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Aging Management Guideline for Commercial Nuclear Power Plants – Battery Chargers, Inverters and Uninterruptible Power Supplies

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Plant Lifetime

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Program

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**AGING MANAGEMENT GUIDELINE
FOR
COMMERCIAL NUCLEAR POWER PLANTS —
BATTERY CHARGERS, INVERTERS AND
UNINTERRUPTIBLE POWER SUPPLIES**

FINAL REPORT

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Abstract

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

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AGING MANAGEMENT GUIDELINE FOR BATTERY CHARGERS, INVERTERS, AND UPSs

1. EXECUTIVE SUMMARY

Continued operation of nuclear power plants for periods that extend beyond their original 40-year license period is a desirable option for many U.S. utilities. U.S. Nuclear Regulatory Commission (NRC) approval of operating license renewals is necessary before such continued operation becomes a reality. Effective aging management for plant components is important to reliability and safety, regardless of current plant age or extended life expectations. However, before granting approval for operation beyond 40 years, the NRC requires that aging evaluations be performed, and that the existence of appropriate aging management programs be demonstrated for components considered important to license renewal which have age-related degradation unique to license renewal. Both the NRC and the utility want assurance that high reliability for plant components which support safety functions is maintained, during both the current license term and throughout the extended life operating period. Early recognition of areas requiring enhancement to achieve effective aging management is also a cost effective approach for utilities to comply with the Maintenance Rule.[1.1]

1.1 Purpose and Objectives of Guideline

This aging management guideline (AMG) provides recommended methods for effective detection and mitigation of aging mechanisms in nuclear plant battery chargers, inverters, and uninterruptible power supplies important to safety and reliable power production. The intent of this guideline is to assist plant maintenance and operations personnel in maximizing the safe, useful life of these components. The guideline also supports the documentation of effective aging management programs required under the License Renewal Rule 10 CFR 54.[1.2]

The components discussed herein are found in both Boiling Water Reactor (BWR) and Pressurized Water Reactor (PWR) facilities. The primary target audiences for this guideline are plant engineering, operations, and maintenance personnel, although it will also be of interest to those involved with nuclear plant extended life programs. The guideline is presented in a manner which allows personnel responsible for performance analysis and maintenance to compare their plant-specific aging mechanisms (expected or already experienced) and aging management program activities to the more generic results and recommendations presented in this guideline.

This AMG was sponsored by the U.S. Department of Energy (DOE), through the Sandia National Laboratories' Technology Center (TC), as part of DOE's Nuclear Plant Lifetime Improvement (PLIM) Program. Sandia's TC commissioned the preparation of this guideline with the following objectives:

- a. Support the goals of the U.S. DOE National Energy Strategy[1.3] and the DOE PLIM Program, which identify life cycle management and license renewal as important elements of the nation's generation planning.

- b. Provide practical guidance to plant technical and maintenance staff for managing aging mechanisms for battery chargers, inverters, and uninterruptible power supplies (UPS), which are critical components to safe plant operation and license renewal.
- c. Define this guidance in a step-by-step, "if-then" approach, with observable and measurable criteria and corrective steps. This guidance is based on industry and vendor research, plant experience, and results of the U.S. NRC's Nuclear Plant Aging Research (NPAR) Program.[1.4]
- d. Cover the majority of component types, manufacturers, applications, and environments, as confirmed by a survey of components in current use in nuclear plants.
- e. Define exclusion bases for components not covered, or those considered not subject to a long-term aging management program.
- f. Provide sufficient bases for the use of this guideline as a reference document for a license renewal application under 10 CFR 54.

1.2 Scope

This AMG defines aging mechanisms and effective life cycle management techniques for commercial nuclear power plant battery chargers, inverters, and uninterruptible power supplies. These components are all important to plant safety and operability, under the current licensing basis and per 10 CFR 54.[1-2]

The strategy for preparing this AMG includes 1) identifying the component types, major subcomponents, and typical operating conditions, 2) collecting and evaluating operating/maintenance history information, 3) identifying the stressors acting on these components, and 4) determining the significance of component aging mechanisms. After completing these tasks and reviewing currently utilized aging management practices, guidelines are presented for effective management of these components.

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

1.2.1 Battery Chargers

Battery chargers convert plant auxiliary AC power to regulated DC power, for charging and floating of batteries, and for other DC power requirements in the plant. Chargers also provide DC input to inverters for critical AC instrument loads. The charger is an integrated unit with transformer, silicon-controlled rectifiers, undervoltage relays, metering, normal\by-pass switch, timer, internal circuit breakers, filter capacitors, cooling fans, and a metal enclosure. Table 1-1 lists the manufacturers of battery chargers for commercial nuclear power plants.

Table 1-1. Battery Charger Manufacturers

Manufacturer	% in Use		Charger Type	Plant Type
	Survey	NPRDS*		
C&D	8.7	20.5	SCR, ** Ferroresonant	BWR, PWR
Custom Power	3.5		SCR	PWR
Cyberex	3.5	2.8	SCR	BWR, PWR
ELGAR		<1		PWR
ELTRA		5.2	SCR	BWR, PWR
Exide	1.7	24.5	SCR	BWR, PWR
Fansteel	<1	<1		BWR
GNB	7	4.0	SCR	BWR
General Electric		<1	SCR	BWR
HDR	<1			PWR
Lamarche	11.8	2.4	Magnetic Amplifier	BWR, PWR
Lester	<1			BWR
Master Control	3		SCR	BWR, PWR
Nife	1.3			BWR, PWR
Power Conversion	54	33.3	SCR, Ferroresonant, Magnetic Amplifier	BWR, PWR
Reliance	<1			BWR
Solid State	1.7	3.1	Ferroresonant	BWR, PWR
Stewart Stevenson	<1			BWR
Westinghouse	3	1.8		PWR

* Nuclear Plant Reliability Data System

** Silicon controlled rectifier

1.2.2 Inverters

Inverters convert DC input power from a battery or battery charger to AC power of a desired voltage and stability to serve critical AC loads, typically instrumentation and control devices required for safe plant operation and shutdown. The inverter includes solid state electronics, silicon-controlled rectifiers, filters, a synchronizing circuit, cooling fans, and a metal enclosure. Inverters are either used with UPS designs, or as stand-alone units for non-essential instrument power supplies. Table 1-2 lists the manufacturers of inverters for commercial nuclear power plants.

1.2.3 Uninterruptible Power Supplies

UPS designs incorporate an inverter, with a static transfer switch, a manual bypass switch, and synchronizing electronics connected to an alternate AC source, to provide a highly reliable source of AC power. This redundancy of design between the normal and alternate sources is required for sensitive and critical AC instrument and control loads. A single or multiple enclosure design configuration may be used based on plant design. Table 1-2 lists the manufacturers of UPSs for commercial nuclear power plants.

Table 1-2. Inverter and UPS Manufacturers

Manufacturer	% in Use		Inverter Type	Plant Type
	Survey	NPRDS		
AVTEC		2.5		PWR
Cyberex	8.8	14.6	PWM*	BWR, PWR
ELGAR	31.8	15.4	Ferroresonant, PWM	BWR, PWR
Exide		18.7	PWM	BWR, PWR
Garret		<1		PWR
General Electric		<1		BWR
GNB		<1		PWR, BWR
Gould	1.1		Ferroresonant	PWR
HDR		<1		BWR
IPMC		<1		PWR
LaMarche	1.1		Ferroresonant	PWR
Liebert/Emerson		<1		BWR
Power Conversion		<1	Ferroresonant	BWR
SOLA		<1		BWR
Solid State	17.6	22.8	Ferroresonant	BWR, PWR
Static Controls	3.3	5.0		PWR, BWR
Topaz	4.4	4.2	PWM	BWR
Westinghouse	31.8	13.4	Ferroresonant	BWR, PWR

* Pulse width modulation

1.3 Conclusions

This AMG evaluates all aging mechanisms for battery chargers, inverters, and UPSs. Section 2 provides an introduction including background, purpose and objectives of this guideline document, scope, and methods. Section 3 provides a description of the components evaluated including the component boundaries, design requirements and applicable codes, manufacturer's design differences, and operating and service history based on plant specific data, industry databases, industry literature, and NRC communications. Section 4 identifies and examines the aging mechanisms first for relevancy, and then the relevant mechanisms are examined to determine which are potentially significant, and which are non-significant. Section 5 examines aging management programs/techniques to determine which are effective for detecting and/or mitigating the potentially significant aging mechanisms.

In general, battery chargers, inverters, and UPSs employed in different plants are constructed from the same materials and subcomponents, and are subjected to similar operating parameters. Additionally, the subcomponent parts of battery chargers are made of the same materials, and are subjected to similar operating conditions, as the subcomponent parts of inverters/UPSs. It was therefore possible to prepare this guideline on a generic basis by examining the stressors and aging mechanisms that affect the subcomponent parts that make up battery chargers, inverters, and UPSs.

1.3.1 Aging Mechanism Conclusions

The aging mechanisms considered in this AMG for the battery charger, inverter, and UPS subcomponents are described in Section 4.2.1 and are:

- Corrosion
- Fatigue
- Wear
- Electronic Drift
- Thermal Aging
- Setpoint Drift
- Radiation
- Fouling
- Material Set

It was determined that setpoint drift was not an aging mechanism in and of itself, but is the result of corrosion, wear, fatigue, and thermal aging (Section 4.2.1.6). Therefore, the effects of setpoint drift were considered with corrosion, wear, fatigue, and thermal aging.

Radiation was determined to be a non-relevant aging mechanism, since battery chargers, inverters, and UPSs are located in mild environments and would not be subject to radiation even under accident conditions (Section 4.2.1.7).

The remaining aging mechanisms were found to be relevant and were evaluated for significance in Section 4.2.2 on a subcomponent basis. Each of these mechanisms was found to be potentially significant for at least one subcomponent part used in battery chargers, inverters,

and UPSs. Table 4-3 summarizes the significance of these aging mechanisms for each subcomponent part.

The aging management programs/techniques that effectively manage the potentially significant aging mechanism subcomponent combinations are discussed in Section 5.

1.3.2 Aging Management Program Guidelines

The aging management programs/techniques presented in this AMG were divided into two groups: commonly used programs/techniques, and less commonly used programs/techniques, and are listed below.

Commonly Used Aging Management Programs/Techniques

- Preventive Maintenance Program
- Technical Specification Surveillance Program
- Equipment Qualification Program
- "Good Housekeeping" Practices - Operator Rounds, Logs, and Checklists
- On-Line Monitoring and Annunciator Response Procedures
- Infrared Thermographic Inspection Program
- Corrective Maintenance
- Operational Experience Reviews and Trending

Less Commonly Used Aging Management Programs/Techniques

- Environment Mitigation
- Waveform Monitoring
- Insulation Resistance Testing
- Transformer Turns Ratio Testing
- Sample Removal and Analysis
- Equipment Replacement/Refurbishment (Obsolescence)
- Environmental Monitoring
- Transient Monitoring and Recording
- Vibration Diagnosis

The commonly used programs/techniques are currently implemented at most nuclear facilities. The alternative programs/techniques may be implemented at some nuclear plants, but in general are not in wide use and may not be formalized with written procedures. The requirements for effective aging management programs are:

- a. The program is documented and administered in a formal manner. Written procedures describe activities, include acceptance criteria, and ensure that corrective action is specified in a timely manner.
- b. The components' required functions are properly addressed.
- c. The components' age-related degradation effects are properly addressed.

AGING MANAGEMENT GUIDELINE FOR BATTERY CHARGERS, INVERTERS, AND UPSs

The aging management programs/techniques are described generically in Section 5.2 (Common Programs) and Section 5.3 (Less Common Programs), and the relationship between these aging management programs/techniques and the potentially significant aging mechanisms determined in Section 4 is examined. The results of this examination are shown in Tables 5-8 (Common Programs) and 5-9 (Less Common Programs). These tables relate the aging management programs/techniques to the potentially significant aging mechanism for the individual charger, inverter, and UPS subcomponents.

Section 5.4 provides qualitative and quantitative "if-then" criteria with decision branches, for use by inspectors, surveillance testers, and/or system engineers, to compare plant-specific program coverage against programs/techniques determined to be effective at detecting and mitigating the potentially significant aging mechanisms. Recommendations are made regarding minimum required programs/techniques, highly recommended programs/techniques, and less used but highly proactive programs/techniques. These criteria and recommendations are summarized in Tables 5-10 and 5-11 for battery chargers and Tables 5-12 and 5-13 for inverters/UPSs.

These tables are repeated in this section as Tables 1-3 through 1-6 and indicate that currently available programs are effective at detecting and mitigating aging mechanisms. No new industry programs are required.

Section 5.5 provides a brief comparison of the results and conclusions of this guideline to the results and conclusions of the NRC's Nuclear Plant Aging Research (NPAR) program. In general, the results and conclusions of this guideline agree with the results and conclusions of the NPAR program.

Section 6 discusses the following issues which may affect plant-specific aging management program planning.

For battery chargers, inverters, and UPSs, equipment obsolescence and improvements in electronics capabilities are becoming a severe problem in terms of original equipment replacement part availability, and loss of "institutional memory" for servicing older electronic units.

Newer technology may provide reduced operations and maintenance (O&M) costs, higher reliability, and greater flexibility in operation. Cost-benefit considerations may spur overall charger/inverter/UPS replacement rather than long-term servicing of existing units.

In addition, manufacturer product line discontinuation or changes, business mergers/dissolutions, and a general lack of manufacturer support and performance data for older units, are a current problem facing maintenance personnel for these components, as evidenced by the plant questionnaire responses gathered during preparation of this guideline.

Table 1-3. Minimum Recommended Aging Management Programs and Activities for Battery Chargers

Program	Activity	Frequency	Aging Mechanisms Addressed	Comments
Preventive Maintenance	Visually Inspect <u>All</u> Sub-components and Connections for Dirt/Discoloration/Deformation	Once/Cycle	Thermal Aging, Fouling	
	Visually Inspect Transformer, Cable, and Wire Insulation for Cracks	Once/Cycle	Thermal Aging	
	Visually Inspect Capacitors for Leaking Oil/Electrolyte	Once/Cycle	Thermal Aging	
	Visually Inspect Transformers, Inductors, Relays, Circuit Boards, Circuit Breakers, Switches, Potentiometers, Wires, Cables, Cooling Fans, Fan Motors, and the Cabinet for Corrosion	Once/Cycle	Corrosion	
	Vacuum/Replace Air Filter	Once/Cycle	Thermal Aging, Fouling	
	Vacuum/Blowout Dirt from Cooling Fan Motor	Once/Cycle	Thermal Aging, Fouling	
	Clean Heat Sink Surfaces with Lint-Free Rag or Soft Bristle Brush	Once/Cycle	Thermal Aging, Fouling	
	Clean SCRs and Transformers with Lint-Free Rag or Soft Bristle Brush	Once/Cycle	Thermal Aging, Fouling	
	Clean and Burnish Relay Contacts	Once/Cycle	Thermal Aging, Fouling, Contact Corrosion	
	Clean Circuit Breakers, Switches, and Potentiometers	Once/Cycle	Thermal Aging, Fouling, Contact Corrosion	

Table 1-3. Minimum Recommended Aging Management Programs and Activities for Battery Chargers (continued)

Program	Activity	Frequency	Aging Mechanisms Addressed	Comments
Preventive Maintenance (continued)	Torque Verification of SCR Mountings	Once/Cycle	Thermal Aging, Fatigue	If the connection requires tightening, then it should be disassembled, cleaned, and reassembled with new thermal compound.
	Verify Tightness of <u>All</u> Fasteners	Once/Cycle	Fatigue	
	Exercise Circuit Breakers, Switches, and Relays	Once/Cycle	Wear, Material Set	
	Physically Check Transformer and Inductor Insulation with a Non-conducting Probe for Flaking	Once/Cycle	Thermal Aging	
	Physically Check Cable and Wire Insulation for Resiliency	Once/Cycle	Thermal Aging	
	Measure, Record, and Trend Capacitance of Filter Capacitors	Once/Cycle	Thermal Aging	If measured capacitance is 5-10% less than previous measurements or nameplate ratings, then the capacitors should be replaced.
	Calibrate Equalize and Float Voltage Settings	Once/Cycle	Setpoint Drift	
	Calibrate Alarm and Trip Relays	Once/Cycle	Setpoint Drift	
	Calibrate Panel Meters	Once/Cycle	Electronic Drift	
	Replace Filter Capacitors	As Recommended by Manufacturer	Thermal Aging	If capacitors rated for higher temperature and voltage are used, then they will have a longer useful life.

Table 1-3. Minimum Recommended Aging Management Programs and Activities for Battery Chargers (continued)

Program	Activity	Frequency	Aging Mechanisms Addressed	Comments
Surveillance (Note 1)	Capacity Testing	Once/Cycle	Thermal Aging, Setpoint Drift	
	Annunciator Checks	Once/Cycle	Thermal Aging, Setpoint Drift, Material Set, Wear, Fatigue, and Corrosion of Relays	
	Measure Output Ripple Voltage	Once/Cycle	Thermal Aging of Filter Capacitors	
"Good Housekeeping" Practices - Operator Rounds, Logs, and Checklists	Log Cabinet Temperature	Once per Shift	Thermal Aging	
	Log Output Voltage and Current	Once per Shift	Thermal Aging, Electronic/Setpoint Drift	
	Listen for Noise	Once per Shift	Thermal Aging (Transformer Hum), Wear (Fan Bearings)	
	Check for Burning Odor	Once per Shift	Thermal Aging	
	Check for Vibration	Once per Shift	Fatigue	
On-Line Monitoring and Annunciator Response Procedures	Alarm for High Cabinet Temperature	Continuous	Thermal Aging	
	Alarm for High/Low Output Voltage	Continuous	Thermal Aging, Setpoint/Electronic Drift	
	Alarm for Loss of Forced Cooling	Continuous	Thermal Aging	If unit is cooled by natural convection, then this activity is not applicable.

Table 1-3. Minimum Recommended Aging Management Programs and Activities for Battery Chargers (continued)

Program	Activity	Frequency	Aging Mechanisms Addressed	Comments
Infrared Thermographic Inspection (Note 2)	Perform and Trend Infrared Thermographic Scans (Note 2)	(Note 2)	Thermal Aging	

Notes:

1. Surveillance program activities can be conducted as part of the plant Technical Specification Surveillance or as part of an Operational Surveillance Program.
2. The Infrared Thermographic Inspection Program should be instituted in accordance with the EPRI NMAC Guide for Infrared Thermography (NP-6973).

Table 1-4. Supplemental Aging Management Programs and Activities for Battery Chargers

Program	Activity	Frequency	Aging Mechanisms Addressed	Comments
Corrective Maintenance	Tuning of SCR Firing Circuit	As Needed (See Comments)	Thermal Aging	If an SCR is replaced, then the associated firing circuit should be tuned.
	Voltage Balancing (i.e., Adjust AC Inputs to get Symmetrical DC Output)	As Needed (See Comments)	Thermal Aging	If a major component is replaced (e.g., transformer, SCR, capacitor, circuit board), then the charger should be voltage balanced.

Table 1-4. Supplemental Aging Management Programs and Activities for Battery Chargers (continued)

Program	Activity	Frequency	Aging Mechanisms Addressed	Comments
Corrective Maintenance (continued)	Filter Capacitor Replacement	As Needed (See Comments)	Thermal Aging	If one filter capacitor fails, then all other filter capacitors should either be tested (measure capacitance) or replaced. When testing, if the capacitance has decreased by 5-10% from the design value, then the capacitor should be replaced.
	Repair of Loose Connections	As Needed	Thermal Aging	If a connection requires tightening, then it should be disassembled, cleaned, and reassembled using new thermal compound.
Equipment Qualification	Qualify Equipment and Maintain the Qualification	On-Going	Thermal Aging, Electronic/Setpoint Drift, Corrosion, Fouling, Material Set, Fatigue, Wear	
Environment Mitigation	Install Cooling Fans on Cabinet	As Needed	Thermal Aging	If cabinet is already force cooled, then additional or back-up fans could be installed.
	Upgrade HVAC*	As Needed	Thermal Aging	
	Install Additional Vents on Cabinet	As Needed	Thermal Aging	
Waveform Monitoring	Monitor Ripple Voltage with an Oscilloscope	As Needed	Thermal Aging of Filter Capacitors	
* Heating, ventilation, and air conditioning				

Table 1-4. Supplemental Aging Management Programs and Activities for Battery Chargers (continued)

Program	Activity	Frequency	Aging Mechanisms Addressed	Comments
Insulation Resistance Testing	DAR* Test on Transformers, Circuit Breakers, Wires, Cables, and Cooling Fan Motors	As Needed	Thermal Aging	If the dielectric absorption ratio is less than 1.25, then investigative and corrective action is warranted.
Transformer Turns Ratio Testing	Transformer Testing	As Needed	Thermal Aging	
Sample Removal and Analysis	Trend the Analyses of Removed Relays, Capacitors, and Cables	As Needed	Thermal Aging	
Equipment Replacement/Refurbishment	Replace Entire Unit	As Needed	Thermal Aging, Electronic/Setpoint Drift, Corrosion, Fouling, Material Set, Fatigue, Wear	
	Replace Subcomponents	As Needed	Thermal Aging, Electronic/Setpoint Drift, Corrosion, Fouling, Material Set, Fatigue, Wear	
Environmental Monitoring	Monitor and Trend Ambient Temperature and Humidity	As Needed	Thermal Aging, Corrosion	
Transient Monitoring and Recording	Monitor and Record Electrical Transients	As Needed	Thermal Aging	
Vibration Diagnosis	Vibration Monitoring and Trending	As Needed	Wear of Cooling Fan and Motor Bearings	
* Dielectric Absorption Ratio				

Table 1-5. Minimum Recommended Aging Management Programs and Activities for Inverters/UPSs

Program	Activity	Frequency	Aging Mechanisms Addressed	Comments
Preventive Maintenance	Visually Inspect <u>All</u> Subcomponents and Connections for Dirt/Discoloration/Deformation	Once/Cycle	Thermal Aging, Fouling	
	Visually Inspect Transformer, Cable, and Wire Insulation for Cracks	Once/Cycle	Thermal Aging	
	Visually Inspect Capacitors for Leaking Oil/Electrolyte	Once/Cycle	Thermal Aging	
	Visually Inspect Transformers, Inductors, Relays, Circuit Boards, Circuit Breakers, Switches, Potentiometers, Wires, Cables, Cooling Fans, Fan Motors, and the Cabinet for Corrosion	Once/Cycle	Corrosion	
	Vacuum/Replace Air Filter	Once/Cycle	Thermal Aging, Fouling	
	Vacuum/Blowout Dirt from Cooling Fan Motor	Once/Cycle	Thermal Aging, Fouling	
	Clean Heat Sink Surfaces with Lint-Free Rag or Soft Bristle Brush	Once/Cycle	Thermal Aging, Fouling	
	Clean SCRs and Transformers with Lint-Free Rag or Soft Bristle Brush	Once/Cycle	Thermal Aging, Fouling	
	Clean and Burnish Relay Contacts	Once/Cycle	Thermal Aging, Fouling, Contact Corrosion	
	Clean Circuit Breakers and Switches	Once/Cycle	Thermal Aging, Fouling, Contact Corrosion	

Table 1-5. Minimum Recommended Aging Management Programs and Activities for Inverters/UPSs (continued)

Program	Activity	Frequency	Aging Mechanisms Addressed	Comments
Preventive Maintenance (continued)	Torque Verification of SCR Mountings	Once/Cycle	Thermal Aging, Fatigue	If the connection requires tightening, then it should be disassembled, cleaned, and reassembled with new thermal compound.
	Verify Tightness of <u>All</u> Fasteners	Once/Cycle	Fatigue	
	Exercise Circuit Breakers, Switches, and Relays	Once/Cycle	Wear, Material Set	
	Physically Check Transformer and Inductor Insulation with a Non-conducting Probe for Flaking	Once/Cycle	Thermal Aging	
	Physically Check Cable and Wire Insulation for Resiliency	Once/Cycle	Thermal Aging	
	Measure, Record, and Trend Capacitance of Capacitors	Once/Cycle	Thermal Aging	If measured capacitance is 5-10% less than previous measurements or nameplate ratings, then the capacitors should be replaced.
	Calibrate Output Voltage and Frequency	Once/Cycle	Electronic/Setpoint Drift	
	Calibrate Alarm and Trip Relays	Once/Cycle	Electronic/Setpoint Drift	
	Calibrate Panel Meters	Once/Cycle	Electronic Drift	
	Replace Capacitors	As Recommended by Manufacturer	Thermal Aging	If capacitors rated for higher temperature and voltage are used, then they will have a longer useful life.

Table 1-5. Minimum Recommended Aging Management Programs and Activities for Inverters/UPSs (continued)

Program	Activity	Frequency	Aging Mechanisms Addressed	Comments
Surveillance (Note 1)	Capacity Testing	Once/Cycle	Thermal Aging, Setpoint Drift	
	Annunciator Checks	Once/Cycle	Thermal Aging, Setpoint Drift, Material Set, Wear, Fatigue, and Corrosion of Relays	
	Measure Output Voltage, Frequency, and Harmonic Distortion	Once/Cycle	Thermal Aging, Electronic/Setpoint Drift	
"Good Housekeeping" Practices - Operator Rounds, Logs, and Checklists	Log Cabinet Temperature	Once per Shift	Thermal Aging	
	Log Output Voltage, Current, and Frequency	Once per Shift	Thermal Aging, Electronic/Setpoint Drift	
	Verify Synchronization	Once per Shift	Thermal Aging, Electronic/Setpoint Drift	
	Listen for Noise	Once per Shift	Thermal Aging (Transformer Hum), Wear (Fan Bearings)	
	Check for Burning Odor	Once per Shift	Thermal Aging	
	Check for Vibration	Once per Shift	Fatigue	
On-Line Monitoring and Annunciator Response Procedures	Alarm for High Cabinet Temperature	Continuous	Thermal Aging	
	Alarm for High/Low Out- put Voltage	Continuous	Thermal Aging, Setpoint/Electronic Drift	
	Alarm for Out of Syn- chronization Condition	Continuous	Thermal Aging	
	Alarm for Loss of Forced Cooling	Continuous	Thermal Aging	If unit is cooled by natural con- vection, then this activity is not applicable.

Table 1-5. Minimum Recommended Aging Management Programs and Activities for Inverters/UPSs (continued)

Program	Activity	Frequency	Aging Mechanisms Addressed	Comments
Infrared Thermographic Inspection (Note 2)	Perform and Trend Infrared Thermographic Scans (Note 2)	(Note 2)	Thermal Aging	

Notes:

1. Surveillance program activities can be conducted as part of the plant Technical Specification Surveillance or as part of an Operational Surveillance Program.
2. The Infrared Thermographic Inspection Program should be instituted in accordance with the EPRI Nuclear Maintenance Application Center (NMAC) Guide for Infrared Thermography (NP-6973).

Table 1-6. Supplemental Aging Management Programs and Activities for Inverters/UPSs

Program	Activity	Frequency	Aging Mechanisms Addressed	Comments
Corrective Maintenance	Tuning of SCR Firing Circuit	As Needed (See Comments)	Thermal Aging	If an SCR is replaced, then the associated firing circuit should be tuned.
	Voltage Balancing/ Frequency Adjustment	As Needed (See Comments)	Thermal Aging Due to Circulating Currents in Ferroresonant Inverters/UPSs	If a major component is replaced (e.g., transformer, SCR, capacitor, circuit board), then the inverter/UPS should be frequency tuned and voltage balanced.

Table 1-6. Supplemental Aging Management Programs and Activities for Inverters/UPSs (continued)

Program	Activity	Frequency	Aging Mechanisms Addressed	Comments
Corrective Maintenance (continued)	Capacitor Replacement	As Needed (See Comments)	Thermal Aging	If one capacitor fails, then all other capacitors should either be tested (measure capacitance) or replaced. When testing, if the capacitance has decreased by 5-10% from the design value, then the capacitor should be replaced.
	Repair of Loose Connections	As Needed	Thermal Aging	If a connection requires tightening, then it should be disassembled, cleaned, and reassembled using new thermal compound.
Equipment Qualification	Qualify Equipment and Maintain the Qualification	On-Going	Thermal Aging, Electronic/Setpoint Drift, Corrosion, Fouling, Material Set, Fatigue, Wear	
Environment Mitigation	Install Cooling Fans on Cabinet	As Needed	Thermal Aging	If cabinet is already force cooled, then additional or backup fans could be installed.
	Upgrade HVAC	As Needed	Thermal Aging	
	Install Additional Vents on Cabinet	As Needed	Thermal Aging	
Waveform Monitoring	Monitor Output Voltage with an Oscilloscope	As Needed	Thermal Aging	
	Monitor SCR Gating Signals with an Oscilloscope	As Needed	Thermal Aging	
	Monitor the Commutating Capacitor Voltage with an Oscilloscope	As Needed	Thermal Aging	

Table 1-6. Supplemental Aging Management Programs and Activities for Inverters/UPSs (continued)

Program	Activity	Frequency	Aging Mechanisms Addressed	Comments
Insulation Resistance Testing	DAR Test on Transformers, Circuit Breakers, Wires, Cables, and Cooling Fan Motors	As Needed	Thermal Aging	If the dielectric absorption ratio is less than 1.25, then investigative and corrective action is warranted.
Transformer Turns Ratio Testing	Transformer Testing	As Needed	Thermal Aging	
Sample Removal and Analysis	Trend the Analyses of Removed Relays, Capacitors, and Cables	As Needed	Thermal Aging	
Equipment Replacement/Refurbishment	Replace Entire Unit	As Needed	Thermal Aging, Electronic/Setpoint Drift, Corrosion, Fouling, Material Set, Fatigue, Wear	
	Replace Subcomponents	As Needed	Thermal Aging, Electronic/Setpoint Drift, Corrosion, Fouling, Material Set, Fatigue, Wear	
Environmental Monitoring	Monitor and Trend Ambient Temperature and Humidity	As Needed	Thermal Aging, Corrosion	
Transient Monitoring and Recording	Monitor and Record Electrical Transients	As Needed	Thermal Aging	
Vibration Diagnosis	Vibration Monitoring and Trending	As Needed	Wear of Cooling Fan and Motor Bearings	

1.4 References

- 1.1 Title 10, U.S. Code of Federal Regulations, Part 50.65, "Requirements for Monitoring the Effectiveness of Maintenance at Nuclear Power Plants."
- 1.2 Title 10, U.S. Code of Federal Regulations, Part 54, "Requirements for Renewal of Operating Licenses for Nuclear Power Plants."
- 1.3 National Energy Strategy, U.S. Department of Energy, February 1991.

- 1.4 NUREG-1144, "Nuclear Plant Aging Research (NPAR) Program Plan - Status and Accomplishments, U.S. Nuclear Regulatory Commission," Revision 2, June 1991.

2. INTRODUCTION

This AMG provides methods which utilities can apply to perform evaluations of: 1) aging mechanisms and 2) current plant programs to assess their effectiveness for aging management. Demonstrating that charger, inverter, and UPS aging is being effectively managed is a key element to long-term safe and reliable plant operation. Early recognition of areas requiring enhancement to achieve effective aging management is also a cost-effective approach for utilities to comply with the Maintenance Rule[2.1] and for those utilities intending to pursue license renewal.[2.2]

The aging mechanisms that occur to these nuclear power plant components must be fully understood to be effectively managed. This knowledge and understanding may be empirical or mechanistic, depending on the nature and potential consequences of a particular aging mechanism. Acquiring aging knowledge requires a detailed awareness of component life cycle features, including material types, fabrication, design specifications, installation methods, and operating, testing, inspection and maintenance activities, all of which interact with functional service and environmental stressors.

The goal of this AMG is that it be practical and useful to utility personnel for 1) assessing the significance of aging mechanisms occurring to their chargers/inverters/UPSs, and 2) evaluating the effectiveness of their programs to detect and mitigate charger/inverter/UPS degradation.

2.1 Background

EPRI investigations began in the early 1980s to research nuclear plant aging and the potential for life extension.[2.3] Simultaneously, the U.S. DOE initiated the PLIM program. These efforts led to the BWR and PWR Pilot Plant Programs for Life Extension at Monticello and Surry during 1985-1988. These pilot programs demonstrated the technical feasibility and economic benefit of extending plant life.[2.4, 2.5, 2.6, 2.7, 2.8]

Subsequently, EPRI and DOE have funded the Lead Plant License Renewal Program, to demonstrate a predictable process and methods for achieving a light water reactor (LWR) renewal license under 10 CFR 54. Battery chargers, inverters, and UPSs have been defined as important components for license renewal and aging management in this program.

Concurrently, the U.S. NRC initiated the NPAR Program to determine relevant and significant aging mechanisms for components and structures in commercial LWR power plants.[2.9] Investigations have been completed for chargers, inverters, and UPS components. Several references are contained in Sections 3 and 4 of this AMG. The NRC also prepared and issued 10 CFR 54, the License Renewal Rule, to allow for the orderly renewal of operating licenses.[2.2] The supporting Standard Review Plan and draft Regulatory Guide identify chargers, inverters, and UPSs as critical plant components to be included in a license renewal evaluation.[2.10, 2.11]

Recent enactment of the Maintenance Rule, 10 CFR 50.65, requires a standardized method of maintenance effectiveness measurement and tracking.[2.1] This rule closely integrates with

the License Renewal Rule in definition of critical components and the measurement of performance degradation possibly due to aging. Effective aging mechanism detection and mitigation of chargers, inverters, and UPS will be essential in both rules.

The nuclear industry has sought to address issues of aging detection and mitigation through generic research programs and products, where appropriate, which can be cited in a License Renewal Application. This has been accomplished through a series of license renewal "Industry Reports" sponsored by EPRI and DOE, and a corresponding series of "Aging Management Guidelines" sponsored by DOE's Technology Center at Sandia National Laboratories. The Industry Reports have focused on generic evaluations related to common elements of nuclear plant design (e.g., vessels, containments, structures, piping), with specific guidance to be considered in plant-unique evaluations. The DOE sponsored Aging Management Guidelines are intended to provide in-depth aging management techniques for use by plant staff for "commodity" types of equipment (e.g., pumps, chargers, and inverters).

This AMG, which evaluates battery chargers, inverters, and uninterruptible power supplies, represents the culmination of several years of research and plant experience review, and should benefit those utilities committed to prudent and economic life cycle management.

Article 54.21 of Reference 2.2 requires that age-related degradation unique to license renewal must be effectively managed. For purposes of this aging management guideline, all age-related degradation and associated aging mechanisms are evaluated. No attempt was made to segregate stressors and/or aging mechanisms that are unique to the license renewal period as defined in Article 54.3 of Reference 2.2.

2.2 Purpose and Objectives of AMG

The purpose of this AMG is to provide cost-effective, practical methods to plant technical staff for the management of aging in battery chargers, inverters, and UPSs, and to provide generic technical support for the license renewal integrated plant assessment under 10 CFR 54. Identifying effective aging management programs and activities will also help utilities to comply with the Maintenance Rule under 10 CFR 50.65.

The step-by-step evaluation approach is:

- For a component type, define which components/subcomponents in the plant are significant for power production or license renewal, and therefore require evaluation. Document bases for methodology used to select these components.
- Define which components/subcomponents are classified as "consumables" or "renewables", and not subject to a formal aging management program.
- Specify component boundaries (inputs, outputs, bounded subcomponents).
- Identify the predominant types of components (manufacturer, type, rating, class, service, etc.), and design similarities and differences relevant to aging management guidelines.

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- Identify types of components which are excluded from AMGs and why (i.e., low number in service, unique to one plant, etc.).
- Identify relevant design and licensing requirements established by plant requirements, and by NRC and code standards (only as they relate to aging management).
- Identify relevant license renewal requirements.
- Examine and review industry operating history for these components, and by trending or other analysis reach conclusions on relevant aging mechanisms.
- Define applicable stressors and associated aging mechanisms.
- Determine relevance and significance of aging mechanisms to components or subcomponents.
- Define generic elements of an "effective" aging management program for potentially significant aging mechanisms.
- Identify and review common maintenance, surveillance, testing, inspection, refurbishment and replacement techniques and programs used for these components, for their effectiveness in aging management (including trending).
- Identify and review "new" or "plant-unique" methods used for aging management.
- Correlate effective programs with component/aging mechanism combinations.
- Prepare guidelines to detect and mitigate potentially significant aging mechanisms for the component class.
 - Establish measurement and verification criteria
 - Establish "if-then" criteria for mitigative or refurbishment activities
- Identify potentially significant aging mechanism/component combinations not addressed by an effective plant program.
- Recommend options for new programs, and enhancements of existing practices, to deal with aging mechanism/component combinations not covered by a current effective program.
- Address issues of technical obsolescence.

AGING MANAGEMENT GUIDELINE FOR BATTERY CHARGERS, INVERTERS, AND UPSs

This AMG is intended for use by nuclear plants performing battery charger, inverter, and UPS aging evaluations, and provides additional information and guidance in the formulation of aging management programs. The guideline provides additional value to nuclear utility personnel as follows:

1. The AMG is a well-researched technical document that can be used by maintenance and system engineering personnel for the identification and characterization of aging mechanisms, and for effective management of age-related degradation in battery chargers, inverters, and UPSs. It also can be used as a base document for plants in complying with the Maintenance Rule or in developing a license renewal application.
2. The development of this AMG utilized an extensive literature search. Therefore, utility personnel can use the guideline as a source document for relevant information about battery chargers, inverters, and UPSs. Some of the references studied include:
 - EPRI Reports
 - NMAC Reports and Maintenance Guides
 - NRC NPAR Reports
 - NRC Bulletins, Information Notices, Generic Letters, and Circulars
 - Vendor Manuals and Service Information
 - Industry Codes and Standards
 - Handbooks
 - Other Domestic Publications
 - Other Foreign References and Technical Papers
3. This AMG consolidates historical maintenance and industry operating information into one source. The plant maintenance/system engineer will find this useful for both the identification of age-related degradation (including root causes), and the verification of appropriate corrective action. Issues discussed in the guideline include:
 - Equipment design differences relevant to aging considerations
 - Equipment obsolescence as it affects aging management
 - Service environments
 - Operating and maintenance history from the INPO NPRDS and NRC Licensee Event Report (LER) databases
 - Additional operating and maintenance history from responses to plant surveys
4. The phenomena of battery charger, inverter, and UPS aging are described in detail. This will be useful for service life and reliability evaluations, and to optimize the service life potential of component replacements and system modifications. The following topics are discussed:
 - Stressors acting on battery charger, inverter, and UPS components

- Aging mechanisms identification
 - Significance of aging mechanisms
 - Age-related degradation of equipment components
 - Potential failure modes
5. The AMG is an effective tool for equipment aging management and personnel training. That is, it:
- Heightens awareness concerning the need for aging management and compliance with Maintenance Rule and License Renewal Rule requirements.
 - Establishes a correlation between the scope and frequency of maintenance practices, and equipment performance and rate of degradation.
 - Generates the information to construct meaningful life cycle management charts and to improve the reliability of cost benefit determinations.
 - Discusses both common and less common maintenance and inspection techniques, and considers how these practices can be utilized to effectively manage aging.
 - Characterizes manifestations of equipment aging for use in training personnel responsible for maintenance and inspection activities.
 - Establishes concepts, principles, and methods for evaluating battery chargers, inverters, and UPSs not in the scope of this guideline.

2.3 Scope

This AMG covers three classes of nuclear plant components:

1. Battery chargers, which provide charging to plant DC system batteries, and which also supply plant DC system loads under normal operation. This includes both essential chargers and non-essential chargers in the plant and switchyard which supply loads important to license renewal under 10 CFR 54. The charger is defined as an integrated unit composed of subcomponents.
2. Inverters, which serve AC instrumentation and control loads from a reliable DC power source. This class includes stand-alone inverters serving essential loads or loads defined as important to license renewal. The inverter is evaluated as an integrated unit composed of subcomponents. Inverters are also a component of uninterruptible power supplies, as defined below.
3. Uninterruptible power supplies, which incorporate an inverter, a rapid-acting static transfer switch, a manual bypass switch and synchronizing electronics connected to an alternate AC source, to provide a highly reliable source of AC power. UPS designs typically feed sensitive and critical loads associated with safe plant operation or shutdown. The evaluation considers the cabinets housing the UPS inverter and

static transfer switch as well as external switches and electronics which provide the alternate AC source.

Section 3 of this AMG describes the components by surveying the equipment used, identifying the materials of construction, and discussing the different types of designs. Section 3 also includes a breakdown of the subcomponents (or subassemblies) that need to be examined. The subcomponents which are classified as renewable are identified. Industry operating, maintenance, and aging management experience for the components is provided and evaluated. This information provides data to support and substantiate the conclusions of this aging management evaluation.

Section 4 of this AMG provides a discussion of the various stressors acting on the subcomponents. Stressors manifest over time into aging mechanisms, which ultimately cause component degradation if not detected and mitigative actions implemented. The relative influence of these stressors to cause degradation of subcomponents is summarized in tabular form. The results of aging studies are used to describe aging mechanisms known to cause degradation. An aging mechanism is potentially significant when, if allowed to continue without detection or mitigation measures, it may cause the component to lose its ability to perform its required function. Aging mechanisms for the subcomponents are identified and evaluated. Operational demands, environmental conditions, failure data, and industry operations and maintenance history are considered, and the significance of the aging mechanisms determined. The approach addresses the theoretical basis for aging degradation and the operating experience.

Section 5 discusses effective aging management techniques for the aging mechanisms determined in Section 4 to be potentially significant. Common maintenance, inspection, testing, and surveillance techniques/programs are described. A brief discussion of less common activities and techniques is also included. The effectiveness of these techniques/programs for managing the potentially significant aging mechanisms is evaluated. Variations in plant aging management programs/techniques are considered. The minimum set of requirements for an effective program/technique is presented in the form of "if-then" criteria.

Section 6 discusses the unique issues of electronic component obsolescence, design technology changes, and diminished manufacturer support which may influence the development of plant-unique aging management programs for these components.

2.4 Generic License Renewal Requirements

The Atomic Energy Act, which permits renewal of licenses, and Title 10 of the Code of Federal Regulations, Part 50.51, did not contain the specific provisions that must be satisfied to renew a license. The nuclear industry urged the NRC to develop standards and procedures. The Nuclear Regulatory Commission issued Title 10 of the Code of Federal Regulations, Part 54, entitled "Nuclear Power Plant License Renewal" to establish the procedures, criteria, and standards governing the requirements for license renewal.

Title 10 of the Code of Federal Regulations, Part 54, requires that age-related degradation unique to license renewal that occurs to systems, structures, and components (SSCs) which are important to license renewal must be managed by effective programs. Effective management of

age-related degradation ensures that an SSC will continue to perform its required function or will not prevent the performance of a required function during the period of extended operation.

2.5 Methods Used to Define Scope

The review and evaluation of plant equipment for license renewal differs from the initial licensing of the plant. A substantial operating history of plant chargers, inverters, and UPSs has been established, and the current licensing basis of the plant has evolved since the original license was issued. Therefore, the basis for license renewal is to continue safe and reliable plant operation in accordance with the current licensing basis taking into consideration the maintenance and operating history. A structured approach is used to identify the plant components which are required for safe and reliable plant operation and important to license renewal.

The License Renewal Rule requires an integrated plant assessment (IPA) to complete a license renewal application. The IPA identifies SSCs important to license renewal, identifies significant age-related degradation which may affect SSC functioning, and evaluates effective programs credited for detecting and managing this aging during the license renewal term. The requirements of the integrated plant assessment are further defined in the NRC's draft Regulatory Guide[2.10] and the NRC's draft Standard Review Plan.[2.11] The integrated plant assessment is reviewed by the NRC during processing of the license renewal application.

Reference 2.11 identifies chargers, inverters, and uninterruptible power supplies in plant DC power systems and instrument AC power systems as important to license renewal. These components supply motive and control power to equipment that is safety-related or important to safety. Sections B.4.3.1 and B.4.3.2 of Reference 2.11 provide the regulatory basis for inclusion of these components in effective aging management programs.

In addition, the battery/battery charger systems associated with control power to breakers and switchgear in the switchyard are identified in Reference 2.11, Section B.4.7.1 as important to license renewal and subject to the requirements of effective aging management. Control of offsite power sources is a Technical Specification Limiting Condition of Operation.

Plant-specific design of emergency (or essential) lighting systems may include self-contained lighting packs with an integrated battery/battery charger. Operation of the emergency lighting system may be credited in the design basis response to fire or loss of offsite power events. If so credited, then the emergency lighting pack battery/battery charger unit is important to license renewal, and subject to an effective aging management program. This is covered by Section B.4.5 of Reference 2.11.

Plant-specific design of computer systems may include portions or all of a computer system which is used in Class 1E safety-related systems for monitoring or control purposes. Post-accident monitoring, safety-grade signal processing, and safety-grade digital control subsystems may meet the definition of 10 CFR 54.3 as important to license renewal. In addition, "information systems" such as the Safety Parameter Display System, and displays associated with Regulatory Guide 1.97 compliance, may be credited in the current licensing basis, and be important to license renewal under 10 CFR 54. Such computer systems may have local battery/charger/uninterruptible power supplies associated with their reliable performance. These

components would then be subject to effective aging management programs. Sections B.4.6 and B.4.8 of Reference 2.11 address these systems.

The plant-specific selection of battery chargers, inverters, and uninterruptible power supplies for effective aging management must first consider the requirements of 10 CFR 54.3. Further guidance on the plant screening process for selecting the components is provided in the draft NRC Regulatory Guide DG-1009.[2.10] At the time of this guideline preparation, the Nuclear Management and Resource Council (NUMARC) had an established draft guidance through a Screening Methodology Ad Hoc Advisory Committee document,[2.12] but the industry had not formally adopted this guidance document.

Beyond the requirements of license renewal, selection of chargers, inverters, and UPS for effective aging management should also consider the plant-unique current licensing basis. Commitments made during resolution of the Station Blackout issue, or in response to individual plant examinations and probabilistic risk analyses, or in response to electrical distribution system functional inspections, may influence the selection of additional components to be covered under the effective aging management guidelines of this document. The recent adoption of the Maintenance Rule, 10 CFR 50.65[2.1] creates interrelated requirements for evaluating maintenance performance and root cause analysis of age-related degradation.

The Monticello and Yankee Rowe Lead Plant License Renewal Programs represented the first application of the License Renewal Rule methodology. These programs determined that **all chargers, inverters, and UPS components currently installed in the plant met the requirements of importance to license renewal**. This suggests that the effective aging management guidance presented in this document should be applied to all such components in a plant. This universal application of effective aging management programs is confirmed by the extent to which Nuclear Plant Aging Research program research has focussed on these components, as detailed in Section 3.

2.6 Methods to Identify Aging Stressors/Mechanisms and Plant Programs

This AMG researches two broad sources of information for determining effective aging management practices, including the identification of aging stressors and mechanisms, and the review of programs which detect and mitigate this aging. These two sources include the following:

1. Industry Research Results

- a. EPRI, and its Nuclear Safety Analysis Center and Nuclear Maintenance Applications Center, have completed several research programs and maintenance guidelines related to chargers, inverters, and UPS systems in nuclear and fossil plant applications.
- b. The Institute of Electrical and Electronic Engineers (IEEE), through its Nuclear Power Engineering Committee, has developed several standards related to design, operation, and maintenance of these components. Subcommittee 3, Working Groups 3.3 and 3.4, of IEEE directs this effort. The IEEE draft standard for

assessing, monitoring, and mitigating aging effects on Class 1E equipment[2.13] is of particular importance.

The IEEE standards have subsequently been referenced in NRC Regulatory Guides and the Standard Review Plan for License Renewal.

- c. The NRC's Nuclear Plant Aging Research Program, as defined in Reference 2.9, has researched aging stressors and mechanisms for these components, including significant compilation of historical performance data. These are documented in a series of NUREG technical reports as detailed in Sections 3.0 and 4.0.
- d. NUREG-0304[2.14] periodically issued by the U.S. NRC, provides abstracts of research and data collection activities performed under NRC sponsorship.
- e. A search was made of relevant industry research papers through the DIALOG database, which accesses a variety of government, academic, and private industry abstract sources.

2. Industry Experience Records

- a. A host utility provided detailed information on charger, inverter, and UPS design performance and aging management techniques, and served to benchmark this guideline document.
- b. Questionnaires were sent to all U.S. nuclear plants, requesting design, operating, and performance/aging data for their chargers, inverters, and UPS. In addition, utilities were asked to submit copies of their procedures and programs for maintenance, testing, and inspection. A 22 percent return was achieved and contributed significant information to this report.
- c. NRC Inspection and Enforcement bulletins, notices, circulars, and letters were reviewed for relevant age-related events, root cause analyses, and mitigative actions for these components.
- d. The Institute of Nuclear Power Operations (INPO) Nuclear Plant Reliability Data System (NPRDS) was accessed for reported failure events related to aging issues. INPO Significant Event Reports and Significant Operating Event Reports were also reviewed for relevant events.
- e. The NRC Licensee Event Report database, which documents component failures, causes, and corrective actions, was accessed via Oak Ridge National Laboratory for the components in review.
- f. The vendors who supplied the majority of chargers, inverters, and UPS systems in use in U.S. nuclear power plants were contacted for information on age-related failures and mitigative techniques which may have been developed.

- g. The Pilot Plant Life Extension reports for Monticello and Surry, as available, and the Monticello and Yankee Lead Plant License Renewal Program Reports, as available, were reviewed as a confirmation of the relevant aging mechanisms and effective aging management programs utilized.

An analysis of these industry documents and databases is provided in Section 3.

Article 54.21 of Reference 2.2 requires that age-related degradation unique to license renewal must be effectively managed. This guideline evaluates all age-related degradation and associated aging mechanisms. **No attempt was made to identify the stressors, aging mechanisms, or the corresponding age-related degradation that are unique to the license renewal period.** Because the "age-related degradation unique to license renewal" screen was not used, the scope of components important to license renewal evaluated in this AMG could be much larger than if the screen were used.

2.7 References

- 2.1 Title 10 of the Code of Federal Regulations, 10 CFR 50.65, "Requirements for Monitoring the Effectiveness of Maintenance at Nuclear Power Plants," July 10, 1991.
- 2.2 Title 10 of the Code of Federal Regulations, 10 CFR 54, "Requirements for Renewal of Operating Licenses for Nuclear Power Plants," December 13, 1991.
- 2.3 Extended Life Operation of Light Water Reactors: Economic and Technological Review, Volume 1-2, EPRI Report NP-2418, Electric Power Research Institute, June 1982.
- 2.4 BWR Pilot Plant Life Extension Study at the Monticello Plant: Phase 1, Final Report, EPRI Report NP-5181M, Electric Power Research Institute, May 1987.
- 2.5 BWR Pilot Plant Life Extension Study at the Monticello Plant: Interim Phase 2, EPRI Report NP-5836M, Electric Power Research Institute, October 1988.
- 2.6 BWR Pilot Plant Life Extension Study at the Monticello Plant: Final Phase 2, EPRI Report NP-6541M, Electric Power Research Institute, September 1989.
- 2.7 PWR Pilot Plant Life Extension Study at Surry Unit 1: Phase 1, EPRI Report NP-5289P, Electric Power Research Institute, July 1987.
- 2.8 PWR Pilot Plant Life Extension Study at Surry Unit 1: Phase 2, EPRI Report NP-6232P, Electric Power Research Institute, March 1989.
- 2.9 NUREG-1144, Nuclear Plant Aging Research (NPAR) Program Plan, U.S. Nuclear Regulatory Commission, Revision 2, June 1991.

- 2.10 NUREG-1299, Standard Review Plan for the Review of License Renewal Applications for Nuclear Power Plants, U.S. Nuclear Regulatory Commission, Draft, November 1990.
- 2.11 Regulatory Guide DG-1009, Standard Format and Content of Technical Information for Applications to Renew Nuclear Power Plant Operating License, U.S. Nuclear Regulatory Commission, Draft, December 1990.
- 2.12 Methodology to Evaluate Plant Systems, Structures, and Components for License Renewal, NUMARC Report Number 90-11, Nuclear Management and Resources Council, December 1990.
- 2.13 IEEE Standard P-1205, IEEE Guide for Assessing, Monitoring, and Mitigating Aging Effects on Class 1E Equipment Used in Nuclear Power Generating Stations, Institute of Electrical and Electronics Engineers, Draft, October 26, 1992.
- 2.14 NUREG-304, Regulatory and Technical Reports (Abstract Index Journal), Annual Compilation for 1992, Volume 16, No. 4, U.S. Nuclear Regulatory Commission, March 1992.

3. EQUIPMENT AND COMPONENTS EVALUATED

This section of the AMG identifies the LWR battery chargers, inverters, and UPSs to be evaluated for life cycle management. Sections 3.1 through 3.4 describe the selection methodology, the equipment in the evaluation scope, and the groupings of subcomponents established for evaluation. The key design codes and standards, operating history, and the associated aging implications are discussed in Sections 3.5 and 3.6, respectively.

3.1 Selection Methodology

Identifying the battery chargers, inverters, and UPSs to be evaluated for life cycle management involved the review of industry documents, plant documents for typical BWRs and PWRs, and a survey of utility engineers. The review of industry documents included the following.

1. Review of 10 CFR 54, Definitions of Systems, Structures, and Components Important to License Renewal[3.1] and the draft Standard Review Plan for License Renewal.[3.2]
2. Review of BWR Lead Plant Project Technical Reports.[3.3]
3. Review of PWR Technical Demonstration Project (EPRI) Technical Findings.[3.4]
4. Review of 10 CFR 50.65 Maintenance Rule.[3.5]

These documents provide current industry thinking with respect to selecting the chargers, inverters, and UPSs that are important to a life cycle management program, and the aging and performance issues that need to be evaluated. The License Renewal Rule and Maintenance Rule use similar criteria for selecting systems, structures, and components that need to be addressed by the requirements of these rules. The License Renewal Rule focuses on the detection and mitigation of age-related degradation, while the Maintenance Rule focuses on maintaining performance. Equipment meeting the selection criteria of these two rules is also important to life cycle management. The methodology used to select the equipment evaluated in this guideline is provided in Section 2.5.

A survey/questionnaire was sent to 110 commercial nuclear power plant facilities in the United States; 24 plants provided plant-specific data. This data was used to determine whether the survey data was representative of the distribution of installed equipment (see Tables 1-1 and 1-2), and for comparison to summaries of maintenance and operation histories. Survey data compared favorably with the distribution of installed equipment and the historical data. No previously unknown degradation mechanism was identified.

3.2 Evaluation Scope

The selection methodology described in Section 3.1 was applied to the components to be evaluated.

3.2.1 Battery Chargers

Battery chargers used in nuclear power plants convert alternating current (AC) to direct current (DC), to provide power to DC-driven equipment and components, as well as to charge and float station and lighting pack batteries. Depending upon the specific plant configuration, battery chargers can be found in the following systems.

1. DC Power Supply System
2. Switchyard DC Control Power System
3. Instrument AC Power System
4. Emergency Lighting System
5. Auxiliary systems such as the Fire Protection System, Security System, and the Plant Communications System, where remote locations or administrative requirements for independent power systems may dictate design.

Based on Reference 3.1 and 3.2 criteria, the battery chargers included in this evaluation are:

1. Essential (Class 1E) chargers for the 250V, 125V, and 48/24V wet-cell batteries used in DC power distribution systems.
2. Chargers for emergency lighting packs.
3. Chargers that support fire protection, anticipated transients without scram, station blackout requirements, or other requirements credited in the plant current licensing basis.
4. Non-1E chargers serving relay/control systems in the switchyard.
5. Non-1E chargers serving equipment which is subject to operability requirements in the plant technical specification limiting conditions for operation.

Chargers are normally continuously in service, except for designs which allow a standby charger to be available.

3.2.2 Inverters and Uninterruptible Power Supplies

Inverters and UPSs in nuclear plants are used to supply a highly reliable and voltage-regulated source of AC power to safety-related equipment and equipment important to plant operation. Inverters convert a DC source to regulated AC power. Inverters connected to DC sources work in conjunction with alternate AC sources and a fast acting, automatic transfer switch to form an "uninterruptible power supply." The UPS ensures redundancy and stability to instrumentation and control loads which monitor, regulate, and protect critical plant functions.

Depending upon the specific plant configuration, inverters and UPSs can be found in the following systems.

1. Instrument AC Power System
2. Switchyard DC Control Power System
3. Auxiliary systems such as the Fire Protection System, the Plant Communication System, various computer systems, and the Plant Security System

Based on Reference 3.1 and 3.2 criteria, the inverters/UPSs included in this evaluation are:

1. Essential (Class 1E) inverters for the 120VAC instrument power.
2. Inverters/UPSs that support fire protection, anticipated transients without scram, and station blackout requirements.
3. Non-1E inverters/UPSs serving relay/control systems in the switchyard.
4. Non-1E UPSs serving equipment which is subject to operability requirements in the plant technical specification limiting conditions for operation.
5. Non-1E UPSs credited in the current licensing basis for computer and information systems.

3.2.3 Subcomponents

Battery chargers, inverters, and UPSs consist of a number of subcomponents. These subcomponents and their basic functions are listed in Table 3-1. The particular subcomponents included in each of these devices varies between types. Section 3.4 describes the differences between the different designs.

Some of the subcomponents listed in Table 3-1 are not required for successful component operation. Table 3-1 identifies those components whose failure would not cause a direct failure of the battery charger, inverter, or UPS.[3.6]

It is regarded as standard maintenance practice to replace or refurbish various components or component parts during normal maintenance activities. These components and parts are designated as "renewable" for the purpose of evaluation. Plant programs are stipulated to be inherently effective to manage "renewables."

The criteria that must be met by the renewable components are:

- The component is a low cost item (cost of repair/refurbishment is less than cost of replacement).
- A large number of functionally identical components is in service in the plant.
- An adequate inventory of replacement components exists.
- The component can be replaced in a time frame that would not require a plant shutdown.
- The renewable components are widely used in other industrial applications.

- The renewable component is typically not refurbished, but replaced on a periodic (prior to failure) basis or corrective basis (if failure of the component does not prevent the system from performing its required function).

Table 3-1 identifies the renewable subcomponents for battery chargers, inverters, and UPSs. Evaluations and additional actions to detect and mitigate age-related degradation are not required.

The remaining charger, inverter, and UPS subcomponents included in this evaluation are identified in Table 3-1.

Table 3-1. Battery Charger, Inverter, and UPS Subcomponents

Subcomponent	Function	Required for Successful Operation	Renewable	Further Evaluation Required
Transformers	Provide instrumentation and control power for the switches, relays, and electronic components inside the device as well as providing the proper voltage to the rectifier in chargers, or regulating the output voltage of ferro-resonant inverters, and isolation of the AC and DC circuits	Yes	No	Yes
Inductors	Provide filtering and alteration of the current/voltage phase relationship necessary for proper operation of the electronic components	Yes	No	Yes
Relays	Provide time delays, under-voltage and over-voltage protection, and remote operation of various components	Yes	No	Yes
Capacitors	Provide filtering and alteration of the current/voltage phase relationship necessary for proper operation of the electronic components	Yes	No	Yes
Silicon Controlled Rectifiers	Provide rectification and regulation of DC power output in chargers and provide inversion and regulation of AC power output in inverters	Yes	No	Yes
Diodes	Provide rectification and regulation of DC power output in chargers and provide inversion and regulation of AC power output in inverters	Yes	No	Yes
Surge Suppressors	Provide AC or DC input voltage transient protection	Yes	No	Yes
Printed Circuit Boards	Provide control logic and instrumentation functions	Yes	No	Yes

Table 3-1. Battery Charger, Inverter, and UPS Subcomponents (continued)

Subcomponent	Function	Required for Successful Operation	Renewable	Further Evaluation Required
Resistors	Provide filtering and alteration of the current/voltage phase relationship necessary for proper operation of the electronic components	Yes	No	Yes
Transistors	Provide amplification and switching of digital signals in control logic	Yes	No	Yes
Molded Case Circuit Breakers	Provide for control and distribution of power and protect the internal components	Yes	No	Yes
Switches	Provide for control and operation of relays	Yes	No	Yes
Float/Equalize Switch	Provides for transfer between charger float and equalization modes	Yes	No	Yes
Transfer Switch	Provides for automatic transfer between normal and alternate source	Yes	No	Yes
Bypass Switch	Provides for manual transfer between normal and alternate source	No	No	No
Potentiometers	Provide for adjustment of charger equalization and float voltages	Yes	No	Yes
Wires and Cables	Provide interconnection of subcomponents	Yes	No	Yes
Cooling Fans and Motors	Provide for forced cooling of components	Yes	No	Yes
Cabinet	Provides support and enclosure for subcomponents	Yes	No	Yes
Timers	Provide for automatic timing of equalize charging with automatic return to float charging	No	No	No
Terminal Blocks	Provide locations for power connection	Yes	Yes	No
Fuses	Provide over-current protection for transformers, relays, and switches	Yes	Yes	No
Fuse Blocks	Provide support and electrical connections for fuses	Yes	Yes	No
Metering Circuits	Provides for monitoring of AC and DC currents, voltages, and frequencies	No	Yes	No
Alarms	Provide warning of abnormal operation	No	Yes	No

Table 3-1. Battery Charger, Inverter, and UPS Subcomponents (continued)

Subcomponent	Function	Required for Successful Operation	Renewable	Further Evaluation Required
Fan Filters	Remove particulates from cooling air	No	Yes	No
Seals and Gaskets	Provide tight seal between cabinet and cabinet door	No	Yes	No
Grease and Lubricants	Provide coatings for electrical connections and lubrication of cabinet door hinges	No	Yes	No
Coatings	Provide environmental protection for the cabinet	No	Yes	No
Studs, Bolts, Nuts, Washers	Secure subcomponents to the cabinet	Yes	Yes	No
Screens	Remove large particulates from cooling air	No	Yes	No
Light Bulbs	Provide indication of certain operating conditions	No	Yes	No

3.3 Component Boundaries

This section defines the boundaries of component evaluation for this guideline. Degradation or failure of interfacing components to the battery chargers, inverters, and UPSs are not evaluated in this guideline.

3.3.1 Battery Chargers

The battery charger is typically a discrete, bounded component. The battery charger's AC input and DC output terminals, and the cabinet shell, serve as the boundary, unless the bypass switch is separate from the cabinet, in which case, the bypass switch is included in the component boundary. Figure 3-1 pictorially illustrates a battery charger schematic and shows the boundary of evaluation. Figure 3-2 illustrates a typical battery charger.

3.3.2 Inverters and UPSs

The inverter/UPS is typically a discrete, bounded component. The inverter and UPS DC input and AC output terminals, and the cabinet shell, serve as the boundary, unless the bypass and/or transfer switches are separated from the cabinet, in which case they will also be included in the component boundary. Figure 3-3 shows an inverter/UPS schematic and its boundary of evaluation. Figure 3-4 illustrates a typical inverter.

Figure 3-1. Battery Charger Boundary of Evaluation.

Figure 3-2. Typical SCR Type Battery Charger.[3.7]

Figure 3-3. Inverter/UPS Boundary of Evaluation.

Figure 3-4. Typical Ferroresonant Inverter.[3.8]

3.4 Description of Components Evaluated

This section describes the chargers, inverters, and UPSs component types and manufacturers' differences which relate to life cycle management practices.

3.4.1 Predominant Types of Equipment

3.4.1.1 Battery Chargers

Three types of battery charger design are used at nuclear facilities:

- Silicon Controlled Rectifier (SCR) Solid State
- Controlled Ferroresonant
- Magnetic Amplifier

The SCR type is the most widely used charger in nuclear applications, making up approximately 75% of the charger population. A typical SCR type battery charger is shown in Figure 3-2. The controlled ferroresonant and magnetic amplifier chargers make up the remaining uses, and are nearly equal in population. Figure 3-5 shows a typical ferroresonant charger. Table 3-2 lists predominant characteristics for each type of charger.

In addition to the large chargers used in DC power systems, this document also addresses battery chargers used in self-contained emergency lighting units. These chargers are typically much smaller and simpler in design.

The following subsections discuss the three types of chargers, their principles of operation, typical design configurations for each charger type, and the design of a charger in a typical emergency lighting unit.[3.6, 3.9] Specific manufacturer design differences are discussed in Section 3.4.2.1.

Silicon Controlled Rectifier Type Charger

As illustrated in Figure 3-6, the SCR type charger includes an input circuit breaker, a transformer, an SCR rectifier, a control/firing module, an output filter, and an output circuit breaker. Power is typically provided from a 480 VAC source to a thermal magnetic molded case input circuit breaker. The transformer reduces power from 480 VAC to 120 VAC. The full wave rectifier consists of two diodes and two SCRs (thyristors) that maintain a constant average voltage DC output. The control/firing module controls the conduction time of the SCRs which changes the output voltage amplitude. The rectifier output voltage is then filtered to eliminate harmonics and ripple.

The control circuits consist of several printed circuit boards, controlling the SCR firing by output voltage and current sensing. The input circuit breaker protects the charger from overloads and short circuits, and is used for isolation when maintenance is performed on the charger. Capacitors, resistors, and fuses are used to protect the rectifier from voltage distortion or overload currents. A DC circuit breaker on the output protects the charger against external faults, and allows the battery to be connected to the charger without causing arcing.

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Figure 3-5. Typical Ferroresonant Type Battery Charger.[3.10]

Figure 3-6. SCR Solid State Type Charger.

Table 3-2. Comparison of Battery Charger Characteristics

Characteristic	SCR Solid State	Controlled Ferroresonant	Magnetic Amplifier
Simple Logic		X	
Simple Output Filter	X	X	X
High Efficiency		X	
Regulating Range		X	X
Transient Response Time	X		
IEEE 650-1979 Qualified	X		
Low Cost			X
Ruggedness			X
Low Noise Generation		X	X
Low Susceptibility to Transient		X	X
Current Limiting	X	X	X
Load Carrying Capability (Range)	X		
Voltage Regulation	X	X	X
Short Circuit Protection	X	X	X
Meets NEMA PE-5-1985 (R1991)	X		
High Power Factor		X	

Controlled Ferroresonant Type Charger

This charger type uses a ferroresonant constant voltage transformer (CVT) to provide voltage regulation and transient suppression of the rectifier input power. The CVT is a current limiting device as well as a voltage regulating circuit at constant frequency. The conventional CVT is modified in modern chargers to improve the input frequency sensitivity of the conventional design. A solid state control circuit, consisting of amplifiers, diodes, and a saturable reactor or capacitor, monitors and regulates the DC output voltage by providing an input back to the transformer secondary.

The block diagram in Figure 3-7 depicts the use of the transformer in a charger application. A secondary winding of the CVT supplies the AC power to a diode rectifier for DC conversion. The DC output is filtered prior to supplying DC loads.

Developed recently, the controlled ferroresonant type charger offers a higher efficiency and tighter voltage regulation than the SCR types.

Figure 3-7. Ferroresonant Type Charger.

Magnetic Amplifier Type Charger

This charger has five basic components: transformer, magnetic amplifier, rectifier, output filter, and a transistorized control circuit. In this charger type, the voltage regulation function is performed by a magnetic amplifier connected in parallel with the transformer and rectifier. Figure 3-8 illustrates the use of a magnetic amplifier in a charger application.

The magnetic amplifier is a device using saturable reactors. These are adjustable inductors in which current/voltage are adjusted by controlling the inductor core properties.

The transformer converts the input voltage to the level required by the rectifier. The rectifier is made up of silicon diodes in a full wave configuration. A filter circuit removes harmonics and ripples from the outgoing DC power.

A transistorized control circuit monitors the output from the filter and controls the saturation condition of the magnetic amplifier. This regulates the power output of the transformer, because it changes impedance as it moves in and out of saturation, as a result of the transistor shunting operation.

Although the magnetic amplifier is considered more rugged and reliable, it is only used at some older nuclear stations.

Emergency Lighting Unit Charger

Emergency lighting units typically consist of a six-volt rechargeable wet cell battery with an integral charger, automatic switching, and attached lamp heads. A voltmeter and indicating lights are usually provided to monitor battery voltage and charger status (i.e., power supply "on", high charge, trickle charge). A test switch is also typically provided. This charger is much smaller and less complex than the system chargers discussed above, and typically consists of an input circuit breaker, a transformer, and a solid state rectifier device. Many utilities classify these charger and associated lighting packs as a "renewable" device.

Figure 3-8. Magnetic Amplifier Type Battery Charger.

3.4.1.2 Inverters

Inverter designs must convert DC power to AC power at the desired frequency stability and voltage, with minimal distortion, in order to ensure satisfactory performance of the critical instrumentation and control loads being served. A typical inverter is shown in Figure 3-4. There are four basic inverter designs which comprise the bulk of units currently in service. These four basic designs are described below.[3.6, 3.9]

Ferroresonant Type Inverter

Employed in nearly 50% of the nuclear plants, these inverters are generally in the small to medium size range, with 7.5 kVA the most common. The circuit, illustrated in Figure 3-9, consists of a DC input filter, to protect the system from transients, a power conversion circuit or SCR bridge, which provides the AC power output, an oscillator that includes the control logic for firing the SCRs and maintains the desired frequency, and a ferroresonant CVT used for AC filtering. The CVT is a current limiting device in that it will provide no more output current than its capacity. At constant frequency, it is also a voltage regulating circuit.

This type of inverter is very simple, and it has inherent current limiting and voltage regulation because of the use of the CVT. Its main disadvantages are its inability to operate for extended durations under light load conditions because of overheating, and its slow transient response to load changes because of the dependence of its operation on magnetic action.

Quasi-Square Wave Inverter

Figure 3-10 shows the simplified diagram of a quasi-square wave inverter unit. The functions of the DC filter, bridge rectifier, and oscillator are the same as in the ferroresonant type inverter. The square waves produced at the SCR bridge are transformed to the desired voltage level, and then added in series to produce a quasi-square wave. This wave is then fed to an AC filter, comparatively large, composed of discrete inductors and capacitors to reduce the undesirable harmonics. Voltage regulation and current limiting are accomplished by controlling the phase difference between the two square waves. The oscillator circuit electronically controls this regulation.

Figure 3-9. Ferroresonant Transformer Inverter.

Figure 3-10. Quasi-Square Wave Inverter.

This type of inverter can provide voltage regulation with varying DC input and varying inverter frequency. The output voltage can easily be adjusted in the field to compensate for distribution load changes. These modern inverters can also withstand short term overload capability.

Pulse Width Modulation (PWM) Inverter

Figure 3-11 shows a simplified circuit of a pulse width modulated inverter. It uses two SCR bridges instead of one. The output waves are generated at higher frequencies than the desired output frequency. Operation at these higher frequencies restricts the harmonics generated to multiples of these high frequencies, thereby allowing the filter size to be reduced and improving the transient performance. The current and voltage are controlled by feedback through the firing of the SCRs.

The major disadvantage of this type of inverter is the complexity of the logic circuitry required, but it offers important advantages which make it widely used at many of the newer nuclear plants. Its advantages include smaller output filters, fast transient response, tolerance to large load unbalances, and suitability for large designs due to the filter design advantage.

Step Wave Inverter

The step wave inverter was developed to maintain the advantages of the quasi-square wave inverter while reducing the AC filter size. It employs a series of SCR bridges to eliminate the low harmonics, producing a step waveform. This highly complex circuit is mainly employed for large inverter units. A typical twelve-step wave inverter has a low maximum total harmonic distortion (prior to AC filtering). Therefore, the AC output filter can be made smaller and improved transient performance obtained. Figure 3-12 shows a simplified circuit of a step wave inverter.

Figure 3-11. Pulse-Width Modulated Inverter.

Figure 3-12. Step Wave Inverter.

3.4.1.3 Uninterruptible Power Supplies

An uninterruptible power supply employs an inverter with an automatic transfer switch to transfer the inverter output load from the normal source of power to an alternate source, when the normal source voltage fails or is substantially reduced. The transfer switches employed at nuclear plants vary in design and features. The two basic designs are briefly described below.

Static Transfer Switch

The static switch is a solid state design. Its power circuit (Figure 3-13) consists of two pairs of SCRs each connected in inverse parallel. One pair is connected between the preferred source (inverter) and the AC load, and the other pair is connected between the alternate source and the AC load. A control logic equipped with sensors monitors overvoltage, undervoltage, loss of voltage, and overcurrent of the normal source. Deviation outside the preset limits will cause the static switch to transfer to the alternate source, by turning on the alternate source SCRs and turning off the preferred source SCRs. Upon restoration of the inverter voltage, for a continuous period of several seconds, it initiates the retransfer to the inverter without load interruption.

Static switches are inherently dependable, with no periodic exercising requirements to maintain high speed operation and no contacts to clean. They are used with modern high performance electronic equipment which cannot tolerate power interruption.

Figure 3-13. Static Switch Functional Schematic.

Electromechanical Transfer Switch

The electromechanical type transfer switch, while slower than the solid state switch, is capable of handling all types and classes of loads. They are frequently used when a motor-generator set is the backup power source.

The electromechanical switch consists of an electrically operated, mechanically held, double throw switch, ensuring that the load will be connected to just one of the sources. The contacts of the transfer switch are designed to withstand the inrush currents of motors as well as all continuous duty requirements. A typical electromechanical transfer switch design uses a single solenoid operator, with a total transfer time of 1/6 of a second. The sensing circuitry is similar to that for a solid state switch. Sensing is housed in a control module assembly, and consists of voltage and frequency devices as well as alarm relays. The control module also includes an in-phase monitor for assuring transfer while both sources are in synchronism, eliminating the problems of transferring motor loads.

3.4.2 Manufacturer's Design Differences

This subsection reviews differences in manufacturers' designs, as they relate to historical performance data, aging mechanisms or effective plant programs.

Based upon a review of design and vendor data, the differences between battery charger, inverter, and UPS manufacturers lie in electrical/electronic design and parts used, rather than physical construction, layout, manufacturing techniques/materials, or environmental conditions. The aging mechanisms discussed in Section 4 are influenced only by the electrical/electronic design characteristics. Therefore, plant personnel may apply the aging management conclusions of Section 5 based upon the charger, inverter, or UPS design, regardless of the specific manufacturer.

3.4.2.1 Battery Chargers

Table 3-3 lists the percentage of chargers in use for each charger manufacturer, as best determined from utility questionnaire responses and from Nuclear Plant Reliability Data System information. Six of these manufacturers were chosen for further evaluation. They are: C&D, Cyberex, Exide, GNB, LaMarche, and Power Conversion Products. These manufacturers were chosen due to percentage in use, charger type, and availability of retrievable data.

The following sections discuss design differences of the manufacturer within each type. Table 3-4 summarizes relevant manufacturer design differences for the different charger types.

Table 3-3. Battery Charger Manufacturers

Manufacturer	% in Use		Charger Type	Plant Type
	Survey	NPRDS		
C&D	8.7	20.5	SCR, Ferroresonant	BWR, PWR
Custom Power	3.5		SCR	PWR
Cyberex	3.5	2.8	SCR	BWR, PWR
ELGAR		<1		PWR
ELTRA		5.2	SCR	BWR, PWR
Exide	1.7	24.5	SCR	BWR, PWR
Fansteel	<1	<1		BWR
GNB	7	4.0	SCR	BWR
General Electric		<1	SCR	BWR
HDR	<1			PWR
Lamarche	11.8	2.4	Magnetic Amplifier	BWR, PWR
Lester	<1			BWR
Master Control	3		SCR	BWR, PWR
Nife	1.3			BWR, PWR
Power Conversion	54	33.3	SCR, Ferroresonant, Magnetic Amplifier	BWR, PWR
Reliance	<1			BWR
Solid State	1.7	3.1	Ferroresonant	BWR, PWR
Stewart Stevenson	<1			BWR
Westinghouse	3	1.8		PWR

AGING MANAGEMENT GUIDELINE FOR BATTERY CHARGERS, INVERTERS, AND UPSs

Table 3-4. Comparison of Battery Chargers by Type and Manufacturer

Manufacturer	AC Circuit Breaker	AC Input Fuses	DC Circuit Breaker	DC Output Fuses	Walk-in Circuit	AC Overload Relay	Surge Protection	Anode Fuses in Rectifiers	AC Power Failure Relay	Transformer	Auxiliary Transformer	Rectifier	Current Limiting	Voltage Regulation	AC Voltage Variations	AC Frequency Variations	DC Output Variations	Environment
SCR Type																		
Cyberex					Yes	No			No	Transforms AC Input Isolates Input/Output		SCR & Diodes Full-Wave Rectifier	SCR Firing Control (Circuit Board)	SCR Firing Control (Circuit Board)	±10%	±5%	±1%	0°C to 40°C [32°F to 104°F]
GNB	No	Yes	No	Yes	No	No	No		No	Transforms AC Input Isolates Input/Output		SCR & Diodes Full-Wave Rectifier	SCR Firing Control (Circuit Board)	SCR Firing Control (Circuit Board)	±10%	±5%	±0.5%	0°C to 50°C [32°F to 122°F] Convection Cooled
Power Conversion	Yes		Yes		No	No	Yes Selenium or Metal Oxide Varistor		No	Transforms AC Input Isolates Input/Output Fused Secondary		SCR & Diodes Full-Wave Rectifier	SCR Firing Control (Circuit Board)	SCR Firing Control (Circuit Board)	±10%	±5%	±0.5%	50°C Max [122°F Max] Natural Convection
Exide	Yes	No	Yes	No	No	Yes	Yes	No	Yes	Transforms AC Input Isolates Input/Output	Control-Voltage Transformers Provide Power to the Firing Control	SCR & Diodes Full-Wave Rectifier	SCR Firing Control (Circuit Board)	SCR Firing Control (Circuit Board)	±10%	±5%	±0.5%	
C & D	Yes		Yes		No	No	Yes (RC Circuit)	Yes	Yes (Alarm Relay)	3 Transformers that Change AC Voltage Level	Provide Power to the Control Circuits (3)	SCR & Diodes Full-Wave Rectifier	SCR Firing Control (Circuit Board)	SCR Firing Control (Circuit Board)	±10%	±5%	±0.5%	-20°C to 50°C [-4°F to 122°F] Natural Ventilation

AGING MANAGEMENT GUIDELINE FOR BATTERY CHARGERS, INVERTERS, AND UPSs

Table 3-4. Comparison of Battery Chargers by Type and Manufacturer (continued)

Manufacturer	AC Circuit Breaker	AC Input Fuses	DC Circuit Breaker	DC Output Fuses	Walk-in Circuit	AC Overload Relay	Surge Protection	Anode Fuses in Rectifiers	AC Power Failure Relay	Transformer	Auxiliary Transformer	Rectifier	Current Limiting	Voltage Regulation	AC Voltage Variations	AC Frequency Variations	DC Output Variations	Environment
Ferroresonant Type																		
C & D	Yes		Yes		No	No			Yes	Constant Voltage Transformer			Shunt of the Resonant Circuit with Switching & an Inductor	Single Control, Board Resonant Capacitor, SCR	+6% -12%	±5%	±0.5 %	0°C to 50°C [32°F to 122°F]
Power Conversion	Yes		Yes		Yes	No			AC Power Failure Alarm	Constant Voltage Transformer		SCR	Shunt of the Resonant Circuit with Switching & an Inductor	Single Control, Board Resonant Capacitor, SCR	±10%	±5%	±0.5 %	0°C to 50°C [32°F to 122°F] Natural Convection
Magnetic Amplifier Type																		
LaMarche	Optional	Yes	Optional	Yes	No	No	Yes	No	Yes	Transforms AC Input. Isolates Input/Output	No	SCR in Full-Wave Config.	Saturating Current Resistor	Zener Diode, Transistor and Saturable Reactor	±10%		±1%	40°C Max. [104°F Max.] Convection Cooled

3.4.2.1.1 Silicon Controlled Rectifier Type Charger

Five of the manufacturers (LaMarche is the exception) make an SCR type charger. Figure 3-6 depicts a typical SCR type charger block diagram that is used by all five manufacturers. The following paragraphs discuss specific design differences and features for each manufacturer.

C&D

The C&D SCR type charger uses a control/firing module that consists of three separate circuits: a phase controlling circuit, a voltage sensing circuit, and a current sensing circuit. This charger is protected by an AC input circuit breaker, a DC output circuit breaker, and a surge suppressor connected across the rectifier unit.

C&D also offers auxiliary transformers and anode fuses on rectifier units.

Cyberex

The Cyberex SCR type charger uses a "walk-in" circuit (Figure 3-14) to decrease the surge currents that occur when the circuit is first turned on due to uncharged output filter capacitors. This charger is protected by an AC input static switch that consist of two pairs of SCRs.

Figure 3-14. Block Diagram for Cyberex SCR Type Battery Charger.

Exide

The control/firing module for the Exide SCR type charger consists of a voltage sensing circuit, a current sensing circuit, and a control circuit. This charger is protected by an AC input circuit breaker or contactors with overload relays, and a DC output circuit breaker.

GNB

The GNB SCR type charger incorporates fused AC input and DC output, but offers an optional DC output breaker, surge suppressors, and alarms.

Power Conversion Products

The Power Conversion Products SCR type charger has a control/firing module that consists of a firing circuit and a sensing/current limit circuit. This charger is protected by surge suppressors, AC input and DC output circuit breakers, and the secondary winding of the transformer is fused. Power Conversion Products also offers alarm relays, fungus proofing, and ground detection.

3.4.2.1.2 Ferroresonant Type Charger

Only two manufacturers (C&D and Power Conversion Products) make ferroresonant type chargers. Figure 3-7 depicts a typical ferroresonant type charger block diagram that will be used as a standard for comparison.

C&D

The C&D ferroresonant type charger uses a control circuit (Figure 3-15) to sense the start of the resonant capacitor charge cycle, and switches the thyristor on to interrupt the cycle. The point of interruption is delayed by an output feedback signal to allow the voltage to rise to a preset level. If the current exceeds a preset level, the signal from the shunt overrides the voltage regulator to limit current. Thus, precise control of voltage and current is maintained. This charger is protected by AC input and DC output circuit breakers, along with surge suppressors and alarms.

Power Conversion Products

The Power Conversion Products ferroresonant type charger uses a triac assembly and a resonant tank circuit (Figure 3-16) to control the output of the power secondary, thus regulating the output voltage of the unit. This charger is protected by AC input and DC output circuit breakers, and offers optional surge suppressors, alarm relays, and fungus proofing.

Figure 3-15. C & D Ferroresonant Battery Charger.

Figure 3-16. Power Conversion Ferroresonant Type Charger Block Diagram.

3.4.2.1.3 Magnetic Amplifier Type Charger

Two manufacturers, LaMarche and Power Conversion Products, have supplied magnetic amplifier type chargers to nuclear power plants. Figure 3-8 depicts a typical magnetic amplifier type charger block diagram. The LaMarche magnetic amplifier type charger uses silicon diodes for rectification. The LaMarche charger is protected by fused AC input and fused DC output. Optional AC input and DC output circuit breakers, surge suppressors, relays, and dual fusing are available from LaMarche.

Power Conversion Products no longer produces magnetic amplifier chargers and no information on previously manufactured models was available.

3.4.2.1.4 Teledyne Big Beam Emergency Lighting Unit Charger

The Teledyne Big Beam emergency lighting unit charger is a solid-state type charger. It consists of an eight-amp high rate charge, equalizing charge rate and the trickle charge for maintaining the battery electro-chemical balance. This charger is fully automatic and maintains the battery at full capacity. It will restore the battery to full capacity in less than 12 hours from 87-1/2% of nominal battery voltage. The battery is a six-volt, lead acid or nickel cadmium battery. The input rating is 120 VAC, 60 Hz, and 120 watts (1 amp). A silicon solid state switch module connects the emergency lamp load to the battery upon failure of the normal AC power supply, and disconnects the lamp load when normal power is restored. A constant reading voltmeter is provided on the front of the unit as is a test switch to simulate a power failure. Lights to indicate power supply "on", high charge, and trickle charge are also provided.

3.4.2.2 Inverters and Uninterruptible Power Supplies

The main circuitries of each type of inverter/UPS are similar, but the design changes depending on the manufacturer. Table 3-5 lists the percentage of inverters/UPSs in use for each manufacturer, as best determined from utility questionnaire responses and from the NPRDS database information. Five manufacturers were chosen for further evaluation based on percentage in use, inverter type, and availability of retrievable data. They are: Elgar, Topaz, Cyberex, Solid State Controls, and Exide. Even though Westinghouse inverters and UPSs were a significant percentage over the total in use, this manufacturer has not been included due to unavailability of further information, coupled with the fact that based on the questionnaire responses, many of these Westinghouse inverters/UPSs are scheduled to be replaced.

Based upon a review of design and vendor data, the differences between manufacturers of battery chargers, inverters, and UPSs lie in electrical/electronic design and parts used, rather than physical construction, layout, manufacturing techniques/materials, or environmental conditions. The aging mechanisms discussed in Section 4 are influenced only by the components' electrical/electronic design characteristics.

Therefore, plant personnel may apply the aging management conclusions of Section 5 based upon the charger, inverter, or UPS design, regardless of the specific component manufacturer.

Table 3-5. Inverter and UPS Manufacturers

Manufacturer	% in Use		Inverter Type	Plant Type
	Survey	NPRDS		
AVTEC		2.5		PWR
Cyberex	8.8	14.6	PWM	BWR, PWR
ELGAR	31.8	15.4	Ferroresonant, PWM	BWR, PWR
Exide		18.7	PWM	BWR, PWR
Garret		<1		PWR
General Electric		<1		BWR
GNB		<1		PWR, BWR
Gould	1.1		Ferroresonant	PWR
HDR		<1		BWR
IPMC		<1		PWR
LaMarche	1.1		Ferroresonant	PWR
Liebert/Emerson		<1		BWR
Power Conversion		<1	Ferroresonant	BWR
SOLA		<1		BWR
Solid State	17.6	22.8	Ferroresonant	BWR, PWR
Static Controls	3.3	5.0		PWR, BWR
Topaz	4.4	4.2	PWM	BWR
Westinghouse	31.8	13.4	Ferroresonant	BWR, PWR

The following sections discuss design differences of the manufacturer within each type. Table 3-6 summarizes relevant manufacturer design differences for the various inverter/UPS types.

AGING MANAGEMENT GUIDELINE FOR BATTERY CHARGERS, INVERTERS, AND UPSs

Table 3-6. Comparison of Inverters/UPSs by Type and Manufacturer

Manufacturer	Input	Output	Circuit Breakers	Input Fuses	Start-Up Circuit	Transformers	Built-in Batteries	Static Transfer Switch	Maintenance Bypass Switch	Alternate Line Transient Protection	Voltage Regulation	Alarm Relay	Meters and Indicators	Environmental	Comments
Pulse Width Modulation Type															
Elgar	210 - 280 VDC	120 VAC Single Phase 60 Hz	Input CB Output CB	Yes		AC Output Transformer	No External Battery	SCRs Automatic Transfer	Contained in a Separate Housing	Circuit Breaker	±25% Sensing Circuit Boards		Volt. Amp. Freq. Meters Status & Failure Ind.	0°C to 50°C [32°F to 122°F] Five Built-in Fans	Precharge Circuit to Charge the DC Input Capacitor Bank Prior to Energizing the Inverters
Exide	Models Available go from 350 VA to 3000 kVA	Models Available go from 350 VA to 3000 kVA	Input CB Bypass CB		Yes	Input Isolation Transformer Optional	Yes	SCRs Included for Units of 50 kVA or More	Manual Bypass Switch		±2% Sensing Circuit Boards		Volt. Amp. and Freq. Meters	10°C to 40°C [50°F to 104°F] Forced Air Cooling	Output Protection with Fuses in the Inverter Circuitry
Topaz	120 VAC	120 VAC 60 Hz				AC Output Isolation Transformer	Yes	Optional SCRs	Contained in a Separate Housing		±3.5% Sensing Circuit Boards		Volt. and Amp. Meters	0°C to 50°C [32°F to 104°F]	
Cyberex	208 or 480 Volt 3 Phase	120/208 V 3 Phase 60 Hz or 120 V 1 Phase 60 Hz				Input & Output Transformer	Yes	SCRs Fully Rated with Automatic Transfer	Standard	Yes	±1.0% Sensing Circuit Boards		Volt. Amp. & Freq. Meters Failure Ind.	0°C to 40°C [32°F to 104°F] Built-in Fans	

AGING MANAGEMENT GUIDELINE FOR BATTERY CHARGERS, INVERTERS, AND UPSs

Table 3-6. Comparison of Inverters/UPSs by Type and Manufacturer (continued)

Manufacturer	Input	Output	Circuit Breakers	Input Fuses	Start-Up Circuit	Transformers	Built-in Batteries	Static Transfer Switch	Maintenance Bypass Switch	Alternate Line Transient Protection	Voltage Regulation	Alarm Relay	Meters and Indicators	Environmental	Comments
Ferroresonant Type															
LaMarche	24, 48, & 120 VDC	120 VAC 60 Hz	AC Circuit Breakers, DC Breakers Optional	Yes		CVT for DC Output	No	Optional			±2% CVT		Meters are Optional	0°C to 50°C [32°F to 122°F] Convection Cooled	Precharge Pushbutton Optional
Power Conversion Products	24, 48 VDC	600 VA to 1.8 kVA				CVT for DC Output		Yes			±5% CVT		Normal, Standby & Failure Ind.		
Solid State Controls	480V, 60 Hz 3 Phase	120 V 60 Hz	Input CB Output CB	Yes	SCR Shorting Printed Circuit Board	AC Input Transformer CVT for DC Output	Yes	SCRs	Manual Bypass Switch		±2% CVT	Yes, on Current & Voltage Sensing Boards	Volt. Amp & Freq. Meters. Status Ind.	10°C to 50°C [50°F to 122°F] Fan Cooled	Current and Voltage Sensing Boards for Alarm or Trip Purposes

3.4.2.2.1 Pulse Width Modulation (PWM) Type Inverter

Four of the five manufacturers evaluated (Elgar, Topaz, Exide, and Cyberex) make Pulse Width Modulation (PWM) type inverters. Figure 3-11 depicts a typical PWM type inverter block diagram that will be used as a standard for comparison.

Elgar UPSs

The uninterruptible power supply unit consists of an SCR inverter, an AC output transformer, an output filter, a static switch, and control logic. The inverter consists of three SCR bridges and associated commutation circuitry that converts DC power to multiple pulse AC power. An output filter then reduces the harmonics and supplies a fundamental sine wave voltage to the inverter output. A battery bank, which powers the inverter, is separately mounted.

Voltage regulation of the output sine wave is accomplished by varying the pulse width of each pulse of the "2 pulse" single-phase inverters. Inverter output frequency is held at a constant 60 Hz by a low-level precision oscillator, or it is varied to enable synchronization of the output voltage with some alternate AC power source.

The static switch is an electronic solid state assembly used to transfer the critical load without interruption from the inverter to the bypass line. It consists of two SCR pairs connected in a single pole, double-throw switch configuration. A manual bypass switch is utilized in the event of inverter malfunction or routine maintenance.

Topaz Inverters

Topaz Powermark inverters feature new PWM technology for computer and other electronic device applications. As the load current demand increases or decreases, the width of the pulses is modulated accordingly, so there is no need for large filters that impede current flow. These inverters respond to changes in load current very quickly.

Exide UPSs

Exide Electronics manufactures uninterruptible power supply systems for a range of power requirements from 350 VA to 3,000 kVA, for single-phase and three-phase applications. The technique used is called "Advanced Switching Technology," and it provides filtered, uninterrupted sine-wave power. The output total harmonic distortion does not exceed 5%. A metering package displays all UPS operating parameters, including input and output voltage and frequency, battery voltage, and DC link voltage. System alarms and power events are stored. The inverter is software-controlled. The output voltage, frequency, and phase angle can be programmed.

A sealed, maintenance-free battery is enclosed to supply back-up power in the event of AC power failure. Incoming AC power is converted to DC by a full wave rectifier. The DC power is then further processed by a high frequency resonant converter to supply power to the inverter. During normal operation, the battery is charged by circuitry within the resonant converter. The inverter converts the DC power at its input to regulated AC power utilizing pulse-width modulation techniques. Fully automatic operation of the UPS is provided through the use

of microprocessor controlled logic. For units with 50 kVA or more capacity, a static switch is included.

Cyberex UPSs

Cyberex static UPS DC and AC distribution panels are equipped with manual transfer switches at the input to select alternate sources to feed their respective loads.

The static inverter design is based on high frequency switching. The frequency reference and logic drive the high frequency switching power stage at a "carrier" frequency, and then modulate it at the desired output frequency. A voltage regulator and current limiter control the modulation. A very small filter is used for the output.

3.4.2.2.2 Ferroresonant Type Inverter

Information on ferroresonant type inverters was available for just one manufacturer, Solid State Controls Inc. Figure 3-9 illustrates a typical ferroresonant inverter circuit that will be used as a standard for discussion.

Solid State Controls UPSs

SCI Series SV static inverters are ferroresonant transformer-based devices. The UPS consists of a regulated rectifier, input and output filters, controls, power switching circuit (inverter), and static switch. A control board supplies pulses which gate on the SCRs at the proper time. There are two pairs of SCRs, turned on in pairs, by simultaneously applying signals to the gate terminals. The resulting waveform is regulated and filtered by a harmonic filter consisting of a CVT in the output block. An automatic static transfer switch detects loss of voltage resulting from power or transformer failure. A reed relay is used to steer gate signals to power the SCRs of the switch.

3.4.2.2.3 Quasi-Square Wave Type Inverter

In the information provided by the five manufacturers chosen, none of the five manufacturers appears to make this type of inverter.

3.4.2.2.4 Step Wave Type Inverter

In the information provided by the five manufacturers chosen, none of the five manufacturers appears to make this type of inverter.

3.5 Design Requirements and Applicable Codes and Regulations

The design, inspection, and testing requirements for electric power systems for nuclear power plants are given by General Design Criteria 17 and 18 in Appendix A to 10 CFR 50. The Standard Review Plan[3.2, 3.11] identifies guidelines which amplify these requirements. Regulatory Guide 1.32[3.12] pertains to the design, operation, and testing of safety-related electric power systems for nuclear power plants and endorses (with some exceptions) IEEE

Standard 308-1974. Regulatory Guide 1.118[3.13] pertains to periodic testing of the protection system and electric power systems for systems important to safety. It provides supplemental guidance to that contained in Regulatory Guide 1.32 regarding periodic testing of electric power systems and endorses (with some exceptions) IEEE Standard 338-1977.

Table 3-7 lists the IEEE standards and recommended practices that are relevant to aging, aging detection, and aging mitigation of battery chargers, inverters, and uninterruptible power supplies. With the exception of IEEE 944-1986 (Recommended Practice for the Application and Testing of Uninterruptible Power Supplies for Power Generating Stations), all of these standards and recommended practices apply only to Class 1E (safety-related) systems and equipment.

Table 3-7. IEEE Standards Relevant to Aging of Battery Chargers, Inverters, and Uninterruptible Power Supplies

Standard Number	Title	Components Covered	Requirements	Recommendations
308-1980	IEEE Standard Criteria for Class 1E Power Systems for Nuclear Power Generating Stations	Battery Chargers Inverters Uninterruptible Power Supplies	<ul style="list-style-type: none"> Periodic equipment tests to detect equipment deterioration and to demonstrate standby equipment operability Periodic system tests to demonstrate (among other things) that each battery charger has sufficient capacity to meet the largest steady state load while also charging the battery from minimum charge state to the fully charged state within the design basis time 	
323-1983	IEEE Standard for Qualifying Class 1E Equipment for Nuclear Power Generating Stations	Battery Chargers Inverters Uninterruptible Power Supplies	<ul style="list-style-type: none"> Qualification programs must address aging considerations Documentation of any scheduled surveillance/maintenance testing, or parts replacement required to maintain qualified life 	
338-1987	The Standard Criteria for the Periodic Surveillance Testing of Nuclear Power Generating Station Safety - Systems	Battery Chargers Inverters	<ul style="list-style-type: none"> Amplifies requirements of IEEE 603-1980 and IEEE 308-1980 Provides design criteria to allow for independent testing of redundant channels during plant operation as well as during shutdown. Provides criteria for functional tests, instrument channel checks, calibration verification, and response time tests. Provides criteria for determining initial test intervals and changes to test intervals. 	

Table 3-7. IEEE Standards Relevant to Aging of Battery Chargers, Inverters, and Uninterruptible Power Supplies (continued)

Standard Number	Title	Components Covered	Requirements	Recommendations
381-1977	IEEE Standard Criteria for Type Tests of Class 1E Modules Used in Nuclear Power Generating Stations	Printed Circuit Boards	<ul style="list-style-type: none"> Supplements and modifies some requirements of IEEE 323-1974 for type testing Class 1E modules Aging must be considered in the same manner as environmental parameters Modules should not be aged prior to testing if it is known or determined that aging will improve the equipment's performance capability. Certain modules may be exempt from advanced life conditioning prior to testing if the criteria outlined in Figure 2 of the standard are met 	
383-1974	IEEE Standard for Type Test of Class 1E Electrical Cables, Field Splices, and Connections for Nuclear Power Generating Stations	Cables, Internal Wiring, Terminal Blocks, and Connections	<ul style="list-style-type: none"> Supplements IEEE 323-1974 Referenced in IEEE 650-1990 Aging due to temperature, radiation, and atmospheric effects must be accounted for Arrhenius plotting is used to determine time and temperature conditions for aging of samples 	
572-1985	IEEE Standard for Qualification of Class 1E Connection Assemblies for Nuclear Power Generating Stations	Battery Chargers Inverters Uninterruptible Power Supplies	<ul style="list-style-type: none"> Provides specific direction for implementation of IEEE 323-1983 as it pertains to connection assemblies. Augments IEEE 383-1974. Provides specific procedures for qualification by type testing, operating experience, and analysis. Provides age-conditioning procedures for type test samples. Provides procedures for ongoing qualification. 	

Table 3-7. IEEE Standards Relevant to Aging of Battery Chargers, Inverters, and Uninterruptible Power Supplies (continued)

Standard Number	Title	Components Covered	Requirements	Recommendations
627-1980	IEEE Standard for Design Qualification of Safety Systems Equipment Used in Nuclear Power Generating Stations	Battery Chargers Inverters Uninterruptible Power Supplies	<ul style="list-style-type: none"> Provides basic principles for design qualification Analysis to determine significant aging mechanisms and development of suitable aging programs to address these significant mechanisms If natural aging is used in qualification program, determination of significant aging mechanisms may not be necessary If there are no significant aging mechanisms for a piece of equipment, then the qualified life is the design life Specific equipment qualification standards that are applicable shall be referenced and applied in whole or in part 	
650-1990	IEEE Standard for Qualification of Class 1E Static Battery Chargers and Inverters for Nuclear Power Generating Stations	Battery Chargers Inverters	<ul style="list-style-type: none"> Provides specific procedures to meet the requirements of IEEE 323-1983 Provides criteria to determine significance of aging mechanisms for specific subcomponents Provides a different sequence for type testing than IEEE 323-1983 Provides a list of subcomponents assumed to have significant aging mechanisms Must document, among other things, any scheduled surveillance/maintenance, periodic testing, and parts replacement required to maintain qualification Must document shelf life requirements 	

Table 3-7. IEEE Standards Relevant to Aging of Battery Chargers, Inverters, and Uninterruptible Power Supplies (continued)

Standard Number	Title	Components Covered	Requirements	Recommendations
944-1986	IEEE Recommended Practice for the Application and Testing of Uninterruptible Power Supplies for Power Generating Stations	Uninterruptible Power Supplies		<ul style="list-style-type: none"> Includes recommended instruments, alarms, and testing requirements
934-1987	IEEE Standard Requirements for Replacement Parts for Class 1E Equipment in Nuclear Power Generating Stations	Battery Chargers Inverters Uninterruptible Power Supplies	<ul style="list-style-type: none"> Provides basic requirements for selection and utilization of replacement parts for Class 1E equipment. Requires a failure review of parts that fail in service. Provides requirements for replacement parts. Provides requirements for control of part replacement procedures. 	
946-1985	IEEE Recommended Practice for the Design of Safety-Related DC Auxiliary Power Systems for Nuclear Power Generating Stations	Battery Chargers		<ul style="list-style-type: none"> Requires all chargers to be qualified in accordance with IEEE 650-1979 Recommends that all battery chargers meet the requirements of NEMA PE 5-1983 Recommends specific instrumentation and alarms
P-1205, Draft 8	IEEE Guide for Assessing, Monitoring, and Mitigating Aging Effects on Class 1E Equipment Used in Nuclear Power Generating Stations	Battery Chargers Inverters Uninterruptible Power Supplies		<ul style="list-style-type: none"> Draft - Use information at your own risk Aging effect tables list stressors, aging mechanisms, aging effects, and monitoring method for polymers, lubricants, and metals

Table 3-8 lists other industry standards that are used in the design, manufacture, and testing of battery chargers, inverters, and uninterruptible power supplies.

The following subsections discuss compliance with the Standard Review Plan, and the specific applicability of these codes, guidelines, standards, and recommended practices to battery charger, inverter, and uninterruptible power supply aging management.

Table 3-8. Other (Non-IEEE) Standards Related to Battery Chargers, Inverters, and Uninterruptible Power Supplies

Standard Number	Title	Components Covered
NEMA PE 1-1993	Uninterruptible Power Systems	Uninterruptible Power Supplies
NEMA PE 5-1985	Utility Type Battery Chargers	Battery Chargers

3.5.1 Compliance With Standard Review Plan

NUREG-0800[3.11] establishes the format and content requirements of the safety analysis reports prepared for nuclear plants during design and construction. NUREG-0800 does not require the licensee to specifically address the provisions for detection and mitigation of aging.

NUREG-1299[3.2] focuses on the license renewal requirements in 10 CFR 54. The format and content of the integrated plant assessment, to be prepared in support of license renewal application, is described. The primary purpose of the assessment is to determine the effectiveness of plant programs to detect and mitigate age-related degradation of SSCs.

NUREG-1299[3.2] is a draft document only. The NRC is expected to issue a new draft of the document for public comment in 1994. This document identifies each system which may be important to license renewal and is intended to be used by the NRC staff during performance of safety reviews of applications for renewal of nuclear power licenses. It provides the framework to ensure that (among other things) the application identifies SSCs that are important to license renewal, significant age-related degradation has been identified and evaluated, and programs to manage aging are or will be implemented. This Standard Review Plan (SRP) discusses aging for typical SSCs important to license renewal. Typical aging age-related degradation mechanisms that could affect the operation and safety of battery chargers, inverters, and uninterruptible power supplies are identified.

The SRP-LR sections were reviewed to ensure that this guideline considers the identified aging mechanisms and programs for management of component aging. Sections 4 and 5 of this guideline include the evaluations and conclusions of component aging and aging management. Where applicable, additional aging mechanisms and aging management programs identified in industry documents and lead plant license renewal studies are discussed.

3.5.2 General Standards

IEEE Standard 308-1980[3.14] requires periodic equipment tests to detect equipment deterioration toward an unacceptable condition, and to demonstrate operability of standby equipment that is not exercised during normal plant operation.

IEEE Standard 323-1983[3.15] provides the general requirements for qualifying Class 1E equipment for accident environments.

IEEE Standard 338-1987[3.16] provides criteria for periodic surveillance testing of safety systems. This standard requires systems to be designed to allow independent testing of redundant channels and load groups during plant operation or shutdown conditions. Testing program requirements are also provided which include criteria for functional tests, instrument channel checks, verification of proper calibration, and response time tests. Criteria for determining initial test intervals and changes to test intervals are also provided.

IEEE Standard 381-1977[3.17] provides specific requirements for type testing Class 1E printed circuit boards, and IEEE Standard 383-1974[3.18] provides type test requirements for Class 1E electrical cables, field splices, and connections.

IEEE Standard 572-1985[3.19] provides specific procedures for qualifying Class 1E connection assemblies. This standard also provides specific direction for implementation of IEEE Standard 323-1983 and augments IEEE Standard 383-1974.

IEEE Standard 627-1980[3.20] provides the basic principles for design qualification of safety systems equipment.

Safety-related (Class 1E) static battery chargers and inverters located in mild environments outside containment are qualified in accordance with IEEE Standard 650-1990[3.21]. This standard provides specific procedures to meet the requirements of IEEE Standard 323-1983. The qualification methods in IEEE 650-1990 employ a combination of type testing and analysis, since battery chargers and inverters are considered too complex to be qualified by analysis alone, and operating experience is also considered to be of limited use as a sole means of qualification. This standard requires battery charger and inverter components to be classified into one of two categories: those for which aging is not a significant failure mechanism and those for which aging is a significant failure mechanism. Criteria are provided to make this determination with extensive technical references provided in Appendices B and C to the standard. Prior to type testing, components with significant aging mechanisms should be aged using natural aging or accelerated aging. The standard provides recommended methods for accelerated aging of specific components. Components with significant aging mechanisms that can be addressed by periodic inservice surveillance/maintenance need not be aged prior to type testing. The standard requires the documentation of any scheduled surveillance/maintenance, periodic testing, and parts replacement required to maintain qualification as well as the documentation of any shelf life requirements. This standard references IEEE Standard 383-1974 to qualify the insulated wire, cable, terminal blocks, and connections used in Class 1E battery chargers.

IEEE Standard 934-1987[3.22] provides the basic requirements for selection and utilization of replacement parts for Class 1E equipment. A failure review for parts that fail in service is required, to determine the most likely cause of failure, and to determine if installation of an identical part is a viable option or if a different part should be specified. This standard also provides requirements for replacement parts supplied by either the original approved equipment supplier, or a supplier other than the original approved equipment supplier, or for repaired or specifically fabricated parts. Requirements for control of part replacement procedures are also included in this standard.

IEEE Standard P-1205, Draft 8[3.23] contains guidelines for assessing, monitoring, and mitigating aging effects on Class 1E equipment. Aging effects tables are provided which list stressors, aging mechanisms, aging effects, and monitoring methods for polymers, lubricants, and metals. This draft guide provides general guidance to address aging of a wide variety of Class 1E equipment.

Regulatory Guide 1.32 endorses IEEE Standard 308-1974 with some exceptions. The only exception that relates specifically to the components addressed in this guideline addresses battery chargers only. The exception states that Section 5.3.4 of IEEE 308-1974 should be interpreted to mean that the capacity of a battery charger should be based on the largest combined demands of the various steady state loads and the charging capacity to restore the battery from the design minimum charge state to the fully charged state, irrespective of the status of the plant during which these demands occur. Section 6.3.4 of the 1980 revision of IEEE Standard 308 clarifies this requirement.

Regulatory Guide 1.118 endorses, with some exceptions, IEEE Standard 338-1977.[3.24] IEEE 338-1977 provides design and operational criteria to develop tests and test procedures for testing safety systems. Aging detection is not specifically addressed, and preventive maintenance is explicitly excluded from the scope of this standard. Therefore, the applicability of Regulatory Guide 1.118 and IEEE 338-1977 to aging of battery chargers, inverters and UPSs is severely limited.

3.5.3 Battery Chargers

The current industry standard used in the design and manufacture of battery chargers is NEMA PE 5-1985,[3.25] which was published in 1986 and reaffirmed in 1991. This standard contains design requirements for environment, performance, construction, testing, and safety of constant-potential type electric utility (semiconductor static converter) battery chargers. Selected operational and environmental requirements are summarized in Table 3-9. This standard does not specifically address age-related concerns.

IEEE Standard 946-1985[3.26] provides recommended practices for the design of safety-related DC auxiliary power systems. It requires chargers to be qualified in accordance with IEEE 650-1979, and recommends that chargers meet the requirements of NEMA PE 5-1983. It also recommends specific instrumentation and alarms for safety-related DC auxiliary power systems.

Table 3-9. Selected NEMA PE 5-1985 Requirements for Battery Chargers

Parameter	Nominal Value	Minimum	Maximum
Input AC Voltage (V)	120	106	127
	208	184	220
	240	212	254
	277	245	293
	480	424	508
	575	508	600
Input AC Frequency (Hz)	50	47.5	52.5
	60	57.0	63.0
Output DC Voltage (V) (Note 1)	12	--	14.4
	24	--	28.8
	48	--	57.6
	120	--	144.0
	240	--	288.0
Operating Ambient Temperature (°C/°F)	--	0/32	50/122
Storage Temperature (°C/°F)	--	4/40	85/185
Altitude (Meters/Feet)	--	--	1000/3300
Humidity (%)	--	--	95%

Note 1: The output voltage of a battery charger depends upon the type of battery and number of cells being charged. The values shown are for a lead-acid battery with a nominal voltage of 2.0 volts per cell.

3.5.4 Inverters and Uninterruptible Power Supplies

The current industry standard for the design and manufacture of uninterruptible power systems is NEMA PE 1-1993.[3.27] IEEE Standard 944-1986[3.28] also provides recommended practices for application and testing of uninterruptible power supplies. It also recommends specific controls, instrumentation, and alarms.

3.6 Operating and Service History

A review of industry data and documents was conducted to determine the industry-wide operating experience with the components evaluated in this guideline. Operating history information was obtained from the host utility, responses to plant questionnaires, NPRDS, and LER searches, industry literature, and NRC IE notices, bulletins, circulars, and generic letters.

The NPRDS was developed in 1973, for collecting data on safety-related equipment. Since then, the data system scope has been expanded to include other systems and components that provide critical safety functions and whose loss of function can initiate a significant transient. Component failure records are to be submitted whenever an NPRDS-reportable component fails to perform one or more of its intended functions. Reporting of failures is a voluntary industry effort and, therefore, there are many variations in interpretation of reportability requirements and

contents and consistency of reports. For example potential failures that were prevented by testing and corrective action may not have been reported. If that is the case, mean-time-between-failure data calculated from reported failure data would not be accurate. Per INPO-89-014, United States nuclear utilities have demonstrated their support of NPRDS by dedicating resources to report all reportable failures that have occurred since January 1, 1984, or when the plant begins commercial operation. Prior to 1984, the LER was widely used for reporting failures.

LERs are submitted to the NRC by nuclear power plants for a number of reasons. Some of the reasons which are applicable to battery chargers, inverters, and uninterruptible power supplies evaluated in this guideline include:

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

The following sections describe the operating histories for battery chargers, inverters, and uninterruptible power supplies.

3.6.1 Battery Chargers

3.6.1.1 Host Utility Data

The host utility plant is a PWR that has six 125 VDC battery chargers in the 125/250 VDC power distribution system, three 125 VDC chargers in the switchyard DC system, four chargers in the fire protection system, one charger in the security system, and 280 chargers integral with 280 emergency lighting units.

Maintenance work orders and work requests from 1980 through 1991 were reviewed for the six chargers in the 125/250 VDC power distribution system. There were 49 work orders and requests for these 6 battery chargers that were related to equipment failure or abnormal operation.

The failed parts involved were circuit boards (44.9%), capacitors (18.4%), relays (16.3%), diodes (8.2%), SCRs (4.1%), resistors (4.1%), transformers (2.0%), and transfer switches (2.0%).

Figure 3-17 depicts the distribution of failed parts from the host utility charger data. In general, the work orders and requests did not identify failure causes.

Figure 3-17. Failed Parts for Host Utility Charger Data.

3.6.1.2 Questionnaire Responses

Questionnaire responses were obtained from 10 utilities covering 24 plants. Table 3-10 summarizes the questionnaire responses that pertain to battery charger system applications. Based on these responses, 23 of the plants (96%) have chargers in a plant 125 VDC system, 18 of the plants (75%) have chargers in a 250 VDC or a 250/125 VDC plant system, 12 plants (50%) have chargers in a 48 VDC or 24 VDC plant system, 15 plants (63%) use chargers in other plant systems, and 2 plants (8%) identified using chargers in emergency lighting packs. Fifteen plants (63%) have chargers in a separate 125 VDC switchyard system, and four plants (17%) have chargers in a 24 VDC or 48 VDC switchyard system. None of the plants indicated having chargers in a 250 VDC switchyard system.

The original chargers are still in use at 16 (67%) of the plants. The chargers at the remaining eight plants were replaced to meet increased capacity requirements, due to increased system loads and/or increased battery capacity. None of the questionnaire responses indicated that any chargers were replaced due to unacceptable performance or due to aging effects.

The questionnaire responses indicated that all of the chargers are located indoors. Twenty of the plants (83%) provide a temperature controlled environment for the chargers. The most closely controlled temperature range is 21°-24°C [70°-75°F], while the widest range is 18°-49°C [65°-120°F]. The lowest allowable temperature is 10°C [50°F], while the highest is 49°C [120°F]. All of these temperatures are within the allowable limits set forth in National Electrical Manufacturers Association (NEMA) Standard PE 5-1985.

The most commonly reported age-related failures, along with the percentage of plants that have experienced such failures, are fatigue-related failures (92%), followed by capacitor failures (88%), thermal aging (33%), electronic burns and cracks (33%), unusual electronic drift (29%), and corrosion (21%).

Table 3-10. Battery Charger Applications from Plant Questionnaires

System	Number of Plants	Total Number of Chargers	Range of Chargers Used in System	Average Number of Chargers Used in System	Median Number of Chargers Used in System
Plant 250/125 VDC	18	39	1 to 9	2.17	1
Plant 125 VDC	23	87	1 to 10	3.78	3
Plant 48/24 VDC	12	37	1 to 5	3.09	4
Plant Other	15	41	1 to 5	2.73	2
Emergency Lighting Panels	2	597	280 to 317	298.5	298.5
Switchyard 250 VDC	0	0	0 to 0	0	0
Switchyard 125 VDC	15	24	1 to 4	1.6	1
Switchyard Other	4	4	1 to 1	1.0	1

3.6.1.3 Nuclear Plant Reliability Data System

A search of the NPRDS yielded 888 reported battery charger failures for 386 chargers at 101 nuclear power plants. Failure causes were not always given, or were sometimes given in ambiguous terms such as "aging" or "end of life." Figure 3-18 depicts the distribution of causes for all reported charger failures. Causes were not given or could not be determined for a majority of the charger failures (41.8%). The largest identifiable failure cause was "aging" (23.7%), followed by setpoint/electrical drift (10.4%), and human error (5.4%). The remaining failure causes each contributed less than 5% to the total reported failures.

Those NPRDS charger failures that appeared to be age-related were identified. Age-related failures include causes such as "aging," setpoint drift, fouling, "end of life," thermal stress, vibration, and wear. There were 443 age-related failures identified for 250 chargers at 90 plants. These failures account for 49.8% of the 888 reported charger failures. Figure 3-19 depicts the distribution of the age-related failure causes. Slightly more than half of the age-related failures (52.1%) were attributed to the ambiguous causes of "aging" (47.6%) and "end of life" (4.5%). The largest definitive age-related failure cause was setpoint/electronic drift (20.7%), followed by fouling (8.1%), and thermal stress (6.3%). The remaining age-related failure causes each contribute less than 5% of the total age-related reported failures.

The NPRDS data was also analyzed to determine which subcomponent part failures contributed the most to charger failures. Figure 3-20 depicts the distribution of failed parts for all reported charger failures. Specific part failures were not identified for 4.8% of the charger failures. The specific parts identified that contribute the most to charger failures are circuit boards (35.8%), potentiometers (8.9%), fuses (7.4%), relays (6.7%), and capacitors (5.0%). All other part failures each contribute less than 5% to the total reported charger failures.

Figure 3-18. Failure Modes for All NPRDS Charger Failures.

Figure 3-19. Failure Modes for Age-Related NPRDS Charger Failures.

Figure 3-20. Failed Parts for All NPRDS Charger Failures.

Figure 3-21 depicts the distribution of failed parts for the 443 age-related charger failures. Specific part failures were not identified for 5.6% of the age-related charger failures. The specific parts identified that contribute the most to age-related charger failures are circuit boards (31.6%), potentiometers (13.1%), relays (7%), and resistors (5.1%). All other part failures each contribute less than 5% to the total identified age-related charger failures.

To further understand the susceptibility of chargers to age-related degradation, the NPRDS data was analyzed to determine the significant aging mechanisms for each subcomponent part. The distribution of causes for age-related failures of each subcomponent part were determined. The following paragraphs describe the results of this effort for the most significant failed parts.

The most significant aging mechanism identified for circuit boards was simply "aging" (60.9%), followed by setpoint drift (16.3%), "end of life" (5.6%), thermal stress (4.9%), fouling (3.5%), and fatigue (3.5%). All other aging mechanisms each contribute less than 2% to age-related circuit board failures.

The aging mechanisms identified for potentiometers are setpoint drift (41.3%), aging (27.6%), fouling (20.6%), corrosion (3.4%), and end of life (3.4%).

The aging mechanisms identified for relays were aging (32.2%), setpoint drift (22.6%), fouling (22.6%), corrosion (5.4%), thermal stress (6.4%), stress (3.2%), fatigue (3.2%), and "end of life" (3.2%).

Figure 3-21. Failed Parts for Age-Related NPRDS Charger Failures.

Although NPRDS reporting is a voluntary industry effort, U.S. nuclear utilities have demonstrated their support by dedicating resources to report all reportable failures that have occurred since January 1, 1984, or after the date of commercial operation, whichever date is latest. However, the reporting of component failure data involves the reporter's interpretation of reporting guidelines, component reportability, and available information about failures. This interpretation may affect the completeness and quality of NPRDS data.[3.29]

Despite these drawbacks, the NPRDS is still the most comprehensive failure data base available to the nuclear industry. If it is recognized that any failure rate data extracted from the NPRDS database will be a bounding value, then it can prove quite useful to determine the mean time between failures, and hence a failure rate, for battery chargers.

Figures 3-22 and 3-23 show the total and age-related number of NPRDS-reported battery charger failures per plant per year, respectively. The trend in both figures shows a significant increase in 1983-88. This increase in failures is consistent with the higher priority that reporting was given by utilities, and the greater emphasis the data system was given in the industry. Since 1989, the total and age-related number of failures reported has decreased. This may be due to an increased emphasis on preventive maintenance practices, improved monitoring methods, or improvements in manufacturer quality and design.

Figure 3-22. All NPRDS Charger Failures by Year.

Figure 3-23. Age-Related NPRDS Charger Failures by Year.

Figures 3-24 and 3-25 show the total and age-related number of reported NPRDS charger failures plotted by equipment service time for the last 20 years (i.e., 1972 to 1992). The plot has been normalized to show failures per plant per year, by dividing the total number of failures occurring for a given equipment service time by the number of plants that have been in service for at least the given service time. In other words, plants with service times less than the equipment service time of interest could not have contributed to the data point, so they are excluded from the normalization factor. This normalization prevents skewing of the data due to more plants being in service at the shorter service times, and contributing to higher total charger failures at these shorter service times. The line drawn through the data is linear, which was a better fit than second order. The relatively flat nature of these curves indicates that charger failure rates do not increase dramatically as the equipment ages. This implies that chargers have a high inherent reliability, or that current maintenance practices are effective at detecting and mitigating charger aging, or both.

Figure 3-24. All Reported NPRDS Charger Failures by Service Time.

Figure 3-25. Age-Related NPRDS Charger Failures by Service Time.

The time between failures for the 386 chargers reported in the NPRDS ranged from 0 days to 8,330 days (199,920 hours). The mean time between failure for the chargers was calculated to be 1,710 days (41,040 hours) with a standard deviation of 1,803 days (43,272 hours). This implies a wide variation in the time between failures. The failure rate corresponding to the mean time between failures is 2.43×10^{-5} failures per hour.

If we consider age-related failures only, then the time between age-related failures identified in the NPRDS ranged from 0 days to 7,855 days (188,520 hours). The mean time between age-related failures was calculated to be 2,336 days (56,064 hours) with a standard deviation of 1,984 days (47,616 hours). Again, this implies a wide variation in the time between age-related failures. The failure rate corresponding to the mean time between age-related failures is 1.78×10^{-5} age-related failures per hour.

In summary, the NPRDS data indicates the following:

- At least 49.8% of the reported charger failures are considered age-related failures.
- The failed parts that contribute the most to age-related charger failures are circuit boards (31.6%), potentiometers (13.1%), and relays (7.0%).
- The most significant identifiable aging mechanisms are setpoint/electronic drift (20.7%), fouling (8.1%), and thermal stress (6.3%).

- Failure rate trends suggest that current maintenance practices are effective at detecting and mitigating aging of battery chargers.
- The mean time between age-related battery charger failures is 2336 days which corresponds to a failure rate of 1.78×10^{-5} age-related failures per hour. Because of the wide variation in failure in the time between failures, this failure rate should be used with caution.

3.6.1.4 Licensee Event Report Database

A search of the Sequence Coding and Search System (SCSS) database for LERs reporting age-related failures of battery chargers was obtained from Oak Ridge National Laboratory. Table 3-11 summarizes the age-related LERs pertaining to battery chargers. Only six LERs concerning age-related battery charger failures were identified, because deterioration or failure of a single battery charger does not usually lead to violation of the plant's Technical Specification, and thus no LER is written. Circuit board failures were the most significant contributor to charger failures (42.8%), followed by unknown part failures (14.3%), relays (14.3%), breakers (14.3%), and resistors (14.3%). "Unknown" was the most frequent failure cause (62.5%), followed by design factors (12.5%), loose connections (12.5%), and corrosion (12.5%). Five of these events (83.3%) occurred during power operation. Only one of these five events (20.0%) resulted in a plant shutdown, which was a controlled shutdown. Another one of these five events (20.0%) resulted in inadvertent safety system actuation, but did not result in a plant shutdown. Two of these five events (40.0%) had no effect on the plant due to back-up battery chargers or due to the availability of the battery.

Table 3-11. Battery Charger LER Data

Event Date	Plant	LER Number	Failed Part(s)	Failure Cause(s)
08/21/80	Pilgrim 1	80-056	Circuit Board	Unknown
10/11/82	Summer 1	82-020	Unknown	Unknown
10/06/83	Dresden 2	83-070	Circuit Board	Loose Connection/ Corrosion
07/15/89	LaSalle 2	89-010	Relay	Unknown
08/08/90	Beaver Valley 1	90-012	Breaker Resistor	Unknown Unknown
03/06/91	Vogtle 1	91-004	Circuit Boards	Design Factors

3.6.1.5 Industry Literature

Table 3-12 identifies the industry reports that are relevant to the operating history of battery chargers and inverters. The following paragraphs discuss the operating history information presented in each report that pertains to battery chargers.

Table 3-12. Industry Literature Pertaining to Battery Chargers, Inverters, and Uninterruptible Power Supplies

Report Number	Report Title	Applicability
NUREG/CR-3226	Station Blackout Accident Analysis (Part of NRC Task Action Plan A-44) (May 1983)	Chargers
NUREG/CR-4470	Survey and Evaluation of Vital Instrumentation and Control Power Supply Events (August 1986)	Chargers Inverters
NUREG/CR-4564	Operating Experience and Aging/Seismic Assessment of Battery Chargers and Inverters (June 1986)	Chargers Inverters
NUREG/CR-4715	An Aging Assessment of Relays and Circuit Breakers and System Interactions (June 1987)	Chargers Inverters
NUREG/CR-4747	An Aging Failure Survey of Light Water Reactor Safety Systems and Components, Vol. 1 (July 1987)	Chargers Inverters
NUREG/CR-5051	Detecting and Mitigating Battery Charger and Inverter Aging (August 1988)	Chargers Inverters
NUREG/CR-5181	Nuclear Plant Aging Research: The 1E Power System (May 1990)	Chargers Inverters
NUREG/CR-5192	Testing of a Naturally Aged Nuclear Power Plant Inverter and Battery Charger (September 1988)	Chargers Inverters
NUREG/CR-5414	Technical Findings for Proposed Integrated Resolution of Generic Issue 128, Electric Power Reliability (November 1989)	Chargers Inverters
NSAC-44	Investigation of Failures in I&C Power Supply Hardware (December 1981)	Inverters

NUREG/CR-4564[3.6] evaluated battery charger operating histories primarily from three data bases: LER data from 1976 to 1984, In-Plant Reliability Data System (IPRDS) data from 1974 to 1981, and NPRDS data from 1973 to 1984. The 101 LER failures showed the classic "bathtub curve," with a high number of failures in the first year of service, followed by a decreased number of failures in years two through four, followed by increased failures in a pronounced wear out region in years five and six. The LERs showed that control cards (circuit boards), relays, and voltage regulators are the three non-protection type components which cause charger failures.

The IPRDS data showed an increasing failure rate with plant age. Relays account for 22.2% of the 45 identified hardware failures, followed by fuses (15.6%), capacitors (13.3%), and diodes (8.9%). Relays dominate both catastrophic as well as incipient IPRDS failures.

The NPRDS data showed that at least 30% of the 70 reported charger failures were age-related. Control and firing modules (circuit boards) dominated the charger failures (24.3%). The top failure modes identified from the data were loose connections (14.3%), testing (10.0%), aging/wear (8.6%), short circuits (5.7%), overheating (4.3%), and personnel error (4.3%).

NUREG/CR-4564 also reviewed data from the S.M. Stoller Corp. Nuclear Power Experience (NPE) data base up to 1985. The 60 NPE reports supplemented the LER and NPRDS data, but did not provide any new information.

Plant maintenance records for several plants that were reviewed by NUREG/CR-4564 revealed the following additional charger problems: contact pitting and "sticking" of the timer (timer failure could damage the battery), drifting of the potentiometer (high equalize voltage could trip the inverter), and thermal aging of control and power cables (due to heat generation inside charger cabinet). The review of plant maintenance records also showed that one utility achieved improved charger performance by replacing capacitors with capacitors having a higher dielectric strength and a higher temperature rating.

NUREG/CR-5051[3.30] updated the LER information that had been reported in NUREG/CR-4564 by reviewing LERs from 1984 to 1986. There were 32 LERs, 16 were "hardware" related and 16 were attributed to "human factors." These additional LERs were consistent with the NUREG/CR-4564 LER, NPRDS and IPRDS reviews. The hardware failures identified were voltage regulators (31.3%), filter networks (31.3%), potentiometers (18.8%), high voltage relays (12.5%), and fuses (6.3%). A plot of failures versus plant age (normalized to the number of plants in operation for the various ages) showed a generally decreasing trend, with peaks early in plant life, at year six, and to a lesser extent at year 12. The peaks were interpreted as the effects of subcomponent aging.

NUREG/CR-4747[3.31] evaluated NPRDS failure data for nine systems, including the Class 1E electric power distribution system. There were 35 identified Class 1E battery charger failures, with a lower bound aging fraction of 0.51 and an upper bound aging fraction of 0.97 (i.e., 51.0% to 97.0% of the charger failures were identified as potentially age related). The identified failure causes were faulty modules/circuit boards (65.7%), electrical failure (8.6%), binding/out of adjustment (5.7%), wear (2.9%), foreign materials intrusion (2.9%), arcing (2.9%), setpoint drift (2.9%), open circuit (2.9%), erroneous/spurious signal (2.9%), and short circuits (2.9%).

NUREG/CR-5181[3.32] evaluated LER, NPRDS, NPE, and plant specific failure data for the entire 1E power system. Charger failures accounted for 9.5% of the 3108 LERs, and 7.3% of the 2260 NPRDS failures. An aging fraction of 0.311 was determined for the NPRDS charger failures (i.e., 31.1% of the reported NPRDS charger failures were attributed to aging). The NPE review combined inverters, chargers, and M-G sets into one category, which accounted for 15.0% of all reported 1E power system failures. The plant specific review ranked chargers as the component with the third highest number of work requests in the 1E power system, topped

only by breakers and batteries. Even excluding work requests for testing and preventive maintenance, chargers still ranked third behind batteries and breakers. Specific failed parts or failure mechanisms for chargers were not discussed.

NUREG/CR-4470[3.33] reviewed LERs from 1969 through 1984 to examine failures of vital instrumentation and control power. Battery charger failures accounted for 7.6% of the 251 vital instrument bus failures. However, specific charger failures were not discussed in the report.

NUREG/CR-5414[3.8] reported LER failure data involving DC power. Out of "more than 100" LERs, 87 were attributed to battery failures, and 24 were attributed to charger failures. Specific charger failures were not discussed.

NUREG/CR-5192[3.34] reported the results of testing of a naturally aged battery charger that was obtained from the Shippingport Atomic Power Station after approximately 11 years of service. The battery charger was a three phase, convection cooled, SCR type charger manufactured by Power Conversion Products, with a rating of 150 amps at 130 VDC at 50°C [122°F]. Steady state testing was conducted over the equipment's entire operating range. Step load changes were also initiated in order to monitor the electrical response. During this testing, component temperatures were monitored and circuit waveforms (ripple voltage) were analyzed. Results indicated that aging had not substantially affected equipment operation. Additionally, the monitoring techniques employed were sensitive to changes in measurable component and equipment parameters indicating the viability of detecting degradation prior to catastrophic failure.

NUREG/CR-3226[3.35] used probabilistic risk analysis methods to evaluate station blackout accident sequences. Battery charger unavailability values of 6×10^{-7} per hour and 4×10^{-6} per hour were reported from the Zion probabilistic risk assessment and the DC power study (NUREG/CR-0666), respectively. NUREG/CR-3226 used an unavailability value of 2×10^{-6} per hour. Specific charger failures were not discussed.

NUREG/CR-4715[3.36] examined relay and circuit breaker failures from the LER, NPRDS, and IPRDS databases. The examination of circuit breakers concentrated on the metal clad type, and is therefore not generally applicable to the molded case circuit breakers used in battery chargers. However, the examination of relay failures may provide insight into battery charger relay failures. All three databases indicated increasing relay failure with age starting in year 9 (NPRDS, IPRDS) or year 17 (LER). The difference in starting year was attributed to differences in reporting requirements between the LERs and the other databases.

NUREG/CR-4715 reviewed 882 LER relay failures from 1972 to 1985 and concluded that 654 (74.1%) were potentially age related. The top age-related failure causes were setpoint drift (27.7%), short or open coil (14.2%), binding (13.3%), failed contact (10.2%), failed electrical part other than a coil or contact (8.7%), dirty contact (5.8%), dirty relay - not contacts (4.3%), and "end of life" (3.5%). The remaining failure causes contributed less than 3.0% to all potentially age-related relay failures.

The NUREG/CR-4715 review of NPRDS data from 1973 to 1985 showed that the number of normally energized relay failures were 61% greater than the number of normally de-energized relay failures. This effect was attributed to greater thermal stress in the normally energized relays. Normally energized relays showed infant mortality in year 1, with wearout in years 7 through 12. Normally de-energized relays do not show any infant mortality but do show similar wearout in years 7 through 12.

The IPRDS review in NUREG/CR-4715 included data from only one plant that had nine years of operating experience. This data showed an initially high relay failure rate in year one, which falls off then increases again in years six to nine. Identified relay failure causes were setpoint drift (41.0%), burned out coils (17.9%), binding (12.8%), bobbin melting (10.3%), unknown (10.3%), dirty contacts (5.1%), and "loose in socket" (2.6%).

3.6.1.6 NRC IE Circulars, Notices, Bulletins, and Generic Letters

The NRC IE Circulars, Notices, Bulletins, and Generic Letters pertaining to battery chargers, inverters, and UPSs are listed in Table 3-13. There were three notices that are relevant to battery chargers: IN 83-04,[3.37] IN 88-57,[3.38] and IN 91-81.[3.39] Each of these are discussed in the following paragraphs.

Information Notice 83-04[3.37] discusses failures of ELMA 24 VDC power supply units, but can be applicable to battery chargers as well. Failure of the units was attributed to overheated capacitors. A possible cause for capacitor overheating was due to improper vertical mounting of the units, which resulted in overheating of the capacitors adjacent to the ferroresonant transformer. Additionally, the manufacturer noted that ferroresonant transformers are substantially less efficient when operated at partial power rather than at full power. These units are operated in parallel, sharing the load, which means that their heat output into their enclosures will be greater than the heat loss output of a single unit supplying the entire load. Unequal load sharing of units that are not perfectly matched will also increase heat output. The manufacturer recommends that if two or more units are used in parallel, the system must be analyzed for load sharing, efficiency at low load, and proper cooling.

Information Notice 88-57[3.38] deals with inverter failures caused by improper torquing of silicon controlled rectifiers (SCRs) to their heat sinks. This resulted in overheating and premature failure of the SCRs. The potential for such failures exists for battery chargers as well as inverters.

Information Notice 91-81[3.39] identifies switchyard problems that contribute to loss of offsite power. A lack of preventive maintenance on battery chargers was identified as one of these problems. The description of the licensee event indicated that three of the four chargers in the switchyard DC control system had non-functional output filter circuits. The cause of these problems was attributed directly to infrequent maintenance of the chargers. It appeared that there had been no maintenance performed on the chargers for six years.

Table 3-13. NRC IE Circulars, Notices, Bulletins, and Generic Letters Related to Battery Chargers, Inverters, and UPSs

Document	Title	Components Covered	Summary
Circular 79-02 January 16, 1979	Failure of 120 Volt Vital AC Power Supplies	Inverters UPSs	<p>An inadvertent ESF actuation occurred because all four static switches automatically transferred to the alternate supply.</p> <p>Contributing factors were:</p> <ol style="list-style-type: none"> 1) Improper setting of time delay relays on DC input voltage trip circuitry. 2) Improper setting of inverter output overcurrent/undervoltage relays. 3) Improper tap settings on AC input transformer.
Information Notice 79-29 November 19, 1979	Loss of Non-Safety-Related Reactor Coolant System Instrumentation During Operation	Inverters UPSs	A non-safety-related inverter tripped due to blown fuses and failed to automatically transfer to the regulated AC power source, causing loss of control room indicators and recorders for the reactor coolant system, except for one wide-range RCS pressure recorder. This condition lasted for approximately three minutes until an operator could reach the equipment room and manually switch the inverter.
Bulletin 79-27 November 30, 1979	Loss of Non-Class 1E Instrumentation and Control Power System Bus During Operation	Inverters UPSs	This bulletin addresses the incident described in the Information Notice 79-29 and requires licensees to review their Class 1E and non-class 1E instrumentation and control systems and review or develop emergency procedures to achieve cold shutdown upon loss of power to each bus supplying such systems. Re-review of IE Circular 79-02 for Class 1E and non-Class 1E inverters is also required to identify design modifications or administrative controls that may be needed.

Table 3-13. NRC IE Circulars, Notices, Bulletins, and Generic Letters Related to Battery Chargers, Inverters, and UPSs (continued)

Document	Title	Components Covered	Summary
Information Notice 83-04 February 18, 1993	Failure of ELMA Power Supply Units	Battery Chargers	<p>Failure of 24 VDC power supply units was attributed to overheating of capacitors. Possible causes of capacitor overheating where improper vertical mounting of the units causing overheating from the adjacent ferroresonant transformer, and operation at less than full power (i.e., two units in parallel) which causes greater heat output from the transformer since it operates at lower efficiency at partial power.</p>
Information Notice 84-80	Plant Transients Induced by Failure of Non-Nuclear Instrumentation Power	Battery Chargers Inverters UPSs	<p>Loss of a 24 VDC power supply was attributed to failure of a capacitor with the wrong ratings.</p> <p>Loss of another 24 VDC power supply was attributed to drift of the low output voltage setpoint.</p> <p>Degraded voltage output of a non-Class 1E inverter was attributed to degraded input voltage from the DC bus.</p> <p>Corrective actions included periodic scheduling of the calibration of DC power supply alarm and trip settings, installation of redundant power supplies, and installation of an automatic transfer switch for the inverter.</p>

Table 3-13. NRC IE Circulars, Notices, Bulletins, and Generic Letters Related to Battery Chargers, Inverters, and UPSs (continued)

Document	Title	Components Covered	Summary
Information Notice 84-84, Revision 1 April 24, 1985	Deficiencies in Ferroresonant Transformers	Inverters UPSs	<p>Two design deficiencies were identified in General Electrical ferroresonant transformers used in Westinghouse inverters:</p> <ol style="list-style-type: none"> 1) Since "fast-on" wire terminations had incorrectly been forced on solder lugs, and could fall off under seismic loads. 2) Some transformer reactors were inadequately secured, which subject to vibration while energized, caused insulation breakdown.
Information Notice 87-24 June 4, 1984	Operational Experience Involving Losses of Electrical Inverters	Inverters UPSs	<p>This notice reports the following findings of an NRC case study on inverter failures:</p> <ol style="list-style-type: none"> 1) Dominant causes of inverter loss are component failure caused by high ambient temperature and/or humidity within the inverter cabinet, or by electrical disturbances at the inverter input/output terminals. Personnel actions (errors) were the second largest contributor to inverter loss. 2) Recommended actions include monitoring inverter enclosure temperature and/or humidity, and evaluating input/output voltages to ensure that manufacturer's recommendation are being considered.
Information Notice 88-57 August 8, 1988	Potential Loss of Safe Shut-down Equipment Due to Premature Silicon Controlled Rectifier Failure	Battery Chargers Inverters UPSs	Improper mounting of SCR to its heat sink can lead to overheating and premature failure.

Table 3-13. NRC IE Circulars, Notices, Bulletins, and Generic Letters Related to Battery Chargers, Inverters, and UPSs (continued)

Document	Title	Components Covered	Summary
Information Notice 91-64 October 9, 1991	Site Area Emergency Resulting From a Loss of Non-Class 1E	UPSs	A poor configuration of the normal and alternate supply for control power, coupled with improper maintenance of the control power battery packs, resulted in loss of power output from five of eight non-Class 1E Exide uninterruptible power supplies (Model 575-60T3-120/208). Corrective actions involve reconfiguration of the control power supplies and annual control power battery pack replacement.
Information Notice 91-64, Supplement 1 October 7, 1992	Uninterruptible Power Supplies		
Information Notice 91-81 December 16, 1991	Switchyard Problems That Contribute to Loss of Offsite Power	Battery Chargers	Three of four non-Class 1E battery chargers in the switchyard DC control system were degraded (output filter circuit not functional) due to infrequent preventive maintenance. The failure of the swing battery charger filter circuit, in particular, contributed significantly to a complete loss of offsite power.

3.6.2 Inverters and Uninterruptible Power Supplies

3.6.2.1 Host Utility Data

The host utility plant is a PWR that has four 125 VDC/120 VAC essential inverters that supply the four essential instrument distribution panels, and two 250 VDC/120 VAC non-essential inverters that supply the two uninterruptible instrument distribution panels. The plant also has a separate inverter for the security system.

Maintenance work orders and work requests from 1982 through 1991 were reviewed for the four essential and two non-essential inverters. There were 197 total work orders and requests for the six inverters. Seventy-seven (39.1%) were for preventive maintenance, cleaning, inspection, or calibration. The remaining 120 (60.9%) were in response to equipment failure or abnormal operation. Of these, the failed parts involved were fuses (34.2%), circuit boards (27.5%), resistors (17.5%), circuit breakers (7.5%), diodes (4.2%), unknown (3.2%), switches (2.5%), relays (1.7%), and transformers (1.7%). Figure 3-26 depicts this distribution of failed

Figure 3-26. Failed Parts for Host Utility Inverter/UPS Data.

parts from the host utility inverter data. In general, the work orders and requests did not identify failure causes, although it was noted that many of the blown fuses were actually due to internal wiring or logic board problems.

3.6.2.2 Questionnaire Responses

Questionnaire responses were obtained from 9 utilities covering 13 plants. Table 3-14 summarizes the questionnaire responses that pertain to inverter and UPS system applications. Based on the responses, 11 of the plants (85%) use inverters/UPSs in the plant 1E systems, seven of the plants (54%) have inverters/ UPSs in the plant non-1E systems, and four (31%) of the plants use inverters/UPSs in the switchyard.

The original inverters/UPSs are still in use at seven (54%) of the plants. Two of the plants (15%) replaced inverters due to excessive logic and power supply failures. One plant (8%) replaced the inverters to meet increased capacity requirements due to increased system loads. Two other plants (15%) replaced UPS systems due to equipment obsolescence.

The questionnaire responses indicated that all of the inverters/UPSs are located indoors. Ten of the plants (77%) provide a temperature controlled environment for the inverters/UPSs. The most closely controlled temperature range is 18°-27°C [65°-80°F], while the widest controlled range is 18°-49°C [65°-120°F]. The lowest allowable temperature is 13°C [55°F], while the highest is 49°C [120°F]. The inverters/UPSs located in uncontrolled environments may be subject to temperatures ranging from -20°-50°C [-40°-122°F].

The most commonly reported aging mechanisms, along with the percentage of plants that have experienced each mechanism, are capacitor failures (77%), thermal aging (77%), electronic burns and cracks (54%), electronic drift (38%), fatigue (38%), and corrosion (15%).

Table 3-14. Inverter/UPS Applications from Plant Questionnaires

System	Number of Plants	Total Number of Inverters/UPSs	Range of Inverters/UPSs Used in System	Average Number of Inverters/UPSs Used in System	Median Number of Inverters/UPSs Used in System
Plant 1E Systems	11	80	1 to 16	7.27	4
Plant Non-1E Systems	7	33	1 to 11	4.71	3
Switchyard	4	4	1 to 1	1.0	1

3.6.2.3 Nuclear Plant Reliability Data System

A search of the NPRDS yielded 703 reported failures for 251 inverters and uninterruptible power supplies at 72 nuclear power plants. Failure causes were not always specified, or were sometimes given in ambiguous terms such as "aging" or "end of life." Figure 3-27 depicts the distribution of causes for all reported inverter and uninterruptible power supply failures. Causes were not given for most of the failures (43.8%). The largest identifiable failure cause was "aging" (23.5%), followed by setpoint/electronic drift (8.5%), and design factors (6.5%). The remaining failure causes each contributed less than 5% to the total reported failures.

The failures that appeared to be age-related were identified. Age-related failures include causes such as "aging," setpoint drift, thermal stress, fouling, and wear. There were 279 age-related failures identified for 144 inverters and uninterruptible power supplies at 63 plants. These failures account for 39.7% of the 703 reported failures. Figure 3-28 depicts the distribution of the age-related failure causes. More than half of the age-related failures (59.1%) were attributed to "aging." The largest definitive age-related failure cause was setpoint/electronic drift (21.5%), followed by thermal stress (5.7%), and fouling (5.0%). The remaining age-related failure causes each contribute less than 5% of the total age-related reported failures.

The NPRDS data was also analyzed to determine which subcomponent part failures contributed the most to inverter and uninterruptible power supply failures. Figure 3-29 depicts the distribution of failed parts for all reported failures. Specific part failures were not identified for 9.4% of the failures. The specific parts identified that contribute the most to inverter and uninterruptible power supply failures are circuit boards (27.0%), fuses (19.5%), capacitors (7.7%), SCRs (6.1%), and transformers (6.1%). All other part failures each contribute less than 5% to the total reported inverter/UPS failures.

Figure 3-30 depicts the distribution of failed parts for the 279 age-related inverter and uninterruptible power supply failures. Specific part failures were not identified for 13.3% of the age-related inverter and uninterruptible power supply failures. The specific parts identified that contribute the most to age-related failures are circuit boards (27.2%), capacitors (8.2%), fuses (7.9%), transformers (6.8%), SCRs (6.4%), and cooling fans (5.0%). All other part failures each contribute less than 5% to the total identified age-related inverter and uninterruptible power supply failures.

Figure 3-27. Failure Modes for All NPRDS Inverter/UPS Failures.

Figure 3-28. Failure Modes for Age-Related NPRDS Inverter/UPS Failures.

Figure 3-29. Failed Parts for All NPRDS Inverter/UPS Failures.

Figure 3-30. Failed Parts for Age-Related NPRDS Inverter/UPS Failures.

To further understand the susceptibility of inverters and uninterruptible power supplies to age-related degradation, the NPRDS data was analyzed to determine the significant aging mechanisms for each subcomponent part. The distribution of causes for age-related failures of each subcomponent part were determined. The following paragraphs describe the results of this effort for the most significant failed parts.

The most significant aging mechanism identified for circuit boards was "aging" (63.2%), followed by setpoint drift (18.4%), fouling (5.3%), connection (5.3%), and stress (5.3%).

The aging mechanisms identified for capacitors are "aging" (91.3%), followed by connection (4.3%), thermal stress (4.3%).

The aging mechanisms identified for fuses are "aging" (59.1%), fouling (13.6%), stress (13.6%), and thermal stress (9.1%).

The aging mechanisms identified for transformers are "aging" (68.4%), thermal stress (15.7%), insulation breakdown (10.5%), and vibration (5.2%).

Figures 3-31 and 3-32 show the total and age-related number of NPRDS-reportable inverter/UPS failures per plant per year, respectfully. The trend in both figures shows a significant increase in failures from 1983-85. This increase is consistent with the higher priority that reporting was given by utilities and the greater emphasis the data system was given in the industry. Since 1985, Figure 3-31 shows a gradual decrease in the number of reported failures. Figure 3-32 shows a decrease in failures from 1985-1988 and an increase in failures from 1988-1991. This fluctuation may or may not be a statistically significant trend given the variations in annual failures. If the assumption is made that the highest and lowest failure rate years are unusual variations and are not considered, the trend of the graph shows an increase in 1983-85 consistent with increased reporting with consistent failure rate since 1985. If this assumption is true, then current maintenance practices are adequate to manage aging degradation.

Figures 3-33 and 3-34 show the total and age-related number of reported NPRDS inverter/UPS failures plotted by equipment service time for the last 20 years (i.e., 1972 to 1992). The plot has been normalized to show failures per plant year, by dividing the total number of failures occurring for a given equipment service time by the number of plants that have been in service for the given service time, or longer. This normalization prevents skewing of the data due to more plants being in service at the shorter service times, and contributing to higher total inverter/UPS failures at these shorter service times. The relatively flat nature of these curves indicates that inverter/UPS failure rates do not increase dramatically as the equipment ages. This implies that inverters/UPSs have a high inherent reliability, or that current maintenance practices are effective at detecting and mitigating inverter/UPS aging, or both. Note that these figures show that the linear fits through the data have more of an increase in failure rate than Figures 3-24 and 3-25 for battery chargers, implying that inverters/UPSs are either more susceptible to aging than battery chargers or the maintenance programs are not as effective.

The time between failures for the 251 inverters and uninterruptible power supplies reported in the NPRDS ranged from 1 day to 7,547 days (181,128 hours). The mean time between failures was calculated to be 1,293 days (31,032 hours) with a standard deviation of

Figure 3-31. All NPRDS Inverter/UPS Failures by Year.

Figure 3-32. Age-Related NPRDS Inverter/UPS Failures by Year.

Figure 3-33. All Reported NPRDS Inverter/UPS Failures by Service Time.

Figure 3-34. Age-Related NPRDS Inverter/UPS Failures by Service Time.

1,540 days (36,960 hours). This implies a wide variation in the time between failures. The failure rate corresponding to the mean time between failures is 3.22×10^{-5} failures per hour.

If we consider age-related failures only, then the time between age-related failures identified in the NPRDS ranged from 2 days to 7,547 days (181,128 hours). The mean time between age-related failures was calculated to be 1,908 days (45,792 hours) with a standard deviation of 1,779 days (42,696 hours). Again, this implies a wide variation in the time between age-related failures. The failure rate corresponding to the mean time between age-related failures is 2.18×10^{-5} age-related failures per hour.

In summary, the NPRDS data indicates the following:

- At least 39.7% of the reported inverter/UPS failures are considered age-related failures.
- The failed parts that contribute the most to age-related inverter/UPS failures are circuit boards (27.2%) and capacitors (8.6%).
- The most significant aging mechanisms are setpoint/electronic drift (21.5%), thermal stress (5.7%), and fouling (5.0%).
- Failure rate trends suggest that current maintenance practices are effective at detecting and mitigating aging of inverters/UPSs.
- The mean time between age-related inverter/UPS failures is 1908 days, which corresponds to a failure rate of 2.18×10^{-5} age-related failures per hour. Because of the wide variations in failure duration, this failure rate should be used with caution.

3.6.2.4 Licensee Event Report Database

A search of the SCSS database for LERs reporting age-related failures of inverters and uninterruptible power supplies was obtained from Oak Ridge National Laboratory. Forty-nine (49) events were reviewed. A greater number of LERs reporting age-related failures of inverters/UPSs were obtained than for battery chargers, suggesting that inverters/UPSs are more susceptible to age-related degradation than are battery chargers.

Unknown part failures were the most significant contributor to inverter failures (30.6%), followed by capacitors (16.3%), circuit boards (14.3%), transformers (10.2%), fuses (8.2%), inductors (6.1%), SCRs (6.1%), diodes (4.1%), and transfer switches (4.1%). "Unknown" was the most frequent failure cause (59.2%), followed by high operating temperatures (24.5%), normal aging (10.2%), and design factors (6.1%). Thirty-six of these events (73.5%) occurred during power operation. Twenty of these events (40.8%) resulted in a reactor trip and plant controlled shutdown. Fifteen of these events (30.6%) resulted in safety system actuation or in loss of one train of redundant safety systems, but did not result in a plant shutdown. Fourteen of these events (28.6%) had no effect on the plant, due to timely repairs and back-up equipment. Figures 3-35 and 3-36 depict the distribution of failed parts and failure modes, respectively, of the LER inverter/UPS failure data.

Figure 3-35. Failed Parts for LER Inverter/UPS Failures.

Figure 3-36. Failure Modes for LER Inverter/UPS Failures.

3.6.2.5 Industry Literature

Table 3-12 identifies the industry reports that are relevant to the operating history of battery chargers, inverters, and UPSs. The following paragraphs discuss the information presented in each report that pertains to inverters/UPSs.

NUREG/CR-4470[3.33] reviewed LERs from 1969 to 1984 to examine failures of vital instrumentation and control power. Inverter failures accounted for 43% of the 251 vital bus failures. Approximately one-third of the inverter failures were caused by the failure of electronic components such as silicon controlled rectifiers, diodes, and capacitors. In addition, another one-third of the inverter failures occurred because of the failure of protective fuses and breakers.

EPRI Report NSAC-44[3.9] focuses on power supply hardware. It reviews 181 LERs from 38 plants over a period of five years. The causes of the failures were capacitors, SCRs or diodes failures (43%), fuses (11%), transformers (2%), human error (10%), transients (7%), environmental (3%), and miscellaneous (24%). This report outlines six measures that, if followed, would reduce the number of inverter failures. The recommendations are to:

- Use capacitors certified for higher temperature, voltage, and current than those expected in the instrumentation and control (I&C) power supply system.
- Periodically replace capacitors.
- Review fuse sizes to ensure that they can handle the load requirements.
- Provide better ventilation of I&C power supply components to increase their life.
- Revise specifications for I&C power supply systems to include temperature monitoring devices and a detailed maintenance program.
- Use higher quality and higher capacity electronic components to increase their life expectancy.

NUREG/CR-4564[3.6] reviewed inverter operating histories from four data bases: LER data from 1976 to 1984, IPRDS data from 1974 to 1981, NPRDS data from 1973 to 1984, and NPE data up to 1985.

The LERs showed that fuses (20.8%), capacitors (16.4%), control modules (10.8%), AC circuit breakers (11.2%), and DC circuit breakers (10.8%) were the components which cause most inverter failures. The most common identified failure modes were personnel error (34.7%), open/short circuit (19.8%), overheating (17.3%), and electrical transients (17.3%).

The IPRDS data indicated that the major causes of inverter failure can be attributed to fuses (29%), capacitors (17%), diodes (11%), and circuit boards (11%), which accounted for 68% of the known failures. A high failure rate early in plant life exists, and a wear out period of three to four years exists for components which could lead to inverter failure.

The NPRDS data showed that at least 30% of the reported failures were age-related. Capacitors and fuses were the two components more likely to cause an inverter failure (21.2% and 28.7%, respectively) followed by control and firing modules (10.9%), diodes (9.7%), and SCRs (8.6%). The most frequent failure modes were overheating (20.9%), short circuit (19.4%), aging/wear (16.4%), personnel error (16.4%), testing (13.4%), and loose connections (13.4%).

The 168 NPE reports did not provide any failure events not included in the LER or the NPRDS data banks, but did supplement the information from these sources, including repair, preventive maintenance, and recovery information.

Plant maintenance records that were reviewed by NUREG/CR-4564 showed that one utility's testing of inverters had contributed to premature aging failures because of the abnormally high voltages applied across the filter capacitor banks. This same utility increased the preventive maintenance frequency from every refueling to 60 days, including visual inspection and changeout of ventilation filters. Another utility improved inverter performance by installing cooling fans inside the inverters' cabinets.

NUREG/CR-4747[3.31] evaluated NPRDS failure data for nine systems including the Class 1E electric power distribution system. There were 63 identified Class 1E inverter failures, with a lower bound aging fraction of 0.29 and an upper bound aging fraction of 0.60 (i.e., 29% to 60% of the inverter failures were identified as potentially age-related). The identified failure causes were faulty modules/circuit boards (28.6%), electrical overloads (14.3%), wear (7.9%), design factors (7.9%), manufacturing errors (3.2%), binding (3.2%), electrical failure (3.2%), setpoint drift (3.2%), and arcing (1.6%).

NUREG/CR-5051[3.30] updated the LER information that had been reported in NUREG/CR-4564 by reviewing LERs from 1984 to 1986. There were 127 LERs. The failures identified were caused by personnel error (18%), electric transient (15%), overheating (10%), loose connections (7%), wear (6%), other (8%), and unknown causes (36%). The components causing these failures were the fuses (24%), capacitors (13%), transformers (6%), SCRs (5%), diodes (4%), and relays (3%).

NUREG/CR-5181[3.32] evaluated LER, NPRDS, NPE, and plant-specific failure data for the entire 1E power system. Inverters accounted for 9.9% of the 3,108 LERs and 11.6% of the 2,260 NPRDS failures. An aging fraction of 0.255 was determined for the NPRDS inverter failures (i.e., 25.5% of the reported NPRDS inverter failures were attributed to aging). The NPE review combined inverters, chargers, and motor-generator sets into one category, which accounted for 15% of all reported 1E power system failures. A review of all the sources of data for operating experience shows that inverters are one of the four components that appear most frequently.

NUREG/CR-5192[3.34] reported the results of testing of a naturally aged inverter that was obtained from the Shippingport Atomic Power Station after approximately 11 years of service. The inverter was a convection cooled, ferroresonant type inverter with a constant voltage transformer, and was manufactured by Solidstate Controls. It was rated at 5 kVA, 41.6 amps at 120 VAC, 60 Hz, at 50°C [122°F]. Steady state testing was conducted over the equipment's entire operating range. Step load changes were also initiated in order to monitor the electrical

response. During this testing, component temperatures were monitored and circuit waveforms were analyzed. Results indicated that aging had not substantially affected equipment operation. Additionally the monitoring techniques employed were sensitive to changes in measurable component and equipment parameters indicating the viability of detecting degradation prior to catastrophic failure.

NUREG/CR-4715[3.36] examined relay and circuit breaker failures from the LER, NPRDS, and IPRDS databases. The examination of circuit breakers concentrated on the metal clad type, and is therefore not generally applicable to the molded case circuit breakers used in inverters. However, the examination of relay failures may provide insight into inverter relay failures. All three databases indicated increasing relay failure with age starting in year 9 (NPRDS, IPRDS) or year 17 (LER). The difference in starting year was attributed to differences in reporting requirements between the LERs and the other databases. This analysis is summarized in the battery charger discussions in Section 3.6.1.

NUREG/CR-5414[3.8] reported LER failures involving DC power. It reviews 94 LERs, totalling 107 events involving inverter failures that occurred during 1982 through 1984. The study includes 35 additional events from the NPRDS database that occurred in the same time frame. The report states that even though previous action has been taken in past years to reduce inverter failure, the actual number of failures in the industry up to that time continued to increase. Specific inverter failures are not discussed in the report.

3.6.2.6 NRC IE Circulars, Notices, Bulletins, and Generic Letters

The NRC IE Circulars, Notices, Bulletins, and Generic Letters pertaining to battery chargers, inverters, and UPSs are listed and summarized in Table 3-13. There were six notices, one circular, and one bulletin pertaining to inverters and uninterruptible power supplies. Most of these documents discuss improper adjustment/calibration of the equipment, concerns about system configuration, and design or manufacturing defects. The most relevant notices as they pertain to aging are IN 87-24,[3.40] IN 88-57,[3.38] IN 91-64,[3.41] and IN 91-64, Supplement 1.[3.42] Each of these are discussed in the following paragraphs.

Information Notice 87-24[3.40] reported findings of an NRC case study of operational experience involving loss of electrical inverters. This study found that the dominant cause of inverter loss was attributed to component failure (i.e., diodes, fuses, SCRs, capacitors, resistors, printed circuit boards, transformers, and inductors). High ambient temperature and/or humidity within the inverter cabinet, as well as electrical disturbances at the inverter input/output terminals, were determined to be major contributing factors to component failures.

Personnel actions (i.e., human errors) were the second largest contributor to inverter losses. The notice recommends that licensees consider internal temperature and/or humidity monitoring of the inverter enclosure, as well as evaluating input and output voltages of the inverter under steady-state and transient conditions, to assure that manufacturer's recommendations are being considered. Review of maintenance and test procedures was recommended as a means to decrease inverter loss due to personnel actions (errors).

Information Notice 88-57[3.38] discusses inverter failures caused by improper torquing of SCRs to their heat sinks, which resulted in overheating and premature failure of the SCRs.

Information Notices 91-64[3.41] and 91-64, Supplement 1[3.42] discuss the failure of non-class 1E UPSs in August of 1991. A major contributor to the loss of these UPSs was inadequate preventive maintenance. Specifically, the vendor (Exide) recommends that the battery packs that supply power to the UPS control logic be replaced every four years. The licensee obtained the UPSs in 1981 and replaced the battery packs in 1984, but then failed to perform subsequent replacements. The other contributing factor to the UPS losses was the configuration of the normal and alternate power supplies to the control logic. The normal power supply was from the maintenance power, with the UPS inverter output as the alternate. The preferred configuration is to use the inverter output as the normal supply, with the maintenance power as the alternate supply. The licensee took steps to provide for annual battery pack replacement and to re-configure the normal and alternate sources of power for the UPS control logic.

3.7 References

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- 3.3 BWR Lead Plant Project Task 2 Summary Report, to be published by Electric Power Research Institute in 1994.
- 3.4 PWR Technical Demonstration Project Technical Reports, to be published by Electric Power Research Institute in 1994.
- 3.5 Title 10, Code of Federal Regulations, Part 50.65, "Requirements for Monitoring the Effectiveness of Maintenance at Nuclear Power Plants," July 10, 1991.
- 3.6 NUREG/CR-4564, Operating Experience and Aging-Seismic Assessment of Battery Chargers and Inverters, Brookhaven National Laboratory, June 1986.
- 3.7 C & D Charter Power Systems Sales Brochure 10-301, Single-Phase Float Chargers for Communications, Switchgear, Control, and Other Stationary Applications, 1990.
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- 3.17 IEEE STD 381-1977, IEEE Standard Criteria for Type Tests of Class 1E Modules Used in Nuclear Power Generating Stations, Institute of Electrical and Electronics Engineers, Inc., 1977.
- 3.18 ANSI/IEEE STD 383-1974, IEEE Standard for Type Test of Class 1E Electrical Cables, Field Splices, and Connections for Nuclear Power Generating Stations, Institute of Electrical and Electronics Engineers, Inc., 1974.
- 3.19 ANSI/IEEE STD 572-1985, IEEE Standard for Qualification of Class 1E Connection Assemblies for Nuclear Power Generating Stations, Institute of Electrical and Electronics Engineers, Inc., 1987.
- 3.20 IEEE STD 627-1980, IEEE Standard for Design Qualification of Safety System Equipment Used in Nuclear Power Generating Stations, Institute of Electrical and Electronics Engineers, Inc., 1980.
- 3.21 IEEE STD 650-1990, IEEE Standard for Qualification of Class 1E Static Battery Chargers and Inverters for Nuclear Power Generating Stations, Institute of Electrical and Electronics Engineers, Inc., 1991.
- 3.22 ANSI/IEEE STD 934-1987, IEEE Standard Requirements for Replacement Parts for Class 1E Equipment in Nuclear Power Generating Stations, Institute of Electrical and Electronics Engineers, Inc., 1987.
- 3.23 IEEE STD P-1205, IEEE Guide for Assessing, Monitoring, and Mitigating Aging

Effects on Class 1E Equipment Used in Nuclear Power Generating Stations, Institute of Electrical and Electronics Engineers, Inc., Draft, October 26, 1992.

- 3.24 ANSI/IEEE STD 338-1977, IEEE Standard Criteria for the Periodic Testing of Nuclear Power Generating Station Safety Systems, Institute of Electrical and Electronics Engineers, Inc., 1977.
- 3.25 NEMA PE 5-1985, Utility Type Battery Chargers, National Electrical Manufacture Association, 1986.
- 3.26 IEEE STD 946-1985, IEEE Recommended Practice for the Design of Safety-Related DC Auxiliary Power Systems for Nuclear Power Generating Stations, Institute of Electrical and Electronics Engineers, Inc., 1985.
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- 3.36 NUREG/CR-4715, An Aging Assessment of Relays and Circuit Breakers and System Interactions, Brookhaven National Laboratory, June 1987.
- 3.37 NRC Information Notice No. 83-04, Failure of ELMA Power Supply Units, U.S. Nuclear Regulatory Commission, February 18, 1983.

- 3.38 NRC Information Notice No. 88-57, Potential Loss of Safe Shutdown Equipment Due to Premature Silicon Controlled Rectifier Failure, U.S. Nuclear Regulatory Commission, August 8, 1988.
- 3.39 NRC Information Notice 91-81, Switchyard Problems that Contribute to Loss of Offsite Power, U.S. Nuclear Regulatory Commission, December 16, 1991.
- 3.40 NRC Information Notice No. 87-24, Operational Experience Involving Losses of Electrical Inverters, U.S. Nuclear Regulatory Commission, June 4, 1987.
- 3.41 NRC Information Notice 91-64, Site Area Emergency Resulting From a Loss of Non-Class 1E Uninterruptible Power Supplies, U.S. Nuclear Regulatory Commission, October 9, 1991.
- 3.42 NRC Information Notice 91-64, Supplement 1, Site Area Emergency Resulting From a Loss of Non-Class 1E Uninterruptible Power Supplies, U.S. Nuclear Regulatory Commission, October 7, 1992.

4. STRESSORS AND AGING MECHANISMS

This section describes applicable stressors and aging mechanisms, and assesses the potential significance of these mechanisms, for static battery chargers, inverters, uninterruptible power supplies, and their subcomponents. These stressors (identified in Section 4.1) and aging mechanisms (Section 4.2) are determined by considering the design of the chargers, inverters and uninterruptible power supplies, their specific service and operating experience, and relevant industry information and reports.

4.1 Determination of Stressors Acting on Components

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

The stressors which may be relevant to battery chargers, inverters, and UPSs, singly or in combination, are:

- Thermal
- Radiation
- Humidity
- Electrical
- Mechanical
- Chemical
- Electrochemical
- Contaminants

The following sections discuss the applicability of each stressor to battery chargers, inverters, and uninterruptible power supplies. Table 4-1 summarizes the results of these evaluations.

4.1.1 Thermal

Thermal stresses result from high or low ambient temperatures, ohmic heating, and temperature cycling. Susceptible parts include transformers, inductors, capacitors, silicon controlled rectifiers, diodes, relays, resistors, circuit boards, wires and cables.

Table 4-1. Summary of Applicable Battery Charger and Inverter/UPS Stressors, Aging Mechanisms, Degradation Type, and Operational Effects

Applicable Stressors	Aging Mechanism	Degradation Type	Operational Effects
THERMAL TYPE			
Elevated Ambient Temperature	Thermal Aging	Insulation Degradation Dielectric Breakdown Semiconductor Barrier Breakdown Changes in Ohmic Values Changes in Capacitance Values	Magnetic Component Failure Capacitor Failure SCR Failure Diode Failure Surge Suppressor Failure Circuit Board Output Changes Wire and Cable Failure Cooling Fan Motor Failure
Ohmic Heating	Thermal Aging	Insulation Degradation Dielectric Breakdown Semiconductor Barrier Breakdown Changes in Ohmic Values Changes in Capacitance Values	Magnetic Component Failure Capacitor Failure SCR Failure Diode Failure Surge Suppressor Failure Circuit Board Output Changes Wire and Cable Failure Cooling Fan Motor Failure
Low Ambient Temperature	Thermal Aging	Cracking of Transformer Moisture Seals, which can lead to Moisture Intrusion, Corrosion, and Insulation Degradation	Transformer Failure
Temperature Gradients	Thermal Stress	Subcomponent Fracture Short or Open Circuits Relay Binding/Excessive Wear	Capacitor Failure (Leaks) SCR Failure Transformer Failure Relay Failure Surge Suppressor Failure Circuit Board Failure
Temperature Cycling	Thermal Fatigue	Magnetic Component Insulation Cracking Cracking of Circuit Board Lines Cracking of Cooling Fan Motor Insulation	Transformer Failure Inductor Failure Circuit Board Failure Cooling Fan Motor Failure

Table 4-1. Summary of Applicable Battery Charger and Inverter/UPS Stressors, Aging Mechanisms, Degradation Type, and Operational Effects (continued)

Applicable Stressors	Aging Mechanism	Degradation Type	Operational Effects
HUMIDITY TYPE			
High Relative Humidity	Corrosion	Accelerates Corrosion Short Circuits to Ground	Magnetic Component Failure Circuit Breaker, Switch, or Relay Contact Degradation Potentiometer Contact Degradation Wire and Cable Conductor Degradation Signal Degradation Cooling Fan Motor Failure Cooling Fan Degradation Cabinet Degradation
ELECTRICAL TYPE			
Applied Overvoltage	Thermal Aging	Overheating of Transformers, Inductors, Relays, Capacitors, Resistors, SCRs, Diodes, Circuit Boards, Surge Suppressors, Wires, Cables, and Cooling Fan Motors	Magnetic Component Failure Capacitor Failure SCR Failure Diode Failure Surge Suppressor Failure Circuit Board Output Changes Wire and Cable Failure Cooling Fan Motor Failure
Applied Undervoltage	Thermal Aging	Overheating of Relays	Relay Coil Failures
Voltage/Inductive Surges	Thermal Aging Fouling	Overheating of SCRs and Capacitors Corona Attack of Insulation Carbon Tracking in Circuit Breakers	Magnetic Component Failure Capacitor Failure SCR Failure Surge Suppressor Failure Circuit Board Failure Circuit Breaker Restrike/Shorting Wire and Cable Failure Cooling Fan Motor Failure
Overcurrent Conditions	Thermal Aging	Overheating of Transformers, Inductors, Relays, Capacitors, Resistors, SCRs, Diodes, Surge Suppressor, Circuit Boards, Wires, Cables, and Cooling Fan Motors	Magnetic Component Failure Capacitor Failure SCR Failure Diode Failure Surge Suppressor Failure Circuit Board Output Changes Wire and Cable Failure Cooling Fan Motor Failure

Table 4-1. Summary of Applicable Battery Charger and Inverter/UPS Stressors, Aging Mechanisms, Degradation Type, and Operational Effects (continued)

Applicable Stressors	Aging Mechanism	Degradation Type	Operational Effects
ELECTRICAL TYPE (Continued)			
External Transients	Thermal Aging Fouling	Overheating of SCRs and Capacitors Corona Attack of Insulation Carbon Tracking in Circuit Breakers	Magnetic Component Failure Capacitor Failure SCR Failure Surge Suppressor Failure Circuit Board Failure Circuit Breaker Restrike/Shorting Wire and Cable Failure Cooling Fan Motor Failure
Arcing	Thermal Aging Corrosion Fouling	Ohmic Heating of Switches, Relays, and Breakers Pitting/Fouling of Switch, Relay, and Breaker Contacts	Relay Coil Failure Circuit Breaker Restrike/Shorting Relay, Switch, or Breaker Contact Failure
Short Circuits	Thermal Aging	Overheating of Transformers, Inductors, Relays, Capacitors, Resistors, SCRs, Diodes, Surge Suppressors, Circuit Boards, Wires, Cables, and Cooling Fan Motors	Magnetic Component Failure Capacitor Failure SCR Failure Diode Failure Surge Suppressor Failure Circuit Board Output Changes Wire and Cable Failure Cooling Fan Motor Failure
Flashover	Corrosion Fouling	Pitting/Fouling of Switch, Relay, and Breaker Contacts Fouling of Transformers, Inductors, and Relay Coils	Magnetic Component Failure Circuit Breaker Restrike/Shorting Relay, Switch, or Breaker Contact Failure
MECHANICAL TYPE			
Routine Operation	Wear Fatigue Thermal Aging Fouling Corrosion	Wear of Moving Parts and Contacts Fatigue of Moving Parts Inductive Surges in Relay Coils Pitting of Potentiometer Contacts Fatigue of Wire and Cable Terminations	Binding and Misoperation of Relays, Circuit Breakers, and Switches Relay Coil Failure Potentiometer Failure Wire and Cable Failure Cooling Fan and Motor Degradation
Fault Interruption	Corrosion	Pitting of Breaker Contacts	Circuit Breaker Misoperation

Table 4-1. Summary of Applicable Battery Charger and Inverter/UPS Stressors, Aging Mechanisms, Degradation Type, and Operational Effects (continued)

Applicable Stressors	Aging Mechanism	Degradation Type	Operational Effects
MECHANICAL TYPE (Continued)			
Friction	Wear	Binding of Relays, Circuit Breakers, and Switches Reduced Circuit Breaker Operating Force Cooling Fan Bearing Wear	Relay Failure/Misoperation Circuit Breaker Failure/ Misoperation Switch Failure/Misoperation Cooling Fan and Motor Failure
Vibration - External Ferromagnetic Resonance Vibration	Fatigue Thermal Aging Corrosion	Material Fatigue Loose Parts or Connections Causing Increased Ohmic Heating Open Circuits Arcing Increased Corrosion	Magnetic Component Failure Capacitor Failure SCR Failure Diode Failure Surge Suppressor Failure Circuit Board Output Changes Loss of Signal Sporadic Operation Intermittent Relay Operation (Chatter) Wire and Cable Failure Cooling Fan and Motor Failure
Dormancy (Lack of Operation)	Material Set	Outgassing, Gelling, or Adherence of Lubricant	Binding of Relays or Circuit Breakers
CHEMICAL TYPE			
Cleaning Solvents	Corrosion	Cracked Insulation Cracked Circuit Board Tracks Corroded Contacts	Magnetic Component Failure Circuit Board Output Changes/Failure Relay, Switch, Breaker or Potentiometer Contact Failure Wire and Cable Failure Cooling Fan Motor Failure
ELECTROCHEMICAL TYPE			
Bimetallic Contact	Corrosion	Corrosion of Circuit Board Contacts	Signal Degradation Loss of Signal

Table 4-1. Summary of Applicable Battery Charger and Inverter/UPS Stressors, Aging Mechanisms, Degradation Type, and Operational Effects (continued)

Applicable Stressors	Aging Mechanism	Degradation Type	Operational Effects
CONTAMINANT TYPE			
Dirt and Dust Accumulation	Fouling Thermal Aging Corrosion Wear	Increased Resistance/ Overheating of Magnetic Components, Relays, Circuit Breakers, SCRs, Diodes, Capacitors, Electronics, Wires, Cables, and Cooling Fan Motors Corrosion of Contacts in Switches, Relays, Potentiometers, and Circuit Breakers Increased Friction in Switches, Relays, Potentiometers, Circuit Breakers, and Cooling Fan Bearings	Magnetic Component Failure Capacitor Failure SCR Failure Diode Failure Surge Suppressor Failure Circuit Board Output Changes/Failure Switch, Relay, or Circuit Breaker Failure Wire and Cable Failure Cooling Fan Motor Failure Cooling Fan Failure

High ambient temperature and ohmic heating can result in thermal stress, which can lead to accelerated aging of the organic insulating materials and other nonmetallics of transformers, inductors, relay coils, circuit breakers, wires, cables, and cooling fan motors. Ohmic heating may result from the inherent design of the components, or from poor or corroded connections having increased electrical resistance. High temperature can also cause overheating of electrolytic and oil filled capacitors, causing loss of capacitance due to electrolyte loss and/or dielectric breakdown. Silicon controlled rectifiers and diodes subjected to excessive operating temperatures may experience a semiconductor barrier breakdown, resulting in short or open circuits. Resistors may change in ohmic value due to overheating caused by high ambient and internal temperatures. Circuit board output values can also change as a result of changes in capacitance and ohmic values caused by high operating temperatures.[4.1, 4.2]

Low ambient temperature can cause cracking of the transformer moisture seals, allowing moisture intrusion which can lead to corrosion of the winding or degradation of the insulation. [4.1]

Temperature gradients can develop within the cabinet due to different operating temperatures of the various subcomponents, and/or due to lack of air convection within a closed cabinet. Temperature gradients can also occur within capacitors, SCRs, transformers, relays, and circuit boards due to high internal operating temperatures. Such gradients can cause unequal thermal stresses on the subcomponents that can lead to premature failure.[4.1]

Temperature cycling can cause thermal fatigue cracking of transformer and inductor insulation, circuit board lines, and the cooling fan motor winding insulation.[4.1]

Therefore, thermal stressors are applicable for battery chargers, inverters, and UPSs.

4.1.2 Radiation

Battery chargers, inverters, and UPSs are normally operated in a mild and controlled environment, and are not exposed to high or sustained levels of radiation. Several radiation studies indicate that the radiation environment is an order of magnitude below the lowest radiation damage threshold for the equipment subcomponents.[4.1]

Therefore, radiation has been determined to be a nonapplicable stressor for battery chargers, inverters, and UPSs.

4.1.3 Humidity

Battery chargers, inverters, and UPSs are normally located in a mild and controlled environment, where spray or steam environments are not expected. As discussed in Section 3.5, chargers are designed in accordance with NEMA standards to meet performance requirements in noncondensing humidity up to 95%. However, when coupled with insulation or connector degradation, ambient moisture can provide a circuit path between the component and ground. Moisture entering connector contact surfaces can increase the corrosion rate. Susceptible parts include transformers, inductors, relays, circuit breakers, switches, potentiometers, circuit boards, wires, cables, cooling fans, cooling fan motors, and cabinets.[4.1]

Therefore, ambient humidity has been determined to be an applicable stressor for battery chargers, inverters, and UPSs.

4.1.4 Electrical

Electrical stressors in battery chargers, inverters, and UPSs result from overvoltage conditions, undervoltage conditions, voltage surges, inductive surges, overcurrent conditions, external transients (e.g. lightning), electromagnetic interference, arcing, and short circuits. Susceptible parts include transformers, inductors, relays, capacitors, resistors, SCRs, diodes, surge suppressors, circuit boards, circuit breakers, switches, wires, cables, and cooling fan motors.

Overvoltage conditions can result in overheating of transformers, inductors, relays, capacitors, resistors, SCRs, diodes, surge suppressors, circuit boards, wires, cables, and cooling fan motors. Undervoltage conditions can result in overheating of relays. The effects of overheating due to these stressors are the same as those discussed above under thermal stressors. [4.1, 4.2, 4.3, 4.4]

Voltage surges, and associated inductive surges, can adversely affect transformers, inductors, relays, SCRs, capacitors, circuit breakers, surge suppressors, circuit boards, wires, cables, and cooling fan motors. Inductive surges in transformers, inductors, and relays can cause insulation breakdown due to corona attack and dielectric failure at weak points. Voltage surges can cause overheating of SCRs, as well as dielectric breakdown and loss of capacitance in capacitors. Circuit breakers can suffer corona effects with resultant carbon tracking due to overvoltage transients. Carbon tracking can contaminate the circuit breaker, enabling restriking, additional arcing, and potential low impedance between phases or phase to ground. Circuit board and surge suppressor subcomponents (i.e. capacitors) can suffer overheating and dielectric

breakdown due to voltage transients. Voltage surges can cause corona effects in cooling fan motor windings, wires, and cables that can damage the insulation.[4.1, 4.2, 4.3, 4.4]

Overcurrent conditions can result in overheating of transformers, inductors, relays, capacitors, SCRs, diodes, resistors, surge suppressors, circuit board subcomponents, wires, cables, and cooling fan motors. The effects of overheating are the same as those discussed above under thermal stressors.[4.1, 4.4]

External transients (e.g. lightning) will result in voltage surges, which can stress transformers, inductors, relays, SCRs, capacitors, circuit breakers, surge suppressors, circuit boards, wires, cables, and cooling fan motors as discussed above.[4.1, 4.2, 4.3, 4.4]

Electromagnetic interference (EMI) occurs when energy is conducted or radiated from man-made sources throughout the plant. Such interference requires a source emitter, a coupling mechanism, and an equipment receptor. Typical sources include high-power equipment, high-voltage lines, switching and inductive devices, and communication transmitters. Equipment susceptible to EMI include sensitive control and protective relays, measurement instruments and recorders, digital computers and acquisition systems, and communication systems. The coupling mechanism depends upon the spacing between circuits, as well as the circuit components (cables, grounds, couplings) and additional components included to shield or attenuate the interference. Battery chargers, inverters, and UPSs are viewed as sources of EMI, with appropriate internal suppression of EMI, and are not considered to be susceptible to EMI.[4.5]

Arcing occurs during normal operation of circuit breakers, switches, and relays. Arcing can cause pitting, corrosion, and carbon fouling of the contacts of these subcomponents, enabling restrike of the circuit breakers, shorting, and additional arcing or flashover to ground. Arcing can also cause ohmic heating of these subcomponents.[4.1, 4.2]

Short circuits can occur due to accumulated moisture, excessive dirt buildup (fouling), or dielectric breakdown of insulation. Short circuits can cause overcurrent conditions in charger subcomponents. The effects of overcurrent conditions were discussed earlier, and can affect transformers, inductors, relays, capacitors, SCRs, diodes, resistors, surge suppressors, circuit board subcomponents, wires, cables, and cooling fan motors.[4.1, 4.2]

Flashover can occur in transformers, inductors, relays, circuit breakers, and switches, due to overvoltage conditions, accumulated moisture, or excessive fouling. Flashover can cause carbon fouling and shorting of these subcomponents, as well as pitting corrosion of the switch, relay, and breaker contacts. These effects can lead to additional shorting and flashover as well as restrike of the circuit breakers.[4.1, 4.2]

With the exception of electromagnetic interference, electrical stressors have been determined to be applicable for battery chargers, inverters, and UPSs.

4.1.5 Mechanical

Mechanical stressors in battery chargers result from routine operation, fault interruption, friction, vibration (including ferromagnetic resonance), and dormancy (i.e. lack of operation).

Susceptible parts include transformers, inductors, capacitors, resistors, transistors, SCRs, diodes, circuit boards, potentiometers, switches, breakers, relays, cooling fans, and cooling fan motors.

Routine operation of relays, circuit breakers, and switches can result in wear of moving parts and contacts, which can result in binding and misoperation. High cycling rates can result in fatigue of the moving parts of these subcomponents. High cycling rates in relays can cause inductive surges which can lead to coil failure. Routine adjustments of potentiometers can result in wear of the contacts, causing a poor connection which can result in electrical pitting and corrosion of the contacts. Bending and pulling of wire and cable terminations during routine maintenance can result in fatigue failure of the conductor, insulation, or connector.[4.1, 4.2, 4.3, 4.4]

Fault interruption causes arcing in the circuit breakers which can lead to pitting of the contacts, and resultant misoperation.

Friction between moving parts of relays, circuit breakers, switches, cooling fans, and cooling fan motors can cause wear of the parts. Friction can also cause binding and resultant misoperation of these subcomponents. Friction can reduce the mechanism operating force in circuit breakers resulting in degraded operating characteristics.[4.2, 4.3]

In general, battery chargers and inverters are located away from rotating/vibrating machinery and are not subject to externally-induced vibration. However, vibration can occur in battery chargers and inverters from ferromagnetic resonance generated in the transformers or other high magnetic components, or to misalignment or dynamic imbalance of the cooling fan and motor. Vibration can also occur due to seismic events. Virtually all battery charger and inverter subcomponents (transformers, inductors, relays, capacitors, resistors, transistors, SCRs, diodes, circuit boards, surge suppressors, potentiometers, switches, breakers, wires, cables, cooling fans, cooling fan motors, and cabinets) can be subject to such vibration. Vibration can cause material fatigue, loose parts, and loose or broken connections, which can result in increased resistance, open circuits, and arcing. Increased circuit resistance can increase ohmic heating, open circuits may cause a loss of signal or sporadic operation, and arcing can cause accelerated corrosion. Vibration can also cause intermittent relay operation (chatter) when such operation is not intended.[4.1, 4.2, 4.4]

Dormancy (lack of operation) can cause binding of relays and circuit breakers due to component outgassing, material set, lubricant gelling, or adherence.[4.2]

Therefore, mechanical stressors have been determined to be applicable for battery chargers, inverters, and UPSs.

4.1.6 Chemical

Battery chargers and inverters are generally located in chemically benign environments outside of containment, and as such are not subject to environmental chemical stressors. However, use of improper cleaning solvents, detergents, compounds or oils on the charger/inverter subcomponents (transformers, circuit boards, circuit breakers, relay contacts,

wires, cables, and cooling fan motors) may attack the materials of construction, resulting in cracked insulation, cracked circuit board tracks, or corroded metal contacts.[4.1, 4.3]

Therefore, chemical stressors have been determined to be applicable for battery chargers, inverters, and UPSs.

4.1.7 Electrochemical

Electrochemical effects can occur in battery chargers and inverters at connection points where dissimilar metals are involved, causing galvanic corrosion which can result in signal degradation and potential ohmic heating. Susceptible locations include circuit board contacts and terminal connections.[4.1]

Therefore, electrochemical stressors have been determined to be applicable for battery chargers, inverters, and UPSs.

4.1.8 Contaminants (Fouling)

Although battery chargers are located in mild environments, dust and dirt may still be present, and can enter the cabinet through the louvered openings and/or fan inlet and build up on subcomponents. Susceptible subcomponents include inductors, relays, circuit breakers, SCRs, diodes, resistors, transistors, capacitors, surge suppressors, switches, potentiometers, circuit boards, connections, and cooling fan motors.

Dirt and dust buildup can affect the circuit impedance, and also create overheating of transformers, inductors, capacitors, silicon controlled rectifiers, diodes, relays, resistors, circuit boards, wires, cables, and cooling fan motors. The effects of circuit resistance changes are described above under electrical stressors. The effects of overheating are discussed above under thermal stressors.

Dirt and dust buildup can also lead to corrosion of contacts, increased friction, and binding in switches, relays, potentiometers, circuit breakers, and cooling fan bearings.

Therefore, contaminants have been determined to be applicable stressors for battery chargers, inverters, and UPSs.

4.2 Description of Applicable Aging Mechanisms

This section defines the aging mechanisms resulting from applicable stressors identified in Section 4.1. Precursors and manifestations, rate of aging, consequences, and mitigating aspects are covered. Once relevant aging mechanisms are defined, an assessment of significance is performed. This utilizes the data compiled and assessed in Sections 3.4 through 3.6, with emphasis on industry historical data and research compiled in Section 3.6. Aging mechanisms are then categorized as "potentially significant" or "nonsignificant." Many aging mechanisms only act at preferred locations, or in specific combinations/ synergies. Potentially significant mechanisms are examined in Section 5 against maintenance/testing/refurbishment/replacement programs used to detect and mitigate aging.

Age-related degradation means a change in a structure's or component's performance, or physical or chemical properties, resulting in whole or in part from one or more aging mechanisms. Aging can affect all structures and components to some degree. The rate, magnitude, or character of age-related degradation can change over time as a result of environmental conditions, service duty, or specific material performance. Existing regulatory and industry programs, and the consensus established by industry codes and standards, continue to address these parameters of aging mechanisms and the means of mitigating age-related degradation.

As defined in 10 CFR 54.3, age-related degradation is unique to license renewal when 1) its effects are different in character or magnitude after the term of the current operating license, or 2) its effects were not explicitly identified and evaluated for the period of extended operation and the evaluation found acceptable by the NRC, or 3) it occurs only during the period of extended operation. The provisions of 10 CFR 54.21(a)(5) require it to be demonstrated that age-related degradation unique to license renewal is addressed, or need not be addressed, in an effective program.

During the license renewal period, all relevant degradation mechanisms are investigated and then, either 1) their relative significance is determined with regard to required functions and margins, and the consequence of unmitigated degradation during the license renewal term, or 2) it is demonstrated that the relative significance of degradation mechanisms is not important because the periodicity and attributes of plant programs ensure detection and mitigation of the factors that contribute to aging, or 3) it is demonstrated that the design and operating features will maintain the required function of the system, structure, or component throughout the license renewal period, and an effective program is not required to address age-related degradation.

This guideline goes beyond this strict interpretation of 10 CFR 54.3, to evaluate all age-related degradation mechanisms for the entire plant operating period (current and renewal license). This provides suitable guidance of most benefit to safe and efficient power production. This guidance is essentially structured to satisfy criterion 2, by creating and implementing effective plant programs. It makes no distinction of whether an age-related degradation mechanism is, or is not, unique to license renewal.

The aging stressors considered in the evaluations have been described in Section 4.1. The structure or component design, constituent materials, and both the normal and abnormal stressors and environments, are considered when establishing the set of relevant mechanisms that could degrade the structure or component. The selection of the relevant mechanisms is also influenced by the review of industry experience (see Section 3.6). Any mechanisms which are not known to contribute to the age-related degradation of the structure or component are not listed in the set of relevant mechanisms, nor is the supporting justification for their exclusion provided in the evaluation.

Determining the significance of an aging mechanism for a structure or component is an integrated evaluation process. The relevant material considerations affecting the degradation processes are evaluated with the design and operational information, to understand the aging mechanisms, rate of degradation, and the consequences of degradation. The term "potentially significant" is applied because these evaluations typically do not result in closed-form solutions

or determinations. Age-related degradation is potentially significant when, if allowed to continue without the detection and mitigative measures of a plant program(s), the component or structure cannot be shown to be capable of performing its required function during the license renewal term. The effectiveness of the credited plant program(s) then requires further evaluation.

The significance of the relevant degradation mechanisms is determined by quantitative and/or qualitative methods if a plant-unique evaluation is applied. Where practical, potentially significant degradation mechanisms are expressed in terms of the degradation sites, susceptible constituent components or parts, root cause and physical manifestation of the degradation, and projected effects of degradation on the structure or component functions.

For some structures and components, the evaluation demonstrates that age-related degradation does not lead to a significant reduction in capability of the structure or component to perform the functions defined as important to license renewal. It is verified that the design provisions and/or operating requirements adequately accommodate the degradation. These structures or components are excluded from further consideration of age-related degradation, and the justification for this determination is documented in this report.

4.2.1 Relevant Aging Mechanisms Identified for Evaluation

This section describes aging degradation mechanisms, and assesses the potential relevance of these mechanisms to battery charger, inverter, and UPS components. The aging mechanisms are determined by considering the design of the components, their service and operating experience, and relevant industry information and reports. The degradation mechanisms to be evaluated are:

- Corrosion
- Fatigue
- Wear
- Electronic Drift
- Thermal Aging
- Setpoint Drift
- Radiation
- Fouling
- Material Set

Table 4-2 summarizes the relevancy of these mechanisms to the battery charger, inverter, and UPS subcomponents respectively. General definitions of these aging mechanisms follow in this section. Section 4.2.2 then evaluates the significance of these mechanisms for the subcomponent types.

Table 4-2. Summary of Battery Charger/Inverter/UPS Subcomponent Stressors, Aging Mechanisms, and Operational Effects

Subcomponent	Applicable Stressors	Aging Mechanisms	Operational Effects
Transformers	Elevated Ambient Temperature Low Ambient Temperature Ohmic Heating Temperature Gradients Temperature Cycling High Relative Humidity Applied Overvoltage Voltage/Inductive Surges Overcurrent Conditions External Transients Short Circuits Flashover Vibration Cleaning Solvents Dirt/Dust Accumulation	Thermal Aging Thermal Stress Thermal Fatigue Corrosion Fatigue Fouling	Transformer Failure
Inductors	Elevated Ambient Temperature Ohmic Heating Temperature Cycling High Relative Humidity Applied Overvoltage Voltage/Inductive Surges Overcurrent Conditions External Transients Short Circuits Flashover Vibration Cleaning Solvents Dirt/Dust Accumulation	Thermal Aging Thermal Fatigue Corrosion Fatigue Fouling	Inductor Failure
Relays	Elevated Ambient Temperature Ohmic Heating Temperature Gradients High Relative Humidity Applied Overvoltage Applied Undervoltage Voltage/Inductive Surges Overcurrent Conditions External Transients Arcing Short Circuits Flashover Routine Operation Friction Vibration Dormancy (Lack of Operation) Cleaning Solvents Dirt/Dust Accumulation	Thermal Aging Thermal Stress Corrosion Wear Electronic Drift Fatigue Material Set Fouling	Coil Failure Contact Failure Binding/Misoperation Setpoint Drift (Timing and Sensing Relays) Chatter

Table 4-2. Summary of Battery Charger/Inverter/UPS Subcomponent Stressors, Aging Mechanisms, and Operational Effects (continued)

Subcomponent	Applicable Stressors	Aging Mechanisms	Operational Effects
Capacitors	Elevated Ambient Temperature Ohmic Heating Temperature Gradients Applied Overvoltage Voltage/Inductive Surges Overcurrent Conditions External Transients Short Circuits Vibration Dirt/Dust Accumulation	Thermal Aging Thermal Stress Fatigue Fouling	Capacitor Failure
Silicon Controlled Rectifiers	Elevated Ambient Temperature Ohmic Heating Temperature Gradients Applied Overvoltage Voltage/Inductive Surges Overcurrent Conditions External Transients Short Circuits Vibration Dirt/Dust Accumulation	Thermal Aging Thermal Stress Fatigue Fouling	SCR Failure
Diodes	Elevated Ambient Temperature Ohmic Heating Applied Overvoltage Overcurrent Conditions Short Circuits Vibration Dirt/Dust Accumulation	Thermal Aging Fatigue Fouling	Diode Failure
Surge Suppressor	Elevated Ambient Temperature Ohmic Heating Temperature Gradients Applied Overvoltage Voltage/Inductive Surges Overcurrent Conditions External Transients Short Circuits Vibration Dirt/Dust Accumulation	Thermal Aging Thermal Stress Thermal Fatigue Electronic Drift Fatigue Fouling	Surge Suppressor Malfunction Surge Suppressor Failure

Table 4-2. Summary of Battery Charger/Inverter/UPS Subcomponent Stressors, Aging Mechanisms, and Operational Effects (continued)

Subcomponent	Applicable Stressors	Aging Mechanisms	Operational Effects
Circuit Boards Resistors Transistors	Elevated Ambient Temperature Ohmic Heating Temperature Gradients Temperature Cycling High Relative Humidity Applied Overvoltage Voltage/Inductive Surges Overcurrent Conditions External Transients Short Circuits Vibration Cleaning Solvents Bimetallic Contact Dirt/Dust Accumulation	Thermal Aging Thermal Stress Thermal Fatigue Electronic Drift Corrosion Fatigue Fouling	Circuit Board Output Changes Circuit Board Failure Signal Degradation
Circuit Breakers	High Relative Humidity Voltage/Inductive Surges External Transients Arcing Flashover Routine Operation Fault Interruption Friction Vibration Dormancy (Lack of Operation) Cleaning Solvents Dirt/Dust Accumulation	Corrosion Fouling Thermal Aging Wear Fatigue Material Set	Contact Degradation Restrike/Shorting Binding/Misoperation
Switches	High Relative Humidity Arcing Flashover Routine Operation Friction Vibration Cleaning Solvents Dirt/Dust Accumulation	Corrosion Thermal Aging Fouling Wear Fatigue	Contact Degradation/ Failure Binding/Misoperation/ Failure
Potentiometers	High Relative Humidity Routine Operation Vibration Cleaning Solvents Dirt/Dust Accumulation	Corrosion Wear Electronic Drift Fatigue Fouling	Contact Degradation Potentiometer Failure

Table 4-2. Summary of Battery Charger/Inverter/UPS Subcomponent Stressors, Aging Mechanisms, and Operational Effects (continued)

Subcomponent	Applicable Stressors	Aging Mechanisms	Operational Effects
Wires and Cables	Elevated Ambient Temperature Ohmic Heating High Relative Humidity Applied Overvoltage Voltage/Inductive Surges Overcurrent Conditions External Transients Short Circuits Routine Operation Vibration Cleaning Solvents Dirt/Dust Accumulation	Thermal Aging Corrosion Fatigue Fouling	Wire and Cable Failure
Cooling Fans	Routine Operation High Relative Humidity Friction Vibration	Corrosion Wear	Degraded Performance/ Failure
Cooling Fan Motors	Elevated Ambient Temperature Ohmic Heating High Relative Humidity Routine Operation Friction Vibration Dirt/Duct Accumulation	Thermal Aging Corrosion Wear Fouling Fatigue	Degraded Performance/ Failure
Cabinet	High Relative Humidity	Corrosion	Loss of Structural Integrity

4.2.1.1 Corrosion

Corrosion includes the damage due to long-term electrical contact pitting and oxidation, resulting in high contact impedance, heat build-up and signal transmission failure. Corrosion may also include chemical changes in exposed metal and organic materials due to the general environment. Contributing degradation factors are contamination, excessive humidity, cleaning solvents, and temperature. Corrosion may generally be found in circuit breakers, switches, relays, transformers, potentiometers, surge suppressors, circuit boards, electronics, cooling fans, cooling fan motors, and cabinets.

4.2.1.2 Fatigue

Fatigue is defined as structural deterioration of material that occurs due to repeated stress/strain cycles of sufficient magnitude, caused by fluctuating loads or temperatures.

Repeated cyclic loading causes crack initiation at the most highly affected locations. Subsequent cyclic loading and/or thermal stress will likely result in crack growth. Contributors to fatigue cracking consist of material, structural and environmental factors, such as operating and/or residual stresses, loading frequency, surface roughness, surface oxidation, and chemical attack. The time between localized fatigue crack initiation and eventual detection of the growing crack may represent a large portion of component life. In addition, normal plant operation or ferromagnetic resonance of magnetic materials may induce mechanical vibration of electrical components, which may result in fatigue (loose parts, wiring connections) and cause a loss of signal or sporadic operation. Fatigue may be found in circuit breakers, switches, relays, potentiometers, transformers, inductors, surge suppressors, circuit boards, electronics, cooling fans, and cooling fan motors.

4.2.1.3 Wear

Wear is the process of relative movement between contacting parts of a component, gradually deteriorating the contact surfaces. Degradation from wear is time-dependant in nature. Wear occurs in circuit breakers, switches, relays, potentiometers, cooling fans, and cooling fan motors.

Wear is not relevant to static switches since there is no relative movement between parts. Therefore, further evaluation is not required for wear of the static transfer switch.

4.2.1.4 Electronic Drift

Electronic drift is a result of time-dependent changes in electronic materials, and affects electronic circuitry, resulting in loss of calibration accuracy and subsequent readjustments. Over time, electronic components may drift out of their adjustable bandwidth range, requiring replacement of the component. Electronic drift occurs in adjustable relays, potentiometers, surge suppressors, circuit boards, and electronics.

4.2.1.5 Thermal Aging

Long-term high temperatures can cause embrittlement or loss of plasticity, and loss of dielectric strength of insulating materials, in electrical equipment. Differential temperatures can cause binding and subsequent wear. Degradation from thermal aging is time-dependent in nature. Thermal aging may occur in transformers, inductors, relays, capacitors, SCRs, diodes, surge suppressors, circuit boards, electronics, circuit breakers, switches, and cooling fan motors.

Thermal aging is not relevant for metallic components such as cabinets existing in mild environments. Therefore, further evaluation is not required for thermal aging of these components.

4.2.1.6 Setpoint Drift

Setpoint drift is not a defined "age-related" degradation mechanism, but is the result of corrosion, wear, fatigue, and thermal aging working independently or synergistically over time.

It is considered separately because it may be a combination of mechanical and electronic degradation.

Setpoint drift is manifested during calibration and/or surveillance testing, and may or may not be reversible. Further evaluation of the effects of setpoint drift is considered with corrosion, wear, fatigue, and thermal aging.

4.2.1.7 Radiation

Exposure to high or sustained levels of radiation may damage nonmetallics such as insulating material. The effects of radiation may cause nonmetallics to harden and crack. Radiation stress effects are similar to the effects of heat, and will be observed as part of visual inspections during regularly scheduled calibration and surveillance activities.

Components which may be affected by radiation would be those components included in the Equipment Qualification Program, which may be subject to radiation under accident conditions. Battery chargers, inverters and UPS systems are located in mild environments, and would not be subjected to radiation even under accident conditions. Therefore, further evaluation of radiation effects on these components is not required.

4.2.1.8 Fouling

Fouling, as it pertains to electrical equipment, is defined as the accumulation of foreign material, such as dust or dirt, from the environment. Such accumulation could potentially reduce the function of a component over time. Fouling can occur in magnetic components, relays, capacitors, SCRs, diodes, circuit breakers, switches, potentiometers, surge suppressors, circuit boards, electronics, and cooling fan motors.

4.2.1.9 Material Set

Material set occurs in organic materials used as lubricants, and is defined as hardening, gelling, or adherence of the organic material to adjacent materials. Material set can cause binding or misoperation of relays and circuit breakers.

4.2.2 Significance of Relevant Aging Mechanisms

The aging mechanisms from Section 4.2.1 that were determined to be relevant for battery charger, inverter, and UPS subcomponents are:

- Corrosion
- Fatigue
- Wear
- Electronic Drift
- Thermal Aging
- Fouling
- Material Set

The following subsections assess the potential significance of these relevant aging mechanisms with respect to the battery charger and inverter/UPS subcomponents. The potential significance is determined based on the ability of the battery charger and inverter/UPS being able to perform its required functions, assuming the degradation mechanism is allowed to continue unmitigated.

4.2.2.1 Corrosion

Corrosion as a potentially significant degradation mechanism has been identified in the Section 3.6 operating experience evaluation.

Circuit Breakers, Switches, Relays, and Potentiometers — Corrosion can occur in the contacts of circuit breakers, switches, relays, and potentiometers due to electrical contact pitting, and can be aggravated by excessive humidity, cleaning solvents, dirt accumulation, and high temperature. Corrosion can result in high contact impedance, heat build-up, and signal transmission failure. Therefore, corrosion is a potentially significant degradation mechanism for circuit breakers, switches, relays, and potentiometers.[4.1, 4.3]

Transformers — Temperature and moisture create environmental stresses on transformers which could result in corrosion of the windings. A reduction of the dielectric strength or insulation resilience may occur, causing the transformer to ultimately fail.[4.6] Therefore, corrosion is a potentially significant degradation mechanism for transformers.

Circuit Boards and Electronics — Temperature and moisture create environmental stresses, and deposited contaminants may affect electronics such as printed circuit boards, resistors, and capacitors, resulting in corrosion of these components. The corrosion may lead to open/short circuits at the terminals or on the board, and loss of signal or sporadic operation.[4.1] Therefore, corrosion is a potentially significant degradation mechanism for circuit boards and electronics.

Wires and Cables — Moisture from high humidity entering cables as a result of cracks in or diffusion through the cable jackets, splices, plug connectors, or the exposed end of the cable, may initiate corrosion of shields or conductor strands. Degradation of the conductor will eventually cause the functional failure of the circuit.[4.6] Cable conductor terminations may deteriorate if they are improperly formed or inadequately protected against moisture and corrosive conditions. In such cases, the resistance of the junction may increase, preventing signal transmission, or, in the presence of high currents, may cause overheating that could result in damage to the conductor or insulation.[4.4] Therefore, corrosion is a potentially significant degradation mechanism for wires and cables.

Cooling Fans and Cooling Fan Motors — The moisture in the air moved by the fans may condense and lead to corrosion of the housings and other metallic parts. Although the housing is galvanized or painted, over time oxidation corrosion can affect its integrity in areas where the coating has thinned or flaked. Oxidation corrosion at motor electrical terminations can increase the contact resistance. Vibration may promote the problem by loosening the connections. Localized heating and more oxidation effects will result. Although this is a very slow process, particularly when the connection is properly installed, severe oxidation corrosion over time may

result in contact surface arcing and burnout. Therefore, corrosion is a potentially significant degradation mechanism for cooling fans and cooling fan motors.[4.1, 4.7]

Cabinet — The battery charger and inverter/UPS cabinets are generally located in mild environments. These metallic enclosures are typically protected by coatings and replaceable desiccant pads. However, over time, untreated protective coating can degrade and give way to oxidation corrosion. Desiccant pads may become nonfunctional. Therefore, corrosion is a potentially significant degradation mechanism for cabinets.

4.2.2.2 Fatigue

Fatigue failures and loose connections as potentially significant failure causes have been identified in the Section 3.6 operating experience review.

Circuit Breakers, Switches, Relays, and Potentiometers — Fatigue may occur in these components due to high cyclic operation and vibration, and can result in contact degradation, loose connections, reduced force output (circuit breakers) and component failure.[4.3] Therefore, fatigue is a potentially significant degradation mechanism for circuit breakers, switches, relays, and potentiometers.

Transformers, Inductors, Capacitors, SCRs, Diodes, Surge Suppressors, Circuit Boards, Electronics, Wires, and Cables — Ferromagnetic resonance generated by magnetic components and transformers can induce high frequency vibration of these components inside the cabinet. Mechanical vibration of these components can also be caused by seismic forces or by forces transmitted through plant piping or structures. Such vibration may result in fatigue (loose parts, wiring connections) of these components. Open circuits may cause a loss of signal or sporadic operation.[4.1] Bending and pulling of wire and cable terminations, which happens most often during periodic maintenance, can cause fatigue. Separating plug-type connectors also involves bending or pulling the cables at the connector interface. Where repeated bending or rough handling of such connectors occur, conductor or insulation failure is possible.[4.4] Therefore, fatigue is a potentially significant degradation mechanism for these subcomponents.

Cooling Fans and Cooling Fan Motors — The fan assembly components potentially affected by vibration-induced fatigue are the rotor, shaft, and motor mounts. Vibration for these components is often associated with sheave alignment and dynamic imbalances of the motor and fan. Motors in general are rigidly designed with large safety margins of mechanical strength. Therefore, fatigue of these small motors' frames, shafts, and large internals is not significant. However, fatigue of the motor mounts is a potentially significant degradation mechanism.[4.1, 4.7]

4.2.2.3 Wear

Wear as a potentially significant degradation mechanism has been identified after long periods of in-service operation in the Section 3.6 data analysis.

Circuit Breakers, Switches, Relays, and Potentiometers — Wear manifests itself on circuit breakers, switches, relays, and potentiometers in the form of physical deterioration due to the

cyclic operation caused by routine operation and periodic testing and adjustment. Wear is the result of rubbing surfaces, binding of linkages, erosion of contact and metal surfaces, burning of arc chutes (breakers), and a loss of adjustment of various components, such as control devices and alignment of poles (breakers).[4.3] Therefore, wear is a potentially significant degradation mechanism for circuit breakers, switches, relays, and potentiometers.

Cooling Fans and Cooling Fan Motors — Parts of the fan assemblies susceptible to wear are the shaft and bearings. These are contacting parts with considerable relative motion. Therefore, wear is potentially significant for the fan shafts and bearings. Motor bearings are also subject to wear due to misalignment, imbalances, and inherent eccentricity of the rotor. On DC motors, the brushes and commutator are also subject to wear. Therefore, wear is potentially significant for fans and fan motors.[4.7, 4.8]

4.2.2.4 Electronic Drift

Electronic drift is an expected mechanism in the electronic components and assemblies of battery chargers and inverters. Failures associated with electronics dominate the population of all age-related failures reviewed in Section 3.6.

Relays — Relays subject to electronic drift are timing and sensing relays, which after a predetermined time or process level (voltage or current) initiate a trip. Normal and abnormal operation of relays can cause aging degradation. Each time relays are in operation or change state, setpoint drift can occur.[4.1, 4.3] Therefore, electronic drift is a potentially significant degradation mechanism for relays.

Potentiometers — A significant number of NPRDS-reported charger failures have been attributed to setpoint drift of the potentiometers (see Section 3.6). Therefore, setpoint drift is a potentially significant degradation mechanism for potentiometers.

Surge Suppressors, Circuit Boards, and Electronics — Electronic components exhibit a normal drift in performance characteristics and calibration due to changes in material properties over time. Abnormal operations, such as loss of power, high/low voltage supply levels, and current/voltage surges, may lead to accelerated electronic drift. This degradation in a device can generally be corrected by recalibration of the adjustable parameters of the electronic circuit. Additionally, a large number of reported circuit board failures was attributed to electronic drift (see Section 3.6). Therefore, electronic drift is a potentially significant degradation mechanism for these components.[4.1]

4.2.2.5 Thermal Aging

Thermal aging as a potentially significant degradation mechanism has been identified in the Section 3.6 operating experience review.

Transformers — High applied voltage or turn-to-turn shorts are two potential initiators of high internal temperatures experienced in transformers. Insulation between windings, or between winding and core or ground, can fail in service when subjected to high voltage stress. The effect is to cause local heating and deterioration of the material, and results in dielectric

failure.[4.6] Therefore, thermal aging is a potentially significant degradation mechanism for transformers.

Circuit Breakers — Thermally-induced stresses in circuit breakers are caused primarily by resistive heating of current carrying conductors. Thermally induced stresses are from two main sources: 1) continuous load components coupled with poor contact mating, and 2) fault currents that are interrupted by the breaker.

If the contacts do not mate properly, the resistance at the point of contact increases and ohmic heating may result, which will cause further contact damage. If uncorrected, the heating will damage the contact support insulation, and a phase-to-ground fault may occur inside the circuit breaker.

The key function of a circuit breaker is to interrupt fault current on the associated power circuit. Even though the circuit breaker is designed to interrupt a fault within its rating, a significant amount of damage can occur during fault interruption. The temperatures and currents can damage the contacts as well as the arc chute materials.[4.3] Therefore, thermal aging is a potentially significant degradation mechanism for circuit breakers.

Relays — One of the prominent stresses in electrical relays results from coil heating due to continuous, long-term energizing of the relay coil. The effect on the coil and other nonmetallic materials is material degradation caused by thermally accelerated chemical reactions, which reduces dielectric strength.

Cabinets containing many continuously energized relays may have an internal temperature that is 11°-22°C (52°-72°F) above the room ambient. These elevated temperatures will accelerate the deterioration of the relay components.[4.3] Therefore, thermal aging is a potentially significant degradation mechanism for relays.

Inductors, Capacitors, Diodes, Surge Suppressors, Circuit Boards, and Electronics — Thermal stresses are a major failure contributor in inductors, capacitors, surge suppressors, printed circuit boards, and other accessories (i.e., diodes, transistors, resistors). Heat, due to overcurrent conditions and internal stresses, causes loss of capacitance and electrolyte in capacitors, dielectric breakdown in diodes and inductor insulation, change of resistance values in resistors, and cracking in the solder of circuit lines, which result in a change of output signals. Failure of these subcomponents may result in failure of the equipment. Therefore, thermal aging is a potentially significant degradation mechanism for inductors, capacitors, diodes, surge suppressors, circuit boards, and electronics.[4.1]

SCRs — Voltage transient sources include flux variations in inductive loads or a supply transformer, and capacitive load changes externally and internally. Internal circuit capacitance and inductance resulting in voltage transients can occur when the SCR is switching from its low to high impedance state. Voltage transients and overtemperature conditions could contribute to premature failure of the SCR.[4.1] Therefore, thermal aging is a potentially significant degradation mechanism for SCRs.

Switches — Thermal aging will result from current interruption during normal operation, and contact heating due to current passing through the mating point. Any oxidation or pitting of the contacts from existing corrosion will cause an increase in contact resistance and generate heat. The heat will affect the nonmetallic parts of the switch supporting the contacts. Thermal aging will be manifested as hot spots and deformation of the nonmetallics, which may lead to degraded switch performance. Therefore, thermal aging is a potentially significant degradation mechanism for switches.

Wires and Cables — Thermal effects on wire and cable insulation may lead to embrittlement or softening (butyl rubber) of the insulation, which promotes development of current leakage paths. Embrittlement eventually leads to cracking, especially in bends, and softening may lead to a conductor bleeding through its insulation. There are two sources of cable insulation heating: ohmic heating caused by current flow in the conductor, and heating from the cable's environment.[4.9] The degraded insulation causes circuit failure by conductor-to-conductor shorts or conductor-to-ground shorts. Therefore, thermal aging is a potentially significant degradation mechanism for wire and cables.

Cooling Fan Motors — Thermal aging degradation of the motor winding's insulation is caused by high temperature, motor starts, extended operation, or high ambient temperature.[4.7, 4.8] The condition of a motor winding's insulation material is measured by its dielectric strength. The dielectric strength decreases over time, and this decrease can be accelerated by the presence of moisture, high temperature, certain chemicals, and radiation.[4.8] These conditions also cause damage to the end rings, brushes, and commutator of a DC motor, resulting in degraded performance. Therefore, thermal aging is a potentially significant degradation mechanism for the cooling fan motors.

4.2.2.6 Fouling

Fouling has not been identified as a significant, discrete failure cause or aging mechanism in the Section 3.6 operating history review except for potentiometers. However, some utility questionnaire respondents indicated that localized fouling from seasonal insects or airborne "seeds" or dust may be significant.

Transformers, Inductors, SCRs, Diodes, Capacitors, Surge Suppressors, Circuit Boards, Electronics, Wires, and Cables — Fouling results from the accumulation of insects, dirt, and dust, and can reduce the amount of heat dissipated from these subcomponents. Fouling can cause overheating of these subcomponents, which can lead to loss of capacitance and electrolyte in capacitors, dielectric breakdown in SCRs and diodes, dielectric breakdown of the insulation in transformers, inductors, wires, and cables, change of resistance values in resistors, and cracking in the solder of circuit lines, which result in a change of output signals. Failure of these subcomponents may result in failure of the equipment. Therefore, fouling is a potentially significant degradation mechanism for transformers, inductors, capacitors, SCRs, diodes, surge suppressors, circuit boards, electronics, wires, and cables.

Relays, Circuit Breakers, Switches, and Potentiometers — Fouling of relay coils can cause overheating of the coil and resultant dielectric breakdown of the coil insulation. Dirt and dust accumulation on the contacts of relays, circuit breakers, switches, and potentiometers can increase

resistance, causing overheating and increased pitting corrosion due to poor contact. Fouling of switches, relays, and circuit breakers can also cause increased friction and misoperation such as binding or restrike in circuit breakers. Fouling was identified as a significant contributor to potentiometer failures reported in the NPRDS database (see Section 3.6). Therefore, fouling is a potentially significant degradation mechanism for relays, circuit breakers, switches, and potentiometers.

Cooling Fan Motors — In the case of an open drip-proof type enclosure, the motor insulation is susceptible to degradation from deposit accumulation and fouling, which reduces insulation resistance and affects heat dissipation. Although the environment is generally not dusty, over a long period of time, dust accumulation can still be a potential threat. Deposits are not a potentially significant problem for a totally enclosed motor. Ventilation blockage of louvered inlets from deposit accumulation is less likely, and can be easily discovered and cleaned. Therefore, fouling is a potentially significant degradation mechanism for open motors.

4.2.2.7 Material Set

Relays and Circuit Breakers — Material set occurs when the organic materials used as lubricants in these subcomponents harden, gel, or adhere to adjacent materials. Such a situation can cause binding of the relays and circuit breakers, resulting in faulty operation. Therefore, material set is a potentially significant degradation mechanism for relays and circuit breakers.[4.3]

4.2.3 Aging Mechanism Synergies and Dependencies

Aging mechanisms were generally evaluated in Sections 4.2.2.1 through 4.2.2.6 as if they manifested individually on a component. Where a direct cause/effect link existed between two mechanisms, this was also discussed. Both theoretical considerations and field history indicate that the effects of two or more aging mechanisms acting simultaneously on a component may modify the degradation and failure. The time duration for significant degradation to occur under these conditions will be less than the duration for each individually acting aging mechanism.

Setpoint drift is a common synergistic mechanism involving wear, fatigue, corrosion and/or thermal aging acting two or more in combination. Setpoint drift is an expected occurrence, and is planned for in the effective plant programs discussed in Section 5. The failure history data presented in Section 3.6 generally does not distinguish between "electronic drift," "electronic failure," and "setpoint drift," so it is not possible to determine from available data at what rate the synergistic setpoint drift mechanism is occurring, relative to the singular electronic drift mechanism.

Fouling is a significant synergistic contributor to the severity and rate of other aging mechanisms, and the need for its mitigation has been recognized through the extent and periodicity of cleaning and vacuuming preventive maintenance programs addressed in Section 5.

Surface discontinuities caused by localized corrosion can increase the peak stresses caused by cyclic loads. This combination of aging mechanisms termed corrosion fatigue is particularly applicable to chargers and inverters exhibiting significant ferromagnetic resonance vibration.

4.3 Summary

Table 4-3 summarizes the significance of aging mechanisms for battery charger and inverter/UPS subcomponents by materials and/or constituent parts. This table also summarizes conclusions presented in Section 3.6 on industry operability data, which consists of NRC IE documents, responses to various utility questionnaires, and NPRDS/LER data.

The industry operability data also revealed that nuclear plant battery chargers, inverters, and UPSs have similar subcomponents, operating environments, stressors, and aging mechanisms. Therefore, potentially significant aging mechanism/component combinations are evaluated in Section 5 for the three component groups as a whole, to determine the effective programs to detect and mitigate these aging mechanisms.

Table 4-3. Summary of Significance of Aging Mechanisms for Battery Charger, Inverter, and UPS Subcomponents

Subcomponent	Aging Mechanism						
	Thermal Aging	Electronic Drift	Corrosion	Fouling	Material Set	Fatigue	Wear
Transformer	PS Insulation	NR	PS Windings	PS Heat Removal	NR	PS Connections Loose Parts	NR
Inductor	PS Insulation	NR	PS Windings	PS Heat Removal	NR	PS Connections Loose Parts	NR
Relay	PS Coil Nonmetallics	PS Timing Relays Sensing Relays	PS Contacts	PS Coils Contacts	PS Lubricants	PS Contacts Connections	PS Linkages Contacts
Capacitor	PS Electrolyte Nonmetallics	NR	NR	PS Heat Removal	NR	PS Connections Loose Parts	NR
SCR	PS Nonmetallics	NR	NR	PS Heat Removal	NR	PS Connections Loose Parts	NR
Diode	PS Dielectric Material	NR	NR	PS Heat Removal	NR	PS Connections Loose Parts	NR
Surge Suppressor	PS Dielectric Material Capacitors Resistors	PS Adjustable Parts	NR	PS Heat Removal	NR	PS Connections Loose Parts	NR
Circuit Board/ Electronics	PS Circuit Lines Capacitors Resistors	PS Adjustable Parts	PS Circuit Boards Resistors Capacitors Terminals	PS Heat Removal	NR	PS Connections Loose Parts	NR

Table 4-3. Summary of Significance of Aging Mechanisms for Battery Charger, Inverter, and UPS Subcomponents (continued)

Subcomponent	Aging Mechanism						
	Thermal Aging	Electronic Drift	Corrosion	Fouling	Material Set	Fatigue	Wear
Circuit Breaker	PS Contacts Insulation Arc Chute	NR	PS Contacts	PS Contacts	PS Lubricants	PS Contacts Connections	PS Linkages Contacts Arc Chutes
Switch	PS Nonmetallics	NR	PS Contacts	PS Contacts	NR	PS Contacts Connections	PS Linkages Contacts
Potentiometer	NR	PS Wiper	PS Contacts	PS Contacts	NR	PS Contacts Connections	PS Linkages Contacts
Internal Wires and Cables	PS Insulation	NR	PS Shields Conductor Strands Connections	PS Heat Removal	NR	PS Connections Insulation	NR
Cooling Fans	NR	NR	PS Housing Metallic Parts	NR	NR	NS	PS Shaft Bearings
Cooling Fan Motors	PS Insulation Brushes End Rings Commutator	NR	PS Housing Metallic Parts Terminals Contacts	PS Insulation	NR	PS Motor Mounts	PS Bearings Brushes Commutator
Cabinet	NR	NR	PS Housing	NR	NR	NR	NR

PS = Aging mechanism is potentially significant for subcomponent

NS = Aging mechanism is not significant for subcomponent

NR = Aging mechanism is not relevant for subcomponent

4.4 References

- 4.1 NUREG/CR-4564, Operating Experience and Aging-Seismic Assessment of Battery Chargers and Inverters, Brookhaven National Laboratory, June 1986.
- 4.2 NUREG-1299, Standard Review Plan for the Review of License Renewal Applications for Nuclear Power Plants, U.S. Nuclear Regulatory Commission, Draft for Comment, November 1990.
- 4.3 NUREG/CR-4715, An Aging Assessment of Relays and Circuit Breakers and System Interactions, Brookhaven National Laboratory, June 1987.

- 4.4 NUREG/CR-4257, Inspection, Surveillance, and Monitoring of Electrical Equipment Inside Containment of Nuclear Power Plants - With Applications to Electrical Cables, Volume 1-2, Oak Ridge National Laboratory, August 1985.
- 4.5 EPRI EL-5036, Power Plant Electrical Reference Series, Vol. 14, Electrical Noise Reduction, Electric Power Research Institute, 1987.
- 4.6 NUREG/CR-5053, Operating Experience and Aging Assessment of Motor Control Centers, Brookhaven National Laboratory, July 1988.
- 4.7 NUREG/CR-4156, Operating Experience and Aging-Seismic Assessment of Electric Motors, Brookhaven National Laboratory, June 1985.
- 4.8 EPRI NP-3887, Life Expectancy of Motors in Mild Nuclear Plant Environments, Electric Power Research Institute, February 1985.
- 4.9 NUREG/CR-4731, Residual Life Assessment of Major Light Water Reactor Components - An Overview, Volume 2, Idaho National Engineering Laboratory, November 1989.

5. EFFECTIVE MANAGEMENT OF AGING MECHANISMS

An effective program for addressing battery charger, inverter, and UPS degradation will provide for both understanding and managing the aging mechanisms. Key elements of an effective program address the technical aging issues and potential consequences of the aging process being mitigated.

Aging mechanisms and their effects must be understood with sufficient accuracy and detail to provide the basis for developing and implementing aging management strategies that address actual or potential root causes of equipment failures. The requisite understanding may be either empirical or mechanistic, depending on the nature and potential consequences of a particular aging mechanism. An understanding of degradation requires a detailed awareness of equipment design, fabrication, installation, testing, inservice operation, and maintenance cycles. Degradation of battery chargers, inverters, and UPSs is a time dependent phenomenon that depends on the interactions of materials with environmental and operational stressors.

The programs discussed in this AMG are suggested and do not exclude other methods. They are meant to be guidelines and offer alternatives, and can be used in different combinations to create plant-specific effective programs.

5.1 Generic Elements of an Effective Aging Management Program

The equipment evaluated in this AMG must continue to safely and reliably function throughout its service life. Degradation of equipment is a regulatory concern when the equipment normally functions to ensure plant safety, and the degradation progresses to the point of impaired safety performance.

The License Renewal Rule[5.1] paragraph 54.21, requires that certain nuclear plant components, including battery chargers, inverters, and UPSs, be subject to programs that effectively manage component degradation and their associated aging mechanisms. Guidance is also provided in the draft Standard Review Plan for license renewal.[5.2] The Maintenance Rule[5.3] requires that nuclear plant components, including chargers, inverters, and UPSs, meet specified performance parameters. In addition, quality assurance criteria[5.4] require development and implementation of programs to ensure that conditions adverse to quality, including degraded charger, inverter, or UPS performance, are promptly identified and corrected.

Criteria have been established for determining if a plant program is effective for detecting and mitigating the effects of aging. These criteria are provided in Reference 5.1 and state that a program is effective if:

- The program is documented, its implementing procedures are approved by on-site review committees, and it is implemented in accordance with plant administrative procedures, and
- The program procedures ensure that the component's required functions are properly addressed considering the effects of age-related degradation, as appropriate, and

- The program establishes specific acceptance criteria against which the need for corrective action is to be evaluated, and requires timely corrective actions to be taken when the acceptance criteria are not met.

Reference 5.3 states in part under paragraph [A] [1] "Each holder of an operating license . . . shall monitor the performance or condition of SSCs . . . in a manner sufficient to provide reasonable assurance that SSCs . . . are capable of fulfilling their intended functions."

Paragraph [A] [2] states in part "Monitoring . . . is not required where it has been demonstrated that the performance or condition of an SSC is being effectively controlled through the performance of appropriate preventive maintenance, such that the SSC remains capable of performing its intended function."

The three criteria for determining program effectiveness are broken down into distinct categories. The following provides further guidance for each category to determine if a program satisfies the criteria.

5.1.1 Program is Documented

The criterion for a program to be documented satisfies 10 CFR 50 Appendix B - Quality Assurance Criteria which states in part "Every applicant for an operating license is required to include, in its final safety analysis report, information pertaining to the managerial and administrative controls to be used to assure safe operation." Therefore, a program being documented means that specific commitments have been and are included on the respective plant docket. Docketed commitments are included in the updated final safety analysis report, responses to Generic Letters, I.E. Bulletins, I.E. Notices, Orders, NUREGs, 10 CFR 50.59 evaluations, notices of violations, open items, etc., and any other programmatic or procedural commitment made to ensure compliance with the Code of Federal Regulations.

5.1.2 Program Implementing Procedures Approved by On-Site Review Committee and Program Implemented Via Administrative Procedures

These two criteria for procedural approvals and administration of the program also satisfy 10 CFR 50 Appendix B. Item I. - *Organization of this Appendix* states in part "the authority and duties of persons and organizations performing activities affecting the safety related functions of structures, systems, and components shall be clearly established and delineated in writing." This Appendix further states in Item II - *Quality Assurance Program*, that "This program shall be documented by written policies, procedures, or instructions and shall be carried out throughout plant life in accordance with those policies, procedures, or instructions."

Each program must be documented with written policies (i.e., administrative procedures) and the program implementing procedures must be reviewed and approved by on-site review committees to ensure that activities affecting the required function of battery chargers, inverters, and UPSs are correctly performed.

5.1.3 Component's Required Functions Properly Addressed

Each charger, inverter, or UPS evaluated in this guideline provides a support function to prevent or mitigate the consequences of postulated accidents that could cause undue risks to the health and safety of the public. Methods by which each component accomplishes this action is termed its required function. A charger, inverter, or UPS may have only one or several required functions.

The significant required function(s) for each charger, inverter, or UPS are identified in the program implementing procedures. The scope and content of all program implementing procedures credited for effective management of aging are reviewed to ensure that aging mechanisms and degradation, affecting the capability of the equipment to satisfy its required function(s), are adequately detected and mitigated.

5.1.4 Age-Related Degradation Effects Properly Addressed

All aging mechanisms occurring to chargers, inverters, and UPSs will manifest and progress at different rates, and are affected by many variables such as material composition, operating service conditions, environmental parameters, geometric configuration, etc. As such, program implementing procedures must be performed at a frequency commensurate with the rate of aging, to ensure detection and mitigation of degradation. Detection and mitigation of degradation provides assurance that the equipment's required function will not be compromised during its service life. Inspection, test, replacement, and refurbishment procedures are performed at frequencies which are based on equipment qualification requirements, regulatory specifications, vendor recommendations, industry experience, observations by knowledgeable plant personnel, etc. and can be adjusted as experience dictates.

5.1.5 Acceptance Criteria Established to Determine Need for Corrective Action, Corrective Actions Specified, and Timely Action Taken

These three criteria for determining program effectiveness also satisfy 10 CFR 50 Appendix B. Item V states in part that "Instructions, procedures, or drawings shall include appropriate qualitative and quantitative acceptance criteria for determining that important activities have been satisfactorily accomplished." Item XVI, *Corrective Action*, states that "Measures shall be established to assure that conditions adverse to quality are promptly identified and corrected."

All program implementing procedures shall contain acceptance criteria in the form of recorded data, documented observances, procedural step signoffs, etc. to demonstrate that activities performed on chargers, inverters, and UPSs for detecting and mitigating degradation have been either satisfactorily accomplished, or corrective actions identified to ensure required function capability. This may include recording of measured process or state variables to provide for trending of slow-acting aging mechanisms.

The corrective actions required may encompass a wide range of activities which cannot be clearly identified in the program implementing procedure. Provisions shall be made, however,

to document what corrective actions were taken. These corrective actions may be in the form of references to work requests, additional diagnosis, retesting, non-destructive examinations, etc.

Program administrative procedures and/or specific implementing procedures shall provide guidance relative to the timeliness of corrective actions taken. This guidance shall be considered with respect to the aggressiveness of the aging mechanism (i.e., rate of degraded performance or function) and the frequency of program activities to detect and mitigate degradation. Performing timely corrective action ensures that equipment required functions are not compromised throughout the equipment's service life.

5.1.6 Program Effectiveness Matrix

Table 5-1 entitled, "Effective Program Criteria and Assessment Matrix," can be used to document the evaluation of a program and corresponding implementing procedures to effectively detect and mitigate charger, inverter, and UPS age-related degradation.

5.2 Effective Programs Commonly Used in the Industry

Demonstrating the adequacy of plant procedures to detect and mitigate degradation is accomplished by 1) substantiating that established programs and procedures effectively ensure the capability of the associated components to perform their required function(s) throughout their entire service life, or 2) taking actions in the form of program and/or procedural enhancements necessary to manage the aging mechanism(s) which are not adequately addressed by current established programs and/or procedures. Adequacy of programs and procedures for detecting and mitigating degradation must be demonstrated using one of these methods.

It is recognized that many battery chargers, inverters, and UPSs are subject to a variety of inspection, test, replacement and/or refurbishment programs to address diverse functional requirements and various aging mechanisms. As such, to establish the adequacy of existing plant programs, several programs may be required for a given component. Through a combination of such programs as necessary, the basis for safe and reliable operation throughout the component's entire service life is established.

The following is a discussion of the commonly used maintenance and surveillance programs determined from other aging studies to be effective in detecting manifestation of aging mechanisms and mitigating the degradation of battery chargers, inverters, and UPSs within acceptable limits.

This section first reviews the responses from utility questionnaires, NPRDS data summaries, and manufacturers' recommendations to determine what are the current practices for battery charger, inverter, and UPS maintenance, surveillance and testing. Industry standards, techniques, and programs for aging management of battery chargers, inverters, and UPSs are then reviewed, and the effectiveness of these programs to detect and mitigate electrical component aging is evaluated. This evaluation will determine which potentially significant degradation mechanisms are managed, and verify that the required functions of the electrical components are maintained.

Table 5-1. Effective Program Criteria and Assessment Matrix

I.D. of Equipment Being Evaluated	Effective Program(s) Name									
Program is Documented (See Note 1)										
Implementing Procedure(s) Approved by O.R.C										
Implemented Via Administrative Procedures										
Component Safety Functions Properly Addressed										
Age-Related Degradation Effects Properly Addressed Mechanism(s) and Rate of Degradation)										
Acceptance Criteria Established to Determine Need for Corrective Action										
Corrective Action Specified										
Timely Action Taken (See Note 2)										
Notes: F = Full compliance P = Partial compliance, subject to program enhancement N = Not in compliance, subject to program enhancement NA = Not applicable 1 = Documented means specific commitments are included on the docket (i.e., Updated SAR, responses to GL, IEB, IEN, NUREGs, Orders, 10 CFR 50.59, etc.) 2 = "Timely" is considered with respect to the aggressiveness of the degradation and frequency of the program activities to ensure that required functions are not compromised.										

Author:

Date:

Reviewer(s):

Date:

5.2.1 Utility Questionnaire Responses, NPRDS Data Review, and Manufacturers' Recommendations Review

The intent of this section is to survey current plant practices utilized, and their periodicities, as best accumulated from various data sources. This will later be compared to recommended practices and potential enhancements to improve aging detection and mitigation.

It must be recognized that the data set of utility questionnaire responses was limited (approximately 22% of operating units). Any interpretation of this data must be weighted by the small sample.

5.2.1.1 Battery Chargers

Utility Questionnaire Responses

Questionnaire responses were obtained from 10 utilities covering 24 plants, in varying degrees of detail. The questionnaire revealed most plants have some type of formalized maintenance procedure. Surveillance testing is the predominant activity performed, with 75% of the plants performing testing on a cyclic basis and 50% doing daily surveillance. Cleaning and inspection activities are also performed by a majority of the plants, with 29% performing cleaning and inspection on an annual or cyclic (18-month) basis. Preventive maintenance calibrations are performed by 21% of the plants with a frequency of up to two years. Only one plant reported doing thermographic scanning every six months and replacement of electrolytic capacitors every three and one-half years. Table 5-2 summarizes the percentage of plants doing each maintenance activity at given frequencies.

NPRDS Database Results

An NPRDS search of testing activities revealed that 88% of the plants perform a check test, with most (35%) doing it on a weekly basis. Seventy-six percent of the plants perform functional testing, with most plants (29%) doing it on a cyclic basis. Only 17% of the plants perform a calibration test, with the majority (11%) doing it on a yearly or cyclic basis. Table 5-3 summarizes the percentage of plants doing each testing activity at given frequencies.

Vendor Recommended Maintenance

Instruction and operating manuals were obtained from a majority of the nuclear industry battery charger vendors identified in the surveys. For preventive maintenance, the information supplied varied considerably from one vendor to another, and even among the literature from a single supplier (i.e., sales bulletins vs. instruction manuals).

Table 5-4 summarizes the vendors' recommendations for the preventive maintenance of battery chargers. The information was obtained from instruction manuals, technical bulletins, and, in some cases, directly from the service representative.

As observed from the table, recommended preventive maintenance consists primarily of keeping the cabinet clean of foreign material and dust, and ensuring that the connections are tight. The frequency of performing these tasks ranges from monthly to semi-annually, with several manufacturers stating that it should be performed "periodically," "occasionally," or "regularly." The generic frequencies are predicated on the equipment's environment, which, for nuclear power plants, tends to be relatively mild when compared with other non-nuclear environments.[5.5]

Table 5-2. Battery Charger Maintenance from Questionnaire Responses

Program	Activity	Frequency	Percentage of Plants
Surveillance	Test/Measure	5 Years	16.7
		18 Months	75.0
		Annually	4.2
		6 Months	4.2
		3 Months	16.7
		Monthly	8.3
		Weekly	20.8
		Daily	50.0
Preventive Maintenance	Inspection	3 Years	4.2
		2 Years	4.2
		18 Months	16.7
		Annually	12.5
		6 Months	12.5
		3 Months	8.3
		Not Given	12.5
	Cleaning	3 Years	4.2
		2 Years	4.2
		18 Months	16.7
		Annually	12.5
		6 Months	4.2
		3 Months	4.2
		Monthly	4.2
		Not Given	12.5
	Calibration	2 Years	8.3
		Not Given	12.5
	Parts Replacement	3.5 Years	8.3
Thermographic Scanning	Inspection	6 Months	8.3
"Good Housekeeping"	Operator Log	8 Hours	8.3

Note: Percentages may total more than 100%, because some plants perform the listed activity at more than one frequency.

Table 5-3. Battery Charger Testing from NPRDS Data

Activity	Frequency	Percentage of Plants
Check Testing	3 Years	1
	2 Years	1
	18 Months	9
	Annually	8
	6 Months	1
	3 Months	2
	Monthly	7
	Weekly	35
	Daily	5
	2 Times/Day	1
	3 Times/Day	16
	6 Times/Day	1
	9 Times/Day	1
Functional Testing	10 Years	1
	5 Years	1
	2 Years	4
	18 Months	29
	Annually	15
	9 Months	2
	3 Months	6
	Monthly	11
	Weekly	6
	6 Times/Day	1
Calibration Testing	5 Years	1
	3 Years	2
	2 Years	2
	18 Months	6
	Annually	5
	Monthly	1

Table 5-4. Manufacturer Recommended Maintenance for Chargers

Manufacturer	Maintenance	Frequency
C&D	— Proper ventilation	Regularly
	— Remove dust	Regularly
	— Fuse clips checked for tension	Regularly
	— Check current limit operation	Regularly
	— Clean contact area	Regularly
	— Replace all filter capacitors when one fails	Regularly
	— Charger kept dry	Regularly
	— Check connections	Regularly
	— Check float and equalize voltage	Regularly
Exide	— Clean, dry, and tighten all connections	Monthly
	— Log voltage readings	Monthly
	— Blow out dust with clean, dry air	Monthly
PCP	— Remove dust and foreign matter	2 Months
	— Check alarms and status lights	Periodically
	— Check meter accuracy	Periodically
	— Mechanically operate AC and DC circuit breakers	Semi-Annual
LaMarche	— Blow out dust	Occasionally
	— Tighten connections	Occasionally
Cyberex	— Clean	Regularly
	— Check output voltage	W/Battery Check

5.2.1.2 Inverters and UPSs

Utility Questionnaire Responses

Questionnaire responses were obtained from 9 utilities covering 13 plants, in varying degrees of detail. The questionnaire revealed that all plants have some type of formalized maintenance procedure that covers all or part of the inverters/UPSs. All of the plants indicated that they perform inspection and cleaning of their inverters and UPSs, with the majority of the plants (54%) doing it on a cyclic basis. A majority of the plants (54%) perform calibration with a frequency from one to three years. Sixty-two percent of the plants reported periodic replacement of capacitors, usually every six years. One plant (8%) periodically replaces circuit boards every eight years, while another plant (8%) replaces internal relays every cycle. Only four plants (31%) perform a surveillance or functional test. Two plants (15%) perform a

thermographic scan every six months. Table 5-5 summarizes the percentage of plants doing each maintenance activity at given frequencies.

NPRDS Database Results

An NPRDS search of testing activities revealed that 62% of the plants perform a check test, with most (34%) doing it on a daily or on a weekly basis. A functional test is performed by 52% of the plants, with most doing it weekly (19%) or annually (19%). Only 14% of the plants perform a calibration test, with most (11%) doing it annually. Table 5-6 summarizes the percentage of plants doing each maintenance activity at given frequencies. Comparison with Table 5-3 shows that battery chargers are inspected more frequently than are inverters or UPSs.

Vendor Recommended Maintenance

Instruction and operating manuals were obtained from a majority of the nuclear industry inverter/UPS vendors. For preventive maintenance, the information supplied varied considerably from one vendor to another, and even among the literature from a single supplier (i.e., sales bulletins vs. instruction manuals).

Table 5-7 summarizes the vendors' recommendations for the preventive maintenance of inverters. The information was obtained from instruction manuals, technical bulletins, and, in some cases, directly from the service representative.

As observed from the table, preventive maintenance consists primarily of keeping the cabinet clean of foreign material and dust, ensuring that the connections are tight, calibration, and replacing parts to maintain equipment qualification. The frequency of performing these tasks ranges from weekly to once every ten years, with several manufacturers stating that it should be performed "periodically," "occasionally," or "regularly." The generic frequencies are predicated on the equipment's environment, which, for nuclear power plants, tends to be relatively mild when compared with other non-nuclear environments.[5.5]

5.2.2 Common Programs and Techniques

The following programs and techniques, which are commonly used in the nuclear plant industry, are examined and analyzed for effectiveness.

- Preventive Maintenance Program
- Technical Specification Surveillance Program
- Equipment Qualification Program
- "Good Housekeeping" Practices — Operation Logs and Checklists
- On-Line Monitoring and Annunciator Response Procedures
- Infrared Thermographic Inspection Program
- Corrective Maintenance
- Operational Experience Reviews and Trending

The following subsections describe these programs and evaluate their effectiveness. A summary of these evaluations is presented in Table 5-8.

Table 5-5. Inverter/UPS Maintenance from Questionnaire Responses

Program	Activity	Frequency	Percentage of Plants
Surveillance	Test/Measure	18 Months	15.4
		Weekly	7.7
		Not Given	7.7
Preventive Maintenance	Inspection	18 Months	53.8
		Annually	15.4
		9 Months	7.7
		6 Months	7.7
		3 Months	7.7
		Not Given	7.7
	Cleaning	18 Months	53.8
		Annually	15.4
		9 Months	7.7
		3 Months	7.7
		Not Given	7.7
	Calibration	3 Years	15.4
		18 Months	7.7
		Annually	15.4
		Not Given	15.4
	Parts Replacement	10 Years	15.4
		8 Years (Circuit Boards)	7.7
		6 Years	23.1
		5 Years	15.4
		4.5 Years	7.7
		18 Months (Internal Relays)	7.7
Thermographic Scanning	Inspection	6 Months	15.4
"Good Housekeeping"	Operator Logs	8 Hours	15.4
		Not Given	7.7

Note: Percentages may total more than 100%, because some plants perform the listed activity at more than one frequency.

Table 5-6. Inverter/UPS Maintenance from NPRDS Data

Activity	Frequency	Percentage of Plants
Check Test	3 Years	11.2
	2 Years	1.6
	Annually	10.1
	3 Months	1.2
	Monthly	4.7
	Weekly	15.2
	Daily	18.3
Functional Test	3 Years	10.1
	2 Years	0.5
	Annually	19.0
	3 Months	0.8
	Monthly	1.7
	Weekly	19.4
Calibration Test	10 Years	0.1
	5 Years	0.3
	3 Years	2.0
	2 Years	0.5
	Annually	11.2

Table 5-7. Manufacturer Recommended Maintenance for Inverters/UPS

Manufacturer	Maintenance	Frequency
Cyberex	— Calibration	When needed
	— Clean	Periodically
	— Check loose connections	Periodically
	— Inspect filters	Weekly
	— Check capacitors	Periodically
	— Check for overheating	Periodically
Elgar	— Clean air filter	Monthly
	— Inspect for overheating	Monthly
	— Clean inside of unit	Quarterly
	— Check connections	Quarterly
	— Measure output voltage	Quarterly
	— Replace all fans	2 Years
	— Replace electrolytic capacitors	9 Years
Westinghouse	— Clean	Periodically
	— Check connections	Periodically
Solid State Controls	— Clean	2 Months
	— Calibrate	2 Months
	— Mechanically operate circuit breakers	2 Months
	— Operate manual bypass switch	2 Months
	— Measure output voltage	Yearly
	— Measure output frequency	Yearly
	— Measure output current	Yearly
	— Replace air filters	Yearly
	— Replace circuit boards	10 Years
	— Replace capacitors	10 Years

AGING MANAGEMENT GUIDELINE FOR BATTERY CHARGERS, INVERTERS, AND UPSs

Table 5-8. Summary of Effectiveness of Common Aging Management Programs

Aging Mechanism	Common Aging Management Programs						
	Preventive Maintenance	Surveillance	Equipment Qualification	"Good Housekeeping" Logs and Checklists	On-Line Monitoring Annunciator Response	Infrared Thermography	Corrective Maintenance
Transformer							
Thermal Aging	Cleaning Visual Inspection Tactile Inspection Audible Inspections (brackets)	Tech. Spec. (Charger) Operational	IEEE 650-1990	Temperature Logging Input/Output Logging Noise Observation Odor Observation	Temperature Output Cooling	Scanning	Circuit Tuning
Corrosion	Visual Inspection		IEEE 650-1990		Output	Scanning	
Fouling	Cleaning Visual Inspection		IEEE 650-1990				
Fatigue	Tactile Inspection Audible Inspections (brackets)		IEEE 650-1990	Vibration Observation Noise Observation	Output	Scanning	
Inductor							
Thermal Aging	Cleaning Visual Inspection Tactile Inspection	Tech. Spec. (Charger) Operational	IEEE 650-1990	Temperature Logging Input/Output Logging Odor Observation	Temperature Output Cooling	Scanning	Circuit Tuning
Corrosion	Visual Inspection		IEEE 650-1990		Output		
Fouling	Cleaning Visual Inspection		IEEE 650-1990				
Fatigue	Tactile Inspection		IEEE 650-1990	Vibration Observation	Output	Scanning	
Relay							
Thermal Aging	Cleaning Visual Inspection	Operational	IEEE 650-1990	Temperature Logging Odor Observation	Temperature Cooling	Scanning	
Electronic and Setpoint Drift	Calibration	Operational	IEEE 650-1990				
Corrosion	Cleaning Visual Inspection	Operational	IEEE 650-1990				
Fouling	Cleaning Visual Inspection		IEEE 650-1990				
Material Set	Tactile Inspection	Operational	IEEE 650-1990				
Fatigue	Tactile Inspection	Operational	IEEE 650-1990	Vibration Observation		Scanning	
Wear	Tactile Inspection	Operational	IEEE 650-1990				
Capacitor							
Thermal Aging	Cleaning Visual Inspection Measurement Part Replacement	Tech. Spec. (Charger) Operational	IEEE 650-1990	Temperature Logging Input/Output Logging Ripple Voltage Logging Odor Observation	Temperature Output Cooling	Scanning	Circuit Tuning Group Replacement
Fouling	Cleaning Visual Inspection		IEEE 650-1990				
Fatigue	Tactile Inspection		IEEE 650-1990	Vibration Observation	Output	Scanning	

AGING MANAGEMENT GUIDELINE FOR BATTERY CHARGERS, INVERTERS, AND UPSs

Table 5-8. Summary of Effectiveness of Common Aging Management Programs (continued)

Aging Mechanism	Common Aging Management Programs						
	Preventive Maintenance	Surveillance	Equipment Qualification	"Good Housekeeping" Logs and Checklists	On-Line Monitoring Annunciator Response	Infrared Thermography	Corrective Maintenance
SCR							
Thermal Aging	Cleaning Visual Inspection	Tech. Spec. (Charger) Operational	IEEE 650-1990	Temperature Logging Input/Output Logging Odor Observation	Temperature Output Cooling	Scanning	Circuit Tuning Connection Rework
Fouling	Cleaning Visual Observation		IEEE 650-1990				
Fatigue	Tactile Inspection		IEEE 650-1990	Vibration Observation	Output	Scanning	
Diode							
Thermal Aging	Cleaning Visual Inspection	Tech. Spec. (Charger) Operational	IEEE 650-1990	Temperature Logging Input/Output Logging Odor Observation	Temperature Output Cooling	Scanning	Circuit Tuning
Fouling	Cleaning Visual Inspection		IEEE 650-1990				
Fatigue	Tactile Inspection		IEEE 650-1990	Vibration Observation	Output	Scanning	
Surge Suppressor							
Thermal Aging	Cleaning Visual Inspection		IEEE 650-1990	Temperature Logging Odor Observation	Temperature Cooling		
Electronic Drift and Setpoint Drift	Calibration		IEEE 650-1990				
Fouling	Cleaning Visual Inspection		IEEE 650-1990				
Fatigue	Tactile Inspection		IEEE 650-1990	Vibration Observation		Scanning	
Circuit Boards and Electronics							
Thermal Aging	Cleaning Visual Inspection	Tech. Spec. (Charger) Operational	IEEE 650-1990	Temperature Logging Input/Output Logging Sync. Logging (Inverter/UPS) Odor Observation	Temperature Output Cooling	Scanning	Circuit Tuning
Electronic Drift and Setpoint Drift	Calibration	Tech. Spec. (Charger) Operational	IEEE 650-1990	Input/Output Logging Sync. Logging (Inverter/UPS)	Output		
Corrosion	Visual Inspection		IEEE 650-1990		Output		
Fouling	Cleaning Visual Inspection		IEEE 650-1990				
Fatigue	Tactile Inspection		IEEE 650-1990	Vibration Observation	Output	Scanning	
Circuit Breaker							
Thermal Aging	Cleaning Visual Inspection	Operational	IEEE 650-1990	Temperature Logging	Temperature Cooling		
Corrosion	Cleaning Visual Inspection		IEEE 650-1990				
Fouling	Cleaning Visual Inspection		IEEE 650-1990				

AGING MANAGEMENT GUIDELINE FOR BATTERY CHARGERS, INVERTERS, AND UPSs

Table 5-8. Summary of Effectiveness of Common Aging Management Programs (continued)

Aging Mechanism	Common Aging Management Programs						
	Preventive Maintenance	Surveillance	Equipment Qualification	"Good Housekeeping" Logs and Checklists	On-Line Monitoring Annunciator Response	Infrared Thermography	Corrective Maintenance
Circuit Breaker (continued)							
Material Set	Tactile Inspection		IEEE 650-1990				
Fatigue	Tactile Inspection		IEEE 650-1990	Vibration Observation		Scanning	
Wear	Tactile Inspection		IEEE 650-1990				
Switch							
Thermal Aging	Cleaning Visual Inspection	Operational	IEEE 650-1990	Temperature Logging	Temperature Cooling		
Corrosion	Cleaning Visual Inspection		IEEE 650-1990				
Fouling	Cleaning Visual Inspection		IEEE 650-1990				
Fatigue	Tactile Inspection		IEEE 650-1990	Vibration Observation		Scanning	
Wear	Tactile Inspection		IEEE 650-1990				
Potentiometer							
Electronic Drift and Setpoint Drift	Calibration	Tech. Spec. (Charger)	IEEE 650-1990	Input/Output Logging	Output		
Corrosion	Cleaning Visual Inspection		IEEE 650-1990				
Fouling	Cleaning Visual Inspection		IEEE 650-1990				
Fatigue	Tactile Inspection		IEEE 650-1990	Vibration Observation	Output	Scanning	
Wear			IEEE 650-1990				
Wires and Cables							
Thermal Aging	Cleaning Visual Inspection	Operational	IEEE 650-1990	Temperature Logging Input/Output Logging Odor Observation	Temperature Output Cooling	Scanning	Circuit Tuning Connection Rework
Corrosion	Visual Inspection		IEEE 650-1990		Output		
Fouling	Cleaning Visual Inspection		IEEE 650-1990				
Fatigue	Tactile Inspection		IEEE 650-1990	Vibration Observation	Output	Scanning	
Cooling Fan							
Corrosion	Visual Inspection		IEEE 650-1990				
Wear			IEEE 650-1990	Noise Observation			
Cooling Fan Motor							
Thermal Aging	Cleaning Visual Inspection	Operational	IEEE 650-1990	Temperature Logging Odor Observation	Temperature Cooling	Scanning	
Corrosion	Visual Inspection		IEEE 650-1990				

Table 5-8. Summary of Effectiveness of Common Aging Management Programs (continued)

Aging Mechanism	Common Aging Management Programs						
	Preventive Maintenance	Surveillance	Equipment Qualification	"Good Housekeeping" Logs and Checklists	On-Line Monitoring Annunciator Response	Infrared Thermography	Corrective Maintenance
Cooling Fan Motor (continued)							
Fouling	Cleaning Visual Inspection		IEEE 650-1990				
Fatigue	Tactile Inspection		IEEE 650-1990	Vibration Observation		Scanning	
Wear			IEEE 650-1990	Noise Observation			
Cabinet							
Corrosion	Visual Inspection		IEEE 650-1990				

5.2.2.1 Preventive Maintenance Program

For a preventive maintenance procedure to be effective, it must be formalized, comprehensive and proactive in philosophy, with the intent of assuring maximum reliability and life in the units. Preventive maintenance activities consist of cleaning, examinations, measurements, calibration, and verification of proper operation. Such activities were reviewed for effectiveness in detecting and mitigating the subcomponent degradation mechanisms defined in Section 4, using the effectiveness criteria of Section 5.1. The established activities are derived from engineering experience, manufacturers' recommendations, environmental conditions and feedback from past maintenance experience. The following paragraphs describe and evaluate preventive maintenance program activities.

Cleaning and visual inspection activities are an important and predominant preventive maintenance currently performed on battery chargers, inverters, and UPSs in nuclear power plants (see Section 5.2.1). Cleaning activities typically involve vacuuming or blowing out accumulated dirt and debris from the cabinet, ventilation louvers, air filters, and fan motors. Soft bristle brushes and lint-free rags are also frequently used to remove accumulated dirt and debris from subcomponents and heat sink surfaces. Relay contacts are typically cleaned and burnished as necessary. Circuit breakers, switches, and potentiometers are also cleaned during these activities. Such cleanings remove dirt, and allow for better heat dissipation and cooling of subcomponents. [5.5, 5.6, 5.7, 5.8]

Cleaning recommendations are documented in the manufacturer's service manual, and are typically performed once per cycle. Therefore, assuming the manufacturer's recommendations constitute effective practices, these activities and periodicity are effective at mitigating thermal aging and fouling of transformers, inductors, relay coils, capacitors, SCRs, diodes, surge suppressors, circuit boards/electronics, circuit breakers, switches, potentiometers (fouling only, since potentiometers are not susceptible to thermal aging), wires, cables, and cooling fan motors. The cleaning and burnishing of relay contacts, and the cleaning of circuit breakers, switches, and potentiometers, mitigate corrosion of the contacts of these subcomponents.

Inspection activities encompass a wide variety of visual, tactile, and measurement techniques. Visual inspection for discolored components, change in color of "varnished" transformer windings, or burned parts or connections can detect thermal aging. Desiccant packs are checked and replaced as necessary. Evidence of fouling or corrosion is also detected by direct observation. Visual examinations can also detect cracked insulation or leaking capacitors caused by thermal aging or thermal fatigue.[5.5, 5.6, 5.7, 5.8]

Manufacturer's recommendations performed on a periodic basis (usually one per cycle) serve as the basis for these visual tests. Thus, visual inspections on a periodic basis are effective at detecting thermal aging and fouling of transformers, inductors, relays, capacitors, SCRs, diodes, surge suppressors, circuit boards/electronics, circuit breakers, switches, potentiometers (fouling only, thermal aging is not significant for potentiometers), wires, cables, and cooling fan motors. Visual inspections can also detect corrosion of transformers, inductors, relays, circuit boards, circuit breakers, switches, potentiometers, wires, cables, cooling fans, cooling fan motors, and the cabinet itself.

Tactile inspections involve physical manipulation of a component or subcomponent part to check for loose or broken parts or connections. Verification of fastener tightness, torque verification of SCRs, and exercising of circuit breakers, switches, and relays are also considered tactile inspections. These inspections will detect loose or broken connections caused by vibration or wear, and will prevent material set in circuit breakers and relays. Tactile inspections are important where ferromagnetic resonance in components is pronounced. Another common tactile inspection is use of a non-conducting probe to check for insulation flaking on transformers and inductors. Such flaking is indicative of thermal aging. A test unit is available to measure aging of jacketed and insulated cable.[5.5, 5.6, 5.7, 5.8]

Manufacturer's recommended practices also provide some guidance for tactile inspections, typically once per cycle. Therefore, tactile inspections on a periodic basis are effective at detecting thermal aging of transformers and inductors, material set, and wear in circuit breakers and relays, and fatigue failures in connections of all subcomponents.

Other preventive maintenance techniques include measurements, calibration, periodic part replacement, and audible level/frequency checks. Measurements as used here refers to measurement of intrinsic subcomponent electrical values such as capacitance, and equivalent series resistance, and leakage current. These measurements are compared to original (installed) or design values to trend for subcomponent aging. Such measurement activities are typically performed on electrolytic capacitors to detect thermal aging.[5.5] Measurements are performed when required to isolate a suspect part.

Calibration activities are typically performed to adjust alarms, meters, internal relays, SCR firing circuits, other control circuits, and battery charger float and equalize voltages. Calibration programs detect electronic drift directly, and may indirectly indicate corrosion, wear, fatigue, or thermal aging.[5.5, 5.6, 5.7, 5.8] Calibration periodicities are initially set by manufacturer's recommendations, and adjusted as needed through feedback of operating experience. Such calibration activities are effective at mitigating setpoint drift of relays, surge suppressors, potentiometers, and control and firing circuit boards.

Chargers, inverters, and UPS systems employ transformers and magnetic components which may be subject to ferromagnetic resonance, evidenced by component "hum." Periodic audible inspections, and possibly frequency analysis, will detect changes in audible characteristics which may evidence physical or state changes in the component.[5.5, 5.9]

Periodic part replacement is typically applied to electrolytic capacitors based on manufacturers' recommendations.[5.5] Part replacement is also used in the Equipment Qualification Program (see Section 5.2.2.3).[5.6] The concept is that certain parts have a limited useful life, and that these parts should be replaced prior to the end of their useful life. Additionally, replacing parts with components rated for higher temperatures and electrical conditions than the original parts can significantly extend the component's useful life.[5.10] Periodic replacement of electrolytic capacitors at 6-10 year intervals, or after one unit of a set has failed, is typically recommended and is effective at mitigating thermal aging of the capacitors.[5.5] In addition, periodic part replacement is performed for the renewables identified in Table 3-1.

Cleaning and inspection activities are best performed when the unit is or can be shut down. Therefore, program periodicities of one cycle, or multiples thereof, are typical for these activities. A "dead panel" inspection is more effective for the activities described in this program.

EPRI's Nuclear Maintenance Applications Center has also addressed preventive maintenance techniques for uninterruptible power supplies[5.11] and emergency lighting battery chargers.[5.12] These guidelines should be used in formulating and/or reviewing effective preventive maintenance programs for these components.

5.2.2.2 Surveillance Program

The Surveillance Program involves periodic testing or observation to verify that structures, systems, and components continue to perform their required function or are in a state of readiness to perform their required function. Plants have Technical Specification surveillance procedures as well as operational surveillance procedures.

The Technical Specifications define the Limiting Conditions for Operation of the plant. The Technical Specifications also define testing requirements to ensure that these conditions are met. The operational surveillance requirements are the various periodic tests and checks not required by the Technical Specifications, but that are required for safe and efficient operation of the plant or to satisfy other regulatory requirements.

The surveillance procedures include appropriate quantitative or qualitative acceptance criteria for determining that important activities have been satisfactorily accomplished. The test results are reviewed for the identification of system problems and appropriate follow-up corrective action. This problem identification and corrective action should include examining for age-related degradation.

Standard Technical Specifications for Westinghouse PWRs[5.13] and General Electric BWR/5s[5.14] were reviewed, as were the Technical Specifications for the host utility PWR. These references are representative of similar references.[5.15, 5.16, 5.17, 5.18, 5.19, 5.20, 5.21] The following paragraphs discuss the results of these reviews as they pertain to battery charger and inverter/UPS surveillance testing.

Battery Chargers

Surveillance requirements from the Standard Technical Specifications for Westinghouse PWRs[5.13] include that the operability of each 250/125 volt battery bank and charger be demonstrated. Specific testing of the chargers is to be done once per 18 months, by verifying that the battery charger will supply at least 400 amperes at 125/250 volts for at least 8 hours during a battery discharge/charge test.

Surveillance requirements from the Standard Technical Specifications for General Electric BWR/5s[5.14] require that each of the three 125 volt batteries and chargers be demonstrated operable using several tests at varying frequencies. Specific testing of the chargers is to be done once per 18 months, by verifying that the charger will supply at least the minimum plant specified amperes at a minimum of the plant specified DC voltage for at least 4 hours.

The Technical Specifications for the host utility PWR follow the Standard Technical Specifications as they relate to battery chargers. The only difference between the specifications is that the battery charger test requires 475 amperes at a minimum of 130 volts for eight hours.

Such Technical Specification surveillance testing will detect degraded output capability of the charger, which could result from degraded transformers, inductors, capacitors, SCRs, diodes, circuit boards/electronics, or potentiometers. The aging mechanisms that are effectively detected are thermal aging and setpoint drift if the surveillance is performed every 18 months or less. Other mechanisms such as corrosion, fouling, and fatigue typically would not be detected until they had caused the subcomponent to fail. Therefore, periodic Technical Specification surveillance testing is effective at detecting thermal aging of transformers, inductors, capacitors, SCRs, diodes, and circuit boards/electronics, as well as setpoint drift of circuit boards/electronics, and potentiometers.

Operational (i.e., non-Technical Specification) surveillance testing can include activities such as annunciator checks, ripple voltage measurements, temperature measurements (cabinet, subcomponent), and parameter measuring and trending (capacitance, resistance).[5.5, 5.9] Annunciator checks can detect degradation of alarm relays caused by thermal aging, setpoint drift, material set, wear (binding, contact wear), fatigue (thermal, mechanical), and corrosion of contacts. Ripple voltage measurements are effective at detecting thermal aging of filter capacitors. Temperature measurements can help detect and mitigate thermal aging of subcomponents, as can parameter measurements. Parameter measurements are commonly taken only on capacitors, but can be useful at detecting thermal aging of transformers, inductors, relay coils, and cooling fan motors.[5.8, 5.22]

Inverters/UPSs

Surveillance requirements in the Standard Technical Specifications for Westinghouse PWRs[5.13] include the determination at least once per seven days that the four 120 volt AC vital buses are being energized by their associated inverters; and that the inverters are being energized by their associated DC buses. It must also be determined that tie breakers between redundant AC and redundant DC buses are opened. This is accomplished by verifying correct breaker alignment and indicated voltage on the buses. Two inverters may be removed from service during shutdown conditions, or for up to 24 hours during a battery equalize charge, provided that 1) their associated AC vital busses are energized from an alternate source, and 2) the AC vital busses associated with the other battery bank are being energized by their associated inverters, which in turn are energized from their associated DC busses.

Surveillance requirements in the Standard Technical Specifications for General Electric BWR/5s[5.14] include the determination at least once per seven days that the three AC distribution systems (each consisting of a 4160 volt bus, a 480 volt bus, and four 120 volt AC distribution panels) are operable and energized by verifying correct breaker alignment and voltage on the buses/panels. Operability of the inverters is not explicitly mentioned or required.

The Technical Specifications for the host utility PWR include surveillance to demonstrate at least once per seven days that the essential AC and vital electrical buses (two 4160 volt, two 480 volt, and four 120 volt) are operable, with the breakers open between redundant buses by verifying correct breaker alignment and indicated power availability. In contrast to the Standard Technical Specifications for Westinghouse PWRs, operability of the inverters is not explicitly mentioned or required.

Thus, it is apparent that Technical Specifications may not explicitly address inverter/UPS operability and, consequently, explicit Technical Specification surveillance testing of inverters/UPSs may not be required. However, from Section 5.2.1.2, almost one-third of the plants that responded to the survey have some type of inverter/UPS operational or Technical Specification surveillance. Because so few (13) plants responded to the survey, no conclusions can be drawn regarding the number of plants that use surveillance practices. These activities typically consist of a functional test to demonstrate inverter capacity, and operability of the static transfer switch. As with battery charger capacity tests, these inverter/UPS tests are effective at detecting thermal aging of transformers, inductors, capacitors, SCRs, diodes, circuit boards, and electronics. Setpoint drift of circuit boards and electronics can also be detected. A test performed at least once per cycle will be effective at detecting these mechanisms.

Other surveillance activities can include annunciator checks, waveform monitoring (AC output, firing circuit output), temperature measurements (cabinet, subcomponents), and parameter measuring and trending (capacitance, resistance).[5.5, 5.9] Annunciator checks can detect degradation of alarm relays due to thermal aging, setpoint drift, material set, wear (binding, contact wear), fatigue (thermal, mechanical), and corrosion of contacts. Waveform monitoring can detect thermal aging of SCRs, capacitors, circuit boards, and electronics, as well as setpoint drift of circuit boards and electronics. Temperature measurements can help detect and mitigate thermal aging of subcomponents as can parameter measurements. Parameter measurements are typically taken only on capacitors, but can be useful at detecting thermal aging of transformers, inductors, relay coils, and cooling fan motors.[5.8, 5.22]

5.2.2.3 Equipment Qualification Program

The Equipment Qualification (EQ) Program provides the process for generating, documenting, and maintaining evidence that electrical equipment important to safety within the scope of 10 CFR 50.49 can perform its safety function during its installed life. Qualification may be achieved by testing, analysis, or by a combination of the two. The Equipment Qualification Program must take into consideration temperature, pressure, humidity, chemical effects, radiation, aging (natural or accelerated), submergence (if applicable), synergistic effects, and margins. Thus, the Equipment Qualification Program is effective at mitigating virtually all aging of EQ equipment.

Safety-related battery chargers, inverters, and UPSs are typically located in mild environments, and are therefore outside the scope of 10 CFR 50.49. However, IEEE Standard 650-1990[5.23] sets forth qualification requirements for Class 1E static battery chargers and inverters used in nuclear power plants (see Section 3.5.1). This standard qualifies the equipment through a combination of analysis and testing, and considers the operating environment (temperature, humidity, radiation, radio frequency interference, electromagnetic interference, seismic vibration) and aging. The Qualification Report required by IEEE Standard 650-1990 identifies any scheduled surveillance/maintenance, periodic testing, and any parts replacement required to maintain qualification. Qualifying battery chargers and inverters in accordance with IEEE Standard 650-1990 and maintaining that qualification can be effective at mitigating aging of all charger or inverter subcomponents.

5.2.2.4 "Good Housekeeping" Practices — Operator Rounds, Logs, and Checklists

General plant operating activities typically include inspections as part of the operator's watch standing guidelines. The guidelines are typically documented as part of an administrative work instruction, which is approved by the on-site operations committee and implemented in accordance with plant administrative procedures. Operators routinely tour the plant (i.e., operator walkdown) to observe equipment conditions and record results on a checklist that contains qualitative and quantitative acceptance criteria. Equipment operation is verified, and parameters such as ambient temperature, input voltage and current, output voltage and current, charger ripple voltage, and inverter synchronization are logged. Unusual noise, odor, leakage, or vibration are also noted. Individual checklist items are performed at various frequencies ranging from hourly to monthly. The frequency is established based on experienced rates of change or degradation potential for the observed item. If acceptance criteria are not met, the operator informs the shift supervisor who initiates corrective or investigative action.

These operator activities can be effective at detecting and mitigating a wide range of charger and inverter aging mechanisms, depending upon the parameter logged. Temperature monitoring and trending can detect and mitigate thermal aging of the charger and inverter subcomponents. Logging and trending of input and output voltage and current values can detect degradation of transformers, inductors, capacitors, SCRs, diodes, circuit boards/electronics, potentiometers, wires, and cables. The predominant mechanism detected in these types of component measurements will be thermal aging. Setpoint drift of circuit boards/electronics and potentiometers may also be detected by logging input and output values. Logging and trending

of charger ripple voltage measurements will detect thermal aging of filter capacitors,[5.5] while verification of inverter synchronization will detect thermal aging of electronic drift of the synchronizing circuit board. Unusual or loud electrical "hum," or change in audible characteristics, can indicate onset of ferromagnetic resonance or thermal aging of magnetic components, while unusual or loud cooling fan operation can indicate wear of the fan or motor bearings.[5.9] Unusual odors can indicate overheating (thermal aging) of electronic components such as transformers, inductors, relays, capacitors, SCRs, diodes, surge suppressors, circuit boards/electronics, wires, cables, and cooling fan motors. Noticing and correcting excess external vibration can mitigate fatigue of failures of connections. Internal vibration is not typically observed on operator rounds because the panel door is not opened.

5.2.2.5 On-Line Monitoring and Annunciator Response Procedures

On-line monitoring of the components is necessary to control the status of the equipment and to detect possible failures. Monitoring of the battery charger, the DC distribution system, the inverter, and the vital AC instrumentation power system is accomplished by voltmeters, ammeters, and ground detection instrumentation located on the battery charging unit. Local and control room alarms for chargers may include loss of AC input, loss of charger, DC bus high or low voltage, DC system trouble, DC bus ground, DC system discharge, directional current relays, high cabinet temperature, or cooling fan failure. Local and control room alarms to monitor inverters/UPSs may include alternate source failure, inverter overload, loss of synchronization, inverter failure, high cabinet temperature, cooling fan failure, blown fuse, and ground fault.[5.2, 5.5]

Typically, there are annunciator response procedures that prescribe the actions that operators must take in response to individual automatic alarms. The procedures are approved by the on-site review committee and are implemented in accordance with plant administrative procedures. The procedures include acceptance criteria and instructional steps to respond to an annunciator alarm. If the operator cannot correct the alarming condition (as in a degraded state), then the operator reports the condition to the shift supervisor who initiates corrective or investigative actions.

Proper alarm setpoints are critical to the effectiveness of this program. If setpoints are too close to operating conditions, spurious alarms may be generated. Conversely, if setpoints are too far from normal operating conditions, alarms may annunciate too late to allow sufficient time for operators to take corrective actions.

A prime example of this latter case is alarming of low DC bus voltage to detect charger failure. Upon loss of the charger, battery voltage for a lead-acid battery drops fast to about 2.05 volts per cell, and then gradually decreases to the discharged state of 1.75 volts per cell when voltage can no longer be maintained. Figure 5-1 shows the discharge for a fully loaded battery rated at an eight-hour duty cycle. Proper setting of the undervoltage relay is necessary to provide early indication of a discharge while still protecting against erroneous alarms caused from voltage dips on the system. From Figure 5-1, it is evident that setting the undervoltage relay at 2.08 volts per cell will alarm within 20 to 30 minutes after the loss of charging, while setting the relay at 2.00 volts per cell will alarm more than one hour after the loss of charging. Setting the relay at 1.90 volts per cell will not cause an alarm until almost four hours after the charging loss, at

Figure 5-1. Stationary Battery Discharge Curve

which point the battery is half depleted, and operators have significantly less time to perform corrective actions before the battery becomes totally depleted. The optimum recommended setting is that which will alarm the low voltage condition in 20 to 30 minutes (i.e., 2.08 volts per cell in this example).

Receipt of high temperature alarms and appropriate response can mitigate thermal aging of all charger and inverter subcomponents that are susceptible to thermal aging. Loss of output or degraded output alarms can indicate subcomponent degradation due to thermal aging, corrosion, electronic/setpoint drift, or fatigue (loose connections). Subcomponents whose degradation may lead to such alarms are transformers, inductors, capacitors, SCRs, diodes, circuit boards/electronics, potentiometers, wires, and cables. Operator response to cooling fan failure alarms (if provided) can effectively mitigate thermal aging of those subcomponents that are susceptible to such aging.

5.2.2.6 Infrared Thermographic Inspection Program

Infrared thermography is a relatively new maintenance tool which converts thermal patterns of heat generation through an infrared imaging camera into equivalent visual patterns of temperature. Surface temperature differences as small as 0.3°C [0.5°F] are displayed in black and white or color "temperature maps." Bulk or "spot" local readings can be taken without touching the component or affecting its operation. A videocassette can be used to record local or bulk temperatures for given areas or components for future trending.[5.24]

Infrared thermography can be performed on a system while the equipment is still in service, and is used to detect "hot spots" in the equipment. Temperature differences can be measured quantitatively, and a qualitative examination can compare the temperature pattern of one component to another component under the same operating conditions.[5.24] This type of program is not typically a formal plant program at this time. However, many plants incorporate thermography in their preventive/predictive maintenance programs. The scans can be used for electrical equipment and connections, rotating equipment, and cables. Thermography would typically be used to monitor the condition of transformers, inductors, relay coils, capacitors, SCRs, diodes, circuit boards/electronics, wires, cables, cooling fan motors, and connections. These scans can detect thermal aging (overheating) of these components, as well as loose (overheating) connections caused by fatigue (vibration). Results of thermographic inspections are used in conjunction with other maintenance program data to determine if corrective action is required to prevent further degradation.

Effective thermographic inspection programs should be developed in accordance with EPRI's Nuclear Maintenance Applications Center guidelines contained in Reference 5.25. Additional guidance is provided in the Infraspction Institute's "Guidelines for Specifying and Performing Infrared Inspections."

Periodic infrared scans can be supplemented by the use of temperature monitoring strips mounted internal to the cabinet, typically over the course of one cycle, to record peak temperatures experienced during normal plant operation.

5.2.2.7 Corrective Maintenance

Corrective maintenance is performed in response to abnormalities detected during operation, inspection, monitoring, or testing. Corrective maintenance is typically performed in response to a component or subcomponent failing to perform its required function, and as such is not effective at detecting or mitigating aging. However, there are certain activities that are typically performed or should be performed during corrective maintenance that are effective at mitigating future aging of charger and inverter subcomponents.[5.5] The following paragraphs discuss these activities.

After replacing an SCR, the firing circuit is typically adjusted to obtain the correct waveform and gate current value. Additionally, after replacing any major component (transformer, SCR, capacitor, circuit board, etc.), the circuits are usually tuned (voltage balanced) according to the manufacturer's instructions to get symmetrical DC charger output, or to reduce circulating currents in ferroresonant inverters. All of these activities reduce electrical stressors which can cause overheating.[5.5] Therefore, these activities are effective at mitigating thermal aging of transformers, inductors, capacitors, SCRs, diodes, circuit boards/electronics, wires, and cables.

When replacing a failed filter capacitor, all other filter capacitors are typically either replaced or are tested for degraded electrical parameters (capacitance, equivalent series resistance, leakage current) and replaced as necessary in accordance with manufacturer recommendation.[5.5, 5.9] This activity is effective at mitigating thermal aging of filter capacitors.

When loose connections are found, they should not simply be tightened, but should be removed, cleaned, and reassembled with new thermal compound (as appropriate). This activity is particularly important when the loose connection is between an SCR and its heat sink.[5.5] This activity is effective at mitigating future thermal aging of SCRs, wires, and cables.

5.2.2.8 Operational Experience Reviews and Trending

Most plants have some sort of formal or informal "operating experience review" procedure or personnel. This process is occasionally an independent body dedicated to detecting and resolving incipient or long-acting problems. The operating experience program is not credited for specifically detecting and mitigating aging of components, but is viewed as a substantial support towards effective aging management. The operating experience program tracks problems identified by in-house and external industry operating experience, and initiates corrective actions to mitigate those problems. This program supports the other aging management programs by providing feedback on charger and inverter failures or degradation. This program also captures Part 21 Notices, NRC Bulletins, Notices and Generic Letters, vendor experience reports, INPO Reports, Significant Operating Events Reports (SOERs), etc. and ensures that all known potential problems are addressed at the plant before failure occurs. Trending failure rates could lead to sufficient statistical data that could provide an indication of aging degradation. Surveillance, preventive maintenance, or replacement could then be scheduled more effectively on the basis of failure trends. The host utility trends charger and inverter currents and voltages to help detect degrading/conditions.

5.3 Less Commonly Used Aging Management Techniques

This section describes alternative techniques, which can be used to supplement the common plant practices described in Section 5.2, but which are not routinely used. These techniques would most likely be used only to diagnose a major problem, or only on a long periodicity basis, because of the potential need to shut down the charger or inverter.

Alternative techniques and programs examined for effectiveness are:

- Environment Mitigation
- Waveform Monitoring
- Insulation Resistance Testing
- Transformer Turns Ratio Testing
- Sample Removal and Analysis
- Equipment Replacement/Refurbishment
- Environmental Monitoring
- Transient Monitoring and Recording
- Vibration Diagnosis

The following subsections describe these programs and evaluate their effectiveness. A summary of these evaluations is presented in Table 5-9.

AGING MANAGEMENT GUIDELINE FOR BATTERY CHARGERS, INVERTERS, AND UPSs

Table 5-9. Summary of Effectiveness of Alternative Aging Management Programs

Aging Mechanism	Alternative Aging Management Programs								
	Environment Mitigation	Waveform Monitoring	Insulation Resistance Testing	Transformer Turns Ratio Testing	Sample Removal and Analysis	Equipment Replacement/Refurbishment	Environmental Monitoring	Transient Monitoring	Vibration Diagnosis
Transformer									
Thermal Aging	Increased Cooling		Resistance Trending Dielectric Absorption Ratio Test	Turns Ratio Test		Replacement	Ambient Temperature	Monitoring	
Corrosion						Replacement			
Fouling						Replacement			
Fatigue						Replacement			Monitoring
Inductor									
Thermal Aging	Increased Cooling					Replacement	Ambient Temperature	Monitoring	
Corrosion						Replacement			
Fouling						Replacement			
Fatigue						Replacement			
Relay									
Thermal Aging	Increased Cooling				Analysis and Trending	Replacement	Ambient Temperature	Monitoring	
Electronic and Setpoint Drift						Replacement			
Corrosion						Replacement			

AGING MANAGEMENT GUIDELINE FOR BATTERY CHARGERS, INVERTERS, AND UPSs

Table 5-9. Summary of Effectiveness of Alternative Aging Management Programs (continued)

Aging Mechanism	Alternative Aging Management Programs								
	Environment Mitigation	Waveform Monitoring	Insulation Resistance Testing	Transformer Turns Ratio Testing	Sample Removal and Analysis	Equipment Replacement/Refurbishment	Environmental Monitoring	Transient Monitoring	Vibration Diagnosis
Relay (continued)									
Fouling						Replacement			
Material Set						Replacement			
Fatigue						Replacement			
Wear						Replacement			
Capacitor									
Thermal Aging	Increased Cooling	Ripple Voltage Commutating Capacitor Voltage			Analysis and Trending	Replacement	Ambient Temperature	Monitoring	
Fouling						Replacement			
Fatigue						Replacement			
SCR									
Thermal Aging	Increased Cooling	SCR Gate to Cathode				Replacement	Ambient Temperature	Monitoring	
Fouling						Replacement			
Fatigue						Replacement			

AGING MANAGEMENT GUIDELINE FOR BATTERY CHARGERS, INVERTERS, AND UPSs

Table 5-9. Summary of Effectiveness of Alternative Aging Management Programs (continued)

Aging Mechanism	Alternative Aging Management Programs								
	Environment Mitigation	Waveform Monitoring	Insulation Resistance Testing	Transformer Turns Ratio Testing	Sample Removal and Analysis	Equipment Replacement/ Refurbishment	Environmental Monitoring	Transient Monitoring	Vibration Diagnosis
Diode									
Thermal Aging	Increased Cooling					Replacement	Ambient Temperature	Monitoring	
Fouling						Replacement			
Fatigue						Replacement			
Surge Suppressor									
Thermal Aging	Increased Cooling					Replacement	Ambient Temperature	Monitoring	
Electronic Drift and Setpoint Drift						Replacement			
Fouling						Replacement			
Fatigue						Replacement			
Circuit Boards and Electronics									
Thermal Aging	Increased Cooling	Inverter Output				Replacement	Ambient Temperature	Monitoring	
Electronic Drift and Setpoint Drift						Replacement			
Corrosion						Replacement			
Fouling						Replacement			
Fatigue						Replacement			

AGING MANAGEMENT GUIDELINE FOR BATTERY CHARGERS, INVERTERS, AND UPSs

Table 5-9. Summary of Effectiveness of Alternative Aging Management Programs (continued)

Aging Mechanism	Alternative Aging Management Programs								
	Environment Mitigation	Waveform Monitoring	Insulation Resistance Testing	Transformer Turns Ratio Testing	Sample Removal and Analysis	Equipment Replacement/ Refurbishment	Environmental Monitoring	Transient Monitoring	Vibration Diagnosis
Circuit Breaker									
Thermal Aging	Increased Cooling		Resistance Trending Dielectric Absorption Ratio Test			Replacement	Ambient Temperature	Monitoring	
Corrosion						Replacement			
Fouling						Replacement			
Material Set						Replacement			
Fatigue						Replacement			
Wear						Replacement			
Switch									
Thermal Aging	Increased Cooling					Replacement	Ambient Temperature		
Corrosion						Replacement			
Fouling						Replacement			
Fatigue						Replacement			
Wear						Replacement			

AGING MANAGEMENT GUIDELINE FOR BATTERY CHARGERS, INVERTERS, AND UPSs

Table 5-9. Summary of Effectiveness of Alternative Aging Management Programs (continued)

Aging Mechanism	Alternative Aging Management Programs								
	Environment Mitigation	Waveform Monitoring	Insulation Resistance Testing	Transformer Turns Ratio Testing	Sample Removal and Analysis	Equipment Replacement/Refurbishment	Environmental Monitoring	Transient Monitoring	Vibration Diagnosis
Potentiometer									
Electronic Drift and Setpoint Drift						Replacement			
Corrosion						Replacement			
Fouling						Replacement			
Fatigue						Replacement			
Wear						Replacement			
Wires and Cables									
Thermal Aging	Increased Cooling		Resistance Trending Dielectric Absorption Ratio Test		Analysis and Trending	Replacement	Ambient Temperature	Monitoring	
Corrosion						Replacement			
Fouling						Replacement			
Fatigue						Replacement			
Cooling Fan									
Corrosion						Replacement			
Wear						Replacement			Monitoring

AGING MANAGEMENT GUIDELINE FOR BATTERY CHARGERS, INVERTERS, AND UPSs

Table 5-9. Summary of Effectiveness of Alternative Aging Management Programs (continued)

Aging Mechanism	Alternative Aging Management Programs								
	Environment Mitigation	Waveform Monitoring	Insulation Resistance Testing	Transformer Turns Ratio Testing	Sample Removal and Analysis	Equipment Replacement/ Refurbishment	Environmental Monitoring	Transient Monitoring	Vibration Diagnosis
Cooling Fan Motor									
Thermal Aging	Increased Cooling (HVAC Upgrade)		Resistance Trending Dielectric Absorption Ratio Test			Replacement	Ambient Temperature	Monitoring	
Corrosion						Replacement			
Fouling						Replacement			
Fatigue						Replacement			
Wear						Replacement			Monitoring
Cabinet									
Corrosion						Replacement			

5.3.1 Environment Mitigation

Adjustment in the operating environment or operational practices is an effective method of mitigating aging degradation. Environmental stressors such as temperature, radiation, and humidity are known to induce aging degradation, particularly in nonmetallic materials. Collection and evaluation of environmental data can provide the bases for adjustment of environmental stressors, such as additional thermal insulation, venting of electrical enclosures, HVAC upgrades, addition of radiation shielding, and periodic decontamination of piping near electrical equipment. Examples of adjustments in operating practices include reducing the period of operation, reducing the amount and rate of start-ups/shutdowns, and optimizing or improving testing practices. [5.26]

Radiation is not a concern for battery chargers, inverters, and UPSs (see Section 4.2.1.7). The primary environmental stressors for this equipment are temperature and humidity. Humidity is generally controlled by the insertion of disposable desiccant packs inside the cabinet. In addition to the measures discussed above (venting of electrical enclosures, HVAC upgrades), the addition of cooling fans to chargers and inverters/UPSs using natural convection cooling is a proactive environment mitigation technique that will reduce the operating temperatures of susceptible subcomponents. Installation of backup fans is recommended on fan cooled units. Such measures are effective at mitigating thermal aging of all charger, inverter, and UPS subcomponents.

5.3.2 Waveform Monitoring

During servicing of battery chargers or inverters, any detected changes in the output voltage or frequency may be readily remedied by available adjustments, and are not, by themselves, an indication of aging degradation. However, a symptom of circuit degradation could be output waveform and changes in value that occur while operating at different loads or outputs.

A ripple test can be performed in battery chargers. The amount of AC voltage existing on the DC output from the battery charger is known as ripple. The ripple is measured with an oscilloscope with the charger operating at varying voltages, to assure that specifications are maintained over the entire operating range. Excessive ripple voltage can indicate thermal aging of the filter capacitors.[5.5]

The inverter circuit waveforms can be observed and photographed on an oscilloscope. The output voltage waveform, the SCR gating signals, and the commutating capacitor's voltage are the three waveforms that should be monitored and compared to the vendor's recommendations and previous measurements. Examination of these waveforms can detect thermal aging of the SCRs, commutating capacitor, and the gate circuit boards.[5.5]

5.3.3 Insulation Resistance Testing

Insulation resistance testing is a non-destructive testing method used to check the quality or condition of insulation. In an insulation-resistance test, an applied voltage, from 100 to 5,000 volts, supplied from a source of constant DC potential, is applied across the insulation. The usual potential source is a megohmmeter, either hand or power operated, that indicates the insulation

resistance directly on a scale calibrated in megohms. The quality of the insulation is evaluated based on the level of the insulation resistance.[5.8, 5.22]

The insulation resistance of many types of insulation is quite variable with temperature, so the data obtained should be corrected to the standard temperature for the class of equipment under test. The megohm value of insulation resistance obtained will also be inversely proportional to the volume of insulation being tested.[5.8, 5.22]

The insulation-resistance test is relatively easy to perform, and is a useful test for all types and classes of insulated electrical equipment. Its main value lies in the charting of data from periodic tests, corrected for temperature, over the life of the equipment, so that deteriorative trends might be detected.[5.8, 5.22]

A second test method, known as the time-resistance method, or the dielectric absorption ratio (DAR) test, is independent of temperature and equipment size, and can provide conclusive results as to the condition of insulation. This method recognizes the fact that a good insulation system shows a continued increase in its apparent resistance value over the period of time in which voltage is applied, while an insulation system that is contaminated with moisture, dirt, and other matter will show a low resistance and non-increasing value. In good insulation, the effect of absorption current decreases as time increases. In bad insulation, the absorption effect is perpetuated by high leakage current. Therefore, the ratio of time-resistance readings can be used to indicate the condition of the insulation system. The ratio of a 60-s reading to a 30-s reading is called the dielectric absorption ratio (DAR).

$$\text{DAR} = \frac{\text{resistance reading at 60 s}}{\text{resistance reading at 30 s}}$$

A DAR ratio below 1.25 is cause for investigation and possible repair of the electrical apparatus. Usually, the DAR readings are confined to the hand-driven megohmmeter.[5.8, 5.22]

By comparing the results against manufacturers' factory data and known data of similar units, and observing changes in benchmark test results over time, insulation resistance testing provides an effective means for detecting defective insulation. These tests should be conducted before and after repair or maintenance is performed. The test data should be recorded for future comparative purposes.

Such insulation resistance testing can be applied to the transformers, circuit breakers, wires, cables, and cooling fan motors on chargers, inverters, and UPSs, and is effective at detecting thermal aging of the insulation.

Other insulation tests include dielectric absorption tests, polarization index tests, and high potential tests. These tests are conducted at much higher DC voltages than the insulation resistance test, and are typically confined to large rotating machines, cable systems, and large power transformers.[5.8, 5.22] They are not considered appropriate for the small transformers and motors used in chargers, inverters, and UPSs.

Insulation tests using alternating current (high potential tests and power factor tests) are considered destructive tests, in that they may cause the equipment under test to fail or may render it unsuitable for further service.[5.22] These tests are also considered unsuitable for the small transformers and motors employed in chargers, inverters, and UPSs.

5.3.4 Transformer Turns Ratio Testing

The turns ratio test is used to determine the number of turns in one winding of a transformer in relation to the number of turns in the other windings of the same phase of the transformer. This test is used both as an acceptance and a maintenance test. It is applicable to all power, distribution, and instrument transformers. The test equipment used will ordinarily be a turns ratio test set designed for the purpose, although, if not available, two voltmeters or two ammeters (for current transformers only) may be used. This test is useful in determining whether a transformer has any shorted turns or improper connections and, on acceptance testing, to verify nameplate information.[5.8, 5.22] Consequently, this test is effective at detecting thermal aging of the transformer due to shorted turns.

5.3.5 Sample Removal and Analysis

Sample removal and analysis is an advanced trending technique used for relays, capacitors, and cables. Representative samples of these subcomponents are removed from the equipment after a known service time and tested for evidence of aging. The evaluations of these subcomponents are kept on file and are compared to evaluations of previously removed subcomponents. Such trending can indicate rates of degradation which can be a valuable input to preventive maintenance programs. Such evaluations can also be a basis for extending the qualified life of safety-related equipment. These analyses are typically effective at detecting thermal aging of the relays, capacitors, and cables.

5.3.6 Equipment Replacement/Refurbishment

Replacement is the substitution of a component or subcomponent, usually degraded or failed, with another that complies with the design requirements.

Components or subcomponents may be replaced prior to reaching the end of design or qualified life or prior to failure based on the results of monitoring. In equipment qualification programs, weak link components are replaced prior to the end of their qualified life such that the longer qualified life of the host equipment is maintained. Filter capacitors, electronic components, and fan motors are components most subject to periodic replacement because of expected service life.

Replacement is also an option to use for equipment which has become obsolete or for which spare parts are no longer available (see Section 6), equipment which fails to meet acceptance criteria, or equipment for which increased reliability is desired.

Refurbishment is the renovation or restoration of a degraded component to an acceptable state, not necessarily its original, undegraded state. The equipment to be refurbished may have selected subcomponents or materials replaced. Examples of refurbishment of equipment are changing the contacts on a breaker, installing new bearings on a motor, or replacing insulation materials.

Equipment replacement and refurbishment is effective at mitigating all types of aging on all components.

5.3.7 Environmental Monitoring

Environmental monitoring and mapping is a trending technique used to evaluate the environmental stressors acting on equipment. The data gathered may identify the need for preventive or corrective actions to preclude an early equipment failure, or may be justification for extending the qualified life of safety-related equipment. During normal operation, surveys with hand-held instruments provide a convenient approach. Hand-held instruments are available for temperature, radiation, and humidity measurements.[5.26]

Temperature monitors include thermistor, thermocouple, Resistance Temperature Detector (RTD), and infrared type. Thermistor, thermocouples, and RTDs can be used to measure ambient air temperature and equipment surface temperature, but are useful only for bulk temperature measurement inside or nearby the charger/inverter cabinet. An infrared (IR) spectroscopy measures the infrared radiation emitted by objects to determine temperature. The IR scope takes much less time to make an accurate reading and does not require contact with the object to be measured. The IR scope also allows the user to quickly scan and locate hot spots (see Section 5.2.2.6, Infrared Thermographic Inspection Program).[5.26]

Humidity measurements also lend themselves to walkdown with hand-held instruments. This may have to be done seasonally to determine any variation. Areas of high humidity should be investigated for signs of condensation within the charger/inverter cabinet and/or failure of desiccants to perform.[5.26]

Chemical exposure monitoring is best performed by physical inspection of suspected areas, but is not expected to be significant within the charger/inverter cabinet.[5.26]

Equipment which requires continuous monitoring will require the use of remote data gathering techniques. Careful attention must be given to the number and placement of monitors in an area. In addition to area ambient temperature, equipment internal and surface temperature is important for equipment in cabinets. The area adjacent to electronic circuit boards and discrete electronic components is most critical.[5.26]

Special attention must be given to items or events that may influence the data being gathered or the frequency of performance. These include: seasonal effects, changes in ventilation, status of HVAC, construction activities, and plant operations and cycles. The results of the monitoring program should be reviewed to ensure that the data accurately reflects the stressors being monitored. This may require changes in monitor location or follow-up monitoring to verify results.[5.26]

This type of monitoring is also important when a thermal stratification problem within the cabinet may be suspected during normal operation.

5.3.8 Transient Monitoring and Recording

The operating experience data for chargers and inverters indicates that electrical transients directly account for 15% of inverter failures (Section 3.6). It can be deduced that components such as capacitors, semiconductors, and fuses which are subjected to transients fail prematurely. It is advantageous, apart from protecting electrical equipment from transients, to monitor the electrical distribution system so that the sources of power disturbances can be located and isolated. State-of-the-art instrumentation is available to monitor the quality of the power source, and may be valuable in isolating or eliminating certain transients.[5.5]

Several instruments have the capability to monitor up to four AC-line signals, including single phase and three phase supplies. They also have environmental input conditioning channels so that temperature or humidity effects can be included in the analysis of an electrical transient. When a transient exceeding a predetermined magnitude is experienced, the instrument prints and displays graphically the response of all inputs. In this manner, common mode effects can be distinguished from normal mode impulses.[5.5]

The time resolution of the devices surveyed is sufficient to detect subcycle disturbances, so that differences between a true momentary loss of voltage versus a sag in line voltage can be distinguished. This could be important in monitoring a plant's uninterruptible power system where an automatic transfer to and from an alternate supply can occur within 0.5 cycles.[5.5]

Other monitor/analyzers perform signal conditioning, which permits power disturbances to be displayed on an oscilloscope. They can be used to check the effectiveness of power conditioning equipment, and to determine whether malfunction of the electronic equipment is caused by crosstalk between the system's peripheral equipment, start-up of a particular motor, or the operation of welding machines in the plant. An option available on one monitor is an audible alarm with indicating lights that shows the occurrence of high line voltage, low line voltage, momentary voltage dropout, power failure, transient spikes, and electrical noise that exceed preset thresholds.[5.5]

Employing such monitoring to isolate or eliminate transients can be effective at mitigating thermal aging of battery charger, inverter, and UPS subcomponents caused by excessive electrical conditions. The subcomponents involved would be transformers, inductors, relays, capacitors, SCRs, diodes, surge suppressors, circuit boards/electronics, circuit breakers, wires, cables, and cooling fan motors.

5.3.9 Vibration Diagnosis

Vibration diagnosis is a technique used to measure ferromagnetic resonance or extended vibration stimuli, and to detect loose or worn subcomponents. Accelerometers mounted on the equipment or its mounting surfaces can measure vibration. Vibration amplitudes and velocities can be measured and transferred to a computer database for storage, analysis, and trending. This technique is useful in detecting external vibration sources, but its effectiveness in detecting aging

degradation in static battery chargers, inverters, and UPSs from internal sources may be limited, and, at best, would be used to detect wear of the cooling fan assembly bearings, and failure of support brackets (broken welds or bolts) holding the transformer.

5.4 Criteria for Effective Aging Management

This section provides qualitative and quantitative criteria for use by inspectors, surveillance testers, and/or system engineers to compare plant-specific program coverage against the programs/techniques described in Sections 5.2 and 5.3 which were determined to be effective at detecting and mitigating the potentially significant aging mechanisms identified in Section 4.2 and summarized in Table 4-3. These discussions are grouped by aging mechanism.

The frequencies of conducting these programs/techniques are based on current codes and standards[5.5-5.14, 5.22-5.26] as well as general industry practice. The failure data conclusions presented in Section 3.6 indicated that current industry practices are effective at detecting and mitigating aging of battery chargers, inverters, and UPSs. Other conclusions, also drawn from the failure data, that were considered in selecting the program/technique implementing intervals are:

- Since battery chargers, inverters, and UPSs are in continuous operation, at least some of the program activities should be implemented on shorter rather than longer intervals (e.g., continuous monitors with alarms, logging of operating parameters once per shift).
- Since circuit board failures dominate NPRDS failure data, actions to detect aging of circuit boards should be implemented on a shorter rather than longer implementing interval.
- Since the primary aging mechanisms for circuit boards are thermal aging and setpoint/electronic drift, the programs implemented more frequently should concentrate on detecting such aging.

5.4.1 Thermal Aging

Table 4-3 identified thermal aging as a potentially significant aging mechanism for the following battery charger, inverter, and UPS subcomponents.

- Transformers
- Inductors
- Relays
- Capacitors
- SCRs
- Diodes
- Surge Suppressors
- Circuit Boards/Electronics
- Circuit Breakers
- Switches
- Wires and Cables

- Cooling Fan Motors

Determining the presence of thermal aging associated with these subcomponents is achieved through a combination of plant programs. Cleaning and visual inspections conducted in accordance with the plant's Preventive Maintenance Program are effective at detecting thermal aging of all of these subcomponents. Tactile inspections conducted in accordance with the plants' Preventive Maintenance Program are effective at detecting thermal aging of transformers, inductors, and SCRs. Measurement inspections conducted in accordance with the plants' Preventive Maintenance Program are effective at detecting capacitor aging. Calibration activities conducted in accordance with the plants' Preventive Maintenance Program are effective at detecting thermal aging of relays and circuit boards. Periodic part replacement conducted in accordance with the plants' Preventive Maintenance Program is effective at mitigating thermal aging of capacitors. Capacity testing in accordance with the plants' Operational or Technical Specification Surveillance Program is effective at detecting thermal aging of transformers, inductors, relays, capacitors, SCRs, diodes, circuit boards/electronics, circuit breakers, switches, wires, cables, and cooling fan motors. Thermographic inspections conducted in accordance with Reference 5.18 are effective at detecting thermal aging of all of these subcomponents. Alarming of high cabinet temperature in accordance with the plants' On-line Monitoring — Annunciator Response Procedures or logging the cabinet temperature in accordance with the plants' "Good Housekeeping" Practices — Operator Rounds, Logs, and Checklists are effective at detecting thermal aging of all of these subcomponents.

Therefore, if high cabinet temperature is alarmed at a setpoint based on the manufacturers' recommendation, or if the cabinet temperature is logged once per shift and compared to manufacturer recommended acceptance criteria, and if thermographic inspections are conducted in accordance with Reference 5.18, and if cleaning, inspection, and calibration activities are performed at least once per fuel cycle, and if parts are replaced according to the manufacturers' recommended schedule, then thermal aging of these subcomponents is effectively managed.

5.4.2 Setpoint/Electronic Drift

Table 4-3 identified setpoint/electronic drift as a potentially significant aging mechanism for the following battery charger, inverter, and UPS subcomponents.

- Relays
- Surge Suppressors
- Circuit Boards/Electronics
- Potentiometers

Detecting the presence of setpoint/electronic drift associated with these subcomponents is achieved through a combination of plant programs. Calibration activities conducted in accordance with the plants' Preventive Maintenance Program are effective at detecting setpoint/electronic drift of all of these subcomponents. Capacity and functional testing in accordance with the plants' Operational or Technical Specification Surveillance Program is effective at detecting setpoint/electronic drift of relays, circuit boards/electronics, and potentiometers. Alarming equipment output parameters in accordance with the plants' On-line Monitoring — Annunciator Response Procedures or logging of output parameters in accordance

with the plants' "Good Housekeeping" Practices — Operator Rounds, Logs, and Checklists are effective at detecting setpoint/electronic drift of circuit boards/electronics and potentiometers.

Therefore, if output parameters are alarmed or logged once per shift with acceptance criteria based on the manufacturer's performance criteria, and if calibration, capacity tests, and functional tests are performed at least once per fuel cycle, then setpoint/electronic drift is effectively managed.

5.4.3 Corrosion

Table 4-3 identified corrosion as a potentially significant aging mechanism for the following battery charger, inverter, and UPS subcomponents.

- Transformers
- Inductors
- Relays
- Circuit Boards/Electronics
- Circuit Breakers
- Switches
- Potentiometers
- Wires and Cables
- Cooling Fans
- Cooling Fan Motors
- Cabinets

Detecting the presence of corrosion associated with these subcomponents is achieved through visual inspections conducted in accordance with the plants' Preventive Maintenance Program. Because the chargers, inverters, and UPSs are located in mild environments with low humidity, corrosion is expected to occur at a very slow rate. Therefore, if visual inspections of the above subcomponents are conducted at least once per fuel cycle, then corrosion of these subcomponents is effectively managed.

5.4.4 Fouling

Table 4-3 identified fouling as a potentially significant aging mechanism for the following battery charger, inverter, and UPS subcomponents.

- Transformers
- Inductors
- Relays
- Capacitors
- SCRs
- Diodes
- Surge Suppressors
- Circuit Boards/Electronics
- Circuit Breakers
- Switches

- Potentiometers
- Wires and Cables
- Cooling Fan Motors

Detecting the presence of fouling associated with these subcomponents is achieved through cleaning and visual inspections conducted in accordance with the plants' Preventive Maintenance Program. Because the chargers, inverters, and UPSs are located in mild environments, with little dust or dirt, fouling is expected to occur at a slow rate. Therefore, if cleaning and visual inspections of the above subcomponents are conducted at least once per fuel cycle, then fouling of these subcomponents is effectively managed.

5.4.5 Material Set

Table 4-3 identified material set as a potentially significant aging mechanism for the following battery charger, inverter, and UPS subcomponents.

- Relays
- Circuit Breakers

Detecting the presence of material set associated with these subcomponents is achieved through tactile inspections conducted in accordance with the plants' Preventive Maintenance Program. From Section 5.2.2.1, the effective tactile inspection to detect material set in these subcomponents is periodic exercising of these subcomponents. Material set is expected to occur at a slow rate. Therefore, if these subcomponents are exercised at least once per fuel cycle, then material set of these subcomponents is effectively managed.

5.4.6 Fatigue

Table 4-3 identified fatigue as a potentially significant aging mechanism for the following battery charger, inverter, and UPS subcomponents.

- Transformers
- Inductors
- Relays
- Capacitors
- SCRs
- Diodes
- Surge Suppressors
- Circuit Boards/Electronics
- Circuit Breakers
- Switches
- Potentiometers
- Wires and Cables
- Cooling Fan Motors

Detecting the presence of fatigue associated with these subcomponents is achieved through a combination of plant programs. Tactile inspections conducted in accordance with the plants'

Preventive Maintenance Program are effective at detecting loose parts and wiring connections of these subcomponents. Thermographic inspections conducted in accordance with Reference 5.18 are effective at detecting loose electrical connections which have increased resistance and will heat up. Therefore, if tactile inspections of these subcomponents for loose connections are conducted at least once per fuel cycle, and if thermographic inspections are conducted in accordance with Reference 5.25, then fatigue of these subcomponents is effectively managed.

5.4.7 Wear

Table 4-3 identified wear as a potentially significant aging mechanism for the following battery charger, inverter, and UPS subcomponents.

- Relays
- Circuit Breakers
- Switches
- Potentiometers
- Cooling Fans and Motors

Detecting the presence of wear associated with these subcomponents is achieved through a combination of plant programs. Tactile inspections conducted in accordance with the plants' Preventive Maintenance Program are effective at detecting wear of the relays, circuit breakers, switches, and potentiometers. Visual and audio observations made in accordance with the plants' "Good Housekeeping" Practices — Operator Rounds, Logs, and Checklists are effective at detecting wear of the cooling fan and motor bearings, commutators, and brushes. Therefore, if tactile inspections are conducted at least once per fuel cycle, and if visual and audio observations are made once per shift, then wear of these subcomponents is effectively managed.

5.4.8 Conclusion

Based on the foregoing discussions, and the effectiveness evaluations in Section 5.2, a minimum comprehensive aging management program for plant and switchyard battery chargers is presented in Table 5-10. This table identifies the minimum recommended programs, specific activities, and implementing intervals to effectively manage all battery charger aging identified in this guideline. If all of these specific activities are implemented at the specified frequency, then aging of the battery chargers will be effectively managed. Supplemental battery charger aging management programs and activities based on the effectiveness evaluations in Sections 5.2 and 5.3 are presented in Table 5-11. These programs and activities are considered desirable but not required to effectively manage battery charger aging.

A minimum comprehensive aging management program for inverters/UPSs is presented in Table 5-12. This table identifies the minimum recommended programs, specific activities, and implementing intervals to effectively manage all inverter aging identified in this guideline. If all of these specific activities are implemented at the specified frequency, then aging of the inverters will be effectively managed. Supplemental inverter aging management programs and activities based on the effectiveness evaluations in Sections 5.2 and 5.3 are presented in Table 5-13. These programs and activities are considered desirable but not required to effectively manage inverter aging.

Table 5-10. Minimum Recommended Aging Management Programs and Activities for Battery Chargers

Program	Activity	Frequency	Aging Mechanisms Addressed	Comments
Preventive Maintenance	Visually Inspect <u>All</u> Subcomponents and Connections for Dirt/Discoloration/Deformation	Once/Cycle	Thermal Aging, Fouling	
	Visually Inspect Transformer, Cable, and Wire Insulation for Cracks	Once/Cycle	Thermal Aging	
	Visually Inspect Capacitors for Leaking Oil/Electrolyte	Once/Cycle	Thermal Aging	
	Visually Inspect Transformers, Inductors, Relays, Circuit Boards, Circuit Breakers, Switches, Potentiometers, Wires, Cables, Cooling Fans, Fan Motors, and the Cabinet for Corrosion	Once/Cycle	Corrosion	
	Vacuum/Replace Air Filter	Once/Cycle	Thermal Aging, Fouling	
	Vacuum/Blowout Dirt from Cooling Fan Motor	Once/Cycle	Thermal Aging, Fouling	
	Clean Heat Sink Surfaces with Lint-Free Rag or Soft Bristle Brush	Once/Cycle	Thermal Aging, Fouling	
	Clean SCRs and Transformers with Lint-Free Rag or Soft Bristle Brush	Once/Cycle	Thermal Aging, Fouling	
	Clean and Burnish Relay Contacts	Once/Cycle	Thermal Aging, Fouling, Contact Corrosion	
	Clean Circuit Breakers, Switches, and Potentiometers	Once/Cycle	Thermal Aging, Fouling, Contact Corrosion	
	Torque Verification of SCR Mountings	Once/Cycle	Thermal Aging, Fatigue	If the connection requires tightening, then it should be disassembled, cleaned, and reassembled with new thermal compound.

Table 5-10. Minimum Recommended Aging Management Programs and Activities for Battery Chargers (continued)

Program	Activity	Frequency	Aging Mechanisms Addressed	Comments
Preventive Maintenance (continued)	Verify Tightness of <u>All</u> Fasteners	Once/Cycle	Fatigue	
	Exercise Circuit Breakers, Switches, and Relays	Once/Cycle	Wear, Material Set	
	Physically Check Transformer and Inductor Insulation with a Non-conducting Probe for Flaking	Once/Cycle	Thermal Aging	
	Physically Check Cable and Wire Insulation for Resiliency (Cable Indenter)	Once/Cycle	Thermal Aging	
	Measure, Record, and Trend Capacitance of Filter Capacitors	Once/Cycle	Thermal Aging	If measured capacitance is 5-10% less than previous measurements or nameplate ratings, then the capacitors should be replaced.
	Calibrate Equalize and Float Voltages	Once/Cycle	Setpoint Drift	
	Calibrate Alarm and Trip Relays	Once/Cycle	Setpoint Drift	
	Calibrate Panel Meters	Once/Cycle	Electronic Drift	
	Replace Filter Capacitors	As Recommended by Manufacturer	Thermal Aging	If capacitors rated for higher temperature and voltage are used, then they will have a longer useful life.
Surveillance (Note 1)	Capacity Testing	Once/Cycle	Thermal Aging, Setpoint Drift	
	Annunciator Checks	Once/Cycle	Thermal Aging, Setpoint Drift, Material Set, Wear, Fatigue, and Corrosion of Relays	

Table 5-10. Minimum Recommended Aging Management Programs and Activities for Battery Chargers (continued)

Program	Activity	Frequency	Aging Mechanisms Addressed	Comments
Surveillance (Note 1) (continued)	Measure Output Ripple Voltage	Once/Cycle	Thermal Aging of Filter Capacitors	
"Good Housekeeping" Practices — Operator Rounds, Logs, and Checklists	Log Cabinet Temperature	Once per Shift	Thermal Aging	
	Log Output Voltage and Current	Once per Shift	Thermal Aging, Electronic/ Setpoint Drift	
	Listen for Noise	Once per Shift	Thermal Aging (Transformer Hum), Wear (Fan Bearings)	
	Check for Burning Odor	Once per Shift	Thermal Aging	
	Check for Vibration	Once per Shift	Fatigue	
On-Line Monitoring and Annunciator Response Procedures	Alarm for High Cabinet Temperature	Continuous	Thermal Aging	
	Alarm for High/Low Output Voltage	Continuous	Thermal Aging, Setpoint/Electronic Drift	
	Alarm for Loss of Forced Cooling	Continuous	Thermal Aging	If unit is cooled by natural convection, then this activity is not applicable.
Infrared Thermographic Inspection (Note 2)	Perform and Trend Infrared Thermographic Scans (Note 2)	(Note 2)	Thermal Aging	

Notes:

1. Surveillance program activities can be conducted as part of the plant Technical Specification Surveillance or as part of an Operational Surveillance Program.
2. The Infrared Thermographic Inspection Program should be instituted in accordance with the EPRI NMAC Guide for Infrared Thermography (NP-6973).

Table 5-11. Supplemental Aging Management Programs and Activities for Battery Chargers

Program	Activity	Frequency	Aging Mechanisms Addressed	Comments
Corrective Maintenance	Tuning of SCR Firing Circuit	As Needed (See Comments)	Thermal Aging	If an SCR is replaced, then the associated firing circuit should be tuned.
	Voltage Balancing (i.e., Adjust AC Inputs to get Symmetrical DC Output)	As Needed (See Comments)	Thermal Aging	If a major component is replaced (i.e., transformer, SCR, capacitor, circuit board), then the charger should be voltage balanced.
	Filter Capacitor Replacement	As Needed (See Comments)	Thermal Aging	If one filter capacitor fails, then all other filter capacitors should either be tested (measure capacitance) or replaced. When testing, if the capacitance has decreased by 5-10% from the design value, then the capacitor should be replaced.
	Repair of Loose Connections	As Needed	Thermal Aging	If a connection requires tightening, then it should be disassembled, cleaned, and reassembled using new thermal compound.
Equipment Qualification	Qualify Equipment and Maintain the Qualification	On-Going	Thermal Aging, Electronic/ Setpoint Drift, Corrosion, Fouling, Material Set, Fatigue, Wear	
Environment Mitigation	Install Cooling Fans on Cabinet	As Needed	Thermal Aging	If cabinet is already force cooled, then additional or backup fans could be installed.
	Upgrade HVAC	As Needed	Thermal Aging	
	Install Additional Vents on Cabinet	As Needed	Thermal Aging	
Waveform Monitoring	Monitor Ripple Voltage with an Oscilloscope	As Needed	Thermal Aging of Filter Capacitors	

Table 5-11. Supplemental Aging Management Programs and Activities for Battery Chargers (continued)

Program	Activity	Frequency	Aging Mechanisms Addressed	Comments
Insulation Resistance Testing	Dielectric Absorption Ratio (DAR) Test on Transformers, Circuit Breakers, Wires, Cables, and Cooling Fan Motors	As Needed	Thermal Aging	If the dielectric absorption ratio is less than 1.25, then investigative and corrective action is warranted.
Transformer Turns Ratio Testing	Transformer Testing	As Needed	Thermal Aging	
Sample Removal and Analysis	Trend the Analyses of Removed Relays, Capacitors, and Cables	As Needed	Thermal Aging	
Equipment Replacement/Refurbishment	Replace Entire Unit	As Needed	Thermal Aging, Electronic/ Setpoint Drift, Corrosion, Fouling, Material Set, Fatigue, Wear	
	Replace Subcomponents	As Needed	Thermal Aging, Electronic/ Setpoint Drift, Corrosion, Fouling, Material Set, Fatigue, Wear	
Environmental Monitoring	Monitor and Trend Ambient Temperature and Humidity	As Needed	Thermal Aging, Corrosion	
Transient Monitoring and Recording	Monitor and Record Electrical Transients	As Needed	Thermal Aging	
Vibration Diagnosis	Vibration Monitoring and Trending	As Needed	Wear of Cooling Fan and Motor Bearings	

Table 5-12. Minimum Recommended Aging Management Programs and Activities for Inverters/UPSs

Program	Activity	Frequency	Aging Mechanisms Addressed	Comments
Preventive Maintenance	Visually Inspect <u>All</u> Subcomponents and Connections for Dirt/Discoloration/Deformation	Once/Cycle	Thermal Aging, Fouling	
	Visually Inspect Transformer, Cable, and Wire Insulation for Cracks	Once/Cycle	Thermal Aging	
	Visually Inspect Capacitors for Leaking Oil/Electrolyte	Once/Cycle	Thermal Aging	
	Visually Inspect Transformers, Inductors, Relays, Circuit Boards, Circuit Breakers, Switches, Potentiometers, Wires, Cables, Cooling Fans, Fan Motors, and the Cabinet for Corrosion	Once/Cycle	Corrosion	
	Vacuum/Replace Air Filter	Once/Cycle	Thermal Aging, Fouling	
	Vacuum/Blowout Dirt from Cooling Fan Motor	Once/Cycle	Thermal Aging, Fouling	
	Clean Heat Sink Surfaces with Lint-Free Rag or Soft Bristle Brush	Once/Cycle	Thermal Aging, Fouling	
	Clean SCRs and Transformers with Lint-Free Rag or Soft Bristle Brush	Once/Cycle	Thermal Aging, Fouling	
	Clean and Burnish Relay Contacts	Once/Cycle	Thermal Aging, Fouling, Contact Corrosion	
	Clean Circuit Breakers and Switches	Once/Cycle	Thermal Aging, Fouling, Contact Corrosion	
	Torque Verification of SCR Mountings	Once/Cycle	Thermal Aging, Fatigue	If the connection requires tightening, then it should be disassembled, cleaned, and reassembled with new thermal compound.

Table 5-12. Minimum Recommended Aging Management Programs and Activities for Inverters/UPSs (continued)

Program	Activity	Frequency	Aging Mechanisms Addressed	Comments
Preventive Maintenance (continued)	Verify Tightness of <u>All</u> Fasteners	Once/Cycle	Fatigue	
	Exercise Circuit Breakers, Switches, and Relays	Once/Cycle	Wear, Material Set	
	Physically Check Transformer and Inductor Insulation with a Non-conducting Probe for Flaking	Once/Cycle	Thermal Aging	
	Physically Check Cable and Wire Insulation for Resiliency (Cable Indenter)	Once/Cycle	Thermal Aging	
	Measure, Record, and Trend Capacitance of Capacitors	Once/Cycle	Thermal Aging	If measured capacitance is 5-10% less than previous measurements or nameplate ratings, then the capacitors should be replaced.
	Calibrate Output Voltage and Frequency	Once/Cycle	Electronic/Setpoint Drift	
	Calibrate Alarm and Trip Relays	Once/Cycle	Electronic/Setpoint Drift	
	Calibrate Panel Meters	Once/Cycle	Electronic Drift	
	Replace Capacitors	As Recommended by Manufacturer	Thermal Aging	If capacitors rated for higher temperature and voltage are used, then they will have a longer useful life.
Surveillance (Note 1)	Capacity Testing	Once/Cycle	Thermal Aging, Setpoint Drift	
	Annunciator Checks	Once/Cycle	Thermal Aging, Setpoint Drift, Material Set, Wear, Fatigue, and Corrosion of Relays	
	Measure Output Voltage, Frequency, and Harmonic Distortion	Once/Cycle	Thermal Aging, Electronic/Setpoint Drift	

Table 5-12. Minimum Recommended Aging Management Programs and Activities for Inverters/UPSs (continued)

Program	Activity	Frequency	Aging Mechanisms Addressed	Comments
"Good Housekeeping" Practices — Operator Rounds, Logs, and Checklists	Log Cabinet Temperature	Once per Shift	Thermal Aging	
	Log Output Voltage, Current, and Frequency	Once per Shift	Thermal Aging, Electronic/Setpoint Drift	
	Verify Synchronization	Once per Shift	Thermal Aging, Electronic/Setpoint Drift	
	Listen for Noise	Once per Shift	Thermal Aging (Transformer Hum), Wear (Fan Bearings)	
	Check for Burning Odor	Once per Shift	Thermal Aging	
	Check for Vibration	Once per Shift	Fatigue	
On-Line Monitoring and Annunciator Response Procedures	Alarm for High Cabinet Temperature	Continuous	Thermal Aging	
	Alarm for High/Low Output Voltage	Continuous	Thermal Aging, Setpoint/Electronic Drift	
	Alarm for Out of Synchronization Condition	Continuous	Thermal Aging	
	Alarm for Loss of Forced Cooling	Continuous	Thermal Aging	If unit is cooled by natural convection, then this activity is not applicable.
Infrared Thermographic Inspection (Note 2)	Perform and Trend Infrared Thermographic Scans (Note 2)	(Note 2)	Thermal Aging	

Notes:

1. Surveillance program activities can be conducted as part of the plant Technical Specification Surveillance or as part of an Operational Surveillance Program.
2. The Infrared Thermographic Inspection Program should be instituted in accordance with the EPRI NMAC Guide for Infrared Thermography (NP-6973).

Table 5-13. Supplemental Aging Management Programs and Activities for Inverters/UPSs

Program	Activity	Frequency	Aging Mechanisms Addressed	Comments
Corrective Maintenance	Tuning of SCR Firing Circuit	As Needed (See Comments)	Thermal Aging	If an SCR is replaced, then the associated firing circuit should be tuned.
	Voltage Balancing/Frequency Adjustment	As Needed (See Comments)	Thermal Aging Due to Circulating Currents in Ferroresonant Inverters/UPSs	If a major component is replaced (i.e., transformer, SCR, capacitor, circuit board), then the inverter/UPS should be frequency tuned and voltage balanced.
	Capacitor Replacement	As Needed (See Comments)	Thermal Aging	If one capacitor fails, then all other capacitors should either be tested (measure capacitance) or replaced. When testing, if the capacitance has decreased by 5-10% from the design value, then the capacitor should be replaced.
	Repair of Loose Connections	As Needed	Thermal Aging	If a connection requires tightening, then it should be disassembled, cleaned, and reassembled using new thermal compound.
Equipment Qualification	Qualify Equipment and Maintain the Qualification	On-Going	Thermal Aging, Electronic/ Setpoint Drift, Corrosion, Fouling, Material Set, Fatigue, Wear	
Environment Mitigation	Install Cooling Fans on Cabinet	As Needed	Thermal Aging	If cabinet is already force cooled, then additional or backup fans could be installed.
	Upgrade HVAC	As Needed	Thermal Aging	
	Install Additional Vents on Cabinet	As Needed	Thermal Aging	

Table 5-13. Supplemental Aging Management Programs and Activities for Inverters/UPSs (continued)

Program	Activity	Frequency	Aging Mechanisms Addressed	Comments
Waveform Monitoring	Monitor Output Voltage with an Oscilloscope	As Needed	Thermal Aging	
	Monitor SCR Gating Signals with an Oscilloscope	As Needed	Thermal Aging	
	Monitor the Commutating Capacitor Voltage with an Oscilloscope	As Needed	Thermal Aging	
Insulation Resistance Testing	Dielectric Absorption Ratio (DAR) Test on Transformers, Circuit Breakers, Wires, Cables, and Cooling Fan Motors	As Needed	Thermal Aging	If the dielectric absorption ratio is less than 1.25, then investigative and corrective action is warranted.
Transformer Turns Ratio Testing	Transformer Testing	As Needed	Thermal Aging	
Sample Removal and Analysis	Trend the Analyses of Removed Relays, Capacitors, and Cables	As Needed	Thermal Aging	
Equipment Replacement/Refurbishment	Replace Entire Unit	As Needed	Thermal Aging, Electronic/ Setpoint Drift, Corrosion, Fouling, Material Set, Fatigue, Wear	
	Replace Subcomponents	As Needed	Thermal Aging, Electronic/Setpoint Drift, Corrosion, Fouling, Material Set, Fatigue, Wear	
Environmental Monitoring	Monitor and Trend Ambient Temperature and Humidity	As Needed	Thermal Aging, Corrosion	

Table 5-13. Supplemental Aging Management Programs and Activities for Inverters/UPSs (continued)

Program	Activity	Frequency	Aging Mechanisms Addressed	Comments
Transient Monitoring and Recording	Monitor and Record Electrical Transients	As Needed	Thermal Aging	
Vibration Diagnosis	Vibration Monitoring and Trending	As Needed	Wear of Cooling Fan and Motor Bearings	

5.5 Comparison with NPAR Results

Table 5-14 compares the results and conclusions presented in this aging management guideline to the results and conclusions obtained in the NRC's Nuclear Plant Aging Research (NPAR) program. In general, the results of this guideline agree with the results of the NPAR program studies. The following paragraphs discuss areas of disagreement.

This guideline identified circuit boards as the battery charger and inverter/UPS subcomponent most susceptible to aging, while circuit boards are hardly mentioned in the NPAR reports. This could be due to the fact that the NPAR reports concentrated on the major subcomponents (transformers, capacitors, inductors, SCRs).

Setpoint drift was identified in this guideline as a primary cause of battery charger and inverter/UPS failures, but was not identified as a significant contributor in the NPAR reports. This discrepancy could be related to the identification of circuit boards as one of the primary failed parts since setpoint drift is the largest identified failure cause for circuit boards.

Personnel errors were identified as a significant contributor to battery charger and inverter/UPS failures in the NPAR studies, but the NPRDS and LER data reviewed in this guideline did not identify a significant number of personnel error induced failures. This may be due to improved training and maintenance procedures since the NPAR studies.

Table 5-14. Comparison of Results and Conclusions with NPAR Program Results and Conclusions

NPAR Report	NPAR Results/Conclusions	Aging Management Guideline Results/Conclusions
NUREG/CR-4564 Operating Experience and Aging/Seismic Assessment of Battery Chargers and Inverters (June 1986)	The charger and inverter subcomponents most susceptible to aging are capacitors, transformers, inductors, SCRs, and diodes.	The charger and inverter subcomponents most susceptible to aging are circuit boards, capacitors, and relays.
	A large number of charger and inverter failures have resulted from fuse operation. Some of these failures may be due to thermal fatigue of the fuse.	Fuse operation contributed significantly to NPRDS inverter failures (19.5%). However, fuse operation contributed only 7.9% to NPRDS age-related inverter failures. The aging management guideline considers fuses to be renewable components.
	Plant configurations help determine battery charger and inverter reliability. Plants with a standby charger or a second full capacity charger generally are most reliable. Inverters with a transfer switch to a separate bypass AC feed appear to be the most reliable. Inverters with rectifiers providing an alternate DC feed have not been nearly as reliable.	The aging management guideline scope did not include system reliability considerations.
	The weak links that may be susceptible to seismic excitation are the cabinet mountings to the floor or wall, subcomponent mountings, wire and cable connections, relays, circuit breakers, transformers, oil filled capacitors, and fuse holders.	Seismic forces were considered to cause vibration of all subcomponents which could contribute to fatigue of these subcomponents.
	Battery charger and inverter failures exhibit the typical "bathtub" curve when plotted against component age. That is, a high number of failures occur in the first year of operation with a pronounced wear-out effect in the fifth and sixth years of operation.	The normalized plots of equipment failures by service time (Figures 3-24, 3-25, 3-33, and 3-34) indicate that the inverter failures tend to exhibit the classic "bathtub" curve, while charger failures appear fairly random with service time.
	Over a nine-year period, 42 reactor trips have been attributed to inverter failures, demonstrating the safety significance of this component. Inoperable ECCS and invertant safety system actuations have also been attributed to inverter failures.	From the LER data reviewed, none of the battery charger failures resulted in a reactor trip while 20 (40.8%) of the inverter failures resulted in reactor trip. One battery charger failure (20.0%) resulted in inadvertent safety system actuation, while 15 (30.6%) of the inverter failures resulted in safety system actuation or in loss of one train of a redundant safety system.

Table 5-14. Comparison of Results and Conclusions with NPAR Program Results and Conclusions (continued)

NPAR Report	NPAR Results/Conclusions	Aging Management Guideline Results/Conclusions
NUREG/CR-4564 (continued)	<p>Battery charger and inverter performance can be improved through a comprehensive preventive maintenance program.</p> <p>Certain performance indicators may be effective in preventing failure due to aging of the equipment. For capacitors this includes equivalent series resistance measurement, capacitance value measurement, power factor measurement, and output waveform monitoring. For magnetic components (transformers, inductors) this includes measurements of temperature rise during operation, insulation resistance, open circuit voltage, and impedance. For semiconductor devices this includes waveform monitoring of the gate drive circuit, and resistance value measurements.</p> <p>Periodic capacity testing should be performed to ensure that the capability of the equipment to supply the required load is not diminished due to aging of key components. (This is already done for many battery chargers, but is not regularly conducted for inverters.)</p>	<p>The aging management guideline presents a recommended comprehensive preventive maintenance program to improve battery charger and inverter performance.</p> <p>Trending of filter capacitor capacitance and measuring charger output ripple voltage are recommended minimum aging management activities. Using an oscilloscope to monitor charger output ripple voltage, inverter output voltage, inverter SCR gating signals, and inverter commutating capacitor voltage are considered supplemental aging management activities.</p> <p>Capacity testing of battery chargers and inverters is part of the recommended minimum aging management programs and activities.</p>
NUREG/CR-5051 Detecting and Mitigating Battery Charger and Inverter Aging (August 1988)	<p>The primary contributors to inverter and battery charger failures are overheating, electrical transients, and personnel errors.</p> <p>The subcomponents susceptible to aging degradation from the above primary stressors are electrolytic capacitors, fuses, magnetics (inductors and transformers), and semiconductors (SCRs).</p>	<p>Most of the NPRDS Reports and LERs were not definitive as to failure causes. The largest identifiable cause in the NPRDS data for chargers and inverters was setpoint drift, which can be caused by excessive thermal conditions. High temperature was the primary identifiable cause of inverter failures in the LER data. Identifiable charger failures in the LER data were evenly divided among design factors, loose connections, and corrosion.</p> <p>The charger and inverter subcomponents determined to be most susceptible to aging are circuit boards, capacitors, and relays.</p>

Table 5-14. Comparison of Results and Conclusions with NPAR Program Results and Conclusions (continued)

NPAR Report	NPAR Results/Conclusions	Aging Management Guideline Results/Conclusions
NUREG/CR-5051 (continued)	<p>The detection techniques found to be most valuable in determining inverter and battery charger aging are component and equipment temperature monitoring, periodic observation of circuit waveforms, and component parameter measurements.</p>	<p>Cabinet temperature monitoring and alarming, capacitance measurements, charger output ripple voltage measurements, and inverter output voltage, frequency, and harmonic distortion measurements are all part of the recommended minimum aging management program activities. Periodic observation of circuit waveforms are considered supplemental aging management activities.</p>
	<p>A comprehensive maintenance program should be established for inverters and battery chargers that address four areas: Inspection, testing, predictive maintenance, and corrective maintenance.</p>	<p>The aging management guideline presents a recommended comprehensive maintenance program to address aging of battery chargers and inverters which addresses inspection, testing, and preventive maintenance. Corrective maintenance is considered a supplemental aging management program.</p>
	<p>To reduce the impact of inverter degradation, the installation of an automatic transfer switch is recommended. A sample reliability improvement calculation for the installation of an automatic transfer switch revealed a seven fold increase in vital AC bus availability.</p>	<p>The aging management guideline scope did not include an evaluation of the AC system reliability or availability.</p>
	<p>Other recommended design improvements include the application of equipment to detect and suppress electrical bus transients, the use of higher voltage and temperature rated components in inverter circuitry, and the addition of forced air cooling to reduce overheating problems.</p>	<p>The use of higher rated components in inverter and battery charger circuitry is recommended in Section 5.2.2.1. The addition of forced air cooling is advocated in Section 5.3.1 and transient monitoring equipment is discussed as an option in Section 5.3.8.</p>
	<p>To reduce personnel induced stresses, training and procedures for the operation and maintenance of this complex equipment should be provided.</p>	<p>The aging management guideline did not identify personnel error as a significant cause of battery charger and inverter failures.</p>
	<p>Periodic component replacement is not an optimum technique to maintain the performance standards of inverters and chargers. Testing and monitoring methods offer the greatest potential for enhancing a preventive maintenance program and reducing or eliminating periodic component changeout.</p>	<p>Periodic component replacement is viewed as a supplemental aging management activity. Testing and monitoring are recommended aging management activities.</p>

Table 5-14. Comparison of Results and Conclusions with NPAR Program Results and Conclusions (continued)

NPAR Report	NPAR Results/Conclusions	Aging Management Guideline Results/Conclusions
NUREG/CR-5051 (continued)	Corrective maintenance practices for inverters and chargers should be defined (e.g., specific torque requirements when replacing SCRs, root-cause evaluations of failed components).	Corrective maintenance is typically performed in response to a component or subcomponent failing to perform its required function, and as such is not effective at detecting or mitigating aging. However certain activities should be performed during or following corrective maintenance to mitigate future aging of charger or inverter subcomponents (e.g., circuit tuning, replacing all capacitors when one fails, cleaning and reassembling loose connections rather than simply tightening them).
NUREG/CR-5192 Testing of a Naturally Aged Nuclear Power Plant Inverter and Battery Charger (September 1988)	<p>A comprehensive visual examination revealed no obvious signs of aging. With the exception of SCRs (which are operating with case temperatures 20% higher than during original acceptance testing) component temperatures and circuit characteristics were similar to original acceptance test measurements. It was concluded that the inverter and battery charger have not aged substantially.</p> <p>Internal panel temperature and individual component temperature monitoring was practical and beneficial. The use of thermocouples was unobtrusive. The results were repeatable and offered insight into component operation.</p> <p>Circuit waveform monitoring (inverter output sine wave, battery charger output ripple voltage, SCR gating current, and commutating capacitor voltage) can detect certain circuit degradation. However, degradation of a resistor, diode, or relay would probably not be evident by observing the output waveforms.</p> <p>Inverter capacitors should be individually fused to prevent inverter failure due to a short circuit in an individual capacitor. Fuse operation should be indicated or alarmed.</p>	<p>Visual inspections and cabinet temperature monitoring/alarming are part of the minimum recommended aging management program. Circuit waveform monitoring is considered a supplemental aging management activity.</p> <p>Cabinet temperature monitoring/alarming is part of the minimum recommended aging management program.</p> <p>Circuit waveform monitoring is considered a supplemental aging management activity.</p> <p>Fusing of individual capacitors was not discussed in the aging management guideline.</p>

Table 5-14. Comparison of Results and Conclusions with NPAR Program Results and Conclusions (continued)

NPAR Report	NPAR Results/Conclusions	Aging Management Guideline Results/Conclusions
NUREG/CR-5192 (continued)	<p>Acceptance testing requirements should be modified to obtain the most severe design operating conditions for all components.</p> <p>Monitoring the internal panel temperature as well as key components such as the transformers, SCRs, inductors, and filter capacitors is recommended to detect overheating prior to degradation and failure.</p>	<p>Acceptance testing requirements were not addressed in the aging management guideline.</p> <p>Cabinet temperature monitoring/alarming is part of the minimum recommended aging management program.</p>
NUREG/CR-4715 An Aging Assessment of Relays and Circuit Breakers and System Interactions (June 1987)	<p>LER data indicated that approximately 43% of the reported protective relay failures and 47% of the timing relay failures were associated with setpoint drift.</p> <p>LER data indicated that the failure rates associated with relay coils, relay binding, and relay electrical components other than coils are increasing with the age of the population.</p> <p>The NPRDS records for the overall population of relays indicate an increasing trend in failures from the seventh through the eleventh year, which have a major contribution from failures of control and time delay relays.</p> <p>Most control and time delay relay failures are detected during functional tests of the associated systems, which are required by plant surveillance programs. Most protective relay failures are detected during system functional tests or periodic calibrations and inspections, also required by plant surveillance programs. Testing and evaluation for prediction of continued operability and evaluation of the level of determination are not being performed.</p>	<p>Setpoint drift was not identified as a failure cause for relays in the LERs concerning battery charger and inverter failures. NPRDS data indicates that setpoint drift is responsible for 11.9% of the relay failures in chargers and 13.6% of the relay failures in inverters.</p> <p>Failure trends with time were investigated for battery chargers and inverters, but failure trends of their subcomponents (i.e., relays) with time were not investigated.</p> <p>Failure trends of relays were not specifically investigated.</p> <p>For battery chargers, NPRDS data indicates that most relay failures are detected by audiovisual alarms (33%) or by operational abnormalities (28%). For inverters, NPRDS data indicates that relay failures are most often detected by operational abnormalities (27%), audiovisual alarms (23%), or during preventive maintenance (23%). Relatively few relay failures were detected during surveillance tests (10% for chargers, 18% for inverters).</p>

Table 5-14. Comparison of Results and Conclusions with NPAR Program Results and Conclusions (continued)

NPAR Report	NPAR Results/Conclusions	Aging Management Guideline Results/Conclusions
NUREG/CR-4715 (continued)	<p>Periodic replacement of relays and relay components could be used to reduce the effects of age-related deterioration. Some manufacturers have determined specific replacement periods for given environments. There are wide variations in replacement practices. Some plants replace upon failure, others replace at increments required by specific qualification programs, and one plant replaces one-quarter of the relays for the reactor protection system at each refueling outage.</p> <p>75% of the LER age-related failures not caused by setpoint drift were associated with coil, spool, contact, and electrical component failure, binding, and dirty contacts. Therefore, failure detection techniques should focus on detection of coil and contact (including dirt buildup) failures and binding.</p> <p>NPRDS data showed that continuously energized relays fail approximately 60% more frequently than deenergized relays, indicating that additional thermal stress from energization is taking its toll on the relays.</p>	<p>Periodic replacement of relays was not a recommended aging management activity.</p> <p>Evaluations of battery charger and inverter subcomponent failures (i.e., relays) were not evaluated beyond the basic failure cause and failure detection method.</p> <p>Specific analyses of relay failures versus energization state were not conducted.</p>
NUREG/CR-4747 An Aging Failure Survey of Light Water Reactor Safety Systems and Components, Vol. 1 (July 1987)	<p>For the Class 1E electric power distribution system, there were 35 Class 1E battery charger failures reported to NPRDS with an aging fraction between 0.51 and 0.97 (i.e., 51.0% to 91.0% of the charger failures were identified as potentially age-related). The primary failure causes were faulty modules/circuit boards (65.7%), electrical failure (8.6%), and binding/out of adjustment (5.7%).</p>	<p>The NPRDS failures examined were not separated by safety classification. Of the 888 battery charger failures studied, 443 (49.9%) were identified as age-related. The primary identified failure causes were setpoint drift (20.7%), fouling (8.1%), and thermal stress (6.3%). The primary failed parts were circuit boards (35.8%), potentiometers (8.9%), and fuses (7.4%).</p>

Table 5-14. Comparison of Results and Conclusions with NPAR Program Results and Conclusions (continued)

NPAR Report	NPAR Results/Conclusions	Aging Management Guideline Results/Conclusions
NUREG/CR-4747 (continued)	There were 63 Class 1E inverter failures reported to NPRDS with an aging fraction between 0.29 and 0.60. The primary failure causes were faulty modules/circuit boards (28.6%), electrical overloads (14.3%), and wear (7.9%).	The NPRDS failures examined were not separated by safety classification. Of the 703 inverter failures studied, 279 (39.7%) were identified as age-related. The primary identified failure causes were setpoint drift (21.5%), thermal stress (5.7%), and fouling (5.0%). The primary failed parts were circuit boards (27.0%), fuses (19.5%), and capacitors (7.7%).
NUREG/CR-5181 Nuclear Plant Aging Research: The 1E Power System (May 1990)	Battery charger failures accounted for 9.5% of 3108 LERs and 7.3% of 2260 NPRDS failures reported for Class 1E power systems.	The aging management guideline scope did not include system failure analysis.
	31.1% of the NPRDS battery charger failures were attributed to aging.	49.9% of the NPRDS battery charger failures were attributed to aging.
	Inverter failures accounted for 9.9% of 3108 LERs and 11.6% of 2260 NPRDS failures reported for Class 1E power systems.	The aging management guideline scope did not include system failure analysis.
	25.5% of the NPRDS inverter failures were attributed to aging.	39.7% of the NPRDS inverter failures were attributed to aging.
	The major causes of faults in chargers and inverters were found to be high voltage, sometimes caused by electrical transients, and high temperature, caused by overloading and inadequate cooling.	The primary identified failure causes in chargers and inverters (based on NPRDS data) are setpoint drift, thermal stress, and fouling.

5.6 References

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- 5.19 NUREG-1432, "Standard Technical Specifications, Combustion Engineering Plants," USNRC, Volumes 1-3, September 1992.
- 5.20 NUREG-1433, "Standard Technical Specifications, General Electric Plants," BWR/4, Volumes 1-3, September 1992.
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- 5.23 IEEE STD 650-1990, IEEE Standard for Qualification of Class 1E Static Battery Chargers and Inverters for Nuclear Power Generating Stations, Institute of Electrical and Electronics Engineers, Inc., 1990.
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- 5.25 EPRI NMAC NP-6973, Infrared Thermography, Electric Power Research Institute, Revision 1, March 1992.
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6. OTHER AGING MANAGEMENT CONSIDERATIONS

The stressors and aging mechanisms affecting the various battery charger, inverter, and UPS components in the scope of this AMG were discussed in Section 4. Section 5 evaluated the potentially significant aging mechanisms with respect to current maintenance inspection, testing, and trending programs and techniques. For the potentially significant aging mechanisms, it was determined that currently available programs and techniques are effective in detecting and/or mitigating degradation, and in ensuring long-term safe and reliable operation of these components.

Two outstanding issues, not associated with specific aging mechanisms or plant programs, may influence or dominate a given plant's aging management program for battery chargers, inverters, and UPSs.

1. Obsolescence of electronic subcomponents and design technology, leading to the unavailability of qualified replacement parts, and a loss of "institutional knowledge" and expertise required for maintenance of older electronics. This issue is compounded by the improved reliability, lower O&M costs, and flexibility of current electronic/computer designs, wherein replacement of outdated technology may be cost-justified and preferred over aging management of older components.

This issue is very relevant to the charger/UPS/inverter group, and is discussed in Section 6.1.

2. Dissolution, merger, and product line changes of vendors who supplied original equipment chargers, UPS, and inverters. This has led to decreased product support and service, loss of institutional knowledge for maintenance and repair, and lack of vendor performance data for older units which would support aging studies.

This issue was identified by many respondents to this guideline's utility questionnaire as a relevant and serious problem for effective aging management. This is discussed further in Section 6.2.

6.1 Obsolescence of Components and Design Technology

Questionnaire responses from several plants and follow-up discussions, and interaction with the host utility for this AMG, indicate that obsolescence of electronic boards, electronic controls, and subcomponents such as rectifiers and filters, is a major problem for effective aging management. The design technology for a large number of units in operation is based on late 1960s or early 1970s electronic standards, quality, and capabilities. Replacement of failed parts, calibration of circuits, and diagnostic testing has been hampered by the following.

1. The unavailability of qualified replacement subcomponents, or entire assemblies such as circuit boards, from the original equipment supplier or an alternate. There is insufficient demand for these parts to maintain a qualified source, and some utilities have resorted to engineering and fabricating their own, or to using a "garage" manufacturer to build custom boards. Although the design and fabrication may be

possible, qualification for service to IEEE and other regulatory standards has proved difficult.

This has led to wholesale replacement of the charger/inverter unit with newer technology, often in combination with battery system replacements or upgrades. The replacement of charger/inverter units with newer technology may also be driven by other factors discussed in steps 2 and 3 below.

2. Technicians qualified to perform maintenance and calibration work on these units have often been schooled in more current technologies, particularly those involving programmable controllers, integrated circuits, and predictive diagnostics. The older technology facing younger or newer employees is not familiar, and a loss of "institutional knowledge" for maintaining older units in a cost-effective manner is occurring as older technicians retire or move on to other duties.
3. New technologies for chargers, inverters, and UPSs employ electronics with much higher reliability, greater flexibility in control and programming, and lower overall operating costs than older units. The O&M savings and reliability improvement often drive replacement programs, particularly in conjunction with battery replacement.

These three factors indicate that utilities may choose to replace the entire unit before "normal" aging mechanisms may require it, based on cost-benefit analysis.

The concept of "users groups" to jointly procure replacement parts, exchange ideas, and compare aging management programs may have only limited success. As was noted in Tables 3-3 and 3-4, there are a large number of former and existing vendors' equipment in current use. For chargers, only Power Conversion, Exide, and C&D groups would be beneficial. For inverter/UPS units, five vendors each have 10-20% of the market. In the preparation of this guideline, several of these vendors demonstrated a lack of potential technical support for long-term aging management of older model lines. This was reflected in utility comments that many of them felt "on their own" for long-term trending of failure data, developing mitigative plans, and procuring parts for their units. Vendor support was not there for the older technologies.

6.2 Vendor Dissolution, Mergers, and Product Line Changes

The preparation of this guideline involved contact with several vendors to obtain information. It is apparent that the dissolution and/or merger of businesses, discontinuation of product lines and the underlying technology, and the general passage of time, make it difficult to obtain product information or performance data relevant to aging management for chargers, inverters, and UPSs. In general, for the age and product types most encountered in preparing this guideline, the following facts hold.

1. There is no long-term performance data maintained by the vendors regarding age-related degradation mechanisms, failure trends, or the success of mitigative programs.
2. There is no commercial interest among vendors in promoting aging management techniques for older equipment.

3. There are few technical personnel available who are familiar with the model types and technologies represented by the current population of chargers, inverters, and UPSs.

Product support and vendor institutional knowledge were identified by the host utility and several questionnaire respondents as significant problems for their plant's power conversion equipment. Because of the relatively small number of units per plant (two-three large chargers, two-three inverters) and diversity of vendors, utility "pressure" on vendors has been only marginally successful in securing long-term support.

6.3 Conclusion

The guidelines presented in this document demonstrate that effective aging management and long-term reliable operation of chargers, inverters, and UPSs are achievable under the current common and less common methods presented in Sections 5.2 and 5.3. Long-term continuation of these programs for the original plant equipment will be limited by replacement parts' unavailability, changing technologies which render older units economically obsolete, and lack of vendor support. In conjunction with battery replacements or upgrades, many plants have or are contemplating changeout of the charger and inverter units to take advantage of new technology and lower operating costs. In this event, the guidelines in this document serve as the foundation for effective aging management "from the start" for these units.

APPENDIX A ACRONYMS

AC	Alternating current
AMG	Aging Management Guideline
ANSI	American National Standards Institute
ATWS	Anticipated Transient Without Scram
BWR	Boiling Water Reactor
CFR	Code of Federal Regulations
CVT	Constant Voltage Transformer
DAR	Dielectric Absorption Ratio
DC	Direct current
DG	Draft Guide
DOE	U.S. Department of Energy
EMI	Electromagnetic interference
EPRI	Electric Power Research Institute
EQ	Equipment Qualification
HVAC	Heating, ventilation, and air conditioning
I&C	Instrumentation and control
IEEE	Institute of Electrical and Electronics Engineers
INPO	Institute for Nuclear Power Operations
IPA	Integrated plant assessment
IPRDS	In-Plant Reliability Data System
IR	Infrared
LCM	Life Cycle Management
LCO	Limiting condition for operation
LER	Licensee Event Report
LWR	Light Water Reactor
MTBF	Mean time between failure
NEMA	National Electrical Manufacturers Association
NMAC	Nuclear Maintenance Application Center (EPRI)
NPAR	Nuclear Plant Aging Research
NPE	Nuclear Power Experience (S.M. Stoller Corp.)
NPRDS	Nuclear Plant Reliability Data System (INPO)
NRC	U.S. Nuclear Regulatory Commission
NUMARC	Nuclear Management and Resource Council
NUREG	Nuclear Regulation (NRC publication)

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O&M	Operations and maintenance
PLEX	Plant life extension
PLIM	Plant Lifetime Improvement
PM	Preventive maintenance
PWM	Pulse width modulation
PWR	Pressurized Water Reactor
RCS	Reactor Coolant System
RTD	Resistance temperature detector
SCR	Silicon controlled rectifier
SCSS	Sequence Coding and Search System
SER	Significant Event Report
SNL	Sandia National Laboratories
SOER	Significant Operating Experience Report
SRP	Standard Review Plan
SSC	System, structure, and component
TC	Technology Center (Sandia National Laboratories)
UPS	Uninterruptible power supply
XMFR	Transformer

APPENDIX B DEFINITIONS¹

accelerated aging artificial aging in which the simulation of natural aging approximates, in a short time, the aging effects of longer-term service conditions

acceptance criterion specified limit of a functional or condition indicator used to assess the ability of an SSC* to perform its design function

age (noun) time from fabrication of an SSC to a stated time

age conditioning simulation of natural aging effects in an SSC by the application of any combination of artificial and natural aging

age-related degradation synonym for **aging degradation**

aging (noun) general process in which characteristics of an SSC gradually change with time or use

aging assessment evaluation of appropriate information for determining the effects of aging on the current and future ability of SSCs to function within acceptance criteria

aging degradation aging effects that could impair the ability of an SSC to function within acceptance criteria

aging effects net changes in characteristics of an SSC that occur with time or use and are due to aging mechanisms

aging management engineering, operations, and maintenance actions to control within acceptable limits aging degradation and wearout of SSCs

aging mechanism specific process that gradually changes characteristics of an SSC with time or use

artificial aging simulation of natural aging effects on SSCs by application of stressors representing plant pre-service and service conditions, but perhaps different in intensity, duration, and manner of application

breakdown synonym for **complete failure**

characteristic property or attribute of an SSC (such as shape, dimension, weight, condition indicator, functional indicator, performance or mechanical, chemical, or electrical property)

* SSC = system, structure, or component

combined effects net changes in characteristics of an SSC produced by two or more stressors

common cause failure two or more failures due to a single cause

common mode failure two or more failures in the same manner or mode due to a single cause

complete failure failure in which there is complete loss of function

condition the state or level of characteristics of an SSC that can affect its ability to perform a design function

condition surrounding physical state or influence that can affect an SSC

condition indicator characteristic that can be observed, measured, or trended to infer or directly indicate the current and future ability of an SSC to function within acceptance criteria

condition monitoring observation, measurement, or trending of condition or functional indicators with respect to some independent parameter (usually time or cycles) to indicate the current and future ability of an SSC to function within acceptance criteria

condition trending synonym for **condition monitoring**

corrective maintenance actions that restore, by repair, overhaul, or replacement, the capability of a failed SSC to function within acceptance criteria

degradation immediate or gradual deterioration of characteristics of an SSC that could impair its ability to function within acceptance criteria

degraded condition marginally acceptable condition of an unfailed SSC that could lead to a decision to perform planned maintenance

degraded failure failure in which a functional indicator does not meet an acceptance criterion, but design function is not completely lost

design basis conditions synonym for **design conditions**

design basis event any of the events specified in the station's safety analysis that are used to establish acceptable performance for safety-related functions of SSCs; events include anticipated transients, design basis accidents, external events, and natural phenomena

design basis event conditions service conditions produced by design basis events

design basis event stressor stressor that stems from design basis events and can produce immediate or aging degradation beyond that produced by normal stressors

design conditions specified service conditions used to establish the specifications of an SSC (generally includes margin of conservatism beyond expected service conditions)

design life period during which an SSC is expected to function within acceptance criteria

design service conditions synonym for **design conditions**

deterioration synonym for **degradation**

diagnosis examination and evaluation of data to determine either the condition of an SSC or the causes of the condition

diagnostic evaluation synonym for **diagnosis**

environmental conditions ambient physical states surrounding an SSC

error-induced aging degradation aging degradation produced by error-induced conditions

error-induced conditions adverse pre-service or service conditions produced by design, fabrication, installation, operation, or maintenance errors

error-induced stressor stressor that stems from error-induced conditions and can produce immediate or aging degradation beyond that produced by normal stressors

failure inability or interruption of ability of an SSC to function within acceptance criteria

failure analysis systematic process of determining and documenting the mode, mechanism, causes, and root cause of failure of an SSC

failure cause circumstances during design, manufacture, test, or use that have led to failure

failure evaluation synonym for **failure analysis**

failure mechanism physical process that results in failure

failure mode the manner or state in which an SSC fails

failure modes and effects analysis systematic process for determining and documenting potential failure modes and their effects on SSCs

failure trending recording, analyzing, and extrapolating in-service failures on an SSC with respect to some independent parameter (usually time or cycles)

functional conditions influences on an SSC resulting from the performance of design functions (operation of a system or component and loading of a structure)

functional indicator condition indicator that is a direct indication of the current ability of an SSC to function within acceptance criteria

inservice inspection methods and actions for assuring the structural and pressure-retaining integrity of safety-related nuclear power plant components in accordance with the rules of this Section [ASME Code, Section XI]

inservice life synonym for **service life**, (especially in discussions involving ASME Code Section XI)

inservice test a test to determine the operational readiness of a component or system [ASME Code, Section XI]

inspection synonym for **surveillance**

installed life period from installation to retirement of an SSC

life period from fabrication to retirement of an SSC

life assessment synonym for **aging assessment**

life cycle management synonym for **life management**

life management integration of aging management and economic planning to: (1) optimize the operation, maintenance, and useful life of SSCs; (2) maintain an acceptable level of performance and safety; and (3) maximize return on investment over the useful life of the plant

lifetime synonym for **life**

maintenance aggregate of direct and supporting actions that detect, preclude, or mitigate degradation of a functioning SSC, or restore to an acceptable level the design functions of a failed SSC

malfunction synonym for **failure**

mean time between failures arithmetic average of operating times between failures of an item [IEEE Std 100]

natural aging aging of an SSC that occurs under pre-service and service conditions, including error-induced conditions

normal aging natural aging from error-free pre-service or service conditions

normal aging degradation aging degradation produced by normal conditions

normal conditions operating conditions of a properly designed, fabricated, installed, operated and maintained SSC excluding design basis event conditions

normal operating conditions synonym for **normal conditions**

normal stressor stressor that stems from normal conditions and can produce aging mechanisms and effects in an SSC

operating conditions service conditions, including normal and error-induced conditions, prior to the start of a design basis accident or earthquake

operating service conditions synonym for **operating conditions**

operational conditions synonym for **functional conditions**

overhaul (noun) extensive repair, refurbishment, or both

performance indicator synonym for **functional indicator**

periodic maintenance form of preventive maintenance consisting of servicing, parts replacement, surveillance, or testing at predetermined intervals of calendar time, operating time, or number of cycles

planned maintenance form of preventive maintenance consisting of refurbishment or replacement that is scheduled and performed prior to failure of an SSC

post-maintenance testing testing after maintenance to verify that maintenance was performed correctly and that the SSC can function within acceptance criteria

preconditioning synonym for **age conditioning**

predictive maintenance form of preventive maintenance performed continuously or at intervals governed by observed condition to monitor, diagnose, or trend an SSC's functional or condition indicators; results indicate current and future functional ability or the nature and schedule for planned maintenance

premature aging aging effects of an SSC that occur earlier than expected because of errors or pre-service and service conditions not considered explicitly in design

pre-service conditions actual physical states or influences on an SSC prior to initial operation (e.g., fabrication, storage, transportation, installation, and pre-operational testing)

preventive maintenance actions that detect, preclude, or mitigate degradation of a functional SSC to sustain or extend its useful life by controlling degradation and failures to an acceptable level; there are three types of preventive maintenance: periodic, predictive, and planned.

qualified life period for which an SSC has been demonstrated, through testing, analysis, or experience, to be capable of functioning within acceptance criteria during specified operating conditions while retaining the ability to perform its safety functions in a design basis accident or earthquake

random failure any failure whose cause or mechanism, or both, make its time of occurrence unpredictable [IEEE Std 100]

reconditioning synonym for **overhaul**

refurbishment planned actions to improve the condition of an unfailed SSC

remaining design life period from a stated time to planned retirement of an SSC

remaining life actual period from a stated time to retirement of an SSC

remaining service life synonym for **remaining life**

remaining useful life synonym for **remaining life**

repair actions to return a failed SSC to an acceptable condition

replacement removal of an undegraded, degraded, or failed SSC or a part thereof and installation of another in its place that can function within the original acceptance criteria

residual life synonym for **remaining life**

retirement final withdrawal from service of an SSC

rework correction of inadequately performed fabrication, installation, or maintenance

root cause fundamental reason(s) for an observed condition of an SSC that if corrected prevents recurrence of the condition

root cause analysis synonym for **failure analysis**

service conditions actual physical states or influences during the service life of an SSC, including operating conditions (normal and error-induced), design basis event conditions, and post design basis event conditions

service life actual period from initial operation to retirement of an SSC

servicing routine actions (including cleaning, adjustment, calibration, and replacement of consumable) that sustain or extend the useful life of an SSC

simultaneous effects combined effects from stressors acting simultaneously

stress synonym for **stressor**

stressor agent or stimulus that stems from pre-service and service conditions and can produce immediate or aging degradation of an SSC

surveillance observation or measurement of condition or functional indicators to verify that an SSC currently can function within acceptance criteria

surveillance requirements test, calibration, or inspection to assure that the necessary quality of systems and components is maintained, that facility operation will be within the safety limits, and that the limiting conditions of operation will be met [10 CFR 50.36] (for use only when specific regulatory and legal connotations are called for)

surveillance testing synonym for **surveillance**, **surveillance requirements**, and **testing** (use only when specific regulatory and legal connotations are called for)

synergistic effects portion of changes in characteristics of an SSC produced solely by the interaction of stressors acting simultaneously, as distinguished from changes produced by superposition from each stressor acting independently

testing observation or measurement of condition indicators under controlled conditions to verify that an SSC currently conforms to acceptance criteria

time in service time from initial operation of an SSC to a stated time

useful life synonym for **service life**

wearout failure produced by an aging mechanism

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1. EPRI TR-100844, "Nuclear Power Plant Common Aging Terminology," prepared by MPR Associates, Inc., November 1992.

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