United States Nuclear Regulatory Commission Official Hearing Exhibit
In the Matter of: Entergy Nuclear Operations, Inc.
(Indian Point Nuclear Generating Units 2 and 3)
ASLBP #: 07-858-03-LR-BD01
Docket #: 05000247 | 05000286
Exhibit #: NYS00320B-00-BD01
Identified: 10/15/2012
Admitted: 10/15/2012
Withdrawn:
Rejected:
Stricken:
Other:

this tool that oil contamination does not result in any degradation effects over and above those that would occur without the presence of oil contamination. The one exception is the potential for oil contamination to provide a source of microorganisms to the gas system. Microorganisms have been found in oil, especially where the oil quality is not maintained and/or the source of the oil is from a reservoir or tank that may be contaminated.

9. Stress corrosion cracking (SCC) of stainless steels is not a significant aging mechanism below 140˚F.

4.2 Overview

The Mechanical Tools are intended to provide an efficient method to identify applicable aging effects for systems and components which are required to undergo an aging management review in compliance with the license renewal rule. Utilization of these tools at the various sites will result in the identification of aging effects that must be managed for plant equipment or that can be justified not to require management during the period of extended operation. Demonstration of the adequacy of aging management programs to manage these effects is outside the scope of this tool as discussed in Section 4.0 of the main document (implementation guideline).

These tools identify potential aging effects and also direct the user to areas in the system where these effects might be preferentially manifested. The discussions in Section 3 identified numerous aging mechanisms and their associated aging "effects" which potentially can occur in the air and gas system equipment addressed by this tool. This tool, Figure 1, then guides the user through logic to determine, based on specific system or component materials, environment and/or operating conditions, whether these effects are applicable. The tool described in the following sections address the "effects" of aging on various materials when subjected to air and/or gas internal environments. The tool is organized such that the individuals utilizing the tool do not require detailed knowledge of aging mechanisms or their effects. The logic does, however, require that the user be familiar with the materials of construction, various applicable environments, and all system operating conditions.

The evaluation logic groups aging effects, such as loss of material and cracking, to efficiently resolve the disposition of equipment. The results not only identify the effects which must be managed but, given the mechanism applicability criteria, can be a valuable input when determining how and where to implement aging management programs.

4.3 Tool Description

Table 4-1 (added in Revision 3) identifies applicable aging effects, and corresponding mechanisms, that may require programmatic oversight (management) for the period of extended operation, as well as the applicability criteria for the occurrence and propagation of the mechanisms. This table summarizes the information depicted on the corresponding logic diagram (Figure 1) and is organized alphabetically by material and aging mechanism. The potential aging effects, together with the detailed mechanism discussions in Section 3.0 and assumptions in Section 4.1 of this appendix, provide the basis for the development of the air and gas tool described below. The materials and environments covered by these tools are described in Section 2.0.

Figure 1 contains the logic and criteria to evaluate aging effects for various materials in an air or gas internal environment. As the EPA is requiring the use of replacements for fluorocarbons and halon and some of the replacement gases are corrosive, any metal that is susceptible to chloride induced pitting and SCC may exhibit degradation. This is covered in the upper branch of the logic, as is a very specific issue that resulted from the NRC document search. Specifically the issue is hydrogen embrittlement of Raychem Cryofit Couplings in the pressurizer gas space sample line. This issue represents the only indication of hydrogen damage uncovered during the document search. A review of information included in the referenced corrosion handbooks and other available information indicates that likelihood of hydrogen damage to material at nuclear plants is extremely low. Therefore, with the exception of the Raychem Cryofit Couplings in a hydrogen environment, hydrogen damage is assumed not to occur. It is included in this tool to address the very specific issue covered by NRC Information Notice 91-87.

Since moisture or fluid is necessary for the propagation of the remaining degradation mechanisms, the logic provides for the exclusion of all "dry" gas and air environments. Components that are subjected only to processed gases that contain little if any moisture are not likely to realize any significant degradation mechanisms regardless of the material. Environments meeting this criteria include dried/filtered air, clean processed nitrogen, carbon dioxide, hydrogen, and halon.

HVAC and other air supply systems contain air with varying degrees of moisture content that, for the most part, will not result in an aggressive environment. Unless situations produce a "wetted" environment in these air systems, the logic provides for the conclusion that, with the exceptions of general corrosion of cast iron or carbon steel and galvanic corrosion of susceptible materials in electrolytic contact with a more cathodic (noble) metal in the galvanic series, there are no aging effects. An example of a situation in which pooled water can occur in air HVAC systems is immediately downstream of a cooler. In cases of extreme condensation on cooler tubes, moisture carryover of entrained particles can occur with subsequent pooling immediately downstream of the coolers. This pooling produces a wetted environment where corrosion of susceptible materials can occur.

The next two logic provisions involve mechanisms that can occur under atmospheric moisture conditions. Although system and component design should preclude the occurrence of galvanic corrosion, it can be a significant aging mechanism as the results are sometimes hard to detect prior to pressure boundary failure. Due to the variety of materials covered by this tool, galvanic corrosion is a concern in moist air and gas systems. General corrosion is another degradation mechanism that can occur under atmospheric moisture conditions. However, of the materials included in this tool, only carbon steel and cast iron are susceptible in moist air and gas systems.

The remainder of the degradation mechanisms included in the tool logic require a wetted surface or pooled liquid environment and the corresponding logic is divided such that stainless steels and nickel-base alloys are addressed, then galvanized steel, then carbon and low-alloy steel, cast iron, copper and copper alloys, and aluminum and aluminum alloys.

All materials are susceptible to microbiologically influenced corrosion (MIC) in wetted locations (e.g., microbes/bacteria in dust particles can enter air intakes and collect in the wetted locations associated with cooling coils). Therefore, a source of the microbe would have to be introduced into an air gas environment for MIC to be of concern. Microorganisms can be introduced into a gas environment from many sources. Some air spaces within the scope of this tool are in raw water systems which may contain the microbes. Fire protection systems may also have air spaces and use raw water as a source of water. Another source of microbe introduction can be from contamination or leakage from a raw water source. As an example, leakage from a raw water chiller or cooler into an air system could result in the introduction of MIC. The leakage may also provide for the wetted environment necessary for the progression of this effect. Contaminated oil if used in air systems can also provide for the introduction of these microorganisms.

Under wetted conditions all materials can be subject to crevice and pitting corrosion in the presence of a contaminant such as chloride or sulfide. However, aluminum bronze with < 8% Al content and low zinc brasses have a high pitting resistance. In the presence of a contaminant, stainless steel, and aluminum alloys containing > 12% Zn or > 6% Mg are susceptible to stress-corrosion cracking (aluminum in its pure form is not susceptible to SCC). In addition, if ammonia or ammonium compounds are present in the air or gas system, high zinc brasses and aluminum bronze are susceptible to SCC.

Selective leaching in a wetted environment can occur with no other contaminants present. The logic tree addresses this issue by singling out high zinc brass and gray cast iron as the materials susceptible to this loss of material effect. (Selective leaching is commonly referred to as dezincification and graphitization for these two metals respectively.) Aluminum bronze is susceptible to a mechanism similar to dezincification and is also included in this category.

The last leg on the logic diagram addresses the thermal embrittlement of galvanized steel at temperatures above 400ºF regardless of the environment.

4.4 GALL Comparison

The information in Chapters IV, V, VII, and VIII in Volume 2 of NUREG-1801, Revision 1, "Generic Aging Lessons Learned (GALL) Report – Tabulation of Results," identifies material, environment(s), aging effects (and associated mechanisms) typically requiring management for license renewal applicants, and the suggested aging management program (AMP) for various mechanical components. GALL Chapter IV, V, VII, and VIII tables all include items for environments addressed by this tool. The identification and evaluation of aging management programs (AMPs) is outside the scope of this tool and should be addressed on a plant-specific basis, as described in Section 4.0 of the main document. Pertinent GALL items are addressed in Table 4-1, with the following material, environment, aging effect, and aging mechanism considerations.

The materials for the pertinent items in GALL Chapter IV, V, VII, and VIII are consistent with the materials addressed by this tool, which are described in Section 2.1. Carbon or low-alloy steel is referred to as "steel" in the GALL items for environments addressed by this tool, and is listed alone or with stainless steel. Cast iron is not listed specifically in the GALL items for environments addressed by this tool but is included with "steel." Copper and copper alloys are referred to as "copper alloy" and aluminum and aluminum alloys are referred to as "aluminum" in the GALL for environments addressed by this tool. In the GALL, the non-metals cited for environments addressed by this tool are referred to as "glass" and "elastomers." Plastics are not listed in the GALL for the environments addressed by this tool.

OAGI0000553_00282

The following GALL Chapters IV, V, VII, and VIII environments are bounded by the environments addressed in this tool, which are described in Section 2.2:

- Air
- Air – indoor uncontrolled (internal)
- Air – indoor uncontrolled (internal/external)
- Air – outdoor (internal)
- Condensation (internal)
- Diesel exhaust
- Dried air
- Gas
- Moist air or condensation (internal)

The GALL items addressing glass in air (VII.J-7, VIII.I-4) concur with the conclusions of Section 3.5 of this tool with respect to there being no applicable aging effects (aging effects requiring management in the GALL) for glass exposed to air. Additionally, the GALL items that cite aluminum (V.F-2, VII.J-2, and VIII.I-1), copper alloy (V.F-3, VII.J-3, VII.J-4, and VIII.I-3), steel (V.F-18, VII.J-22, VII.J-23, and VIII.I-15), and stainless steel (IV.E-5, V.F-15, VII.J-18, VII.J-19, and VIII.I-12) exposed to a dried air or gas environment concur with the conclusions of this tool with respect to corrosion mechanisms requiring wetting (e.g., condensation) or other contaminants.

GALL Chapter VII items (VII.F1-7, VII.F2-7, VII.F3-7, and VII.F4-6) cite hardening and loss of strength due to elastomer degradation in uncontrolled air, internal or external, without describing the relevant conditions for elastomer degradation. These GALL items concur with Section 3.5 of this tool, which references EPRI report 1002590 [19] for discussion of the applicable aging effects for elastomers, and includes a description of the relevant conditions for the degradation of elastomers, such as temperature, radiation, sunlight, and ozone (natural rubbers). Additionally, certain GALL Chapter VII items (VII.F1-6, VII.F2-6, VII.F3-6, and VII.F4-5) cite loss of material due to wear as an aging effect requiring management for elastomer seals and components that contain air, which is more conservative than the discussion in Section 3.5 of this tool.

The GALL does not evaluate mechanisms separately, as is done in Section 3.0 of this tool. Additionally, the aging mechanisms identified in GALL Chapters V, VII, and VIII are grouped without clear indication as to mechanisms (e.g., crevice corrosion) that are indicated as applicable to certain components but not to others. The aging effects/mechanisms cited in GALL Chapters V, VII, and VIII as requiring management for metals in the air, moist air, or condensation environments includes loss of material and cracking (diesel exhaust), with the following groupings of mechanisms depending on material susceptibility:

- General (steel only), pitting and crevice corrosion – from exposure to diesel exhaust
- General and pitting corrosion – of steel exposed to internal condensation
- General corrosion – of steel exposed to uncontrolled indoor air

- General corrosion and fouling – of drywell and suppression chamber spray system steel exposed to uncontrolled indoor air
- General, pitting, and crevice corrosion – of steel exposed to internal condensation, moist air or condensation, outdoor air, or uncontrolled indoor air
- General, pitting, crevice and (for drain pans and drain lines) microbiologically influenced corrosion – of steel exposed to internal condensation
- Pitting and crevice corrosion – of stainless steel and copper alloy exposed to internal condensation
- Stress corrosion cracking – of stainless steel exposed to diesel exhaust

The GALL items for the above environments do not identify galvanic corrosion in the air and gas environments, whereas per Section 3.1.2, galvanic corrosion is evaluated in this tool and is applicable to carbon and low-alloy steel, cast iron, and aluminum/aluminum alloys in wetted locations. The GALL does not identify cracking, due to SCC, in air and gas environments except for stainless steel exposed to diesel exhaust, whereas it is evaluated in this tool, in Section 3.2.2, for aluminum and aluminum alloys, certain copper alloys, and stainless steel.

The GALL Chapter IV, V, VII, and VIII items that identify aging effects for external surfaces, closure bolting, and heat exchangers are addressed separately in Appendix E, Appendix F, and Appendix G, respectively. Likewise, GALL items for fatigue are evaluated separately in Appendix H and are not addressed in this tool.

Table 4-1 Aging Effects Summary - Air/Gas					
Material	**Aging Effect / Mechanism**	**Mechanism Applicability Criteria**	**NUREG-1801 (GALL) Item No.**	**Tool vs GALL Match**	**Relevant Sections, Assumptions, and Discussion**
All Metals	Cracking / Hydrogen Embrittlement	1. H_2 environment *and* 2. RayChem Cryofit Couplings present	None	No	Sections 2.2.3, 3.2.1 Hydrogen embrittlement and Raychem Cryofit couplings are not addressed in GALL.
All Metals	Loss of Material / Pitting and/or Crevice Corrosion	1. Replacement gas for fluorocarbons (refrigerants) or halon (fire suppressants) used *and* 2. Replacement gas is corrosive	IV.E-5 V.F-18, V.F-4, V.F-15 VII.J-2, VII.J-3, VII.J-4, VII.J-18, VII.J-19, VII.J-22, VII.J-23 VIII.I-1, VIII.I-3, VIII.I-12, VIII.I-15	No	Sections 2.1, 2.2.6, 2.2.7, 3.1.3, 3.1.4 Assumptions 4.1.1, 4.1.3, 4.1.6, 4.1.7 Specified GALL items indicate no aging effects in dried air or gas environments for copper alloy, steel, stainless steel. GALL does not address potential for corrosiveness of replacement gases in Chapters IV, V, VII, VIII, or IX.

OAGI0000553_00285

Table 4-1 Aging Effects Summary - Air/Gas					
Material	**Aging Effect / Mechanism**	**Mechanism Applicability Criteria**	**NUREG-1801 (GALL) Item No.**	**Tool vs GALL Match**	**Relevant Sections, Assumptions, and Discussion**
Aluminum and Aluminum Alloys	Loss of Material / Galvanic Corrosion	1. Gas is not dried air, N_2, CO_2, H_2, halon, or fluorocarbons *and* 2. Material is in contact with a more cathodic (noble) metal in the galvanic series, in the presence of an electrolyte Note: Moisture collected in crevices and other low points in air systems, and condensation, provide an electrolyte. Aggressive species (such as salt air) in air system intakes also provide an electrolyte.	V.F-2	No	Sections 2.1.4, 3.1.2 Assumption 4.1.3 GALL Chapters IV, V, VII, and VIII do not include items that cite galvanic corrosion in any air or condensation environment. Specified GALL item indicates there are no aging effects requiring management for aluminum exposed to uncontrolled air. GALL items VII.F1-14, VII.F2-12, VII.F3-14, and VII.F4-10 cite only pitting and crevice corrosion (see below) for aluminum exposed to condensation.
	Loss of Material / MIC	1. Gas is not dried air, N_2, CO_2, H_2, halon, or fluorocarbons *and* 2. Component subject to wetted environment *and* 3. Potential source of MIC	V.F-2	No	Sections 2.1.4, 3.1.6 Assumption 4.1.8 GALL Chapters IV, V, VII, and VIII do not include items that cite MIC of aluminum in any air or condensation environment. Specified GALL item indicates there are no aging effects requiring management for aluminum exposed to uncontrolled air.
	Loss of Material / Pitting and Crevice Corrosion	1. Gas is not dried air, N_2, CO_2, H_2, halon, or fluorocarbons *and* 2. Component subject to wetted environment *and* 3. A potential for concentrating contaminants exists	VII.F1-14, VII.F2-12, VII.F3-14, VII.F4-10	Yes	Sections 2.1.4, 3.1.3, 3.1.4 Assumptions 4.1.1, 4.1.3, 4.1.6, 4.1.7 Specified GALL items cite pitting and crevice corrosion as aging effects requiring management for aluminum exposed to condensation (wetted environment).

OAGI0000553_00286

Table 4-1 Aging Effects Summary - Air/Gas					
Material	**Aging Effect / Mechanism**	**Mechanism Applicability Criteria**	**NUREG-1801 (GALL) Item No.**	**Tool vs GALL Match**	**Relevant Sections, Assumptions, and Discussion**
Aluminum and Aluminum Alloys (Cont'd)	Cracking / SCC	1. Gas is not dried air, N_2, CO_2, H_2, halon, or fluorocarbons *and* 2. Component subject to wetted environment *and* 3. A potential for concentrating contaminants exists *and* 4. Alloy with > 12% Zn or > 6% Mg	V.F-2	No	Sections 2.1.4, 3.2.2 Assumptions 4.1.4, 4.1.6, 4.1.7 GALL Chapters IV, V, VII, and VIII do not address SCC of aluminum in any air or condensation environment. Specified GALL item indicates there are no aging effects requiring management for aluminum exposed to uncontrolled air.
Carbon and Low-Alloy Steel *and* Cast Iron	Loss of Material / General Corrosion	1. Gas is not dried air, N_2, CO_2, H_2, halon, or fluorocarbons	V.B-1, V.A-19, V.D2-1, V.D2-16 VII.D-2	Yes	Sections 2.1.3, 2.1.5, 3.1.1 Assumptions 4.1.6, 4.1.7 Specified GALL items cite general corrosion for steel exposed to uncontrolled air. GALL item V.D2-1 also cites fouling of BWR drywell and suppression chamber spray system components. Fouling as an aging mechanism is no different than pitting or crevice corrosion (discussed below). GALL item VII.D-2 also lists pitting corrosion of compressed air system components due to internal condensation, but does not cite crevice. See pitting and crevice and MIC discussions below.

OAGI0000553_00287

Table 4-1 Aging Effects Summary - Air/Gas					
Material	**Aging Effect / Mechanism**	**Mechanism Applicability Criteria**	**NUREG-1801 (GALL) Item No.**	**Tool vs GALL Match**	**Relevant Sections, Assumptions, and Discussion**
Carbon and Low-Alloy Steel *and* Cast Iron (Cont'd)	Loss of Material / Galvanic Corrosion	1. Gas is not dried air, N_2, CO_2, H_2, halon, or fluorocarbons *and* 2. Material in contact with a more cathodic (noble) metal in the galvanic series, in the presence of an electrolyte Note: Moisture collected in crevices and other low points in air systems, and condensation, provide an electrolyte. Aggressive species (such as salt air) in air system intakes also provide an electrolyte.	See Below	No	Sections 2.1.3, 2.1.5, 3.1.2 Assumption 4.1.3 GALL Chapter IV, V, VII, and VIII items do not address galvanic corrosion in any air or internal condensation environment. See pitting and crevice corrosion discussion below for steel exposed to wetting (e.g., condensation); otherwise GALL items cite only general corrosion for steel in air environments, as described above.
	Loss of Material / Pitting and/or Crevice Corrosion	1. Gas is not dried air, N_2, CO_2, H_2, halon, or fluorocarbons *and* 2. Component subject to a wetted environment *and* 3. A potential for concentrating contaminants exists (e.g., due to alternate wetting and drying)	V.D2-17, V.A-2, V.A-3 VII.D-2, VII.F1-3, VII.F2-3, VII.F3-3, VII.F4-2, VII.G-23, VII.H2-2, VII.H2-21 VIII.B1-6, VIII.B1-7, VIII.G-34	No	Sections 2.1.3, 2.1.5, 3.1.3, 3.1.4 Assumptions 4.1.1, 4.1.3, 4.1.6, 4.1.7 Specified GALL items cite general, crevice, and pitting corrosion of steel in wetted environments (e.g., condensation), except as below: • Item VII.D-2 cites pitting and general corrosion (but not crevice) for steel exposed to condensation. • Items V.A-2 and V.A-3 cite general, pitting, and crevice corrosion for steel encapsulation components exposed to air. V.A-3 clarifies that items refer to air with leakage (wetting) and also includes boric acid corrosion (See Appendix E). • VII.F items also list MIC for drain pans/lines. • VII.H2-2 item addresses corrosion of steel or stainless steel exposed to diesel exhaust.

OAGI0000553_00288

Table 4-1 Aging Effects Summary - Air/Gas					
Material	**Aging Effect / Mechanism**	**Mechanism Applicability Criteria**	**NUREG-1801 (GALL) Item No.**	**Tool vs GALL Match**	**Relevant Sections, Assumptions, and Discussion**
Carbon and Low-Alloy Steel *and* Cast Iron (Cont'd)	Loss of Material / MIC	1. Gas is not dried air, N_2, CO_2, H_2, halon, or fluorocarbons *and* 2. Component subject to wetted environment *and* 3. Potential source of MIC	VII.F1-3, VII.F2-3, VII.F3-3, VII.F4-3	Yes	Sections 2.1.3, 2.1.5, 3.1.6 Assumption 4.1.8 Specified GALL items list general, pitting, crevice in steel ducting due to internal condensation (see pitting and crevice discussion above) and, for drain lines and drain pans (wetted surfaces where airborne microbes may collect and thrive), MIC.
Cast Iron *and* Copper and Copper Alloys	Loss of Material / Selective Leaching	1. Gas is not dried air, N_2, CO_2, H_2, halon, or fluorocarbons *and* 2. Component subject to wetted environment *and* 3. Material is gray cast iron *or* Brass/bronze >15% Zn *or* Aluminum bronze > 8% Al *and* 4. Material is not "inhibited" copper alloy Note: Small amounts of alloying elements such as tin, phosphorus, arsenic, and antimony (e.g., 1% tin to brass) effectively inhibit dezincification. Aluminum bronzes are inhibited by adding 0.02 to 0.10% As.	None	No	Sections 2.1.5, 2.1.6, 3.1.8 Assumption 4.1.6, 4.1.7 GALL Chapters IV, V, VII, and VIII do not include items for selective leaching of cast iron or copper alloys exposed to internal condensation (or other wetted location) in air environments.

OAGI0000553_00289

Table 4-1 Aging Effects Summary - Air/Gas					
Material	**Aging Effect / Mechanism**	**Mechanism Applicability Criteria**	**NUREG-1801 (GALL) Item No.**	**Tool vs GALL Match**	**Relevant Sections, Assumptions, and Discussion**
Copper and Copper Alloys	Loss of Material / Galvanic Corrosion	1. Gas is not dried air, N_2, CO_2, H_2, halon, or fluorocarbons *and* 2. Material in contact with a more cathodic (noble) metal in the galvanic series, in the presence of an electrolyte Note: Moisture collected in crevices and other low points in air systems, and condensation, provide an electrolyte. Aggressive species (such as salt air) in air system intakes also provide an electrolyte.	VII.G-9	No	Sections 2.1.6, 3.1.2 Assumption 4.1.3 GALL Chapters IV, V, VII, and VIII do not include items for copper alloy exposed to moist air or for galvanic corrosion in moist air or uncontrolled air environments. Specified GALL item cites only pitting and crevice corrosion (see discussion below) of copper alloy exposed to condensation. GALL items V.F-3 and VIII.I-2 indicate that there are no aging effects requiring management for the external surface of copper alloys exposed to uncontrolled air.
	Loss of Material / Pitting and Crevice Corrosion	1. Gas is not dried air, N_2, CO_2, H_2, halon, or fluorocarbons *and* 2. Component subject to wetted environment *and* 3. A potential for concentrating contaminants exists *and* 4. Material is Brass/Bronze > 15% Zn *or* Aluminum Bronze > 8% Al	VII.G-9	Yes	Sections 2.1.6, 3.1.3, 3.1.4 Assumptions 4.1.1, 4.1.3, 4.1.6, 4.1.7 Specified GALL item cites pitting and crevice corrosion of copper alloy, with distinguishing Zn or Al content, to condensation (wetted environment).

OAGI0000553_00290

Table 4-1 Aging Effects Summary - Air/Gas					
Material	**Aging Effect / Mechanism**	**Mechanism Applicability Criteria**	**NUREG-1801 (GALL) Item No.**	**Tool vs GALL Match**	**Relevant Sections, Assumptions, and Discussion**
Copper and Copper Alloys (Cont'd)	Loss of Material / MIC	1. Gas is not dried air, N_2, CO_2, H_2, halon, or fluorocarbons *and* 2. Component subject to wetted environment *and* 3. Potential source of MIC	VII.G-9	No	Sections 2.1.6, 3.1.6 Assumption 4.1.8 GALL Chapters IV, V, VII and VIII do not include items for copper alloy exposed to moist or uncontrolled air, or to internal condensation. Also, the GALL includes MIC of only steel in internal condensation.
	Cracking / SCC	1. Gas is not dried air, N_2, CO_2, H_2, halon, or fluorocarbons *and* 2. Ammonia or ammonium salts present (e.g., from organic decay or fertilizer entering air system intakes from outside) *and* 3. Component susceptible to wetted environment *and* 4. Material is Brass > 15% Zn *or* Aluminum Bronze > 8% Al	None	No	Sections 2.1.6, 3.2.2 Assumptions 4.1.4, 4.1.6, 4.1.7 GALL Chapters IV, V, VII, and VIII do not include items for cracking of copper alloys.
Galvanized Steel	Loss of Material / General Corrosion	1. Gas is not dried air, N_2, CO_2, H_2, halon, or fluorocarbons *and* 2. Temperature < 212˚F *and* 3. Component subject to wetted environment *and* 4a. pH > 12 or pH < 6 *or* 4b. Temperature > 140˚F and < 200˚F	VII.J-6	No	Sections 2.1.7, 3.1.1 Only GALL items V.F-1 and VII.J-6 specifically address galvanized steel exposed to uncontrolled air, with V.F-1 addressing the external surface of ducting. Both items indicate there are no aging effects that require management for galvanized steel exposed to uncontrolled air.

OAGI0000553_00291

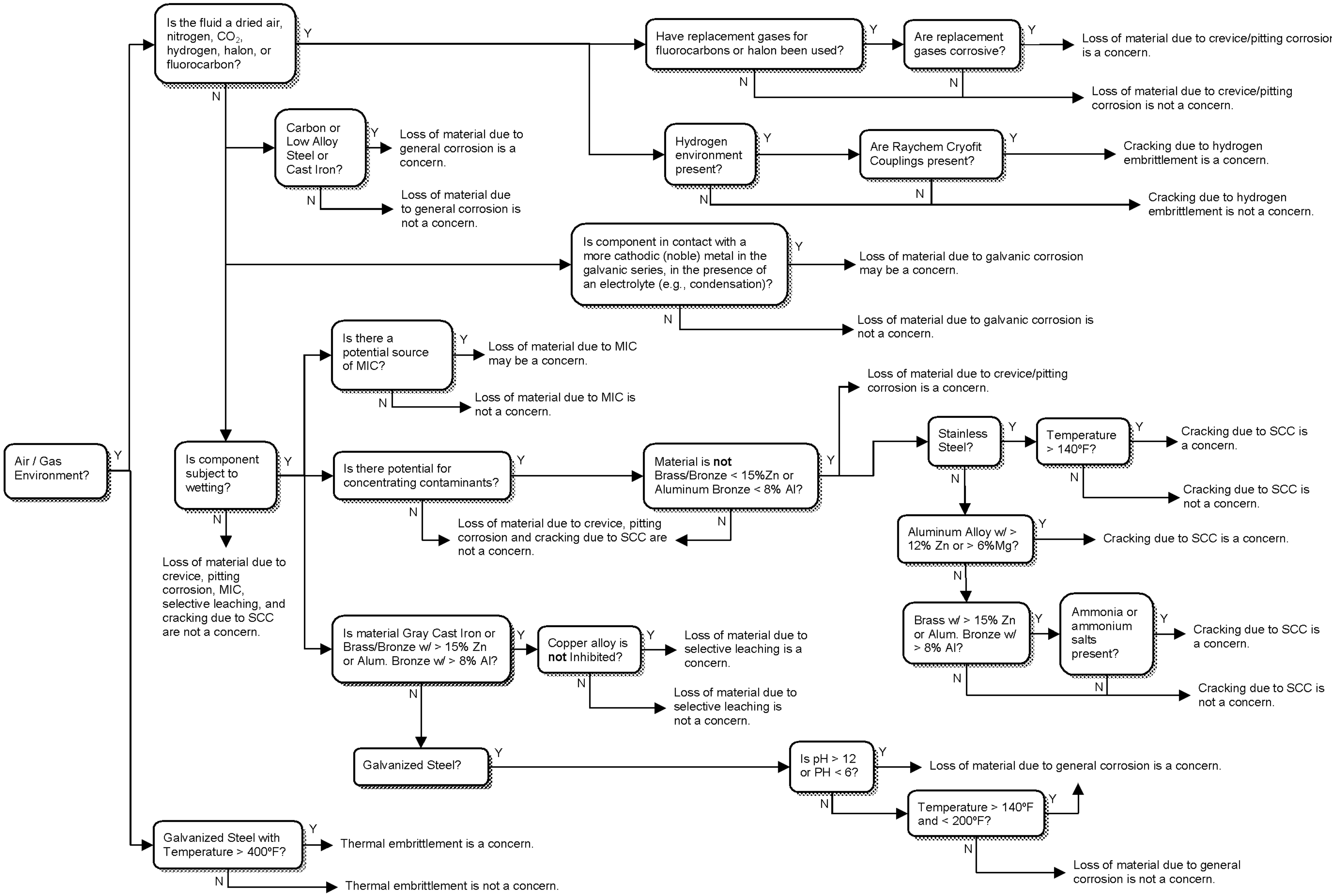
Table 4-1 Aging Effects Summary - Air/Gas					
Material	**Aging Effect / Mechanism**	**Mechanism Applicability Criteria**	**NUREG-1801 (GALL) Item No.**	**Tool vs GALL Match**	**Relevant Sections, Assumptions, and Discussion**
Galvanized Steel (Cont'd)	Reduction of Fracture Toughness / Thermal Embrittlement	1. Temperature > 400ºF	None	No	Sections 2.1.7, 3.3.1 GALL Chapters IV, V, VII, and VIII items do not address reduction (loss) of fracture toughness in air and gas environments.
Stainless Steel and CASS *and* Nickel-Base Alloys	Loss of Material / Pitting and Crevice Corrosion	1. Gas is not dried air, N_2, CO_2, H_2, halon, or fluorocarbons *and* 2. Component subject to wetted environment *and* 3. A potential for concentrating contaminants exists	V.D2-35, V.A-26, V.D1-29 VII.D-4, VII.F1-1, VII.F2-1, VII.F3-1, VII.H2-2	Yes	Sections 2.1.1, 2.1.2, 3.1.3, 3.1.4 Assumptions 4.1.1, 4.1.3, 4.1.6, 4.1.7 Specified GALL items cite pitting and crevice corrosion for stainless steel when exposed to internal condensation (wetting). GALL item VII.H2-2 cites pitting and crevice corrosion of stainless steel exposed to diesel exhaust with no indication of whether wetting is involved.
	Loss of Material / MIC	1. Gas is not dried air, N_2, CO_2, H_2, halon, or fluorocarbons *and* 2. Component subject to wetted environment *and* 3. Potential source of MIC	V.D2-35, V.A-26, V.D1-29 VII.D-4, VII.F1-1, VII.F2-1, VII.F3-1, VII.H2-2	No	Sections 2.1.1, 2.1.2, 3.1.6 Assumption 4.1.8 GALL Chapters IV, V, VII, and VIII do not include items for MIC of SS or nickel-base alloys in air or internal condensation environments. As per above, specified items only cite pitting and crevice corrosion in wetted (i.e., condensation) environments and diesel exhaust.

OAGI0000553_00292

Table 4-1 Aging Effects Summary - Air/Gas					
Material	**Aging Effect / Mechanism**	**Mechanism Applicability Criteria**	**NUREG-1801 (GALL) Item No.**	**Tool vs GALL Match**	**Relevant Sections, Assumptions, and Discussion**
Stainless Steel and CASS	Cracking / SCC	1. Gas is not dried air, N_2, CO_2, H_2, halon, or fluorocarbons *and* 2. Component subject to wetted environment *and* 3. A potential for concentrating contaminants exists *and* 4. Temperature > 140ºF	VII.H2-2	Yes	Sections 2.1.4, 3.2.2 Assumptions 4.1.4, 4.1.6, 4.1.7 Specified GALL item lists SCC of stainless steel exposed to diesel exhaust (where a concentration of contaminants is possible, as are periodic temperatures above 140ºF).

OAGI0000553_00293

Figure 1 Air/Gas Tool



OAGI0000553_00294

5. REFERENCES

1. *Metals Handbook,* Desk Edition, American Society for Metals, 1985.

2. G. Robison, E. Grubbs, M. Rinckel, and R. Starkey, "Demonstration of the Management of Aging Effects for the Reactor Coolant System Piping," BAW-2243A, Framatome ANP, Lynchburg, VA, June 1996.

3. J. F. Copeland, et al., "Component Life Estimation: LWR Structural Materials Degradation Mechanisms," EPRI NP-5461, Electric Power Research Institute, Palo Alto, CA, September 1987.

4. H. H. Uhlig, Ph.D., ed., *Corrosion Handbook,* John Wiley & Sons, Ninth Printing, May 1948.

5. M. G. Fontana, *Corrosion Engineering,* Third Edition, McGraw-Hill, Inc., Copyright 1986.

6. J. F. Copeland, et. al., "Component Life Estimation: LWR Structural Materials Degradation Mechanisms," EPRI NP-5461, Project 2643-5 Interim Report, September 1987.

7. Sandia National Laboratories, "Aging Management Guideline for Commercial Nuclear Power Plants - Heat Exchangers," Contractor Report No. SAND93-7070; UC-523, June 1994.

8. W. H. Ailor, *Atmospheric Corrosion,* McGraw-Hill, New York, 1986.

9. D. J. DePaul, ed., *Corrosion and Wear Handbook for Water Cooled Reactors,* McGraw-Hill, New York, 1957.

10. Sandia National Laboratories, "Aging Management Guideline for Commercial Nuclear Power Plants - Tanks and Pools," Contractor Report No. SAND96-0343; UC-523, 1996.

11. R. Nickell, M. A. Rinckel, "Evaluation of Thermal Aging Embrittlement for Cast Austenitic Stainless Steel Components," TR-106092, Research Project 2643-33, Final Report, March 1996.

12. BWNT Chemical Cleaning - N_2 Procurement Specification, Document No. 51-1203933-04, BWNT[1], Lynchburg, VA, December 1993.

13. R. H. Jones, *Stress Corrosion Cracking,* American Society of Metals, Materials Park, OH, 1992.

14. *Handbook of Compressed Gases,* Compressed Gas Association, Inc., Copyright 1966, published by Van Nostrand Reinhold Company.

15. *Handbook of Air Conditioning System Design,* by Carrier Air Conditioning Company, Copyright 1965, published by McGraw-Hill Book Company.

---

[1] Available from Framatome ANP, Lynchburg, VA.

OAGI0000553_00295

16. EPRI TR-103515-R1, *BWR Water Chemistry Guidelines-1996 Revision,* EPRI Project 2493, Project Manager C. J. Wood, Final Report, December 1996.

17. Landes and D. E. McCabe, “Toughness of Austenitic Stainless Steel Pipe Welds,” Report No. EPRI NP-4768, Westinghouse Electric Corporation, Pittsburgh, Pennsylvania, October 1986.

18. NUREG 1801, Vol. 1, Revision 1, “Generic Aging Lessons Learned (GALL) Report – Tabulation of Results,” U.S. Nuclear Regulatory Commission, September 2005.

19. “Aging Effects for Structures and Structural Components (Structural Tools) Revision 1,” EPRI 1002950, July 2003.

20. “BWR Containments License Renewal Industry Report,” Revision 1, EPRI TR-103840, July 1994.

21. Roff, W. J., *Fibres, Plastics, and Rubbers A Handbook of Common Polymers,* Academic Press Inc., New York, 1956.

22. *Engineered Materials Handbook: Engineering Plastics,* American Society for Metals (ASM) International, Copyright 1988.

23. *Metals Handbook,* Ninth Edition, Volume 13, “Corrosion,” American Society of Metals (ASM) International, Copyright 1987.

24. M.G. Fontana and R.W. Staehle, “Advances in Corrosion Science and Technology - Volume 5,” Plenum Press, Copyright 1976.

25. Engineered Materials Handbook (Desk Edition), “Design and Engineering Properties of Glasses,” American Society of Metals, International, Copyright 2002.

26. Engineered Materials Handbook (Desk Edition), “Introduction to Engineering Plastics – Environmental Factors,” American Society of Metals, International, Copyright 2002.

27. *Metals Handbook,* Ninth Edition, Volume 11, “Failure Analysis and Prevention,” Article – Effect of the Environment on the Performance of Plastics, ASM International, Copyright 2003.

28. P.A. Schweitzer, “Corrosion Resistance Tables – Metals, Nonmetals, Coatings, Mortars, Plastics, Elastomers and Linings, and Fabrics,” Fourth Edition, Parts A, B and C, Marcel Dekker, Copyright 1995.

29. F.L. LaQue and H.R. Cupson, “Corrosion Resistance of Metals and Alloys,” Rhinehold Publishing Company, New York, 2nd Edition, Copyright 1963.

Appendix E - External Surfaces

The External Surfaces Tool provides a method for identifying the aging effects on external surfaces of mechanical components manufactured from carbon and low-alloy steel, cast iron, copper and copper alloys (brass, bronze, and copper-nickel alloys), nickel-base alloys, stainless steel, and titanium and titanium alloys, as well as from aluminum and aluminum alloys, galvanized steel, and non-metals (e.g., glass, plastics, elastomers) and insulation. The other Mechanical Tools focus on a specific material and a particular environment (e.g., stainless steel in a treated water environment). For the other tools, the environment analyzed was for the internal fluid. The bases and supporting documentation for the external surfaces of carbon and low-alloy steel, cast iron, copper and copper alloys (brass, bronze, copper-nickel alloy), nickel-base alloys, stainless steel, titanium and titanium alloys, aluminum and aluminum alloys, and galvanized steel components are discussed and developed in this appendix.

CONTENTS

Page

1. INTRODUCTION 1-1

2. MATERIAL AND ENVIRONMENT 2-1

2.1 Materials 2-1

2.1.1 Stainless Steels 2-1

2.1.2 Nickel-Base Alloys 2-2

2.1.3 Carbon Steel and Low-Alloy Steel 2-2

2.1.4 Cast Iron 2-2

2.1.5 Copper and Copper Alloys (Brass, Bronze, and Copper-Nickel) 2-4

2.1.6 Aluminum and Aluminum Alloys 2-4

2.1.7 Titanium and Titanium Alloys 2-4

2.1.8 Galvanized Steel 2-5

2.1.9 Non-Metals 2-5

2.2 Environments 2-7

2.2.1 Indoor (Protected from Weather) 2-7

2.2.2 Outdoor (Exposed to Weather) 2-7

2.2.3 Buried (Underground/Below Grade) 2-8

2.2.4 Embedded 2-8

2.2.5 Submerged 2-8

3. AGING EFFECTS 3-1

3.1 Loss of Material 3-1

3.1.1 General Corrosion 3-1

3.1.2 Galvanic Corrosion 3-4

3.1.3 Crevice Corrosion 3-5

3.1.4 Pitting Corrosion 3-6

3.1.5 Erosion 3-7

3.1.6 Microbiologically Influenced Corrosion (MIC) 3-7

3.1.7 Wear and Fretting 3-7

3.1.8 Macroorganisms 3-8

3.1.9 Selective Leaching 3-8

3.1.10 Boric Acid Wastage 3-9

3.2 Cracking 3-9

3.2.1 Hydrogen Damage 3-9

3.2.2 Stress Corrosion Cracking/Intergranular Attack 3-11

3.2.3 Mechanical/Thermal Fatigue 3-12

3.3 Reduction of Fracture Toughness 3-13

3.3.1 Thermal Aging 3-13

3.3.2 Radiation Embrittlement 3-13

OAGI0000553_00298

3.4 Distortion 3-13
3.5 Galvanized Steel 3-13
3.6 Non-Metals and Insulation 3-14
3.6.1 Glasses 3-14
3.6.2 Plastics 3-15
3.6.3 Elastomers 3-16
3.6.4 Insulation 3-16
3.7 Summary of Potential Aging Effects 3-18
3.8 Applicable NRC Generic Correspondence 3-19

4. FLOW DIAGRAM / SUMMARY TABLE DEVELOPMENT 4-1
4.1 Assumptions 4-1
4.2 Overview 4-2
4.3 Tool Description 4-3
4.4 GALL Comparison 4-5

5. REFERENCES 5-1

LIST OF FIGURES

Page

Figure 1 External Surface Tool.. 4-19

LIST OF TABLES

Page

Table 4-1 Aging Effects Summary - External Surfaces 4-8

1. INTRODUCTION

The External Surfaces Tool provides a method to identify applicable aging effects on the external surfaces of non-Class 1 mechanical components. Appendices A through D evaluate aging effects for the internal fluid surfaces for specific materials and environments (e.g., stainless steel in a borated water environment). This external surface tool considers aging effects resulting from exposure to the diverse external environments. Since the other tools only analyze fluid environments, there is a need for a tool that addresses aging of external surfaces.

The External Surfaces Tool may be applied to all the Non-Class 1 mechanical components within the license renewal scope. This tool focuses on the external surfaces of mechanical fluid system components (piping, pumps, valves, fittings, etc.). However, these aging effects may be applied to similar material and environment combinations outside of non-mechanical system components, provided that all assumptions and considerations discussed herein are verified for the particular application.

Identified aging effects include loss of material, cracking, change in material properties (e.g., reduction of fracture toughness, distortion), and loss of mechanical closure integrity. Bolted closures are evaluated separately in Appendix F. In addition, cracking due to fatigue should be addressed using the Fatigue Tool in Appendix H.

The bases and supporting documentation for the aging effects on external surfaces of carbon steels, low-alloy steels, cast iron, stainless steels, nickel-base alloys, copper and copper alloys, and aluminum and aluminum alloys are provided in this appendix. Because galvanized steel is widely used in outdoor environments, a detailed discussion of specific aging effects for galvanized steel is also included both in the discussions and in the tool logic. For completeness, titanium and titanium alloys are also included since these materials have found increased usage in nuclear plant service. Aging effects for the external surfaces of non-metals, such as glass, plastics, and elastomers, are also described for completeness, since these materials are addressed in the other appendices.

Thermal insulation is installed on mechanical fluid system components in many nuclear plant systems as a barrier to conserve energy, control heat transfer, control temperature, retard freezing, provide personnel protection, and/or as a fire barrier [26]. These insulating functions are not typically credited in nuclear plant safety analyses or for compliance with a regulated event such as station blackout (SBO), except for fire barriers, wraps and stops, and in cases where insulation is credited in a plant's design basis (e.g., instances where insulating characteristics are a necessary factor in room heat load determinations). Therefore, except for fire barriers/wraps/stops and in plant-specific cases where credited with a design basis insulating function, insulation is typically not required to support any intended function of the mechanical system components to which it is attached. This tool conservatively includes a discussion on the potential effects of aging on typical insulating materials since degradation could possibly have an adverse impact on the underlying metals or on design-basis insulating functions, or could cause the insulation to become loose and interfere with other intended functions.

2. MATERIAL AND ENVIRONMENT

This External Surfaces Tool provides the logic and considerations to identify the applicable aging effects on external surfaces for non-Class 1 mechanical components. The tool may also be applied to the internal surfaces of non-Class 1 mechanical components in ambient air environments, such as ventilation systems, as a complement or supplement for Appendix D. The materials addressed in this tool are discussed in Section 2.1 and the environments are described in Section 2.2.

2.1 Materials

The materials addressed in this tool include (1) wrought and cast stainless steels, including weld metals, (2) nickel-base alloys, including nickel-base alloy weld metal, (3) carbon steels and low-alloy steels, (4) aluminum and aluminum alloys, (5) cast iron, (6) copper and copper alloys (brass, bronze, and copper-nickel), (7) galvanized steel, and (8) non-metals such as glass, plastics, and elastomers.

2.1.1 Stainless Steels

The stainless steels discussed in this tool are divided into the following categories: (1) wrought stainless steels, (2) cast stainless steels, and (3) weld metals. Each is discussed below.

Wrought Stainless Steels

Wrought stainless steels are commonly divided into five groups: (1) austenitic, (2) ferritic, (3) martensitic, (4) precipitation hardening, and (5) duplex stainless steels. Definitions of the aforementioned groups of stainless steels are provided in Reference 11 and are not repeated here. Martensitic and precipitation hardening stainless steels are typically used for bolting and are not addressed in this tool. Bolted closures are addressed in Appendix F.

Cast Stainless Steels

The cast stainless steels addressed in the External Surfaces Tool all contain ferrite in an austenitic matrix (i.e., CF series) and are commonly known as cast austenitic stainless steel (CASS). Typical alloys used in nuclear applications include CF-8 (and CF-8A) and CF-8M which are cast counterparts of wrought Types 304 and 316, respectively. Other castings include CF-3 and CF-3M which are cast counterparts of Types 304L and 316L, respectively. Alloys CF-3M and CF-8M are modifications of CF-3 and CF-8 containing 2% to 3% molybdenum and slightly higher nickel content to enhance resistance to corrosion and pitting. CF-8A is a modification to CF-8 in that a controlled amount of ferrite imparts higher tensile properties.

Stainless Steel Weld Metal

The welding materials used to join stainless steels depend upon the type of material being joined. For example, Type 304 wrought austenitic stainless steels may be joined using either gas metal-arc welding (GMAW), submerged-arc welding (SAW), or shielded metal-arc welding (SMAW) processes with a Type 308 electrode or welding rod. The various welding processes used to join wrought stainless steels include SMAW, SAW, GMAW, gas tungsten-arc welding (GTAW), and plasma-arc welding (PAW). Flux core arc welding (FCAW) may have been used but to a lesser

OAGI0000553_00303

extent. Stainless steel welding processes typically used include SMAW, GTAW, GMAW, and electroslag [11]. The weld metal is assumed to be equivalent to the wrought austenitic stainless steels with respect to the discussions of loss of material and resistance to cracking (initiation) in Section 3.0. Higher strength of the weld metal results in enhanced load bearing capacity compared to base metal; lower toughness of the weld metal may result in a reduced ability to support structural loads if the weld metal cracks. The strength and toughness of non-flux welds, such as GMAW and GTAW, were shown to be similar to the surrounding base metal.

2.1.2 Nickel-Base Alloys

The nickel-base alloys that are typically used for nuclear applications include nickel-chromium-iron alloys such as Alloy 600 and Alloy 690. These materials are used primarily for their oxidation resistance and strength at elevated temperatures. The applications are typically restricted to the reactor coolant system (e.g., reactor vessel CRDM nozzles), but may also be found in selected non-Class 1 components such as the core flood tanks. In addition, Alloy 600 may also be used in fasteners, which are discussed in Appendix F.

Welding of nickel-chromium-iron alloys is typically performed using arc-welding processes such as GTAW, SMAW, and GMAW [11]. Submerged arc welding may also be used provided the welding flux is carefully selected. Alloy 82 and Alloy 182 are typical filler metals used to join Alloy 600 components to carbon or alloy steel vessels in the reactor coolant system. In addition, Alloy 52 and Alloy 152 are typical filler metals used to join Alloy 690 components to carbon or alloy steel vessels in the reactor coolant system.

2.1.3 Carbon Steel and Low-Alloy Steel

Carbon steel is used throughout nuclear plants in various applications. It is used where high corrosive resistance is not required and is the material of choice for pumps, valves, tanks, and fittings in most plant water, air, and gas systems. The term carbon steel as used in the aging evaluation applies to all carbon and low-alloy steels.

2.1.4 Cast Iron

The term cast iron identifies a large family of ferrous alloys. Cast iron typically contains more than 2% carbon and from 1 to 3% silicon. The four basic types of cast iron are (1) white iron, (2) gray iron, (3) ductile iron, and (4) malleable iron. White cast irons have high compressive strength and good retention of strength and hardness at elevated temperature, but they are most often used for their excellent resistance to wear and abrasion. Gray cast iron has several unique properties that are derived from the existence of flake graphite in the microstructure. Gray iron can be machined easily at hardnesses conducive to good wear resistance. It has outstanding properties for applications involving vibrational damping or moderate thermal shock. Ductile cast iron is similar to gray iron in composition, but during casting of ductile iron, magnesium and cerium are added to the molten iron to give the final product higher strength and ductility. Malleable iron has similar properties to ductile iron, however, it is more expensive to manufacture and is only used for thin section castings, and for parts requiring maximum machinability or where a high modulus of elasticity is required.

OAGI0000553_00304

This External Surfaces Tool evaluates only the more widely used white, gray, and ductile cast iron alloys. Although comprising three general categories, various alloying elements can be and are added to cast iron alloys to promote an array of hardness, corrosion resistance, heat resistance, and abrasion resistance properties [11].

White Cast Iron

This category of cast iron is so named because of the characteristically white fracture surfaces, which occur due to the lack of any graphite in their microstructures. Carbon is present in the form of carbides. These cast irons are hard, brittle, and have high compressive strength with good retention of strength and hardness at elevated temperatures. The hardness of this form of iron results in a high resistance to wear and abrasion; therefore, these irons are used primarily where there is a need for resistance to wear and abrasion [11].

Gray Cast Iron

This form of cast iron is the most common of the iron alloys in nuclear plants. It is most commonly found in raw water systems (particularly in fire suppression water systems). In these iron alloys, the carbon is above the solubility limit of austenite at the eutectic temperature [1]. During cooling and solidification, a substantial portion of the carbon content separates out of the liquid and forms flakes of graphite. This material is usually selected because of the relatively low cost and ease of machining and excellent resistance to wear [5]. Another attribute of this material is its ability to be cast in thin sections. Gray cast iron alloys also contain outstanding properties for applications involving vibrational damping or moderate thermal shock.

Ductile Cast Iron

Ductile cast iron is commonly known as nodular or spheroidal-graphite iron. It is similar to gray iron but with the addition of small amounts of magnesium and/or cerium added to the molten iron in a process called nodulizing. The resultant graphite grows as tiny spheres rather than the flakes in gray iron due to these additives. The major advantages that these ductile cast irons exhibit when compared to gray iron are a combination of high strength and ductility, which results from the graphite spheres [5, 11]. Nickel, chromium, and/or copper can be added to improve material strength and hardenability properties. Larger amounts of silicon, chromium, nickel, or copper can also be added for improved resistance to corrosion or for high-temperature applications [5]. Cement-lined ductile iron is typically used for buried piping that is exposed to raw water, as described in Appendix B.

Alloy Cast Irons

Various alloying elements can be added to cast iron to improve corrosion and abrasion resistance, heat resistance, and mechanical properties. However, these alloys are not widely used in the nuclear industry. The main advantage of using cast iron is the relatively low cost and abundance. When special material properties are required, it is likely that other materials would be used. A discussion of some of the most common cast iron alloys is included in Appendix A of this document, which provides insight for the occasional application that may be encountered during plant evaluations. These iron alloys are but a few of the many diverse iron alloys available. However, due to the specialized nature of the alloys, the availability and the cost, they have a very limited application at most plants.

OAGI0000553_00305

2.1.5 Copper and Copper Alloys (Brass, Bronze, and Copper-Nickel)

Bronze and brass are copper alloys using predominantly copper, tin, and zinc with various other alloying agents present in differing amounts. Brass is an alloy of copper and zinc with other metals in varying lesser amounts. Bronze is any of various alloys of copper and tin, sometimes with traces of other metals. Other copper alloys, most notably copper-nickel alloys, are used in other applications.

Brass and bronze products are available in both cast and wrought product forms with most alloy compositions available in both. Brasses and bronzes containing tin, lead, and/or zinc have only moderate tensile and yield strengths and high elongation. Aluminum bronzes, manganese bronzes, and silicon brasses/bronzes are used where higher strength alloys are required. Various alloys of brass and bronze are used in a number of applications including fire protection sprinkler systems, compressed air, and instrument air systems.

2.1.6 Aluminum and Aluminum Alloys

Aluminum and its alloys have limited use in nuclear plant applications. However, due to its high resistance to corrosion in atmospheric environments, in fresh and salt water, and in many chemicals and their solutions, it can be found in various applications. Typical applications of aluminum at nuclear plants are in various instruments in gas and fluid systems. Aluminum and aluminum alloys may also have limited use as ductwork in air supply systems. Aluminum and aluminum alloys can also be used in the housings of fans and heaters.

2.1.7 Titanium and Titanium Alloys

Titanium alloys were originally developed in the early 1950s for aerospace applications due to their high strength to density ratios. However, the excellent corrosion resistance properties of titanium, specifically in chloride containing fluids, have led to widespread use in industrial applications, including the nuclear industry. The corrosion resistance of titanium is a result of the formation of a continuous, stable, highly adherent protective oxide layer on the metal surface. The metal itself is very reactive, with a high affinity for oxygen, and reforms damage to this layer instantaneously [24].

The most commonly used grades of titanium in industrial applications include unalloyed titanium (ASTM grades 1-4) and alloys comprised of varying amounts of palladium, molybdenum, nickel, aluminum, and valladium (ATSM grades 7, 12, 9, and 5). Varying the alloy compositions gives slight differences in corrosion protection from one alloy to another, often at a higher cost. Within nuclear plants, titanium and titanium alloys are utilized in heat exchanger tubing and piping exposed to seawater, among other applications.

The oxide film on titanium and titanium alloys provides an effective barrier to attack by most gases in wet or dry conditions, including oxygen, nitrogen, NH_3 CO_2, CO, and H_2S. This protection extends to temperatures in excess of 300°F. The outstanding resistance of titanium and titanium alloys to rural, marine, and urban atmospheric exposure has been documented [24].

2.1.8 Galvanized Steel

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 iron and steel by one of three processes: hot dip galvanizing, electro-galvanizing, or zinc spraying. A majority of the galvanized steel sheet metal is produced by the hot dip process [11, p. 4-26]. The hot dip process is one in which 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. This produces a gradual transition through the coating with no discrete line of demarcation.

Galvanized steel is used where corrosion resistance in an atmospheric environment is required. The relatively low production cost and appearance make galvanized steel an ideal choice for ducts and associated ventilation components [11, pp. 4-26, 4-94]. Galvanized carbon steel is widely used, and because of its potential impact (under certain conditions) on the base material, is addressed separately in Section 3.5.

2.1.9 Non-Metals

Glasses

Glass is an amorphous, inorganic oxide, mostly silica, cooled to a rigid condition without crystallization. Hydrofluoric acid and caustic attack glass, and it shows a slight attack in hot water. There are a wide variety of glass compositions with modifiers, fluxes, and stabilizers added to obtain various properties, including corrosion resistance [5]. No definitive instances of glass failure due to an aging effect have been recorded in industry operating experience searches. Also, the external surfaces of glass components are not exposed to hydrofluoric acids or caustics or hot water.

Plastics

Non-metallic materials such as plastics are also used where temperatures, pressures, and stresses are not limiting and in media (such as aqueous chloride solutions) which cause localized corrosion in metals and alloys. While plastics do not dissolve like metals, they do potentially degrade due to moisture absorption, loss in mechanical properties, hardening, and discoloration. When compared to metals and alloys, plastics are weaker, more resistant to chloride ions, less resistant to oxidizing acids, less resistant to solvents, and have much lower temperature limitations [5]. Polyvinyl chloride (PVC) is a thermoplastic material composed of polymers of vinyl chloride. Manufactured from sodium chloride (NaCl) and natural gas, PVC is relatively unaffected by water, concentrated alkalis, and non-oxidizing acids, oils, and ozone [30]. Polyvinylidene fluoride (PVDF) is a member of the fluorocarbon family of plastics and is a homopolymer of vinylidene fluoride. Extruded as pipe, it is rigid and resists abrasion, as well as being chemically resistant, especially to halogens. It is impervious to deionized water which can cause organic and inorganic particulates to leach from PVC. PVDF is highly corrosion resistant and can withstand years of in-ground exposure to moisture and chemicals [30].

OAGI0000553_00307

Unlike metals, thermoplastics do not display corrosion rates. Rather than depending on an oxide layer for protection, they depend on chemical resistance to the environment to which they are exposed. The plastic is either completely resistant to the environment or it deteriorates. Therefore, acceptability for the use of thermoplastics within a given environment is a design driven criteria. Once the appropriate material is chosen, the system will have no aging effects.

Elastomers

Elastomers are defined as rubber or polymer that has properties similar to those of rubber. They are used in nuclear plants in various capacities, such as joint sealants, flexible connections, and moisture barriers. The outstanding characteristic of rubber and elastomers is resilience or low modulus of elasticity. Flexibility accounts for most applications. However, chemical and abrasion resistance, and good insulating qualities, result in many corrosion applications. Generally speaking, the natural rubbers have better mechanical properties than the synthetic or artificial rubbers (e.g., neoprene), but the synthetics have better corrosion resistance [5]. For example, natural rubbers are degraded by ozone and sunlight, whereas synthetic rubbers are not affected by ozone and are typically much more resistant to sunlight (or other forms of ultraviolet radiation) [5 and 25].

Insulation

The characteristics of thermal insulation are mainly determined by its composition. For that reason, the major types of insulation include fibrous, granular, cellular, and reflective. Inorganic fibers may be glass, rock wool, slag wool, alumina silica, asbestos, or carbon. Granular insulation is generally calcium silicate. Many mass insulations (e.g., fibrous, granular, or cellular types in rigid, semi-rigid, flexible, blanket/batt, cement, and mastic forms) are produced using two or more of the types listed above to obtain the desired properties. Reflective insulation systems are in most instances made of aluminum or stainless steel. Securements for insulation include wire, straps, etc. that are typically metal, depending on the chemical atmospheric conditions and the metal/location of the component to which it is affixed. Fasteners may be adhesives or stainless steel skewers, pins, and/or clips. A galvanized wire netting or expanded metal lath may also be used as a reinforcement [26].

The types of insulation typically in use for nuclear power plant systems include fibrous (e.g., fiberglass, mechanically bonded glass fiber blanket), granular/cellular (e.g., calcium silicate or asbestos), and reflective (e.g., MIRROR). Kaowool brand and other fire wrap/stop insulation materials are also used as fire barriers in nuclear plant service. Glass fiber for insulation is usually a pure glass fiber with various types of binders that will absorb and wick water and has a maximum service temperature of 450ºF. Calcium silicate is a cementitious mixture that readily absorbs and wicks water, with a maximum service temperature of 1200ºF [24]. Reflective insulation is constructed of layers of aluminum or stainless steel panels with air between.

OAGI0000553_00308

2.2 Environments

The external surfaces of non-Class 1 mechanical system components are exposed to environmental conditions during normal plant operation that may be divided into the following general categories:

1. Indoor (protected from weather)
2. Outdoor (exposed to weather)
3. Buried (underground/below grade)
4. Embedded (encased in concrete)
5. Submerged (also in a “splash zone” or continuously wetted)

2.2.1 Indoor (Protected from Weather)

Indoor environments are protected from weather but may include ambient temperatures up to 150°F and various levels of relative humidity (up to 100 percent), depending on whether the atmosphere in a particular building/facility/structure is controlled (air-conditioned). Components inside buildings and facilities can be exposed to some amount of moisture based on relative humidity and to wetted locations (e.g., due to leakage, condensation, etc.), as well as to some neutron and gamma radiation.

The external surfaces of components in systems with lower than ambient internal fluid temperatures (e.g., Chilled Water, Service Water, etc.) are expected to be intermittently or frequently wetted due to condensation, whereas components in high temperature systems (e.g., Main Steam, Feedwater, etc.) are expected to have external surface temperatures > 212°F which precludes moisture accumulation. Components in indoor locations may also be exposed to alternate wetting and drying due to leakage from plant fluid systems (e.g., boric acid from PWR borated water systems) that could result in a concentration of contaminants in wetted locations.

Components located indoors may also temporarily be in contact with aggressive chemicals resulting from accidental spills. However, the aging effects that could result from this temporary exposure are considered rare and event driven and as such are not considered a normal condition of the environment that requires evaluation. In addition, spills are normally addressed in a expedited manner such that aging effects would not occur.

2.2.2 Outdoor (Exposed to Weather)

Components located outdoors are exposed to atmospheric conditions and weather with temperatures generally ranging from -15°F to 115°F, relative humidity up to 100 percent, and negligible radiation levels. Furthermore, outdoor environments may be classified as industrial, marine (seashore), or rural and may contain airborne contaminants (corrosive chemicals) such as halides, sulfates, ozone, and other aggressive substances (e.g., acid rain, sulfur dioxide, chlorine gases, sulfur gases in areas near major industrial plants, pesticides, dust or other crop treatments in rural areas) that can influence the nature, rate, and severity of corrosion.

Depending on the specific equipment location and operating conditions, frequent wetting or alternate wetting and drying can occur. Outdoor equipment is typically exposed to alternate wetting and drying that can concentrate contaminants. For example, salt water (i.e., sea or brackish water spray or where it is used as a deicing agent) is slightly alkaline and a good electrolyte with a high chloride content. Thus, salt air can aggressively attack most steels and metal alloys in applicable locations.

Components located in trenches are considered to be exposed to an outdoor (exposed to weather) environment even though located below grade, for the purposes of this tool (e.g., aging effect identification).

2.2.3 Buried (Underground/Below Grade)

Natural soils have variable characteristics and properties including moisture, pH (alkalinity or acidity), permeability of water and air (compactness or texture), oxygen, salts, stray currents, and biological organisms that can affect the electrical resistance of the soil. Depending on the particular site groundwater table levels, buried components may also be exposed to chemicals in the groundwater. The groundwater chemistry may be acidic or contain chlorides and sulfates that can play a major role in the determination of the degradation of below-grade components.

2.2.4 Embedded

Non-Class 1 mechanical piping components may be routed through concrete floors, slabs, or walls. The external surfaces of these components are firmly encased in the concrete of the floor, slab, or wall. Similar to structural reinforcing steel [25], the external surfaces of such piping components are embedded and the impact of a concrete environment on aging effects must be addressed. For non-Class 1 mechanical piping components that simply pass through a concrete floor or wall (e.g., from one room or elevation to another), the indoor environment, described in Section 2.2.1, is the more limiting environment and impact of concrete on aging effects need not be addressed.

2.2.5 Submerged

Some of the external surfaces under consideration will be subjected to a completely submerged environment. These conditions are commonplace in intake structures and piping entering the plant from the raw water sources or in treated water pools (e.g., BWR suppression chambers). Although not completely submerged, some equipment is located in what is called a “splash zone.” This location is typically adjacent to a raw water source such as a lake or ocean where either a continuous wetting or “splashing” of a component due to wind, surf, waves, etc. provides an environment not unlike that of a fully submerged component. Piping and supports within the torus of older BWRs also fall into “splash zones.” The environment for submerged or continuously wetted equipment is considered to be a raw or treated water environment for the purposes of this tool.

3. AGING EFFECTS

This document addresses the aging effects resulting from a variety of aging mechanisms. Where specific mechanisms are not applicable under the environmental and material conditions covered by the tool, reasoning is provided for a "not applicable" determination. For those mechanisms that are applicable for the equipment covered by this tool, a discussion of the conditions necessary for the mechanism is included. Many degradation mechanisms are covered in this tool. However, the aging effects resulting from these mechanisms in indoor, outdoor, and buried environments can be included in four categories: 1) loss of material, 2) cracking, 3) reduction of fracture toughness, and 4) distortion. These categories are addressed in the following subsections.

For the identification of applicable aging effects of submerged, "in a splash zone," or continuously wetted components, the user should use the Treated Water Tool (Appendix A) or Raw Water Tool (Appendix B) of this report as appropriate.

The high alkalinity of concrete (pH > 12.5) provides an environment that protects embedded steel from corrosion/degradation. However, when the pH is reduced (pH < 11.5) by the intrusion of aggressive ions (e.g., chlorides > 500 ppm), corrosion can occur. A reduced pH could be caused by leaching of alkaline products through cracks, entry of acidic materials, carbonation, contaminated concrete mix, or moisture intrusion [1, 15]. However, good design and construction practices are sufficient to preclude embedded steel corrosion. Therefore, corrosion/degradation of embedded metals is not an applicable aging effect. The user of this tool is referred to EPRI report 1002950, *Aging Effects for Structures and Structural Components (Structural Tools), Revision 1* [25] for additional evaluation of the effects of aging on the concrete which may protect embedded metals.

3.1 Loss of Material

Aging mechanisms that may lead to loss of material on external surfaces include general (atmospheric) corrosion, galvanic corrosion, crevice corrosion, pitting corrosion, erosion, microbiologically influenced corrosion (MIC), wear and fretting, macroorganisms (biofouling), selective leaching, and boric acid wastage (PWRs). Loss of material may be visually observed as material dissolution, corrosion product build-up, and pitting. Loss of material may be uniform or localized.

3.1.1 General Corrosion

General corrosion is the result of a chemical or electrochemical reaction between a material and an aggressive environment. General corrosion is normally characterized by uniform attack resulting in material dissolution and sometimes corrosion product buildup [2]. At ordinary temperatures and in neutral or near neutral media, oxygen and moisture are the primary factors for the corrosion of iron [3]. Generally, when humidity exceeds 70 percent, an invisible film of moisture forms on the surface of metal, providing an electrolyte. 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 [24].

OAGI0000553_00311

A significant effort has been expended by corrosion researchers to understand the factors that influence outdoor marine and urban atmospheric corrosion. Relative humidity, temperature, sulfur dioxide, and chloride concentrations are among the more important variables. Outdoor atmospheric parameters can be significantly altered inside buildings and the work by Ailor [6] and others assume the indoor level of pollutants is a certain percentage of the outdoor level. Tests show that metals do corrode indoors; however, the corrosion rate increases rapidly when exposed to an outdoor environment.

Outdoor atmospheres can be classified as industrial, marine, or rural for the purposes of this tool. Corrosion is caused by moisture and oxygen but is accelerated by contaminants such as sulfur compounds and sodium chloride. For example, corrosion of carbon steel on the seacoast is 400 to 500 times greater than in the desert area. Steel specimens 80 feet from the shoreline corroded 12 times faster than those 800 feet away. Sodium chloride is the primary contaminant of concern. Industrial atmospheres can be 50 to 100 times more corrosive than desert areas [6]. Also, locations where moisture condenses or accumulates (i.e., wetting) and does not dry out for long periods of time can cause damage sometimes referred to as sheltered corrosion [6]. For the purposes of this logic tool, the rate of general corrosion will not be evaluated. However, based on plant-specific conditions, corrosion rates may be low enough that loss of material due to corrosion is not an applicable aging effect. Because atmospheric corrosion is an electrolytic process and a very thin film of water (such as due to humidity) is all that is required [24] and high humidity is common to interior and exterior plant environments, general corrosion is considered to be an applicable aging effect for susceptible materials in indoor and outdoor environments unless the surface temperature would preclude moisture accumulation (>212°F).

Carbon steel and cast iron, with and without organic coatings and cathodic protection, are most common for underground components [5], although other materials (such as stainless steels, copper and copper alloys, and aluminum and aluminum alloys) may also be used. Generally poor aeration and high values of acidity, electrical conductivity, salt content, and moisture content are characteristics of corrosive soils. Well aerated soils, especially those derived from limestone, usually are not corrosive. High-resistance soils are generally not very corrosive unless they are poorly aerated [3].

Stainless Steel

The austenitic Cr-Ni steels of the 18-8 type (18%Cr, 8%Ni) are resistant to corrosion in atmospheric conditions both for interior and exterior exposures and under conditions of high or low humidity, as well as when buried. Approximate compositions of Type 304 and Type 316 stainless steel [11] are shown below.

	%C	%Mn	%Si	%Cr	%Ni	%Mo
Type 304	0.08	2.0	1.0	18-20	8-10.5	....
Type 316	0.08	2.0	1.0	16-18	10-14	2-3.0

There is much test data on atmospheric corrosion of stainless steel reported in Reference 6. Most of this data shows that about 12% chromium for industrial and rural areas and about 15% chromium for marine atmospheres is sufficient to prevent significant corrosion. As identified above, both 304 and

316 stainless steels contain chromium at levels sufficient to provide resistance to corrosion in both industrial and marine environments. Type 316 is more resistant than type 304 to general corrosion and pitting, due to the higher nickel and molybdenum content [6].

Nickel-Base Alloys

Nickel-base alloys have very good resistance to atmospheric corrosion. Nickel 200 will become dull and acquire a thin adherent film. A greater tarnish will result in industrial sulfur-containing atmospheres than in rural or marine atmospheres. Corrosion of Alloy 400 is negligible in all types of atmospheres, although a thin gray-green patina will develop. Nickel alloys containing chromium and iron (e.g., Alloys 600 and 800) also have very good atmospheric corrosion resistance, but may develop a slight tarnish after prolonged exposure, especially in industrial atmospheres [25]. As such, general corrosion of the external surfaces of nickel-base alloys is not an applicable aging mechanism in indoor or outdoor environments.

Carbon Steel, Low-Alloy Steel, and Cast Iron

Carbon steel, as well as low-alloy steel and cast iron are susceptible to general corrosion in the presence of oxygen and moisture (e.g., from humidity) [5] in both indoor and outdoor environments although it is expected to be more prevalent in intermittently and frequently wetted locations.

For the purposes of this logic tool, buried carbon steel and cast iron components are considered to be susceptible to corrosion because of the potential for oxygen levels, moisture content, biological organisms, and contaminants. Multi-layered coatings and cathodic protection programs may be evaluated and credited on a plant-specific basis to manage or prevent the effects of corrosion, as described in Section 4.0 of the main document.

Copper and Copper Alloys

Copper alloys are used when resistance to general corrosion is required. These copper metals are used in atmospheric, fresh, and salt water in place of other more susceptible metals such as carbon steel or cast iron [33]. General corrosion of copper and copper alloys results from prolonged contact with environments in which the corrosion rate is very low. Other substances that cause uniform thinning at a faster rate include oxidizing acids, sulfur-bearing compounds, NH3, and cyanides. Copper corrodes at negligible rates in unpolluted air, water, and deaerated non-oxidizing acids [24]. Copper exhibits good resistance to urban, marine, and industrial atmospheres. Copper alloys are resistant to neutral and slightly alkaline solutions with the exception of those containing ammonia, which causes stress corrosion (discussed separately) and sometimes rapid general attack [5]. A patina forms on copper and copper alloys from prolonged exposure, which gives the surface a weathered appearance. However, due to the protective film which forms on the surface of copper and copper alloys combined with the very low (negligible) corrosion rates in urban, marine, and industrial atmospheres, general corrosion is not considered an aging mechanism for copper and copper alloys in indoor, outdoor, or buried environments.

An exception that requires plant-specific evaluation is the presence of ammonia in the outdoor environment (e.g., from organic decay), in which case the general attack of copper and copper alloys may be rapid and result in a loss of function.

OAGI0000553_00313

Aluminum and Aluminum Alloys

Most aluminum alloys have excellent resistance to general (atmospheric) corrosion, often called weathering, and in many outdoor applications such alloys do not require shelter, protective coatings, or maintenance. Corrosion by weathering of most aluminum alloys is restricted to mild surface roughening by shallow pitting, with no general thinning. Such attack is more severe for alloys with high copper contents, which are seldom used in outdoor applications without protection [24]. In most indoor atmospheres where pools of contaminated water do not remain in prolonged contact with aluminum alloys, or where extended contact with moist, porous materials is avoided, corrosion is not a concern. In particular, aluminum alloys are highly resistant to warm, humid conditions where there is appreciable moisture condensation so long as contact with porous materials is avoided [3]. Also, experience has shown that soils, at least to the depth normally used to bury pipelines (and other components), are non-corrosive to aluminum and aluminum alloys over large areas of North America [24]. Therefore, loss of material due to general corrosion is not an applicable aging effect for aluminum and aluminum alloys in indoor, outdoor, or buried environments.

Titanium and Titanium Alloys

The excellent corrosion resistance of titanium metals results from the formation of very stable, continuous, highly adherent, and protective oxide films on metal surfaces. Because titanium metal itself is highly reactive and has an extremely high affinity for oxygen, these beneficial surface oxide films form spontaneously and instantly when fresh metal surfaces are exposed to air and/or moisture. As such, general corrosion of titanium and titanium alloys is effectively inhibited by exposure to oxidizing species [24]. Therefore, general corrosion of titanium and titanium alloys is not an applicable aging mechanism in indoor, outdoor, or buried environments.

3.1.2 Galvanic Corrosion

Galvanic corrosion occurs when metals with different electrochemical potentials are in contact in the presence of a corrosive conducting environment (an electrolyte) [5]. Generally the effects of galvanic corrosion are precluded by design (e.g., isolation to prevent electrolytic connection or using similar materials). Carbon and low-alloy steels have lower potentials than stainless steels and would be preferentially attacked in a galvanic couple. The rate of galvanic corrosion is governed by the relative size of the anode to cathode in the presence of moisture and water. The material with the lower potential (active) in the galvanic series is the anode and it sacrifices to the cathode (noble). If the surface area of the anode is appreciably larger than the cathode, then the galvanic corrosion rate is slow. Conversely, if the surface area of the anode is much smaller than the cathode, then the galvanic corrosion rate can be very fast.

Galvanic corrosion can occur in the atmosphere, the severity of which depends largely on the type and amount of moisture present [3, 24]. Generally, when humidity exceeds 70 percent, an invisible film of moisture forms on the surface of metal, providing an electrolyte. The ratio between humidity and temperature determines the thickness of the film. In indoor and certain outdoor environments, the thinness and low conductivity of the electrolyte film limit galvanic effects [24]. A saltwater environment is more corrosive than a rural atmosphere; therefore, galvanic corrosion will be greater near the seashore than in a dry rural area [3]. For plants whose operating experience has shown exposure to an aggressive species such as salt air in marine (seashore) areas or sulfur dioxide, etc. in industrial areas, the conductivity of the normal atmosphere (humidity, rain, etc.) is increased and

OAGI0000553_00314

galvanic corrosion may be an applicable aging effect. Frequent or prolonged wetting, such as from condensation or groundwater, also provide an electrolyte with sufficient conductivity for galvanic corrosion to occur.

When connected to more cathodic (noble) materials, carbon and low-alloy steels, cast irons, and aluminum and aluminum alloys are anodic (active) and susceptible to galvanic corrosion in wetted locations (e.g., condensation) of indoor and outdoor environments, in a buried environment, or in an outdoor environment where plant operating experience shows aggressive species (e.g., in seashore or industrial areas).

Copper and copper alloys are in the middle of the galvanic series and are cathodic (noble) to carbon steel, low-alloy steel, cast iron, or aluminum and aluminum alloys but are anodic (active) to stainless steel, nickel-base alloys, and titanium and titanium alloys. When connected to more cathodic (noble) materials, copper and copper alloys are susceptible to galvanic corrosion in wetted locations (e.g., condensation) of indoor and outdoor environments, in a buried environment, or in an outdoor environment where plant operating experience shows aggressive species (e.g., in seashore or industrial areas).

Stainless steel and nickel-base alloys are more corrosion resistant and cathodic (noble) in galvanic couples and are, therefore, not susceptible to a loss of material because of galvanic corrosion.

The coupling of titanium and titanium alloys with dissimilar metals usually does not accelerate the corrosion of titanium. However, galvanic couples between titanium and certain active metals and excessive cathodic charging from impressed current cathodic protection systems are the usual causes of excessive hydrogen absorption. The effect of this excessive hydrogen absorption is discussed in Section 3.2.1 below.

3.1.3 Crevice Corrosion

Crevice corrosion is intense, localized corrosion within crevices or shielded areas in a component. It occurs most frequently in joints and connections, or points of contact between metals and nonmetals, such as gasket surfaces, lap joints, and under bolt heads and is normally associated with a stagnant or low flow solution (an electrolyte) [5]. Crevice corrosion is strongly dependent on the presence of dissolved oxygen. Although oxygen depletion in crevices may occur as a result of the corrosion process, oxygen is still required for the onset of corrosion, and bulk fluid oxygen content or the presence of contaminants such as chlorides is necessary for the continued dissolution of material in the crevice [7]. Any surface exposed to atmospheric conditions will be saturated in oxygen above the threshold levels for crevice corrosion to occur (0.1 ppm) [7].

Typically, atmospheric pollutants and contaminants, both indoors and outdoors, are insufficient to concentrate and thereby promote crevice corrosion. Crevice corrosion may also occur in severe marine atmospheres. In contrast to seawater immersion, however, the attack is quite minimal [24]. Alternate wetting and drying is particularly harmful as this leads to a concentration of atmospheric pollutants and contaminants. Indoors, crevice corrosion is a concern in locations of frequent or prolonged wetting, or of alternate wetting and drying. Outdoors, precipitation tends to wash a surface rather than concentrate contaminants and, as such, crevice corrosion may be a concern for only plants whose operating experience has shown surface exposure to an aggressive species (such as salt air, sulfur dioxide, and acid rain). Contaminants in groundwater are typically assumed to be aggressive and to promote crevice corrosion. As such, crevice corrosion is a concern in buried environments.

Carbon steels, low-alloy steels, cast irons, stainless steels, aluminum and aluminum alloys, and nickel-base alloys are all susceptible to crevice corrosion to some degree [3, 5]. This form of corrosion, as the name implies, requires a crevice where contaminants and corrosion products can concentrate. In addition to oxygen, moisture is required for the mechanism to operate [3, 5]. For most copper alloys, the location of crevice attack will be outside but immediately adjacent to the crevice due to the formation of metal ion concentration cells. Classic crevice corrosion resulting from oxygen depletion and attack within crevices is less common with copper alloys [24].

Titanium alloys generally exhibit superior resistance to crevice corrosion as compared to stainless steel and nickel-base alloys, but the susceptibility in hot chloride solutions increases significantly with increasing temperature and decreasing pH. Crevice attack will generally not occur below a temperature of 160ºF [24]. Therefore, crevice corrosion of titanium and titanium alloys is not an applicable aging mechanism except where temperatures are above 160ºF and plant operating experience has shown exposure to an aggressive environment (e.g., salt air, acid rain, or sulfur dioxide), such as in marine (seashore) and industrial areas.

In summary, crevice corrosion is a concern for carbon steel, low-alloy steel, stainless steel, aluminum and aluminum alloys, copper alloys, nickel-base alloys, and cast iron in wetted locations of indoor and outdoor environments, and in a buried environment; crevice corrosion may be a concern in outdoor environments when plant operating experience has shown an aggressive environment such as salt air, acid rain, or sulfur dioxide (e.g., in marine (seashore) or industrial areas). Crevice corrosion of titanium and titanium alloys is not a concern except in outdoor environments when the temperature is > 160ºF and plant operating experience has shown an aggressive environment such as salt air, acid rain, or sulfur dioxide (e.g., in marine (seashore) or industrial areas).

3.1.4 Pitting Corrosion

Pitting corrosion is a corrosion mechanism that is more common with passive materials such as austenitic stainless steels and aluminum and aluminum alloys than with non-passive materials; however, all materials of interest are susceptible to pitting corrosion under certain conditions. Unless cupric, ferric, or mercuric halides are present in the environment, oxygen is required for pitting initiation. Areas where aggressive species can concentrate are particularly susceptible to pitting. Most pitting is the result of halide contamination, with chlorides, bromides, and hypochlorites being prevalent [5]. On the exterior surfaces of the mechanical equipment addressed by this tool, pitting is a significant aging effect for carbon and low-alloy steels, cast irons, stainless steels, nickel-base alloys, and aluminum and aluminum alloys exposed to weather (outdoors) when plant operating experience has shown a corrosive (aggressive) ambient environment (such as salt air, acid rain, or sulfur dioxide) in marine (seashore) or industrial areas. While copper alloys are generally resistant to pitting corrosion, copper zinc alloys with greater than 15% zinc are susceptible. Aluminum bronze with greater than 8% Al is also susceptible to pitting in stagnant conditions. Pitting corrosion is not typically a concern for titanium and titanium alloys regardless of the media because of the protective oxide film and the corresponding anodic pitting potentials that are very high (> 1 V) [24].

Also, any wetted or alternately wetted and dried surfaces tend to concentrate aggressive species and are prone to pitting corrosion. Environments that are conducive to pitting include, but are not limited to 1) components exposed to frequent leakage or water pooling, 2) equipment located in the "splash" zone, 3) insulated equipment subject to sweating, 4) components where condensation is normal due to a lower than ambient internal fluid temperature, and 5) buried components, since groundwater is assumed to be aggressive.

3.1.5 Erosion

Erosion is the loss of material induced by flowing fluid. For external surfaces, this mechanism is only a concern for submerged equipment. Submerged equipment is addressed in the raw water and treated water tools (Appendix B and Appendix A of these Mechanical Tools), which consider the effects of erosion.

3.1.6 Microbiologically Influenced Corrosion (MIC)

Microbiologically influenced corrosion (MIC) is corrosive attack accelerated by microbiological activity. Although the bacteria can survive between -10 and 212^{o}F, this corrosion mechanism typically occurs at temperatures between 50 and 120^{o}F [12]. Microbiological organisms disrupt the protective oxide layer and produce corrosive substances and deposit solids that accelerate the electrolytic reactions of corrosive attack, generally in the form of pitting or crevice corrosion. This aging mechanism is facilitated by stagnant conditions, fouling, internal crevices, contact with untreated water, and contact with contaminated soils. Nearly all materials of interest can be affected. In austenitic stainless steels MIC is almost always confined to welds and weld heat affected zones (HAZ). MIC in carbon and low-alloy steels is usually not isolated to particular locations as in stainless steels [9, 10]. Any continuously or frequently wetted areas, including damp soils, should be considered potential MIC susceptible locations.

3.1.7 Wear and Fretting

Wear is the result of relative motion between components. Fretting is the loss of material which occurs as a result of relative motion between two materials. A repeated removal of the normal corrosion product surface film and subsequent development of a new film results in a process similar to flow-accelerated corrosion except under non-flowing conditions. Examples of fretting corrosion are repeated small displacements between piping and supports as a result of either thermal cycling or vibration. The result of wear or fretting is localized loss of material at the interface.

All materials addressed in this tool are susceptible to wear or fretting. However, in most instances during normal plant operations the relative displacements or movement between the external surfaces of components are small and the resulting loss of material minimal. Instances of significant wear or fretting are not related to normal aging and are expected to manifest well before the period of extended operation and be corrected. As such, it is expected that loss of material due to wear or fretting from normal plant operations is insufficient to result in loss of component function during the period of extended operation. Therefore, loss of material due to fretting is not an applicable aging effect for the external surfaces of non-Class 1 components. Loss of material due to wear is not an applicable aging effect for the external surfaces of non-Class 1 components, except for crane rails, doors, and elastomers. Crane rails and doors are passive non-Class 1 components that experience a higher amount of relative motion during normal plant operations and are addressed in the Structural Tools [25]. Elastomers are also addressed in the Structural Tools and in Section 3.6 below.

3.1.8 Macroorganisms

Aqueous macroorganisms such as barnacles, mussels, clams, and algae are applicable only to submerged equipment or other components located in the "splash zone" of a raw water source. All such equipment should be evaluated using the raw water tool (Appendix B of these Mechanical Tools).

3.1.9 Selective Leaching

Selective leaching is the removal of one element from a solid alloy by corrosion processes. The most common example is the selective removal of zinc in brass alloys (dezincification). Copper-zinc alloys containing greater than 15% zinc are susceptible to selective leaching, while copper alloys with a copper content in excess of 85% resist dezincification. Yellow brass (30% zinc and 70% copper) and Muntz metal (40% zinc and 60% copper) are both susceptible to selective leaching. The addition of small amounts of alloying elements such as tin, phosphorus, arsenic, and antimony also inhibit dezincification [11, 5]. The addition of 1% tin to brass, for example, decreases the susceptibility to selective leaching [11]. Naval brass is essentially an inhibited Muntz metal produced by the addition of 0.75% tin to the 40% zinc and 60% copper compound.

Aluminum bronzes containing greater than 8% aluminum are also susceptible to de-alloying of the aluminum in a similar manner to the dezincification of brass [5]. This degradation effect has been noted specifically in acid solutions; however, it was also noted that massive effects occurred where the solution contained chloride ions [5]. Unless they are inhibited by adding 0.02 to 0.10% arsenic, aluminum brasses and bronzes should be considered susceptible to selective leaching.

Gray cast iron can also display the effects of leaching particularly in relatively mild environments. This process initiates with selective leaching of the iron or steel matrix from the graphitic network. The graphite is cathodic to iron, providing a galvanic cell. The iron is dissolved, leaving a porous mass consisting of graphite, voids, and rust. If the cast iron is in an environment that corrodes this metal rapidly (e.g., saltwater), uniform corrosion can occur with a rapid loss of material strength which can go undetected as the corrosion appears superficial [5].

Selective leaching is a process similar to galvanic corrosion in that an electrolyte is required. Also similar to galvanic corrosion, the electrolyte that forms on metals in moist air environments lacks sufficient potential for the mechanism to occur. For plants whose operating experience has shown exposure to an aggressive species such as salt air in marine (seashore) areas or sulfur dioxide, acid rain, etc. in industrial areas, the conductivity of the normal atmosphere (humidity, rain, etc.) is increased and selective leaching may be an applicable aging effect for susceptible materials. Frequent or prolonged wetting, such as from condensation or groundwater, also provide an electrolyte with sufficient conductivity for selective leaching to occur.

Therefore, loss of material due to selective leaching is an applicable aging effect for uninhibited copper alloys with > 15 % Zn or > 8 % Al and for gray cast iron in locations of prolonged or frequent wetting in indoor and outdoor environments, in a buried environment, or in an outdoor environment where plant operating experience shows aggressive species (e.g., in seashore or industrial areas).

3.1.10 Boric Acid Wastage

As described in Appendix F, Bolted Closures, boric acid corrosion has been identified as an aging mechanism for the nuclear power industry, specifically for Pressurized Water Reactors (PWRs), and typically requires specific programs/activities for management. Leakage from PWR systems that contain borated water can result in the concentration of boric acid crystals on the external surface of components as the borated water evaporates from the external surface. This concentrated boric acid aggressively attacks the material, resulting in a loss of material by severe wastage [25]. The focus of the boric acid corrosion issue has been on susceptible bolting and Class 1 component materials (e.g., reactor vessel heads). However, leakage from plant systems that contain borated water can also degrade other susceptible materials in a PWR. Leakage from the boiling water reactor (BWR) Standby Liquid Control system, which contains sodium pentaborate (a mixture of borax and boric acid), may also concentrate, but the less acidic crystals are not aggressive to metals (such as carbon steel) as are the boric acid crystals concentrated from leakage of PWR borated water systems.

Components of PWR systems that are located near systems containing borated water, such as Reactor Coolant, Containment Spray, etc., are susceptible to the accumulation of boric acid crystals from leakage that can aggressively attack susceptible materials. Only stainless steels and nickel-base alloys have specific experimental evidence of resistance to concentrated boric acid. There have been no incidents to show that stainless steels or nickel-base alloys are subject to boric acid corrosion. Specific experimental results show that wrought stainless steels and high nickel alloys are not affected by borated water leakage effects [27]. Additionally, resistance of copper and copper alloys to boric acid as a corrosive media is excellent, with the exception of the high-zinc brasses (e.g., > 15% Zn) [24]. Similar to the resistance of stainless steels and nickel-base alloys, concentrated boric acid is not known to attack titanium and titanium alloys. As a result, loss of material by boric acid wastage is not an applicable aging effect for stainless steel or nickel-base alloy, copper and copper alloy with < 15% Zn, and titanium and titanium alloy components.

As such, loss of material by boric acid wastage is an applicable aging effect for carbon and low-alloy steel, cast iron, copper alloys with > 15% Zn, and aluminum and aluminum alloy components whose external surface is subject to leakage from a PWR borated water system(s). Leakage from the borated Standby Liquid Control (SLC) system of BWRs will not provide a similar concentration of boric acid and loss of material by boric acid wastage is not a concern.

3.2 Cracking

3.2.1 Hydrogen Damage

Hydrogen damage results from the absorption of hydrogen into the metal. It includes the degradation mechanisms of decarburization, hydrogen attack, hydrogen blistering, and hydrogen embrittlement [2, 5]. Decarburization is produced by moist hydrogen at high temperatures and is

OAGI0000553_00319

extremely slow below 1000°C [3], which is well above the temperatures experienced at nuclear power plants. Hydrogen attack also occurs at temperatures above those experienced at nuclear power plants, except as addressed in Appendix D with respect to PWR pressurizer gas space. Hydrogen damage usually manifests itself as hydrogen embrittlement in high strength metals and hydrogen blistering in low strength steels, alloys, and irons. Corrosion and the application of cathodic protection, electroplating, and other processes are major sources of hydrogen in metals [5].

Hydrogen blistering has been seen in low strength carbon and low-alloy steels in the temperature range of 30-300˚F [8]. Hydrogen blistering is most prevalent in the petroleum industry, occurring in storage tanks and in refining processes [5]. Blistering occurs predominantly in low strength alloys (e.g., carbon steel, copper and copper alloys, and some aluminum and aluminum alloys) after they have been exposed to aggressive corrosive environments (such as H_2S) or cleaned by pickling.

Another term for hydrogen embrittlement is sulfide stress cracking if the cracking is caused by the presence of hydrogen sulfide. A few ppm of absorbed hydrogen can cause cracking [5]. At yield strengths of less than 120 ksi for carbon and low-alloy steels, concern over hydrogen cracking is alleviated except when the material is temper embrittled [2]. Since the yield strength of most of the piping and components in nuclear power plant applications is on the order of 30 to 45 ksi, hydrogen embrittlement is considered not applicable to the external surfaces of carbon and low-alloy steels in the nuclear power plant applications. The yield strength of even the hardest cast irons is less than 100 ksi, with plain cast irons in the same range as that noted above for the carbon and low-alloy steel applications and therefore cast irons are not susceptible to hydrogen embrittlement. Copper and copper alloys are not susceptible to attack by hydrogen unless they contain copper oxide. Only tough pitch coppers (i.e., copper and copper alloys with small amounts of oxygen) in a reducing atmosphere are susceptible to hydrogen embrittlement [24]. High-strength aluminum alloys are susceptible to hydrogen embrittlement with exposure to gaseous hydrogen or to internal hydrogen from electrochemical charging [24].

In most cases, austenitic stainless steels are immune to hydrogen damage although nickel-base alloys may be somewhat susceptible [2, 3]. Titanium and titanium alloys suffer hydrogen damage primarily by hydride-phase formation. Galvanic couples between titanium and certain active metals and excessive charging from impressed-current cathodic protection systems are the usual cause of excessive hydrogen absorption. No hydrogen uptake and embrittlement problems occur when a titanium metal is coupled to fully passive materials in a given environment. These compatible materials may include other titanium alloys, stainless steels, copper alloys, and nickel-base alloys, depending on conditions [24].

However, the external surfaces of components in nuclear power plant applications are not exposed to hydrogen sulfide, or to gaseous H_2. It is not expected that equipment within the scope of this tool will experience the corrosive environment necessary for hydrogen blistering or embrittlement, with the environments of buried fuel oil storage components clarified below. Also, a review of the failure data for BWR and PWR systems shows no evidence of hydrogen blistering or embrittlement on external surfaces of nuclear power plant components. Therefore, hydrogen blistering is considered not applicable to the external surfaces of carbon (and low-alloy) steels, cast iron, aluminum and aluminum alloys, and copper and copper alloys in nuclear power plant applications. Similarly, hydrogen embrittlement is considered not applicable to the external surfaces of susceptible nickel-base alloys, tough pitch coppers and copper alloys, and titanium and titanium alloys in nuclear plant applications.

As described in Section 3.2.1 of Appendix C, the Oil and Fuel Oil Tool, improper voltage settings for cathodic protection systems that protect the external surface of fuel storage components that are buried may produce free hydrogen in the storage tanks, consistent with experience in the petroleum industry. However, excess hydrogen is not expected to be generated on the external surface and hydrogen embrittlement is considered not applicable to the external surface of buried components where a cathodic protection system is utilized.

3.2.2 Stress Corrosion Cracking/Intergranular Attack

Stress corrosion cracking is a mechanism requiring a tensile stress, a corrosive environment, and a susceptible material in order to occur. Intergranular attack is similar to stress corrosion cracking except that stress is not necessary for it to proceed. However, due to the typical operating temperature ranges of environments included in this application, IGA is generally not a concern. In the case of SCC of carbon and low-alloy steels, the literature shows the mechanism is possible, citing SCC in aqueous chlorides as the most common form. However, in the discussion of prevention and control, one of the most reliable methods of preventing SCC of carbon and low-alloy steels is to select a material with a yield strength of less than 100 ksi [16]. The yield strength of carbon steels typically used in non-Class 1 systems is on the order of 30-45 ksi. Industry data does not support a widespread problem of SCC in low strength carbon steels. However, there was one reported case, suspected to be nitrate induced, of SCC of carbon steel in a treated water system, which is not an environment included in this appendix but is addressed in Appendix A, Treated Water. For these reasons, SCC of carbon and low-alloy steels is considered not applicable for this tool. SCC in higher strength bolting materials is discussed in the Bolted Closure Tool in Appendix F.

Stainless steels exposed to buried or alternately wetted and dried environments (other than normal outdoor environments) may be susceptible to cracking in these locations since sufficient aggressive contaminants may be concentrated to provide an environment conducive to SCC. Submerged stainless steel material may also be susceptible to SCC; however, the user is advised to evaluate submerged equipment using the raw water tool (Appendix B of these Mechanical Tools) or treated water tool (Appendix A of these Mechanical Tools) as appropriate.

SCC of stainless steels exposed to atmospheric conditions and contaminants is considered plausible only if the material temperature is above 140°F. In general, SCC very rarely occurs in austenitic stainless steels below 140°F [18, 24]. Although SCC has been observed in systems at lower temperatures than this 140°F threshold, all of these instances have identified a significant presence of contaminants (halogens, specifically chlorides) in the failed components. Additionally there does not appear to be a threshold level of stress for SCC, with the stress level merely dictating the time to failure. However, if stainless steel is known not to be sensitized, then SCC of the material need not be considered an applicable aging effect in an atmospheric environment. There is data in Reference 6 indicating that as-welded Types 304 and 316 resisted SCC, which provides an indication that sensitization does not always lead to SCC. When considering the stainless steel cracking logic, SCC may be assumed for high carbon content stainless steels such as Type 304 and 316, but not for low carbon content stainless steels such as Type 304L and 316L. Therefore, SCC of stainless steel is not a concern in buried or indoor environments but may be a concern in continuously or frequently wetted locations in outdoor environments if temperatures are > 140°F, or if plant operating experience shows exposure to salt air (e.g., seashore areas) or other aggressive species (e.g., sulfur dioxide or acid rain in industrial areas).

Pure aluminum is not susceptible to SCC; however, aluminum alloys containing more than 12% zinc or more than 6% magnesium are very susceptible to cracking under mild corrosive environments [5]. Aluminum alloys are susceptible to SCC in air and water vapor environments, particularly in corrosive environments containing chloride solutions and saltwater. A determination should be made from plant-specific operating experience if such conditions exist at the plant, and if such conditions are likely to occur in the future, particularly for plants in marine (seashore) and/or industrial areas. Therefore, cracking due to stress corrosion is not applicable to aluminum and aluminum alloys protected from weather (indoor), but is an applicable aging effect for aluminum and aluminum alloys exposed to weather where operating experience has shown concentrations of aggressive contaminants (such as saltwater in the atmosphere).

The best known example of stress corrosion cracking of copper alloys is probably the "season cracking" of brass, so called due to its similarity to the cracking of seasoned wood. Ammonia (NH_3) and ammonium (NH_4^+) salts are the corrosive substances most often associated with SCC of copper alloys. These compounds are sometimes present in the atmosphere. Both oxygen and moisture are necessary for ammonia to be corrosive to copper alloys; carbon dioxide is also thought to contribute to the process in NH_3 atmospheres. Moisture films on metal surfaces will dissolve significant quantities of NH_3, even from atmospheres with low NH_3 concentrations [4, 5, 24]. Brasses containing less than 15% Zn are highly resistant to SCC, even under severe conditions. Additionally, brass is susceptible to SCC in moist air containing trace amounts (0.05 to 0.5 vol%) of sulfur dioxide (SO2) [24]. Bronze and other copper alloys are considerably more resistant to stress corrosion cracking than the brass (copper-zinc) alloys [4]. An exception is aluminum bronze, which has demonstrated a susceptibility to SCC in moist ammonia environments. For the purpose of this tool the bronzes, with the exception of aluminum bronze, are considered immune to stress-corrosion cracking.

However, the nuclear plant indoor, outdoor, and buried environments addressed by this tool typically do not contain detectable amounts of ammonia, ammonium salts, or sulfur dioxide. As such, SCC of copper alloys is not a concern in indoor or buried environments and is also not a concern in outdoor environments, unless plant-specific operating experience indicates detectable amounts of ammonia and ammonium compounds (e.g., due to organic decay, bird excreta, or cleaning solvent) or sulfur dioxide (e.g., in industrial areas). For plants with such operating experience, SCC of high zinc (> 15% Zn) brasses and aluminum bronzes (e.g., > 8%Al) are a concern in moist (e.g., humidity) and wetted locations.

3.2.3 Mechanical/Thermal Fatigue

Aging effects of mechanical and thermal fatigue are addressed separately in Appendix H.

3.3 Reduction of Fracture Toughness

3.3.1 Thermal Aging

Thermal embrittlement is a mechanism where the mechanical properties of a material (strength, ductility, toughness) are affected as a result of prolonged exposure to high temperatures. Carbon steel, low-alloy steel, wrought austenitic stainless steel, and nickel-base alloys are not susceptible to thermal embrittlement when exposed to normal nuclear plant operating environments [13, 14, 17, 18, 19]. However, CASS materials are susceptible to thermal embrittlement depending upon material composition and time at temperature. Castings with high ferrite and high molybdenum contents are more susceptible to thermal embrittlement than those with lower values.

CASS materials subjected to sustained temperatures below 250°C (482°F) will not incur a reduction of room temperature Charpy impact energy below 50 ft-lb for exposure times of approximately 300,000 hours (for CASS with ferrite content of 40%) and approximately 2,500,000 hours (for CASS with ferrite content of 14%) [Figure 1; Reference 20]. When considering a maximum exposure time of approximately 420,000 hours over 48 EFPY, a temperature of 482°F is conservatively chosen below which reduction of fracture toughness is not applicable. This threshold is chosen because (1) the majority of nuclear grade materials are expected to contain a ferrite content well below 40%, and (2) the 50 ft-lb limit is very conservative when applied to cast austenitic materials—it is typically applied to ferric reactor vessel materials (e.g., 10 CFR 50 Appendix G).

Since most non-Class 1 external surface temperatures are below the screening threshold of 482°F, CASS materials are not subject to reduction of fracture toughness for the period of extended operation. Also, CASS materials are not typically used in Main Steam or Feedwater systems where external surfaces temperatures are high due to the high temperature of the process fluid during normal plant operations.

3.3.2 Radiation Embrittlement

Radiation embrittlement can result in a decrease in fracture toughness of metals; however, it requires a neutron fluence far exceeding neutron exposures of components and systems in the non-Class 1 category [2, 14]. Therefore, radiation embrittlement is considered not applicable.

3.4 Distortion

Distortion may be caused by plastic deformation due to high temperature related phenomena (e.g., creep). In general, distortion is addressed by the design codes and is not considered an applicable aging effect. Creep is not a concern for low-alloy steels below 700˚F, for austenitic alloys below 1000˚F, and Ni-base alloys below 1800˚F [14]. Creep is not a plausible aging mechanism since the necessary high temperatures do not occur in nuclear plant systems.

3.5 Galvanized Steel

Galvanized steel is carbon steel protected from the environment by coating the external surfaces with zinc. Zinc is used because of its corrosion resistance in an external environment and because it provides galvanic protection of the base metal where discontinuities or damage of the coating has

OAGI0000553_00323

occurred [5]. The zinc corrosion products tend to be alkaline thereby neutralizing normal acidic moisture that occurs in industrial environments [7].

In the pH range between 6 and 12, zinc undergoes negligible corrosion under most environmental conditions. When exposed to water, the corrosion resistance of zinc is maintained only in this pH range. Outside this pH range, the increased corrosion rate significantly reduces the usefulness of zinc as a protective coating. In an outdoor environment, on buried components, and in a saltwater environment, the corrosion protection of the zinc coating is enhanced by the buildup of corrosion products deposited out of solution [5]. These deposits do not occur in distilled water and, as a result, the corrosion rates in distilled water are significantly higher than in contaminated water.

Temperature affects the corrosion rate of galvanized steel. Several studies indicate that between 140°F and 200°F, the corrosion products are significantly more conductive than those formed above or below this temperature band. The corrosion products at 185°F were noted to be about 1,000 times more conductive (a measure of impurities) than those at 75°F (in distilled water) [7]. Therefore, the potential for significant degradation of the zinc coating can occur on wetted surfaces in this temperature range. For example, corrosion may occur between insulation and galvanized piping if there is condensation or leakage.

Galvanized carbon steel is also susceptible to the effects of embrittlement at elevated temperatures. It was originally thought that galvanized steel could be used at temperatures up to the melting point of zinc (approximately 785°F) [8]. More recent studies have indicated the potential for embrittlement of galvanized steel at temperatures significantly below the melting point of zinc. Observed crack propagation in galvanized steel is typically intergranular. At lower temperatures, the time required for failure increases as does the associated minimum required stress level necessary to cause embrittlement [21].

Based on work discussed in Reference 21, as well as an "application upper temperature limit" established by the American Galvanizers Association, embrittlement of galvanized steel should be considered a plausible aging mechanism if exposed to temperatures above 400°F.

3.6 Non-Metals and Insulation

Based on the wide variety of available glasses, plastics, elastomers, and (conservatively) insulation systems and the corresponding variety of properties and characteristics, proper selection and use of these materials is a design consideration and is assumed for the purposes of this tool. The effects of aging on these materials exposed to the same indoor and outdoor environments as the metals addressed above are evaluated in the following subsections.

3.6.1 Glasses

Because most silicate glasses have a high resistance to corrosion in normal environments, glass is frequently considered to be an inert substance. Silica is almost insoluble in an aqueous environment at temperatures below 482°F. Acid attack of soda-lime and borosilicate glass compositions is minimal due to the formation of protective, highly siliceous surface layer, except for hydrofluoric and phosphoric (at high temperatures) acids [28]. Indoor and outdoor environments do not typically contain contaminants that could concentrate and chemically attack glass.

"Weathering" is a term commonly given to the attack of glass surfaces by atmospheric gases and moisture whereby the surface of the glass becomes dimmed, fogged, and in extreme cases pitted (high humidity or exposure to alternating cycles of moisture condensation and evaporation can leach alkalis from the surface that react with water and create a very-high pH environment on the surface of the glass that can cause the silicate network to dissolve and visible deposits to form) [29]. But with most common compositions (i.e., soda-lime glasses), increased surface alkalinity and enhancement of the attack are needed to cause problems. High silica (e.g., > 96%), borosilicate, and aluminoborosilicate glasses are fully resistant to the weathering phenomenon [28]. Since the indoor and outdoor environments do not contain contaminants that could concentrate and enhance alkaline attack of glasses, chemical degradation or hydrolysis of glass is not an applicable aging mechanism in indoor and outdoor environments.

3.6.2 Plastics

The environment can be a severely limiting factor in the selection and use of plastic materials. The differences between an office and industrial environment are as significant as the differences between indoor and outdoor exposure, with four critical parameters for proper selection: operating temperature, stress level, chemical exposure, and adjoining materials [30]. In indoor and outdoor locations, the temperatures to which the external surfaces of plastics are exposed are dictated by the ambient conditions in the location and by internal temperatures, with condensation likely in applications with below-ambient internal fluid temperatures. Stress levels are assumed to be adequate for degradation since determination of the actual residual, or molded-in, stresses is not feasible for the purposes of this tool.

The chemical resistance of many engineering plastics is excellent. Plastics are used routinely in environments in which metals would rapidly fail. However, most plastics have specific weaknesses in terms of chemical attack. Failure of plastics due to chemical exposure can be classified as plasticization, chemical reaction, and environmental stress cracking. Plasticization requires exposure to a fluid with which a given plastic has somewhat similar characteristics, because the fluid may diffuse into, and dissolve, the plastic. Chemical reactions occur between a plastic and an environmental substance that lowers molecular weight or otherwise degrades mechanical properties. Environmental stress cracking is a phenomenon in which a stressed part develops crazing and/or cracking from exposure to an aggressive substance [30].

Chemical environments can actually degrade a polymer (plastic) by breaking down the polymer chains and altering the material properties. Certain polymer types are more susceptible than others to specific degradation mechanisms, which can include hydrolysis, thermal degradation, oxidation, and photo degradation, but all polymers can be degraded by at least one mechanism. With exposure to aqueous environments, hydrolytic degradation of susceptible polymers can occur at very slow rates but can become perceptible at conditions of either low (<4) or high (>10) pH. Thermal degradation of susceptible polymers (e.g., high molecular weight polymers) can occur upon exposure to elevated temperatures such as experienced during molding or extrusion operations, but would be much slower in end-use environments due to the lower temperature. Oxidation may occur when many polymers are exposed to oxygen-containing environments; however, susceptible polymers typically have additive stabilizers and antioxidants that will preserve polymer properties at least until the additives have been consumed. Ultraviolet (UV) radiation can be the source of energy that will abstract an atom from the polymer backbone and start the oxidation process. Oxidation initiated by UV radiation will result in eventual loss of properties; although plastics exposed to UV typically have chemical additives which retard these processes, these additives eventually will be consumed and the degradation will proceed [31].

Assuming proper selection, the indoor and outdoor environments addressed by this tool do not typically contain contaminants that could concentrate, or experience elevated temperatures that could result in plasticization and environmental stress cracking of plastics. Furthermore, polymers such as PVC and PVDF are resistant to seawater environments up to temperatures of 150°F and 270°F, respectively. PVDF is also resistant to moist/wet sulfur dioxide up to temperatures of 200°F, whereas Type 1 PVC is resistant to moist/wet sulfur dioxide up to 100°F [32].

Conservatively, chemical attack is an applicable aging mechanism for plastics (e.g., PVC, PVDF) located in outdoor and indoor environments due to exposure to UV radiation (e.g., sunlight, fluorescent lighting, etc.), ozone or ionizing radiation. Also, for plants whose operating experience has included exposure to aggressive species such as sulfur dioxide in industrial areas, chemical attack and environmental stress cracking is an applicable aging mechanism for plastics other than PVDF located outdoors.

3.6.3 Elastomers

For a complete discussion of the aging effects of typical elastomers used in nuclear plants, the user of this Tool is referred to Chapter 7 of EPRI report 1002950, *Aging Effects for Structures and Structural Components (Structural Tools), Revision 1* [25]. While not addressed in EPRI report 1002590, which is focused on sedentary structural components, elastomers in mechanical systems (e.g., joint seals and flexible connections) may also experience wear as a result of their flexible nature and the small vibrations and/or movement of rotating components (e.g., fans). As such, loss of material due to wear of elastomers materials may be a concern. However, this concern is dependent on the specific elastomer (for which abrasion resistances vary) and condition, and thus requires plant-specific consideration.

3.6.4 Insulation

For a complete discussion of the aging effects of, and industry experience with, typical cementitious and fibrous fire barrier (fire wraps and fire stops) insulating materials used in nuclear plants, the user of this tool is referred to Chapter 6 of EPRI report 1002950, *Aging Effects for Structures and Structural Components (Structural Tools), Revision 1* [25]. For a discussion of the aging effects with insulation/jacketing for electrical cables and connections used in nuclear plants, the user of this tool is referred to EPRI report 1003057, *License Renewal Electrical Handbook* [34]. As described in Section 2.1.9 of this appendix, reflective insulation systems (e.g., MIRROR) are constructed of aluminum or stainless steel panels; steel bands and appurtenances are typically used for affixing insulation systems to piping and components, and some mass insulation systems are fully encapsulated in metal (aluminum or stainless steel). The aging effects for reflective insulation systems (e.g., MIRROR) and for mounting bands/straps and appurtenances are the same as those for the similar materials evaluated in Sections 3.1-3.4 and do not warrant separate evaluation. In addition to the aging effects evaluated in Sections 3.1-3.4, metal-encapsulated mass insulation systems are evaluated below.

OAGI0000553_00326

Degradation of mass insulation systems may become a concern only when (1) that degradation can result in degradation/failure of the components to which it is affixed, (2) plant-specific credit is taken for a design-basis insulating (thermal resistance) function in a safety analysis or for compliance with a regulated event (e.g., ATWS, SBO), and (3) that degradation may cause the insulation to become loose and interfere with an intended function.

Metals do not corrode because they are covered with insulation, but require contact with water and a free supply of oxygen or other aggressive species. Thermal insulation received from manufacturers and distributors is dry, or nearly so, and if it remains dry there is no corrosion problem for the underlying metals [24]. Furthermore, the mass insulation systems used in nuclear power plants are typically selected to limit chemical impurities (such as halides, primarily chlorides) that could leach out of wetted insulation from either the insulating material or the protective covering/adhesives/sealants and attack the underlying metals [26]. The use of insulation is not credited, explicitly or implicitly, with precluding the aging effects for underlying metals evaluated in Sections 3.1 through 3.5. However, the user of this tool should confirm that the requirements for insulation at their plants preclude contaminants in the insulation that could attack the underlying metal if wetted.

The thermal resistance characteristics of mass insulation systems are not expected to naturally degrade over the course of their service life, as proper selection, design, and installation for the specific service and condition is assumed. However, similar to cementitious or fibrous fire wraps, aging effects that may result in degradation of insulation, including the thermal resistance characteristics, are loss of material, cracking, change in material properties, and separation [25]. These effects could also result in loosening of the insulation and its dropping from the piping or component to which it is affixed and, thereby, interfering with an unrelated intended function.

Mechanical damage of mass insulation systems (e.g., personnel stepping on or impacting it during maintenance and other activities) is not considered to be a passive aging mechanism, but is event-driven and is evaluated and corrected as necessary rather than being allowed to continue for prolonged periods. Unless protective coverings of mass insulation systems are damaged, loss of insulating material is not a concern. Also, glass, which is similar to fiberglass strands, is evaluated in Section 3.6.1 for exposure to indoor and outdoor environments with no applicable aging effects. Other design considerations for mass insulation systems include the expected thermal extraction and contraction of the insulated metals, shrinkage in insulation for high temperature systems, and vibration which can result in differential movement of the insulation [26]. As such, cracking and separation of mass insulation systems are not a concern since the associated mechanisms of vibration, movement, and shrinkage during normal plant operations are precluded by design.

Mass insulation systems used in nuclear plant applications typically are sealed and include a combination of insulating material and a weather barrier, vapor barrier, condensate barrier, or covering for the specific service. Weather barriers may be constructed of metal jackets with suitable vapor vents [26]. Weather barriers are typically included with the mass insulation systems for warm or hot equipment [24]. Vapor barriers typically included with mass insulation systems are used to prevent moisture in the atmosphere, in the form of vapor, from entering insulation installed on surfaces of components with lower than ambient temperatures and are therefore used in cold and dual service applications [26]. This outer covering (or barrier) protects mass insulation from the

OAGI0000553_00327

weather, solar/UV radiation, or atmospheric contaminants, and from mechanical damage but permits the evaporation of any moisture vapor [26].

Typically, atmospheric pollutants and contaminants, both indoors and outdoors, are insufficient to concentrate and thereby attack properly designed, selected, and installed weather/vapor barriers or covering of mass insulation systems. Also, the coverings protect the insulating materials from exposure to corrosive elements that could change their material properties. Damage to mass insulation systems is quickly addressed after discovery of corrosive chemical leaks or spills. Irradiation of insulating materials is a factor in the design and selection of mass insulation systems.

Ultra-violet and infra-red rays and the oxidizing effects of the air may also cause deterioration of barriers and coverings over time [26]. Also, industrial environments contain some contaminants (e.g., sulfur dioxide, acid rain, etc.) which may cause reaction with or corrosion of insulation system barriers or coverings. Likewise, plants located near coast lines will be surrounded by salt-laden air, which can subject the surfaces of the weather/vapor barriers or covering to corrosion in outdoor locations. Therefore, degradation of insulation is not an age-related concern, except in outdoor environments due to exposure to sunlight (UV radiation) and in instances where plant-specific operating experience has shown exposure to aggressive chemicals such as sulfur dioxide in industrial areas and salt air in marine (seashore) areas.

3.7 Summary of Potential Aging Effects

Table 4-1 contains a summary of the various aging mechanisms and applicable aging effects considered for various metals during the development of this tool. Also included are the conditions necessary for these aging effects to be manifested and the various metals that are susceptible to these effects. Figure 1 provides a depiction of the corresponding logic and decision points for the various aging mechanisms that are applicable for external surfaces in indoor air, outdoor air, and buried environments.

One significant point in the mechanism and effects relationship is that loss of material due to general corrosion is uniform, whereas it is localized for the other corrosion mechanisms. This may be an important factor in determining the effectiveness of detection and management programs. For example, with uniform corrosion, wall thinning can lead to gross failure (although the rate is very slow and usually predictable). With localized loss of material, the material loss is concentrated, with relatively small material weight loss leading to a through-wall failure (although the rate can be very fast and unpredictable). Through-wall failures associated with localized corrosion are generally pin-hole type leaks, allowing time for identification and repair before impairing component or system function.

Additionally, EPRI report 1002590 [25] addresses the potential aging effects (and mechanisms) for elastomers, including the conditions necessary for the effects to be manifested. That information is not duplicated in this tool. However, due to their flexibility, wear of elastomers may be a potential aging mechanism for elastomers.

Also, degradation, such as cracking or change in material properties, is a potential aging effect for plastic surfaces (e.g., PVC, PVDF) from exposure to UV radiation (e.g., sunlight, fluorescent lighting, etc.), ozone, or ionizing radiation, and also for plastics other than PVDF located outdoors at plants whose operating experience has included exposure to aggressive species such as sulfur dioxide in industrial areas.

3.8 Applicable NRC Generic Correspondence

The NRC generic correspondence (Circulars, IE Bulletins, Information Notices, and Generic Letters) was reviewed for correspondence related to the external surfaces of components. Several entries were found that related to fatigue failures of small bore attached piping and corrosion of threaded fasteners. One entry was found related to standing water due to condensation affecting original accident analysis assumptions. Various entries related to the accumulation of boric acid deposits from system leakage. Thermal and mechanical fatigue correspondence will be discussed in Appendix H. Correspondence related to boric acid leakage is addressed in Appendix F since bolted enclosures are the source of most boric acid leakage. However, it is recognized that boric acid leakage can extend beyond the bolted closure such as at nozzle weld locations caused by stress corrosion cracking (SCC) or intergranular attack (IGA).

Information Notices

IN 80-05: Chloride Contamination of Safety-related Piping and Components

Bechtel Power Corporation determined at the Wolf Creek Project that a fire retardant coating is potentially corrosive to stainless steel. Albi "Duraspray" is used to fireproof exposed structural steel in some power plants. It does not appear to affect unprimed inorganic zinc coated, or galvanized steel; however, it may be corrosive to stainless steel, bare aluminum, or copper. The Notice advised readers to protect all affected material from overspray and droppage of cementitious oxychloride materials.

IN 85-34: Heat Tracing Contributes to Corrosion Failure of Stainless Steel Piping

In 1984, Pilgrim Nuclear Power Station reported seven through-wall cracks in 50 feet of type 304 stainless steel piping. The 1 inch piping was installed in a horizontal position in the post-accident sampling system. The lines were intended to have a slope for draining, but interface requirements led to a horizontal line with sagging. The pipe carries gas samples and heat tracing was used to keep it dry. During evaporation, the chlorides present in the water concentrated where the pipe sagged. Repeated evaporation led to a buildup of chemicals and eventually caused corrosion of the piping that was kept hot by the heat tracing. Although this was a case of cracking from the inside out, the external heat tracing initiated the concentration of chlorides which promoted the stress corrosion cracking.

IN 02-11: Recent Experience with Degradation of Reactor Pressure Vessel Head

This information notice alerted Pressurized Water Reactor (PWR) licensees about findings from recent inspections and examinations of a degraded reactor pressure vessel head at a site, and also describes industry operating experience with boric acid corrosion of reactor coolant pressure boundary components in PWR plants. Several instances of boric acid corrosion that have been identified are associated with the reactor pressure vessel (RPV) head. The primary effect of boric acid onto ferritic steel is wastage or general dissolution of the material. The information notice reiterates the importance of minimizing boric acid leakage, detecting and correcting leaks in a timely

OAGI0000553_00329

manner, and promptly cleaning any boric acid residue. Related generic communications are also listed in this information notice, including (descriptions not provided in this tool) Information Notices 80-27, 82-06, 86-08 (and Supplements), 90-10, 94-63, 96-11, and 01-05, Generic Letters 88-05 and 97-01, and IE Bulletins 82-02 and 01-01.

IN 02-13: Possible Indicators of Ongoing Reactor Pressure Vessel Head Degradation

This information notice alerted PWR licensees to possible indicators of reactor coolant pressure boundary degradation. In response to issues regarding wastage of ferritic steel RPV head components at a site, the NRC issued notices 02-01 and 02-11 (description not provided in this tool) and sent an augmented inspection team to investigate the degradation. Several possible indicators of reactor coolant pressure boundary degradation were identified, including unidentified reactor coolant system (RCS) leakage and containment air cooler and radiation element fouling. In 1998, increased fouling caused by boron deposits was identified and a flow from the containment air coolers resulted in boric acid deposits elsewhere within containment, including on service water piping, stairwells, and other areas of low ventilation. As such, RCS leakage, boron deposits, and corrosion products in containment air coolers and radiation monitors may indicate degradation of the reactor coolant pressure boundary.

IN 03-07: Water in the Vent Header/Vent Line Spherical Junctions

This information notice alerted licensees of recent issues involving the pressure suppression containment system in BWRs with a Mark I containment. During a recent refueling outage at a site, unanticipated standing water was found inside the vent header/vent line (VH/VL) spherical junctions (vent system low point or "bowl"). The weight of this standing water inside the VH/VL spherical junctions was not included in the generic Mark I containment accident analysis because the spherical junctions are assumed to remain dry. The source of the water is believed to be condensation in the relatively cool vent header lines. The original plant design of some Mark I containments had drain lines from the spherical junctions to the torus. Some of the plants having these drain lines removed them in the early 1980s to eliminate a potential torus bypass path. The licensee's analysis of the standing water in the spheres concluded that the mass could become entrained in the initial blowdown and would increase the thrust loads during a LOCA. The calculated stress level for the VH/VL junction exceeded the original design acceptance criteria (ASME Service Level A/B), but remained below ASME Service Level C and the higher acceptance stress level limits for operability (ASME Service Level D).

IN 05-02: Pressure Boundary Leakage Identified on Steam Generator Bowl Drain Welds

This information notice alerted PWR licensees to cracking and leakage indications found on steam generator bowl drains. Boric acid deposits from pressure boundary leakage in the vicinity of a SG bowl drain were identified at a site, during bare metal visual examinations of Alloy 600/82/182 components. Further examination, including dye penetrant testing, confirmed that PWSCC had resulted in cracking of a drain line weld. This finding is consistent with the industry operating experience, except that no evidence of boric acid corrosion of the ferritic material was identified. The NRC has issued a number of generic communications related to PWSCC in the reactor coolant system of PWRs. These generic communications, such as Information Notice 04-11 and Bulletin 03-02, address leakage from various Alloy 600/82/182 components.

4. FLOW DIAGRAM / SUMMARY TABLE DEVELOPMENT

4.1 Assumptions

1. Components that are submerged, in the “splash” zone of raw or treated water sources, or continuously wetted other than by condensation, are essentially subjected to a raw or treated water environment. The external surfaces of these components should be evaluated using Appendix B and Appendix A of these tools, which consider the aging effects applicable to raw water and treated water environments, respectively.

2. Oxygen level is a significant parameter in many aging mechanisms. This tool assumes that the level of oxygen in the atmosphere and surrounding buried components is above the threshold value to cause corrosive effects.

3. Atmospheric environments contain chemical species including oxygen, halides, sulfates, and other aggressive corrosive substances that can influence the nature, rate, and severity of corrosion. However, it is assumed that these contaminants cannot be concentrated to levels that will promote corrosion unless subjected to factors such as cyclic (wet-dry) condensation, prolonged durations of contaminated insulation or accidental contamination, or leakage. Additionally, atmospheric environments in sea coast areas may contain high concentrations of salt and those in industrial areas may contain high concentrations of sulfur dioxide, acid rain, etc.

4. The environment surrounding buried equipment usually contains oxygen and other aggressive species. For the purposes of this tool, the buried path assumes that a component is exposed to oxygen and chlorides, halides, sulfates, etc.

5. Crevice corrosion requires a crevice (an opening usually a few thousandths of an inch or less in width) to occur. The logic will assume conservatively that the potential exists for crevices in all components and systems.

6. Some aging effects are the result of mechanisms that require stresses to operate. It is unreasonable to expect an evaluator to establish the presence of stresses resulting from the manufacturing process or post-installation welding for every component under consideration. In these cases, the logic conservatively assumes that the threshold stress exists for the mechanism to occur.

7. The stainless steel logic determines SCC to be a plausible aging mechanism in saltwater only when the material is above 140°F. Although it is recognized that SCC may occur at lower temperatures, this occurs only with high levels of contaminants present, not just atmospheric conditions.

8. Microorganisms of various types that influence corrosion either directly or indirectly are assumed to exist for the buried environment and in frequently wetted outdoor environments (e.g., water pooling/ponding).

9. Coatings and linings are not automatically credited since the techniques for installation and preservation are varied and plant specific. Each user of this tool must assure that a program is in place to verify the integrity of the coating.

10. The zinc coating on galvanized steel has demonstrated high rates of corrosion in a distilled water environment between 140 and 200°F. A similar environment can occur when condensation or leakage from insulated pipe results in a wetted condition between the insulation and the galvanized material. The tool logic identifies loss of material as a significant aging effect for galvanized steel under such conditions.

11. Air-conditioning is not automatically credited for humidity control since not all plant buildings/structures/facilities are air-conditioned and not all HVAC systems are included in the scope of license renewal. Where control and air-conditioning of an area is credited with precluding an aging effect (e.g., in the control room and/or switchgear room(s)), each utility must assure that a program is in place to ensure the integrity of the AC system function.

12. Thermoplastics and insulation systems are assumed to be selected, designed, and installed for the specific service and conditions.

4.2 Overview

The Mechanical Tools provide a method to identify applicable aging effects for systems and components which are required to undergo an aging management review in compliance with the license renewal rule. Utilization of these tools will result in the identification of aging effects for plant equipment that must be managed during the renewal period. Demonstration of the adequacy of aging management programs is outside the scope of this tool as described in Section 4.0 of the main document.

These tools identify potential aging effects and direct the user to areas in the system where these effects might be preferentially manifested. The previous sections identified numerous aging mechanisms and their associated aging "effects" which potentially can occur. This logic tool, Table 1 and Figure 1, guides the user to determine, based on specific materials, environments, and operating conditions, whether these effects are applicable. This tool is organized such that individuals utilizing the tool do not require a detailed knowledge of aging mechanisms or their effects. The logic does, however, require that the user be familiar with the materials of construction and the various environments.

Utilization of the tool documents the disposition of aging mechanisms and the resultant aging effects for the external surfaces of non-Class 1 nuclear plant components. The results identify the effects which must be managed and can help guide how and where to implement aging management programs.

OAGI0000553_00332

4.3 Tool Description

Table 1 (added in Revision 3) identifies applicable aging effects, and corresponding mechanisms, that may require programmatic oversight (management) for the period of extended operation, as well as the applicability criteria for the occurrence and propagation of the mechanisms. This table summarizes the information depicted on the corresponding logic diagram (Figure 1) and is organized alphabetically by material and aging mechanism. The potential aging effects, together with the detailed mechanism discussions in Section 3.0 and assumptions in Section 4.1 of this appendix, provides the basis for the development of the air and gas tool described below. The materials and environments covered by these tools are described in Sections 2.1 and 2.2, respectively.

Figure 1 contains the logic to evaluate aging effects for the external surfaces of carbon and low-alloy steels, cast iron, copper and copper alloys, aluminum and aluminum alloys, austenitic stainless steels, nickel-base alloys, and titanium and titanium alloys that are located indoors (protected from weather), outdoors (exposed to weather), or are buried (underground). It also contains the logic where accelerated aging effects for the external surfaces of galvanized steel can be identified.

The lower branch evaluates all external surfaces for loss of material because of wear/fretting, whether located indoors, outdoors, or buried. The middle branch evaluates the effect of humidity and moisture. The upper branch includes a temperature threshold of 212°F that applies to all materials, as moisture must be present for corrosion to occur, and evaluates exposure to prolonged wetting other than humidity (e.g., leakage, condensation, pooling/ponding), as well as the effect of an aggressive environment such as may be found in industrial and seashore areas. Except for the effects of general corrosion addressed in the middle branch, aging effects (corrosion rates) for external surfaces of components are considered to be insignificant unless the surface is subject to intermittent or frequent wetting (e.g., condensation, leakage, pooling/ponding) other than due to humidity or where plant operating experience has shown exposure to aggressive atmospheric environments such as sulfur dioxide in industrial areas and saltwater in marine/seashore areas. The external surfaces of susceptible materials for PWR components located indoors and subject to leakage from borated water systems may be significantly corroded by the resulting concentration of boric acid. Buried components are considered to be wetted and the damp soil to contain some level of contaminants and microbes. Galvanic corrosion is only applicable to carbon and low-alloy steel, cast iron, copper and copper alloys, and aluminum and aluminum alloys in wetted locations whether indoors, outdoors, or buried or where experience shows an aggressive (e.g., saltwater atmosphere). The figure evaluates the aging effects/mechanisms that apply to all materials, such as MIC and wear/fretting, and then separately evaluates in the upper branch the aging effects for stainless steel, nickel-base alloys, titanium and titanium alloys, and for carbon and low-alloy steel, cast iron, copper and copper alloys, and aluminum and aluminum alloys.

Stainless Steel, Nickel-Base Alloy, Titanium and Titanium Alloys

The decision blocks in this logic ask whether the external surface is exposed to wetting other than humidity or to an aggressive environment with temperature less than 212ºF. These blocks are intended to remove from further aging consideration all material which is not exposed to a harsh environment. Surfaces of other materials in sheltered locations and not subject to cyclic wetting and drying or frequent moisture exposure can be excluded from further consideration. Material in indoor environments fits this category except in wetted locations. The question of whether a surface is wetted other than due to humidity includes alternately (cyclic) wetted and dried situations where aggressive species can concentrate such as for buried components or alternately wetted and dried conditions where the source fluid could contain contaminants but does not include exposure to only rain. Alternate wetting and drying resulting from rain has shown a tendency to "wash" the exterior surface material rather than concentrate contaminants [6]. Examples of this type of wetting include insulated components subject to sweating, tanks and components subject to cyclic condensation when frequently filled from an external source, and chronic leakage areas. Surfaces subjected to a wetted and/or aggressive atmospheric environment are susceptible to pitting and crevice corrosion, as well as to SCC (stainless steel), at temperatures > 140°F. MIC damage is also a concern if the component is buried or in contact with a raw water source in outdoor locations. The "no" path includes stainless steel, nickel-base alloy, and titanium and titanium alloy material subjected to either indoor or outdoor atmospheric conditions. These materials are not susceptible to pitting, crevice, or other forms of corrosion/cracking under these conditions unless exposed to an aggressive atmosphere such as where plant operating experience has shown exposure in industrial and seashore, particularly saltwater, environments.

Carbon and Low-Alloy Steel, Cast Iron

Both paths of the logic addressing whether a surface is wetted or exposed to an aggressive environment include carbon and low-alloy steel and cast iron. Carbon and low-alloy steel, and cast iron are susceptible to general corrosion due to moisture (humidity) and in wetted locations or when exposed to aggressive environments. Carbon and low-alloy steels and cast iron are also susceptible to localized corrosion in wetted locations or when exposed to aggressive environments. Furthermore, gray cast iron is susceptible to selective leaching in wetted locations or when exposed to an aggressive environment. The logic for wetted surfaces or those exposed to aggressive environments also asks whether the surface is exposed to leakage from a PWR borated water system and then separates carbon and low-alloy steels from galvanized steel. As discussed in assumption 3 in Section 4.1 of this tool, the buried environment includes oxygen and other contaminants in the soil as an aggressive species. For equipment that is not buried, oxygen should **not** be considered an aggressive species when answering this logic question. The "no" path from this block inherently assumes oxygen is present.

Galvanized Steel

The logic provides galvanized steel decision points to identify aging effects due to degradation of the zinc coating. Although other paintings and coatings are utilized, the widespread use of galvanized steel for environmental protection was a factor in including specific logic in this exterior surface tool. Because this logic addresses the integrity of the galvanized steel, specific aging effects of the base carbon steel are not included in the galvanized steel paths. The expectation of no material loss due to general corrosion of the galvanized material does not preclude the necessity for a program to assure coating integrity. Conditions expected to result in more rapid deterioration of the coating than anticipated during design require consideration of the effect on the base material. If depletion of the zinc coating via general corrosion concerns is indicated using the galvanized steel branch, aging effects for the base material can be identified by following the carbon steel logic when the coating is no longer intact.

Copper and Copper Alloys, Aluminum and Aluminum Alloys

The copper and copper alloys / aluminum and aluminum alloys portion of the logic addresses the aging effects for these materials in wetted locations or when exposed to aggressive atmospheric environments. As discussed in Section 3.1.6, these materials are susceptible to MIC attack. Copper alloys with high zinc and aluminum contents will experience crevice and pitting corrosion in an aggressive environment. Section 3.1.9 defines the materials susceptible to selective leaching. These materials include high content copper alloys (zinc>15% and aluminum>8%) that are not "inhibited" (by the addition of small amounts of tin, arsenic, etc.) and are included in the logic. In addition, aluminum alloys with > 12% zinc or > 6% magnesium are susceptible to stress corrosion cracking in wetted locations that concentrate contaminants and when exposed to aggressive atmospheric environments.

4.4 GALL Comparison

The information contained in Chapters IV, V, VII, and VIII of Volume 2 of NUREG-1801, Revision 1, "Generic Aging Lessons Learned (GALL) Report – Tabulation of Results," identifies material, environment(s), aging effects (and associated mechanisms) typically requiring management for license renewal applicants, and the suggested aging management program (AMP) for various mechanical components. GALL Chapter IV, V, VII, and VIII tables all include items for environments addressed by this tool. The identification and evaluation of aging management programs (AMPs) is outside the scope of this tool and should be addressed on a plant-specific basis, as described in Section 4.0 of the main document. Pertinent GALL items are addressed in Table 4-1, with the following component, material, environment, aging effect, and aging mechanism considerations.

GALL Chapter VII includes items for structural components such as crane rails/girders (VII.B-1 and VII.B-3), fire barrier penetration seals/doors/barriers (VII.G-1, VII.G-2, VII.G-3, VII.G-4, VII.G-28, VII.G-29, VII.G-30, and VII.G-31), and structural steel (VII.A1-1) that are not addressed in this tool. The user of this tool is referred to the Structural Tools [25] for evaluation of the aging effects for these components. Component identification is also outside the scope of this tool.

The materials for the pertinent items in GALL Chapters IV, V, VII, and VIII are consistent with the materials addressed by this tool, which are described in Section 2.1. Stainless steel is referred to as "stainless steel" and nickel-base alloys are referred to as "nickel alloy" in the GALL items for environments addressed by this tool. Carbon or low-alloy steel is referred to as "steel" or "steel (with or without coating or wrapping)" in the GALL items for environments addressed by this tool. Coatings are not credited with precluding aging effects in this tool. Cast iron is included with "steel" in the GALL for environments addressed by this tool, except where gray cast iron is identified in "soil" environments. Copper and copper alloys are referred to as "copper alloy," as "copper alloy < 15% Zn," and as "copper alloy > 15% Zn" for various environments and aging effects addressed by this tool. Aluminum and aluminum alloys are referred to as "aluminum" in the GALL items for environments addressed by this tool. Items are included in the GALL for galvanized steel in environments addressed by this tool. The non-metals that are listed in the GALL are referred to as "glass" and "elastomers." Plastics and insulation are not listed in the GALL for the environments addressed by this tool.

OAGI0000553_00335

The following GALL Chapter IV, V, VII, and VIII environments for mechanical components are bounded by the environments addressed in this tool, which are described in Section 2.2:

GALL Environments	Appendix E Environments
▪ Air – indoor controlled (external) ▪ Air – indoor uncontrolled ▪ Air – indoor uncontrolled (external) ▪ Air with borated water leakage ▪ Air with leaking secondary-side water and/or steam ▪ Air with reactor coolant leakage ▪ Condensation ▪ Condensation (external)	Indoor air (protected from weather)
▪ Air – outdoor (external) ▪ Condensation ▪ Condensation (external)	Outdoor air (exposed to weather)
▪ Concrete	Embedded
▪ Soil	Buried

The GALL items (IV.E-4, IV.E-6, V.F-14, V.F-17, VII.J-17, VII.J-21, VIII.I-11, and VIII.I-14) that address steel and stainless steel in "concrete" concur with the conclusions of Section 2.2.4 of this tool with respect to there being no aging effects requiring management (applicable aging effects) for embedded surfaces. The GALL items for steel, galvanized steel, and aluminum exposed to controlled indoor air environments (V.F-1, V.F-16, VII.J-1, VII.J-20, VIII.I-13) concur with the consideration that there are typically no applicable aging effects in temperature/humidity controlled environments. "Controlled" indoor environments include areas such as the control room envelope, where conditioning and/or control is an intended function of the corresponding HVAC system(s).

The GALL items (V.F-6, VII.J-10, and VIII.I-5) that address glass in (uncontrolled) air concur with the conclusions of Section 3.6.1 of this tool with respect to there being no aging effects requiring management (applicable aging effects) for the external surfaces of glass components. Similarly, a GALL Chapter V item (V.B-4) cites hardening and loss of strength due to elastomer degradation in uncontrolled air without describing the relevant conditions for elastomer degradation. This GALL item concurs with Section 3.6.3 of this tool, which references EPRI report 1002590 [25] for discussion of the applicable aging effects for elastomers, and includes a description of the relevant conditions for the degradation of elastomers, such as temperature, radiation, sunlight, and ozone (natural rubbers). Additionally, certain GALL Chapter VII items (VII.F1-5, VII.F2-5, VII.F3-5, and VII.F4-4) cite loss of material due to wear as an aging effect requiring management for elastomer seals and components in air, which is more conservative than the discussion in Section 3.6.3 of this tool.

OAGI0000553_00336

The GALL does not evaluate mechanisms separately, as is done in Section 3.0 of this tool. The aging effect cited in GALL Chapters IV, V, VII, and VIII for the external surface of metals includes loss of material, with the following mechanism or groupings of mechanisms depending on material susceptibility and/or environment:

- Boric acid corrosion (steel, aluminum, and copper alloys > 15% Zn)
- Erosion (of PWR steam generator secondary side external surfaces due to leakage)
- General corrosion (of steel exposed to indoor air, outdoor air, and condensation)
- General, pitting, and crevice corrosion (of steel exposed to outdoor air)
- General, pitting, crevice, and microbiologically influenced corrosion (of steel with or without wrapping/coating exposed to soil)
- Pitting and crevice corrosion (of aluminum, copper alloy, or stainless steel exposed to soil or condensation)
- Selective leaching (of gray cast iron exposed to soil)

The GALL items for the above environments do not identify galvanic corrosion of external surfaces, whereas per Section 3.1.2, galvanic corrosion is evaluated in this tool and is applicable to carbon and low-alloy steel, cast iron, copper and copper alloys, and aluminum/aluminum alloys in wetted or buried locations, i.e., in the presence of an electrolyte, if connected to a more cathodic (noble) metal in the galvanic series. The GALL also does not identify cracking, due to SCC, of external surfaces, whereas it is evaluated in this tool, in Section 3.2.2, for aluminum and aluminum alloys, certain copper alloys, and stainless steel.

The GALL Chapter IV, V, VII, and VIII items that identify aging effects for closure bolting, and heat exchangers, except the external surfaces of shells/channels, are addressed separately in Appendix F and Appendix G, respectively. Likewise, GALL items for fatigue are evaluated separately in Appendix H and are not addressed in this tool.

Table 4-1 Aging Effects Summary - External Surfaces					
Material	**Aging Effect / Mechanism**	**Mechanism Applicability Criteria**	**NUREG-1801 (GALL) Item No.**	**Tool vs GALL Match**	**Relevant Sections, Assumptions, and Discussion**
All Metals	Loss of Material / MIC	1. Temperature < 212°F and pH < 10.5 *and* 2a. Surface is buried *or* 2b. Surface is subject to prolonged wetting other than humidity in outdoor locations (e.g., from condensation, leakage, ponding/pooling) Note: Intermittently or frequently wetted locations inside buildings do not typically promote MIC on external surfaces unless there has been an intrusion of groundwater or other aggressive contaminants (e.g., in industrial or marine areas). Any such instances are not typical and require plant-specific evaluation.	V.B-9, V.D1-26, V.D2-27 VII.C1-16, VII.C1-18, VII.C3-8, VII.C3-9, VII.G-20, VII.H1-7, VII.H1-9, VII.H2-19, VII.G-25 VIII.E-1, VIII.E-28, VIII.G-1, VIII.G-31	No	Sections 2, 3.1.6 Assumptions 4.1.4, 4.1.8 Specified GALL items also list general (steel), crevice, and pitting corrosion of steel (with or without coatings/wrappings) that is exposed to soil (buried), or list only pitting and crevice for stainless steel that is exposed to soil (buried), without indication as to why one material is resistant when another is not. See discussions below. GALL does not include items for MIC in outdoor air environments. Furthermore, GALL items for stainless steel exposed to soil (V.D1-26, V.D2-27, VII.C1-16, VII.C3-8, VII.G-20, VII.H1-7, VII.H2-19, VIII.E-28, and VIII.G-31) do not list MIC with crevice and pitting corrosion, although the material is susceptible if buried. No other materials are identified as being exposed to soil (buried) in GALL Chapters IV, V, VII, or VIII.
Aluminum and Aluminum Alloys	Loss of Material / Boric Acid Wastage	1. Surface is exposed to leakage from PWR borated water systems	V.D2-18 VII.A3-4, VII.E1-10	Yes	Sections 2.1.6, 3.1.10 Specified GALL items list boric acid corrosion of aluminum in air with borated water leakage.

OAGI0000553_00338

Table 4-1 Aging Effects Summary - External Surfaces					
Material	**Aging Effect / Mechanism**	**Mechanism Applicability Criteria**	**NUREG-1801 (GALL) Item No.**	**Tool vs GALL Match**	**Relevant Sections, Assumptions, and Discussion**
Aluminum and Aluminum Alloys (Cont'd)	Loss of Material / Crevice and/or Pitting Corrosion	1. Temperature < 212°F *and* 2a. Surface is buried or exposed to a concentration of contaminants[1] *or* 2b. Surface is exposed to an aggressive environment in outdoor locations[2]	V.F-2 VII.F1-14, VII.F2-12, VII.F3-14, VII.F4-10, VII.J-1	Yes	Sections 2.1.6, 3.1.3, 3.1.4 Assumptions 4.1.2, 4.1.4, 4.1.5 GALL items V.F-2 and VII.J-1 indicate that no aging effects require management for aluminum exposed to uncontrolled indoor air. Remaining specified GALL items cite pitting and crevice corrosion of aluminum exposed to condensation. GALL Chapters IV, V, VII, and VIII do not include items for aluminum in an outdoor or buried environment.
	Loss of Material / Galvanic Corrosion	1. Temperature < 212°F *and* 2. Component is connected to a more cathodic (noble) metal in the galvanic series *and* 3a. Surface is buried or exposed to a concentration of contaminants[1], which provide an electrolyte *or* 3b. Surface is exposed to an aggressive environment in outdoor locations[2], which provide an electrolyte	None	No	Sections 2.1.6, 3.1.2 GALL Chapters IV, V, VII, and VIII do not include items for galvanic corrosion of external component surfaces, only for internal surfaces of copper alloy exposed to treated water (Appendix A) and for heat exchanger components exposed to closed-cycle cooling water or raw water (Appendix G).

OAGI0000553_00339

Table 4-2 Aging Effects Summary - External Surfaces					
Material	**Aging Effect / Mechanism**	**Mechanism Applicability Criteria**	**NUREG-1801 (GALL) Item No.**	**Tool vs GALL Match**	**Relevant Sections, Assumptions, and Discussion**
Aluminum and Aluminum Alloys (Cont'd)	Cracking / SCC	1. Temperature < 212ºF *and* 2. Alloy has > 12% Zn or > 6% Mg *and* 3a. Surface is buried or exposed to a concentration of contaminants[1] *or* 3b. Surface is exposed to an aggressive environment in outdoor locations[2]	None	No	Sections 2.1.6, 3.2.2 GALL Chapters IV, V, VII, and VIII do not include items for cracking of aluminum (due to SCC), regardless of the environment.
Carbon and Low-Alloy Steel *and* Cast Iron	Loss of Material / Boric Acid Wastage	1. Surface is exposed to leakage from PWR borated water systems	V.A-3, V.A-4, V.D1-1, V.E-9 VII.A3-2, VII.E1-1, VII.I-10 VIII.H-9	Yes	Sections 2.1.3, 3.1.10 Specified GALL items list boric acid corrosion of steel, including cast iron, exposed to air with borated water leakage. GALL item V.A-3 also lists general, pitting, and crevice corrosion of the internal surface of steel encapsulation components. Boric acid corrosion of these internal surfaces (addressed in Appendix D) is only possible if the components encapsulate PWR components containing borated water.

OAGI0000553_00340

Table 4-1 Aging Effects Summary - External Surfaces					
Material	**Aging Effect / Mechanism**	**Mechanism Applicability Criteria**	**NUREG-1801 (GALL) Item No.**	**Tool vs GALL Match**	**Relevant Sections, Assumptions, and Discussion**
Carbon and Low-Alloy Steel *and* Cast Iron (Cont'd)	Loss of Material / Crevice and/or Pitting Corrosion	1. Temperature < 212°F *and* 2a. Surface is buried or exposed to a concentration of contaminants[1] *or* 2b. Surface is exposed to an aggressive environment in outdoor locations[2]	V.B-9 VII.C1-18, VII.C3-9, VII.G-25, VII.H1-8, VII.H1-9, VII.H1-11 VIII.E-1, VIII.E-39, VIII.G-1, VIII.G-40	No	Sections 2.1.3, 3.1.3, 3.1.4 Assumptions 4.1.2, 4.1.4, 4.1.5 Specified items cite general, pitting, and crevice corrosion of steel exposed to outdoor air or, for steel (with or without coatings or wrappings) exposed to soil (buried), also cite MIC. However, specified GALL items do not cite conditions/criteria for the mechanisms to be applicable. Furthermore, GALL Chapter V, VII, and VIII items are not consistent with respect to crevice and pitting corrosion requiring management in outdoor air or condensation. GALL items VII.H1-8, VII.H1-11, VIII.E-39, and VIII.G-40 cite crevice and pitting corrosion for steel exposed to outdoor air, whereas GALL items V.E-8, VII.I-9, and VIII.H-8 (not specified for this item) cite only general corrosion of steel in outdoor air. GALL items V.C-2, V.E-10, VIII.H-10, and VII.I-11 (not specified for this item) cite only general corrosion as requiring management for steel exposed to condensation, whereas this tool describes criteria/conditions where pitting and crevice may conservatively occur due to condensation (and concentration of contaminants).

OAGI0000553_00341

Table 4-1 Aging Effects Summary - External Surfaces					
Material	**Aging Effect / Mechanism**	**Mechanism Applicability Criteria**	**NUREG-1801 (GALL) Item No.**	**Tool vs GALL Match**	**Relevant Sections, Assumptions, and Discussion**
Carbon and Low-Alloy Steel *and* Cast Iron (Cont'd)	Loss of Material / General Corrosion	1. Temperature < 212˚F *and* 2a. Surface is exposed to humidity and/or intermediate or frequent wetting *or* 2b. Surface is buried Note: General corrosion is of particular concern outdoors where plant operating experience has shown exposure to aggressive species (such as near seashore and industrial areas) and indoors where surface is wetted such as due to condensation from lower than ambient internal fluid temperatures. Plant-specific conditions may also support corrosion rates being low enough that loss of material due to general corrosion is not a concern.	V.A-1, V.B-3, V.B-9, V.C-1, V.C-2, V.D2-2, V.E-7, V.E-8, V.E-10 VII.C1-18, VII.C3-9, VII.D-3, VII.F1-2, VII.F2-2, VII.F3-2, VII.F4-1, VII.G-25, VII.H-9, VII.I-8, VII.I-9, VII.I-11 VIII.E-1, VIII.G-1, VIII.H-7, VIII.H-8, VIII.H-10	Yes	Sections 2.1.3, 3.1.1 Assumptions 4.1.2, 4.1.4, 4.1.11 Specified GALL Chapter V, VII, and VIII items cite general corrosion as requiring management in uncontrolled indoor air, condensation, outdoor air, and buried environments. As described for items above, certain items also list pitting and crevice corrosion in outdoor air, whereas others do not and no justification for the difference is provided in the GALL (or its basis NUREG/CR). Also, certain items also list pitting and crevice corrosion and MIC as requiring management for steel (with or without coatings or wrappings) exposed to soil, as described above.

OAGI0000553_00342

Table 4-1 Aging Effects Summary - External Surfaces					
Material	**Aging Effect / Mechanism**	**Mechanism Applicability Criteria**	**NUREG-1801 (GALL) Item No.**	**Tool vs GALL Match**	**Relevant Sections, Assumptions, and Discussion**
Carbon and Low-Alloy Steel *and* Cast Iron (Cont'd)	Loss of Material / Galvanic Corrosion	1. Temperature < 212°F *and* 2. Component is connected to a more cathodic (noble) metal in the galvanic series *and* 3a. Surface is buried or exposed to a concentration of contaminants[1], which provide an electrolyte *or* 3b. Surface is exposed to an aggressive environment in outdoor locations[2], which provide an electrolyte	None	No	Sections 2.1.3, 3.1.2 GALL Chapter IV, V, VII and VIII items do not address galvanic corrosion of external component surfaces.
Cast Iron *and* Copper and Copper Alloys	Loss of Material / Selective Leaching	1. Temperature < 212°F *and* 2. Material is gray cast iron or brass/bronze >15% Zn or aluminum bronze > 8% Al *and* 3. Material is **not** an inhibited copper alloy (e.g., with small amounts of tin, phosphorous, arsenic, and antimony) *and* 4a. Surface is buried or exposed to prolonged wetting other than humidity[1] *or* 4b. Surface is exposed to an aggressive environment in outdoor locations[2]	V.B-8, V.D1-21, V.D2-24 VII.C1-12, VII.C3-5, VII.G-15, VII.H1-5, VII.H2-15 VIII.E-22, VIII.G-25	No	Sections 2.1.4, 2.1.5, 3.1.9 Assumption 4.1.4 Specified GALL items are all for gray cast iron exposed to soil. GALL Chapter IV, V, VII, and VIII items do not list selective leaching of external surfaces of copper alloys.

OAGI0000553_00343

Table 4-1 Aging Effects Summary - External Surfaces					
Material	**Aging Effect / Mechanism**	**Mechanism Applicability Criteria**	**NUREG-1801 (GALL) Item No.**	**Tool vs GALL Match**	**Relevant Sections, Assumptions, and Discussion**
Copper and Copper Alloys	Loss of Material / Boric Acid Wastage	1. Material is a copper alloy with > 15% Zn *and* 2. Surface is exposed to leakage from PWR borated water systems	V.E-11, V.F-5 VII.I-12, VII.J-5	Yes	Sections 2.1.5, 3.1.10 Specified GALL items cite boric acid corrosion for copper alloys > 15% Zn, or indicate that no aging effects require management for copper alloy < 15% Zn (items V.F-5 and VII.J-5), in air with borated water leakage.
	Loss of Material / Crevice and/or Pitting Corrosion	1. Temperature < 212°F *and* 2a. Surface is buried or exposed to a concentration of contaminants[1] *or* 2b. Surface is exposed to an aggressive environment in outdoor locations[2]	VII.F1-16, VII.F2-14, VII.F3-16, VII.F4-12	Yes	Sections 2.1.5, 3.1.3, 3.1.4 Assumptions 4.1.2, 4.1.4, 4.1.5 Specified GALL items list crevice and pitting corrosion for copper alloys exposed to external condensation.
	Loss of Material / Galvanic Corrosion	1. Temperature < 212°F *and* 2. Component is connected to a more cathodic (noble) metal in the galvanic series *and* 3a. Surface is buried or exposed to a concentration of contaminants[1], which provide an electrolyte *or* 3b. Surface is exposed to an aggressive environment in outdoor locations[2], which provide an electrolyte	None	No	Sections 2.1.5, 3.1.2 GALL Chapter IV, V, VII, and VIII items do not address galvanic corrosion of external component surfaces.

OAGI0000553_00344

Table 4-1 Aging Effects Summary - External Surfaces					
Material	**Aging Effect / Mechanism**	**Mechanism Applicability Criteria**	**NUREG-1801 (GALL) Item No.**	**Tool vs GALL Match**	**Relevant Sections, Assumptions, and Discussion**
Copper and Copper Alloys (Cont'd)	Cracking / SCC/IGA	1. Material is Brass > 15% Zn or aluminum bronze with > 8% Al *and* 2. Surface is subject to moisture (humidity) or intermittent or prolonged wetting *and* 3. Ammonia (NH_3), ammonium salts, or sulfur dioxide is present (e.g., from organic decay, in industrial areas) Note: Mechanism, as well as rapid loss of material due to general corrosion, is a concern if plant-specific operating experience shows presence of ammonia, ammonium salts, or sulfur dioxide.	None	No	Sections 2.1.5, 3.1.1, and 3.2.2 GALL Chapters IV, V, VII, and VIII do not include items for cracking of copper alloys.
Galvanized Steel	Loss of Material / General Corrosion	1. Temperature < 212°F *and* 2. Component buried or subject to prolonged wetting other than humidity (e.g., condensation, leakage, pooling) *and* 3a. pH > 12 or pH < 6 *or* 3b. Temperature > 140°F and < 200°F	V.F-1 VII.J-6	Yes	Sections 2.1.8, 3.1.1, 3.5 Assumptions 4.1.2, 4.1.4, 4.1.10 Specified GALL items indicate that no aging effects require management for galvanized steel in uncontrolled indoor air, but no technical basis is provided for the determination.

OAGI0000553_00345

Table 4-1 Aging Effects Summary - External Surfaces					
Material	**Aging Effect / Mechanism**	**Mechanism Applicability Criteria**	**NUREG-1801 (GALL) Item No.**	**Tool vs GALL Match**	**Relevant Sections, Assumptions, and Discussion**
Galvanized Steel (Cont'd)	Loss of Material / Boric Acid Wastage	1. Surface is exposed to leakage from PWR borated water systems Note: It is conservatively assumed that galvanized steel is susceptible to boric acid wastage based on a lack of definitive evidence to the contrary.	None	No	Sections 2.1.8, 3.1.10 GALL Chapters IV, V, VII, and VIII do not include items addressing boric acid corrosion of galvanized steel.
	Reduction of Fracture Toughness / Thermal Embrittlement	1. Temperature > 400ºF	None	No	Sections 2, 3.3.1, 3.5 GALL Chapters IV, V, VII, and VIII do not include items addressing thermal embrittlement of galvanized steel.

OAGI0000553_00346

Table 4-1 Aging Effects Summary - External Surfaces					
Material	**Aging Effect / Mechanism**	**Mechanism Applicability Criteria**	**NUREG-1801 (GALL) Item No.**	**Tool vs GALL Match**	**Relevant Sections, Assumptions, and Discussion**
Nickel-Base Alloys *and* Stainless Steel	Loss of Material / Pitting and/or Crevice Corrosion	1. Temperature < 212°F *and* 2a. Surface is buried or subject to a concentration of contaminants[1] *or* 2b. Surface is exposed to an aggressive environment in outdoor locations[2]	IV.E-1, IV.E-2 V.D1-26, V.D2-27, V.F-11, V.F-12, V.F-13 VII.C1-16, VII.C3-8, VII.F1-1, VII.F2-1, VII.F3-1, VII.G-20, VII.H1-7, VII.H2-19, VII.J-14, VII.J-15, VII.J-16 VIII.E-28, VIII.G-31, VIII.I-9, VIII.I-10	Yes	Sections 2.1.1, 2.1.2, 3.1.3, 3.1.4 Assumptions 4.1.2 GALL items V.D1-26, V.D2-27, VII.F1-1, VII.F2-1, VII.F3-1, VII.C1-16, VII.C3-8, VII.G-20, VII.H1-7, VII.H2-19, VIII.E-28, and VIII.G-31 cite crevice and pitting corrosion of stainless steel exposed to soil (buried) or condensation (e.g., concentration of contaminants). Otherwise, the specified GALL items indicate that no aging effects require management for nickel alloys exposed to uncontrolled indoor air or for stainless steel exposed to uncontrolled indoor air or air with borated water leakage.

OAGI0000553_00347

Table 4-1 Aging Effects Summary - External Surfaces					
Material	**Aging Effect / Mechanism**	**Mechanism Applicability Criteria**	**NUREG-1801 (GALL) Item No.**	**Tool vs GALL Match**	**Relevant Sections, Assumptions, and Discussion**
Stainless Steel	Cracking / SCC	1. Temperature < 212˚F *and* 2. Temperature > 140˚F *and* 3a. Surface is buried or subject to a concentration of contaminants[1] *or* 3b. Surface is exposed to an aggressive environment in outdoor locations[2]	None	No	Sections 2.1.1, 3.2.2 Assumptions 4.1.2, 4.1.4, 4.1.6, 4.1.7 GALL Chapter IV, V, VII, and VIII items for SCC of stainless steel are all focused on wetted internal surfaces.
Titanium and Titanium Alloys	Loss of Material / Crevice Corrosion	1. Temperature < 212ºF *and* 2. Temperature > 160ºF *and* 3a. Surface is buried or subject to a concentration of contaminants[1] *or* 3b. Surface is exposed to an aggressive environment in outdoor locations[2]	None	No	Sections 2, 3.1.3 Assumptions 4.1.2, 4.1.4 GALL Chapters IV, V, VII, and VIII do not include items for titanium or titanium alloys.

1 Prolonged or frequent wetting (e.g., from condensation, leakage, ponding/pooling) or alternate wetting and drying can concentrate contaminants from the atmosphere and they can thereby become aggressive species for metals. Infrequent or intermittent wetting (e.g., limited time periods with condensation) are not expected to concentrate contaminants sufficiently to become aggressive for metals.

2 Where plant-specific operating experience has shown exposure to aggressive species in outdoor locations, such as salt air in marine areas and sulfur dioxide, acid rain etc. in industrial areas, the normal atmosphere should be considered to be aggressive to exposed metals.

OAGI0000553_00348

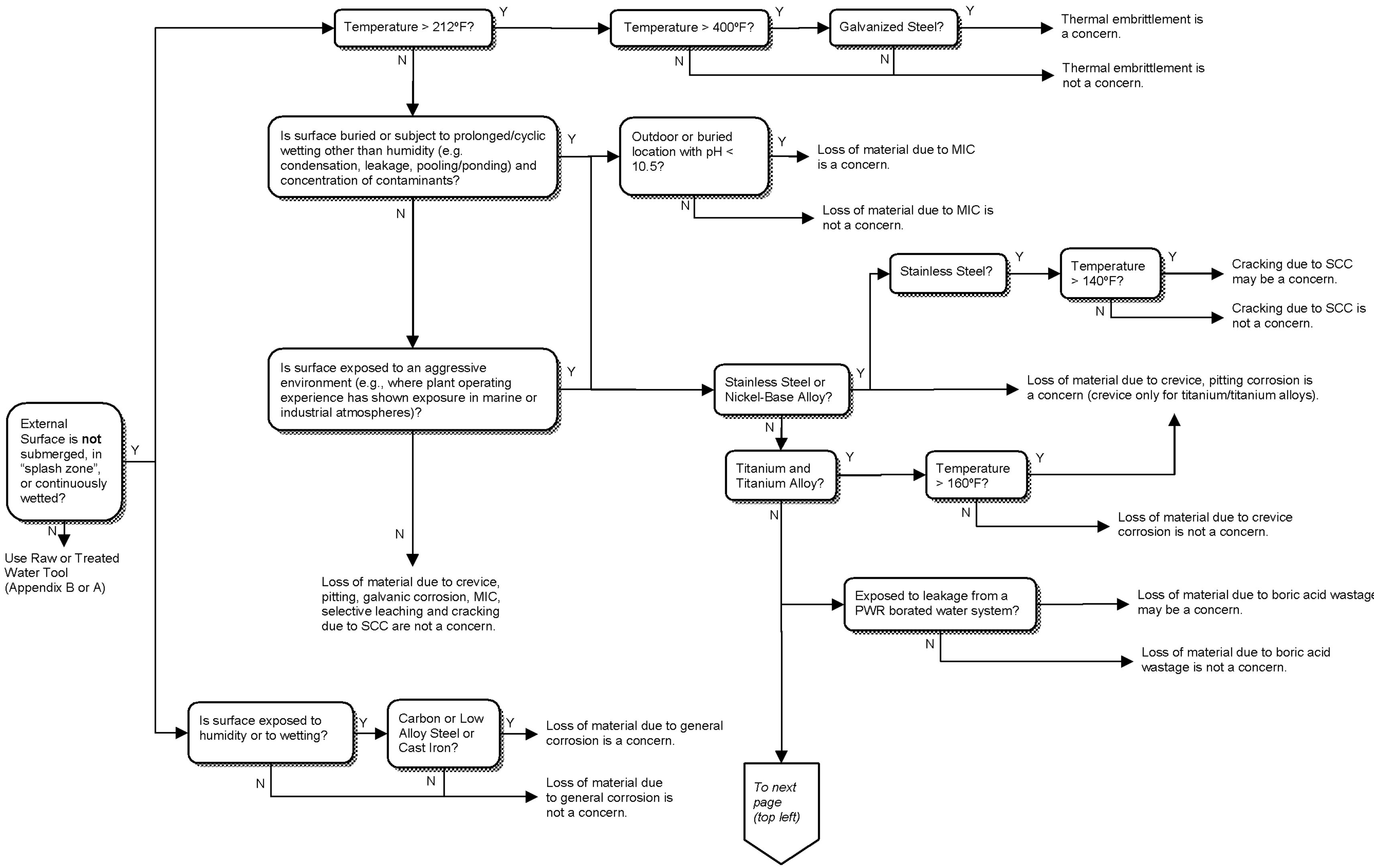
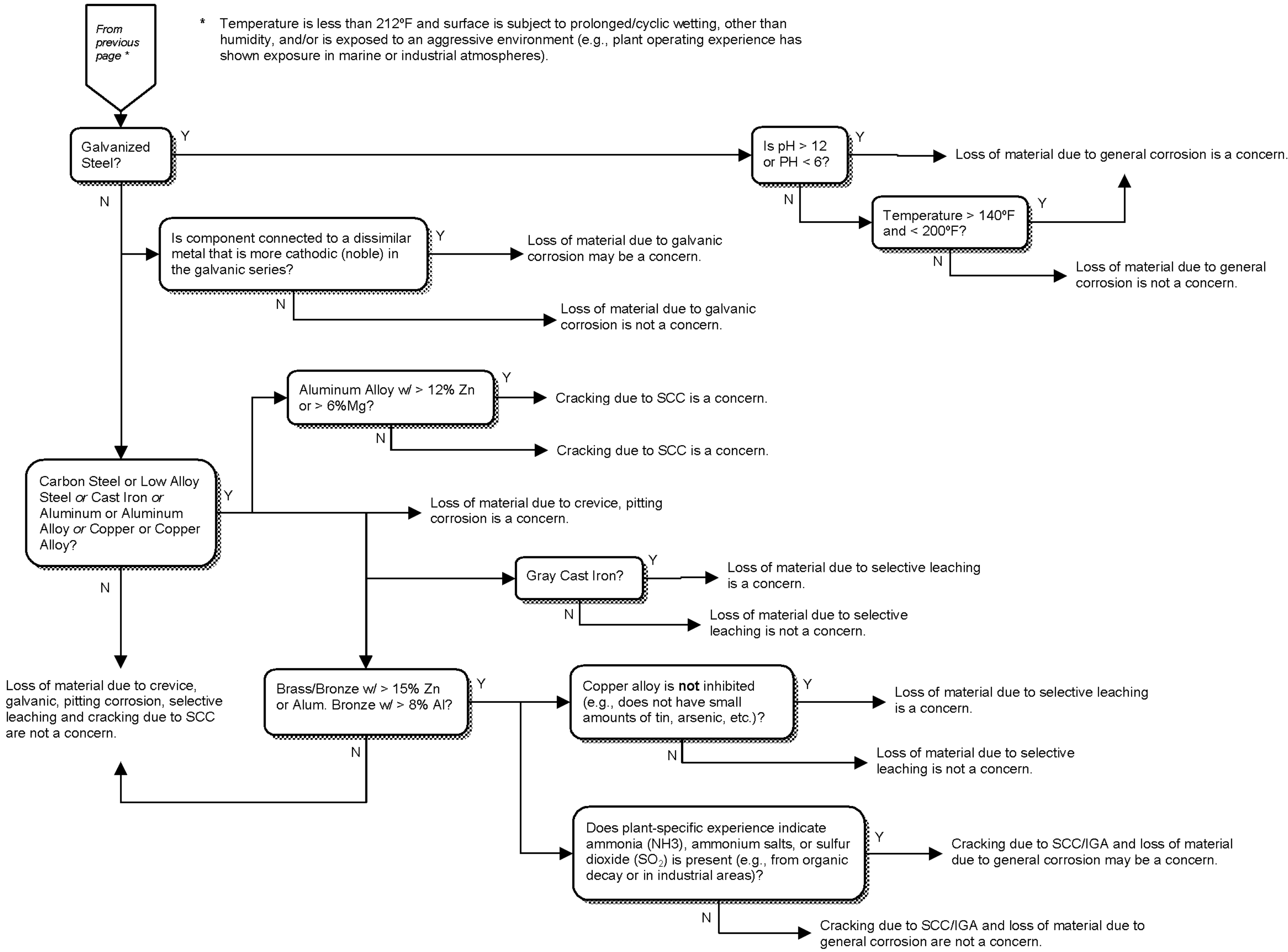


Figure 1 External Surface Tool

OAGI0000553_00349

Figure 1 External Surface Tool



OAGI0000553_00350

5. REFERENCES

1. G. E. Troxell, H. E. Davis, and J. W. Kelly, *Composition and Properties of Concrete,* Second Edition, McGraw-Hill, 1968.

2. J. F. Copeland, et al., "Component Life Estimation: LWR Structural Materials Degradation Mechanisms," EPRI NP-5461, Electric Power Research Institute, Palo Alto, CA, September 1987.

3. H. H. Uhlig, *Corrosion Handbook,* John Wiley and Sons, 1948.

4. Leech, Miller, Renwick, and Wright, "Conquering Service Water Pipe Corrosion," article, *Pipework and Valves,* January, 1984.

5. M. G. Fontana, *Corrosion Engineering,* Third Edition, McGraw-Hill, New York, 1986.

6. W. H. Ailor, *Atmospheric Corrosion,* John Wiley and Sons, New York, 1982.

7. D. J. DePaul, ed., *Corrosion and Wear Handbook for Water Cooled Reactors,* McGraw-Hill, New York, 1957.

8. B. Craig, "Environmentally Induced Cracking," *Metals Handbook,* Ninth Edition, Vol. 13, Corrosion, American Society for Metals International, Materials Park, OH, 1987.

9. "Standard Format and Content of Technical Information for Application to Renew Nuclear Power Plant Operating Licenses," Draft Regulatory Guide DG-1009, U.S. Nuclear Regulatory Commission, Washington D.C., December 1990.

10. B. E. Crane, G. O. Hayner, and D. H. Pope, "Microbiologically Influenced Corrosion in Condenser Water Boxes at Crystal River-3," *Proceedings of the Third International Symposium on Environmental Degradation of Materials in Nuclear Power Reactors,* American Nuclear Society, La Grange Park, IL, 1987, p. 647.

11. *Metals Handbook,* Desk Edition, American Society for Metals, Materials Park, OH, 1985.

12. D. H. Pope, "A Study of Microbiologically Influenced Corrosion in Nuclear Power Plants and a Practical Guide for Countermeasures," EPRI NP-4582, EPRI, Palo Alto, CA, May 1986.

13. G. Robison, E. Grubbs, M. Rinckel, and R. Starkey, "Demonstration of the Management of Aging Effects for the Reactor Coolant System Piping," BAW-2243A, Framatome ANP, Lynchburg, VA, June 1996.

14. "PWR Reactor Coolant System License Renewal Industry Report," Project RP 2643-32, Electric Power Research Institute, Palo Alto, CA, May 1992.

OAGI0000553_00351

15. D. Deng, et al., "Class 1 Structures License Renewal Industry Report; Revision 1," EPRI TR-103842, Electric Power Research Institute, Palo Alto, CA, Final Report, July 1994.

16. R. H. Jones, *Stress Corrosion Cracking,* American Society of Metals, Materials Park, OH, 1992.

17. S. Yukawa, "Review and Evaluation of the Toughness of Austenitic Steels and Nickel Alloys after Long-Term Elevated Temperature Exposures," WRC Bulletin 378, Welding Research Council, New York, NY, January 1993.

18. D. Peckner and I. M. Bernstein, Eds., *Handbook of Stainless Steels,* McGraw-Hill, New York, 1977.

19. "System Material Analysis Department Report on the Evaluation of Material from Dresden Unit 2 Reactor Head Closure Studs," CECo Document M-03166-93, Commonwealth Edison Company, Chicago, IL, May 1993.

20. Nickell, M. A. Rinckel, "Evaluation of Thermal Aging Embrittlement for Cast Austenitic Stainless Steel Components," TR-106092, Research Project 2643-33, Final Report, March 1996.

21. F. L. LaQue and H.R. Cupson, "Corrosion Resistance of Metals and Alloys." Reinhold Publishing Company, New York, 2nd Edition, Copyright 1963.

22. J. C. Lynn, W. R. Warke, and P. Gordon, "Solid Metal-Induced Embrittlement of Steel," Materials Science and Engineering 18 (1975), Pages 51-62.

23. "Flow-Accelerated Corrosion in Power Plants," Revision 1, EPRI TR-106611, 1998.

24. *Metals Handbook,* Ninth Edition, Volume 13, "Corrosion," American Society of Metals International, Copyright 1987.

25. "Aging Effects for Structures and Structural Components (Structural Tools)," EPRI 1002950 (successor to TR-114881, 1997), July 2003.

26. J.F. Malloy, "Thermal Insulation," Van Nostrand Reinhold Company, Copyright 1969.

27. J.F. Hall, "Literature Survey of Low Alloy Steel Fastener Corrosion in PWR Plant," EPRI Report NP-3784, August 1984.

28. M.G. Fontana and R.W. Staehle, "Advances in Corrosion Science and Technology - Volume 5," Plenum Press, Copyright 1976.

29. Engineered Materials Handbook (Desk Edition), "Design and Engineering Properties of Glasses," American Society of Metals, International, Copyright 2002.

30. Engineered Materials Handbook (Desk Edition), "Introduction to Engineering Plastics – Environmental Factors," American Society of Metals, International, Copyright 2002.

OAGI0000553_00352

31. Metals Handbook, Ninth Edition, Volume 11, "Failure Analysis and Prevention," Article – Effect of the Environment on the Performance of Plastics, ASM International, Copyright 2003.

32. P.A. Schweitzer, "Corrosion Resistance Tables – Metals, Nonmetals, Coatings, Mortars, Plastics, Elastomers and Linings, and Fabrics," Fourth Edition, Parts A, B and C, Marcel Dekker, Copyright 1995

33. EPRI NP-3944 "Erosion/Corrosion in Nuclear Plant Steam Piping: Causes and Inspection Program Guidelines," April 1985.

34. EPRI Report 1003057, "License Renewal Electrical Handbook," December 2001.

OAGI0000553_00353

Appendix F - Bolted Closures

Bolting applications within the scope of license renewal may be divided into pressure boundary bolting and structural and component support bolting. Pressure boundary bolting applications, which are addressed in this appendix, include bolted flange connections for vessels and heat exchangers (i.e., manways and hand holes), flanged joints in piping, body-to-bonnet joints in valves, and pressure retaining bolting associated with pumps and miscellaneous process components; these bolted joints are hereafter referred to as bolted closures. Structural and component support bolting is not addressed in this appendix but is included in the structural tools being developed separately.

CONTENTS

Page

1. INTRODUCTION 1-1
1.1 Purpose 1-1
1.2 Regulatory Bolting Safety Issue 1-1

2. BOLTED CLOSURES – SCOPE 2-1

3. AGING EFFECTS 3-1
3.1 Loss of Pre-Load 3-1
3.1.1 Embedment 3-1
3.1.2 Cyclic Load Embedment 3-2
3.1.3 Gasket Creep 3-2
3.1.4 Thermal Effects 3-2
3.1.5 Self-Loosening 3-2
3.2 Cracking of Bolting Materials 3-3
3.3 Loss of Material – Corrosion of Bolting Materials 3-4
3.4 Reduction of Fracture Toughness 3-5
3.5 Operating Experience and Generic Communications 3-5
3.5.1 NPRDS Review 3-5
3.5.2 NRC Generic Communications 3-5

4. SUMMARY 4-1
4.1 GALL Comparison 4-1

5. REFERENCES 5-1

OAGI0000553_00355

LIST OF TABLES

Table 4-1 Aging Effects Summary – Bolted Closures 4-4

OAGI0000553_00356

1. INTRODUCTION

1.1 Purpose

Bolting applications within the scope of license renewal may be divided into pressure boundary bolting and structural and component support bolting. Pressure boundary bolting applications, which are addressed in this appendix, include bolted flange connections for vessels and heat exchangers (i.e., manways and hand holes), flanged joints in piping, body-to-bonnet joints in valves, and pressure retaining bolting associated with pumps and miscellaneous process components; these bolted joints are hereafter referred to as bolted closures. (Structural and component support bolting is addressed in the Structural Tools) [6]. A bolted closure includes the constituents of a bolted joint, e.g., seating surfaces (i.e., flange set surfaces), gasket (if applicable), and pressure retaining bolting. Only non-Class 1 bolted closures are addressed in this document.

Aging management programs required to assure bolted closure integrity will be addressed on a plant-specific basis using general recommendations provided in Section 4.0. The scope of bolted closures is discussed in Section 2.0, and typical aging effects that may cause loss of mechanical closure integrity are discussed in Section 3.0.

1.2 Regulatory Bolting Safety Issue

The NRC noted that from 1964 to the early 1980s there had been an increasing number of reported failures of high-strength bolting in safety-related equipment and Class 1 component supports [1]. The most common failures of pressure retaining bolting in safety-related equipment were attributed to boric acid corrosion wastage and a few instances of stress corrosion cracking (SCC). The most frequently observed failure mode for structural bolting was SCC of low-alloy quenched and tempered steels and maraging steels.

The bolting safety issue originally was an integral part of the NRC's unresolved safety Issue A-12, which dealt with fracture toughness concerns related to steam generator and reactor coolant pump supports. The NRC then recognized the need to assess bolting safety issues separately and issued Generic Safety Issue 29, "Bolting Degradation or Failure in Nuclear Power Plants." The safety aspects of GSI 29 included concerns over degradation of fasteners that comprise critical bolting applications in nuclear power plants. In June 1982, the NRC issued IE Bulletin 82-02, which required responsive actions by all pressurized-water-reactor licensees because threaded fastener failures had shown an increasing frequency of occurrence. In response to the NRC concerns over fastener integrity, the Atomic Industrial Forum (AIF) joined with the Material Properties Council (MPC) to form the Joint AIF/MPC Task Group on Bolting in June 1982. When the NRC prioritized generic issues in November 1982, GSI 29 was assigned a high priority.

The Joint AIF/MPC Task Group on Bolting developed a comprehensive industry program to resolve GSI 29. Specifically, a 19-task Generic Bolting Program was developed and the Electric Power Research Institute organized a matrix-managed Generic Bolted Joint Integrity Program to carry out the recommendations contained in the task list. Results of the 19-task program are contained in a two-volume EPRI report, NP-5769 [2], which was published in April 1988. The work completed to resolve GSI 29, as documented in the EPRI report [2], showed that (1) existing requirements, (2)

OAGI0000553_00357

leak-before-break criteria for Class 1 joints, and (3) existing programs should minimize the risk resulting from the failure of safety-related bolting in current plants. In addition, the NRC staff concurred with the recommendations and guidelines provided in Section 1, Volume 2 of the EPRI report [2].

A major finding of the Generic Program was that the design of critical closure joint bolting involves enough redundancy to ensure that there is no pressing concern regarding bolting integrity. In addition, it was recommended that licensees implement plant-specific bolting integrity programs that reflect the information and recommendations made by the industry-sponsored programs on bolting issues. While the focus of the study was on Class 1 bolted closures, all safety-related closures were considered.

OAGI0000553_00358

2. BOLTED CLOSURES – SCOPE

The scope of the bolted closure tool includes surfaces of bolted flange connections for vessels (i.e., manways, hand holes, etc.), flanged joints in piping, body-to-bonnet joints in valves, and pressure retaining bolting associated with pumps and miscellaneous process components. As discussed in Section 2.0 of the Implementation Guideline, gaskets, packing, seals, and o-rings are typically excluded from the scope of license renewal where these components are not relied upon for a SSC to perform its intended function.

Pressure boundary bolting, typically referred to as fasteners, includes nuts, bolts, studs, and capscrews. Typical fastener materials include carbon steel—A307, A36, SAE J429, A325, A449, and A490; low-alloy steel—A193 B7, B7M, A 320 L7, L7M, L70; and austenitic stainless steel—A193 B8 and B8M, and A320 B8 and B8M.

Class 1 to Non-Class 1 Boundary

The Class 1 ISI boundary typically extends to and includes either the first or second isolation valve or a flow restricting orifice in branch lines attached to the reactor coolant system main coolant piping and other major RCS (PWRs) or primary system (BWRs) components. For flanged connections that define a Class boundary, the Class 1 portion includes the face of the first flange (the bolts may be considered part of the non-Class 1 piping). For threaded joints, the Class 1 boundary includes the threaded joint in screwed connections.

OAGI0000553_00359

3. AGING EFFECTS

The governing aging effect to consider for bolted closures is loss of mechanical closure integrity. Loss of mechanical closure integrity may be attributed to one or more of the following aging effects that may be applicable to the bolted joint: loss of pre-load, cracking of bolting material, loss of bolting material, and reduction of fracture toughness of bolting material. In the discussion presented below, aging mechanisms that may result in the aforementioned aging effects are discussed. The mechanisms discussed are not intended to represent a comprehensive list of aging mechanisms and are provided for general information only. The discussion of aging mechanisms is extracted from the EPRI manuals on good bolting practices [3, 4].

3.1 Loss of Pre-Load

Pre-load is the tension force developed in a fastener when it is tightened against a joint. The pre-load in a bolt is often less than expected and decrease of the pre-load may be attributed to, but not limited to, one or more of the following effects: embedment, cyclic load embedment, gasket creep, thermal effects (e.g., yield stress effect, modulus of elasticity effect, and stress relaxation), and self-loosening. These effects are discussed at length in References 3 and 4 and are briefly summarized below. These effects are typically addressed upon installation and subsequent maintenance of the joint.

In addition to being precluded by design, the loss of pre-load in a mechanical joint can only result in leakage, not failure of that joint. This leakage does not impact the pressure boundary such that the component's intended function is not accomplished. It is noted that in ASME Section III (NX-2121), gaskets, seals, and O-rings are not considered to perform a pressure retaining function and therefore, these parts are typically not considered to support a component intended function. It follows that the loss of pre-load from the above mechanisms does not result in loss of mechanical closure or loss of pressure boundary integrity. Therefore, loss of pre-load is not an applicable aging effect.

3.1.1 Embedment

Fastener and joint surfaces are microscopically rough. When first assembled, these surfaces (nut, bolt threads, joint members, etc.) only contact each other on high spots.

When initially loaded the high spots tend to creep and flow. Pre-load is lost as the parts settle in together. The corresponding loss of pre-load is considered small and will have minimal effect on connection integrity.

OAGI0000553_00360

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, pre-load losses of 25% or even 50% may occur.

3.1.3 Gasket Creep

Gaskets must be partially plastic to function properly and will creep after initial loading. Pre-load loss at room temperature may be 2-5% and will occur in 10 to 20 minutes after initial loading.

3.1.4 Thermal Effects

A joint subjected to a change in temperature can lose pre-load. Differential expansion between bolts and joint members can increase stresses and increase embedment or gasket creep. The bolt 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. Creep of bolts and gaskets can be promoted by high temperature through a process called stress relaxation.

At elevated temperatures, a material subject to constant stress below its yield strength will flow plastically and permanently change dimensions in the direction of the stress. Also at elevated temperatures, a fastener will produce less and less clamping force with time, referred to as relaxation. Such elements as material, temperature, initial stress, manufacturing method, and design affect the rate of relaxation. Relaxation is a critical condition in the design of fasteners for service at elevated temperatures. A bolted joint at 1200°F can lose as much as 50% of preload. Furthermore, elevated temperature behavior, e.g., where relaxation might occur, begins at approximately 400°F for aluminum alloys, 700°F for low-alloy steels, and higher for austenitic stainless steels [8]. Aluminum bolting is not typically used in nuclear plant applications. As such, stress relaxation is a consideration in the design of bolting for service at elevated temperatures, and the temperatures experienced at nuclear plants are below the 700°F where relaxation might occur. Therefore, loss of preload due to thermal effects is not an applicable aging effect.

3.1.5 Self-Loosening

Vibration, flexing of the joint, cyclic shear loads, thermal cycles, and other factors can cause whole or partial self-loosening of a fastener. Self-loosening is not an applicable aging effect since it would be detected early in component service life and actions are taken to prevent recurrence, except as noted. Vibration of equipment that is infrequently operated, such as diesel generators, may result in self loosening of associated fasteners that may not be detected early in service life. Plant-specific consideration of its bolting practices and history is suggested.

OAGI0000553_00361

3.2 Cracking of Bolting Materials

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

Stress Corrosion Cracking (SCC)

Stress corrosion cracking (SCC) is a condition in which a fastener that is statically loaded well below the material yield strength can suddenly fail. SCC occurs through the combination of high stress (both applied and residual tensile stresses), a corrosive environment, and a susceptible material. SCC bolted closure fastener failures have occurred in materials with apparently nominal chemical and mechanical properties [2]. Service and laboratory failures have been observed for 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 fasteners.

Reported failures of bolting owing to SCC have been limited to high strength or ultra high strength bolting (i.e., $Sy > 150$ ksi). Some failures occurred with materials specified as medium strength (i.e., 120 ksi $< Sy <$ 150 ksi), however these SCC failures were primarily due to poor heat treatment resulting in overly hard material condition [2]. The medium strength material failures due to SCC have been related to poor quality control and not due to aging. Specifically, the failures that have been reported for two classes of bolting materials are for high-nickel maraging steels and low-alloy quenched and tempered (LAQT) steels. Both high-nickel maraging steels and LAQT steels are commonly used for NSSS component support bolting. Since none of the reported failures occurred in bolts of less than 1.25-inch diameter, it is recommended that only high strength bolts or studs greater than one inch nominal diameter be reviewed for SCC as a potential aging mechanism.

A common factor in several of the reported failures appears to be the use of lubricants containing molybdenum disulfide (MoS_2) [2]. Laboratory tests indicate that hydrogen sulfide (H_2S) may result from MoS_2 decomposition in aqueous environments; however, there is no data that conclusively shows that MoS_2 decomposition will cause SCC. Data generated by the oil and gas industry shows 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. However, in response to NRC IE Bulletin 82-02, utilities verified that threaded fastener lubricants have specified maximum allowable chloride and sulfur content to minimize the potential for SCC. Additionally, utilities verified that specific maintenance procedures and training were performed to address bolted closures and tensioning and detensioning practices.

The use of appropriate materials (such as ASTM A193 Gr. B7) for bolting also reduces the potential for SCC of fasteners by maintaining fastener minimum yield strengths below threshold values found in Reference 2. Additionally, sound maintenance bolt torquing practices can control bolting material stresses. A review of industry failure databases and NRC generic communications supports the fact that these actions (material selection, proper maintenance and torquing procedures, removal of contaminants from lubricants) have been effective in eliminating the potential for SCC of bolting materials.

OAGI0000553_00362

Therefore, cracking of bolting due to stress corrosion cracking is not an applicable aging effect for typical non-Class 1 nuclear plant bolting materials, but may be a concern in plant-specific instances where high-strength bolting materials or molybdenum disulfide (MoS_2) lubricants are used.

Fatigue

Cracking of bolting due to fatigue is typically characterized by the following: (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 non-Class 1 bolting applications due to low operating temperatures compared to the Class 1 bolting applications. High cycle fatigue is not a concern for license renewal since it would be discovered during the current license period in most cases where systems are frequently operated. For standby systems subject to periodic testing, such as HPCI, failure caused by high cycle fatigue may be a longer term issue. Evaluation of high cycle fatigue for infrequently used systems is not addressed and should be considered on a case-by-case basis by the user of this document.

3.3 Loss of Material – Corrosion of Bolting Materials

Loss of material due to boric acid wastage is the most common aging affect that has been observed for carbon and low-alloy steel fasteners. Stainless steel fasteners are highly resistant to loss of material due to general corrosion and to boric acid wastage.

Consistent with the applicable aging effects identified for external surfaces, documented separately in Appendix E, the following aging effects are conservatively considered to be applicable to carbon and alloy steel bolting materials:

- Loss of material due to general corrosion in moist environments (e.g., if temperatures are < 212ºF)
- Loss of material due to crevice or pitting corrosion in prolonged or frequently wetted locations (such as due to condensation, submersion, or in the "splash" zone)
- Loss of material due to boric acid wastage in PWR locations susceptible to leakage from systems containing borated water.

3.4 Reduction of Fracture Toughness

Reduction in fracture toughness due to irradiation embrittlement is not applicable to the non-Class 1 bolted closure scope since these closures are not within the beltline region of the reactor vessel. Some precipitation hardened martensitic stainless steels (e.g., 17-4 PH) may be susceptible to thermal embrittlement [2] in high temperature applications, which could lead to a reduction in fracture toughness.

3.5 Operating Experience and Generic Communications

3.5.1 NPRDS Review

A review of NPRDS information was performed to determine documented instances of loss of mechanical closure integrity of bolted connections for non-Class 1 mechanical systems. As discussed in Appendices A and B, failures of gaskets, packing, and O-rings are the most common failure mode for bolted closures. The failures were detected during ISI, IST, surveillance testing, and system walkdowns. However, failures of gaskets, packing, and O-rings result in leakage and typically are not considered to result in loss of mechanical closure integrity. The only exception to this would be a situation where a gasket/seal is utilized to provide a radiological boundary/barrier and thus may support an intended function. Gaskets, packing, and O-rings are considered consumables and (in general) are not relied upon for the performance of intended functions under 10 CFR 54 [5]. Therefore, these items do not require an aging management review.

3.5.2 NRC Generic Communications

Information Notices

IN 80-29: Broken Studs On Terry Turbine Steam Inlet Flange

When removing the governor and stop valve on the Unit 1 steam driven emergency feedwater pump at Arkansas Nuclear One for repair of a steam leak at the steam inlet flange, Arkansas Power and Light discovered that five of the eight studs securing the flange were broken. The failed studs are 3/4 in. diameter by 3-1/2 in. long and are thought to be of ASTM A-193 grade B7 steel. The turbine flange bolting is generally covered with insulation and not visible for inspection. From the information available, the bolting has not been removed or inspected since installation seven to eight years ago. Licensees are encouraged to carefully examine insulation in the flange to turbine casing region for evidence of leakage and consider inspection of the turbine steam inlet flange bolting. Further, during surveillance testing, care should be taken to observe if abnormal vibration or other transients occur which could promote loss of bolting integrity.

Generic Letters

GL 88-05: Boric Acid Corrosion of Carbon Steel Reactor Pressure Boundary Components in PWR Plants

GL 88-05 was issued by the NRC in response to repeated instances at multiple sites of minor reactor coolant fluid leaks (below technical specification limitations) causing severe corrosion of low-alloy carbon steel components, including bolting. The RCS fluid boric acid concentration is typically too low to cause damage to these components. However, once exposed to ambient conditions, the leaked fluid loses a substantial portion of its water through evaporation, leaving behind a highly

OAGI0000553_00364

concentrated boric acid solution or boric acid crystals. Although this GL is primarily geared toward the RCS pressure boundary and Class 1 components, it is included here due to the fact that loss of material due to boric acid wastage applies to non-Class 1 components as well.

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.

IE Bulletins

BL 82-02: Degradation of Threaded Fasteners in Reactor Coolant Pressure Boundary of PWR Plants

BL 82-02 alerted licensees to instances of degradation of threaded fasteners in closures in the reactor coolant pressure boundary and required appropriate corrective actions. Degradation of RCPB fasteners was reported at selected plants and resulted from boric acid wastage at bolted closures. In addition, BL 82-02 reported that sealant compounds, such as Furmanite, may contain variable compositions of halogens and sulfur which are leachable and promoters of SCC. BL 82-02 also reported that certain lubricants may contain a significant level of sulfide constituent, which can promote SCC. The actions taken in response to BL 82-02 were submitted to the NRC by each of the participating utilities.

OAGI0000553_00365

4. SUMMARY

As discussed in Sections 1.2 and 3.3, the most common failures of bolted closures in safety-related equipment have been attributed to boric acid wastage, with a few instances of stress corrosion cracking (SCC) of the bolting. Section 3 discusses loss of material and cracking as applicable aging effects for bolted closures.

Appropriate design and installation practices can eliminate cracking as an applicable aging effect for bolting. If high strength bolts (with tensile strengths above 150 ksi) are precluded by design, through specification or procurement, and if the use of lubricants containing molybdenum disulfide is controlled/prohibited, then SCC is not an applicable aging effect for the bolting.

As such, except in plant-specific instances where high strength bolting materials or molybdenum disulfide lubricants are used, there are no aging effects that are applicable to bolting materials other than those that are applicable to the external surfaces of components joined by bolting (described in Appendix E).

Table 4-1 identifies the applicable aging effects for bolting, and corresponding mechanisms, that may require programmatic oversight (management) for the period of extended operation, as well as the applicability criteria for the occurrence and propagation of the mechanisms.

4.1 GALL Comparison

The information in Chapters IV, V, VII, and VIII of Volume 2 of NUREG-1801, Revision 1, "Generic Aging Lessons Learned (GALL) Report – Tabulation of Results," identifies material, environment(s), aging effects (and associated mechanisms) typically requiring management for license renewal applicants, and the suggested aging management program (AMP) for various mechanical components. GALL Chapter IV, V, VII, and VIII tables all include items for bolting addressed by this tool. The identification and evaluation of aging management programs (AMPs) is outside the scope of this tool and should be addressed on a plant-specific basis, as described in Section 4.0 of the main document. Pertinent GALL items are addressed in Table 4-1, with the following component, material, environment, aging effect, and aging mechanism considerations.

Component identification is outside the scope of this tool. The GALL Chapter IV, V, VII, and VIII items that are applicable to this tool include those for bolting, closure bolting, control rod drive head penetration flange bolting, duct closure bolting, high pressure pump closure bolting, and steam generator closure bolting as the "Structure and/or Component." The materials for the pertinent items in GALL Chapter IV, V, VII, and VIII are consistent with the materials in this tool and include high-strength low-alloy steel, high-strength steel, low-alloy steel, stainless steel, and steel, or a combination.

Specific environments are not described in this tool, but the indoor air and outdoor air environments described in Appendix E, the External Surfaces Tool, are implicit to the consideration of bolting, since the bolting joins external surfaces and is not exposed to the internal medium of the joined components, except through leakage. The following GALL Chapter IV, V, VII, and VIII environments describe conditions that are considered in this tool for determining whether an aging effect is applicable:

- Air – indoor uncontrolled (external)
- Air – outdoor (external)
- Air with borated water leakage
- Air with reactor coolant leakage
- Air with steam or water leakage
- Condensation (external)
- System temperature up to 340°C (644°F)

The GALL does not evaluate mechanisms separately, as is done in Section 3 of this tool. The following aging effects are cited in GALL Chapters IV, V, VII, and VIII for the various bolting components, with the mechanism or groupings of mechanisms, depending on material susceptibility and/or environment:

- Cracking/cyclic loading, stress corrosion cracking
- Crackling/stress corrosion cracking
- Loss of material/boric acid corrosion
- Loss of material/general corrosion
- Loss of material/general, pitting, and crevice corrosion
- Loss of material/wear
- Loss of preload/thermal effects, gasket creep, and self-loosening

GALL item IV.A2-6 cites loss of material due to wear as an aging effect requiring management for stainless steel PWR control rod drive head penetration flange bolting exposed to air with reactor coolant leakage. No further basis is provided in the GALL as to the cause of bolting wear. GALL Chapter IV, V, VII, and VIII items do not otherwise address wear of bolting, except for Class 1 bolting (e.g., reactor vessel closure studs). Wear of bolting is not an aging mechanism evaluated in this tool.

GALL items IV.C1-11 (BWR reactor coolant pressure boundary piping and components) and IV.C2-10 (PWR reactor coolant pressure boundary piping and components) are the only items in GALL Chapters IV, V, VII, or VIII that explicitly address fatigue of bolting. This is consistent with the corresponding discussion in Section 3.2 of this appendix, which indicates that cracking due to thermal fatigue is not a concern for non-Class 1 bolting. Otherwise, fatigue related items are addressed separately in Appendix H.

Gall items IV.D1-10 and IV.D2-6 cite loss of preload/thermal effects, gasket creep, and self-loosening as an aging effect requiring management for steam generator (PWR) closure bolting exposed to system temperatures up to 644°F. GALL item IV.A2-8 cites loss of preload/thermal effects, gasket creep, and self-loosening as an aging effect requiring management for stainless steel

(PWR) control rod head penetration flange bolting exposed to air with reactor coolant leakage. GALL items V.E-5, VII.I-5, and VIII.H-5 also cite loss of preload/thermal effects, gasket creep, and self-loosening as an aging effect requiring management for steel closure bolting exposed to uncontrolled indoor air. GALL Chapter IX definitions and terms standardizing aging effects further indicate that thermal effects include differential expansion, creep, or stress relaxation, and that self-loosening includes vibration, joint flexing, cyclic shear loads, and thermal cycles. This GALL description is based on references such as EPRI NP-5067, which was also used as a reference during the development of this tool, and includes indication that the aging effect/mechanism had been accepted by the industry as being in the scope of license renewal.

However, the mechanisms for a loss of preload are addressed in Sections 3.1.1 through 3.1.5 and were determined to not be applicable aging mechanisms. While PWR steam generator closure and control rod drive head penetration flange bolting will experience higher temperatures than other non-Class 1 closure bolting, none of the nuclear plant closure bolting will experience temperatures above 700ºF, where stress relaxation (thermal effects) may be expected (as described in Section 3.1.4).

OAGI0000553_00368

Table 4-1 Aging Effects Summary – Bolted Closures				
Aging Effect / Mechanism	**Mechanism Applicability Criteria**	**NUREG-1801 (GALL) Item No.**	**Tool vs GALL Match**	**Relevant Section(s) and Discussion**
Cracking / SCC	1. Surface is subject to prolonged or frequent wetting other than humidity (e.g., from condensation, leakage) *and* 2a. High-strength bolts are used (e.g., Sy > 150 ksi) *or* 2b. Molybdenum disulfide lubricants are used. Note: Any instances where high-strength bolts or molybdenum disulfide lubricants are used for bolted closures are not typical and require plant-specific evaluation.	IV.C2-7, IV.D1-2 V.E-3 VII.E1-8, VII.I-3 VIII.H-3	Yes	Section 3.2 Specified GALL Chapter V, VII, and VIII items cite stress corrosion cracking as a mechanism for cracking of high-strength steel closure bolting that is exposed to air with steam or water leakage (a corrosive environment). These GALL items also list cyclic loading as a mechanism for high-strength steel closure bolting exposed to air with steam or water leakage. Cyclic loading is considered to be a design consideration and is not addressed in this tool as an applicable aging mechanism for cracking of fasteners. Also, GALL items IV.C2-7 and IV.D1-2 each cite cracking due to stress corrosion cracking as an aging effect requiring management for steel, high strength low-alloy steel, stainless steel, or combination PWR control rod drive head penetration flange bolting exposed to air with reactor coolant leakage.
Loss of Material / Boric Acid Wastage	1. Surface is exposed to leakage from PWR borated water systems	V.E-2 VII.I-2 VIII.H-2	Yes	Section 3.3 Specified GALL items cite loss of material due to boric acid corrosion as an aging effect requiring management for steel bolting exposed to air with borated water leakage.

OAGI0000553_00369

Table 4-1 Aging Effects Summary – Bolted Closures				
Aging Effect / Mechanism	**Mechanism Applicability Criteria**	**NUREG-1801 (GALL) Item No.**	**Tool vs GALL Match**	**Relevant Section(s) and Discussion**
Loss of Material / General Corrosion	1. Temperature < 212˚F	V.B-2, V.E-6 VII.F1-4, VII.F2-4, VII.F3-4, VII.F4-3, VII.I-6, VII.I-7 VIII.H-6	No	Section 3.3 Specified GALL item cites loss of material due to general corrosion as an aging effect requiring management for steel closure bolting exposed to air with steam or water leakage or uncontrolled indoor air.
Loss of Material / Crevice and Pitting Corrosion	1. Temperature < 212˚F *and* 2. Bolting is subject to prolonged or frequent wetting other than humidity (e.g., from condensation, leakage)	V.E-1, V.E-4 VII.D-1, VII.I-1, VII.I-4 VIII.H-1, VIII.H-4	Yes	Section 3.3 Specified GALL items also list general corrosion of steel bolting, closure bolting, and closure bolting exposed to condensation (a wetted environment), outdoor air, and uncontrolled indoor air.

OAGI0000553_00370

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. Grimes, C. I., "Consumables," License Renewal Issue No. 98-0012, United States Nuclear Regulatory Commission, April 20, 1999.

6. "Aging Effects for Structures and Structural Components (Structural Tools), Revision 1," EPRI 1002950, August 2003.

7. *Metals Handbook,* Ninth Edition, Volume 13, "Corrosion," ASM International 1987.

8. *Metals Handbook,* Ninth Edition, Volume 11, "Failure Analysis and Prevention," ASM International 1986.

Appendix G - Heat Exchangers

This appendix provides the guidance, exceptions, and clarifications for using the "Aging Management Guideline for Commercial Nuclear Power Plants – Heat Exchangers" [1] to assist in the identification of aging effects of heat exchangers defined to be within the license renewal scope. It provides a summary of the aging effects identified in the aforementioned guideline and identifies inconsistencies between that guideline and the logic described in the other Mechanical Tools (appendices).

CONTENTS

Page

1. INTRODUCTION 1-1
1.1 Background 1-1
1.2 Scope 1-1
1.3 Purpose and Objective 1-2

2. GUIDANCE FOR HEAT EXCHANGER EVALUATIONS 2-1

3. AMG HEAT EXCHANGERS EVALUATED 3-1

4. HEAT EXCHANGERS IN THE SCOPE OF LICENSE RENEWAL 4-1

5. EXCEPTIONS/CLARIFICATIONS/CAUTIONS 5-1

6. SUMMARY OF RESULTS FROM HEAT EXCHANGER AMG 6-1

7. COMPARISON TO GALL HEAT EXCHANGER ITEMS 7-1

8. REFERENCES 8-1

OAGI0000553_00373

LIST OF TABLES

Page

Table 3-1 Heat Exchangers Evaluated by the AMG 3-2
Table 6-1 Materials/Environment Combinations Evaluated in AMG 6-1
Table 6-2 Significant Aging Mechanisms for a Primary Water Environment 6-3
Table 6-3 Significant Aging Mechanisms for a Treated Water Environment 6-4
Table 6-4 Significant Aging Mechanisms for a Closed Cooling Water Environment ... 6-6
Table 6-5 Significant Aging Mechanisms for a Raw Water Environment 6-7
Table 6-6 Significant Aging Mechanisms for a Lubricating Oil Environment 6-9
Table 6-7 Significant Aging Mechanisms for an Air Environment 6-10
Table 7-1 GALL - Tool Environments 7-2
Table 7-2 GALL Comparison for Heat Exchangers / Primary Water Environment 7-4
Table 7-3 GALL Comparison for Heat Exchangers / Treated Water Environment 7-7
Table 7-4 GALL Comparison for Heat Exchangers / Closed Cooling Water Environment 7-11
Table 7-5 GALL Comparison for Heat Exchangers / Raw Water Environment 7-16
Table 7-6 GALL Comparison for Heat Exchangers / Lubricating Oil Environment .. 7-19
Table 7-7 GALL Comparison for Heat Exchangers / Air Environment 7-21

OAGI0000553_00374

1. INTRODUCTION

1.1 Background

In the development of the other Mechanical Tools for the evaluation of aging effects, the approach to the identification of aging effects is less complex than the case for heat exchangers. That is, most components can be evaluated from the standpoint of a single material in a single environment (e.g., carbon steel material in a raw water environment). For heat exchangers, there are usually multiple materials and multiple environments. Although the other Mechanical Tools can be used for heat exchangers depending on the specific material/environment combination, it is convenient to address all heat exchanger aging effects with one source.

The "Aging Management Guideline for Commercial Nuclear Power Plants – Heat Exchangers" [1] prepared by MDC-Ogden provides a single source to evaluate the many variables associated with aging of heat exchangers. After a review of the technical content of the Aging Management Guideline (AMG), the decision was made to use selected portions of the AMG for aging effect identification, with appropriate guidance as outlined in this appendix.

1.2 Scope

This appendix provides a review of the aging effects for heat exchangers that are within the scope of license renewal. The scope of this appendix includes the boundary of the heat exchangers up to their interface with the system piping/ducting, the typical heat exchanger materials, and the environments associated with heat exchanger service applications.

Plant-specific lists of systems within the scope of license renewal were reviewed to determine the types of heat exchangers that may be subject to an aging management review. In most instances the heat exchangers that may be subject to an aging management review are within the scope of the AMG (Table 1-2 of Reference 1). This appendix provides guidance to the evaluator for the review of heat exchangers by summarizing the AMG results in a format more consistent with the other Mechanical Tools. This summary of results in a material/environment format, and the subsequent guidance, provide the information necessary to evaluate heat exchangers that are not within the scope of the AMG.

Section 3.6 of the AMG, "Operating and Service History," which includes a review of NRC LERs, NPRDS, NRC generic correspondence, and operating plant data, is considered applicable as used in the development of aging evaluation logic.

This appendix endorses, with exceptions and clarifications (as detailed in Section 5 of this appendix), Sections 1 through 4 of the AMG. Discussions regarding aging management programs, which are presented in Section 5 of the AMG, have not been reviewed in detail. The generic results and recommendations of Section 5 of the AMG may be of use to the users of these Mechanical Tools in their discussion of plant-specific aging management programs; however, this appendix only addresses the aging effects evaluation of heat exchangers.

OAGI0000553_00375

Many heat exchangers are utilized in cooling and environmental control systems with fluorocarbons or another refrigerant as the working fluid. In general, fluorocarbons are non-corrosive to all common metals except at very high temperatures. An uncontaminated fluorocarbons system will not experience corrosive effects. However, the EPA is requiring the use of replacements for freon. Some of the replacement gases are corrosive, flammable, and toxic. Any metal that is susceptible to chloride induced pitting and SCC may exhibit degradation. If replacement gases are corrosive, then the systems where they are used must be screened for potential aging effects. For heat exchangers and cooling systems using fluorocarbons or other refrigerants, the applicant is referred to Appendix D of these Mechanical Tools.

The aging effects for the external surfaces of the heat exchangers (e.g., shells and channels/headers) are evaluated in Appendix E. The aging effects for the bolted closures (i.e., flanged connections and bolting) are evaluated in Appendix F. The thermal fatigue related effects are evaluated in Appendix H. Steam generators (PWR) have been extensively evaluated in other industry studies and therefore are not in the scope of the AMG [1] or this appendix.

1.3 Purpose and Objective

The purpose and objectives of this appendix are to provide directions, exceptions, and/or clarifications for using the AMG for heat exchangers to assist in the identification of aging effects of heat exchangers defined to be within the scope of license renewal.

The appendix includes:

- A summary guideline for using the AMG evaluations and this appendix
- A summary of applications, materials, and environments covered by the AMG
- A listing of the various BWR and PWR heat exchangers included within the AMG together with the major tube/shell materials and the fluid environment assumed in the AMG
- Exceptions and/or clarifications to the evaluation logic developed in the AMG
- A summary of the AMG evaluation results in a material/environment format
- Information necessary to evaluate heat exchangers within license renewal scope but not in the AMG scope

2. GUIDANCE FOR HEAT EXCHANGER EVALUATIONS

The Sandia Aging Management Guideline (AMG) for Heat Exchangers [1] provides a detailed evaluation of the aging effects applicable to a specific set of heat exchangers. Based on various inputs, a set of heat exchangers was identified in the AMG that 1) are within the scope of license renewal, and 2) are expected to require aging management review under the license renewal rule requirements. (Section 3.0 of this appendix provides a summary of the heat exchangers included in the AMG evaluation.)

The Sandia AMG utilizes an approach similar to the other Mechanical Tool Appendices for evaluating the effects of aging. The approach is a typical materials/environment evaluation where the significance of specific aging effects is based on the materials used and the fluid environment to which these materials are subjected. The AMG also makes assumptions concerning the design of components, water chemistry of the various environments, and system parameters (such as flow rates) during the evaluation of aging effects.

The AMG method is similar in approach to an aging management review that would be conducted if the other appendices of these Mechanical Tools were applied to heat exchangers. Since the other Mechanical Tool Appendices were not intended to address heat exchangers, the other appendices differ slightly from the heat exchanger AMG with regard to the treatment of wear and fouling. In the other Mechanical Tools, wear is considered the result of performance of an active function and is not identified as an applicable aging mechanism, whereas the AMG treats wear as a significant aging mechanism for some heat exchanger components. Wear and fretting on internal pressure boundary surfaces is under review by the NRC and industry. The users of this tool should review regulatory correspondence and industry technical reports, etc., after the issuance of this document to determine if heat exchanger pressure boundary items should be evaluated for wear and fretting.

Fouling and its effect on heat transfer must be considered for license renewal. The AMG contains a comprehensive treatment of fouling in heat exchangers and should be used to evaluate reduction of heat transfer. The other Mechanical Tool Appendices do not address the heat transfer function.

An alternative to applying the Sandia AMG in its entirety is to perform the aging effects evaluation using the other material/environment tools with additional consideration of wear and fouling as aging effects. If this alternative is used, the sections in the AMG dealing with fouling and wear provide excellent guidance to the identification of materials and subcomponents susceptible to reduction of heat transfer, wear, and fouling. The AMG evaluates many material/environment combinations and identifies all significant aging effects. The aging effects for the heat exchanger subcomponents are described in detail in Section 4.3.2 of the AMG for the material and environment combinations. Tables 6-2 through 6-7 of this appendix summarize the significant aging effects for the heat exchangers identified in the AMG.

Section 4.3.2 of the AMG contains information that can be used to identify the aging effects of specific material and environment combinations. However, caution must be used when applying the summary of aging effects identified in Tables 4-3 through 4-8 of the AMG. The AMG tables summarize the aging effects based on the environment and subcomponent only. When a subcomponent has more than one material the aging effects for all materials are not identified in the

OAGI0000553_00377

tables. In order to determine the aging effects of a specific heat exchanger material, it is necessary to refer back to the written descriptions in Section 4.3.2. For example, AMG Table 4-7 identifies general corrosion and IGSCC as significant for the tubes/coils in a raw water environment. Stainless steel is susceptible to IGSCC in a raw water environment; however, it is not susceptible to general corrosion in that environment. Conversely, carbon steel in a raw water environment is susceptible to general corrosion but is not susceptible to IGSCC.

For those combinations which are not directly or indirectly covered by the AMG, an alternative approach to identifying significant aging mechanisms must be used. If the logic developed in the other Mechanical Tool Appendices is applied, wear and fouling must also be considered since the logic for these aging effects is not included. The summary tables in Section 6 of this appendix provide an indication of the materials and environment combinations for which wear and fouling may be significant aging mechanisms.

There are two approaches that can be used to identify aging effects for heat exchangers, i.e., using this appendix or the Sandia AMG. A third option is to use the other Mechanical Tool appendices for a majority of the evaluation and to use this appendix and the AMG for the balance of the issues. All three methods are described briefly below. Because of the many different materials and some unique environment considerations, it may not be possible to identify all aging effects for all heat exchangers using these methods. A small number of plant-specific applications may still require independent aging effects evaluations. The tables in Section 6 of this document, combined with the AMG and the other Mechanical Tools, should provide the information necessary to complete the identification of applicable aging effects.

Depending on the heat exchanger design and materials of construction, one of the three methods to identifying the significant aging effects for heat exchangers will be optimal. If the AMG heat exchanger material, environment, and application match exactly the heat exchanger being evaluated, the best way to evaluate aging will be to use the AMG. The second method is to use the modified AMG summary tables in Section 6 of this appendix to identify the significant aging effects. This second method is appropriate if the materials and environment are covered in the AMG evaluation and included in these summary tables. Due to the generic nature of this data, some plant-specific work may be required when using this option to provide consistency with the other Mechanical Tool appendices. The third method, where the heat exchangers are evaluated using only these Mechanical Tools, determines aging effects based on the materials and environments included therein. This method may require significant additional work since some aging effects specific to heat exchangers are not covered in the other Mechanical Tools.

An applicant may decide to use more than one method to evaluate the various heat exchangers. Flexibility is a fundamental attribute of this tool.

Method 1: Evaluations for Specific Heat Exchangers Using the AMG

The AMG evaluates specific heat exchangers, environments, and materials. Before using the AMG the following inputs must be compiled: materials of construction, fluid or air environment (based on the AMG classifications), and the heat exchanger design. When there is an exact match to a heat exchanger in the AMG, the results of the AMG aging effects identification are valid. The summary tables for the environments and heat exchanger components listed in the AMG Tables 4-3 through

4-8 may identify aging effects that do not apply to a specific application because all significant aging effects for all materials are listed. The AMG must be reviewed to screen out those aging effects that are not applicable for a particular material or a particular application. The list of exceptions/clarifications and cautions in Section 5 of this appendix should be reviewed to assure consistency with the other Mechanical Tools.

Method 2: Use the Material/Environment Tables in Section 6 of This Appendix

The tables included in Section 6 of this appendix summarize the aging effects evaluations in the AMG but are presented in a material/environment format. (These tables present the AMG results in a form that is consistent with the Mechanical Tool approach to aging effects identification.) As in Method 1, the materials of construction, specific environments, and application must be identified prior to using the tables. The summary tables in Section 6 can then be used to identify the significant aging effects for the combination of materials and environments being evaluated. The exceptions/clarifications/cautions contained in Section 5 of this appendix should be reviewed and aging effects modified (if necessary) to assure consistency with the overall Mechanical Tool approach. An advantage to using this method is that the review is not limited specifically to the applications, materials, and environment combinations contained in the AMG. However, there may still be some heat exchangers and or specific aging effects that cannot be completely evaluated using these summary tables. Plant-specific evaluations may then be required to identify the significant aging effects.

Method 3: Use the Mechanical Tools to Identify Aging Effects

These Mechanical Tools provide a logic to identify significant aging effects for material and environment combinations. These same tools can be used to evaluate heat exchangers. However, not all materials, environments, and aging effects are evaluated in the Mechanical Tools. The AMG in these cases can provide information and evaluations of some of the materials and effects not covered in the other Mechanical Tool logics. Wear and fouling of heat exchanger components are examples of mechanisms that are not included in the other Mechanical Tools. Some of the logic in the Mechanical Tools, although applicable to heat exchangers, may have to be interpreted differently. For example, pitting and crevice corrosion require stagnant or low flow conditions. In some heat exchanger applications there may be areas of low flow even when system flow is high.

There may not be any single approach that deals adequately with all heat exchangers. There may also be some exceptions that will require plant-specific aging effects identification since they are not covered by any of the three approaches (none of the approaches, for example, cover refrigerant lines and coils in air conditioners). However, using one or more of these approaches should provide acceptable results for most of the heat exchangers requiring aging management review.

OAGI0000553_00379

3. AMG HEAT EXCHANGERS EVALUATED

The Sandia AMG provides evaluations of aging effects for limited applications, materials, and environments. Heat exchangers falling outside these specific applications can be evaluated using information contained in the AMG; however, a more detailed approach is required and the summary tables of the AMG may be of limited use. The important criterion, as in all the aging evaluations contained in these appendices, is to determine the specific material and environment and perform the aging effects evaluation using the sources of information or tools available.

Table 3-1 summarizes the combinations of materials and environments that are considered in the AMG and are applicable to both BWRs and PWRs. The combinations of materials and environments included in the AMG comprise a majority of the plant-specific heat exchangers that require aging management review under the license renewal requirements. There are likely to be many heat exchangers, however, that are not specifically included in the AMG evaluation. Table 3-1 provides a summary of the specific heat exchangers covered in the AMG. Even if a plant-specific application is not included, the summary of aging effects for similar heat exchangers and/or applications (i.e., identical materials and environments on the tube and shell side) should enable most heat exchangers to be evaluated with very little, if any, additional review necessary.

Table 3-1 was prepared utilizing the information contained in the following sections of the AMG: 1) Section 3.4.5, Description of Predominant Types of Heat Exchangers, 2) Table 3-5, Process and Cooling Fluid Media BWR Heat Exchangers, and 3) Table 3-6, Process and Cooling Fluid Media PWR Heat Exchangers. It represents all the materials, environments, and types of coolers that are evaluated in the AMG. This table provides a summary and easy reference for the material and environment combinations considered in the AMG. Using this information, it is easy to discern that no heat exchangers evaluated in the AMG contain raw water on the shell side of the heat exchanger. That application is, therefore, not considered in the AMG and aging effects are not identified.

Table 3-1 Heat Exchangers Evaluated by the AMG

	MATERIAL		FLUID	
Tube/Shell	**Tube Side**	**Shell Side**	**Tube Side**	**Shell Side**
RWCU Regen. (BWR)	SS	SS	Primary	Primary
RWCU Non-Regen. (BWR)	SS	CS	Primary	Closed
Letdown Hx	SS	CS	Primary	Closed Cooling
HP Gland Seal Cond (BWR)	SS	CS	Treated	Primary
Seal Return Cooler	SS	CS	Primary	Closed Cooling
Spent Fuel Pool Cooler	SS	CS	Treated	Closed Cooling
Component Cooling Water Hx	SS, Admiralty, 90-10 /Cu-Ni, Alum-Brass	CS	Raw	Closed Cooling
Residual Heat Removal (PWR)	SS	CS or CS w/SS overlay	Primary or Borated	Closed Cooling
Residual Heat Removal (BWR)	SS	CS	Raw	Primary
Emer. Diesel Gen. Jacket Cooling	Admiralty, Copper Alloys	CS	Raw	Treated or Closed Cooling
Lube Oil (EDG, HPCI, RCIC)	Admiralty, Copper Alloys SS	CS	Treated Water or Raw Water	Lubricating Oil
Misc. Oil Coolers	Admiralty, Copper Alloys	CS	Closed Cooling	Lubricating Oil
Fin/Coil	**Coil Side**	**Open Side**	**Coil Side**	**Open Side**
Containment/ Drywell Air Coolers	Copper or 90-10 Cu-Ni	Alum., Copper, or 90-10 Cu-Ni	CCW, Service, Raw, or Chilled	Containment or Drywell Atmos.
ECCS Room Coolers	Copper or 90-10 Copper Nickel	Alum., Copper, or 90-10 Cu-Ni	Raw or Closed Cooling	Air

OAGI0000553_00381

The fluid environments identified in the AMG differ only slightly from the environments considered in the other Mechanical Tool appendices. The Mechanical Tools do not address PWR primary water as it is addressed specifically in a separate Reactor Coolant System AMG. The remaining water systems are categorized as either treated or raw water. The raw water category in the AMG and as used in these tools are the same. The treated water category in these Mechanical Tools includes both the treated and closed cooling water as defined in the AMG. The difference between treated and closed cooling systems as evaluated in the AMG is the addition of corrosion inhibitors and/or biocides to the closed cooling water. Both treated and closed cooling water as addressed in the AMG are considered to contain filtered and demineralized but not deaerated water. As in these Mechanical Tools, the AMG classifies the borated spent fuel pool water in PWRs as treated water.

Primary Water

This refers to reactor coolant which has been deaerated/deoxygenated. This water may contain up to 200 ppb dissolved oxygen. Primary water in PWR plants also contains a borated solution. During refueling outages aerated primary coolant can have dissolved oxygen contents above 8 ppm when the reactor vessel head is removed for refueling. However, refueling outages are usually brief, temperatures are low, and halogen levels are still controlled to below the threshold values. No pitting or crevice corrosion has been observed in reactor internals under these conditions as a result of extended outages. Therefore crevice corrosion is not expected during refueling outages.

Treated Water

This refers to water which has been filtered and demineralized but generally not deaerated. The water may contain up to 5 ppm dissolved oxygen and small amounts of chemicals (i.e., potassium chromate, and sodium nitrite) for process use. The spent fuel pool water in PWR plants contains 2000 to 2500 ppm boron.

Closed Cooling Water

This refers to treated water containing corrosion inhibitors and biocides.

Lubricating Oil

This refers to low to medium viscosity hydrocarbons used for bearing gear and engine lubrication.

Air

This refers to the surrounding ambient air of various rooms, containment, or the drywell. Air-side filters are typically provided to remove particulates from the air stream.

Raw Water

This refers to water entering a plant from a river, lake, pond, or bay, which has not been chemically treated or demineralized. In general, the water has been rough-filtered to remove large particles and contains biocidal additives for microorganism control. The sodium chloride content in lake or river water is typically less than 1,000 mg/l, while either ocean or brackish water has a sodium chloride content of greater than 1,000 mg/l.

OAGI0000553_00382

4. HEAT EXCHANGERS IN THE SCOPE OF LICENSE RENEWAL

The extent to which plants rely on balance of plant (BOP) equipment for compliance with license renewal rule requirements determines which equipment falls within the scope of license renewal. Some plants may designate very little BOP equipment as being within the license renewal scope under its CLB. Other plants may take credit for BOP equipment to meet regulated events or design basis events. For example, if the main condenser is used as a source of water to demonstrate compliance with a design basis event or a regulated event (e.g., LOCA and Appendix R), then the main condenser may require AMR.

Heat exchangers are devices that transfer heat to establish or maintain a desired process or equipment temperatures. Several heat exchanger types are used in nuclear power plants, many serving as interfaces between plant systems. The major heat exchanger types utilized in nuclear power plants are the shell-and-tube heat exchanger, which can be shell-and-U-tube or shell-and-straight-tube, and the fin-coil cooling units. The boundaries of the evaluation for shell-and-tube heat exchangers are defined by the shell and channel head and their nozzles for piping attachments. For fin-coil heat exchangers, the boundaries of the evaluation are defined by the coil (tube) headers and their nozzles for piping attachments. Each heat exchanger can be broken down into subassemblies and components [1].

The following is a standard description of the heat exchanger components addressed in this appendix:

Shell-and-Tube Heat Exchangers –

- **Channel Head** – also known as waterbox, end bell, bonnet, or head – includes nozzles, covers, and a divider (partition) plate(s)
- **Tube Sheet(s)** – also known as tube plate(s)
- **Tubes**
- **Shell** – also known as case – includes nozzles, covers
- **Shell Side Internals** – includes various subcomponents such as impingement plates, tie rods, baffles/partitions, and support plates

Fin-Coil Heat Exchangers (used for containment or room cooling) –

- **Coil (Tube) Headers** – includes nozzles
- **Coil(s)** – tube(s) that may be finned for external air flow

The following list of heat exchangers identifies "typical" heat exchangers that can be identified as within the scope of license renewal. This list is not complete, but is included to emphasize the variety of heat exchangers that are expected to require aging management review. Some of these heat exchangers will be exact matches in application, material, and environment to those evaluated in the AMG; others will require additional work to assure that all aging effects are identified. The list is broken down into two distinct types of heat exchangers. The shell-and-tube heat exchangers have fluids on both the tube and shell sides. The fin-coil type heat exchangers are used for containment or room cooling. Air flows across a baffled tube bundle in these coolers with a cooling fluid on the tube side. For these fin-coil heat exchangers there is no shell side, as the tubes are open to the air flow.

OAGI0000553_00383

Shell-and-Tube Type

- Residual Heat Removal Coolers
- Reactor/Seal Return Letdown Coolers (PWR)
- RWCU Regenerative and Non-Regenerative (BWR)
- Emergency Diesel Jacket Water Coolers
- Makeup Pump Coolers
- Reactor Building Spray Pump Jacket Coolers
- Residual Heat Removal Pump Jacket Coolers
- Station Blackout Diesel Heat Exchangers
- Fire Pump Coolers
- Post Accident Sampling Coolers
- Electrical Room Chiller Unit Condensers
- Reactor Coolant Pump Thermal Barriers (PWR)
- RC Drain Tank Heat Exchanger (PWR)
- Pump Lube Oil Coolers
- Main Condensers
- RCP Upper and Lower Oil Coolers (PWR)
- Generator Thrust Bearing and Guide Bearing Coolers
- Spent Fuel Coolers
- Component Cooling Water Coolers
- Service Water Coolers
- Raw Water Coolers
- Diesel Generator Standby Heaters

Fin-Coil Type

- Reactor Building Coolers
- Drywell Coolers
- Emergency Core Cooling System Room Coolers
- Control Room Coolers
- Electrical Equipment Room Coolers
- RCP Motor Air Coolers (PWR)
- Air Conditioners
- Diesel Generator Radiators

Even where specific heat exchanger applications are addressed, the AMR can sometimes require plant-specific evaluations. For example, the decay heat or residual heat removal coolers will require AMR at all plants. However, the material used for construction, the design parameters, and the tube and shell side environment may differ from plant to plant. The conditions covered in the AMG do not include an evaluation of raw water on the shell side of the decay heat removal coolers. A plant that has raw water on the shell side would, therefore, have to perform additional evaluations to complete the identification of aging effects if using the AMG and this appendix.

While evaluating heat exchangers using the Sandia AMG, the basis and assumptions must be completely understood before using the results of the aging effects evaluations. When conditions and assumptions for the heat exchanger being evaluated are an exact match with those in the AMG, the results are valid. Where the conditions and/or assumptions do not exactly match, more evaluation is necessary to assure the results.

Also, additional heat exchangers may be in the scope of license renewal because their failure could result in leakage, flooding, or wetting of safety-related components. However, such heat exchangers are not addressed in the AMG, and can be evaluated using the other Mechanical Tools, since heat transfer is not required from such heat exchangers for license renewal considerations.

OAGI0000553_00385

5. EXCEPTIONS/CLARIFICATIONS/CAUTIONS

1. As is the case in the other Mechanical Tools, credit for an aspect of a plant program is not implicitly credited with precluding the occurrence of an aging effect/mechanism. For example, corrosion inhibitors prevent general corrosion of carbon steel, but general corrosion is an applicable aging mechanism and the program which adds and monitors corrosion inhibitor concentrations may be explicitly credited with managing the effects of aging, as described in Section 4.0 of the main document.

2. In Sections 4.3.1.5.4 and 4.3.2 of the AMG, the discussions conclude that microorganisms are present in treated and closed cooling water systems. Although the AMG describes closed cooling water as containing corrosion inhibitors and biocides, the discussions of MIC indicate that for treated or closed cooling water, the potential exists for the presence of MIC. While the Mechanical Tools logic identifies MIC as a concern for treated water, it is only a concern if the treated water has been contaminated, such as from an outside source, from temporary alignments, or from an interfacing system that contains water from a natural or open source.

3. The evaluations of closed water systems also in the AMG do not consistently apply the addition of corrosion inhibitors. General corrosion is deemed a significant aging mechanism in closed water systems (assumed to contain corrosion inhibitors), yet the discussions for galvanic corrosion indicate that the inclusion of corrosion inhibitors limits this type of corrosion.

4. During the evaluation of aging effects in heat exchangers, consideration is often given in the AMG to common design aspects of heat exchangers such as sacrificial anodes and surface coatings to control aging. The aging evaluation takes credit for these design attributes, often without qualification. It is incumbent on a user of this tool to ensure the continued integrity of such design attributes in order to apply the conclusions drawn in the AMG.

   The AMG interpretation of thermal embrittlement and creep for the different heat exchanger materials of construction should be examined carefully. The initial screening logic temperature threshold used in the AMG for creep and thermal embrittlement for all heat exchangers is 200°F. The heat exchangers exceeding this temperature threshold (letdown, excess letdown, RWCU regenerative and seal water heat exchanger) were further evaluated with stainless steel and titanium being the only materials exceeding the temperature threshold for any extended period. The subsequent evaluation concluded that titanium and stainless steel were not susceptible to creep or thermal embrittlement. The evaluation also indicated that CASS is susceptible to thermal embrittlement, but that none of the heat exchangers evaluated contained cast austenitic stainless steel.

   The conclusion drawn in the AMG (i.e., creep and thermal embrittlement are not applicable) is likely a valid conclusion based on the logic in the Mechanical Tools. To be consistent with the other Mechanical Tools (appendices), creep of metals is not a concern at PWR or BWR plant temperatures and should be eliminated from consideration for that reason. Thermal embrittlement of cast austenitic stainless steel is a concern if the equipment is operated at high temperatures. The treated water tool (Appendix A of these Mechanical Tools) uses a threshold temperature of 482°F above which cast austenitic stainless steel (CASS) is susceptible to thermal embrittlement.

5. In the AMG carbon steel is evaluated in a primary water application only for a BWR application. This evaluation should not be extrapolated to a PWR primary water environment which contains boric acid.

6. Section 4.3.1.6.1 of the AMG states, "IGSCC has been reported for stainless and high alloy steel components exposed to borated water service applications (PWR applications). Therefore, if the heat exchanger components are stainless or high alloy steel and exposed to borated fluids, then IGSCC is a significant aging mechanism." This conclusion is contrary to the Mechanical Tool for treated water and the RCS aging evaluation. Failures attributed to IGSCC have been reported (e.g., IN 79-19); however, those failures were attributed to other contaminants such as chlorides and thiosulfate, and not boric acid. The treated water tool (Appendix A) should be consulted to determine the threshold values for oxygen and contaminant levels above which SCC may be a concern.

7. The heat exchanger AMG states that mechanical fatigue is a significant aging mechanism for all heat exchanger components regardless of materials and operating history. The remainder of the Mechanical Tools treat high cycle fatigue as a plant-specific phenomenon to be included as an aging effect dependent on the AMR approach employed. The AMG determinations should be followed because of the thermal stresses and cycles experienced by heat exchanger components.

8. Raw water was not evaluated as an environment on the shell side of the heat exchangers in the AMG since no such applications were identified in which that situation existed. The B&W PWR plants contain at least one heat exchanger where raw water flows on the shell side. The AMG does evaluate the various materials of interest on the shell side in a raw water environment and the tables in Section 6 of this appendix list those applicable aging effects.

9. Pitting is an aging mechanism that is only prevalent in stagnant or low flowing conditions. The AMG identifies pitting as a concern only in a raw water environment and without regard to flow conditions. Because of the design and configuration of most heat exchangers, stagnant and low flow areas likely exist even during system flow conditions. Caution should be used if attempting to rule out pitting based on flow conditions.

10. The logic as to conditions conducive to pitting and crevice corrosion contained in the Mechanical Tools differs from the AMG discussions. The Mechanical Tools assume that the necessary conditions for pitting and crevice corrosion can exist in raw, treated, and closed cooling water systems. The treated water tool (Appendix A) establishes minimum contaminant (such as a halide or sulfate) and oxygen concentrations necessary for pitting and/or crevice corrosion to be a concern. The raw water tool (Appendix B) assumes that contaminants are present and does not include minimum concentrations in the aging effects logic. The AMG considers pitting and crevice corrosion to be significant only in raw water systems. The AMG considers both treated and closed cooling water not to be conducive to the propagation of pitting or crevice corrosion. The AMG takes credit for the water quality control programs to prevent pitting and crevice corrosion in treated and closed cooling water systems.

    To provide consistency with the Mechanical Tools, pitting and crevice corrosion should be evaluated in accordance with the treated water and raw water logic contained in Appendices A and B, respectively, of these Mechanical Tools.

11. The discussion in item 9 is also applicable to the AMG discussions on SCC. The AMG assumes that the treated and closed cooling system environments are not conducive to SCC. No basis for that assertion is provided and it is in disagreement with the treated water tool (Appendix A). In this treated water tool, SCC is a plausible aging mechanism for stainless steel in treated or closed water systems containing contaminants and/or oxygen concentrations above the identified thresholds. Additionally, some microorganisms convert nitrites to nitrates. The use of nitrite corrosion inhibitors in the presence of these microorganisms could potentially lead to nitrate-induced stress corrosion cracking in carbon and low-alloy steel.

    As in the pitting and crevice corrosion discussion in item 9, SCC should be evaluated in accordance with the treated water and raw water logic contained in Appendices A and B, respectively, of these Mechanical Tools.

12. The significance of galvanic corrosion as an aging mechanism is, in most cases, left unqualified in the AMG. The AMG states:

    "Galvanic corrosion may be significant when, given a corrosive environment such as raw or treated water, two materials in close proximity are far apart on the galvanic series chart. In these situations, if sacrificial anodes or cathodic protection is not utilized, the more anodic material may experience significant galvanic corrosion."

    Galvanic corrosion, by this definition, is only considered significant for treated water and raw water systems. The AMG deems the addition of corrosion inhibitors sufficient to preclude galvanic corrosion in closed cooling water systems. The treated water Mechanical Tool does not credit the addition of corrosion inhibitors as a method of prevention for the effects of galvanic corrosion. Although corrosion inhibitors may limit the susceptibility of materials to galvanic corrosion, improper treatment can actually increase the corrosive environment and thus increase the corrosion rate (Reference 2, Page 73). To provide consistency with the other tools, the treated water tool (Appendix A) should be used for galvanic corrosion evaluations of AMG classified closed cooling water systems.

    In Table 6-5 (Section 6), galvanic corrosion of carbon and low-alloy steel on the shell side of heat exchangers is identified as a significant aging mechanism. The AMG makes this assertion based on the applications where stainless steel on the primary side is matched with carbon steel on the shell side. While it may be true that under these conditions carbon or low-alloy steel may be in contact with stainless steel tubes or tubesheets, construction and design practices will typically make provisions for these types of situations. Either welding materials, sacrificial anodes, or isolation devices will likely be used to prevent galvanic corrosion where dissimilar materials are in contact. The use of these design practices is included in the AMG with the distinction made that galvanic corrosion is only a significant aging mechanism if this type of design protection is not included. Sacrificial anodes are a method to prevent significant corrosion of the heat exchanger material. However, it is incumbent upon an applicant to have in place a program to inspect or otherwise assure the integrity of these sacrificial anodes. If an installed sacrificial anode has been depleted or becomes unattached, it will no longer protect the component, and severe corrosion may follow.

OAGI0000553_00388

13. Oil is only evaluated on the shell side of the heat exchangers in the AMG. Since oil is usually a non-corrosive environment and flow rates for oil containing systems are typically low, the extrapolation of significant aging effects to the tubes, tubesheet, and waterbox are made for oil environments. Fouling is identified as a significant aging effect for oil systems where the oil source is the bottom of a tank or reservoir. This could lead to corrosion products or contamination of the oil supply. Such contamination could also result in some forms of corrosion; however, none are found to be applicable. If the oil source is from the bottom of a reservoir or tank, the applicability of corrosion aging effects should be evaluated further.

14. Erosion is not covered in the Mechanical Tools specifically as it applies to heat exchangers. The discussions of this aging effect as it pertains to heat exchangers are, therefore, limited to the evaluations in the AMG. Since the AMG specifically evaluates the various subcomponents and environments for only those applications within the scope of the AMG, not all materials, environments, and applications are evaluated. (Raw water, for example, is evaluated on the tube side but not on the shell side of heat exchangers.) The materials evaluated on the tube side of heat exchangers are similar to the materials on the shell side and, with the exception of flow conditions, the susceptibility of the material to erosion is no different.

    The AMG includes consideration of a select group of heat exchangers and the identification of aging effects is limited to that select set. Plant-specific requirements and applications will require aging management review of heat exchangers that are not included in the AMG. If using the AMG as a tool to identify aging effects for heat exchangers outside the AMG scope, all assumptions and operating conditions assumed in the AMG for the evaluation must be verified. Even where there appears to be an exact match with a heat exchanger covered in the AMG, a review of the AMG assumptions and operating conditions considered may be necessary to completely remove erosion as a concern. The AMG specifically identifies the included heat exchanger designs, manufacturer, materials used, operating conditions assumed, etc. If a plant-specific application violates any of the AMG evaluation criteria, the conclusions may no longer be valid. Statements similar to "...as long as the heat exchangers are not subjected to temperatures above..." and "most plants treat closed cooling water with corrosion inhibitors, as long as an inhibitor is used then this aging effect is not a concern" are found in the AMG. The erosion evaluation makes similar assumptions and statements. Heat exchanger tube plugging and changes in system and equipment operation can change internal flowpaths and fluid velocities such that fluid velocities fall outside those assumed in the AMG.

    Erosion becomes a concern where previously it was not. The summary tables in Section 6 contain summary notes of the erosion evaluations in the AMG.

15. Section 4.3.2.1.4 of the AMG erroneously makes the statement that inhibited admiralty brass contains less than 15% zinc and is not susceptible to IGSCC and/or TGSCC. Inhibited admiralty brass contains 28% zinc and is susceptible to SCC. The inhibited admiralty brass provides resistance to dezincification but not SCC.

16. The AMG lists numerous NRC Bulletins, Notices, Generic Letters, and Circulars applicable to the in-scope heat exchangers. It does not include discussion of NRC Circular 80-11, "Emergency Diesel Generator Lube Oil Cooler Failures," specifically, pressure boundary failures that occurred as a result of severe corrosion of the tube to tubesheet solder joint in oil coolers manufactured by EMD of General Motors. This corrosion resulted from the

combination of soft solder in a raw water environment and in the presence of Calgon CS, a borated-nitrite type inhibitor. Calgon CS should not be used in situations where the solder joint composition is a soft solder of lead-tin composition. Although this issue has likely been addressed at plants due to the date of the Circular, corrosion of this solder joint is a significant aging mechanism for these specific coolers under the conditions identified and should be considered during the aging evaluation.

OAGI0000553_00390

6. SUMMARY OF RESULTS FROM HEAT EXCHANGER AMG

The Sandia Aging Management Guideline for Heat Exchangers (AMG) evaluates numerous heat exchangers that are constructed of various materials exposed to a variety of different environments. However, the AMG does not evaluate all material/ environment combinations.

In addition to materials and environments, heat exchangers are discussed in the AMG on a subcomponent basis. Because of the number of variables involved, not all combinations of materials, environments, and subcomponents are evaluated. The AMG limits its evaluation to those applications covered by the in-scope heat exchangers. No AMG heat exchanger applications, for example, have raw water on the shell side; therefore, this combination is not included. The evaluation of the primary water only includes stainless steel and titanium (carbon steel is evaluated only for a very specific and limited duration situation in BWRs).

Although not all combinations of materials, environments, and subcomponents are evaluated, as is shown in Table 6-1, most of the material/environments combinations are evaluated. The results of the material/environment evaluations for the covered subcomponents are easily extrapolated to the other subcomponents (for example, the significant aging effects using raw water on the shell side of heat exchangers have been extrapolated using information contained in the AMG). Where results are component specific or system condition specific (such as FAC), additional work may be required to complete the aging effects identification.

Table 6-1 Materials/Environment Combinations Evaluated in AMG

MATERIAL	PRIMARY WATER	TREATED WATER	CLOSED COOLING WATER	RAW WATER	LUBE OIL	CONTAIN. ATMOS.
Stainless Steel and High Alloy Steel	X	X	X	X	X	X
Carbon and Low-Alloy Steel	X	X	X	X	X	X
Copper, Cu-Ni Alloys, Muntz Metal		X	X	X	X	X
Inhibited Admiralty Brass		X	X	X	X	X
Titanium	X	X	X	X	X	X
Aluminum						X

The AMG evaluation of aging effects provides an in depth evaluation of a significant number of heat exchangers within the scope of license renewal. The specific heat exchangers evaluated are identified in Section 3 of this appendix. The methodology and approach used in the AMG is to first

OAGI0000553_00391

evaluate the many aging mechanisms for the environments and materials within the scope of the AMG. An initial screening of the aging mechanisms is performed which provides a determination of susceptibility of the heat exchanger subcomponents to these aging mechanisms. A detailed aging effects evaluation is then completed for the subcomponents to identify the "significant" aging mechanisms for the materials and subcomponents.

The results of the aging mechanism evaluations are tabulated in the AMG Tables 4-3 through 4-8. These tables summarize the significant aging effects that are applicable to the heat exchanger subcomponents, each table representing a specific environment. Because of the many materials used throughout the heat exchangers, applying these tables to a specific heat exchanger is difficult at best. Since heat exchangers typically include two distinct environments, two tables are required. These tables summarize the significant aging mechanisms for a particular subcomponent and, since many materials are evaluated, not all identified aging effects may be applicable to the specific application being evaluated. AMG Table 4-4 for treated water systems is an example of a situation in which both stainless and carbon steel tubesheets are evaluated. This table indicates that in a treated water environment general corrosion and stress corrosion cracking are both significant aging mechanisms for tubesheets. This table does not indicate that general corrosion is only significant for carbon steel and not for stainless steel, while stress corrosion cracking is only significant for stainless steel and not carbon steel.

Although some exceptions do exist, the significant aging mechanisms identified are material and environment specific. The detailed review of the AMG evaluation and summary of aging effects supports this assertion. For example, general corrosion is a significant aging mechanism for carbon steel in treated water but the material location within the heat exchanger is not relevant. Galvanic corrosion, however, may be dependent on the particular subcomponent design, since the susceptibility to galvanic corrosion is based on contact with different materials.

The tables below represent a summary of the AMG aging mechanism evaluation from a materials and environment perspective. Where exceptions to the AMG are taken to provide consistency with these Mechanical Tools, appropriate notes are included. Any subcomponent-specific information is included as notes to these tables. Any conditions not following a typical material/environment evaluation are also noted. Each table represents a specific environment, with significant aging effects identified for the materials evaluated in the AMG.

OAGI0000553_00392

Table 6-2 Significant Aging Mechanisms for a Primary Water Environment

MATERIALS	Thermal Embrit.	Creep	Mech. Fatigue	General Cor.	Pitting Cor.	Galvanic Cor.	MIC	SCC	Erosion / FAC	Wear	Fouling
Stainless Steel			X					X		X	X
Carbon Steel			X						X	X	X
Titanium			X							X	X

Notes:

1. Thermal embrittlement and creep are discussed in Section 5, item No. 4.
2. Stainless Steel is used for all PWR applications in a primary water environment. Carbon steel in a primary water environment only applies to BWR Residual Heat Removal (RHR) and Gland Seal heat exchangers (the RHR heat exchanger can contain either treated or primary water). The other BWR heat exchangers utilize stainless steel for primary water applications.
3. Stress Corrosion Cracking is discussed in Section 5, item No. 6.
4. Erosion / FAC. Primary water is fine filtered to remove particulate and de-ionized to achieve purity. It also contains corrosion inhibitors to minimize abrasive corrosion products. Dissolved oxygen levels in primary water applications are controlled to minimize accumulation of abrasive corrosion products. As long as the water chemistry is controlled and fluid velocities are maintained within specified limits, erosion for most heat exchanger components is not a significant aging mechanism. Exceptions are the shell/nozzles/internals components. Normally the shell/nozzles/internals components are constructed of stainless steel in high velocity applications; however, if they are constructed of carbon steel (as in the BWR RHR and Gland Seal condenser) and are exposed to fluid velocities greater than 6 ft/sec then erosion is a significant aging mechanism. This minimum threshold velocity is in agreement with the raw water tool (Appendix B). FAC is the increased loss of material caused by flow. The normally protective oxide film dissolves into the stream of flowing fluid. The material removal process is considered to be one of oxide dissolution. Wear rates tend to increase with increasing bulk velocity.
5. Wear is identified as a significant aging mechanism for all tube and tubesheet materials and in all environments within the scope of the AMG.

OAGI0000553_00393

Table 6-3 Significant Aging Mechanisms for a Treated Water Environment

MATERIALS	Thermal Embrit.	Creep	Mech. Fatigue	General Cor.	Pitting Cor.	Galvanic Cor.	MIC	SCC	Erosion / FAC	Wear	Fouling
Stainless and high alloy steel			X				X			X	X
Carbon and low alloy steel			X	X		X	X		X	X	X
Cu, Cu-alloys Muntz metal			X	See Note 2			X	See Note 5	X	X	X
Inhibited Adm. Brass			X				X	X	X	X	X
Titanium			X				X			X	X

Notes:

1. Thermal embrittlement and creep are discussed in Section 5, Item No. 4.
2. Muntz metal (and other copper alloys with greater than 15% zinc) are susceptible to selective leaching (dezincification) in a treated water environment. Inhibited admiralty brass provides resistance to dezincification based on 1% tin content.
3. Galvanic corrosion is discussed in Section 5, Item No. 12. Raw water on the shell side is not specifically addressed in the AMG since no heat exchangers in the scope of the AMG contain raw water on the shell side. At least one application has been identified in which raw water flows through the shell side of the RHR heat exchangers. The treated water evaluations indicate that galvanic corrosion is a significant aging mechanism for shell/nozzle/internals and waterbox/channel head/divider plate subcomponents where materials used are not close together on the galvanic chart and where sacrificial anodes or cathodic protection is not provided. This same logic would apply to a raw water environment.
4. MIC can attack any material but is only a significant aging mechanism for treated water systems if the treated water has been contaminated, such as from an interfacing system that contains raw water, and a biocide is not used. The use of nitrite corrosion inhibitors (> 10,000 ppm) in the presence of some microorganisms could potentially lead to nitrate-induced stress corrosion cracking.
5. Stress Corrosion Cracking is a significant aging mechanism for copper alloys with greater than 15% zinc content. Muntz metal contains approximately 40% zinc.

OAGI0000553_00394

6. Erosion / FAC. Treated water applications contain fine corrosion products that will collect at the bottom of tanks and reservoirs. These particles are highly abrasive and can be pumped into the various heat exchanger components. Treated water also is considered to be a corrosive fluid owing to its high oxygen content.

<u>Tubes</u>	Treated water on the shell side was only evaluated for stainless steel with no significant effect identified.
	Treated water on tube inside surfaces was evaluated. If tubes are made from copper nickel alloys or admiralty brass, erosion is a significant aging mechanism based on high dissolved oxygen and potential particulate content.
<u>Tubesheet</u>	If tubesheet is made from Muntz metal or carbon steel, erosion and FAC are significant aging mechanisms.
<u>Shell</u>	Only the BWR RHR cooler is evaluated for shell side treated water. Erosion and FAC are not significant because operation is only intermittent in that mode. However, the AMG in at least one place also lists HPCI gland seal condenser with shell side treated water. The same logic of intermittent operation should also apply to that heat exchanger.
<u>Waterbox</u>	If waterbox components are made from carbon steel, erosion and FAC is a significant aging mechanism.

7. Wear is a significant aging mechanism for all tube and tubesheet materials and in all environments within the scope of the AMG.

8. In treated water applications corrosion product particulates can accumulate at the bottom of tanks or reservoirs. Fouling is a significant aging mechanism where the water supply originates at the bottom of a tank or reservoir.

OAGI0000553_00395

Table 6-4 Significant Aging Mechanisms for a Closed Cooling Water Environment

MATERIALS	Thermal Embrit.	Creep	Mech. Fatigue	General Cor.	Pitting Cor.	Galvanic Cor.	MIC	SCC	Erosion / FAC	Wear	Fouling
Stainless and high alloy steel			X				X			X	
Carbon and low alloy steel			X	X			X		X	X	
Cu, Cu-alloys Muntz metal			X	See Note 2			X	Note 5		X	
Inhibited Adm. Brass			X				X	X		X	
Titanium			X				X			X	

Notes:

1. Thermal embrittlement and creep are discussed in Section 5, Item No. 4.
2. Muntz metal (and other copper alloys with greater than 15% zinc) are susceptible to selective leaching (dezincification) in a closed cooling water environment. (Inhibited admiralty brass is not susceptible due to 1% tin content which hinders deposition of copper.
3. Corrosion inhibitors are added to closed cooling systems. The AMG credits the addition of corrosion inhibitors as a means to minimize galvanic corrosion effects.
4. MIC is a significant aging mechanism for closed cooling water systems if the water has become contaminated, such as such as from an interfacing system containing raw water, and a biocide is not used. The use of nitrite corrosion inhibitors (> 10,000 ppm) in the presence of some microorganisms could potentially lead to nitrate-induced stress corrosion cracking in carbon and low-alloy steel.
5. Stress Corrosion Cracking is a significant aging mechanism for copper alloys with greater than 15% zinc content. Muntz metal contains approximately 40% zinc.
6. Erosion / FAC. Closed cooling water is fine filtered to remove particulate and deionized to achieve purity. It also contains corrosion inhibitors to minimize abrasive corrosion products. As long as the water chemistry is controlled and fluid velocities are maintained within specified limits, erosion for most heat exchanger components is not a significant aging mechanism. One exception is the shell/nozzles/internals components. Normally the shell/nozzles/internals components are constructed of stainless steel in high velocity applications; however, if they are constructed of carbon steel and are exposed to fluid velocities greater than 6 ft/sec then erosion is a significant aging mechanism (see Table 6-2, note 4). FAC is a mechanism by which fluid flow dissolves away the protective oxide layer, causing increased corrosion and reoxidation. FAC rates are greatest at temperatures between 250 and 340°F and in fluid conditions of pH < 9.5. Although FAC rates tend to increase with increasing bulk velocity, there is no practical velocity threshold below which FAC does not occur. Under these conditions, FAC is a significant aging mechanisms.
7. Wear is a significant aging mechanism for all tube and tubesheet materials and in all environments within the scope of the AMG.

OAGI0000553_00396

Table 6-5 Significant Aging Mechanisms for a Raw Water Environment

MATERIALS	Thermal Embrit.	Creep	Mech. Fatigue	General Cor.	Pitting Cor.	Galvanic Cor.	MIC	SCC	Erosion	Wear	Fouling
Stainless and high alloy steel			X		X		X	X		X	X
Carbon and low alloy steel			X	X	X	X	X		X	X	X
Cu, Cu-alloys Muntz metal			X	X	X	X	X	X	X	X	X
Inhibited Adm. Brass			X	X	X	X	X	X	X	X	X
Titanium			X				X			X	X

Notes:

1. Thermal embrittlement and creep are discussed in Section 5, Item No. 4.
2. General corrosion of copper nickel or inhibited admiralty tubes is a significant aging mechanism if operation of the heat exchanger is cyclic.

   General corrosion of carbon and low-alloy steel in a raw water environment is a significant aging mechanism. Although raw water was not evaluated on the shell side of heat exchangers, various other components (e.g., tubesheet, waterbox) are evaluated in this environment.

   General corrosion in the form of selective leaching (dezincification) of Muntz metal tube sheets is a significant aging mechanism.
3. Pitting is a significant aging mechanism for all materials with the exception of titanium. Pitting is not a concern for titanium or its alloys. The susceptibility to pitting is dependent on contaminants, oxygen, and fluid velocity. Section 4.3.2.1.3 of the AMG contains threshold velocities for several materials. Due to the cyclic operating nature of many heat exchangers and the complex fluid flow paths, it is likely that all heat exchangers will experience flow rates below these threshold values at various locations even under full flow conditions.
4. The AMG credits good design practices with preventing the occurrence of galvanic corrosion for the tubes and tubesheet material. Where necessary, sacrificial anodes or cathodic protection are utilized and galvanic corrosion is not a concern. Raw water on the shell side is not specifically addressed in the AMG since no heat exchangers in the scope of the AMG contain raw water on the shell side. There is at least one application where raw water flows through the shell side of the RHR heat exchangers. The treated water evaluations indicate that galvanic corrosion is a significant aging mechanism for shell/nozzle/internals and waterbox/channel head/divider plate subcomponents where materials used are not close together on the galvanic chart and where sacrificial anodes or cathodic protection is not provided. This same logic applies to a raw water environment.
5. Microbiologically induced corrosion is a significant aging mechanism for all materials in a raw water environment. Plant-specific use of biocides to prevent MIC is performed at some plants. This would reduce the susceptibility to MIC damage. The use of nitrite corrosion inhibitors in the presence of some microorganisms could potentially lead to nitrate-induced stress corrosion cracking in carbon and low-alloy steel.

OAGI0000553_00397

6. Stress corrosion cracking is a significant aging mechanism for stainless steel and copper alloys containing greater than 15% zinc. Muntz metal (40% zinc) and inhibited admiralty brass (28% zinc) are susceptible to SCC.

7. Erosion

   Raw water applications contain fine particles such as sand and silt that pass through the rough screens. These particles are highly abrasive and raw water is considered to be a corrosive fluid. Erosion of many heat exchanger materials in this environment is a significant aging mechanism.

   The AMG identified no application in which raw water was on the shell side of the heat exchangers. Although not specifically evaluated, the susceptibility of the shell side erosion can be extrapolated using the tube, tubesheet, and waterbox evaluations.

   <u>Tubes</u> Admiralty brass and copper nickel alloys are susceptible to erosion.

   <u>Tubesheet</u> Carbon steel and Muntz metal are susceptible to erosion.

   <u>Shell/Nozzle/Internals</u> Carbon/low-alloy steel are susceptible.

   <u>Waterbox/Channel Head/Divider Plate</u> Carbon/low-alloy steel are susceptible.

8. Wear is a significant aging mechanism for all tube and tubesheet materials and in all environments within the scope of the AMG.

OAGI0000553_00398

Table 6-6 Significant Aging Mechanisms for a Lubricating Oil Environment

MATERIALS	Thermal Embrit.	Creep	Mech. Fatigue	General Cor.	Pitting Cor.	Galvanic Cor.	MIC	SCC	Erosion / FAC	Wear	Fouling
Stainless and high alloy steel			X							X	X
Carbon and low alloy steel			X							X	X
Cu, Cu-alloys Muntz metal			X							X	X
Inhibited Adm. Brass			X							X	X
Titanium			X							X	X

Notes:

1. All heat exchangers evaluated operate with oil on the shell side. The AMG bases aging effects identification on strict controls for the quality and purity of the lubricating oil and the fact that they are regularly checked. The AMG assumes that very little corrosion occurs in lubricating oil systems because oxygen content is low, oils are not good electrolytes, and purification systems are generally installed and/or corrosion inhibitors added to maintain the oil free of corrosion products.
2. Thermal embrittlement and creep are discussed in Section 5, Item No. 2.
3. Mechanical fatigue is assumed for all materials and all environments in heat exchanger applications.
4. Galvanic corrosion is not a significant aging mechanism. According to the AMG even contaminated-condition oils are not good electrolytes.
5. MIC is not a significant aging mechanism. AMG basis is that even in the contaminated condition, oils do not support microorganism growth. This is contradictory to the oil/fuel oil tool (Appendix C) which assumes that contaminated oil may contain moisture and microorganisms.
6. SCC is not a significant aging mechanism. AMG basis is that the operating environment and temperatures do not support the mechanisms. This is also contradictory to the oil tool logic which assumes that moisture may be present and could initiate SCC.
7. Neither erosion nor flow-accelerated (FAC) corrosion are significant aging mechanisms. FAC occurs when the base material is susceptible to general corrosion in fluid environments. This is not the case with an oil environment. Additionally, the low flow rates and low contaminant levels in these systems do not support particulate flow erosion.
8. Wear is a significant aging mechanism for all tube and tubesheet materials and in all environments within the scope of the AMG.
9. Fouling is a significant aging mechanism in oil applications where the source of oil is the bottom of a tank or reservoir and, therefore, could result in the carryover of particulate matter. All oil applications in the AMG have the lubricating oil on the shell side of the heat exchanger. The shell material is carbon or low-alloy steel while the tube material may consist of any of the materials listed in the table (except carbon and low-alloy steel).

OAGI0000553_00399

Table 6-7 Significant Aging Mechanisms for an Air Environment

MATERIALS	Thermal Embrit.	Creep	Mech. Fatigue	General Cor.	Pitting Cor.	Galvanic Cor.	MIC	SCC	Erosion / FAC	Wear	Fouling
Stainless and high alloy steel			X							X	X
Cu, Cu-alloys Muntz metal			X							X	X
Inhibited Adm. Brass			X							X	X
Titanium			X							X	X
Aluminum, Aluminum Alloys			X							X	X

Notes:

1. Thermal embrittlement and creep are discussed in Section 5, Item No. 4.
2. Air coolers evaluated are all open coil/fin type coolers. Therefore, no tube side or shell side considerations are made.
3. Mechanical fatigue is assumed for all materials and all environments in heat exchanger applications.
4. The removal of the material oxide layer will only occur when the component wall is continuously wetted. Therefore, FAC does not occur in air systems. Due to the flow rates and contamination conditions, erosion is not an applicable mechanism in a nuclear plant air system.
5. Wear is a significant aging mechanism for all tube and tubesheet materials and in all environments within the scope of the AMG.
6. Materials for the tube side and exterior tubesheet were not well defined in the AMG for all the air coolers. As a result, corrosive effects on the tubes, tube baffles, and exterior of the tube sheets may not be adequately evaluated.
7. Fouling of the air side can occur from the accumulation and build up of dust, dirt, and debris on and between the fins of open coil/fin type coolers.

OAGI0000553_00400

7. COMPARISON TO GALL HEAT EXCHANGER ITEMS

The information in Chapters IV, V, VII, and VIII of Volume 2 of NUREG-1801, Revision 1, "Generic Aging Lessons Learned (GALL) Report – Tabulation of Results," identifies material, environment(s), aging effects (and associated mechanisms) typically requiring management for license renewal applicants, and the suggested aging management program (AMP) for various mechanical components. GALL Chapters IV, V, VII, and VIII all include items for heat exchangers addressed by this tool. GALL Chapter IV items for heat exchangers addressed by this tool are limited to isolation condenser components. The identification and evaluation of aging management programs (AMPs) is outside the scope of this tool and should be addressed on a plant-specific basis, as described in Section 4.0 of the main document. Pertinent GALL items are addressed in Tables 7-1 through 7-7, with the following component, material, environment, aging effect, and aging mechanism considerations.

As described in Section 1.2 above, steam generators (PWR) are not in the scope of the AMG and are not addressed in this appendix. Corresponding GALL Chapter IV items in Sections IV.D1 and IV.D2 are also not addressed. Refer to Appendix A of this document for pertinent discussions. The GALL Chapter IV, V, VII, and VIII items that are applicable to this tool include the following as the "Structure and/or Component":

- Heat exchanger components
- Heat exchanger tubes
- Isolation condenser components
- Motor cooler
- Non-regenerative heat exchanger components
- PWR heat exchanger components
- Regenerative heat exchanger components

The materials for the pertinent items in GALL Chapter IV, V, VII, and VIII are consistent with the materials in this tool. Carbon steel, low-alloy steel and cast iron are listed as "steel" in the pertinent GALL Chapter IV, V, VII, and VIII items. Gray cast iron is listed in the pertinent GALL Chapter V, VII, and VIII items with respect to its susceptibility to selective leaching, but is otherwise considered as steel. The pertinent GALL Chapter IV, V, VII, and VIII heat exchanger items also list stainless steel, alone or in combination with "steel" or with "steel with stainless steel cladding." The pertinent GALL Chapter V, VII, and VIII items refer to copper and copper alloys as "copper alloy" or "copper alloy > 15% Zn." There are no GALL items for aluminum or for titanium heat exchanger components. With the exception of titanium, which is addressed in Section 5, the materials addressed in this appendix are identified in Section 3.

The following GALL Chapter IV, V, VII, and VIII environments are bounded by the environments addressed in this tool, which are described in Section 3 and addressed separately in Tables 6-2 through 6-7 respectively:

Table 7-1 GALL Environments and Tool Environments

GALL Environment(s)	Appendix G Environment
▪ Reactor coolant ▪ Treated borated water > 60°C (>140°F) ▪ Treated water > 60°C (>140°F) ▪ Treated water	Primary Water (see also treated water)
▪ Treated water ▪ Treated water > 60°C (>140°F) ▪ Treated borated water > 60°C (>140°F)	Treated Water
▪ Closed cycle cooling water ▪ Closed cycle cooling water > 60°C (>140°F)	Closed Cooling Water
▪ Raw water	Raw Water
▪ Lubricating oil	Lube Oil
▪ Air – indoor uncontrolled (external) ▪ Air – outdoor (external)	Air

The following aging effects are cited in GALL Chapters IV, V, VII, and VIII for the various heat exchanger components, with the mechanism or groupings of mechanisms, depending on material susceptibility and/or environment:

- Cracking/ cyclic loading
- Cracking/ stress corrosion cracking
- Cracking/ stress corrosion cracking, cyclic loading
- Cracking/ stress corrosion cracking, intergranular stress corrosion cracking
- Loss of material/ general, pitting and crevice corrosion
- Loss of material/ general, pitting, crevice, and galvanic corrosion
- Loss of material/ general, pitting, crevice, and microbiologically influenced corrosion
- Loss of material/ general, pitting, crevice, and microbiologically influenced corrosion, and fouling
- Loss of material/ general, pitting, crevice, galvanic, and microbiologically influenced corrosion, and fouling
- Loss of material/ microbiologically influenced corrosion
- Loss of material/ pitting and crevice corrosion
- Loss of material/ pitting, crevice, and galvanic corrosion
- Loss of material/ pitting, crevice, and microbiologically influenced corrosion
- Loss of material/ pitting, crevice, and microbiologically influenced corrosion, and fouling

- Loss of material/ pitting, crevice, galvanic, and microbiologically influenced corrosion, and fouling
- Loss of material/ selective leaching
- Reduction of heat transfer/ fouling

The GALL is consistent with the conclusions of the AMG and this tool, in that there are no items that indicate thermal embrittlement or creep require management for heat exchanger components. GALL Chapter VII includes an item addressing fatigue of heat exchanger components (VII.E1-4) that is not related to steam generators. The AMG lists mechanical fatigue as an applicable aging mechanism for heat exchanger materials in all environments. Fatigue, including fatigue of heat exchangers, is evaluated separately in Appendix H of these Mechanical Tools.

The GALL Chapter V, VII, and VIII heat exchanger items addressing crevice corrosion are not consistent with the AMG, and therefore are not consistent with this appendix, in that the AMG does not address crevice corrosion as an applicable mechanism for heat exchangers. Also, the AMG identifies pitting corrosion as an applicable mechanism for heat exchanger materials, other than titanium, only when exposed to raw water. This is not consistent with the pertinent GALL Chapter V, VII, and VIII items, which list pitting and crevice corrosion as aging mechanisms requiring management for heat exchanger components, or with item 10 of Section 5 of this Appendix.

Table 7-2 GALL Comparison for Heat Exchangers / Primary Water Environment				
Material	**Aging Mechanism**	**NUREG-1801 (GALL) Item No.**	**Tool vs GALL Match**	**Relevant Section(s) and Discussion**
Stainless Steel *and* Carbon Steel *and* Titanium	Fouling	V.D2-13 VII.E3-6	No	Sections: Table 3-1, Table 6-2 Specified items cite reduction of heat transfer due to fouling of stainless steel heat exchanger tubes in the BWR emergency core cooling system (e.g., RHR) and reactor water cleanup system, respectively, that are exposed to treated water. GALL items for BWR isolation condenser components (IV.C1-4, IV. C1-5 and IV. C1-6) exposed to reactor coolant do not cite reduction of heat transfer as an aging effect requiring management, but the corresponding GALL recommendations for aging management include eddy-current testing of tubes. Letdown Hx, Seal Return Cooler, and RHR Hx (PWR) are not easily differentiated from other heat exchangers in the GALL Chapter V and VII heat exchanger items. See Table 6-3 below. Titanium (and its alloys) is not a material for GALL heat exchanger items.
	Wear	None	No	Sections: Table 3-1, Table 6-2 GALL Chapter IV, V, VII, and VIII heat exchanger items do not list loss of material due to wear as an aging effect requiring management in any environment, except for PWR steam generator components that are not addressed in this tool. Titanium (and its alloys) is not a material for GALL heat exchanger items.

OAGI0000553_00404

Table 7-2 GALL Comparison for Heat Exchangers / Primary Water Environment				
Material	**Aging Mechanism**	**NUREG-1801 (GALL) Item No.**	**Tool vs GALL Match**	**Relevant Section(s) and Discussion**
Carbon Steel	Erosion/FAC	None	No	Sections: Table 3-1, 5 (Item 14), Table 6-2 GALL Chapter IV, V, VII, and VIII heat exchanger items do not list loss of material due to erosion or FAC as an aging effect requiring management in any treated or closed cycle cooling water or reactor coolant environment.
	General, Pitting and Crevice Corrosion	IV.C1-6	No	Sections: Table 3-1, 5 (Items 9, 10, and 12), Table 6-2 Specified GALL item cites loss of material due to general (steel only), pitting, and crevice corrosion for isolation condenser (BWR) components exposed to reactor coolant. AMG does not identify any aging mechanisms for loss of material, other than erosion/FAC addressed above, as significant in primary water environments. See also Table 6-3 below, for steel heat exchanger components exposed to treated water.

OAGI0000553_00405

Table 7-2 GALL Comparison for Heat Exchangers / Primary Water Environment				
Material	**Aging Mechanism**	**NUREG-1801 (GALL) Item No.**	**Tool vs GALL Match**	**Relevant Section(s) and Discussion**
Stainless Steel	SCC	IV.C1-4, IV.C1-5 VII.E1-5, VII.E1-9, VII.E3-3, VII.E3-19	Yes	Section(s): Table 3-1, 5 (Items 6 and 11), Table 6-2 Specified GALL items cite cracking due to SCC and IGSCC for stainless steel (and steel) isolation condenser components of a BWR exposed to reactor coolant and stainless steel (or stainless steel clad) heat exchanger components in the RWCU or CVCS systems exposed to treated water > 60ºC (140ºF). AMG does not identify any aging mechanisms for loss of material, other than erosion/FAC addressed above, as significant in primary water environments. Additionally, items VII.E1-5 and VII.E1-9 cite cracking due to cyclic loading, along with SCC, for stainless steel heat exchanger components of the PWR Chemical and Volume Control Systems (CVCS), which are used during normal plant operations. GALL Item IV.C1-5 cites cracking due only to cyclic loading of BWR isolation condenser components. This appendix, and the AMG, are considered to include cycling loading with the mechanical fatigue mechanism, which requires plant-specific evaluation (Item 6 of Section 5). See also Table 6-3 below, for stainless steel heat exchanger components exposed to treated water.
	Pitting, Crevice Corrosion	IV.C1-6	No	Sections: Table 3-1, 5 (Items 9, 10, and 12), Table 6-2 Specified GALL item cites loss of material due to pitting and crevice corrosion for isolation condenser (BWR) components exposed to reactor coolant. AMG does not identify any aging mechanisms for loss of material, other than erosion/FAC addressed above, as significant in primary water environments. See also Table 6-3 below, for stainless steel heat exchanger components exposed to treated water.

OAGI0000553_00406

Table 7-3 GALL Comparison for Heat Exchangers / Treated Water Environment

Material	Aging Mechanism	NUREG-1801 (GALL) Item No.	Tool vs GALL Match	Relevant Section(s) and Discussion
All Materials	Fouling	V.A-6, V.D2-13 VII.A4-4, VII.E3-6 VIII.E-10, VIII.E-13, VIII.E-7, VIII.F-10, VIII.G-10	Yes	Sections: Table 6-3 Specified GALL items list reduction of heat transfer due to fouling as an aging effect requiring management for stainless steel and copper alloy (VIII.E-10, VIII.F-7, and VIII.G-10) heat exchanger tubes. Per Table 6-3, note 8, accumulation of particulates in the bottom of a tank or reservoir can cause fouling of heat exchanger tubes exposed to treated water if the water supply originates from the bottom; otherwise particulates in treated water are considered to be too low to cause fouling. While the GALL items address only stainless steel and copper alloy, consistent with the AMG, other materials are susceptible to fouling, if the above conditions are met in a treated water environment. Titanium (or its alloys) is not included in the GALL heat exchanger items.
	Wear	None	No	Sections: Table 6-3 GALL Chapter IV, V, VII, and VIII heat exchanger items do not cite loss of material due to wear as an aging effect requiring management in any environment, except for PWR steam generator components that are not addressed in this appendix. Titanium (or its alloys) is not included in the GALL heat exchanger items.
	MIC	None	No	Sections: 5 (Item 2), Table 6-3 GALL Chapter IV, V, VII, and VIII heat exchanger items do not list loss of material due to MIC as an aging effect requiring management in treated water environments, only in closed cooling water, lubricating oil, or raw water environments. Titanium (or its alloys) is not included in the GALL heat exchanger items.

OAGI0000553_00407

Table 7-3 GALL Comparison for Heat Exchangers / Treated Water Environment				
Material	**Aging Mechanism**	**NUREG-1801 (GALL) Item No.**	**Tool vs GALL Match**	**Relevant Section(s) and Discussion**
				Per item 2 of Section 5 of this appendix and Appendix A, Treated Water, MIC is only a concern in treated water if plant-specific operating experience shows recurring or unabated contamination from an open and/or natural source.
Carbon Steel	General, Galvanic, Crevice, Pitting Corrosion	VIII.E-7, VIII.E-37, VIII.F-28	Yes	Sections: 5 (Items 9, 10, and 12), Table 6-3 Specified GALL item cites loss of material due to general, pitting, and crevice corrosion in treated water for heat exchanger components, whereas the other Tools (e.g., Appendix A) and Section 5 clarifications indicate all of the specified aging mechanisms are applicable in treated water. Item VIII.E-7 also cites galvanic corrosion of steel heat exchanger components of the Condensate system. AMG lists only general and galvanic corrosion as significant mechanisms for carbon and low-alloy steel in a treated water environment.
	Erosion/FAC	None	No	Sections: 5 (Item 14), Table 6-3 GALL Chapter IV, V, VII, and VIII heat exchanger items do not list loss of material due to erosion or FAC as an aging effect requiring management in any treated or closed cycle cooling water or reactor coolant environment.

OAGI0000553_00408

Table 7-3 GALL Comparison for Heat Exchangers / Treated Water Environment				
Material	**Aging Mechanism**	**NUREG-1801 (GALL) Item No.**	**Tool vs GALL Match**	**Relevant Section(s) and Discussion**
Cu, Cu-Alloys, Muntz Metal, Inhibited Adm. Brass	SCC	None	No	Sections: 5 (Items 6 and 15), Table 6-3 GALL Chapter IV, V, VII, and VIII heat exchanger items do not list cracking due to SCC of copper alloys (regardless of Zn content) as an aging effect requiring management in treated, closed cycle cooling, or raw water environments. As per Appendix A, Treated Water, of these Mechanical Tools, ammonium or ammonium salts are necessary for SCC of copper alloys with > 15% Zn.
	Galvanic, Crevice, Pitting Corrosion	None	No	Sections: 5 (Items 9, 10 and 12), Table 6-3 GALL Chapter IV, V, VII, and VIII heat exchanger items do not list loss of material due to pitting (or crevice) or galvanic corrosion of copper alloys as an aging effect requiring management in treated water environments, but only in closed cycle cooling water or raw water environments, as described in Table 6-4 and Table 6-5, respectively.
Cu, Cu-Alloys, Muntz Metal (Cast Iron)	Selective Leaching	VII.E1-3, VII.F1-9, VII.F3-9 (V.A-18, V.D1-13)	Yes	Sections: Table 6-3 Specified GALL Chapter VII items cite loss of material due to selective leaching as an aging effect requiring management for copper alloys with > 15% Zn that are exposed to treated water. As per Appendix A of these Mechanical Tools and Note 2 of Table 6-3, copper alloys that are inhibited, by the addition of small amounts of arsenic, tin, etc., are resistant to dezincification (selective leaching). Specified GALL Chapter V items list loss of material due to selective leaching as an aging effect requiring management for gray cast iron motor cooler components exposed to treated water. Otherwise, cast iron is included with "steel" in the GALL items for treated water. AMG does not specifically address cast iron, nor does it exclude its inclusion with carbon and low-alloy steel, and only addresses selective leaching of copper alloys, as described above. However, cast iron heat exchanger components would also be susceptible to selective leaching.

OAGI0000553_00409

Table 7-3 GALL Comparison for Heat Exchangers / Treated Water Environment				
Material	**Aging Mechanism**	**NUREG-1801 (GALL) Item No.**	**Tool vs GALL Match**	**Relevant Section(s) and Discussion**
Stainless Steel	SCC	VIII.F-3	Yes	Sections: 5 (Items 6 and 11), Table 6-3 Specified GALL item cites cracking due to SCC as an aging effect requiring management for stainless steel heat exchanger components exposed to treated water > 60°C (>140°F) in a PWR steam generator blowdown system. See also Table 6-3 for cracking of stainless steel heat exchanger components exposed to primary water, as described in Table 3-1.
	Pitting, Crevice Corrosion	VII. A4-2 VIII.E-4, VIII.E-36, VIII.F-27	Yes	Sections: 5 (Items 9 and 10), Table 6-3 Specified GALL items cite loss of material due to pitting and crevice corrosion as aging effects requiring management for stainless steel or stainless steel cladding exposed to treated water.

OAGI0000553_00410

Table 7-4 GALL Comparison for Heat Exchangers / Closed Cooling Water Environment				
Material	**Aging Mechanism**	**NUREG-1801 (GALL) Item No.**	**Tool vs GALL Match**	**Relevant Section(s) and Discussion**
All Materials	MIC	VII.E3-1, VII.E4-1	No	Sections: 5 (Item 2), Table 6-4 Specified GALL items list loss of material due to MIC for stainless steel and stainless steel clad heat exchanger components in BWR Reactor Water Cleanup and Shutdown Cooling systems only that are exposed to closed cycle cooling water. The other GALL items for closed cycle cooling water do not list MIC as a mechanism for loss of material, for any material. Titanium (or its alloys) is not included in the GALL heat exchanger items. Per item 2 of Section 5 of this appendix and Appendix A of these Mechanical Tools, MIC is only a concern in treated water (including closed cooling water) if plant-specific operating experience shows recurring or unabated contamination from an open and/or natural source.
	Wear	None	No	Sections: Table 6-4 GALL Chapter V, VII, and VIII heat exchanger items do not list loss of material due to wear as an aging effect requiring management in any environment. Titanium (or its alloys) is not included in the GALL heat exchanger items.

OAGI0000553_00411

Table 7-4 GALL Comparison for Heat Exchangers / Closed Cooling Water Environment				
Material	**Aging Mechanism**	**NUREG-1801 (GALL) Item No.**	**Tool vs GALL Match**	**Relevant Section(s) and Discussion**
Carbon and Low-Alloy Steel	General, Galvanic, Crevice, Pitting Corrosion	V.A-9, V.D1-6, V.D2-7 VII.A3-3, VII.A4-3, VII.C2-1, VII.E1-6, VII.E3-4, VII.E4-2, VII.F1-11, VII.F2-9, VII.F3-11, VII.F4-8 VIII.A-1, VIII.E-6, VIII.F-5, VIII.G-5	Yes	Sections: 5 (Items 3, 9, 10, and 12), Table 6-4 Specified GALL items cite loss of material due to general, pitting, crevice, and galvanic corrosion in closed cycle cooling water for heat exchanger components, whereas the other Tools (e.g., Appendix A) and section 5 clarifications indicate all of the specified aging mechanisms are applicable in treated (closed cooling) water.
	Erosion/FAC	None	N/A	Sections: 5 (Items 3 and 14), Table 6-4 GALL Chapter IV, V, VII, and VIII heat exchanger items do not list loss of material due to erosion or FAC as an aging effect requiring management in any treated or closed cycle cooling water or reactor coolant environment.

OAGI0000553_00412

Table 7-4 GALL Comparison for Heat Exchangers / Closed Cooling Water Environment				
Material	**Aging Mechanism**	**NUREG-1801 (GALL) Item No.**	**Tool vs GALL Match**	**Relevant Section(s) and Discussion**
Carbon and Low-Alloy Steel (Cont'd)	Fouling	VII.F1-13, VII.F2-11, VII.F3-13, VII.F4-9 VIII.A-2, VIII.E-14, VIII.F-11, VIII.G-14	No	Section(s): Table 6-4 Specified GALL items cite reduction of heat transfer due to fouling as an aging effect requiring management for steel heat exchanger components exposed to closed cooling water. AMG, and Table 6-4, do not list fouling as a significant mechanism in a closed cooling water environment. However, note 8 of Table 6-3, Treated Water, may also be applicable to closed cooling water if the water supply originates at the bottom of a tank or reservoir.
Cu, Cu-Alloys, Muntz Metal, Inhibited Adm. Brass	Galvanic, Crevice, Pitting Corrosion	V.A-5, V.D1-2, V.D2-3 VII.E1-2, VII.F1-8, VII.F3-4	Yes	Sections: 5 (Items 3, 9, 10 and 12), Table 6-4 Specified GALL items cite loss of material due to pitting, crevice, and galvanic corrosion of copper alloy heat exchanger components exposed to closed cycle cooling water. The same effects, though not identified in the AMG, are applicable to copper alloy components in a treated (closed cooling) water environment, per the specified items of Section 5 and Appendix A, Treated Water, of these Mechanical Tools.
	SCC	None	No	Sections: 5 (Items 3, 6 and 15), Table 6-4 GALL Chapter IV, V, VII, and VIII heat exchanger items do not list cracking due to SCC of copper alloys (regardless of Zn content) as an aging effect requiring management in treated, closed cycle cooling, or raw water environments. As per Appendix A, Treated Water, of these Mechanical Tools, ammonium or ammonium salts are necessary for SCC of copper alloys with > 15% Zn.

OAGI0000553_00413

Table 7-4 GALL Comparison for Heat Exchangers / Closed Cooling Water Environment				
Material	**Aging Mechanism**	**NUREG-1801 (GALL) Item No.**	**Tool vs GALL Match**	**Relevant Section(s) and Discussion**
Cu, Cu-Alloys, Muntz Metal, Inhibited Adm. Brass (Cont'd)	Fouling	V.A-11 VII.C2-2, VII.F1-12, VII.F2-10, VII.F3-12 VIII.E-8	No	Section(s): Table 6-4 Specified GALL items cite reduction of heat transfer due to fouling as an aging effect requiring management for copper alloy heat exchanger components exposed to closed cooling water. AMG, and Table 6-4, do not list fouling as a significant mechanism in a closed cooling water environment. However, note 8 of Table 6-3, Treated Water, may also be applicable to closed cooling water, if the water supply originates at the bottom of a tank or reservoir.
Cu, Cu-Alloys, Muntz Metal	Selective Leaching	V.A-6, V.B-5, V.D1-3, V.D2-4	Yes	Sections: 5 (Items 3, 6, and 15), Table 6-4 Specified GALL Chapter V items cite loss of material due to selective leaching as an aging effect requiring management for copper alloys with > 15% Zn that are exposed to closed cycle cooling water. As per Appendix A of these Mechanical Tools and Note 2 of Table 6-4, copper alloys that are inhibited, by the addition of small amounts of arsenic, tin, etc., are resistant to dezincification (selective leaching).
Stainless Steel	Pitting, Crevice Corrosion	V.A-7, V.D1-4, V.D2-5 VIII.E-2, VIII.F-1, VIII.G-2	Yes	Sections: 5 (Items 9 and 10), Table 6-3 Specified GALL items cite loss of material due to pitting and crevice corrosion as an aging effect requiring management for stainless steel exposed to treated water.

OAGI0000553_00414

Table 7-4 GALL Comparison for Heat Exchangers / Closed Cooling Water Environment				
Material	**Aging Mechanism**	**NUREG-1801 (GALL) Item No.**	**Tool vs GALL Match**	**Relevant Section(s) and Discussion**
Stainless Steel (Cont'd)	SCC	VII.E3-2	Yes	Sections: 5 (Items 6 and 11), Table 6-4 Specified GALL item cites cracking due to SCC as an aging effect requiring management for stainless steel or stainless steel clad heat exchanger components exposed to closed cycle cooling water > 60ºC (>140ºF) in a BWR RWCU system (e.g., cooling water outlet of the non-regenerative heat exchanger).
	Fouling	V.A-13, V.D1-9, V.D2-10 VII.C2-3, VII.E3-5, VII.E4-3 VIII.E-11, VIII.F-8, VIII.G-11	No	Section(s): Table 6-4 Specified GALL items cite reduction of heat transfer due to fouling as an aging effect requiring management for stainless steel heat exchanger components exposed to closed cooling water. AMG, and Table 6-4, do not list fouling as a significant mechanism in a closed cooling water environment. However, note 8 of Table 6-3, Treated Water, may also be applicable to closed cooling water if the water supply originates at the bottom of a tank or reservoir.

OAGI0000553_00415

Table 7-5 GALL Comparison for Heat Exchangers / Raw Water Environment				
Material	**Aging Mechanism**	**NUREG-1801 (GALL) Item No.**	**Tool vs GALL Match**	**Relevant Section(s) and Discussion**
All Materials	Fouling	V.A-15, V.D1-11, V.D2-12, V.D2-15 VII.C1-6 VII.C1-7, VII.C3-1, VII.G-7, VII.H2-6 VIII.G-16 VIII.E-9, VIII.E-12, VIII.F-6, VIII.F-7, VIII.G-9, VIII.G-13	Yes	Sections: 5 (Item 8), Table 6-5 Specified GALL items list reduction of heat transfer due to fouling as an aging effect requiring management for steel, stainless steel, and copper alloy heat exchanger tubes exposed to raw water. Titanium (or its alloys) is not included in the GALL heat exchanger items. As described below, certain GALL items also identify fouling as a mechanism for loss of material in raw water environments.
	Wear	None	No	Sections: 5 (Item 8), Table 6-5 GALL Chapter V, VII, and VIII heat exchanger items do not list loss of material due to wear as an aging effect requiring management in any environment. Titanium (or its alloys) is not included in the GALL heat exchanger items.

OAGI0000553_00416

Table 7-5 GALL Comparison for Heat Exchangers / Raw Water Environment				
Material	**Aging Mechanism**	**NUREG-1801 (GALL) Item No.**	**Tool vs GALL Match**	**Relevant Section(s) and Discussion**
Carbon and Low-Alloy Steel	Crevice, Galvanic, General, Pitting Corrosion or MIC or Erosion	V.A-10, V.D1-7, V.D2-8 VII.C1-5 VIII.E-6, VIII.F-5, VIII.G-7	Yes	Sections: 5 (Items 8, 9, 10, 12 and 14), Table 6-5 Specified GALL items cite loss of material due to general, pitting, crevice, galvanic, and microbiologically influenced corrosion and fouling of steel heat exchanger components exposed to raw water. GALL items for heat exchangers, and other raw water/metal items, do not list erosion as an aging mechanism for loss of material.
Cu, Cu-Alloys, Muntz Metal *and* Inhibited Adm. Brass	Crevice, Pitting, Galvanic Corrosion or MIC or Erosion	VII.C1-3	Yes	Sections: 5 (Items 8, 9, 10, 12, and 14), Table 6-5 Specified GALL item cites loss of material due to pitting, crevice, galvanic, and microbiologically influenced corrosion and fouling of copper alloy heat exchanger components exposed to raw water. GALL items for heat exchangers, and other raw water/metal items, do not list erosion as an aging mechanism for loss of material.
	SCC	None	No	Sections: 5 (Items 8 and 15), Table 6-5 GALL Chapter IV, V, VII, and VIII heat exchanger items do not list any copper alloys as being susceptible to cracking. Furthermore, Appendix B of these Mechanical Tools indicates that ammonia or ammonium salts are necessary for SCC of copper alloys with > 15% Zn or > 8% Al.

OAGI0000553_00417

Table 7-5 GALL Comparison for Heat Exchangers / Raw Water Environment

Material	Aging Mechanism	NUREG-1801 (GALL) Item No.	Tool vs GALL Match	Relevant Section(s) and Discussion
Cu, Cu-Alloys, Muntz Metal	Selective Leaching	VII.C1-4	Yes	Sections: 5 (Items 8 and 15), Table 6-5 Specified GALL Chapter VII item cites loss of material due to selective leaching as an aging effect requiring management for copper alloys with > 15% Zn that are exposed to raw water. As per Appendix A of these Mechanical Tools and Note 2 of Table 6-5, copper alloys that are inhibited, by the addition of small amounts of arsenic, tin, etc., are resistant to dezincification (selective leaching).
Stainless Steel	Pitting Corrosion, Crevice Corrosion, MIC	V.A-6, V.D1-5, V.D2-6 VIII.E-3, VIII.F-2, VIII.G-4	Yes	Sections: 5 (Items 8, 9, and 10), Table 6-5 Specified GALL items cite loss of material due to pitting, crevice, and microbiologically influenced corrosion, and fouling for stainless steel heat exchanger components exposed to raw water.
	SCC	None	Yes	Section(s): 5 (Items 6, 8, and 11), Table 6-5 GALL Chapter V, VII, and VIII heat exchanger items do not list cracking due to SCC of stainless steel or stainless steel cladding exposed to raw water. Per Note 11 of Section 5 of this appendix and Appendix B, Raw Water, of these Mechanical Tools, SCC of stainless steel is considered plausible only if temperatures are > 140ºF, which is not typical of raw water systems.

OAGI0000553_00418

Table 7-6 GALL Comparison for Heat Exchangers / Lubricating Oil Environment				
Material	**Aging Mechanism**	**NUREG-1801 (GALL) Item No.**	**Tool vs GALL Match**	**Relevant Section(s) and Discussion**
All Materials	Fouling	V.A-12, V.A-14, V.A-17, V.D1-8, V.D1-10, V.D1-12, V.D2-9, V.D2-11, V.D2-14 VIII.G-8 VIII.G-12 VIII.G-15	No	Sections: Table 6-6 Specified GALL items cite reduction of heat transfer due to fouling as an aging effect requiring management for copper alloy, steel, and stainless steel heat exchanger tubes exposed to a lubricating oil environment. Titanium (or its alloys) is not included in the GALL heat exchanger items. AMG does not address fouling as a mechanism for loss of material, per se, but with respect to an accumulation of particulates, if the source of the oil is the bottom of a tank or reservoir that results in carryover of particulate matter.
	Wear	None	No	Sections: 5 (Item 13), Table 6-6 GALL Chapter V, VII, and VIII heat exchanger items do not list loss of material due to wear as an aging effect requiring management in any environment. Titanium (or its alloys) is not included in the GALL heat exchanger items.
Carbon and Low-Alloy Steel	General, Crevice, Pitting Corrosion and MIC	VII.H2-5 VIII.G-6	No	Sections: 5 (Item 13), Table 6-6 Specified GALL items cite general, pitting, crevice, and microbiologically influenced corrosion of steel heat exchanger components exposed to lubricating oil. The GALL items include no indication of whether the lubricating oil contains water. AMG and Table 6-6 do not list general, crevice, pitting, or microbiologically influenced corrosion as significant aging mechanisms in a lube oil environment. Per Item 13 of Section 5 of this appendix and Appendix C, Lubricating Oil and Fuel Oil, of these

OAGI0000553_00419

Table 7-6 GALL Comparison for Heat Exchangers / Lubricating Oil Environment				
Material	**Aging Mechanism**	**NUREG-1801 (GALL) Item No.**	**Tool vs GALL Match**	**Relevant Section(s) and Discussion**
				Mechanical Tools, there are no aging effects in lubricating oil environments, unless the oil is contaminated by the intrusion of water. Also, GALL item VII.H2-5 also cites fouling as a mechanism for loss of material of steel heat exchanger components, Emergency Diesel Generator System, whereas item VIII.G-6, Auxiliary Feedwater System, does not. The GALL includes no basis/justification for inclusion of a mechanism for one system's components but not another's, when the environment and material are the same or similar.
Stainless Steel	Crevice, Pitting Corrosion and MIC	VIII.G-3	No	Sections: 5 (Item 13), Table 6-6 Specified GALL item cites pitting, crevice, and microbiologically influenced corrosion of stainless steel heat exchanger components exposed to lubricating oil. The GALL item includes no indication of whether the lubricating oil contains water. AMG and Table 6-6 do not list general, crevice, pitting, or microbiologically influenced corrosion as significant aging mechanisms in a lube oil environment. Per Item 13 of Section 5 of this appendix and Appendix C, Lubricating Oil and Fuel Oil, of these Mechanical Tools, there are no aging effects in lubricating oil environments, unless the oil is contaminated by the intrusion of water.

OAGI0000553_00420

Table 7-7 GALL Comparison for Heat Exchangers / Air Environment				
Material	**Aging Mechanism**	**NUREG-1801 (GALL) Item No.**	**Tool vs GALL Match**	**Relevant Section(s) and Discussion**
All Materials	Fouling	None	No	Sections: Table 6-7 GALL Chapter IV, V, VII, and VIII items do not list fouling in an air environment, either as a mechanism for loss of material or for reduction of heat transfer. Titanium and aluminum (or their alloys) are not included in the GALL heat exchanger items.
	Wear	None	No	Sections: Table 6-7 GALL Chapter V, VII, and VIII heat exchanger items do not list loss of material due to wear as an aging effect requiring management in any environment. Titanium and aluminum (or their alloys) are not included in the GALL heat exchanger items.
Carbon and Low-Alloy Steel	General, Crevice, Pitting Corrosion	VII.F1-10, VII.F2-8, VII.F3-10, VII.F4-7, VII.G-5, VII.G-6, VII.H2-3, VII.H2-4	Yes	Sections: 5 (Items 9, 10 and 12), Table 6-7 Specified GALL items cite general, crevice and pitting corrosion of steel heat exchanger components exposed to uncontrolled air, either indoor (external) or outdoor (external). For the purposes of this tool the external surface is considered to be the outer surface of heat exchanger tubes. The AMG does not list general or pitting corrosion as significant mechanisms in an air environment, and does not address crevice corrosion. However, consistent with Appendix E, External Surfaces, the Mechanical Tools indicate that general corrosion is an applicable mechanism for steel in moist air environments and that pitting corrosion (as well as crevice corrosion) is an applicable mechanism if a surface is frequently or continually wetted, such as the outer surface of a tube filled with raw or chilled water could be expected to be.

OAGI0000553_00421

8. REFERENCES

1. Sandia National Laboratories, "Aging Management Guideline for Commercial Nuclear Power Plants-Heat Exchangers," Contractor Report No. SAND93-7070, June 1994.

2. M. G. Fontana, *Corrosion Engineering,* Third Edition, Copyright 1986, McGraw Hill.

Appendix H
Non-Class 1 Fatigue Screening Criteria

This non-Class 1 fatigue screening document provides a methodology for identifying components that may be susceptible to cracking due to fatigue. Cracking due to other aging mechanisms may be assessed using the material- and environment-based tools presented in Appendices A through E. Fatigue of bolting materials is not addressed in this tool but is treated separately in the Bolted Closure Tool in Appendix F. This document may be applied when evaluating susceptibility to fatigue cracking of the following components: pipe, tubing, fittings, tanks, vessels, heat exchangers, valve bodies and bonnets, pump casings, bellows, and miscellaneous process components.

CONTENTS

Page

1. INTRODUCTION 1-1

2. SCOPE, MATERIALS, AND ENVIRONMENTS 2-1
2.1 Scope 2-1
2.2 Materials 2-1
2.3 Environments 2-1

3. CRACKING DUE TO FATIGUE 3-1
3.1 Compliance to Design Requirements 3-1
3.1.1 Piping and In-Line Components 3-1
3.1.2 Pressure Vessels, Heat Exchangers, Storage Tanks, and Pumps 3-3
3.2 Unanticipated Thermal Fatigue 3-3

4. FLOW CHART DEVELOPMENT 4-1
4.1 Screening Criteria for Piping and In-Line Components 4-1
4.1.1 System Level 4-1
4.1.2 Component Level 4-1
4.2 Screening Criteria for Pressure Vessels, Heat Exchangers, Storage Tanks, and Pumps 4-1
4.2.1 ASME Section VIII 4-2
4.2.2 ASME Section III 4-2
4.2.3 Other Codes and Standards 4-2
4.2.4 Screening Criteria 4-3

5. COMPARISON TO GALL FATIGUE ITEMS 5-1

6. REFERENCES 6-1

LIST OF FIGURES

Page

Figure 4-1 ANSI B31.1 and ASME III Non-RCPB Piping, Expansion Bellows, In Line Components, and CLB Requirements 4-4
Figure 4-2 ASME III and ASME VIII Non-RCPB Pressure Vessels, Heat Exchangers, Storage Tanks, and Pumps 4-5

OAGI0000553_00425

LIST OF TABLES

Page

Table 3-1 Stress Range Reduction Factors (f) 3-2
Table 5-1 GALL Environments for Fatigue Items 5-2
Table 5-2 GALL Comparison – Non-Class 1 Fatigue Items 5-3

1. INTRODUCTION

The non-Class 1 fatigue screening document (hereafter referred to as the Fatigue Tool) provides a logic and methodology by which systems within the scope of license renewal may be evaluated to determine locations susceptible to fatigue cracking. Cracking due to other aging mechanisms may be assessed using the material- and environment-based tools presented in Appendices A through E. Fatigue of bolting materials is not addressed in this tool but is treated separately in the Bolted Closure Tool in Appendix F. The Fatigue Tool may be applied when evaluating susceptibility to fatigue cracking of the following components: pipe, tubing, fittings, tanks, vessels, heat exchangers, valve bodies and bonnets, pump casings, and miscellaneous process components.

Fatigue failures in mechanical piping and components are sometimes categorized as either low cycle (typically less than 10,000 cycles) or high cycle (typically millions of cycles). Low cycle fatigue failure might occur after fewer than 10,000 cycles but only if strains exceed the yield strain. High cycle fatigue failure might occur at strains below the yield strain but only after many cycles. High cycle fatigue concerns are generally associated with high speed rotating or reciprocating equipment, vibration, or local thermal cycling due to hot and cold fluid mixing—i.e., thermal striping. Most nuclear power plant *design* fatigue applications reside within the low cycle regime.

A review of operating plant performance history [Volume 2 of Reference 1] reveals three general classifications of fatigue issues that have been observed in operating plants: vibrational fatigue failures, thermal fatigue failures, and plant license/design basis concerns. Vibrational fatigue is not considered in the Fatigue Tool since failures due to vibration are typically detected early in component service life [1] and actions are taken to prevent recurrence. Cracking due to vibrational fatigue is not an applicable aging effect for the period of extended operation. For standby systems subject to periodic testing, such as HPCI, failure caused by high cycle fatigue may be a longer term issue. Evaluation of high cycle fatigue for infrequently used systems is not addressed in this appendix and should be considered on a case-by-case basis by the user of this document.

Cracking due to thermal fatigue is considered in the Fatigue Tool. Thermal fatigue is attributed to thermal stresses that occur whenever expansion or contraction that result from heating or cooling of a body is prevented; the constraints that prevent expansion or contraction can be either externally imposed or self-imposed due to the configuration of the body and the temperature distribution. Locations that are susceptible to aging (including cracking due to thermal fatigue) must be identified in accordance with the requirements of 10 CFR 54.21 (a)(3) for components within the scope of license renewal.

Plant license/design basis fatigue concerns address the design requirements associated with the components in question. For example, ANSI B31.1, ANSI B31.7, and ASME Section III include design requirements to prevent fatigue failures of piping and components. Specific editions of these Codes are part of the current licensing basis (CLB) for each nuclear plant. For license renewal, it is necessary to demonstrate that the piping and components comply with the fatigue requirements of these codes considering the stress cycles through the period of extended operation in accordance with 10 CFR 54.21 (c).

OAGI0000553_00427

The non-Class 1 scope is large and the majority of the scope is not subject to significant cyclic thermal loading. The purpose of this document is to provide guidelines (screening criteria) for reviewing the non-Class 1 scope to identify the small subset which should be evaluated in more detail. Piping and components in this subset will either be shown acceptable by analysis, will be included in an augmented inspection program, or will be repaired or replaced. The scope of components covered by the Fatigue Tool, including materials and environments, is discussed in Section 2.0. The susceptibility of various components to thermal fatigue is discussed in Section 3.0. The development of the screening criteria to be applied to the components within the scope of license renewal is presented in Section 4.0. A comparison of the fatigue screening to fatigue related items in NUREG-1801, "Generic Aging Lessons Learned" (the GALL report) is presented in Section 5.0.

OAGI0000553_00428

2. SCOPE, MATERIALS, AND ENVIRONMENTS

The scope of components covered in the Fatigue Tool is discussed in Section 2.1. Materials of construction and operating environments that apply to the components within this scope are summarized in Sections 2.2 and 2.3, respectively.

2.1 Scope

Class 1 components are exposed to conditions that exceed the screening thresholds established in this appendix and are also subject to additional considerations, as outlined in the resolution of Generic Safety Issue GSI-190. As such, this appendix is not applicable to Class 1 components.

This document is intended for application to the following non-Class 1 components: pipe, tubing, fittings, tanks, vessels (except containment vessels), heat exchangers, valve bodies and bonnets, pump casings, bellows type expansion joints, miscellaneous process components, and other components that received fatigue evaluations in accordance with NRC requirements (e.g., BWR torus attached piping). The component evaluation boundary is consistent with the evaluation boundaries for the following design codes: ASME III (NC and ND), B 31.7 Class II and III, ASME VIII (Division 1 and 2), and B31.1. Tanks and vessels designed in accordance with TEMA and API are not within the scope of this appendix.

2.2 Materials

The materials that may be evaluated with the Fatigue Tool include carbon, low-alloy, and high tensile steels, austenitic steels, nickel-chromium-iron alloy, nickel-iron-chromium alloy, and nickel-copper alloy steels. These materials should be evaluated for metal temperatures as designated by the Code of Record in the current licensing basis or the original design.

The subsequent sections of the Fatigue Tool specifically address carbon steel and stainless steel. As in Appendices A through E, the discussions and logic for carbon steel are considered to be applicable to low-alloy steel. Likewise, the discussions and logic for stainless steels are considered to be applicable to nickel-base alloys.

Due to the varying microstructures, textures, and surface treatments for the various aluminum and titanium alloys, which are the main variables for the fatigue life of those materials, plant-specific evaluation is recommended. Refer to the pertinent articles contained in Volume 19 of the ASM Handbook, "Fatigue and Fracture," Copyright 1996 by the American Society of Metals (ASM) International for additional information.

2.3 Environments

The environments for the piping and components that may be evaluated with the Fatigue Tool are those defined in Appendices A through E. However, this tool addresses the thermal stresses to which piping and components may be subjected during normal operation without consideration of the impact of any loss of material during the period of extended operation resulting from the presence of corrosives in these environments.

If loss of material occurs in the environments covered by this tool, then further case-by-case evaluation is required to assess the impact of the loss of wall thickness caused by aging mechanisms during the license renewal period. For example, the use of this tool is non-conservative when assessing fatigue damage if the component being evaluated is in a configuration subject to high stress intensification factors or subjected to thermal cycles and is also susceptible to general corrosion or pitting corrosion.

3. CRACKING DUE TO FATIGUE

Non-Class 1 piping and components that require further evaluation of thermal fatigue to demonstrate suitability for license renewal will be identified through reviews for the following:

a) Compliance to Design Requirements

   Non-Class 1 piping and components will be reviewed to determine if thermal fatigue design requirements in ANSI B31.1, ASME III, and ASME VIII are met considering additional thermal cycles due to extended operation. Thermal expansion stress (S_e) is included in this evaluation because the value of S_e must not exceed the alternating stress (S_a) which is a function of the stress range reduction factor. Local strain is considered in the calculation of S_e and is not a function of time.

b) Unanticipated Thermal Fatigue

   NRC bulletins and information notices were reviewed to identify non-Class 1 piping and components which may have experienced unanticipated thermal fatigue.

3.1 Compliance to Design Requirements

As discussed in Section 1.0, compliance to code design requirements for the period of extended operation must be demonstrated in accordance with 10 CFR 54.21 (c). A review of design codes typically applicable to the non-Class 1 license renewal scope was performed. The results of the review were used to prepare the criteria discussed in Sections 3.1.1 and 3.1.2.

3.1.1 Piping and In-Line Components

Most non-Class 1 piping and in-line components (i.e., fittings and valves) are designed in accordance with ANSI B31.1 or ASME III Subsections NC and ND. Under these Codes, secondary stresses (i.e., stress due to thermal expansion and anchor movements) are evaluated for fatigue using Stress Intensification Factors (SIFs) and stress range allowables. The early SIFs and allowables are based for the most part on the Mark l fatigue tests. Later SIFs are based on experimental and analytical studies and the relationship between the SIF and the ASME III Class 1 stress indices for moment loading (C2 and K2). The allowable secondary stress range is 1.0 S_A for 7000 cycles or less and is reduced in steps to 0.5 S_A for greater than 100,000 cycles. No increase is allowed for less than 7000 cycles. Typical stress range reduction factors are shown in Table 3-1.

Evaluation of localized peak stresses due to thermal transients is not required by ANSI B31.1 or ASME III NC/ND. The basis for not requiring evaluation of peak stresses is that adequate protection against fatigue is provided by the rules existing in the Code for design conditions. Also, thermal transients are generally less severe for non-Class 1 piping.

OAGI0000553_00431

Table 3-1 Stress Range Reduction Factors (f)

Number of Equivalent Full Temperature Cycles *N*	*f*
7,000 and less	1.0
7,000 to 14,000	0.9
14,000 to 22,000	0.8
22,000 to 45,000	0.7
45,000 to 100,000	0.6
100,000 and over	0.5

Primary stresses in non-Class 1 piping due to earthquake, fluid transients, and other cyclic primary loads are evaluated against conservative stress limits designed to prevent ductile failure but are not specifically evaluated as a contributor to fatigue. Again, this is due to conservatism in the Code for design conditions, and also due to the very small number of stress cycles postulated for earthquakes and fluid transients.

High cycle fatigue is not a concern for license renewal since it would be discovered during the current license period in most cases where systems are frequently operated, as is supported by the following discussion of NRC information notice 2002-026. For standby systems subject to periodic testing, such as HPCI, failure caused by high cycle fatigue may be a longer term issue. Evaluation of high cycle fatigue for infrequently used systems is not addressed further in the Fatigue Tool and should be considered on a case-by-case basis by the user of this document.

IN 02-026: Failure of Steam Dryer Cover Plate After a Recent Power Uprate

This information notice alerted licensees of failure of a steam dryer cover plate during operation following a power uprate at a boiling water reactor (BWR). In March 2002, a BWR completed a refueling outage which included a modification to add baffle plates to the steam dryer to reduce the excessive moisture carryover expected as a result of an extended power uprate. In June 2002, the unit began experiencing fluctuations in steam flow, reactor pressure and level, and moisture carryover in the main steam lines. The licensee discovered that a dryer cover plate on the outside of the steam dryer had broken loose. Preliminary results of scale model testing indicated that the failure of the plate was due to high cycle fatigue driven by flow-induced vibration. This fatigue was attributed to excessive vibration caused by the synchronization of the cover plate resonance frequency, the nozzle chamber standing acoustic wave frequency, and the vortex shedding frequency. The licensee concluded that the three frequencies synchronized in a very narrow band of steam flow at or near the steam flow required to reach full power under the power uprate. This experience supports high cycle fatigue being a design issue and not a license renewal concern.

OAGI0000553_00432

3.1.2 Pressure Vessels, Heat Exchangers, Storage Tanks, and Pumps

Most non-Class 1 pressure vessels, heat exchangers, storage tanks, and pumps are designed in accordance with ASME VIII or ASME III Subsection NC or ND (i.e., Class 2 or 3)[1]. Some tanks and pumps are designed to other industry Codes and standards such as American Water Works Association (AWWA) standards and Manufacturer's Standardization Society (MSS) standards. Only ASME Section VIII Division 2 and ASME Section III Subsection NC-3200 include fatigue design requirements. Conservatism in ASME Section VIII Division 1 and ASME Section III NC-3100/ND-3000 compensates for excluding requirements for detailed fatigue analysis. Also, it is expected that the component designer would have specified ASME Section VIII Division 2 or NC-3200 if cyclic loading and fatigue usage could be significant.

Both ASME Section VIII Division 2 and ASME Section III NC-3200 include provisions for "exemption from fatigue," which is actually a simplified fatigue evaluation based on materials, configuration, temperature, and cycles.

Fatigue analysis is not required for ASME Section VIII Division 1, Section III NC-3100 or ND vessels. It is also not required for NC/ND pumps and storage tanks (< 15 psig). The applicable design Code for each component is noted in the component Code Data Report, Design Specification, and Stress Report. It is also noted on the nameplate attached to each component.

3.2 Unanticipated Thermal Fatigue

Actual fatigue failures encountered in piping and components have arisen not because of inadequacies in design methodology, but because unanticipated thermal fatigue loads were present that were not accounted for in the original design. In particular, thermal stratification, cycling, and striping in feedwater piping have resulted in numerous instances of pipe cracking due to fatigue. A search of NRC bulletins and notices to find issues related to thermal stratification in the feedwater/auxiliary feedwater piping and piping connected to the RCS has been performed. The results of this search are summarized below.

IE Bulletins

BL 79-13 (Revisions 0, 1, 2): Cracking in Feedwater System Piping

Cracking in feedwater system piping was addressed under IE Bulletin 79-13. Licensees with CE and Westinghouse steam generators reported crack indications in 16" feedwater elbows adjacent to steam generator nozzle elbow welds. No indications of cracking were found in B&W units. The NRC requested all PWR facilities to conduct examinations during the first refueling outage. Of the 54 PWRs facilities that were required to respond, cracks were found and corrected at 18 of them. It was recommended that licensees continue to perform inspections to detect possible future degradation in feedwater piping.

---

[1] ASME III Subsection NC applies to Class 2 piping and components. Class 2 was designated Class B in early Codes. ASME Subsection ND applies to Class 3 piping and components. Class 3 was designated Class C in early Codes.

OAGI0000553_00433

BL 88-08: Thermal Stresses in Piping Connected to Reactor Coolant Systems

Thermal stresses in piping connected to reactor coolant systems were addressed under IE Bulletin 88-08. Leaks due to cracked welds in unisolable sections of piping connected to the RCS primary piping occurred at Farley 2, Tihange 1 (Belgium), and Genkai (Japan). As a result, the NRC requested licensees to review systems connected to the RCS and provide assurance that unisolable sections of piping will not be subjected to combined cyclic and static thermal and other stresses that could cause fatigue failure during the life of the plant. This is a TLAA issue for Class 1 components and will be addressed on a plant-specific basis.

Information Notices

IN 84-87: Piping Thermal Deflection Induced by Stratified Flow

Information Notice 84-87 notified power reactor facilities of damage to a feedwater system due to piping thermal deflection from stratified flow. At WNP (now Columbia Generating Station) feedwater pipe hangers and snubbers were damaged and a flange loosened, allowing a small leak. This event was attributed to thermal stratification during unit startup. The NRC requested licensees to consider actions to avoid similar problems.

IN 88-01: Safety Injection Pipe Failure

Information Notice 88-01 alerts addressees to a potentially generic problem concerning the reliability of piping in safety-related systems because of valve leakage that resulted in thermal cycling of the piping. On December 9, 1987, while restarting Farley Unit 2 after a refueling outage, the licensee noted increased moisture and radioactivity within containment. The unidentified leak rate for the RCS was determined to be 0.7 gpm. By ultrasonic testing, the licensee found an indication of a crack on the interior surface of the 6-inch ECCS piping connected to the cold leg of RCS Loop B. The indication was located at a weld connecting an elbow and a horizontal spool. Further, the indication was on the underside of the pipe and extended circumferentially 60 degrees in both directions from the bottom of the pipe. The crack extended through the wall for approximately 1 inch at the center of the indication. Visual and metallographic examinations showed that the weld had failed as a result of fatigue after roughly one million stress cycles. The stress loads were thermal, and the problem was corrected by directing the valve leakage away from the ECCS manifold.

IN 89-80: Potential for Water Hammer, Thermal Stratification, and Steam Binding in High-Pressure Coolant Injection Piping

Information Notice 89-80 identifies the potential for water hammer, thermal stratification, and steam binding in high pressure coolant injection piping resulting from failure of high-pressure coolant injection (HPCI) valves in boiling water reactors (BWRs) during operation of the reactor at power. On February 21, 1989, with Dresden Unit 2 operating at power, temperature was greater than normal in the HPCI pump and turbine room. The abnormal heat load was caused by feedwater leaking through uninsulated HPCI piping to the condensate storage tank. During power operation, feedwater temperature is less than 350°F, and feedwater pressure is approximately 1025 psi. Normally, leakage to the condensate storage tank is prevented by the injection check valve, the injection valve, or the discharge valve on the auxiliary cooling water pump. On October 23, 1989, with the reactor at power, leakage had increased sufficiently to raise the temperature between the injection valve and the HPCI pump discharge valve to 275°F and at the discharge of the HPCI pump

OAGI0000553_00434

to 246°F. Pressure in the HPCI piping was 47 psia. On the basis of the temperature gradient and the pressure in the piping, the licensee concluded that feedwater leaking through the injection valve was flashing and displacing some of the water in the piping with steam. The event at Dresden is significant because the potential existed for water hammer or thermal stratification to cause failure of the HPCI piping and for steam binding to cause failure of the HPCI pump.

IN 91-19: Steam Generator Feedwater Distribution Piping Damage

Information Notice 91-19 was prepared to alert plants to the degradation that was possible in the feedwater system piping due to thermal stress, cracking, erosion, and corrosion.

IN 91-28: Cracking in Feedwater System Piping

Information Notice 91-28 notified addressees of the issuance of NUREG/CR-5285 that documented the close-out of the Bulletin 79-13 responses for the 54 PWRs that were required to respond. The report recommended that licensees continue to perform inspections to detect possible degradation in feedwater piping.

IN 91-38: Thermal Stratification in Feedwater System Piping

Information Notice 91-38 identified concerns with thermal stratification in feedwater system piping and the resulting unacceptable pipe movement. At Beaver Valley 1 global stratification occurred over a long stretch of horizontal feedwater piping inside the containment. Instrumentation detected top to bottom temperature differentials as much as 200°F. The horizontal section is preceded by a 20′ vertical section that did not provide adequate mixing to prevent stratification. It was concluded that the vertical sections offer little (if any) protection from stratification. The NRC requested licensees to consider actions to avoid similar problems.

Summary

It is concluded that unanticipated thermal fatigue is managed by plant-specific actions resulting from IE Bulletins 79-13 and 88-08, and the heightened awareness to this issue due to the aforementioned Information Notices.

OAGI0000553_00435

4. FLOW CHART DEVELOPMENT

Screening criteria for addressing non-Class 1 components may be addressed within the following two component groups: (1) piping and in-line components, and (2) pressure vessels, heat exchangers, storage tanks, and pumps.

4.1 Screening Criteria for Piping and In-Line Components

Screening criteria for piping and in-line components are depicted in Figure 4-1. Screening consists of system and component level reviews.

4.1.1 System Level

The first step in system level screening is to identify piping which may have Normal/Upset Condition operating temperature in excess of 220°F for carbon steel or 270°F for austenitic stainless steel. These values are based on recommendations in the EPRI Fatigue Management Handbook, Volume 2, Section 4.2 (Reference 1), which indicate that systems or portions of systems with operating temperatures below these thresholds may generally be excluded from fatigue concerns since the fluid temperature would not be expected to vary more than 150°F for carbon steel or 200°F for stainless steel. However, any local component residual stress and/or geometry specific stress intensification factors can result in lower temperature thresholds, and, therefore, must be evaluated on a plant-specific case-by-case basis.

The second system level step is to determine if the equivalent full temperature cycles[1] considering the period of extended operation are below the limit used for original design (usually 7000 cycles). Separate evaluation of individual pipe stress calculations is required if the cycle limit is exceeded during extended life.

4.1.2 Component Level

If the equivalent full temperature cycles[1] considering extended operation exceed the limit used for original design (usually 7000 cycles), evaluation of individual pipe stress calculations are required to confirm qualification. The stress range reduction factor, "f," should be applied to reduce the allowable stress. If calculated stress levels are below the reduced allowable, suitability for extended operation is demonstrated. If not, further evaluation is required.

4.2 Screening Criteria for Pressure Vessels, Heat Exchangers, Storage Tanks, and Pumps

Screening criteria for pressure vessels, heat exchangers, storage tanks, and pumps are depicted in Figure 4-2. The first step is to identify components which may have Normal/Upset Condition operating temperature in excess of 220°F for carbon steel or 270°F for austenitic stainless steel. This prescreening will generally eliminate components from further fatigue review based on a

---

[1] **Equivalent full temperature cycles are generally much less than total cycles considering small temperature changes. Equivalent full temperature cycles may be computed in accordance with ANSI B31.1, section 102.3.2 or ASME III NC 3611.2.**

OAGI0000553_00436

temperature criteria (since the fluid temperature will not vary more than 150°F for carbon steel or 200°F for stainless steel), unless there are any local component residual stress and/or geometry specific stress intensification factors which can result in lower temperature thresholds and, therefore, must be evaluated on a plant-specific case-by-case basis.

In the second step, the screening criteria are dependent upon the applicable design requirements. Code Data Reports, Design Specification, Stress Reports, component nameplates, or contract files will indicate whether the pressure vessel, storage tank, or pump is designed and fabricated in accordance with ASME VIII Division 1 or Division 2, ASME III NC or ND (i.e., Class 2 or 3), or other Codes/Standards requirements.

4.2.1 ASME Section VIII

Under ASME Section VIII, only Division 2 vessels require evaluation for thermal fatigue (i.e., design requirements—see Section 3.1). Most non-Class 1 Pressure Vessels are designed and fabricated according to ASME VIII Division 1 requirements and are suitable for the period of extended operation without further evaluation.

If Section VIII Division 2 vessels were specified, the Design Specification and/or Stress Report should be reviewed to determine the number of stress cycles assumed for design. If the number of stress cycles considering the period of extended operation is below the number used for design, the component is suitable for the period of extended operation without further evaluation. If "exemption from fatigue" criteria were used, the basis for the exemption (i.e., number of cycles) should be reviewed to confirm that the exemption remains valid for the period of extended operation.

4.2.2 ASME Section III

Under ASME Section III, only Class 2 Pressure Vessels and Heat Exchangers designed in accordance with NC-3200 require evaluation for thermal fatigue (see Section 3.1). Fatigue evaluation is not required for ASME III Class 2 and 3 Pumps, Class 2 and 3 Storage Tanks (< 15 psig), or Class 3 Pressure Vessels.

If Class 2 Pressure Vessels and Heat Exchangers are specified, the Design Specification should be reviewed to determine if evaluation for fatigue was required (i.e., if NC-3200 design requirements were specified). If so, the Design Specification and/or Stress Report should be reviewed to determine the number of stress cycles assumed for design. If the number of stress cycles considering extended life is below the number used for design, the component is suitable for life extension without further evaluation. If "exemption from fatigue" criteria were used, the basis for the exemption (i.e., number of cycles) should be reviewed to confirm that the exemption remains valid for extended life.

4.2.3 Other Codes and Standards

Under AWWA and MSS standards, fatigue evaluation is not required for pumps and storage tanks.

OAGI0000553_00437

4.2.4 Screening Criteria

Design Codes for the following components do not require evaluation for fatigue. These components are acceptable for operation in the extended period associated with license renewal without further evaluation.

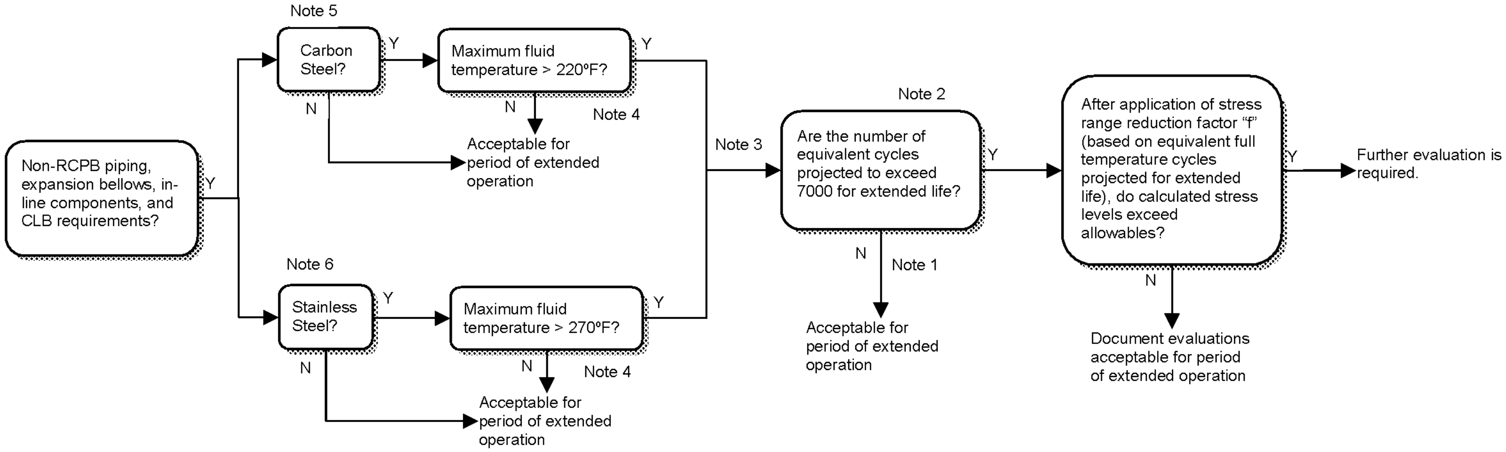
- ASME Section VIII Division 1 Components
- ASME Section III Class 2 and 3 (or Class B and C) Pumps
- ASME Section III Class 2 and 3 (or Class B and C) Storage Tanks (pressure < 15 psig)
- ASME Section III Class 3 (or Class C) Pressure Vessels
- AWWA or MSS Pumps and Storage Tanks

The following components may require evaluation for fatigue. See Figure 4-2 for additional details.

- ASME Section VIII Division 2 Components
- ASME Section III Class 2 Pressure Vessels and Heat Exchangers and Expansion Bellows

OAGI0000553_00438

Figure 4-1 ANSI B31.1 and ASME III Non-RCPB Piping, Expansion Bellows, In Line Components, and CLB Requirements

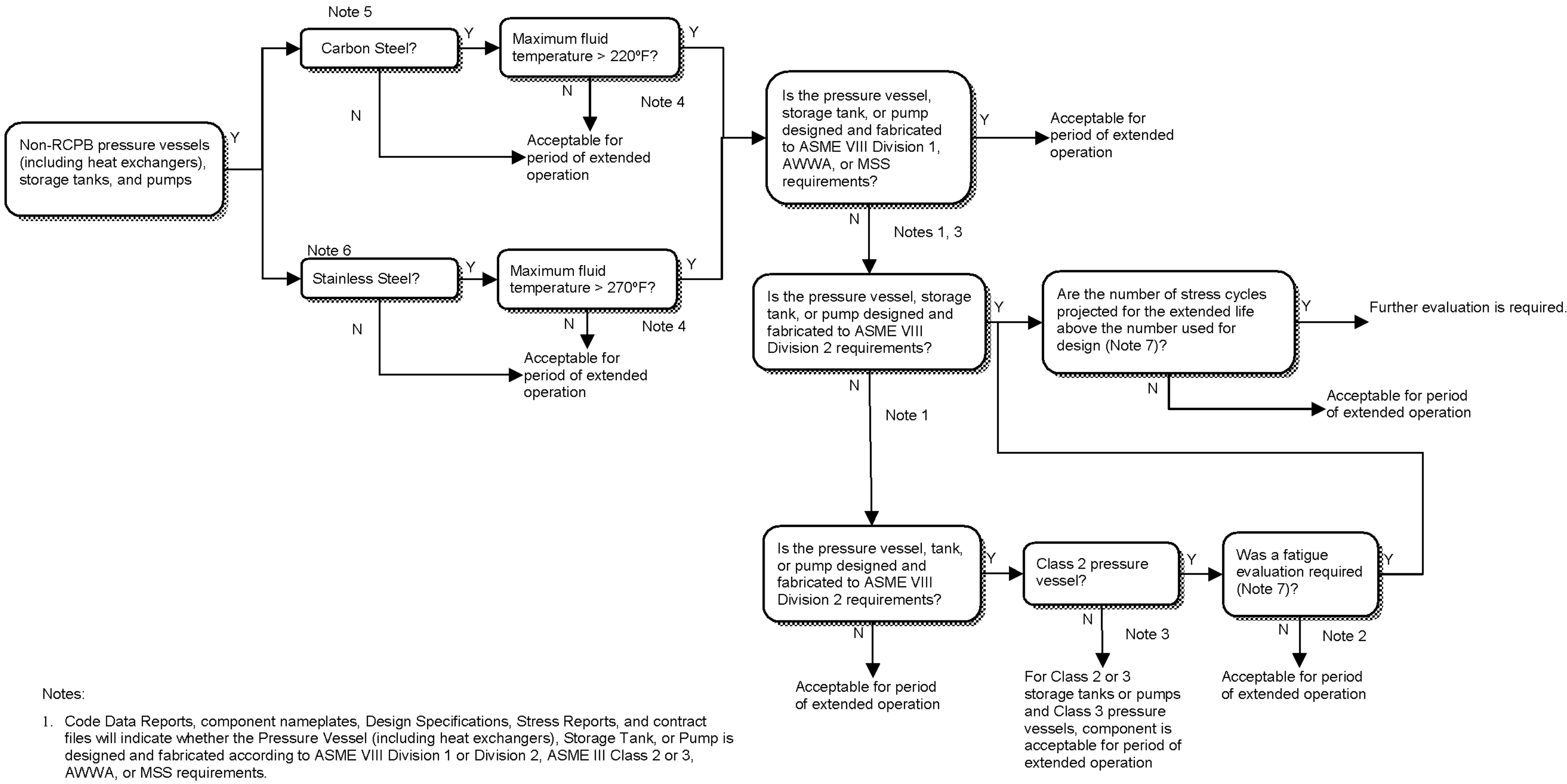


Notes:

1. If the range of temperature change varies, equivalent full temperature cycles may be computed in accordance with ANSI B31.1, section 102.3.2 or ASME III NC 3611.2.
2. Individual pipe stress calculations may be reviewed to determine if > 7000 cycles was assumed for the 40 year design basis calculations. If so, substitute that value in the cycle comparison.
3. Temperature limits from EPRI TR-104534, Vol. 2, Section 4.2.
4. Configurations subject to high stress intensification factors and/or geometry/component specific residual stresses may require further evaluation.
5. Considered to also apply to low-alloy steel.
6. Considered to also apply to nickel-base alloys.

OAGI0000553_00439

Figure 4-2 ASME III and ASME VIII Non-RCPB Pressure Vessels, Heat Exchangers, Storage Tanks, and Pumps



Notes:

1. Code Data Reports, component nameplates, Design Specifications, Stress Reports, and contract files will indicate whether the Pressure Vessel (including heat exchangers), Storage Tank, or Pump is designed and fabricated according to ASME VIII Division 1 or Division 2, ASME III Class 2 or 3, AWWA, or MSS requirements.
2. Under ASME III rules, only Class 2 Pressure Vessels (including heat exchangers) designed according to subsection NC-3200 require evaluation for fatigue.
3. Fatigue evaluation is not required for ASME VIII Division 1 components, ASME Class 2 and 3 Pumps, Class 2 and 3 Storage Tanks (pressure < 15 psig), Class 3 Pressure Vessels, and AWWA or MSS tanks or pumps.
4. Configurations subject to high stress intensification factors and/or high residual stresses that are geometry/component specific may require further evaluation.
5. Also considered to apply to low-alloy steel.
6. Also considered to apply to nickel-base alloys.
7. Review Design Specification and/or Design Report to determine the number of stress cycles assumed or whether a fatigue evaluation was required.

OAGI0000553_00440

5. COMPARISON TO GALL FATIGUE ITEMS

The information in Chapters IV, V, VII, and VIII of Volume 2 of NUREG-1801, Revision 1, "Generic Aging Lessons Learned (GALL) Report – Tabulation of Results," identifies material, environment(s), aging effects (and associated mechanisms) typically requiring management for license renewal applicants, and the suggested aging management program (AMP) for various mechanical components. GALL Chapter IV, V, VII, and VIII tables all include items for fatigue addressed by this tool. The identification and evaluation of aging management programs (AMPs) is outside the scope of this tool and should be addressed on a plant-specific basis, as described in Section 4.0 of the main document. Pertinent GALL items are addressed in Table 5-2, with the following component, material, environment, and aging effect/mechanism considerations.

As described in Section 4.1 and Section 4.2 respectively, this fatigue tool includes screening criteria for the evaluation of cracking due to fatigue for piping and piping components (e.g., pumps), and for heat exchangers, pressure vessels, storage tanks, and pumps designed to ASME Section VIII or Section III requirements. The components addressed by this fatigue tool, therefore, include the components listed for fatigue items in GALL Chapters IV, V, VII, and VIII, with certain clarifications:

- This tool does not distinguish between external and internal surfaces, as do the GALL items (as described in the environment discussions below).
- Fatigue cracking of closure bolting is evaluated in Appendix F.
- GALL Chapter IV (Reactor Coolant) fatigue items are primarily for Class 1 components and considered for this tool if the component could also include non-Class 1 components (e.g., steam generator components, pressurizer relief tank, and reactor vessel internals components, such as steam dryers).
- Certain GALL Chapter IV and VII fatigue items (IV.A1-7, IV.A2-20, and VII.B-2) are for structural components, such as support skirts and crane girders.

The materials for the pertinent items in GALL Chapters IV, V, VII, and VIII are consistent with the materials in this tool. Carbon steel, low-alloy steel, and cast iron are listed as "steel" in the pertinent GALL Chapter IV, V, VII, and VIII items. The pertinent GALL Chapter IV, V, VII, and VIII fatigue items also list stainless steel, alone or in combination with "steel," "steel with stainless steel cladding," or nickel-base alloy. There are no GALL items for fatigue of aluminum (or aluminum alloys) or for titanium (or titanium alloys). The materials addressed in this appendix are identified in Section 2.2.

OAGI0000553_00441

As described in Section 2.3, this tool evaluates thermal stresses on components without regard to the environments to which they are exposed. As such, the following GALL Chapter IV, V, VII, and VIII environments are bounded by this tool:

Table 5-1 GALL Environments for Fatigue Items
▪ Air – indoor uncontrolled
▪ Air – indoor uncontrolled (external)
▪ Reactor coolant and secondary feedwater/steam
▪ Secondary feedwater / steam
▪ Steam or treated water
▪ System temperature up to 288°C (550°F)
▪ System temperature up to 340°C (644°F)
▪ Treated borated water
▪ Treated Water

All of the items addressing fatigue in GALL Chapters IV, V, VII, and VIII cite "cumulative fatigue damage/fatigue" as the aging effect requiring management. Certain other items cite cracking due to cyclic loading, mechanical loading, and/or thermal loading, in conjunction with stress corrosion cracking. However, loading-related degradation is dependent on the design, installation, and operation of a component, and so requires plant-specific evaluation, and is not addressed in this tool.

Also, the pertinent GALL Chapter IV, V, VII, and VIII items do not in all cases include temperature thresholds during normal plant operations. However, some of the GALL environments listed above are above the thresholds in all cases, such as secondary feedwater/steam, steam, system temperature up to 288ºC (550ºF), and system temperature up to 340°C (644°F), whereas the others may or may not be above the thresholds, depending on the system.

OAGI0000553_00442

Table 5-2 GALL Comparison – Non-Class 1 Fatigue Items				
Material	**Aging Effect / Mechanism**	**NUREG-1801 (GALL) Item No.**	**Tool vs GALL Match**	**Relevant Discussion**
Carbon Steel	Cracking / Fatigue	IV.C1-11, IV.C2-10, IV.C2-23, IV.D1-11, IV.D2-10 V.D2-32 VII.E1-18, VII.E3-17 VIII.B1-10, VIII.B2-5, VIII.D1-7, VIII.D2-6, VIII.G-37	Yes	Figures 4-1 and 4-2 of this tool include decision points for temperature thresholds > 220°F for carbon steel (also applies to low-alloy steel). The specified GALL items do not identify temperature thresholds for applicability; however, as clarified below the items are for internal or external environments of systems that would exceed the threshold and require further evaluation. • Items IV.C1-11 and IV.C2-10 cite cumulative fatigue damage due to fatigue for steel (and stainless steel) reactor coolant system piping and components due to system temperatures above 550°F and 644°F, respectively. • The other specified GALL Chapter IV items are for fatigue of secondary side steam generator or pressurizer relief tank components. • Item V.D2-32 cites fatigue of steel BWR emergency core cooling system piping and components, which only see temperatures above 220°F during testing or emergency operation (# cycles to be determined or code fatigue requirements determined). • Specified GALL Chapter VII items cite fatigue of steel PWR Chemical and Volume Control, BWR Reactor Water Cleanup, and BWR Shutdown Cooling piping and components, a portion of which experience temperatures above 220°F (# cycles to be determined or code fatigue requirements determined). • Specified GALL Chapter VIII items are for fatigue of steel Main Steam piping and components exposed to steam or treated water and Feedwater piping and components exposed to treated water. Also, GALL item VIII.G-37 lists fatigue of PWR auxiliary feedwater piping and components, portions of which may or may not experience temperatures above 220°F, depending on the system's design for a given plant.

OAGI0000553_00443

Table 5-2 GALL Comparison – Non-Class 1 Fatigue Items				
Material	**Aging Effect / Mechanism**	**NUREG-1801 (GALL) Item No.**	**Tool vs GALL Match**	**Relevant Discussion**
Stainless Steel	Cracking / Fatigue	IV.B1-14, IV.B2-31, IV.B3-24, IV.B4-37, IV.B4-38, IV.C2-10, IV.C2-11, IV.C2-23 V.D1-27, V.D2-32 VII.E1-4, VII.E1-16, VII.E3-14, VII.E3-17, VII.E4-13	Yes	Figures 4-1 and 4-2 of this tool include decision points for temperature thresholds > 270ºF for stainless steel (also applies to cast austenitic stainless steel). The specified GALL items do not identify temperature thresholds or otherwise clarify applicability. However, as clarified below the items are for internal or external environments of systems that would exceed the threshold and require further evaluation. • The specified GALL Chapter IV items are for fatigue of vessel internals, some of which are non-Class 1 (e.g., BWR steam dryer), external surfaces of PWR reactor coolant system piping and components, and the cladding of a PWR pressurizer relief tank (# cycles to be determined or code fatigue requirements determined). • Specified GALL Chapter V items list fatigue of stainless steel BWR and PWR emergency core cooling system piping and components, which only experience temperatures above 270ºF during testing or emergency operation (# cycles to be determined or code fatigue requirements determined). • Specified GALL Chapter VII items list fatigue of stainless steel PWR Chemical and Volume Control System piping and components and heat exchanger shell side components, and BWR Reactor Water Cleanup System piping and components, a portion of which experience temperatures above 270ºF (# cycles to be determined or code fatigue requirements determined).
Nickel-Base Alloy	Cracking / Fatigue	IV.B1-14, IV.B2-31, IV.B3-24, IV.B4-37, IV.B4-38, IV.D1-21, IV.D2-15	Yes	Figures 4-1 and 4-2 of this tool include decision points for temperature thresholds > 270ºF for stainless steel (also applied herein to nickel-base alloys). The specified GALL items do not identify temperature thresholds or otherwise clarify applicability. However, as clarified below the items are for internal or external environments of systems that would exceed the threshold and require further evaluation. • The specified GALL Chapter IV items list fatigue of vessel internals, some of which are non-Class 1 (e.g., BWR steam dryer), and steam generator components that include nickel alloys (cycles to be determined or code fatigue requirements determined).

OAGI0000553_00444

6. REFERENCES

1. *EPRI Fatigue Management Handbook,* TR-104534-V1, -V2, and -V3, Research Project 3321-01, December 1994.

OAGI0000553_00445

Export Control Restrictions

Access to and use of EPRI Intellectual Property is granted with the specific understanding and requirement that responsibility for ensuring full compliance with all applicable U.S. and foreign export laws and regulations is being undertaken by you and your company. This includes an obligation to ensure that any individual receiving access hereunder who is not a U.S. citizen or permanent U.S. resident is permitted access under applicable U.S. and foreign export laws and regulations. In the event you are uncertain whether you or your company may lawfully obtain access to this EPRI Intellectual Property, you acknowledge that it is your obligation to consult with your company's legal counsel to determine whether this access is lawful. Although EPRI may make available on a case-by-case basis an informal assessment of the applicable U.S. export classification for specific EPRI Intellectual Property, you and your company acknowledge that this assessment is solely for informational purposes and not for reliance purposes. You and your company acknowledge that it is still the obligation of you and your company to make your own assessment of the applicable U.S. export classification and ensure compliance accordingly. You and your company understand and acknowledge your obligations to make a prompt report to EPRI and the appropriate authorities regarding any access to or use of EPRI Intellectual Property hereunder that may be in violation of applicable U.S. or foreign export laws or regulations.

The Electric Power Research Institute (EPRI)

The Electric Power Research Institute (EPRI), with major locations in Palo Alto, California, and Charlotte, North Carolina, was established in 1973 as an independent, nonprofit center for public interest energy and environmental research. EPRI brings together members, participants, the Institute's scientists and engineers, and other leading experts to work collaboratively on solutions to the challenges of electric power. These solutions span nearly every area of electricity generation, delivery, and use, including health, safety, and environment. EPRI's members represent over 90% of the electricity generated in the United States. International participation represents nearly 15% of EPRI's total research, development, and demonstration program.

Together...Shaping the Future of Electricity

Program:

Nuclear Power

© 2006 Electric Power Research Institute (EPRI), Inc. All rights reserved. Electric Power Research Institute and EPRI are registered service marks of the Electric Power Research Institute, Inc.

Printed on recycled paper in the United States of America

1010639

ELECTRIC POWER RESEARCH INSTITUTE

3420 Hillview Avenue, Palo Alto, California 94304-1395 • PO Box 10412, Palo Alto, California 94303-0813 USA

800.313.3774 • 650.855.2121 • askepri@epri.com • www.epri.com