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Nuclear power plant Generic Aging Lessons Learned (GALL)

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ABSTRACT

The purpose of the generic aging lessons learned paper was to provide a systematic review of plant aging information to assess materials and component aging issues related to operation and license renewal of nuclear power plants. The results were documented using a standardized tabular and electronic database format and definitions of aging-related degradation mechanisms and effects. Results reveal that all significant aging issues are currently being addressed by the U.S. Nuclear Regulatory Commission regulatory process.

1. INTRODUCTION

Approximately 110 nuclear electrical power generating plants operating in the United Sates of America generated roughly 20% of the nations electrical demand. Some of these plants have been in operation for many years. It is well established that many of the critical components in nuclear power plants are subject to time-dependant degradation, or aging, as a result of normal plant operations. In recognition of the potentially adverse effects of the aging process on plant safety, the United States Nuclear Regulatory Commission's (USNRC) Office of Nuclear Regulatory Research began by establishing the Nuclear Plant Aging Research (NPAR) Program. The principal objective of this program was to develop a basic understanding of age-related degradation (ARD) processes and their effect on nuclear power plant systems, structures, and components. In addition, the Nuclear Energy Institute (NEI), formerly the Nuclear Management and Resources Council (NUMARC), developed a series of license renewal industry reports (IRs) to support a prospective applicant when submitting an application for a renewed license under the requirements of Title 10, Part 54, of the U.S. Code of Federal Regulations (10 CFR Part 54) [1]. The IRs describe the NUMARC assessment of plant aging issues and management strategies for several components and structures.

To develop appropriate technical criteria for addressing the aging issues related to nuclear power plant license renewal, the USNRC initiated an activity to assess and integrate the age-related information from all USNRC documentation to include NPAR reports, generic communications, and License Event Reports (LERs) and to use the results of this assessment to supplement and update license renewal guidance previously developed. This activity was called the Generic Aging Lessons Learned (GALL) Program, the results of which have been documented in NUREG/CR-6490 (ANL-96/13), "Nuclear Power Plant Generic Aging Lessons Learned (GALL), Main Report and Appendices A and B."

NUREG/CR-6490 presents the results of the GALL review program. The GALL effort was sponsored by the USNRC with significant input provided through a joint effort involving 12 technical experts from Argonne National Laboratory (ANL) and Idaho National Engineering Laboratory (INEL). ANL reviewed information on mechanical, structural, and thermal-hydraulic components and systems and INEL reviewed information on electrical components and systems. The results of these reviews were compiled using a standardized tabular format and standardized definitions of ARD effects. All tabulated review information is contained in Appendices A (Volume 1) and B (Volume 2) of NUREG/CR-6490. The information is also available in a computerized data base format based on the software program FoxPro. The data base allows rapid queries and sorts of the large amount of information generated by the review.

2. DESCRIPTION OF REVIEW PROCESS

More than 550 documents containing nuclear power plant information were reviewed for "GALL" information. The USNRC staff performed searches for current operating experience documents covering the 5 year period, 1989-1994, using the USNRC's Nuclear Documents Managements System (NUDOCS). The period preceding 1989 was documented in the NPAR program reports which are also summarized in NUREG/CR-6490. The searches used the following terms: aging, degradation, and failures. A total of 163 NPAR reports, 31 USNRC Generic Letters, 265 USNRC Information Notices, 82 LERs, 5 USNRC Bulletins, and 10 NUMARC Industry Reports (IRs) containing mechanical, structural, thermal-hydraulic, and electrical systems and components were reviewed under the GALL program. The results of these reviews were compiled by using a standardized tabular format and standardized definitions of ARD and effects. A standardized and consistent set of definitions and descriptors for all aging mechanisms encountered during the review was developed for the GALL effort. Individual aging mechanisms and effects were identified and defined, and these are listed and described in Table 8 of NUREG/CR-6490. This list will help focus and systematize future reactor aging studies.

The reports, notices, letters, and bulletins reviewed are listed in Tables 2 though 7 of NUREG/CR-6490. The results from each reviewed document are summarized in the GALL tables contained in Appendices A (volume 1) and B (volume 2) of the two volume

NUREG/CR-6490 report. A separate table was prepared for each of the NPAR reports and NUMARC IRs; findings from the USNRC Generic Letters, USNRC Information Notices, USNRC Bulletins, and LERs are tabulated by year in separate tables. All of the GALL table information has also been entered into a FoxPro data base software program that can be used on IBM PC-compatible systems to retrieve and categorize information on structures and components and their related aging effects.

The information contained in the GALL tables is a summary of that provided in the reviewed reports. It was found that not all of the reports, notices, and bulletins reviewed contained relevant information on Age-Related Degradation (ARD) processes. A number of the NPAR reports described programs, methodologies, computer codes, etc., for studying and analyzing aging processes in nuclear components, but did not provide detailed information on the processes themselves. The tables for these reports contain a standard statement indicating this fact. Almost all of the USNRC Generic Letters, USNRC Information Notices, LERs, and USNRC Bulletins reviewed contained detailed information on the failure of specific components, but the failures were sometimes judged not to be aging-related by the reviewer or by the author of the reviewed document. For example, failures caused by improper heat treatment, preexisting defects introduced during manufacturing, or overloads or other abuse during operation were not considered aging-related by the reviewer, even though the failure might not have occurred until the component had been in service for some time. GALL table entries are not provided for USNRC Generic Letters, USNRC Information Notices, LERs, and USNRC Bulletins judged not to contain detailed information on specific aging effects and their impact on specific plant components. The structure of the information documented in NUREG/CR-6490 and in the database is in such format that enables a researcher to easily access information on a particular aging issue.

In the future, information documented in NUREG/CR-6490 may be used as a reference tool for reviewers performing license renewal application reviews or for the USNRC staff reviewing a licensee submittal. Indeed, a prospective license renewal applicant or nuclear power plant licensee may use this document as one of the sources for determining applicable aging effects to be addressed in a license renewal application.

3. OBSERVATIONS AND FINDINGS

More than 550 documents comprising 163 NPAR reports, 31 USNRC Generic Letters, 265 USNRC Information Notices, 82 Licensee Event Reports, 5 USNRC Bulletins, and 10 NUMARC Industry Reports (IRs) were reviewed under the GALL program. The results of these reviews were systematically summarized in a tabular format, using standardized definitions of ARD mechanisms and effects developed for this study (see Exhibits 1 & 2).

Table A.1 Gall Report for NPAR Reports Page 64A

Document: NUREG/CR-4769, Risk Evaluations of Aging Phenomena in Linear Aging Reliability Model and Its Extensions
Reviewed by: Jeffrey L. Binder, ANL

Document: NUREG/CR-4967, Nuclear Plant Aging Research on High Pressure Injection Systems
Reviewed by: Steve U. Choi, ANL

Item	System	Structure/Comp	Subcomponent	Materials	Manufacturer	ARD mechanism	ARD effects
1	PWR high pressure injection system	Piping	Thermal sleeves and nozzles	Not stated	Not stated	FAT/THERM	Cumulative fatigue damage
2	PWR high pressure injection system	Piping	Elbows	Not stated	Not stated	FAT/THERM	Cumulative fatigue damage
3	PWR high pressure injection system	Piping	Pipe	Stainless steel	Not stated	FAT	Cumulative fatigue damage
4	PWR high pressure injection system	Piping	Pipe	Stainless steel	Not stated	CORR/SCC	Crack initiation and growth
5	PWR high pressure injection system	Piping	Pipe welds and flanges	Not stated	Not stated	VIBR	Crack initiation and growth, loosening
6	PWR high pressure injection system	Piping	Pipe welds	Type 304 SS	Not stated	CORR/SCC	Crack initiation and growth
7	PWR high pressure injection system	Piping	Nozzles, safe ends, and threaded fasteners	Ferritic (carbon) steel	Not stated	CORR	Crack initiation and growth
8	PWR high pressure injection system	Valves	Stem, packing, and body	Not stated	Not stated	CLOG	Blockage of flow passages
9	PWR high pressure injection system	Valves	Packing, seat, and disk	Not stated	Not stated	WEAR	Attrition
10	PWR high pressure injection system	Valves	Packing, seat, and disk	Not stated	Not stated	CONTAM	Buildup of deposits
11	PWR high pressure injection system	Pumps	Impeller blades	Types 304 and 316 SS	Not stated	CORR/MIC	Loss of material; corrosion product buildup
12	PWR high pressure injection system	Instrumentation and controls	Switches and relays	Not stated	Not stated	WEAR	Attrition
13	PWR high pressure injection system	Instrumentation and controls	Contacts	Not stated	Not stated	CORR	Corrosion product buildup
14	PWR high pressure injection system	Instrumentation and controls	Insulation	Not stated	Not stated	FAT/THERM	Cumulative fatigue damage

Table A.1 Gall Report for NPAR Reports Page 64B

Document: NUREG/CR-4769, Risk Evaluations of Aging Phenomena in Linear Aging Reliability Model and Its Extensions
Reviewed by: Jeffrey L. Binder, ANL

Document: NUREG/CR-4967, Nuclear Plant Aging Research on High Pressure Injection Systems
Reviewed by: Steve U. Choi, ANL

Effect of Aging on Component Function	Contrib to Failure	Reported progs	Rel.progs	Report Recommendations	Page No.	Item
High-pressure injection/makeup nozzles have developed through-wall cracks due to thermal fatigue. All cracks were associated with loose thermal sleeves.	Not stated	Not discussed in report	ASME Sec III & Sec XI IWB	Not stated	29, 30, 33, 36, 53	1
Elbows in the safety injection piping between the cold leg and the first check valve have developed through-wall cracks.	Not stated	Not discussed in report	ASME Sec XI IWB	Not stated	33	2
Cracks or through-wall leakage.	Not stated	Not discussed in report	ASME Sec XI IWB	Not stated	30, 36	3
Cracking was discovered in some safety system pipes containing borated water, but no losses due to this problem were reported.	Not stated	Not discussed in report	ASME Sec XI IWB	Not stated	30	4
Cracks have occurred due to vibration and dynamic loading (water hammer).	Not stated	Not discussed in report	ASME Sec XI IWB	Not stated	30	5
Cracks occur in the weld heat affected zone.	Not stated	Not discussed in report	ASME Sec XI IWB	Not stated	30, 53, H-3	6
Not stated.	Not stated	Not discussed in report	ASME Sec XI IWB	Not stated	53, H-3	7
MOVs and check valves have failed to operate due to boron crystallization on the valve stems and in the valve packing and body. Boric acid crystals have caused blockage, resulting in malfunction of an HPI pump in one instance.	Not stated	Not discussed in report	ASME Sec XI IWV	Not stated	30, 33, 53, H-3	8
Leakage, fail to operate, and blockage.	Not stated	Not discussed in report	ASME Sec XI IWV	Not stated	30, 36	9
Leakage, fail to operate, and blockage.	Not stated	Not discussed in report	ASME Sec XI IWV	Not stated	30, 36	10
Not stated.	Not stated	Not discussed in report	ASME Sec XI IWP	Not stated	30, 33	11
Not stated.	Not stated	Not discussed in report	If Class 1E 10CFR 50.49 otherwise PS TS Req.	Not stated	33	12
Not stated.	Not stated	Not discussed in report	If Class 1E 10CFR 50.49 otherwise PS TS Req.	Not stated	33	13
Not stated.	Not stated	Not discussed in report	If Class 1E 10CFR 50.49 otherwise PS TS Req.	Not stated	33	14

EXHIBIT 1. Sample GALL Tables from Appendix A - Mechanical.

Document: NUREG/CR-4156, Operating Experience and Aging-Seismic Assessment of Electric Motors
Reviewed by: L. C. Meyer, INEL

Document: NUREG/CR-4156, Operating Experience and Aging-Seismic Assessment of Electric Motors
Reviewed by: L. C. Meyer, INEL

Item	System	Structure/Comp	Subcomponent	Materials	Manufacturer	ARD mechanism	ARD effects	Effect of Aging on Component Function	Contrib to Failure	Reported progs	Rel.progs	Report Recommendations	Page No.	Item
1		3 Phase Induction & Synchronous Motors	Stator - Conductors and Structural Components	Copper	Not stated	VIB, THERM, AND SHRINK	Loosening of laminations and locking devices	Not stated	Occasional	Not discussed in report	IEEE 334-1974 Section 14	Preventive maintenance programms, operational readiness acceptance criteria, in-situ testing and monitoring programs [2]	S-2, 2-15, and 4-23	1
2		3 Phase Induction & Synchronous Motors	Stator - Insulation	Mica, glass, resins, enamels, mylars, fiber, varnish, and nonhygroscopic materials	Not stated	THERM, OXIDAT, MOIST-EL, AND RAD	Degraded dielectric properties & tensile strength, brittle	Degraded operation or failure to function	Occasional	Not discussed in report	IEEE 334-1974 Section 14	Preventive maintenance programms, operational readiness acceptance criteria, in-situ testing and monitoring programs [2]	S-2, 2-15, & 4-23	2
3		3 Phase Induction & Synchronous Motors	Rotor - Contuctors and Structural Components	Copper	Not stated	VIB & THERM	Rotor embalence, loose parts, and overheating	Frame distortion, shift in rotor center of gravity, insuficient cooling, winding short short or overheating of rotor coils leading to burnt motor and failure to function.	Occasional	Not discussed in report	IEEE 334-1974 Section 14	Preventive maintenance programms, operational readiness acceptance criteria, in-situ testing and monitoring programs [2]	S-2, 2-20, 4-23	3
4		3 Phase Induction & Synchronous Motors	Rotor - Insulating Materials	Mica, glass, resins, enamels, mylars, fiber, varnish, and nonhygroscopic materials	Not stated	CURSTR, THERM, RAD, AND MOIST-EL	Insulation damage, winding short, overheating of rotor coils	Excess current due to aging from many starts, cage winding failure due to jogging, over heating of rotor coils leading to burnt motor, winding shorts, insulation shrinkage results in decreased output or failure to function.	Occasional	Not discussed in report	IEEE 334-1974 Section 14	Preventive maintenance programms, operational readiness acceptance criteria, in-situ testing and monitoring programs [2]	2-15, S-2, 4-24	4
5		3 Phase Induction & Synchronous Motors	Rotor - Commutator and Brushes	Mica, copper, carbon, and steel in spring mechanism	Not stated	WEAR, FAT, DIRT, CONTAM, AND OXIDAT	Brush wearout, relaxed spring, oil deposits, & loose contact	Loose brush connection, dirt & foreign particles, wear out of carbon brushes, relaxed spring load in the brush holder mechanisms, dirt/ moisture on commutator and oxidation effects results in decreased output or failure to function.	Occasional	Not discussed in report	IEEE 334-1974 Section 14	Preventive maintenance programms, operational readiness acceptance criteria, in-situ testing and monitoring programs [2]	2-22, S-2, 4-25	5
6		3 Phase Induction & Synchronous Motors	Bearings	Steel, brass, and bronze	Not stated	VIB, THERM, WEAR, CONTAMIN, AND LOSLUBE	Material attrition, cracking of bearings, scoring of surface	Seized bearings, and overheating, excessive vibration could cause fracture and bearing scoring, corrosion due to exposure to air.	Occasional	Not discussed in report	IEEE 334-1974 Section 14	Preventive maintenance programms, operational readiness acceptance criteria, in-situ testing and monitoring programs [2]	2-15, 4-22, 4-23, 4-25, 4-26, and 4-27	6
7		3 Phase Induction & Synchronous Motors	Bolts, Flanges, and Housing	Steel, cast iron, brass, and copper	Not stated	VIB, CORR, FAT, THERM, AND MECHSTR	Sheared bolts, cracked flanges or housing, overheated frame	Failure to function or degraded operation	OCCCASIONAL	Not discussed in report	IEEE 334-1974 Section 14	Preventive maintenance programms, operational readiness acceptance criteria, in-situ testing and monitoring programs [2]	2-15, 4-24, 4-25, 4-25, 4-27, and 4-28	7
8		3 Phase Induction & Synchronous Motors	Seals and Gaskets	Polymers	Not stated	THERM, VIB, AND RAD	Cracking, shrinking, leaking of oil or water, embrittlement	Decreased output or failure to function.	Occasional	Not discussed in report	IEEE 334-1974 Section 14	Preventive maintenance programms, operational readiness acceptance criteria, in-situ testing and monitoring programs [2]	5-15 & 4-28	8
9		3 Phase Induction & Synchronous Motors	MOV's Break Coils	Copper	Not stated	THERM, CORR, CURSTR	Corrosion product buildup, current overload, & misoperation	Burning of motor windings, jamming of break coil, overload the motor drawing large currents into the windings results in failure to operate.	Rare	Not discussed in report	Vendor specific, GL 89-10, NUREG-1352	Preventive maintenance programms, operational readiness acceptance criteria, in-situ testing and monitoring programs [2]	5-15 & 4-28	9
10		3 Phase Induction & Synchronous Motors	Conduit Box, Leads, and Connections	Copper	Not stated	VIB AND CORR, CONTAM, MOIST-EL	Leak, poor electrical contact, loose leads, improper seals	Degraded insulation, shorts, or open circuits result in decreased output or failure to function.	Occasional	Not discussed in report	No specific program	Preventive maintenance programms, operational readiness acceptance criteria, in-situ testing and monitoring programs [2]	4-28	10
11		3 Phase Induction & Synchronous Motors	Motor	See sub-components	Not stated	WEAR, THERM, VIB, CURSTR, RAD, FAT, AND MOIST-EL	Misaligned parts, burned out motor, & disengaged motor	Burned or dead motor, disengaged motor, & overcurrent results in decreased output or failure to function.	Rare	Not discussed in report	IEEE 334-1974 Section 14	Preventive maintenance programms, operational readiness acceptance criteria, in-situ testing and monitoring programs [2]	4-29	11

EXHIBIT 2. Sample GALL Tables from Appendix A - Electrical.

The review reveals (1) that there are no new issues with respect to the components subject to ARD and the degradation mechanisms responsible and (2) that all ongoing significant issues are currently being addressed by the regulatory process. However, (3) the aging of passive components has been high-lighted for continued scrutiny.

Included in NUREG/CR-6490, are recommendations of the referenced report's author for each aging issue and which are contained in Appendices A and B of NUREG/CR-6490. The GALL effort then added the ANL/INEL judgement of the validity of the author's recommendations based on present day understanding of the issue. The characterization of the issue is noted by one of four possible aging issue current relevance categorization indicators with the all-important "may potentially need further evaluation," indicating the possibility of emerging aging issues. This characterization of particular issues, however, appears only a few times and where it does appear the issue is currently being addressed by the regulatory process. A summary of general observations concerning specific aging issues and the components affected are presented below.

3.1 *Mechanical, Structural, and Thermal-Hydraulic Components and Systems*

As expected, corrosion and corrosion-related processes were the dominant mechanism of age related degradation (ARD) in coolant piping and steam generators. Where high-velocity fluids were present in piping, erosion/corrosion was also a significant mechanism. Additionally for piping, feedwater nozzles, and interfacing tanks and other components, nonuniform water temperature fields aggravated by thermal buoyancy can cause large induced structural thermal stresses of either quasi-steady, low-cycle, or thermal shock nature and can lead to cracking or significant structural distortion. These thermal stresses are usually not accounted for in component design and are highly plant and mode-of-operation-dependant. They can occur under normal or intermittent operation of plant systems and tend to be worse under low flow conditions. For reactor internals, irradiation-assisted stress corrosion cracking was an important source of degradation where high radiation fields were present. Other forms of corrosion, as well as vibrational fatigue, also contributed to internals degradation.

Pump and valve casings were likewise found to be subject to corrosion and erosion/corrosion related degradation. Thermal embrittlement was an important mechanism in cast stainless steel pump and valve components. Moving parts in pumps and valves suffered from ARD produced by wear, vibration, fatigue, and erosion/corrosion. Valve and pump seals and other elastomer components were subject to degradation by physical and chemical degradation at elevated temperature and/or prolonged exposure to the service environment.

The principle degradation mechanism affecting concrete structures was leaching and breakdown of cement phases under the action of aggressive chemicals, degradation due to freeze-thaw cycles, and corrosive attack of the embedded rebar. The responsible mechanism(s) for some concrete wall cracking was found to be not well understood.

Diesel generators, air compressors, and ventilating and air conditioning equipment suffered principally from wear, vibration, and fatigue associated with reciprocating motion, as well as corrosion and wear induced by contamination. Heat exchangers and steam generators were subject to contamination and corrosion, as well as biofouling, thermal fatigue, and vibrational fatigue. Vibrational fatigue, wear, and elevated temperature degradation of damping fluids commonly caused degradation in snubbers.

Table 1 lists aging issues found to occur almost equally in boiling water reactor (BWR) and pressurized water reactor (PWR) plants and tend to center on various forms of corrosion and fatigue. Another important commonality of the components listed in this table is that they are all what are termed passive components as described in 10 CFR Part 54 [11]. This may be of considerable significance because the literature reviewed seems to indicate that passive components are not as extensively or thoroughly covered by current plant maintenance procedures. Furthermore, surveillance and monitoring methods and instrumentation and procedures have not been as extensively developed or employed for passive components subjected to the highlighted aging mechanisms, nor are some of the passive component aging mechanisms as well understood. Thus, plant life extension by employing component replacement and maintenance could be more tenuous for the passive components. Furthermore, passive components tend to be some of the most costly in a plant and are frequently not as easy to replace. For these reasons, the knowledge base for predicting relevant aging effects behavior and significance, which is essential to the development of robust plans for aging reduction, monitoring procedures, and maintenance, is very important for passive components.

3.2 *Electrical Components and Systems*

Breakers and relays were usually covered together in the same report; the predominant aging-related failure mechanisms were contact wear, sticking linkage, loss of lubrication, or elevated temperature. Normally energized relay coils were frequently mentioned as high failure-rate items because of the insulation breakdown caused by elevated temperature due to self-heating from the continuous current. Breakers are routinely refurbished on periodic schedules. Instrumentation and control (I&C) systems, including breakers and sensors, are made up of many small components that are routinely replaced after a number of years of service, as determined by qualification programs. Thus aging is controlled by scheduled maintenance and periodic replacement. Redundancy in the Reactor Protection System and Engineered Safety Features Actuation Systems allows for taking a channel out of service for maintenance.

Degradation of cable insulation and jackets is the major effect of cable aging, due primarily to radiation and elevated temperature. Despite sizable efforts to develop electrical and mechanical methods of detecting cable insulation degradation, there are no reliable methods of detecting degradation of electrical cable insulation in a reactor containment. Electrical parameters, while relatively easy to measure, were found not to give a good indication of mechanical degradation of the cable insulation. The mechanical indentor method was successful only for some of the jacket insulation types.

TABLE 1. Selected Examples of Issues Significant to Passive Structures & Components

Reactor Type	Component	Material	Degradation Process	References
PWR	Instrumentation and control rod drive (CRD) housing nozzles	Low-alloy steel (A533B, A508) with Type 308 or 309 SS clad	Environmentally assisted fatigue. Appropriate design rules do not yet exist in the American Society of Mechanical Engineers (ASME) Boiler & Pressure Vessel Code	NUREG/CR-5490 [2]
BWR and PWR	Closure Studs	A-540, B22, B2, or B24	Environmentally assisted fatigue, fretting, and boric acid corrosion if leakage present	NUREG/CR-5490 [2]
PWR	CRD system components	Various	Dropped or stuck rod due to failure by fatigue, mechanical wear, or stress corrosion cracking	NUREG/CR-5555 [3]
BWR	Jet pump & holdown beams	Inconel X-750	Cracking and possible failure form vibrational and/or environmentally assisted fatigue and stress corrosion cracking	NUREG/CR-5754 [4]
BWR	Reactor Internals	Various	Crack initiation, growth, and possible failure from irradiation-assisted stress corrosion cracking (IASCC)	NUREG/CR-5754 [4]
PWR	Lower core support structure components	Type304 stainless steel (SS), A-286, Inconel X-750, and others	Cracking and possible failure from vibrational fatigue and IASCC	NUREG/CR-6048 [5]
BWR	Pressure vessel upper head	Low-alloy steel (A533B, A508) with Type 308 or 309 SS clad	Cracking, possibly stress corrosion cracking (SCC), of weld clad, with cracks penetrating into underlying base metal	Information Notice (IN) 90-29 [6]
BWR	Core Shroud	Type 304 SS	SCC (or IASCC) leads to circumferential cracking of core shroud and concerns about possible structural failure in an accident or seismic event	IN 93-79 [7], IN 94-42 [8]
BWR	Recirculating coolant pump seals	Cemented WC in Ni binder	Preferential corrosive dissolution on Ni binder under certain undefined conditions leads to excessive seal leakage and possible eventual pump failure	
BWR and PWR	All piping and feedwater nozzles and interfacing tanks and components	Commonly used materials, low alloy steels	Large thermally induced stresses, either quasi-steady or low-cycle transient, thermal fatigue, induced by nonuniform coolant temperature fields aggravated by thermal-buoyancy-caused stratification under no-flow/low-flow levels, cause wall cracking/gross abnormal component distortion, usually not accounted for in component design, highly plant and mode-of-operation dependant	NUREG/CR-4731 Vols. 1 & 2 [9]
BWR and PWR	Shielding wall concrete and other locations	Reinforced concrete	Actual process and mechanisms unclear; shows up as large surface cracks not caused by structural loading	NUREG/CR-4652 [10]

Motors and generators occasionally fail due to bearing wear caused by vibration and winding insulation breakdown from elevated temperatures. Brushes also age due to wear. Battery chargers and inverters are small electrical systems made up of many electronic components that, like the instrumentation and control (I&C) system, can be taken out of service for maintenance because of redundancy. Many of the electrical I&C components are included in plant quality assurance (QA) programs that require periodic replacement. Inverter failures have caused numerous problems. Many of the electrical I&C components are included in plant quality assurance programs that require periodic replacement. A more detailed analysis may be carried out at a later date to assess the significance of these mitigative practices and the aging processes.

4. CONCLUSIONS

A preliminary assessment of the GALL tables reveals that all significant issues with respect to structure and component aging are currently being addressed by the USNRC regulatory process. Nonetheless, the aging of certain structures and components and the resulting aging effects, particularly in the category of what are termed passive structures and components, have been high-lighted for continued scrutiny and evaluation. Among these issues erosion/corrosion and fatigue of mechanical and structural components and degradation of electrical insulation of cables and other electrical items are the most notable. The material documented in NUREG/CR-6490 may be referenced by both operators of currently licensed nuclear power plants and those wishing to extend their current operating license for a additional operating period.

5. REFERENCES

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