applicable aging effects and the associated aging mechanisms for the materials and environments discussed in this chapter is provided in Table 5-1.

Table 5-1 Applicable Aging Effects for Concrete Structures and Structural Members

APPLICABLE AGING EFFECTS	ENVIRONMENT		
	Below Grade	**Above Grade, Interior**	**Above Grade, Exterior**
Loss of Material			
Freeze-Thaw	NA	NA	NA
Abrasion & Cavitation	NA	NA	Y
Elevated Temperature	NA	Y	NA
Aggressive Chemicals	NA	NA	NA
Corrosion of Embedded Steel Reinforcing	NA	NA	NA
Cracking			
Freeze-Thaw	NA	NA	NA
Reaction with Aggregates	NA	NA	NA
Shrinkage	NA	NA	NA
Settlement	NA	NA	NA
Elevated Temperature	NA	Y	NA
Irradiation	NA	NA	NA
Fatigue	NA	NA	NA
Change in Material Properties			
Leaching of $Ca(OH)_2$	NA	NA	NA
Aggressive Chemicals	NA	NA	NA
Elevated Temperature	NA	Y	NA
Irradiation	NA	NA	NA
Creep	NA	NA	NA

Key: Y means aging mechanism is applicable for concrete structures in this environment.
NA means aging mechanism is not applicable for concrete structures in this environment.

5.3.6 Industry Experience

An operational history review was performed to review the generic communications related to concrete and the related aging effects. The following is a brief overview of the results of this review:

NRC Information Notices

Information Notice 87-65, Plant Operation Beyond Analyzed Conditions
Noted that high temperatures in areas can cause degradation and accelerated aging of materials. The IN identified concrete as one of the materials that could be susceptible to accelerated aging at elevated temperatures.

Information Notice 87-67 , Lessons Learned from Regional Inspections of Licensee Actions in Response to IE Bulletin 80-11
Described deficiencies discovered regarding unanalyzed conditions and faulty assumptions in the qualification of block walls. The IN identified that some utilities had developed programs for periodic inspections to ensure structural integrity was maintained.

NRC Bulletins

Bulletin 80-11, Masonry Wall Design
Addressed the potential for problems with the structural adequacy of hollow, unreinforced block walls. Although age-related degradation was not the primary concern of the Bulletin, it did discuss the potential for cracking due to reactions and thermal effects. Also, some licensees chose to develop programs that required periodic inspections to ensure the structural integrity of these walls is maintained.

NRC Regulatory Guides

Regulatory Guide 1.127, "Inspection of Water-Control Structures Associated with Nuclear Power Plants,"
Has been used as a basis for inspections of age related degradation by some utilities and is included here for completeness.

NUREGs

NUREG-1522, "Assessment of Inservice Conditions of Safety-Related Nuclear Plant Structures,"
Provides information related to the conditions of structures and civil engineering features at six older plants (licensed prior to 1977). In addition, the report provides information that helps detect, alleviate, and correct the degraded conditions of structures and civil

engineering features. Information in this NUREG was provided from direct inspection of these plants by NRC staff.

Summary of the Review of Industry Correspondence

The review of the generic communications confirmed the aging effects identified in this report. No new aging mechanisms were identified. Each utility will include their responses to the NRC communication in their site specific aging management reviews as required to verify the identified concern has been adequately addressed.

5.4 Aging Management Programs

Since the concrete structures have experienced few significant aging effects, there are few generic aging management programs in place at nuclear power plants. Where plants have significant aging effects such as settlement, a settlement monitoring program may be in place. It is not expected that aging management programs are in place that are generic to the participating nuclear power plants in the scope of this report.

The previous sections provided a methodology to determine which aging effects were applicable to a concrete structures. For those aging effects that were determined to be significant, aging management programs must monitor the effects to ensure the structure can continue to perform its intended functions.

5.5 References

1. "Class 1 Structures License Renewal Industry Report; Revision 1," EPRI Report TR-103842, July 1994 (Also NUMARC 96-06, revision 1, 12/91)

2. "Concrete Component Aging and Its Significance Relative to Life Extension of Nuclear Power Plants," NUREG/CR-4652, September, 1986

3. "Structural Aging Assessment Methodology for Concrete Structures in Nuclear Power Plants," ORNL/NRC/LTR-90-17, March 1991.

4. Cement and Concrete Terminology, ACI 116R-90.

5. "Technical Report on B&W Utility Reactor Buildings," B&WOG Report GC 95-10, Rev. 0.

6. "Building Code Requirements for Reinforced Concrete," ACI Standard 318.

7. ASME Boiler and Pressure Vessel Code, Section III, Division 2.

8. "Report on Aging of Nuclear Power Plant Reinforced Concrete Structures," NUREG/CR 6424, March, 1996.

9. Guideline for Monitoring the Condition of Structures at Nuclear Power Plants, Revision C," NEI 96-03, March 14,1996.

10. "Requirements for Class CC Concrete Components of Light-Water Cooled Plants," ASME Section XI, Subsection IWL.

11. B&W Generic License Renewal Program, "Non-Class 1 Mechanical Implementation Guideline and Mechanical Tools, BAW-2270, Revision 1, B&W Owner's Group, Framatome Technologies, Inc., Lynchburg, VA, November 1996

12. Best -Estimate 48 EFPY Fluence at Inside Surface of Biological Shield, B&W Owners Group, Framatome Technologies, Inc., 32-1266105-00, Lynchburg, Virginia, January 1997

6. FIRE BARRIERS

This chapter addresses aging of fire wraps and fire stops, which are used throughout power plants as fire protection devices. Fire wrap is a generic term used for all applied fireproofing with the exception of fire resistant electrical cable insulation, which is not within the scope of this report. A fire stop is the fireproofing in penetrations between adjacent fire areas or zones. The material used in these passive devices are generally certified for a 40-year service life in nuclear plants. A description of items covered in this chapter is provided in Section 6.1. Environments that structural steel and steel components are exposed to are discussed in Section 6.2. Aging effects for material and environment combinations are discussed in Section 6.3. Recommendations for aging management programs are provided in Section 6.4.

6.1 Description and Scope

Fire wrap and fire stops are composites consisting of materials such as steel, concrete, and silicone. Some commercially available examples of fire wrap and fire stops are Maranite Board, Heymic Wrap, Bisco, Thermolag, and Pyrocrete. For a discussion of aging effects associated with concrete or non-composite silicone refer to Chapters 5 and 7, respectively.

Fire wrap materials have specific fire ratings and are produced in various forms which may be sprayed on, troweled on, or boxed/clad/wrapped onto structural steel members and other items including, but not limited to, metal decks, electrical cable trays and conduits, HVAC ducts, and instrumentation. Fire wrap material may also be used to meet electrical separation requirements between electrical trains, when physical separation is restricted by spatial considerations. Steel banding, i.e., wire and other appurtenances used to secure fire wrap to the item being protected, is considered to be a part of the fire wrap itself, although aging effects for steel are addressed in Chapter 2.

Many fire wrap materials used during the initial period of plant construction are cementitious fireproofing containing asbestos or silicates as their main fire-retarding constituent. Materials used later are virtually asbestos free, as in the case of radiant heat shields used in many 10 CFR 50 Appendix R modifications.

Fire stops consist of materials that are used to close gaps between adjacent fire areas or fire zones. In piping or electrical conduit penetrations, and in seismic gaps between adjacent structures (when matched by fire area/zone delineation), the fire stop is the material between the pipe/conduit and the fire area/zone principal barrier (wall or floor). Fire stops may also be applied or located in cable tray and air duct penetrations. The fire stop materials may be flexible sealants of silicone rubber or foam (pumped or poured into place), rigid nonshrink mineral fiberboards, fire wrap items discussed above, or

trowelable caulks and putties each having a specific fire rating. Occasionally, fire stop materials may be plain concrete or grout that are covered in Chapter 5.

Fire wraps and fire stops are typically rated at one and three hours. The temperature of the item they protect is maintained at or below 250°F above ambient (usually stated as 75 °F), while withstanding maximum exposure temperatures of 1700°F and 1925°F in one and three hour fires, respectively, in accordance with ASTM E 119.

6.2 Environment

Fire wrap and fire stops are exposed to many environments. Located inside plant buildings, fire wrap and fire stops are exposed to ambient environment within each location. When fire stops are located in an exterior wall, they are protected from the weather by concrete, grout, or seals and caulks.

Internal ambient plant temperatures range from freezing to 150^{o} F, and relative humidity is 100 percent. Fire stops in penetrations through floor slabs may be inundated and damaged by water or spilled liquids (including corrosive fuels and aggressive chemicals), but this condition would not be long term, be quickly cleaned, and would have little, if any, effect on aging.

6.3 Aging Effects

Manufacturers and vendors of fire wrap and fire stop materials maintain that the serviceable life of these materials will exceed the 40 year plant life. Fire protection engineers agree and have not observed indications to the contrary. However, aging effects that may result in loss of intended function of the fire wrap include loss of material, cracking/delamination, change in material properties, and separation.

6.3.1 Loss of Material

The aging mechanisms that may cause loss of material for fire wrap and fire stops is flaking, scouring, and abrasion. Additional causes of fire wrap material loss include damage by inadvertent impulsive contact during removal for maintenance activities or plant modifications; these additional causes are not age related and are addressed as part of the plant maintenance and housekeeping procedures.

6.3.1.1 Flaking

Flaking may occur as fire wrap fibers are freed from the material surface and either become airborne or fall free from the fire wrap. This mechanism may be expected for sprayed-on fire proofing material. The fibers may be freed over time owing to the force of gravity, airflow in the vicinity of the fireproofing, and vibrations induced into the fireproofed members. The rate of this mechanism is typically linear with respect to time. If flaking occurs for a sufficiently long time period, it could potentially reduce the

fireproofing thickness such that the required fire proof rating is not maintained. Marinate board and other rigid fire wrap materials (including trowelable grades) with smooth, hard finishes, and fire stop foams have not been observed to readily release fibers from the surfaces and are not susceptible to flaking. Therefore, loss of material due to flaking is an applicable aging effect for some fire wraps but not for fire stops.

6.3.1.2 Scouring

Scouring may occur when an external liquid or gaseous stream flows over the fire wrap or fire stop causing erosion of the surface. This external stream could be air from a ventilation duct or pressure relief device, steam from a relief valve, or water and other liquid from a drain or blowdown line. The friction caused by the movement of the external medium over the surface of the fire wrap material may reduce its thickness such that the required fireproof rating is not maintained.

Scouring of fire wrap or fire stop material by steam or liquid is not expected to occur in nuclear plants. Scouring by air would require high velocities that are not found in air handling systems in the plants. Therefore, loss of material due to scouring is not an applicable aging effect for fire wrap and fire stops.

6.3.1.3 Abrasion

Abrasion may occur when a vibrating item is in contact with the surface of the fire wrap. This mechanism can occur in two ways: First, the fire wrapped item (e.g., electrical raceway) may experience continuous movement or vibration. Abrasion can occur at the location where the wrapped item interfaces with a rigid component (e.g., a support member). The second way is similar except that the fire wrapped component is fixed (e.g., steel beam) and it interfaces with another moving or vibrating component (e.g., pipe). In both instances the interaction of the two components may abrade the fire wrap such that the required fire proof rating is not maintained in a localized area. Therefore, loss of material due to abrasion is an applicable aging effect for fire wrap. Fire stops may also be susceptible to abrasion when in contact with vibrating equipment.

6.3.2 Cracking/Delamination

The aging mechanisms that may cause cracking or delamination in fire wrap and fire stops are vibration, movement, and shrinkage.

6.3.2.1 Vibration

Vibration of the protected item may cause cracking or delamination of fire wrap and fire stop material over time. Cracking will most likely appear in sprayed-on fire proofing that protects steel floor beams and floor decking, while delaminations may form in fire stop silicone rubber and foams. Over time, vibration of steel members and decks under rotating equipment or other sources of vibration may break down the bond between steel

and the fire proofing causing cracks to form. Fatigue based splits or delaminations may form in flexible fire stop material from the same environment. These degradations may reduce the protective capacity of the fire proofing and may result in inadequate protection of structural components or allow fire and/or hot gases to spread across firewall penetrations. Therefore, cracking/delamination due to vibration is an applicable aging effect for fire wrap and fire stops.

6.3.2.2 Movement

The differential movement of the fire barriers may cause cracking of fire wrap material if it is attached to two independent systems supporting the wrapped item. This condition is precluded in design and by initial fire proofing inspections. Sprayed-on fire proofing is not affected since it is typically applied to structural components that do experience differential movements during normal plant operation. Therefore, cracking/delamination due to movement is not an applicable aging effect for fire wrapping.

Fire stops between adjacent structures may be affected by differential movement initially. Although such movements are not expected to increase in the license renewal period, cracking /delamination due to movement is an applicable aging effect for fire stops.

6.3.2.3 Shrinkage

Shrinkage may occur over time where fire penetration seal material comes in contact with pipe surfaces. Shrinkage has been observed with silicone foam seal material when used for fire stops. Therefore, cracking/delamination due to shrinkage is an applicable aging effect for fire stops. Shrinkage is not an applicable aging effect for fire wrap.

6.3.3 Change in Material Properties

6.3.3.1 Chemical Exposure

Material properties may be affected by corrosive chemicals (e.g., diesel fuel) in contact with fire proofing, but this type of change is not age related as it affects the material in short time durations. Damage to fire wraps and fire stops is quickly addressed after discovery of corrosive chemical leaks and spills in accordance with plant procedures. Therefore, a change in material properties due to chemical exposure is not an applicable aging effect for fire wrap and fire stops.

6.3.3.2 Irradiation Damage

The gamma irradiation damage threshold value is the radiation dose at which at least one of the material's physical properties begins to change. The reported radiation damage threshold value for organic polymers of 10^6 rads is conservative for fire wrap and fire stop materials (Bisco SF-20 silicon foam, for example, resists radiation effects up to 2×10^8 rads) and may not affect the fire retarding properties of fire wrap or fire stop materials

at these levels [2]. Therefore a change in material properties is not an expected aging effect for fire wrap and fire stops provided the radiation dose is below 10^6 rads.

6.3.4 Separation

Separation is the destruction of adhesion between a fire barrier material and an adjacent surface. Separation has been observed in fire stops where material separation creates a gap allowing communication between the different zones. The aging mechanisms that may cause separation in fire stops include vibration, movement and shrinkage. These aging mechanisms are not applicable to fire wrap since it is typically not associated with separation of fire zones.

6.3.4.1 Vibration

Vibration of the protected item may cause separation (disbondment) of fire barrier material over time. Separation as a potential aging effect will most likely to appear in fire stops used to close gaps between fire zones. Over time, vibration of steel members and decks under rotating equipment pipe and conduit movement or other sources of vibration may break down the bond between adjacent structures/components and the fire proofing causing separation and gaps to appear. This degradation may reduce the protective capacity of the fire proofing material and may result in inadequate isolation allowing fire to spread across firewall penetrations and fire zones. Therefore, separation due to vibration is an applicable aging effect for fire stops.

6.3.4.2 Movement

Fire stops between adjacent structures may have been affected by initial differential movement. Although such movements are not expected to increase in the license renewal period, separation due to movement is an applicable aging effect for fire stops.

6.3.4.3 Shrinkage

Shrinkage may occur over time where fire penetration seal material comes in contact with pipe, conduit, steel members, and other penetration surfaces. This has been observed with silicone foam seal material. Therefore, separation due to shrinkage is an applicable aging effect for fire stops.

6.3.5 Industry Experience

Industry failure data and NRC generic communications were reviewed to determine if there are any aging effects or mechanisms that should be considered for fire wraps and fire stops. This review included searches of INPO Nuclear Plant Reliability Data System databases, NRC Inspection and Enforcement Information Bulletins, Licensee Event Reports, and Generic Letters.

A search of NPRDS did not reveal any failures related to fire wrap or fire stops. NRC generic communications (Information Notices, Circulars, IE Bulletins, and Generic Letters) dating back to 1973 were reviewed for their applicability to fire barriers. The majority of generic communications that are applicable to fire barriers address design, installation, or maintenance issues. No instances of age-related degradation were reported in the applicable Circulars, IE Bulletins, and Generic Letters. However, from the descriptions presented in the applicable Information Notices it was concluded that age-related degradation may have contributed to some of the reported failure. Failures reported in Information Notices that may be attributed to age-related degradation are reported below.

Information Notices

IN 88-04, Supplement 1-- Inadequate Qualification and Documentation of Fire Barrier Penetration Seals

There have been instances where the silicon foam fire barrier seal material around diesel generator exhaust stacks ignited. This was attributed to the failure of metal clad insulation between the exhaust stack and the foam sealant. The metal clad insulation was degraded by repeated thermal expansion and contraction of the exhaust stack. This was an age related failure of the fire barrier system. In addition, the ignition point for the foam sealant used was not adequate for the situation in which it was being used.

This notice also discussed an instance where the silicone foam sealant in a fire barrier penetration for the main steam line “baked” and pulled away from the line. The maximum temperature rating of the sealant was well below the normal operating temperature for the main steam line. The failure of this fire barrier seal appears to be age related though it is unclear if it has to do with constant exposure to temperature (shrinkage) or movement of the steam line (vibration or differential movement between the steam line and sealant).

IN 88-56--Potential Problems with Silicone Foam Fire Barrier Penetration Seals

Inspections of silicone foam fire barrier penetration seals have detected voids in the foam, gaps between the foam and the penetration, piping or cables and cracks in the foam. The presence of voids was attributed to installation problems. The presence of gaps was variously attributed to installation problems or shrinkage and contraction due to temperature change. The notice states that “the reasons for silicone foam splitting [cracking] are not completely understood”. At least some of the nonconforming conditions detected are due to an age related mechanism (shrinkage). This notice also mentions damaged fire resistant boards but does not indicate the reason for the damage.

IN 91-47--Failure of Thermo-Lag Fire Barrier Material to Pass Fire Endurance Test

Walkdowns identified degradation of Thermo-Lag 1- and 3-hour rated fire barriers which included small holes, cracks, and unfilled seams (gaps). Further investigations indicated that in many cases the fire barrier material had not been installed according to the manufacturers recommendations. Subsequent testing of cable tray and conduit configurations indicated that published fire resistance ratings were not met. Although

this notice does not specify the reasons for the degradation observed during the walkdowns, it is plausible that they occurred due to shrinkage, differential movement, vibration, or other age related degradation mechanisms.

IN 94-28--Potential Problems with Fire Barrier Penetration Seals
Inspections of fire barrier penetrations showed nonconformities with design. The notice mentions installation issues as the cause of some of the nonconformities and also states that "..several silicone foam seals were degraded…" Therefore, at least some of the nonconformities in the fire barrier penetration seals were due to unspecified degradation mechanisms which could have been age related.

As a result of the review of industry and NRC data, no additional aging effects were identified.

6.3.6 Summary of Applicable Aging Effects

The previous sections discuss various aging mechanisms of fire wraps and fire stops in plant buildings. Experience to date indicates that these items have no associated technological problems; however, potential aging effects, such as loss of material cracking / splitting and separation of the fire barrier material have been observed. A summary of applicable aging effects and associated aging mechanisms for fire wrap and fire stops are provided below.

Table 6-1 Applicable Aging Effects for Fire Wrap and Fire Stops

APPLICABLE AGING EFFECT	FIRE WRAP	FIRE STOPS
Loss of Material		
Flaking	Yes	No
Scouring	No	No
Abrasion	Yes	Yes
Cracking/ Delamination		
Vibration	Yes	Yes
Movement	No	Yes
Shrinkage	No	Yes
Change in Material Properties		
Chemical Exposure	No	No
Gamma Irradiation Exposure	NA for $< 10^6$ rads	NA for $< 10^6$ rads
Separation		
Vibration	No	Yes
Movement	No	Yes
Shrinkage	No	Yes

6.4 Aging Management Programs

The rate of degradation in fire wraps and fire stops caused by applicable aging effects is expected to be gradual, if perceptible at all. However, 10 CFR 50 Appendix R programs include related surveillance and maintenance procedures which require periodic inspection of existing fireproofing and address repairs and sealing of new penetrations. The fire wrap and fire stop inspection criteria is defined, and aging degradation of the material used in these items will be noted, reported, and corrected as required.

6.5 References

1. S. S. Schwartz and S. H. Goodman, Plastics Materials and Processes, Van Nostrand Reinhold Company, 1982

2. T. N. Bowmer, L. K. Cowen, J. H. O'Donnell, and T. J. Winzon, "Degradation of Polysterene by Gamma Irradiation: Effect of Air on the Radiation Induced Changes in Mechanical and Molecular Properties," Journal of Applied Polymer Science, Vol. 24, 425, (1979).

7. ELASTOMERS

This chapter of the Structural Tools is intended to cover elastomers used in structural applications within the scope of license renewal. A description of elastomers is provided in Section 7.1. Environments that elastomers are exposed to are discussed in Section 7.2. Aging effects for material and environment combinations are discussed in Section 7.3. Recommendations for aging management programs are provided in Section 7.4.

7.1 Description and Scope

Elastomers are used throughout nuclear plants as vibration isolators, construction and expansion joint sealants, and moisture barriers. The American Society for Testing and Materials [1] defines an elastomer as "rubber or polymer that has properties similar to those of rubber." Rubber is capable of recovering from large deformations quickly and forcibly. Elastomers included within this review chapter are rubber, neoprene, and silicone. Silicone addressed in this review do not include silicone based fire barriers, which are addressed in Chapter 6.

Natural rubber occurs in over 200 species of plants. The hevea brasiliensis tree accounts for over 99% of the world's natural rubber production. Most applications for natural rubber require that the rubber be vulcanized. Unvulcanized rubber is generally not very strong, does not maintain its shape after a large deformation, and can be very sticky. The vulcanization process, which includes the addition of sulfur and/or other additives to crude rubber, increases the retractive force of the rubber and reduces the amount of permanent deformation remaining after removal of the deforming force. Thus, vulcanization increases elasticity while it decreases plasticity. While natural rubber has higher tensile strength than synthetic varieties, the performance profiles of synthetics show some properties markedly superior to those of natural rubber, particularly heat, oil, and ozone resistance [2]. Weathering of natural rubber results in molecular chain breaking and softening.

Butyl rubbers are characterized by high resistance to gas permeation and to ozone, water, sunlight, heat, vegetable oils, and aging. They have low resilience at room temperature or below but show a large increase in resilience with increase in temperature up to 212 °F [4].

Neoprene is chemically and structurally similar to natural rubber, and its mechanical properties are also similar. Its resistance to oils, chemicals, sunlight, weathering, aging, and ozone is outstanding. It retains its properties at temperatures up to 250 °F [3]. Most neoprenes crystallize readily at temperatures near 32 °F, which limits their low-temperature uses [4].

Nitrile rubbers have outstanding resistance to oils and other solvents. They also have excellent abrasion and age resistance. Low-temperature properties are poor but can be improved by the use of certain plasticizers [4].

Silicone elastomers are polymers composed basically of silicon and oxygen atoms. Silicone elastomers are the most stable group of all the elastomers. They are outstanding in resistance to high and low temperatures, oils, and chemicals. High-temperature grades have maximum continuous service temperatures up to 600 °F [3]. Other important characteristics include a high degree of chemical inertness, resistance to weathering, good dielectric strength, and low surface tension [5]. Silicone elastomers appear completely hydrophobic to liquid water [4]. Estimated service life is from 5 to 10 years at 302 °F and 40 years at 194 °F.

7.2 Environment

Elastomers are exposed to different environments throughout the plant. Elastomers may be exposed to fluids, ambient conditions, temperatures up to 150 °F, and radiation.

7.3 Aging Effects

The information used to document the associated aging effects for elastomers exposed to internal and external environments is gathered from industrial sources. Where specific mechanisms are not applicable under the environmental and material conditions, justification is provided for a “not applicable” determination. For those effects that are applicable, a detailed discussion of the environmental conditions necessary for the effects to occur is included. Aging effects discussed below include material property changes and cracking. These effects are caused by exposure to ultraviolet radiation, oxygen, ozone, heat, and radiation. This chapter evaluates potential aging effects for elastomers to determine which are applicable and need to be addressed by aging management programs.

7.3.1 Aging Effects Assessment

Ultraviolet Radiation and Ozone

Rubber is decomposed by exposure to ultraviolet radiation. Ultraviolet radiation sources at nuclear plants include solar radiation and ultraviolet or fluorescent lamps. The deterioration of rubber is greatly accelerated in the presence of oxygen. Cracking and checking, which may occur when rubber is exposed to air and sunlight, are due mainly to reaction with ozone. Neoprene and nitrile rubbers have good resistance to sunlight and ozone, and silicone and butyl rubber are relatively unaffected by sunlight and ozone [4]. Ultraviolet degradation may be prevented by means of an opaque covering.

In addition to accelerating ultraviolet radiation degradation, oxygen also accelerates thermal and radiation degradation as discussed below. Thermal and radiation-induced degradation may proceed without oxygen, but the presence of oxygen increases the aging rate of most common elastomers [6].

Cracking owing to ultraviolet radiation and ozone is an applicable aging effect for rubber, and is not an applicable aging effect for neoprene, and butyl, nitrile, and silicone rubbers.

Thermal Exposure

Thermal exposure of elastomers can result in decreased tensile strength or ultimate elongation, cracking, chain scission, or cross-linking [5]. Cross-linking refers to the process where long chain molecules typically present in elastomers are bonded together. Cross-linking makes the elastomer brittle, increases the modulus of elasticity, and promotes surface cracking. Chain scission is the breaking of chemical bonds in elastomers, which usually results in reduced tensile strength and modulus of elasticity.

Elastomers are tested for short-term and long-term temperature durability. Maximum temperature ratings for butyl rubber, neoprene, nitrile rubber, and silicone elastomers are provided in Table 7-1.

Table 7-1 Thermal Ratings of Elastomers [4]

Material	Approximate Continuous Temperature Rating
Butyl Rubber	150 °F
Rubber	130 °F
Neoprene	160 °F
Nitrile Rubber	175 °F
Silicone Rubber	275 °F

The relationship between temperature and longevity for some common elastomers used in penetrations is provided in the *Aging Management Guideline for Electrical and Mechanical Penetrations* [7]. A common aging endpoint was specified for all of the data (50% retention of elongation) so that the results would be comparable. The thermally superior material considered is silicone rubber, which displays an extrapolated time to 50% elongation in excess of 10^4 years at 194 °F. Neoprene is on the other extreme with an extrapolated time to 50% elongation in 10 years at 149 °F. In general, if the ambient temperature is less than about 95 °F, then thermal aging may be considered nonsignificant for the period of extended operation [7].

Material property changes and cracking owing to thermal stresses is an applicable aging effect for rubber, neoprene, and silicone elastomers in environments where the temperatures exceed the limits defined above.

Ionizing Radiation

Ionizing radiation can profoundly alter the molecular structure and macroscopic properties of elastomers. Effects of radiation-induced degradation of elastomers may include embrittlement, cracking or crazing, swelling, discoloration and melting. Rubber, neoprene, and silicone elastomers ultimately become harder, stiffer and eventually brittle when exposed to radiation [5]. Lowest reported dose thresholds for radiation degradation are provided for butyl rubber, rubber, neoprene, nitrile rubber, and silicone elastomers in Table 7-2.

Table 7-2 Radiation Dose Thresholds for Elastomers [6,7,8]

Material	Lowest Reported Threshold (Rads)
Butyl Rubber	10^6
Rubber	10^7
Neoprene	10^6
Nitrile Rubber	10^7
Silicone Elastomers	10^6

Material property changes and cracking owing to radiation is an applicable aging effect for rubber, neoprene, and silicone elastomers in environments where the radiation exceeds the limits defined above.

7.3.2 Industry Experience

Industry failure data and NRC generic communications were reviewed to determine if there are any additional aging effects that should be considered for elastomers. This review included searches of INPO Nuclear Plant Reliability Data System (NPRDS) databases, NRC Inspection and Enforcement (IE) Information Notices and Bulletins, and NRC Licensee Event Reports (LER). The search was performed for rubber, neoprene, and silicone vibration isolators, sealants, and elastomers.

Most of the industry experience failures related to these materials were associated with piping, penetration, and equipment sealants. The one reported failure associated with aging was the failure of a silicone sealant in the containment floor above the steel liner plate of a post-tensioned concrete containment building [9]. The failure of the sealant resulted in exposure of the steel liner plate to standing water and possible corrosion. The report did not address the cause of the sealant failure.

7.3.3 Summary of Applicable Aging Effects

The previous sections discuss various aging effects for butyl rubber, rubber, neoprene, nitrile rubber, and silicone elastomers when exposed to ultraviolet radiation, thermal exposure and ionizing radiation stresses. Applicable aging effects for butyl rubber, rubber, neoprene, nitrile rubber, and silicone elastomers are changes in material properties and cracking. Depending on the material, these aging effects may result from ultraviolet radiation, thermal exposure, or ionizing radiation. A summary of the associated mechanisms for each of the materials is provided in Table 7-3.

Table 7-3 Applicable Aging Effects for Elastomers

	Change in Material Properties and Cracking Applicability of Aging Mechanisms		
Material	Ultraviolet Radiation	Thermal Exposure	Ionizing Radiation
Butyl Rubber	NA	NA for < 95° F	NA for < 10^6 rads
Rubber	Applicable	NA for < 95° F	NA for < 10^7 rads
Neoprene	NA	NA for < 95° F	NA for < 10^6 rads
Nitrile Rubber	NA	NA for < 95° F	NA for < 10^7 rads
Silicone Elastomers	NA	NA for < 95° F	NA for < 10^6 rads

Key:
NA - Aging Effects are not applicable for this mechanism.
NA for < - Aging Effects are not applicable for this mechanism below the specified limit.

7.4 Aging Management Programs

Change in material properties and cracking were identified as applicable aging effects for butyl rubber, rubber, neoprene, nitrile rubber, and silicone elastomers. Neoprene, nitrile rubber, butyl rubber and silicone elastomers will not exhibit aging effects as long as they are not exposed to temperature and radiation in excess of the limits specified in Table 7-3. Rubber will not exhibit material property changes and cracking as long as it is not exposed to temperature and radiation in excess of the limits specified in Table 7-3 and is protected from ultraviolet radiation and ozone.

Each plant is responsible for (1) identifying elastomers that are in environments that exceed these limits; (2) demonstrating that the aging effects will be managed for the period of extended operation; and (3) identifying those elastomers, such as Viton, silicone

derivatives, and elastomeric roofing compounds that are not addressed by this chapter of the Strucutural Tools, including establishing limits and demonstrating that the aging effects will be managed for the period of extended operation.

7.5 References

1. "Standard Terminology Relating to Rubber," ASTM D-1566 - 95a, American Standards for Testing and Materials, Philadelphia, Pennsylvania, 1995.

2. Elastomeric Materials, The International Plastics Selector, Inc. San Diego California, 1977.

3. Materials Handbook, McGraw-Hill, Inc., New York, New York, 1991.

4. Engineering Materials Handbook, McGraw-Hill, Inc., New York, NY, 1958.

5. Concise Encyclopedia of Polymer Science and Engineering, John Wiley & Sons, 1990.

6. "Radiation Data for Design and Qualification of Nuclear Plant Equipment," EPRI NP-4172M, Electric Power Research Institute, Palo Alto, California, August 1985.

7. W.M. Denny et al.,"Aging Management Guideline for Electrical and Mechanical Penetrations," Draft report, Sandia National Laboratories., Contract AI-7321, March 1, 1996

8. M.H. Van de Voorde and C. Restat, "Selection Guide to Organic Materials for Nuclear Engineering", CERN 72-7, European Organization for Nuclear Research, Geneva, 1972.

9. INPO Operating Plant Experience Report No. 3022.

8. EARTHEN STRUCTURES

This chapter of the Structural Tools is intended to cover passive and long-lived earthen structures in the scope of license renewal, and is based primarily on NRC Regulatory Guide 1.127, "Inspection of Water-Control Structures Associated with Nuclear Power Plants" [1]. The earthen structures covered in this chapter are discussed in Section 8.1. Environments that earthen structures are exposed to are discussed in Section 8.2. Aging effects for material and environment combinations are discussed in Section 8.3. Recommendations for aging management programs are provided in Section 8.4.

8.1 Description and Scope

Earthen structures occur in some form at most nuclear power plant facilities. Functions performed by earthen structures vary but are generally associated with control or storage of water. Accordingly, earthen structures perform a variety of safety-related functions for the participating nuclear power plant sites including reservoirs for emergency power generation and plant ultimate heat sink and dikes for flood protection and wave abatement.

Earthen structures are constructed from materials found at the construction site or a nearby location. These materials, usually of a soil and rock composition, are not changed or made "new," such as reinforced concrete or other construction materials during the construction process. In their natural state, these materials do not age significantly over the life of the facility.

Therefore, aging effects identified in this chapter will address the overall structure as a facility. Although soil and rock as a material do not age significantly, aging effects can degrade the form and function of the structure. These effects are addressed in this chapter.

Earthen structures are used in the following general applications of structures as defined in Regulatory Guide 1.127 [1]:

- dams
- slopes
- canals
- other water-control structures associated with emergency cooling water systems and flood control, such as levees and submerged levees

The application of earthen structures in nuclear power plants are many. However, the scope will be limited to water-control structures specifically built for use in conjunction with a nuclear power plant. The scope will be further limited to earthen structures whose failure could cause radiological consequences adversely affecting public health and safety.

8.2 Environment

The environments that earthen structures are exposed to is limited. However, some specific environments should be considered and these may be divided into the following general categories:

1) Submerged

2) Surface soil exposed to the atmosphere/weather (rain, sun, wind, and temperature)

3) Below-surface soil (significant overburden pressures)

Earthen structures, for the most part, are expected to have portions that are submerged and portions that are exposed to the atmosphere. Some earthen structures are completely submerged. These structures are typically underwater levees that were constructed at a strategic location to retain water for an ultimate heat sink in the event of a downstream dam failure. Areas of significant overburden are usually unavoidable; see Section 8.3.2 for further discussions of overburden.

Earthen structures addressed in this report are exposed to many climatic conditions. All earthen structures within the scope of this report are at times subjected to a wide range of temperatures. Even though climates vary for each site, the relative differences in these conditions have very little significance on the aging effects described in this section.

8.3 Aging Effects

Earthen structures have extremely low failure rates. In fact, statistics on dam (earthen and concrete) failures, based on the sum of operation years of a regional group of dams, show a frequency of one failure every 1500 to 1800 dam years [3]. These statistics indicate that earthen structures have a natural resistance to aging. The aging effects that will be evaluated for all earthen structures in the following sections include loss of material, loss of form (settlement and shifting), and change in material properties.

The information used to document the associated aging effects of earthen structures is gathered from industrial and scholastic resources.

8.3.1 Loss of Material

Loss of material is primarily manifested in earthen structures as erosion. The aging effect of erosion is generally the result of one or more of the following aging mechanisms: wind, rain impact, surface (runoff) and subsurface (seepage) flow, and wave action (including underwater currents and flows). The list of aging mechanisms may be reduced due to design, operating conditions, and environmental conditions, as described in the following sections.

8.3.1.1 Wind Erosion

During dry periods, wind can erode loose surface soil from the earthen structure. Wind erosion is generally limited to earthen structures that do not offer good ground cover vegetation or rip-rap. If sufficient ground cover in the form of vegetation and/or rip-rap to prevent wind erosion is provided, this is not an applicable aging effect. Earthen structures, specifically canals, dams, emergency cooling ponds, and levees, are normally protected by vegetation and/or rip-rap. Therefore, loss of material (erosion) is not an applicable aging effect for earthen structures subjected to wind erosion that are protected by vegetation and/or rip-rap.

Earthen structures, specifically canals, dams, emergency cooling ponds, levees, and submerged levees have specific designs for each of the participating nuclear power plants. Therefore, each utility should review their current design to ensure that the aging effects of wind erosion are addressed. Loss of material (erosion) is an applicable aging effect for earthen structures (with the exception of submerged levees) subjected to wind erosion, pending individual plant design review.

8.3.1.2 Rain Impact

The energy of raindrops impacting soil can loosen the particles and scour exposed surfaces. However, this is not an applicable aging effect for earthen structures. The applicable aging effect that does occur as the result of rain impact is erosion, which occurs when the loosened soil is carried away by surface flow. Surface erosion typically has little or no effect on surfaces that are covered by sufficient ground cover vegetation or rip-rap, since ground cover will dissipate the energy of the raindrops, disrupt surface flow, and help hold surface soil in place. Earthen structures, specifically canals, dams, emergency cooling ponds, and levees, are normally protected by vegetation and/or rip-rap. The effect of rain impact is not applicable for submerged levees. Therefore, loss of material (erosion) is not an applicable aging effect for earthen structures subjected to rain impact erosion that are protected by vegetation and/or rip-rap.

Earthen structures, specifically canals, dams, emergency cooling ponds, levees, and submerged levees, have specific designs for each of the participating nuclear power plants. Therefore, each utility should review their current design to ensure that the aging

effects of rain impact are addressed. Loss of material (erosion) is an applicable aging effect for earthen structures (with the exception of submerged levees) subjected to rain impact, pending individual plant design review.

8.3.1.3 Surface and Subsurface Flow

Surface flow of rain runoff can cause soil surfaces to erode resulting in surface scour or gullies. Subsurface flow is caused by water seeping through the soil and forming underground soil "pipes." If left unchecked, surface and subsurface flow may eventually threaten the structural integrity of the earthen structure.

The possibility of this effect is minimized by good design practices such as limiting embankment slopes to minimize overland flow velocities and providing concrete or rip-rap cover over spillways and areas with high fluid velocities and hydraulic jumps. The use of impermeable clay liners may be used to keep the earthen structure sealed to prevent subsurface flow and the detrimental effects of seepage forces. An additional preventive measure is to provide periodic inspections of areas of expected high flow near earthen structures. Indications of subsurface flow include new downhill springs or sudden unexplained water level drops, surface cracks, and unexplained settlement.

Earthen structures, specifically canals, dams, emergency cooling ponds, levees, and submerged levees, have specific designs for each of the participating nuclear power plants. Therefore, each utility should review their current design to ensure that the aging effects of surface and subsurface flow are addressed. Surface flow is not applicable for submerged levees. Loss of material (erosion) is an applicable aging effect for earthen structures subjected to surface and subsurface flow, pending individual plant design review.

8.3.1.4 Wave Action (including underwater currents and flows)

The shore line around water-retaining earthen structures may experience loss of material owing to wave action. This effect is primarily caused by wind blowing across the water surface or by surface flow. This effect could cause a loss of slope stability owing to the undercutting erosion action of the waves. Seepage is an additional condition that could occur due to thinning of impermeable clay liners. This effect is typically not a concern if good design practices were employed such as limiting the slope of the embankment or installing rip-rap at the shoreline. Periodic inspection may be used to determine extent of undercutting, if any.

Submerged levees may also experience the effects of underwater currents or flows. These currents could be naturally occurring or man-made, such as boating traffic or suction from an intake structure. Generally, if the submerged levee is far below the surface of the water, this is not a concern. However, a periodic inspection of the levee should be performed. The integrity of a submerged levee may be performed using soundings from the water surface or by visual inspection using qualified divers.

Earthen structures, specifically canals, dams, emergency cooling ponds, levees, and submerged levees, have specific designs for each of the participating nuclear power plants. Therefore, each utility should review their current design to ensure that the aging effects of wave action (including underwater currents and flows) are addressed. Loss of material (erosion) is an applicable aging effect for earthen structures subjected to wave action (including underwater currents and flows), pending individual plant design review.

8.3.2 Loss of Form

Loss of form is manifested in earthen structures in the form of slope instability, cracking, deformation, and sediment accumulation. These effects are a result of one or more of the following aging mechanisms: settlement, surface (runoff) and subsurface (seepage) flow, frost action, sedimentation. The list of aging mechanisms may be reduced owing to design, operating conditions, and environmental conditions, as described in the following sections.

8.3.2.1 Settlement Assessment

Settlement is found, to some degree, in all earthen structures. As the below-surface soil is loaded, it settles under the pressure of the overburden. Unacceptable settlement can occur when overburden is applied to inferior or poorly compacted soil, such as silt or unconsolidated clay. In addition, uneven settlement may cause cracking in the earthen structure. However, most settlement is typically discovered during or soon (generally less than one year) after construction.

Potential causes for settlement later in life include secondary effects of other problems within the earthen structure. Settlement may occur as a result of seepage through thin or degraded areas of the impermeable soil liner (see below for additional discussion), or if large water fluctuations occur where expansive clay was used in the construction of the embankment.

Settlement may occur later in life when particular soils, such as organic or unconsolidated clay, were used during original construction. These types of soils are not able to sustain large overburden pressures. Settlement may be amplified if additional surcharge loads are applied to these soils such as building foundations or vehicular traffic. This is not considered an aging effect, but careful examination of original soil borings, structure design considerations, and added surcharge loading in the area of the earthen structure should be considered for each applicable earthen structure.

As previously mentioned, most settlement from poor construction practice or inferior materials is discovered early in the life of the structure. Conditions causing settlement later in life may be detected and corrected with a careful periodic inspection program.

Earthen structures, specifically canals, dams, emergency cooling ponds, levees, and submerged levees, have specific designs for each of the participating nuclear power plants. Therefore, each utility should review their current design to ensure that the aging effects of settlement are addressed. Loss of form is an applicable aging effect for earthen structures subjected to settlement, pending individual plant design review.

8.3.2.2 Surface and Subsurface Flow

Erosion near or at the base of an embankment or under an embankment may cause distortion or instability in the earthen structure. Due to the loss of material, earthen structures, such as embankments, may experience lateral and/or vertical movement. See Section 8.3.1 for additional information concerning erosion.

Earthen structures, specifically canals, dams, emergency cooling ponds, levees, and submerged levees, have specific designs for each of the participating nuclear power plants. Therefore, each utility should review their current design to ensure that the aging effects of surface and subsurface flow are addressed. Surface flow is not applicable for submerged levees. Loss of form is an applicable aging effect for earthen structures subjected to surface and subsurface flow, pending individual plant design review.

8.3.2.3 Frost Action

When the daily mean temperature remains below 32 °F for a period of three or more days, soil moisture begins to freeze. As ground water continues to freeze, earthen structures may experience deformation caused by a phenomenon called *frost heave* [5]. Frost heave is caused by water in the soil which expands approximately 10% when it freezes. For instance, saturated soil with a void ratio of 0.7 would experience a 4% heave. Over a period of extended cold periods, frost heave may cause permanent deformation to an earthen structure. However, this effect only occurs in areas with deep frost line with fine grain soils.

Frost heave will occur to some extent for all soils exposed to subfreezing temperatures. If the amount of frost heave is not perceivable without instrumentation, then it is not an applicable aging mechanism. In areas that experience noticeable frost heave, careful periodic inspections should be performed to determine if any permanent deformation is occurring.

Earthen structures, specifically canals, dams, emergency cooling ponds, levees, and submerged levees, have specific designs for each of the participating nuclear power plants. Therefore, each utility should review their current design to ensure that the aging effects of frost action are addressed. Frost action is not applicable for submerged levees. Loss of form is an applicable aging effect for earthen structures subjected to frost action, pending individual plant design review.

8.3.2.4 Sedimentation

As surface flow (runoff) travels toward the water-control structure, it acquires small particles of soil and organic material. When the runoff reaches the water-control structure, the energy of the flow is dissipated and the suspended particles settle to the bottom of the pond or reservoir. This effect is unavoidable and is a particular concern where the storage capacity of the retaining structure is required for emergency cooling or flood water retention.

For ultimate heat sink water sources, periodic soundings of the depth of the pond are required to ensure that the required water volume is available for the design basis accident. Likewise, periodic measurements of flood control structures (like reservoirs) should be made to ensure that adequate storage capability is available during the design basis flood event.

Earthen structures, specifically canals, dams, emergency cooling ponds, levees, and submerged levees, have specific designs for each of the participating nuclear power plants. Therefore, each utility should review their current design to ensure that the aging effects of sedimentation are addressed. Sedimentation is not applicable for dams and levees. Loss of form is an applicable aging effect for earthen structures subjected to sedimentation, pending individual plant design review.

8.3.3 Change in Material Properties

The primary change to material properties for earthen structures is desiccation. Desiccation may occur when soil is exposed to the air for extended periods of time. Water not ionically combined with the soil is drawn toward the surface where it evaporates [4]. Highly plastic preloaded clay is especially susceptible owing to its potential for shrinking and loss in pliability. This, in turn, may cause the exposed surface of the clay to become brittle and flake off or delaminate. Desiccation, coupled with surface flow, wind, or wave action may accelerate these effects of erosion.

Desiccation is not an applicable aging mechanism for submerged structures, since the soil is continuously exposed to water. Examples include areas like the bottom liner of emergency cooling ponds or submerged levees. Therefore, no provisions are required to manage desiccation for continuously submerged portions of earthen structures regardless of the material used in construction.

The effects of desiccation may be controlled through proper material selection and embankment slope during design and construction. In addition, the presence of vegetation can minimize this effect since plants tend to hold moisture in the soil. Periodic inspections may be used to determine if material has been lost due to desiccation.

Earthen structures, specifically canals, dams, emergency cooling ponds, levees, and submerged levees, have specific designs for each of the participating nuclear power plants. Therefore, each utility should review their current design to ensure that the aging effects of desiccation are addressed. Desiccation is not applicable for submerged levees. Loss of form is an applicable aging effect for earthen structures subjected to desiccation, pending individual plant design review.

8.3.4 Industry Experience

An operational history review was performed to review the generic communications related to earthen structures and the related aging effects. A review of the following types of generic communications was performed: INPO O&MRs and NRC Information Notices, Bulletins, and Regulatory Guides. No correspondence was found that was directly related to aging of earthen structures; thus, no new aging mechanisms were identified. The lack of reports reflects the high reliability of earthen structures and the lack of significant age-related degradation.

Due to the applicability of dams outside NRC jurisdiction, industry information on dams in general was also reviewed. The following provide a summary of the information from this investigation:

Previous investigations into the frequency of dam failure indicate that it decreases with later years of construction [7]. This is generally attributed to improvements in the methods of design and construction. The age of the dam is another factor that has been identified as having an effect on the rate of dam failure. Approximately half of the dam failures occur during the first five years of operation [8].

The Executive Committee of the United States Committee on Large Dams (USCOLD) authorized the Dam Safety Committee's Subcommittee on Dam Incidents and Accidents to compile a list of dam incidents from 1972 through 1986. The compilation of data was documented in *Lessons from Dam Incidents, USA-11* [9]. There were 164 incidents documented for earthen dams over fifty feet in height. Six of the incidents were major failures of an operating dam which permitted the damage to be successfully repaired with the dam returned to operational status. The majority of the incidents (84 were identified as repairs) were required because of deterioration or to upgrade certain features of the dam. The cause of the incidents were due to piping, sliding, overtopping, or deficiency in the construction or design of the dam/foundation/spillway.

8.3.5 Summary of Applicable Aging Effects

The previous sections discuss various aging mechanisms and the applicability within the bounds of the specific material and environments for earthen structures. Aging effects and associated aging mechanisms which are deemed plausible under these conditions have been identified. A summary of aging effects with the associated aging mechanism, and the applicability to different earthen structures is provided in Table 8-1.

Table 8-1 Applicable Aging Effects for Earthen Structures

APPLICABLE AGING EFFECTS	EARTHEN STRUCTURE TYPE				
	Canal	**Dam**	**Emergency Cooling Pond**	**Levee**	**Submerged Levee**
Loss of Material (Erosion)					
Wind Erosion	Y	Y	Y	Y	N
Rain Impact	Y	Y	Y	Y	N
Surface Flow	Y	Y	Y	Y	N
Subsurface Flow	Y	Y	Y	Y	Y
Wave Action	Y	Y	Y	Y	Y
Loss of Form					
Settlement	Y	Y	Y	Y	Y
Surface Flow	Y	Y	Y	Y	N
Subsurface Flow	Y	Y	Y	Y	Y
Frost Action	Y	Y	Y	Y	N
Sedimentation	Y	N	Y	N	Y
Change in Material Properties					
Desiccation	Y	Y	Y	Y	N

Key: Y means aging effect is applicable for the earthen structure.
N means aging effect is not applicable for the earthen structure.

8.4 Aging Management Programs

All participating nuclear power plants sites have current inspection programs specifically suited for the in-scope earthen structure(s) at each individual site. These programs vary with the function of the earthen structure. However, each utility should review their current program to ensure that their current program addresses all applicable aging effects discussed in this section.

8.5 References

1. NRC Regulatory Guide 1.127, "Inspection of Water-Control Structures Associated with Nuclear Power Plants", Revision 1, March 1978.

2. C. H. Oglesby and R. G. Hicks, Highway Engineering, Fourth Edition, John Wiley & Sons, 1982.

3. E. Gruner, "Classification of Risk", Proceedings International Congress on Large Dams, Vol. 1, Madrid, 1973, pp. 55-68.

4. K. Terzaghi and R. B. Peck, Soil Mechanics in Engineering Practice, Second Edition, John Wiley and Sons, Inc., 1967.

5. G. B. Sowers and G. F. Sowers, Introductory Soil Mechanics and Foundations, Third Edition, The MacMillan Company, 1970.

6. J. L. Sharard, Earth and Earth-Rock Dams, Engineering Problems of Design and Construction, John Wiley and Sons, Inc., 1963.

7. Baecher, G. B., M. E. Pate, and R. DeNeufville, Risk of Dam Failure in Benefit-Cost Analysis, Water Resources Research, Vol. 16, No. 3, 1980

8. Benjamin, Jack R., and Associates, A Database for the Evaluation of the Frequency of Random Dam Failure, Report 120-010-01, Palo Alto, California

9. American Society of Civil Engineers (ASCE), Lessons from Dam Incidents, USA-11, New York, New York, 1988

9. TEFLON

This chapter of the Structural Tools is intended to cover teflon as used in structural applications. TEFLON is typically used in component supports at sliding surfaces. A description of TEFLON is provided in Section 9.1. Environments that TEFLON are exposed to are discussed in Section 9.2. Aging effects for the material and environment combinations are discussed in Section 9.3. Recommendations for aging management programs are provided in Section 9.4.

9.1 Description and Scope

TEFLON is the trade name for polytetrafluoroethylene. TEFLON has a unique position in the plastics industry owing to its chemical inertness, heat resistance, excellent electrical insulation properties, and the low coefficient of friction in a wide temperature range [1]. Because of the low coefficient of friction, TEFLON is used in many applications as a sliding surface.

9.2 Environment

TEFLON is exposed to many environments throughout nuclear power plants. TEFLON may be exposed to relative humidity up to 100 percent, temperatures up to 140°F, and gamma radiation. Exposure to high energy neutrons (E > 1 MeV) is not addressed in this chapter. TEFLON has outstanding hydrolytic and high thermal stability because of its strong carbon-fluorine bond. The maximum recommended use temperature for TEFLON is 302 °F [1]. Therefore, humidity and high temperature are not significant in the aging of TEFLON.

9.3 Aging Effects

The information used to document the associated aging effects for TEFLON is gathered from industrial sources. The only aging effect to consider is material property change owing to exposure to gamma radiation.

9.3.1 Material Property Change

Gamma Radiation

When polytetrafluoroethylene is attacked by radiation, degradation is due to random scission of the polymer chain. Scission is the breaking of chemical bonds in the polymer. In the absence of oxygen, the relative stability of the scission products protects the materials from rapid deterioration. In an air or oxygen environment, accelerated scission and rapid degradation occur [1]. Several property changes occur after scission. Tensile strength, ultimate elongation, and Young's modulus all decrease. The flexure modulus

increases. TEFLON embrittles during irradiation in the presence of oxygen as a result of scission [1]. The lowest reported dose threshold for radiation degradation is 10^4 rads [2,3,4].

Material property change owing to radiation is an applicable aging effect for TEFLON in environments where gamma radiation exceeds the limit defined above.

9.3.2 Industry Experience

Industry failure data and NRC generic communications were reviewed to determine if there are any additional aging effects that should be considered for TEFLON. This review included searches of INPO Nuclear Plant Reliability Data System (NPRDS) databases, NRC Inspection and Enforcement (IE) Information Bulletins, and NRC Licensee Event Reports (LER). The search was performed for TEFLON, polytetrafluoroethylene, and sliding surfaces.

The search did not identify any documented instances of aging associated with TEFLON in structural applications. Radiation degradation of TEFLON was identified in other applications.

9.3.3 Summary of Applicable Aging Effects

The applicable aging effect for TEFLON change in material properties owing to gamma radiation dose which exceeds 10^4 rads.

9.4 Aging Management Programs

Each participating nuclear power plant is responsible for identifying TEFLON that is located within environments which exceed the gamma radiation dose limits, and demonstrating that the aging effects will be managed for the period of extended operation.

9.5 References

1. Concise Encyclopedia Of Polymer Science and Engineering, John Wiley & Sons, 1990.

2. "Radiation Tolerance of TEFLON Resins," The Journal of TEFLON, Reprint No. 37, E. I. DuPont De Nemours & Company, Inc., Plastics Department, Wilmington, Delaware, 1988.

3. "Radiation Data for Design and Qualification of Nuclear Plant Equipment," EPRI NP-4172M, Electric Power Research Institute, Palo Alto, California, August 1985.

4. Selection Guide to Organic Materials for Nuclear Engineering, CERN 72-7, European Organization for Nuclear Research, Geneva, 1972.

10. SUMMARY AND CONCLUSIONS

Structures and structural components subject to aging management review have been identified by each of the participating nuclear power plants in accordance with 10 CFR Part 54. After reviewing materials of construction and associated operating environments for structures and structural components subject to aging management review, material and environment based age-related degradation guidelines were developed that may be used to identify applicable aging effects associated with structures and structural components subject to aging management review.

In addition, technical elements of aging management programs were established for material and environment combinations for which applicable aging effects are identified; however, demonstration of aging management will be performed on a plant-specific basis using the NEI 95-10 Industry Guideline for Implementing the Requirements of 10 CFR Part 54. Time limited aging analyses (TLAA) applicable to structures and structural components within the scope of license renewal will be identified and resolved on a plant-specific basis and are not addressed in this topical report.

Structures subject to aging management review support, house, and protect systems and components that are relied upon to operate the plant safely. These structures must be capable of withstanding, without loss of function, the effects of design basis events. Examples of structures within the scope of license renewal include the auxiliary building and intake structure. Structures are constructed from structural members such as beams, columns, floors, walls, and foundations.

Structural components subject to aging management review, which are attached to or reside within structures, are used to support mechanical components, electrical components, and other structural members. The category of other structural members includes, but is not limited to, (1) structural components whose function is to carry dynamic loads caused by postulated design basis events, e.g., pipe whip restraints, jet barriers, and missile shields; (2) electrical and instrumentation enclosures; (3) pipe, conduit, and cable tray supports; (4) fire barriers; (5) elastomers; and (6) teflon. Structural components are constructed from structural members such as beams, girders, joists, trusses, columns, frames, and bolting.

Structures and structural components subject to aging management review were divided into the following major groups based on materials of construction and operating environments.

1) Structural steel and steel components
2) Structural steel and steel components in fluid environments
3) Threaded fasteners
4) Concrete structures and concrete components

5) Fire barriers
6) Elastomers
7) Earthen structures
8) Teflon

The aging effects evaluation for each group included (1) identification of items within the scope of license renewal, including the corresponding materials of construction; (2) identification of representative bounding operating environments; (3) determination of applicable aging effects; and (4) recommendations for technical elements of aging management programs. A summary of applicable aging effects is provided in Table 10-1.

Table 10-1 Summary of Applicable Aging Effects

Section	Materials	Environment	Applicable Aging Effect(s)	Section
Structural Steel and Steel Components	carbon steel low-alloy steel galvanized steel stainless steel	steel exposed to atmosphere/weather and steel protected from atmosphere/weather- ambient conditions, temperatures to 150 °F, relative humidity of 100%, and radiation	loss of material owing to general corrosion for carbon and low-alloy steel loss of material for galvanized steel exposed to atmosphere/weather	Section 2.3.6
Structural Steel and Steel Components in Fluid Environments	carbon steel low-alloy steel stainless steel	raw water borated water--stainless steel only	raw water--loss of material for carbon, low-alloy; cracking of stainless steel borated water-cracking of stainless steel	Section 3.3.5
Threaded Fasteners	carbon steel low-alloy steel stainless steel	fasteners exposed to atmosphere/weather and fasteners protected from atmosphere/weather---ambient conditions, temperatures to 150 °F, relative humidity of 100%, and radiation	loss of material by corrosion for carbon and low-alloy steels SCC of high strength (Sy> 150 ksi) LAQT and maraging bolting materials	Section 4.3.5
Concrete Structures and Concrete	concrete and reinforced concrete	below grade above grade, interior above grade, exterior	below grade--none above grade interior--loss of material, cracking, and	Section 5.3.5

Table 10-1 Summary of Applicable Aging Effects

Section	Materials	Environment	Applicable Aging Effect(s)	Section
Components			change in material properties above grade exterior--loss of material	
Fire Barriers	silicone rubber, foam, mineral fiberboards	ambient conditions, temperature up to 150°F, rel. humid. 100 %	fire Wrap—loss of material and cracking fire stops—loss of material, cracking, and separation	Section 6.3.6
Elastomers	rubber, neoprene, and silicone	fluids, ambient conditions, temperatures up to 150 °F, and radiation	change in material properties by gamma radiation	Section 7.3.3
Earthen Structures	soil and rock	submerged, surface exposed to weather, and below-surface soil	loss of material for canals, dams, cooling ponds, levees, and submerged levees loss of form for canals, dams, cooling ponds, levees, and submerged levees change in material properties for canals, dams, cooling ponds, and levees	Section 8.3.5
Teflon	polytetrafluoro ethylene	ambient conditions, temperatures to 150 °F, relative humidity 100%, and radiation	change in material properties by gamma radiation	Section 9.3.3

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11. CERTIFICATION

This report is an accurate description of aging effects for structures and structural components of the participants in the B&W Owners Group Generic License Renewal Program.

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This report is approved for release.

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David J. Firth Date
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Target:
Nuclear Power

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